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Science reports of the Tohoku University. 2nd series, Geology. Special volume

Volume 6

Page range 465-476

Year 1973-02-28

URL http://hdl.handle.net/10097/29004
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Abstract

Submarine coring in a cross-section from Kawasaki to Kisarazu in Tokyo Bay is described and discussed as to paleoenvironment indication and submarine geology in correlation with geological age.

INTRODUCTION

Southern Kanto is one of the typical regions for the studies of Quaternary geology in Japan. And, since the past several ten years, the Quaternary geology of southern Kanto progressed from the standpoints of geomorphology, tephrochronology, mineralogy and paleontology. The results of the studies have been published by the Kanto Loam Research Group (1965), Kaizuka (1964) and many other persons (see references at end of article).

Our knowledge on the Alluvial deposits and subsurface geology of the environs of Tokyo and the coastal area of Tokyo Bay have been summarized by the Tokyo Foundation Research Society (1959), Kaizuka (1964), Nakagawa (1965), Naruse, et al. (in Chiba Pref., 1969), the Kanto Quaternary Research Group (1969, 1970) and others with reference to the change in sea level, climate and tectonics.

To interpret the subsurface (submarine) geology of the central part of Tokyo bay, 10 bore holes separated intervals of 1–1.5 km., each of about 100 to 150 meters in depth, were drilled along a traverse of 15 km length from Kawasaki on the west coast of the bay to Kisarazu on the opposite side.

To know the sedimentary environment, and sedimentary cycles of the formations below the bay bottom of the traverse, about 200 samples from the drilled wells were treated for diatom study. In the central and western parts of the section, it is interesting to know that two cycles of formations are in the same well, and their features indicate fluctuation of the sea level during the Upper Pleistocene to Holocene Epoch.

The writer wishes to express his gratitude to Mr. Kei Ichikawa, Kanto Regional Construction Bureau, Ministry of Construction, Mr. Ryūich Okamoto and Mr. Keiji Kozima, Public Works Research Institute, Ministry of Construction, Mr. Hidetaka Kuroda, Suncoh Consultants Co., for the opportunity to study the cores from below the bottom of Tokyo Bay and for their kind advice during this study. Thanks are also due to Dr. Shigemoto Tokunaga, Geological Survey of Japan, and Dr. Naoaki Aoki, Geological and Mineralogical Institute, Tokyo University of Education, for their valuable information concerning the micropaleontology of this area.

Particular thanks are due to Professor Kotora Hatai, Institute of Geology and Paleontology, Tohoku University, for his contiguous encouragement and reading the manuscript.

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GEOMORPHOLOGY

The bottom surface of Tokyo Bay along the Kawasaki to Kisarazu section, about 15 kilometers in length, is about 30 meters in depth from the sea level in the central part, and from the coast to about 1 kilometer offing Kawasaki the depth is about 20 meters. The central part of the bay is about 11 kilometers in width, and shows a monotonous flat bottom with no evidence of river valley profile.

At about 1.5 kilometers offing Kisarazu, the depth of the sea bottom is less than 2 meters, and there the bottom surface exhibits the structure of deltaic deposits, which extend toward the central part to grade into the smooth central flat plain.

GEOLaGY

Along the traverse from Kawasaki to Kisarazu, 10 bore holes were drilled at about 1 to 1.5 kilometers interval and to the depth of 100 to 150 meters from the sea bottom (Fig. 1).

The geologic succession constructed from the cores drilled along the traverse is tentatively classified based upon the lithofacies and sedimentary environments as shown in Table 1.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (m)</th>
<th>Environment</th>
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<tbody>
<tr>
<td>A</td>
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<td></td>
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<tr>
<td>A₂ Member</td>
<td>60</td>
<td>marine</td>
</tr>
<tr>
<td>A₁ Member</td>
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<td>terrestrial</td>
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<td>unconformity</td>
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<tr>
<td>B</td>
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<td>C</td>
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</tr>
<tr>
<td>D</td>
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<td>terrestrial</td>
</tr>
<tr>
<td>E</td>
<td>30+</td>
<td>marine</td>
</tr>
</tbody>
</table>

A Formation

The A Formation (Fig. 2) is the youngest of the deposits and covers with unconformity the B Formation in the central and western sides, and lies upon C Formation with unconformity at the eastern part. The thickness of A Formation is about 65 to 68 meters at the coast of Kawasaki and about 55 meters in the central part of the bay. The formation is divided into two members, the upper, A₂ member consists of marine sediments, and the lower, A₁ member of the deposits of a terrestrial environment.

