Bull. Na'n. Sci. Mus., Tokyo, Ser. C, **25**(3, 4), pp. 73–104, December 22, 1999

# Stratigraphy and Taphonomic Features of Diatomaceous Shale of the Pleistocene Shiobara Group, in Tochigi, Japan

**Takumi Tsujino and Haruyoshi Maeda**

Department of Geology and Mineralogy, Division of Earth and Planetary Sciences,
Graduate School of Science, Kyoto University, Kyoto, 606–8502 Japan

**Abstract** The Shiobara Group, the Pleistocene lacustrine deposits, is distributed at the northern slope of the Quaternary Takahara Volcano in Tochigi Prefecture. It is subdivided into two formations, the Kamishiobara and Miyajima formations redefined here. The Kamishiobara Formation consists of gravel and sand beds of talus, debris apron, alluvial fan/fan-delta and rock fall facies, and corresponds to marginal facies of the paleo-Shiobara lake. The Miyajima Formation is composed of laminated diatomaceous mudstone, and represents a lacustrine profundal facies in the central part of lake. The southern coast was bordered by lava flow on gentle slope of the Takahara Volcano. These features imply a caldera lake. The laminated mudstone of the Miyajima Formation yields numerous well-preserved fossils such as leaves, insecta and fishes, which are flattened but retain details of soft tissue. Diatomaceous opal-A in the original laminated soft mudstone (opal-A zone) changes diagenetically into opal-CT in "hard shale" (opal-CT zone). Preservational states of plant megafossil are closely related to the diagenesis of opal. The primary organic structure is preserved in opal-A zone. However, a few fossil occurs in opal-A zone. The plant fossils from opal-CT zone are abundant and morphologically well-preserved, while organic materials are altered. Extraordinary well-preserved fossils occur from the opal-CT zone.

**Key words:** diagenesis, diatomaceous laminated mudstone, lacustrine, Middle Pleistocene, taphonomy

## Introduction

Along the backbone mountains of northeastern Japan, many lacustrine deposits, adjoining volcanoes, have been developed during late Cenozoic. These lacustrine deposits are largely diatomaceous, well-laminated and yield numerous plant fossils.

The Shiobara Group in the northwestern Tochigi Prefecture, central Japan (Fig. 1), is the youngest among such type of the late Cenozoic lacustrine deposits. Many paleontological studies for this group have long been made. This is because the group yields extraordinary well-preserved fossil biotas, such as leaves, fruits, seeds, woods and flowers (e.g., Nathorst, 1883; Endo, 1931; Suzuki, 1973), insects (Hiura, 1966; Fujiyama, 1968, 1969, 1979, 1983), fishes (Uyeno, 1967), frogs (Shikama, 1955) and mice (Hasegawa & Aoshima, 1988), showing soft-tissue preservation. Recently, Onoe (1989) made a revision of the flora from the group, along with paleoclimatic analysis

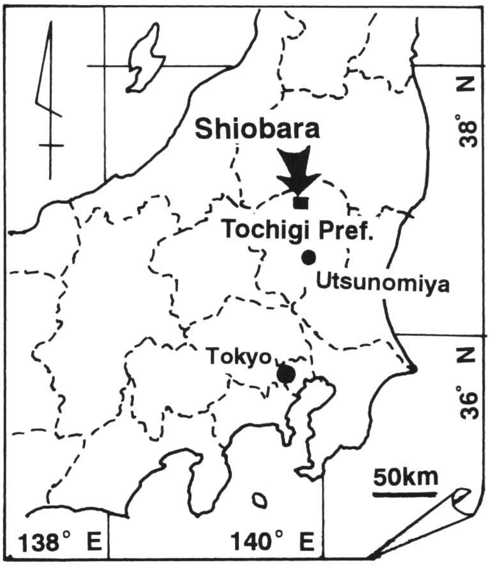


Fig. 1. Index map of the study area, in the Tochigi Prefecture, Japan.

on the basis of both the plant mega- and microfossils. The flora were principally similar to that of the present cool-temperature climate, e.g., interglacial climate.

Many geologists also have investigated the group for a long time (e.g., Kanehara, 1900; Yabe, 1929; Niino, 1933; Gohara *et al.*, 1952; Takahashi & Uchida, 1956; Akutsu, 1964; Suzuki, 1972; Suzuki *et al.*, 1978 etc.). Among them, Akutsu (1964) studied the geology of the Shiobara and its vicinity in detail. He described the laminated mudstone and diatom frustules contained in the laminated mudstone of the Shiobara Group. He revealed that lamination reflects the periodical changes of limnological conditions of sedimentation and reproduction of diatom, and the changes have probably been seasonal, repeated annually.

However, the geological setting and detailed sedimentary features of the whole Shiobara Group are still obscure. Takahashi & Uchida (1956), Akutsu (1960, 1964), Suzuki (1972) and Onoe (1989) studied the group, and gave different stratigraphic divisions each other. Except trunk fossils (Suzuki, 1973), most of fossils described in the previous papers occur only from one outcrop in the Konoha Kaseki'en (Fossil Museum; Pl. 1, fig. 1). A few provisional taphonomic works revealed that opal-A of diatom frustules diagenetically changed to opal-CT in the group (Terada & Konishi, 1992; Maeda *et al.*, 1996). As well as the stratigraphy, the taphonomic implications of the group remain largely to be done.

To clarify these problems, we closely observed the all outcrops of the group by bed by bed. Based on the field and laboratory observations, this paper aims to 1) propose a new stratigraphic scheme of the Shiobara Group, 2) describe sedimentary profile of the group, and 3) describe the range of diagenetic change of the diatomaceous mudstone in relation to the modes of plant fossil preservation from taphonomic point of view.

## Geologic setting

The Quaternary Takahara Volcano is situated at the southern part of the Nasu Volcanic Zone (Kanehara, 1900; Ikeshima & Aoki, 1962). The Shiobara Basin is located at the northern slope of the Quaternary Takahara Volcano (Fig. 1), and shapes like crescent convexed northerly, extending about 5 km (E-W)×2 km (N-S). The mountain of basement rocks lies between 700 m to more than 1400 m in altitude, in contrast main part of the basin lies about 600 m high. The Pleistocene Shiobara Group is distributed in the central part of the basin, and considered as a caldera lake deposits (Onoe, 1989).

The group unconformably covers the pre-Tertiary Shiranzawa Quartz-porphyry at northern margin of the basin, the Early to Middle Miocene Fukuwata and Kanomatazawa formations at the eastern margin, and the Late Miocene-Pliocene Kotaki Rhyolite at the western margin (Fig. 3; Suzuki, 1958; Iwao & Imai, 1955). On southern margin of the basin, the group is overlain by lavaflows of the Takahara Volcano.

At several places the group is covered by terrace gravel beds, altered volcanic ash layers etc. The only upper part of the Shiobara Group crops out in general. The strata of the Shiobara Group incline southward, or basinward at less than 10°. Neither large faults nor folding structures are observed in the Shiobara area.

*Geologic age*: The lacustrine Shiobara Group yields no stage diagnostic fossils. It is hardly difficult to extend the range of $^{14}$C dating back to the Pleistocene (Behre & Plicht, 1992). The group had been considered as the Pliocene (Nathorst, 1883; Kanehara, 1900). After reexaminations by Yabe (1929), Endo (1931, 1934, 1935), Koizumi (1940), Akutsu (1964), Onoe (1989), it has generally been accepted as the Pleistocene. The Shiobara flora corresponds after extinction of the *Metasequoia* flora (Suzuki & Nasu, 1988) in the Early Pleistocene (Onoe, 1989). The terrace which unconformably overlie on the group is composed of at least four terrace planes (Tayama, 1929; Takahashi & Uchida, 1956; Hayakawa *et al.*, 1985). The Uppermost Terrace is compared with the Late Pleistocene Nasuno Middle Terrace Plane (Hayakawa *et al.*, 1985). Therefore, the age of the group is presumed as the interglacial epoch of the Middle Pleistocene.

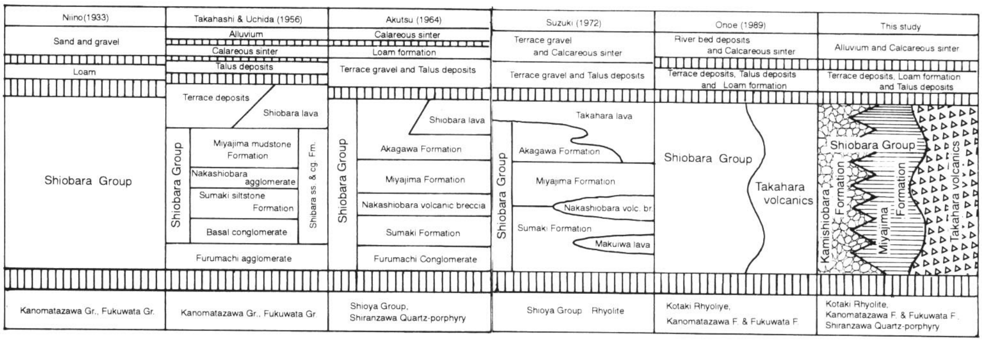


Fig. 2. Comparison of the lithostratigraphic divisions of the Shiobara Group.

## Stratigraphy

### Shiobara Group

The Pleistocene Shiobara Group (Yabe, 1929) unconformably covers the basement rocks and is unconformably overlain by terrace deposits. The Takahara Volcanic Rocks interfingers and/or overlaps the group in the southern area. The exposed part of the Shiobara Group is 270 m thick. Based on the drill hole data, it attains in total about 600 m thick (Suzuki, 1972; Suzuki *et al.*, 1978).

The group is composed of gravel, sand, felsic tuff and diatomaceous laminated mudstone, intercalated with the volcanics. The previous workers subdivided the group into several stratigraphic units by intercalation of andesite lavas as key beds (Takahashi & Uchida, 1956; Akutsu, 1960, 1964; Suzuki, 1972, etc.). These intercalated volcanics are, however, distributed only in the restricted area and are not traceable.

The group is characterized by abrupt lateral change of facies. In this paper, the group is lithologically divided into following two formations with revised diagnoses, the Kamishiobara and Miyajima formations. The former represents a marginal terrigenous facies, while later represents a central profundal facies of the paleo-Shiobara lake. The geological map of the Shiobara area is shown in Fig. 3. The locality map of study area is shown in Fig. 4. Lithologic change presented in columnar sections (Fig. 5) means rather abrupt lateral change of facies than vertical change at Shiranzawa, Tsurusawa, Utozawa, Akagawa, Shiozawa and Tanahatazawa routes.

