Early Miocene Nonmarine Diatoms From the Pine Ridge Area, Sioux County, Nebraska

By GEORGE W. ANDREWS

CONTRIBUTIONS TO PALEONTOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 683-E

A description of an early Miocene nonmarine diatom assemblage from the Great Plains region and its stratigraphic and paleoecologic significance

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON:1971

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

W. A. Radlinski, *Acting Director*

Library of Congress catalog-card No. 74-611764

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents (paper cover)
Stock Number 2401-1163

CONTENTS

ILLUSTRATIONS

[Plates follow index]

TABLE

EARLY MIOCENE NONMARINE DIATOMS FROM THE PINE RIDGE AREA, SIOUX COUNTY, NEBRASKA

By George W. Andrews

ABSTRACT

The Monroe Creek Sandstone of early Miocene age contains diatomaceous sediments at two stratigraphic levels in outcrops on the Pine Ridge escarpment, Sioux County, Nebr., 2 to 10 miles southwest of Crawford. The formation is dated as early Miocene by contained vertebrate faunas in the western Nebraska area; potassium-argon dating of the underlying Gering Formation and the overlying Harrison Sandstone limits the age of the Monroe Creek to between 21.3×10^6 and 25.6×10^6 years.

The Monroe Creek Sandstone contains what is here termed the "Pine Ridge diatom assemblage," consisting of 21 species and varieties of nonmarine diatoms. Seven of these species are new, and three others were known previously only from the late Eocene of Wyoming. Ten species and varieties are still living in modern nonmarine environments. The diatom assemblage suggests that deposition occurred in a shallow lake that had seasonal fluctuations in alkalinity. The diatomaceous sediments show evidence for deposition in a shallow, widespread playalike lake during temporary interruptions in Monroe Creek clastic sedimentation. The relatively large number of extinct species in the assemblage should be helpful in stratigraphic correlation once their ranges are more precisely known. The earliest occurrence of still-living species and varieties of nonmarine diatoms is also important in determining the age of diatom assemblages. The information available suggests that nonmarine diatom species may be somewhat longer ranging than other types of fossils. Thus, extinct diatoms may be more useful for stratigraphic correlation in Miocene and older assemblages, whereas the presence or absence of still-living forms may be more useful for correlation in Pliocene and later assemblages.

INTRODUCTION

Diatomiferous sediments crop out in two distinctive "white beds" in the Monroe Creek Sandstone, which is exposed along the Pine Ridge escarpment in eastern Sioux County, Nebr. These diatomaceous beds can be observed extensively in an area 2 to 10 miles southwest of Crawford, Nebr., but they are relatively inaccessible in most places because of the steep face of the escarpment. An early Miocene age is indicated by the vertebrate fossil faunas of the Monroe Creek and associated formations in western Nebraska.

The Monroe Creek Sandstone contains the oldest Tertiary nonmarine diatom assemblage yet discovered from the Great Plains area of North America. It is intermediate in age between the late Eocene assemblage from central Wyoming described by Lohman and Andrews (1968) and the late Miocene assemblage from Kilgore, Nebr., described by Andrews (1970). The preservation of the Pine Ridge diatom assemblage, though not excellent, is adequate for a meaningful study. Its age is confirmed by the independent evidence of vertebrate paleontology. The Pine Ridge diatom assemblage from the Monroe Creek Sandstone provides valuable information for determining the stratigraphic ranges of Tertiary nonmarine diatoms, as it is the first early Miocene diatom assemblage from North America to be systematically studied.

The diatomiferous beds of the Monroe Creek Sandstone were first observed by the author in 1962. Samples for diatom study were collected during the summers of 1962 and 1966.

ACKNOWLEDGMENTS

Thanks are expressed to Kenneth E. Lohman, Division of Paleobotany, The Smithsonian Institution, and to Sergius H. Mamay, U.S. Geological Survey, for their critical review of the manuscript and their many helpful comments.

PINE RIDGE DIATOMACEOUS BEDS

LOCATION

Diatomaceous sediments of the Monroe Creek Sandstone crop out as two "white beds" in the otherwise drab strata on the Pine Ridge escarpment west of Crawford, Nebr. The location of the Pine Ridge area in western Nebraska is shown in the index map (fig. 1).

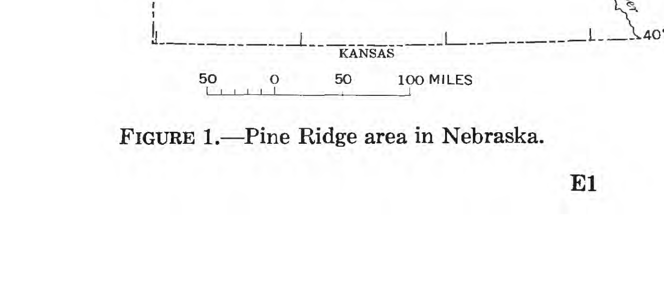


Figure 1.—Pine Ridge area in Nebraska.

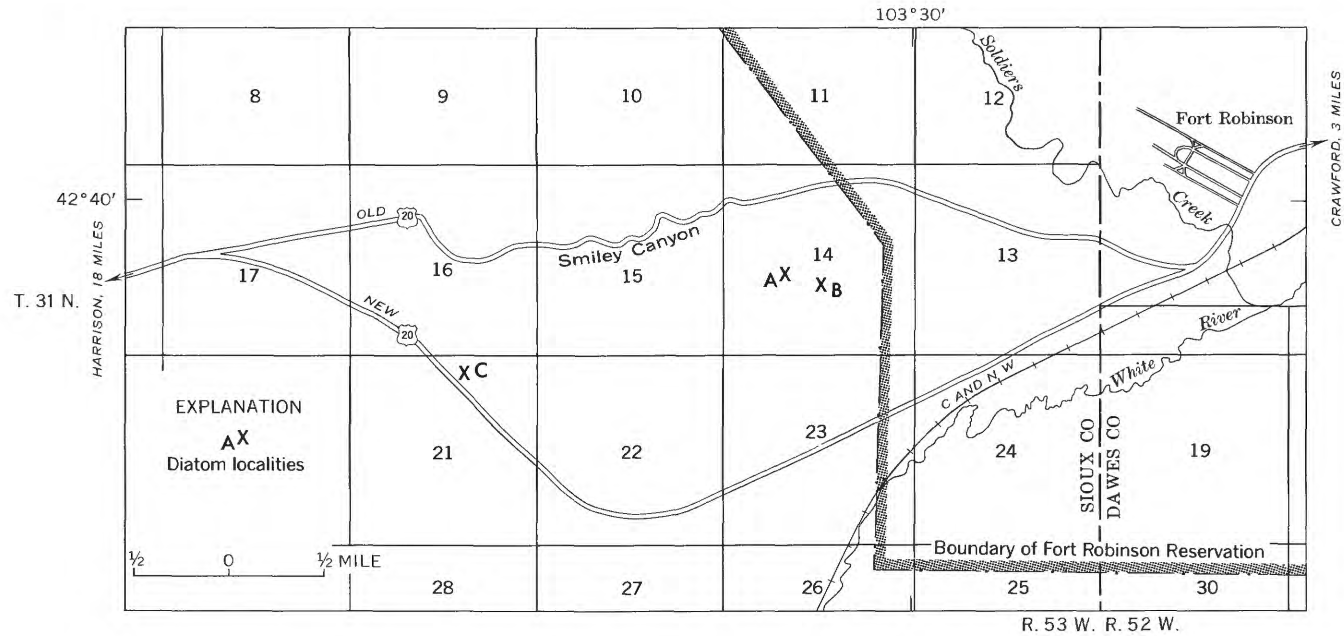


FIGURE 2.—Pine Ridge fossil diatom localities, Sioux County, Nebr.

The diatomaceous sediments were examined and collected at the three localities shown in detail in figure 2. Locality A is about one-half mile southeast of the lower end of Smiley Canyon on the northwest-facing cliff of Pine Ridge in the NW$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 14, T. 31 N. R. 53W., Sioux County. Locality B is farther to the southeast along the same ridge, on the end of the easternmost point of the high part of Pine Ridge between the Smiley Canyon and White River drainage basins in the SE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 14. Locality C is on the northeast side of a tributary valley to the White River, a short distance northeast and uphill from new (in 1967) U.S. Highway 20, downslope from a spirelike erosional remnant of Monroe Creek Sandstone, and in the NW$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 21, T. 31N., R. 53W., Sioux County.

The outcrops at localities A and B can be reached from the point where old U.S. Highway 20 enters the lower end of Smiley Canyon by following Pine Ridge in a southeasterly direction about one-half and three-quarters mile, respectively, and climbing nearly to the top of the ridge. Locality C is readily accessible by climbing a short distance from new U.S. Highway 20. The diatomiferous "white beds" crop out at an altitude of about 4,400 feet according to the Alliance, Nebr., 1:250,000 map of the Army Map Service (1958), the only topographic map available for the region.

LITHOLOGY

Locality A

The exposure at locality A is a basal 4-foot section of typical drab brownish-gray silty fine sand of the Monroe Creek Sandstone. The diatomaceous "white bed", which overlies the basal section, is a 1-foot layer of intensively bored and disturbed sediments, as illustrated in figure 3. This layer originally was deposited as a 2-inch bed of white thinly laminated crinkly limestone overlain by a 10-inch bed of white moderately soft calcareous clay. After these original sediments were bored, the borings and interstices were filled by fine

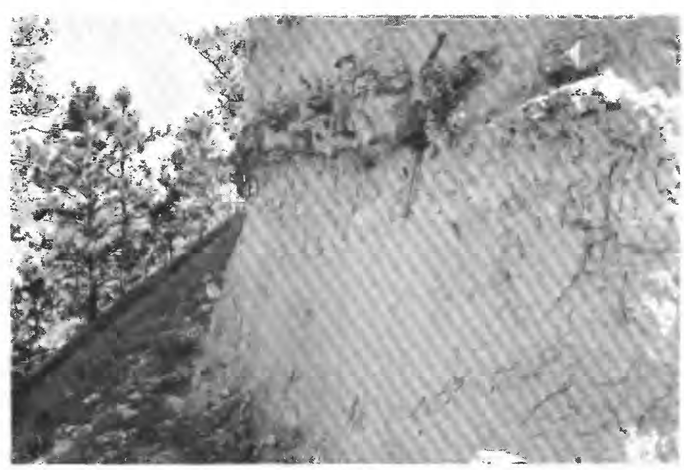


FIGURE 3.—Diatomaceous "white bed" at locality A indicated by hammer. USGS diatom localities 5972 and 5973.

sand and silt from the overlying sediments of typical Monroe Creek Sandstone lithology. Samples for diatom study were carefully selected to eliminate, as far as possible, these contaminating bore fillings. Although these fillings are not significantly younger than the enclosing matrix, they are less likely to contain diatoms than the finer grained original sediments. Both the laminated limestone (USGS diatom loc. 5972) and the softer overlying calcareous clay (USGS diatom loc. 5973) contain identifiable diatoms. A larger assemblage was obtained from the limestone, probably because of better preservation.

