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Biostratigraphy, Paleomagnetism and Sedimentology of Late Cenozoic Sediments in Northwestern Hokkaido, Japan

By

Hiroshi Ujiié

Department of Paleontology, National Science Museum, Tokyo

Tsunemasa Saito, Dennis V. Kent, Peter R. Thompson

Lamont-Doherty Geological Observatory of Columbia University, New York

Hakuyu Okada

Geoscience Institute, Shizuoka University, Shizuoka

George deVries Klein

Sedimentology Laboratory, Department of Geology, University of Illinois, Urbana, Illinois

Itaru Koizumi

Institute of Geological Sciences, Osaka University, Toyonaka

Howard E. Harper, Jr.

Department of Geological Sciences, Harvard University, Massachusetts

and

Tomindo Sato

Japan Petroleum Exploration Company, Otemachi, Tokyo

Abstract

Four Neogene sedimentary basins in northwestern Hokkaido (latitudes 44°–45° N.), the northernmost island of Japan, were studied to establish a combined microfossil-paleomagnetic sedimentologic stratigraphy. The measured section near Atsuta encompasses a shoaling depositional sequence from upper bathyal depths in the lower part to stagnant, nearshore conditions near the top of the sequence. Magnetostratigraphic evidence and age-diagnostic diatoms indicate the section to be Late Miocene age covering the interval from early Epoch 5 through Epoch 6, and possibly to late Epoch 7.

The second measured section located north of Shosanbetsu exposes sediments derived from a volcano-clastic source and deposited on a continental slope with oversteepened slopes. Rich diatom floras from the sequence are assignable to the *Denticula seminae* var. *fossilis–D. kamtschatica* and *D. kamtschatica* Zones. A mag-

netic signature containing one reversal was observed in the upper part of the section, although the data seem to indicate the lower section to be dominantly normally magnetized. In the northwest Pacific deep-sea sequences, the zonal boundary of these two diatom zones lies between the Nunivak (="b") and "c" Events of the Gilbert Epoch, thus the distinct magnetic reversal observed in the upper part of the sequence is correlated with the top of the Nunivak Event.

Neogene strata developed near Wakkanai City, the northwestern tip of Hokkaido, appear to have been deposited during a time interval of predominantly reversed geomagnetic polarity. Diatom floras suggest a correlation of these strata with the *Denticula kamtschatica* Zone which in turn corresponds, in the northwest Pacific deep-sea sequences, to the lower Gilbert Series below a horizon midway between the Nunivak and "c" Events.

Diatom rich sediments of the Shimo-Ebekorobetsu area belong to the Yuchi Formation and comprise two assemblages assignable to the *D. kamtschatica* Zone and the superjacent *Denticula seminae* var. *fossilis–D. kamtschatica* Zone.

From northern Honshu through Hokkaido to Sakhalin, in the western Pacific coastal region, beds containing the large pecten *Fortipecten takahashii* (YOKOYAMA) constitute a marker horizon useful for inter-regional correlation. In its southern range of distribution, *F. takahashii* is a diagnostic species in the lower part of the Tatsunokuchi Formation from which diatom floras assignable to the *D. seminae* var. *fossilis–D. kamtschatica* Zone are described. The *F. takahashii* bed occurs in the Shosanbetsu section, lying within the same diatom zone as the Tastunokuchi Formation and is in a reversely magnetized interval above the Nunivak Event (3.9 m.y. B.P.).

The Neogene marine sediments of northwestern Hokkaido were deposited in the back-arc basin and reveal evidence of active arc magmatism at the time of deposition. In this tectonically active back-arc region, sediment-collecting basins shifted from area to area, accumulating sediments only for a relatively short period of time when spurts of active subsidence occurred in a given sedimentary basin.

INTRODUCTION

A geological field party consisting of five scientists from the United States (HARPER, KENT, KLEIN, SAITO and THOMPSON), and four from Japan (KOIZUMI, OKADA, SATO and UJIIÉ) was organized in August, 1975, to investigate lithological, micropaleontological and paleomagnetic characteristics of Late Cenozoic sediments exposed along the western and southeastern coast of Hokkaido, the northernmost island of Japan. After arriving in Sapporo in the evening of August 15, all the members gathered, the following morning, at the Sapporo District Mining Office of the Japan Petroleum Exploration Co., Ltd. (JAPEX), to finalize the itinerary and duration of survey of each proposed study area. The JAPEX library containing an extensive collection of the literature on local geology of Hokkaido was a great help in planning our field survey. The afternoon of August 16 was spent visiting Dr. Masao MINATO, Professor of Hokkaido University, who has contributed so much to our knowledge of the geology of Hokkaido (*e.g.*, MINATO *et al.*, 1965). At the conclusion of our pre-field trip meeting, the scope of our study and some of the problems which could be solved through this joint field work were outlined, and are summarized below.

Beginning at around 20 m.y. B.P., orogenic movements occurred in the Japanese Islands (UYEDA and MIYASHIRO, 1974). This orogeny, known as the Mizuho Orogeny, submerged much of the northern half of the Japanese Islands, causing the accumulation of thick sedimentary sequences in various parts of Japan. Thick marine strata were laid in various sedimentary basins of Hokkaido during the Mizuho Orogeny (MINATO *et al.*, pl. 30-23). These sediments should provide an important record of the developmental stages of the orogeny. The delineation of a precise chronology is of fundamental importance to our understanding of the tectonic, sedimentological and climatic history of Hokkaido and other parts of Northeast Japan. Because of the high northern latitude of Hokkaido, such useful planktonic guide fossils as calcareous nannoplankton and planktonic foraminifera have been found to be of little stratigraphic importance. Biostratigraphic zonations established by abundantly occurring siliceous microfossils such as diatoms and Radiolaria, however, have as yet to be fully calibrated with the standard chronostratigraphic framework largely established by means of the varied floras and faunas of tropical and subtropical latitudes.

The major objective of this field work was therefore to establish a multiple microfossil zonal scheme which could be calibrated against the magnetostratigraphy. Under the International Program of Ocean Drilling of the Deep Sea Drilling Project (IPOD), a series of drilling sites is planned for the Kuril Arc and the Sea of Okhotsk, an area just north of Hokkaido. Thus, the multiple microfossil zonations to be established from the sequence Hokkaido are expected to provide an important stratigraphic framework to the planned IPOD operation. With these objectives in mind, the participants of the field work included specialists of diatoms (HARPER and KOIZUMI), benthonic and planktonic foraminifera (SAITO, SATO, THOMPSON and UJIIÉ), Radiolaria (non-participating member, LING), sedimentology (KLEIN, OKADA), and paleomagnetism (KENT).

In order to establish a combined paleomagnetic and microfossil stratigraphy on a reasonably continuous and fossiliferous sedimentary sequence spanning a considerable duration of geologic time, four sedimentary basins developed along the western coast of Hokkaido were selected to be examined by the field party (Fig. 1). These basins are from south to north: 1) the Japan Sea coast south of the town of Atsuta; 2) the Japan Sea coast between Utakoshi and Hatsuura, north of the town of Shosanbetsu; 3) the environs of Wakkanai City; and 4) along tributaries of the Shimo-Ebekorobetsu River in the township of Horonobe. Additional basins in the south-eastern Hokkaido, along the Pacific coast of Japan were visited but no systematic sampling was made due to paucity of suitable sedimentary exposures.

In the foregoing chapters, reports on specific subjects of research by individual investigators are arranged, after which are added general conclusions synthesizing the

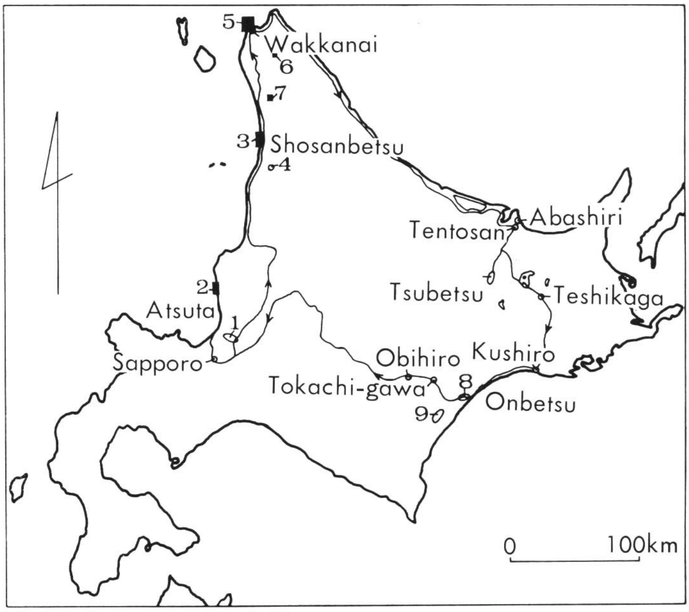


Fig. 1. Location map showing the surveyed areas in Hokkaido. 1. Zaimokuzawa area; 2. Atsuta coast; 3. Shosanbetsu coast; 4. Chikubetsu coal field; 5. Wakkanai area; 6. Magarifuchi area; 7. Shimo-Ebekorobetsu area; 8. Chokubetsu area; 9. Noyaushi area.

results of all the participants. It is recommended that reference to whole or part of this collaborate work be made in one of the following forms, as appropriate:

UJIIÉ, H., SAITO, T., *et al.*, 1977. Biostratigraphy, Paleomagnetism and sedimentology of Late Cenozoic sediments in northwestern Hokkaido, Japan. Bulletin of the National Science Museum, Ser. C (Geol.), Vol. 3, no. 2, pp. 49–102.

KENT, D. V., 1977. Paleomagnetism of Late Cenozoic sediments of Hokkaido, Japan. *In*: UJIIÉ, H., SAITO, T., *et al.*, Biostratigraphy, paleomagnetism and sedimentology of Late Cenozoic sediments in northwestern Hokkaido, Japan. Bulletin of the National Science Museum, Ser. C (Geol.), vol. 3, no. 2, pp. 78–85.

Acknowledgment

This cooperative field work participated by scientists from the United States and Japan was carried out during August and September of 1975. Participation of both Japanese and U.S. scientists was made possible with financial support from the Japan Society of the Promotion of Science (Grant No. 4R028) and the U.S. National Science Foundation (Grant No. OIP75–17409). The laboratory work by the U.S. scientists were further aided by the National Science Foundation (Grant No. DES75–14430). The authors are especially grateful to Dr. Yutaka IKEBE, a member of the Board of Directors of the Japan Petroleum Exploration Company (JAPEX) for making available the company facilities for field work to the project. We wish to thank Dr. Seiichi

KOMURA of the JAPEX Sapporo District Mining Office for providing valuable data on the geology and physiography of the study areas. Mr. N. SAWARA of the JAPEX Sapporo Office kindly assisted in transporting collected samples. Ms. Mary PERRY drafted the stratigraphic columns of the Atsuta and Shosanbetsu sections. Ms. Rusty LOTTI provided overall clerical assistance for the final report. This assistance is greatly appreciated. This is Lamont-Doherty Geological Observatory Contribution No. 2529.

Field Method

The field party decided to sample the sea cliff sections at approximately 8–10 m (vertical) intervals. Using the average regional dip from previously reported measures, the required horizontal distance was calculated. For the actual field work, a 100 m metal tape measure was stretched along the sea shore, and bearings were measured with a Brunton Compass. Because of the often irregular coastline and varying degrees of dip and strike of the strata, the stratigraphic thickness (t) of the Atsuta and Shosanbetsu Sections were calculated according to the methods of MERTIE (1940):

(1) $t=s\ (\sin\alpha\sin\delta\cos\sigma\pm\cos\delta\sin\sigma)$,

where s=the distance between two stations, α=the angle between the traverse bearing and the strike of the bed, δ=the dip angle of the bed, σ=the vertical angle between the elevations of the two stations.

In the case of measuring along the seashore, there is no elevation change and equation becomes:

(2) $t=s\ (\sin\alpha\sin\delta)$.

Unfortunately, as MERTIE (1940) points out, the typical beds encountered in the field are undulating and *e.g.* 2 needs the following adjustment for the resulting curvature:

(3) $\sin\delta=\dfrac{\cos\delta_1\cos\delta_2}{\sin(\delta_2-\delta_1)}\cdot(\sec\delta_2-\sec\delta_1)$,

where δ_1 and δ_2 are the dip of any two adjacent beds.

Since the strikes also vary, the same adjustment is made for the bearing-strike angle α, and both terms are substituted into *e.g.* 2. In these equations, the measurement of the dip angle is particularly critical, and greatly affects the resulting thickness. A large possible error thus could have been introduced into our calculated thicknesses, particularly at the Shosanbetsu Section where the shallow dips are at the limit of reliability for a Brunton Compass.

At each station, a pick was used to expose a fresh sediment surface, and then an oriented paleomagnetic sample and large paleontology samples were collected. Each sample was given a consecutive number: *e.g.* HT4 indicates the fourth sample of the field work and from the Tobetsu Formation, Hokkaido Island. Samples marked with (′) or (″) denote additional samples at a given station from a layer slightly above or below the paleomagnetic sample.

List of samples

1. Zaimokuzawa area
   [Zaimokuzawa Formation]
   HZ1—HZ2
   [Tobetsu Formation]
   HT3
2. Atsuta coast
   [Tobetsu Formation]
   HT4a, b—HT15
   [Morai Formation]
   HM16—HM37
   [Bannosawa Formation]
   HB38—HB39
   [Atsuta Formation]
   HA40—HA47′
3. Shosanbetsu coast
   [Mochikubetsu Formation]
   HMo48—HMo56
   [Embetsu Formation]
   HE57—HE98
4. Chikubetsu coal field
   [Sankebetsu Formation, sandstone]
   HSk1-1—HSk1-2
   [Sankebetsu Formation, alternation]
   HSk2-1—HSk2-3
   [Chikubetsu Formation, sandstone]
   HCh1-1
   [Chikubetsu Formation, mudstone]
   HCh2-1—HCh2-2
5. Wakkanai area
   [Koetoi Formation]
   HK99-HK108
   [Wakkanai Formation]
   HW109-HW123
   [Masuporo Formation]
   HMp124—HMp125
6. Magarifuchi area
   [Masuporo Formation]
   HMp126—HMp130
   [Onishibetsu Formation]
   HO131—133′
   [Soya Coal bearing Formation]
   HS132—133
   [Magarifuchi Formation]
   HMg134—135
7. Shimo-Ebekorobetsu area
   [Yuchi Formation]
   HY136—HY143
8. Chokubetsu area
   [Shiranuka Formation]
   HSn144—HSn145, HSn148—HSn149
   [Atsunai Formation]
   HAt146—HAt147, HAt?152
   [Chokubetsu Formation]
   HC150
   [Nuibetsu Formation]
   HN151, HN153—HN154′
9. Noyaushi area
   [Ikeda Formation]
   HI155
   [Taiki Formation]
   HTk156

GEOLOGIC SETTINGS OF THE STUDY AREAS

T. SAITO and H. UJIIÉ

Introduction

The geology of Hokkaido is being described in a series of 1: 50,000 scale geological maps of Japan surveyed and published by the Geological Survey of Japan and by the Geological Survey of Hokkaido, Hokkaido Development Agency. The areas of our joint field works are all covered by one of these geological maps and detailed geologic data are available for each of the areas. Furthermore, MINATO *et al.* (1965) provided a comprehensive review of the geologic development of the Japanese Islands encompassing much of the data on local geology available at that time. The geologic development of the Japanese Islands has since then been reviewed and synthesized in terms of the concept of plate tectonics by UYEDA and MIYASHIRO (1974).

Atsuta Section

The sampling was largely done along the coast between Morai and Atsuta where a long nearly continuous cliffed coast provides excellent exposures of Late Cenozoic sediments (Fig. 2). The sea cliff is capped by well-developed and level Pleistocene terraces. The present elevation of the terrace immediately above the sea cliff stands about 30 m. The geology of this area was studied by TSUSHIMA *et al.* (1956) who established a stratigraphic succession of marine sediments as follows:

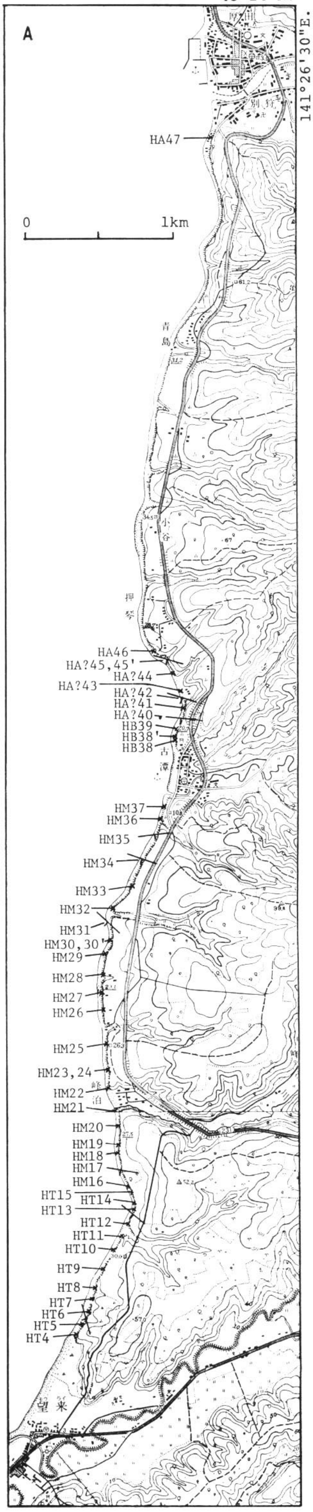
Stratigraphic unit	Lithology	Thickness in meters
Tobetsu Formation	Massive greenish-gray siltstone; base conformable with the subjacent unit.	more than 300
Morai Formation	Stratified siltstone, more strongly lithified than the overlying Tobetsu Formation; base conformable with the subjacent unit.	220–300
Bannosawa Formation	Predominantly green, glauconitic, medium-grained massive sandstone; base conformable with the subjacent unit.	100–350
Atsuta Formation	Dark gray, massive (occasionally stratified) mudstone, containing numerous marly concretions; base conformable with the subjacent unit.	260–700
Hattari Formation	Alternations of sandstone and mudstone; the formation rests unconformably on the Paleozoic Kumanejiri Formation to the north of study area.	500+

In the vicinity of Tobetsu town, just south of the area studied, the Tobetsu Formation is conformably overlain by the Late Pliocene Zaimokuzawa Formation consisting largely of extensively bioturbated, coarse-to-medium-grained sands. A large amount of dessication breccia are also observed in this formation. Molluscan fossils from these formations were reported by TSUSHIMA *et al.* (1956) who used these fossils to reconstruct paleoenvironmental conditions in which these sediments were laid. The following is a summary of their discussion:

Three mollusks, *Thyasira bisecta* (CONRAD), *Serripes* cf. *notabilis* SOWERBY, and *Dentalium* cf. *yokoyamai* MAKIYAMA were reported from the Tobetsu Formation. The megafossil assemblage from the underlying Morai Formation is apparently more diverse and includes *Solemya* (*Acharax*) *tokunagai* (YOKOYAMA), *Acila* (*Acila*) *vigilia* SCHENCK, *Portlandia* (*Megayoldia*) cf. *thraciaeformis* (STORER), *Calyptogena pacifica* DALL, *Thyasira bisecta* (CONRAD) and *Dentalium* cf. *yokoyamai* MAKIYAMA. TSUSHIMA *et al.* (1956) interpreted the assemblage to be indicative of upper bathyal waters. From numerous calcareous concretions of the Bannosawa Formation, these authors

43°24'N.

141°26'30"E.



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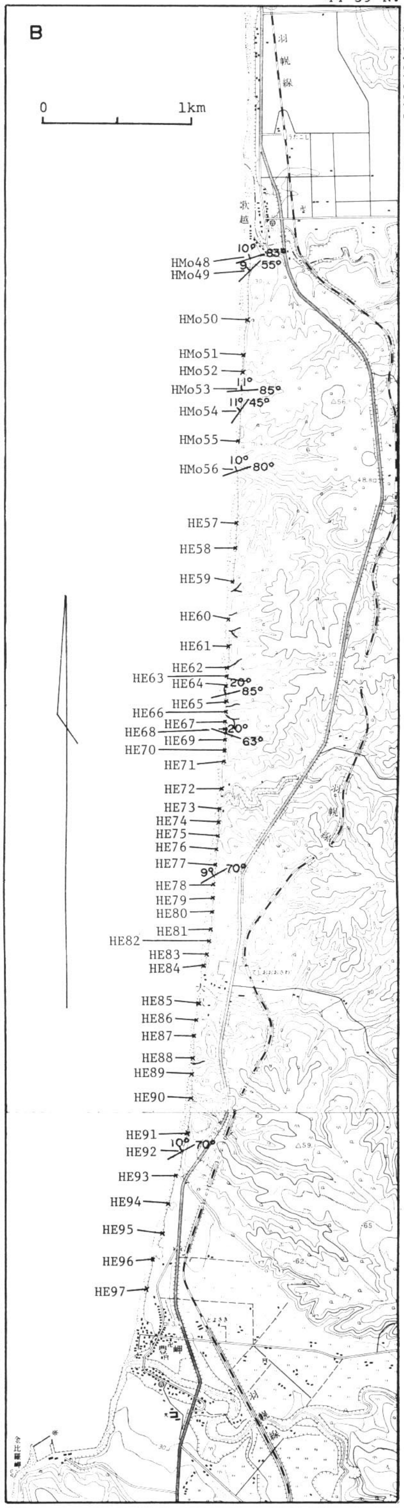
141°48'30"E.



reported *Macoma tokyoensis* MAKIYAMA. Several other fossils found from the Bannosawa include *Acila vigilia* SCHENCK, *Dentalina* cf. *yokoyamai* MAKIYAMA, *Ancistrolepsis* sp. and *Neptunea phoeniceus* DALL. The lower parts of the Bannosawa are regarded to be an equivalent but different facies of the Atsuta Formation. The Atusta Formation yields, among others, *Solemya tokunagai, Adulomya* sp., *Portlandia thraciaeformis, Propeamussium tateiwai* KANEHARA, *Calyptogena pacifica, Periploma bessioensis* (YOKOYAMA), and *Dentalium yokoyamai.* These fossils are interpreted to have been deposited in waters of moderate depth between 100 and 600 meters. Megafossils are very rare in the Hattari Formation and, so far only *Patinopecten yessoensis* (JAY), *Cardium* sp., and *Buccinum* sp. have been reported.

TSUSHIMA *et al.* (1956) point out that many mollusks occurring in the upper parts of the sequence are also present in the lower parts and that no distinct faunal zones are recognizable. These molluscan data are interpreted to indicate that the sequence from the Hattari to Tobetsu Formations were deposited in a gradually changing, but continuous sedimentation cycle.

Shosanbetsu Section

The measured stratigraphic section was located again along the sea coast between the hamlets of Utakoshi and Toyosaki, about 10 km north of the town of Shosanbetsu. Sedimentary sequences are well exposed along a cliffed coast which stretches nearly continuously between these two hamlets. The sea cliff is likewise capped by extensive, well-developed Pleistocene terraces ranging in elevation from 30 to 60 meters. Along the measured section, sediments are in general trending east-northeast and dipping gently to a northerly direction (Fig. 3).