### **Kamishiobara Formation** (newly defined)

The Kamishiobara Formation is a marginal terrigenous facies of the paleo-Shiobara lake. It nearly corresponds to previous the "Furumachi Agglomerate", the "Basal Conglomerate" of the Shiobara Group and the "Shiobara Sandstone and Conglomerate Formation" of Takahashi and Uchida (1956) or the "Furumachi Conglomerate", the gravel facies of the "Sumaki Formation", "Miyajima Formation" and

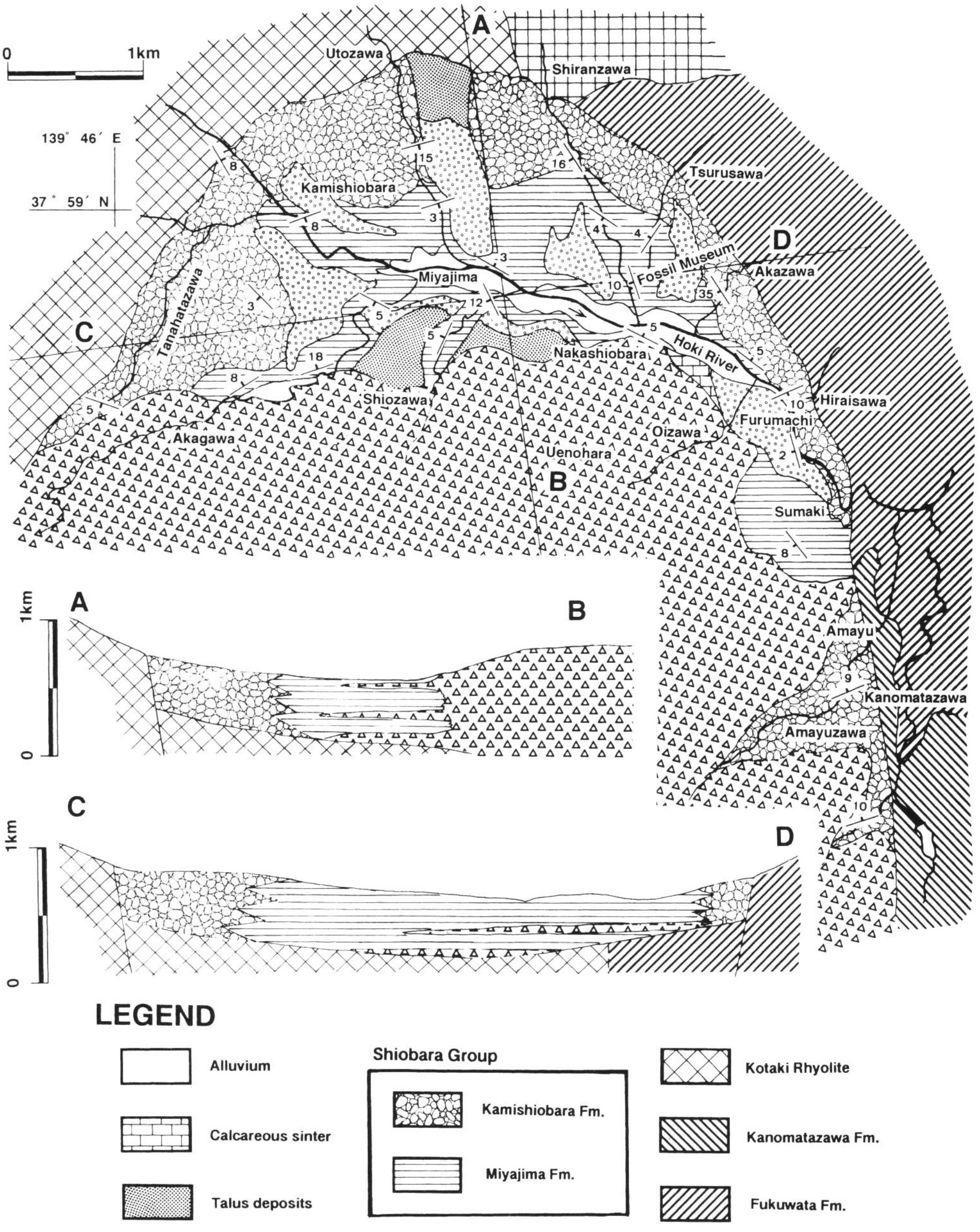


Fig. 3. Geologic map and cross sections of the Shiobara area.

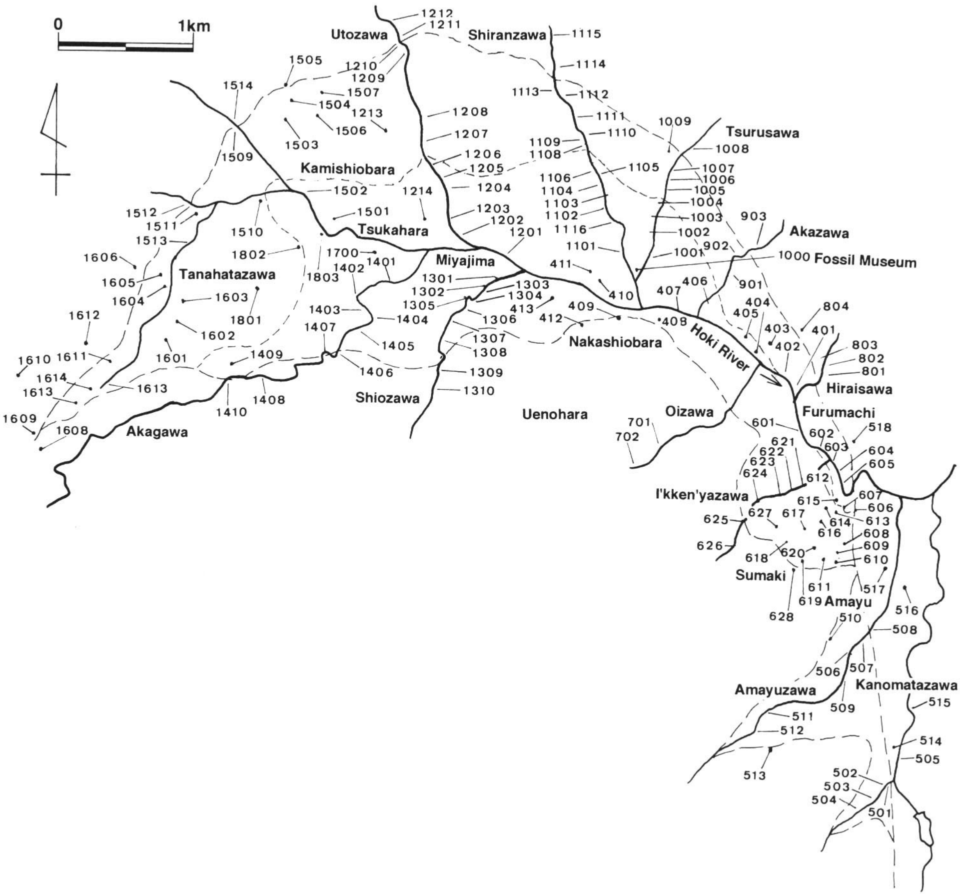


Fig. 4. Locality map of the study area.

"Akagawa Formation" of Akutsu (1964) (Fig. 2).

*Stratotype*: Locs. 1109–1113; the upper course of the Shiranzawa Valley (Fig. 4).

*Thickness*: 270 m. Based on drilling hole data (Suzuki *et al.*, 1978), it is presumed more than 600 m thick.

*Distribution*: On the eastern, western and northern margins of the Shiobara basin or and just above the basement rocks. The formation is not distributed in the southern margin of the Shiobara basin, or near the Takahara Volcanics.

*Stratigraphic relation*: On the northern, eastern and western margins of the Shiobara basin, the formation abuts with the basement rocks. It is covered by the Upper Pleistocene terrace and talus deposits. The Kamishiobara Formations interfingers with the Miyajima Formation (Locs. 404, 615, 617, 620, 622, 1109; Figs. 4, 6,

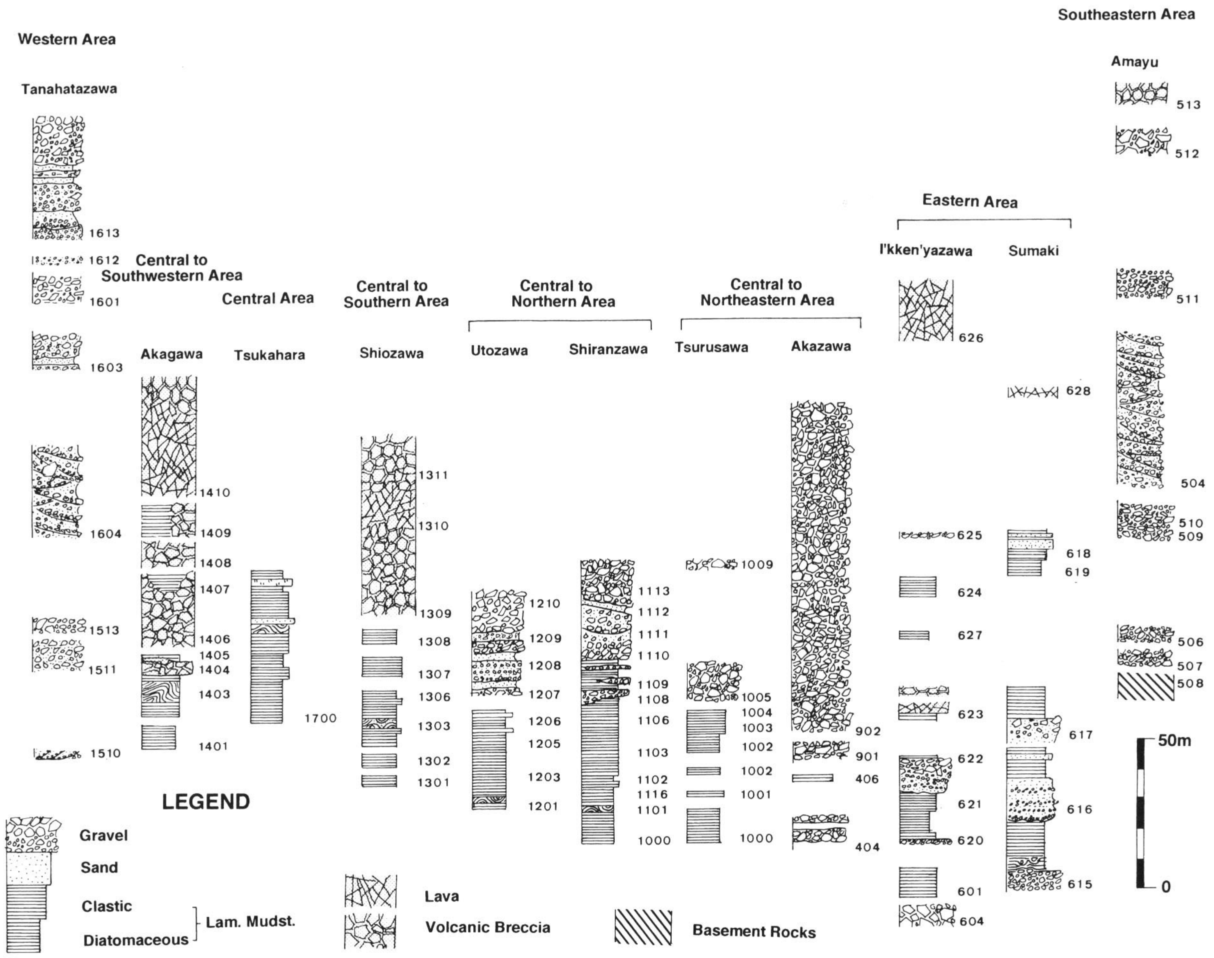


Fig. 5. Columnar sections of the Shiobara Group.

7). At Loc. 1109, more than five layers of gravel beds of Kamishiobara Formation and laminated mudstone of the Miyajima Formation are alternated. One of the gravel beds, 40 cm in maximum thickness, is lenticularly shaped, which vanishes laterally in the outcrop. At the southern part of the same outcrop, no gravel beds are intercalated and only the Miyajima Formation is exposed.

*Lithology*: The formation is mainly composed of subangular- to rounded gravel and sand. Based on sedimentary features, the formation can be divided into following four facies: A, B, C and D.

A facies is characterized by clast-supported subangular to angular gravel beds. The distribution is only restricted just on the boundaries of the basement rocks (Locs. 902, 1005–1009, 1509, 1511, 1513, 1613–1615, etc.). The gravels are ill-sorted and range from granule up to boulder. Most of gravels are derived from the adjoining basement rocks. The matrix is reddish gray, poorly sorted, lithic, tuffaceous volcanic sand (Loc. 902, etc.) or white poorly-sorted sand composed of quartz (Locs. 1509, 1511). The gravel beds are massive facies at the rim of the basin, and gradually grades basinward into showing crudely bedding and slight imbrication. For example, the gravel beds dip to south at about 30° at Loc. 901 (Pl. 1, fig. 2). This facies rapidly changes basinward to lacustrine profundal facies in the northeastern margin and gradually grades basinward to other coarse-grained facies in the other margins. Exceptionally the lithology represents massive gravel beds in matrix-supported at Loc. 1513, or alternation of massive gravel and gravelly mudstone at Locs. 1613.