Locality B

The "white bed" exposed at locality B, illustrated in figure 4, is approximately 2 feet thick. This section is correlative with that exposed at locality A, but the laminated limestone is missing, and the diatomaceous sediments consist of white relatively soft silty clay. The white clay is again thoroughly bored, and the borings are filled with fine sand and silt typical of the overlying beds of the Monroe Creek Sandstone. A sample from a silty layer at the top of the "white bed" (USGS diatom loc. 5974) was unfossiliferous. Samples of carefully selected fragments of coherent white clay from the lower part of the bed (USGS diatom locs. 5510 and 5975) contained a sparse assemblage of poorly-preserved diatoms.

Locality C

At locality C two distinct "white beds" are exposed, separated by about 12 feet of drab brownish-gray silty sandstone of typical Monroe Creek Sandstone lithology, as shown in figure 5. The lower "white bed", shown in figure 6, is about 8 to 10 inches thick, and it shows some variation in thickness and considerable evidence of boring. This bed can be divided into a lower 6-to 8-inch moderately hard white silty limestone (USGS diatom loc. 5976) and an upper 2-inch softer white silty calcareous clay (USGS diatom loc. 5977). This entire "white bed" is thoroughly bored and contains abundant calcareous internal molds of fossil gastropods. The lower "white bed" is underlain by mottled gray and brown fine sand which has a somewhat whitened appearance immediately below the "white bed." It is overlain by typical grayish-brown massive Monroe Creek Sandstone containing pipy concretions. The hard white gastropod-bearing limestone contains the best preserved and most abundant diatom assemblage of those studied for this report. The upper calcareous clay contains a sparse assemblage.

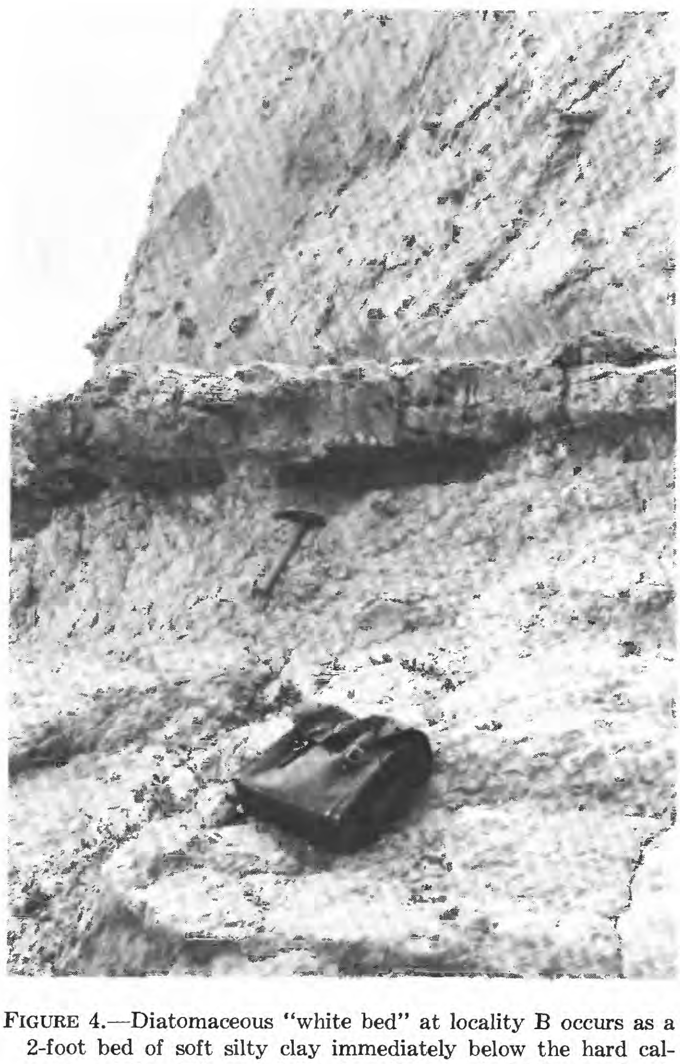


FIGURE 4.—Diatomaceous "white bed" at locality B occurs as a 2-foot bed of soft silty clay immediately below the hard calcareous ledge. The overlying deposit is typical Monroe Creek Sandstone with pipy concretions. USGS diatom localities 5510, 5574, and 5575.

FIGURE 5.—Lower and upper "white beds" at locality C, as indicated. The interval between the two diatomaceous beds is about 12 feet thick.

FIGURE 6.—Diatomaceous lower "white bed" at locality C. The hammer head rests on hard white silty limestone (USGS diatom loc. 5976) and indicates the overlying soft white silty clay (USGS diatom loc. 5977).

The upper "white bed" exposed at locality C is irregular in thickness, and the white sediments themselves range within this small outcrop from 0 to 12 inches in thickness. This variation appears to be due to erosion or planation of the upper surface of the bed. The white relatively soft calcareous clays are thoroughly bored, and the bore fillings are composed of typical Monroe Creek fine sand and silt similar to that of the overlying beds. Although the actual white sediments of this zone are discontinuous, they are underlain by a 2-foot layer of mottled brown and light-gray sand, somewhat lighter in color at the top than typical Monroe Creek sediments. This bed seems to have lateral persistence, which may account for the widespread presence of the upper "white bed" in vertical scarp faces of the Pine Ridge. Fragments of white calcareous siltstone from the upper "white bed" at locality C (USGS diatom loc. 5978) contain a moderately varied diatom assemblage with fair preservation.

Although it appeared to the author that the single "white bed" at localities A and B correlated with the upper "white bed" of locality C, the only criterion for correlation was lithologic similarity. These diatomaceous beds are certain to be lenticular although they have a lateral extent of several miles in the Crawford area. The age difference of the diatomaceous beds is not great enough to be significant, and the paleoecological factors were probably similar during deposition of all of the diatom-bearing strata.

THE ARIKAREE GROUP

The lower Miocene strata now included in the Arikaree Group were first named and mapped by Darton (1899, p. 743–747). However, Darton clearly distinguished the upper part of the modern Arikaree Group as his "Arikaree Formation" and recognized it as distinct from his underlying Gering Formation. He did point out (p. 743–744) that in some localities there is difficulty in identifying a definitive contact between his Gering and Arikaree Formations. Hatcher (1902, p. 116–117) divided the Arikaree Formation of Darton (1899) into two units: the Monroe Creek Beds and the Harrison Beds. Hatcher was inconsistent in his report, for on p. 118 he included the Gering Sandstone and the "Monroe Creek" in the "Arikaree" but then placed his "Harrison" as the lowermost unit in his overlying "Loup Fork".

The stratigraphic terminology of the lower Miocene rocks of western Nebraska was clarified by Schultz (1938), who redefined the Arikaree Formation of Darton (1899) as a group. Schultz (1938) included as subdivisions in his newly defined Arikaree Group the Gering Formation of Darton and the Monroe Creek Beds and Harrison Beds of Hatcher (1902). This classification was accepted by Lugn (1939, p. 1251–1253), and according to current terminology of the U.S. Geological Survey (Keroher and others, 1966, p. 132, 1497, 1686, 2559), the Arikaree Group contains the following three units in ascending order: Gering Formation, Monroe Creek Sandstone, Harrison Sandstone.

STRATIGRAPHY

The Monroe Creek Sandstone, the middle unit of the Arikaree Group, contains what is here termed the "Pine Ridge diatom assemblage." This is named for the Pine Ridge, a 500-foot escarpment in northwestern Nebraska with a near vertical face that is composed mainly of Monroe Creek Sandstone. Thus, although this formation is extensively exposed for more than 150 miles, the outcrops are so steep in many places that detailed study is difficult.

The Monroe Creek Sandstone is a massive, semiconsolidated brownish-gray silty fine sand. It is distinctly bedded, but this bedding is commonly inconspicuous because of the uniform lithology throughout the stratigraphic section. So-called "pipy" concretions are characteristic of the formation; they are locally restricted to certain layers, but in some places they are seemingly scattered indiscriminately in the massive outcrops. These concretions are typical Monroe Creek clastic sediments densely cemented by calcium carbonate; their hardness contrasts sharply with the semiconsolidated matrix material. The pipy concretions of the Monroe Creek Sandstone were studied by Schultz (1941), who reported that they have a preferred orientation in axial direction.

Lugn (1939, p. 1252) stated that the Monroe Creek Sandstone as exposed along the Pine Ridge between Crawford and Harrison, Nebr., ranges in thickness from about 285 to more than 360 feet. He also differentiated between two units of distinctive lithology in the formation. The lower part of the formation consists of from 185 to about 220 feet of gray fine to medium sand, and the upper part consists of from 100 to nearly 150 feet of finer grained pink to buff sandy silt and clay. The Pine Ridge diatom assemblage occurs in two "white beds" of calcareous silt, fine sand, volcanic ash, and diatoms. One or both of the beds is exposed in various places on the cliffs of the Pine Ridge escarpment near Crawford, Fort Robinson, and Smiley Canyon. No measured stratigraphic sections of the Monroe Creek Sandstone have been published for this area. The diatomaceous "white beds" clearly fall within Lugn's upper unit of the formation in the finer grained and more distinctly bedded sediments.

GEOLOGIC AGE

The Monroe Creek Sandstone in western Nebraska is dated by contained vertebrate remains as well as by the fossil vertebrate faunas of the underlying and overlying formations. Fossil vertebrates are not as common in the Monroe Creek Sandstone as in the overlying Harrison Sandstone. Darton (1899, p. 747) reported that "vertebrate remains were collected in small numbers" from the Gering and Monroe Creek Formations. He also reported that fresh-water mollusks had been found in these beds, and that one particularly abundant mollusk fauna was found in a matrix of diatomaceous earth at a locality south of Gering, Nebr. The author has searched in vain for this diatomaceous bed in the area of Scottsbluff and the bluffs south of Gering. This deposit is probably similar to the diatom-bearing sediments of the Pine Ridge area studied for this report.

