DEPOSITIONAL ENVIRONMENT OF THE ESKRIDGE SHALE (LOWER PERMIAN)

by

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INTRODUCTION

Pennsylvanian and Early Permian rocks of the Mid-Continent are noted for their repetition of lithologies. Several workers have proposed theories to explain these repetitions or cyclothems. Weller (1931) attributed cyclothems to transgressions and regressions of the epicontinental sea, which were caused by diastrophic control or eustatic sea level changes or both. Moore (1936) expanded Weller's theory by applying the concept of megacyclothems to Kansas' more complex rock sequence and proposed an "ideal cyclothem" for Pennsylvanian rocks (Fig. 1). Moore and Merriam (1959) later modified this "ideal" for Lower Permian units, which lack sandstone and coal, and contain instead red shale and evaporite deposits. Elias (1937) studied the general ecologic tolerances of modern marine assemblages and inferred the water depth requirements of similar fossil organisms which occur in cyclothem units (Fig. 2). McCrone (1963) used more recent data to modify Elias' lithologic divisions and their water depths (Table 1).

Heckel (1977) modified cyclic sedimentation theory by considering the tectonics of the Mid-Continent during Late Palaeozoic time. Palaeotopographic highs in the areas now represented by Missouri, Oklahoma, Arkansas, and Texas restricted access to the open sea (Fig. 3). During times of maximum transgression, development of a thermocline produced anoxic bottom conditions in the deepest part of the basin. These conditions are represented by black, phosphatic ("core") shales which are bracketed by normal marine limestones, whereas "outside" shales are indicative of shallowest water deposition (Fig. 4). Evaporites in Lower Permian units suggest an overall reduction in depth which prevented development of a thermocline and deposition of black "core" shales.

Selley (1970) attributed cyclicity to fluctuations in mountain building. As source areas were uplifted, the detrital supply was increased. As erosion reduced relief in the source area, sediment supply was also reduced. Uplift and erosion were continually repeated, producing a natural oscillation in sedimentary environments.

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Figure 1. Moore's ideal Pennsylvanian cyclothem (from Cubitt, 1979, p. 6).

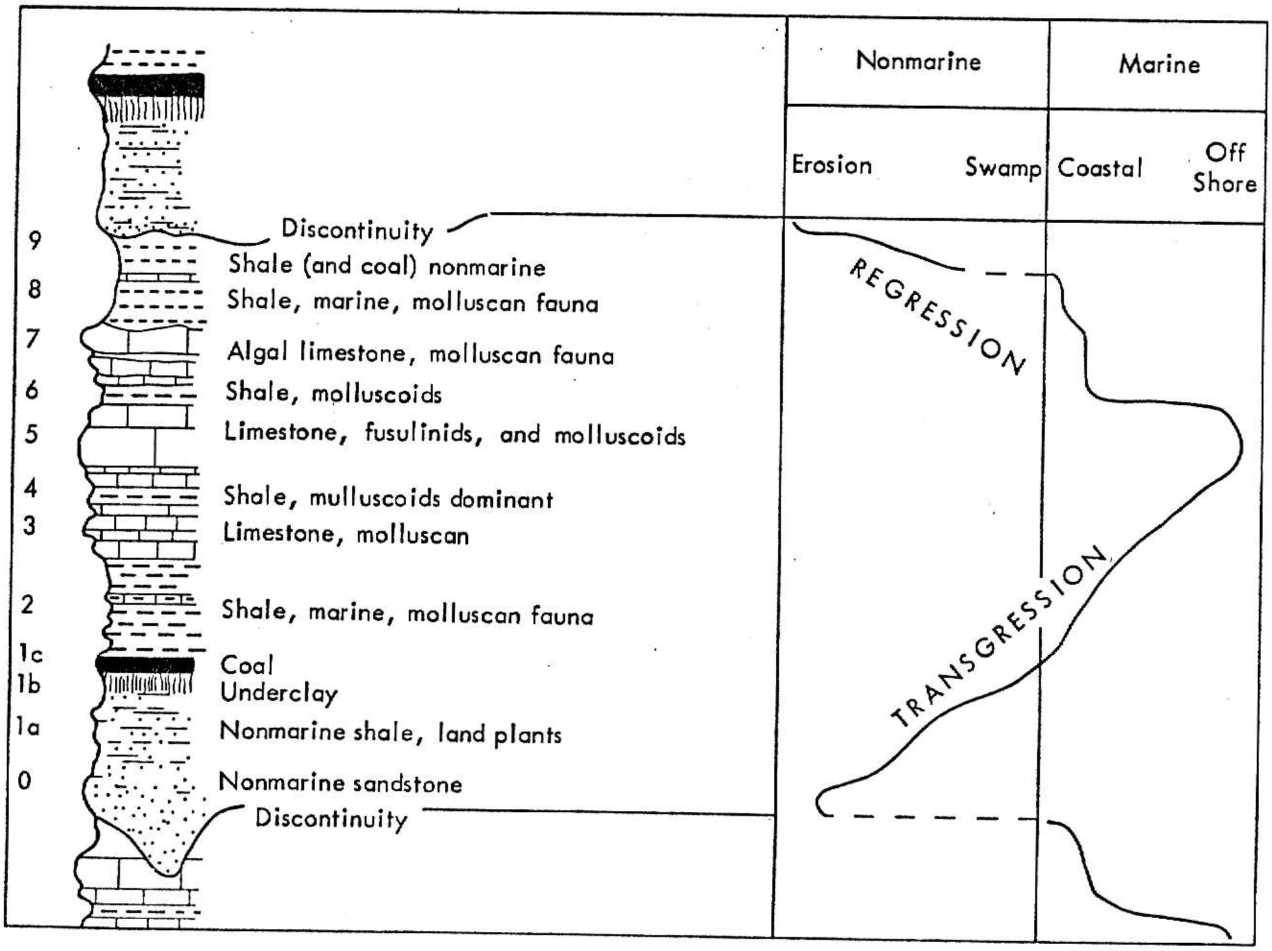
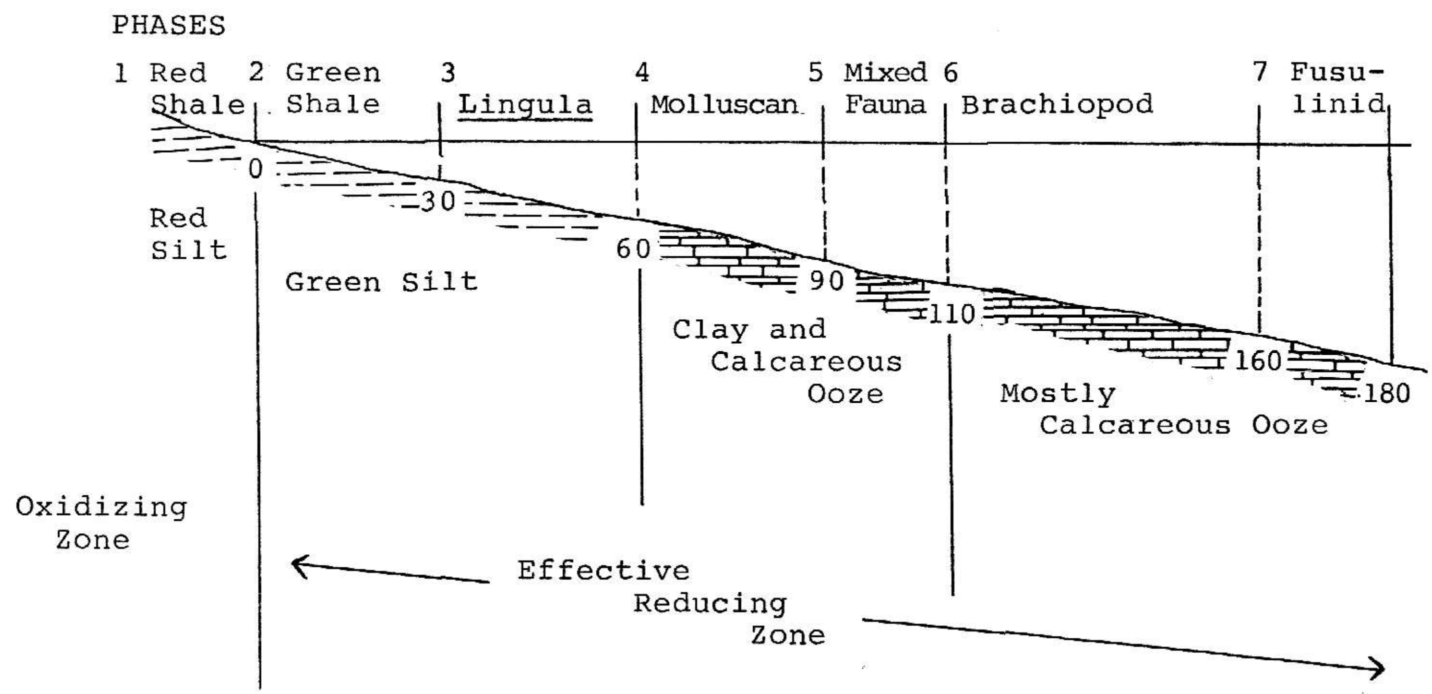


Figure 2. Elias' model of deposition for the Big Blue Series (modified from Elias, 1937, p. 410).



Characteristics:
1) Red Shale--no marine fossils, clay to fine sand
2) Green Shale--no marine fossils, clay to fine sand
3) _Lingula_--_Lingula_, sandy, varved?
4) Molluscan--inarticulate brachiopods, calcareous algae, bryozoans
5) Mixed Fauna--articulate brachiopods, burrowing bivalves, calcareous algae, bryozoans
6) Brachiopod--calcareous brachiopods, corals, bryozoans
7) Fusulinid--fusulinids

Table 1. McCrone's modification of Elias' depth of deposition for the Big Blue Series (McCrone, 1963, p. 64).

Red shale facies	high intertidal
Green shale facies	low intertidal
Black shale facies	0 to 10 feet
Osagite limestone facies	0 to 10 feet
Aphanitic limestone facies	0 to 10 feet
Algal limestone facies	0 to 20 feet
Bioclastic limestone facies	10 to 20 feet
Conglomeratic-bioclastic facies	10 to 20 feet
Fusuline limestone facies	10 to 40+ feet
Shelly shale-limestone facies	10 to 50+ feet

Figure 3. Tectonic framework of the Mid-Continent during the Permian (from Cubitt, 1979, p. 12).

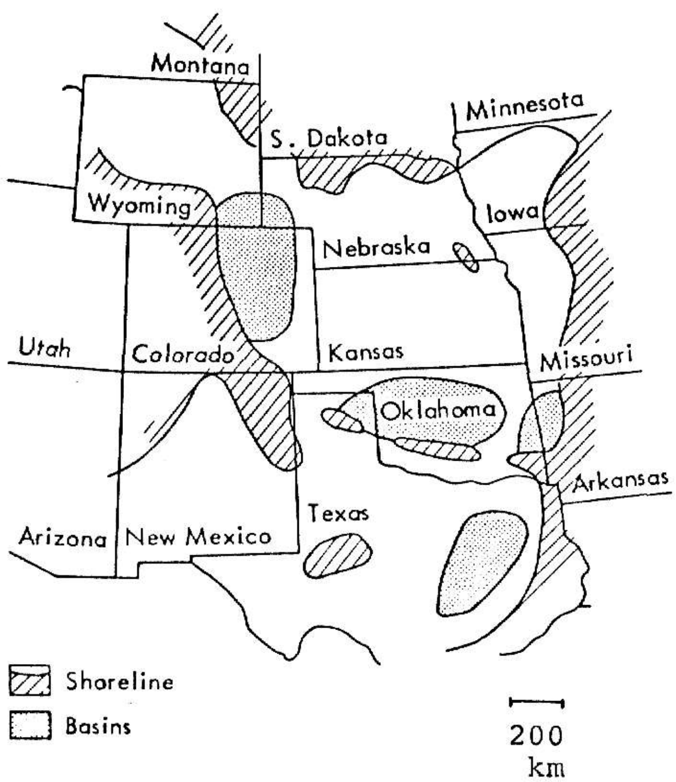
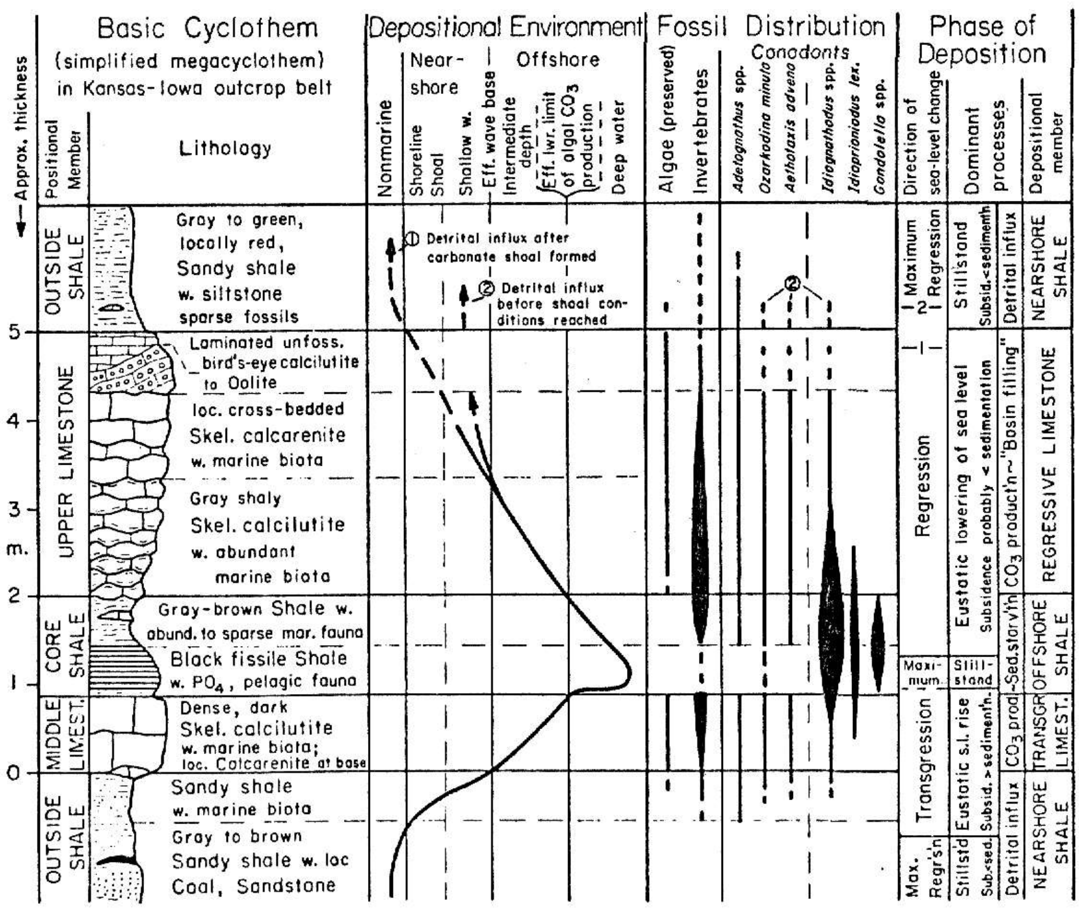


Figure 4. Heckel's model for deposition during the Pennsylvanian with anoxic bottom conditions (from Heckel, 1977, p. 1047).



Previous Work

Everyone discussing the theory of cyclic sedimentation has considered Permian red beds and associated units as indicators of shallow water deposition or a climatically dry environment or both. However, conflict exists over the depositional environment represented. Some workers have assigned these units to a totally non-marine environment (Lane, 1964), and others to a totally marine environment (Cubitt, 1979). Still others have considered these beds to be transitional, but disagree as to where the boundary between the two environments should be drawn.

The Eskridge Shale is one of the Lower Permian units which has been assigned to several near-shore environments. Moore (1936) assigned the Eskridge Shale to the early stages of a transgression and determined that red and green shales which contained no marine fossils were representative of periods of emergence and the calcareous zones in the green shales were marine. Elias (1937) argued that for ferric oxide (red color) to be preserved, subaerial exposure was required because a great accumulation of organic carbon in the subtidal zone produced a reducing environment. The boundary between oxidation (red color) and reduction (green color) was mean sea level. Green shales lacking marine fossils were deposited below mean tide level but above depths required by most shelled organisms of the time (0 to 30 feet). Wells (1950) based his conclusions on color and stratigraphy, and assumed that red beds required oxidizing environments. However, he concluded that red units indicated both marine and non-marine deposition along a fluctuating shoreline while the green shales were near-shore marine. Lane (1964) found fresh and possible brackish water microfossils in the Eskridge. He suggested that the deposition of red beds occurred on "a broad subaerial backshore *** with semipermanent ponds of fresh or slightly brackish water" (p. 16) and reduction in the ponds after deposition produced the green color. Cubitt (1979) studied the geochemistry, mineralogy and petrology of shale units throughout the Upper Palaeozoic. He interpreted the clayey shale facies of the Pennsylvanian as prodeltaic marine muds and the red, green and purple facies of the Lower Permian as calcareous equivalents of this facies.

Studies of cyclothemic equivalents of the Eskridge Shale also produce conflicting conclusions. Hattin (1957) studied the Wreford megacyclothem of which the Speiser Shale is the cyclothemic counterpart of the Eskridge. He determined from stratigraphic and palaeontologic data that red shale is non-marine and chiefly subaerial, whereas green shale is near-shore marine and possibly brackish. McCrone (1963) considered the red of the Roca Shale, a cyclothemic equivalent of the Eskridge, to be a detrital product of erosion from red soils. These units "*** were deposited at shallow, possibly intertidal, depths in slightly hyperhaline water ***" (p. 65). Green units are interpreted as intertidal deposits in slightly brackish water.

Comparison of interpretations point out the differences in opinion among these workers (Fig. 5). The majority of workers have based their conclusions on the assumption that red beds are indicative of non-marine deposition. However, recent studies (Berner, 1971; Broecker, 1974 and Walker, 1974) have shown that red beds are not good environmental indicators because they occur in a wide variety of depositional environments today.

All these previous studies have inferred depositional environments using only one or two lines of evidence, e.g. microfossils or stratigraphy or palaeontology.

Purpose

This investigation uses a combination of field observations and data from laboratory analyses to infer the most reasonable depositional environment and position in the cyclothem sequence for the Eskridge Shale.

GEOLOGIC SETTING

Stratigraphy

The Eskridge Shale is bounded by the Grenola Limestone below and the Beattie Limestone above (Fig. 6). The Neva Limestone Member of the Grenola Limestone and the Cottonwood Limestone Member of the Beattie Limestone have been studied (Lane, 1958 and Laporte, 1962, respectively) and determined to represent

Figure 5. Idealized sequence of a lower Permian "outside" shale and different authors' interpretation of the environment of deposition and relative depths of marine waters.

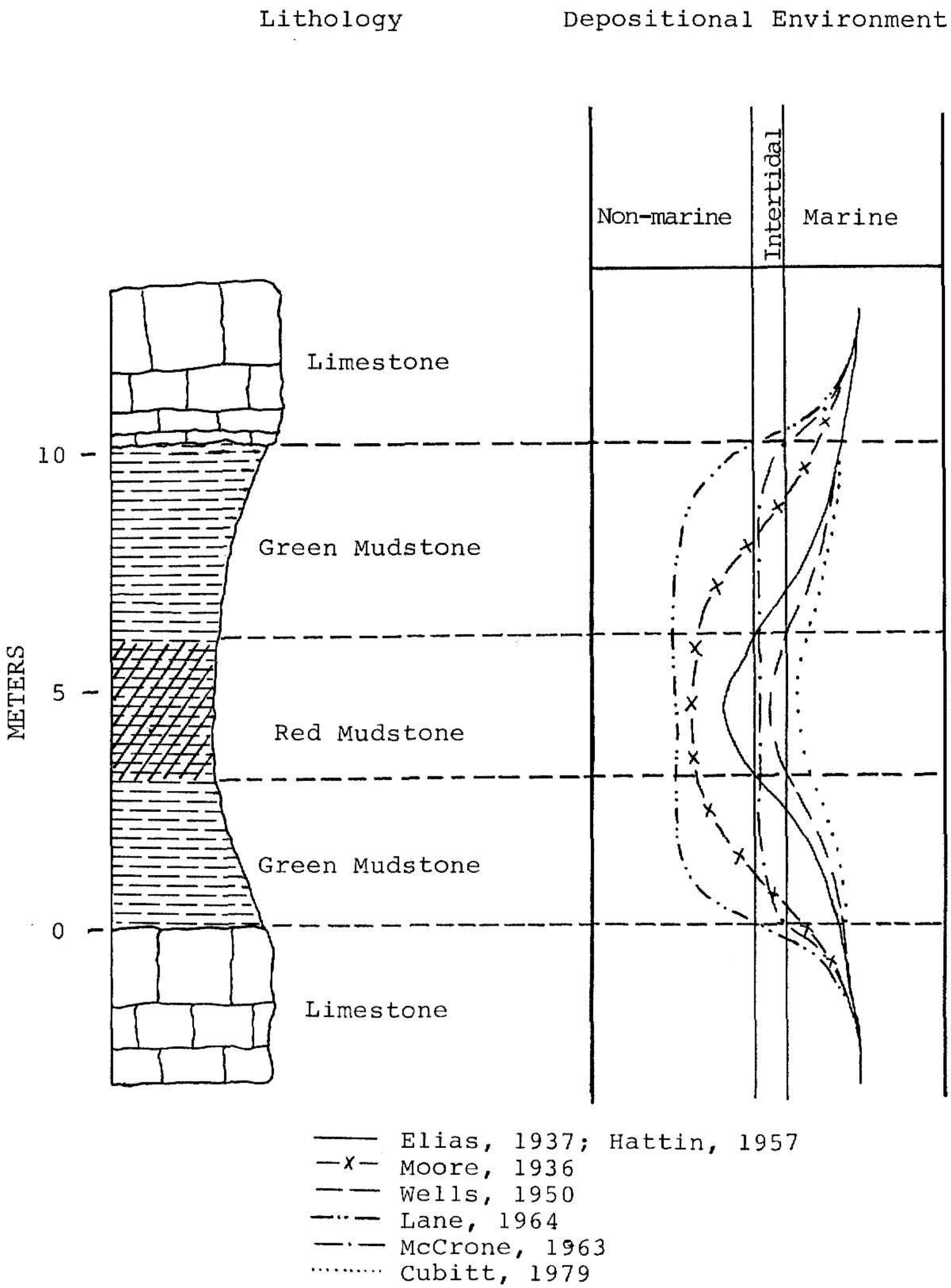
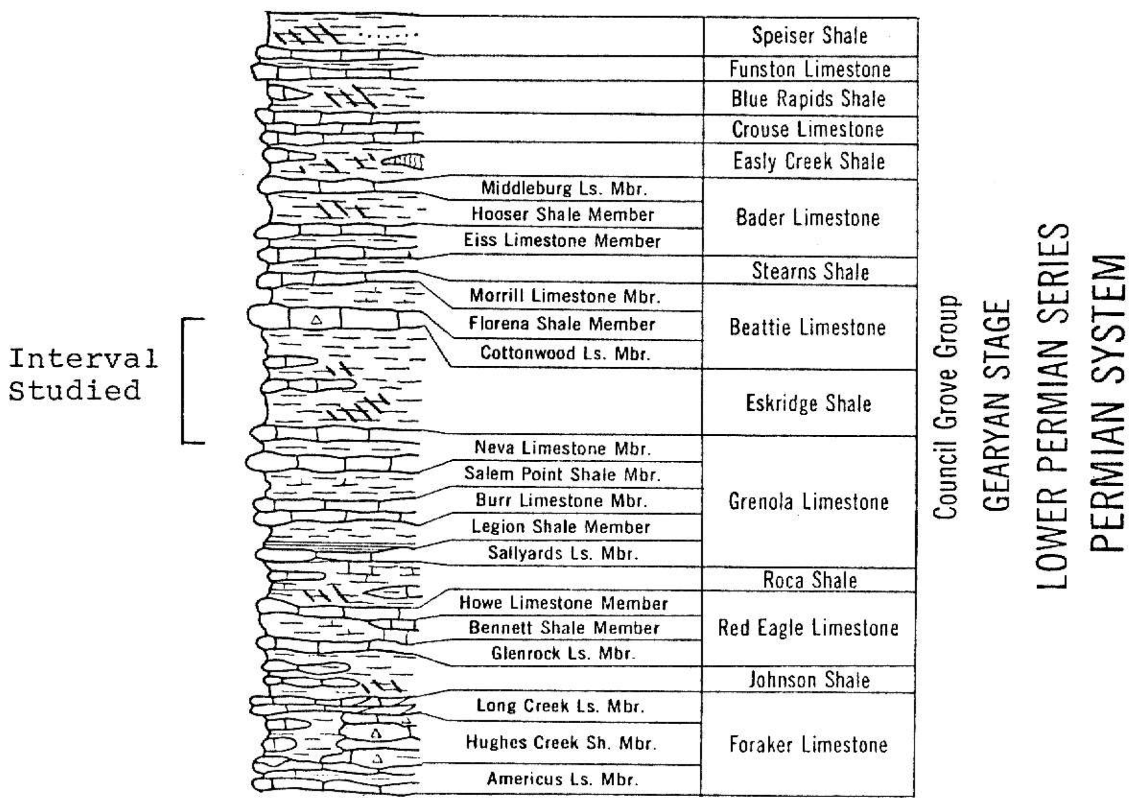


Figure 6. Stratigraphy of the Council Grove Group (from Zeller, 1968).



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normal marine conditions. However, Lane investigated the Neva Limestone Member only in southern Kansas and it appears to be less marine in the north.

The Eskridge Shale outcrops in a nearly north-south belt from eastern Marshall County to eastern Cowley County in Kansas. Wells (1950) measured almost 50 sections of the Eskridge Shale and found that the thickness ranges from 8 to 13 meters and there are from one to six thin, clayey limestone units. These limestone beds are usually less than 0.7 meter thick. The terrigenous units of the Eskridge are usually called shale and the formal name uses that term; however, because the majority of these units lack fissility they are here termed mudstone. Colors range from shades of red and brown to shades of olive and green.

Structure

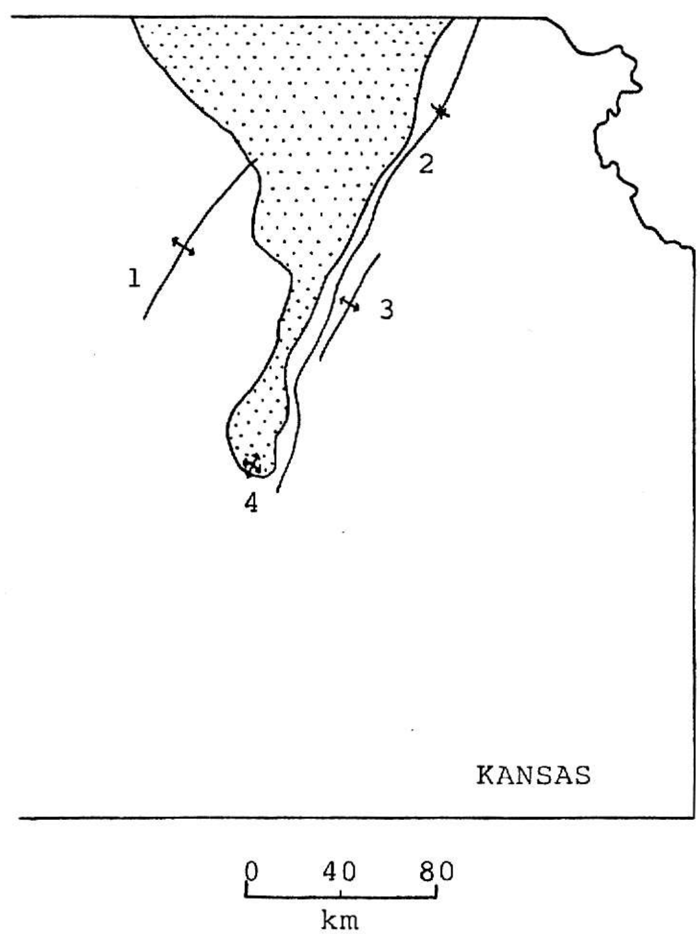
Surface expression of geologic structure is minimal. In Kansas, Mississippian through Permian age rocks dip genly (less than 1°) to the west. However, in the subsurface several major basins and anticlines exist (Fig. 7). Most movement occurred prior to the major unconformity of Late Mississippian and Early Pennsylvanian time (Chelikowsky, 1972). These structures are generally masked by Upper Pennsylvanian sedimentary rocks. The affect of these basins on Permian deposition is not fully known.

METHODS OF INVESTIGATION

Field Methods

General Statement.--Field observations provide the most direct and basic data available for determining depositional environment. Careful selection of sections and careful observations are a prerequisite to laboratory studies. Selection of sections to be studied was based on three criteria: (1) location in relation to palaeotopographic features, (2) location in relation to other possible sections, and, (3) completeness and accessibility of the section. Topographic features influencing the area during the time of deposition are shown in Figure 3.

Figure 7. Subsurface structures affecting deposition in the Palaeozoic (modified from Merriam, 1963, p. 184).



1. Abilene Anticline; 2. Brownville Syncline; 3. Alma-Davis Ranch Anticline; 4. Elmdale Dome; shaded area is the Nemaha Anticline.

Specific features influencing the eastern Kansas area were the Nemaha Anticline and the "Greenwood Shoal" (Laporte, 1962) (Fig. 8). Sections on each side of the axis of the Nemaha Anticline were sought to determine the affect of this structure, if any. The "Greenwood Shoal" reduced circulation with the open sea to the south and sections were limited to those north of this shoal. To study lateral variability, reasonably spaced sections were necessary. Finally, complete sections, including contacts with the Neva and Cottonwood, were desirable for study of these contacts.

Sections chosen include the type section and three others (Fig. 9). The type section was included because it is nearly complete and should be the most "typical" of all Eskridge Shale sections available. The other sections were chosen in relation to the type section because they fit the above criteria: (1) two sections are on the east flank of the Nemaha Anticline, two are on the west and all are north of the "Greenwood Shoal"; (2) two sections are relatively close to each other (within 5 km) and 50 to 80 kilometers from the other two sections, and (3) all the sections are relatively complete.

Description of Lithology.--Careful field work provides information on vertical and lateral variablity, sedimentary structures and orientation of fossils. These are basic data necessary for determining depositional environments. Units were separated on the basis of lithology, color or texture. Each unit was measured to the nearest centimeter and described according to lithology, both fresh and weathered color (Goddard and others, 1979), textures, structures and lateral variability, and fossil content (Ager, 1963, p. 317-318). Measured sections are in Appendix I. Three exposures could not be measured in one continuous vertical section. Offsets are noted in the measured sections and accompanied by pace and compass maps where necessary.

Collection of Samples.--Samples were collected from the upper Neva Limestone Member through the lower Cottonwood Limestone Member, where possible, to evaluate lithologic contacts and to correlate with data from previous studies. Terrigenous units were separated

Figure 8. Nemaha Anticline and "Greenwood Shoal" as topographic features during the Permian (modified from Laporte, 1962 and Merriam, 1963).

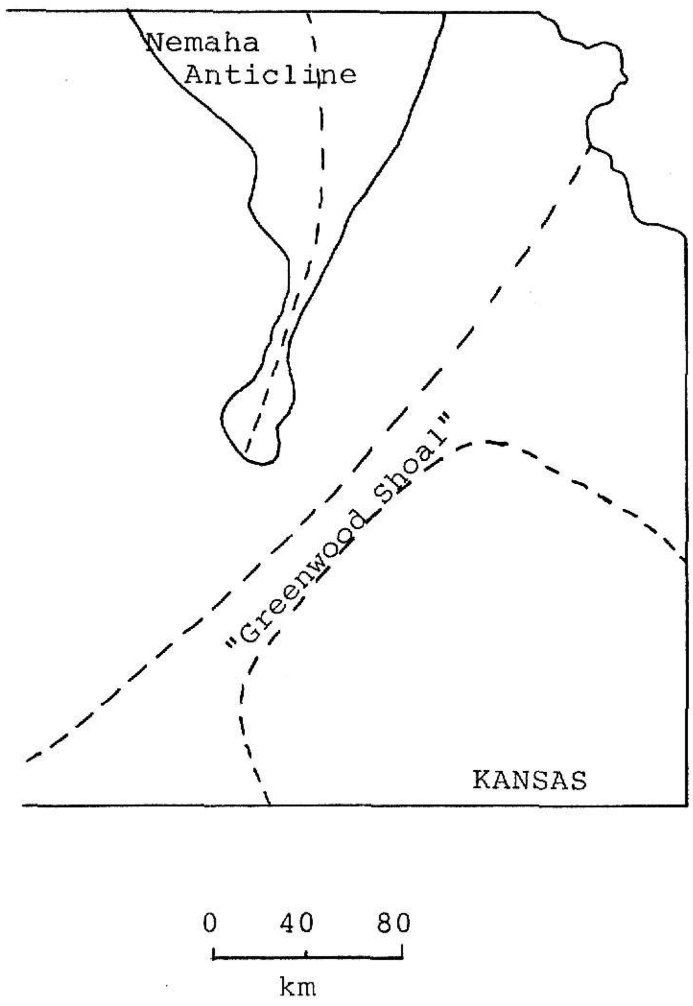
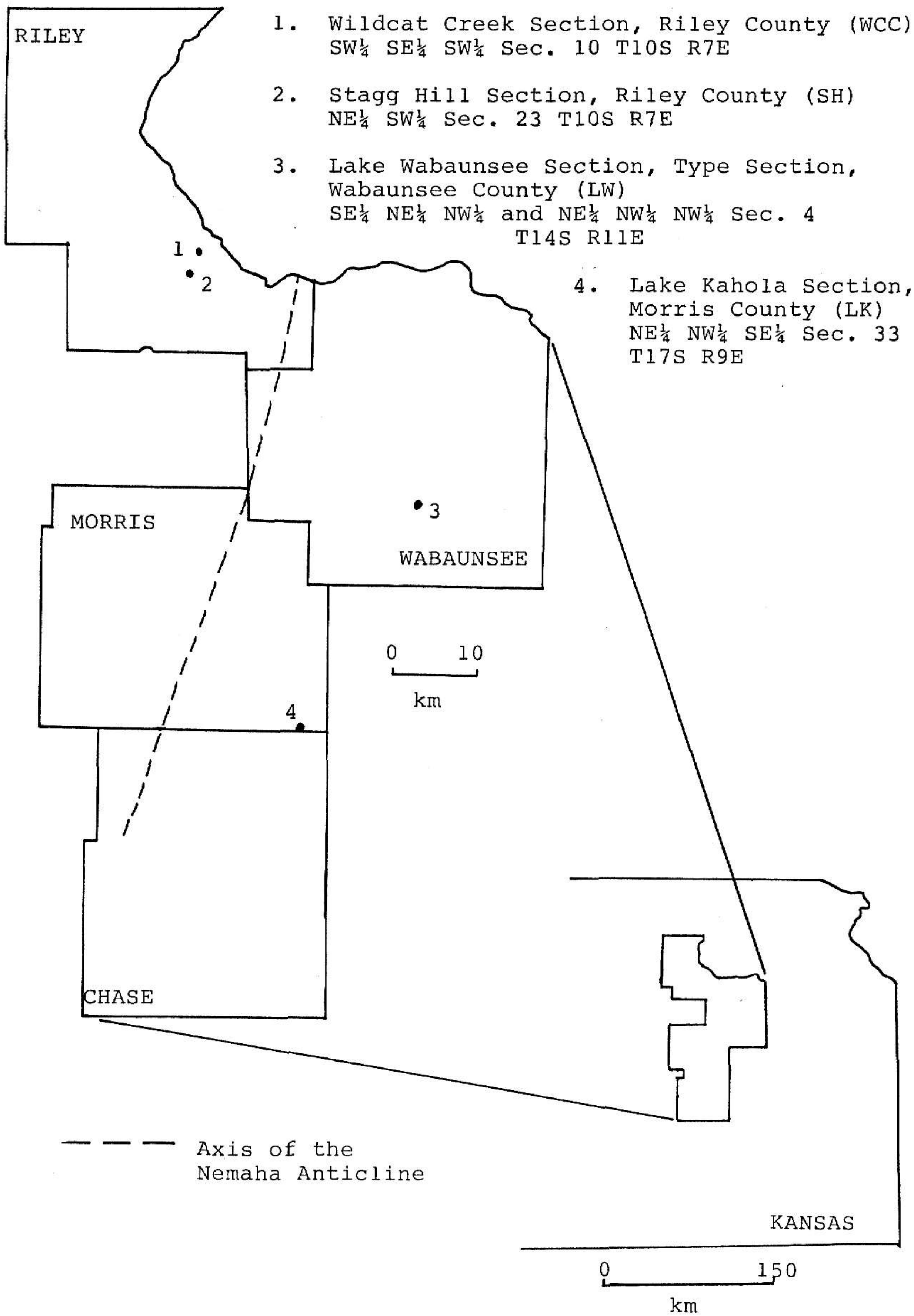


Figure 9. Location of measured sections.



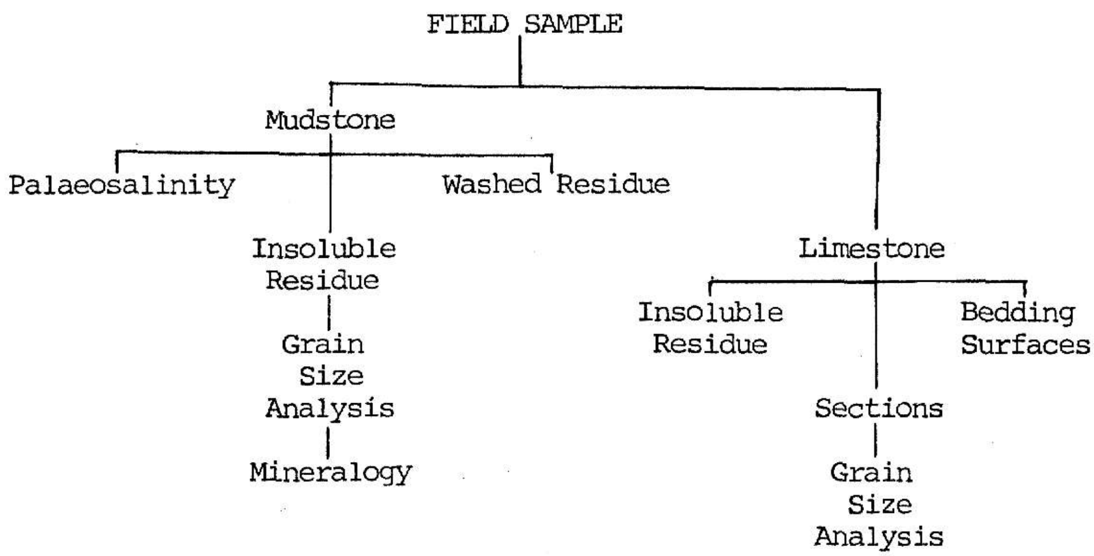
by visible lithologic differences and numbered chronologically. If the unit's thickness was greater than 0.16 meter, it was subdivided into the necessary number of subunits (e.g. 4A, 4B, 4C, and 4D) so that none was greater than 0.16 meter. Units were subdivided to test for differences in microfossils and mineralogic content within major lithologies. The value 0.16 meter was chosen because it conveniently subdivided the units. For terrigenous units, weathered debris was removed, the unit measured, subunits marked on the outcrop and fresh samples collected. For carbonate units, slabs were collected, each bedding plane numbered and the "up" direction marked. Samples were collected for all measured sections, although only those from the type section were analysed because of the number of samples and the time involved in each analysis. Correlation of laboratory results with field observations help identify depositional "packages" (lithologic units) and the depositional environment. These "packages" can then possibly be identified from field observations alone and applied to other sections.

Laboratory Methods

General Statement.--Several standard laboratory methods were selected to provide a wide range of data for determination of the depositional environment of the Eskridge Shale. Results from previous studies were integrated and compared to those obtained in this study. Terrigenous and carbonate units are treated separately because of their different textures and the applicability of a technique to each lithology (Fig. 10).

Terrigenous Units.--All terrigenous units of the Eskridge Shale are fine grained. Sedimentary structures are generally lacking, except for a few mudcracks and some bioturbation. There are, however, differences in color. Thus, determination of depositional environment solely from field observations is difficult. Therefore, laboratory analyses are necessary to recognize subtle changes not easily observed in the field and hopefully to define the environment more closely.

Figure 10. Laboratory procedures for terrigenous and carbonate units.



Washed residue.--Terrigenous units generally lacked macrofossils and many lacked microfossils. Possible depositional environments can be limited when organisms preserved in situ or transported only a short distance are found and their environmental tolerances considered. Samples were washed and picked for macrofossils and microfossils (Fig. 11). The results are tabulated in Appendix II.

Insoluble residue.--Changes in detrital influx are reflected in the clastic to carbonate ratio. Increased carbonate percentage could represent reduction in terrigenous sediment supply, an increase in distance from shore, increased fossil content, or a combination of these. Calcite and dolomite can occur as cement or as secondary minerals or both which alters the primary carbonate to clastic ratio. It was not possible to distinguish primary and secondary calcite with the methods used in this study. Dolomite is not always completely removed by glacial acetic acid. When dolomite occurred, its approximate weight was determined by estimating its percentage using the petrographic microscope and calculating its weight in the total sample. These estimated values were then removed and the ratios readjusted. Percent insoluble residue is compiled in Appendix III. These residues were then analysed for grain size.

Grain size.--Grain size is dependent on energy at the time of deposition, distance from and grain size of the source area and rate of deposition. Maximum grain size is related to maximum current energy, but is also dependent upon other factors. Grain size tends to decrease as distance from the source increases. If the source supplies only a limited range of grain sizes, only sizes equal to or smaller than those occurring in the source area will be found at the site of deposition. When the rate of deposition is high, time available for reworking and winnowing of smaller grains is reduced. All these factors interact to produce the final grain size distribution. Grain size data are in Appendix IV. After separation into size fractions (Fig. 12), the mineralogy of the samples was determined.

Figure 11. Flow sheet, washed residue procedure.