B facies is mainly distributed in the northwestern margin of the basin and characterized by crudely stratified, subangular to subrounded gravels and intercalation of sand beds. These beds dip basinward, south-southwest at 16° (Loc. 1109), or south at about 15° (Loc. 1208). Occasionally the gravel beds have an erosional surface at the base (Loc. 1111, Fig. 5). The gravels range from granule to boulder in size, and are moderately sorted and occasionally show graded bedding. The matrix is poorly sorted, white, lithic, tuffaceous volcanic sand. A facies grades basinward into this facies. This facies grades basinward into lacustrine profundal facies.

A or B facies adjacent to the rim of the basin grades basinward into C facies, which is characterized by tabular and trough cross-stratified coarse-grained volcanic sand, rounded granule and gravelly mudstone beds (Loc. 504; Pl. 1, fig. 3). Cobbles are sometimes contained. C facies is distributed in the western margin and southern part of the basin. In the western area the gravels of this facies are derived from the Kotaki Rhyolite and the Takahara Volcano. This facies grades basinward (toward the northeast) to argillaceous deposits of lacustrine profundal facies, *via* cross-stratificated sand and silt beds containing granule (Locs. 1510, 1801–1802; Fig. 2). In the southeastern area this facies is isolatedly distributed. Most of gravels are derived from the Takahara Volcanics in contact to those of the western area. This facies is covered with the Takahara Volcanics. This gravel beds in the southeastern area (Amayu: Locs. 506–512) are called the "Amayu Mud Flow" by Takahashi and Uchida

(1956) or the “Shionoyu Gravel” by Akutsu (1964). The gravel beds belong to this facies.

D facies is typically observed at Loc. 615 (Fig. 4) in the eastern margin of the basin (Sumaki). This outcrop is situated at 80 m west from the boundary between the Kamishiobara Formation and the basement Fukuwata Formation. It is characterized by laminated mudstone of the Miyajima Formation (lacustrine profundal: described later) containing floated subangular pebble to cobble and interbedded gravel beds (Fig. 7). The cobbles are embedded directly and isolatedly in the laminated mudstone. The mudstone laminations surrounding the pebble, particularly. Those of the underside are distorted. They intensely bend downward along the pebble shape. On the other hand gravel beds of A facies wedge laterally into the lacutrine profundal laminated mudstone. The gravels exhibit crudely bedding and imbrication in coarse sand matrix are inter. The gravel bed contains intraclast of the laminated mudstone. It is succeeded upward with the laminated mudstone of the Miyajima Formation.

*Remarks*: In Furumachi (Locs. 601–605) and Loc. 615, on the north of Sumaki, the lowest part of the Kamishiobara Formation of A facies is exposed. It consists of clast-supported massive cobble gravel beds of the 10 m thick at least. The matrix is well cemented with opal-A, based on X-ray diffractometry. It is succeeded upward and westward to the laminated mudstone which frequently interbedded with sand and gravel. At first Niino (1933) considered that the gravel beds are talus deposits subsequently hardened by issuing hot spring waters, or recent river gravels were compactly consolidated by hot spring waters. Gohara *et al.* (1952) thought the gravels as a “green tuff” breccia, while Takahashi and Uchida (1956) stated that the gravels were merely an andesitic agglomerate with subrounded to rounded blocks. Akutsu (1964) separated the gravels from other stratigraphic units, and assigned them to the Shiobara Group. He defined the gravel beds as the lowermost unit of the Group, the “Furumachi Conglomerate”. Suzuki (1972) included these gravel beds in the Sumaki Formation.

Except their well-cementation, the composition of gravels and the sedimentary structure are not different form the Kamishiobara Formation, in other places. Therefore, we include the gravels in the Kamishiobara Formation.

**Miyajima Formation** (revision of Takahashi and Uchida, 1956)

The Miyajima Formation is a lacustrine profundal facies of paleo-Shiobara lake. The formation corresponds to the “Sumaki Siltstone Formation” and the “Miyajima Formation” of Takahashi and Uchida (1956), or the siltstone facies of the “Sumaki Formation”, the “Miyajima Formation” and the “Akagawa Formation” of Akutsu (1964) (Fig. 2).

*Stratotype*: Loc. 1201; the Hoki River at Miyajima (Fig. 4).

*Thickness*: The upper 130 m is exposed. Based on the drilling hole data (Suzuki *et al.*, 1978), it attains more than 410 m thick.

*Distribution*: Nakashiobara and Sumaki; the central and eastern area of the basin.

*Stratigraphic relation*: The formation unconformably covers the basement rocks (Suzuki, 1972), or interfingers with the Kamishiobara Formation and volcanics of Takahara Volcano. The formation interfingers and underlain with the Kamishiobara Formation in marginal part. It is also overlain by the terrace deposits with unconformity at places (e.g., Loc. 410).

*Lithology*: The formation is characterized by laminated mudstone and siltstone. They are intercalated with sandstone, tuff and volcanic breccia. The Miyajima Formation subdivided into two facies: E and F, based on sedimentary features.

E facies is typically distributed in the stratotype in the central part of the basin (Loc. 1201). It is characterized by rhythmic thin alternation of the white diatomaceous lamina and the bluish gray or light gray lamina of clastics (Pl. 2, fig. 1). The white lamina consists mostly of frustules of a diatom species, *Stephanodiscus niagarae* Ehrenberg. The gray lamina consists of clastic, silt-sized grains of quartz, feldspar and reworked volcanic glass fragments showing bubble-wall structure (Pl. 2, fig. 2). The average thickness of the gray lamina is 0.59 mm, and that of the white lamina is 1.45 mm. As Akutsu (1964) mentioned, gray laminae and beds show graded bedding and changes upward into the white lamina, and the white lamina abruptly changes upward into the gray lamina with sharp boundary. The laminated mudstone is frequently interbedded with grayish or reddish brown medium-grained sandstone showing graded bedding near the border of the Kamishiobara Formation such as at Locs. 1205, 1206. Massive bluish gray or light gray mudstone 5–30 cm thick are also frequently intercalated in the laminated mudstone. The bluish gray layers contain abundant fine grained andesitic fragment under microscope, and often show reddish brown after weathering. This facies gradually grades marginward or upward into the following clastic laminated facies (Figs. 6, 8).

F facies is typically exposed at Loc. 1306. It comprises bluish gray or light gray clastic laminated mudstone interbedded with massive or graded sand and silt beds of 1–50 cm thick. The gray lamina and the white lamina are not clearly discriminated but amalgamated one another. Purely diatomaceous white lamina about 1.5 mm thick are rarely intercalated. The clastic laminae are several times thicker than those of E facies. The average thickness of clastic lamina is 4.5 mm. Clastic grains and reworked volcanic ash are concentrated in the lower part of laminae or beds. Diatom frustules are also common (Pl. 2, fig. 4), but are diluted with clastics. The based boundary of each lamina is sharp boundary. In the upper part of lamina diatom frustules are often concentrated.

*Ichnofossils*: Ichnofossil was not reported in the Shiobara Group. *Skolithos* isp., however, were found in a few places so rarely as to preserve lamination (Locs. 1206, 1214, 1304-1306, 1405, 1409, Fig. 8).

*Fossils*: The formation yields abundant plant fossils, such as, *Fagus crenata*, *F.*

Table 1. Floral and Faunal lists of the Miyajima Formation. Plant fossils collected in this study are listed. The insect fossils collected by us and the undescribed collections of the Fossil Museum are listed. Numerals show the number of specimens.

| Species | Opal-CT zone | | | | | | | Opal-A zone | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1000 | 1002 | 1003 | 1101 | 1102 | 1103 | 1116 | 410 | 621 | 1201 | 1214 |
| Flora | | | | | | | | | | | |
| *Acer distylum* | | | | | 1 | | | | | | |
| *Acer japonicum* | 2 | | | | | 1 | | | | | |
| *Acer mono* var. *marmoratum* | 1 | | | | | | | | | | |
| *Acer plamatum* subsp. *palmatum* | 2 | | | | | | | | | | |
| *Acer shirasawanum* | | | | | | | | 1 | | | |
| *Actinidia polygama* | | | | | | | | | | 1 | |
| *Alnus firma* | 2 | 1 | 1 | | | | | | | | |
| *Alnus hirsura* var. *sibiraca* | 1 | 2 | | 1 | | 2 | 1 | | 1 | 1 | 1 |
| *Alunus crispa* | 3 | | | | | | | | | 1 | |
| *Alunus faurei* | 5 | 1 | 1 | | | | | | | | |
| *Betula maximowicziana* | 1 | | | 2 | | 2 | | | 3 | | |
| *Betula schumidtii* | 18 | 2 | 2 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 |
| *Carpinus cordata* | 2 | | | | | | | | 1 | | |
| *Carpinus laxifolia* | 4 | | | | | 1 | | | | | |
| *Carpinus tschonoskii* | 5 | 1 | | 1 | | 2 | | | 1 | | |
| *Cercidiphyllum japonica* | 2 | | | | | | | | | | |
| *Corylus heterophylla* | 2 | | | | | 1 | | | 1 | | |
| *Fagus crenata* | 15 | 1 | 1 | 2 | 2 | 1 | | | 2 | 1 | 1 |
| *Fagus japonica* | 9 | 4 | 3 | 3 | | 2 | | | | | |
| Graminae gen. et sp. indet. | | | | | | | | | | | 1 |
| *Hydrangea paniculata* | 1 | | | | | | | | | | 1 |
| *Lindera membranacea* | | | | | | 1 | | | | 1 | |
| *Populus sieboldii* | 2 | | | | | | 1 | | | | |
| *Pterocarya rhoifolia* | 2 | 1 | | | | | 1 | | | | |
| *Quercus mongolia* | 1 | | | | | | | | | | |
| *Rhododendron degronianum* | 1 | | | | | 1 | | | | | |
| *Sorbus alnifolia* | 2 | | | | | | | | | | |
| *Stewartia pseudo-camellia* | 2 | | | | | | | | | 1 | |
| *Tilia japonica* | 2 | | | | | | | | | | |
| *Trochodendron aralioides* var. *longifolium* | | 1 | | | | | | | | 1 | |
| *Tsuga sieboldii* | 1 | | | | | 3 | | | | 2 | |
| *Ulmus davidiana* var. *japonica* | 2 | | | | | | | | | | |
| Insecta | | | | | | | | | | | |
| Aphididae gen. et sp. indet. | 1 | | | | | | | | | | |
| Bibionidae gen. et sp. indet. | 6 | | | | | | | | | | |
| Braconidae gen. et sp. indet. | 1 | | | | | | | | | | |
| Chironomidae gen. et sp. indet. | 1 | | | | | | | | | | |

Table 1. (Continued)

| Species | Opal-CT zone | | | | | | | Opal-A zone | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1000 | 1002 | 1003 | 1101 | 1102 | 1103 | 1116 | 410 | 621 | 1201 | 1214 |
| Cibicidae gen. et sp. indet. | 1 | | | | | | | | | | |
| Ecdyonuridae gen. et sp. indet. et sp. indet. | 5 | | | | | | | | | | |
| Ephemeroptera gen. | 7 | | | | | | | | | | |
| Formicidae gen. et sp. indet. | 2 | | | | | | | | | | |
| Ichneumonidae gen. et sp. indet. | 2 | | | | | | | | | | |
| *Macromia* sp. | 1 | | | | | | | | | | |
| Mycetophilidae gen. et sp. indet. | 11 | | | | | | | | | | |
| *Necrodes nigricornis* | 1 | | | | | | | | | | |
| *Pentatoma* sp. | 2 | | | | | | | | | | |
| Pentatomidae gen. et sp. indet. | 23 | | | | | | | | | | |
| Scaridae gen. et sp. indet. | 15 | | | | | | | | | | |
| Silphidae gen. et sp. indet. | 2 | | | | | | | | | | |
| Tiplidae gen. et sp. indet. | 1 | | | | | | | | | | |

*japonica*, *Catsanea crenata*, *Betula schmidtii* and so on. Animal fossils: insecta (Hiura, 1966; Fujiyama, 1968, 1969, 1979, 1983), spiders, fishes (Uyeno, 1967), frogs (Shikama, 1955) and mammal mice (Hasegawa & Aoshima, 1988) were also found. The plant fossils collected in this study and arthropod fossils collected in the Fossil Museum and undescribed is listed in Table 1.