Hatcher (1902, p. 117) stated that the Monroe Creek Sandstone is generally barren of vertebrate fossils but that the beds near the top of the formation were known to contain *Promerycochoerus*. Cook and Cook (1933, p. 22–27) published a list of fossil vertebrates from the Monroe Creek beds of western Nebraska. They also suggested that the Gering and Monroe Creek Formations be assigned a late Oligocene age and that the Oligocene-Miocene boundary be drawn at the contact of the Monroe Creek Sandstone with the overlying Harrison Sandstone. This age was not adopted by other geologists, and Cook (1960, p. 204) accepted the consensus of an early Miocene age for the Gering and Monroe Creek Formations. A summary of the fossil oreodonts from the Arikaree Group of Nebraska was given by Schultz and Stout (1961, p. 12) on the basis of several reports by Schultz and Falkenbach. The consensus from paleontological studies, mainly on fossil vertebrates, is that the Monroe Creek Sandstone is of early Miocene age.

The Arikaree Group of Nebraska has also been dated by the potassium-argon radiometric technique (Evernden and others, 1964, p. 178, 186–187). They gave a date of 25.6×10^6 years for a sample of volcanic ash 11 feet above the base of the Gering Formation at Scottsbluff (KA 985). They also gave a date of 21.3×10^6 years for a sample of tuff from the Harrison Sandstone at a level about 30 feet stratigraphically below the Agate fossil quarry (KA 481). No date is at present available specifically for the Monroe Creek Sandstone but these radiometric dates for the underlying and overlying formations limit well the age of the formation and its contained diatom assemblage.

In summary, the Pine Ridge diatom assemblage is relatively accurately dated by its stratigraphic position in the Monroe Creek Sandstone. The stratigraphic relations of the three formations of the Arikaree Group are not particularly complicated, and their relation to the underlying and overlying formations is well defined. The formations of the Arikaree Group are dated as early Miocene by the contained fossil vertebrate faunas. Furthermore, radiometric dating of adjacent formations limits the age of the diatom assemblage to between 21.3×10^6 and 25.6×10^6 years.

DIATOM ASSEMBLAGE

The samples were prepared for diatom study following standard procedures of the USGS diatom laboratory. All the samples were calcareous, and they were first treated with hydrochloric acid to remove carbonates. The residue contained little organic matter, and the diatom-sized particles were concentrated by differential settling and decanting. The cleaned samples were mounted in Kollolith, a synthetic resin with a refractive index approximating that of Canada Balsam. Individual specimens were located by systematic traversing by a mechanical stage, and their locations in the strewn mounts were recorded as coordinates of the mechanical stage. The relative abundance of each species or variety of diatom in six studied assemblages is shown in table 1. The forms are listed according to estimated relative frequency on a glass slide viewed at 250 magnification, as follows: abundant, at least one specimen in all fields of view; common, one specimen in many (but not all) fields of view; frequent, several specimens observed on slide, but seen only in a few fields of view; rare, one or two specimens on slide. The exact geographic location

TABLE 1.—*Relative abundance of diatoms from the Monroe Creek Sandstone*

[A, abundant; C, common; F, frequent; R, rare]

	USGS diatom locality					
	5972	5973	5510 5975	5976	5977	5978
Melosira italica (Ehrenberg) Kützing	--	--	--	F	R	--
Fragilaria brevistriata Grunow	--	--	--	A	--	--
var. *inflata* (Pantocsek) Hustedt	--	--	--	C	--	R
Eunotia sp.	--	--	--	R	--	R
Cocconeis placentula Ehrenberg	R	R	R	--	--	F
Achnanthes cincta Andrews, n. sp.	R	--	--	R	--	--
Anomoeoneis bicapitata Andrews, n. sp.	--	--	--	--	--	R
costata (Kützing) Hustedt	--	--	--	R	--	--
Navicula netroformis Andrews, n. sp.	--	--	R	F	R	R
Pinnularia brevicostata Cleve	--		--	F	--	--
elliptica Lohman and Andrews	--	F	--	F	R	--
fusana Andrews, n. sp	--	--	--	F	R	--
microstauron (Ehrenberg) Cleve	R	--	R	R	R	R
scapha Lohman and Andrews	F		R	R	--	R
subrostrata Lohman and Andrews	F	--	F	C	R	R
Amphora deflecta Andrews, n. sp.	F	R	--	--	--	--
punctata Andrews, n. sp.	--	R	R	R	--	R
Cymbella cistula var. *maculata* (Kützing) Van Heurck	F	F	--	F	R	F
lanceolata (Ehrenberg) Brun	--	--	R	R	--	R
Gomphonema affine var. *insignis* (Gregory) Andrews	--	--	--	F	--	--
Hantzschia recta Andrews, n. sp.	--	--	--	F	--	--

and stratigraphic level of these collections are given in the discussion of the location and the lithology of the Pine Ridge diatomaceous beds. USGS diatom localities 5510 and 5975 were placed together in table 1 because they represent collections made at different times from the same site and the same bed.

STRATIGRAPHIC SIGNIFICANCE

This report is the second part of a continuing stratigraphic study of Tertiary nonmarine diatom assemblages of the Great Plains region of North America. The first part was a report on a late Miocene diatom assemblage (Andrews, 1970), from the Valentine Formation of Lugn (1938) near Kilgore, Nebr. Also of significance to this study is the description of the late Eocene diatom assemblage from the Wagon Bed Formation of Wyoming by Lohman and Andrews (1968), even though that assemblage is technically outside the Great Plains region. The Pine Ridge assemblage of this report is intermediate in age between the Wagon Bed and Kilgore assemblages and somewhat bridges the extensive time gap between late Eocene and late Miocene. It also is from a part of the stratigraphic section where known diatom assemblages are rare probably because of poor preservation.

The Pine Ridge diatom assemblage contains 21 recognized species and varieties of diatoms. Of these, seven species are new—*Achnanthes cincta, Anomoeoneis bicapitata, Navicula netroformis, Pinnularia fusana, Amphora deflecta, Amphora punctata,* and *Hantzschia recta.* Three species—*Pinnularia elliptica, Pinnularia scapha,* and *Pinnularia subrostrata*—are known previously only from the Wagon Bed Formation (middle and late Eocene). The Pine Ridge assemblage has four species in common with the late Eocene, the aforementioned Pinnularias and the long-ranging *Melosira italica.* The Pine Ridge assemblage contains five diatom species and varieties in common with the late Miocene Kilgore assemblage—*Melosira italica, Fragilaria brevistriata, Pinnularia brevicostata, Cymbella cistula* var. *maculata,* and *Gomphonema affine* var. *insignis.* All these are long-ranging forms still living in modern assemblages.

A significant difference from modern diatom assemblages is indicated by the relatively high number (about 50 percent) of extinct taxa in this early Miocene assemblage. Of equal importance is the lack of many modern diatom species, genera, and even families, which suggests that some of the modern forms might not yet have evolved by early Miocene time. It is impossible to say how typical the Pine Ridge assemblage is of early Miocene diatom assemblages or what percent it contains of early Miocene nonmarine diatoms to be found in other deposits. Furthermore, it is difficult to determine many ecological factors influencing the composition of this particular deposit. The significant differences between this assemblage and other studied assemblages, both fossil and modern, must be explored.

The only centric diatom observed in the Pine Ridge assemblage is *Melosira italica,* and the genera *Cyclotella* and *Stephanodiscus,* both common to modern assemblages, are absent. The subfamily Tabellarioideae is totally absent and the subfamily Fragilarioideae is represented by two closely related forms of *Fragilaria brevistriata.* The Eunotiaceae are represented by one problematical form of *Eunotia* which needs more study. Of the suborder Monoraphidineae, *Cocconeis* and *Achnanthes* occur only as single species. The common modern naviculoid genera *Mastogloia, Caloneis, Neidium, Diploneis,* and *Stauroneis* are absent; *Navicula* is represented by only one species, and *Anomoeoneis* by two species. The genus *Pinnularia,* with six species, shows more variety in forms than any other genus in the assemblage. Both *Amphora* and *Cymbella* are present in the Pine Ridge assemblage, and *C. cistula* var. *maculata* is also common in the late Miocene at Kilgore. *Gomphonema* is represented both here and at Kilgore by only one form, *G. affine* var. *insignis,* and the early Miocene specimens of this form in the Pine Ridge assemblage seem much less variable than the late Miocene specimens of the Kilgore assemblage. The

Epithemiaceae and the Surirellaceae are absent in both the Pine Ridge and Kilgore assemblages.

The Pine Ridge assemblage contains 12 genera of nonmarine diatoms and 21 species and varieties, 50 percent of which are extinct. For comparison, the late Eocene Wagon Bed assemblage of Lohman and Andrews (1968) shows nine genera with 34 species and varieties, 80 percent extinct; the late Miocene Kilgore assemblage of Andrews (1970) shows 15 genera with 45 species and varieties, 16 percent extinct; the late Pleistocene Hixton assemblage of Andrews (1966) shows 23 genera with 73 species and varieties, 3 percent extinct. Two trends are obvious from modern to progressively older assemblages: (1) the older the deposit, the greater the number of extinct species present, and (2) the older the deposit, the fewer species and varieties present. The decline in numbers of living taxa with age is somewhat greater than the decline in total numbers of taxa.

A comparison of the ranges of living nonmarine diatoms and marine mollusks for part of the Tertiary Period is shown in figure 7. The data on the diatoms are

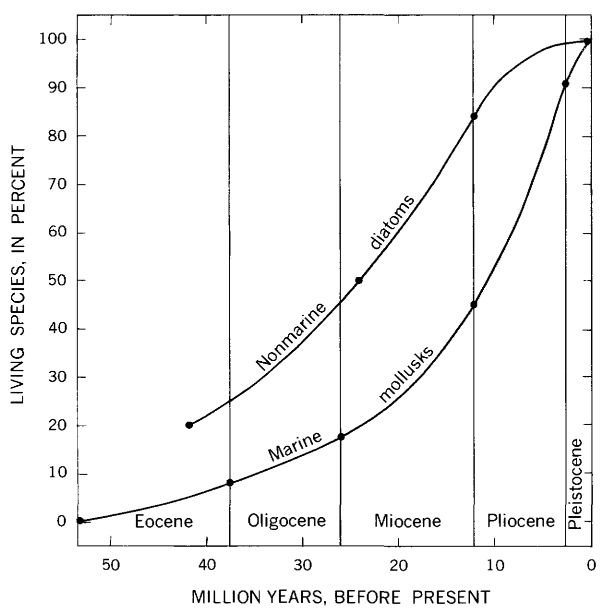


FIGURE 7.—Ranges of living nonmarine diatom species compared with those of living mollusk species during the Tertiary Period.

drawn from these studies; data on the mollusks are adapted from Dunbar (1949, p. 397) and based on the classical Lyellian data of progressive Tertiary extinction. This chart is tentative and is a crude approximation of the actual situation. It does suggest, however, that nonmarine diatom species tend to be somewhat longer ranging than marine mollusk species. The percentage of modern diatom species living in the Pleistocene and most of the Pliocene was high, and the extinct species in these deposits may be too few to be useful in stratigraphic correlation. Using extinct diatom species to determine the age of a deposit is more effective in Miocene or older deposits. It is increasingly apparent that successful stratigraphic correlation using nonmarine diatoms requires study of the total assemblage and consideration of the species absent as well as those present. Further study of other well-dated deposits will help determine the stratigraphic ranges of living and extinct species. The earliest geologic occurrence of living diatom species should be helpful in stratigraphic correlation, especially in the later Tertiary deposits.