Sample

↓

Oven Dry (24 hr)

↓

Weigh 50 g

↓

Soak in Kerosene (24 hr)

↓

Decant Kerosene

↓

Add Boiling H_2O (24 hr)

↓

Wet Sieve (4Ø)

↓

Oven Dry

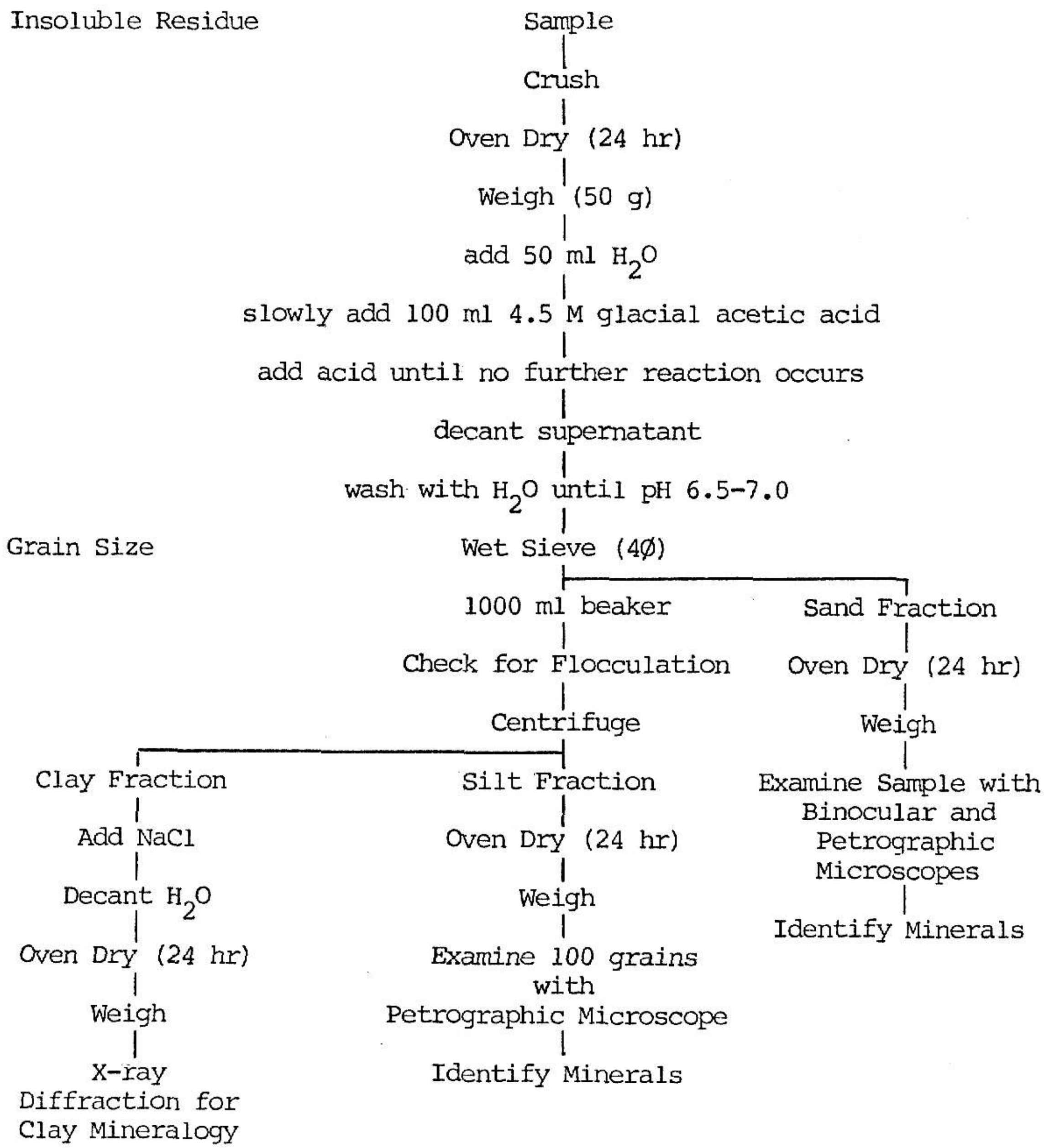
↓

Dry Sieve

↓

Retain each Fraction
for Identification

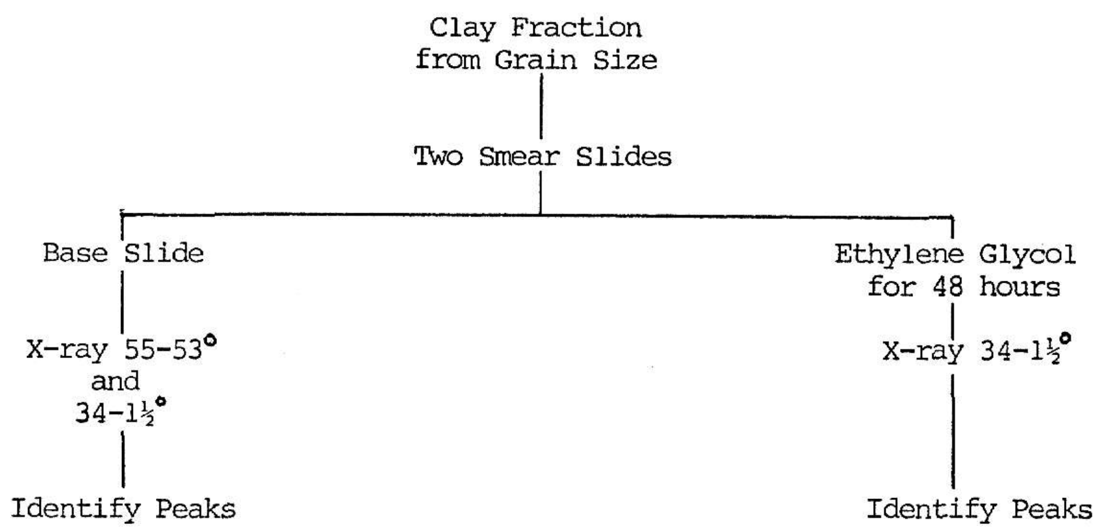
Figure 12. Flow sheet, insoluble residue, grain size and mineralogy procedure.



Mineralogy.--Mineralogy of the units may provide information on the source rocks and weathering in the source area, depositional environment and diagenesis. To X-ray the clay fraction, it had to be separated from the sand and silt fractions. Because this separation was necessary for the grain size analysis, these same samples could be used for mineralogic determinations. The sand and silt fractions were examined petrographically (Fig. 12) and the clay fractions were X-rayed (Fig. 13). Mineralogy of sands is listed in Appendix V, silts in Appendix VI, and clays in Appendix VII.

Palaeosalinity.--There have been no previous geochemical estimates of palaeosalinity made for the Eskridge Shale. Two possible methods for determining palaeosalinity are boron concentration (Degens, Williams and Keith, 1957) and sedimentary phosphate ratios (Nelson, 1967). Boron concentrations provide only a general distinction between marine and non-marine conditions and were not attempted. The sedimentary phosphate method provides palaeosalinity values to $\pm 4‰$. Precipitation of calcium and iron phosphate is dependent on water salinity with calcium phosphate dominant in marine waters and iron phosphate dominant in fresh water. The ratio of calcium phosphate to calcium plus iron phosphate reflects salinity at the time of deposition. This method has been successfully applied to other units (Jeppesen, 1972 and Gundrum, 1977). Samples from Jeppesen's work were still available and used to check the procedure. Two major problems, however, exist with this method. If the source area contains marine rocks, the ratio of calcium and iron phosphate may reflect this earlier exposure to marine waters and not be re-equilibriated in a fresh water environment. And, under reducing conditions, iron releases the phosphate anion and complexes with sulfur forming pyrite (Müller, 1969), thus decreasing the amount of iron phosphate in the rocks. Obviously, anything that alters the original iron and calcium phosphate ratio will indicate an erroneous salinity value. A decrease in iron phosphate results in a calculated salinity value that is too high. However, there are data indicating reasonable salinities for rocks in which pyrite and iron phosphate coexist (Guber, 1969). Salinity values are in Appendix VIII.

Figure 13. Flow sheet, clay mineralogy.



Carbonate Units.--All carbonate units of the Eskridge Shale at these four sections are thin-bedded (less than 3 centimeters). Small skeletal fragments occur in most units; their abundance is usually low but greater than in terrigenous units. The depositional environment of these units is more easily determined than for the terrigenous units because of the greater number of fossils.

Bedding surfaces.--Upper surfaces of carbonate units were sketched. Fossils were identified and their condition and orientation noted. The amount of abrasion and fragmentation is related to the amount of transport and energy. If the ecological requirements of fossils are known and considered and the fossils are preserved in life position, they provide powerful clues to the environment of deposition. Sketches and lists are in Appendix IX.

Petrology.--Point counts of thin sections from carbonate units were made. Microspar, spar, and each fossil type were counted and their percentage calculated. The texture and orientation of fossils were noted. Such information provides evidence of the history prior to deposition and the environment of deposition. These data are in Appendix X.

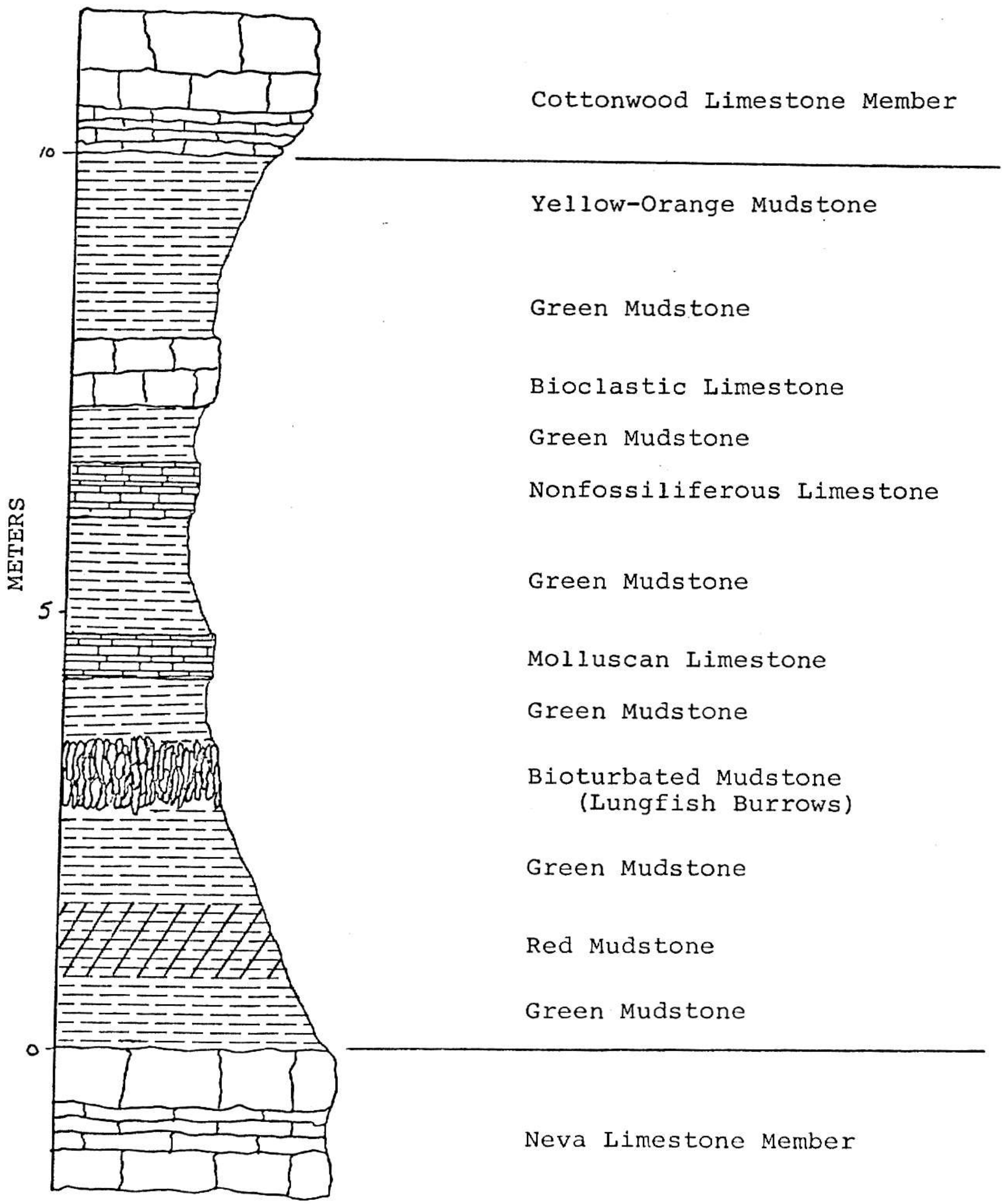
Insoluble residue.--One method directly applicable to both terrigenous and carbonate units is insoluble residue analysis. The main difference in treatment between the two is a reduction in sample size for carbonates. Application of this method to all the units indicates fluctuations in detrital influx during Eskridge deposition (Appendix III).

INTERPRETATION OF DATA

General Statement

Several lithologic units in the Eskridge Shale and similar shales are easily recognized in the field and are repetitive in time and space. Therefore, the physical characteristics and probable depositional environment of each unit will be discussed separately. A generalized section (Fig. 14) of the Eskridge shows the lithologic units recognized in this study. Grain size, mineralogy and palaeontology of the mudstones are uniform and use of any single technique does not distinquish lithologic units. When coupled with stratigraphic position; however, they make it possible

Figure 14. Diagrammatic section showing lithologies recognized in this study of the Eskridge Shale.



to infer depositional environments. Field observations and laboratory results plus comparison with similar cyclothemic units are combined to develop a better understanding of each lithologic unit.

As mentioned above, the sedimentary phosphate method for determining palaeosalinity has two major problems. Inheritance of calcium and iron phosphate from a previous exposure to marine water and the alteration of iron phosphate to pyrite under reducing conditions can cause erroneous calculated palaeosalinities. Reference samples from Jeppesen (1972) produced satisfactory results; therefore, the technique used for these analyses was satisfactory. This suggests that pyrite or erosion of marine rocks may be responsible for extremely low (less than 0.04 ppm) iron phosphate values and the palaeosalinity values are probably not reliable. For example, green mudstone/shale was deposited in the widest range of environments (see page 31), but the palaeosalinity values only range from 31.8 to 34.7‰ which is within experimental error (±4‰). Therefore, these data are not considered in determining depositional environments.

Neva Limestone Member

The Neva Limestone Member of the Grenola Limestone is light yellowish gray to greenish gray. At the Wildcat Creek locality, it is a massive, micritic, and homogenous limestone with no macrofossils and has a sharp, undulatory contact with the Eskridge. At the Stagg Hill locality, it is platy to massive with 25 to 75 percent skeletal fragments. At Lake Wabaunsee, the Neva ranges from a laminated, homogenous micrite with gypsum casts, occassional bivalves and ostracodes to a biosparite with algal-coated bivalves cemented by sparite. At Lake Kahola, the Neva includes a poorly cemented unit made up almost entirely of Permorphous and a few high-spired gastropods. Above this unit is a calcareous mudstone containing the same fossil assemblage. This is overlain by a thin-bedded limestone containing the same fossils concentrated in pockets. Above this limestone is a massive boxwork layer that ends abruptly and is replaced laterally by a clayey, laminated limestone suggestive of intertidal algal mats. Descriptions of the upper Crouse Limestone (Voran, 1977) are similar to the Neva at Lake Wabaunsee. The laminations and gypsum casts are nearly identical. Voran interpreted the Crouse that contains these features as high intertidal to supratidal.

Insoluble residues average 13.2 percent and range from 5 to 30 percent. They consist mainly of clay minerals in the clay-sized fraction with some quartz in the silt-sized fraction. Grain size of the carbonate fraction ranges from clay- to silt-sized matrix with sand-sized skeletal grains.

Fossils are abraded, fragmented and disarticulated. Productid spines, bivalve fragments, high-spired gastropods, crinoids, bryozoans, ostracodes and fish fragments occur in different values of density and diversity (Appendices IX and X). Pellets or intraclasts or both are common in the beds containing algal-coated bivalves.

Lane (1958) interpreted the Grenola Limestone in southern Kansas as a transgressive sequence with the Neva representative of the most marine conditions. The fusulinid phase reported by Lane was not observed in the four sections of this study. A greater density and diversity of organisms occurs in the south than in the exposures I studied.

Intraclasts indicate strong current or wave action. Algal-coated bivalves indicate energy sufficient to "flip" the shells and water depths shallow enough for active algal growth. Laminated beds with gypsum casts have articulated ostracodes filled with sparite and indicate tidal flat or intertidal conditions with little or no reworking of the sediment and increased salinity.

The biotic assemblage suggests marginal marine conditions. However, the degree of fragmentation and abrasion indicates considerable transport or a swash zone environment.

The Neva Limestone Member in the study area contains some marine organisms, but none are preserved in life position. Abrasion, fragmentation, orientation and algal coatings suggest relatively high energy, marginal marine conditions whereas laminated beds with gypsum casts suggest intertidal conditions.

Red Mudstone

Beds of red mudstone range from pale brown to grayish red, lack fissility, and weather into blocks of different sizes. Sedimentary structures are lacking, perhaps because of bioturbation (Byers, 1974); or they were not recognized. Possibly

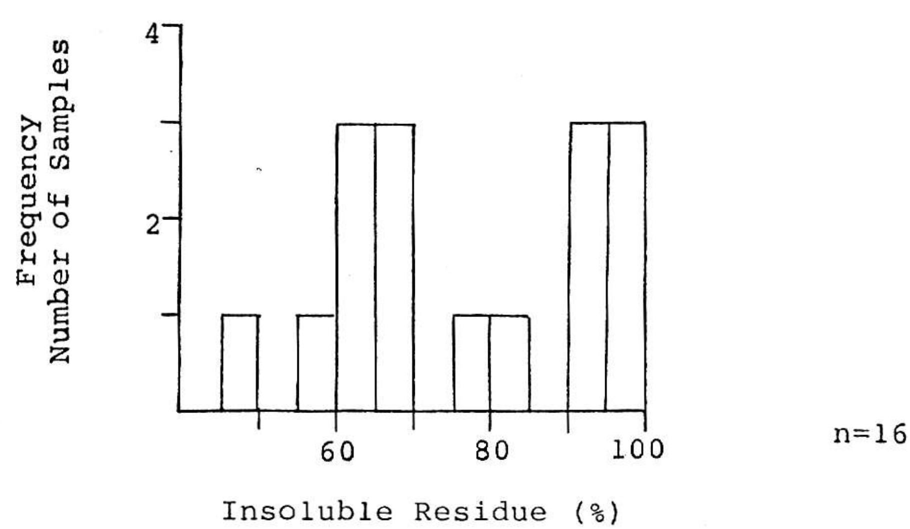
X-radiography would reveal structures not detectable by other means; however, none were observed by West (personal communication) using this technique.

Green mudstone occurs above and below the red mudstone. The contacts may be sharp, mottled, or thin bands of alternating colors.

Lateral variability is limited to thickness and number of beds of red mudstone, but other physical characteristics remain constant. All red mudstone is calcareous in which part are fragments of bivalves. The percentage of insoluble ranges from 49 to 97 with the majority falling in one of two modes: 57 to 67 percent and 90 to 97 percent (Fig. 15).

The sand fraction is composed entirely of quartz with little secondary gypsum and pyrite. Quartz also dominates the silt fraction (average 98.6 percent, range 94 to 99 percent) which contains 0 to 5 percent heavy minerals and 0 to 2 percent hematite (Appendix VI). Illite is the dominant mineral (average 98.4 percent, range 95 to 100 percent) of the clay fraction occurring alone or with a few percent chlorite and quartz (Appendix VII). Vermiculite occurs in the red mudstone of the upper part of the Eskridge at the type section.

Figure 15. Distribution of insoluble residue in red mudstone.



The majority of beds of red mudstone lack fossils. A few units contain bivalve and fish fragments, but the content is less than 50 fragments per 50 gram sample. Lane (1964) found foraminifers (Deckerella), ostracodes (Cavellina, Sansabella, Kelletina, Hollinella, and Carbonita) and holothurian ossicles in the Eskridge. Hattin (1957) found only rare charophyte oogonia in the red shales of the Wreford megacyclothem.

The fine grain size probably indicates relatively quiet conditions and skeletal fragments much larger (very coarse sand) than the average grain size (fine silt) suggest the fossils have not been transported very far.

Lack of feldspar and dominance of quartz and clay minerals suggest the source area was deeply weathered or had a limited mineralogy, as do some sedimentary sources.

The general lack of biogenic sedimentary structures indicates either an environment that was hostile to all organisms or a favorable environment in which the sediment was completely reworked. The lack of preserved hard parts and trace fossils suggests conditions were usually not favorable for most organisms. The controlling factors may have been fluctuations of salinity, temperature, high detrital influx, turbidity, or some combination of these.

Red beds have in the past been considered to be indicators of subaerial deposition in a warm, humid climate and red soils developing in a humid climate could have been the source. For the red to have been preserved means that oxidizing conditions prevailed and prevented reduction of iron in the sediments. These conditions were believed to occur only subaerially (Elias, 1937 and Hattin, 1957) . More recent studies have shown that red soils also develop in arid climates (Walker, 1975) and are deposited and preserved not just subaerially but also under marine conditions, usually in the deep sea (Broecker, 1974). Lack of organic carbon in the sediments and sufficient water circulation could prevent reducing conditions, thereby, preserving the red color. Thus red beds are not necessarily subaerial in origin. Red beds could be indicative of two very different soil producing environments--humid, subtropical regions and arid regions with a lack of vegetation (Van Houten, 1964).

The lack of plant fossils and the presence of evaporites suggest this region may have been arid or semi-arid during the Permian. Organic carbon may have been the controlling factor, its absence allowing for the preservation of red.

In southern Kansas, Hattin (1957) found channel sandstones in beds of red shale of the Speiser Shale and interpreted them to be flood plain deposits. No sandstone was found in my study area, and, considering the tectonics at the time with highest relief to the south (Fig. 3), beds of sandstone would not be expected this far north. Wells (1950) interpreted units of red shale as generally marine deposits that contain very little organic carbon. McCrone (1963) also considered the red shale to be marine, possibly intertidal. He suggested salinity may have been above normal at times. Heckel (1972) felt red beds were indicative of non-marine deposition unless they contained marine fossils. He based his interpretation on the difficulties in preserving red in most marine environments.

The units of red mudstone of the Eskridge are probably indicative of the shallowest phase of deposition because of their stratigraphic position, lack of marine fossils, and preservation of color. Whether they were subaerial, intertidal or very shallow marine is difficult to determine; possibly they were deposited under all of these conditions.

Green Mudstone/Shale

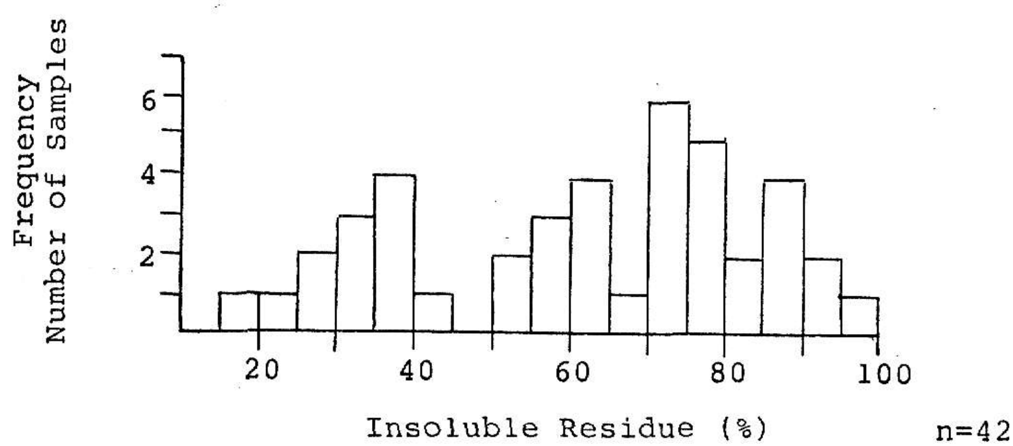
Green mudstone/shale range from pale olive and light olive gray to dark greenish gray and greenish black, it can be blocky, thin-bedded, or fissile and contains a few mudcracks. The darker beds tend to be thin-bedded or fissile. Blocky or paper thin beds of black shale occur as lenses in some beds of green mudstone.

Contacts with black shale are gradational and many are indicated by a mottled zone. Contacts with red mudstone are sharp or gradational, but contacts with beds of limestone are sharp.

Beds of green mudstone change laterally in thickness and number of units. Black shale is sparse and occurs only at the Wildcat Creek section. The black shale and darker green mudstone contain macerated plant debris and at one locality pinnules of Neuropteris were identified.

Green mudstone tends to be more calcareous than red mudstone. The insoluble residue content ranges from 19 to 90 percent with the majority in one of two modes: 25 to 39 percent and 71 to 78 percent (Fig. 16). Several subunits (LW 4A through 4G, 8A, 8B, 9B, 15A, 15B, 15C, 22B, and 22C) can be classified as limestone because they contain more than 50 percent carbonate.

Figure 16. Distribution of insoluble residue in green mudstone.



Mineralogy of the green mudstone is similar to that of the red mudstone. Quartz (average 97.2 percent, range 92 to 100 percent) and illite (average 97.3 percent, range 94 to 100 percent) dominate the silt and clay fractions, respectively. Chlorite is nearly twice as abundant (average 2.46 percent) than it is in red mudstone (average 1.30 percent) (Appendix VI). Secondary gypsum and pyrite are sparse. Secondary dolomite occurs in the lower part of the section.

Most units of green mudstone are unfossiliferous or contain less than 20 skeletal fragments per 50 gram sample. Subunits 14A and 17A from the Wabaunsee section are exceptions and both overlie limestones. Subunit 17A which overlies a molluscan limestone contains fish fragments and well-preserved Bairdia. In subunit 14A, overlying a clayey bioclastic limestone, bivalve and fish fragments, Bairdia and high-spired gastropods occur. At the Stagg Hill locality, green mudstone overlying a molluscan limestone contains Aviculopecten, Permorphous and Juresania in hydrodynamically stable positions.

Lane (1964) found charophytes, foraminifers (Ammodiscus and Ammovertella) and ostracodes (Carbonita, Sansabella, Candona?, Bairdiacypris, Gutschikia, Cavellina, and Hollinella). He suggested that green shale represents a reducing environment in backshore, fresh- to brackish-water, ponds. Hattin (1957) interpreted the ostracodes and terrestrial plant debris as indicative of near-shore brackish conditions. McCrone (1963) felt green shale is intertidal. Both Heckel (1972) and Cubitt (1979) concluded that green shale are prodelta to delta-front deposits.

Fine grain size may indicate low-energy conditions. Marine fossils usually indicate marine conditions. Low biologic density and diversity suggests conditions may have been harsh because of abnormal salinity, unfavorable water depths, high turbidity or a combination of these conditions.

Stratigraphic position of the units of green mudstone, between red mudstone and marine limestone, suggests they are transitional. The ostracodes indicate brackish conditions, mudcracks may indicate subaerial exposure and plant debris could suggest near-shore conditions. Green mudstone may represent overbank fluvial deposits with high organic carbon, intertidal or brackish to normal marine deposits and probably developed under all these conditions at different places and times.

Yellow-Orange Mudstone

Beds of yellow-orange mudstone are grayish orange and grayish yellow to yellowish gray. They are platy with very thin to medium bedding and are transitional units between the Eskridge and the Cottonwood. At all localities they occur just below the Cottonwood. The contact with the underlying mudstone is sharp to gradational and with the overlying platy beds of the lower Cottonwood it is gradational.

Lateral variability is limited to thickness and slight color changes. The insoluble residue decreases upward (Appendix III) and ranges from 32 to 53 percent with the contact between the Cottonwood and Eskridge somewhere within this lithology.

Mineralogy and grain size are similar to that of the red and green mudstones. There is less than 0.05 percent sand-sized grains. Quartz dominates (average 95.3 percent, range 94 to 98 percent) the silt fraction and heavy minerals range from 2 to 6 percent. Only a trace of quartz occurs in the clay fraction in which illite dominates (average 98.3 percent, range 97 to 99 percent) with less than 2.6 percent chlorite. Secondary gypsum and pyrite are sparse.

The most striking difference between this and the other units of mudstone is the increase in biologic diversity and density which also increase upward within the unit. Productid spines and fragments, bivalve fragments, crinoid stems and calyx plates, echinoid spines, and the ostracodes <u>Bairdia</u>, <u>Bairdiacypris</u>, and <u>Hollinella</u> occur throughout the unit. High-spired and planispiral gastropods are only in subunit 22C just below the Cottonwood.

Marine organisms, such as crinoids and echinoids, with narrow salinity tolerances suggest that this was an area of normal marine conditions with a lower rate of terrigenous influx. The site of deposition must have been fairly calm to prevent removal of silt- and clay-sized grains. Gastropods and ostracodes are adapted to soft-bottom conditions. The other organisms usually prefer firmer bottoms and their density may have been dependent on the abundance of appropriate attachment sites furnished by shelled forms.

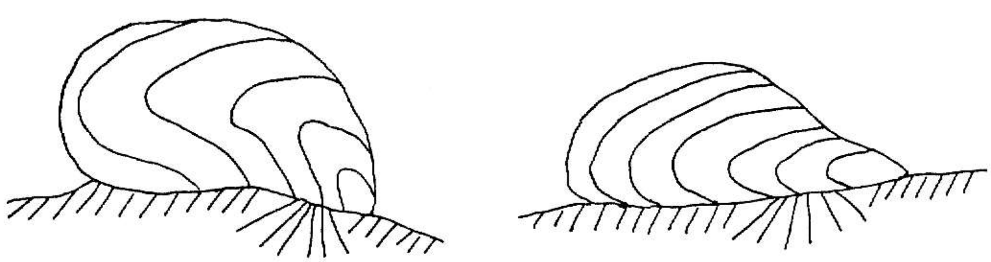
The fossiliferous yellow-orange units of mudstone are transitional between a time of high detrital influx represented by the Eskridge and one of low detrital influx represented by the Cottonwood. They probably reflect normal salinity and temperature conditions with small fluctuations and therefore could represent deeper water than the other mudstones.

Molluscan Limestone

Beds of molluscan limestone are light gray to greenish gray. At the Wildcat Creek and Stagg Hill localities, only a single bed, 0.04 to 0.09 meter thick, occurs, but at lakes Wabaunsee and Kahola, several beds with a total thickness of up to 0.62 meter occur. Contacts with green mudstone above and below are sharp.

The molluscan limestone is micritic with 12 to 25 percent insolubles (average 12 to 14 percent) that consists of clay-sized particles and less than 10 percent quartz silt. Its thickness and position in the section change laterally. Biotic content also differs from one locality to another. Most beds of this limestone contain Aviculopecten, Septimyalina, and Bellerophon. Septimyalina is absent at the type locality, but Clavicosta? and Pseudomonotis? are present. Bellerophon is absent at lakes Kahola and Wabaunsee.

Species of Septimyalina seem to be preserved in life position. Their orientation is similar to that of their closest living analogue, Mytilus. The ventral side is more flattened, possibly due to compaction, in Septimyalina than in Mytilus and is parallel to bedding (Fig. 17). Mytilus is adapted to the intertidal and shallow subtidal zone and can close its shell tightly during low tide, retaining water within the shell. Occurrences of Septimyalina suggest it probably was adapted similarly to fluctuating conditions and preferred shallow waters (Newell, 1942).



A. Mytilus (x1). B. Septimyalina (x1).

Figure 17. Orientation of Septimyalina and Mytilus.

Pectens are found with their commissural plane parallel to bedding. Pectens lie on one valve or byssally attach to a firm object (Newell, 1937). Whether these specimens are preserved in life position and whether most valves are articulated is unknown. Those valves where articulation can be determined are usually disarticulated which suggests some transport; they may have floated in from slightly deeper water after the animal died.

A locality approximately 9 kilometers from the Wildcat Creek and Stagg Hill localities was observed during field reconnaissance. The "normal" fossil assemblage was absent and replaced by a pebble conglomerate containing clay balls and limestone intraclasts. Laterally it grades into a sandy conglomerate in which smaller limestone clasts are strewn across a bedding surface or occur as stringers. The "normal" assemblage occurs in the sandy conglomerate in reduced numbers and several valves of Septimyalina are articulated but are not in a life orientation.

Septimyalina and Bellerophon are absent at the type section. Clavicosta? and Pseudomonotis? are found with Aviculopecten?. Most fossils are preserved as molds and difficult to identify. If the identification of Pseudomonotis, a primitive oyster, is correct, then the presence of a firm substrate to which it could have cemented is suggested (Newell and Boyd, 1970).

The texture of the lower part of the unit is similar to that of units of molluscan limestone elsewhere. The upper part, however, contains skeletal fragments and high-spired gastropods which reflects an increase in energy levels. Pecten shells are algal coated and bedding is more "disturbed", possibly bioturbated.

At localities where the molluscan limestone occurs as a single bed, shells are disarticulated, parallel to bedding, and generally concave down in the lower part of the unit. On the upper surface, however, individuals are articulated, parallel to bedding or in life position.

Elias (1937) interpreted this facies as representative of relatively deep conditions (60 to 90 feet). His molluscan phase generally contained a more diverse assemblage including burrowing bivalves (*e.g.* *Wilkingia* and *Aviculopinna*), bryozoans, and gastropods. Gastropods are not common at most localities studied and the other forms are absent.

Hattin (1957) described and pictured limestone beds from the Wreford megacyclothem that are almost identical to these beds. He suggested they were shallow and slightly brackish marine units. The lack of crinoids, echinoids, and bryozoans suggests restricted conditions due to extremes of bottom conditions, such as temperature, salinity or substrate stability.

Laporte (1962) described a shelly facies of the Cottonwood Limestone Member that contains the elements of molluscan limestone discussed here plus several other bivalves (*Aviculopinna*, *Schizodus*, and *Wilkingia*) and brachiopods (*Derbyia*, *Meekella*, *Neochonetes*, *Reticulatia*, and *Juresania*). He interpreted the environment of deposition as offshore with good circulation, low turbulence, and intermediate to low terrigenous influx. The reduced fossil assemblage of the limestone units of the Eskridge suggests some restriction of conditions that prevented the bivalves and brachiopods of the shelly facies from living in this environment. Reduced or fluctuating salinity, higher turbulence or terrigenous influx may have prevented these organisms from settling in these areas.

Localities where intraclasts occur certainly indicate higher energy. Units with disarticulated bivalves could indicate a moderate current. Where *Septimyalina* appear to be *in situ*, calm waters or rapid burial is suggested. By analogy to *Mytilus*, a living form similar to *Septimyalina*, these beds suggest a shallow, brackish environment with moderate to low detrital influx.

Bioturbated Mudstone

Units of bioturbated mudstone range from light bluish gray to greenish black. This unit occurs only at the Wildcat Creek locality, therefore, it has not been studied in the detail of the type section at Lake Wabaunsee. Bioturbation is evidenced by roughly cylindrical burrows that range from 3 to 7 centimeters in diameter and from 5 to 10 centimeters in length; in all probability they are lungfish burrows. The unit is almost entirely burrows, probably representing several periods of burrowing. Green mudstone occurs above and below the unit. The interior of these burrows appears desiccated (cracked), but no lungfish remains were found.

Lungfish were adapted to life in freshwater lakes and rivers which periodically dried up. To prevent desiccation during these dry episodes, they aestivated or burrowed (Beerbower, 1968). Their burrows indicate a river or freshwater pond that periodically dried up. However, this was not the last site available to lungfish because no lungfish bones have been found in any of these burrows.

Nonfossiliferous Limestone

Nonfossiliferous limestone occurs as a very light gray, irregular, almost nodular bed within a red mudstone; or it may be pale olive to light olive gray, laminated, clayey and occur within a green mudstone or with a green mudstone below and a yellow-orange mudstone above.

The light gray nonfossiliferous limestone is silty with only 14 percent insolubles. It is persistent in outcrop, but occurs only at the Lake Wabaunsee locality. Its occurrence within a red mudstone suggests it may be a freshwater limestone or a caliche deposit. The lack of internal bedding or other structure makes it difficult to interpret.

The green nonfossiliferous limestone has a higher insoluble content, probably 40 to 60 percent based on field estimate. At Lake Kahola mudcracks occur, but usually the only structures are fine laminations which are probably indicative of conditions with high detrital influx which regularly fluctuated, possibly with algal mats. Mudcracks indicate a period of extended subaerial exposure. The laminations and mudcracks suggest these units are intertidal (Reineck and Singh, 1973).

Bioclastic Limestone

There are two types of bioclastic limestone--"clean" and "dirty". The "clean" bioclastic limestone consists almost entirely of comminuted skeletal fragments containing virtually no silt or clay. The grain size is coarse to very coarse and, by visual estimates, it is moderate to moderately well sorted.

This unit has been reworked and winnowed by relatively high energy currents or waves transporting a marginal marine assemblage. High-energy conditions must have prevailed long enough to sort and abrade the skeletal fragments.

The "dirty" or clayey bioclastic limestone has 4 to 16 percent insolubles with a matrix of 12 to 64 percent micrite. Coarse sand to granule-sized skeletal fragments in a fine-grained matrix results in a bimodal distribution. Organic grains are fragments of algal-coated bivalves, ostracodes and gastropods that commonly occur as stringers or in pockets. Abundance of fine-grain sizes (up to 65 percent) indicates little reworking. This limestone also contains a marginal marine assemblage. High-energy conditions did not prevail long enough to remove the fine fraction and sort and round the skeletal grains.

Cottonwood Limestone Member

The Cottonwood Limestone Member of the Beattie Limestone shows very little lateral variation throughout the study area. It is very pale orange to pale yellowish brown; beds are platy at the base becoming thicker upward. Insolubles decrease from about 30 percent at the base to 18 percent (Laporte, 1962) and contain mostly clay-sized grains with some quartz silt. The massive upper bed(s) form(s) good outcrops and is easily located in the field.

Laporte (1962) identified five facies within the Cottonwood of which only the bioclastic facies in the lower part and the fusuline facies in the upper part are present at localities in the study area. He described the bioclastic facies as containing comminuted productids, bivalves, gastropods, trilobites, crinoids, and bryozoans and the fusuline facies as consisting almost entirely of fusulinids. This describes well the Cottonwood at all four sections studied.

Laporte (1962) interpreted the deposition of the bioclastic and fusuline facies as a "shallow, well-lit, moderately turbulent, offshore environment" (p. 539) with some restriction of circulation.

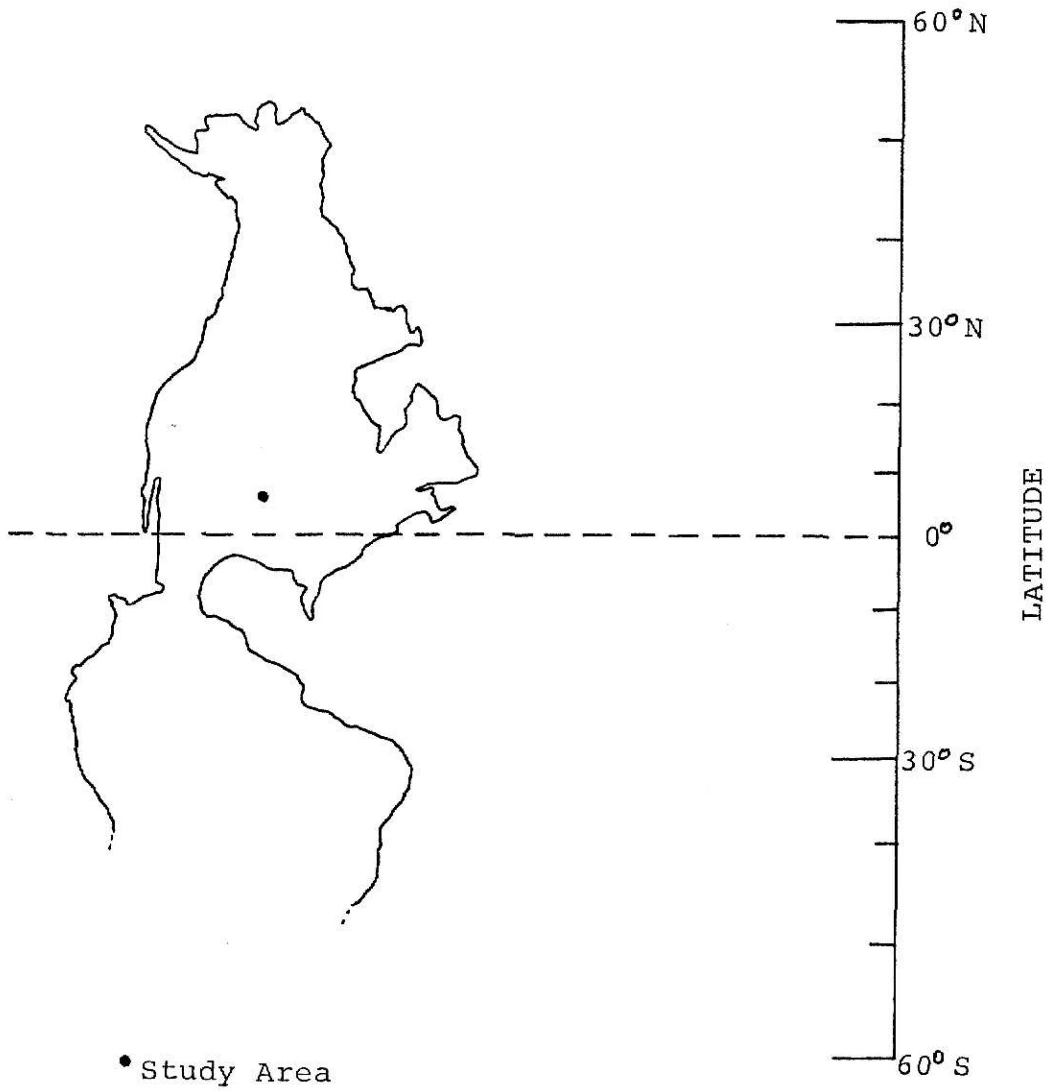
INTEGRATION OF DATA

Climate

Smith, Briden and Drewry (1971) have determined that during the Early Permian, the study area was in an equatorial position (Fig. 18). Present-day equatorial environments are basically tropical or savannah. These environments are known to produce red soils today (Walker, 1975) and erosion of these soils can then produce red beds under the proper sedimentary conditions. Red color can be preserved when organic carbon is destroyed before sediment burial which occurs in tropical climates or when little vegetation is present as in arid climates (Berner, 1971). Red beds with abundant kaolinite are indicative of a source area in a warm, humid climate, but illite-chlorite dominated clay assemblages provide no specific information on climate. Where red-bed facies are associated with coal or other plant deposits, these beds are probably indicative of warm, humid climates. However, when they are associated with evaporite deposits they are indicative of hot, dry climates (Van Houten, 1964).

Stratigraphic evidence indicates an overall trend toward dryer conditions from Pennsylvanian to the end of Permian time (McKee and others, 1967). Deeper water during the Pennsylvanian resulted in the development of thermoclines, but reduction in water depths during the Permian prevented thermocline development and deposition of black, phosphatic shales (Heckel, 1977). Extensive evaporite deposits are common in the Late Permian. Gypsum casts in the Neva Limestone Member (Appendix X) and gypsum pseudomorphs of salt in the lower Eskridge Shale (Appendix V) are indicative of hypersaline conditions generally attributed to arid conditions. Tropical conditions of the Late Pennsylvanian and arid conditions of the Late Permian indicate an overall reduction in humidity. The climate during Early Permian times was probably transitional between these two extremes.

