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Paleoecology of late quaternary Molluscan-Ostracod assemblages from the Norwood site, southeastern Minnesota

Kevin L. Malmquist
University of North Dakota

PALEOECOLOGY OF LATE QUATERNARY MOLLUSCAN-OSTRACOD ASSEMBLAGES FROM THE NORWOOD SITE, SOUTHEASTERN MINNESOTA

by

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This thesis submitted by Kevin Lee Malmquist in partial fulfillment of the requirements for the Degree of Master of Arts from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

Alan M. Cvancara
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This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

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Title PALEOECOLOGY OF LATE QUATERNARY MOLLUSCAN-OSTRACOD ASSEMBLAGES FROM THE NORWOOD SITE, SOUTHEASTERN MINNESOTA

Department Geology

Degree Master of Arts

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Date April 30, 1979

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ABSTRACT

Well-preserved fossils, including mollusks, ostracods, beetles and plant remains were extracted from sediments at the Norwood Site in southeastern Minnesota during July, 1977. Stratigraphic units, in ascending order, were: (1) sandy claystone, (2) clayey siltstone, (3) sandy siltstone, and (4) laminated peat. Unit 1 was interpreted to be till or sediment that slumped or flowed into the lake. Unit 2 and the lower part of unit 3 were interpreted to be lacustrine sediments. The upper part of unit 3 was interpreted to be a shoreline deposit. Unit 4 was interpreted to be a terrestrial or marginal lacustrine deposit. Total thickness of the section was 1.7 m. Wood from the boundary of units 3 and 4 yielded a radiocarbon date of 12,400±60 years B.P. Sediment samples yielded at least 2 species of sphaeriid bivalves, 3 species of gastropods, and 6 species of ostracods. The low diversity in number of species and the age of the sediments suggested that these individuals may have been the first species to inhabit the study area after the Grantsburg glaciation. Both mollusks and ostracods were most abundant and diverse in unit 2 and the lower part of unit 3. The fossil assemblage of these units indicated a permanent lake with vegetation. The lack of mollusk fossils and better sediment sorting in the upper part of unit 3 suggested a shoreline environment. Abundant plant remains and the absence of mollusk fossils in unit 4 indicated a terrestrial or marginal lacustrine environment. Pollen analysis indicated that the lake was surrounded by tundra and, later, a spruce forest.

INTRODUCTION

Location

During the summer of 1957, construction of the Bevens Creek Drainage Ditch in southeastern Minnesota exposed peat and organic silt containing numerous plant and animal fossils. In the fall of 1957, Dr. H. E. Wright Jr., of the University of Minnesota, discovered fossiliferous sediments on the south-facing slope of the Bevens Creek Drainage Ditch (Fig. 2), hereafter referred to as the Norwood Site. The site was at SE¼NW¼ Sec. 2, T. 114 N., R. 26 W., 230 m east of Sibley County road 31, on the north side of Bevens Creek Drainage Ditch, 6.4 km south-southeast of Norwood, northeastern Sibley County, Minnesota (Fig. 1). The location of the site by latitude and longitude was 44°40' north latitude, 93°50' west longitude.

Purpose

Primary objectives were to identify and photograph the mollusks and ostracods from the Norwood Site and to determine the amount of reactive carbonate, combustible carbon, and grain-size distribution of each lithologic sample. Secondary objectives were to interpret the paleoecology of the organisms studied, so as to interpret the paleoenvironments existing at the site during Late Quaternary time. This study intended to determine if paleoecology and paleoenvironmental inferences based on the selected organisms and inorganic evidence agree with those based on plant and insect fossils, currently being studied

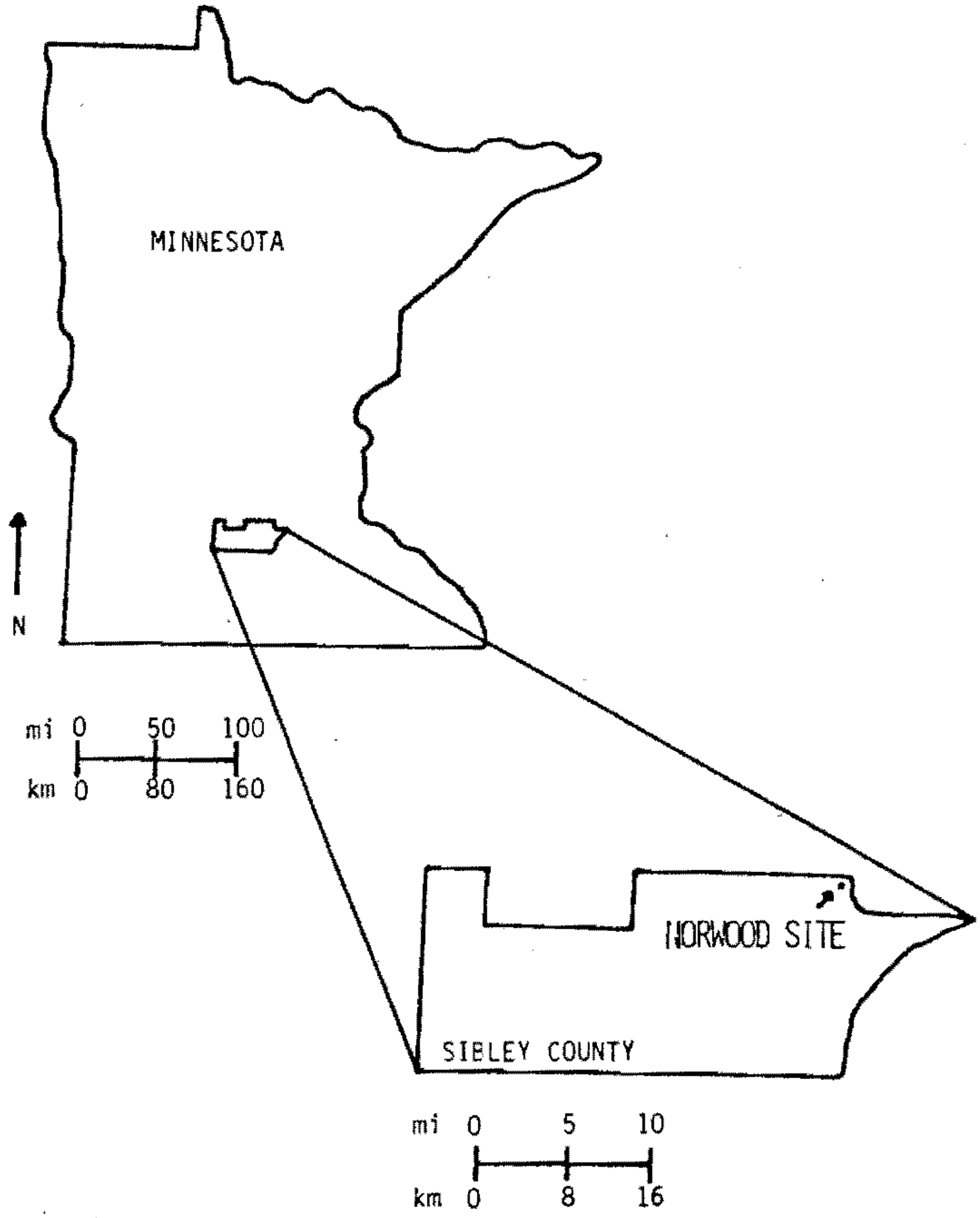

Fig. 1. General location of the Norwood Site, Minnesota.

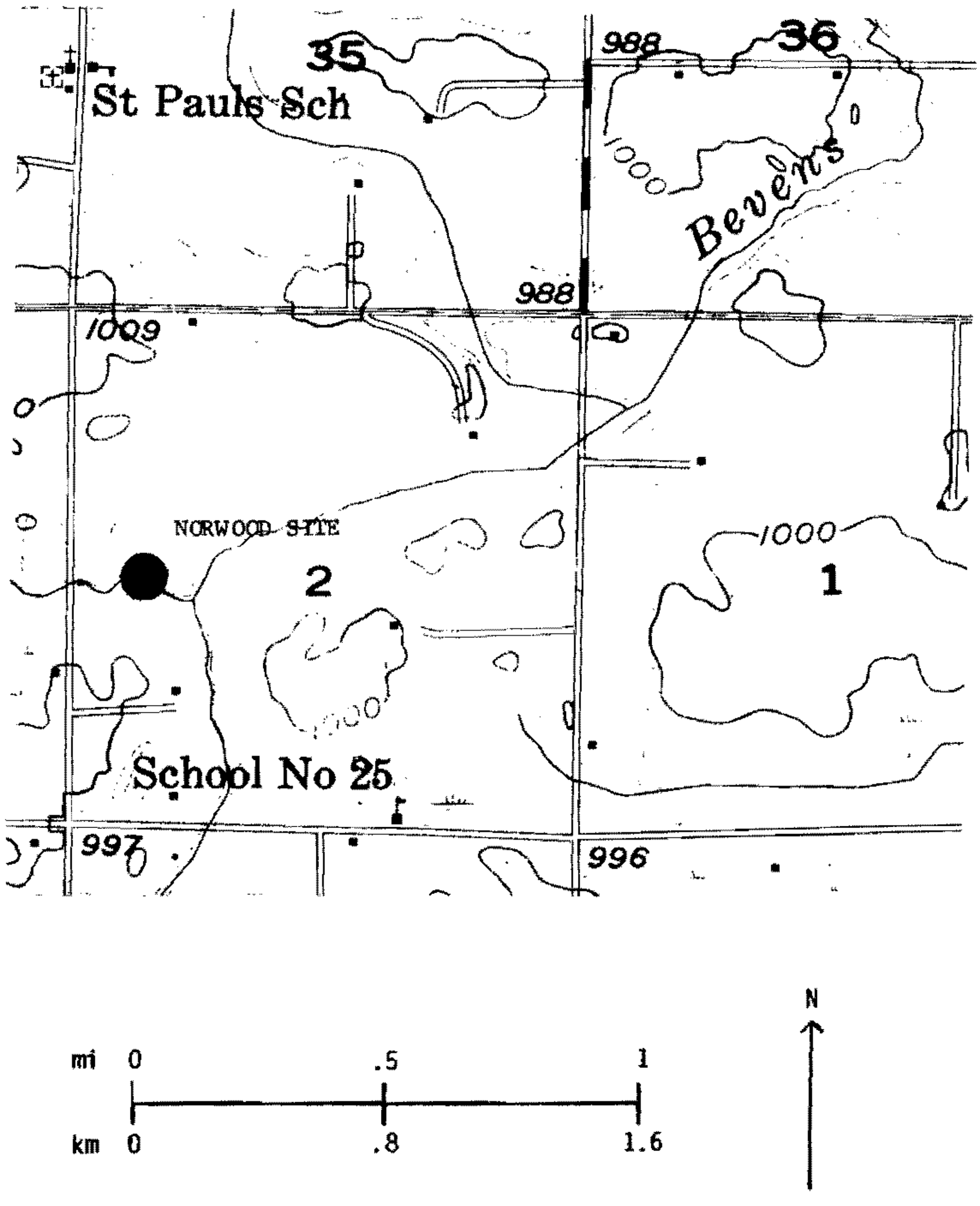

Fig. 2. Specific location of the Norwood Site, Minnesota (U.S. Department of Interior Geological Survey, 1957).

by other workers. When research on insect and plant fossils has been completed, the combined use of mollusks, ostracods, insects, plant remains, and sediment analysis should provide a more detailed environmental reconstruction.

Regional Setting

Wright and Ruhe (1965, p. 33) suggested that the surface topography of the region resulted from glacial sediment modifying the Minnesota and Minneapolis Lowlands, two major depressions in the bedrock topography.

Sediments from the Norwood Site contained large percentages of shale, which is characteristic of the glacial drift deposited by the Des Moines Lobe (Clayton, 1979). Wright and Ruhe (1965, p. 39) stated that the Des Moines Lobe and the Grantsburg Sublobe advanced through the study area as early as 40,000 years B.P. Wright (1979) suggested that these glacial lobes had probably completely melted from the area by 12,700-11,800 years B.P.

Pollen studies from Kirchner Marsh in southeastern Minnesota by Winter (1962) suggested that the region was occupied by a spruce-dominant flora 12,000-10,000 years B.P. Studies of pollen and macroplants from sediments at the Norwood Site suggested that these sediments were deposited during the existence of a much earlier tundra-dominant flora, perhaps on a stagnating ice sheet (Wright, 1979).

Previous Work

Relatively few Late Quaternary molluscan-ostracod assemblages in Minnesota have been studied in detail. Tuthill (1963) identified mollusks from Glacial Lake Agassiz sediments in Red Lake County, Minnesota and suggested a paleoecological interpretation for that site. Tuthill et al. (1964) compared a Late Pleistocene fossil molluscan fauna from North Dakota with a Recent molluscan fauna from Minnesota and suggested paleoenvironmental interpretations for Late Pleistocene slough sites in North Dakota. Cvancara identified mollusks from the Snake Curve Section in Red Lake County, Minnesota and provided paleontological evidence for the history of Glacial Lake Agassiz (Moran et al., 1971). Bickley identified mollusks from the Mosbeck Site in northwestern Minnesota and presented a paleoenvironmental interpretation of the Late Quaternary history of Lake Agassiz (Ashworth et al., 1972). Cvancara studied mollusks at the Gould Site in northeastern Minnesota and presented a paleoenvironmental interpretation of Glacial Lake Aitkin (Cvancara et al., 1979).

Mollusks and ostracods from Late Quaternary lake and slough deposits in North Dakota, South Dakota, and Canada were studied by the following authors. McAndrews identified mollusks from the Woodworth Pond in Stutsman County, North Dakota and presented a paleoenvironmental interpretation for the Missouri Coteau during Late Quaternary time (McAndrews et al., 1967). Delorme identified ostracods from Pleistocene sediments in southwestern Manitoba and suggested a paleoenvironmental interpretation for the area (Klassen et al., 1967). Bright identified mollusks from a sediment core from Pickerel Lake in northeastern South Dakota and presented a paleoenvironmental reconstruction for that area (Watts and Bright, 1968). Tuthill (1969) attempted a comparison of the Late Wisconsinan molluscan fauna of the

Missouri Coteau with a modern Alaskan analogue. Delorme (1968, 1971b) identified ostracods from Pleistocene sediments in the Yukon and from Holocene sediments near Somerset, Manitoba and presented paleoecological interpretations for those sites. Delorme (1969) identified ostracods from Late Quaternary slough sites in Manitoba and Ontario and interpreted the paleoecology at those sites. Paleoenvironmental reconstructions at the Seibold Site, a Late Quaternary slough site in southeastern North Dakota, included mollusk identification by Bickley (1970) and ostracod identification by Delorme (Cvancara *et al.*, 1971). Comparisons between the Seibold Site and other Late Quaternary slough deposits were also attempted (Bickley *et al.*, 1971). Tuthill identified mollusks from the Itasca Bison Kill Site in Itasca County, Minnesota and suggested a paleoecological interpretation for that site (Shay, 1971). Okland (1978) identified mollusks from the McClusky Canal Site in central North Dakota and presented a paleoecological interpretation for that site.

Previous work related directly to the Norwood Site included Carbon 14 dating and pollen analyses of the sediments by Wright (1979). The identification of insect fragments by Allan Ashworth and Donald Schwert, North Dakota State University, Fargo, and plant macrofossils by W. A. Watts, University of Dublin, Ireland, was in progress (Ashworth, 1979).