*Remarks*: The Miyajima Formation is developed in the Tsurusawa Valley (Locs. 1000–1005), the Shiranzawa Valley (Locs. 1101–1109), and at Locs. 402–405 along the Hoki River. In these places the laminated mudstone is composed of much thinner alternation of white lamina and gray lamina. The mudstone is much harder and consolidated than the others. Such "hard shale" is well jointed and is found from both E and F facies. This may be due to diagenesis of diatom frustules (Terada & Konishi, 1992; Maeda *et al.*, 1996; discussed later).

At Sumaki, the eastern area of the basin, lithology of the Miyajima Formation abruptly changes laterally and vertically (Fig. 5). F facies is mainly developed. It is interbedded with D facies of the Kamishiobara Formation (Loc. 615; described before). At places E facies is developed (Loc. 611, 619, 627).

The strata are slumped and show convoluted lamination and asymmetrical folding at many places. At some places pebbly sand is recognized in slumped interval. The slump folds of laminated mudstone indicate the basinward slope at that time. Directions of slumping ware determined from axis and form of folding (Fig. 8).

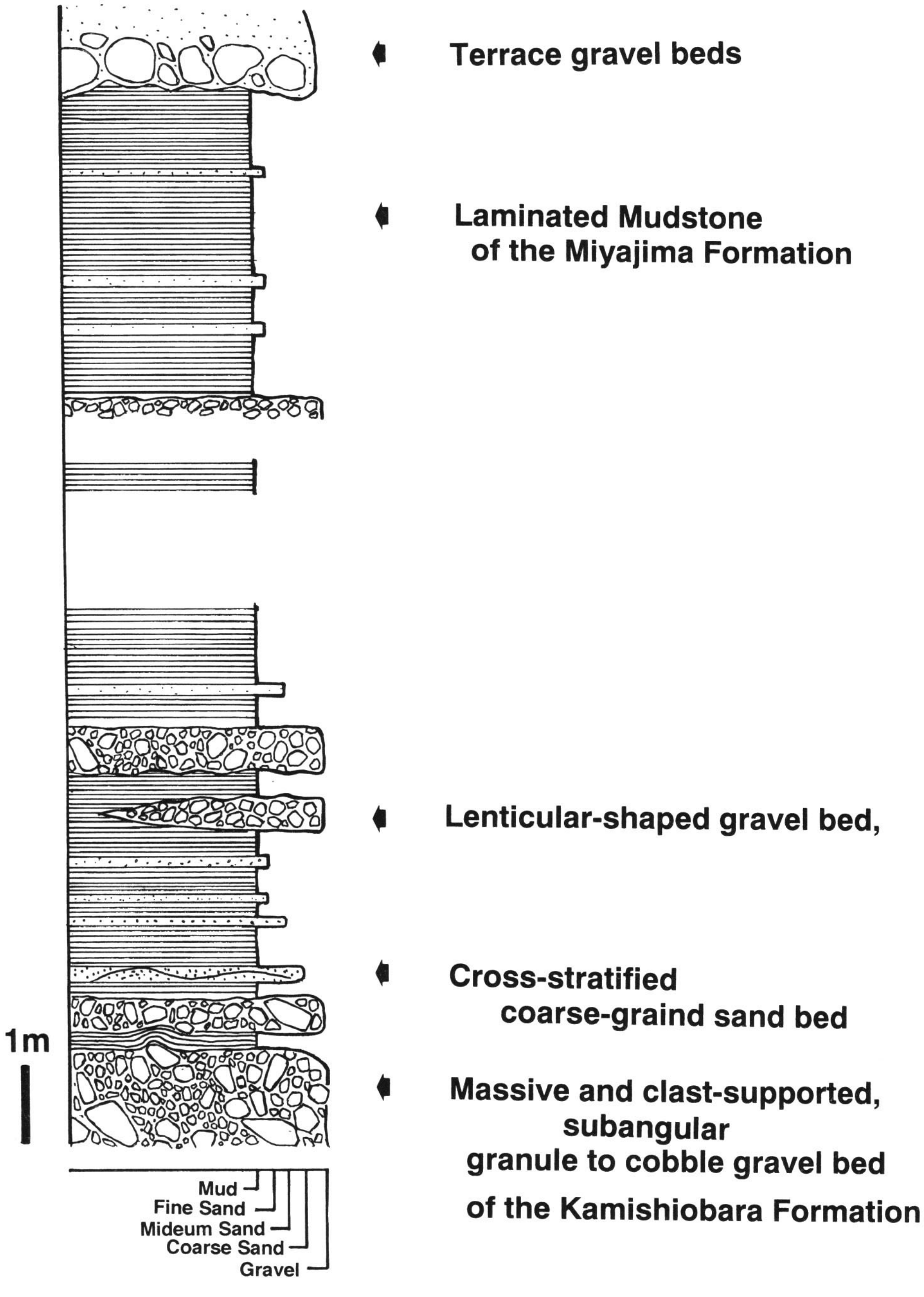


Fig. 6. Columnar section showing interfingering of the Kamishiobara and Miyajima formations at Loc. 1109.

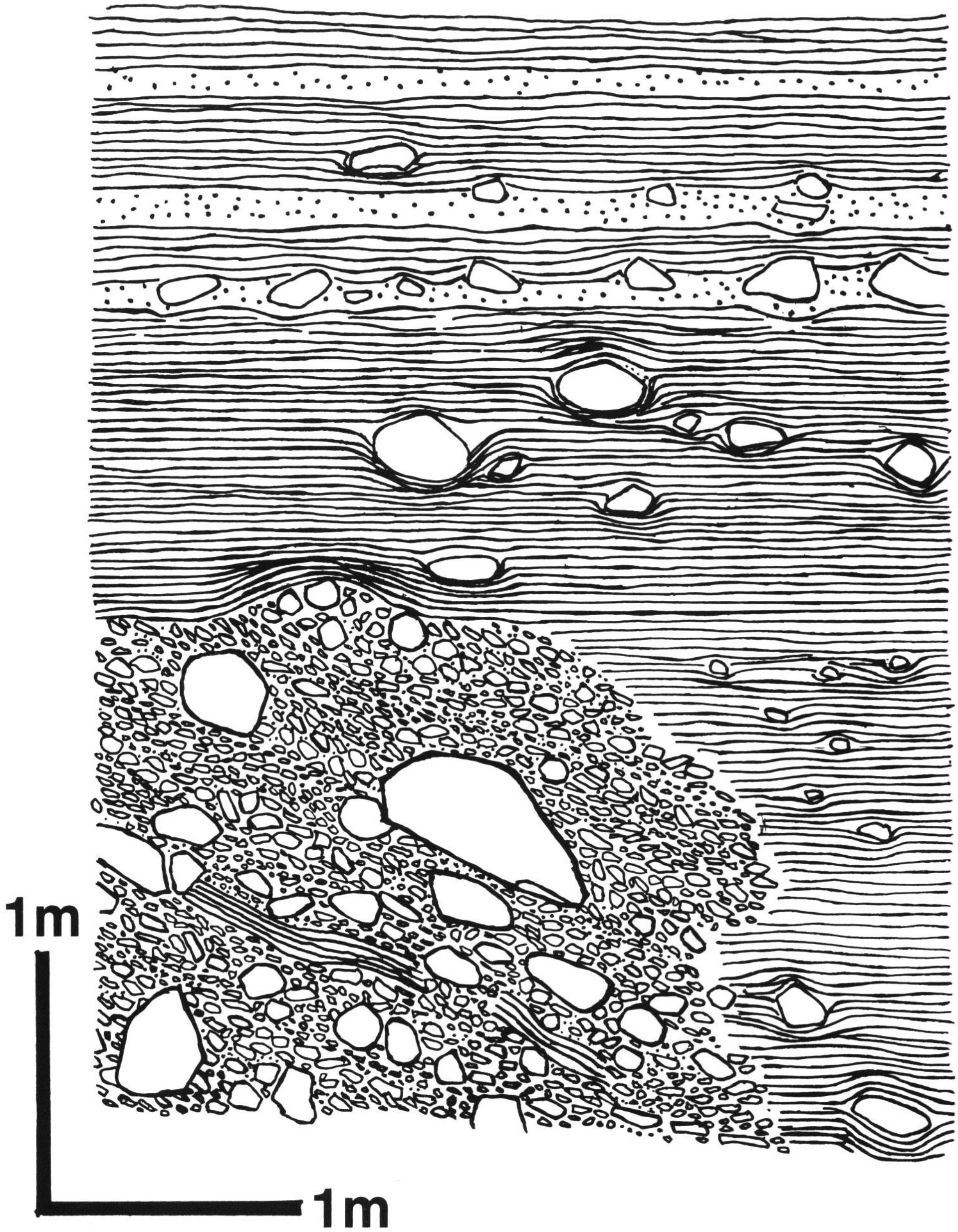


Fig. 7. Sketch of the outcrop showing rock-fall to the paleo-Shiobara lake in the eastern border of the basin (Loc. 615). Cobbles and pebbles are embedded isolatedly and directly in the laminated mudstone. Laminae are intensely bend downward along the pebble shape.

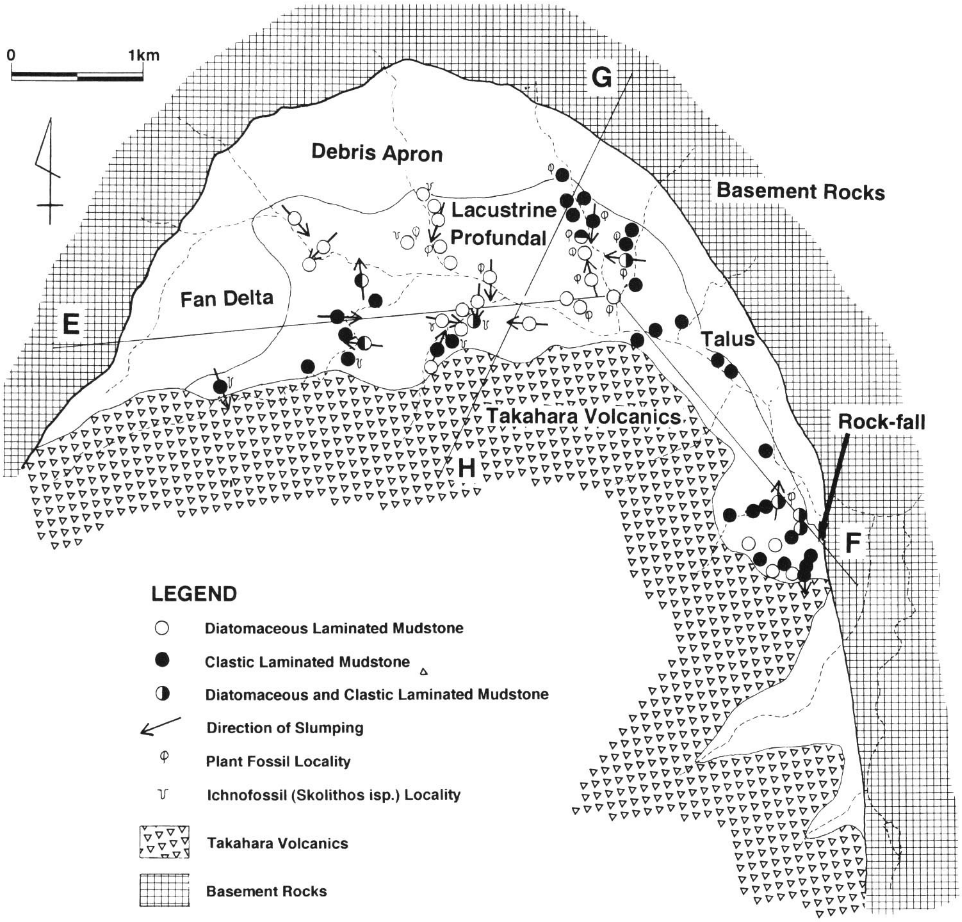


Fig. 8. Paleogeographic distribution of the mudstone facies, ichnofossil, direction of slumping and mass movements and reconstruction of sedimentary environments. E–F, G–H indicate locations of profile track-line in Fig. 12.