HATA (1961) described the geology of this area. The sequence and lithologies of Late Cenozoic stratigraphic units recognized by him are as follows:

Stratigraphic unit	Lithology	Thickness in meters
Mochikubetsu Formation	Gray, fine-grained sandstone with pebbly sandstone near its top; base conformable with the underlying unit.	120
Embetsu Formation	Gray-to-light bluish-gray, diatomaceous mudstone with a basal, strongly cross-bedded, greenish-gray-to-brownish gray, coarse-grained sandstone of as much as 300 m in thickness; base conformable with the underlying units.	450 – 1000
Kinkomanai Formation	Consisting of three distinct facies: lower dark-gray-to-siltstone, middle gray-to-greenish-gray fine-grained sandstone, and upper dark-gray-to-gray massive siltstone; base unconformably overlying the Kotanbetsu Formation (a correlative formation of the Masuporo Formation of Wakkanai area) with a basal tuffaceous conglomeratic sandstone of 2 to 8 m thick.	

← Fig. 2. Left: Location map along the Atsuta coast. Right: Location map along the Shosanbetsu coast. (For prefix-abbreviation of sampling points, see p. 54. as well as in Figures 3 to 6.)

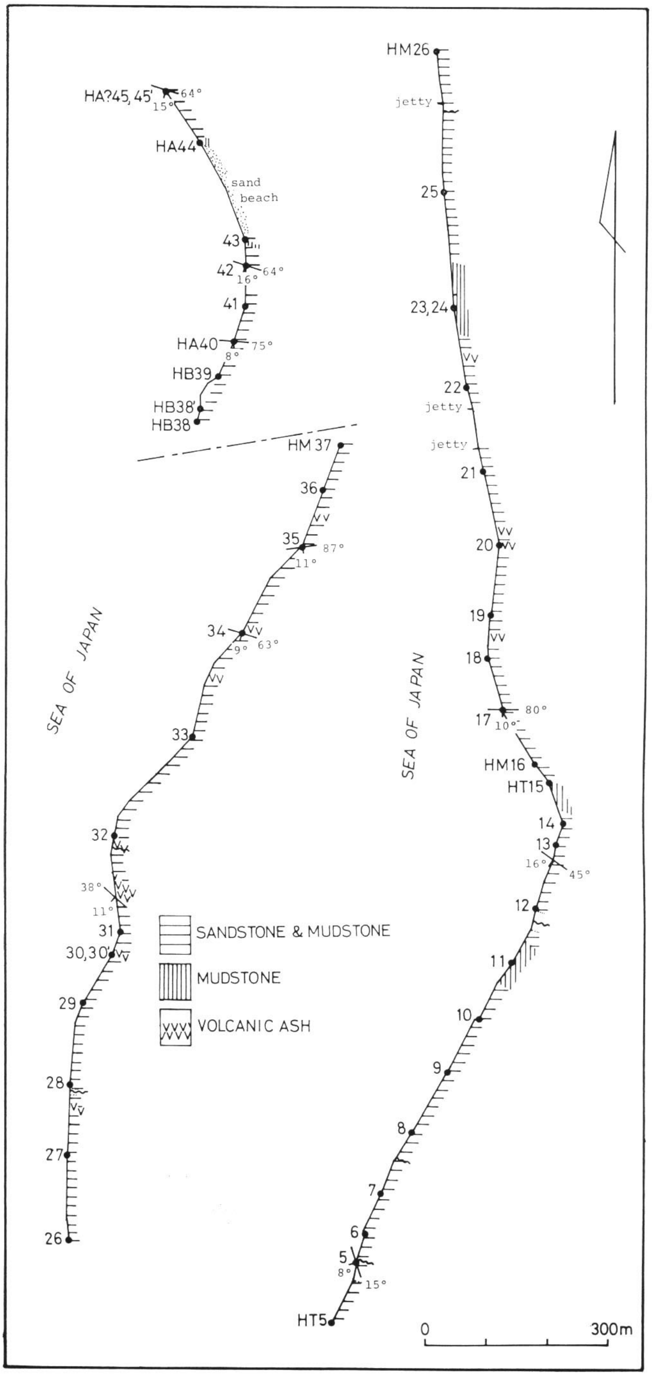


Fig. 3. Route map along the Shosanbetsu coast (original scale 1: 5,000).

Our systematic sampling was carried out from the highest exposed horizon of the Mochikubetsu Formation down to the top of the lower sandstone facies of the Embetsu Formation. Sandstones of the lower sandstone facies are lithified to such a greatly varied degree that systematic collections of geomagnetically oriented samples were very difficult.

Also, because of the stratigraphic hiatus existing between the Kinkomanai and the underlying Kotanbetsu Formation, no attempt was made to sample the latter formation.

HATA (1961, table 10) described a diverse molluscan fauna consisting of more than forty species from the Mochikubetsu Formation. Some characteristic species of the fauna include *Acila gottschei* (BÖHM), *Astarte borealis* SCHUMACHER, *Clinocardium californiense* DESHAYES, *Glycymeris yessoensis* (SOWERBY), *Dosinia japonica* (REEVE), *Macoma calcarea* (GMELIN), *M. incongrua* (MARTENS), *Mactra sulcataria* REEVE, *Cadella lubrica* (GOULD), *Panope japonica* Adams, and *Fortipecten takahashii* (YOKOYAMA). HATA (1961) interprets these mollusks to have been deposited in shallow marine environments having water temperature of slightly warmer than that existing today off the coast of study area.

In considering the age of the Mochikubetsu Formation, the occurrence of *Fortipecten takahashii* is particularly noteworthy. This large species (more than 12 cm in diameter) of the Pectinidae with its strongly convex right valve, was originally described by YOKOYAMA in 1930 from Sakhalin, and, since then, it was reported as far south as Namie-machi (approximately at latitude 37°30′N.), Fukushima Prefecture on the Pacific side of the Japanese Islands (HAYASAKA and HANGAI, 1966). In its southern range of distribution, *Fortipecten takahashii* is a diagnostic species in the lower part of the Tatsunokuchi Formation from which diatom floras were described by KOIZUMI (1972; 1973). The occurrences of *F. takahashii* in northern Japan were summarized by MASUDA (1962), who showed that this species is stratigraphically short-ranging but has a wide geographic distribution. ZHIDKOVA *et al.* (1968) examined the distribution of *F. takahashii* in Sakhalin and established the *Fortipecten takahashii–Swiftpecten swiftii* var. *etchegoini* Assemblage-zone to represent the interval defined by them as "Middle Pliocene". HATA (1961) noted the occurrence of *F. takahashii* at about 600 m south of the hamlet of Utakoshi in the same sea cliff examined by us. The HATA's locality roughly corresponds to our sampling location 51 or 52 where we also noted the presence of pelecypods (Fig. 23, see Shosanbetsu section summary). The significance of *F. takahashii* for stratigraphic correlation of Late Neogene sediments of Hokkaido will be discussed more fully in our concluding chapter.

Megafossils are rarely found from the mudstone facies of the Embetsu Formation. During our field work, *Neptunea vinosa* (DALL)* was found in the vicinity of our sampling location 78. From the sandstone facies assigned by us to the top of the Kinkomanai Formation, HATA (1961) reported *Portlandia* (*Megayoldia*) *thraciaeformis*

* This gastropod was described from the Yuchi Formation exposed along the Paromautnai River, approximately 180 km north of Location 78, by KANEHARA (1937).

(STORER), *Thyasira bisecta* (CONRAD), *Spisula* (*Mactromeris*) *voyi* (GABB), *Spisula* (*Spisula*) cf. *sachalinensis* (SCHENCK), *Macoma optiva* (YOKOYAMA), etc.

The Environs of Wakkanai

Wakkanai City is the northernmost population center (latitude 45°25′N.) in Japan and is located on the western shore of the Gulf of Soya. The city clings to a narrow coastal plain extending along the foot of a northerly trending mountainous terrain (highest elevation 210.8 m) which juts out to the Sea of Japan forming the Cape Noshappu at its northern terminus (Fig. 4). Samplings were carried out along many steep gullies which cut into the mountainous terrain.

The geology of Wakkanai City and its environs was described by OSANAI (1954) who established the following stratigraphic succession:

Stratigraphic unit	Lithology	Thickness in meters
Koetoi Formation	Greenish-gray, massive diatomaceous mudstone; lithological change from the Koetoi to the underlying unit conformable and very gradual.	850+
Wakkanai Formation	Dark gray, indurated, hard, thinly bedded mudstone, occasionally intercalating tuff layers; base not exposed in the Wakkanai region.	1000+

The Koetoi Formation is unconformably overlain by the Pleistocene Numakawa Formation which consists of brackish water to lacustrine sand, gravel and clay. No molluscan fossils have so far been reported from the Koetoi Formation. The Wakkanai Formation yields fish scales throughout and occasionally fossil mollusks. However, taxonomically identifiable mollusks come generally from the lower part since the shells in the middle and upper parts of the formation are mostly found as casts. The mollusks reported by OSANAI (1954) from the Wakkanai include *Solemya tokunagai* YOKOYAMA, *Sarepta* cf. *speciosa* ADAMS, *Portlandia japonica* (ADAMS and REEVE), *Thyasira bisecta* (CONRAD), *Serripes pauperculus* (YOKOYAMA), *S. groenlandicus* (BRUGUIÈRE), and *S. yokoyamai* OTUKA. No environmental interpretation of the fauna was given by him.

In the Makubetsu River valley, in the vicinity of the town of Magarifuchi, about 25 km to the southeast of Wakkanai City, marine formations underlying the Wakkanai Formation are exposed. These are the Masuporo Formation and the subjacent Onishibetsu Formation. The Masuporo is unconformably overlain by the Wakkanai but it is conformable with the underlying Onishibetsu. TAKAHASHI and ISHIYAMA (1968) described the geology of this area. The Masuporo Formation, nearly 1,500 m thick, consists largely of dark bluish gray silty sandstone and grades downward into a basal conglomeratic facies frequently containing large boulders. The Onishibetsu is only from 30 to 40 m thick and consists of blue-greenish gray siltstone. Molluscan

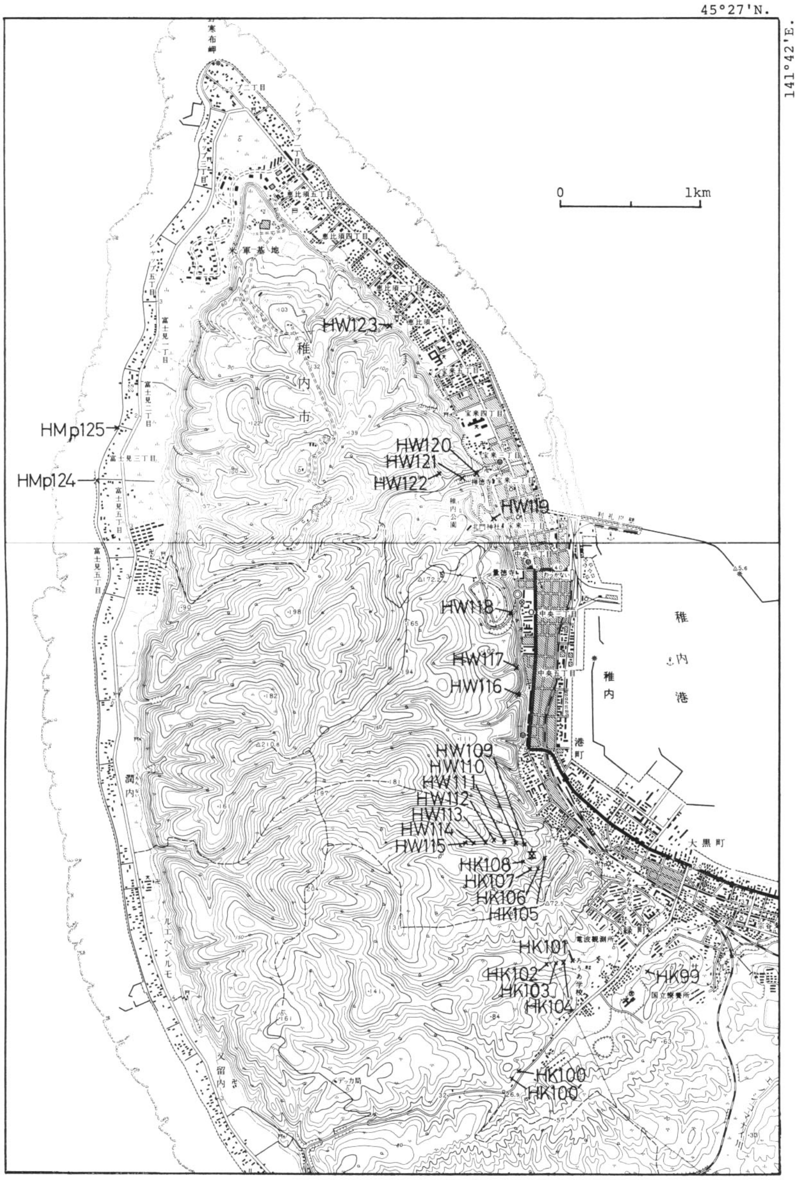


Fig. 4. Location map in the Wakkanai area.

fossils of the Onishibetsu Formation include *Periploma besshoensis* (YOKOYAMA), *Portlandia scapha* (YOKOYAMA), *P. japonica* (ADAMS and REEVE), *Macoma optiva* (YOKOYAMA), and *M. tokyoensis* (YOKOYAMA) and are correlated with a molluscan fauna described from the Chikubetsu Formation of Early Miocene age (KANNO and MATSUNO, 1960). The type section of the Chikubetsu Formation, located about

30 km southeast of the Shosanbetsu section was also studied by us. No paleomagnetic samples were taken from the Magarifuchi locality, but sediments were collected for microfossil analyses along the Uryuya-gawa River valley (Fig. 5).

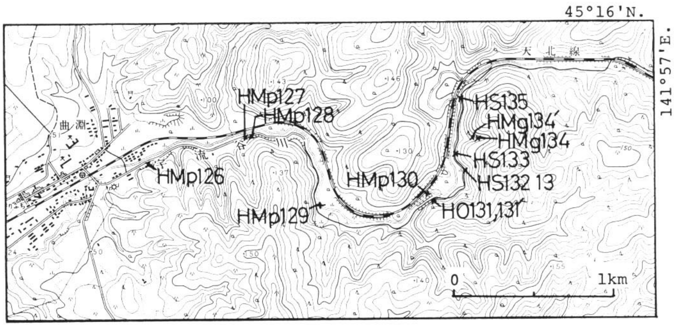


Fig. 5. Location map in the Magarifuchi area.

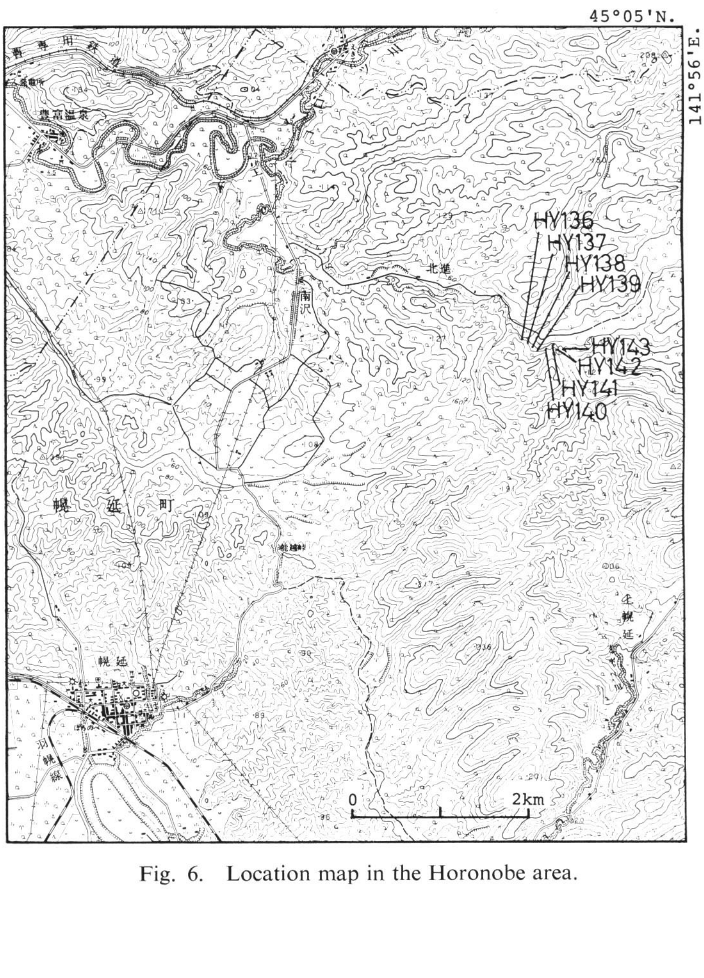


Fig. 6. Location map in the Horonobe area.

Preliminary study of diatoms by KOIZUMI indicates that samples HMp126–129 from the Masuporo Formation can be assigned to the *Denticula lauta* Zone of KOIZUMI (1973) which was in turn correlated by him with the *Orbulina suturalis–Globorotalia peripheroronda* Partial-range Zone (Zone N. 9) of BLOW (1969). Neither diatoms or foraminifera were found in our samples from the Onishibetsu Formation.

Tributaries of Shimo-Ebekorobetsu River

The geology of this area was described in detail by NAGAO (1960). In the Penke-Ebekorobetsu River bed, a tributary of the Shimo-ebekorobetsu River, bluish-dark-gray, fine-grained sandstones of the Yuchi Formation are well exposed (Fig. 6). The Yuchi Formation has a wide geographic distribution in the gently undulating, hilly terrain of the northwestern coastal region of Hokkaido from just south of Wakkanai to the town of Embetsu over the distance of some 70 km (TAKAHASHI and ISHIYAMA, 1968; HATA and TSUSHIMA, 1969). The characteristic molluscan fossils reported from this formation include *Acila gottschei* (BÖHM) and *Fortipecten takahashii*. The latter species also occurs in the Mochikubetsu Formation as mentioned previously under the Atusta Section. Because of its wide geographic distribution and of its distinct molluscan fauna, the Yuchi Formation was selected for our study. The formation at this locality yields a rich diatom flora, but no foraminifera have been found. The diatom floras are described in detail by HARPER in the latter part of this report.

SEDIMENTARY FACIES AND DEPOSITIONAL STYLE

G. de V. KLEIN

This section describes the depositional facies of the sedimentary rocks at the sections at Atsuta and Shosanbetsu (Hatsuura) where adequate outcrop control exists. Each facies is subdivided according to dominant lithologic type, grain size distribution, association of sedimentary structures, types of sedimentary sequences and biogenic structures. These parameters permit determination of the mode of sediment deposition and the environment of deposition. Our approach follows that of DERAAF *et al.* (1965), KLEIN (1975) and KLEIN *et al.* (1972).

Facies 1

Main Facts: This facies occurs only at the section at Atsuta and is represented in the Tobetsu, Morai, Bannosawa and Atsuta Formations. This facies consists of volcano-clastic siltstones which are light to dark gray. Interbedded in subordinate amounts are coarser-grained, sand-sized, graded volcanic ash beds and mudstone layers. The dominant component of each unit is volcanic ash and associated plagioclase and hornblende.

In the upper part of Facies 1, limestone nodules are present, occurring within a narrow interval from about 65 to 85 meters from the top of the section. These nodules are of replacement origin. Within the middle zone of this facies, calcareous nodules and carbonate replacement zones are present. These are less erodable on sea cliffs and range in diameter from 10 cm to 3 m.

Sedimentary structures are rare in this facies. Many of the coarser ash beds show graded bedding; in some instance, the graded beds are amalgamated with particle sizes changing from coarse granule to fine sand (Fig. 7). The siltstone beds are also graded, and in fact grade up into interbedded mudstones. Within this facies, a cyclic repetition of siltstone and mudstone is common, with the basal portion of the siltstones showing a sharp contact. The upper siltstone beds grade upward into a mudstone (Fig. 8). Each such alternation is about 1 m thick. This motif of sedimentation is common in the lower half to third of the section and provides a distinct bedding style similar to coarser-grained flysch successions. In the lower third of this facies, the sand content increases to about 20 percent. Here, graded bedding and parallel laminae are more common.

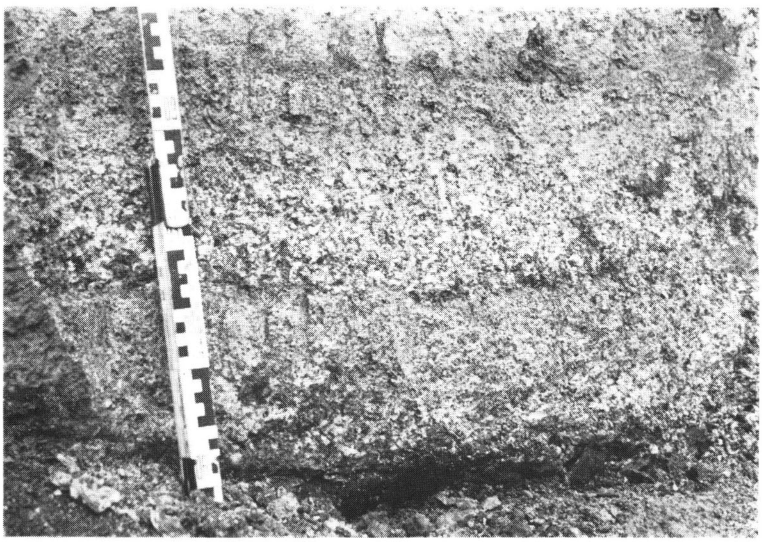


Fig. 7. Amalgamated graded volcanic ash beds, Atsuta. Scale in cm.

Several horizons are bioturbated, with the trace fossil *Chondrites* being the most common type. A reworked shallow-water pelecypod, *Mactra* sp., was also recovered.

Origin of Facies 1: Facies 1 was derived dominantly from a volcanic island arc source. The depositional mode of sedimentation was a combination of ash falls, turbidity currents and hemipelagic processes. Both sandy and silty turbidites were emplaced within a shelf-edge continental slope environment representing the eastern edge of an enlarged version of the present Sea of Japan. Evidence for silty and sandy

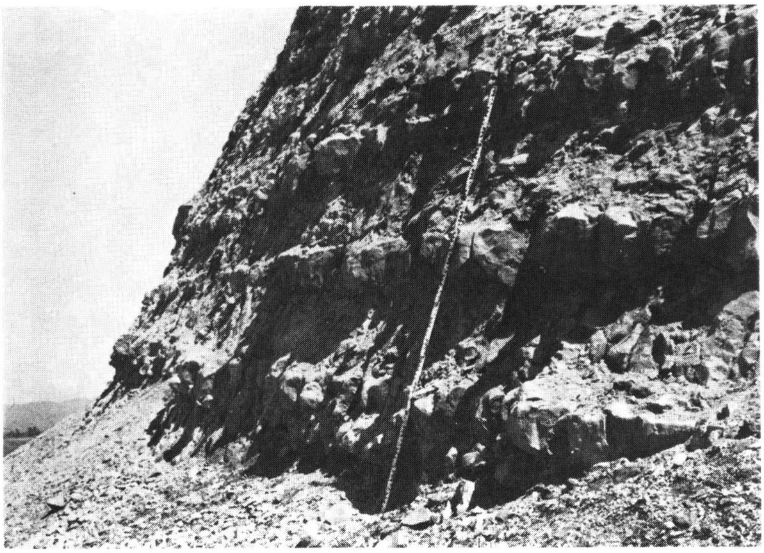


Fig. 8. Repeated cyclic arrangement of coarse siltstone grading into fine siltstone and mudstone, Atsuta. Scale in cm.

turbidites includes the graded ash layers, graded ashy sandstone layers and the alternations of siltstone grading into mudstones (Fig. 8). Unusual in this facies are the silty graded cycles which, although common to several deep-water marginal basins such as the Shikoku Basin and West Philippine Sea (KARIG, INGLE *et al.*, 1975), are rare or absent in most land successions.