MATERIALS AND METHODS

Field Methods

During July 1977, Allan Ashworth and Glen Wollan of North Dakota State University, John Hoganson of the University of North Dakota, and Joseph Goebel of the Minnesota Geological Survey relocated the overgrown site with a 1-inch Giddings Soil Probe. Sediments containing well-preserved fossils, including mollusks, ostracods, beetles, and plant remains were then exposed by a backhoe. The section was measured and described, and bulk sediment samples of approximately 10 kg were collected at 10-cm intervals from the exposed section. After sampling, the excavated site was refilled.

Laboratory Methods

Samples obtained from Allan Ashworth during March 1978, were split into subsamples of 200 ml for removal of fossil shells, 50 g for sediment grain-size analysis, and two 5-g samples for determining reactive carbonate and combustible carbon content. Excess sample was stored in one quart plastic containers.

The 200-ml samples were soaked in 3% Calgon for 24 hours. All samples disaggregated readily. After soaking, samples were washed through a sieve of 0.25 mm and dried for picking. The samples were examined with a binocular microscope under low power (7X) and all recognizable mollusk material was picked. Due to the large number of ostracod shells only one-eighth of each 200-ml sample was picked. Splitting the sample reduced the number of individuals to be identified to a workable amount. The number of ostracods per 200 ml was calculated. The sample from 295-305 cm contained a large amount of fossil plant material. This fibrous material caused the sample to mat so badly that it was difficult to separate most fossils without damaging them. Although this sample was not picked, the presence or absence of mollusks and ostracods was noted. Samples containing fossil shell material were assigned UND (University of North Dakota, Department of Geology) Accession numbers.

The 50-g samples were soaked in deionized water for 6 hr. After disaggregation they were washed through a sieve of 625 μ. The fine sediment passing through the sieve was caught in a five quart plastic pail and transferred to 100-ml graduated cylinders. Silt and clay percentages were determined by pipette analysis whereas sand percentages were determined by sieve analysis following the procedures given by Folk (1974, pp. 33-40). Due to the large amount of fossil plant material in the sample from 295-305 cm, grain size analysis of this sample was not attempted.

Combustible carbon content was determined by drying 5-g samples at 100^{o} for 24 hr, weighing them, igniting them in a furnace at 600^{o} C for 30 min, and calculating the weight loss. This procedure was modified after Gross (1971, pp. 586-587).

Reactive carbonate content was determined by treating dried samples with 10% HCl, adding deionized water, and decanting all excess liquid. The samples were then dried and carbonate content determined by weight loss. This procedure was modified after Gross (1971, pp. 590-591).

Mollusk specimens were identified and later compared with specimens from the University of North Dakota's fossil collection. Identifications were based on Clarke (1973) and La Rocque (1968) for the gastropods, Burch (1975) and La Rocque (1967) for the pill clams, and Delorme (1970a-d, 1971a) for the ostracods. Specimens from the sample designated A2423.01 were collected at a depth of 4.3 m. Subsequent samples and the contained specimens were collected at 10-cm intervals, up to A2423.12 at a depth of 3.2 m.

RESULTS

Stratigraphy

Four units were distinguished on the basis of lithology and fossil content (Fig. 3). Diagrams showing grain-size analyses are shown in Appendix A. These four units, from oldest to youngest, were: (1) sandy claystone, (2) clayey siltstone, (3) sandy siltstone, and (4) laminated peat.

Unit 1 was an unsorted, grey, sandy claystone containing pebbles, little organic material, and no fossils. Grain-size distribution for this unit was 30-43% sand, 18-27% silt, and 34-47% clay. This unit contained 4-6% combustible carbon and 14-21% reactive carbonate. A bottom contact for this unit was not observable. It was overlain by a poorly sorted, grey, clayey siltstone approximately 0.8 m thick containing few pebbles and little organic matter. Grain-size distribution for this unit was 6-30% sand, 34-62% silt, and 24-53% clay. This unit contained 4-9% combustible carbon and 15-21% reactive carbonate. Mollusks were present throughout this unit but were abundant only in the upper 0.3 m. Ostracods were present throughout this unit but were abundant only in the upper and lower 0.3 m. Unit 3 was a poorly to well sorted, sandy siltstone approximately 0.45 m thick containing few pebbles, little organic material, few mollusks, and abundant ostracods. Grain-size distribution for this unit was 15-39% sand, 41-72% silt, and 8-19% clay. This unit contained 3-7% combustible carbon and 2-19%

reactive carbonate. Ostracods were present throughout this unit but abundant only in the lower 0.1 m. Unit 4 was laminated peat 0.1 m thick containing 42% combustible organic matter, 4% reactive carbonate, abundant ostracod shells and no mollusk shells. This unit was overlain by a clayey siltstone that was not sampled because of its high degree of oxidation (Fig. 3).

Units 1, 2, and 3 were similar. The main differences were that unit 1 was unsorted and contained the greatest percentage of pebbles and coarse sand, whereas units 2 and 3 were poorly to well sorted and contained the greatest abundance of mollusk and ostracod shells. Unit 4 was easily distinguished from the other units by the great abundance of plant material.

Wood collected from the boundary of units 3 and 4 was dated at an age of 12,400$\pm$60 radiocarbon years B.P. (Wright, 1979).

Paleontology

The Norwood Site contained a limited variety of well-preserved mollusk, ostracod, insect, and plant fossils. Mollusks and ostracods were studied in detail. Three species of gastropods, Gyraulus parvus, Lymnaea cf. L. stagnalis, and Valvata sincera; two species of pelecypods, Pisidium nitidum and Pisidium ventricosum; and six species of ostracods, Cypridopsis vidua, Ilyocypris bradyi, Candona candida, Candona rawsoni, Candona sp. 1 and Candona sp. 2, were identified. The occurrence of all fossils in the measured section was given in Appendix B. The stratigraphic occurrence of mollusks and ostracods was shown in Fig. 4 and 5.

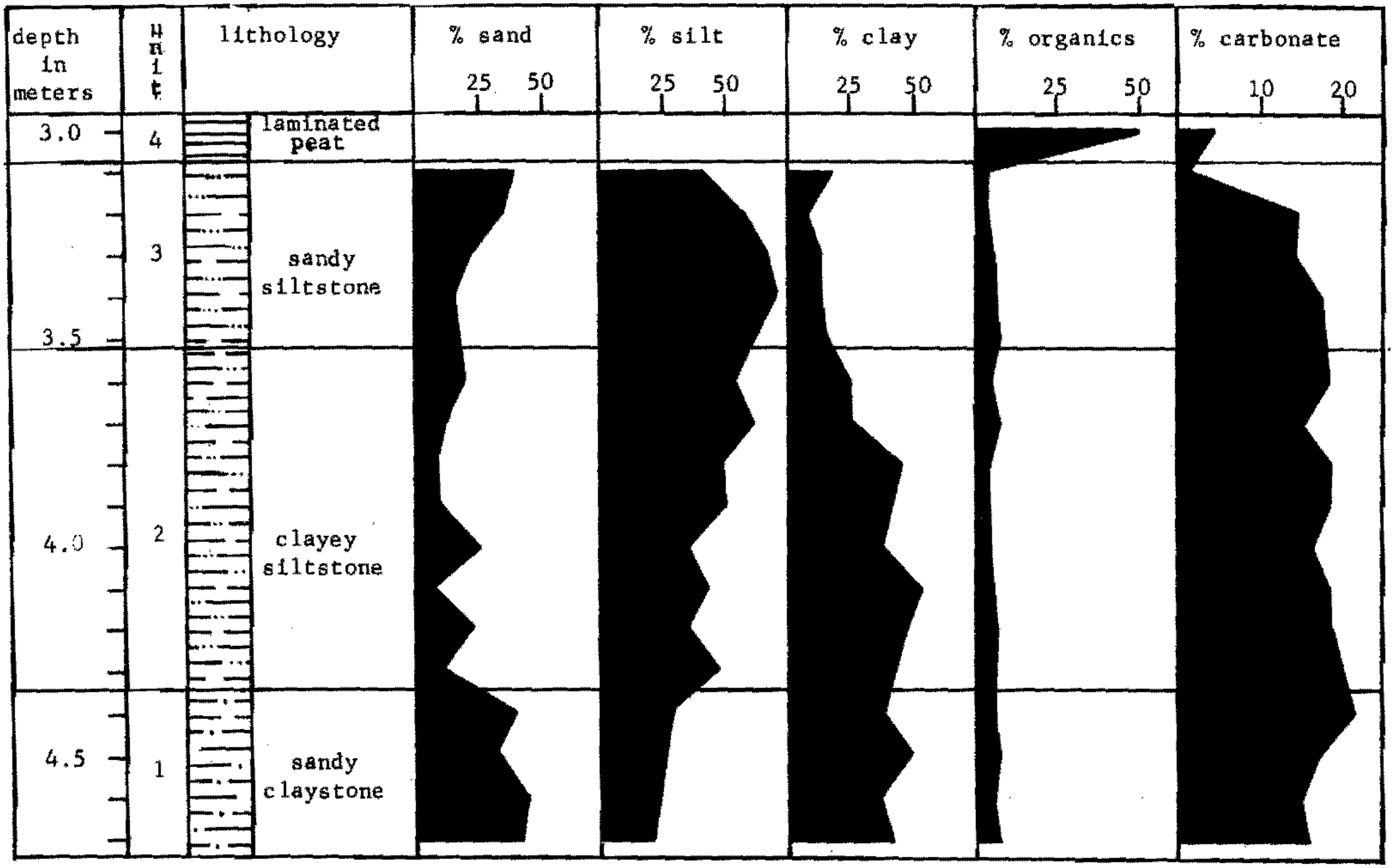

Fig. 3. Stratigraphy and sediment composition at the Norwood Site, Minnesota.

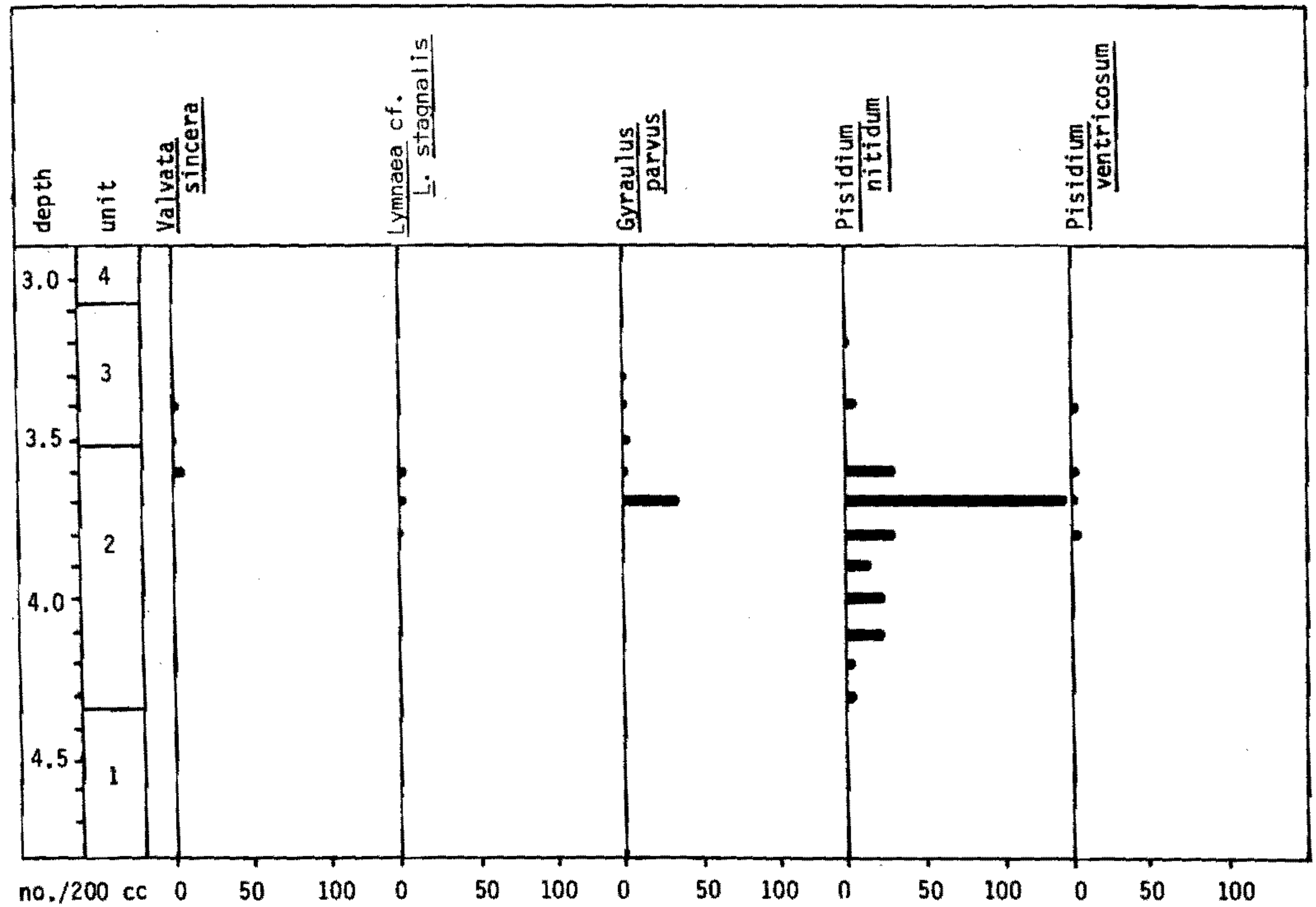

Fig. 4. Stratigraphic occurrence of mollusks at the Norwood Site, Minnesota.

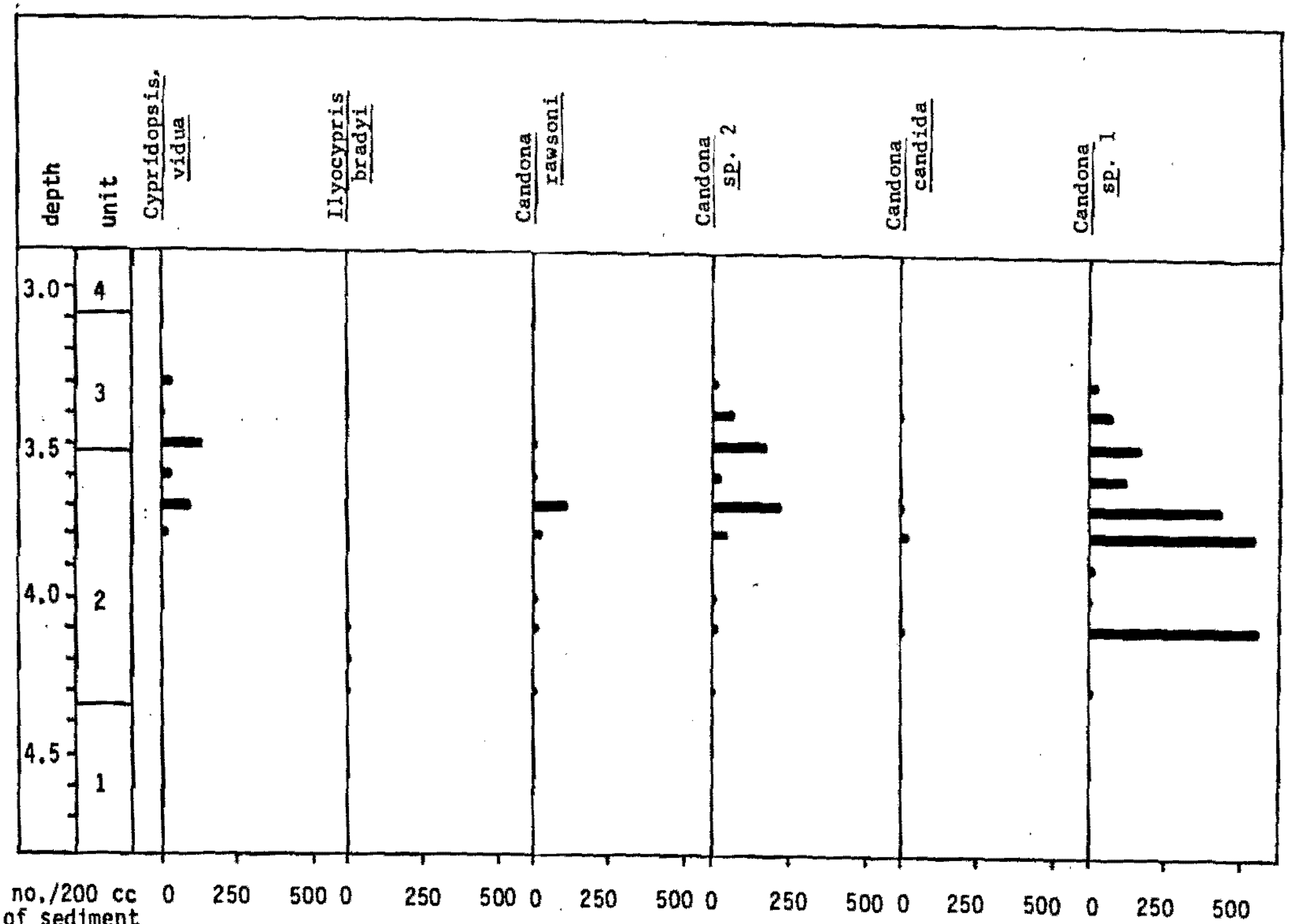

Fig. 5. Stratigraphic occurrence of ostracods at the Norwood Site, Minnesota.