## Stratigraphic relation to the Takahara Volcanics

The Shiobara Group is intercalated with the Takahara Volcanics such as andesite lava and breccia in the eastern area, Sumaki, and southwestern area of the basin (Locs. 1401–1404). Each intercalated bed abruptly changes lithologically in lateral and is not traceable as a key bed for whole of group.

In the eastern area intercalated beds of the Takahara Volcanics are observed on four horizons at six localities (Locs. 616, 617, 618, 620, 622, 623). Each bed disappears or changes its lithology within a short distance.

Intercalated beds represent as sand or scoria beds, volcanogenic gravel, breccia and lava. The bed at Loc. 616 shows coarse-grained or upward-coarsing scoria at the base and overlying andesitic sand beds of 14 m in total thickness. This bed grades laterally into 5 m thick andesite breccia (Loc. 622). At the upper horizon, the Miyajima Formation is intercalated with inverse-graded, matrix-supported, subangular pebbly to cobbly andesitic gravel bed, 13 m thickness with andesitic sand matrix (Loc. 617). This bed grades to well-jointed andesite lava of more than 8 m in thickness (Loc. 623). The lava contains the angular mud clasts of the laminated mudstone, and is overlain by clastic laminated mudstone. The contact limb of the lava has glassy chilled margin and brecciated at some part. The laminated mudstone is deformed plastically around the basal contact. These features suggest that the andesite lava flowed into the paleo-Shiobara lake, and was interbedded with the lacustrine profundal (Fig. 2).

*Remarks*: This andesite lava flows described above are called the "Nakashiobara Agglomerate" by Takahashi and Uchida (1956) and the "Nakashiobara Volcanic Breccia" by Akutsu (1964) and Suzuki (1972). They considered that this andesite corresponds to volcanic breccia at Nakashiobara and that the andesite stratigraphically separates the mudstone of the Group. The andesite lava flows and breccia, however, are only exposed at two localities, Locs. 617, 623, and their lithology extremely change on lateral.

The andesite breccia at Nakashiobara covers the Shiobara Group and forms a lava plateau, which is equal to Uenohara lava plateau by Ikeshima and Aoki (1962). The Shiobara Group is not distributed above the andesite. There cannot be reasonably assumed that the "Nakashiobara Volcanic Breccia" of Akutsu (1964) separates the group, as stated by Onoe (1989).

## Sedimentological and Mineralogical Features of the Diatomaceous Mudstone

Terada and Konishi (1992) and Maeda *et al.* (1996) mentioned that diatom frustules composed of opal-A in laminated mudstone of the Miyajima Formation changes to spherules of opal-CT at the Fossil Museum, Konoha Kaseki'en (Loc. 1000, Pl. 1, fig. 1). We closely observed the textures of mudstone of the group in cross and thin sections and under scanning electron microscope (SEM) and decided mineralogical composition from X-ray diffractometer (XRD).

### Textures of the diatomaceous mudstone

*Macro scale observation*: The central facies of the Miyajima Formation is generally composed of diatomaceous laminated soft mudstone (Locs. 413, 612, 611, 617, 627, 1201–1206, 1301–1305, 1308, 1404, 1501, 1502, 1700, 1803). In contrast at the Fossil Museum and its environs the laminated "hard shale" is developed (Pl. 2, figs. 1, 2).

The "hard shale" as same as soft mudstone of the same facies comprises alterna-

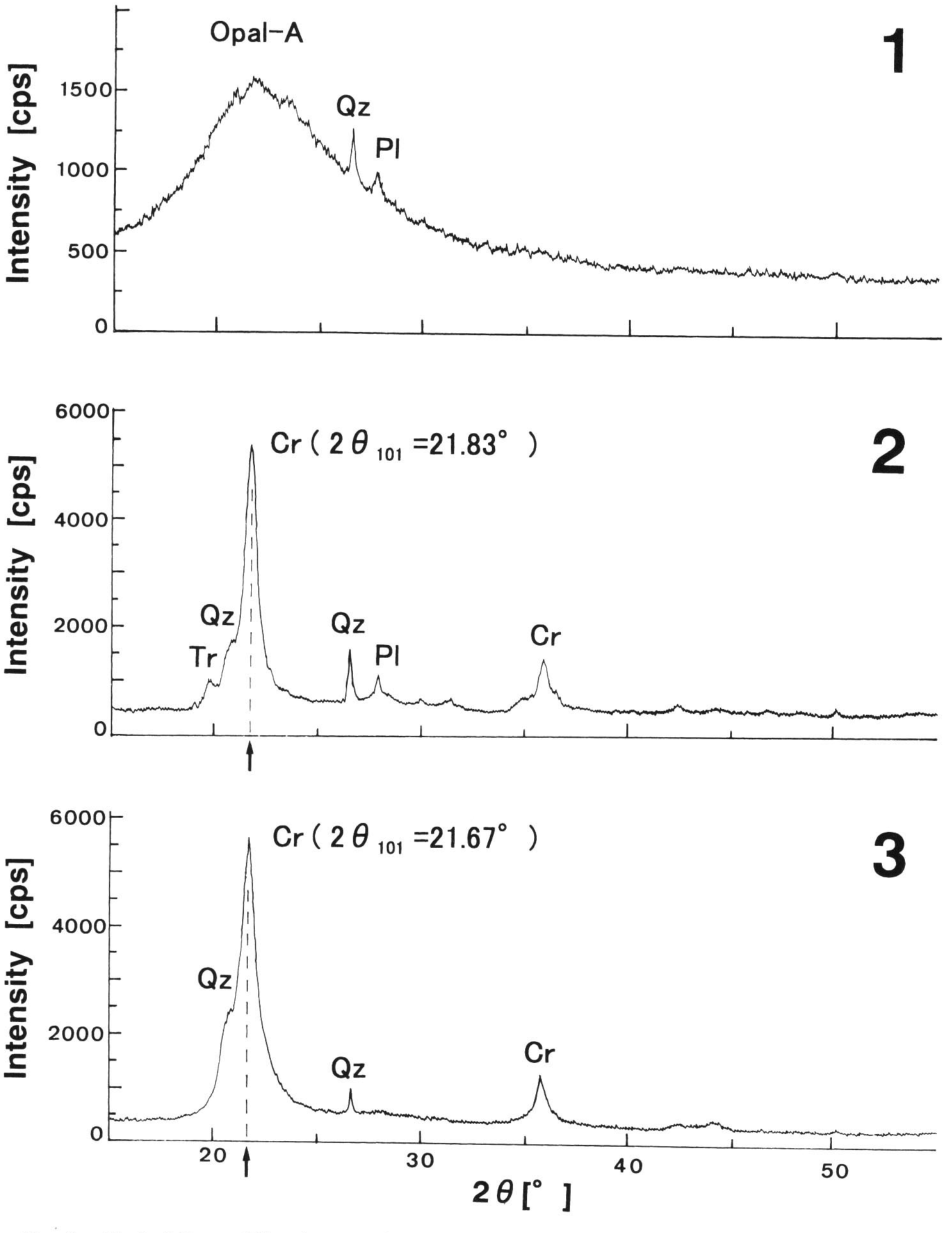


Fig. 9. Typical X-ray diffraction powder patterns of white laminae in the Miyajima Formation: 1. opal-A in the white lamina of soft mudstone (Loc.1304); 2. opal-CT in the white lamina of "hard shale" (Loc. 1102); 3. opal-CT in the white lamina of "hard shale" (Loc. 1000). This shows lowest $2\theta$ value of cristobalite (101). Cr, Tr, Qz and Pl identify diffraction peaks of cristobalite, tridymite, quartz and plagioclase. $2\theta_{101}$(Cr) values were corrected using quartz as internal standard.

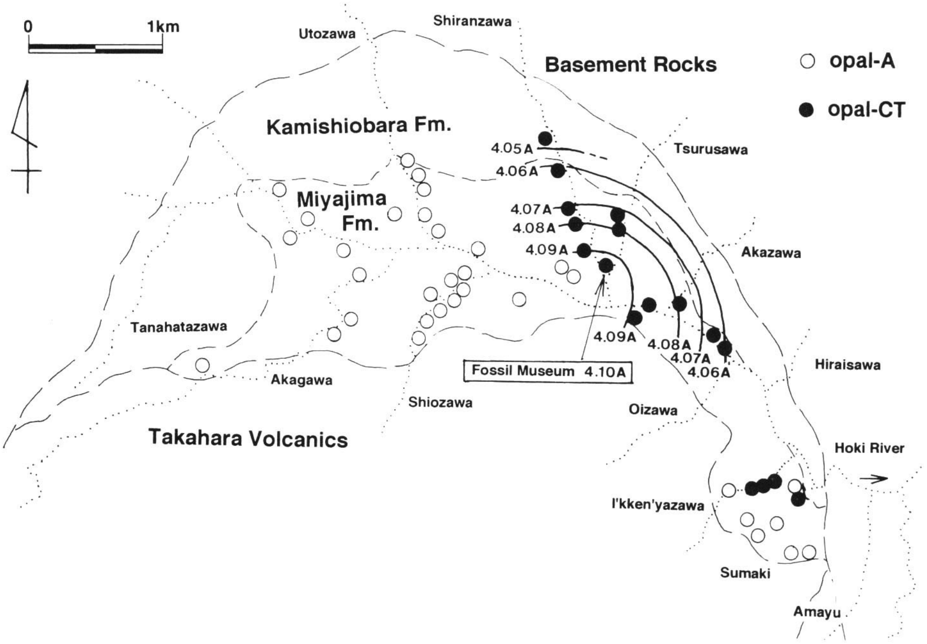


Fig. 10. Diagenetic zonations showing isometric lines of d(101) spacing of cristobalite. Solid line indicates expected contour line. Open circles show opal-A of diatom. Solid circles show opal-CT.

tion of white and gray laminae. The white lamina of diatomaceous soft mudstone of the central facies is 1.45 mm in average thickness, and that of "hard shale" is 0.49 mm in average thickness. The gray lamina of the former mudstone is 0.59 mm in average thickness and that of the later is 0.26 mm in average thickness. The mudstone of the marginal facies changes a little in thickness (Pl. 2, fig. 3, 7).

*Optical microscopic observation*: Textures of each mudstone were observed in thin sections with a microscope (Pl. 2, figs. 2, 4, 6, 8). Thin sections were cut perpendicularly to the bedding plane. The white lamina is composed mostly of diatom frustules measuring 10–50 $\mu$m in diameter. Clastic grains of quartz, feldspar and volcanic glass are concentrated in gray lamina. On the contrary, the white lamina of the "hard shale" is composed of opaque spherules measuring 2–5 $\mu$m in diameter.

*Scanning electronic microscopic observation (SEM)*: Freshly broken surfaces coated with Au were observed with SEM. Diatom frustules are well-preserved in the white lamina of soft mudstone (Pl. 3, fig. 1). In contrast, diatom frustules disappear in white lamina of the "hard shale". Instead of diatom frustules, bladed crystals forming microspherules are abundant there (Pl. 3, fig. 2). These are lepispheres composed of opal-CT (Segnit *et al.*, 1970). In thin section they are observed as the opaque spherules.