Facies 2

Main Facts: This facies is exposed at the Shosanbetsu section and characterizes the Mochikubetsu, upper Embetsu and Kotanbetsu Formations. The dominant lithology of Facies 2 consists of dark gray mudstone containing fine-grained ash and clay minerals. Within this mudstone, however, are slump blocks of sandstone ranging in diameter from 20 cm to 5 m (Fig. 9). These sandstone blocks are sometimes folded and contorted; internally, they are parallel-laminated, micro-cross-laminated or cross-stratified (at top of facies). The slump blocks show imbrication in one horizon 900 meters from the top.

Besides the sedimentary structures within the slump blocks themselves, the only other structures present are thick-bedding, demarcated by changes of the mudstone to a much siltier phase, and load casts, which were observed 250 m from the top of the Shosanbetsu section.

Within this facies, a variety of reworked fossils were observed. These include pelecypods, gastropods (including *Neptunea vinosa*) and shallow-water foraminifera (*Cribroelphidium ezoense*). In addition, charcoal fragments and a fragment of bored

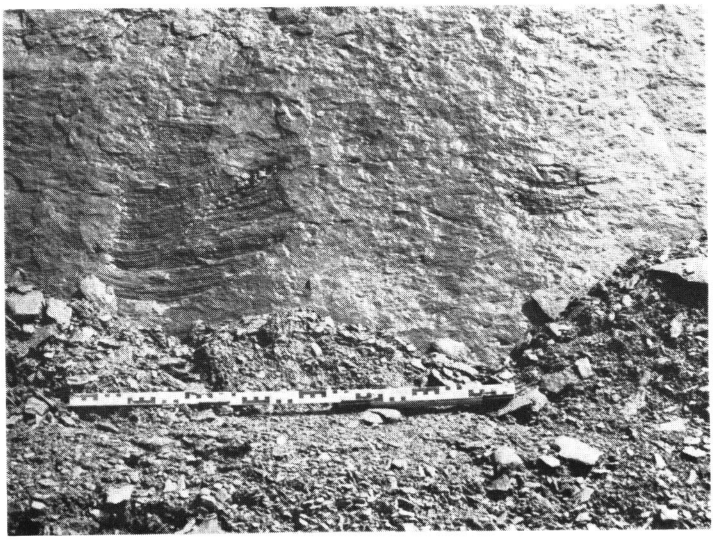


Fig. 9. Slump blocks of partly deformed bedded sandstone encased in silty mudstone, Shosanbetsu. Scale in cm.

wood were observed.

Origin of Facies 2: This facies was also derived from a volcano-clastic source. The environmente of deposition appears to be either a continental slope, or a delta front, both with oversteepened slopes. The presence of small- to medium-sized slump blocks within the Facies 2 mudstones is similar to the slump phenomena of a larger scale described by SHEPARD (1973) from the Magdelena Delta of Colombia, and by COLEMAN (1976) from the Mississippi Delta. The continuous thickness of this facies, in excess of 1,200 m, argues against a deltaic succession, in our view, and is more consistent with a continental slope environment where similar slump features are common to areas of oversteepened slopes (DOYLE *et al.*, 1976). The paleoecological data (see foraminifera section) fit our sedimentological interpretation.

Facies 3

Main Facts: This facies comprises the lower Embetsu and Kinkomanai Formations and was observed south of Toyosaki. Although not sampled paleontologically or magnetically, it is shown at the base of our section (Fig. 23) for sedimentological reasons.

This facies consists of interbedded mudstone, mudstone and sandstone interlayers, and thick-bedded sandstones. These lithologies are organized into a coarsening-upward sequence (Fig. 10) which straddles the boundary between the Embetsu and Kinkomanai formations. The basal portion of the cycle consists of parallel-laminated interbedded claystone and siltstone. The interbedded lithologies show

Fig. 10. Coarsening-upward sequence of basal prodelta mudstones, interlayered sandstone-mudstone zone of delta front, and uppermost delta plain sandstone. Arrow shows interval represented by such a sequence. Sandstones below in right foreground represent turbidites. Toyosaki.

sharp basal and upper contacts. The middle portion of the cycle consists of interbedded thin sandstones and mudstones. These thin sandstones contain parallel laminae. The base and top of these thin sandstones are sharp.

The upper portion of the cycle consists of coarse-grained, volcano-clastic sandstone. These are thick-bedded. These beds are cross-stratified, with average set thicknesses of about 2.5 m (Fig. 11). The cross-stratification shows generally a

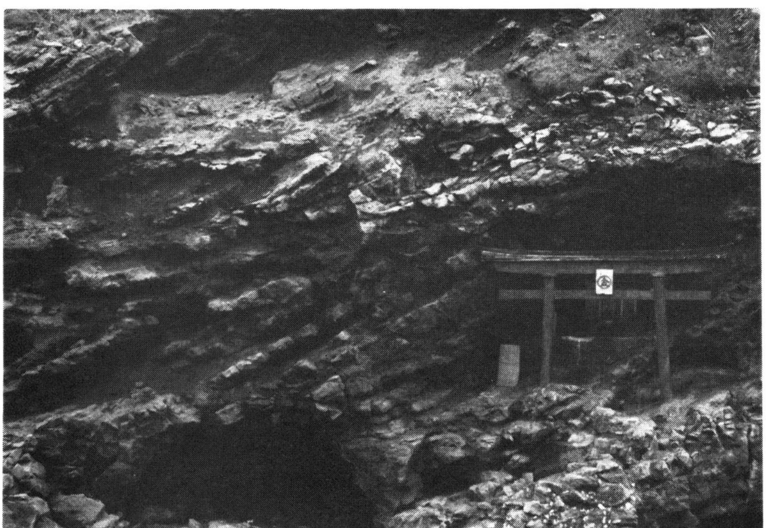


Fig. 11. Thick planar and through cross-stratification in delta plain facies of coarsening-upward cycle at Toyosaki. Shrine gate is 2 m high.

northerly orientation (Fig. 12). Set boundaries are sharp. Locally, the basal portion of the cross-stratified sets show channel scours into the underlying beds.

Below this coarsening upward sequence (Fig. 12—refers to stratigraphic log) are clastic, graded turbidite sandstones. These are coarse- to medium-grained, and are organized into a series of amalgamated graded beds. Below these turbidites are silty mudstones with slump blocks representing Facies 2.

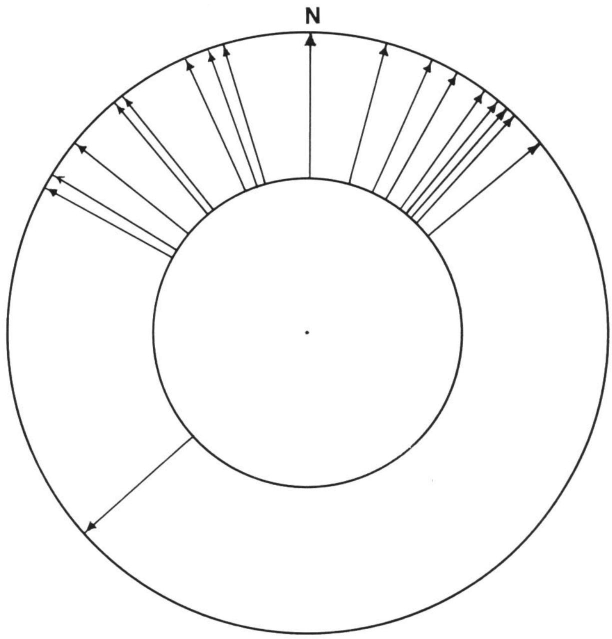


Fig. 12. Paleocurrent diagram of cross-stratification, deltaic sandstones at Toyosaki.

Origin of Facies 3: Facies 3 is organized as a coarsening-upward sequence. This cycle is identical to similar coarsening-upward cycles described from the Mississippi Delta (see summary by COLEMAN, 1976) and from some ancient successions such as by ASQUITH (1970), HOBDAY and MATTHEWS (1975), KLEIN (1974) and KLEIN *et al.*, (1972). The basal mudstone represents the prodelta zone of such a delta, the middle interlayered sandstone and mudstone interval represents the delta front, and the thick-bedded, cross-stratified sandstone represents a bar-finger sand facies of the delta plain.

The basal turbidites underneath the cycles appear to represent seasonal turbidite influxes produced by seasonal flooding, which changes the density contrast of the river effluent to higher density than oceanic waters (hyperpycnal jet inflow of BATES, 1953). These dense water-sediment mixtures move down the delta front as a turbidity current (see COLEMAN, 1976 for review) and deposit sand just beyond the prodelta zone. These basal turbidites are identical to the basal turbidites reported from below the modern Niger Delta by BURKE (1972), who supposed a similar origin.

This deltaic succession represents a coastal margin along the earlier, older and enlarged Sea of Japan, and appears in a transitional relationship with deeper-water sediments of Facies 2 below. They indicate an episode of coastal progradation along the eastern side of the Sea of Japan, perhaps associated with the Miocene and later uplifts of Hokkaido Island (OKADA, 1974). Such a transition from deeper-water to shallower-water facies characterized many geosynclinal associations (PETTIJOHN, 1975; PETTIJOHN *et al.*, 1973; POTTER and PETTIJOHN, 1963). In our example, we observed such a transitional succession in a marginal basin (back-arc basin). A similar situation characterizes the present-day Coral Sea marginal basin where the sedimentary boundary is dominated by the Fly River Delta (GALLOWAY, 1975; BURNS, ANDREWS, *et al.*, 1973; ANDREWS, PACKHAM, *et al.*, 1975). Perhaps the preservation potential of such transitions is higher in marginal basins than in geosynclines as previously proposed, or possibly, so-called geosynclinal successions may in reality be marginal basin successions.

MINERALOGY, PETROLOGY, AND SEDIMENTARY HISTORY

Hakuyu OKADA

This section describes mineralogical and petrological characteristics of Neogene sediments exposed on the sea cliffs near Atsuta and Shosanbetsu, northwestern Hokkaido. This study aims at establishing the origin and source of the sediments toward a better understanding of their tectonic significance in relation to the back-arc tectonics.

Geologic Setting

The Neogene sediments examined are exposed excellently along the sea cliff near Atsuta and Shosanbetsu and are summarized in the columnar sections (Figs. 22, 23). The sedimentary basins collecting these deposits represent in tectonic terms back-arc basins active during the Miocene to Pliocene.

(1) Atsuta Section

The strata in the Atsuta section have been subdivided into the Atsuta, Bannosawa, Morai, and Tobetsu Formations in upward sequence (TSUSHIMA *et al.*, 1956), all of which are conformable with each other, although the Tobetsu Formation is overlain unconformably by Pleistocene terrace deposits. The lithofacies of the entire succession is defined as Facies 1 as described by KLEIN (p. 63–65).

The Atsuta Formation is composed of light-to-dark-gray siltstone intercalated with thin layers of light gray ash and bands of calcareous nodules of varying sizes.

The Bannosawa Formation consists of light-grayish-blue-green, massive, silty, fine-grained sandstone, in which calcareous nodules of irregular shapes occur sporadically. The sandstone is more or less glauconitic.

The Morai Formation is characterized by moderately bioturbated siltstone frequently interbedded with graded ash beds 3 to 25 cm thick, and sometimes with fine- to medium-grained sandstone beds, in which a 1.5 m-thick channel-fill sandstone was noted. Calcareous nodules of varying diameters ranging from 10 cm to 3 m occur commonly, sometimes forming bands. Rarely, *Dentalium* and bivalve shells are found together with *Teredo*-bored wood fragments.

The Tobetsu Formation consists of light-to-moderate-brown siltstone with many horizons of calcareous nodules, usually 10 cm in size, at several meter intervals. The siltstone is bioturbated at some horizons and yields *Thyasira* (?) sp. and *Teredo*-bored wood fragments. Thin vitric tuff beds showing load structures as a sedimentary feature are sometimes intercalated (HT12′; see Fig. 16) and they bear a cherty or glassy appearance.

(2) Shosanbetsu Section

This coastal section has been subdivided stratigraphically into the Kotanbetsu, Kinkomanai, Embetsu, and Mochikubetsu Formations in upward sequence (HATA *et al.*, 1961). According to regional mapping done by HATA and others, the Kinkomanai Formation overlies the Kotanbetsu with an unconformity, although all others are conformable.

The Kotanbetsu Formation, more than 3,000 m in thickness, is characterized by gravity-flow deposits comprising turbidites, pebbly mudstones, and olistostromes. Sedimentological studies of these sediments are being continued by OKADA.

The Kinkomanai Formation has an eroded base filled by rounded cobbles and boulders against the underlying Kotanbetsu Formation. This 8 m-thick basal deposit grades upward into very massive siltstone accompanied by a few meter-thick graded sandstone beds at lower horizons. Pumice and tuff beds are sometimes intercalated. The main sequence characterized by massive siltstone is moderately bioturbated and contains calcareous nodules of varying sizes. Within the siltstone contained are also slump blocks of laminated sandstones and isolated foreign pebbles. Bivalve shells, such as *Macoma, Portlandia, Mya,* and so on, are commonly found chiefly from middle and lower horizons. They represent a mixed fauna of shallow- and deep-water inhabitants (HATA, 1961).

The Embetsu Formation consists of a lower sandstone member and an upper siltstone member. The former is characterized by coarse-grained, calcite-cemented arenite showing large-scale cross-stratification (Facies 3 defined in p. 66–69). Parts of breast bones of a whale of medium size have been discovered in a middle horizon of this sequence. The latter member consists mostly of very massive, greenish siltstone and partly of massive, greenish clay, both of which are generally bioturbated. Throughout the sequence slump blocks of parallel- or cross-laminated sandstone of varied sizes are quite common along with isolated pebbles and granules of slate, hornfelsed sandstone, and others. Calcareous nodules are not common. Gastropods (*Neptunea vinosa*), pelecypods, echinoids, wood fragments with or without *Teredo*-borings, and charcoal fragments are also found.

The Mochikubetsu Formation comprises interbedded claystone, sandy siltstone, and sandstone. The base of siltstone and sandstone beds is generally sharp. Thicker sandstone beds show cross-stratification and some thin beds are graded. Slump blocks of laminated sandstone and isolated fine-grained pebbles are common in mudstone. Thin ash layers are also intercalated. Pelecypods of *Macoma* sp. and others are found.

The sequences characterized by gravity-flow deposits are assigned to Facies 2 by KLEIN (see p. 65, 66).

Material and Methods of Study

The material used in this study was collected at sea-cliff exposures at Atsuta and near Shosanbetsu. The specimens with prefix HT, HM, HB, HA, HMo, and HE were taken from the same locations as for microfossils and magnetic samples.

Heavy mineral analysis of coarser material (mainly sandstone and coarse siltstone) was carried out according to OKADA's (1960) technique. More than two hundred non-opaque heavy mineral grains were counted on each grain mount. Some selected sandstone samples were used for thin-section analyses in order to evaluate modal composition by means of point counts. Results of the modal analyses are presented by OKADA's (1974) method.

Clay samples were investigated by X-ray diffraction analysis using a JEOL diffractometer (CuKF radiation with a Ni filter). Identification of clay minerals was made by means of (1) ethylene glycol treatment (for montmorillonite *versus* haloysite) and (2) 6N hydrochloric acid treatment (for kaolinite *versus* chlorite). The ZnO interior standard method was applied to the quantitative estimation of these clay minerals (AOYAGI, 1967).

Composition of Sediments

Major constituents of sandstones selected from the Morai Formation, Bannosawa Formation, and the sandstone member of the Embetsu Formation show the predominance of volcanic plagioclase and andesite clasts together with pumice and glass fragments (Table 1). Quartz-deficiency of these sandstones is another important feature (Fig. 13, Pl. 2, figs. 1–4). Rock fragments other than volcanics include clasts of chert, sandstone, slate, and occasional metamorphic rocks.

The composition of sandstone of the Kotanbetsu Formation is generally characterized by abundant older sediment clasts in addition to volcanic fragments. Quartz is a ubiquitous but generally minor constituent (Pl. 1, figs. 3, 4). The Kotanbetsu sandstone along with the lower Embetsu sandstone is classified as matrix-deficient lithic arenite (Fig. 13).

Heavy mineral investigations on sandstones and siltstones reveal four distinct

Table 1. Composition of sandstones

Specimen \ Constituent	Quartz	Feldspar	Rock Fragments									Glauconite	Calcite cement	Matrix	Organic remains
			Chert	Slate and Sandstone	Igneous	Pumice and Glass fragments	Metamorphics	Pyroxene	Amphibole	Opaque minerals	Serpentinite				
HM34'	0	34.99	0	0	32.42	2.40	0	4.80	0.51	+	0	0	3.95	20.93*	0
HB39	0	15.26	0.25	4.74	29.74	0.53	0	0	0	2.11	0	15.26	2.37	29.74	0
TYS1	1.19	20.44	0.85	19.59	26.58	0	2.90	1.19		+	0	0.34	23.34	1.02	2.56
TYS2	3.71	5.66	4.10	9.18	25.78	20.71	0.98	0.98	0	+	0	0	22.85	0	6.05
KU6501	6.74	5.29	2.37	32.24	14.03	17.49	0	0	0	+	0	0.16	21.68	0	0
KU6503	3.04	10.13	3.65	53.85	13.97	0	0.41	0	0	+	0	0	14.95	0	0
KU6504	7.19	10.68	0.97	43.89	21.75	0	0.17	0	0	+	0	0.39	14.96	0	0
KU6506	3.25	9.56	4.21	49.33	17.59	0	0	0	0	+	0	0.96	15.10	0	0
KU6510	5.81	8.30	2.29	46.89	16.39	0	1.25	0	0	+	0	1.66	0	17.41*	0
KU6511	3.45	23.35	0.21	6.71	56.30	0	0	0	0	+	0	0	2.11	7.87*	0
KU6512	3.20	8.46	3.58	55.83	15.23	0	0	0	0	+	0	0	0.55	13.15	0
KU6513	2.34	8.46	3.60	38.31	24.28	0	0	0	0	+	0	1.08	21.93	0	0
KU6514	1.33	12.40	3.14	35.54	23.97	0	0	0	0	+	0	0.16	23.31	0.15	0
KU6515	4.66	7.89	1.08	37.64	26.17	0	0.33	0	0	+	1.26	0	20.97	0	0
KU6519	4.02	9.76	5.17	29.45	28.30	0	0	0	0	+	0	0.16	23.14	0	0
KU6521	1.72	9.70	2.48	44.49	15.59	0	0	0	0	+	0	0.19	25.45	0.38	0
KU6526	3.28	7.95	1.72	40.19	19.01	0	0.78	0	0	+	1.41	0	25.34	0	0

N.B. HM: Morai Formation, HB: Bannosawa Formation, TYS: Sandstone member of the Embetsu Formation, KU: Kotanbetsu Formation. +: trace, *: including glass shards

mineral assemblages (Table 2): (1) augite–hypersthene–hornblende–oxyhornblende–glaucophane, (2) zircon-garnet–augite–diopside–hypersthene–hornblende–oxyhornblende–glaucophane, (3) augite–hypersthene–hornblende–oxyhornblende, and (4) zircon–tourmaline–garnet–augite–hornblende. The first suite characterizes the Morai Formation; the second one is represented by the Mochikubetsu Formation and the mudstone member of the Embetsu Formation; the third one by the sandstone member of the Embetsu Formation; and the fourth by the Kotanbetsu Formation. Among these assemblages, the Kotanbetsu Formation yields a sharply contrasting heavy mineral suite in that zircon, tourmaline, rutile, and garnet are important components, some of which are rounded.

High concentrations of pyroxene and amphibole in all the assemblages are quite characteristic of the Neogene sequence in the studied area. This means, particularly for the presence of hypersthene and oxyhornblende, a volcanic source of much of sands and silts. Glaucophane grains, not abundant but persistently found in the Neogene sequence except for the Kotanbetsu Formation, are important as an index mineral for glaucophane schist source. The Kotanbetsu Formation is characterized by contribution of sediments from older sedimentary rocks in addition to andesitic volcanics.

The clay minerals recognized in the studied sequence are montmorillonite, illite, mixed layer comprising illite–montmorillonite, and chlorite (Table 3). Among them, montmorillonite generally predominates over others. Chlorite is of the next important mineral, which is ubiquitous in all the clay samples. In a few samples it is more abundant than montmorillonite. Illite is also a wide-spread but minor con-

Table 2. Heavy mineral compositions of sandstones and sandy siltstones

Mineral component \ Specimen no.	HM23	HM27'	HM32'	HM34'	HB39'	HMo48'	HMo55	HMo58'	HE67'	HE69'	HE73	TYS1	TYS2	TYS3	KU6504	KU6510	KU6526
Opaque minerals	6.03	42.31	69.07	15.15	45.45	20.60	29.70	30.95	12.20	63.60	30.00	10.89	19.25	25.37	83.08	69.23	65.77
Transparent minerals	93.97	57.69	30.93	84.85	54.55	79.40	70.30	69.05	87.80	36.40	70.00	89.11	80.75	74.63	16.92	30.77	34.23
Zircon, Euhedral, colorless			6.55		1.97	1.39		0.87	0.81	4.33	2.46			0.98	25.71	21.10	7.88
Zircon, Euhedral, pale pink			2.80			0.46				1.44					6.43	5.96	3.45
Zircon, Rounded, colorless																0.92	
Zircon, Rounded, pale pink								0.43							7.14	1.83	0.99
Zircon, Rounded, purple																0.46	
Tourmaline															2.14		
Rutile															1.42		
Garnet, colorless						0.46		0.43		1.44	2.46				24.29	9.18	1.97
Garnet, pale pink							0.44								10.71	2.75	1.97
Garnet, orange						0.46											0.49
Augite	31.11	20.00	0.47	4.39	2.46	31.02	20.19	12.61	17.74	16.83	17.24	45.25	41.63	57.07	7.14	8.26	15.76
Diopside						0.46	1.31	0.43	0.81		0.49						
Hypersthene	6.67	1.46		85.37			2.52	0.87	0.40	1.44		32.58	7.69	12.20			
Hornblende, green			3.74		0.49	5.56	6.55	10.00	6.85	15.38	14.78		2.26		2.86	7.34	8.87
Hornblende, greenish brown	62.22	39.51	7.94	7.32	88.67	37.50	48.13	49.16	49.60	35.10	44.34	20.36	41.18	24.88	7.88	16.46	11.82
Hornblende, brown		20.49	77.10	1.46		11.57	9.17	11.74	16.13	15.38	16.75		3.62	1.95		21.06	33.50
Oxyhornblende		11.22		1.46	0.99	6.02	6.55	9.13	6.85	4.33	1.48	1.81	2.72	2.44			
Glaucophane		0.49	0.47		2.46	0.94	2.18	1.30	0.81	1.93							
Epidote						0.46	0.44	0.43								1.38	
Apatite					0.99												
Chlorite						0.46		0.43					0.45	0.48			0.49
Biotite		6.83	0.93		1.48	3.24	2.52	0.87		1.92			0.45			1.92	11.82
Anatase								0.43							0.71		
Spinel					0.49			0.87							3.57	1.38	0.99
Heavy mineral weight percentage	30.86	0.97	0.16	0.26	0.96	1.39	0.28	1.19	0.17	0.58	0.33	2.58	2.05	3.50	0.12	0.23	0.10

N.B. HM: Morai Formation, HB: Bannosawa Formation, HMo: Mochikubetsu Formation, HE: Embetsu Formation (mudstone member), TYS: Embetsu Formation (sandstone member), KU: Kotanbetsu Formation.