Figure 18. Position of the equator during Early Permian times (Smith, Briden, Drewry, 1971, Text-Fig. 10).



The general lack of plant debris in near-shore deposits and the lack of marsh deposits suggests that the climate may have been too dry for extensive plant growth. Plants did not extensively exploit arid environments until the post Palaeozoic (Delevoryas, 1963). However, plant debris in a few localities of the Eskridge is similar to part of the fauna of the Roca Shale, a cyclothemic counterpart of the Eskridge, which indicates periodic moist climate (Warren, 1969).

Lungfish burrows indicate periods when the ponds or rivers in which these fish lived dried up, suggesting semi-arid conditions. Ephemeral streams occur when rainfall is not sufficient to provide run-off all year. Therefore, these extreme periods were probably not annual, but may have represented times of drought. However, sufficient moisture was needed to provide a means for transporting sediments.

Evidence indicates that during deposition of the Eskridge Shale the climate was semi-arid with periodic extended dry spells.

Depositional Environment

General Aspects.--Red beds represent very shallow to subaerial or deep sea deposition. If the red units within the Eskridge Shale are representative of deepest water conditions, they were deposited farthest from shore with good bottom circulation and very little organic carbon (Reineck and Singh, 1973). The sequence, red mudstone-green mudstone-marine limestone, would then suggest that green mudstone is normal marine and relatively deep. However, evidence shows that green mudstone ranges from intertidal (laminations and mudcracks) to brackish marine (abundant brackish ostracodes) to normal or near-normal marine (ostracodes, gastropods, and bivalves). Plant debris would not be expected in far-offshore marine shale, however, it does occur in these beds of green mudstone. The expected sequence and assemblages as the sea shallowed from "deep" marine to normal marine should be found; they are not. Therefore, the evidence rules out "deep" water deposition for the red beds of the Eskridge Shale. The Eskridge is representative of the shallowest marine to subaerial phases of deposition.

Sequence of Environments.--The sequence of lithologies reflects fluctuations in different controlling factors: (1) terrigenous influx, (2) salinity, (3) water depth or distance from shore, and (4) amount of organic carbon deposited with the sediments. The generalized section can be interpreted in view of these controlling factors as summarized in Table 2. The general lack of sedimentary structures makes interpretation of these units difficult. The basic sequence can be described as follows: (1) intertidal to marine conditions and relatively low terrigenous influx (Neva Limestone Member), (2) marine to intertidal conditions with a wide range of salinities and high terrigenous influx (green mudstone), (3) fresh water to subaerial conditions, possibly intertidal, with a lack of organic carbon, and high terrigenous influx (red mudstone), (4) a return to conditions similar to 2 above, sometimes interrupted by pond or river conditions (bioturbated mudstone), (5) a slight marine incursion with low to normal salinity and very shallow water and relatively low terrigenous influx (molluscan limestone), (6) another return to conditions of 2, (7) intertidal conditions with moderate terrigenous influx (nonfossiliferous limestone), (8) another return to conditions of 2, (9) brackish to marginal marine conditions with relatively high energy (bioclastic limestone), (10) marine conditions with normal salinity and high terrigenous influx (yellow-orange mudstone), and (11) marine conditions with normal salinity and low terrigenous influx (Cottonwood Limestone Member) (Fig. 19).

This generalized description of relative environments must be explained in relation to the overall tectonic and sedimentologic framework of the Permian. The model used must provide for variations in fresh water influence, amount of terrigenous influx and depth or distance from shore.

Orogenic development is not a steady process, but consists of periods of active uplift or subsidence followed by relatively quiescent periods. Uplift increases erosion and the production of terrigenous debris. This increased influx of detritus was carried by sluggish, sediment-filled rivers into the basin of deposition infilling it to different levels. Sluggish, overloaded rivers suggest something similar to braided streams with

Table 2. Lithologies recognized in the Eskridge Shale and the controlling factors determining their outcrop characteristics.

Lithology	Terrigenous Influx	Salinity	Distance from Shore/Depth	Organic Carbon
Marine limestone (Cottonwood and Neva)	low	normal	far/relatively deep	moderate
Bioclastic limestone	low to moderate	normal	shallow to moderate	moderate
Molluscan limestone	low	brackish	intertidal to shallow	moderate
Nonfossiliferous limestone	moderate to high	brackish	intertidal to shallow	moderate to high
Yellow-Orange mudstone	high	normal	moderate	moderate
Green mudstone	high	hypersaline, normal to brackish	intertidal to relatively deep	moderate to high
Red mudstone	high	fresh to brackish	subaerial to shallow	low
Bioturbated mudstone	high	fresh	backshore	moderate

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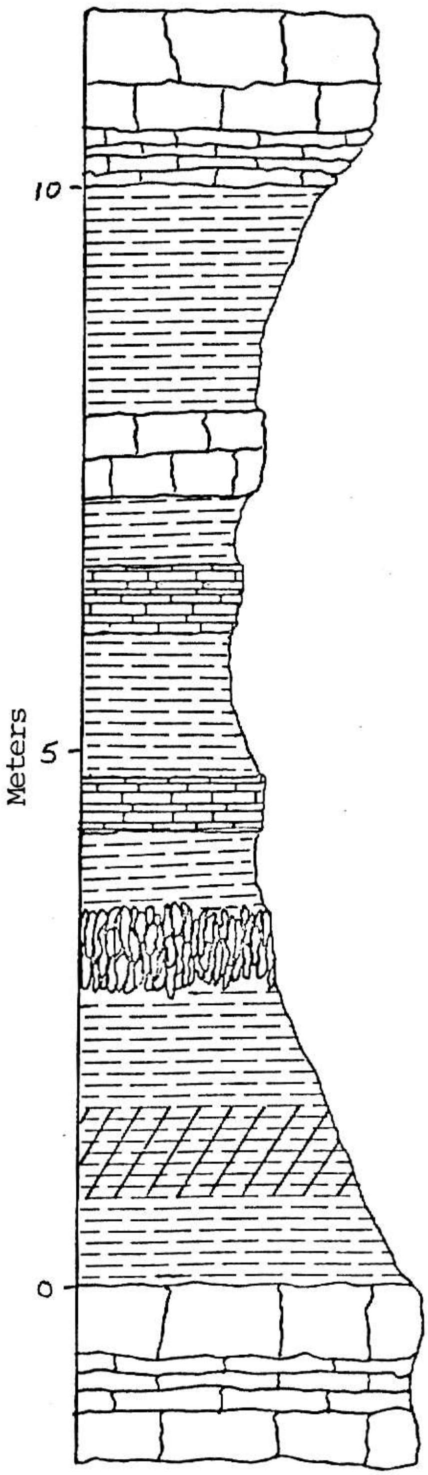
Figure 19. Diagrammatic vertical sequence and lithologic parameters of the Eskridge Shale.



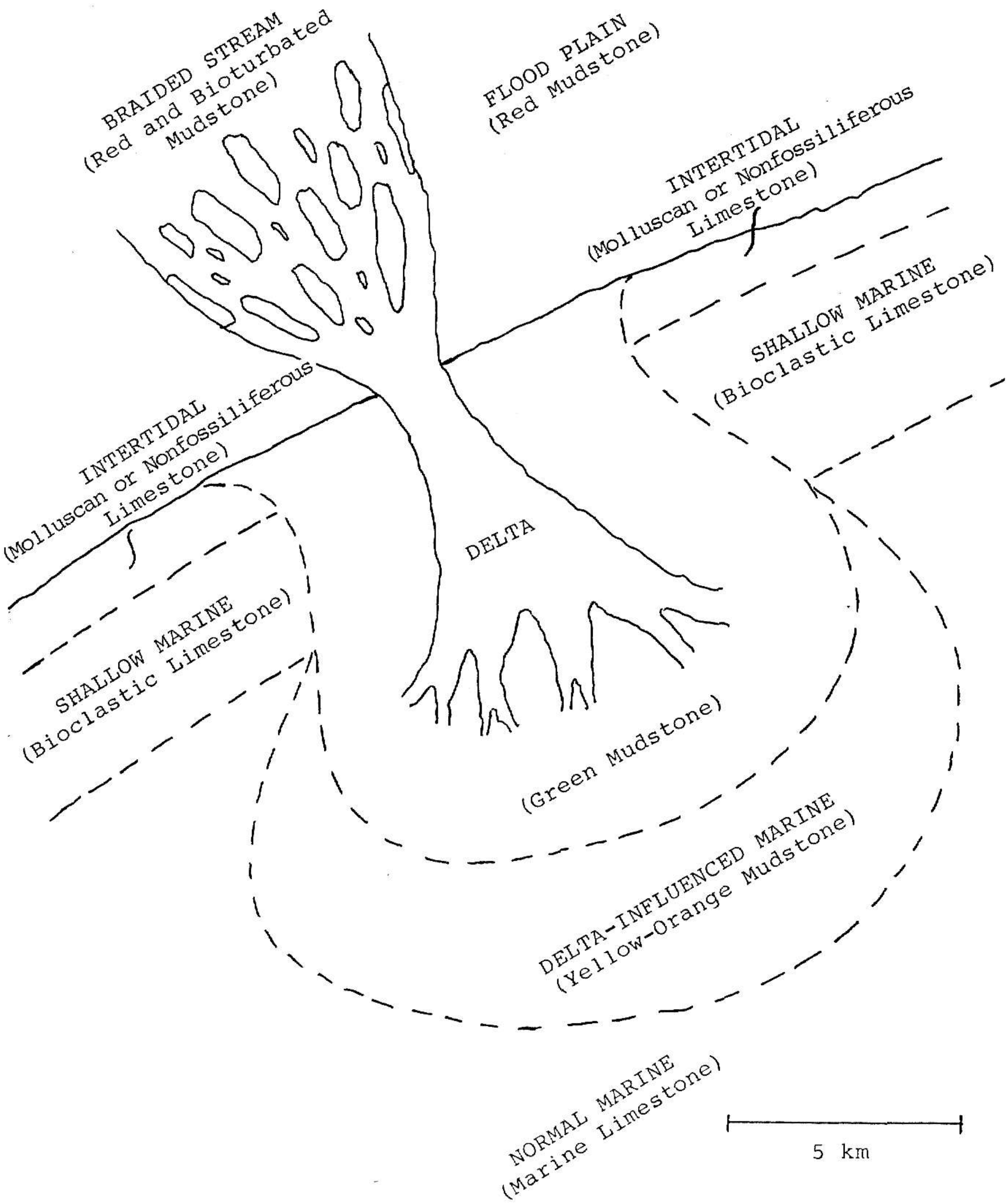
Lithology	Terrigenous Influx	Salinity
Cottonwood Limestone Member	low	normal
Yellow-Orange Mudstone	high	normal
Green Mudstone	high	hypersaline, normal to brackish
Bioclastic Limestone	low to moderate	normal
Green Mudstone (same as Green Mudstone above)		
Nonfossiliferous Limestone	moderate to high	brackish
Green Mudstone (same as Green Mudstone above)		
Molluscan Limestone	low	brackish
Green Mudstone (same as Green Mudstone above)		
Bioturbated Mudstone	high	fresh
Green Mudstone (same as Green Mudstone above)		
Red Mudstone	high	fresh to brackish
Green Mudstone (same as Green Mudstone above)		
Neva Limestone Member	low	normal to brackish

Fossils	Sedimentary Structures	Depositional Environment
brachiopods, bivalves, crinoids, echinoids, bryozoans, fusulinids, trilobites, gastropods, mostly fragments	none	shallow, normal marine, offshore, moderate energy
brachiopods, bivalves, crinoids, echinoids, ostracodes, gastropods, mostly fragments	none	shallow, normal marine, offshore
brachiopods, ostracodes, gastropods, worm tubes, fish fragments, mostly fragments	gypsum after salt casts	intertidal to brackish to marginal marine
bivalves, gastropods, ostracodes	none	nearshore, marginal marine
none	laminations, mudcracks	intertidal to shallow marine
bivalves, bellerophontids	laminations or none	low intertidal to subtidal
lungfish burrows	none	fresh water pond or river
fish and bivalve fragments	none	subaerial, fluvial, intertidal?
bivalves, gastropods, ostracodes, brachiopods, crinoids, bryozoans, echinoids.	laminations, gypsum casts	intertidal to subtidal

poor delta development. During periods of low influx, the study area was characterized by brackish to normal marine conditions (Neva Limestone Member). During the initial stages of influx, marine to brackish conditions continued to dominate. Green mudstone was deposited in marine to intertidal environments. As the delta continued to fill the basin, low gradients developed; low backshore areas became ponds which frequently dried up (lungfish burrows). These areas must have supported a limited flora and fauna. Red beds can be developed by subaerial exposure with a low water table and periodic wetting (Walker, 1975). They may have been deposited as prodelta to delta front sediments under marine conditions, exposed and "reddened" or they may represent flood plain deposits or both. These were periods of overwhelming detrital influx and probably fluctuating salinities as the amount of fresh water varied and mixed with marine waters. Dry periods were especially significant during this time as suggested by the lungfish burrows and lack of plant debris. When delta abandonment occurred, the result was a change from fresh water dominance to a mixing of fresh and marine waters until marine conditions predominated. Periodically, detrital influx ceased or was reduced, possibly during dry periods when rivers dried up and therefore were not carrying sediment in to the basin. During these periods, shallow, quiet, brackish areas are represented by molluscan limestone, whereas more agitated waters are represented by "dirty" and "clean" bioclastic limestone (Fig. 20). Which limestone was deposited depended on local conditions. As erosion reduced relief in the source area and thus detrital influx, marine waters dominated (green and yellow-orange mudstones). When relatively little detrital influx was reaching this area, clearer water, marine conditions prevailed (Cottonwood Limestone Member).

The sequence of units is not constant, even at localities close to each other. Local depressions would have collected more detritus. Delta building may have produced thick sequences at one locality whereas a nearby locality was off to one side of the major site of deposition and received relatively little sediment (Reading, 1978 and Reineck and Singh, 1973).

Figure 20. Diagrammatic sketch of one delta complex showing environments of deposition of lithologies recognized in this study of the Eskridge Shale.



The lack of laminations in red mudstone is not typical of flood plain or intertidal deposits. Neither environment would be expected to be intensely bioturbated which would remove laminations. The lack of structures, however, is negative evidence and cannot be used to rule out stratigraphically reasonable environments.

Eustatic sea level changes caused by waxing and waning of glaciers (Crowell, 1978) may have resulted in the shoreline sweeping across this area to produce the large scale transgressions and regressions of the Pennsylvanian and Permian. Delta formation and abandonment controlled localized deposition during periods of high detrital influx (Heckel, 1977 and Wanless, 1966) so that "outside" shales show considerable lateral and vertical differences.

Because of rapid lateral changes, correlation was difficult, even over relatively small distances. Only the most general correlations could be made (Fig. 21). The Wildcat Creek and Stagg Hill localities are on the northwest flank of the Nemaha Anticline, whereas the Lake Wabaunsee and Lake Kahola localities are on the southeast (Fig. 9). Correlation between these two "sets" is very difficult. The two sections to the southeast of the Nemaha axis show much less continental influence than do the two sections to the northwest. There is less vertical change suggesting more constant conditions and are fewer red units. The unit containing lungfish burrows at Wildcat Creek could possibly correlate with the red interval just above the Neva at Stagg Hill. The yellow-orange mudstone increases in thickness from the north to the south suggesting longer periods of a marine environment with high terrigenous influx.

Overall palaeogeography (Fig. 8) suggests more marine conditions in southern Kansas. The Nemaha Anticline could have been a slight topographic high that restricted circulation with the more open marine areas to the south. These conditions would produce a shallower, more restricted region represented by the Wildcat Creek and Stagg Hill localities. More marine conditions to the south are represented by the Lake Wabaunsee and Lake Kahola localities.

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SUMMARY

The Eskridge Shale represents a shallow marine environment with high terrigenous influx. It is typical of "outside" shales with rapid lateral and vertical change. From the base of the formation to the top, marine waters regressed and then transgressed. Shallowest marine, fluvial, and subaerial deposition are represented by red mudstone. Rivers and backshore fresh water ponds were limited. Rivers were overloaded and transported sediment slowly. Green mudstone represents intertidal, brackish, and normal marine deposition that are transitional between red beds and marine limestone. Repetitions of red and green mudstone reflect shifting positions of deltas. Areas between deltas at any one time received relatively little terrigenous influx and are represented by molluscan and bioclastic limestones. As terrigenous influx was reduced, marine conditions became more dominant until limestone deposition resumed.

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REFERENCES CITED

Ager, D.V., 1963, Principles of paleoecology: New York, McGraw-Hill Book Co., Inc., 371 p.

Beerbower, J.R., 1968, Search for the past, 2nd ed.: Englewood Cliffs, N.J., Prentice-Hall, 512 p.

Berner, R.A., 1971, Principles of chemical sedimentology: New York, McGraw-Hill Book Co., Inc., 240 p.

Biscaye, P.E., 1965, Mineralogy and sedimentation of Recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans: Geol. Soc. America Bull., v. 76, p. 803-832.

Broecker, W.S., 1974, Chemical oceanography: New York, Harcourt Brace Jovanovich, Inc., 214 p.

Brown, G., (ed.), 1961, X-ray identification and crystal structure of clay minerals: Min. Soc. London, 544 p.

Byers, C.W., 1974, Shale fissility: relation to bioturbation: Sedimentology, v. 21, p. 479-484.

Chelikowsky, J.R., 1972, Structural geology of the Manhattan, Kansas area, in Field Trip Guidebook, Sixth Annual Meeting, South Central Section, Geol. Soc. America, 1972: p. 51-80.

Crowell, J.C., 1978, Gondwanan glaciation, cyclothems, continental positioning, and climate change: Amer. Jour. Sci., v. 278, p. 1345-1372.

Cubitt, J.M., 1979, The geochemistry, mineralogy and petrology of Upper Paleozoic shales of Kansas: Kansas Geol. Survey Bull. 217, 117 p.

Degens, E.T., Williams, E.G., and Keith, M.L., 1957, Environmental studies of Carboniferous sediments. Part I: Geochemical criteria for differentiating marine from fresh-water shales: Am. Assoc. Petroleum Geol. Bull., v. 41, no. 11, p. 2427-2455.

Delevoryas, T., 1963, Morphology and evolution of fossil plants: New York, Holt, Rinehart and Winston, 189 p.

Elias, M.K., 1937, Depth of deposition of the Big Blue (Late Paleozoic) sediments in Kansas: Geol. Soc. America Bull., v. 48, p. 403-432.

Folk, R.L., 1974, Petrology of sedimentary rocks: Austin, Hemphill Publishing Co., 182 p.

Gibbs, R.J., 1965, Error due to segregation in quantitative clay mineral X-ray diffraction mounting techniques: Am. Miner., v. 50, p. 741-751.

Gibbs, R.J., 1968, Clay mineral mounting techniques for X-ray diffraction analysis: a discussion: Jour. Sed. Petrology, v. 38, p. 242-244.

Goddard, E.W., and others, 1979, Rock-color chart: Geol. Soc. America.

Guber, A.L., 1969, Sedimentary phosphate method for estimating paleosalinities: a paleontological assumption: Science, v. 163, p. 744-746.

Gundrum, L.E., 1977, Chonetid mode of life: Kansas State Univ., M.S. thesis, 202 p.

Hattin, D.E., 1957, Depositional environment of the Wreford Megacyclothem (Lower Permian) of Kansas: Kansas Geol. Survey Bull. 124, 150 p.

Heckel, P.H., 1972, Recognition of ancient shallow marine environments, in Rigby, J.K. and Hamblin, W.M., (eds.), Recognition of ancient sedimentary environments: Soc. Econ. Paleontologists and Mineralogists Spec. Paper 16, p. 226-286.

Heckel, P.H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Mid-Continent North America: Am. Assoc. Petroleum Geol. Bull., v. 61, no. 7, p. 1045-1068.

Jackson, M.L., 1958, Soil chemical analysis: Englewood Cliffs, N.J., Prentice-Hall, Inc., 498 p.

Jeppesen, J.A., 1972, Petrology of part of the Wewoka Formation (Pennsylvanian) in Hughes County, Oklahoma: Kansas State Univ., M.S. thesis, 88 p.

Lane, N.G., 1958, Environment of deposition of the Grenola Limestone (Lower Permian) in southern Kansas: Kansas Geol. Survey Bull. 130, pt. 3, p. 117-164.

Lane, N.G., 1964, Paleoecology of the Council Grove Group (Lower Permian) in Kansas, based on microfossil assemblages: Kansas Geol. Survey Bull. 170, pt. 5, 23 p.

Laporte, L.F., 1962, Paleoecology of the Cottonwood Limestone (Permian), northern Mid-Continent: Geol. Soc. America Bull., v. 73, p. 521-544.

McCrone, A.W., 1963, Paleoecology and biostratigraphy of the Red Eagle cyclothem (Lower Permian) in Kansas: Kansas Geol. Survey Bull. 164, 114 p.

McKee, E.D., and others, 1967, Paleotectonic maps of the Permian System, U.S. Geol. Survey, Misc. Geol. Investigations Map I-450, Washington, D.C., U.S. Govt. Printing Office, 164 p.

Merriam, D.F., 1963, The geologic history of Kansas: Kansas Geol. Survey Bull. 162, 317 p.

Moore, R.C., 1936, Pennsylvanian and "Permian" rocks of the Kansas-Missouri region, in Kansas Geol. Soc. Guidebook, 10th Annual Field Conference, 1936: p. 7-73.

Moore, R.C., and Merriam, D. F., 1959, Kansas Field Conference--1959, Kansas Geol. Survey Guidebook, p. 1-55.

Müller, G., 1969, Sedimentary phosphate method for estimating paleosalinities: limited applicability: Science, v. 163, p. 812-813.

Nelson, B.W., 1967, Sedimentary phosphate method for estimating paleosalinities: Science, v. 154, p. 917-920.

Nelson, B.W., 1968, Applications of the Chang and Jackson procedure to analysis of sedimentary phosphate: unpublished mimeograph, 4 p.

Newell, N.D., 1937, Late Paleozoic pelecypods: Pectinacea: Kansas Geol. Survey Bull. 10, pt. 1, 123 p.

Newell, N.D., 1942, Late Paleozoic pelecypods: Mytilacea: Kansas Geol. Survey Bull. 10, pt. 2, 115 p.

Newell, N.D., and Boyd, D.W., 1970, Oyster-like Permian Bivalvia: Amer. Mus., Nat. Hist. Bull., v. 143, p. 221-281.

Reading, H.G., (ed.), 1978, Sedimentary environments and facies: New York, Elsevier, 557 p.

Reineck, H.E., and Singh, I.B., 1973, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Scott, D.R., 1973, Marine benthic communities of the Reading Limestone (Upper Pennsylvanian) Atchison County, Kansas: Kansas State Univ., M.S. thesis, 135 p.

Selley, R.C., 1970, Ancient sedimentary environments: London, Chapman and Hall, Ltd., 237 p.

Smith, A.G., Briden, J.C., and Drewry, G.E., 1971, Phanerozoic world maps, in Hughes, N.F., (ed.), Organisms and continents through time: Palaeont. Assoc. Spec. Paper 12, p. 1-42.

Twiss, P.C., 1979, personal communication.

Van Houten, F.B., 1964, Origin of red beds--some unsolved problems, in Nairn, A.E.M., (ed.), Problems in palaeoclimatology: London, William Clowes and Sons, p. 647-659.

Voran, R.L., 1977, Fossil assemblages, stratigraphy and depositional environment of the Crouse Limestone (Lower Permian) in north central Kansas: Kansas State Univ., M.S. thesis, 208 p.

Walker, T.R., 1974, Formation of red beds in moist tropical climates: a hypothesis: Geol. Soc. America Bull., v. 85, no. 4, p. 633-638.

Walker, T.R., 1975, Red beds in the western interior of the United States, U.S. Geol. Survey Prof. Paper 853, pt. 2, p. 49-56.

Wanless, H.R., 1966, Local and regional factors in Pennsylvanian cyclic sedimentation: Kansas Geol. Survey Bull. 169, v. 2, p. 593-606.

Warren, K.M., 1969, The Mill Creek Flora, Roca Shale, Wabaunsee County, Kansas: Kansas State Univ., M.S. thesis, 49 p.

Weller, J.M., 1931, The conception of cyclical sedimentation during the Pennsylvanian period: Illinois Geol. Survey Bull., no. 60, p. 163-177.

Wells, J.D., 1950, A study of the Eskridge Shale: Kansas State Univ., M.S. thesis, 35 p.

West, R.R., 1980, personal communication.

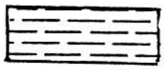
Zeller, D.E., (ed.), 1968, The stratigraphic succession in Kansas: Kansas Geol. Survey Bull. 189, 81 p.

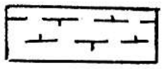
APPENDIX I

Measured Sections

LEGEND

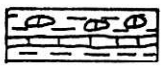
Lithologic Symbols

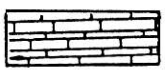
 Mudstone

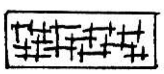
 Calcareous Mudstone

 Bioturbated Mudstone

 Black Mudstone

 Interbedded Mudstones and Limestones

 Limestone

 Honeycomb or Boxwork Limestone

On the following pages, numbers indicate units and letters indicate subunits.

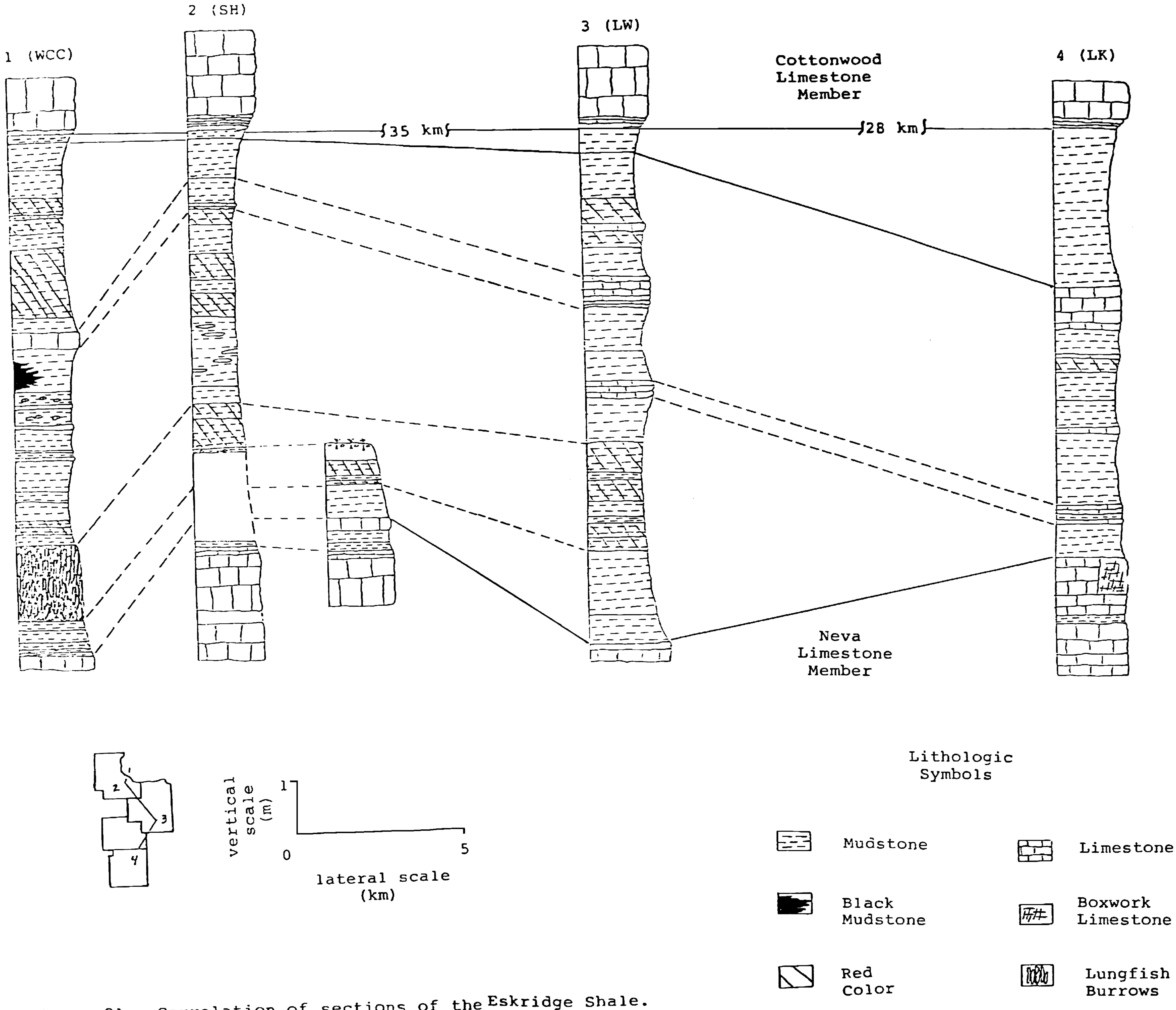
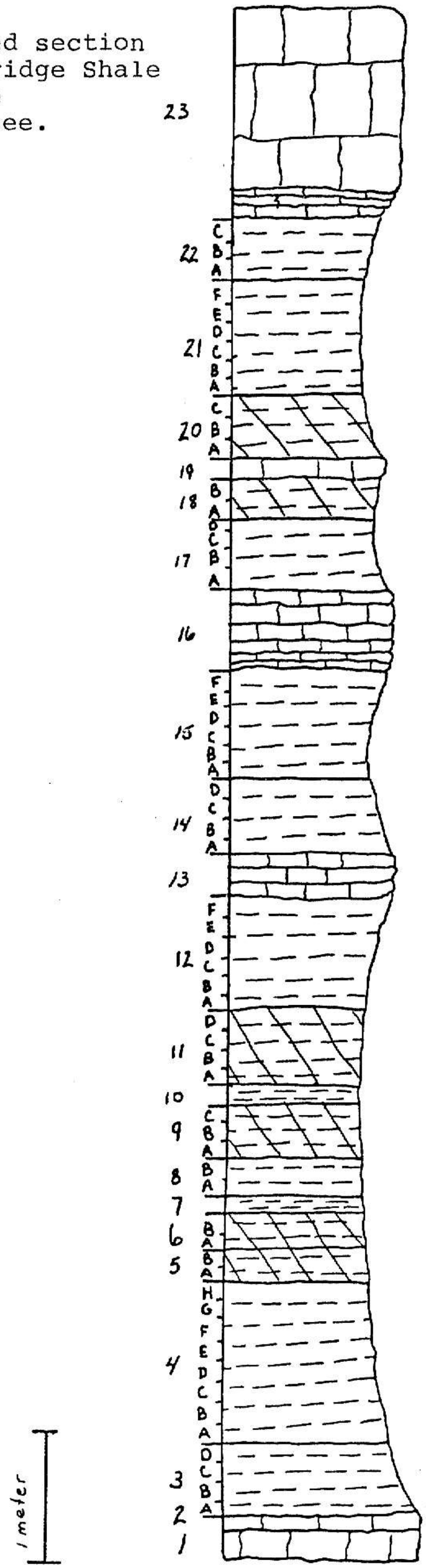


Figure 21. Correlation of sections of the Eskridge Shale.

Measured section of Eskridge Shale at Lake Wabaunsee.



LAKE WABAUNSEE

Date Measured: July 21, 1979   Measured By: L. L. Pecchioni

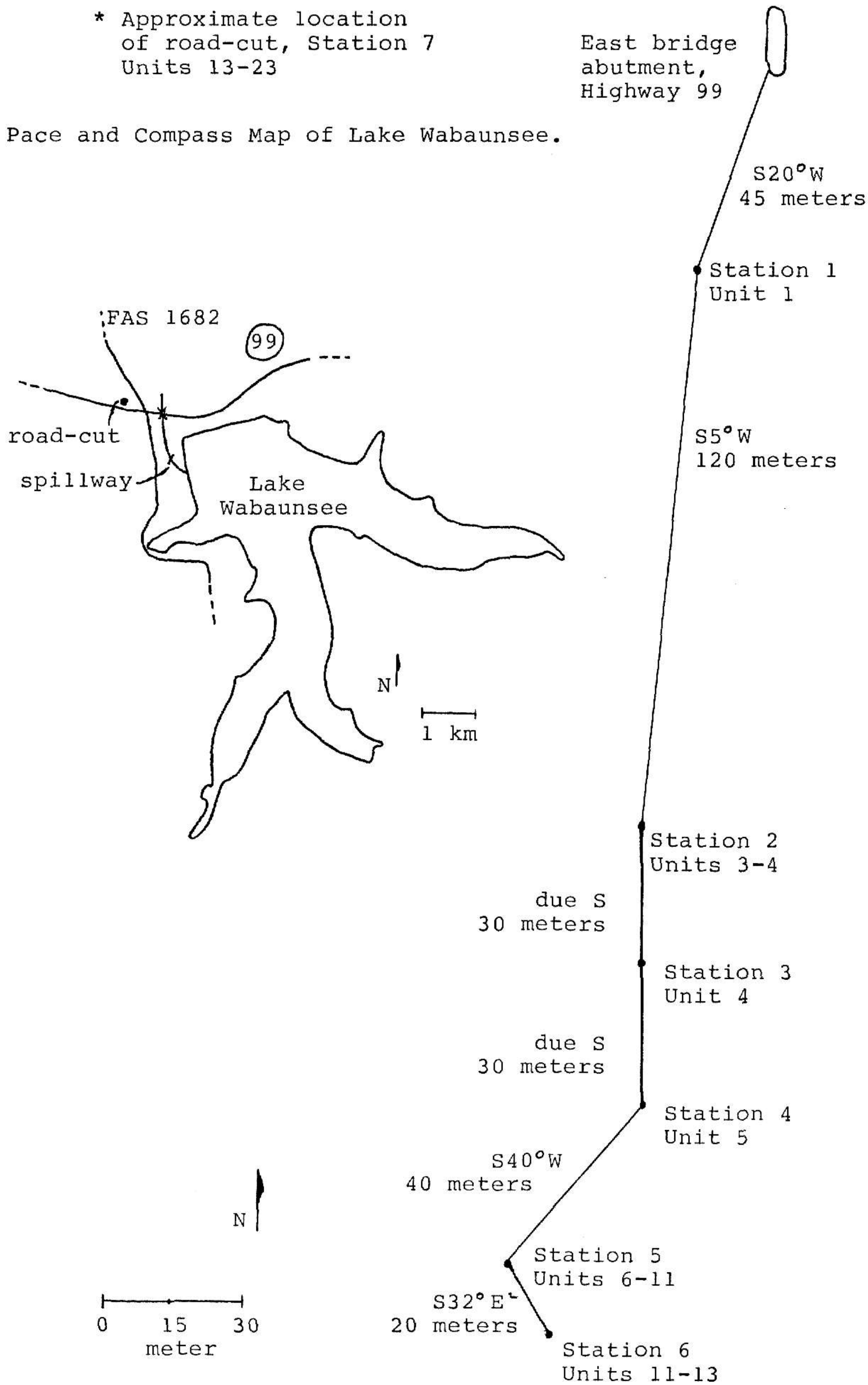
Locality: Spillway at Lake Wabaunsee and roadcut on State Highway 99, SE¼, NE¼, NW¼ and NE¼, NW¼, NW¼, Section 4, T14S, R11E, Wabaunsee County, Kansas.

Unit	Description	Thickness
1	Limestone, light gray (N7) fresh, greenish gray (5 GY 6/1) weathered, thin beds to more massive upward, crinoid, echinoid, brachiopod and bivalve fragments concentrated in clayey layers, absent in others, fine sand size range, abraded, fragmented, disarticulated.	0.36
2	covered.	
3	Mudstone, very calcareous, grayish olive green (5 GY 3/2) fresh, grayish olive green (5 GY 3/2) to grayish yellow green (5 GY 7/2) weathered, 20-30 mm beds, moderate brown (5 YR 3/4) fresh and weathered lens from 0.32 to 0.41 m, iron oxide stains, contact sharp.	0.58
4	Mudstone, very calcareous, greenish black (5 G 2/1) fresh, pale yellowish green (5 GY 7/2) weathered, fairly resistant, bedding about 10 mm, contact gradational.	1.23
5	Mudstone, pale yellowish brown (10 YR 6/2) grading into grayish olive (10 Y 4/2) fresh, greenish gray (5 GY 6/1) weathered, conchoidal blocks weather platy, contact gradational.	0.29
6	Mudstone, calcareous, moderate brown (5 YR 3/4) fresh and weathered, blocky to platy, mottled with green until green becomes dominant, contact gradational.	0.27
7	Mudstone, grayish olive (10 Y 4/2) fresh, yellowish gray (5 Y 7/2) weathered, blocky, contact gradational.	0.13
8	Mudstone, olive gray (5 Y 3/2) fresh, yellowish gray (5 Y 7/2) weathered, blocky, contact gradational.	0.30
9	Mudstone, grayish brown (5 YR 3/2) fresh, pale brown (5 YR 5/2) weathered, blocky, contact gradational.	0.43

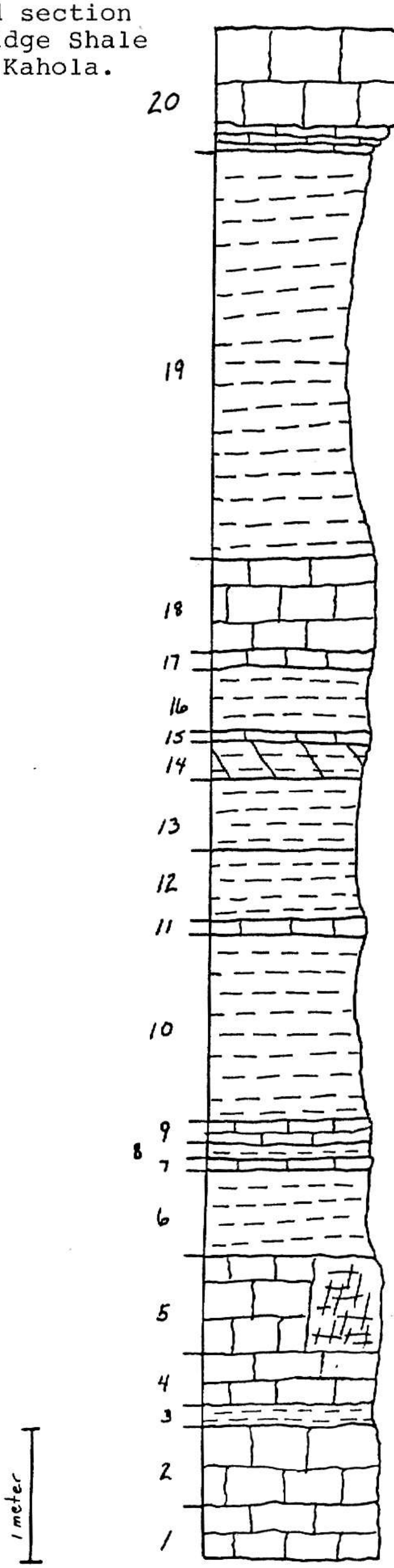
Unit	Description	Thickness
10	Mudstone, grayish olive (10 Y 4/2) fresh, very pale orange (10 YR 8/2) weathered, platy, contact gradational.	0.14
11	Mudstone, dark yellowish brown (10 YR 4/2) fresh and weathered, blocky, some signs of deformation at point where green pinches out, small lenses (10-20 mm) of green (10 GY 5/2) fresh and weathered, irregulary spaced, contact gradational.	0.60
12	Mudstone, grayish green (10 GY 5/2) fresh, pale yellowish green (10 GY 7/2) weathered, platy (1-3 mm) pinches out on north side of spillway, maximum thickness reached within 3 m from point where bed is absent, contact sharp.	0.91
13	Limestone, light olive gray (5 Y 6/1) fresh, yellowish gray (5 Y 7/2) weathered, high-spired gastropods, bivalve fragments, concentrated in middle layer in stringers, pockets and bands, abraded, fragmented, contact sharp.	0.31
14	Mudstone, grayish olive (10 Y 4/2) with black mottling fresh, pale olive (10 Y 6/2) weathered, platy, contact gradational.	0.58
15	Mudstone, light olive gray (5 Y 5/2) fresh, pale olive (10 Y 6/2) weathered, blocky, contact sharp.	0.88
16	Limestone, light gray (N7) fresh, light olive gray (5 Y 6/1) weathered, beds 0.20 m at bottom, 0.002-0.150 m middle, 0.10-0.15 m at top, Aviculopecten and other pectens in lower beds may be in life position, gastropods and skeletal fragments in upper beds are abraded and fragmented, some stringers, body fossils weathered out, iron stains, contact sharp.	0.62
17	Mudstone, dusky yellow green (5 GY 5/2) fresh, grayish yellow green (5 GY 7/2) weathered, platy, contact gradational.	0.53
18	Mudstone, brownish gray (5 YR 4/1) fresh, light olive gray (5 Y 6/1) weathered, blocky, contact sharp.	0.32
19	Limestone, very light gray (N8) fresh, yellowish gray (5 Y 8/1) weathered, nodular to irregular bedding, nonfossiliferous, contact sharp.	0.16

Unit	Description	Thickness
20	Mudstone, pale brown (5 YR 5/2) mottled with green, fresh, dusky yellow (5 Y 6/4) weathered, blocky, contact gradational.	0.49
21	Mudstone, dusky yellow green (5 GY 5/2) fresh, greenish gray (5 GY 6/1) weathered, platy, contact gradational.	0.92
22	Mudstone, grayish orange (10 YR 7/4) fresh, very pale orange (10 YR 8/2) weathered, platy, contact sharp.	0.48
23	Limestone, very pale orange (10 YR 8/2) fresh, dark yellowish orange (10 YR 6/6) to very pale orange (10 YR 8/2) weathered, lowermost beds platy (2-15 mm), uppermost beds massive, fine sand sized skeletal grains of crinoids, bivalves, bryozoans, all abraded and fragmented, grade into fusulinid and chert layer.	1.66
	Total thickness (m)	12.19

Pace and Compass Map of Lake Wabaunsee.



Measured section
of Eskridge Shale
at Lake Kahola.