A₂ member. The member is composed mainly of dark blue silt, but near the coast of Kawasaki, it is intercalated with sand layers in its upper and lower parts. The thickness of the member respectively is about 60 to 64 meters in well No. 32 and No. 25, and 25 to 27 meters thick in the central part (well Nos. 20 to 21), but abruptly decreases its thickness to 6 to 3 meters at the eastern side (well Nos. 13 and 28). In the member there were found shell fragments, foraminifera, pollen grains and diatoms.

A₁ member. The member is composed mainly of alternations of sand and silt layers, and is intercalated with a gravel to coarse grained sand layer at the base; this is inferred to be basal gravel. The thickness of the member is about 25 to 30 meters in the central part of the bay and at the western part it gradually lessens in thickness, to a few meters, and at the east in well No. 21 it is about 13 meters in thickness. The member abuts
Fig. 1. Index map of the area investigated.
Fig. 2. Schematic profile of the Kawasaki to Kisarazu subsurface section. The data of columnar sections were received from the members of the Ministry of Construction.
on C Formation at the eastern part, and is absent in well No. 13.

The base of the A1 member is the boundary of the A and B formations, and the depth from sea level is about -60 to -64 meters at the western part and -75 to -84 meters at the central part of the section.

**B Formation**

The B Formation is distributed in the central and western parts of the section, and reveals valley-filled deposits. The formation is covered with unconformity by A Formation and rests with unconformity on C Formation. The maximum thickness is 20 to 25 meters. The formation is composed of two members, the upper B2, and the lower B1, members. The B2 member consists of deposits of a marine environment and the lower B1, the sediments of terrestrial origin.

In well No. 20 cores, the boundary of the A and B formations could not be determined and there was no evidence of marine sediments.

**B2 member.** The B2 member is composed of alternations of sand and sandy silt, and is 2 to 6 meters thick. As shown in Fig. 2, the member is distributed in the western half of this section, from well No. 12 to No. 25. But, as already mentioned, the member is absent in well No. 20.

In well No. 12 cores, *Ostrea* shell fragments were found at about -55.5 meters from the bottom of the bay (-52 meters from sea level), and 14C dating of the shell gave the absolute age of older than 37,500 years before the present (Kojima, 1972).

**B1 member.** The member is distributed in the central and western half of the section, its upper part is composed of the alternations of sand and silt layers, and the lower is of a thick gravel bed. Toward the east, the member abuts on C Formation, and is not distributed beyond well No. 21. The thickness of the gravel bed is about 10 to 20 meters in the central part (well Nos. 12 and 36), and 3 to 9 meters at the western side.

At the base of the formation, there is developed a valley profile of low relief, and the level of the base of B1 member at well No. 12, is about -102 meters from sea level (-75.5 meters from bay bottom).

The B Formation is the deposit of one cycle of sedimentation, and its base shows an erosion surface.

**C Formation**

The C Formation is divided into two parts, the upper C2 and the lower C1 members.

The C2 member is distributed in the eastern half of the section (Fig. 2) and is composed of alternations of sand and silt intercalated with pumice pebbles in the upper part. The thickness is about 27 meters. Compared with the A and B formations, the sand and silt of this member is more indurated, and according to the results of sonic prospecting, the surface of this member shows the features of having been subjected to stream erosion and the relics of valley structure can be observed.

The C1 member is composed of dark blue massive silt in the upper part, and coarse grained massive sand in the lower. The maximum thickness is about 80 meters. The upper silt facies is distributed in the central to eastern parts, and the lower sand facies extends from well No. 25 to No. 28.

The C Formation is considered to be the foundation rocks of the B and A formations.

**D Formation**

The D Formation is very thin, about 4 meters in thickness and is composed of
alternations of silty layers. The formation lies in the lower part of well No. 21, at -97.0 to -99.5 meters from the bay bottom, and extends down to -112.2 to -118.2 meters in well No. 28.

E Formation

The formation is the lowest and considered to be the basal one along the traverse. It is found in the lower part of well No. 28, and is composed of massive sand layers.

DIATOM ASSEMBLAGES

For the purpose of interpreting the sedimentary environments of the formations below the bottom of Tokyo Bay, about 200 core samples from ten drilled wells were studied for their diatom flora. The procedure for the preparation of the diatom slide and diatom study are according to Akutsu (1972).

To determine the sedimentary environments of the formations, the following methods were tentatively used.

1. Counting the number of marine and fresh-water diatom species, which occurred during the course of counting 100 to 200 valves on the slides of each samples, under the microscope.