Three species of gastropods were identified in units 2 and 3 at depths of 3.8-3.3 m. Gyraulus parvus was abundant only at 3.7 m (31 individuals per 200 ml). It occurred at 3.6-3.3 m but in concentrations of less than 5 individuals per 200 ml. Lymnaea cf. L. stagnalis occurred at 3.8, 3.7, and 3.6 m but in concentrations of 3 individuals per 200 ml or less. Valvata sincera was identified at 3.6 m (8 individuals per 200 ml), 3.5 m (1 individual per 200 ml), and 3.4 m (4 individuals per 200 ml). The greatest concentration of gastropods, 34 individuals per 200 ml, was found at a depth of 3.7 m whereas the greatest diversity, 3 species, was at 3.6 m.

Two species of sphaeriids were identified in units 2 and 3 at depths of 4.3-3.2 m. Pisidium nitidum occurred throughout units 2 and 3 at concentrations of less than 40 individuals per 200 ml, except at 3.7 m where it was abundant (175 individuals per 200 ml) and at 3.3 m where it was not present. Pisidium ventricosum was identified at depths of 3.8-3.4 m at concentrations of 6 individuals per 200 ml or less except at 3.5 m where it was not present. The highest concentration of sphaeriids was found at 3.7 m (182 individuals per 200 ml) and the occurrence of both species was recorded only at 3.8-3.6 m and at 3.4 m.

Six species of ostracods were identified in units 2 and 3 at depths of 4.4-3.3 m (Fig. 5). The ostracod assemblage from the Norwood Site was dominated by Candona sp. 1 and Candona sp. 2. Candona sp. 1 was identified at 4.3-3.3 m at concentrations of 136 individuals per 200 ml or more except at 3.3, 3.4, 3.9, 4.0 and 4.3 m (96 individuals per 200 ml or less). Candona sp. 2 occurred at 4.3-3.3 m at concentrations of 80 individuals per 200 ml or less except at 3.7 and 3.5 m where it was abundant (192 individuals per 200 ml or more) and at 4.2 and 3.9 m where it was not present. Candona rawsoni was identified at 4.3-3.5 m in concentrations of 32 individuals per 200 ml or less except at 3.7 m where it was quite abundant (128 individuals per 200 ml) and at 4.2 and 3.9 m where it was not present. Candona candida occurred at 4.1 m (16 individuals per 200 ml), 3.8 m (32 individuals per 200 ml), 3.7 m (16 individuals per 200 ml) and 3.4 m (8 individuals per 200 ml). Ilyocypris bradyi occurred at 4.3-4.1 m at maximum concentrations of 16 individuals per 200 ml. Cypridopsis vidua was identified at 3.8-3.3 m in concentrations of 96 individuals per 200 ml or more except at 3.8 m (24 individuals per 200 ml), 3.6 m (48 individuals per 200 ml), and 3.4 m (8 individuals per 200 ml). The highest concentration of ostracods was found at 3.7 m (920 individuals per 200 ml), whereas the highest diversity, 5 species, was at 3.7, 3.8 and 4.1 m.

Mollusks were absent from units 1 and 4. Ostracods were absent in unit 1 and abundant in unit 4.

DISCUSSION

General paleoecological considerations

Interpreting past ecologic conditions from fossil assemblages is considered to be a well established practice. Interpretations were based on species whose ecological preferences were known from present day studies. It was assumed that these ecological preferences did not change over the time span involved.

Molluscan-ostracod paleoecology

A rather sparse molluscan-ostracod assemblage occurred in the sediments at the Norwood Site (Fig. 4 and 5). Units 1 and 4 contained no molluscan fossils. Unit 1 contained no ostracod fossils. The absence of such fossils in these units suggested that: (1) the study site may not have been ecologically suitable for habitation by these individuals; (2) mollusks or ostracods may not have had sufficient time to migrate into the area after the Grantsburg glaciation; (3) the rate of sedimentation may have been so great as to cause an extremely low concentration of shells in the sediment; (4) the depositional environment may not have been conducive to shell preservation. Further study of these units was needed to substantiate any of these interpretations.

Both diversity and abundance of mollusks and ostracods were greatest in unit 2 and the lower portion of unit 3 (Fig. 4 and 5). The molluscan-ostracod assemblages of these strata were dominated by

Gyraulus parvus, Pisidium nitidum, Candona sp. 1, and Candona sp. 2. Gyraulus parvus, often found in shallow, protected bodies of water with dense vegetation (La Rocque, 1968, p. 491), was abundant in these layers. Pisidium nitidum was characteristic of large ponds, lakes, creeks, or rivers and was most often found in shallow water with aquatic plants (Herrington, 1962, p. 45). This species occurred throughout these zones. Other mollusks and ostracods found in unit 2 and in the lower part of unit 3 included: Lymnaea cf. L. stagnalis, which was often found in quiet, stagnant, permanent bodies of water (La Rocque, 1968, p. 435); Pisidium ventricosum, which was indicative of lakes and large rivers (Herrington, 1962, p. 47); Valvata sincera, which was characteristic of permanent lakes and open, deep water (La Rocque, 1968, p. 364); Candona candida, which was often found in shallow ponds and lakes (Delorme, 1970c, p. 1103); Candona rawsoni, which often occurred in permanent lakes (Delorme, 1970c, p. 1116); Cypridopsis vidua, which was common throughout the interior plains of Canada (Delorme, 1970b, p. 255); Ilyocypris bradyi, which was indicative of permanent lakes and rivers (Delorme, 1970d, p. 1258).

Ostracod fossils were present in unit 4. Their presence, and the absence of mollusks, suggested that this unit may have been deposited in a terrestrial or marginal lacustrine environment containing small, temporary pools of water suitable for habitation by ostracods and not mollusks.

The low diversity in the number of species and the age of the sediments suggested that the mollusks and ostracods from the Norwood

Site may represent a pioneer group, the first species to inhabit the study area after the Grantsburg glaciation.

Depositional environments

Of the various Late Quaternary slough and lake sites described from Minnesota, North Dakota, and South Dakota, the Seibold Site (Bickley, 1970) and McClusky Canal Site (Okland, 1978) in North Dakota were perhaps most similar to the present study area in the type of exposure and methods of investigation. Most other studies used samples obtained with pollen coring apparatus, and few present more than a general description of the sediments. Interpretations of the depositional environments present at the Norwood Site during Late Quaternary time followed the interpretations made by Bickley (1970) and Okland (1978).

The lack of sediment sorting (Fig. 3) and fossil shell material (Fig. 4 and 5), and the abundance of pebbles (Appendix A) suggested that unit 1 may be till. This unit may have been deposited by active ice or perhaps by slumping or flowing from adjacent slopes into the lake. Such slumping and flowage of till was common on top of the stagnant ice of the Missouri Coteau in North Dakota (Clayton, 1967, p. 26). The presence of beetle fragments in this unit (Ashworth, 1979) suggested that this unit was probably not deposited by active ice.

Better sediment sorting (Fig. 3) and the presence of mollusk and ostracod shells (Fig. 4 and 5), which implied the presence of water at the Norwood Site, suggested that the lower portion of unit 2 was deposited in a lacustrine environment. Bickley and Clayton (1972) interpreted poorly fossiliferous, silty units from the Seibold Site in

North Dakota to be slopewash from hillsides surrounding the lake. This interpretation explained the low degree of sorting of the sediments (Appendix A) and the relatively few fossils found in the lower portion of this unit.

An increase in the amount of fine sediment (Fig. 3) and in the number of mollusk and ostracod shells in the upper portion of unit 2 and the lower portion of unit 3 (Fig. 4 and 5) suggested that the amount of slopewash from hillslopes surrounding the lake may have diminished or that the sampled site may have been farther from the lake margin. The presence of *Candona candida*, an ostracod, and the occurrence of *Gyraulus parvus* and *Pisidium nitidum*, the dominant members of the mollusk assemblage, suggested that these strata were deposited in shallow, protected bodies of water containing some aquatic vegetation. The occurrence of *Valvata sincera* and *Candona rawsoni*, which were indicative of permanent lakes, suggested that the Norwood Site may have been located at the edge of a permanent lake. Shells of these species may have been transported to the study site after the organisms' death, as suggested by the relatively low number of individuals. The molluscan and ostracod assemblages suggested that the upper part of unit 2 and the lower part of unit 3 were deposited in shallow water in the quiet, vegetated edge of a permanent lake.

An increase in the degree of sediment sorting (Appendix A) and in the amount of sand present (Fig. 3), and a decrease in the number of mollusk and ostracod shells in the upper 20 cm of unit 3 (Fig. 4 and 5) suggested either a lowering of the water level and the approach of a shoreline or, perhaps, the lateral shift of a spit or delta into the study site.

An increase in the amount of combustible carbon, which resulted from the presence of abundant plant remains, a decrease in the amount of reactive carbonate (Fig. 3), and the absence of mollusks (Fig. 4), suggested that unit 4 was deposited in a terrestrial or marginal lacustrine environment. The presence of ostracods suggested that some standing water may have been present.

Changes in the depositional environments from glacial or mass wasting to lacustrine and eventually to terrestrial or marginal lacustrine suggested an increase in the stability of the climate.

Post-glacial history

Approximately 14,000 years ago, the Grantsburg Sublobe was present in central Minnesota (Clayton, 1979). Prior to 12,400±60 radiocarbon years, a lake developed at the Norwood Site. How this lake formed is not known. It may have formed on top of the melting ice sheet or in a natural depression filled by runoff or melt water. Tundra and a later spruce forest were present in the area. This lake was in existence during the time of tundra pollen deposition at the Madelia Site (Jelgersma, 1962) and spruce forest pollen deposition at Kirchner Marsh (Winter, 1962). The lake contained a sparse fauna of gastropods, sphaeriid bivalves, ostracods, and aquatic plants. Mollusk and ostracod evidence suggested that this lake was replaced by a terrestrial or marginal lacustrine environment at about 12,400±60 radiocarbon years B.P.

Regional correlation

Most Late Quaternary slough or lake sequences in Minnesota are younger than those at the Norwood Site. Sediments from only two sites could be correlated with the sediments from the Norwood Site. Pollen analyses of the Madelia Site in south-central Minnesota (Jelgersma, 1962) suggested a transition from park tundra to spruce forest at approximately 12,600 years ago. This correlated with the change from tundra to spruce forest at the Norwood Site prior to 12,400±60 radiocarbon years B.P. (Wright, 1979). The spruce zone deposited before 11,500 years B.P. in Kirchner Marsh (Winter, 1962) was approximately the same age or younger than the spruce zone at the Norwood Site.

CONCLUSIONS

Stratigraphic units recognized at the Norwood Site were, in ascending order: (1) sandy claystone, (2) clayey siltstone, (3) sandy siltstone, and (4) laminated peat. Unit 1 was interpreted to be till or sediment that slumped or flowed into the lake. Unit 2 and the lower part of unit 3 were interpreted to be lacustrine sediments. The upper part of unit 3 was interpreted to be a shoreline deposit. Unit 4 was interpreted to be a terrestrial or marginal lacustrine deposit. Total thickness of the section was 1.7 m.

A radiocarbon date on wood from the boundary of units 3 and 4, indicated that units 1, 2, and 3 were deposited prior to $12,400 \pm 60$ radiocarbon years B.P.

The biota at the site included 2 species of sphaeriid bivalves, 3 species of gastropods, and 6 species of ostracods. The low diversity in the number of species and the age of the sediments, suggested that these species may represent a pioneer group, the first species to inhabit the study area after the Grantsburg glaciation. Fossil abundance and diversity were greatest in the upper part of unit 2 and in the lower part of unit 3. The fossil assemblage of these units indicated a permanent lake with vegetation. The absence of mollusk and ostracod fossils and better sediment sorting in the upper part of unit 3 indicated a shoreline environment. Abundant plant remains and the lack of mollusk fossils in unit 4 suggested a terrestrial or marginal lacustrine environment. The presence of ostracods in unit 4 suggested that small temporary pools of water suitable for habitation by ostracods and not mollusks may have been present. Pollen analysis indicated that the lake was surrounded by tundra and, later, a spruce forest sometime prior to 12,400$\pm$60 radiocarbon years B.P.

Changes in the depositional environments from glacial or mass wasting to lacustrine, from lacustrine to terrestrial or marginal lacustrine, and a transition from a tundra to a spruce forest flora, suggested a general warming in the area and an increase in the stability of the climate.

SYSTEMATIC PALEONTOLOGY

Molluscan classification in this paper followed La Rocque (1968), except for the pill clams, which were based on Clarke (1973) and Herrington (1962). Synonymies for the gastropods were available in Clarke (1973) and La Rocque (1968); and for the pill clams in Clarke (1973), La Rocque (1967), and Herrington (1962). Ostracod classification in this paper followed Delorme (1970a-d, 1971a).

The sample designated UND Acc. A2423.01 was collected at a depth of 4.3 m. Subsequent samples were collected at 10-cm intervals to a depth of 3.2 m.

Phylum Arthropoda

Class Crustacea

Subclass Ostracoda

Order Podocopida

Suborder Podocopina

Superfamily Cypridacea

Family Candonidae

Genus *Candona*

Diagnosis.--Shell compressed to only moderately inflated venter concave valves subequal to equal, valve surface smooth to faintly punctate, inner lamella broadest anteriorly, outer margin semicircular to inclined and inflated (Delorme, 1970c, p. 1099).

Candona sp. 1

Plate II, Figures 3, 6

Material.--265 specimens, UND Acc. A2423.01, A2423.03-A2423.11.

Hypotype.--UND Cat. No. 14293.

Remarks.--This group contained individuals that were identifiable to genus but not species.

Candona sp. 2

Plate II, Figures 9, 12

Material.--86 specimens, UND Acc. A2423.01, A2423.03, A2423.04, A2423.06-A2423.11.

Hypotype.--UND Cat. No. 14294.