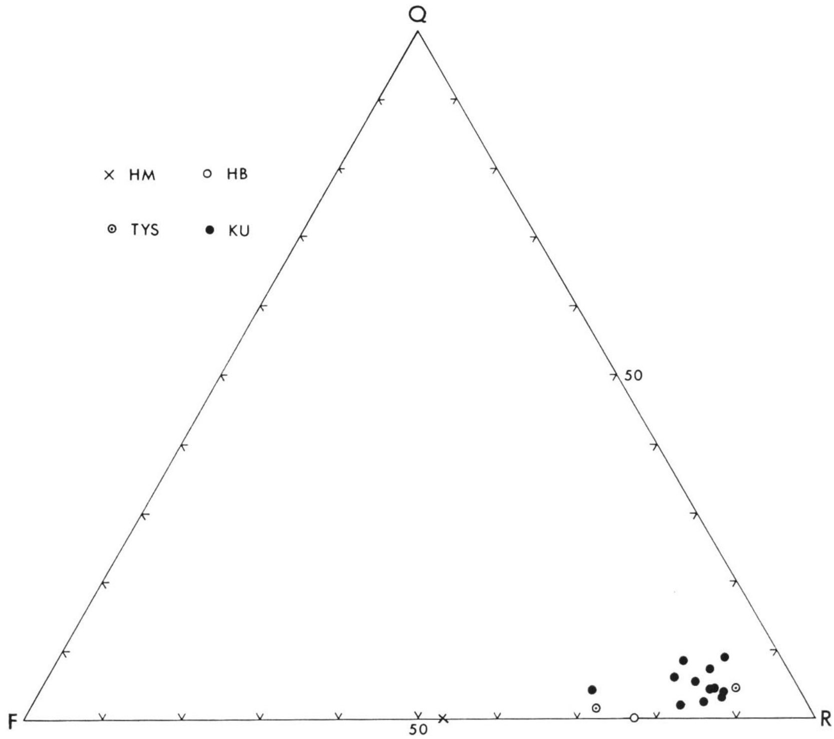


Fig. 13. Ternary diagram showing sandstone compositions. Q: quartz, F: feldspar, R: rock fragments. HM: Morai Formation, HB: Bannosawa Formation, TYS: sandstone member of the Embetsu Formation, KU: Kotanbetsu Formation.

stituent. There seems to be no particular stratigraphic trend in compositions of these minerals.

The zeolite mineral clinoptilolite begins to appear in the Morai Formation (Pliocene) of the Atsuta section and in the Embetsu Formation (Late Miocene) of the Shosanbetsu section. The sequence in which clinoptilolite exists is assigned to the clinoptilolite zone of a burial diagenesis by IIJIMA and UTADA (1971). The time difference in its appearance between the Atsuta and Shosanbetsu successions may be due to difference in burial depth. This mineral is an altered product of volcanic glasses and other pyroclastics, which are common in these strata.

In the studied sections two kinds of nodules are found. Most common are greenish-gray marly nodules or, in other words, limestone nodules, which usually occur either as little elongated spheres or as thick lenses and vary in the longest diameter from some ten centimeters up to three meters. Larger nodules of a few meters in diameter occur sporadically (Fig. 14), whereas the smaller ones measuring some ten centimeters in size form layers and bands (Fig. 15). The other kind are dark gray,

Table 3. Mineral composition of clays

Sample \ Mineral Composition	Montmorillonite	Illite	Chlorite	Mixed Layer Illite-Montmorillonite	Clinoptilolite	Cristobalite	Quartz	Feldpar	Dolomite
HT3	● 30	+	• 6				40	9	
HT8'-1		+	• 4				9	4	36
HT8'-2	o 14	• 6	• 8				35	13	
HT11	o 14	• 4	• 6				26	6	
HT12'-A	+	• 4	• 6	+		30	12	3	
HT12'-B	o 15	o 12	● 20			13	25	7	
HM25'-2A	+	• 6	+			33	25	5	
HM25'-2B	● 22	• 8	o 15		4	7	45	12	
HM25'	● 30	• 3	• 4	• 3	3	8	35	12	
HM26'	o 14	• 3	• 7	• 6	2		30	10	
HM28'	• 6	• 4	o 14	+	6	20	27	7	
HM29'-A	● 28	• 6	• 8	• 3	5		35	7	
HA44	• 8	• 7	● 20		6	4	38	9	
HA47	o 16	• 3	o 15				33	6	
HMo55	o 17	• 4	o 11	• 4			27	18	
HE62	o 14	• 5	o 14	• 6			30	16	
HE69	• 8	• 4	• 8		3		27	10	
HE72	• 9	• 6	• 9				25	7	
HE77	o 14	• 4	• 4				30	8	
HE83	o 14	• 3	o 18				38	7	
HE85	⊙ 17	• 4	o 10				35	7	
HE90	● 20	• 4	• 7		3		25	6	
HE96	● 20	• 5	o 14	+			38	7	

N.B. ●: 20-30%, o: 10-20%, •: 3-10%, +: traceable amount.
HT: Tobetsu, HM: Morai, HA: Atsuta, HMo: Mochikubetsu, HE: Embetsu Formations.

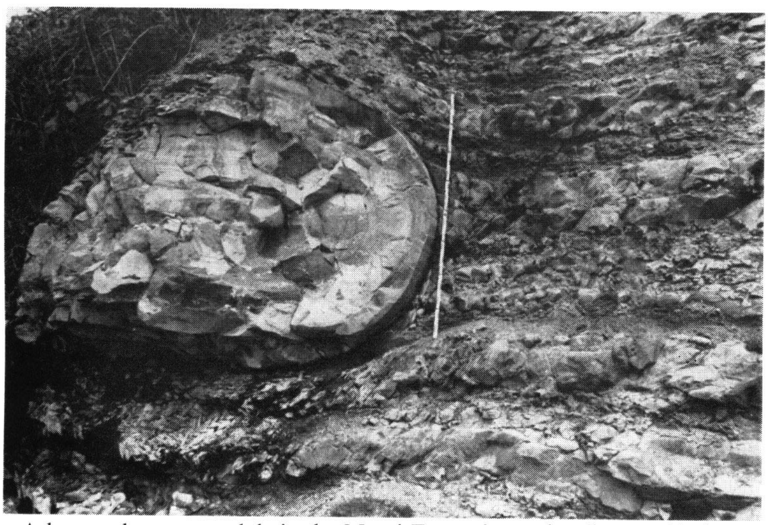


Fig. 14. A large calcareous nodule in the Morai Formation at locality HM31, Atsuta. Scale bar is 2 m long.

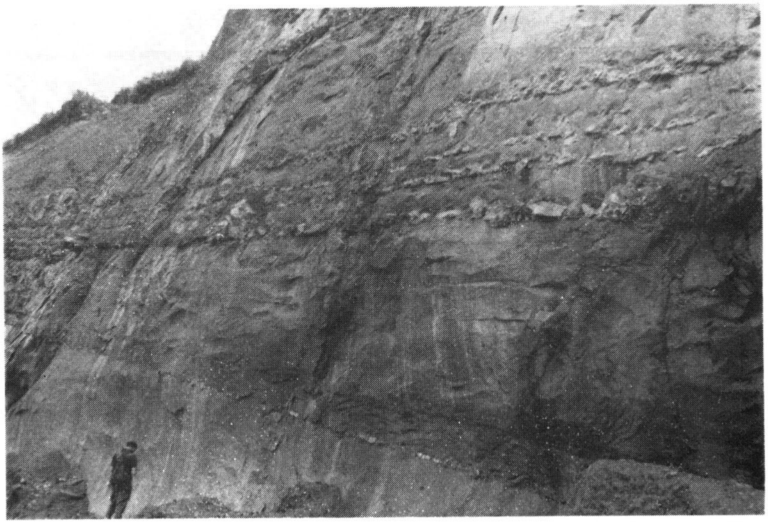


Fig. 15. Bands of calcareous nodules in the Tobetsu Formation around locality HT13, Atsuta.

Fig. 16. Cherty nodule in the Tobetsu Formation from which Specimen HT12′ came.

hard nodules which display a cherty or glassy appearance (Fig. 16) and are irregular in shape. They are characteristic of the Tobetsu Formation.

Petrological and mineralogical examinations of these two kinds of nodules reveal the following facts. Limestone nodules from the Tobetsu Formation consist of chlorite and biotite-bearing, plagioclase-and-authigenic-pyrite-common, diatomaceous limestone (Pl. 1, fig. 1). One sample (HT8′–1) shows the formation of a considerable quantity of dolomite (Table 3). Cherty nodules comprise quartz, plagioclase and diatom-bearing, vitric tuff (Pl. 1, fig. 2). One sample (HT12′) from the Tobetsu Formation is interesting in that fresh core parts of a nodule (HT12′-A) are rich in cristobalite accompanied by small amounts of quartz, feldspar, illite, and chlorite grains, whereas the somewhat weathered outer parts of it (HT12′-B) are characterized by an increased concentration of quartz, feldspar, montmorillonite, illite, and chlorite as well as by a marked decrease in cristobalite (Table 3).

Concluding Remarks

Mineralogic and petrologic study of the Neogene sequences in northwestern Hokkaido indicate that marine sediments in this region comprise not only airborne ash but also clastics of acidic-to-intermediate volcanic rocks. These intermediate volcanic rocks, largely andesite, are characterized by augite, hypersthene, hornblende, and oxyhornblende. These mineralogic features of the sediments are in harmony with DICKINSON's (1974) concept that deposits of the back-arc basin carry a wide variety of pyroclastic materials. This also means that the sediments reflect active arc magmatism at the time of deposition related to active plate motion. The magmatism in the studied area is closely related to very active Miocene igneous events in the northwest Pacific (see MATSUDA *et al.*, 1967). This period seems to coincide with a change in spreading direction in the North Pacific (MENARD and ATWATER, 1968; MORGAN, 1968; JACKSON *et al.*, 1972; and others) and also with a resumption in spreading (VINE, 1966).

In addition to pyroclastic materials, the presence of clastics of older sediments of sandstone, slate, and chert distinguishes the Kotanbetsu Formation, whereas the occurrence of metamorphic clasts, for instance glaucophane schists and others, characterizes the Morai, Bannosawa, Mochikubetsu, and Embetsu Formations. These clasts along with those pyroclastic materials mentioned above may have been derived from the eastern and southeastern arc ranges.

The Kotanbetsu Formation characterized by turbidites and olistostromes represents basin-floor sediments, whereas the sandstone member of the Embetsu Formation consists of litharenite which is well sorted by traction currents in the delta plain environment. Other muddy facies of the Embetsu, Morai, Tobetsu, Bannosawa, and Atsuta Formations, which are marked by slump blocks of synsedimentary laminated sandstone as well as graded beds and channel-fill sandstone, may have been deposited in slope environments.

The auther wishes to thank Drs. Kazuo TAGUCHI and Kiyohiro MITSUI of Tohoku University for their kind help in clay mineral analysis.

PALEOMAGNETISM OF LATE CENOZOIC SEDIMENTS OF HOKKAIDO

D. V. KENT

A survey of paleomagnetic polarity was made on the Atsuta, Shosanbetsu and Wakkanai sections of western Hokkaido, Japan. Hand samples, taken at stratigraphic intervals of approximately 8 to 10 m at the Atsuta and Shosanbetsu sections and at various localities in the Wakkanai area were chiseled from the outcrop following removal of up to 1 meter of weathered rock surface and, after that, a flat carved-out surface was oriented using a magnetic compass. In the laboratory using a band saw, two or three cubic specimens (2.5 cm on a side) were cut from each sample for magnetic measurement. These replicate specimens are numbered for example 101A, 101B, and 101C. The natural remanent magnetization (NRM) was measured with a 7 Hz spinner magnetometer (MOLYNEUX, 1972) and a low-field AC bridge was used for measuring magnetic susceptibility. Alternating field (AF) demagnetization experiments were made using an apparatus similar to that described by MCELHINNY (1969).

Shosanbetsu Section

The change in NRM intensity and direction with progressive AF demagnetization for three specimens from the Shosanbetsu section reveals the NRM to be only partially stable (Fig. 17). Specimen 49A shows an increase in remanent intensity and the paleomagnetic directions approach a reversed position (southerly declination, negative inclination) with AF demagnetization up to 200 Oersteds. This behavior can be attributed to the gradual removal of a normal magnetic component that has been superimposed on a more stable reversed magnetization. However, the normal and presumably secondary component may not have been removed entirely even after 250 Oe because the inclination direction is still much shallower than that expected for the site latitude. Note that a spurious remanent intensity and direction is apparently obtained after 300 Oe AF demagnetization.

The NRM of specimens 59A and 69A shows somewhat erratic magnetic behavior with progressive AF demagnetization, for the directions do not appear to stabilize after 100 Oe (59A) to 200 Oe (69A). In spite of a large (and spurious) secondary component of magnetization, these specimens may be considered to possess a normally directed component of magnetization, although, on the basis of the demagnetization characteristics alone, the origin of this magnetization cannot be established. It is therefore possible that some of the Shosanbetsu sediments have been remagnetized in the direction of a recent (normal) magnetic field and do not retain an appreciable amount of the magnetization acquired at or near the time of their formation.

In order to at least partially remove unstable magnetizations and to avoid spurious magnetic components that might be acquired at higher demagnetization fields, a 100 Oe alternating field was selected for blanket demagnetization of all specimens. For establishing polarity stratigraphy, only the declination is used since inclination appears

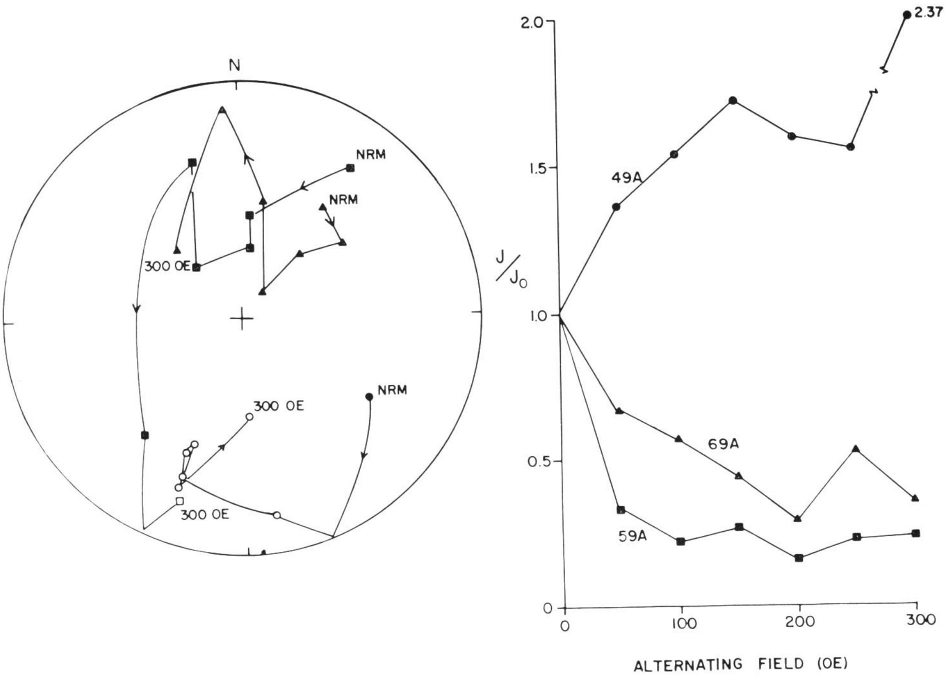


Fig. 17. The change in direction and intensity of the NRM of three specimens from the Shosanbetsu section after applying progressive alternating field demagnetization. Directions on lower (upper) hemisphere of equal area projection are plotted as filled (open) symbols.

to be preferentially affected by stable secondary magnetizations that often result in inclination values that are obviously too shallow. Declination data are considered reliable when there is a 15° or less difference between specimens from the same stratigraphic horizon (the reliable data are indicated by solid circles in Fig. 18).

A magnetization polarity transition apparently occurs within the Mochikubetsu Formation, between samples 53 and 54 (approximately 180 m from the top of the measured section). The upper part of the Mochikubetsu Formation is interpreted as reversely magnetized and the lower part of the Mochikubetsu Formation and the upper part of the underlying Embetsu are normally magnetized. Between 540 m (sample 64) and the base of the section exists an erratic magnetic signature. Despite the disturbed nature of the data, it is likely that this part of the section is dominantly of normal magnetic polarity; the erratic magnetic directions may be attributed in part to inadvertent sampling of slump blocks that occur in the section (KLEIN p. 65).

The overall variation of NRM intensity and susceptibility appears to nearly coincide with the gross lithologic change occurring at the formation boundary (Fig. 18). For example, the mean susceptibility in the Mochikubetsu and Embetsu Formations is 1.11×10^{-5} Gauss/Oersted and 0.46×10^{-5} G/Oe, respectively, while the mean NRM intensity for these formations is 3.79×10^{-6} G and 0.45×10^{-6} G. Al-

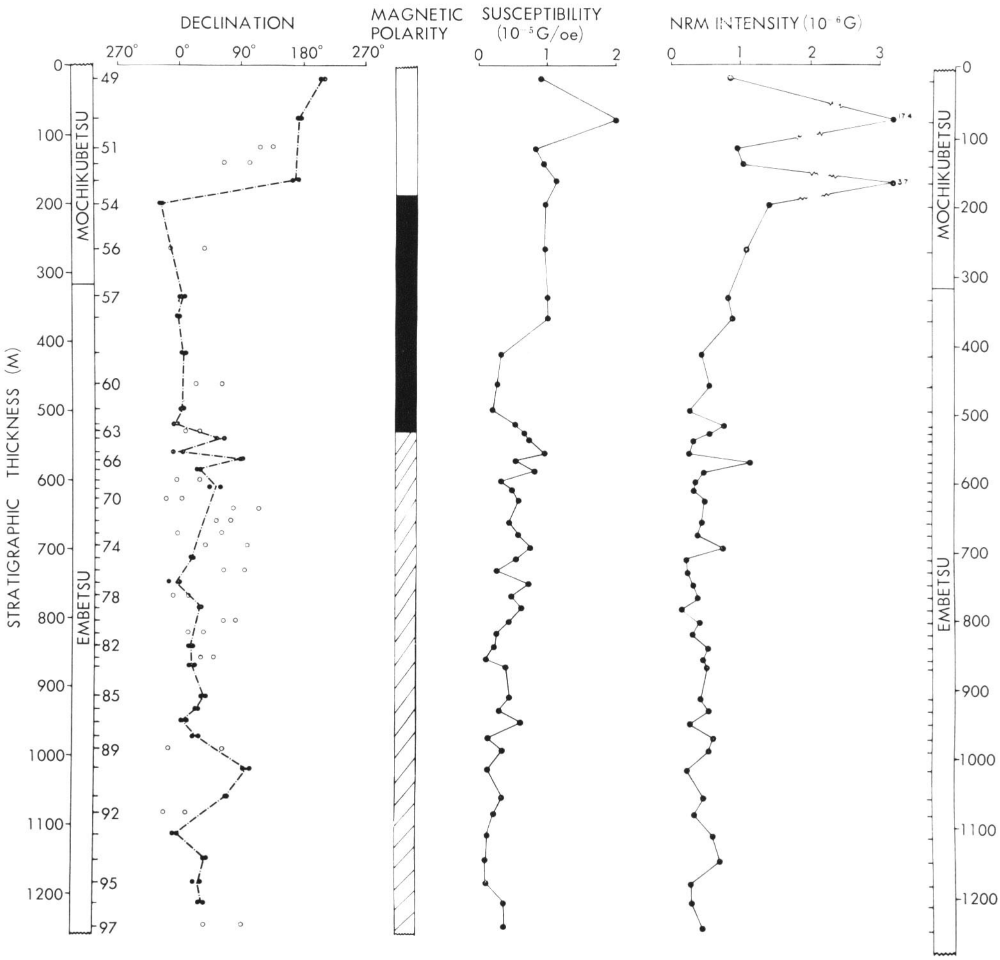


Fig. 18. The remanent declination after 100 oe AF, the initial susceptibility and the NRM intensity plotted against stratigraphic position in the Shosanbetsu section. Dashed line in declination column joins samples, noted with filled symbols, in which specimen declinations converged to within 15°. Interpretation of magnetic polarity is indicated by open (reversed polarity), shaded (normal polarity), and hachured (polarity uncertain but likely to be normal) patterns.

though there is a gradational increase in NRM intensity from the Embetsu to the Mochikubetsu Formations, there is a rather abrupt change in susceptibility approximately 50 meters below the base of the Mochikubetsu.

Atsuta Section

Progressive AF demagnetization characteristics of the NRM for specimens from the Atsuta section are similar to those of the Shosanbetsu (Fig. 19). Appreciable secondary components of magnetization contribute to the NRM and are only partially removed by AF demagnetization. Sample 16A most likely contains a stable reversed component of magnetization as evidenced by the southerly trend in declination. However, a persistent downward directed secondary component inhibits inclination from becoming negative even after demagnetization in 200 Oe to 300 Oe. Samples 6A-1 and 36A are interpreted as normally magnetized, in spite of spurious magnetizations that occur after demagnetization in 150 Oe to 200 Oe.