LAKE KAHOLA

Date Measured: July 26, 1979 Measured by: L. L. Pecchioni

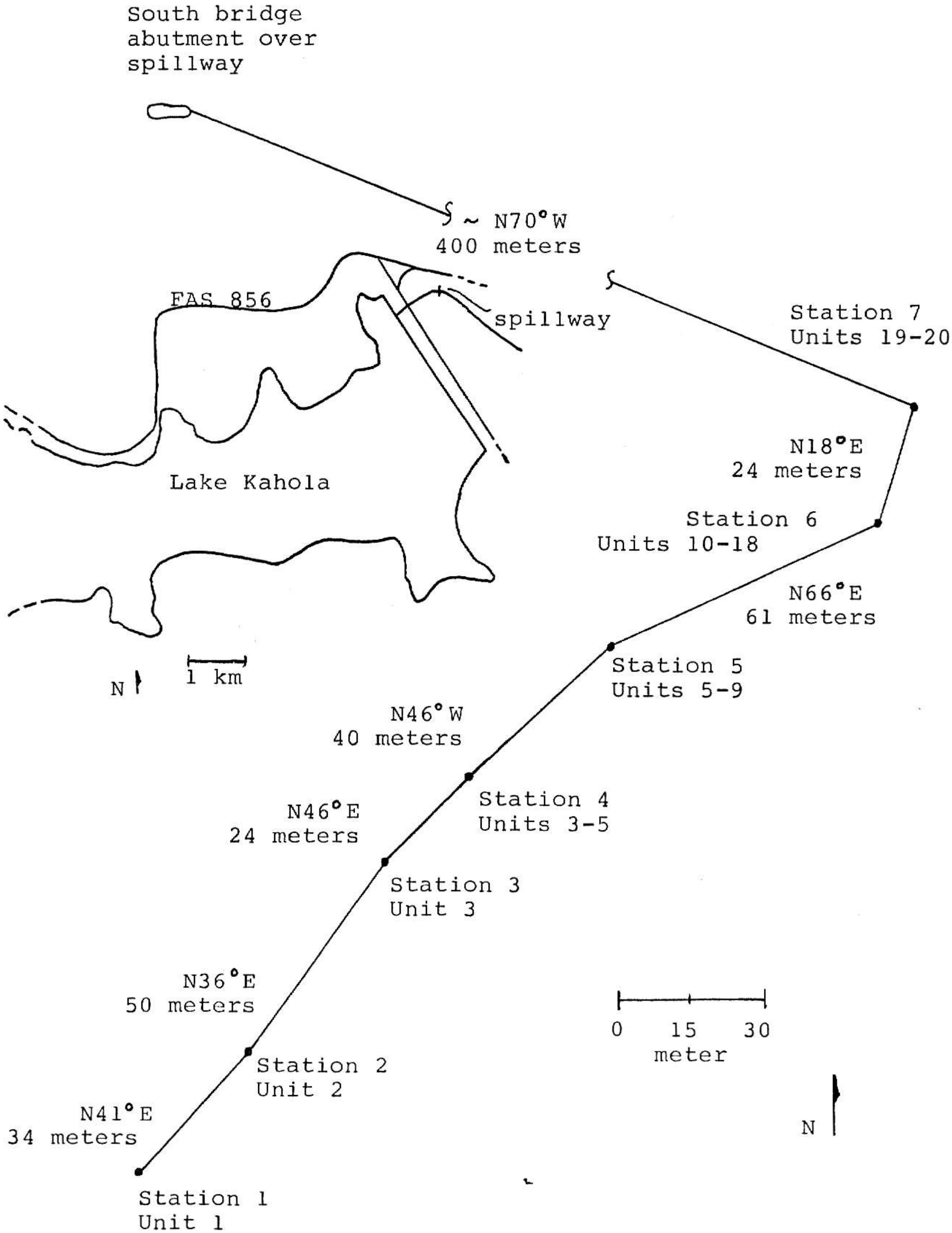
Locality: Spillway at Lake Kahola, NE¼, NW¼, SE¼, Section 33, T17S, R9E, Morris County, Kansas.

Unit	Description	Thickness
1	Limestone, light olive gray (5 Y 6/1) to greenish gray (5 GY 6/1) fresh, grayish orange (10 YR 7/4) to pale yellowish brown (10 YR 6/2) weathered, bedding more massive upward (0.005 to 0.30 m), <u>Permorphous</u> and high-spired gastropods, little matrix or cement, contact sharp.	0.41
2	Limestone, yellowish gray (5 Y 7/2) fresh and weathered, grayish yellow green (5 GY 7/2) in lower portions, iron stains, thin bedded (0.003 to 0.02 m), gastropods and bivalve abraded fragments, contact gradational.	0.61
3	Mudstone, calcareous, pale greenish yellow (10 Y 8/2) fresh and weathered, platy (3 to 8 mm), gastropods and bivalve fragments less dense than in unit 2, contact arbitrary and gradational.	0.12
4	Limestone, greenish gray (5 GY 6/1) to grayish yellow green (5 GY 7/2) fresh, yellowish gray (5 Y 7/2) to pale olive (10 Y 6/2) weathered, iron stains, gastropods and bivalve fragments have patchy distribution with some barren spots, wavy bedding within unit, contact sharp.	0.48
5A	Limestone, grayish orange (10 YR 7/4) with grayish yellow green (5 GY 7/2) mottled fresh, dusky yellow (5 Y 6/4) weathered, weathers to a honeycomb structure, thickness varies from 0.20 to 0.61 m with the mudstone above varying to keep thickness between units 4 and 7 constant, present south of station 4, absent north, pinches to 0.2 m then disappears, no evidence of faulting, nonfossiliferous, contact sharp.	0.34
5B	Limestone, clayey, very pale orange (10 YR 8/2) fresh, grayish orange (10 YR 7/4) weathered, thin bedded, laminated algal mats?, beds above and below are not offset, thickness from top of unit 4 to bottom of unit 7 is 1.38 m, where the honeycomb is the same interval is 1.37 m, nonfossiliferous except possible algae, contact sharp.	0.71

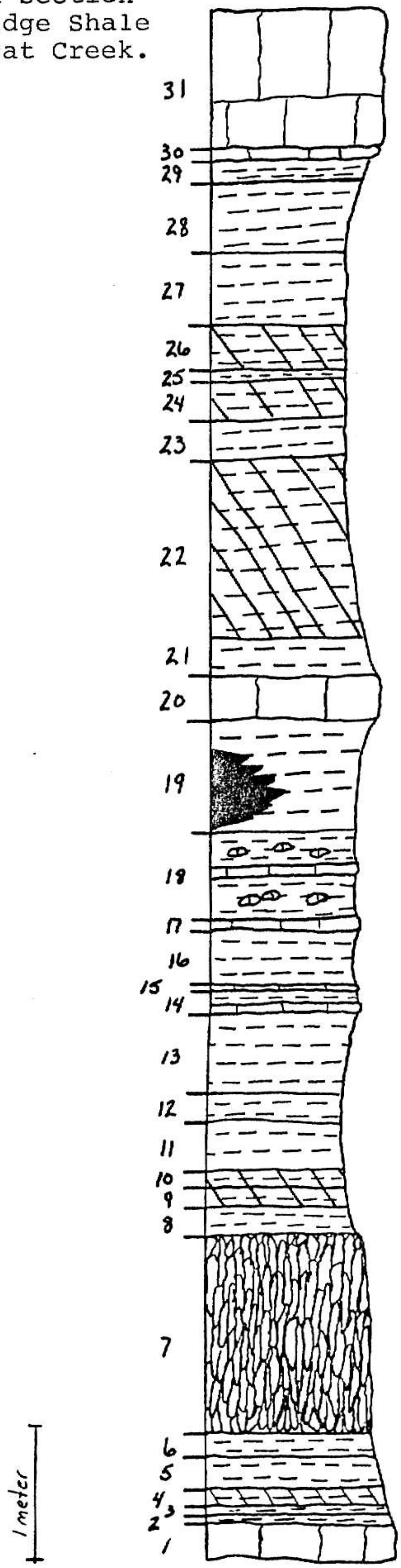
Unit	Description	Thickness
6	Mudstone, pale olive (10 Y 6/1) fresh, yellowish gray (5 Y 8/1) weathered, lateral transition in upper 0.25 to 0.63 m to light gray (N7) fresh and greenish gray (5 GY 6/1) weathered, beds 0.005 to 0.06 m, contact sharp.	0.67
7	Limestone, light olive gray (5 Y 6/1) fresh, dusky yellow (5 Y 6/4) weathered, massive, poorly preserved bivalve fragments, *Aviculopecten* and *Septimyalina* parallel to bedding, contact sharp.	0.11
8	Mudstone, grayish yellow green (5 GY 6/2) fresh and weathered, laminated, thins to 0.03 m, contact sharp.	0.06
9	Limestone, between light olive gray (5 Y 6/1) and greenish gray (5 GY 6/1) fresh, yellowish gray (5 Y 7/2) weathered, thin beds (0.002 to 0.015 m), very good bench former in spillway, clay infilling shells or clay balls?, *Septimyalina* and *Aviculopecten* fragmented and abraded, mostly parallel to bedding, patchy distribution, contact sharp.	0.21
10	Mudstone, dark greenish gray (5 GY 4/1) fresh and weathered, grades into dusky yellow brown (5 GY 5/2) by 0.00 to 0.10 m, blocky, wavy structure 〰, 0.04 m resistent bed (N4), "paper" thin, position in unit changes laterally, contact sharp.	1.43
11	Limestone, greenish gray (5 GY 6/1) fresh, pale olive (10 Y 6/2) weathered, micritic, some possibly terrigenous clasts, thins out at northwest end of spillway to small (0.05 x 0.05 m) nodules , thickens to maximum within 2 m and is persistent, nonfossiliferous, contact sharp.	0.12
12	Mudstone, dark greenish gray (5 GY 4/1) fresh, moderate olive brown (5 Y 4/4) weathered, conchoidal, large blocks, contact arbitrary and gradational.	0.48
13	Mudstone, grayish green (10 GY 5/2) fresh, grayish yellow green (5 GY 7/2) weathered, bedding thins upward (0.002 to 0.03 m), contact sharp.	0.56
14	Mudstone, moderate brown (5 YR 3/4) fresh and weathered, blocky, contact gradational.	0.31

Unit	Description	Thickness
15	Limestone, light brownish gray (5 YR 6/1) fresh, greenish gray (5 GY 6/1) weathered, fine grained, nodular near top and interbedded with mudstone the same as in unit 16, contact gradational.	0.08
16	Mudstone, grayish yellow green (5 GY 7/2) fresh and weathered, blocky, contact gradational.	0.51
17	Limestone, light olive gray (5 Y 6/1) fresh, yellowish gray (5 Y 7/2) weathered, laminations accentuated by iron stains, micritic, not very clayey, mudcracks on upper surface, contact gradational.	0.12
18	Limestone, pale olive (10 Y 6/2) fresh, grayish yellow (5 Y 8/4) weathered, clayey, massive and resistent, but breaks up like a mudstone into blocks, lacks macrofossils, contact sharp.	0.74
19	Mudstone, yellowish gray (5 Y 7/2) fresh and weathered, thin (1 to 3 mm) beds, dark brown to black stains throughout, probably iron or organic, constant appearance throughout, contact sharp and undulatory.	3.09
20	Limestone, pale yellowish brown (10 YR 6/2) fresh, dark yellowish orange (10 YR 6/6) weathered, platy at bottom and massive at top, finely comminuted fragments of crinoids, bryozoans, bivalves, brachiopods, and fusulinids, thickness varies from 0.77 to 1.02 m.	0.95
	Total thickness (m)	11.77

Pace and compass map of Lake Kahola.



Measured section
of Eskridge Shale
at Wildcat Creek.



WILDCAT CREEK

Date Measured: June 7, 1979 Measured by: L. L. Pecchioni

Locality: Road-cut on Federal-Aid Secondary Highway 1925, SW¼, SE¼, SW¼, Section 10, T10S, R7E, Riley County, Kansas.

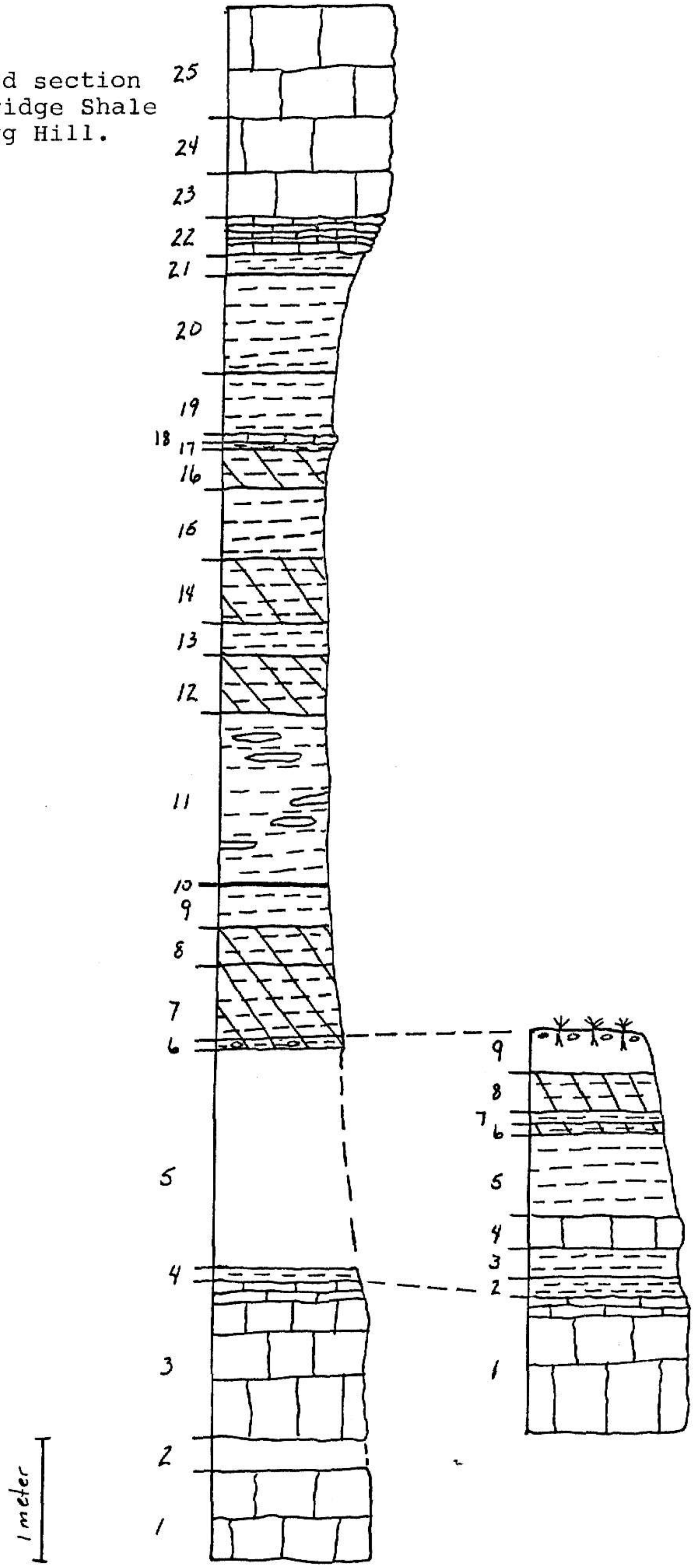
Unit	Description	Thickness
1	Limestone, yellowish gray (5 Y 7/2) fresh and weathered, massive, lacks macrofossils, contact sharp and undulatory.	0.29
2	Mudstone, slightly calcareous, light olive gray (5 Y 5/2) fresh with red mottling, light greenish gray (5 GY 8/1) weathered, very fine blocky, contact sharp.	0.07
3	Mudstone, calcareous, pale olive (10 Y 6/2) fresh, grayish yellow green (5 GY 7/2) weathered, laterally discontinuous, contact sharp.	0.03
4	Mudstone, calcareous, lower 0.03 m grayish red (5 R 4/2) fresh, light greenish gray (5 GY 8/1) weathered, sharp color change, upper 0.14 m grayish olive (10 Y 4/2) fresh, weathered same color as in lower part, small to medium blocks, contact gradational.	0.17
5	Mudstone, calcareous, grayish olive (10 Y 4/2) fresh, pale olive (10 Y 6/2) weathered, blocky, thins upward from 30 to 10 mm or less blocks, contact gradational.	0.26
6	Mudstone to shale, calcareous, grayish olive green (5 GY 3/2) fresh, pale olive (10 Y 6/2) weathered, blocky, thins upward until fissile, contact gradational.	0.18
7	Mudstone, slightly calcareous, lower 0.35 m light bluish gray (5 B 7/1), 0.35 to 1.00 m medium gray (N5), upper 0.48 m light greenish gray (5 GY 8/1), all weathered colors, color contacts gradational, elongate cylinders (vertical burrows?), 3 to 7 cm diameter, 5 to 10 cm long, contact gradational.	1.48
8	Mudstone, grayish olive green (5 GY 3/2) fresh, grayish olive (10 Y 4/2) weathered, blocky, contact gradational.	0.21

Unit	Description	Thickness
9	Mudstone, very calcareous, dusky yellowish brown (10 YR 2/2) fresh, dark yellowish brown (10 YR 4/2) weathered, blocky, contact gradational.	0.14
10	Mudstone, calcareous, moderate brown (5 YR 3/4) fresh, pale brown (5 YR 5/2) weathered, blocky, contact gradational.	0.12
11	Mudstone, calcareous, olive gray (5 Y 4/1) fresh, light greenish gray (5 GY 8/1) weathered, blocky, smaller blocks upward, contact gradational.	0.39
12	Mudstone, calcareous, dark greenish gray (5 GY 4/1) fresh, light greenish gray (5 GY 8/1) mottled with brown weathered, blocky, iron stains, contact gradational.	0.20
13	Mudstone, calcareous, grayish olive green (5 GY 3/2) fresh, grayish yellow green (5 GY 7/2) to grayish olive green (10 Y 4/2) weathered, blocky, iron stains, contact sharp.	0.63
14	Interbedded limestone and shale, light olive gray (5 Y 6/1) fresh and weathered, iron stains, usually two limestones and two shales, thicknesses vary, nonfossiliferous, contact sharp.	0.13
15	Limestone, greenish gray (5 GY 6/1) fresh and weathered, iron oxide stains, massive, *Aviculopecten* is preserved with the commissural plane parallel to bedding, the presence of the lower valves is not known, *Septimyalina* is preserved with the commissural plane perpendicular to bedding on the upper surface, this may be life position, lower in the bed they are disarticulated and parallel to bedding, *Bellerophon* is preserved with the aperture parallel to bedding and may be in life position, contact sharp.	0.04
16	Mudstone to shale, light olive gray (5 Y 5/2) fresh, dusky yellow (5 Y 6/4) weathered, platy to fissile, *Aviculopecten* molds rare, contact sharp.	0.42
17	Limestone, light olive gray (5 Y 6/1) fresh, yellowish gray (5 Y 8/1) weathered, biomicritic, massive, abraded and fragmented bivalves throughout bed, contact sharp.	0.09

Unit	Description	Thickness
18	Shale interbedded with nodular limestone, shale--moderate olive brown (5 Y 4/4) fresh, light olive gray (5 Y 5/2) weathered, limestone--medium gray (N5) fresh, very light to light gray (N8 to N7) weathered, nodules 1 to 5 cm, persistent bed from 0.47 to 0.52 m, otherwise nodules are random throughout unit, contact gradational.	0.67
19	Mudstone, 0.00 to 0.19 m olive gray (5 Y 4/1) fresh, light olive gray (5 Y 6/1) to greenish gray (5 GY 6/1) weathered, 0.19 to 0.47 m brownish black (5 YR 2/1) to moderate olive brown (5 Y 4/4) mottled, when darker dominant bedding is paper thin, 0.47 to 0.84 m moderate olive brown (5 Y 4/4) fresh, dusky yellow (5 Y 6/4) weathered, blocky to very fine blocky, plant debris throughout (*Neuropteris*), contact sharp and undulatory.	0.84
20	Limestone, very light gray (N8) fresh, light brownish gray (5 YR 6/1) weathered, wavy bedding (1 to 6 mm), iron stains, bivalves are abraded and fragmented, random throughout unit, contact sharp.	0.33
21	Mudstone, calcareous, pale olive (10 Y 6/2) mottled with light brown (5 YR 6/4) fresh, grayish orange pink (5 YR 6/4) weathered, contact gradational.	0.27
22	Mudstone, calcareous, grayish red (5 R 4/2) mottled with light olive green (5 Y 5/2) fresh, pale red (10 R 6/2) weathered, small to medium blocks, contact gradational.	1.38
23	Mudstone, very calcareous, greenish gray (5 GY 6/1) fresh, light greenish gray (5 GY 8/1) weathered, blocky to platy, very rare *Aviculopecten* molds, contact gradational.	0.26
24	Mudstone, calcareous, pale brown (5 YR 5/2) fresh, very pale orange (10 YR 8/2) weathered, small blocks, contact gradational.	0.34
25	Mudstone, olive gray (5 Y 4/1) fresh, yellowish gray (5 Y 8/1) weathered, small blocks, contact gradational.	0.04
26	Mudstone, calcareous, pale yellowish brown (10 YR 6/2) fresh, grayish orange pink (5 YR 7/2) weathered, small blocks, contact gradational.	0.37

Unit	Description	Thickness
27	Mudstone, calcareous, dusky yellow brown (5 GY 5/2) fresh, greenish gray (5 GY 6/1) weathered, blocky, contact gradational.	0.52
28	Mudstone, calcareous, pale olive (10 Y 6/2) and dark greenish yellow (10 Y 6/6) mottled fresh, dusky yellow (5 Y 6/4) weathered, iron stains, blocky, contact gradational.	0.54
29	Mudstone, calcareous, grayish yellow (5 Y 8/4) fresh, yellowish gray (5 Y 7/2) weathered, platy, beds about 4 mm, contact sharp and undulatory.	0.14
30	Limestone, grayish orange (10 YR 7/4) fresh and weathered, platy, no macrofossils, contact gradational and undulatory.	0.08
31	Limestone, very pale orange (10 YR 8/2) fresh, very light gray (N8) to pinkish gray (5 YR 8/1) weathered, thin bed in lower part, upper part massive, finely comminuted crinoids, bryozoans, bivalves, brachiopods, trilobites, upper part mainly fusulinids, some chert in upper part.	1.02
	Total thickness (m)	11.65

Measured section
of Eskridge Shale
at Stagg Hill.



STAGG HILL

Date Measured: Feb. 19, 1981 Measured by: L. L. Pecchioni

Locality: Road-cuts on Kansas Highway 18, start C of S line, finish C of E line, NE¼, SW¼, Section 23, offset to describe covered interval, C of N½, SE¼, SW¼, Section 23, T10S, R7E, Riley County, Kansas.

Unit	Description	Thickness
1	Limestone, grayish orange (10 YR 7/4) fresh, pale yellowish brown (10 YR 6/2) weathered, massive beds thin upward to 40 mm, sand-sized skeletal fragments of crinoids, bivalves, bryozoans, brachiopods are concentrated in layers with micrite, skeletal percentage in bands ranges from 25 to 50 %, occassionally up to 75%, slightly vuggy.	0.73
2	covered.	0.25
3	Limestone, very light gray (N8) fresh, medium gray (N5) to yellowish gray (5 Y 8/1) weathered, massive lower beds contain about 40% abraded skeletal fragments of brachiopods, bivalves, crinoids randomly scattered throughout beds, micrite cement, bedding planes irregular and poorly developed, upper thin (average 0.13 m) beds consist of about 50% abraded brachiopod, crinoid, bivalve and bryozoan fragments oriented parallel or subparallel to bedding, contact gradational.	1.22
4	Mudstone, between pale olive (10 Y 6/2) and light olive (10 Y 5/4) fresh, light olive gray (5 Y 6/1) weathered, thin bedded, lacks fossils.	0.14
5	covered.	1.75
6	Mudstone, grayish red (5 R 4/2) fresh, grayish red (10 R 4/2) weathered, contains layers of hard, mottled, lumpy nodules, caliche-like, contact gradational.	0.08
7	Mudstone, grayish red (10 R 4/2) to brownish gray (5 YR 4/1) fresh, grayish brown (5 YR 3/2) weathered, mottled with green until green dominant, blocky, brick red lens, little or no silt, contact gradational.	0.58

Unit	Description	Thickness
8	Mudstone, greenish gray (5 GY 6/1) fresh and weathered, calcareous, blocky, contact gradational.	0.31
9	Mudstone, dusky yellow (5 Y 6/4) to moderate olive brown (5 Y 4/4) fresh, light olive gray (5 Y 6/1) weathered, blocky, contact sharp.	0.31
10	Mudstone, light olive gray (5 Y 6/1) fresh, very light gray (N8) to dark yellowish orange (10 YR 6/6) weathered, very calcareous, hard "nodular" layer, iron stains, laterally grades into a limonite layer and then disappears, contact sharp.	0.003
11	Mudstone, light olive gray (5 Y 5/2) fresh, yellowish gray (5 Y 7/2) weathered, slightly calcareous, platy, iron stains, dark gray mottling, lateral difference in number of hard limonite layers, from one to five, unit becomes grayer upward, contact mottled and gradational.	1.39
12	Mudstone, pale red (10 R 6/2) fresh, grayish pink (5 R 8/2) weathered, calcareous, platy, slightly resistent, slightly silty, contact gradational.	0.47
13	Mudstone, grayish olive (10 Y 4/2) fresh, light olive gray (5 Y 6/1) weathered, platy to small blocks, calcareous, no silt, contact mottled and gradational.	0.24
14	Mudstone, pale brown (5 YR 5/2) fresh, pale red (10 R 6/2) weathered, platy to small blocks, calcareous, contact mottled and gradational.	0.52
15	Mudstone, moderate olive brown (5 Y 4/4) fresh, yellowish gray (5 Y 7/2) weathered, blocky, calcareous, contact mottled and gradational.	0.53
16	Mudstone, dark yellowish brown (10 YR 4/2) fresh, pale yellowish brown (10 YR 6/2) weathered, blocky, calcareous, contact mottled and gradational.	0.29
17	Mudstone, greenish gray (5 GY 6/1) fresh, yellowish gray (5 Y 8/1) weathered, blocky, calcareous, contact sharp.	0.09

Unit	Description	Thickness
18	Limestone, greenish gray (5 GY 6/1) fresh, light greenish gray (5 GY 8/1) weathered, lower 35 mm micritic with less than 1% skeletal fragments, upper 40 mm contains lenses and stringers of fossils and clay balls interbedded with micrite, upper 5 to 8 mm concentration of skeletal fragments of bivalves, brachiopods, rare gastropods, ostracodes (?), slightly abraded, well sorted at about 1 mm, oriented at all angles to bedding, skeletal fragments more common than clay balls in lower part, reverse proportions in upper layer; laterally grades into a coarser layer with Acanthopecten and Aviculopecten fragments, productid spines, gastropods, larger pecten fragments hydrodynamically stable, contact sharp.	0.09
19	Mudstone, pale olive (10 Y 6/2) fresh and weathered, pockets of abraded debris, larger fragments of pectens and brachiopods than in unit 18, gradually contains whole Juresania and Aviculopecten in hydrodynamically stable position, grades into yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1) fresh and weathered, small (less than 5 mm) Permorphous shells, articulated, parallel or subparallel to bedding, plant debris also present, grades into light olive gray (5 Y 5/2) fresh and weathered, larger Permorphous, more plant debris, Aviculopecten molds, harder and more calcareous than lower layers, contact gradational.	0.50
20	Mudstone, greenish gray (5 GY 6/1) fresh, light greenish gray (5 GY 8/1) weathered, has yellow-orange mottling, blocky, crumbly, contact gradational.	0.77
21	Mudstone, grayish orange (10 YR 7/4) fresh, very pale orange (10 YR 8/2) and pale yellowish orange (10 YR 8/6) weathered, some black mottling, contact sharp.	0.18
22	Limestone, yellowish gray (5 Y 8/1) fresh, very pale orange (10 YR 8/2) and yellowish gray (5 Y 8/1) weathered, platy with thickness increasing upward from 5 to 10 mm beds to 20 mm beds, skeletal fragments concentrated in thin layers, abraded brachiopods, crinoids and bivalves, contact gradational.	0.31
23	Limestone, white (N9) fresh, medium light gray (N6) weathered, abraded sand-sized crinoid, brachiopod, bivalve and echinoid fragments are parallel or subparallel to bedding, contact gradational.	0.35

Unit	Description	Thickness
24	Limestone, very pale orange (10 YR 8/2) fresh, very pale orange (10 YR 8/2) to pale yellowish orange (10 YR 8/6) weathered, fossil content and orientation same as in unit 23, chert nodules throughout bed, contact gradational.	0.44
25	Limestone, pinkish gray (5 YR 8/1) fresh, very pale orange (10 YR 8/2) and yellowish gray (5 Y 8/1) weathered, micrite cement, fusulinids weathered out on surface, at all angles to bedding, lower 40 mm layered, lower 80 mm contain most of fossils, upper approximately 10 mm nearly barren, some chert.	0.92

Offset to describe covered interval (unit numbers unique for each site)

Unit	Description	Thickness
1	Limestone, same as at other locality with platy beds at top, contact sharp.	1.08
2	Mudstone, olive gray (5 Y 4/1) fresh, yellowish gray (5 Y 8/1) weathered, platy, contact gradational.	0.17
3	Mudstone, grayish orange (10 YR 7/4) fresh and weathered, platy, contact sharp.	0.24
4	Limestone, grayish orange (10 YR 7/4) fresh, yellowish gray (5 Y 7/2) weathered, thin bedded at bottom to massive upward, slightly laminated near top, clayey, apparently barren of fossils, contact sharp.	0.25
5	Mudstone, pale olive (10 Y 6/2) fresh, yellowish gray (5 Y 7/2) weathered, slightly calcareous, platy to small blocks, contact gradational.	0.65
6	Mudstone, dark yellowish brown (10 YR 4/2) fresh and weathered, small blocks, calcareous, no silt, contact gradational.	0.06
7	Mudstone, pale olive (10 Y 6/2) fresh, yellowish gray (5 Y 8/1) weathered, small blocks, very calcareous, contact gradational.	0.07
8	Mudstone, blackish red (5 R 2/2) fresh, grayish red (5 R 4/2) weathered, blocky, slightly calcareous, appears to have a metallic luster, contact gradational.	0.35

Unit	Description	Thickness
9	Soil with hard nodules, extremely calcareous, probably equivalent to unit 6 at first locality.	0.30
	Total thickness (m) (at first locality)	12.46
	Total thickness (m) (using units 1-9 at second locality for units 1-6 at first locality)	11.46

APPENDIX II

The methods used here are based on those of Scott (1973) and Lane (1964).

Disaggregation

Approximately 60 grams of sample was oven dried (at about 60°C) for 24 hours. A sample of 49 to 51 ± 0.1 gram was soaked in kerosene for 24 hours. The kerosene was decanted, boiling water added and allowed to stand for 24 hours. The sample was wet sieved at 4∅, then oven dried for 24 hours. Then the sample was dry sieved into +10, +18, +35 and +60 mesh size fractions.

Picking

Each fraction was examined with a binocular microscope three times to increase the probability of finding all microfossils. Organic constituents were identified as completely as possible and tabulated.

Symbols

 fusulinid
 trepostome bryozoan
 fenestrate bryozoan
 echinoid spine
 crinoid fragment
 productid brachiopod spines
 trilobite
 high-spired gastropod
 planispiral gastropod
 mollusc prismatic layer
 unidentified bivalve
 unidentified ostracode
 <u>Hollinella</u>
 <u>Bairdia</u>
 <u>Bairdiacypris</u>
 fish fragment
 <u>Spirorbis</u>
 pecten
 <u>Septimyalina</u>
 algal coating

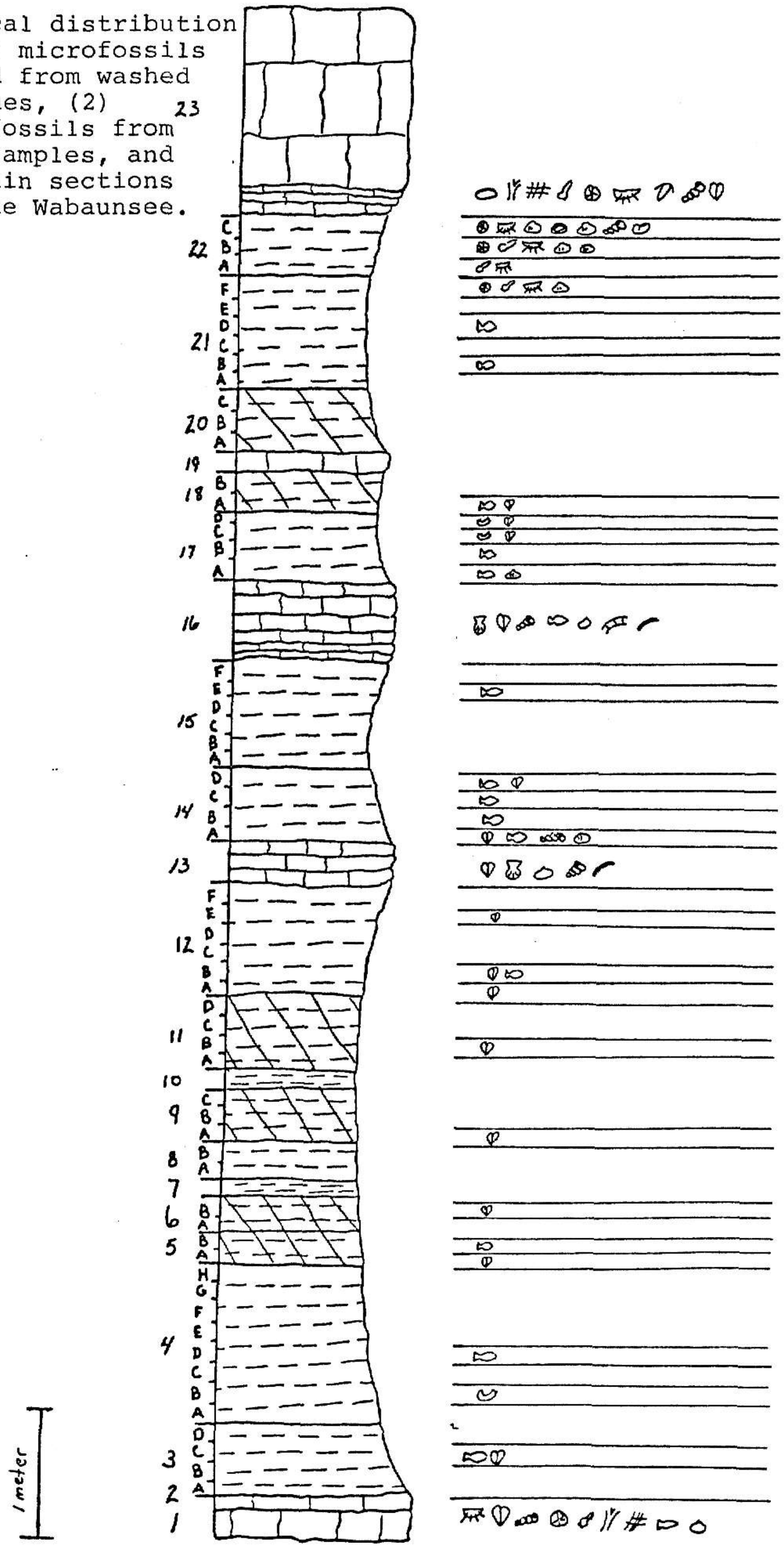
Number of specimens per 50 gram sample picked from washed residues.

Sample	Fossil	Number of Specimens
3C	fish fragments	7
	bivalve fragments	15
4B	<u>Spirorbis</u>?	1
4D	fish fragments	6
5A	brachiopod or bivalve fragments	42
5B	fish fragments	11
6B	brachiopod or bivalve fragments	27
9A	brachiopod or bivalve fragments	48
11B	brachiopod or bivalve fragments	7
12A	brachiopod or bivalve fragments	3
12B	brachiopod or bivalve fragments	5
	fish fragments	12
12E	brachiopod or bivalve fragments	113
14A	brachiopod or bivalve fragments	87
	fish fragments	29
	high-spired gastropod	1
	<u>Bairdia</u>	8
14B	fish fragments	17
14C	fish fragments	21
14D	fish fragments	18
	bivalve fragments	1
15E	fish fragments	12
17A	fish fragments	7
	<u>Bairdia</u>?	2
17B	fish fragments	6
17C	<u>Spirorbis</u>?	3
	brachiopod or bivalve fragments	1
17D	<u>Spirorbis</u>?	5
	brachiopod or bivalve fragments	1

Number of specimens per 50 gram sample picked from washed residue.

Sample	Fossil	Number of Specimens
18A	fish fragments	6
	brachiopod or bivalve fragments	18
21B	fish fragments	15
21D	fish fragments	7
21F	crinoid stems	8
	echinoid spines	8
	brachiopod spines	79
	Bairdia?	1
22A	echinoid spines	8
	brachiopod spines	16
22B	crinoid stems	6
	echinoid spines	5
	brachiopod spines	5
	Bairdia?	2
	Hollinella?	6
22C	crinoid stems	68
	brachiopod spines or fragments	176
	Bairdia?	7
	Bairdiacypris?	16
	Hollinella?	72
	high-spired gastropods	30
	planispiral gastropod	1

Vertical distribution of (1) microfossils picked from washed residues, (2) macrofossils from hand samples, and (3) thin sections at Lake Wabaunsee.



APPENDIX III

Terrigenous units were treated for carbonates and then analysed for grain size and mineralogy. Because clay mineralogy of the insoluble fractions was determined, glacial acetic acid instead of hydrochloric acid was used to remove carbonates. This substitution results in slower digestion of carbonates, but does not remove chlorite which is soluble in HCl. Insoluble residues of carbonate units were prepared using smaller quantities of rock to reduce the amount of acid needed. The method is from Scott (1973).

Terrigenous Units

Approximately 60 grams of sample was crushed to pea size in a jaw crusher followed by oven drying at about 60°C for 24 hours. A 50.000 ± 0.001 gram sample was placed in a weighed (± 0.001 gram) 500 ml beaker. Approximately 50 ml of distilled water was added to slow down the initial reaction. One hundred milliliters of 4.5 M glacial acetic acid was added in 10 ml aliquots over a period of one hour, again, to slow down the initial reaction. Another 100 ml of glacial acetic acid was added at the end of two hours and the sample stirred. The sample was stirred twice over the next 24 hours to facilitate digestion of all the carbonates. At the end of 24 hours, samples were allowed to settle (from 3 to 24 hours) until the supernatant was clear. Clear supernatant was decanted and the sample washed with distilled water until a pH of 6.5 to 7.0 was obtained. Total insoluble residue was obtained by adding the weights of each size fraction after their separation.

Mineralogical determinations showed secondary minerals were present in some samples. To obtain the terrigenous fraction at the time of deposition, the weight of the secondary minerals was removed from the original and insoluble residue weights and the percentage of insoluble residue recalculated. This provides values that more accurately reflect terrigenous influx.

Carbonate Units

Carbonate units were treated in the same manner, but only 1.0000 ± 0.0001 gram of sample was treated. Sufficient acid was added to digest all the carbonate in a 48 hour period. Insoluble residues were carefully washed until a pH of 6.5 to 7.0 was obtained. The sample was placed in a weighed (± 0.0001 gram) 50 ml beaker, dried for 24 hours, cooled, weighed and retained for optical observations.

Insoluble residue weights in grams and percentages (Lake Wabaunsee section).

Sample	Original Weight	Original Insoluble Weight	Secondary Weight	Adjusted Original Weight	Adjusted Insoluble Weight	Insoluble Residue Percent
1A	0.9998	0.5004	------	------	------	50.05
1B	1.0011	0.2214	------	------	------	22.12
1C	0.9998	0.0897	------	------	------	8.97
1D	0.9998	0.1089	------	------	------	10.89
1E	0.9999	0.0517	------	------	------	5.17
1F	1.0005	0.0853	------	------	------	8.52
1G	1.0003	0.0807	------	------	------	8.07
1H	1.0004	0.0884	------	------	------	8.84
1I	1.0000	0.1217	------	------	------	12.17
1J	1.0005	0.1500	------	------	------	14.99
1K	1.0008	0.1525	------	------	------	15.24
1L	0.9997	0.1341	------	------	------	13.41
3A	50.001	42.599	0.379	49.622	42.220	85.08
3B	50.002	41.011	0.198	49.804	40.813	81.95
3C	50.001	38.067	0.001	50.000	38.066	76.13
3D	50.000	26.340	0.536	49.464	25.804	52.17
4A	50.000	25.618	15.616	34.384	10.002	29.09
4B	50.001	26.601	19.459	30.542	7.142	23.38
4C	50.000	25.905	17.725	32.275	8.180	25.34
4D	50.001	28.390	15.238	34.763	13.152	37.83
4E	50.001	24.649	17.181	32.820	7.468	22.75
4F	50.001	23.787	13.079	36.922	10.708	29.00
4G	50.005	28.293	14.437	35.568	13.856	38.96
4H	50.002	29.167	0.010	49.992	29.157	58.32
5A	50.000	30.445	0.081	49.919	30.364	60.83
5B	50.000	39.960	1.222	48.778	38.738	79.42
6A	50.000	32.784	0.736	49.264	32.048	65.05
6B	50.000	41.637	0.050	49.950	41.587	83.26
7	50.001	39.009	------	------	------	78.02

Insoluble residue weights in grams and percentages (Lake Wabaunsee section).

Sample	Original Weight	Original Insoluble Weight	Secondary Weight	Adjusted Original Weight	Adjusted Insoluble Weight	Insoluble Residue Percent
8A	50.000	26.253	13.215	36.785	13.038	35.44
8B	50.000	29.623	15.627	34.373	13.996	40.72
9A	50.000	29.169	0.836	49.164	28.333	57.63
9B	50.000	25.804	2.324	47.676	23.480	49.25
9C	50.001	29.934	0.030	49.971	29.904	59.84
10	50.001	30.014	0.010	49.991	30.004	60.02
11A	50.000	48.210	------	------	------	96.42
11B	50.000	48.659	------	------	------	97.32
11C	50.000	48.556	------	------	------	97.11
11D	50.001	46.476	------	------	------	92.95
12A	50.000	36.174	0.004	49.996	36.170	72.34
12B	50.001	33.001	3.180	46.821	29.821	63.69
12C	50.000	31.729	0.350	49.650	31.379	63.20
12D	50.000	36.106	0.130	49.870	35.976	72.14
12E	50.000	38.063	0.059	49.941	38.004	76.10
12F	50.001	42.411	0.001	50.000	42.410	84.82
13A	1.0004	0.1112	------	------	------	11.12
13B	1.0003	0.0400	------	------	------	4.00
13C	1.0001	0.1598	------	------	------	15.98
13D	1.0004	0.0593	------	------	------	5.93
13E	1.0006	0.0945	------	------	------	9.44
14A	50.000	46.271	0.002	49.998	46.269	92.54
14B	50.000	48.075	0.001	49.999	48.074	96.15
14C	50.000	44.694	0.008	49.992	44.686	89.39
14D	50.001	43.164	0.021	49.980	43.143	86.32

Insoluble residue weights in grams and percentages (Lake Wabaunsee section).