Remarks.--This group contained individuals other than *Candona* sp. 1 that were identifiable to genus but not species.

Candona candida (Müller)

Plate II, Figures 4, 5

> *Diagnosis*.--Shell reniform in side view; both extremities acutely pointed, posterior blunter, sides convex in dorsal view, greatest width posterior of center. Dorsum evenly arched; venter moderately concave; anterior margin broadly and evenly rounded; posterior margin acutely rounded, postero-dorsum convex; very little difference in basic shape between female and male. Duplicature narrow; inner lamella broad anteriorly (0.13 mm wide), narrower ventrally and postero-ventrally (0.07 mm and 0.09 mm wide); inner margin semi-circular in outline anteriorly, acutely rounded posteriorly; vestibule large anteriorly, poorly developed posteriorly. Shell surface smooth (Delorme, 1970c, p. 1103).

Material.--9 specimens, UND Acc. A2423.03, A2423.06, A2423.07, A2423.10.

Hypotype.--UND Cat. No. 14295.

Geographic range.--Delorme, (1970c, p. 1103) stated that *Candona candida* occurred throughout the Canadian Prairies.

Remarks.--Delorme, (1970c, p. 1103) stated that this species was often found in shallow ponds and lakes.

Candona rawsoni Tressler

Plate II, Figures 10, 11

> *Diagnosis*.--Shell reniform in side view; anterior extremity acutely pointed, posterior blunt especially in female, side convex, greatest width posterior of center. Dorsum arched; venter concave, anteroventral notch in male; anterior margin evenly rounded; posterior truncated, left valve of female meets venter at obtuse angle with marked posterodorsal flange extended posteriorly and more evenly rounded on right valve, male posterior more evenly rounded. Shell surface smooth. Duplicature very narrow; anterior inner lamella broad (0.13 mm wide), 0.06 mm wide ventrally, 0.10 mm wide posteriorly and steeply inclined towards adductor scars; inner margin semicircular in outline anteriorly and posteriorly; vestibules very well developed anteriorly, reduced posteriorly (Delorme, 1970c, p. 1115).

Material.--29 specimens, UND Acc. A2423.01, A2423.03, A2423.04, A2423.06–A2423.09.

Hypotype.--UND Cat. No. 14296.

Geographic range.--Delorme (1970c, p. 1116) reported this species present throughout the Canadian Prairies.

Remarks.--Delorme (1970c, p. 1116) stated that *Candona rawsoni* commonly occurred in both temporary and permanent water bodies.

Family Cyprididae

Subfamily Cypridopsinae

Genus *Cypridopsis* Brady

> *Diagnosis*.--Shell inflated, venter concave, valves subequal with posterior outer lamella near free margin sometimes with small inconspicuous dentioles, inner lamella normally inclined and concentrically striated (Delorme, 1970b, p. 253).

Cypridopsis vidua (Müller)

Plate II, Figures 7, 8

Diagnosis.--Shell subtriangular to subovate in side view; anterior acutely pointed, posterior bluntly rounded, sides moderately inflated greatest width anterior of center in dorsal view. Dorsum obtusely rounded meeting anterior and posterior without break in curvature, highest point slightly anterior of center; venter concave anterior and posterior evenly and broadly rounded. Shell surface pitted at terminations of normal pore canals. Duplicature narrow (0.02 mm wide); anterior inner lamella inclined (0.15 mm wide) and concentrically striated, posterior inner lamella 0.08 mm wide, ventral inner lamella duplicature (0.08 mm wide) with conspicuous radial pore canals; anterior inner margin semicircular in outline; anterior vestibule well developed (Delorme, 1970b, p. 255).

Material.--55 specimens, UND Acc. A2423.06-A2423.11.

Hypotype.--UND Cat. No. 14297.

Geographic range.--Delorme (1970b, p. 255) stated that Cypridopsis vidua was the most common Canadian ostracod, occurring throughout the interior plains of Canada.

Family Ilyocyprididae

Subfamily Ilyocypridinae

Genus Ilyocypris Brady and Norman

Diagnosis.--Carapace normally compressed, dorsum straight, venter concave, valve surface usually pitted or reticulate, bisulcate, with or without alae on the lateral surface (Delorme, 1970c, p. 1251).

Ilyocypris bradyi Sars

Plate II, Figures 1, 2

Diagnosis.--Shell subquadrate in side view; anterior extremity acutely pointed, posterior rounded, sides nearly parallel, greatest width posterior of center in dorsal view. Dorsum straight to slightly convex with hump above sulci, venter slightly concave, anterior and posterior margins broadly rounded, greatest height anterior of center. Surface valves pitted, alae absent, pustules on anterior and posterior margins, bisulcate with anterior sulcus longer, three deep pits located ventrally of sulci marking positions of muscle attachment. Duplicature narrow, inner lamella 0.1 mm wide, venter and posterior narrower (0.07 mm wide), anterior vestibule weakly developed (Delorme, 1970a, p. 1252).

Material.--4 specimens, UND Acc. A2423.01-2423.03.

Hypotype.--UND Cat. No. 14298.

Geographic range.--Delorme (1970c, p. 1252) stated that I. bradyi occurs throughout the Canadian Prairies.

Remarks.--Ilyocypris bradyi was most commonly found in permanent and intermittent streams (Delorme, 1970c, p. 1252).

Phylum Mollusca

Class Pelecypoda

Order Eulamellibranchia

Superfamily Sphaeriacea

Family Sphaeriidae

Genus Pisidium Pfeiffer

Diagnosis.--Shells very small (2mm) to medium-sized (12 mm), ovate but asymmetrical in most species (with anterior produced and posterior abruptly rounded), slightly inflated to globose, and with umbones located posterio-dorsally (Clarke, 1973, p. 163).

Pisidium nitidum Jenyns

Plate I, Figures 7, 8

Diagnosis.--Shell moderately small, walls thin, rhomboid, of small diameter; beaks subcentral, broad, not very prominent; periostracum glossy; striae moderately fine, uniform and distinct (in some lots quite prominent), heavy striae around beaks not as common in North American specimens as in European; dorsal margin long, evenly curved, joins ends without angle; ventral margin more gently curved; anterior end with a rounded slope joining ventral margin low in a rounded point; posterior end vertical or undercut, joining ventral margin imperceptibly; hinge long, of moderate width and somewhat curved; laterals of moderate length, straight or flaring outward at distal end; cusps rather prominent, but inclined to be blunt on top; cusp of A distal or on distal side of centre, of PI, PII and AII rather distal; cardinals subcentral; C3 gently curved, of uniform width except at posterior end, and almost parallel with hinge-plate; C2 slightly heavier than C4; C4 straight or gently curved, about parallel with C2; space between the 2 of uniform width, straight or a little curved, and usually directed across hinge-plate at a gentle angle. The cardinals of P. nitidum are much as in P. subtruncatum but shorter (Herrington, 1962, p. 45).

Material.--327 specimens, UND Acc. A2423.01, A2423.08, A2423.10, A2423.12.

Hypotype.--UND Cat. No. 14299.

Geographic range.--Burch (1975, p. 7) reported this species present in most parts of the continental United States, except Alaska, and all Canadian provinces except Nova Scotia.

Remarks.--Clarke (1973, p. 192) stated that this species was commonly found in rivers, stream, lakes and permanent ponds. Vegetation was usually present and the bottoms were most often mud. Herrington (1962, p. 46) stated that this species prefers shallow water.

Pisidium ventricosum Prime

Plate I, Figures 9, 10

Diagnosis.--Shell very small, walls thin, more or less oval in outline, well inflated; striae moderate to very fine, evenly spaced; periostracum glossy; beaks rather prominent and well posterior; dorsal margin short and well rounded; ventral margin long and more openly rounded; posterior end well rounded and vertical; anterior end descending rather low, round, shell without an angle; hinge very short, far back but almost parallel with ventral margin; hinge-plate narrow; laterals short; cusps short and high with near-vertical ends; cusps of AII proximal, of PII and AI central or on distal side of centre; cardinals close to anterior cusps; C3 curved, but not much enlarged at posterior end . . . ; C2 and C4 short; C2 almost parallel with hinge-plate, straight, sometimes slightly curved, or just a peg; C4 straight or slightly curved, sometimes parallel with hinge-plate, but more often directed slightly downward, then not parallel with C2; proximal end of posterior sulcus of right valve closed by a pseudocallus on inner side of proximal end of PIII and, therefore, does not run out on top of hinge-plate (Herrington, 1962, p. 47).

Material.--19 specimens, UND Acc. A2423.06-A2423.08, A2423.10

Hypotype.--UND Cat. No. 14300.

Geographic range.--Burch (1975, p. 8) reported this species present from northern Canada to the northern United States from Maine to Washington, south in the Rocky Mountains to Mexico.

Remarks.--Herrington (1962, pp. 46-47) and La Rocque (1967, p. 349) treated *P. ventricosum* as a form of the European species *P. obtusale*. Clarke (1973, p. 203) reported this species present in lakes, permanent ponds, rivers, and streams. Vegetation was present in variable amounts and bottoms were most often mud.

Class Gastropoda

Subclass Prosobranchia

Order Mesogastropoda

Superfamily Valvatacea

Family Valvatidae

Genus *Valvata* Müller

Diagnosis.--Shell small, spiral, dextral, turbinate, or subdiscoidal; whorls rounded or carinated; aperture entire, circular; lip simple, sharp; operculum orbicular, multispiral, whorls with a thin elevated edge (La Rocque, 1968, p. 358).

Valvata sincera Say

Plate I, Figures 3, 6

Diagnosis.--Shell nearly as high as it is wide, without any carinae, usually black when found in nature; whorls 4, covered with fine regularly spaced crowded riblets; these are crossed in early whorls by minute revolving lines; aperture round; outer lip thin; umbilicus open (La Rocque, 1968, p. 364).

Material.--13 specimens, UND Acc. A2423.08-A2423.10.

Hypotype.--UND Cat. No. 14301.

Geographic range.--La Rocque (1968, p. 64) reported this species present from Newfoundland, Quebec, and Maine west to western Ontario and Manitoba, south to southern Michigan and northern New York.

Remarks.--La Rocque (1968, p. 64) stated that Valvata sincera was characteristic of large perennial bodies of water.

Subclass Pulmonata

Order Basommatophora

Superfamily Lymnacea

Family Lymnaeidae

Genus Lymnaea Lamarck

Diagnosis.--Shell large, thin, with an acute, slender spire and expanded body whorl; axis gyrate, forming a (generally) pervious spiral coil without a true umbilicus; the callus on the body whorl closely appressed; the outer lip flaring more or less, simple, sharp, normally without any thickening (La Rocque, 1968, p. 434).

Lymnaea cf. L. stagnalis Linnaeus

Plate I, Figures 4, 5

Diagnosis.--Elongate or oval, ventricose at the anterior end, thin; periostracum yellowish horn to brownish black; surface shining, growthlines numerous, crowded, more or less elevated, crossed by numerous fine, impressed spiral lines; apex smooth, brownish horn in color; whorls 6 to 7, rapidly increasing, all but the last two rather flat sided; last whorl very large, considerably dilated and inflated, inclining to form a shoulder; spire long, pointed, acute, occupying about half the length of the entire shell; sutures distinct, in some cases impressed; aperture large, broadly ovate, dilated, particularly at the upper part; peristome thin, acute, anterior part rounded; parietal wall with a rather wide spreading callus which is closely appressed to the body and either completely closes the umbilicus or leaves a very small chink; pillar of the columella gyrate, commonly forming a more or less heavy, oblique ascending plait (La Rocque, 1968, p. 435).

Material.--7 specimens, UND Acc. A2423.06-A2423.08.

Hypotype.--UND Cat. No. 14302.

Geographic range.--La Rocque (1968, p. 299) reported this species present in North America, south to about the 40th parallel.

Remarks.--All identified individuals were immature specimens. Tuthill *et al*. (1964, p. 355) stated that this species was commonly found in shallow temporary bodies of water. Although a dominant member of modern slough populations in Minnesota, Tuthill (1969, p. 66) found it to be rare in the Wisconsinan deposits of the Missouri Coteau. Clarke (1973, p. 299) reported that this species was characteristic of all permanent water bodies that supported substantial vegetation. He did not find this species in temporary ponds.

Superfamily Planorbacea

Family Planorbidae

Subfamily Planorbinae

Genus *Gyraulus* Charpentier

Diagnosis.--Shell dextral, small, with few rapidly increasing whorls, fully exposed above and below, with a nearly median periphery, rounded or obtusely angulated, but not acutely carinated (La Rocque, 1968, p. 483).

<u>Gyraulus parvus</u> (Say)

Plate I, Figures 1, 2

<u>Diagnosis</u>.--Shell small, ultradextral, depressed, with a rounded periphery; shell color bright horn to jet black, commonly pearly; surface shining in the light colored specimens, dull in the dark examples; lines of growth oblique, crowded, fine, commonly crossed on the base by several fine spiral lines; nucleus small, rounded, sculpture of distinct spiral striae; whorls about 3½, rapidly enlarging, rounded below the periphery and somewhat flattened above on the body whorl and flattened above in all the spire whorls; spire flat, the first two whorls sunken below the body whorl; sutures very deeply impressed; base slightly concave, the body whorl flattened, umbilical region wide, shallow, exhibiting all the volutions; aperture long-ovate, very nearly in the same plane as the body whorl in most specimens but somewhat oblique in some examples; outer lip acute, thin, simple, the superior margin produces very much over the inferior margin; parietal wall with a thin wash of callus; interior of aperture yellowish white or whitish (La Rocque, 1968, p. 491).

<u>Material</u>.--39 specimens, UND Acc. A2423.07, A2423.11.

<u>Hypotype</u>.--UND Cat. No. 14303.

<u>Geographic range</u>.--Clarke (1973, p. 403) reported this species present from Alaska and northern Canada to Cuba, and Atlantic to Pacific coasts.

<u>Remarks</u>.--Clarke (1973, p. 403) reported this species present in ponds, lakes, ditches, and streams. Bottom sediments were variable but most frequently mud. It was almost always found on aquatic vegetation. La Rocque (1968, p. 491) reported that it preferred sheltered bodies of water containing vegetation.

Plate I. Mollusk fossils from the Norwood Site, Minnesota

Figure

1, 2. *Gyraulus parvus*, UND Cat. No. 14303, apical and umbilical views, 15x.

3, 6. *Valvata sincera*, UND Cat. No. 14301, apical and umbilical views, 15x.

4, 5. *Lymnaea* cf. *L. stagnalis*, UND Cat. No. 14302, lateral and apertural views, 20x.

7, 8. *Pisidium nitidum*, UND Cat. No. 14299, left valve, external and internal views, 20x.

9, 10. *Pisidium ventricosum*, UND Cat. No. 14300, left valve, external and internal views, 30x.