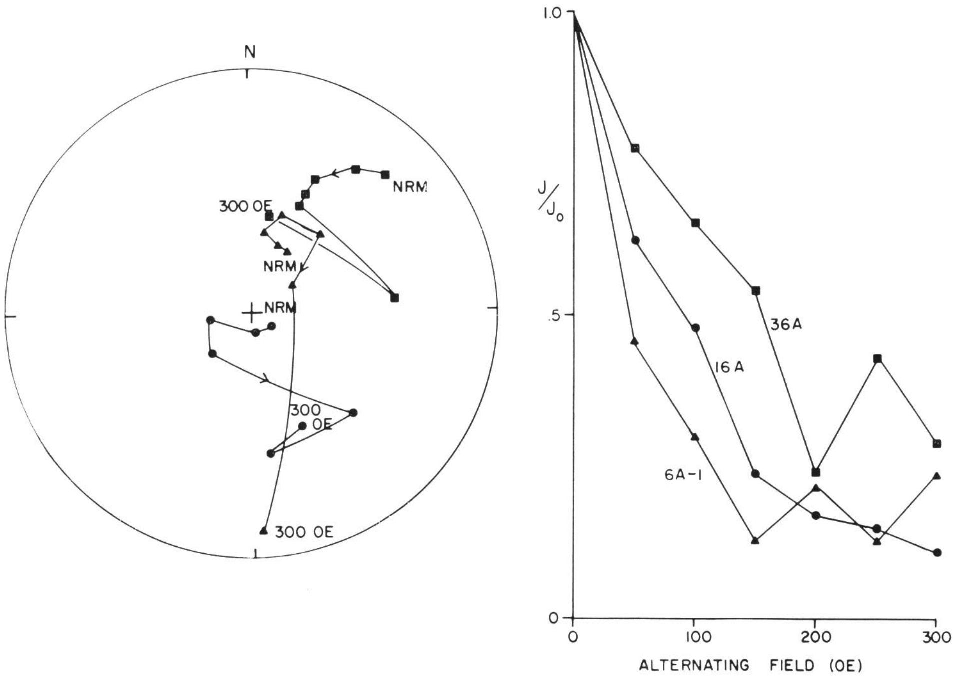


Fig. 19. The change in direction and intensity of the NRM of three specimens from the Atsuta section after applying progressive alternating field demagnetization. Directions on lower hemisphere of equal area projection are plotted as filled symbols.

All specimens were partially AF demagnetized in 100 Oe and, in Figure 20 the magnetic data are plotted with respect to stratigraphic position. In general, the internal consistency of the remanent directions is poor and there are relatively few samples with closely grouped declinations.

The NRM intensity is low in the Atsuta Formation, averaging 0.54×10^{-6} G with an abrupt increase into the Bannosawa and Morai Formations where the average NRM intensity is 2.02×10^{-6} G. There is a more gradational decrease in NRM intensity going from the Morai and into the Tobetsu Formations until a generally low level of intensity, similar to that of the Atsuta, is approached; the mean NRM intensity

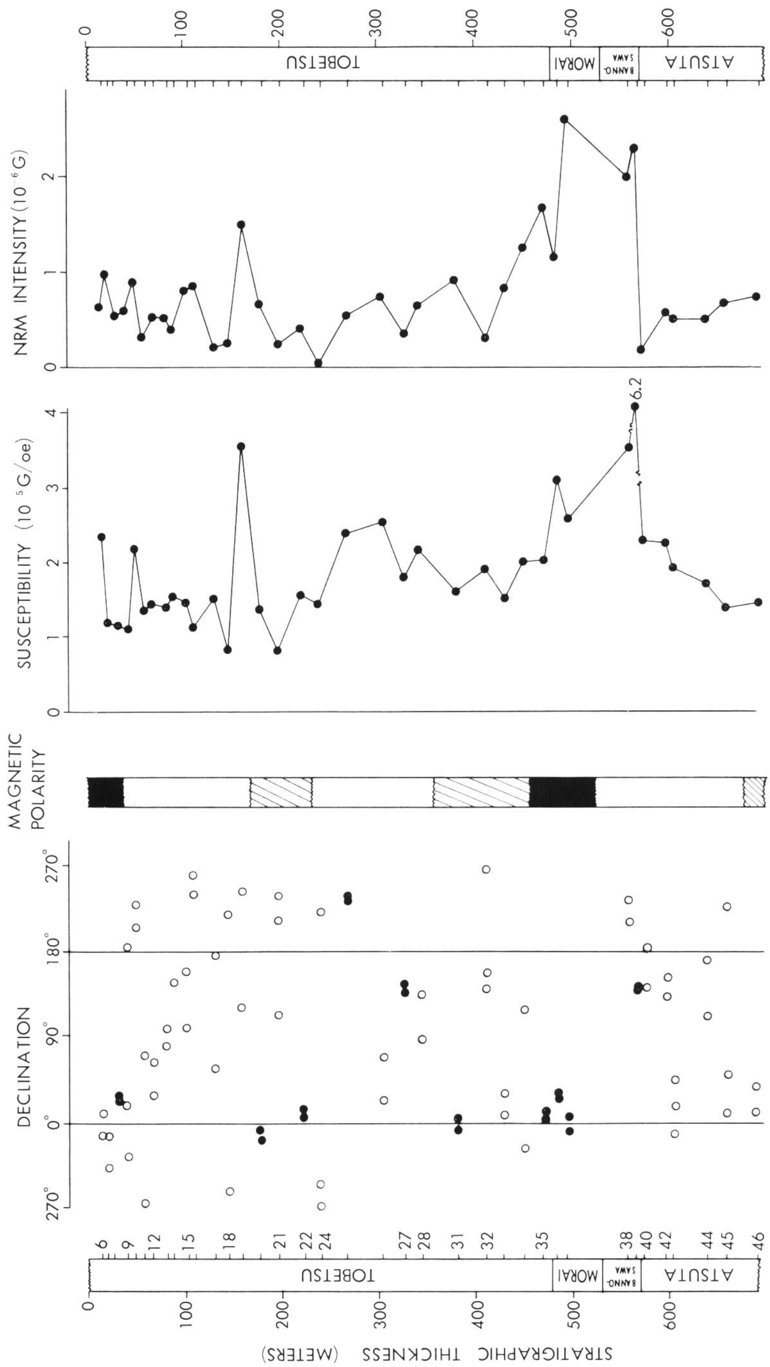


Fig. 20. The remanent declination after 100 oe AF, the initial susceptibility and the NRM intensity plotted against stratigraphic position in the Atsuta section. Samples in which specimen declinations converge to within 15° are noted with filled symbols. Interpretation of magnetic polarity is indicated by open (reversed polarity), shaded (normal polarity), and hachured (polarity uncertain but likely to be normal) patterns.

of the Tobetsu Formation is 0.66×10^{-6} G. The near parallel variation of susceptibility in the section indicates a dominant lithologic control on the remanent intensities as was found to be the case in the Shosanbetsu section.

Despite the marginal quality of the data, a somewhat tenuous but reasonable interpretation of the magnetic polarity stratigraphy is offered (Fig. 20). The high scatter in remanent directions may be indicative of only partially cleaned reversed original mangetizations, and on this basis one can hypothesize that a large part of the section was deposited during an interval of dominantly reversed polarity. A normally magnetized zone occurs from near the contact between the Morai and Bannosawa Formations into the base of the Tobetsu Formation; the uppermost part of the Tobetsu Formation may also be normally magnetized. Other zones that may possibly represent deposition during a normal polarity time interval are indicated by hachures in the polarity column. However, it must be emphasized that there is little real evidence from the magnetic properties of the sediments to justify firm conclusions regarding the magnetic polarity stratigraphy of this section.

Wakkanai Locality

A number of samples were collected for paleomagnetic study at various localities from the Koetoi and Wakkanai Formations that outcrop in and around Wakkanai. The section was not measured so no stratigraphic column with magnetic polarity interpretation is presented here. The direction and intensity of NRM, after 100 Oe AF demagnetization, and the interpretation of magnetic polarity at each sample locality is listed in Table 4; the location of the sampling sites are shown in Figure 4.

The magnetic properties of these sediments are similar to those of the Atsuta and Shosanbetsu sections; that is, the sediments are weakly magnetized and appreciable secondary magnetic components contribute to the NRM that are only partially removed by AF demagnetization. The interpretation of magnetic polarity for each sample was made primarily on the basis of the remanent declination directions: those samples with dominantly southerly declinations were considered reversed, with dominantly northerly declinations normal, while those samples with intermediate declination directions were considered of indeterminate polarity. This analysis suggests that the Keotoi and Wakkanai Formations were formed during a time interval of predominantly reversed geomagnetic polarity.

Discussion

The magnetic data from these sediments are considered to be only of marginal utility for precisely defining paleomagnetic polarity sequences for the purpose of dating and correlation. Primarily on the basis of the internal consistency of declination, the change in polarity in the Mochikubetsu Formation may represent a reversal of the geomagnetic field when these sediments were deposited, but, because of the

Table 4. Intensity and direction of NRM and the inferred Magnetic Polarity for samples from the Wakkanai area. Samples are serially numbered in downward sequence; samples 100–108 are from the Koetoi Formation and the remainder from the Wakkanai Formation

NATURAL REMANENT MAGNETIZATION*

Sample	Intensity (10^{-8}G)	Decl.	Incl.	Polarity Interpretation
100 A	4.8	31.3	12.0	
B	3.1	58.3	9.7	Normal
C	8.4	344.6	61.3	
101 A	7.1	112.0	10.0	
B	12.2	111.7	36.8	Reversed
C	11.6	113.1	51.9	
102 A	11.9	122.2	47.1	
B	7.4	177.4	32.3	Reversed
C	8.3	120.6	35.9	
103 A	7.4	38.9	43.3	
B	5.0	125.4	55.2	Reversed
C	5.8	139.0	71.9	
104 A	4.7	164.3	15.3	
B	3.3	165.7	29.3	Reversed
C	10.1	127.0	42.2	
105 A	12.7	291.0	- 6.1	
B	14.2	60.5	77.7	?
C	8.7	243.7	78.2	
106 A	5.4	304.5	79.6	
B	7.5	184.0	66.2	Reversed
C	7.3	134.7	63.2	
107 A	2.8	136.7	24.3	
B	5.5	180.6	30.4	Reversed
C	4.4	158.2	-13.0	
108 A	7.6	97.3	51.7	
B	5.0	107.8	70.5	?
C	6.8	84.0	32.9	
109 A	5.6	79.2	35.6	
B	6.9	53.4	47.4	?
C	14.9	93.9	44.4	
110 A	8.1	141.7	24.6	
B	4.8	165.8	27.3	Reversed
C	13.7	154.8	16.6	
111 A	5.9	127.4	65.0	
B	8.1	145.8	61.6	Reversed
C	16.3	153.8	55.0	
112 A	5.4	93.4	62.9	
B	5.3	158.5	88.2	Reversed
C	14.8	227.1	79.3	
113 A	1.7	189.7	25.7	
B	4.2	190.0	6.3	Reversed
C	7.8	115.3	14.9	
114 A	2.6	150.7	12.3	
B	4.8	173.0	23.1	Reversed
C	4.8	121.9	- 2.9	
115 A	4.3	85.5	16.5	
B	6.3	229.3	64.3	Reversed
C	12.4	127.3	45.9	
116 A	18.4	123.3	45.1	
B	13.7	138.2	-29.9	Reversed
C	15.7	149.1	47.8	
117 A	11.3	289.3	-62.3	
B	7.6	50.3	52.1	?
C	12.8	311.3	77.5	
118 A	9.3	114.5	-28.9	
B	7.1	54.5	- 5.5	?
C	32.3	91.9	29.4	
119 A	11.6	101.8	64.8	
B	7.6	153.1	73.3	?
C	13.7	16.1	78.3	
120 A	30.6	54.9	58.2	
B	26.8	63.5	65.5	?
C	26.3	92.2	68.3	
121 A	22.3	149.4	67.3	
B	23.2	37.8	61.5	?
C	39.0	42.0	55.9	
122 A	17.8	6.4	35.2	
B	13.0	45.4	23.8	Normal
C	9.5	49.8	38.4	
123 A	14.8	38.1	8.9	
B	17.8	354.8	32.6	Normal
C	12.3	331.6	31.5	
124 A	4.2	225.2	-19.1	
B	6.8	191.5	4.3	Reversed
C	8.0	180.0	-31.1	
125 A	4.5	149.0	3.5	Reversed
B	6.6	80.6	-37.7	

* After 100 oe AF demagnetization

poor overall coherence of remanent directions within the section as well as between specimens within a horizon, the interpretation of a magnetic polarity sequence in the Atsuta section (Fig. 20) and for the Wakkanai area should be considered a tenuous. A caution must be taken because the scatter in remanent directions could be caused by unstable magnetic properties, superimposed on normal and reversed magnetic components within each sample that cannot be separated effectively with AF demagnetization techniques, or some combination of these and other causes.

There are other outcrop sections of Late Cenozoic marine sediments, particularly those bordering marginal or inland seas, that also appear to possess poor magnetic properties for paleomagnetic polarity determinations. For example, the lower part of the Neogene section exposed on the Oga Peninsula, facing the Sea of Japan, apparently has been remagnetized into the present magnetic field (KENT, 1973). Similarly, a suite of samples collected from the Neogene section exposed on the Noto Peninsula, 350 km southwest of Oga, was entirely of normal polarity that is most likely the result of recent remagnetization (KENT, D. V., unpub. ms.). In southen Italy, WATKINS *et al.* (1974) also found predominantly normally magnetized sediments in an outcropping marine section of Plio-Pleistocene age, and proposed that post-depositional chemical remanent magnetism was responsible for the directions.

In summary, the process that is responsible for the apparent remagnetization and magnetic instability in the Hokkaido Neogene deposits has not been well established. It is possible that the NRM of the sediments might be related to the formation, under anoxic conditions in the Sea of Japan, of iron sulphides that were subsequently oxidized in the present environment, as supposed by KOBAYASHI and NOMURA (1972) for some Sea of Japan sediment cores.

I wish to thank N. D. OPDYKE and J. C. LIDDICOAT for critically reading the manuscript. Maria PANISELLO and Doris LAFFERTY provided able assistance in the preparation and magnetic measurements of the samples.

DIATOM BIOSTRATIGRAPHY

Howard HARPER, Jr.

The fossil planktonic diatom remains in samples collected from Neogene basins on the island of Hokkaido, Japan have been examined to determine the stratigraphy and age of the studied sections. Of these sections, the Shosanbetsu and Atsuta were the longest and most continuously sampled for microfossils and paleomagnetics and thus the major emphasis is placed on them. The sections in the Wakkanai and Shimo-Ebekorobetsu areas have also been examined but due to their shortness only approximate correlations are made. The stratigraphic distribution of diatom taxa in these sections has been used to correlate them to previous work in the North Pacific and to fit them to the standard European time scale.

All samples were processed in 15% solution of hydrogen peroxide over low heat to disaggregate the rock and free the diatom remains from the matrix. The resulting residues were dried on coverslips and permanently mounted on glass microscope slides with Carmount-165 mounting medium. Slides were then scanned under oil at 1000x and 200 planktonic diatom specimens were counted to obtain relative abundances, additional scans were made at 1000x and 400x until at least 1000 specimens had been examined to determine the presence of rarer taxa. Abundance data were not obtained for every sample, although presence or absence data were.

The Diatom Flora

Overall, the diatom assemblages from the Hokkaido samples were similar to those reported from Kamchatka and Sakhalin (Sheshukova-Poretzkaya, 1967) and from the island of Honshu, Japan and North Pacific deep-sea samples (Koizumi, 1968; 1973; 1975a; 1975b; Burckle and Todd, 1976).

The Atsuta section (samples 4–47) contained usefully preserved diatoms in samples 4–18 and 26 from the Tobetsu and Morai Formations. The section assemblage is dominated by *Thalassiosira decipiens* (Grunow) Jørgensen (10–50% of each assemblage), *Thalassionema nitzschioides* Grunow (10–20%), *Rouxia californica* Peragallo (5–20%) and *Nitzschia rolandii* Schrader (0–20%). The diatom assemblage encountered in the Atsuta section did not readily fit into the diatom zonal scheme of Koizumi (1975b). The lack of abundant *Denticula hustedtii* Simonsen and Kanaya or *D. kamtschatica* Zabelina makes assignment to either of their respective zones difficult. The most abundant stratigraphically important species is *Rouxia californica*, however, this species ranges from the lower part of the *D. kamtschatica* Zone to well below the *D. hustedtii* Zone. Several species which are restricted to the *D. hustedtii* Zone are also present but in abundances of less than 1% and the possibility of reworking cannot be positively excluded. These species are: *D. hustedtii, Coscinodiscus endoi* Kanaya, *C. temperi* Brun, and *Synedra jouseana lineata* Sheshukova. The first appearance of *Thalassiosira nidulus* (Tempère and Brun) Jousé was placed within the *D. kamtschatica* Zone by Koizumi (1975b), however, it is present throughout the diatomaceous part of the Atsuta section. Another problem is the species *N. rolandii*, which resembles and may be confused with *D. kamtschatica*, although no true *D. kamtschatica* was present in the Atsuta section (see the taxonomic note). Based on the presence of *D. hustedtii* and the other restricted species, this section is placed within the uppermost part of the *D. hustedtii* Zone, making the first appearance of *Thalassiosira nidulus* earlier than reported by Koizumi (1975b) (see taxonomic notes).

The Atsuta section may represent a stratigraphic interval not yet reported from outcrop sections in the Japanese area, lying above a well-developed *D. hustedtii* zonal assemblage with abundant *D. hustedtii* and associated species and below the first appearance of true *D. kamtschatica*, indicative of that zone. Examination of samples of Deep Sea Drilling Project (DSDP) Hole 192 shows a very similar assemblage to that of the Atsuta section in samples 24–2–22 cm and 23–1–102 cm. Although KOIZUMI (1973; 1975b) placed these samples within the lower part of the *D. kamtschatica* Zone, the first true *D. kamtschatica* does not occur until his sample 22–1–102 cm. The assemblage includes, *T. nidulus, Thalassiosira antiqua* (GRUNOW) CLEVE, *T. decipiens, Synedra jouseana lineata, C. temperi* and *N. rolandii*. There are also rare specimens of *D. hustedtii* and *Actinocyclus ingens* RATTRAY, however, in sample 25–1 82 cm these species are very abundant, typical of the *D. hustedtii* Zone.

The Shosanbetsu section (samples 48–98) contained good diatom remains in all samples collected from both the Mochikubetsu and Embetsu Formations. The presence

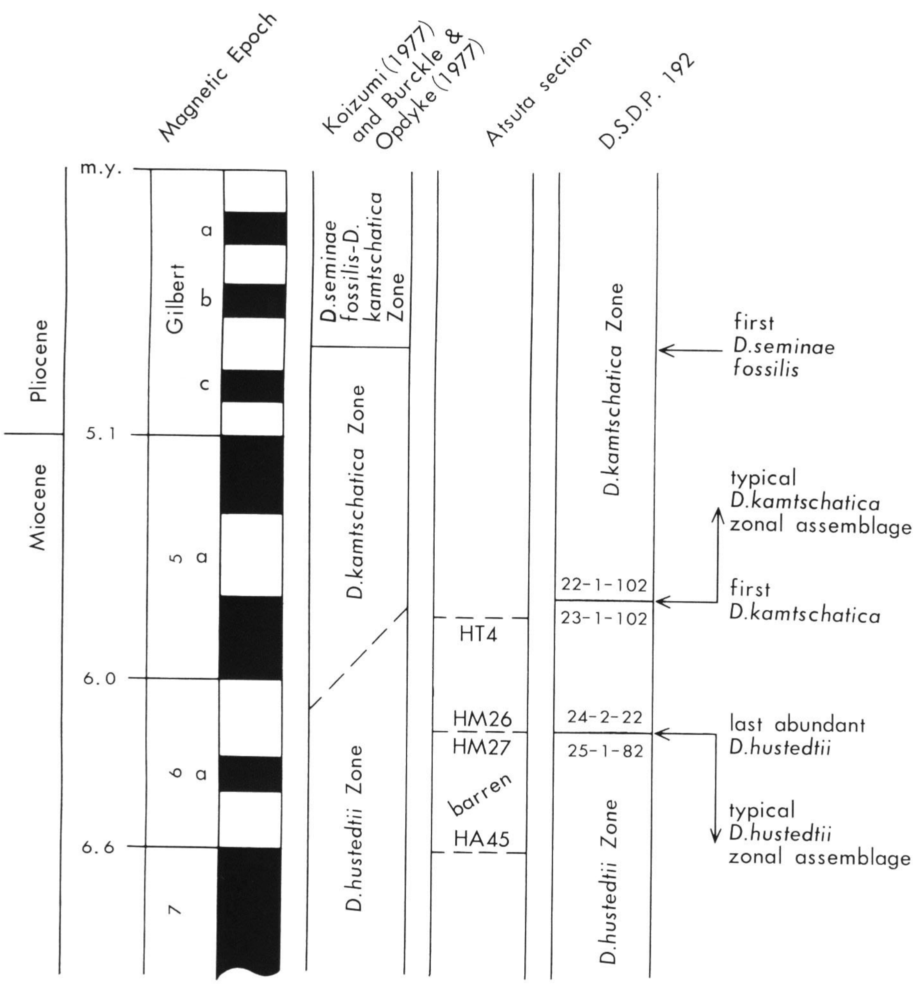


Fig. 21. Diatom biostratigraphy of the Atsuta section and at D. S. D. P. Site 192, correlated with the standard zonning scheme and paleomagnetic dating.

of *D. kamtschatica* (30–70%) and the absence of *D. seminae fossilis* SCHRADER in samples 59–98 place this part of the section in the *D. kamtschatica* Zone of KOIZUMI (1975b). The presence of *Cosmiodiscus insignis* JOUSÉ in sample 98 suggest that this part of the section is in the upper part of the *D. kamtschatica* Zone. The first appearance of *D. seminae fossilis* in sample 58 and its concurrent range with *D. kamtschatica* in samples 58–48 place this part of the section in the *D. seminae fossilis–D. kamtschatica* Zone of KOIZUMI. The presence of *D. hyalina* SCHRADER and the absence of *Actinocyclus oculatus* JOUSÉ suggest that the upper samples are within the lower part of this zone. The local ranges of two unnamed species of *Thalassiosira*, here designated species 1 and 2, may prove to be additional stratigraphic markers.

The Shimo-Ebekorobetsu section (samples 136–143), collected from the Yuchi Formation, contained well-preserved diatoms in all samples. The assemblage is similar to the Shosanbetsu section with the first appearance of *D. seminae fossilis* in sample 141 and it ranges concurrently with *D. kamtschatica* in samples 141–136. *D. kamtschatica* is present in all samples, *Thalassiosira* sp. 1 occurs in samples 143–140 and *Thalassiosira* sp. 2 in samples 141–140. If the ranges of these species are as restricted here as in the Shosanbetsu section then this part of the Yuchi Formation (samples 143–142) represents only the uppermost part of the *D. kamtschatica* Zone.

Samples collected from the Koetoi and Wakkanai Formations in the area near Wakkanai contained diatom assemblages that would place these formations within the *D. kamtschatica* Zone but below the level of the Yuchi Formation.