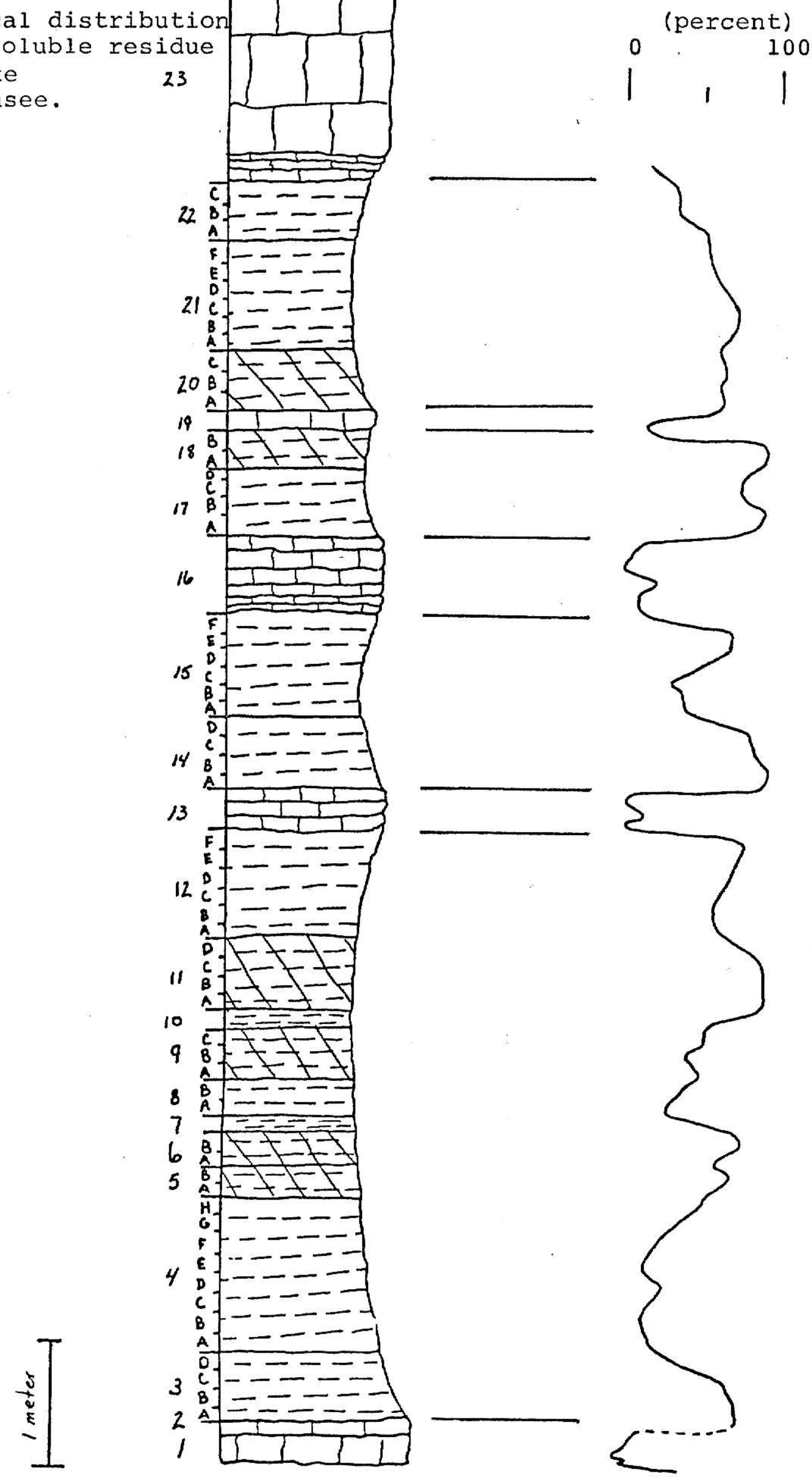
Sample	Original Weight	Original Insoluble Weight	Secondary Weight	Adjusted Original Weight	Adjusted Insoluble Weight	Insoluble Residue Percent
15A	50.000	31.230	17.120	32.880	14.110	42.91
15B	50.001	30.981	18.268	31.733	12.713	40.06
15C	50.000	29.260	19.002	30.998	10.258	33.09
15D	50.000	29.638	6.644	43.356	22.994	53.04
15E	50.000	35.922	0.115	49.885	35.807	71.78
15F	50.000	35.367	0.627	49.373	34.740	70.36
16A	0.9997	0.1891	------	------	------	18.92
16B	1.0006	0.1298	------	------	------	12.97
16C	1.0001	0.1294	------	------	------	12.94
16D	1.0001	0.1425	------	------	------	14.25
16E	0.9999	0.2559	------	------	------	25.59
16F	0.9999	0.0407	------	------	------	4.07
16G	0.9999	0.0451	------	------	------	4.51
16H	1.0004	0.0550	------	------	------	5.50
16I	1.0004	0.0883	------	------	------	8.83
17A	50.001	42.130	0.002	49.999	42.128	84.26
17B	50.001	45.013	0.037	49.964	44.976	90.02
17C	50.000	37.875	0.583	49.917	37.292	75.46
17D	50.000	38.790	0.023	49.977	38.767	77.57
18A	50.000	46.476	0.001	49.999	46.475	92.95
18B	50.001	45.352	0.012	49.989	45.340	90.70
19	50.000	14.117	7.273	42.727	6.844	16.02
20A	50.000	33.276	0.012	49.988	33.264	66.54
20B	50.001	31.873	0.079	49.922	31.794	63.69
20C	50.000	33.758	0.241	49.759	33.517	67.36

Insoluble residue weights in grams and percentages (Lake Wabaunsee section).

Sample	Original Weight	Original Insoluble Weight	Secondary Weight	Adjusted Original Weight	Adjusted Insoluble Weight	Insoluble Residue Percent
21A	50.000	31.809	0.024	49.976	31.785	63.60
21B	50.000	36.080	0.113	49.887	35.967	72.10
21C	50.001	36.836	------	------	------	73.67
21D	50.000	33.728	0.042	49.958	33.686	67.43
21E	50.000	29.279	0.003	49.997	29.276	58.56
21F	50.000	27.519	0.016	49.984	27.503	55.02
22A	50.000	27.164	0.810	49.190	26.354	53.58
22B	50.000	18.649	1.083	48.917	17.566	35.91
22C	50.000	17.246	1.081	48.919	16.165	33.04
23	0.9995	0.1855	------	------	------	18.56

Insoluble Residues

Vertical distribution of insoluble residue at Lake Wabaunsee.



APPENDIX IV

Sand Fraction

Following the removal of solubles as described in Appendix III, the sand fraction was removed by wet sieving. A 230 mesh (4∅) sieve was placed over an 8" funnel leading into a 1000 ml sedimentation tube. Sediment trapped on the sieve was gently worked to break up grains adhering to one another. After drying the sieve, it was shaken over the funnel to remove any silt or clay particles previously trapped by water tension. Sand was transferred to a weighed ($\pm$ 0.001 gram) 50 ml beaker, oven dried (at about 60°C) for 24 hours, cooled, weighed and saved for mineralogical determinations.

Silt Fraction

Water was added to the sedimentation tube to bring the total up to 1000 ml. This was allowed to sit overnight as a check for flocculation which did not occur in any of the samples.

Silt and clay (less than 2 μ fraction) were separated by centrifuging in 100 ml tubes filled to a depth of 10 cm. Room temperature was checked and the appropriate time to centrifuge at 2100 rpm was determined using Jackson (1958). Recentrifuging clays showed very minor contamination by silts, but clays were often not completely removed from the silt fraction in one centrifuging. Therefore, the "silt" fraction was always recentrifuged. A third centrifuging was not necessary. The silt fraction was transferred to a weighed ($\pm$ 0.001 gram) 500 ml beaker, oven dried for 24 hours, cooled, weighed, and saved for mineralogic determination. While determining mineralogy, median silt grain size was determined by measuring the longest dimension of one hundred grains.

Clay Fraction

The clay fraction was returned to the sedimentation tube and one to two grams of NaCl added to flocculate the clays. After 24 hours, the excess water was decanted. The salt was washed from the clays by adding distilled water, shaking, and centrifuging for 30 minutes at 2100 rpm. If the suspension was clear, it was decanted and the sample rewashed. When some grains remained in suspension after centrifuging, the salt was removed.

The centrifuge tube was shaken and rinsed out. This procedure reduced the amount of water and concentrated the clay fraction which was transferred to a weighed (± 0.001 gram) 500 ml beaker, oven dried for 24 hours, cooled, weighed, and saved for mineralogical determination.

Grain size of insoluble residue in grams (Lake Wabaunsee section).

Sample	Original Weight	Adjusted Insoluble Weight	Sand Fraction	Silt Fraction	Clay Fraction
3A	50.001	42.220	0.019	33.353	8.848
3B	50.002	40.813	0.153	29.276	11.384
3C	50.001	38.066	0.004	24.776	13.286
3D	50.000	25.804	0.005	18.106	7.693
4A	50.000	10.002	0.004	5.344	4.654
4B	50.001	7.142	0.003	1.685	5.454
4C	50.000	8.180	0.001	3.307	4.873
4D	50.001	13.152	0.001	5.919	7.233
4E	50.001	7.468	0.001	1.266	6.202
4F	50.001	10.708	0.001	3.657	7.051
4G	50.005	13.856	0.005	5.779	8.072
4H	50.002	29.157	0.483	18.831	9.843
5A	50.000	30.364	0.037	20.503	9.824
5B	50.000	38.738	0.315	28.000	10.423
6A	50.000	32.048	0.012	22.092	9.944
6B	50.000	41.587	0.022	28.018	13.547
7	50.001	------	0.001	28.889	10.120
8A	50.000	13.038	0.009	2.542	10.487
8B	50.000	13.996	0.098	3.696	10.202
9A	50.000	28.333	------	21.257	7.076
9B	50.000	23.480	------	15.866	7.614
9C	50.001	29.904	------	20.132	9.772
10	50.001	30.004	------	22.257	7.747
11A	50.000	------	------	15.062	33.148
11B	50.000	------	------	16.363	32.296
11C	50.000	------	------	16.141	32.415
11D	50.001	------	------	17.652	28.824
12A	50.000	36.170	0.003	29.007	7.160
12B	50.001	29.821	0.022	21.970	7.829
12C	50.000	31.379	------	22.948	8.431
12D	50.000	35.976	------	23.660	12.316
12E	50.000	38.004	------	25.781	12.223
12F	50.001	42.410	0.004	27.766	14.640
14A	50.000	46.269	------	32.829	13.440
14B	50.000	48.074	------	35.141	12.933
14C	50.000	44.686	------	28.823	15.863
14D	50.001	43.143	------	28.565	14.578

Grain size of insoluble residue in grams (Lake Wabaunsee section).

Sample	Original Weight	Adjusted Insoluble Weight	Sand Fraction	Silt Fraction	Clay Fraction
15A	50.000	14.110	------	3.506	10.604
15B	50.001	12.713	------	4.117	8.596
15C	50.000	10.258	------	3.313	6.945
15D	50.000	22.994	0.001	13.992	9.002
15E	50.000	35.807	------	25.400	10.407
15F	50.000	34.740	------	25.397	9.343
17A	50.001	42.128	------	21.326	20.802
17B	50.001	44.976	------	31.254	13.722
17C	50.000	37.292	------	14.571	22.721
17D	50.000	38.767	------	14.655	24.112
18A	50.000	46.475	------	33.932	12.543
18B	50.001	45.340	------	33.318	12.022
19	50.000	6.844	0.030	3.475	3.339
20A	50.000	33.264	------	19.960	13.304
20B	50.001	31.794	------	19.524	12.270
20C	50.000	33.517	------	20.991	12.526
21A	50.000	31.785	------	21.525	10.260
21B	50.000	35.967	------	25.938	10.029
21C	50.001	------	------	26.856	9.980
21D	50.000	33.686	------	24.326	9.360
21E	50.000	29.276	------	22.022	7.254
21F	50.000	27.503	------	19.854	7.649
22A	50.000	26.354	0.055	17.869	8.430
22B	50.000	17.566	------	11.574	5.992
22C	50.000	16.165	------	11.032	5.133

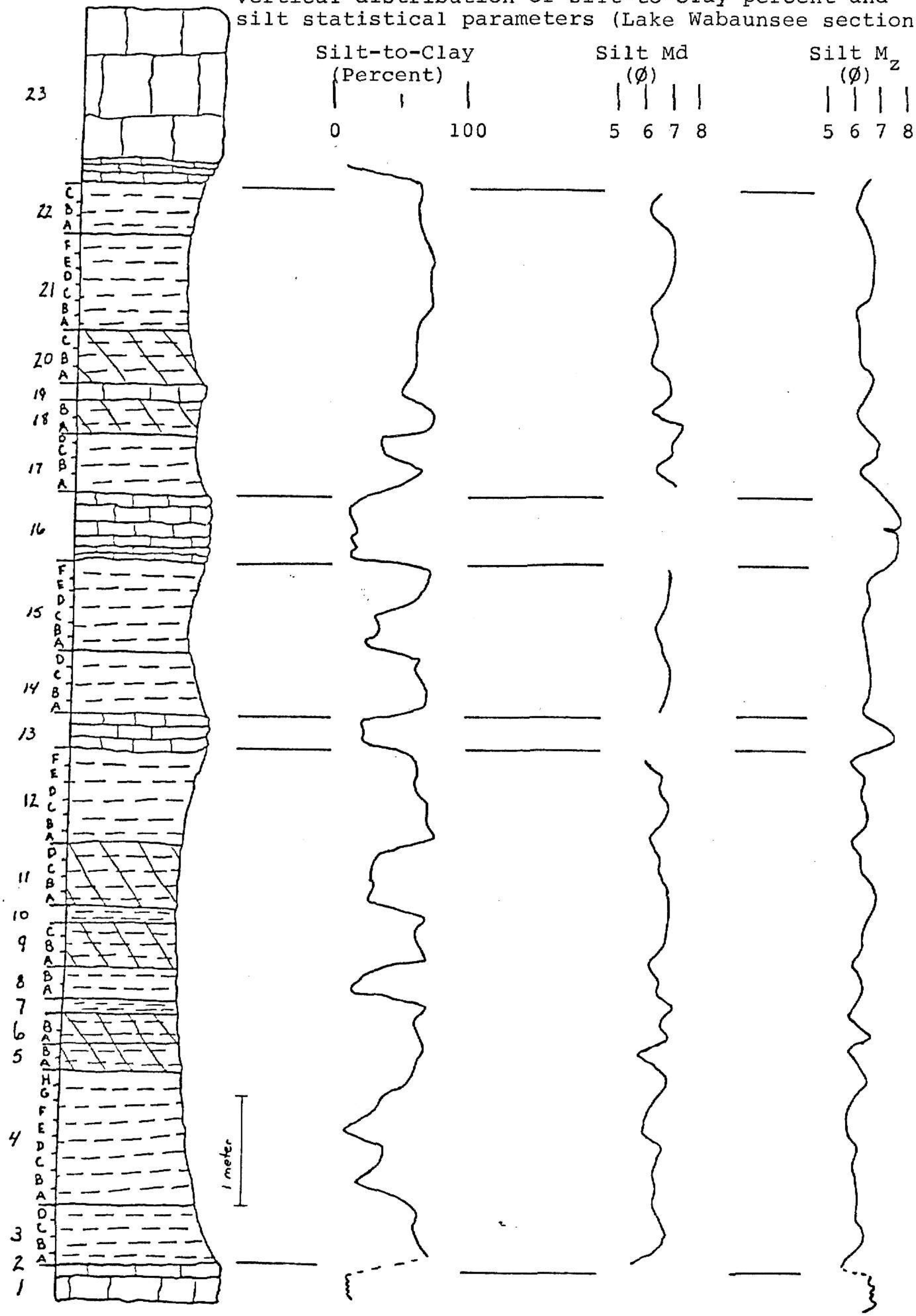
Percentage in sand, silt and clay fractions, Folk name and statistical parameters (Lake Wabaunsee section). Rock names and statistical parameters are according to Folk (1974).

Sample	Sand	Silt	Clay	Folk Name	Md	M_z	σ_I
3A	0.04	79.00	20.96	siltstone	5.94	6.07	1.21
3B	0.37	71.73	27.89	siltstone	6.82	6.66	1.08
3C	0.01	65.09	34.90	mudstone	7.10	6.96	0.90
3D	0.02	70.17	29.81	siltstone	6.79	6.53	0.98
4A	0.04	53.43	46.53	mudstone	6.62	6.62	1.12
4B	0.04	23.59	76.36	claystone	6.70	6.55	1.05
4C	----	40.43	59.57	mudstone	6.57	6.46	1.05
4D	----	45.00	55.00	mudstone	7.00	6.58	1.04
4E	----	16.95	83.05	claystone	6.20	6.21	0.75
4F	----	34.15	65.85	mudstone	6.29	6.22	0.87
4G	0.04	41.71	58.26	mudstone	6.62	6.46	0.92
4H	1.66	64.58	33.76	mudstone	7.16	6.99	0.78
5A	0.12	67.52	32.35	siltstone	7.00	6.65	0.95
5B	0.81	72.28	26.91	siltstone	6.06	6.19	1.00
6A	0.04	68.93	31.03	siltstone	7.20	7.05	0.82
6B	0.05	67.37	32.58	siltstone	6.90	6.57	1.01
7	----	74.06	25.94	siltstone	7.36	6.21	0.91
8A	0.07	19.50	80.43	claystone	6.74	6.59	0.87
8B	0.70	26.41	72.89	claystone	6.90	6.74	0.59
9A	----	75.03	24.97	siltstone	6.42	6.36	0.91
9B	----	67.57	32.43	siltstone	7.01	6.73	0.76
9C	----	67.32	32.68	siltstone	7.01	6.73	0.70
10	----	74.18	25.82	siltstone	7.04	6.73	0.86
11A	----	31.24	68.76	claystone	7.19	7.16	0.51
11B	----	33.63	66.37	mudstone	7.21	7.10	0.59
11C	----	33.24	66.76	claystone	6.74	6.58	0.64
11D	----	37.98	62.02	mudstone	6.73	6.58	0.67
12A	0.01	80.20	19.79	siltstone	6.39	6.25	0.85
12B	0.07	73.67	26.25	siltstone	7.00	6.81	0.55
12C	----	73.13	26.87	siltstone	7.10	6.88	0.81
12D	----	65.77	34.23	mudstone	6.81	6.62	0.64
12E	----	67.84	32.16	siltstone	6.99	6.73	0.64
12F	0.01	65.47	34.52	mudstone	6.17	6.11	0.98
14A	----	70.95	29.05	siltstone	6.83	6.66	0.86
14B	----	73.10	26.90	siltstone	7.09	6.92	0.49
14C	----	64.50	35.50	mudstone	7.09	6.95	0.62
14D	----	66.21	33.79	mudstone	7.00	6.75	0.61

Percentage in sand, silt and clay fractions, Folk name and statistical parameters (Lake Wabaunsee section).

Sample	Sand	Silt	Clay	Folk Name	Md	M_z	σ_I
15A	----	24.85	75.15	claystone	6.90	6.70	0.60
15B	----	32.38	67.62	claystone	6.61	6.54	0.76
15C	----	32.30	67.70	claystone	6.72	6.55	0.73
15D	----	60.85	39.15	mudstone	7.00	6.89	0.73
15E	----	70.94	29.06	siltstone	7.02	6.84	0.72
15F	----	73.11	26.89	siltstone	7.03	6.92	0.57
17A	----	50.62	49.38	mudstone	7.20	7.12	0.57
17B	----	69.49	30.51	siltstone	6.50	6.46	0.83
17C	----	39.07	60.93	mudstone	7.20	7.07	0.67
17D	----	37.80	62.20	mudstone	7.18	7.14	0.59
18A	----	73.01	26.99	siltstone	7.02	6.72	0.83
18B	----	73.48	26.52	siltstone	6.30	6.26	0.95
19	0.44	50.77	48.79	mudstone	7.02	6.79	0.73
20A	----	60.00	40.00	mudstone	7.01	6.95	0.52
20B	----	61.41	38.59	mudstone	6.30	6.28	0.81
20C	----	62.63	37.37	mudstone	6.54	6.42	0.76
21A	----	67.72	32.28	siltstone	6.50	6.43	0.72
21B	----	72.12	27.88	siltstone	6.34	6.33	0.73
21C	----	72.91	27.09	siltstone	6.76	6.64	0.61
21D	----	72.21	27.79	siltstone	7.02	6.77	0.62
21E	----	75.22	24.78	siltstone	7.08	6.85	0.58
21F	----	72.19	27.81	siltstone	7.06	6.82	0.78
22A	0.21	67.80	31.99	siltstone	6.78	6.61	0.88
22B	----	65.89	34.11	mudstone	6.23	6.21	0.85
22C	----	68.25	31.75	siltstone	6.60	6.39	0.84

Vertical distribution of silt-to-clay percent and silt statistical parameters (Lake Wabaunsee section).



APPENDIX V

The minerals from the sand fraction of each sample were picked using a binocular microscope. These grains were then identified using a petrographic microscope. Only three minerals were observed--quartz, gypsum and pyrite. The quartz is clear, subrounded to subangular, fine to very fine sand. It was identified by its lack of cleavage, hardness and positive relief when viewed with a petrographic microscope in an oil with a refractive index of 1.53. Gypsum was identified by its crystal form, lack of effervescence in HCl and hardness. The clustered, well developed crystal habit indicates gypsum is secondary. One unusual occurrence of gypsum is its replacement of salt casts. These were found in the washed residue of Lake Wabaunsee samples 4A, 4B and 4C. Pyrite was identified by its color, form and striations. Well developed cubes suggest the pyrite was also secondary.

Only quartz is present as a terrigenous mineral in the sand fraction. Percentages of gypsum and pyrite were not estimated.

Presence of gypsum and pyrite in samples (Lake Wabaunsee section).

Sample	Gypsum	Pyrite
3A	x	x
3B	x	x
3C	x	x
3D	x	x
4A	x	x
4B	x	x
4C	x	
4D	x	
4E		
4F	x	
4G		x
4H	x	x
5A	x	x
5B	x	
6A	x	x
6B	x	x
7		x
8A	x	
8B		
9A	x	x
9B		
9C		x
10	x	x
11A		x
11B		x
11C		
11D		x
12A	x	x
12B	x	x
12C	x	x
12D		
12E		
12F		
14A		x
14B		x
14C		x
14D		x
15A		x
15B	x	x
15C		
15D	x	x
15E		x
15F	x	x
17A		
17B	x	x
17C	x	x
17D	x	x
18A	x	x
18B	x	x
19	x	x
20A		x
20B		x
20C		x
21A		x
21B	x	x
21C		x
21D		x
21E		x
21F		x
22A	x	x
22B		x
22C		

APPENDIX VI

The silt fraction of the insoluble residue was observed with a petrographic microscope. An oil with a refractive index of 1.54 was used to help distinguish feldspars from quartz. One hundred grains were identified and the maximum dimension measured. Quartz was identified by its low positive relief, low interference color, lack of cleavage and frequent presence of vacuoles and rutile inclusions. Tourmaline was identified by its high positive relief, pleochroism (usually in the greens) and prismatic crystal form. Many grains retained pyramidal end forms and showed relatively little abrasion. Rutile was identified by its very high relief, strong birefringence, slender crystal habit and pleochroism. These probably weathered out of quartz grains. Zircon was identified by its lack of color and pleochroism, high positive relief and high interference color. Crystal form was not well developed or preserved. Hematite was identified by its red color, very high positive relief and tabular shape.

Because 100 grains were counted, values for number of grains identified are also percentages.

The graph of silt mineralogy is included with the clay size fraction in Appendix VII.

Percentage of minerals in silt fraction (Lake Wabaunsee section).

Sample	Quartz	Hematite	Total Z+T+R	Tourmaline	Rutile	Zircon
3A	96	3	1	1	0	0
3B	97	0	3	2	1	0
3C	99	0	1	0	1	0
3D	98	0	2	2	0	0
4A	93	5	2	1	1	0
4B	99	0	1	0	0	1
4C	98	0	2	0	1	1
4D	97	0	3	2	1	0
4E	94	0	6	6	0	0
4F	95	1	4	4	0	0
4G	98	0	2	2	0	0
4H	94	0	4	4	0	0
5A	98	0	2	1	1	0
5B	98	0	2	1	1	0
6A	96	1	3	2	1	0
6B	96	1	3	3	0	0
7	97	2	1	1	0	0
8A	96	2	2	1	1	0
8B	94	4	2	2	0	0
9A	94	3	3	3	0	0
9B	96	2	2	1	1	0
9C	98	1	1	0	1	0
10	99	0	1	1	0	0
11A	95	2	3	2	1	0
11B	99	1	0	0	0	0
11C	97	2	1	0	1	0
11D	99	0	1	1	0	0
12A	96	0	4	3	1	0
12B	98	0	2	2	0	0
12C	99	0	1	1	0	0
12D	97	1	2	1	1	0
12E	100	0	0	0	0	0
12F	100	0	0	0	0	0

Percentage of minerals in silt fraction (Lake Wabaunsee section).

Sample	Quartz	Hematite	Total Z+T+R	Tourmaline	Rutile	Zircon
14A	98	0	2	2	0	0
14B	98	0	2	1	1	0
14C	94	0	6	4	2	0
14D	98	0	2	2	0	0
15A	97	0	3	2	1	0
15B	95	0	5	1	4	0
15C	100	0	0	0	0	0
15D	96	2	2	2	0	0
15E	100	0	0	0	0	0
15F	98	0	2	1	1	0
17A	98	0	2	1	1	0
17B	99	0	1	1	0	0
17C	97	2	1	1	0	0
17D	92	3	5	3	1	1
18A	98	1	1	1	0	0
18B	98	2	0	0	0	0
19	96	1	3	3	0	0
20A	95	3	2	2	0	0
20B	95	0	5	4	0	1
20C	97	0	3	3	0	0
21A	97	0	3	3	0	0
21B	98	0	2	2	0	0
21C	100	0	0	0	0	0
21D	100	0	0	0	0	0
21E	97	0	3	1	2	0
21F	96	0	4	2	1	1
22A	98	0	2	1	1	0
22B	94	0	6	3	3	0
22C	94	0	6	2	3	1

APPENDIX VII

Mineralogy of the clay fraction was determined by X-ray diffraction. Two slides were made for each sample by the smear method (Gibbs, 1968). This method was used because differential settling of clay minerals in the pipette method produces erroneous percentages (Gibbs, 1965). Semi-quantitative results were obtained by weighted peak height areas (Biscaye, 1965).

The machine settings were:

Chart Speed: 30 inches/hour
Scanning Speed: 1° /minute
Target: Ni filtered CuK alpha
Divergent and Antiscatter Slit: 1°
Receiving Slit: 0.003 inch
KV Setting: 35
mamp Setting: 18
Time Constant: 2 seconds
Scale Factor: 1 K

One slide was used to run a base pattern from 55 to 53 degrees to check for pyrite and then from 34 degrees to the undeviated ray for the major clay peaks. The other slide was treated with ethylene glycol for a minimum of 48 hours.

Identification of minerals was based on peak spacings and characteristics (Brown, 1961 and Twiss, personal communication). Illite was identified by the strong 001 (10 Å) and 003 (3.3 Å) reflections. These peaks are not affected by glycolation. The sharp peaks suggest illite is relatively well crystallized. Chlorite was identified by its 001 (14 Å), 002 (7 Å) and 003 (4.67 Å) reflections. These peaks are not affected by glycolation. The 002 and 004 reflections are usually stronger than the 001 and 003 reflections indicating these are iron-rich chlorites. Vermiculite has peaks coinciding with chlorite in untreated samples, however, treatment with ethylene glycol results in a slight expansion to about 15 Å. Vermiculite is found only in the upper quarter of the section. Kaolinite peaks coincide with chlorite peaks, however, kaolinite generally has stronger, better developed peaks than chlorite. The 2.383 Å peak for kaolinite is usually strong enough to be noticed, but for chlorite it is not. No 2.383 Å peaks were seen on these X-ray diffraction patterns. The 001 (3.32 Å) peak for quartz coincides with the

003 peak for illite. The presence of quartz is confirmed by a peak at 4.27 Å. Quartz in amounts of only one to two percent can mask clay minerals and has well developed peaks. The poorly developed, small peaks found in these samples suggest only a trace of quartz.

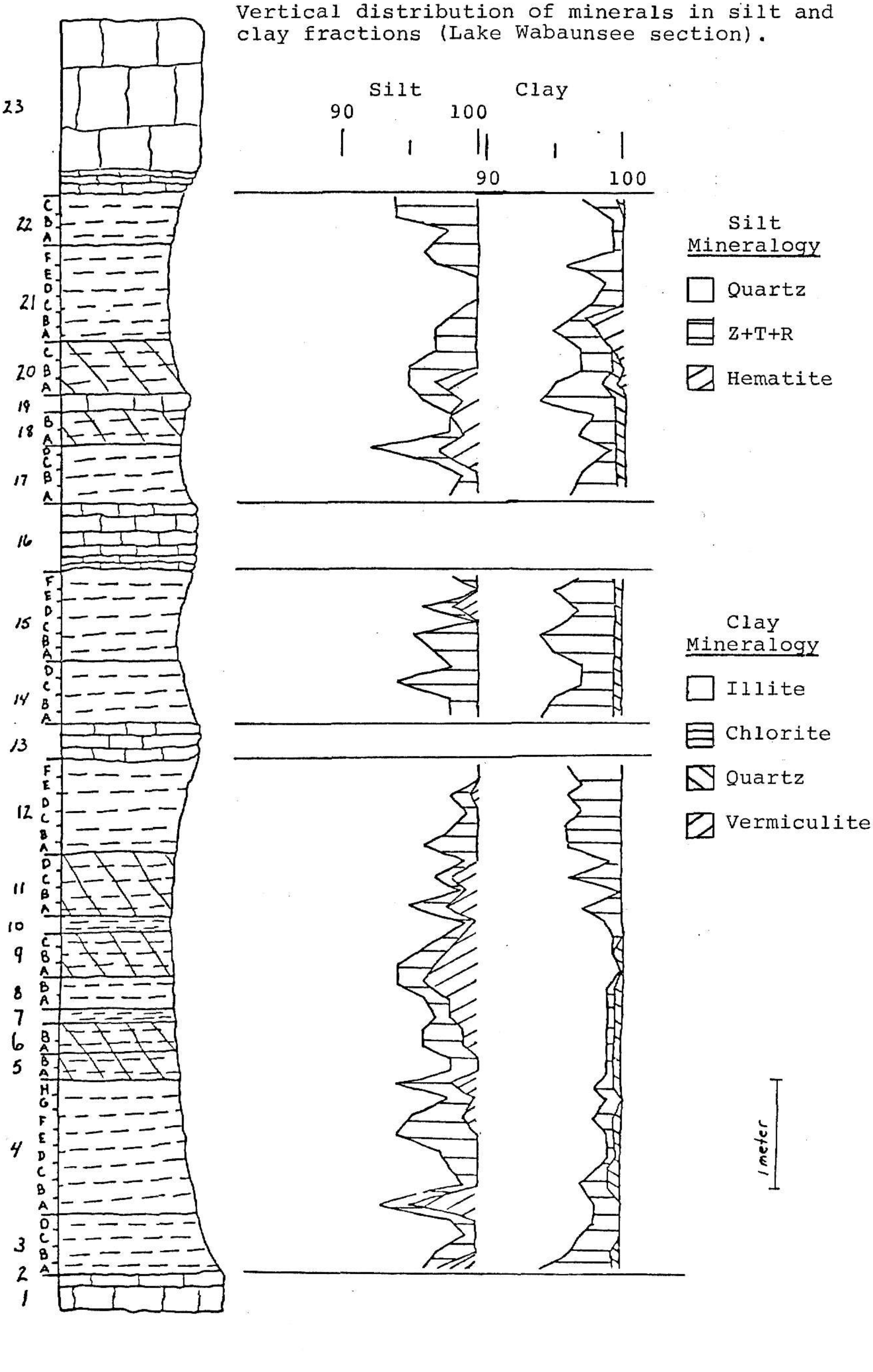
Percentage of clay minerals in clay fraction (Lake Wabaunsee section).

Sample	Illite	Chlorite	Quartz	Vermiculite
3A	94	5	trace	-----
3B	96	3	trace	-----
3C	97	3	-----	-----
3D	98	2	-----	-----
4A	98	2	-----	-----
4B	97	2	trace	-----
4C	98	1	trace	-----
4D	99	trace	trace	-----
4E	99	trace	trace	-----
4F	98	1	trace	-----
4G	99	1	-----	-----
4H	98	1	trace	-----
5A	99	trace	trace	-----
5B	99	trace	trace	-----
6A	99	trace	-----	-----
6B	99	trace	trace	-----
7	99	trace	-----	-----
8A	99	trace	-----	-----
8B	99	trace	trace	-----
9A	100	-----	-----	-----
9B	99	-----	trace	-----
9C	99	trace	-----	-----
10	99	1	-----	-----
11A	97	3	-----	-----
11B	100	-----	-----	-----
11C	96	4	-----	-----
11D	99	trace	-----	-----
12A	96	4	-----	-----
12B	96	4	-----	-----
12C	97	3	-----	-----
12D	96	4	-----	-----
12E	97	3	-----	-----
12F	96	4	-----	-----

Percentage of clay minerals in clay fraction (Lake Wabaunsee section).

Sample	Illite	Chlorite	Quartz	Vermiculite
14A	94	5	trace	-----
14B	95	4	trace	-----
14C	97	2	trace	-----
14D	97	2	trace	-----
15A	95	4	trace	-----
15B	94	5	trace	-----
15C	96	3	trace	-----
15D	97	2	trace	-----
15E	95	4	trace	-----
15F	97	2	trace	-----
17A	96	3	trace	-----
17B	97	2	trace	-----
17C	98	1	trace	-----
17D	99	trace	trace	-----
18A	97	2	trace	-----
18B	98	1	trace	-----
19	94	5	trace	-----
20A	95	3	trace	trace
20B	97	2	trace	-----
20C	97	2	-----	trace
21A	95	3	-----	2
21B	96	trace	-----	3
21C	98	2	-----	-----
21D	99	1	-----	-----
21E	96	3	-----	-----
21F	99	trace	-----	-----
22A	99	trace	-----	-----
22B	99	trace	-----	-----
22C	97	2	trace	-----

Vertical distribution of minerals in silt and clay fractions (Lake Wabaunsee section).



APPENDIX VIII

The Sedimentary Phosphate Method (SPM) was used to determine palaeosalinity (Nelson, 1967). The lowermost subunit from each unit (3A, 4A, 5A, etc.) was analysed first to determine general variation throughout the Eskridge. Then, the other subunits were analysed to check variance within units. Unfortunately, mechanical failure of necessary equipment prevented the analysis of samples 17D, 18B, 20B, 20C, 21B, 21C, 21D, 21E, 21F, 22B, and 22C. Variation in the lower units indicated it was unreasonable to wait for repairs to complete these analyses.

Samples from Jeppesen (1972) were used as references. Calcium and iron phosphate values for these samples were different from the values obtained by Jeppesen, but the ratio between values was very close and showed my procedure was satisfactory (see following table). These values are marked with an * in the data table.

Sample	ppm Fe	ppm Ca	$\frac{Ca}{Ca+Fe}$	Salinity
E4 Jeppesen	0.271	0.105	0.279	7.3
E12 Jeppesen	0.020	0.345	0.945	32.9
E4 Pecchioni	0.630	0.233	0.270	7.0
E12 Pecchioni	0.048	0.532	0.917	31.3

Nelson (1967; 1968) and Jeppesen (1972) described the procedure and reagents for this analysis in detail. The graph for conversion of percent transmittance into phosphate ppm based on my standards is given. Also, the graph for conversion of the phosphate ratio into salinity is given (Nelson, 1967).

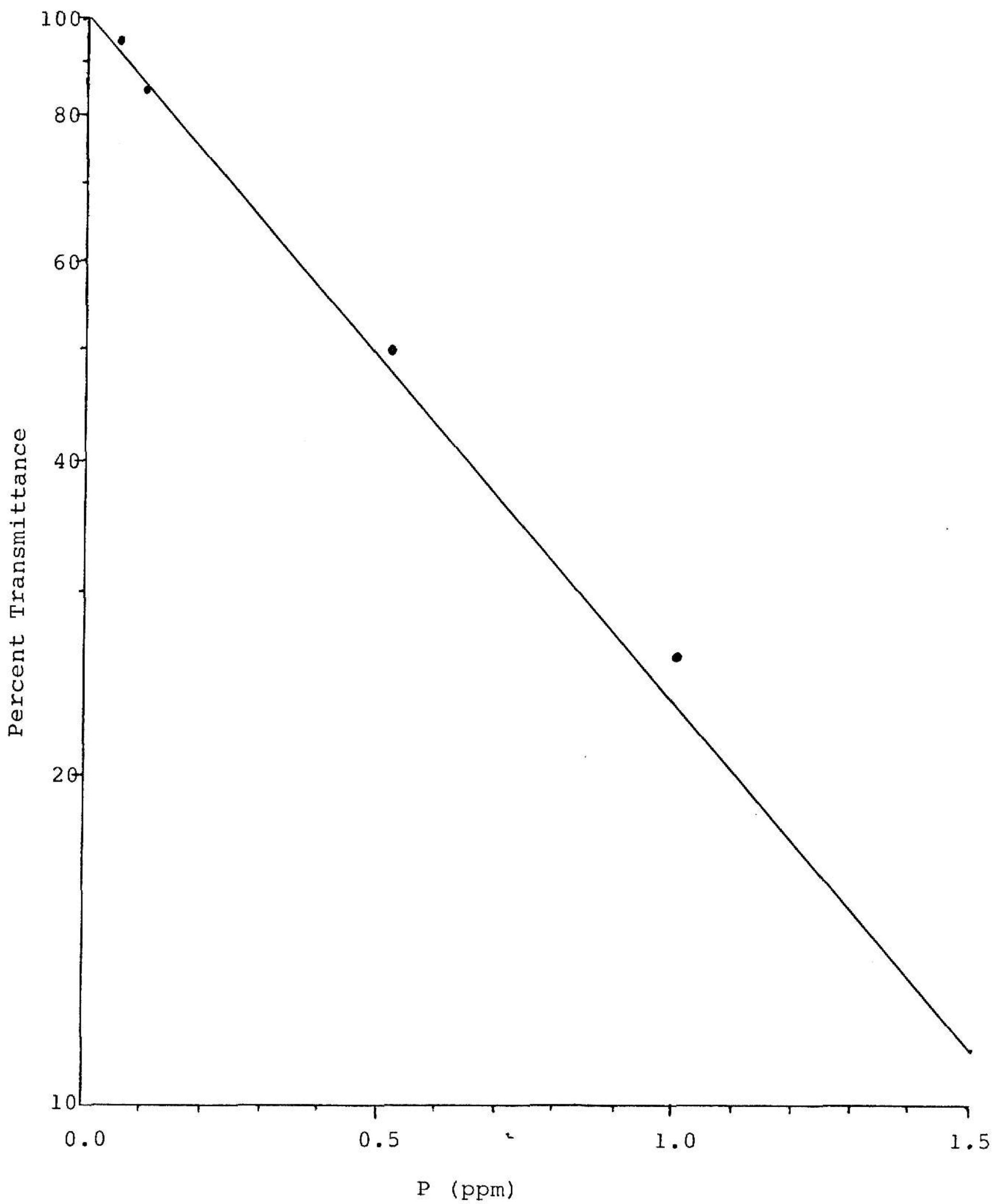
Iron and calcium phosphate values and palaeosalinity (Lake Wabaunsee section).

Sample	%T Fe	ppm Fe	%T Ca	ppm Ca	$\frac{Ca}{Ca+Fe}$	Salinity
E4	41.0	0.630	71.8	0.233	0.270	7.0*
E12	93.4	0.048	47.2	0.532	0.917	31.3*
3A	99.0	0.008	39.8	0.652	0.988	34.4
3B	99.0	0.008	48.6	0.509	0.984	34.3
3C	99.0	0.008	18.0	1.219	0.993	34.6
3D	99.2	0.005	47.4	0.529	0.991	34.5
4A	98.8	0.010	57.8	0.385	0.975	33.9
4B	98.4	0.012	64.6	0.309	0.963	33.4
4C	98.2	0.014	64.0	0.316	0.958	33.3
4D	98.8	0.010	65.4	0.298	0.968	33.7
4E	99.0	0.008	55.8	0.415	0.981	34.2
4F	98.8	0.010	49.4	0.499	0.980	34.2
4G	99.0	0.008	52.4	0.456	0.983	34.3
4H	99.6	0.004	16.2	1.290	0.997	34.7
5A	98.8	0.010	20.0	1.142	0.991	34.5
5B	99.0	0.008	20.0	1.142	0.993	34.6
6A	99.0	0.008	55.0	0.420	0.981	34.2
6B	98.8	0.010	40.2	0.645	0.985	34.4
7	99.0	0.008	28.8	0.860	0.991	34.5
8A	98.4	0.012	45.0	0.564	0.979	34.2
8B	98.6	0.009	45.0	0.564	0.984	34.3
9A	98.0	0.015	48.2	0.516	0.972	33.7
9B	99.0	0.008	59.4	0.368	0.979	34.2
9C	98.8	0.010	51.0	0.477	0.979	34.2
10	98.0	0.015	54.4	0.430	0.966	33.5
11A	97.0	0.020	61.8	0.340	0.944	32.8
11B	95.0	0.036	62.6	0.331	0.902	31.0
11C	97.0	0.020	65.8	0.293	0.936	32.6
11D	95.0	0.036	63.0	0.270	0.882	30.8
12A	99.0	0.008	40.0	0.649	0.988	34.4
12B	96.0	0.029	40.0	0.649	0.957	33.2
12C	98.2	0.014	71.8	0.233	0.943	32.8
12D	96.8	0.022	64.4	0.311	0.934	32.4
12E	97.8	0.016	62.8	0.329	0.954	33.1
12F	95.6	0.032	63.6	0.320	0.909	31.8

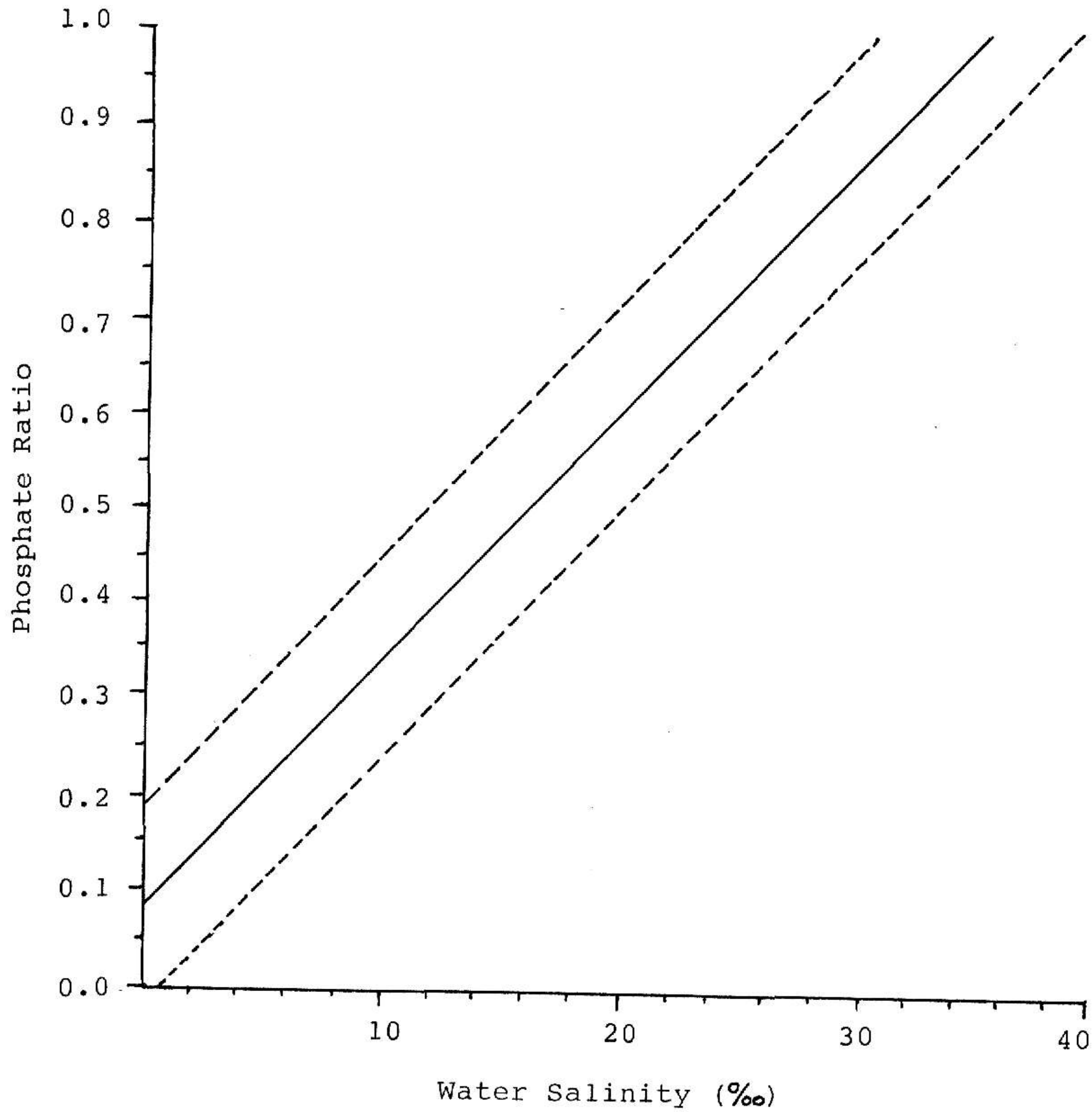
Iron and calcium phosphate values and palaeosalinity. (Lake Wabaunsee section).