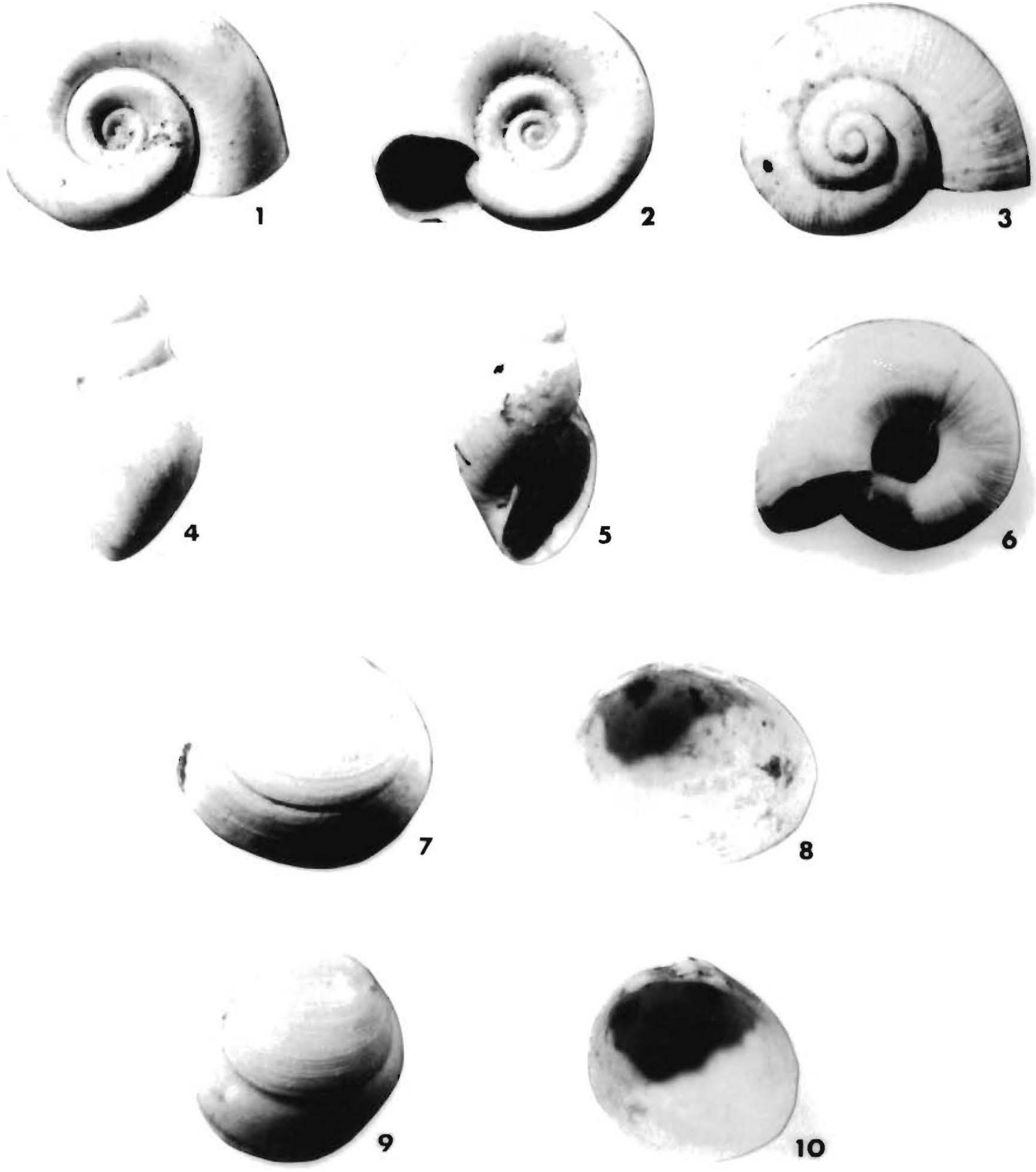
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Plate II. Ostracod fossils from the Norwood Site, Minnesota

Figure

1, 2. Ilyocypris bradyi, UND Cat. No. 14298, left valve, external and internal views, 40x.

3, 6. Candona sp. 1, UND Cat. No. 14293, right valve, internal and external views, 40x.

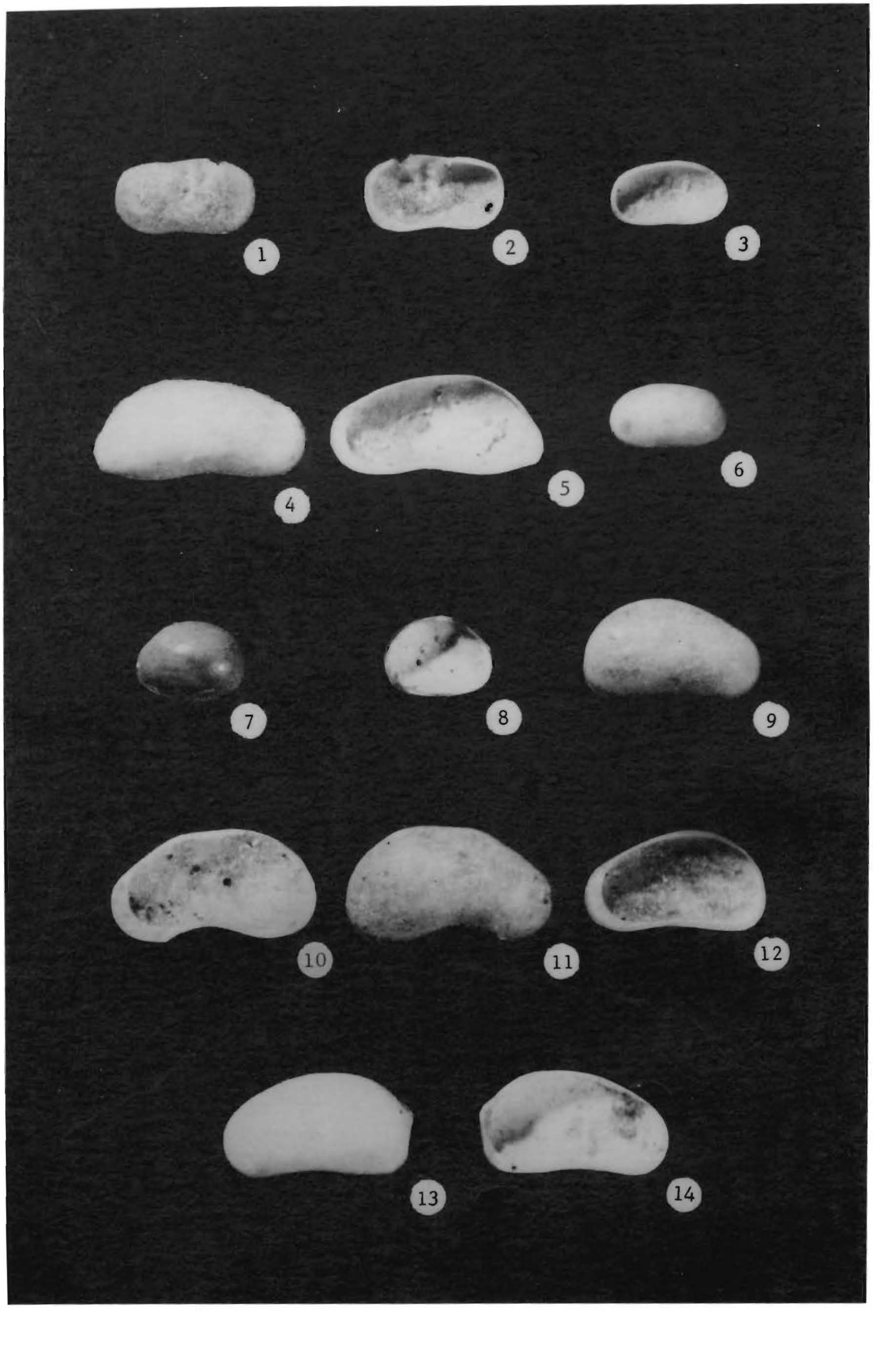
4, 5. Candona candida, UND Cat. No. 14295, right valve, external and internal views, 40x.

7, 8. Cypridopsis vidua, UND Cat. No. 14297, left valve, external and and internal views, 40x.

9, 12. Candona sp. 2, UND Cat. No. 14294, right valve, external and internal views, 40x.

10, 11. Candona rawsoni, UND Cat. No. 14296, male, right valve, external view; left valve, internal view, 40x.

13, 14. Candona rawsoni, UND Cat. No. 14296, female, left valve, external and internal views, 40x.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APPENDICES

APPENDIX A

Fig. 6. Results of grain size analysis.