PALEOECOLOGIC INTERPRETATION

The modern ecology of the 10 living species and varieties of nonmarine diatoms in the Pine Ridge assemblage provides some clues to the early Miocene paleoecology of the deposit. One assumes, of course, that these forms have preferred similar ecologic conditions from the early Miocene to the present, an assumption that cannot be proved. The relatively small percentage of centric and other planktonic species suggests deposition in a relatively shallow pond or sheet of water. This depositional environment is confirmed by the occurrence of such shallow-water species as *Cocconeis placentula* and *Cymbella lanceolata*. The evidence concerning alkalinity and salt content is conflicting. Only one species, *Anomoeoneis costata*, shows a preference for saline water, and *Fragilaria brevistriata* var. *inflata* and *Cocconeis placentula* show some preference for alkaline waters. On the other hand, *Pinnularia brevicostata* and *P. microstauron* prefer waters of low mineral content. Possibly the shallow ponds in which this assemblage was deposited fluctuated seasonally in alkalinity depending upon the inflow of fresh water. The abundance of lime in the diatom-bearing layers suggests that alkaline waters were present part of the time. Data are not sufficient to justify speculation about the water temperature during deposition of the diatomaceous sediments.

The physical stratigraphy, distribution, lithology, and fossil nonmarine mollusks of the diatom-bearing "white beds" also provide clues to the paleoecology of the deposit. The fresh-water limestone and calcareous clastic lithology suggest shallow-water deposition and moderate evaporation of water. The relatively thin beds suggest that the lakes in which the diatoms grew were of short duration. The distribution of the diatomaceous sediments over several miles suggests a thin sheet of water of considerable lateral extent.

The diatomaceous "white beds" of the Monroe Creek Sandstone were deposited during interruptions in the deposition of fine silty sand. Probably little more was involved than temporary diversion of stream waters laden with clastic materials to another area. Perhaps a playa lake formed, having extremely shallow water and seasonal fluctuations. These lakes existed long enough for fresh-water limestones be deposited, for diatoms to live and be deposited, and for a mollusk assemblage, which caused extensive bioturbation of the sediments, to be disseminated throughout the lake basin. Conditions changed, and mixed clastic and carbonate sedimentation continued for a time; later, the lakes were filled by a fresh influx of typical Monroe Creek clastic material. Clastic sedimentation slowed twice in the Pine Ridge area, allowing deposition of the two diatomaceous "white beds." The diatom assemblages of these two beds are similar, indicating that ecologic conditions during both episodes were similar. This similarity in diatom assemblages and the stratigraphic proximity of the two diatom-bearing "white beds" indicate that a relatively short time elapsed between the deposition of these two beds.

SYSTEMATIC DESCRIPTIONS

The classification of diatoms used in this report is based on a proposed classification by K. E. Lohman (unpub. data) and was previously used in Lohman and Andrews (1968) and Andrews (1970). It follows the suggestions of Moore (1954) to the rank of class and follows in many respects the earlier classifications proposed by Schütt (1896), Karsten (1928), and Hendey (1937). As in previous reports, the treatment of the nomenclature in the generic and lower ranks is conservative, although this does not imply complete agreement with all the accepted nomenclature. Previously designated infraspecific taxonomic designations in current use are retained without enthusiasm, for reasons outlined by Andrews (1970, p. A8). To adhere to the binomial system as closely as possible, all new taxa are described by the author as species in this report.

The descriptions in this report refer to the specimens observed in the Pine Ridge diatom assemblage and do not necessarily reflect the total variation of each form. The descriptions of previously described species and varieties are brief; more complete diagnoses are in the general works cited in the synonymies. The first citation in each synonymy is that of the author of the taxon. The second citation includes references to the taxon in the literature in chronologic order using the nomenclature accepted in this report. The third and remaining citations include synonyms, misidentifications, and incorrect attributions of authorship, also in chronologic order. References not examined by the author are marked with an asterisk. The comments on the ecology of the modern diatom taxa are adapted from Patrick and Reimer (1966), Hustedt (1927–30, 1931–59, 1961–66), and Hustedt (1930). The known geologic ranges of the species and varieties are based on the results of this and previous studies; they may be modified by further investigations.

Kingdom PROTISTA Haeckel, 1866
Subkingdom PROTOCTISTA Hogg, 1860
Division CHRYSOPHYTA Pascher, 1914
Class DIATOMOPHYCEAE Rabenhorst, 1864
Order CENTRALES Schütt, 1896
Suborder DISCINEAE Kützing, 1844
Family COSCINODISCACEAE Kützing, 1844
Subfamily MELOSIROIDEAE Kützing, 1844
Genus MELOSIRA Agardh, 1824

Melosira italica (Ehrenberg) Kützing

Plate 1, figures 1, 2

Gaillonella italica Ehrenberg, 1836, Kgl. preuss. Akad. Wiss. Berlin, Ber., 1836, p. 53.

Melosira italica (Ehrenberg) Kützing, 1844, Die kieselschaligen Bacillarien oder Diatomeen, p. 55, pl. 2, fig. 6.
Hustedt, 1927, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, pt. 1, p. 257–262, fig. 109.
Lohman and Andrews, 1968, U.S. Geol. Survey Prof. Paper 593–E, p. 12, pl. 1, fig. 6.
Andrews, 1970, U.S. Geol. Survey Prof. Paper 683–A, p. A9, pl. 1, fig. 4.

Gallionella crenulata Ehrenberg, 1843, Kgl. preuss. Akad. Wiss. Berlin, Phys. Abh., 1841, p. 376, pl. 2, fig. I, 41; pl. 3, fig. I, 28; pl. 4, fig. I, 31.

Melosira crenulata (Ehrenberg) Kützing, 1833, Die kieselschaligen Bacillarien oder Diatomeen, p. 55, pl. 2, fig. 8.

Meloseira crenulata (Ehrenberg) Kützing. Boyer, 1927, Acad. Nat. Sci. Philadelphia Proc., v. 78, supp., p. 29.

Description.—Valves cylindrical, bound in chains of frustules; margin denticulate; mantle finely punctate, puncta arranged in longitudinal, sometimes slightly spiral, rows; about 20 rows of puncta in 10μ. Diameter, about 7μ–15μ; height of single valve, about 10μ.

Remarks.—*M. italica* is frequent in USGS diatom locality 5976 and rare in locality 5977.

M. italica is common in modern fresh-water environments as a pelagic form in lakes and as a littoral form in smaller bodies of water.

Known geologic range.—From late Eocene to present.

Diameter of figured specimens (USGS diatom cat. Nos. 3702–25 and 3702–20), 15μ, 11μ.

Order PENNALES Schütt, 1896
Suborder ARAPHIDINEAE Karsten, 1928
Family FRAGILARIACEAE Kützing, 1844
Subfamily FRAGILARIOIDEAE Kützing, 1844
Genus FRAGILARIA Lyngbye, 1819

Fragilaria brevistriata Grunow

Plate 1, figures 3, 4

Fragilaria brevistriata Grunow *in* Van Heurck, 1885, Synopsis des diatomées de Belgique, p. 157.
Hustedt, 1931, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, pt. 2, p. 168–170, fig. 676 a–e.
Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 128–129, pl. 4, fig. 16.
Andrews, 1970, U.S. Geol. Survey Prof. Paper 683–A, p. 11, pl. 1, fig. 18, 19.

Description.—Valve linear-lanceolate, often with subrostrate, rounded apices; transverse striae about 13 to 14 in 10μ, marginal to a broad central hyaline area. Length, about 15μ; width, about 4μ to 6μ.

Remarks.—This species is usually seen in girdle view as chains of frustules, and well-oriented specimens in valve view are much less common. The transverse striae are of moderate length and more closely resemble the striae in the species as illustrated by Patrick and Reimer (1966) and Andrews (1970) than as illustrated by Grunow in Van Heurck (1881, pl. 45, fig. 32) and Hustedt (1931). The forms in the Pine Ridge assemblage resemble *F. denticulata* Lohman and Andrews (1968, p. 14, pl. 1, fig. 11, 12) but have slightly less robust and more closely spaced transverse striae. The species in this assemblage may be transitional between *F. denticulata* and later forms of *F. brevistriata.*

The species is abundant in USGS diatom locality 5976.

Living representatives of the species are tolerant of a wide range of fresh-water environments.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3737–37 and 3737–38), both 15μ.

Fragilaria brevistriata var. inflata (Pantocsek) Hustedt

Plate 1, figures 5, 6

Fragilaria inflata Pantocsek, 1902, Resultate Wiss. Erforsch. Balatonsees, v. 2, pt. 2, sec. 1, p. 79, pl. 9, fig. 219–221.
Fragilaria brevistriata var. *inflata* (Pantocsek) Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 145, fig. 152.
Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 129, pl. 4, fig. 16.

Description.—Valve broadly fusiform with small rounded apices; short marginal transverse striae, about 14 in 10μ, with a large hyaline central area. Length, about 12μ; width, about 7μ.

Remarks.—This variety occurs with the type, and it is difficult to separate the two when seen as chains of frustules in girdle view.

The variety is common in USGS diatom locality 5976 and rare in locality 5978.

Living representatives of the variety prefer slightly alkaline waters.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3737–39 and 3702–42), 12μ, 16μ.

Suborder RAPHIDIOIDINEAE Karsten, 1928
Family EUNOTIACEAE Kützing, 1844
Subfamily EUNOTIOIDEAE Kützing, 1844

Eunotia sp.

Plate 1, figure 7

Description.—Valve with slightly concave ventral side and more highly convex dorsal side; apices blunt, smoothly rounded, subrostrate; terminal nodules small, indistinct, on ventral side of valve near the apices. Length, about 28μ to 40μ; width, about 8μ.