Sample	%T Fe	ppm Fe	%T Ca	ppm Ca	$\frac{Ca}{Ca+Fe}$	Salinity
14A	97.4	0.018	21.4	1.195	0.985	34.4
14B	97.4	0.018	32.6	0.795	0.978	34.2
14C	97.8	0.016	30.2	0.850	0.982	34.2
14D	98.6	0.009	53.2	0.446	0.980	34.2
15A	97.6	0.015	46.8	0.537	0.973	33.7
15B	98.8	0.010	47.0	0.534	0.982	34.2
15C	99.0	0.008	57.6	0.388	0.980	34.2
15D	97.2	0.019	21.8	1.083	0.983	34.2
15E	98.4	0.012	22.0	1.075	0.989	34.5
15F	97.4	0.017	22.2	1.070	0.984	34.3
17A	98.8	0.010	8.6	1.745	0.994	34.6
17B	96.6	0.024	9.0	1.710	0.986	34.4
17C	99.0	0.008	30.0	0.853	0.986	34.4
18A	98.6	0.009	47.2	0.532	0.983	34.2
19	99.0	0.008	49.6	0.501	0.984	34.3
20A	98.8	0.010	57.6	0.388	0.975	33.7
21A	99.0	0.008	54.0	0.434	0.982	34.2
22A	99.2	0.005	58.4	0.378	0.987	34.4

Percent transmittance versus ppm Phosphorus.

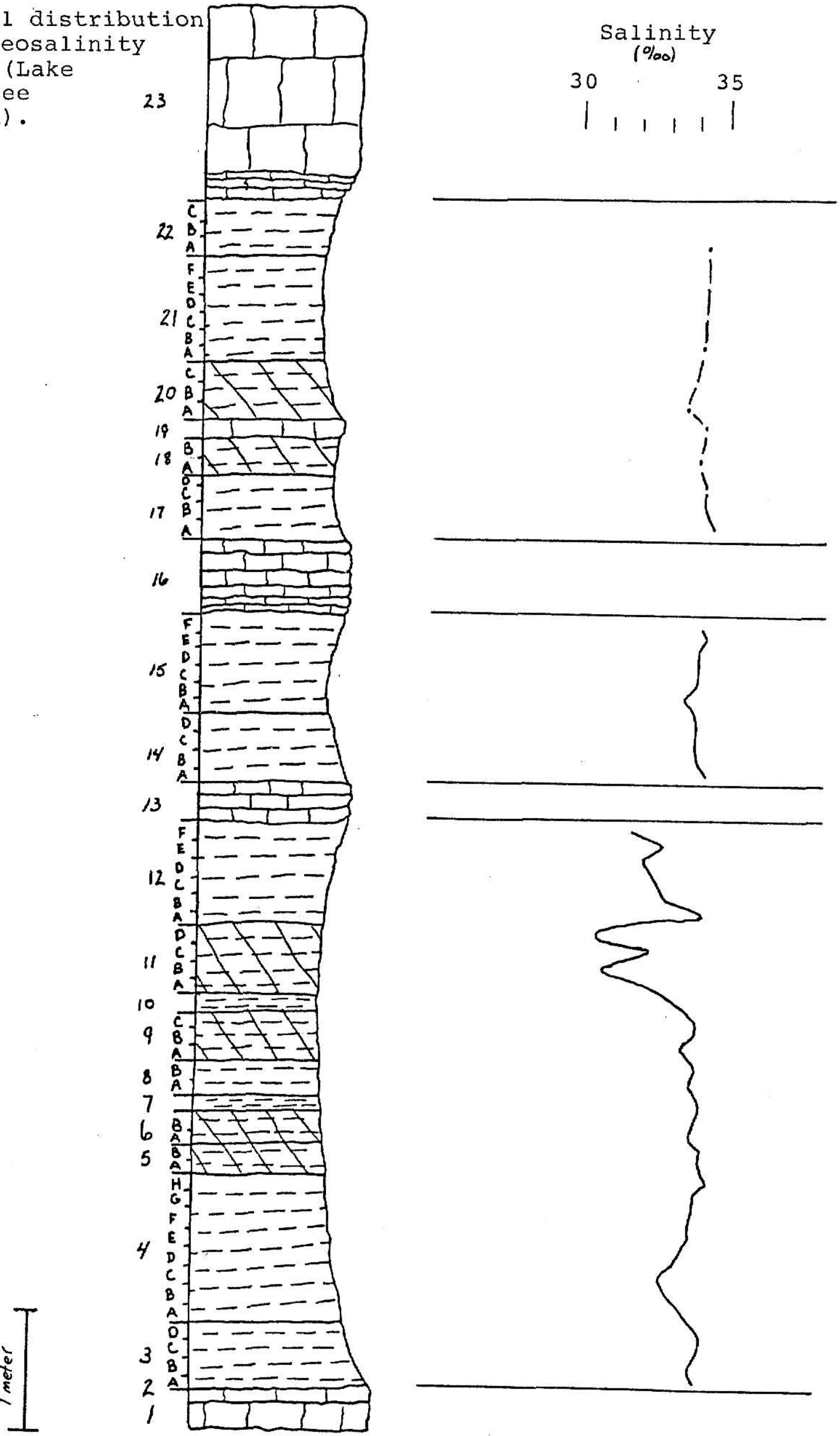


Phosphate fraction relationship to water salinity (Nelson, 1967 and Gundrum, 1977).



$$\text{Phosphate Ratio} = \frac{Ca}{Ca+Fe}$$

Vertical distribution of palaeosalinity values (Lake Wabaunsee section).



APPENDIX IX

Upper bedding planes, unless otherwise noted, were mapped by placing a piece of plexiglass over the slab. The outline of the slab and skeletal remains were traced and then transferred to paper. Therefore, the sketches are actual size. Fossils were numbered, identified and orientation and condition noted (adapted from Gundrum, 1977).

Bedding surfaces are numbered according to the unit they represent. The prefix LW stands for Lake Wabaunsee. The number indicates the unit number, e.g. 13. The letter indicates the subunit within the unit with A the lowermost bed, B the next, and so on. Therefore, LW 13E is the fifth bed in limestone 13 at Lake Wabaunsee.

Abbreviations used are as follows:

Fossil Types

b or b--unidentified fragments of a bivalve or brachiopod
frag --unidentified fragment
bryo --unidentified bryozoan fragment
gast --unidentified gastropod (high-spired)
br --unidentified brachiopod fragment
bs --brachiopod spine
cri --unidentified crinoid fragment
ech --unidentified echinoid fragment
biv --unidentified bivalve fragment
ft --fish tooth
bur --burrow
pit --bivalve resting trace?
ost --ostracode
pec --unidentified pecten fragment
Per --*Permorphous*
Avic --*Aviculopecten*
Pseu --*Pseudomonotis*
Clav --*Clavicosta*
Derb --*Derbyia*

Orientation

A slash mark (/) separates bedding orientation from convexity or apical position.

Bedding orientation:

lap--long axis parallel to bedding
si --slightly inclined to bedding (0-30°)
mi --mildly inclined to bedding (30-60°)
per--perpendicular to bedding (60-90°)

Convexity:

ccu--concave up
cvu--convex up
au --anterior up
pu --posterior up

Apical position:

apu--apex up
apd--apex down

Valve

r --right
l --left
? --valve indeterminate

Articulation

n --disarticulated
y --articulated
? --articulation indeterminate

Abrasion and Fragmentation

If a fossil has been abraded or fragmented, the appropriate column is marked with an x.

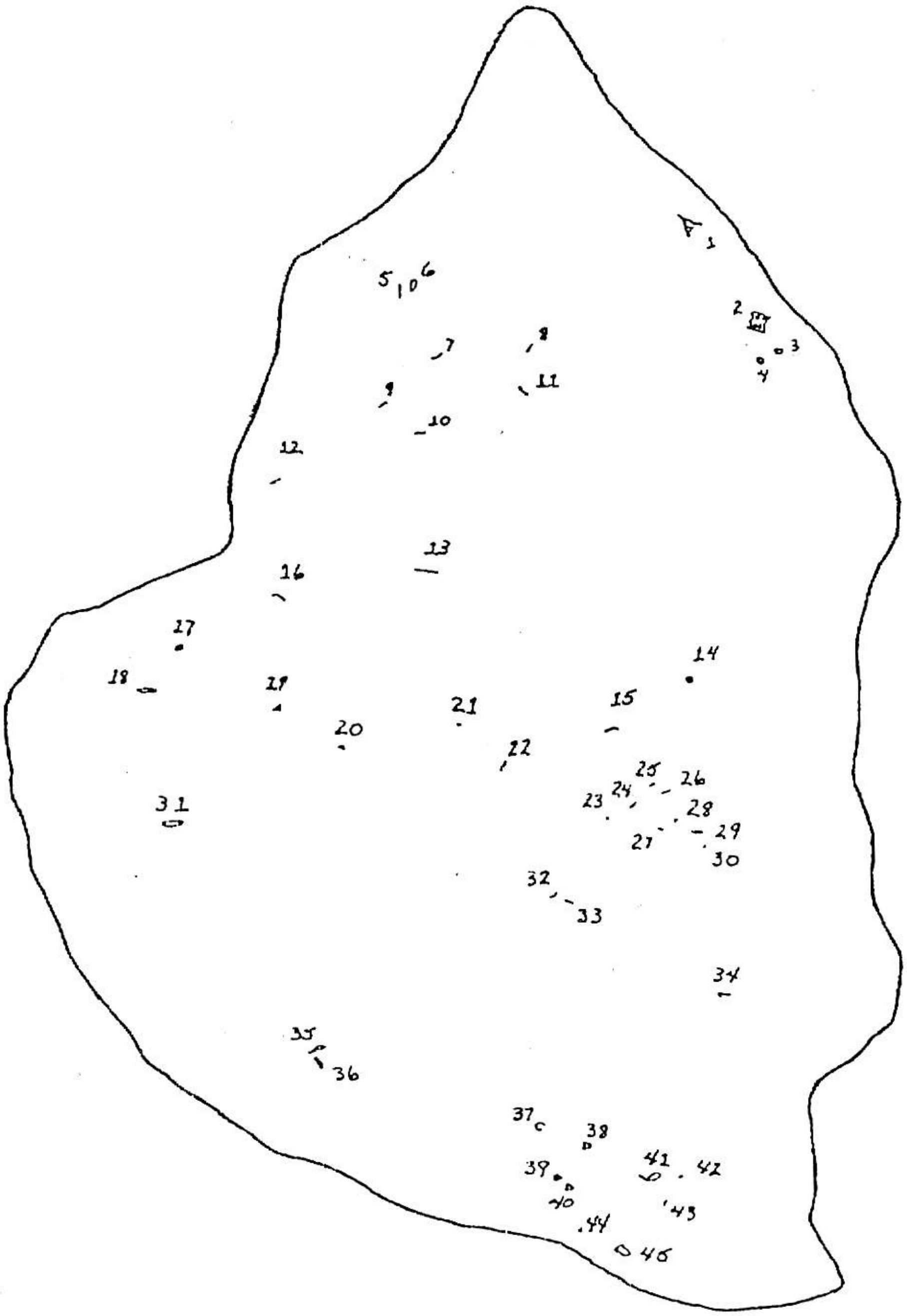
Preservation Type

o --original or replaced shell
m --mold
o/m--original or replaced shell and mold

Life or Non-life

If a fossil is preserved in life position, this column is marked with an x. If the orientation is questionably a life orientation, this column is marked with a question mark. If the orientation is not a life orientation, the column is not marked.

Bedding plane sketch of LW 1A.

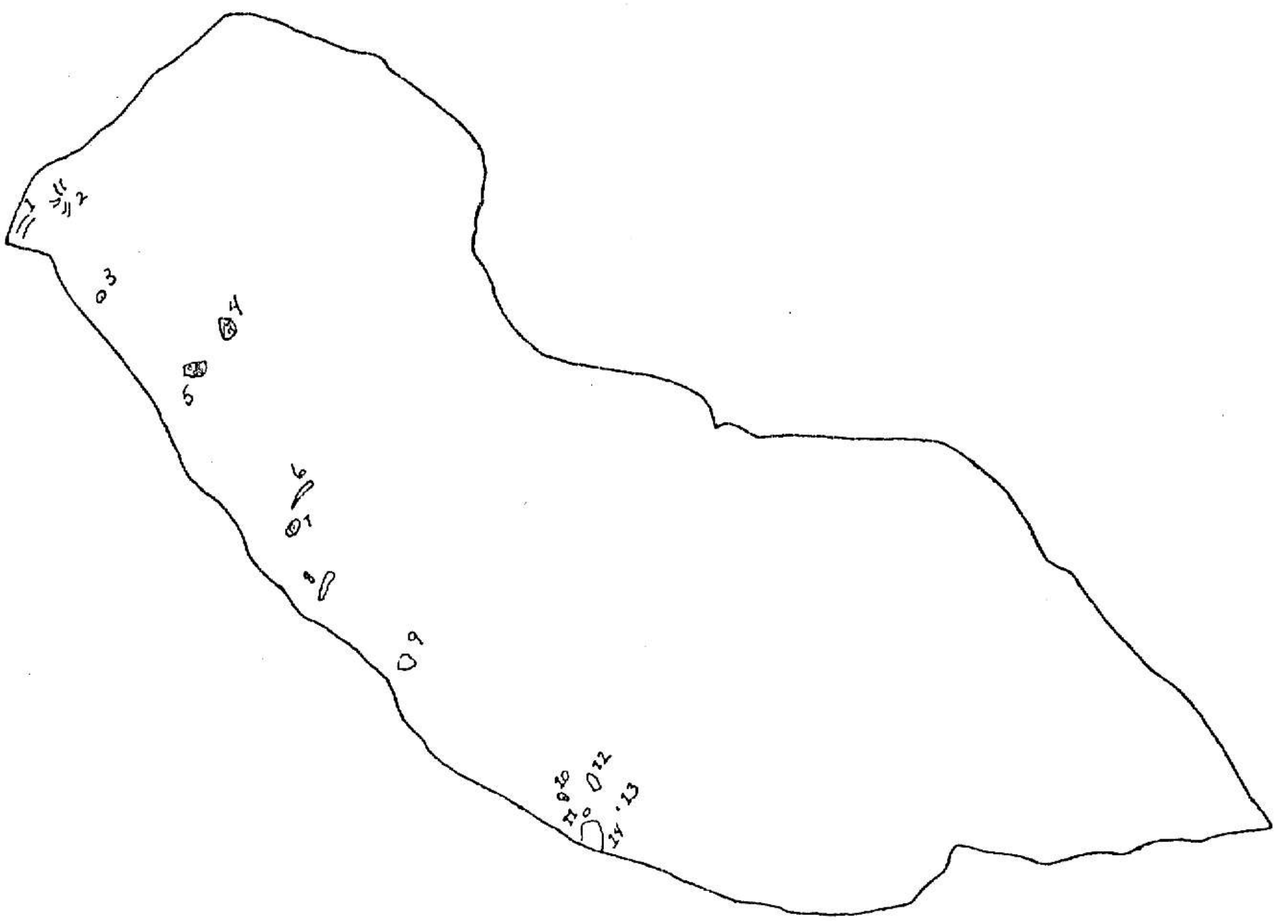


Unit number LW 1A.

Spec No	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	bs	si/lap			x	x	o	
2	bryo	si/lap			x	x	o	
3	frag	per/--			x	x	o	
4	frag	si/---			x	x	o	
5	b or b	si/cvu	?	n	x	x	o	
6	b or b	per/?	?	n	x	x	o	
7	bs	si/lap			x	x	o	
8	bs	si/lap			x	x	o	
9	frag	mi/?			x	x	o	
10	bs	si/lap			x	x	o	
11	frag	mi/cvu			x	x	o	
12	frag	mi/cvu			x	x	o	
13	biv	per/?	?	n	x	x	o	
14	frag	mi/?			x	x	o	
15	biv	per/au	?	n		x	o	
16	frag	si/?			x	x	o	
17	b or b	mi/cvu	?	n	x	x	o	
18	b or b	si/cvu	?	n	x	x	o	
19	bs	si/lap			x	x	o	
20	bryo	si/lap			x	x	o	
21	frag	mi/lap			x	x	o	
22	bs	si/lap			x	x	o	
23	bs	si/lap			x	x	o	
24	bs	si/lap			x	x	o	
25	bs	si/lap			x	x	o	
26	bs	si/lap			x	x	o	
27	bs	si/lap			x	x	o	
28	bs	si/lap			x	x	o	
29	bs	si/lap			x	x	o	
30	bs	si/lap			x	x	o	
31	b or b	mi/ccu	?	n	x	x	o	
32	bryo	si/lap			x	x	o	
33	bs	si/lap			x	x	o	
34	b or b	si/ccu	?	n	x	x	o	
35	b or b	mi/ccu	?	n	x	x	o	
36	b or b	mi/ccu	?	n	x	x	o	
37	b or b	si/ccu	?	n	x	x	o	
38	b or b	mi/ccu	?	n	x	x	o	
39	b or b	per/au	?	n	x	x	o	
40	b or b	mi/ccu	?	n	x	x	o	
41	gast	per/apu				x	m	
42	b or b	mi/cvu	?	n	x	x	o	
43	b or b	per/au	?	n	x	x	o	
44	b or b	mi/cvu	?	n	x	x	o	
45	b or b	si/ccu	?	n	x	x	o	

Unit number LW 1C.

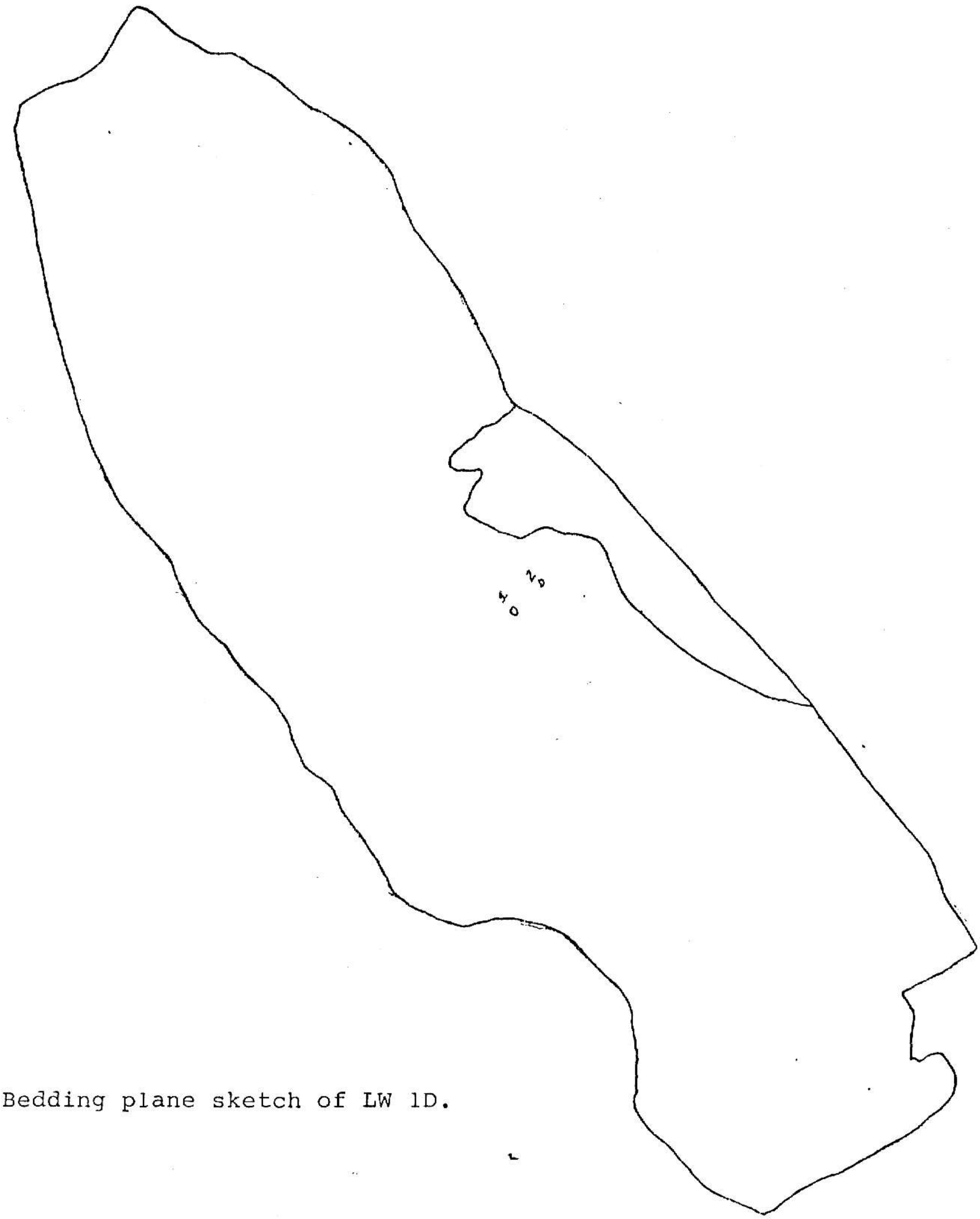
Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	bur	mi					m	x
2	bur	si					m	x
3	cri	si/---				x	o	
4	biv	si/cvu	?	n		x	o	
5	bryo	si/lap				x	o	
6	ech	si/lap			x	x	o	
7	ech	si/cvu				x	o	
8	ech	si/lap			x	x	o	
9	biv	si/ccu	?	n	x	x	o	
10	ech	si/lap				x	o	
11	frag	si/---			x	x	o	
12	biv	si/cvu	?	n		x	o	
13	frag	si/---			x	x	o	
14	biv	si/ccu	?	n		x	o	



Bedding plane sketch of LW 1C.

Unit number LW 1D.

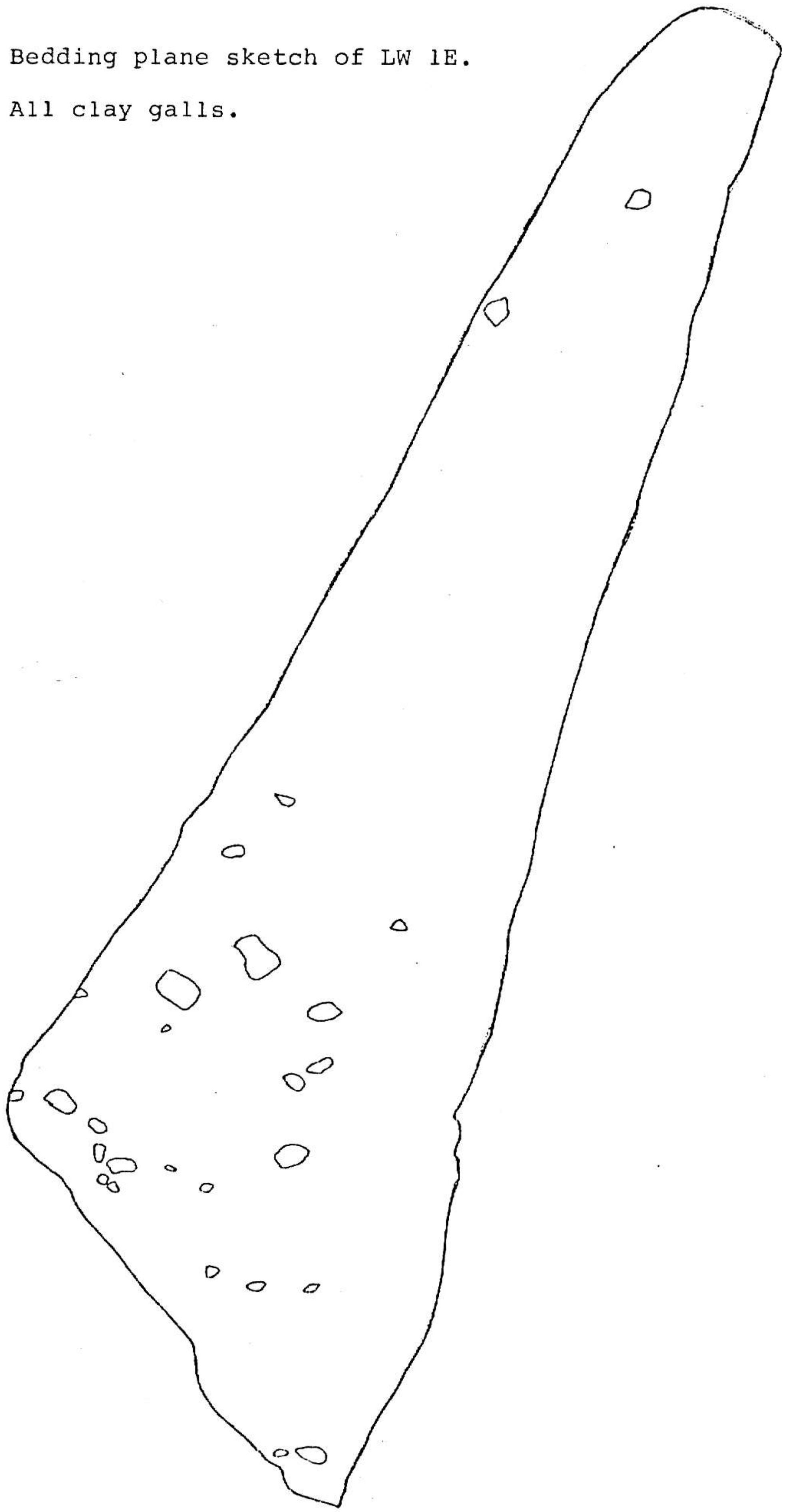
Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	ft	si/cvu			x	x	o	
2	ft	si/cvu			x	x	o	



Bedding plane sketch of LW 1D.

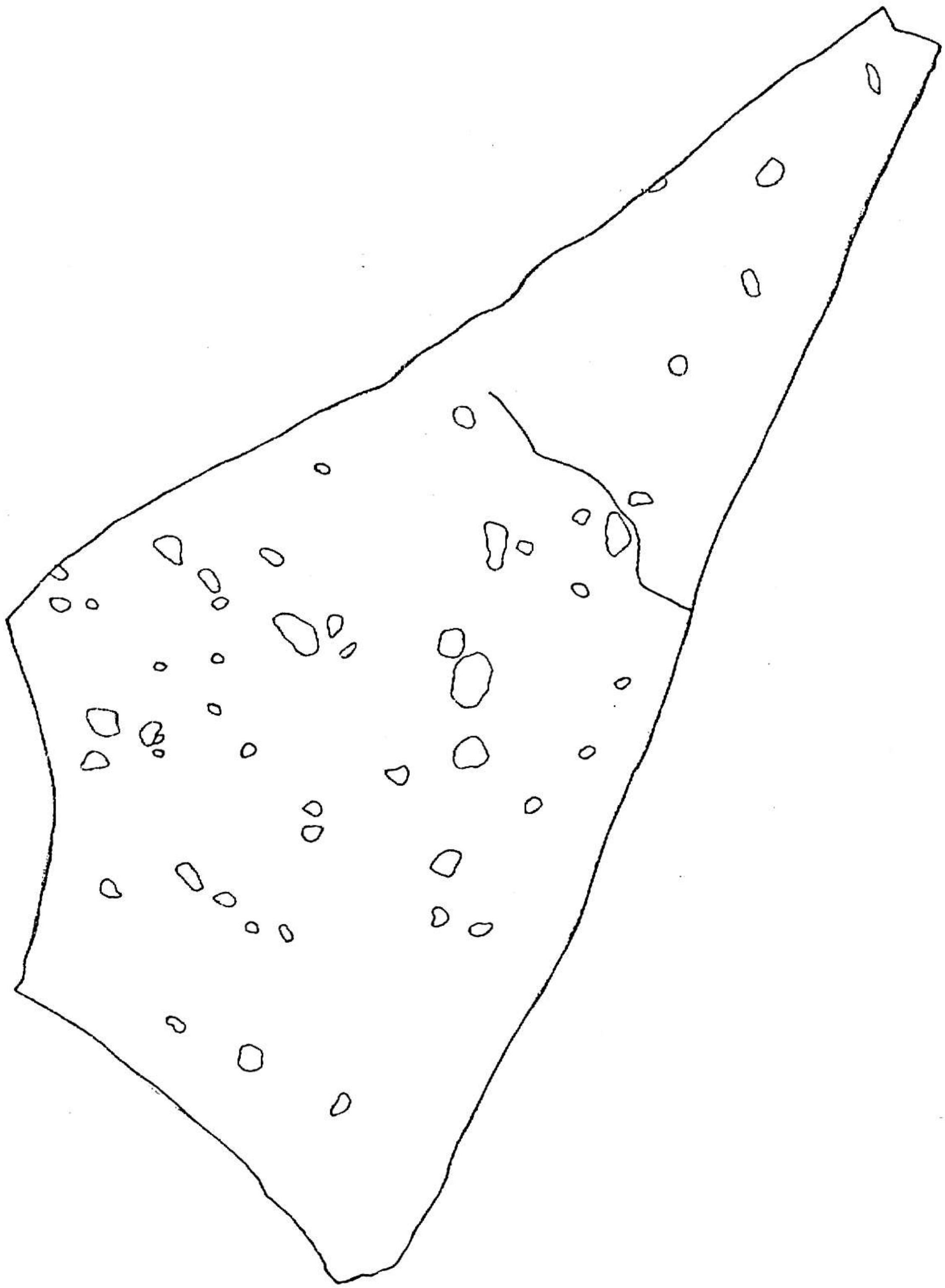
Bedding plane sketch of LW 1E.

All clay galls.



Bedding plane sketch of LW 1G.

All clay galls.



Bedding plane sketch of LW 13A, lower surface.

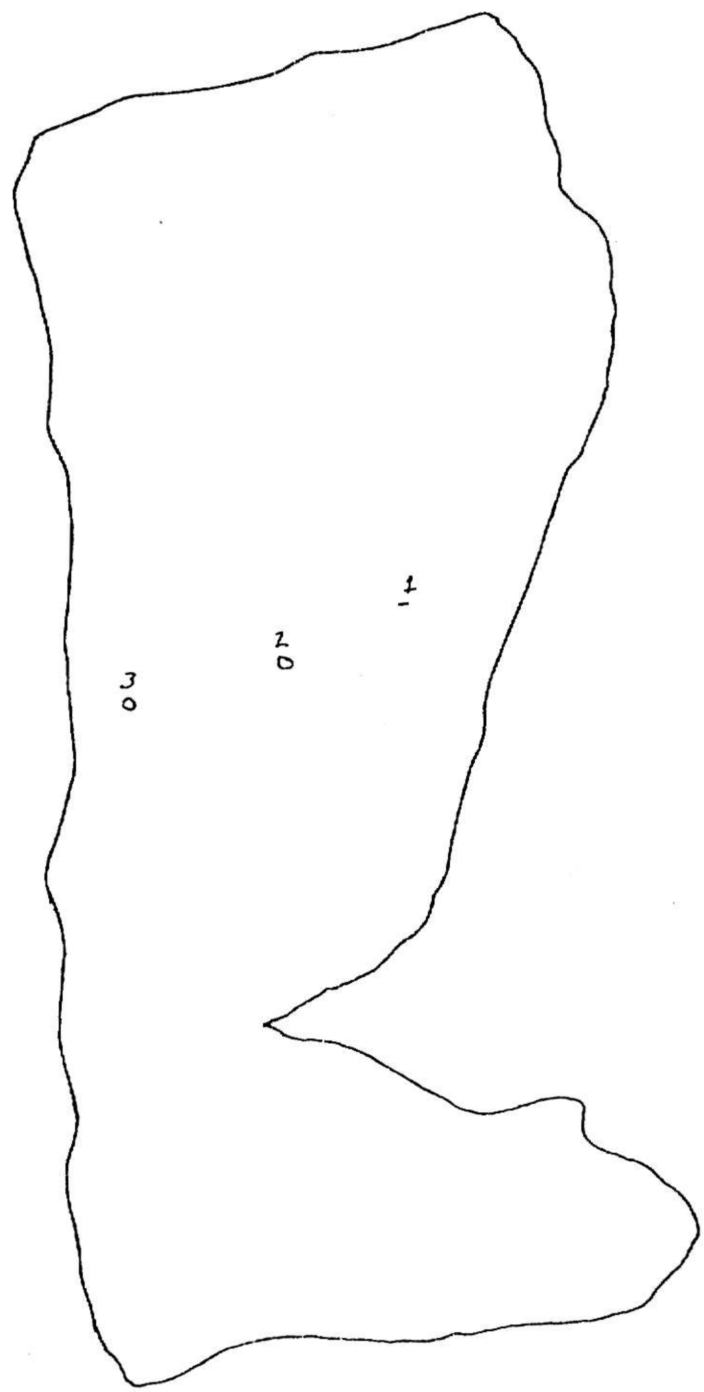
Unit number LW 13A, lower surface.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	bur	si					m	x
2	bur	si					m	x
3	bur	si					m	x
4	bur	si					m	x
5	bur	si					m	x
6	pit	si/cvu					m	x
7	pit	si/cvu					m	x
8	pit	si/cvu					m	x
9	pit	si/cvu					m	x
10	pit	si/cvu					m	x
11	pit	si/cvu					m	x
12	pit	si/cvu					m	x
13	pit	si/cvu					m	x
14	pit	si/cvu					m	x
15	pit	si/cvu					m	x
16	pit	si/cvu					m	x
17	pit	si/cvu					m	x
18	pit	si/cvu					m	x
19	pit	si/cvu					m	x
20	pit	si/cvu					m	x
21	pit	si/cvu					m	x
22	pit	si/cvu					m	x
23	pit	si/cvu					m	x
24	pit	si/cvu					m	x
25	pit	si/cvu					m	x
26	pit	si/cvu					m	x
27	pit	si/cvu					m	x
28	pit	si/cvu					m	x
29	pit	si/cvu					m	x
30	pit	si/cvu					m	x
31	bur	si					m	x
32	bur	si					m	x
33	bur	si					m	x
34	bur	si					m	x
35	bur	si					m	x
36	pit	si/cvu					m	x
37	pit	si/cvu					m	x
38	pit	si/cvu					m	x
39	bur	si					m	x
40	bur	si					m	x
41	bur	si					m	x
42	bur	si					m	x
43	bur	si					m	x
44	bur	si					m	x
45	bur	si					m	x
46	bur	si					m	x
47	bur	si					m	x
48	pit	si/cvu					m	x
49	pit	si/cvu					m	x
50	pit	si/cvu					m	x
51	pit	si/cvu					m	x
52	pit	si/cvu					m	x
53	bur	si					m	x

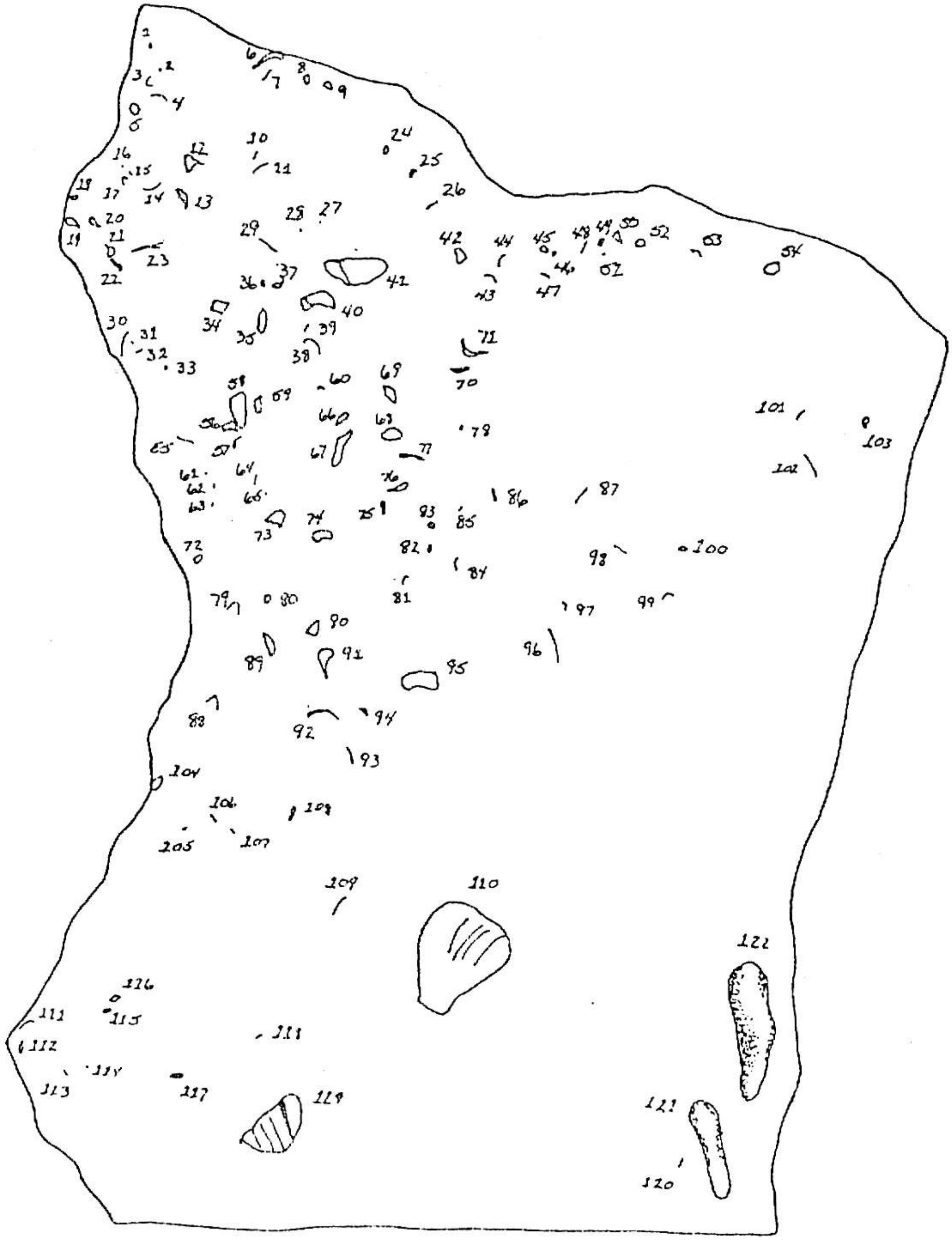
Unit number LW 13B.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	frag	si/---			x	x	o	
2	biv	si/---	?	n	x	x	o	
3	biv	si/---	?	n	x	x	o	

Bedding plane sketch of LW 13B.



Bedding plane sketch of LW 13C.