Depth 4.7 meters

Unit Number 1

Lithology sandy claystone

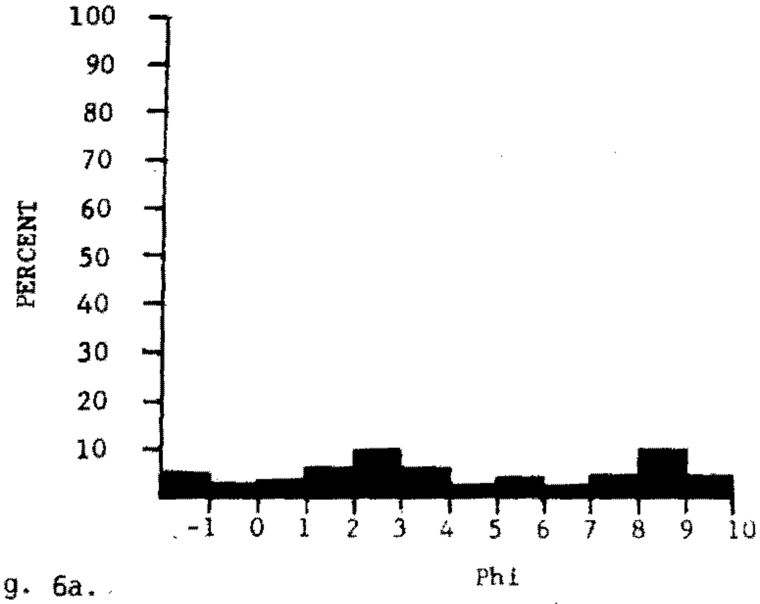

Fig. 6a. Histogram

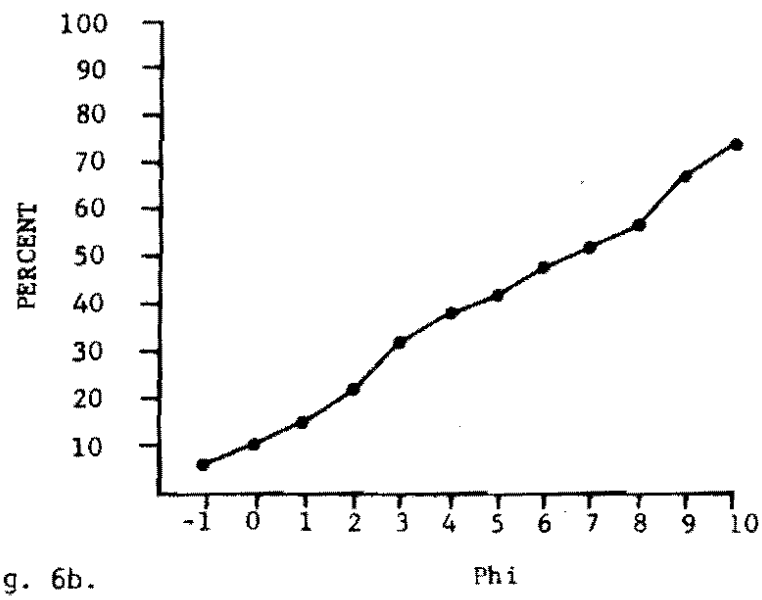

Fig. 6b. Cumulative Curve

Depth 4.6 meters

Unit Number 1

Lithology sandy claystone

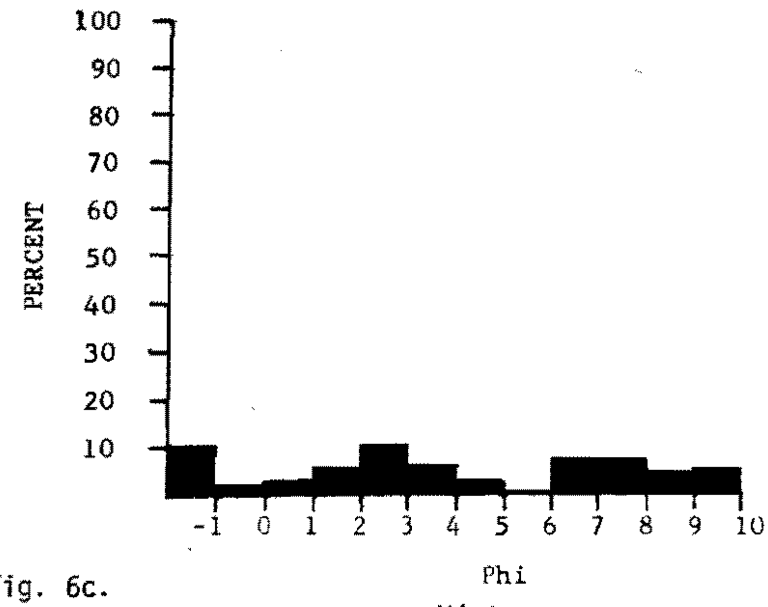

Fig. 6c. Histogram

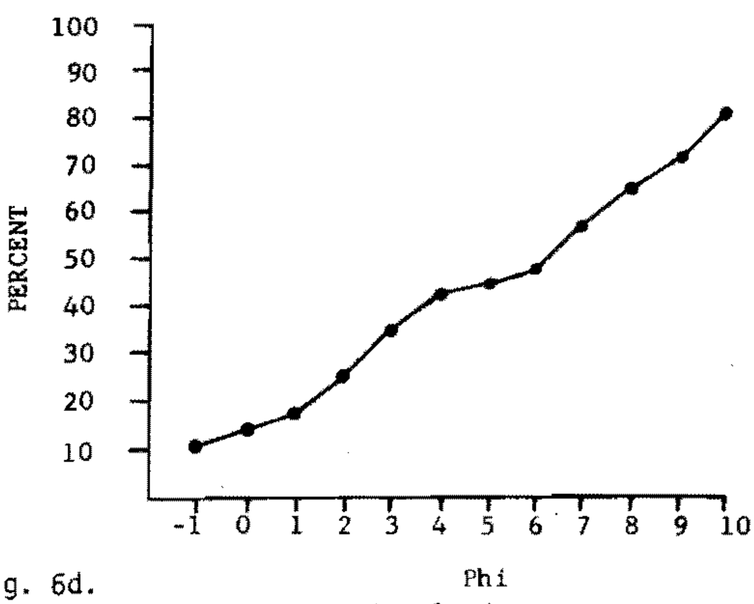

Fig. 6d. Cumulative Curve

Depth 4.5 meters

Unit Number 1

Lithology sandy claystone

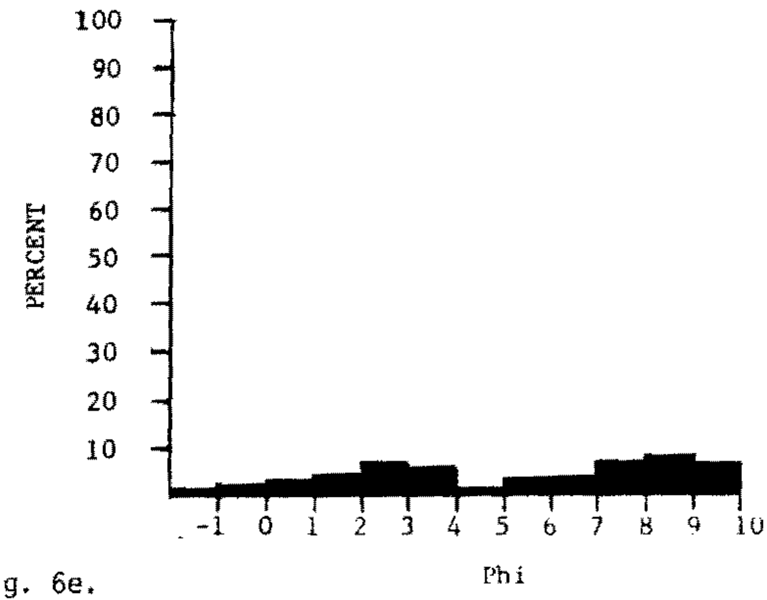

Fig. 6e. Histogram

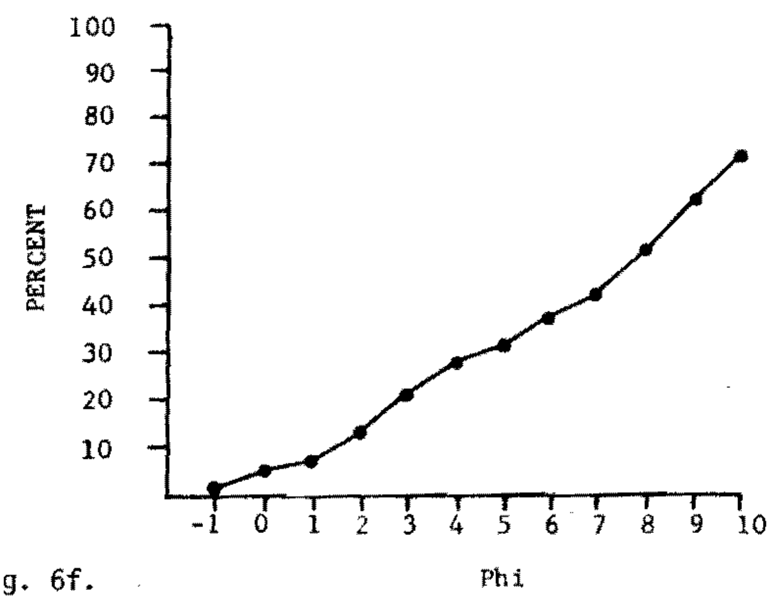

Fig. 6f. Cumulative Curve

Depth 4.4 meters

Unit Number I

Lithology sandy claystone

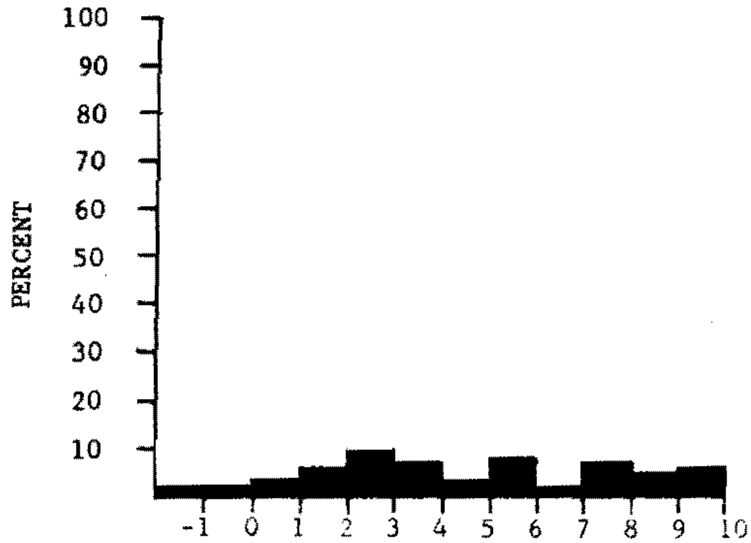

Fig. 6g. Phi

Histogram

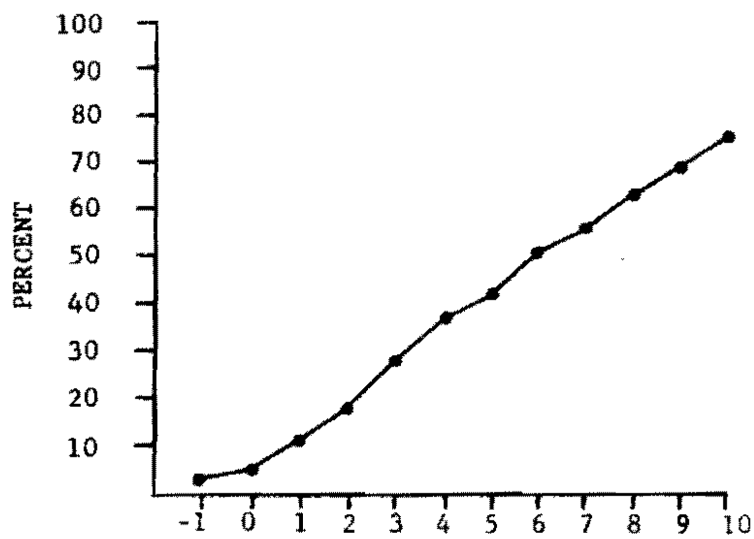

Fig. 6h. Phi

Cumulative Curve

Depth 4.3 meters

Unit Number 2

Lithology clayey siltstone

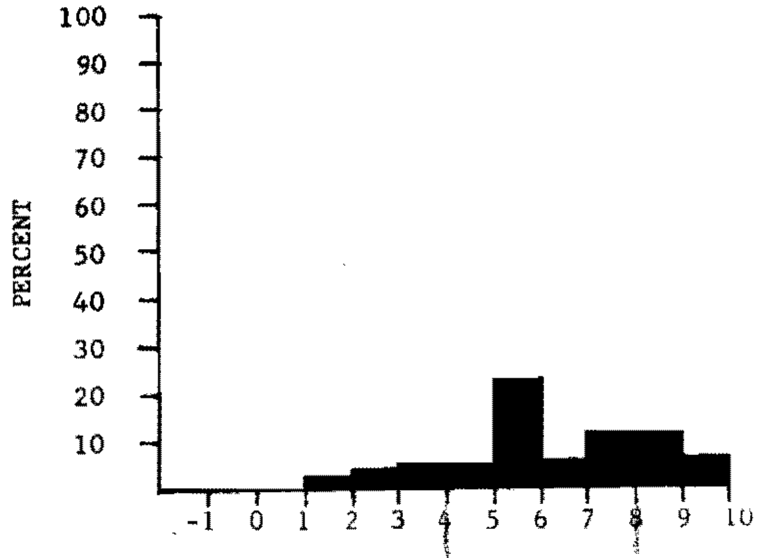

Fig. 6i. Histogram

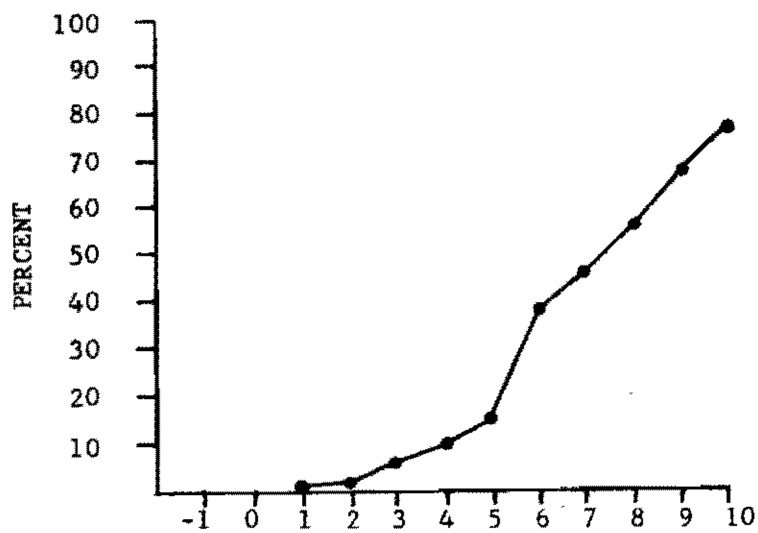

Fig. 6j. Phi

Cumulative Curve

Depth 4.2 meters

Unit Number 2

Lithology clayey siltstone

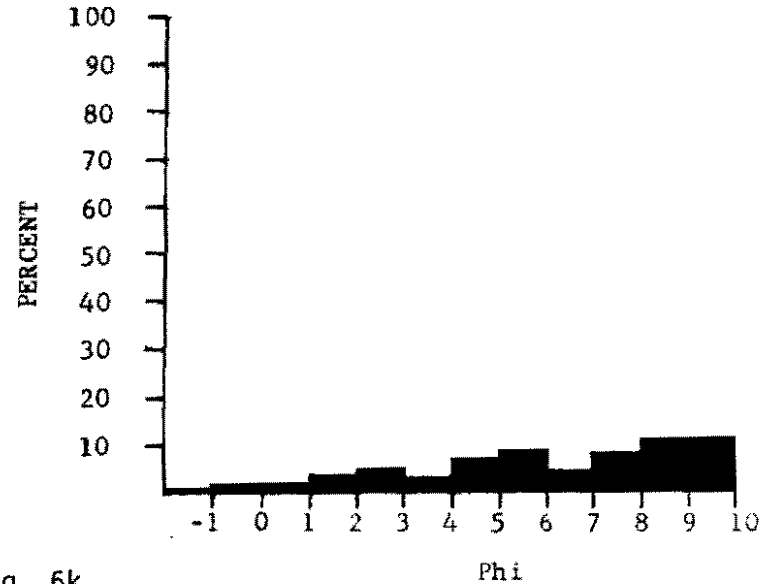

Fig. 6k. Histogram

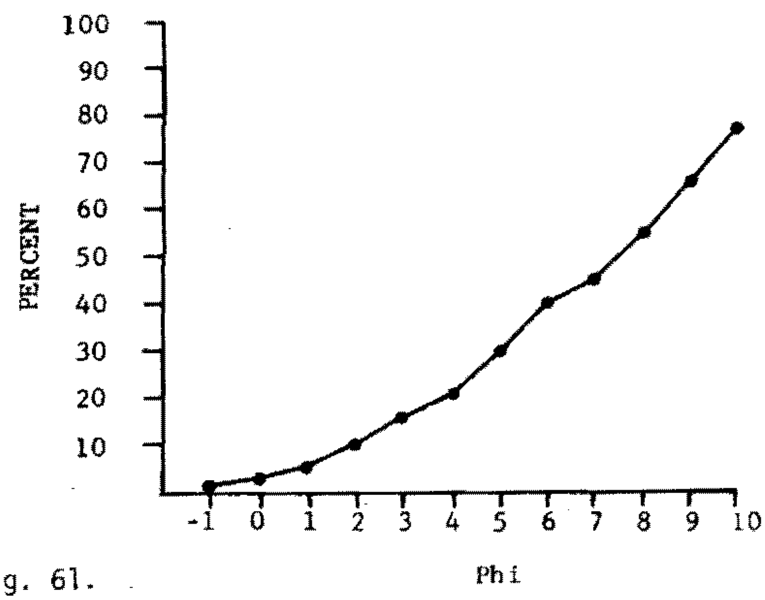

Fig. 6l. Cumulative Curve