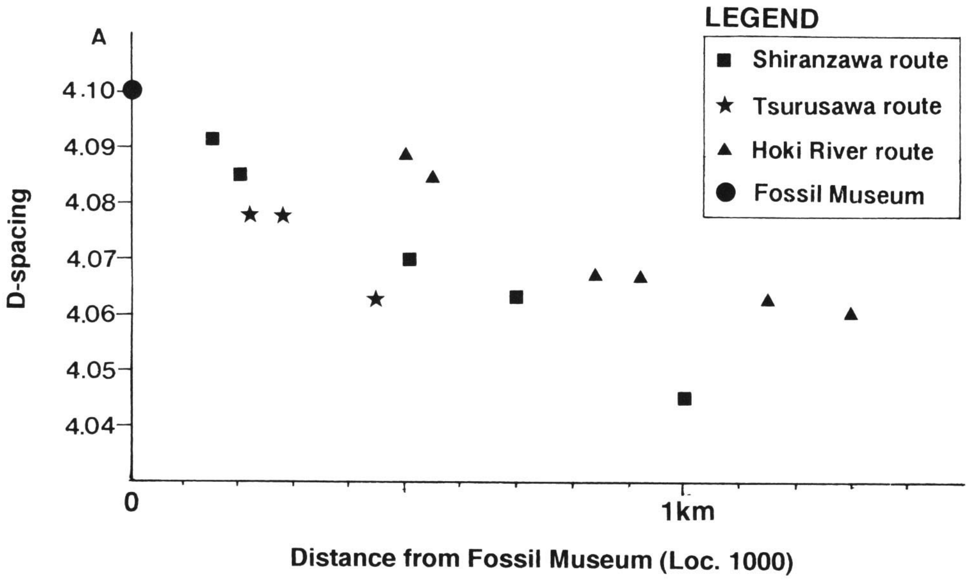


Fig. 11. Diagram showing the relation between d(101) spacing of cristobalite and the distance from the Fossil Museum.

## Mineralogical composition of the diatomaceous mudstone

Mineralogical compositions of each lamina were decided from X-ray diffractometry (XRD) at $2\theta=1.2°/\text{min.}$ using nickel-filtered Cu-K$\alpha$ radiation. Fig. 9 shows the white lamina of the diatomaceous soft mud is composed of opal-A or amorphous opal and that of "hard shale" is composed of opal-CT (Fig. 10). Opal-A of soft mud is correlated with the original component of diatom frustules. Opal-CT consists of the interlayering of cristobalite and tridymite (Flörke, 1955a, b; Jones & Segnit, 1971). The values of d(101) spacing of cristobalite was determined by $2\theta$ values corrected using quartz as internal standard.

XRD analysis reveals that degree of minerallization of opal differs geographically (Figs. 10, 11). These are traceable and mappable as several diagenetic zones. D(101) spacings are contoured (Fig. 10). The western area of the basin remains in the primitive diagenetic zone of opal-A stage (opal-A zone). On the west of Nakashiobara (Locs. 410, 411, 1000, 1101), the opal-A zone suddenly changes to the advanced diagenetic zone of opal-CT stage (opal-CT zone). The eastern area belongs to the opal-CT zone. The highest value of the d(101) spacing is located at the Fossil Museum. The values decrease northward and eastward. At Sumaki opal-CT is found in a scattered pattern. Roughly speaking, the soft mudstone corresponds to the opal-A zone, while the "hard shale" to the opal-CT zone.

## Preservational States of Plant Fossils

The Miyajima Formation yields abundant plant fossils. Trunk fossils are embedded in the sandstone, siltstone and slumped beds inserted in diatomaceous laminated mudstone. Leaf fossils are mainly preserved in the top of gray lamina of diatomaceous laminated mudstone. Their preservational states are variable by diagenetic opal-A and opal-CT zones. Some taphonomic features seem diagnostic to the diagenetic stage.

### Preservation in opal-A zone

*Localities*: Locs. 410, 621, 1201, 1214, 1403, 1405, 1409, etc.

*Trunk fossils*: In general trunk fossils in opal-A zone are rarely compressed. They are mostly woody brown in color, very fresh and similar to recent trounce in appearance. A few trunk fossils are black in color, and are coalified. Textures of the wood are preserved in detail (Pl. 3, fig. 3). Cell walls are almost intact. Xylem parenchyma can be observed. Dispersal layer is early wood and condensed layer is late wood. The transition from the early wood to the late wood is abrupt. According to analysis of energy dispersal X-ray microprobe analyzer (EDX) with Be filter, they contain no characteristic heavy elements. The EDX with Be filter cannot detect light elements such as C.

*Leaf fossils*: The leaf fossils in opal-A zone are excellently well-preserved, coalified and impressed. Well-preserved and coalified leaf fossils are able to be exfoliated from matrix of laminated mudstone. Well-preserved leaves are thin film like and light brown or orange (Pl. 3, fig. 5). They are similar to recent dry leaf, but more thin and fragile. Major venation of primary and secondary veins and reticulate fine venation are observed (Pl. 3, fig. 7). Coalified leaf fossils (*Fagus crenata*) are black thin film of about 80 $\mu$m thick. Coalified leaves are opaque, and it is often difficult to examine the detail of fine venation without a chemical preparation. Leaf fossils are cracked along the venation pattern under drying condition after occurrence. Impressed leaf fossils are mould (Pl. 3, fig.8) and organic material had been dissolved. Major venation of primary and secondary veins are impressed. Reticulate fine venation are not preserved. According to EDX analysis, leaf fossils in opal-A zone contain no characteristic heavy elements.

### Preservation in opal-CT zone

*Localities*: Locs. 1000, 1002, 1003, 1102, 1103, 1116, etc.

*Trunk fossils*: Trunk fossils in opal-CT zone are dark brown or black in color and harder than those in opal-A zone. They are remarkably compressed. For example, a trunk fossil of 4 cm wide is compacted up to 4 mm thick. Fossils are composed of black substance, and opaque even though in thin section. Detail structures of the woods are not preserved. In contrast to recent trunks and trunk fossils in opal-A zone, no layered structures such as growth rings are observable (Pl. 3, fig. 4). Cell walls cannot be observed. The black substance consisting of fossil is the complex of spheres and plates etc. The spheres are less than 5 $\mu$m in diameter, and do not show lepisphere-like structure. The results of EDX indicate that trunk fossils in opal-CT zone contain S, P, Ca and Fe at least.

*Leaf fossil*: Leaf fossils are preserved as a film of brown matter of about 30 $\mu$m thick (*Fagus crenata*, NSM-PP 11230; Pl. 3, fig. 6), and unable to be exfoliated from the matrix of laminated mudstone. It is harder than the matter of leaf fossils in opal-A zone. Major venation of primary, secondary vein and fine venation are observed. The veins are composed of dark brown substance in pieces. Lamina is composed of thin light brown substance. According to analysis of EDX, veins and lamina contain Fe and S at least.

## Discussion

### Interpretation of sedimentary facies

The facies of the Shiobara Group are variable at places and abruptly changes in lateral. The paleo-Shiobara lake is sedimentologically profiled from the facies distribution (Fig. 12). Description, distribution and interpretation of individual facies show in Fig. 13.

*A facies*: The facies is distributed along rim of the lake except the southern margin. The facies features described above characterize debris flow units deposited in short distance transportation (Middletone & Hampton, 1976). It is consistent with talus depositional system on adjacent to steep slope (Nelson, 1992; Larsen & Crossey, 1996). Crude bedding may reflect the approach to the angle of repose. This facies corresponds to a talus.

*B facies*: The facies is distributed along western margin of the lake. The features imply reworked debris-flow deposits, and suggest the influence of fluvial current. This facies is interpreted to be accumulated at the foot of a slope where the gravel and sand beds build gravelly debris aprons such as described at Crater Lake (Nelson *et al.*, 1986) and Oligocene Creede Formation (Larsen & Crossey, 1996). Gravels and sand grains derived from the steep slope of the basement rocks is transported by sediment gravity flows along subaerial debris chutes into the lake and deposited as debris-flow beds near the basin margin.

*C facies*: This facies is distributed in western and southeastern area of the lake. The poorly-sorted gravel beds are debris flow deposits (Lowe, 1979), which are recognized in proximal deposits of several alluvial fans (Miall, 1992; Waresback & Turbeville, 1990). The cross-stratified gravel and sand beds indicate transportation by strong streams. The features imply a alluvial fan/fan-delta origin (Nemec & Steel, 1988).

In the western area, the facies prograding to lacustrine profundal suggest that fa-

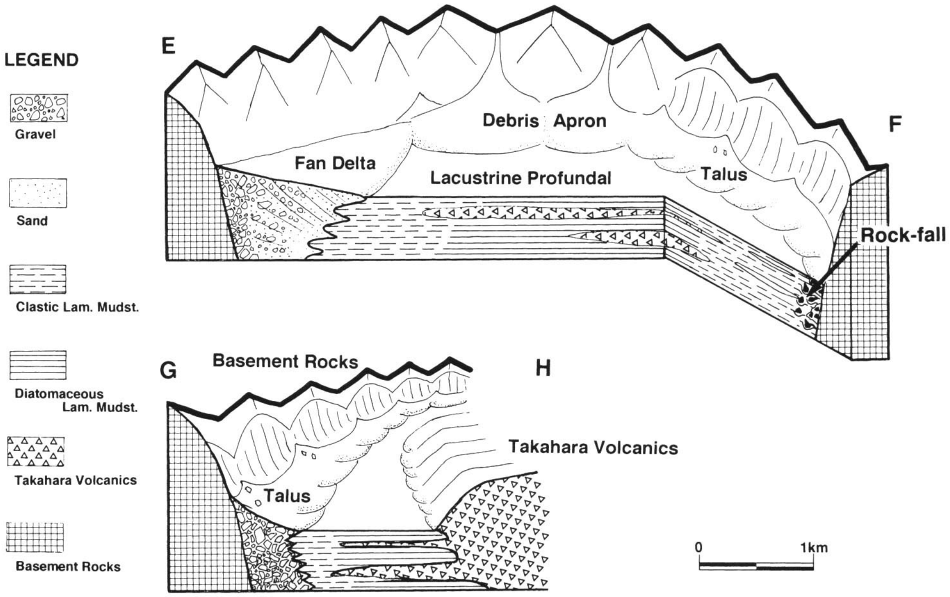


Fig. 12. Depositional profiles of the Shiobara Group along E–F and G–H track-line shown in Fig. 8.

cies was deposited in subaquatic condition. This facies shows fan-shaped distribution extending from southwest to northeast (Fig. 5). The facies corresponds to fan-delta.

The southeastern area is isolated from the main part of the basin by the Takahara Volcanics. In this area, the distribution and composition of the facies suggest that sediments were derived from southwest Takahara Volcano. Absence of subaqueous sedimentary feature indicates a volcanogenic-alluvial fan (Waresback & Turbeville, 1990) at the foot of the Takahara Volcano.

*D facies*: The facies is distributed at the eastern rim of the lake. The features seem to show the rock-fall origin of the embedded pebble. The Kamishiobara and the Miyajima Formations interfingered with each other there. The eastern rim of the lake was a steep wall, consisting the basement rocks, which falling to the deep lake bottom.

*E and F facies*: The facies features indicate deep profundal, hemipelagic and stagnant condition with a little terrigeneous influx. The diatomaceous laminated mudstone corresponds to central facies of lacustrine profundal and the clastic laminated mudstone corresponds to marginal facies of lacustrine profundal.