Remarks.—These specimens show a typical outline of *Eunotia* with a strong rim and terminal nodules. The center of the valve is hyaline and shows no discernable striae. This may result from poor preservation, striae too fine to be resolved with the light microscope, or no striae in this species. It is hoped that the structure of this form can be determined more fully in the future by the scanning electron microscope. This is the earliest known occurrence of the genus *Eunotia* in North America.

Rare in USGS diatom localities 5976 and 5978.

Known geologic range.—Early Miocene.

Length of figured specimen (USGS diatom cat. No. 3704–19), 29μ.

Suborder MONORAPHIDINEAE Karsten, 1928
Family ACHNANTHACEAE Kützing, 1844
Subfamily COCCONEOIDEAE Schütt, 1896
Genus COCCONEIS Ehrenberg, 1838

Cocconeis placentula Ehrenberg

Plate 1, figures 8, 9

Cocconeis placentula Ehrenberg, 1838, Die Infusionsthierchen als vollkommene Organismen, p. 194.*
Hustedt, 1933, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, pt. 2, p. 347–348, fig. 802a, b.
Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 240–241, pl. 15, fig. 7.

Description.—Valve elliptical and relatively little arched; transverse striae about 20 in 10μ, finely punctate; pseudoraphe narrow, linear, not expanded into a central area; raphe valve not observed. Length, 20μ to 27μ, width about 10μ to 14μ.

Remarks.—The species is frequent in USGS diatom locality 5978 and rare in localities 5972, 5973, and 5975.

Living representatives of the species are epiphytic on aquatic plants and other objects and are common in circumneutral to alkaline waters.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3704–12 and 3700–1), 27μ, 24μ.

Subfamily ACHNANTHOIDEAE Schütt, 1896
Genus ACHNANTHES Bory, 1822

Achnanthes cincta Andrews, n. sp.

Plate 1, figures 10, 11

Diagnosis.—Valve elliptical-lanceolate with rounded apices; striae about 18 in 10μ on both valves, slightly radiate. Both valves have a hyaline central belt or stauros in which two or three central striae are lacking. Raphe valve with thin straight raphe in narrow axial area; pseudoraphe valve with narrow pseudoraphe which expands to the margins of the valve at the central stauros. Length, about 21μ; width, about 5 to 6μ.

Holotype: USGS diatom catalog No. 3737–35 (pl. 1, figures 10, 11) length, 21μ; width, 5μ. From USGS diatom locality 5976.

Remarks.—This species is readily distinguished by its elliptical-lanceolate shape and by the stauros on both the raphe and pseudoraphe valves. Most species of *Achnanthes* with a bilateral central hyaline area on the raphe valve do not show this feature on the pseudoraphe valve. Superficially *A. cincta* most closely resembles *A. exigua* var. *elliptica* Hustedt, but that variety is much smaller in size and has much finer striations.

Rare in USGS diatom localities 5972 and 5976.

Known geologic range.—Early Miocene.

Suborder BIRAPHIDINEAE Karsten, 1928
Family NAVICULACEAE Kützing, 1844
Subfamily NAVICULOIDEAE Kützing, 1844
Genus ANOMOEONEIS Pfitzer, 1871

Anomoeoneis bicapitata Andrews, n. sp.

Plate 1, figures 12, 13

Diagnosis.—Valve small, linear, with broadly rounded, extremely capitate apices; raphe straight, hairlike; axial area narrow, bounded on each side by a single row of prominent puncta; central area defined by a slight asymmetric expansion of the axial area toward one side of valve; transverse striae radiate, about 24 in 10μ, fine, formed of distinct puncta arranged in longitudinally undulating rows. Length, 26μ to 33μ; width, about 7μ.

Holotype: USGS diatom cat. No. 3704–16 (pl. 1, fig. 12), length, 26μ; width, 7μ. Paratype: USGS diatom catalog No. 3704–15 (pl. 1, fig. 13), length, 33μ; width, 7μ. Both from USGS diatom locality 5978.

Remarks.—This small species of *Anomoeoneis* is distinctive in its extremely bicapitate apices. In some specimens the ends of the valve have the appearance of rounded knobs attached to the main part by slender stalks. The punctation, typical of *Anomoenoneis,* is sometimes so fine that observation is difficult.

Rare in USGS diatom locality 5978.

Known geologic range.—Early Miocene.

Anomoeoneis costata (Kützing) Hustedt

Plate 1, figure 14

Navicula costata Kützing, 1844, Die kieselschaligen Bacillarien oder Diatomeen, p. 93, pl. 3, fig. 56.

Anomoeoneis costata (Kützing) Hustedt, 1959, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, pt. 2, p. 744–747, fig. 1111.

Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 376, pl. 32, figs. 3, 8.

Description.—Valve elliptical-lanceolate with rounded apices showing very slight attenuation; axial area narrow, bounded by a single row of pronounced puncta; central area asymmetrical, expanding on one side to reach the margin of the valve; other areas between the axial area and margins filled with transverse striae, about 19 in 10μ, composed of undulating longitudinal rows of puncta. Length, about 38μ; width, about 11μ.

Remarks.—*A. costata,* as it occurs in the Pine Ridge deposit, shows several minor differences from modern forms. It is somewhat smaller and more finely striated, and the axial area is narrow rather than wide. The Pine Ridge form also shows a slight tendency for attenuation of the apices. This Miocene form, however, does not differ significantly enough from the modern *A. costata* to be assigned to a separate species. Perhaps this Miocene form is ancestral to the two modern species, *A. costata* and *A. sphaerophora,* for it seems to show some characteristics of each species.

The species is rare in USGS diatom locality 5976.

Living representatives of the species occur in inland waters of medium to high salt concentration.

Known geologic range.—From early Miocene to present.

Length of figured specimen (USGS diatom cat. No. 3702–36), 38μ.

Genus NAVICULA Bory, 1822

Navicula netroformis Andrews, n. sp.

Plate 1, figures 15–17

Diagnosis.—Valve fusiform, lanceolate, with rostrate to subcapitate apices; transverse striae fine, 15 in 10μ, somewhat radial and showing fine puncta; raphe fine and straight, occupying a narrow axial area, which expands into a smoothly rounded central area one-third to one-half the width of the valve; striae sometimes irregularly spaced marginal to the central area, but regularly shortened around the central area. Length, 30μ to 37μ; width, 9μ to 10μ.

Holotype: USGS diatom catalog No. 3702–34 (pl. 1, fig. 15), length, 35μ; width, 9μ. Paratype: USGS diatom catalog No. 3703–5 (pl. 1, fig. 16), length, 37μ; width, 10μ. Paratype: USGS diatom catalog No. 3737–8 (pl. 1, fig. 17), length, 30μ; width, 9μ. Holotype and second paratype from USGS diatom locality 5976; first paratype from locality 5977.

Remarks.—*N. netroformis* closely resembles *N. exigua* var. *capitata* Patrick in general outline. It differs significantly, however, in its smoothly rounded hyaline central area. The apices of *N. netroformis* are also slightly less capitate than those of *N. exigua* var. *capitata.*

Frequent in USGS diatom locality 5976; rare in localities 5510, 5977, and 5978.

Known geologic range.—Early Miocene.

Genus PINNULARIA Ehrenberg, 1843

Pinnularia brevicostata Cleve

Plate 1, figures 18, 19

Pinnularia brevicostata Cleve, 1891, Soc. pro Fauna et Flora Fennica Acta, v. 8, no. 2, p. 25, pl. 1, fig. 5.

Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 329–330, fig. 609.

Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 623, pl. 60, fig. 1.

Andrews, 1970, U.S. Geol. Survey Prof. Paper 683–A, p. 17, pl. 3, fig. 2.

Description.—Valve linear-elliptical with rounded apices; broad, hyaline axial area nearly half the width of the valve; striae short, 11 in 10μ, slightly radiate at center and convergent at the apices; raphe filamentous with prominent, slightly deflected central pores and terminating as a "question mark" near the apices. Length, about 65μ; width, about 15μ.

Remarks.—The form occurring in this assemblage does not show any central swelling of the valve and shows only a slight suggestion of lateral expansion of the central area.

The species is frequent in USGS diatom locality 5976.

Living representatives of the species prefer cool waters of low mineral content.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3737–16 and 3702–24), 65μ, 45μ.

Pinnularia elliptica Lohman and Andrews

Plate 1, figures 20, 21

Pinnularia elliptica Lohman and Andrews, 1968, U.S. Geol. Survey Prof. Paper 593–E, p. 19, pl. 2, figs. 1, 2.

Description.—Valve elliptical-lanceolate with narrowly rounded apices; some specimens show a slight tendency toward protracted apices; axial area narrow near the apices increasing gradually to about one-third to one-half the width of the valve at the center, hence, no distinct central area; transverse costae 11 to 16 in 10μ, curved, strongly radiate near the center, slightly divergent near the apices; valve strongly curved laterally, with broad hyaline marginal band observed only in oblique view of specimens and fragments. Length of observed specimens, 100μ to 190μ; width, about 30μ to 40μ.

Remarks.—This species is poorly preserved in the Pine Ridge assemblage, and it is usually found as fragments. These fragments indicate that the upper size limits of the species may be much greater than indicated above, and large specimens may show fewer costae in 10μ than indicated above. Because the relatively large thin valves have such a high lateral convexity, they have often been broken by the normal processes of sedimentation and diagenesis.

The species occurs frequently in USGS diatom localities 5973 and 5976 and rarely in locality 5977.

Known geologic range.—From late Eocene to early Miocene.

Length of figured specimens (USGS diatom cat. Nos. 3702–16 and 3702–29), about 166μ, 190μ.

Pinnularia fusana Andrews, n. sp.

Plate 1, figures 25–27

Diagnosis.—Valve large, fusiform, lanceolate-elliptical with broad, rostrate apices; ends bluntly rounded; raphe straight, terminating in pronounced central pores; axial area narrow at the apices, increasing regularly to about one-third the width of the valve at the center; a rounded, slightly expanded central area is noticeable in some specimens but not in others; transverse costae, 9 to 10 in 10μ, radial near the center, divergent near the apices, sometimes showing an attenuated S-shape. Length, 68μ to 130μ; width, 22μ to 30μ.

Holotype: USGS diatom catalog No. 3737–10 (pl. 1, fig. 25), length, 78μ; width, 22μ. Paratype: USGS diatom catalog No. 3702–31 (pl. 1, fig. 26), length, 68μ; width, 22μ. Paratype: USGS diatom catalog No. 3702–4 (pl. 1, fig. 27), length 87μ; width, 24μ. All from USGS diatom locality 5976.