2. Percentages of marine and fresh-water diatom valves among the 100 to 200 diatom valves counted during the determination.

During the determination, such marine and brackish water species as Coscinodiscus lacustris Grunow and Diploneis Smithii (Breb.) Cleve were included among the marine species. The fresh to brackish water species, such as Navicula mutica Kützing and Anomoeoneis sphaerophora (Kütz.) Pfitzer were included among the fresh-water species.

Figs. 3 and 4 show graphically the results of 27 core samples in well No. 32, treated in the method mentioned above. In Fig. 3, samples Nos. 9, 10, 11 and 12 contained only marine diatom species, thus they were composed of 100 per cent marine valves. The samples may thus be inferred as deposits of marine environments. Even though sample Nos. 1 to 8 contained marine and fresh-water diatom species, their sedimentary environments points to marine environments although the influences of land was seeming stronger than the above mentioned samples.

Pure terrestrial deposits are composed mostly of fresh-water diatom species, as shown in samples Nos. 17, 19 and 20 in Fig. 3. While sample No. 18 yielded two marine species and two marine valves among the 100 diatom valves counted, it also had a species of fresh to brackish habitat, Anomoeoneis sphaerophora (Kütz.) Pfitzer. The sedimentary environment of the deposits may be inferred to be of a fresh to brackish water condition.

Based on the diatom assemblages of the core samples as well as the lithology of the sediments, the sedimentary environments of the formations of this geologic section are classified as shown in Table 1.

The sedimentary environments and characteristic diatom species of the formations are described briefly in the following.

The A2 member is the deposits of a marine environment, the dominant marine diatom species being Cyclotella stylum Brightwell, Melosira sulcata (Ehr.) Kützing and Thalassionema nitzschioides Grunow. They are littoral to neritic species. Common and rare species are Actinocyclus Ehrenbergii Ralfs, Actinocyclus undulatus (Bail.) Ralfs, Cocconeis scutellum Ehrenberg, Coscinodiscus lineatus Ehr., Coscinodiscus eccentricus Ehr., Diploneis weissflogi (A.S.) Cleve, Rhaphoneis surirella (Ehr.) Grun., Trachyneis aspera (Ehr.) Cleve.
Melosira sulcata occurs abundantly in the middle to the lower part of the member, as shown in Fig. 2. This zone can be traced from well No. 25 to No. 13; but in well No. 28 there occurs epiphytic marine species as Rhaphoneis surirella, which indicates a shallower marine environment. This zone may be considered as the deposits of the most transgressive phase of the Yurakucho (Jōmon) transgression.

The A1 member yielded mainly fresh-water diatom species, but well No. 36 intercalated marine diatom assemblages. The dominant fresh-water species are Achnanthes lanceolata Bréb., Cocconeis placentula (Ehr.), Cymbella sinuata Gregory, Cymbella ventricosa Kütz., Epithemia turgida (Ehr.) Küt., Gomphonema angustatum (Kütz.) Rabh., Navicula bacillum Ehr., Navicula lanceolata (Agardh) Kütz., Pinnularia gibba Ehr., Rhopalodia gibba Ehr., Rhopalodia gibberula (Ehr.) O. Müll., and Syndra ulna (Nitz.) Ehr.

The A1 member of well No. 36 is composed mainly of terrestrial deposits, but at the levels of −31.9 to −32.6 and −37.0 to −40.0 meters, marine diatom species, such as Melosira sulcata (Ehr.) Kütz. and Thalassionema nitzschioides Grun. were intercalated. These horizons are inferred to be marine sediments.
Fig. 4. Diagram showing the number of diatom species, percentage of diatom valves, classification of the formations and the sedimentary environments inferred from the diatom assemblages (well No. 27).

The B2 member consists of thin marine deposits, and in it were found marine diatom species as well as *Ostrea* shell fragments and foraminifera. The abundant marine diatom species are *Melosira sulcata* (Ehr.) Kütz., *Cyclotella stlrorum* Brightwell and *Thalassionema nitzschioides* Grun. These diatom assemblages indicate a shallow marine environment.