Depth 4.1 meters

Unit Number 2

Lithology clayey siltstone

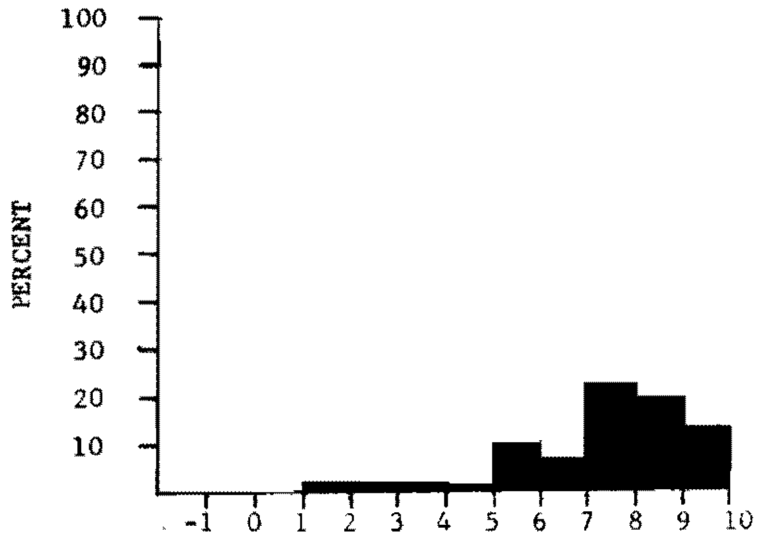

Fig. 6m. Phi
Histogram

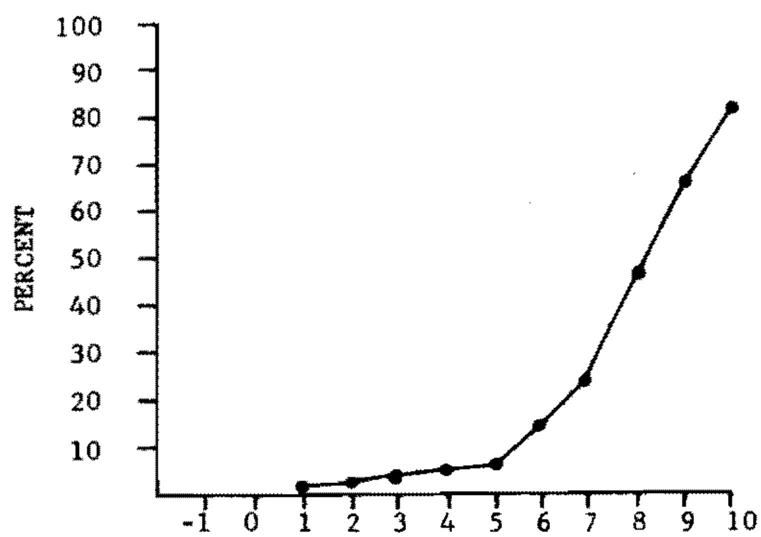

Fig. 6n. Phi
Cumulative Curve

Depth 4.0 meters

Unit Number 2

Lithology clayey siltstone

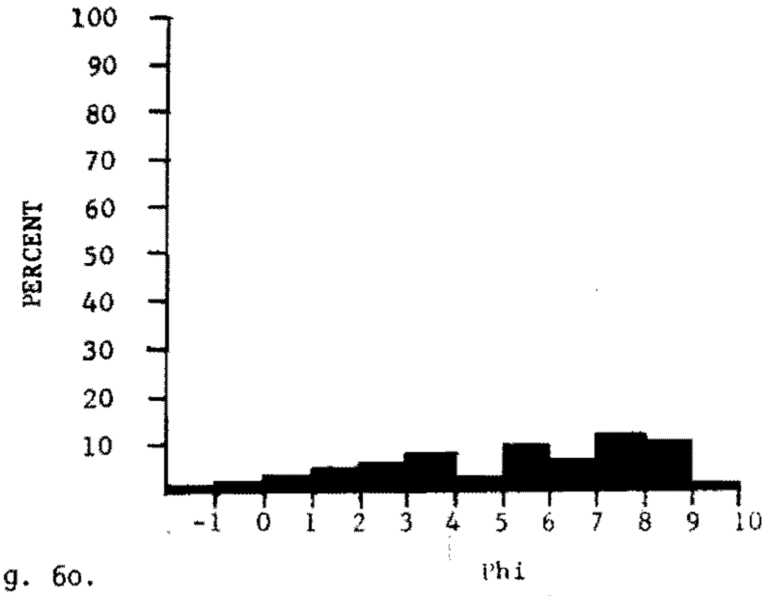

Fig. 6o. Histogram

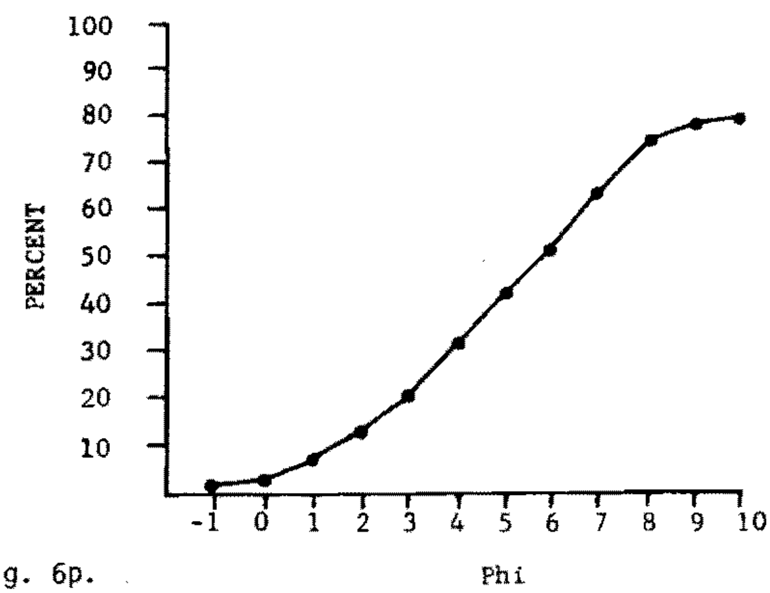

Fig. 6p. Cumulative Curve

Depth 3.9 meters

Unit Number 2

Lithology clayey siltstone

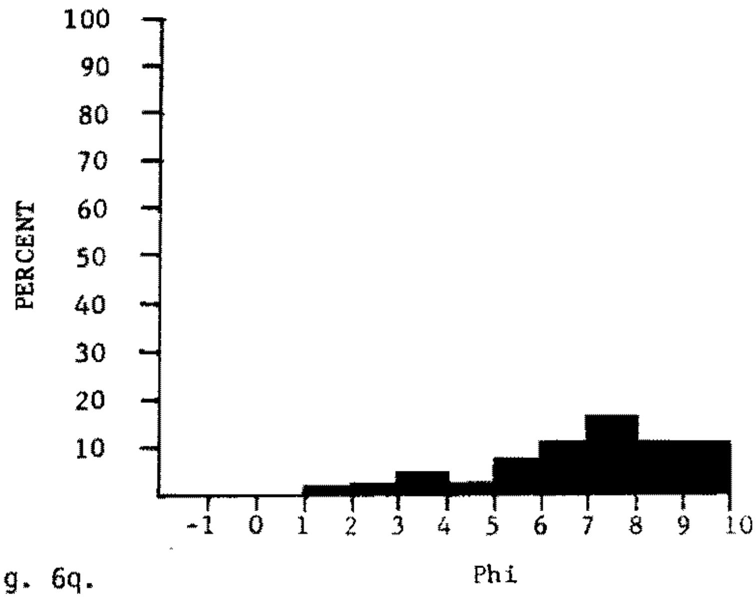

Fig. 6q. Histogram

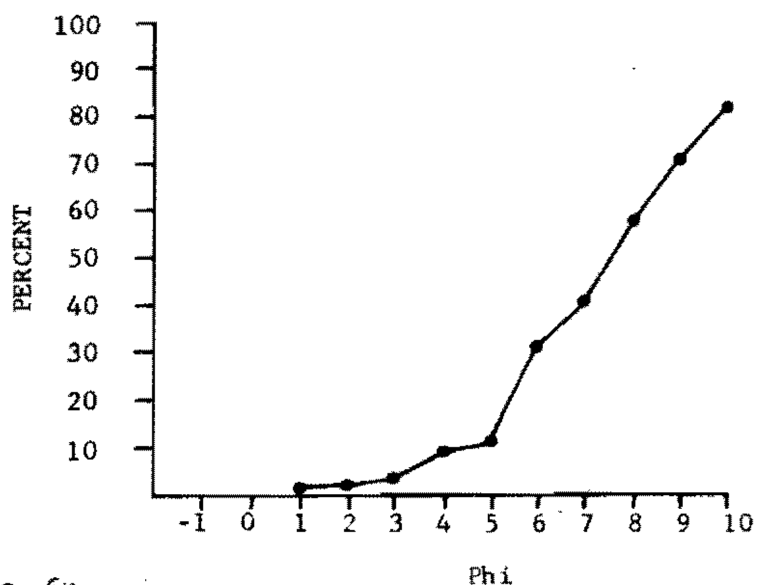

Fig. 6r. Cumulative Curve

Depth 3.8 meters

Unit Number 2

Lithology clayey siltstone

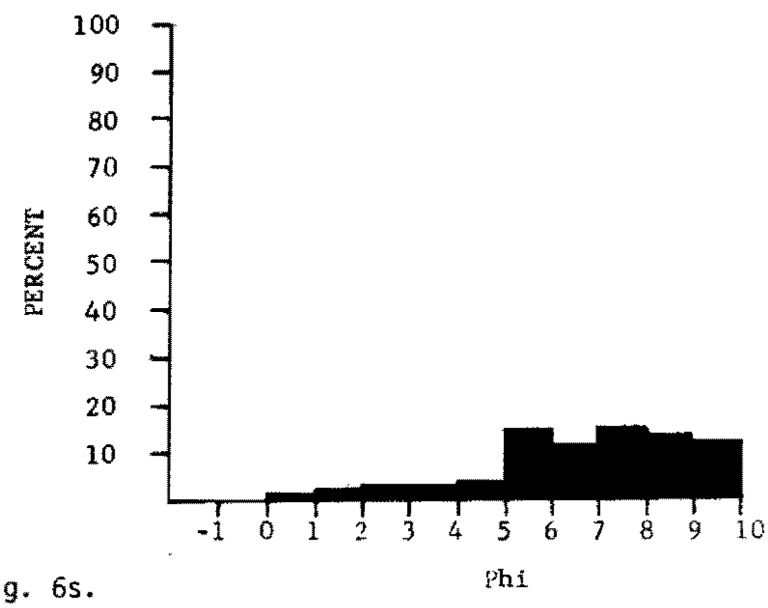

Fig. 6s.

Histogram

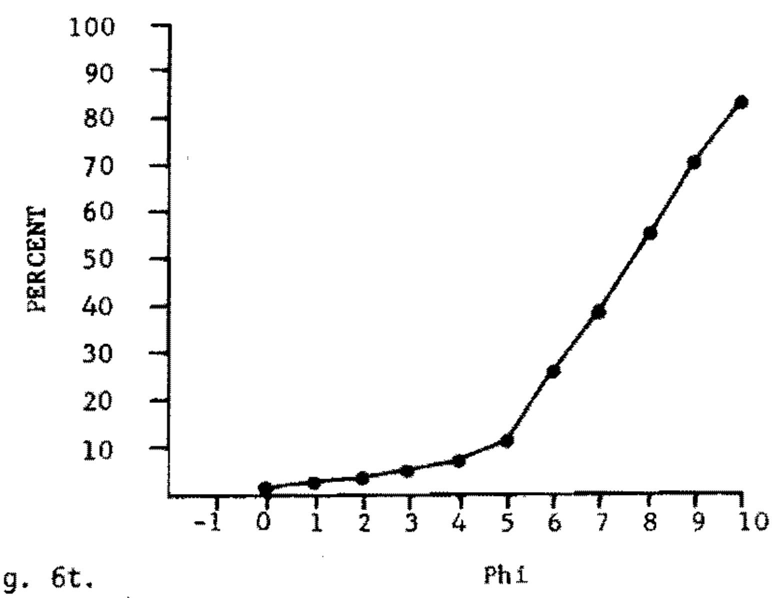

Fig. 6t.

Cumulative Curve

Depth 3.7 meters

Unit Number 2

Lithology clayey siltstone

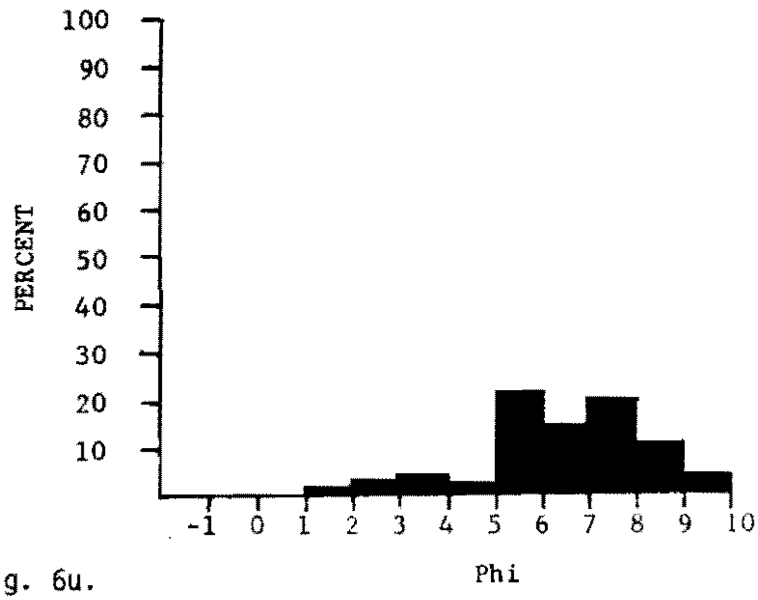

Fig. 6u.

Histogram

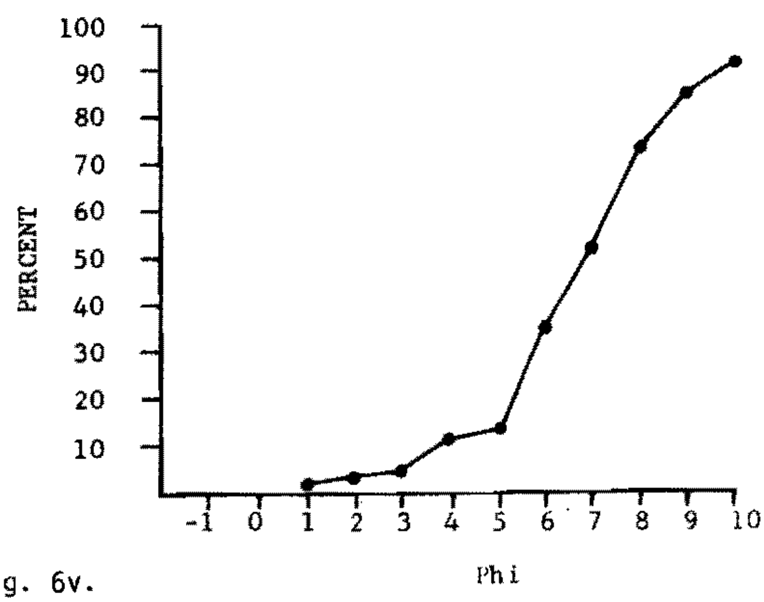

Fig. 6v.

Cumulative Curve

Depth 3.6 meters

Unit Number 2

Lithology clayey siltstone

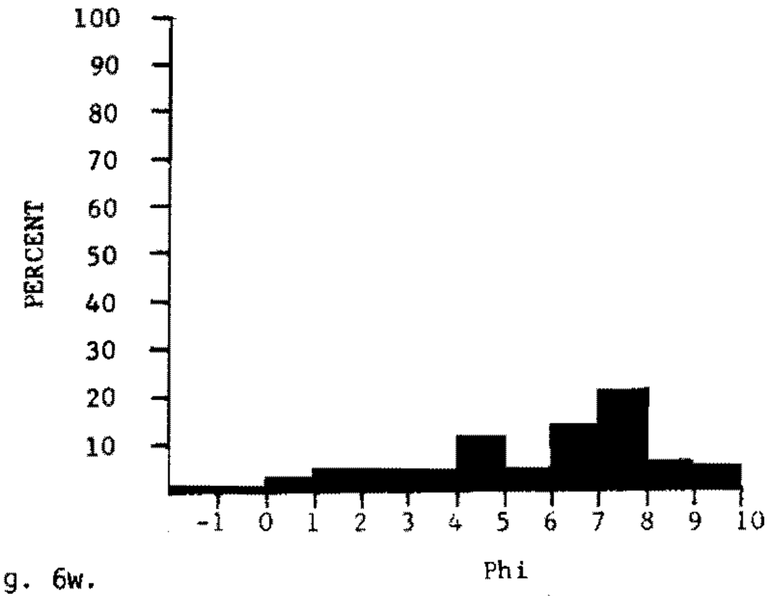

Fig. 6w.

Histogram

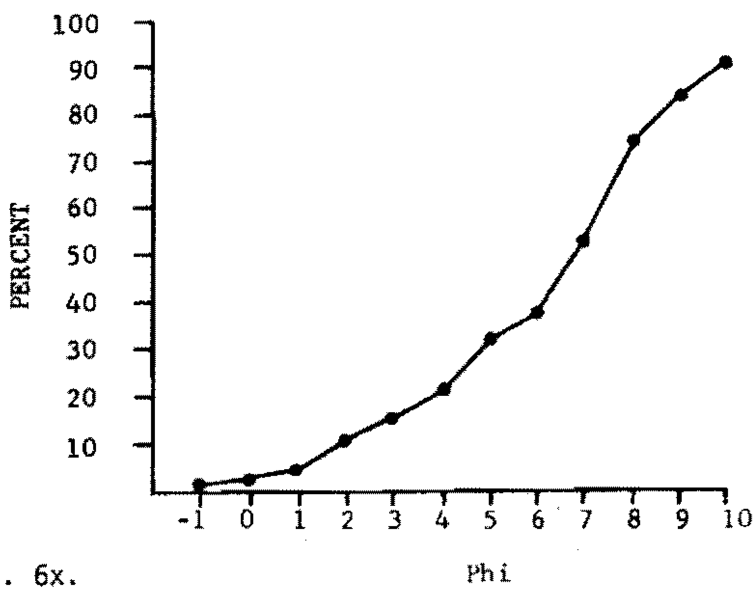

Fig. 6x.