Remarks.—*P. fusana* has obvious affinities for both *P. elliptica* and *P. subrostrata.* It has a distinctive external shape, however, which differentiates it from these species. *P. fusana* differs from *P. elliptica* in having distinctly rostrate protracted apices. It differs from *P. subrostrata* in the markedly elliptical lateral margins, which contrast with the weakly elliptical or subparallel lateral margins of the latter species. Some specimens of *P. fusana* show no expanded central area typical of *P. elliptica;* others show a definitely expanded central area similar to that of *P. subrostrata.*

Frequent in USGS diatom locality 5976; rare in locality 5977.

Known geologic range.—Early Miocene.

Pinnularia microstauron (Ehrenberg) Cleve

Plate 1, figures 22–24

Stauroptera microstauron Ehrenberg, 1843, Kgl. preuss. Akad. Wiss. Berlin, Phys. Abh., 1841, p. 423, pl. 1, fig. IV, 1.

Pinnularia microstauron (Ehrenberg) Cleve, 1891, Soc. pro Fauna et Flora Fennica Acta, v. 8, no. 2, p. 28.

Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 320, fig. 582.

Patrick and Reimer, 1966, Acad. Nat. Sci. Philadelphia Mon. 13, p. 597–598, pl. 55, fig. 12.

Description.—Valve linear with broadly rostrate apices; axial area narrow, tapering toward the central area, which expands to the margins of the valve; striae about 13 in 10μ, markedly radiate near the center, but becoming convergent toward the apices. Length, 32μ to 60μ; width, 8μ to 10μ.

Remarks.—*P. microstauron* has affinities with *P. brebissonii,* reported by Lohman and Andrews (1968, p. 18–19) from the late Eocene of Wyoming.

The species is rare in USGS diatom localities 5972, 5975, 5976, 5977, and 5978.

P. microstauron is tolerant of a variety of fresh-water environments, but seems to prefer oligotrophic, slightly acid waters.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3737–31, 3702–47, 3737–27), 35μ, 40μ, 60μ.

Pinnularia scapha Lohman and Andrews

Plate 2, figures 1, 2

Pinnularia scapha Lohman and Andrews, 1968, U.S. Geol. Survey Prof. Paper 593–E, p. 20, pl. 2, fig. 5.

Description.—Valve elliptical with bluntly rounded apices; transverse costae 9 to 10 in 10μ, radial at the center but convergent near the apices; axial area narrow, expanding at the central area into a transverse fascia, more or less quadrangular and oriented with one diagonal parallel to the longitudinal axis. Length, 41μ to 59μ; width, 14μ to 15μ.

Remarks.—This species shows affinities for *P. subrostrata,* which is more common in the Pine Ridge assemblage. It differs mainly in its smoothly rounded apices and somewhat more quadrangular central area. The quadrangular central area seems less consistently well developed in the Pine Ridge specimens than in the late Eocene form described by Lohman and Andrews (1968, p. 20).

The species is frequent in USGS diatom locality 5972 and rare in localities 5510, 5976, and 5978.

Known geologic range.—From late Eocene to early Miocene.

Length of figured specimens (USGS diatom cat. Nos. 3699–18 and 3702–35), 48μ and 50μ.

Pinnularia subrostrata Lohman and Andrews

Plate 2, figures 3–5

Pinnularia subrostrata Lohman and Andrews, 1968, U.S. Geol. Survey Prof. Paper 593–E, p. 21, pl. 2, fig. 16.

Description.—Valve linear-elliptical with broadly rounded subrostrate apices; lateral margins straight to slightly convex; axial area narrow, expanding rapidly near the center into a rounded or diagonally subquadrangular central area; transverse costae, 9 to 12 in 10μ, radial at center, convergent near apices. Length, 39μ to 108μ; width, 13μ to 20μ.

Remarks.—This species is distinguished from *P. scapha* mainly by its more linear outline and its broad subrostrate apices. It shows considerable variation in outline and shape of the central area. It is more linear and less biconvex than *P. fusana.*

P. subrostrata is common in USGS diatom locality 5976, frequent in localities 5510, 5972, 5973, 5975, and rare in 5977 and 5978. The preservation of specimens is good.

Known geologic range.—Late Eocene to early Miocene.

Length of figured specimens (USGS diatom cat. Nos. 3699–19, 3737–11, 3699–13), 54μ, 60μ, 52μ.

Family CYMBELLACEAE Agardh, 1830
Genus AMPHORA Ehrenberg, 1840

Amphora deflecta Andrews, n. sp.

Plate 2, figures 6, 7

Diagnosis.—Frustule elliptical with protracted truncated apices; connective zone about one-third the width of the frustule, hyaline, with vague, ill-defined longitudinal markings; valve half elliptical-lanceolate with smoothly elliptical dorsal side and nearly straight ventral side; apices protracted, capitate, deflected ventrally; raphe fine, straight, near the ventral side of the valve, deflected ventrally near the apices, and having small central pores deflected dorsally; axial area narrow, not expanding into a central area; transverse striae fine, about 30 in 10μ, punctate, slightly radial, filling the entire lateral area. Length, 26μ to 34μ; width of valve, about 4μ to 6μ.

Holotype: USGS diatom catalog No. 3700–9 (pl. 2, fig. 6), length, 34μ; width of valve, 6μ; from USGS diatom locality 5973. Paratype: USGS diatom catalog No. 3699–20 (pl. 2, fig. 7), length, 26μ; width of frustule, 15μ; from USGS diatom locality 5972.

Remarks.—*A. deflecta* is readily distinguished by its ventrally deflected capitate apices and fine uniform striation.

Frequent in USGS diatom locality 5972 and rare in locality 5973.

Known geologic range.—The early Miocene.

Amphora punctata Andrews, n. sp.

Plate 2, figures 8–10

Diagnosis.—Valve lanceolate with slightly produced subrostrate apices; ventral margin straight; dorsal margin smoothly rounded until slightly deflected near the apices; raphe straight, located close to the ventral margin; transverse striae fine but sharp, about 20 in 10μ, continuous near both the raphe and the dorsal margin, but broken in the center of the valve into elongate puncta aligned in irregularly undulating longitudinal rows. Length, 35μ to 54μ; width, 11μ to 13μ.

Holotype: USGS diatom catalog No. 3443–7 (pl. 2, fig. 8), length, 48μ; width, 13μ. Paratype: USGS diatom catalog No. 3443–13 (pl. 2, fig. 9), length, 47μ; width, 11μ. Paratype: USGS diatom catalog 3702–33 (pl. 2, fig. 10), length, 40μ; width, 12μ.

Remarks.—*A. punctata* does not seem to resemble closely any of the previously described nonmarine forms of *Amphora*. It is distinguished by its half-lanceolate shape, slightly rostrate apices, and undulating rows of transversely elongated puncta.

Rare in USGS diatom localities 5510 and 5976.

Known geologic range.—Early Miocene.

Cymbella cistula var. maculata (Kützing) Van Heurck

Plate 2, figures 11–13

Frustulia maculata Kützing, 1834, Algarum aquae dulcis Germanicarum, Dec., no. 85.*

Cymbella cistula var. *maculata* (Kützing) Van Heurck, 1880, Synopsis des diatomées de Belgique, p. 64, pl. 2, fig. 16, 17.

Cleve, 1894, Kgl. svenska vetensk. akad. Handl., v. 26, no. 2, p. 173.

Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 363, fig. 676b.

Andrews, 1970, U.S. Geol. Survey Prof. Paper 683–A, p. A19, pl. 3, fig. 10.

Cymbella cistula maculata (Kützing) A. Schmidt. Boyer, 1927, Acad. Nat. Philadelphia Proc., v. 79, supp., p. 280.

Description.—Valve asymmetric with markedly convex dorsal side and curved raphe; ventral side basically concave, but with enough central swelling so that the side becomes slightly convex; axial area narrow, without noticeable expansion into a central area; striae, 9 to 10 in 10μ at center, more closely spaced near the apices, coarsely punctate, radiate throughout the valve. Length, 28μ to 57μ; width, about 10μ to 12μ.

Remarks.—The species observed in this assemblage is a bit less asymmetric than previously described late Miocene and modern forms. The type variety was not observed, and only the variety *maculata* occurs in this deposit.

C. cistula var. *maculata* is frequent in USGS diatom localities 5972, 5973, 5976, and 5978; it is rare in locality 5977.

Living representatives of the variety are common and widespread in fresh-water environments.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3702–5, 3702–28, 3704–2), 49μ, 44μ, 43μ.

Cymbella lanceolata (Ehrenberg) Brun

Plate 2, figures 14, 15

Cocconema lanceolatum Ehrenberg, 1838, Die Infusionsthierchen als vollkommene Organismen, p. 224.*

Cymbella lanceolata (Ehrenberg) Brun, 1880, Diatomées des Alpes et du Jura, p. 57, pl. 3, fig. 19.

Boyer, 1927, Acad. Nat. Sci. Philadelphia Proc., v. 79, supp., p. 279.

Cymbella (Cocconema) lanceolatum (Ehrenberg) Van Heurck, 1880, Synopsis des diatomées de Belgique, pl. 2, fig. 7.

Cymbella lanceolata (Ehrenberg) Van Heurck. Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 364, fig. 679.

Description.—Valve half-lanceolate with convex dorsal side and nearly straight ventral side with slight central swelling; apices rounded; raphe slightly arched and centered in a narrow axial area which does not expand into a noticeable central area; transverse striae, 11 to 12 in 10μ, composed of distinct puncta. Length, 68μ to 80μ; width, about 15μ to 16μ.

Remarks.—This species has obvious affinities with *C. cistula* var. *maculata*, but it is larger and has a more elongate, lanceolate outline. It is difficult to determine whether Brun or Van Heurck deserve credit for revising the species, as both placed *Cocconema lanceolatum* in the genus *Cymbella* in 1880.

C. lanceolata is rare in USGS diatom localities 5975, 5976, and 5978.

Living representatives of the species are common in fresh water, especially as a littoral form in standing water.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3704–17 and 3702–5), 74μ, 80μ.

Family GOMPHONEMACEAE Kützing, 1844
Genus GOMPHONEMA Agardh, 1824

Gomphonema affine var. insignis (Gregory) Andrews

Plate 2, figures 16–18

Gomphonema insigne Gregory, 1856, Micros. Soc. Quart. Jour., v. 4, p. 12, pl. 1, fig. 39.
Grunow, *in* Van Heurck, 1880, Synopsis des diatomées de Belgique, pl. 24, fig. 39–41.
Gomphonema affine var. *insignis* (Gregory) Andrews, 1970, U.S. Geol. Survey Prof. Paper 683–A, p. 20, pl. 3, figs. 12–16.
Gomphonema lanceolatum var. *insignis* (Gregory) Cleve, 1894, Kgl. svenska vetensk. akad. Handl., v. 26, no. 2, p. 183.
Hustedt, *in* Pascher, 1930, Die Süsswasser-flora Mitteleuropas, no. 10, p. 376, fig. 701.
Gomphonema lanceolatum insigne (Gregory) Cleve. Boyer, 1927, Acad. Nat. Sci. Philadelphia Proc., v. 79, supp., p. 295.