## Profile of the paleo-Shiobara lake

The Middle Pleistocene Shiobara Group was deposited in a small lake, adjoining the Takahara Volcano. Surrounding the Takahara Volcano, the Takahara and Ino-

| G. | Fm. | Fc. | Description | Distribution | Interpretation | |
|---|---|---|---|---|---|---|
| Shiobara Group | Kamishiobara Fm. | A | massive or crudely stratificated angular to subangular gravel beds | All of the border | Talus | Lacustrine marginal facies |
| | | B | stratificated gravel and sand beds | Northern margin | Debris Apron | |
| | | C | stratificated gravel beds | Western (fan-shaped) and Southeastern area | Fan Delta or Alluvial Fan | |
| | | | cross-stratificated gravelly sand beds | | | |
| | | | cross-stratificated sand beds | | | |
| | | D | embedded angular gravels in laminated mudstone | Eastern border | Rock-fall | |
| | M. Fm. | E | diatomaceous laminated mudstone | Central area | Lacustorine Profundal | Lacustrine facies |
| | | F | clastic laminated mudstone | Margin of Central area | Margin of Lacustorine Profundal | |

Fig. 13. Facies descriptions, distributions and interpretations of the Shiobara Group.

hara lake deposits at the western foot (Suzuki, 1958), and the Akadaki Formation at the southeastern foot (Suzuki, 1956) are distributed. The paleo-Shiobara and other lakes are considered as caldera lakes of the Takahara Volcano (Onoe, 1989). Our field observation supports the paleo-Shiobara lake is a caldera lake, because all the rim of the basin form steep slopes and volcanics are interfingered with lacustrine profundal facies. Especially, quite a steep wall falls to deep lake bottom in the eastern rim.

Talus is mostly developed, on the border of the basement. Debris apron in the northwestern margin and fan-delta in the western area suggest that lake-fill clastic sediment mainly derived from west. This feature suggests western mountains of basement rock. This geographical setting is closely similar to the recent.

The eastern area (Sumaki) is paleogeographically separated from the main part of the paleo-Shiobara lake with isthmus of the basement rocks and lava-flows and andesite breccias of the Takahara Volcano. The facies easily changes in lateral and vertical, as it reflects unsettled depositional environment in small lake (Fig. 5). However extensive distribution of laminated diatomaceous mudstone indicates that this area had been deep enough to retain a profundal facies consisting mostly of biogenic sediments for a long time.

Continuous deposition of the thick laminated diatomaceous sediments suggests that deep profundal, hemipelagic and stagnant condition keep for a long time in the paleo-Shiobara lake. The bioturbation of few ichnofossil producer is so weak that the lamination are still preserved. The most of the Miyajima Formation were deposited under the anaerobic or toxic bottom water.

The Takahara Volcanics is intercalated and directly covered with lacustrine profundal laminated mudstone of the Miyajima Fomation. The southern margin of the Takahara Volcano might have formed gentle slope and been still subaquatic when the lacustrine profundal mudstone is deposited. Abundance of lithic fragment derived from the Takahara Volcanics in the western area indicates that the Takahara Volcano formed a steep slope enough to supply with gravels after the latter period of the Shiobara lake.

### Taphonomic aspects of the fossiliferous Shiobara Group

The Miyajima Formation yields extraordinary well-preserved fossil biotas showing soft-tissue preservation (Shikama, 1955; Fujiyama, 1968; Hasegawa & Aoshima, 1988; Onoe, 1989 etc.), and represents a kind of konservat Fossil-Lagerstätten (Seilacher *et al.*, 1985). These fossils were, however, mostly collected from only one fossiliferous site, i.e. the Fossil Museum (Loc. 1000). However, spectra of sedimentary features and fossil preservation in the whole group, which may imply important keys on taphonomy, have not been observed yet.

Our observation reveals that isometric lines which border traceable diagenetic zones are clearly observed, besides abrupt lateral facies change of the laminated mudstone (Fig. 11). Well-laminated diatomaceous soft mudstone of the Miyajima Formation grades diagenetically into compacted "hard shale" toward the center of the paleo-Shiobara lake: i.e., around the Fossil Museum. This reflects degradation of diatom frustules composed of opal-A to lepispheres of opal-CT.

In relation, the preservational states of plant fossils are different from the opal-A to opal-CT zones (Pl. 2, figs. 5–8). Veins of leaf fossils are superficially simplified in completely consolidated "hard shale" by opal-CT in the Fossil Museum. It means that original biogenic micro-structures and textures can be easily destroyed by crystallization of opal-CT to excess (Maeda *et al.*, 1996). Therefore, balanced silicification during early diagenesis seems important for fossil preservation, particularly for soft tissues.

## Conclusional Remarks

Besides the Shiobara Group, similar lacustrine fossiliferous deposits have been developed among volcanic mountains in Japan since Miocene: e.g., Kabutoiwa (Koshimizu; 1982, 1984), Kusu (Uyeno *et al.*, 1975), Sado (Fujiyama, 1985), Chojabaru (Ishida *et al.*, 1970), Sanzugawa (Huzioka & Uemura, 1974) etc. Though some of them are seemed to be caldera lakes and show similar diagenetic change of diatomaceous opal, taphonomic implication retain greatly to be done. Such Shiobara-type Fossil-Lagerstätten can be peculiar to the active island arcs and imply important taphonomic aspects.

## Acknowledgments

We wish to express my sincere thanks to Profs. K. Chinzei (Osaka Gakuin Univ.), F. Masuda (Kyoto Univ.) and Emeritus Prof. M. Tashiro for their helpful discussion during the course of this work. Thanks are extended to Drs. T. Hirajima, N. Shimobayashi, T. Sakai for EDX and X-ray diffractmetry analyses or his critical reading of the manuscript. We are also grateful to N. Kato and staffs of the Konoha Fossil Museum for their kind assistance during our field survey. We thank Y. Maeda, H. Tanaka, N. Sakakura, B. Tojo and our colleagues for their valuable discussion on taphonomy in the "Ammo Seminar" of Kyoto Univ. Drs. Y. Saito, Y. Shigeta, K. Uemura (National Science Museum, Tokyo) gave us useful advice for publication of this paper. Finally we dedicate this paper to late Prof. Mitsuo Yamanaka (Kochi Univ.) who kindly supported our study and gave us valuable comments from the view point of botany, ecology and palynology.

This study was partly supported by Grant-in-Aid (no. 9715) for JSPS Fellows from the Japanese Ministry of Education, Science, Sports and Culture, and also by the Inamori Foundation Grant.

## References

Akutsu, J., 1960. Laminated diatomaceous siltstones developed in the Miyajima Formation, Shiobara Group, Tochigi Prefecture. *Sci. Rep. Tohoku Univ.*, 2nd ser. (Geol.), spec. vol. **4**: 544–554, pls. 42–43. (In Japanese with English abstract.)

Akutsu, J., 1964. The geology and paleontology of Shiobara and its vicinity, Tochigi Prefecture. *Sci. Rep. Tohoku Univ.*, 2nd ser. (Geol.), **35**: 211–293, pls. 57–66.

Behre, K. E. & J. van der Plicht, 1992. Towards as absolute chronology for the last glacial period in Europe: radiocarbon dated from Oerel, northern Germany. *Vegetation History and Archaeobotany*, **1**: 111–117.

Endo, S., 1931. On the climate of the Pleistocene age in Japan. *Jour. Geol. Soc. Tokyo*, **38**: 520–531. (In Japanese.)

Endo, S., 1934. Some Japanese Cenozoic plants. On the Fossil *Acer* from the Siobara Pleistocene Plant Beds. *Japan. Jour. Geol. Geogr.*, **11**: 239–253, pls. 28–35.

Endo, S., 1935. A Pleistocene flora of Japan as an indicator of climatic condition. *Jour. Geol. Soc. Tokyo*, **42**: 658–674.

Flörke, O., 1955a. Zur Frage des "Hich-Cristobalit" in Opalen, Bentoniten und Glaesern. *Neues Jahrb. Mineral Mh.*: 217–224.

Flörke, O., 1955b. Strukturanomalien bei Tridymit und Cristobalit. *Berlin Deut. Keram Ges.*, **32**: 369–381.

Fujiyama, I., 1968. A Pleistocene fossil Papilio from Shiobara, Japan. *Bull. Natn. Sci. Mus., Tokyo*, **11**(1): 85–95, pls. 1–3.

Fujiyama, I., 1969. A Miocene cicada from Nasu, with an additional record of a Pleistcene cicada from

Shiobara, Japan (Tertiary insect fauna of Japan, 3). *Bull. Natn. Sci. Mus., Tokyo*, **12**(4): 863–874, pl. 1.

Fujiyama, I., 1979. Some Late Cenozoic cicadas from Japan. *Bull. Natn. Sci. Mus., Tokyo*, Ser. C, **5**(4): 139–152.

Fujiyama, I., 1983. A Pleistocene nymphalid butterfly from Shiobara, Japan. *Bull. Natn. Sci. Mus., Tokyo*, Ser. C, **9**(4): 121–128.

Fujiyama, I., 1985. Early Miocene insect fauna of Seki, Sado island, Japan, with notes on the occurrence of Cenozoic fossil insects from Sado to San-in District. *Mem. Natn Sci. Mus., Tokyo*, **18**: 35–55, pls. 3–5. (In Japanese with English abstract.)

Gohara, Y., S. Ijiri, M. Ichihara, K. Sueyama, T. Narikoshi, Y. Kuwano, Y. Fujita, T. Matsui, M. Minato & T. Utashiro, 1952. Group Study of Shiobara Lake Deposits. *Earth Science (Chikyu Kagaku)*, **8**: 31–39. (In Japanese.)

Hasegawa, Y. & M. Aoshima, 1988. Two fossil mice from Pleistocene lake deposits of Shiobara, Tochigi Prefecture. *Bull. Tochigi Pref. Mus.*, **5**: 1–5. (In Japanese with English summary.)

Hayakawa, T., K. Hirose & M. Noguchi, 1985. Development of fluvial along upperstream of Hoki River, Tochigi Prefecture, Japan. *Bull. Fac. Educ. Ibaraki Univ.*, **34**: 1–22. (In Japanese with English summary.)

Hiura, I., 1966. On two species of fossil Pentatomidae from the Shiobara Group (Middle Pleistocene), Central Japan (Insecta: Heteroptera). *Bull. Osalka Mus. Nat. Hist.*, **19**: 39–45, pls. 2. (In Japanese with English abstract.)

Huzioka, K. & K. Uemura., 1974, The Late Miocene Sanzugawa Flora of Akita Prefecture, Northeast Honshu, Japan. *Bull. Natn. Sci. Mus., Tokyo*, **17**(4): 325–363, pls. 1–11.

Ikeshima, R. & K. Aoki, 1962. Petrology of Takahara volcano. *Jour. Mineral. Petrol. Economic Geologists*, **48**: 97–107. (In Japanese with English abstract.)

Ishida, S., I. Fujiyama, T. Hayashi, Y. Noguchi & Y. Tomoda, 1970. Geology and Paleontology of the Chojaburu Diatomite, Iki, Japan. *Mem. Natn. Sci. Mus., Tokyo*, **3**: 49–62, pls. 11–14. (In Japanese with English abstract.)

Iwao, S. & I. Imai, 1955. Explanatory text of the geological map of Japan, scale 1 : 75,000; Shiobara, zone 19, col. V, sheet 82. 158 pp, map 1. Geol. Surv. Japan. (In Japanese with English abstract.)

Jones, J. & E. Segnit, 1971. The nature of opal. 1, Nomenclature and constituent phases. *Jour. Geol. Soc. Australia*, **18**(1): 57-68.

Kanehara, N., 1900. Report of the geological survey of Takahara Volcano. *Shinsai Yobo Chosa Kai Rep.*, **31**: 1–45. (In Japanese.)

Koizumi, G., 1940. Shiobara Pleistocene Fossil-Flora. *Acta Phytotaxonomica et Geobotanica*, **9**: 1–27. (In Japanese.)

Koshimizu, T., 1982. Neogene insect fossils collected from the Kabutoiwa Plant Bed, Nagano and Gunma Prefectures of Japan. "*Chigaku kenkyu*", **33**: 397–426. (In Japanese with English abstract.)

Koshimizu, T., 1984. Neogene avian, amphibian and arthropod fossils collected from the Kabutoiwa Plant Bed in Nagano and Gunma Prefectures of Japan. "*Chigaku kenkyu*", **35**: 73–87. (In Japanese with English abstract.)