The B1 member is composed of two lithofacies, the lower gravel and the upper of alternations of sand and silt. The lower yielded no diatom fossils but in the upper were found abundant fresh-water diatom species. Among them the dominant species are *Synedra ulna* (Nitz.) Ehr., *Cocconeis placentula* (Ehr.), *Cymbella ventricosa* Kütz., Diplolepis ovalis (Hilse) Cleve, *Epithemia turgida* (Ehr.) Kütz., *Gomphonema angustatum* (Kütz.) Rabh., *Navicula mutica* Kütz., *Pinnularia brevicostata* Cleve, *Pinnularia borealis* Ehr., *Pinnularia gibba* Ehr., and *Pinnularia viridis* (Nitz.) Ehr. Epiphitic species are abundant. Fresh to brackish water species as *Anomoeoneis sphaerophora* (Kütz.) Pfitzer and *Gyrosigma* sp. occur in some samples, but from the assemblages of the species, the member should be considered as deposits of a non-marine environment.

The C Formation compared with the A and B formations, the diatom contents of the C Formation are not so abundant.

The C2 member yielded both marine and fresh-water species. The marine species which appeared in the member are *Actinocyclus sp.*, *Actinoptychus undulatus* (Bail.) Ralfs, *Coscinodiscus lacustris* Grun., *Nitzschia tryblionella* Hantzsch, *Thalassionema nitzschioides* Grun., *Coscinodiscus marginatus* Ehr., and *Denticula* sp. are rare.

The dominant fresh-water species are *Fragilaria construens* (Ehr.) Grun., *Melosira granulata* (Ehr.) Ralfs and *Diplolepis ovalis* (Hilse) Cleve. Epiphtic fresh-water species
such as *Cymbella* spp., *Gomphonema* spp., *Pinnularia* spp., and *Synedra ulna* (Nitz.) Ehr. also occurred.

The number of marine species and marine valves which occurred from the member are less than that of the fresh-water species; marine species are contained in general. The depositional condition of the member may be inferred to be of a marine to brackish environment.

The C₁ member is composed of the upper siltstone facies and the lower sandstone facies. The upper siltstone facies yielded dominant diatom valves but in the lower they are rarely preserved.

The dominant marine species which occurred from the siltstone facies are *Actinocyclus Ehrenbergii* Ralfs, *Actinoptychus splendens* (Shadh.) Ralfs, *Coscinodiscus excentricus* Ehr., *Cyclotella stylosum* Brightwell, *Melosira sulcata* (Ehr.) Kütz., *Thalassicocysta nitzschiodes* Grun., and *Trachyneis aspera* (Ehr.) Cleve. Littoral and neritic species are abundant.

The sandstone facies contained poorly preserved diatom valves, but the marine species above mentioned occurred in association with some fresh-water species.

In well No. 21, the D Formation yielded abundant fresh-water diatom valves but no marine species. The dominant species are *Fragilaria construens* (Ehr.) Grun., and its variety, *Fragilaria virescens* Ralfs, and the marine to brackish water species *Diploneis Smithii* (Bréb.) Cleve appeared rarely. The condition of the deposits may be considered to be of a fresh to slightly brackish environment.

The D Formation is situated at -97.0 to -99.5 meters in well No. 21. The same facies is not recognized in well No. 28, but at the levels of -112.2 to -118.2 meters of well No. 28, fresh-water diatom species appeared dominantly associated with marine species such as *Actinocyclus Ehrenbergii*, *Diploneis interrupta* (Kütz.) Cleve. And the assemblages point to a marine littoral condition.

The levels of wells No. 21 and No. 28 mentioned above, may be traced based upon the evidence of the lithofacies and the association of the diatom species.

**SEDIMENTARY ENVIRONMENT AND UNCONFORMITY**

From the evidences of the marine and fresh-water diatom compositions and of the other marine fossils, the sedimentary environments of the formations distributed below the bottom of the central part of Tokyo Bay are determined as follows.

The A Formation is composed of two members, the lower A₁ member was deposited under a mainly terrestrial condition, and it is intercalated partly with marine to brackish water deposits. The upper A₂ member is the deposits of a marine environment and marine diatoms as well as marine shells and foraminifera occurred dominantly.

The B Formation is divided into two members, the upper B₂ is the deposits of a marine environment and the lower, B₁ is a terrestrial deposit.

The C Formation is mainly of deposits of a marine environment, and D is the sediments of terrestrial to shallow marine environments.

From the lithofacies of the formations as well as paleontological evidences, the bases of the A and B formations may be interpreted to be surfaces of an unconformity.

The base of B Formation may be the surface eroded out of C Formation by stream erosion in the central and western parts of the section, and the gravel bed of the lower part of B₁ may be the basal deposits of a stream.

The unconformity at the base of A Formation may be an erosion surface formed after the transgression of B₂ member. The surface of the section is low and undulated and does not show a valley profile. The basal gravel developed in the central part gradually
changes to a sand facies, and it is assumed to be the deposits of a terrestrial loaded stream.