Description.—Valve lanceolate-clavate to almost lanceolate, rounded on upper end, but tapering to a somewhat more acutely pointed lower end; axial area about one-fourth the width of the valve; asymmetrical central area formed by a few striae lacking on one side of valve; single stigma, not prominent, on opposite side from central area; transverse striae about 10 in 10μ. finely punctate. Length, 34μ to 58μ; width, 8μ to 10μ.

Frequent in USGS diatom locality 5976.

The variety is common in a wide range of modern fresh-water environments.

Known geologic range.—From early Miocene to present.

Length of figured specimens (USGS diatom cat. Nos. 3702–19, 3702–39, and 3702–45), 55μ, 52μ, 54μ.

Family NITZSCHIACEAE Grunow, 1860
Subfamily NITZSCHIOIDEAE Grunow, 1860
Genus HANTZSCHIA Grunow, 1880

Hantzschia recta Andrews, n. sp.

Plate 2, figures 19–22

Diagnosis.—Valve linear, long and narrow; ventral margin straight to slightly convex; dorsal margin nearly straight at center and curving convexly toward the apices in some specimens, slightly convex throughout its length in other specimens; apices attenuated, terminating in small, rounded, subcapitate ends; keel puncta about 5 to 8 in 10μ, irregularly spaced; transverse striae fine, about 22 in 10μ. Length, 66 to 83μ; width, about 6μ to 8μ.

Holotype: USGS diatom catalog No. 3737–28 (pl. 2, fig. 19), length, 83μ; width, 8μ. Paratype: USGS diatom catalog No. 3737–17 (pl. 2, fig. 20), length, 72μ; width, 8μ. Paratype: USGS diatom catalog No. 3737–23 (pl. 2, figs. 21, 22), length, 80μ; width, 6μ.

Remarks.—This species differs from modern freshwater species of *Hantzschia* in lacking the arcuate outline caused by a concave ventral margin. The transverse striae are also finer and more closely spaced.

The species is frequent in USGS diatom locality 5976.

Known geologic range.—Early Miocene.

SELECTED REFERENCES

Andrews, G. W., 1966, Late Pleistocene diatoms from the Trempealeau Valley, Wisconsin: U.S. Geol. Survey Prof. Paper 523–A, 27 p., 3 pls.

——— 1970, Late Miocene nonmarine diatoms from the Kilgore area, Cherry County, Nebraska: U.S. Geol. Survey Prof. Paper 683–A, 24 p., 3 pls.

Brun, Jacques, 1880, Diatomées des Alpes et du Jura, et de la region Suisse et Française des environs de Genève: Paris, 145 p., 9 pls.

Cook, H. J., 1960, New concepts of Late Tertiary major crustal deformations in the Rocky Mountain region of North America: Internat. Geol. Cong., 21st, Copenhagen, 1960, Rept., pt. 12, p. 198–212.

Cook, H. J., and Cook, M. C., 1933, Faunal lists of the Tertiary Vertebrata of Nebraska and adjacent areas: Nebraska Geol. Survey, Paper 5, 58 p.

Darton, N. H., 1899, Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U.S. Geol. Survey Ann. Rept. 19, pt. 4, p. 719–785, pls. 74–117.

Dunbar, C. O., 1949, Historical geology: New York, John Wiley and Sons, 567 p.

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: Am. Jour. Sci., v. 262, no. 2, p. 145–198.

Hatcher, J. B., 1902, Origin of the Oligocene and Miocene deposits of the Great Plains: Am. Philos. Soc. Proc., v. 41, no. 169, p. 113–131.

Hendey, N. I., 1937, The plankton diatoms of the southern seas: Discovery Reports, v. 16, p. 151–364, pls. 6–13.

Hustedt, Friedrich, 1927–30, 1931–59, 1961–66, Die Kieselalgen Deutschlands, Österreichs, und der Schweiz, Band 7 *of* Rabenhorst, G. L., Kryptogamenflora ***: Leipzig, Akademische Verlagsgesellschaft, pt. 1, 920 p., 542 figs., 1927–30; pt. 2, 845 p., 637 figs., 1931–1959; pt. 3, lieferungen 1–4, p. 1–816, figs. 1180–1788, 1962–66.

——— 1930, Bacillariophyta (Diatomeae), Heft 10 *of* Pascher, Adolf, ed., Die Süsswasser-flora Mitteleuropas: Jena, Gustav Fischer, 466 p., 875 figs.

Karsten, George, 1928, Bacillariophyta (Diatomeae), *in* Engler, Adolf, Die natürlichen Pflanzenfamilien. Band 2, Peridineae (Dinoflagellatae), Diatomeae (Bacillariophyta), Myxomycetes: Leipzig, Wilhelm Engelmann, p. 105–303, 329 figs.

Keroher, G. C., and others, 1966, Lexicon of geologic names of the United States for 1936–1960: U.S. Geol. Survey Bull. 1200, 3 v., 4341 p.

Lohman, K. E., and Andrews, G. W., 1968, Late Eocene nonmarine diatoms from the Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Prof. Paper 593–E, 26 p., 2 pls.

Lugn, A. L. 1938, The Nebraska State Geological Survey and the "Valentine problem": Am. Jour. Sci., 5th ser., v. 36, no. 213, p. 220–227.

——— 1939, Classification of the Tertiary System in Nebraska: Geol. Soc. America Bull., v. 50, no. 8, p. 1245–1275, 1 pl.

Moore, R. C., 1954, Kingdom of organisms named Protista: Jour. Paleontology, v. 28, no. 5, p. 588–598.

Patrick, Ruth, and Reimer, C. W., 1966, The diatoms of the United States, v. 1: Acad. Nat. Sci. Philadelphia Mon. 13, 688 p., 64 pls.

Schütt, Franz, 1896, Bacillariales (Diatomeae), *in* Engler, Adolf, and Prantl, K. A. E., Die natürlichen Pflanzenfamilien: Leipzig, pt. 1, Abt. 1b, p. 31–153, 282 figs.

Schultz, C. B., 1938, the Miocene of western Nebraska: Am. Jour. Sci., 5th ser., v. 35, p. 441–444.

——— 1941, The pipy concretions of the Arikaree: Nebraska Univ. State Mus. Bull., v. 2, no. 8, p. 69–82.

Schultz, C. B., and Stout, T. M., 1961, Field conference on the Tertiary and Pleistocene of western Nebraska: Nebraska Univ. State Mus. Spec. Pub. 2, 55 p.

Van Heurck, Henri, 1880–85, Synopsis des diatomées de Belgique: Anvers, Atlas, pls. 1–30, 1880; pls. 31–77, 1881; pls. 78–103, 1882; pls. 104–132, 1883; text, index to Atlas, 120 p., 1884; text, description, 235 p., 1885.

Wood, H. E., 2d, and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48, 1 pl.

INDEX

[Italic page numbers indicate major references and descriptions]

PLATES 1, 2

Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225.

PLATE 1

FIGURE 1, 2. *Melosira italica* (Ehrenberg) Kützing, × 960, (p. E8).
- 1. USGS diatom cat. No. 3702–25. Diameter, 15 μ.
- 2. USGS diatom cat. No. 3702–20. Diameter, 11 μ.

3, 4. *Fragilaria brevistriata* Grunow, × 960, (p. E9).
- 3. USGS diatom cat. No. 3737–37. Length, 15 μ.
- 4. USGS diatom cat. No. 3737–38. Length, 15 μ.

5, 6. *Fragilaria brevistriata* var. *inflata* (Pantocsek) Hustedt, × 960, (p. E9).
- 5. USGS diatom cat. No. 3737–39. Length, 12 μ.
- 6. USGS diatom cat. No. 3702–42. Length, 16 μ.

7. *Eunotia* sp. × 960, (p. E9). USGS diatom cat. No. 3704–19. Length, 29 μ.

8, 9. *Cocconeis placentula* Ehrenberg, × 960, (p. E9).
- 8. USGS diatom cat. No. 3704–12. Length, 27 μ.
- 9. USGS diatom cat. No. 3700–1. Length, 24 μ.

10, 11. *Achnanthes cincta* Andrews, n. sp., × 960, (p. E10).
- 10. Holotype, USGS diatom cat. No. 3737–35. Length, 21 μ. Pseudoraphe valve.
- 11. Holotype, raphe valve.

12, 13. *Anomoeoneis bicapitata* Andrews, n. sp., × 960, (p. E10).
- 12. Holotype, USGS diatom cat. No. 3704–16. Length, 26 μ.
- 13. Paratype, USGS diatom cat. No. 3704–15. Length, 33 μ.

14. *Anomoeoneis costata* (Kützing) Hustedt, × 960, (p. E10). USGS diatom cat. No. 3702–36. Length, 38 μ.