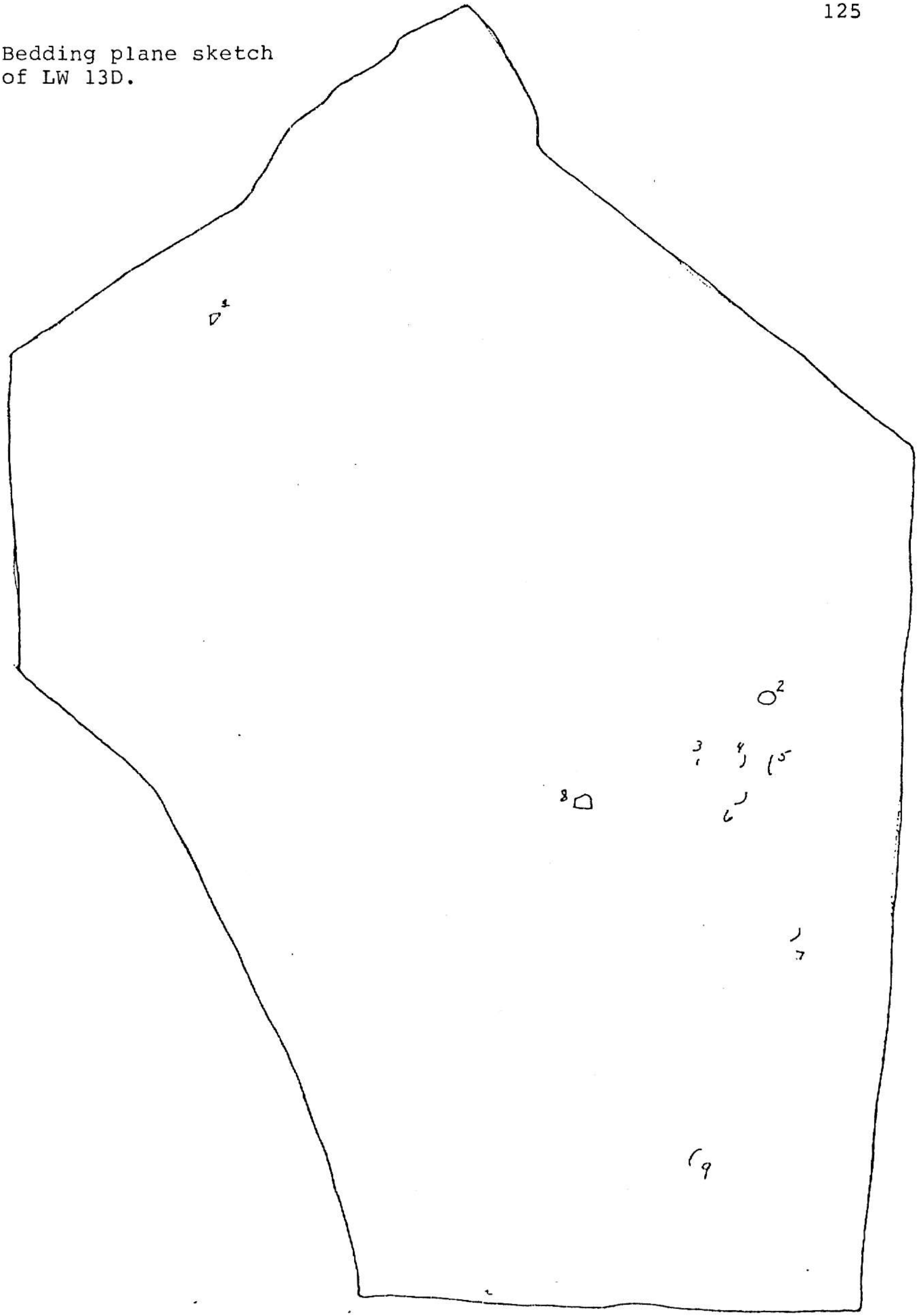
Unit number LW 13C.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	frag	si/lap				x	o	
2	frag	si/alp				x	o	
3	biv	per/au	?	n		x	o	
4	biv	per/au	?	n		x	o	
5	biv	si/ccu	?	n		x	o	
6	biv	si/ccu	?	n		x	o	
7	biv	mi/cvu	?	n		x	o	
8	Avic?	si/cvu	?	n		x	o	
9	biv	si/cvu	?	n		x	o	
10	biv	si/cvu	?	n	x	x	o	
11	biv	si/cvu	?	n	x	x	o	
12	biv	si/cvu	?	n	x	x	o	
13	br	mi/cvu	?	n	x	x	o	
14	frag	si/cvu	?		x	x	o	
15	frag	si/cvu	?		x	x	o	
16	frag	si/cvu	?		x	x	o	
17	frag	si/ccu	?		x	x	o	
18	biv	si/ccu	?	n	x	x	o	
19	biv	si/ccu	?	n		x	o	
20	biv	si/ccu	?	n		x	o	
21	biv	si/ccu	?	n		x	o	
22	br	mi/cvu	?	n		x	o	
23	biv	per/au	?	n		x	o	
24	biv	si/cvu	?	n	x	x	o	
25	biv	mi/cvu	?	n	x	x	o	
26	biv	per/cvu	?	n	x	x	o	
27	biv	si/ccu	?	n	x	x	o	
28	biv	si/cvu	?	n	x	x	o	
29	biv	per/au	?	n	x	x	o	
30	biv	mi/cvu	?	n	x	x	o	
31	biv	si/cvu	?	n	x	x	o	
32	frag	mi/cvu			x	x	o	
33	gast	si/apd					o	
34	br	si/cvu	?	n	x	x	o	
35	biv	si/cvu	?	n	x	x	o	
36	biv	mi/cvu	?	n	x	x	o	
37	biv	mi/cvu	?	n	x	x	o	
38	biv	per/au	?	n		x	o	
39	frag	si/---			x	x	o	
40	biv	si/ccu	?	n		x	o	
41	Per?	si/cvu	?	y?		x	o	
42	br	si/cvu	?	n	x	x	o	
43	biv	per/au	?	n		x	o	
44	biv	per/au	?	n		x	o	
45	frag	si/---			x	x	o	
46	cri	si/---			x	x	o	
47	biv	si/cvu	?	n	x	x	o	
48	biv	mi/ccu	?	n		x	o	
49	biv	si/cvu	?	n	x	x	o	
50	biv	mi/cvu	?	n	x	x	o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
51	biv	si/cvu	?	n	x	x	o	
52	biv	si/cvu	?	n	x	x	o	
53	biv	per/cvu	?	n	x	x	o	
54	biv	si/lap	?	n	x	x	o	
55	frag	si/lap				x	o	
56	biv	mi/ccu	?	n	x	x	o	
57	biv	per/ccu	?	n	x	x	o	
58	biv	si/ccu	?	n	x	x	o	
59	br	si/cvu	?	n	x	x	o	
60	frag	si/lap			x	x	o	
61	biv	si/cvu	?	n	x	x	o	
62	biv	si/cvu	?	n	x	x	o	
63	biv	si/cvu	?	n	x	x	o	
64	biv	si/cvu	?	n	x	x	o	
65	biv	si/cvu	?	n	x	x	o	
66	biv	si/cvu	?	n	x	x	o	
67	biv	si/cvu	?	n	x	x	o	
68	Per?	si/cvu	r?	n	x	x	o	
69	Per?	si/cvu	l?	n	x	x	o	
70	biv	si/ccu	?	n	x	x	o	
71	biv	mi/ccu	?	n	x	x	o	
72	frag	si/lap			x	x	o	
73	biv	si/ccu	?	n	x	x	o	
74	biv	si/cvu	?	n	x	x	o	
75	biv	mi/cvu	?	n	x	x	o	
76	biv	si/cvu	l?	n	x	x	o	
77	biv	si/cvu	?	n	x	x	o	
78	br	si/ccu	?	n	x	x	o	
79	biv	mi/ccu	?	n	x	x	o	
80	biv	si/cvu	?	n	x	x	o	
81	biv	mi/cvu	?	n	x	x	o	
82	frag	si/lap			x	x	o	
83	frag	si/lap			x	x	o	
84	biv	mi/ccu	?	n	x	x	o	
85	biv	si/cvu	?	n	x	x	o	
86	biv	mi/cvu	?	n	x	x	o	
87	biv	per/au	?	n	x	x	o	
88	biv	mi/ccu	?	n	x	x	o	
89	biv	mi/ccu	?	n	x	x	o	
90	biv	si/cvu	?	n	x	x	o	
91	Per?	si/cvu	l?	n	x	x	o	
92	biv	si/cvu	?	n	x	x	o	
93	biv	mi/cvu	?	n	x	x	o	
94	biv	si/ccu	?	n	x	x	o	
95	Per?	si/cvu	l?	n	x	x	o	
96	biv	mi/ccu	?	n		x	o	
97	biv	si/cvu	?	n	x	x	o	
98	biv	si/cvu	?	n	x	x	o	
99	biv	mi/ccu	?	n	x	x	o	
100	biv	si/cvu	?	n	x	x	o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
101	biv	si/cvu	?	n	x	x	o	
102	biv	si/cvu	?	n	x	x	o	
103	biv	si/cvu	?	n	x	x	o	
104	Per?	si/ccu	r?	n		x	o	
105	biv	mi/cvu	?	n		x	o	
106	biv	per/au	?	n		x	o	
107	biv	mi/cvu	?	n	x	x	o	
108	biv	mi/cvu	?	n	x	x	o	
109	br?	mi/cvu	?	n		x	o	
110	Avic?	si/cvu	?	?	x		o	
111	biv	si/ccu	?	n	x	x	o	
112	biv	si/cvu	?	n	x	x	o	
113	biv	per/au	?	n		x	o	
114	biv	si/cvu	?	n	x	x	o	
115	biv	si/cvu	?	n	x	x	o	
116	biv	mi/cvu	?	n	x	x	o	
117	Per?	si/cvu	l?	n	x	x	o	
118	biv	mi/ccu	?	n	x	x	o	
119	Avic?	si/cvu	?	n	x	x	o	
120	frag	si/lap			x	x	o	
121	bur	si/---					m	x
122	bur	si/---					m	x

Bedding plane sketch
of LW 13D.



Unit number LW 13D.

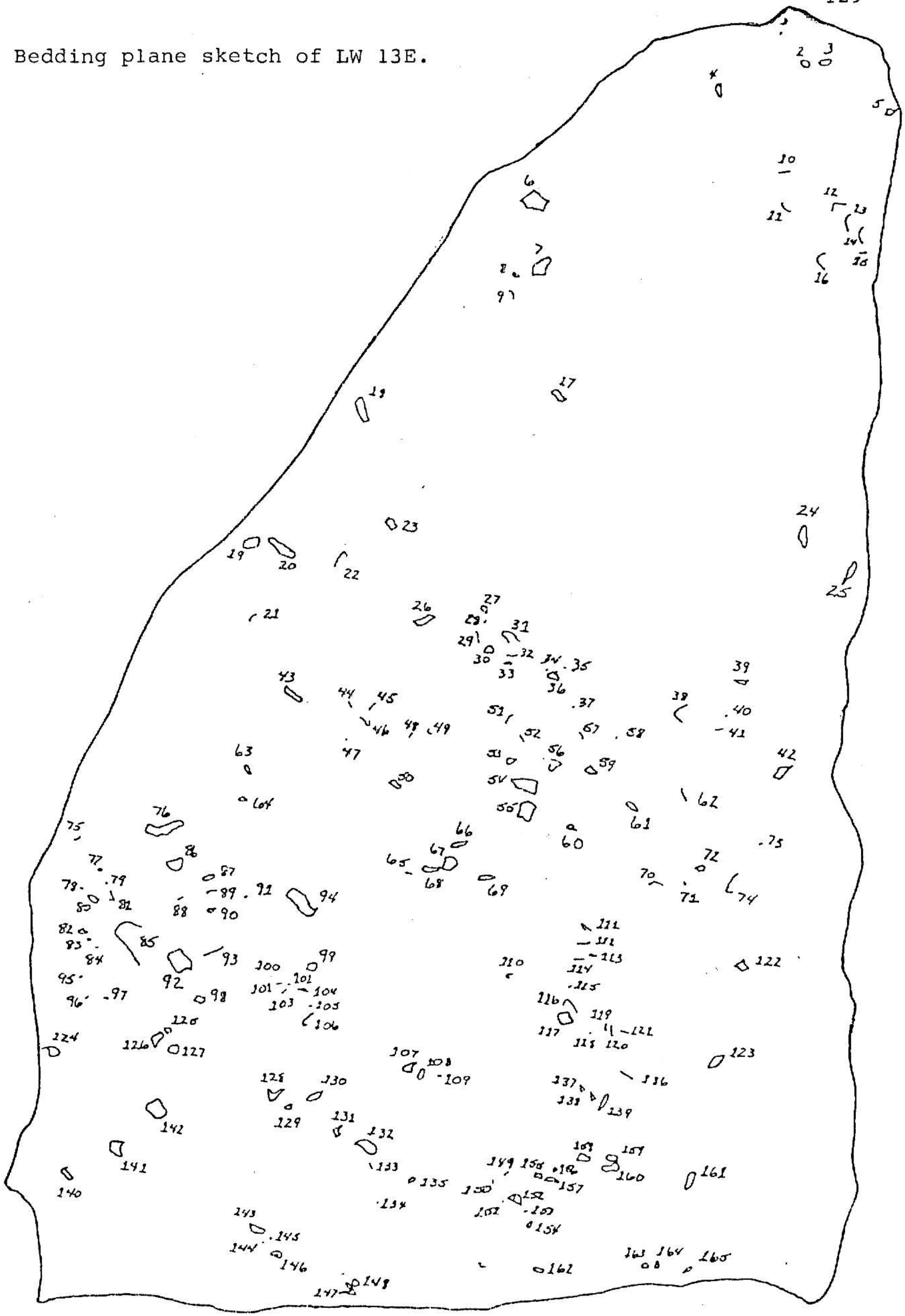
Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	biv	si/cvu	?	n	x	x	o	
2	biv	per/au		y		x	o	
3	biv	per/au	?	n		x	o	
4	biv	per/au	?	n		x	o	
5	biv	per/au	?	n		x	o	
6	biv	per/au	?	n		x	o	
7	biv	per/au	?	n		x	o	
8	biv	si/cvu	?	n	x	x	o	
9	biv	per/au	?	n		x	o	

Bedding plane sketch of LW 13D, lower surface.

Unit number LW 13D, lower surface.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	bur	si					m	x
2	bur	si					m	x
3	bur	si					m	x
4	bur	si					m	x
5	bur	si					m	x
6	bur	si					m	x
7	bur	si					m	x
8	bur	si					m	x
9	bur	si					m	x
10	bur	si					m	x
11	bur	si					m	x
12	bur	si					m	x
13	bur	si					m	x
14	bur	si					m	x
15	bur	si					m	x
16	bur	si					m	x
17	bur	si					m	x
18	bur	si					m	x
19	bur	si					m	x
20	bur	si					m	x
21	bur	si					m	x
22	bur	si					m	x
23	bur	si					m	x
24	bur	si					m	x
25	bur	si					m	x
26	bur	si					m	x
27	bur	si					m	x
28	bur	si					m	x
29	bur	si					m	x
30	bur	si					m	x
31	bur	si					m	x
32	bur	si					m	x
33	bur	si					m	x
34	bur	si					m	x
35	bur	si					m	x
36	bur	si					m	x

Bedding plane sketch of LW 13E.



Unit number LW 13E.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	biv	si/cvu	?	n	x	x	o	
2	br	si/cvu	?	n	x	x	o	
3	biv	si/cvu	?	n	x	x	o	
4	biv	si/cvu	?	n		x	o	
5	br	si/cvu	?	n	x	x	o	
6	br	si/cvu	?	n	x	x	o	
7	Per?	si/cvu	r?	n	x	x	o	
8	b or b	si/cvu	?	n	x	x	o	
9	b or b	mi/cvu	?	n	x	x	o	
10	b or b	mi/cvu	?	n	x	x	o	
11	br	si/cvu	?	n	x	x	o	
12	br	si/cvu	?	n	x	x	o	
13	br	per/ccu	?	n	x	x	o	
14	b or b	per/au	?	n	x	x	o	
15	ost	si/cvu	l?	n?			o	
16	b or b	per/ccu	?	n	x	x	o	
17	br	si/cvu	?	n	x	x	o	
18	br	si/ccu	?	n	x	x	o	
19	biv	si/ccu	?	n	x	x	o	
20	biv	si/cvu	?	n	x	x	o	
21	b or b	si/ccu	?	n	x	x	o	
22	br	si/ccu	?	n	x	x	o	
23	biv	si/cvu	?	n	x	x	o	
24	b or b	si/ccu	?	n	x	x	o	
25	b or b	si/cvu	?	n	x	x	o	
26	br	si/cvu		y?		x	o	
27	ost	si/cvu	?	n	x	x	o	
28	ost	per/au		y			o	
29	br	si/cvu	?	n	x	x	o	
30	b or b	si/ccu	?	n	x	x	o	
31	biv	si/ccu	?	n	x	x	o	
32	biv	si/cvu	?	n	x	x	o	
33	ost	si/cvu	?	n	x	x	o	
34	ost?	si/ccu	r	n	x	x	o	
35	gast	si/apu			x		o	
36	biv	si/ccu	?	n	x	x	o	
37	biv	mi/cvu	?	n	x	x	o	
38	biv	mi/cvu	?	n	x	x	o	
39	br	si/ccu	?	n	x	x	o	
40	biv	si/cvu	?	n	x	x	o	
41	biv	si/cvu	?	n	x	x	o	
42	biv	si/cvu	?	n	x	x	o	
43	biv	si/cvu	?	n	x	x	o	
44	biv	si/cvu	?	n	x	x	o	
45	biv	si/ccu	?	n	x	x	o	
46	b or b	mi/ccu	?	n	x	x	o	
47	br	mi/cvu	?	n	x	x	o	
48	biv	si/cvu	?	n	x	x	o	
49	biv	si/cvu	?	n	x	x	o	
50	biv	si/cvu	?	n	x	x	o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
51	biv	si/cvu	?	n	x	x	o	
52	biv	mi/cvu	?	n	x	x	o	
53	br	si/cvu	?	n	x	x	o	
54	biv	si/cvu	?	n	x	x	o	
55	biv	si/cvu	?	n	x	x	o	
56	br	si/ccu	?	n	x	x	o	
57	biv	si/cvu	?	n	x	x	o	
58	biv	si/ccu	?	n	x	x	o	
59	b or b	si/ccu	?	n	x	x	o	
60	b or b	si/lap	?	n	x	x	o	
61	b or b	si/lap	?	n	x	x	o	
62	biv	si/ccu	?	n	x	x	o	
63	br	si/cvu	?	n	x	x	o	
64	biv	si/cvu	?	n	x	x	o	
65	ost	si/cvu	?	?		x	o	
66	b or b	si/cvu	?	n	x	x	o	
67	br	si/ccu	?	n	x	x	o	
68	biv	si/cvu	?	n	x	x	o	
69	biv	si/ccu	?	n	x	x	o	
70	biv	si/cvu	?	n	x	x	o	
71	biv	si/ccu	?	n	x	x	o	
72	b or b	si/cvu	?	n	x	x	o	
73	b or b	si/ccu	?	n	x	x	o	
74	br	si/ccu	?	n	x	x	o	
75	b or b	si/ccu	?	n	x	x	o	
76	biv	si/ccu	1?	n	x	x	o	
77	ost?	si/cvu	1?	n	x	x	o	
78	biv	si/cvu	?	n	x	x	o	
79	biv	si/cvu	?	n	x	x	o	
80	biv	si/ccu	?	n	x	x	o	
81	biv	si/cvu	?	n	x	x	o	
82	biv	si/ccu	?	n	x	x	o	
83	biv	si/cvu	?	n	x	x	o	
84	biv	si/ccu	?	n	x	x	o	
85	biv	si/ccu	1?	n	x	x	o	
86	b or b	si/ccu	?	n	x	x	o	
87	b or b	si/cvu	?	n	x	x	o	
88	b or b	mi/cvu	?	n	x	x	o	
89	biv	per/au	?	n	?	x	o	
90	b or b	si/cvu	?	n?	x	x	o	
91	br?	si/cvu	?	n?	x	x	o	
92	b or b	si/ccu	?	n	x	x	o	
93	b or b	si/cvu	?	n	x	x	o	
94	biv?	si/cvu	?	y?	x	x	o	
95	b or b	si/ccu	?	n	x	x	o	
96	b or b	si/cvu	?	n	x	x	o	
97	b or b	si/ccu	?	n	x	x	o	
98	b or b	si/cvu	?	n	x	x	o	
99	b or b	si/cvu	?	n	x	x	o	
100	biv	mi/cvu	?	n	x	x	o	

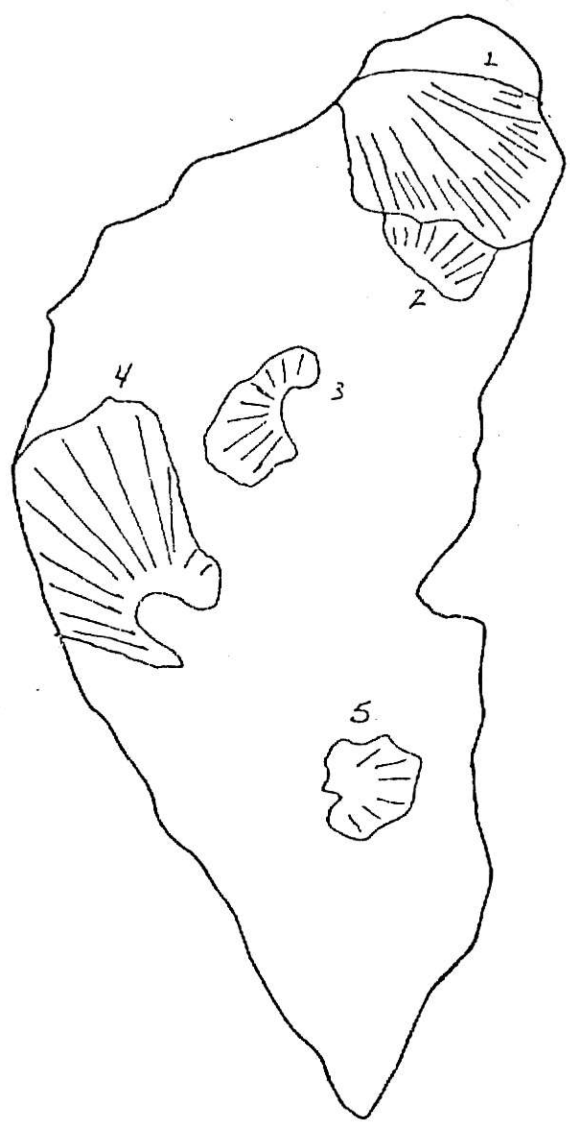
Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
101	biv	si/cvu	?	n	x	x	o	
102	biv	si/cvu	?	n	x	x	o	
103	biv	si/cvu	?	n	x	x	o	
104	b or b	si/cvu	?	n	x	x	o	
105	b or b	si/cvu	?	n	x	x	o	
106	b or b	si/cvu	?	n	x	x	o	
107	b or b	si/cvu	?	n	x	x	o	
108	ost?	si/cvu	l?	?	x	x	o	
109	b or b	si/cvu	?	n	x	x	o	
110	biv	si/cvu	?	n	x	x	o	
111	br	si/cvu	?	n	x	x	o	
112	biv	mi/ccu	r?	n	x	x	o	
113	b or b	per/au	?	n	x	x	o	
114	b or b	mi/cvu	?	n	x	x	o	
115	biv	si/cvu	?	n	x	x	o	
116	b or b	si/ccu	?	n	x	x	o	
117	biv	mi/ccu	?	n	x	x	o	
118	biv	mi/cvu	?	n	x	x	o	
119	b or b	si/cvu	?	n	x	x	o	
120	b or b	si/ccu	?	n	x	x	o	
121	b or b	mi/cvu	?	n	x	x	o	
122	br?	si/cvu	?	n	x	x	o	
123	b or b	si/cvu	?	n	x	x	o	
124	biv	si/cvu	?	n	x	x	o	
125	biv	si/cvu	?	n	x	x	o	
126	br?	si/cvu	?	n	x	x	o	
127	b or b	si/ccu	?	n	x	x	o	
128	biv	si/ccu	?	n	x	x	o	
129	biv	si/cvu	?	n	x	x	o	
130	biv	si/cvu	?	n	x	x	o	
131	br?	si/cvu	?	n	x	x	o	
132	biv	si/ccu	?	n	x	x	o	
133	b or b	si/ccu	?	n	x	x	o	
134	b or b	si/cvu	?	n	x	x	o	
135	b or b	si/cvu	?	n	x	x	o	
136	b or b	mi/ccu	?	n	x	x	o	
137	b or b	mi/cvu	?	n	x	x	o	
138	b or b	si/cvu	?	n	x	x	o	
139	b or b	per/cvu	?	n	x	x	o	
140	biv	si/ccu	?	n	x	x	o	
141	b or b	mi/ccu	?	n	x	x	o	
142	b or b	si/ccu	?	n	x	x	o	
143	b or b	mi/cvu	?	n	x	x	o	
144	b or b	si/cvu	?	n	x	x	o	
145	b or b	si/cvu	?	n	x	x	o	
146	b or b	si/cvu	?	n	x	x	o	
147	biv	si/ccu	?	n	x	x	o	
148	b or b	si/cvu	?	n	x	x	o	
149	b or b	si/cvu	?	n	x	x	o	
150	gast	si/apd			x	x	o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
151	b or b	si/ccu	?	n	x	x	o	
152	b or b	si/ccu	?	n	x	x	o	
153	ost?	si/cvu	r?	?	x	x	o	
154	b or b	si/cvu	?	n	x	x	o	
155	b or b	si/ccu	?	n	x	x	o	
156	ost?	si/cvu	?	n	x	x	o	
157	b or b	si/ccu	?	n	x	x	o	
158	b or b	mi/ccu	?	n	x	x	o	
159	b or b	si/ccu	?	n	x	x	o	
160	b or b	mi/cvu	?	n	x	x	o	
161	biv	si/cvu	?	n	x	x	o	
162	b or b	si/cvu	?	n	x	x	o	
163	b or b	si/cvu	?	n	x	x	o	
164	b or b	si/cvu	?	n	x	x	o	
165	b or b	si/cvu	?	n	x	x	o	

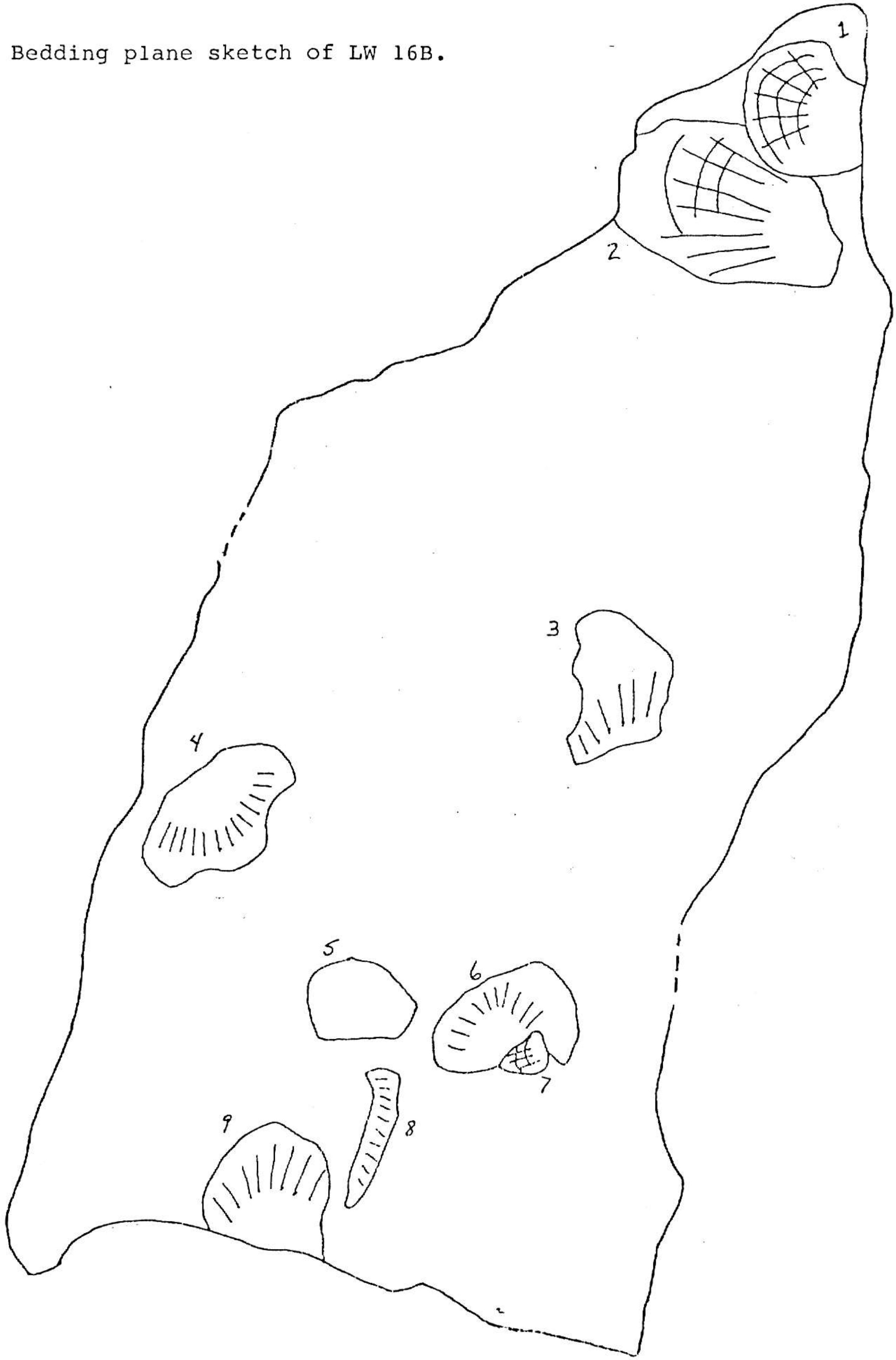
Unit number LW 16A.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	Avic?	si/cvu	?	?		x	m	?
2	Avic?	si/cvu	?	?		x	m	?
3	Avic?	si/cvu	?	?		x	m	?
4	Avic?	si/cvu	?	?		x	m	?
5	Avic?	si/ccu	?	n		x	m	?

Bedding plane sketch of LW 16A.



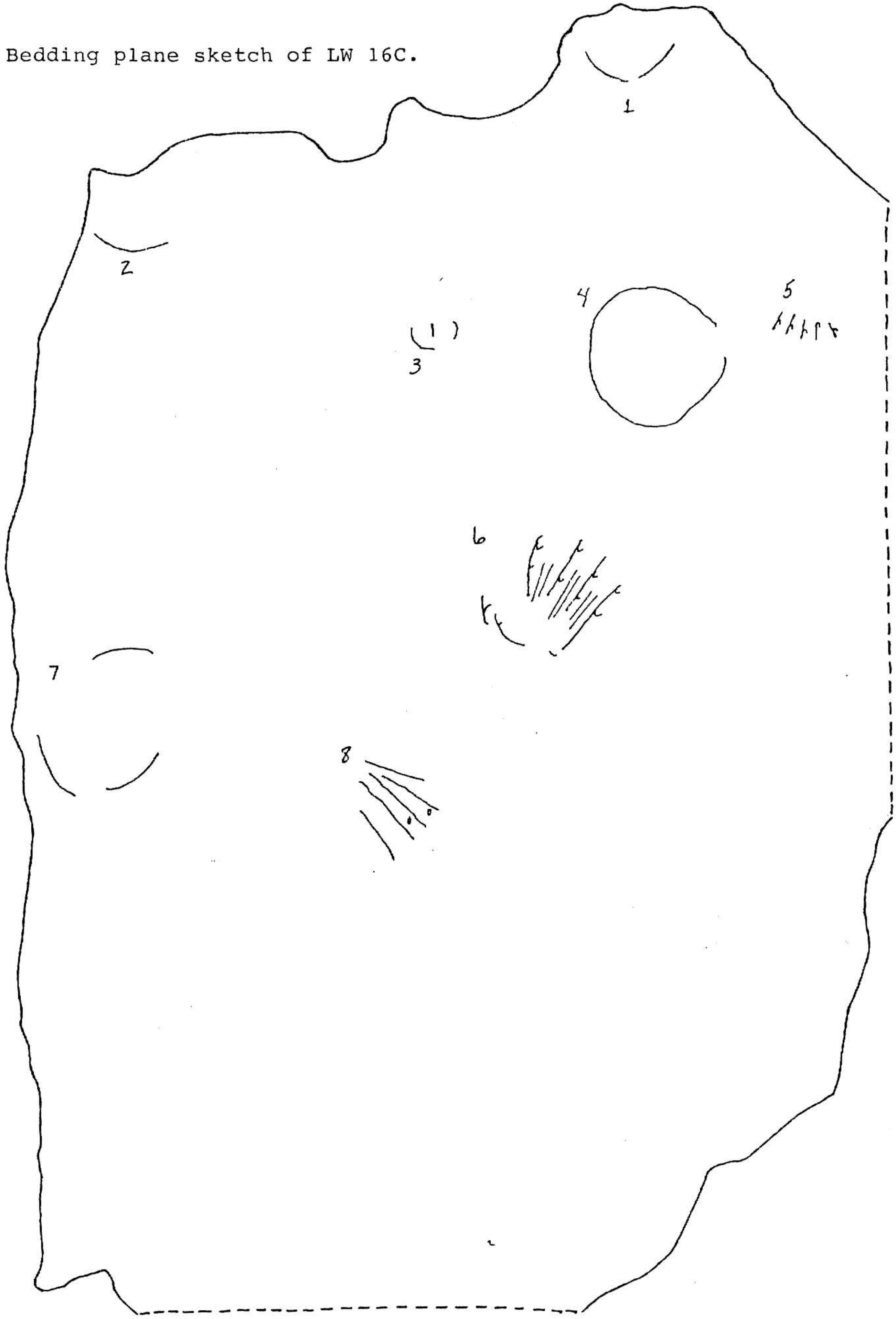
Bedding plane sketch of LW 16B.



Unit number LW 16B.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	Avic?	si/ccu	?	n		?	m	?
2	Avic?	si/ccu	?	n		?	m	?
3	Pseu?	si/cvu	?	?		x	m	?
4	Avic?	si/cvu	?	?		?	m	?
5	biv	si/cvu?	?	?		?	o/m	?
6	Avic?	si/cvu	?	?		x	m	?
7	Avic?	si/cvu	?	?		x	m	?
8	Avic?	si/cvu	?	?		x	m	?
9	Avic?	si/cvu	?	?		x	m	?

Bedding plane sketch of LW 16C.



Unit number LW 16C.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	biv	si/cvu	?	?		x	o/m	
2	biv	per/au	?	?		x	m	
3	biv	si/cvu?	?	?		x	o/m	
4	biv	si/cvu	?	?			o/m	
5	Clav?	si/cvu	?	n?		x	m	
6	Pseu?	si/cvu	?	?		x	m	
7	biv	si/cvu?	?	?			m	
8	Clav?	si/ccu	?	n?		x	m	

Unit number LW 16D.

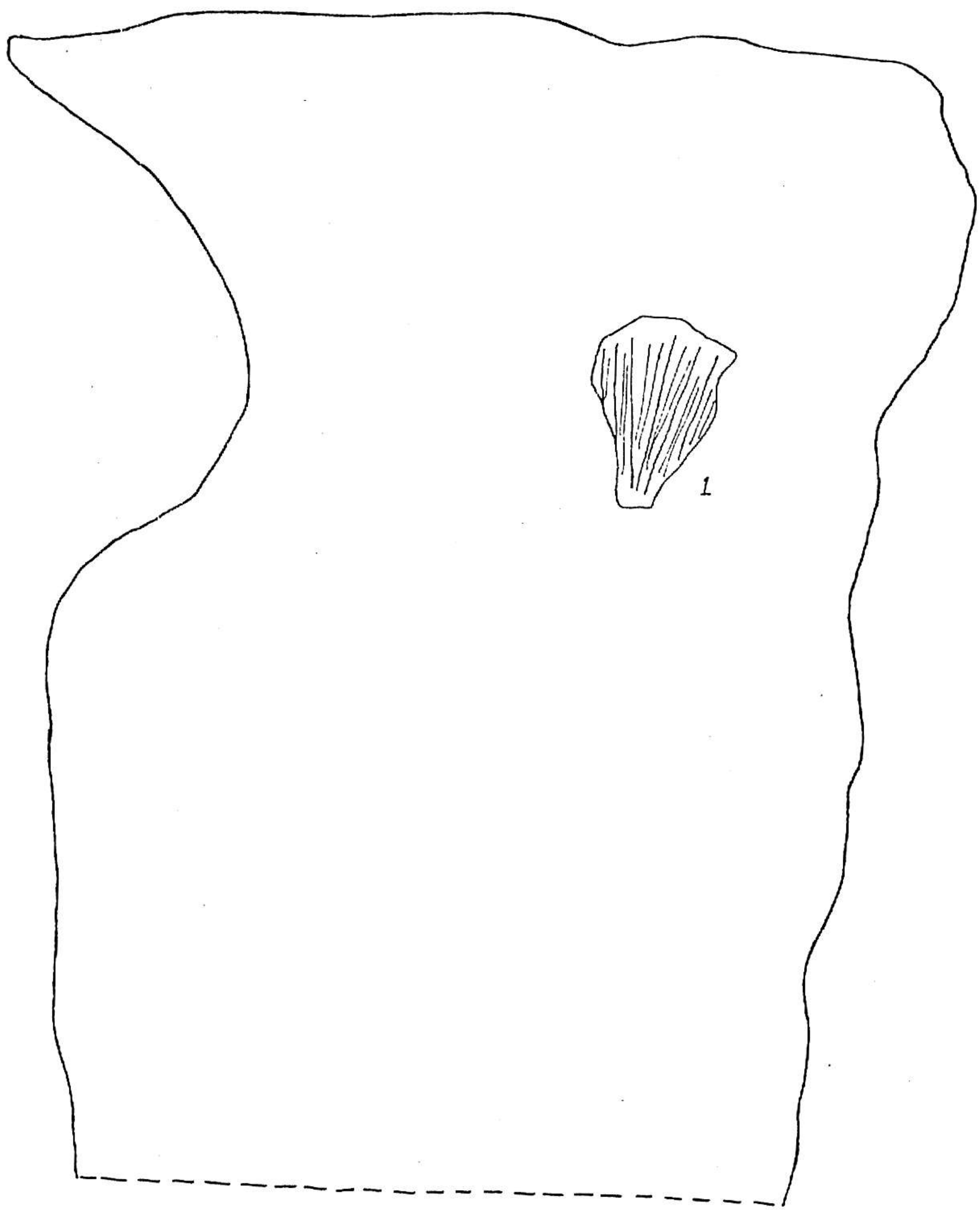
Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	Avic?	si/ccu	l?	n		x	m	?
2	Avic?	si/cvu	r?	?		x	m	?
3	Clav?	si/cvu	l?	?		?	m	?
4	Avic?	si/ccu	r?	n		?	m	?
5	Pseu?	si/cvu	l?	?		?	m	?
6	biv	si/cvu	?	?		x	m	
7	Clav?	si/cvu	?	?		?	m	?

Bedding plane sketch of LW 16D.

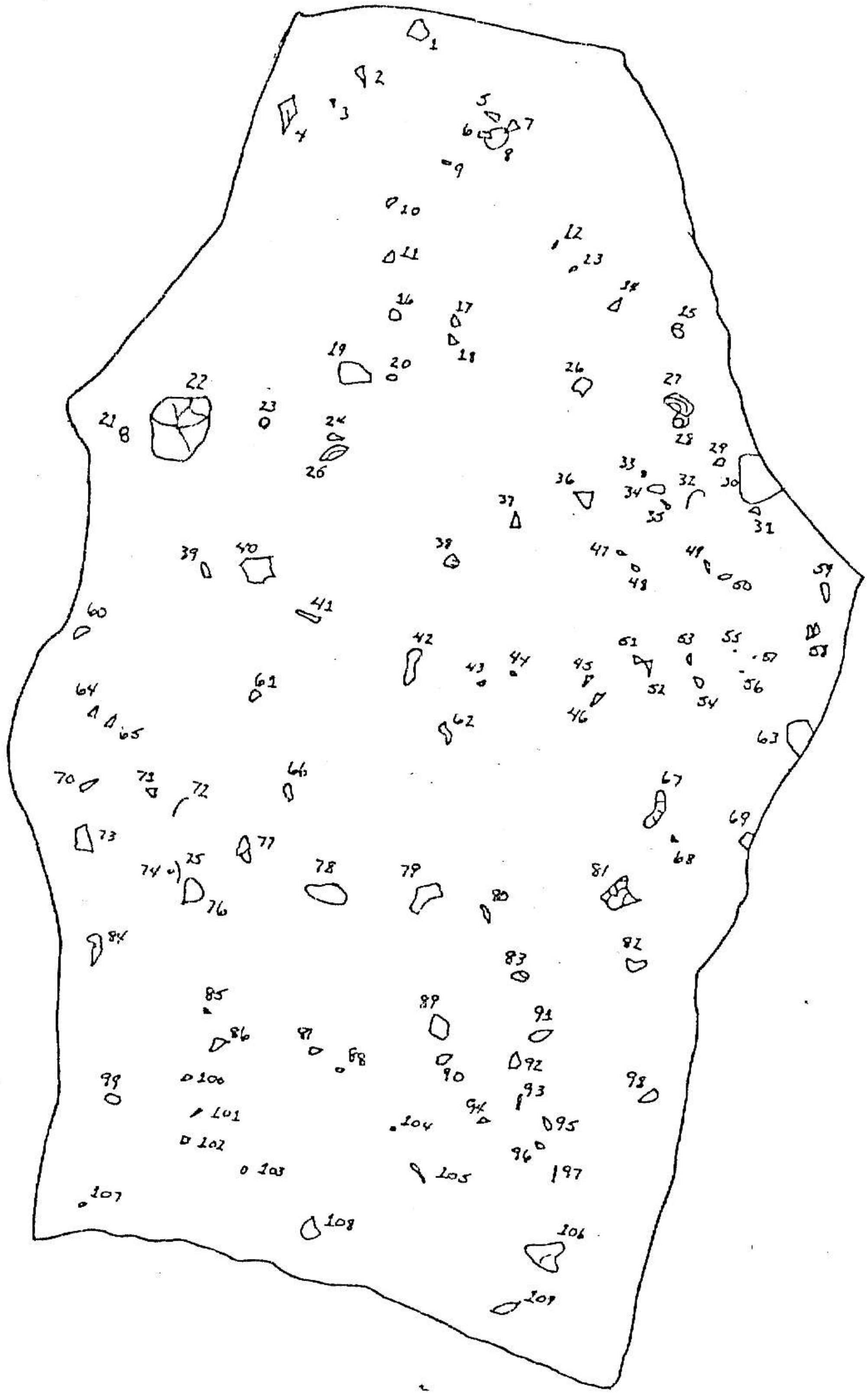
Unit number LW 16E.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	Avic?	si/cvu	1?	?	x	?	m	?

Bedding plane sketch of LW 16E.



Bedding plane sketch of LW 16F.