Geologic Age

Figure 24 gives the correlations of the studied sections to the diatom zonation of KOIZUMI (1975b) with the additional use of *Thalassiosira* sp. 1 and 2 to better refine the relationship of the Shimo-Ebekorobetsu and Shosanbetsu sections. The base of the *D. seminae fossilis–D. kamtschatica* Zone, the first appearance of *D. seminae fossilis*, has been found to occur between the Gilbert b and c Events in core material from the northwest Pacific (BURCKLE and OPDYKE, 1977) and a similar assignment can be made here for the normal event in the lower part of the Shosanbetsu section. This gives an Early Pliocene age to this entire section and similarly to the Shimo-Ebekorobetsu section and to the upper part of the *D. kamtschatica* Zone. The Atsuta section, the upper part of which is diatomaceous, did not contain specimens of *D. kamtschatica* and is correlated with the *D. hustedtii* Zone. The age of the first appearance of *D. kamtschatica* in this area is not well-established and may be confounded in the literature by the presence of *N. rolandii*. KOIZUMI (1977) presents some absolute age data on the first appearance of *D. kamtschatica* from three land sections in the northern part of Honshu: 1) a glauconite K-Ar date of 6.4 m.y. B.P. below a typical *D. hustedtii* zonal assemblage, 2) a glauconite K-Ar date of 5.7–6.1 m.y. B.P. falling between a typical *D. hustedtii* zonal assemblage and an atypical *D. kamtschatica* zonal assemblage (*D. hustedtii* 1%, *T. antiqua* 4%, *C. temperi* 11%, *A. ingens* 2% and *D. kamtschatica*

9%), and 3) a series of fission tracks dates from a tuff, the stratigraphically highest and youngest being 5.8±0.95 m.y. B.P. and the lowest being 6.4±2.1 m.y. B.P., with an atypical *D. hustedtii* zonal assemblage (*D. hustedtii* 1%, *A. ingens* 3%, *D. hyaline* 1%, *R. californica* 1%, *Synedra jouseana* 3%, and *T. decipiens* 1%) below and a typical *D. kamtschatica* assemblage above (*D. kamtschatica* 45%). KOIZUMI gives an "average" age of 6.2 m.y. for the first appearance of *D. kamtschatica*. Using the above data and assuming that these are true *D. kamtschatica* and not *N. rolandii*, the top of the *D. hustedtii* Zone must be younger than *ca.* 6.1 m.y. B.P. and the base of the *D. kamtschatica* Zone must be older than *ca.* 5.8 m.y. B.P. The data presented earlier from D.S.D.P. Hole 192 showed that the Atsuta assemblage falls stratigraphically between typical assemblages of the *D. hustedtii* and *D. kamtschatica* Zones. The paleomagnetic interpretation places the diatomaceous part of the Atsuta section within a time interval almost precisely between the radiometric age limits just mentioned (Fig. 21) and within the Late Miocene.

Taxonomic Notes

Nitzschia rolandii SCHRADER, emend. HARPER

Nitzschia rolandii SCHRADER (1973), Pl. 26, figs. 3, 4; Pl. 5 figs. 31, 42.
Denticula kamtschatica ZABELINA.—SCHRADER (1973), Pl. 2, figs. 4, 5.—KOIZUMI (1968), Pl. 34, fig. 8.

Emended description: Rectangular in girdle view, 2–3μ high for single valve. In valve view, elongate, narrowly elliptical to linear with parallel margins, in smaller forms becoming more inflated. Length ranges from 5 to 30μ, averaging 13μ. Transapical costae present, straight medially to curved apically, 7–11 per 10μ, averaging 9.7μ. Intercostal membrane finely punctate, with 3–4 rows of transapical striae clearly visible in electron microscopy, faintly visible in phase contrast, and invisible in normal optical microscopy. The transapical costae extend internally into the valve in the manner of pseudosepta. The pseudosepta branch near the raphe with adjacent pseudosepta usually sharing branches. The original description of SCHRADER (1973) has been expanded to include forms of smaller size and with a smaller density of transapical costae.

Discussion: In progressively younger horizons, it appears that the number of costae-pseudosepta per 10 μ decreases in this species, and the sharing of the branches becomes inconsistent. In this way *N. rolandii* appears to grade into *Denticula kamtschatica* ZABELINA, which has 5–6 pseudosepta per 10 μ and an irregular branching pattern. Since most specimens of *D. kamtschatica* are missing their septa, the distinction between these two species should emphasize the number of costae-pseudosepta per 10 μ and their branching pattern. In the Hokkaido sections, *N. rolandii* ranges from the upper part of the *Denticula hustedtii* Zone to within the *Denticula kamtschatica* Zone. In D.S.D.P. Hole 173, *N. rolandii*, as originally defined by SCHRADER, ranges within the upper part of the range of *D. hustedtii* but does not overlap with *D. kamts-*

chatica. Misidentification of *D. kamtschatica* with smaller *N. rolandii* is the probable reason for this discrepancy.

Thalassiosira nidulus (TEMPÈRE and BRUN) JOUSÉ

There appear to be two forms of this species in the literature. One, *sensu* JOUSÉ (1961), is small (9–22 μ) with sharply tapering spines. This form seems to first occur within the *D. kamtschatica* Zone. The other form is that first described in BRUN and TEMPÈRE (1889) on pages 57–58. This form is much larger (30–45 μ) and has a different type of spine. It first occurs in the *D. hustedtii* Zone. Further work is needed to decide if these two forms are separate species or end members of a continuous lineage.

FORAMINIFERA

P. R. THOMPSON

Microfossils were separated from the rock samples by several methods depending on the rock type. The coarse siltstones of the Morai, Bannosawa and Atsuta Formations were easily disaggregated with tap water and hydrogen peroxide, and then wet sieved. Fine-grained sandstones and diatomites of the Tobetsu, Mochikubetsu and Embetsu Formations were hammered to chestnut-sized fragments, oven-heated to drive off interstitial moisture, covered with saturated sodium sulfate (Na_2SO_4) solution, and allowed to crystalize. Following the crystallization of sodium sulfate, the crystal-covered rock was boiled with water and the commercial product Calgon ($Na_3C_6H_5O_7 \cdot 2H_2O$) and wet sieved. In both cases, wet sieving was done on a 74 μ-opening screen, and the samples were again oven dried and stored in small envelopes.

Microfossils including diatoms, planktonic and benthonic foraminifera, porous volcanic debris and carbonized organic matter were separated from the mineral matter by flotation with Trichloroethylene (C_2HCl_4). This process was carried out under a fume hood, and the residues decanted onto filter paper, allowing recovery of the liquid. The filter paper was air dried and floated fractions were stored on standard $1'' \times 3''$ micropaleontological slides.

Figures 22, 23 and 24 show the relative proportions of various foraminifera recovered by flotation out of the disaggregated residues of the initial 1000 cc each of collected samples. Foraminifera were present in samples HM27–HA47′ from the Atsuta section, in samples HMo50, HMo52, and HMo53 from the Shosanbetsu section, and in samples HK100–HW110 from the Wakkanai section. It is interesting to note that diatoms are abundant in samples containing a quantity of volcanic debris, whereas foraminifera are abundant where these components are relatively low.

Similar foraminiferal species and assemblages as those described below have been noted on Sakhalin (VOLOSHINOVA *et al.*, 1970) and in the northern Japan oil fields (MATSUNAGA, 1963), and probably indicate the presence of similar bathymetric condi-

Table 5. Occurrence chart of foraminifera in the Atsuta section.

FAMILY GENUS - SPECIES	ATSUTA SECTION FORAMINIFERA																					
	27	28	29	30	30'	31	32	33	34	35	36	37	38'	40	41	42	43	45	45"	46	47	47'
Nonionidae																						
Cribroelphidium yabei (Asano)	-	-	-	1	9	-	-	-	-	-	-	-	-	-	-	11	120	-	-	-	14	-
Nonion scaphum Fichtel & Moll	-	-	-	-	-	-	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-
N. pacificum (Cushman)	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	3	-	-	-	-	-
N. pompilioides (Fichtel & Moll)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14	3	-	-	35	-
N. grateloupi (d'Orbigny)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-
Buliminidae																						
Uvigerina akitaensis Asano	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	VA	1
U. subperegrina Cushman & Kleinpell	-	-	-	-	-	2	-	-	-	-	-	-	1	-	-	-	2	-	-	-	-	-
U. nitidula Schwager	-	-	-	1	-	-	-	-	1	2	-	-	-	-	-	1	-	-	-	-	-	-
U. peregrina latalata Stewart & Stewart	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	55	1	-	-
U. yabei Asano	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-
Hopkinsina wakimotoensis Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	24	73	-	20	1	50	-
Angulogerina kokozuraensis Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	3	5	-	12	1	26	-
Bulimina subclava Cushman & Stewart	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2	-	-	-	-	-
Textulariidae																						
Textularia spp.	-	-	-	-	A	85	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	3
Valvulinidae																						
Goesella schenoki Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	30	50
Martinottiella communis (d'Orbigny)	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	A	VA
Quinqueloculina spp.	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-
Miliolidae																						
Pyrgo spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Cassidulinidae																						
Cassidulina kasiwazakiensis Husezima & Maruhasi	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	4	1	8	-	-	-
Globocassidulina subglobosa (Brady)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	18	-
Epistominella pulchella Husezima & Maruhasi	-	-	-	-	2	-	-	-	-	-	-	-	-	4	-	90	-	-	-	-	-	-
E. japonica (Asano)	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	20	150	-	10	-	C	-
Opthalmididae																						
Cornuspira involvens (Reuss)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Lituolidae																						
Haplophragmoides cf. *emaciatus* (Brady)	-	-	-	-	-	10	14	-	-	-	-	-	-	-	-	-	50	-	18	-	10	5
H. compressus LeRoy	-	-	-	-	-	80	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
H. renzi Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	30	6	10	2
H. cf. *trullissatus* (Brady)	20	50	1	1	-	50	-	-	10	25	50	20	-	50	1	40	50	2	-	-	10	15
Cyclammina japonica Asano	3	10	1	-	-	-	8	1	3	-	2	-	-	-	-	30	1	-	6	-	30	30
C. pusilla Brady	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	6	-	30	15
Chilostomellidae																						
Pullenia salisburyi Stewart & Stewart	-	-	-	-	-	-	-	-	-	1	-	-	-	6	-	8	16	-	1	-	8	-
P. bulloides d'Orbigny	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-
Sphaeroidina sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	2	-	4	-
Anomalinidae																						
Cibicides cf. *refulgens* (Montfort)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	2	-
C. aknerianus (d'Orbigny)	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
C. lobatus (Walker and Jacob)	-	-	-	-	-	-	-	-	-	1	-	-	-	3	-	7	7	-	3	-	11	-
Anomalina glabrata Cushman	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	100	-
A. globulosa Chapman & Parr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-
Rotaliidae																						
Gyroidina orbicularis d'Orbigny	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-
Lagenidae																						
Robulus iotus (Cushman)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	7	-	-	-	2	-
Pseudoglandulina laevigata (d'Orbigny)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-
Dentalina setaensis Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	1	-
D. communis d'Orbigny	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	-
D. subsoluta (Cushman)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	-
Nodosaria catenulata Brady	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
N. subraphana Asano	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
N. semirugosa d'Orbigny	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	8	2		3	3	1	-
Sarcenaria schencki Brady	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lagena asanoi Matsunaga	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
L. elongata (Ehrenberg)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
L. spp.	-	-	-	-	1	-	-	-	-	-	-	-	-	3	-	4	14	-	-	-	-	-
Oolina costata (Williamson)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	2	-	P	-
O. globosa (Montagu)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	3	-	5	-	P	-
O. hexagona (Williamson)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	P	-
Fissurina fasciata (Egger)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	-	1	-	P	-
Frondicularia sp.	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	6	-	-	-	-	-	-
Trochamminidae																						
Trochammina sp.	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Globigerinidae																						
Globigerina bulloides d'Orbigny	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
Globigerina spp.	-	-	-	-	-	-	-	-	-	-	-	-	2	2	2	7	26	1	-	-	-	-
Globigerinita glutinata (Egger)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	8	-	-	-	-	-
Globorotalia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	2	-	-	-
TOTALS	23	60	2	8	A	237	23	1	16	32	54	20	7	107	5	286	652	8	189	13	VA	128+

tions. With the paleontologic and paleomagnetic controls established in this study, it should also be possible to set up a preliminary chronologic framework between the tectonic events of the area from the marine sedimentary record.

Benthonic foraminifera from the Atsuta section (Figs. 22; Pl. 6) indicate a shoaling from outer slope depths in the Atsuta Formation to stagnant, near-shore conditions in the upper part of the Morai. Above sample HM27, no foraminifera were recovered. Planktonic foraminifera were present in samples HB40–HA45, but gave only general age assignment.

Samples HA47′–HA46 from the base of the Atsuta section contain abundant *Martinottiella communis* (D'ORBIGNY), (?) *Goesella schencki* ASANO, and *Uvigerina akitaensis* ASANO, along with common *Melonis pompilioides* (FICHTEL and MOLL), *Haplophragmoides* spp. and *Cyclammina* spp. MATSUDA (1957) reported recent foraminiferal biocoenosis typified by *U. akitaensis* from Toyama Bay of the Sea of Japan, recording it from upper bathyal depths of about 200–400 m.

Above this, samples HA45–HB40 are dominated by *Epistominella pulchella* HUSEZIMA and MARUHASI, *E. japonica* (ASANO), *Cribroelphidium yabei* (ASANO), *Hopkinsina wakimotoensis* ASANO, and common costate-to-spinose uvigerinids and planktonic forms such as *Globigerina bulloides* D'ORBIGNY, *G. woodi* JENKINS, and *Globigerinita glutinata* (EGGER). This assemblage indicates outer shelf depths of 200–400 m (BANDY, 1953, 1964) and surface water masses of temperate latitudes. Sample HA44 was barren. TSUSHIMA *et al.* (1956, p. 7) reported *Cribrostomoides* from this section, but no individuals referable to this genus were noted; and they also reported *Bulimina pupoides* D'ORBIGNY, which might be instead referable to the genus *Hopkinsina.*

Samples HB 38–HM30 are relatively poor in foraminifera. Sample HB 39 was barren. *Haplophragmoides* cf. *trullissatus* (BRADY) dominates the lower samples and *H. compressus* LEROY and *H.* cf. *emaciatus* (BRADY) appear later. Samples HM31 and HM30′ have abundant *Textularia* spp. Minor components in the assemblage include uvigerinids, lagenids and lituolids. The fauna suggests inner shelf depths of 50–100 m (BANDY, 1964).

Samples HM29–HM27 representing the top of benthonic foraminiferal occurrences in the Atsuta section, are dominated by *Haplophragmoides* cf. *trullissatus* (BRADY) and *Cyclammina japonica* ASANO; both decrease their abundance upwards. This assemblage indicates shallow, probably stagnant conditions less than 50 m deep (WALTON, 1964).

The magnetic stratigraphy and diatom biostratigraphy for this section indicates that the measured sequence ranges from the bottom of Epoch 5 to the top of Epoch 7; the age of this span varies from paper to paper but averages about 0.6 m.y., giving an average sedimentation rate of about 1 m/1000 years, a reasonable figure for tectonically active continental margins. Further, foraminiferal evidence gives a general figure of 1000 m+ regressive emergence over the interval HA47–HM27. The occurrences of shallower-living forms in many of the deeper deposits probably indicate down-slope displacement of such species.

The Shosanbetsu section (Figs. 2, 23; Pl. 7) produced foraminifera only from samples HMo50, HMo52 and HMo53, and very abundantly from HMo52. The assemblage in these samples is dominated by *Cribroelphidium yabei* (ASANO), *Elphidium hughesi foraminiferosum* CUSHMAN, *E. etigoense* HUSEZIMA and MARUHASI, *Cassidulina kasiwazakiensis* HUSEZIMA and MARUHASI, *Buccella frigida* (CUSHMAN) and *Epistominella pulchella* HUSEZIMA and MARUHASI. This is probably an outer shelf deposit about 200 m deep (BANDY, 1953, 1964; WALTON, 1964). HATA (1961, p. 45) reported the additional species *Elphidium subgranulosum* ASANO, *Cribroelphidium tomitai* TAI, *Virgulina schreibersiana* CZJZEK, *Discorbinella bradyi* (CUSHMAN), *Buccella frigida calida* (CUSHMAN and COLE), *Globocassidulina subglobosa depressa* (ASANO and NAKAMURA), and *Cassidulina yabei* ASANO and NAKAMURA.

Table 6. Occurrence chart of foraminifera in the Shosanbetsu section

FAMILY	GENUS - SPECIES	SHOSANBETSU SECTION FORAMINIFERA 50	52	53
Nonionidae				
	Cribroelphidium yabei (Asano)	-	VA	45
	C. ezoense (Asano)	2	-	-
	Nonion scaphum Fichtel & Moll	-	-	5
	N. pompilioides (Fichtel & Moll)	-	-	10
	N. akitaensis Asano	20	-	-
	N. aimonoi Matsunaga	14	-	-
	Nonionella miocenica stella Cushman & Moyer	10	-	3
	Pseudononian japonicum Asano	-	R	-
	Astrononion hamadaense Asano	34	-	10
	Elphidium hughesi foraminosum Cushman	VA	VA	-
	E. etigoense Husezima & Maruhasi	2	A	-
Cassidulinidae				
	Cassidulina kasiwazakiensis Husezima & Maruhasi	2	A	8
	Globocassidulina subglobosa (Brady)	7	C	12
	Epistominella pulchella Husezima & Maruhasi	A	A	60
Anomalinidae				
	Cibicides cf. *refulgens* (Montfort)	C	-	-
	C. lobatulus (Walker & Jacob)	-	C	-
Rotaliidae				
	Buccella frigida (Cushman)	150	C	20
	Eponides nipponicus Husezima & Maruhasi	-	C	-
Lagenidae				
	Lagena sesquistriata Brady	-	C	-
	L. laevis (Montagu)	-	-	1
	L. asanoi Matsunaga	-	R	-
Globigerinidae				
	Globigerina spp.	P	VA	P
	Neogloboquadrina pachyderma (Ehrenberg)	-	A	-
	Globigerinita minuta (Natland)	-	VA	-
	TOTALS	A	VA	C

Planktonic foraminifera were common in these Shosanbetsu samples and include *Globigerina bulloides* D'ORBIGNY, several new species of *Globigerina* to be described elsewhere, *Globigerinita minuta* (NATLAND) and *Neogloboquadrina pachyderma* (EHRENBERG). BRADSHAW (1959, text-figs. 13 and 20) indicated that both *N. pachyderma* and *G. minuta* are common to abundant in cold modern surface waters slightly northeast of Hokkaido; LIPPS and WARME (1960) recorded them as commonly occurring in sediments in the Sea of Okhotsk to the north, ICHIKURA and UJIIÉ (1976), and INGLE (1975) recorded them in varying proportions from the Sea of Japan. Although the major current introducing planktonic foraminifera into the Sea of Japan today is the Tsushima Current from the south (UJIIÉ, 1973), the composition of the fauna at the Shosanbetsu section indicates more influence from the north, perhaps through the Liman Current or its equivalent at that time, and with little or no southern influence.

The sharp boundary between the foraminifera-bearing and foraminifera-lacking sediments in this section is bothersome. Sedimentary evidence shows considerable slumping throughout the section studied, and raises the possibility that these foraminifera-bearing intervals might have been reworked, or more likely, that the barren section was deposited during an extremely active tectonic period with concomitant influx of terrigenous sediments.

The Wakkanai area was not sampled continuously, so that no composite section is presented here. Benthonic foraminifera (Table 7; Pl. 7) were recovered only from a series of samples representing the uppermost Koetoi Formation and lower Wakkanai Formation in a stream cut near the Minato Elementary School. *Martinottiella* sp. was present in very low numbers throughout the samples, and one sample near the top of the Koetoi produced abundant *Hopkinsina* sp., *Nonion labradoricum* (DAWSON) or *Nonion scaphum* (FICHTEL and MOLL), *Globocassidulina subglobosa* (BRADY), and

Table 7. Occurrence chart of benthonic foraminifera in the Wakkanai section

FAMILY	GENUS - SPECIES	WAKKANAI SECTION FORAMINIFERA					
		100	102	104	106	108	110
Valvulinidae							
	Martinottiella communis (d'Orbigny)	2	1	-	2	8	3
Chilostomellidae							
	Sphaeroidina bulloides d'Orbigny	-	-	1	-	-	-
Buliminidae							
	Hopkinsina sp.	-	-	-	-	50	-
	Bulimina ovula d'Orbigny	-	-	-	-	10	-
Nonionidae							
	Nonion labradoricum (Dawson)	-	-	-	-	7	-
Cassidulinidae							
	Globocassidulina subglobosa (Brady)	-	-	-	-	20	-
Polymorphinidae							
	Guttulina bulloides (Reuss)	-	-	-	-	10	-
	Guttulina sp.	-	-	-	-	10	-
	TOTALS	2	1	1	2	115	3

Bulimina ovula D'ORBIGNY. This is probably an outer shelf or upper bathyal assemblage of 200–1500 m depth (BANDY, 1953, 1964).

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SUMMARY AND CONCLUSIONS

A combined biostratigraphical, magnetostratigraphical and sedimentological study of Late Cenozoic sediments was made on stratigraphic sequences representing four sedimentary basins in northwestern Hokkaido. Two of these sequences were given intensive paleomagnetic and sedimentological analyses. From the data obtained, we can draw the following conclusions about geologic events during the period approximately from 6.5 m.y. to 3.8 m.y. B.P.

The measured section near Atsuta along the Sea of Japan coast encompasses the Tobetsu, Morai, Bannosawa and Atsuta Formations in downward sequence and is assigned to the magnetostratigraphic interval from the early Epoch 5 through Epoch 6, and possibly to the top of Epoch 7 (Fig. 22). The boundary between Epoch 5 and Epoch 6 is recognized near the topmost part of the measured section in the Tobetsu Formation. The Tobetsu Formation contains a rich diatom flora assignable to the *Denticula hustedtii* Zone of KOIZUMI (1973). No foraminifera have been found in the Tobetsu Formation, but they occur consistently in the lower part of the section from the top of the Morai Formation downward to the Atsuta Formation. The foraminiferal evidence indicates a shoaling of depositional environments from upper bathyal depths in the Atsuta Formation to stagnant, near-shore conditions near the top of the Morai Formation.