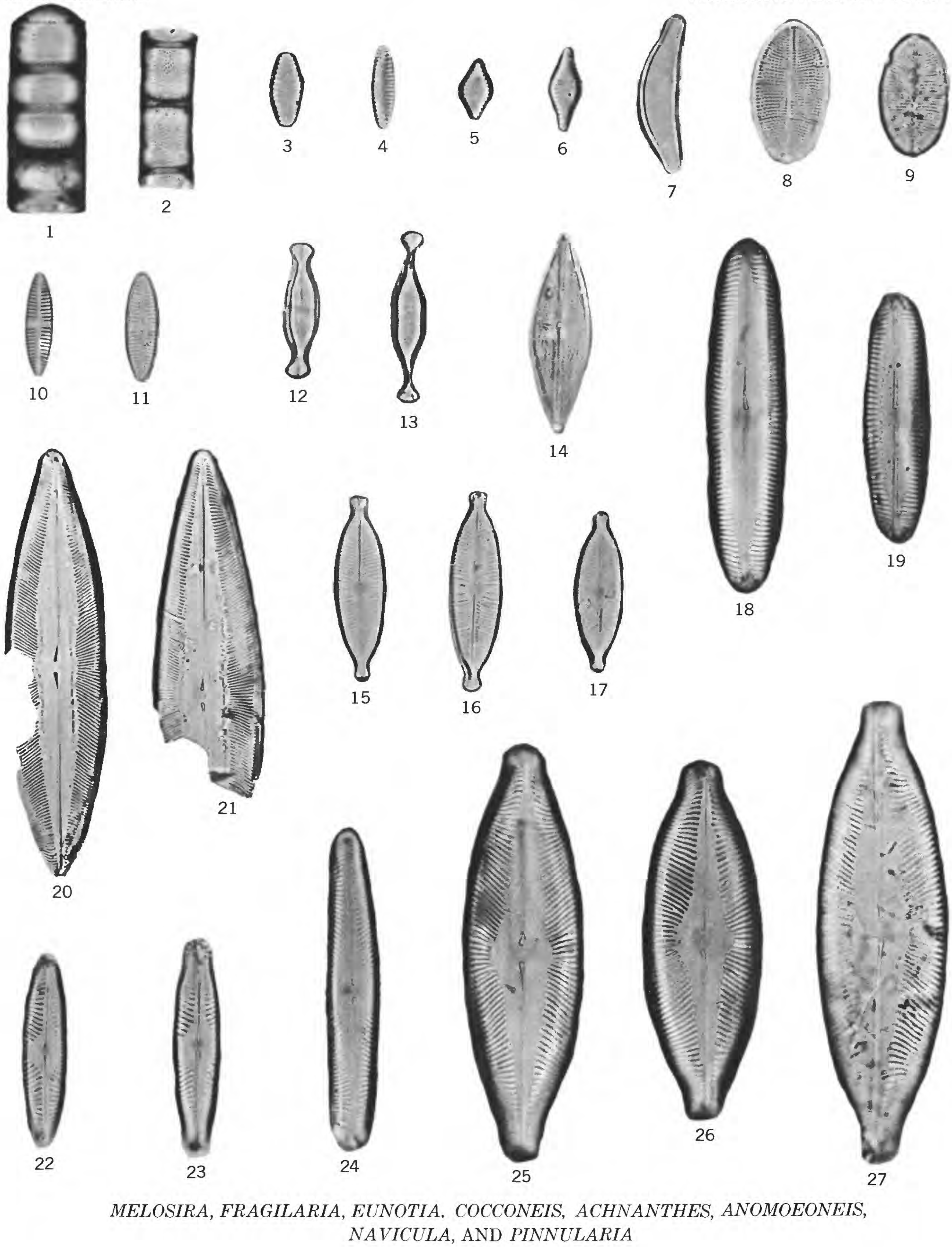
15–17. *Navicula netroformis* Andrews, n. sp., × 960, (p. E10).
- 15. Holotype, USGS diatom cat. No. 3702–34. Length, 35 μ.
- 16. Paratype, USGS diatom cat. No. 3703–5. Length, 37 μ.
- 17. Paratype, USGS diatom cat. No. 3737–8. Length, 30 μ.

18, 19. *Pinnularia brevicostata* Cleve, × 960, (p. E11).
- 18. USGS diatom cat. No. 3737–16. Length, 65 μ.
- 19. USGS diatom cat. No. 3702–24. Length, 45 μ.

20, 21. *Pinnularia elliptica* Lohman and Andrews, × 475, (p. E11).
- 20. USGS diatom cat. No. 3702–16. Length, about 166 μ.
- 21. USGS diatom cat. No. 3702–29. Length, about 190 μ.

22–24. *Pinnularia microstauron* (Ehrenberg) Cleve, × 960, (p. E12).
- 22. USGS diatom cat. No. 3737–31. Length, 35 μ.
- 23. USGS diatom cat. No. 3702–47. Length, 40 μ.
- 24. USGS diatom cat. No. 3737–27. Length, 60 μ.

25–27. *Pinnularia fusana* Andrews, n. sp., × 960, (p. E11).
- 25. Holotype, USGS diatom cat. No. 3737–10. Length, 78 μ.
- 26. Paratype, USGS diatom cat. No. 3702–31. Length, 68 μ.
- 27. Paratype, USGS diatom cat. No. 3702–4. Length, 87 μ.



MELOSIRA, FRAGILARIA, EUNOTIA, COCCONEIS, ACHNANTHES, ANOMOEONEIS, NAVICULA, AND *PINNULARIA*

PLATE 2

FIGURE 1, 2. *Pinnularia scapha* Lohman and Andrews, × 960, (p. E12).
- 1. USGS diatom cat. No. 3699–18. Length, 48 μ.
- 2. USGS diatom cat. No. 3702–35. Length, 50 μ.

3–5. *Pinnularia subrostrata* Lohman and Andrews, × 960, (p. E12).
- 3. USGS diatom cat. No. 3699–19. Length, 54 μ.
- 4. USGS diatom cat. No. 3737–11. Length, 60 μ.
- 5. USGS diatom cat. No. 3699–13. Length, 52 μ.

6, 7. *Amphora deflecta* Andrews, n. sp., × 960, (p. E12).
- 6. Holotype, USGS diatom cat. No. 3700–9. Length, 34 μ.
- 7. Paratype, USGS diatom cat. No. 3699–20. Length, 26 μ.

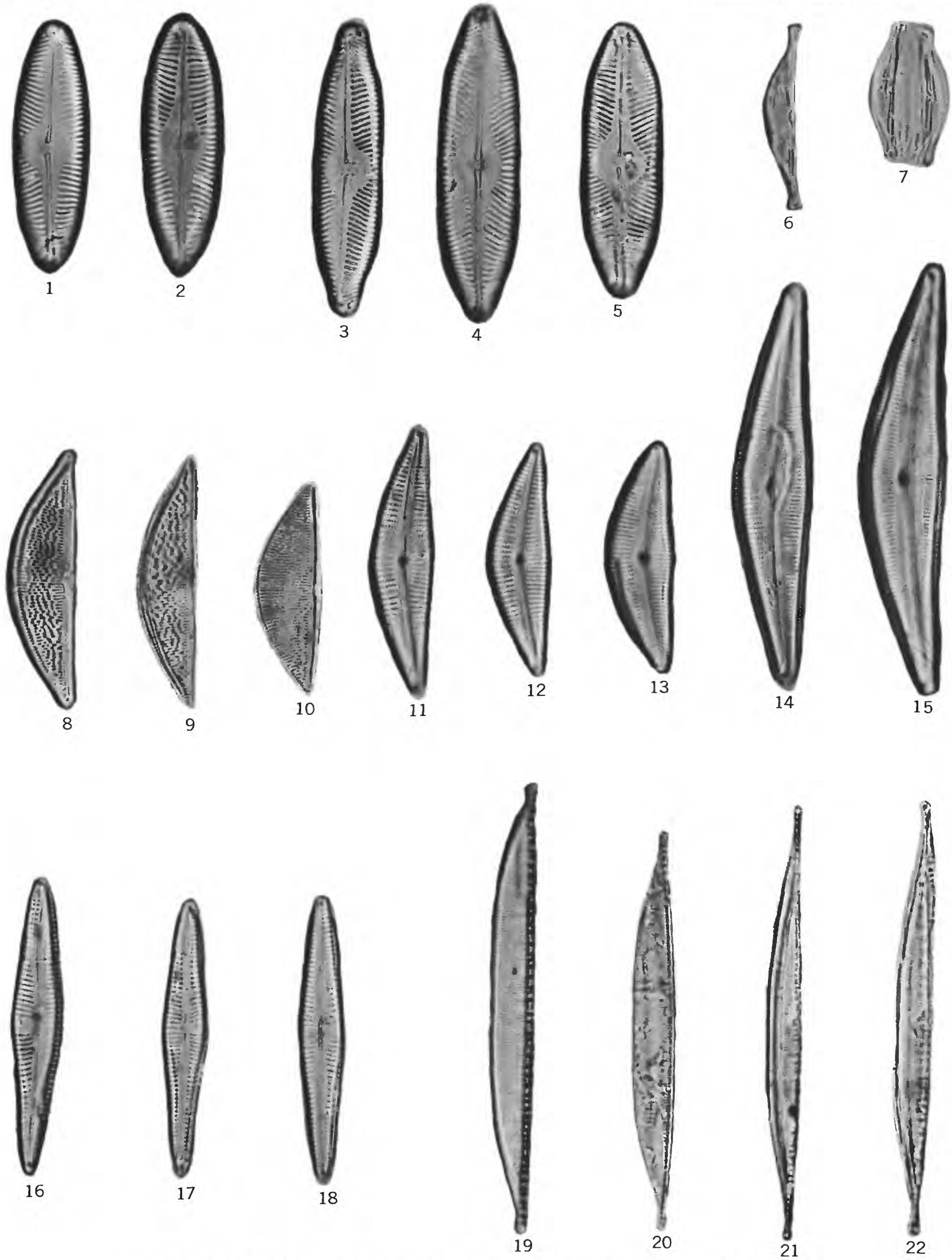
8–10. *Amphora punctata* Andrews, n. sp., × 960, (p. E13).
- 8. Holotype, USGS diatom cat. No. 3443–7. Length, 48 μ.
- 9. Paratype, USGS diatom cat. No. 3443–13. Length, 47 μ.
- 10. Paratype, USGS diatom cat. No. 3702–33. Length, 40 μ.

11–13. *Cymbella cistula* var. *maculata* (Kützing) Van Heurck, × 960, (p. E13).
- 11. USGS diatom cat. No. 3702–5. Length, 49 μ.
- 12. USGS diatom cat. No. 3702–28. Length, 44 μ.
- 13. USGS diatom cat. No. 3704–2. Length, 43 μ.

14, 15. *Cymbella lanceolata* (Ehrenberg) Brun, × 960, (p. E13).
- 14. USGS diatom cat. No. 3704–17. Length, 74 μ.
- 15. USGS diatom cat. No. 3702–5. Length, 80 μ.

16–18. *Gomphonema affine* var. *insignis* (Gregory) Andrews, × 960, (p. E14).
- 16. USGS diatom cat. No. 3702–19. Length, 55 μ.
- 17. USGS diatom cat. No. 3702–39. Length, 52 μ.
- 18. USGS diatom cat. No. 3702–45. Length, 54 μ.

19–22. *Hantzschia recta* Andrews, n. sp., × 960, (p. E14).
- 19. Holotype, USGS diatom cat. No. 3737–28. Length, 83 μ.
- 20. Paratype, USGS diatom cat. No. 3737–17. Length, 72 μ.
- 21. Paratype, USGS diatom cat. No. 3737–23. Length, 80 μ. Top valve.
- 22. Same specimen as figure 21, bottom valve.



PINNULARIA, AMPHORA, CYMBELLA, GOMPHONEMA, AND *HANTZSCHIA*