In this section or transverse the C Formation and the older formations form the basement complex. The B Formation fills the valley trough in the surface of C, and A covers B and C formations with unconformity.

**SEA LEVEL CHANGES**

The A and B formations are composed of one cycle of sedimentation, respectively, and unconformities are detected at the base of both A and B formations. The A and B formations are interpreted as valley-filled deposits, and the history of sedimentation of the formations is summarized as follows.

1. The base of B Formation. The C Formation was subjected to stream erosion and this formed the unconformity plane at the base of B Formation. Subsequently the surface was covered with the gravel bed of B₁ member. The lowest level of the base of the B Formation is about −105 meters, and during this time, the sea level was situated at a level lower than −105 meters.
2. Deposition of B₁ member. The terrestrial environment prevailed.
3. Marine transgression and deposition of B₂ member. Sea level rose more than −60 meters.
4. Regression of the sea and differential erosion of the depositional plane of the B₂ member, the sea level was lowered to more than −85 meters.
5. Deposition of A₁ member. The sedimentary environment is mainly terrestrial, but the sea level gradually rose and intercalated thin marine layers.
6. Marine transgression (Yūrakucho or Jōmon transgression) and deposition of the A₂ member.

**CORRELATION**

The A Formation is the youngest deposit and its uppermost part is being subjected to deposition. It is roughly correlated to the Yūrakucho Formation.

There are no data concerning the absolute ages of the deposits, but according to Kigoshi and Miyazaki (1966), the absolute ages of the Alluvial deposits around Tokyo Bay are 10,000 to 15,000 years. Thus, the A Formation may be inferred to be deposits of the same ages.

The level of the base of the A Formation is situated at about −85 meters. When this unconformity was being made, the sea was at a level lower than −85 meters.

According to Iseki (1958), the depth of the bed rocks of large river valleys, filled with the Late Quaternary deposits are situated at 60 to 80 meters below the present sea level.

Muto (1968) studied the Alluvial deposits of Iwaki City, Fukushima Prefecture, and reported that the level of the buried valley filled with Alluvial deposits was at about −70 meters below sea level.

Hase (1967) studied the Alluvial Plains of Sendai and Ishinomaki, Miyagi Prefecture, and showed that the depth of the buried valleys filled with the Alluvial deposits, were at about −60 to −90 meters.

In the environs of the Keiyo Industrial Area, at the eastern part of Tokyo Bay, the depth of the base of the Alluvial deposits (Chiba Pref., 1969) is at about −40 to −60 meters. The levels of the base of the Alluvial deposits mentioned above are about −60 to −90 meters below the sea level, and coincide with the deepest part of A Formation.

The B Formation is composed of one cycle of sedimentation and it rests with unconformity on C Formation in the central part of this section. The B₂ member shows a
marine sedimentary facies, and $^{14}$C dating of the *Ostrea* shell which occurred from this member gives the absolute age of older than 37,500 years (Kojima, 1972). The evidences prove one transgression prior to the transgression of the A Formation or the Yurakuchō transgression.

Core samples, collected at 57.08 to 59.35 meters depth, off the coast of Funabashi City, Chiba Prefecture, gave the absolute ages of 35,400+ (Gak-620) and 35,600+ (Gak-621) (Chiba Pref., 1969). The data mean that the sediments which accumulated at about 35,000 to 37,000 years ago are distributed beneath Tokyo Bay.

The base of B Formation shows a denudation surface which was constructed before the transgression of the B$_2$ marine transgression, and the deepest part of the denudation valley is at about −105 meters from sea level. It is assumed that the sea level when denudation occurred, was lower than −105 meters.

Chujo (1962) recognized the Paleo-Tokyo River at the entrance of Tokyo Bay, by the sonic prospecting survey, and mentioned that two river channel floors are developed in the valley, the older one is about −95 meters in depth and the younger one is about −75 meters. There are no available data for determination of the relationship with the Paleo-Tokyo River and buried valleys of this section, the depths of the younger and older ones coincides with the base of the A and B formations, respectively.

Detailed correlations of the C and D formations with those developed in the environs of Kisarazu City, have not been settled, but from the lithofacies and structure of the formations, these basement rocks are probably some part of the Shimosa Group (Aoki, *et al.*, 1971a, b). The Shimosa Upland in the vicinity of Kisarazu, is the depositional plane of the Shimosa, or Narita Group, and it is evident that the B and A formations are younger than the Shimosa or Narita Group.

REFERENCES


Japanese with English abstract).