In the coastal section north of Shosanbetsu, a long and nearly continuous sequence of Neogene sediments is exposed. These sediments are divided into the Mochikubetsu, Embetsu, Kinkomanai, and Kotambetsu Formations in downward sequence (Fig. 23). A combined micropaleontological and magnetostratigraphical study was made only for the Mochikubetsu and Embetsu Formations, although sedimentological studies were carried out down to the base of the section. A magnetic polarity reversal occurs near the middle of the Mochikubetsu Formation with the reversely magnetized upper part being underlain by the normally magnetized sequence. The lower two-thirds of the Embetsu Formation is characterized by an erratic magnetic signature, although the data seem to indicate the sequence to be of dominantly normal magnetic polarity. Rich diatom floras occur throughout the Mochikubetsu and Embetsu Formations and are used to correlate these formations with the *Denticula seminae* var. *fossilis–Denticula kamtschatica* Zone. In the northwest Pacific deep-sea sequences, the first appearance of *D. seminae* var. *fossilis* SCHRADER which defines the boundary between the *D. seminae* var. *fossilis–D. kamtschatica* Zone and the subjacent *D. kamtschatica* Zone is

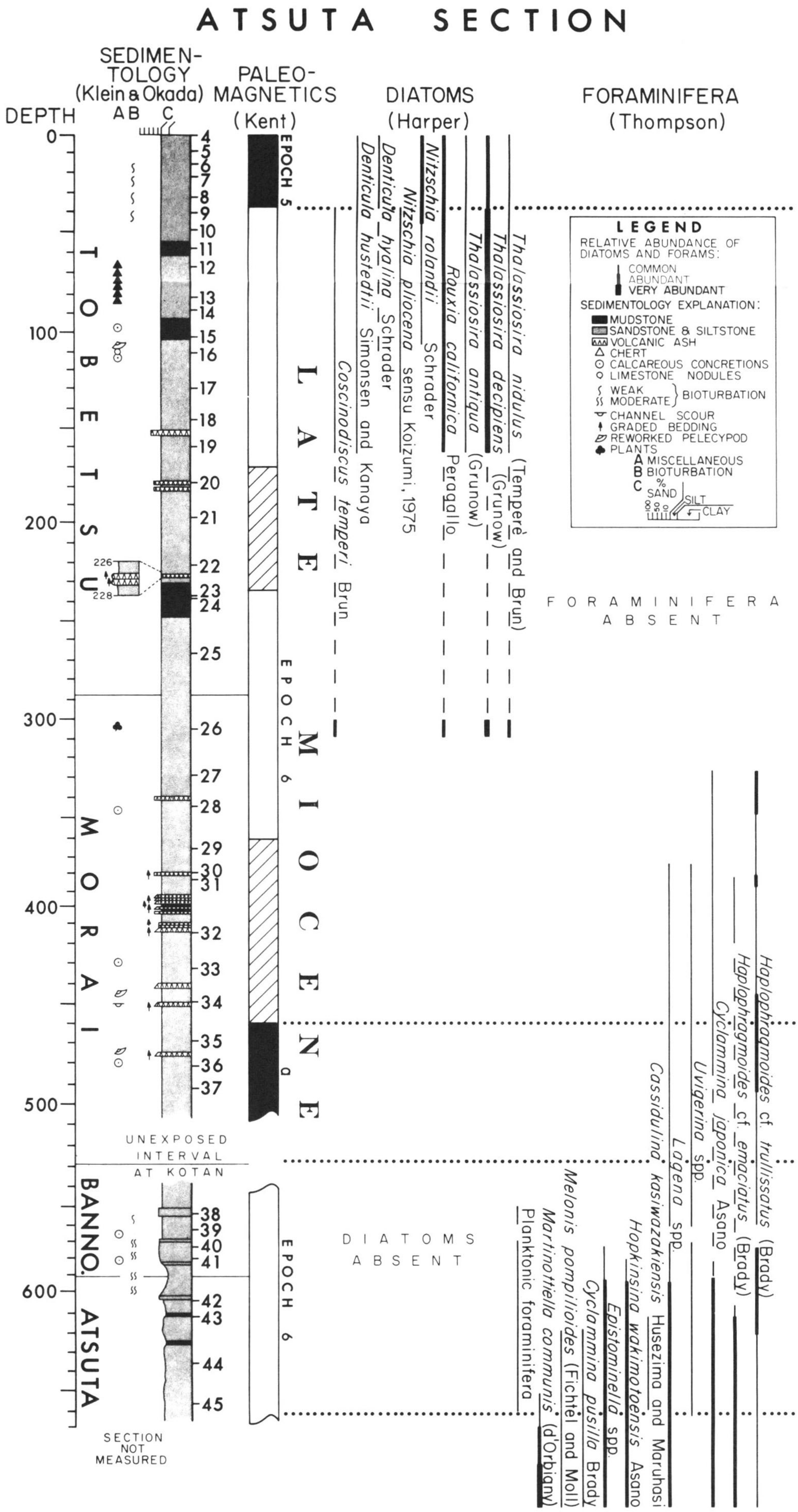

Fig. 22. Composite stratigraphy of the Atsuta section.

SHOSANBETSU SECTION

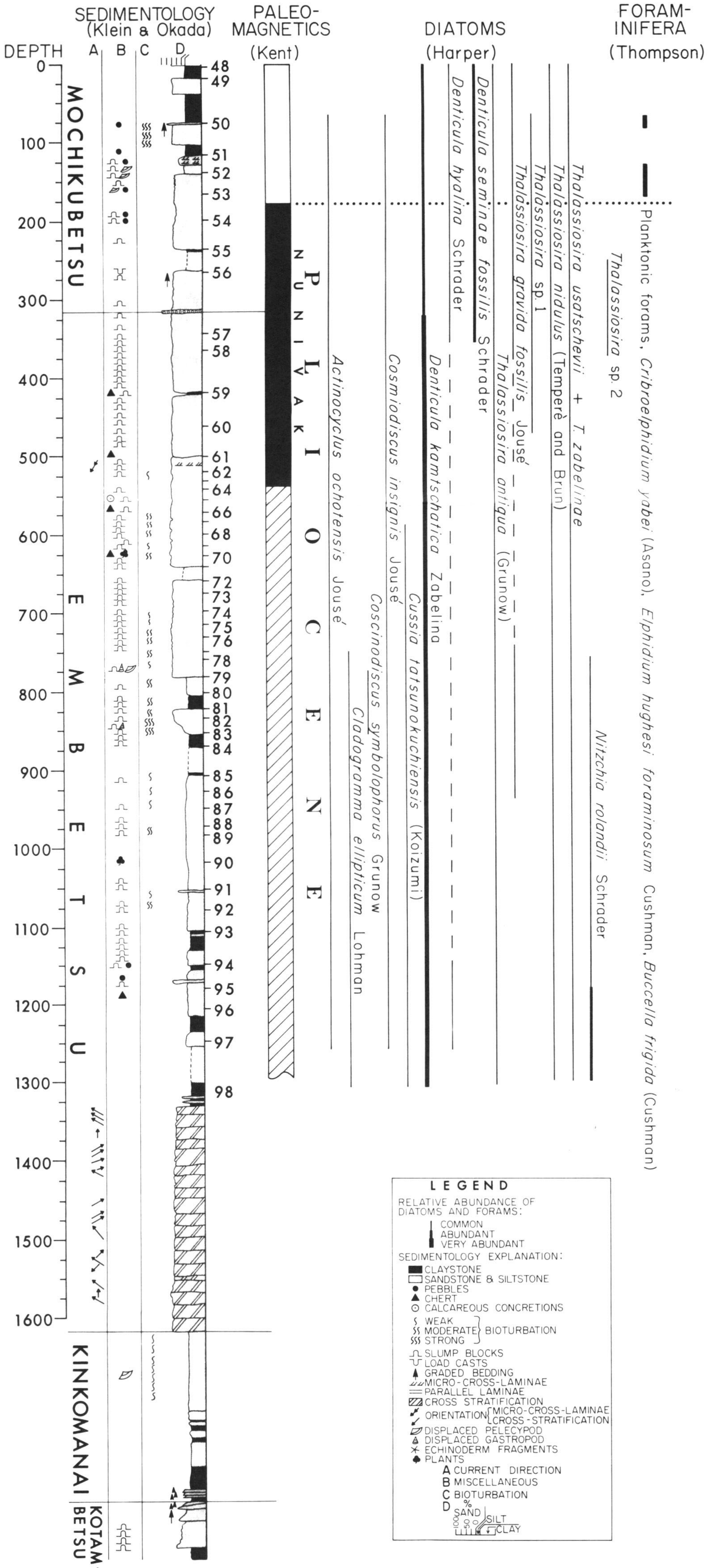

Fig. 23. Composite stratigraphy of the Shosanbetsu section.

known to occur between the Nunivak (="b") and "c" Events of the Gilbert Reversed Magnetic Polarity Epoch. The normal polarity interval occurring in the lower part of the Mochikubetsu and the upper part of the Embetsu Formations is correlated with the Nunivak Event on this evidence. Sporadic occurrences of foraminifera are noted in the upper part of the Mochikubetsu Formation. The faunal data indicate an outer shelf depositional environment for the foraminifera-bearing part of the Mochikubetsu Formation.

Magnetic polarity measurements of representative samples of the Koetoi and Wakkanai Formations reveal that these formations were deposited during a time interval of predominantly reversed geomagnetic polarity. Diatom floras suggest a correlation of these formations with the *Denticula kamtschatica* Zone which spans an interval from a horizon midway between the Nunivak and Gilbert "c" Events down to the base of the "a" Event of Epoch 5 (Fig. 24). Since the Epoch 5 is predominantly a normally magnetized interval, it is reasonable to assign the Koetoi and Wakkanai Formations to the early part of the Gilbert Reversed Epoch. Only benthonic foraminifera, represented by a few species, are found from the uppermost Koetoi Formation and lower Wakkanai Formation. This assemblage probably represents outer shelf or upper bathyal depositional environments.

The Yuchi Formation distributed in the Shimo-Ebekorobetsu area yields a rich diatom flora similar to that found in the Shosanbetsu section, and comprises two assemblages assignable to the uppermost part of the *Denticula kamtschatica* Zone and the superjacent *Denticula seminae* var. *fossilis–D. kamtschatica* Zone.

From the Pacific coastal region of northern Honshu through Hokkaido to Sakhalin, beds containing *Fortipecten takahashii* (YOKOYAMA) constitute a marker horizon useful for inter-regional stratigraphic correlation. In its southern range of distribution, *F. takahashii* is a diagnostic species in the lower Tatsunokuchi Formation. A diatom flora examined by KOIZUMI (1972; 1973) from the Tatsunokuchi Formation is characterized by the concurrent occurrence of *Denticula kamtschatica* and *D. seminae* but without *Rhizosolenia praebergonii* MUKHINA and thus is assignable to the lower part of the *D. seminae* var. *fossilis–D. kamtschatica* Zone. This same bed bearing *F. takahashii* is present in the middle part of the Mochikubetsu Formation of the Shosanbetsu section and the associated diatom flora is indicative of the *D. seminae* var. *fossilis–D. kamtschatica* Zone. Although these two localities are separated by some 800 km, the beds characterized by *F. takahashii* lie within the identical diatom zone, suggesting a remarkable value of *F. takahashii* as an index fossil. The *F. takahashii* horizon of the Mochikubetsu occurs in a reversely magnetized interval above the Nunivak Event of the Gilbert Reversed Epoch, to which an approximate date of 3.9 m.y. B.P. can be assigned according to the paleomagnetic reversal chronology of OPDYKE (1972).

Sedimentological, mineralogical and petrological studies indicate that Neogene marine sediments of northwestern Hokkaido were deposited in the back-arc basin and the sediments reveal evidence of active arc magmatism at the time of deposition related to active plate movement. These marine strata comprise not only airborne

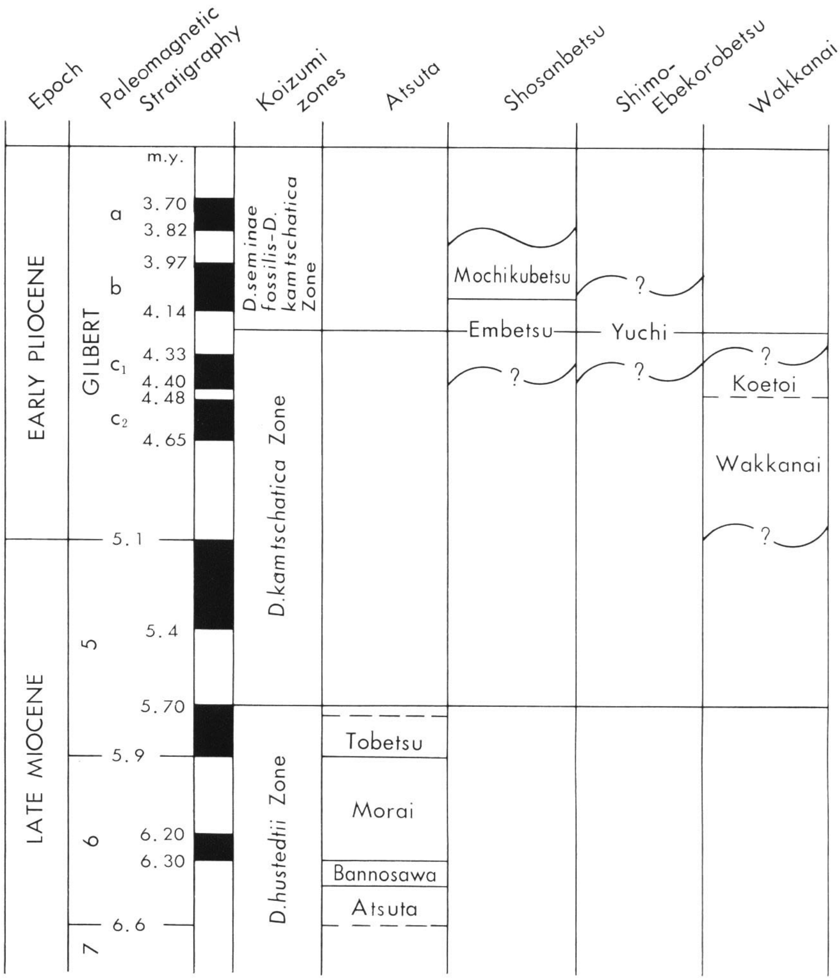

Fig. 24. Correlation chart of the surveyed sequences in the framework of paleomagnetic and diatom stratigraphies.

ash but also clastics of acidic-to-intermediate volcanic rocks. Three major sedimentary facies are represented in the Neogene sequence: The Tobetsu, Morai, Bannosawa, and Atsuta Formations belong to Facies 1. This facies, occurring only in the Atsuta section and consisting of volcano-clastic siltstones, was derived largely from a volcanic island arc and its depositional mode was a combination of ash falls, turbidity currents and hemipelagic processes. Facies 2 is represented by the Mochikubetsu, upper Embetsu and Kotambetsu Formations of the Shosanbetsu section and is dominated by dark gray mudstone containing slump blocks of sandstone ranging in diameter from 20 cm to 5 m. This facies, also consisting of sediments originated from a volcano-clastic source, was depostited on a continental slope with oversteepened slopes. Sediments bearing similar slump features are observed in intercanyon slope areas of the northeastern United States Continental Slope. The lower Embetsu and Kinkomanai Formations consist of interbedded mudstone, mudstone and sandstone interlayers, and thick-bedded sandstones and compose Facies 3. This facies is organized as a coarsening-upward sequence and a sequence similar to this is known from the Mississippi Delta. The depositional environment of Facies 3 is considered to be a delta front.

Using the magnetostratigraphically derived dates for the Atsuta and Shosanbetsu sections, we estimate the rate of sediment accumulation in these sedimentary basins to be on the order of 100–150 cm per 1000 years. A correlation of strata in various sedimentary basins of northwestern Hokkaido clearly indicates that, although sediments were accumulating at a remarkably fast rate whenever sediments were supplied in these basins, the sedimentation was apparently never continuous in a given basin (Fig. 24). In the northernmost part of Hokkaido, for example the Wakkanai Formation of probable early Gilbert age is unconformably underlain by the Masuporo Formation of Middle Miocene age, separated by a stratigraphic hiatus spanning several million years. It appears that in such a tectonically active back-arc region, sediment-trapping basins were kept moving from area to area, collecting sediments only for a relatively short period of time when spurts of active subsidence took place in a given area.

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Explanation of Plates

Plate 1

(Bar equals 0.5 mm)

Fig. 1. Photomicrograph of a calcareous nodule (Specimen HT12′) from the Tobetsu Formation Atsuta; open nicols.

Fig. 2. Photomicrograph of a cherty nodule (Specimen HT8′-A) from the Tobetsu Formation, Atsuta; open nicols.

Figs. 3, 4. Photomicrographs of a calcareous litharenite (Specimen KU 6501) from the Kotanbetsu Formation, Shosanbetsu. 3, open nicols; 4, crossed nicols.

Plate 2

(Bar equals 0.5 mm)

Figs. 1, 2. Photomicrographs of a tuffaceous lithic sandstone (Specimen HM34′) from the Morai Formation, Atsuta. 1, open nicols; 2, crossed nicols.

Figs. 3, 4. Photomicrographs of a calcareous litharenite (Specimen TYSl) from the sandstone member of the Embetsu Formation. 1, open nicols; 2, crossed nicols.

Plate 3

(Bar equals 10 μ)

Figs. 1–4. *Denticula kamtschatica* Zabelina. 1, HE87; 2–4, HE85.

Fig. 5. *Denticula seminae fossilis* Schrader. HE57.

Fig. 6. *Denticula hustedtii* Simonsen and Kanaya. HM17.

Fig. 7. *Cussia tatsunokuchiensis* (Koizumi) Schrader. HE87.

Fig. 8. *Cladogramma ellipticum* Lohman. HE97.

Figs. 9–11. *Nitzschia rolandii* Schrader. 9, HT6; 10, HE89; 11, HE98.

Fig. 12. *Thalassiosira decipiens* (Grunow) Jørgensen. HM18.

Figs. 13, 14. *Thalassiosira nidulus* sensu Jousé, smaller form. Both HE61.

Fig. 15. *Thalassiosira antiqua* (Grunow) Cleve. HE 89.

Figs. 16, 17. *Nitzschia pliocena* sensu Koizumi. 16, HM26. 17, HM18.

Fig. 18. *Rouxia californica* Peragallo. HM26.

Plate 4

(Bar equals 10 μ)

Fig. 1. *Thalassiosira nidulus* sensu Brun and Tempère, HT6.

Figs. 2, 3. *Thalassiosira gravida fossilis* Jousé. Both HE89.

Fig. 4. *Cosmiodiscus insignis* Jousé. HE98.

Fig. 5. *Thalassiosira* sp. 1. HE61.

Figs. 6, 7. *Thalassiosira* sp. 2. Both HE59.

Plate 5

(Bar A equals 10 μ for figures 1, 2, 3, 5, 6)
(Bar B equals 1 μ for figures 4, 7, 8)
All SEM Photos

Figs. 1–4, 8. *Denticula kamtschatica* Zabelina.
1, HE98, exterior view; 2, HE98, interior view of pseudosepta and their branching; 3, DSDP 192–18–4, interior view of septa; 4, HE98, interior view of septa; 8, HE98, interior view of pseudosepta and their branching.

Fig. 5–7. *Nitzschia rolandii* SCHRADER.
5, HE98, interior view of secondary pseudosepta and their branching; 6, DSDP 192–18–4, interior view of secondary pseudosepta and their branching; 7, HT6, interior view.

Plate 6

Figs. 1, 2. *Cyclammina pusilla* BRADY, HA47: 1, umbilical side, ×69; 2, edge view, ×74.

Figs. 3a, b. *Cyclammina japonica* ASANO, HA47: 3a, umbilical side, ×20; 3b, edge view, ×20.

Fig. 4. *Textularia* sp.?, HM31: side view, ×38.

Figs. 5a, b. *Haplophragmoides* cf. *trullissatus* (BRADY), HM31: 5a, umbilical side, ×55; 5b, edge view, ×55.

Fig. 6. *Martinottiella communis* (D' ORBIGNY), HA47: Side view, ×74.

Figs. 7a, b. *Uvigerina akitaensis* ASANO, HA47: 7a, side view, ×84; 7b, umbilical view, ×84.

Figs. 8a, b. *Hopkinsina wakimotoensis* ASANO, HA43: 8a, side view, ×104; 8b, umbilical view, ×190.

Figs. 9a, b. *Anomalina glabrata* CUSHMAN, HA47: 9a, umbilical side, ×124; 9b, side view, ×124.

Figs. 10a, b. *Cribroelphidium yabei* (ASANO), HA43: 10a, side view, ×130; 10b, edge view, ×130.

Plate 7

Figs. 1a, b. *Elphidium hughesi foraminosum* CUSHMAN, HMo52: 1a, side view, ×80; 1b, edge view ×80.

Figs. 2a, c. *Buccella frigida* (CUSHMAN), HMo52: 2a, umbilical view, ×117; 2b, side view, ×117; 2c, spiral view, ×117.

Figs. 3a, b. *Globocassidulina subglobosa* (BRADY), HMo52: 3a, umbilical view, ×183; 3b, side view, ×183.

Figs. 4, 5a, b. *Epistominella pulchella* HUSEZIMA and MARUHASI, HMo52: 4, spiral view, ×104; 5a, side view, ×130; 5b, umbilical view, ×130.

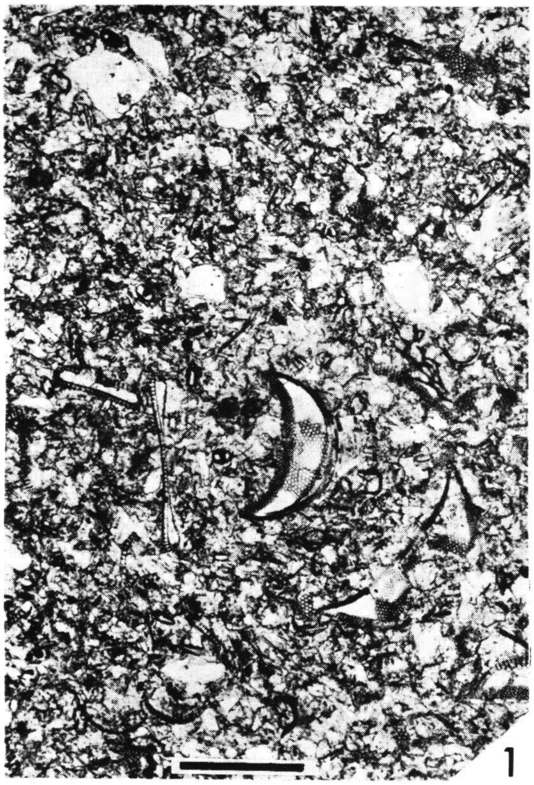
Figs. 6a, b. *Hopkinsina* sp., HK108: 6a, side view, ×84; 6b, top view, ×146.

Fig. 7. *Guttulina* sp., HK108: spiral view, ×111.

Fig. 8. *Guttulina bulloides* (REUSS), HK108: spiral view, ×93.

Fig. 9a, b. *Goesella schencki* ASANO, HK108: 9a, side view, ×87; 9b, top view ×139.