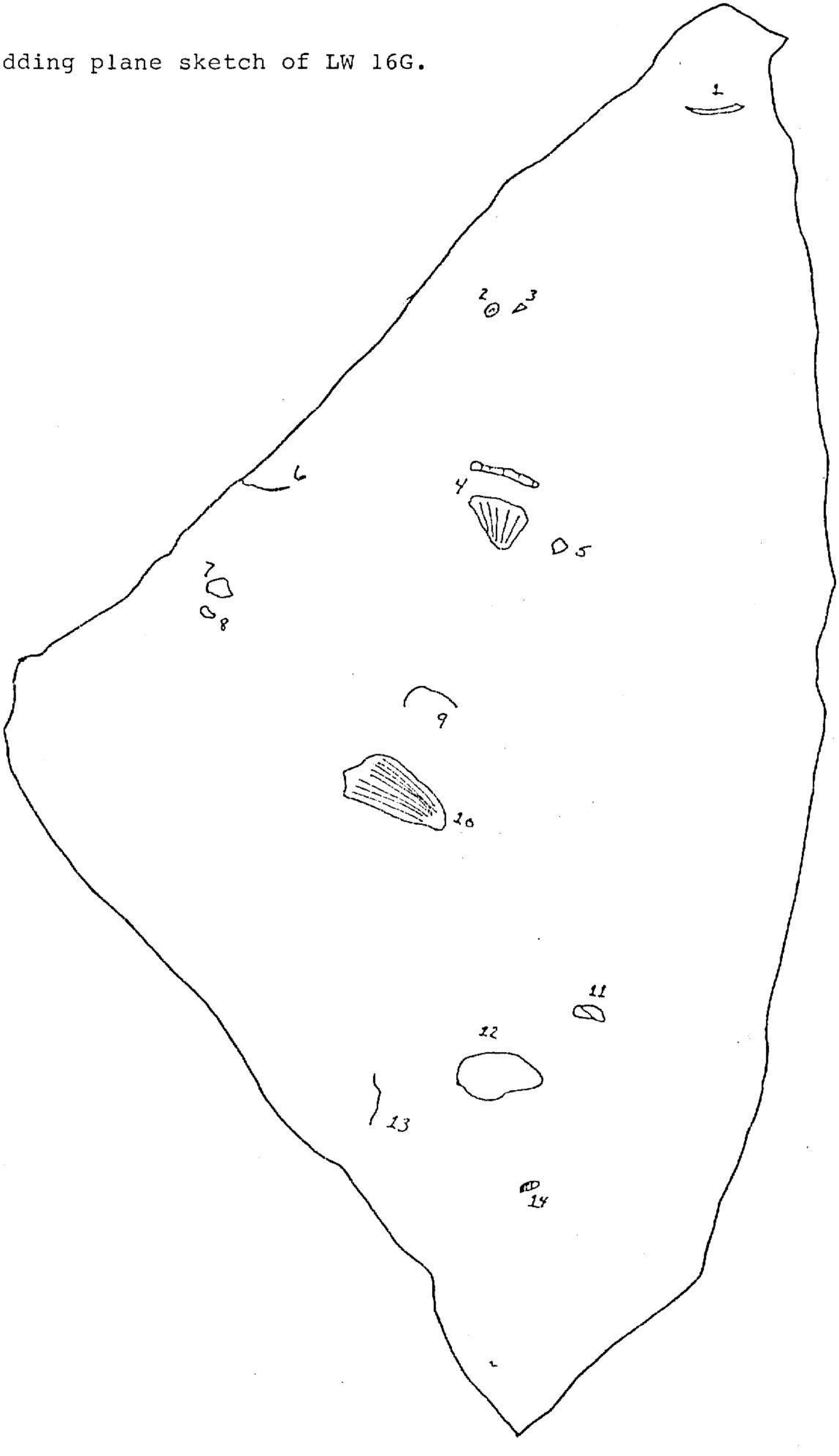
Unit number LW 16F.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	frag	si/lap			x	x	o	
2	gast	si/apu					o	
3	gast	si/apd					o	
4	biv	si/cvu	?	n	x	x	o	
5	gast	si/apd					o	
6	gast	si/apu					o	
7	gast	si/apu			x		o	
8	biv	si/ccu	?	n	x	x	o	
9	gast	si/apu			x	x	o	
10	biv	si/ccu	?	n	x	x	o	
11	biv	si/ccu	?	n	x	x	o	
12	gast	si/apu			x		o	
13	biv	si/cvu	?	n	x	x	o	
14	gast	si/apu					o	
15	biv	si/ccu	?	n	x	x	o	
16	biv	si/ccu	?	n	x	x	o	
17	biv	si/cvu	?	n	x	x	o	
18	biv	si/ccu	?	n	x	x	o	
19	biv	si/ccu	?	n	x	x	o	
20	biv	si/cvu	?	n	x	x	o	
21	gast	si/apu			x	x	o	
22	biv	si/cvu	?	n	x	x	o	
23	biv	mi/au	r?	y?		x	o	
24	gast	si/apu			x		o	
25	biv	si/ccu	?	n	x	x	o	
26	pec	si/cvu		y			o	
27	Per?	si/cvu		y	x	x	o	
28	biv	si/cvu	?	n	x	x	o	
29	gast	si/apu			x	x	o	
30	biv	si/ccu	?	n		x	o	
31	gast	si/apd				x	o	
32	biv	per/au	r?	n		x	o	
33	gast	si/apd			x	x	o	
34	gast	si/apd					o	
35	gast	si/apu			x	x	o	
36	biv	si/ccu	?	n		x	o	
37	gast	si/apu					o	
38	biv	si/ccu	?	n	x	x	o	
39	gast	si/apu					o	
40	biv	si/ccu	?	n		x	o	
41	gast	si/apu					o	
42	biv	si/ccu	?	n	x	x	o	
43	gast	si/apd				x	o	
44	gast	si/apd				x	o	
45	gast	si/apd					o	
46	gast	si/apd					o	
47	gast	si/apd					o	
48	gast	si/apd					o	
49	gast	si/apd					o	
50	gast	si/apu					o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
51	gast	si/apd					o	
52	gast	si/apd					o	
53	gast	si/apu				x	o	
54	gast	si/apd				x	o	
55	gast	si/apu					o	
56	gast	si/apd				x	o	
57	gast	si/apd					o	
58	biv	mi/cvu	?	n		x	o	
59	gast	si/apd					o	
60	gast	si/apd					o	
61	gast	si/apd				x	o	
62	gast	si/apu					o	
63	biv	si/cvu	?	n	x	x	o	
64	gast	si/apu				x	o	
65	gast	si/apd					o	
66	biv	si/ccu	?	n	x	x	o	
67	biv	si/cvu	?	n		x	o	
68	biv	si/cvu	?	n	x	x	o	
69	biv	si/cvu	?	n	x	x	o	
70	gast	si/apd					o	
71	gast	si/apd			x	x	o	
72	biv	per/au	?	n		x	o	
73	biv	si/cvu	?	n		x	o	
74	gast	si/apu					o	
75	biv	si/ccu	?	n	x	x	o	
76	biv	si/cvu	?	n	x	x	o	
77	biv	si/cvu	?	n	x	x	o	
78	biv	si/cvu	?	n	x	x	o	
79	biv	si/cvu	?	n		x	o	
80	biv	si/cvu	?	n	x	x	o	
81	biv	si/cvu	?	n		x	o	
82	biv	si/ccu	?	n	x	x	o	
83	biv	si/ccu	?	n	x	x	o	
84	biv	si/ccu	?	n	x	x	o	
85	gast	si/ccu	?	n		x	o	
86	gast	si/apd					o	
87	gast	si/apd					o	
88	gast	si/apd				x	o	
89	biv	si/cvu	?	n	x	x	o	
90	biv	si/cvu	?	n	x	x	o	
91	biv	si/cvu	?	n	x	x	o	
92	biv	si/ccu	?	n		x	o	
93	bs	si/lap			x	x	o	
94	gast	si/apu					o	
95	gast	si/apd					o	
96	biv	si/cvu	?	n	x	x	o	
97	biv	per/au	?	n	x	x	o	
98	gast	si/apd					o	
99	frag	si/---			x	x	o	
100	gast	si/apd					o	

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
101	gast	si/apu			x		o	
102	biv	si/ccu	?	n	x	x	o	
103	bs	si/lap					o	
104	frag	si/---			x	x	o	
105	gast	si/apd					o	
106	biv	si/ccu	?	n		x	o	
107	biv	si/cvu	?	n	x	x	o	
108	biv	si/ccu	?	n	x	x	o	
109	biv	si/ccu	?	n		x	o	

Bedding plane sketch of LW 16G.



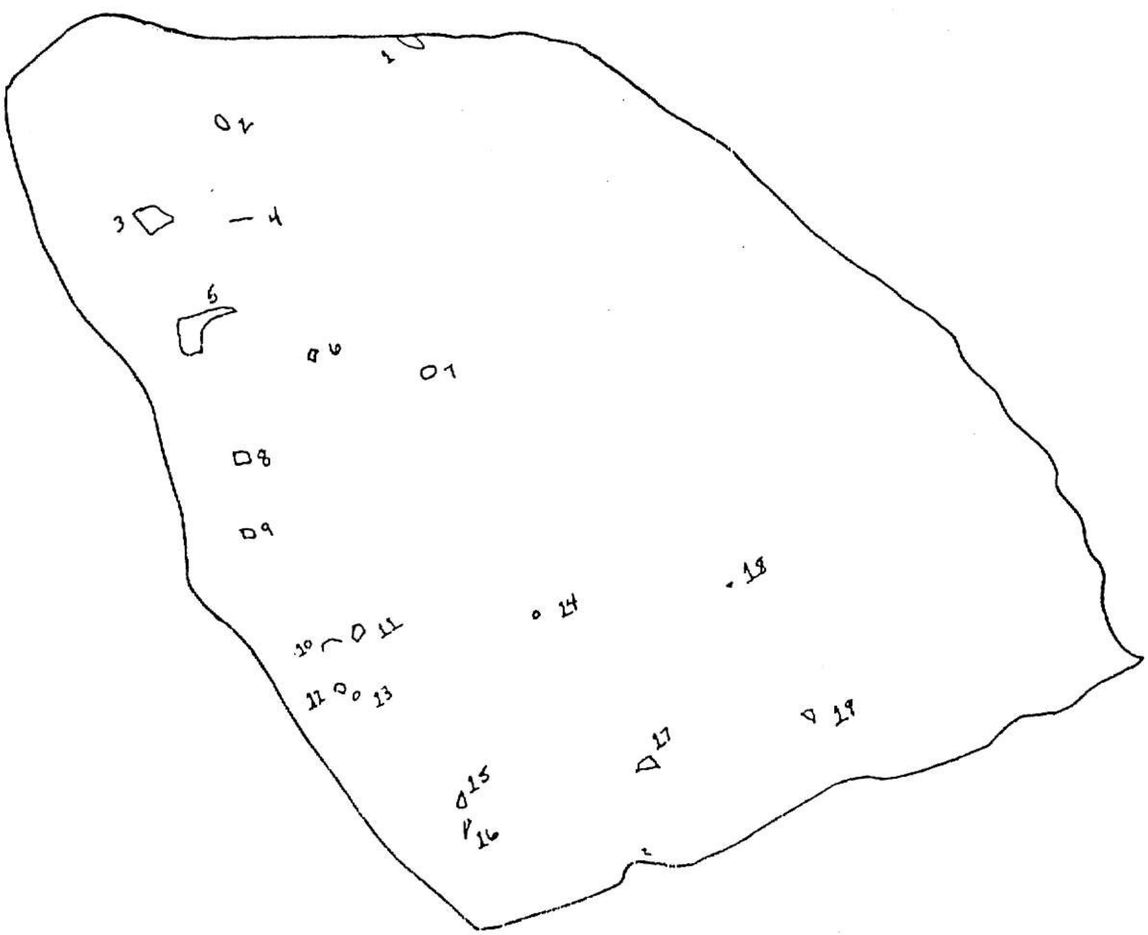
Unit number LW 16G.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	biv	per/au	?	n		x	o	
2	gast	mi/apd			x	x	o	
3	biv	si/cvu	?	n	x	x	o	
4	Avic?	si/cvu	?	n		x	m	
5	biv	si/cvu	?	n	x	x	o	
6	biv	per/au	?	n		x	o	
7	Avic?	si/cvu	?	n		x	m	
8	biv	si/cvu	?	n	x	x	o	
9	biv	per/au	?	n		x	o	
10	Avic?	si/cvu	?	n		x	m	
11	biv	mi/ccu	?	n	x	x	o	
12	Per?	si/ccu	?	n			o	
13	biv	per/au	?	n		x	o	
14	Pseu?	mi/ccu	?	n		x	o	

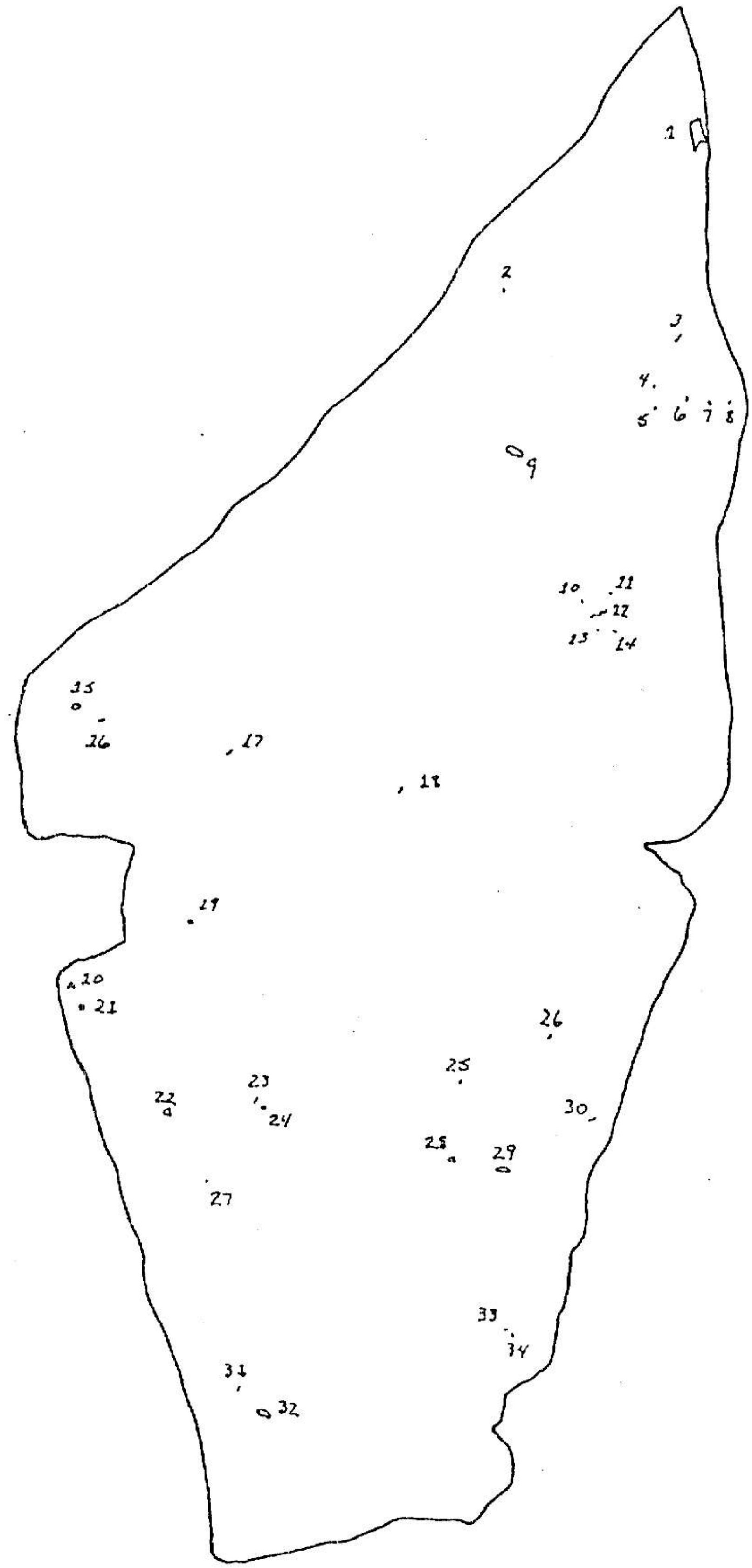
Unit number LW 16H.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	biv	si/ccu	?	n	x	x	o	
2	biv	si/cvu	?	n	x	x	o	
3	biv	si/ccu	?	n		x	o	
4	ech?	si/lap				x	o	
5	biv	mi/ccu	?	n	x	x	o	
6	biv	si/ccu	?	n	x	x	o	
7	biv	si/ccu	?	n	x	x	o	
8	biv	si/ccu	?	n	x	x	o	
9	biv	si/cvu	?	n	x	x	o	
10	biv	per/au	?	n		x	o	
11	biv	si/ccu	?	n	x	x	o	
12	biv	si/cvu	?	n	x	x	o	
13	biv	si/cvu	?	n	x	x	o	
14	frag	si/lap			x	x	o	
15	biv	si/cvu	?	n	x	x	o	
16	biv	per/au	?	y?		x	o	
17	biv	si/cvu	?	n	x	x	o	
18	biv	si/cvu	?	n	x	x	o	
19	biv	si/ccu	?	n	x	x	o	

Bedding plane sketch of LW 16H.



Bedding plane sketch of LW 16I.



Unit number LW 16I.

Spec	Type	Orient	Val	Art	Abras	Frag	Pres Type	Life
1	ft	si/cvu			x	x	o	
2	biv	per/au	?	?		x	o/m	
3	biv	si/cvu	?	n	x	x	o	
4	biv	si/cvu	?	n	x	x	o	
5	biv	per/cvu	?	n	x	x	o	
6	biv	si/cvu	?	n	x	x	o	
7	biv	si/cvu	?	n	x	x	o	
8	biv	si/cvu	?	n	x	x	o	
9	bs	si/lap			x	x	o	
10	cri?	per/--			x	x	o	
11	ft	si/cvu			x	x	o	
12	b or b	per/au	?	n	x	x	o	
13	ft?	si/---			x	x	o	
14	ft?	si/---			x	x	o	
15	ost?	mi/cvu	?	?	x	x	o	
16	ost?	si/cvu	?	?	x	x	o	
17	ost?	mi/cvu	?	?	x	x	o	
18	ost?	per/au	?	?		x	o	
19	ft?	si/cvu			x	x	o	
20	frag	mi/cvu	?	?		x	o	
21	ost?	mi/cvu	?	?		x	o	
22	frag	si/cvu				x	o	
23	ft?	si/cvu			?	x	o	
24	ft?	si/cvu			?	x	o	
25	ft?	si/cvu				x	o	
26	ft?	si/cvu				x	o	
27	ft?	si/cvu				x	o	
28	ft?	mi/ccu				x	o	
29	ost?	per/au		y		x	o	
30	ft?	si/cvu				x	o	
31	biv	si/ccu	?	n		x	o	
32	frag	si/cvu				x	o	
33	ft?	mi/---				x	o	
34	ft?	per/--				x	o	

APPENDIX X

Thin sections were made of each limestone at Lake Wabaunsee (Units 1, 13, 16 and 23). An array of points at 2.0 mm by 2.5 mm intervals were counted covering the entire slide. Thicker beds therefore have more points. Grain size and mineralogy of the matrix were noted and fossils identified. In point count lists, fossils named refer to skeletal fragments. Brachiopod refers to spines or fragments or both. Fossils in parentheses were observed in the slide, but did not fall under one of the points of the array. Length measurements were made of the maximum dimension of the fragments. Any structures (e.g. laminations, concentration of shells in layers) or other features (e.g. orientation of shells, recrystallization) were noted. All skeletal fragments were considered when shell orientation was determined, not just those that fell under the array of points. Pellets or intraclasts or both are referred to as intraclasts in point-count lists. Recrystallization masks the boundaries and makes it difficult to determine if these are pellets or intraclasts. Most are elongate and rounded, but some are irregular shaped and have angular outlines. Rock names are according to Folk (1974). Brief statements on possible depositional environments are included with each description.

LW 1A

Point Count:

Type	Number of Points	Percentage
Sparite	11	2.81
Microspar	303	77.49
Intraclast	10	2.56
Bryozoan	5	1.28
Bivalve	9	2.30
Gastropod	2	0.51
Ostracode	2	0.51
Brachiopod	28	7.16
Crinoid	21	5.37
Total	391	99.99

Description:

Intraclasts average 0.17 mm in diameter and range up to 0.71 mm. They are mainly confined to the bottom few millimeters of the bed. Skeletal fragments are randomly oriented with shells concave up and down, parallel to bedding through all degrees to perpendicular to bedding. Bivalve fragments average 0.35 mm, brachiopod fragments are up to 2.82 mm. Bedding is "disturbed" and appears to be swirled. Sparite is patchy. The disturbance and patchy appearance of sparite may be due to bioturbation. Fossils and matrix are recrystallized.

Rock Name: Biomicrite

Deposition:

This unit was probably deposited rapidly. The abundance of fine fraction indicates relatively low energy after deposition. The fossils may have been transported, but the bioturbation could not have been. This is probably marginal to normal marine.

LW 1B

Point Count:

Type	Number of Points	Percentage
Sparite	1	0.34
Microspar	245	82.49
Intraclast	12	4.04
Bryozoan	2	0.67
Bivalve	1	0.34
Ostracode	1	0.34
Brachiopod	26	8.75
Crinoid	9	3.03
(Trilobite)	-	----
Total	288	100.00

Description:

Intraclasts are confined to the lower few millimeters and average 0.35 mm. Skeletal fragments are randomly oriented with subequal numbers concave up and down. Orientation to bedding ranges from parallel to perpendicular to bedding. Bivalves average 1.03 mm and brachiopods average 0.25 mm. No laminations are present and fossils are evenly distributed except for one corner which is barren. Fossils and matrix have been recrystallized.

Rock Name: Biomicrite

Deposition:

This bed was deposited under essentially the same conditions as the bed below it, LW 1A.

LW 1C

Point Count:

Type	Number of Points	Percentage
Sparite	93	21.98
Microspar	270	63.83
Intraclast	14	3.31
Bryozoan	3	0.71
Bivalve	2	0.47
Gastropod	3	0.71
Brachiopod	32	7.56
Crinoid	6	1.42
Total	423	99.99

Description:

Intraclasts average about 0.25 mm and occur throughout the bed in the microspar. Fossils and sparite occur in patches. Skeletal fragments occur about equally concave up and down. They are parallel or subparallel to bedding. Bedding is swirled which may indicate bioturbation. Sparite increases upward, occurring not only with fossils, but as patches in the microspar as well. Crinoids and a few brachiopods are being replaced by chalcedony. The other fossils and matrix are partially recrystallized.

Rock Name: Biomicrite

Deposition:

This bed was deposited under essentially the same conditions as the two beds below it, LW 1A and 1B.

LW 1D

Point Count:

Type	Number of Points	Percentage
Sparite	46	11.19
Microspar	297	72.26
Pore Space	9	2.19
Intraclast	22	5.35
Echinoid	1	0.24
Bivalve	5	1.22
Gastropod	3	0.73
Ostracode	1	0.24
Brachiopod	13	4.62
Crinoid	8	1.95
(Bryozoan)	-	----
Total	405	99.99

Description:

Intraclasts average 0.25 mm and are concentrated in the microspar. Fossils usually are parallel or subparallel to bedding. Some, however, are at high angles (45° to 60°). Bivalves average 2.1 mm and are up to 3.5 mm long. Brachiopods average 1.41 mm and range up to 3.5 mm. Sparite is concentrated with the fossils in patches. The upper 5 mm of the bed are all microspar with no fossils or sparite. Fossils and matrix are partially recrystallized.

Rock Name: Biopelmicrite

Deposition:

Early deposition of this bed was under high energy conditions with some reworking. This was followed by quieter conditions and little reworking. This is probably marginal to normal marine.

LW 1E

Point Count:

Type	Number of Points	Percentage
Sparite	2	0.65
Microspar	304	99.02
Ostracode	1	0.32
(Brachiopod)	-	----
(Bivalve)	-	----
Total	307	99.99

Description:

This bed is a homogenous micrite with a few ostracodes present. The ostracodes are mostly disarticulated and generally concave down (10 to 2). A few brachiopod spines are present. Bivalves are restricted to the upper and lowermost parts of the bed. A small stringer of sparite occurs near the top. Sparite occurs inside articulated ostracodes. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

This unit was deposited under quiet, uniform conditions. There are no laminations and only one stringer of sparite. The bivalves at the bottom and top indicate slightly higher energy conditions.

LW 1F

Point Count:

Type	Number of Points	Percentage
Sparite	105	17.02
Microspar	503	81.52
Gypsum Cast	7	1.13
Bivalve	1	0.16
Brachiopod	1	0.16
(Ostracode)	-	----
Total	617	99.99

Description:

Laminations consist of alternating layers of microspar and fine sparite. It is a very homogenous unit and has a low fossil density. Bivalves average 1.23 mm and brachiopods average 0.52 mm. Gypsum casts occur mainly along the upper and lower 5 mm although a few occur inside these layers. Sparite increases in abundance upward. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

The fine laminations and gypsum casts indicate intertidal conditions. There was sufficient evaporation to cause gypsum to precipitate.

LW 1G

Point Count:

Type	Number of Points	Percentage
Sparite	46	10.72
Microspar	347	80.88
Intraclast	17	3.16
Gypsum Cast	1	0.23
Bivalve	3	0.70
Algal Coating	8	1.86
Brachiopod	7	1.63
(Gastropod)	-	----
(Echinoid)	-	----
(Ostracode)	-	----
Total	429	99.98

Description:

This bed consists of nearly barren microspar except for a band of fossils concentrated from 11 to 16 mm above the base. Fossils are randomly oriented although the bivalves tend to be parallel to bedding. Bivalves average 1.27 mm, brachiopods average 1.41 mm and algal coatings average 0.08 mm in thickness. There are two poorly defined areas of sparite that may be burrows. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

Quiet conditions prevailed throughout deposition of most of this bed, except for the higher energy period that deposited the fossils.

LW 1H

Point Count:

Type	Number of Points	Percentage
Sparite	21	15.44
Microspar	115	84.56
(Brachiopod)	-	----
(Bivalve)	-	----
Total	136	100.00

Description:

This is a homogenous micrite with very slight laminations of alternating micrite and fine sparite. The boundaries between these layers are vague. These could possibly be recrystallized algal stromatolites. Fossils are very rare and small (bivalves average 0.56 mm and brachiopods average 0.35 mm). A healed tectonic fracture i s filled with coarse sparite. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

Conditions were quiet and harsh as indicated by the fine grain size and lack of fossils. This may have been low intertidal or just beyond the reach of the tidal zone and either hypersaline or brackish.

LW 1I

Point Count:

Type	Number of Points	Percentage
Sparite	42	23.60
Microspar	135	75.84
Gypsum Cast	1	0.56
(Brachiopod)	-	----
(Gastropod)	-	----
Total	178	100.00

Description:

This bed is very similar to bed LW 1H. It has laminations of micrite and fine sparite, but they are better developed than in the bed below. The layers are not parallel. Sparite is very fine (0.017 mm), except in a healed tectonic fracture (average 0.13 mm) and inside the gastropod. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

The laminations and gypsum casts indicate intertidal, hypersaline conditions.

LW 1J

Point Count:

Type	Number of Points	Percentage
Sparite	66	27.05
Microspar	178	72.95
(Bivalve)	-	----
(Brachiopod)	-	----
Total	244	100.00

Description:

This bed is quite similar to LW 1H. Laminations are due to alternating grain size of calcite. There are a few places where the laminations are absent. These may be burrows. There appears to be some hematite staining which is probably secondary. Fossils are extremely rare. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

This bed represents a continuation of intertidal conditions. Salinity may be reduced or returned to normal because no gypsum casts are present.

LW 1K

Point Count:

Type	Number of Points	Percentage
Sparite	74	28.91
Microspar	182	71.09
(Gypsum Cast)	-	----
Total	256	100.00

Description:

There are no fossils in this bed, otherwise, it is very similar to the beds below it. Laminations are more even and distinctive than in the bed below. The laminations are disturbed in a few places which may indicate bioturbation. The bed is partially recrystallized.

Rock Name: Micrite

Deposition:

This bed is representative of continued intertidal conditions with hypersaline waters to precipitate gypsum.

LW 1L

Point Count:

Type	Number of Points	Percentage
Sparite	69	22.48
Microspar	238	77.52
(Ostracode)	-	----
Total	307	100.00

Description:

This bed is similar to the ones below it. The laminations are well developed, but a few patches suggest there may have been some bioturbation. Ostracodes are usually disarticulated. Fossils and matrix are partially recrystallized.

Rock Name: Micrite

Deposition:

This unit is representative of intertidal deposition with salinity possibly near normal.

LW 13A

Point Count:

Type	Number of Points	Percentage
Sparite	86	27.56
Microspar	154	49.36
Intraclast	54	17.31
Bivalve	17	5.45
Ostracode	1	0.32
Total	312	100.00

Description:

This bed is made up of three distinct units. The lower 4 mm are mainly shells and intraclasts with the microspar content increasing upward. The next 4 mm is made up entirely of shells cemented with sparite. The bivalves are parallel to bedding and usually concave down (19 to 6). Sparite is slightly larger below the bivalve shells and microspar often drapes over the tops of the shells. The upper 4 mm consists of concave down shells with microspar patchy and disturbed. The intraclasts are elongate and have angular outlines, but may be pellets. They average 0.12 mm. Bivalves average 1.75 mm and ostracodes average 0.17 mm. Fossils and matrix are partially recrystallized.

Rock Name: Biopelmicrite

Deposition:

The sequence of conditions begins with high energy where intraclasts are plucked up and moved with bivalve shells. Quieter conditions followed as a thin micrite layer was deposited. A return to high energy conditions deposited more intraclasts and bivalve shells with very little terrigenous debris. This was cemented with sparite. Finally, quieter conditions returned with micrite being deposited along with the shells. This part may have been burrowed slightly. The shell layers may represent storm lag deposits.

LW 13B

Point Count:

Type	Number of Points	Percentage
Sparite	261	54.95
Microspar	34	7.16
Pore Space	64	13.47
Intraclast	24	5.05
Bivalve	17	3.58
Algal Coating	75	15.79
(Gastropod)	-	----
Total	480	100.00

Description:

Microspar is limited to thin layers at the top and bottom of this bed. Sparite is mainly infilling original pore space (up to 0.71 mm crystals). The sparite is being dissolved producing "pore space" that is limited to the lower 15 mm and the upper 18 mm of the bed. Intraclasts average 0.35 mm and range up to 3 mm. They occur mostly in the lower 23 mm of the bed. Bivalves (average 1.4 mm) are algal coated (average thickness 0.04 mm), parallel or subparallel to bedding, and evenly distributed between concave up and down. Algal coatings are equal thickness on all sides of the shells. Some shells have been crushed and the break is filled with sparite. Fossils and matrix are partially recrystallized.

Rock Name: Biosparite

Deposition:

The bed was deposited under high energy conditions in relatively shallow water. Energy was high enough to "flip" shells periodically. This allowed algae to grow on all sides. This is probably representative of near normal marine conditions.

LW 13C

Point Count:

Type	Number of Points	Percentage
Sparite	56	21.29
Microspar	186	70.72
Intraclast	8	3.04
Bivalve	6	2.28
Gastropod	1	0.38
Ostracode	3	1.14
Algal Coating	3	1.14
(Brachiopod)	-	----
Total	263	99.99

Description:

This bed has a patchy distribution of sparite and fossils. Sparite is concentrated inside articulated shells (usually ostracodes) and zones that appear to have been disturbed (burrows?). Ostracodes occur in lenses and are randomly oriented with respect to bedding. The bivalves (average 1.25 mm) are algal coated (0.03 mm thick) and generally subparallel to bedding. Several shells have been crushed and the fractures filled with fine sparite. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

This bed reflects a reduction in energy from the bed below. The shells were probably not exposed as long because the algal coatings are thinner. Energy must have been high enough to "flip" them because algal coatings occur on all sides.

LW 13D

Point Count:

Type	Number of Points	Percentage
Sparite	113	46.50
Microspar	22	9.05
Pore Space	4	1.65
Intraclast	29	11.93
Bivalve	11	4.53
Gastropod	1	0.41
Ostracode	1	0.41
Algal Coating	62	25.51
Total	243	99.99

Description:

The bed consists of five distinct layers. The lower 10 mm contains intraclasts and algal coated bivalves with very little microspar. The next 17 mm contains microspar and fine sparite with a few algal coated bivalves. This layer appears to be disturbed. The next 5 mm have no microspar and contains sparite with a few bivalves. The next 1 mm is very dark and fine grained. It has been stained with hematite or limonite. The upper 1 to 7 mm is made up of microspar and intraclasts and appears to be disturbed. Bivalves average 1.63 mm and intraclasts average 0.17 mm ranging up to 1.06 mm. Algal coatings average 0.06 mm thick. Fossils and matrix are partially recrystallized.

Rock Name: Biopelsparite

Deposition:

This bed was deposited under alternating high and low energy conditions. At times, energy was high enough to "flip" shells and at others, low enough to deposit mud.

LW 13E

Point Count:

Type	Number of Points	Percentage
Sparite	126	31.34
Microspar	193	48.01
Intraclast	22	5.47
Bivalve	24	5.97
Gastropod	1	0.25
Ostracode	6	1.49
Algal Coating	30	7.46
Total	402	99.99

Description:

Intraclasts (average 0.35 mm) are more abundant in the lowest part of the bed. Bivalves (up to 2.11 mm) that are concave down have sparite underneath them. They are usually parallel to bedding, but some are oriented at up to 60° to bedding. They occur about evenly concave up and down (11 to 8). There is some evidence of disturbance. A healed tectonic fracture has been filled with sparite. Fossils and matrix are partially recrystallized.

Rock Name: Biopelmicrite

Deposition:

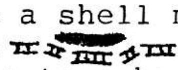
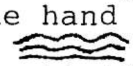
Energy conditions were high enough to "flip" shells. Water depths were shallow enough for algae to encrust the shells.

LW 16A

Point Count:

Type	Number of Points	Percentage
Sparite	31	8.47
Microspar	254	69.40
Pore Space	17	4.64
Intraclast	4	1.09
Prismatic Layer from Mollusc Shell	60	16.39
(Ostracode)	-	----
Total	366	99.99

Description:

This bed is a micrite with shells being dissolved and sparite precipitated in their place. The shells have been crushed during compaction. They are parallel to bedding except for a few small fragments that were reoriented when crushed. One intraclast directly above a shell may have been the controlling factor in shell breakage  . These prismatic layers (up to 2.82 mm) are probably pectens because only pectens have been identified in the hand sample and they have cross sections that appear as such:  . Intraclasts average 0.71 mm. Fossils and matrix are partially recrystallized.

Rock Name: Biomicrite

Deposition:

The fine grain size indicates quiet waters. The mollusc shells are disarticulated and may have floated in after the animal died.

LW 16B

Point Count:

Type	Number of Points	Percentage
Sparite	14	4.33
Microspar	246	76.16
Pore Space	1	0.31
Intraclast	8	2.48
Prismatic Layer	54	16.72
(Ostracode)	-	----
Total	323	100.00

Description:

Sparite is generally infilling pore space where mollusc shells are being dissolved. The molluscs are generally parallel to bedding except where crushing has caused reorientation. Over half of all shells are in the lower 2 mm and 80 to 90 percent occur in the lower 6 to 7 mm. Molluscs are probably pectens as in LW 16A. Fossils and matrix are partially recrystallized.

Rock Name: Biomicrite

Deposition:

Mollusc shells probably floated in after the animal died and settled to the bottom in quiet waters.

LW 16C

Point Count:

Type	Number of Points	Percentage
Sparite	74	19.58
Microspar	261	69.05
Pore Space	9	2.38
Intraclast	4	1.06
Ostracode	1	0.26
Prismatic Layer	29	7.67
Total	378	100.00

Description:

This bed is similar to the two beds below it except the fossil density is lower. Sparite occurs inside articulated ostracodes and in patches. The majority of molluscs occur in the lower 2 mm and are broken as in previous beds. Fossils and matrix partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

This bed is indicative of a continuation of quiet conditions. The mollusc shells probably floated in after the animal died and settled to the bottom.

LW 16D

Point Count:

Type	Number of Points	Percentage
Sparite	41	11.23
Microspar	255	69.86
Pore Space	37	10.14
Intraclast	4	1.10
Prismatic Layer	25	6.85
Ostracode	3	0.82
Total	365	100.00

Description:

Intraclasts (average 0.25 mm, up to 1.23 mm) occur throughout the bed. Matrix inside articulated mollusc shells is being dissolved. Sparite is generally infilling articulated ostracodes, pore space and along prismatic strands. This bed is quite similar to the beds below it. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

This bed reflects a continuation of the same conditions as the beds below it.

LW 16E

Point Count:

Type	Number of Points	Percentage
Sparite	41	8.52
Microspar	418	86.90
Intraclast	8	1.66
Bivalve	7	1.46
Ostracode	3	0.62
Gastropod	4	0.83
Total	481	99.99

Description:

The lower half of this bed is almost completely intraclasts (average 0.33 mm, up to 0.88 mm) in microspar with only a few bivalves and ostracodes. The upper half of the bed contains most of the fossils. Sparite infills articulated ostracodes and occurs in patches. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

This bed is a continuation of the conditions of the beds below it.

LW 16F

Point Count:

Type	Number of Points	Percentage
Sparite	73	26.74
Microspar	181	66.30
Dolomite	7	2.56
Bivalve	8	2.93
Gastropod	1	0.37
Ostracode	3	1.10
Total	273	100.00

Description:

The bedding within this bed is swirled and disturbed. Fossils are parallel or subparallel to bedding. Bivalves average 2.82 mm. Dolomite is confined to the lowermost and uppermost parts of the bed. This is a thin, irregular bed. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous Micrite

Deposition:

The orientation of fossils and thin bed thickness suggest this bed was deposited rapidly. Dolomite is secondary because of the large rhomb size.

LW 16G

Point Count:

Type	Number of Points	Percentage
Sparite	292	35.52
Microspar	412	50.12
Dolomite	24	2.92
Intraclast	26	3.16
Bivalve	33	4.01
Gastropod	2	0.24
Ostracode	13	1.58
Algal Coating	12	1.46
Prismatic Layer	8	0.97
Total	822	99.98

Description:

Intraclasts (average 0.88 mm, up to 3.5 mm) occur concentrated along the bottom. Sparite infills articulated ostracodes, occurs along shells, and as patchy recrystallization. Dolomite rhombs are present throughout the bed. Their average size (0.16 mm) indicates they are secondary. Gastropods are mud and micrite filled. Intraclasts and fossils are at all angles to bedding. The beds appear to be disturbed and may have been bioturbated. Fossils and matrix are partially recrystallized.

Rock Name: Biopelmicrite

Deposition:

Energy conditions had to be high enough to transport intraclasts and skeletal fragments, but did not last long enough to winnow out the fine fraction.

LW 16H

Point Count:

Type	Number of Points	Percentage
Sparite	105	23.33
Microspar	222	49.33
Dolomite	5	1.11
"Disturbed Area"	72	16.00
Intraclast	18	4.00
Bivalve	21	4.67
Gastropod	1	0.22
Ostracode	3	0.67
Algal Coating	3	0.67
Total	450	100.00

Description:

This bed contains two different lithologies. The lower part contains "disturbed areas" which have poorly defined boundaries. These areas consist of micrite and sparite in irregular patterns and are probably the result of bioturbation. Bedding in this part is greatly disturbed and fossils occur at angles up to 60° to bedding. The upper 10 mm appear to be undisturbed. Fossils in this part are parallel to bedding. Intraclasts (average 0.52 mm, up to 2.64 mm) occur in this part. Bivalves average 3.52 mm and algal coatings average 0.02 mm in thickness.

Rock Name: Biopelmicrite (Dismicrite)

Deposition:

Energy must have been high enough at times to transport the intraclasts and skeletal fragments and to "flip" shells. Shallow water is indicated by the presence of algae.

LW 16I

Point Count:

Type	Number of	Percentage
Sparite	37	11.18
Microspar	191	57.70
Dolomite	2	0.60
"Disturbed Area"	97	29.30
Bivalve	2	0.60
Gastropod	1	0.30
Ostracode	1	0.30
Total	331	99.98

Description:

This bed is similar to LW 16H, except there are fewer bivalves and intraclasts and less dolomite. Alternation of disturbed and less disturbed areas are approximately the same thickness. Sparite occurs infilling articulated shells. Fossils are parallel to bedding and at least 50 percent are articulated. Bivalves average 0.71 mm and intraclasts average 0.25 mm. Fossils and matrix are partially recrystallized.

Rock Name: Fossiliferous (Dis)Micrite

Deposition:

Quiet water conditions prevailed while the sediments were mildly bioturbated. The low diversity and density of fossils suggest restricted conditions.

LW 23

Point Count:

Type	Number of Points	Percentage
Sparite	20	5.63
Microspar	258	72.68
Intraclast	15	4.22
Bivalve	5	1.41
Gastropod	2	0.56
Trilobite	3	0.85
Brachiopod	26	7.32
Crinoid	18	5.07
Echinoid	3	0.85
Bryozoan	5	1.41
Total	345	100.00

Description:

Intraclasts (average 0.17 mm) occur throughout the bed. Fossils are randomly oriented with respect to bedding. Bivalves average 1.06 mm, trilobites average 0.51 mm, brachiopods average 0.71 mm, and echinoderms average 0.31 mm. There is no apparent internal bedding. Fossils and matrix are partially recrystallized.

Rock Name: Biomicrite

Deposition:

The increased diversity and density of organisms compared to other limestone units indicates more favorable conditions. The presence of several forms with restricted tolerance ranges indicates normal marine conditions. The abrasion and fragmentation of fossils suggest transport before deposition and relatively high energy.

DEPOSITIONAL ENVIRONMENT OF THE ESKRIDGE SHALE (LOWER PERMIAN)

by

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ABSTRACT

The Eskridge Shale ranges from 8 to 13 meters in thickness, contains thick beds of red and green mudstone and thin beds of limestone, and changes vertically and laterally. The general lack of sedimentary structures and fossils has resulted in a long debate about its depositional environment. Interpreted environments range from non-marine to marine.

Field observations, laboratory analyses, and comparison with previous work were used to postulate the environment of deposition. Attempts to use the sedimentary phosphate method to estimate palaeosalinity failed. Grain size, mineralogy, and fossils of the mudstones are nearly uniform. However, coupling these data with the stratigraphic sequence and comparing them with data from previous studies, it is possible to infer general depositional environments.

The Eskridge is typical of "outside" shales with its rapid vertical and lateral changes; the subenvironments required to produce the different lithologies which occur in the Eskridge could be explained by a system of braided streams and small deltas that frequently shifted positions. Each lithology could reflect differences in terrigenous influx, salinity, water depth, and organic carbon as a result of river and delta positions at any given time.

The underlying unit, the Neva Limestone Member of the Grenola Limestone, represents intertidal to normal marine conditions which were present prior to the main influx of detritus. As detrital influx increased, green mudstone/shale was deposited in intertidal and shallow subtidal environments with moderate to high amounts of organic carbon. Red mudstone was deposited with very little organic carbon in braided streams and on flood plains. Bioturbated mudstone with lungfish burrows represents areas of streams or related ponds that dried up. The occurrence of lungfish burrows and the lack of plant debris suggest a semi-arid climate with dry periods. Green mudstone/shale and sometimes non-fossiliferous

limestone were deposited when the delta shifted. Repetitions of red and green beds reflect subsequent delta shifts. Then beds of limestone were deposited in protected areas which received very little detritus. In quiet, brackish areas, molluscan (*Aviculopecten*, *Septimyalina*, and *Bellerophon*) limestone was deposited. In more agitated areas, bioclastic limestone was deposited. As detrital influx began to decrease, beds of yellow-orange mudstone were deposited, probably under near-normal marine conditions. As detrital influx diminished, normal marine conditions prevailed, and the overlying unit, the Cottonwood Limestone Member of the Beattie Limestone, was deposited.