Cumulative Curve

Depth 3.5 meters

Unit Number 3

Lithology sandy siltstone

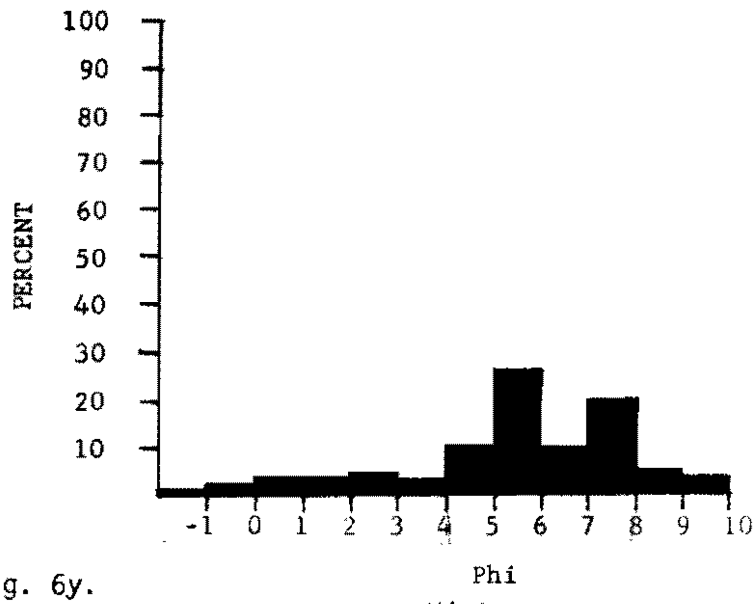

Fig. 6y. Histogram

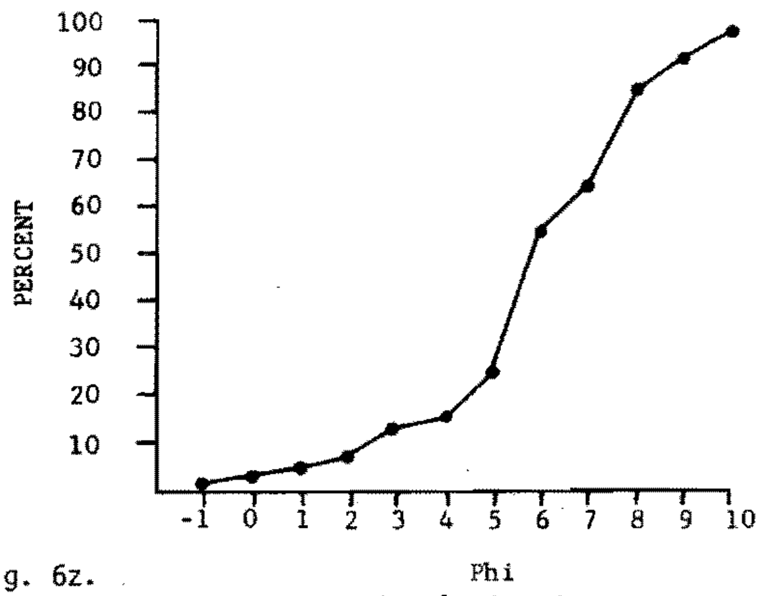

Fig. 6z. Cumulative Curve

Depth 3.4 meters

Unit Number 3

Lithology sandy siltstone

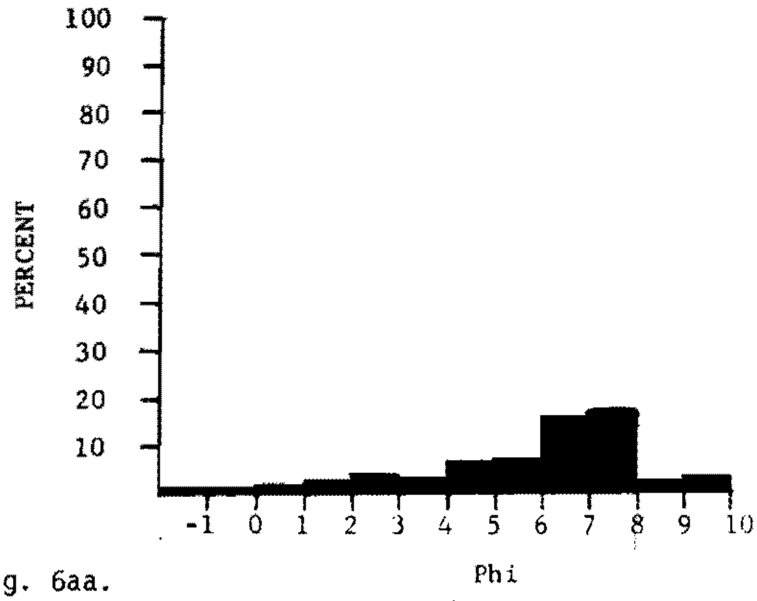

Fig. 6aa. Histogram

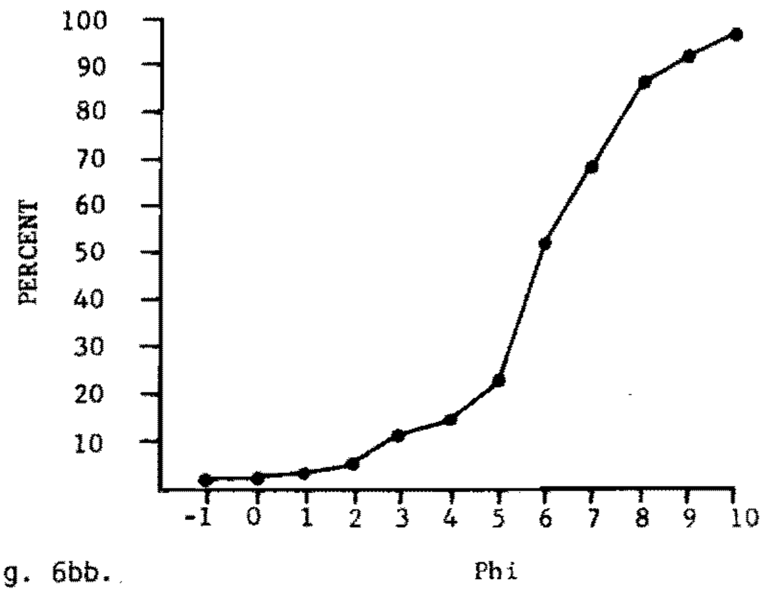

Fig. 6bb. Cumulative Curve

Depth 3.3 meters

Unit Number 3

Lithology sandy siltstone

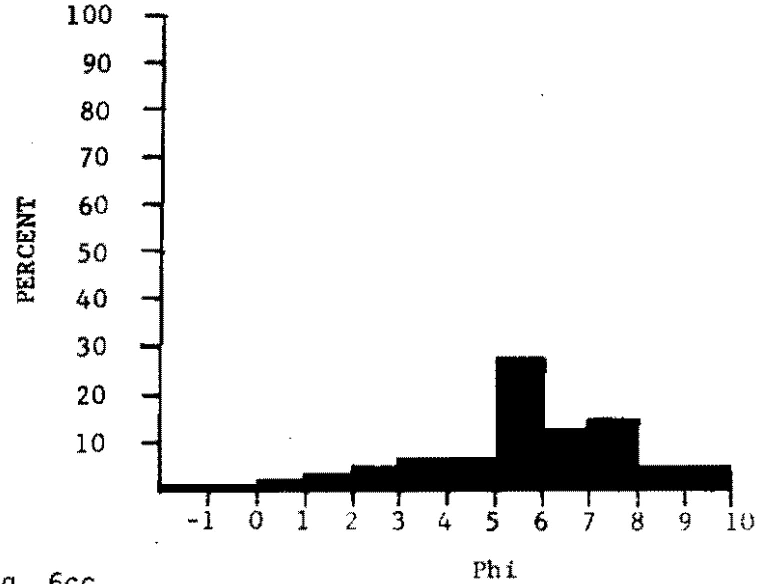

Fig. 6cc. Histogram

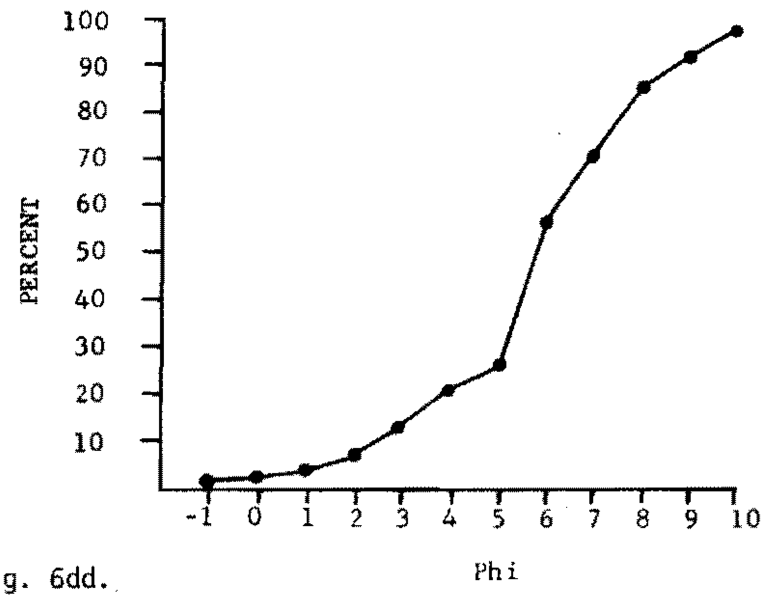

Fig. 6dd. Cumulative Curve

Depth 3.2 meters

Unit Number 3

Lithology sandy siltstone

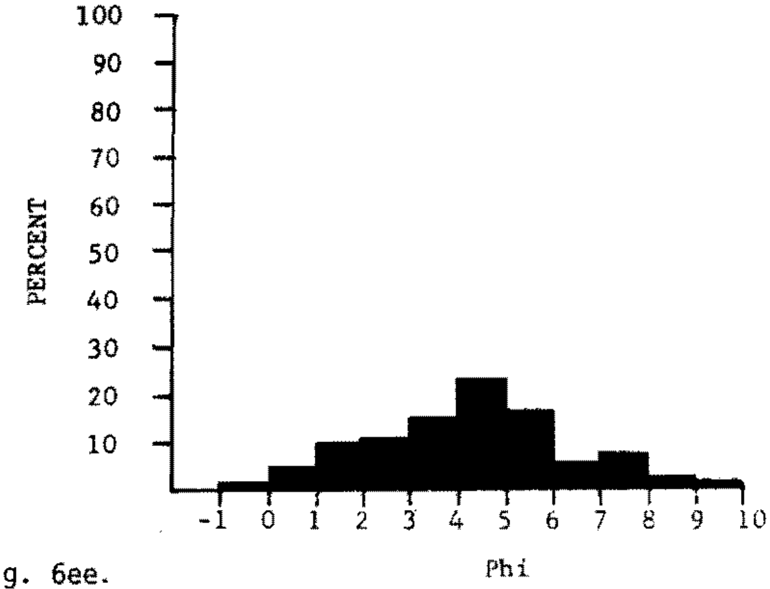

Fig. 6ee. Histogram

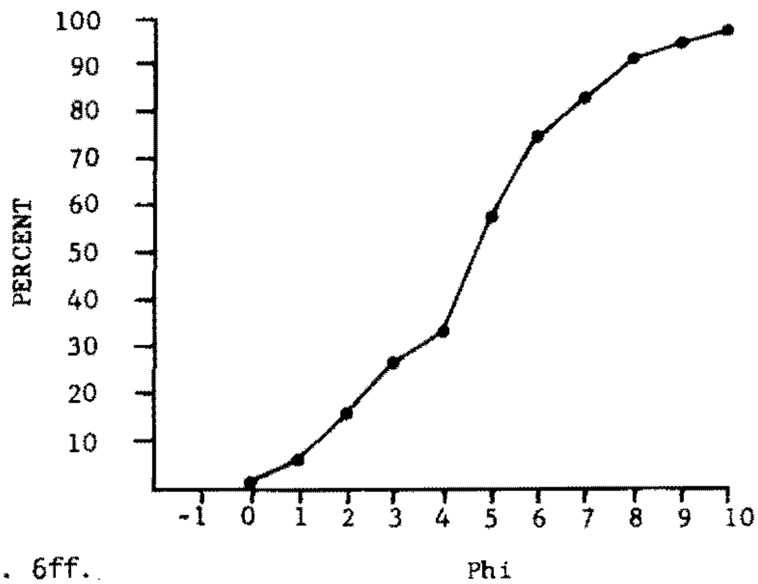

Fig. 6ff. Cumulative Curve

Depth 3.1 meters

Unit Number 3

Lithology sandy siltstone

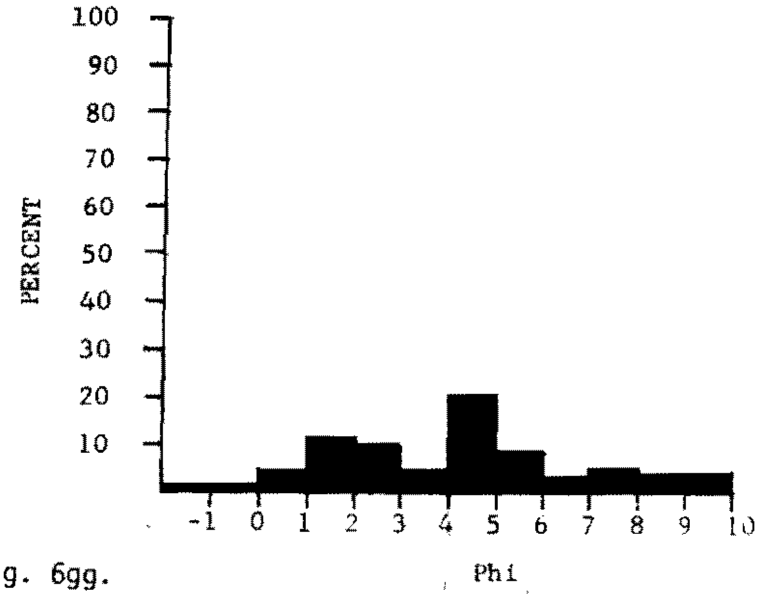

Fig. 6gg.

Histogram

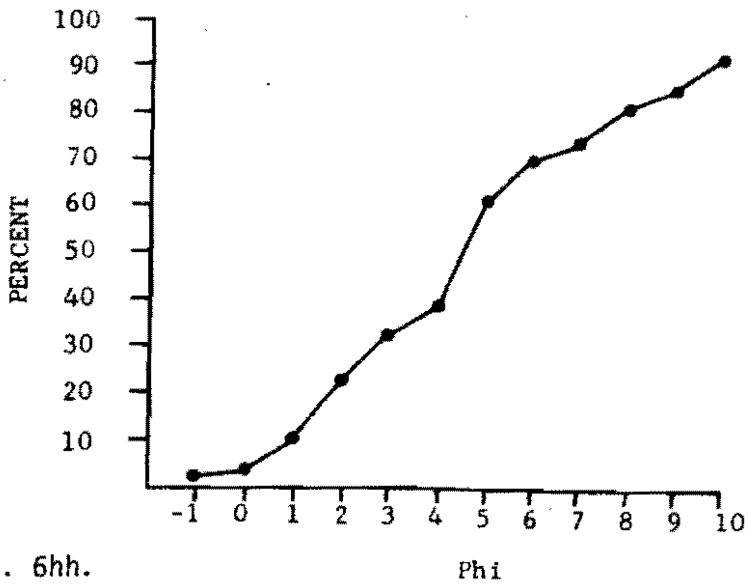

Fig. 6hh.

Cumualtive Curve

APPENDIX B

STRATIGRAPHIC OCCURRENCE OF MOLLUSK

AND OSTRACOD FOSSILS IN THE MEASURED SECTION,

NORWOOD SITE, MINNESOTA

TABLE 1

STRATIGRAPHIC OCCURRENCE OF MOLLUSK AND OSTRACOD FOSSILS IN THE MEASURED SECTION, NORWOOD SITE, MINNESOTA

Unit Number	2			
Lithology	clayey siltstone			
UND Acc. No.	A2423.01[1]	A2423.02	A2423.03	A2423.04
Taxon				
a. *Pisidium nitidum*	6	5	20	21
b. *P. ventricosum*				
c. *Valvata sincera*				
d. *Lymnaea* cf. *L. stagnalis*				
e. *Gyraulus parvus*				
f. *Candona* sp. 1	1		4	1
g. *C.* sp. 2	1		4	2
h. *C. candida*			2	
i. *C. rawsoni*	1		3	2
j. *Cypridopsis vidua*				
k. *Ilyocypris bradyi*	2	1	1	

TABLE 1--Continued

	2			
	clayey siltstone			
	A2423.05	A2423.06	A2423.07	A2423.08
a.	15[2]	38	175	29
b.		6	5	4
c.				8
d.		1	3	3
e.			31	1
f.	2	75	54	17
g.		8	29	5
h.		4	2	
i.		4	16	1
j.		3	14	6
k.				

TABLE 1--Continued

	3			
	sandy siltstone			
	A2423.09	A2423.10	A2423.11	A2423.12
a.		7		2
b.		4		
c.	1	4		
d.				
e.	4	2	1	
f.	23	12	4	
g.	24	10	3	
h.		1		
i.	2			
j.	19	1	12	
k.				

[1]Sample designated UND Acc. A2423.01 was collected at a depth of 4.3 m. Subsequent samples were taken at 10-cm intervals, up to A2423.12 at a depth of 3.2 m.

[2]Number of mollusks identified per 200 cc of sediment or number of ostracods identified per 25 cc of sediment.

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