Fig. 10a, b. *Nonion scaphum* (FICHTEL and MOLL), HMo53: 10a, side view, ×141; 10b, edge view, ×141.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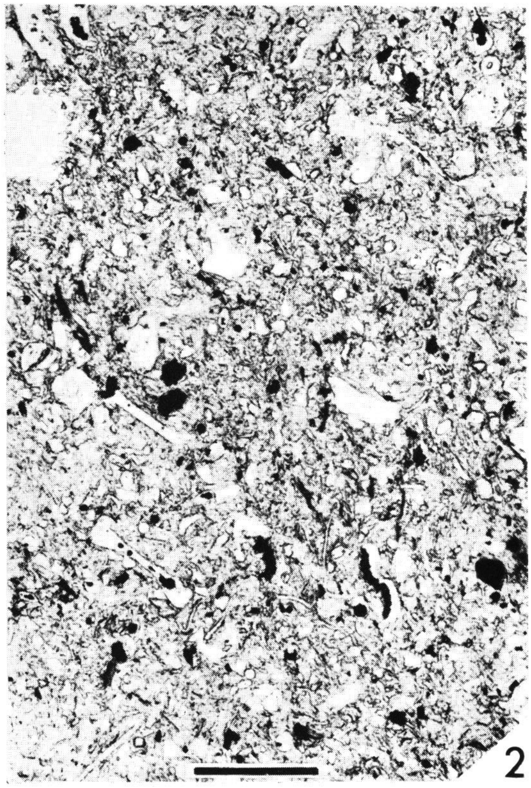
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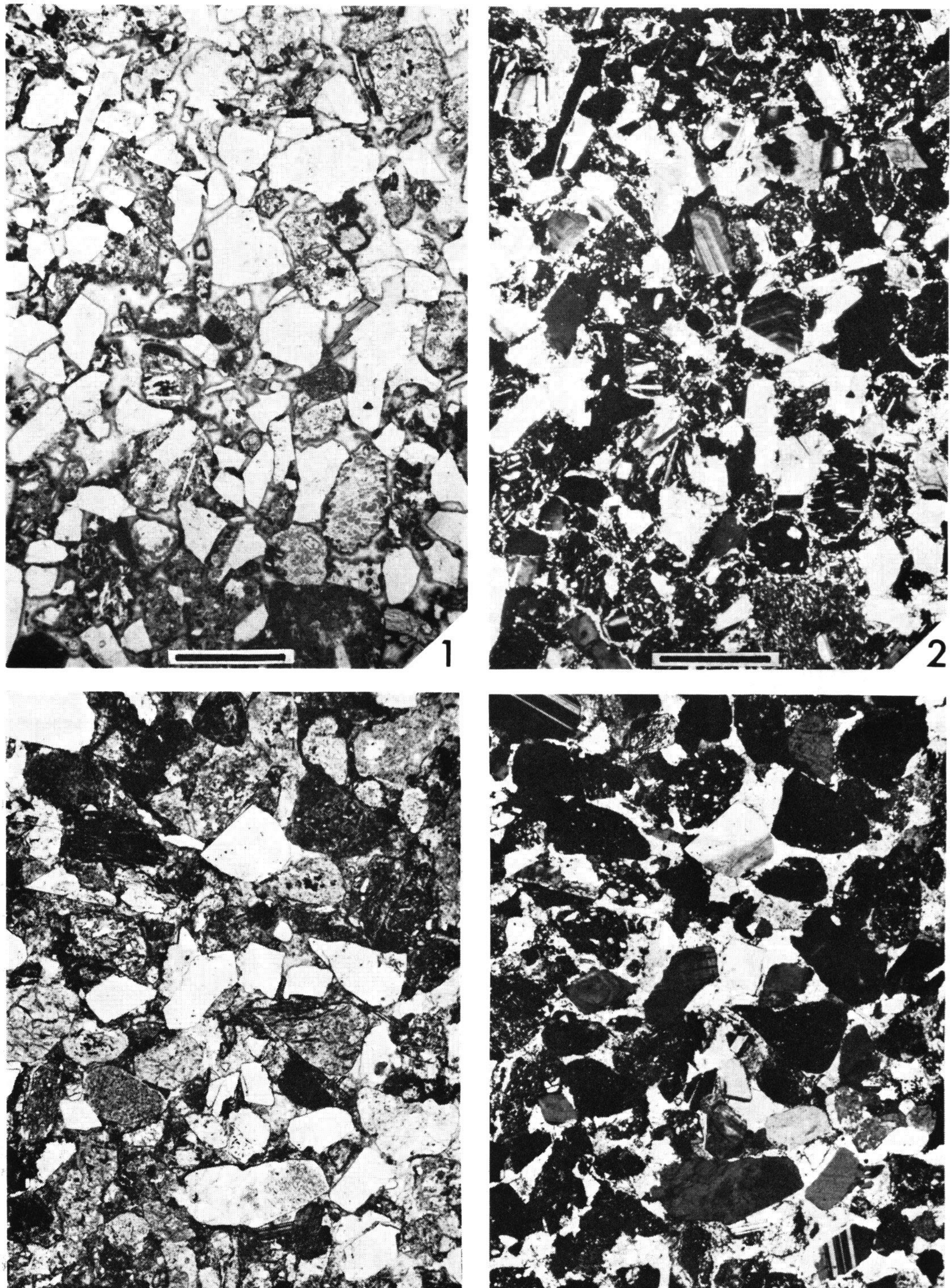
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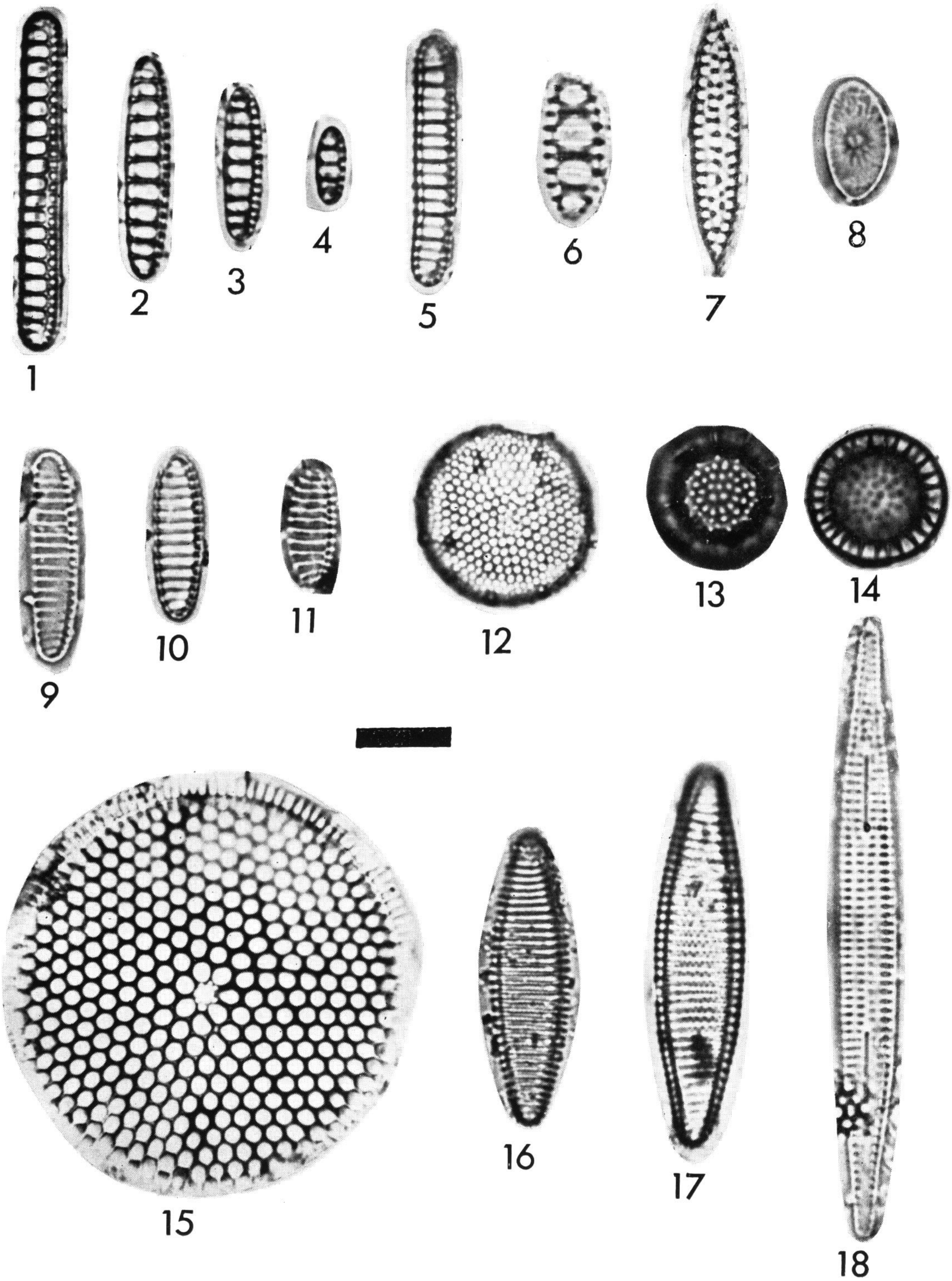
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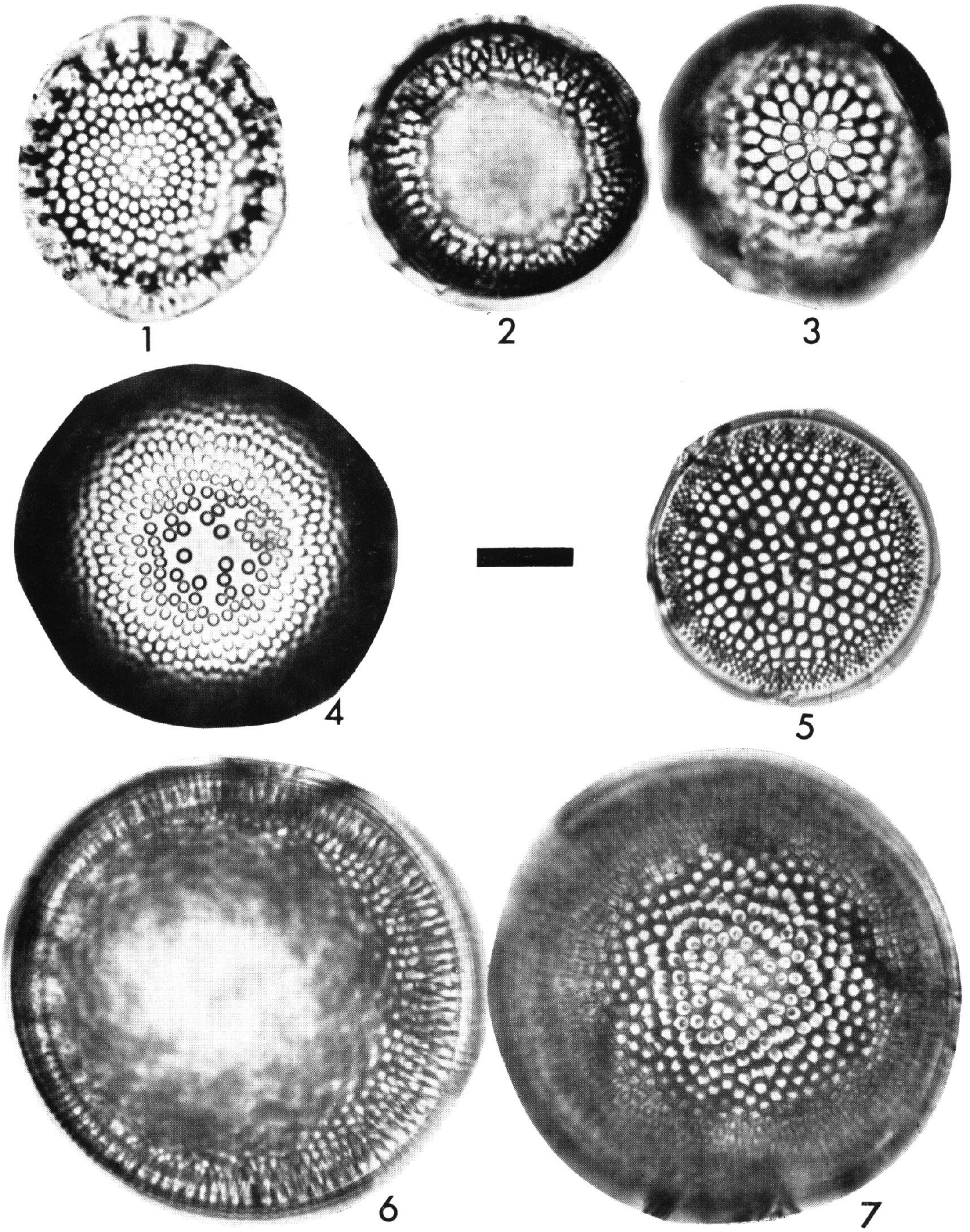
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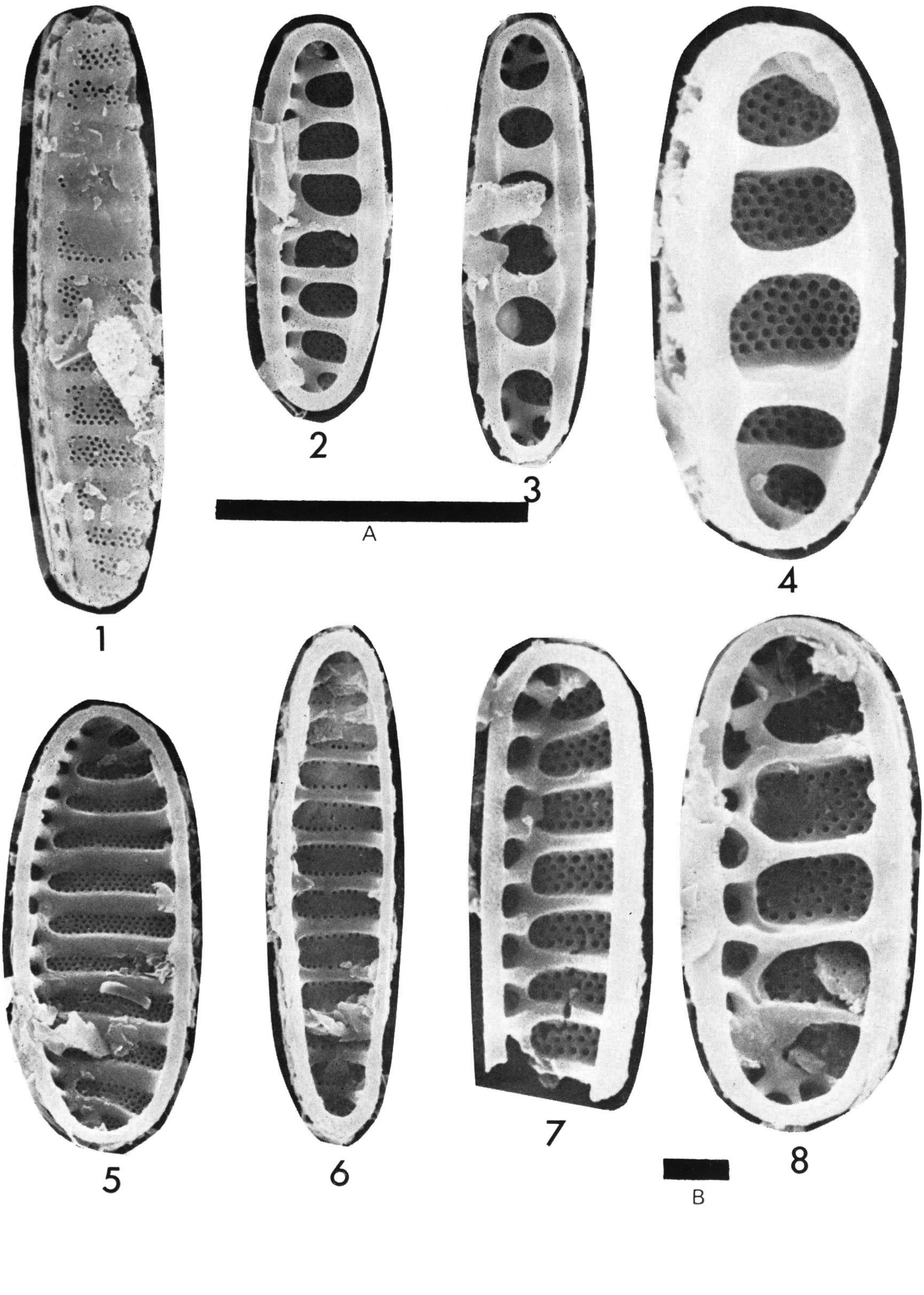
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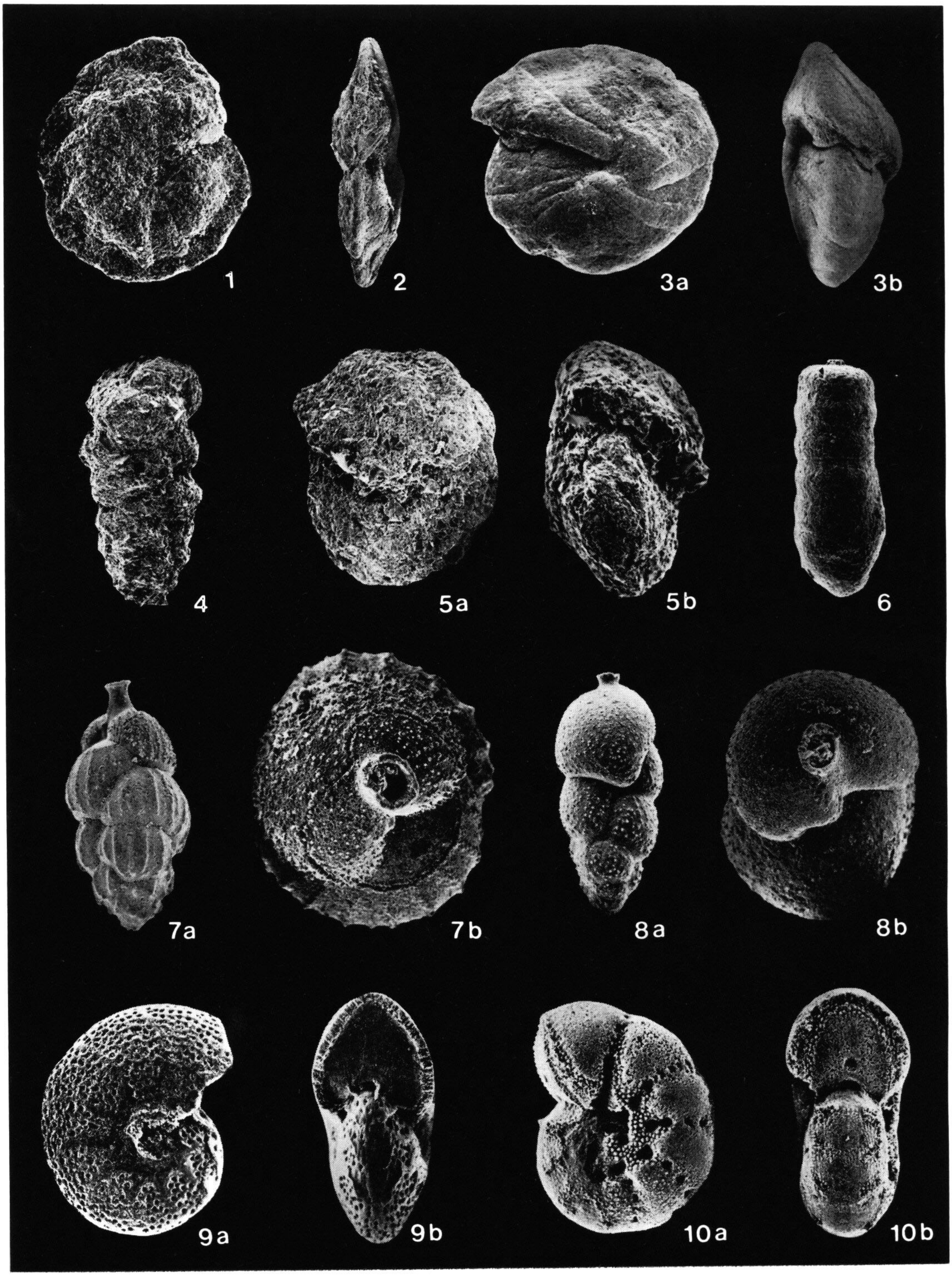
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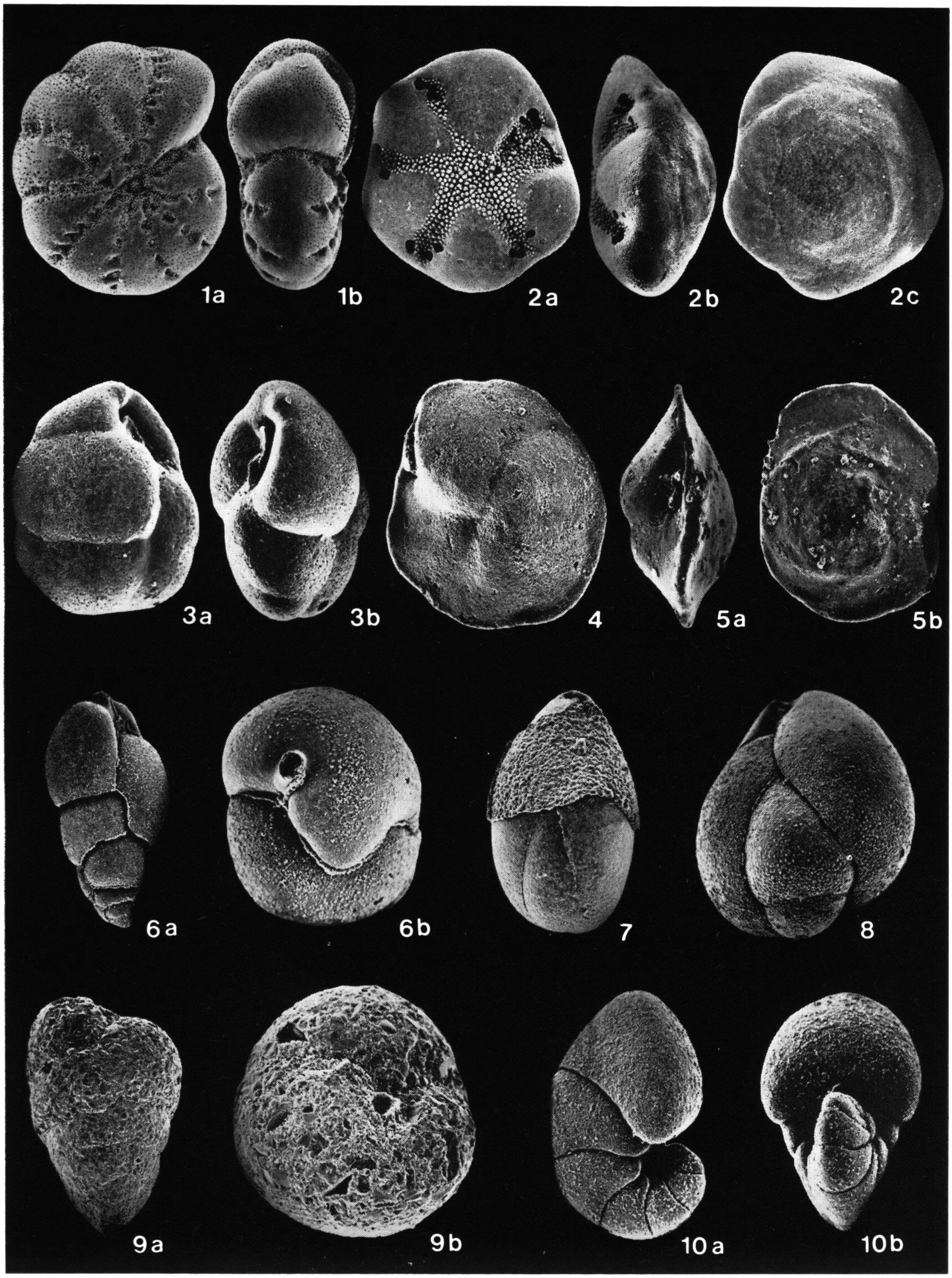
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