Larsen, D. & L. J. Crossey, 1996. Depositional environments and paleolimnology of an ancient caldera lake: Oligocene Creede Formation, Colorado. *Geol. Soc. Amer. Bull.*, **108**: 526–544.

Lowe, D. R., 1979. Sediment gravity flows: Their classification and some problems of application to natural flows and deposits, *In* Doyle, L. J. & O. H. Pilkey (eds.), Geology of continental slopes: society of Economic Paleontologists and Mineralogist Special Publication. **27**, pp. 75–82. SEPM. Tulsa, Oklahoma.

Maeda, H., Y. Maeda, M. Yamanaka & P. A. Allison, 1996. Taphonomy of the diatomaceous laminated mudstone of the Shiobara Group, the Pleistocene lacustrine deposits. *Abstracts with Programs, the*

*1996 Annual Meeting, the Palaeontological Society of Japan*: 37. (In Japanese.)

Miall, A. D., 1992. Alluvial deposits. *In* Walker, R. G. & N. P. James (eds.), Facies models, response to sea level change, pp. 119–142. Geol. Assoc. St. John's.

Middletone, G. V. & M. A. Hampton, 1976. Subaqueous sediment transport and deposition by gravity flows. *In* Stanley D. J. & D. J. P. Swift (eds.), Marine sediment transport and environmental management, pp. 197–218. Wiley, New York.

Nathorst, A.G., 1883. Contributions a la flore fossile du Japan. *KG. Sv. Vet. Ak. Handl.*, **20**(2): 3–92.

Nelson, A. R., 1992. Lithofacies analysis of colluvial sediments—An aid in interpreting the recent history of Quaternary normal faults in the Basin and Range Province, western United States. *Jour. Sediment. Petrol.*, **62**: 607–621.

Nelson, C. H., A. W. Meyer, D. Thor, & M. Larsen, 1986. Crater lake, Oregon: a restricted basin with base-of-slope aprons of nonchannelzed turbidites. *Geology*, **14**: 238–241.

Nemec, W. & R. J. Steel, 1988. Fan deltas—sedimentology and tectonic setting. 444 pp. Blackie and Son, Glasgow.

Niino, H., 1933. Geology of north-eastern margin of Shimotsuke Mountain region (1). *Geol. Soc. Tokyo, Jour.*, **40**: 517–532. (in Japanese.)

Onoe, T., 1989. Palaeoenvironmental analysis based on the Pleistocene Shiobara flora in the Shiobara volcanic basin, central Japan. *Rep. Geol. Surv. Japan*, 269: 1–207. (In Japanese with English abstract.)

Segnit, E., C. Anderson & J. Jones, 1970. A scanning microscope study of the morphology of opal. *Search*, **1**: 349–351.

Seilacher, A., W. E. Reif & F. Westphal, 1985. Sedimentological, ecological and temporal patterns of fossil Lagerstätten. *Phil. Trans. Royal Soc. London*, Ser. B, **311**(1148): 5–24.

Shikama, T., 1955. Note on an occurrence of fossil rana from Siobara, Tochigi Prefecture. *Sci. Rep. Yokohama Natn. Univ.*, 2nd sec., **4**: 35–40.

Suzuki, A., 1956. Sedimentological studies on the lake deposits in the Shiobara Mountain region. (part 1) on the sedimentary environment of the Akadaki lake deposit. *Bull. Utsunomiya Univ.*, 2nd sec., **6**: 103–114. (In Japanese with English abstract.)

Suzuki, A., 1958. Sedimentological studies on the lake deposits in the Shiobara Mountain region. (part 2) on the lake and swamp deposits in the western part of Mt. Takahara. *Bull. Utsunomiya Univ.*, 2nd sec., **8**: 65–71.

Suzuki, A., 1972. Geology and hotspring of the Shiobara Basin. *Inst. Geol. Paleontol. Tohoku Univ., Iwai Jun-ichi Memorial*: 581–588. (In Japanese.)

Suzuki, A., K. Uzuki, I. Hitomi & N. Ishikawa, 1978. Geology and hot spring in the Okushiobara Spa, Tochigi-ken. *Bull. Fac. Educ. Utsunomiya Univ.*, 2nd sec., **28**: 31–45. (In Japanese with English abstract.)

Suzuki, M., 1973. Fossil woods from the Pleistocene of Shiobara, Tochigi Prefecture. *J. Japan. Bot.*, **48**(6): 173–182, pls. 1–8. (In Japanese with English abstract.)

Suzuki, K. & T. Nasu, 1988. Plant biostratigraphy of the Plio-Pleistocene series in Japan. *Mem. Geol. Soc. Japan*, **30**: 169–180. (In Japanese with English summary.)

Takahasi, S. & T. Uchida, 1956. Geological history of Shiobara Fossil Lake. *Sci. Rep. Yokohama Natn. Univ.*, 2nd sec., **5**: 77–108. (In Japanese with English abstract.)

Tayama, R., 1929. River terraces developed in the eastern slope of Shiobara Volcano and Shiobara Basin. *Geographical Review of Japan.*, **5**: 577–595. (In Japanese.)

Terada, K. & K. Konishi, 1992. Sedimentary petrology of varved mudstone developed in the Shiobara Group (middle-Pleistocene), Tochigi Prefecture. *The Grant-in-Aid for Scientific Research (A) "The Rhythm of Earth and Banded Structures" Research Report*: 82–88. (In Japanese with English abstract.)

Uyeno, T., 1967. Pleistocene cyprinid fish from Tochigi Prefecture, Japan. *Shigen Kagaku Kenkyusho Iho*

(*Miscellaneous Reports of the Research Institute for Natural Resources*), **69**: 131–134.

Uyeno, T., S. Kimura & Y. Hasegawa, 1975. Freshwater fishes from Late Cenozoic deposits in Kusu Basin, Oita Prefecture, Japan. *Mem. Natn. Sci. Mus., Tokyo*, **8**: 57–66, pls. 6–9. (In Japanese with English abstract.)

Waresback, D. B., & B. M. Turbeville, 1990. Evolution of a Plio-Pleistocene volcanogenic-alluvial fans: The Puye Formation, Jemez Mountains, New Mexico. *Geol. Soc. America. Bull.*, **102**: 298–314.

Yabe, H., 1929. Shiobara Volcano and its relation to geological structure. *Geographical Review of Japan*, **5**: 142–158. (In Japanese.)

## Explanation of Plates

**Plate 1.**

Fig. 1. Central lacustrine profundal facies: Laminated diatomaceous mudstone of the Miyajima Formation at the Fossil Museum (Konoha Kaseki'en; Loc. 1000).

Fig. 2. Talus facies: Crudely bedded gravel beds of the Kamishiobara Formation at Loc. 901.

Fig. 3. Fan-delta/Alluvial fan facies: Tabular cross laminated pebbly sand beds of the Kamishiobara Formation at Loc. 504.

**Plate 2.**

Fig. 1. Cross section of the diatomaceous laminated mudstone of the Miyajima Formation at Loc. 1201. Diatom frustules of opal-A are well preserved (opal-A zone). Scale bar: 1 cm long.

Fig. 2. Thin section of the diatomaceous laminated mudstone of the Miyajima Formation from Loc. 1201 (opal-A zone). Opened nicol. Scale bar: 1 mm long.

Fig. 3. Cross section of the clastic laminated mudstone of the Miyajima Formation at Loc. 1403. Diatom frustules of opal-A are well-preserved (opal-A zone). Scale bar: 1 cm long.

Fig. 4. Thin section of the clastic laminated mudstone of the Miyajima Formation at Loc. 621. Diatom frustules of opal-A are well-preserved (opal-A zone). Opened nicol. Scale bar: 1 mm long.

Fig. 5. Cross section of the diatomaceous laminated mudstone of Miyajima Formation at Loc. 1000. Diatom frustules of opal-A are altered to opal-CT (opal-CT zone). Scale bar: 1 cm long.

Fig. 6. Thin section of the diatomaceous laminated mudstone of the Miyajima Formation at Loc. 1000 (opal-CT zone). Opened nicol. Scale bar: 1 mm long.

Fig. 7. Cross section of the clastic laminated mudstone of the Miyajima Formation at Loc. 404. Diatom frustules of opal-A are altered to opal-CT (opal-CT zone). Scale bar: 1 cm long.

Fig. 8. Thin section of the diatomaceous laminated mudstone of the Miyajima Formation at Loc. 404 (opal-CT zone). Opened nicol. Scale bar: 1 mm long.

**Plate 3.**

Fig. 1. SEM photograph in a white lamina of the diatom frustules of the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc.1201). Diatom frustules are well-preserved (opal-A zone). Scale bar: 10 $\mu$m long.

Fig. 2. SEM photograph of opal-CT lepispheres in the white lamina of the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1000). Diatom frustules of opal-A change to many lepispheres of opal-CT (opal-CT zone). Scale bar: 10 $\mu$m long.

Fig. 3. Cross section of a trunk fossil in the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1403; transmitted light). Diatom frustules are well-preserved (opal-A zone). The organic structure is well-preserved. Scale bar: 100 $\mu$m long.

Fig. 4. SEM (cross section) of a trunk fossil in the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1000, opal-CT zone). The organic matter and structures are altered. Scale bar: 10 $\mu$m long.

Fig. 5. A leaf fossil in the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1201, opal-A zone; transmitted light). Main vein, lateral veins and venation are preserved. Scale bar: 1 mm long.

Fig. 6. A fossil leaf of *Fagus crenata* (NSM-PP 11230) from the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1000, opal-CT zone). The organic matter is altered, while main vein, lateral veins and venation are preserved. Scale bar: 1 mm long.

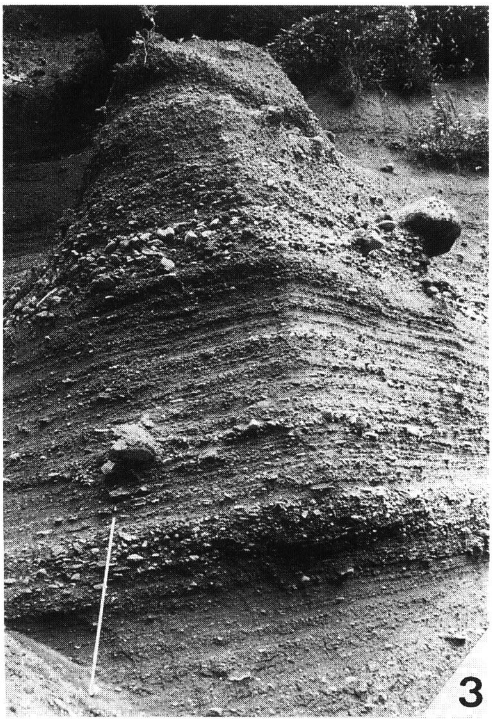
Fig. 7. A coalified leaf fossil at the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1201, opal-A zone). The fossil is cracked along the main vein, lateral veins and venation pattern. Scale bar: 5 mm long.

Fig. 8. A impressed leaf fossil from the diatomaceous laminated mudstone facies of the Miyajima Formation (Loc. 1201, opal-A zone). Leaf material has been dissolved. The main vein and the lateral veins are impressed. Scale bar: 5 mm long.


コノハ石
塩原化石
木の葉の化石は地中に埋蔵されていますか
ら表面から見えませんが　正面の山の石を掘
り出して割りますと植物の化石が出て参り
ます．化石となって出てくる植物は百数十種
に及び　いずれも此の地方に現在繁茂してい
るものです．年代は新生代第四紀洪積世のも
ので石質は堆積岩で数十万年を経たものと言
はれます．当時塩原は湖水だったのですが，
塩原火山の噴火等により火山灰が此の湖水に
積って出来たものです．学界ではここを「塩
原化石湖」と称しいろいろの研究資料として
います．木の葉の化石ばかりではなく蛙，魚
昆虫類もたまに発掘されますが，其の内珍
らしい化石は陳列館に展示されておりますか
ら，ごゆっくり御覧下さい．

1

2



3

**Plate 1**

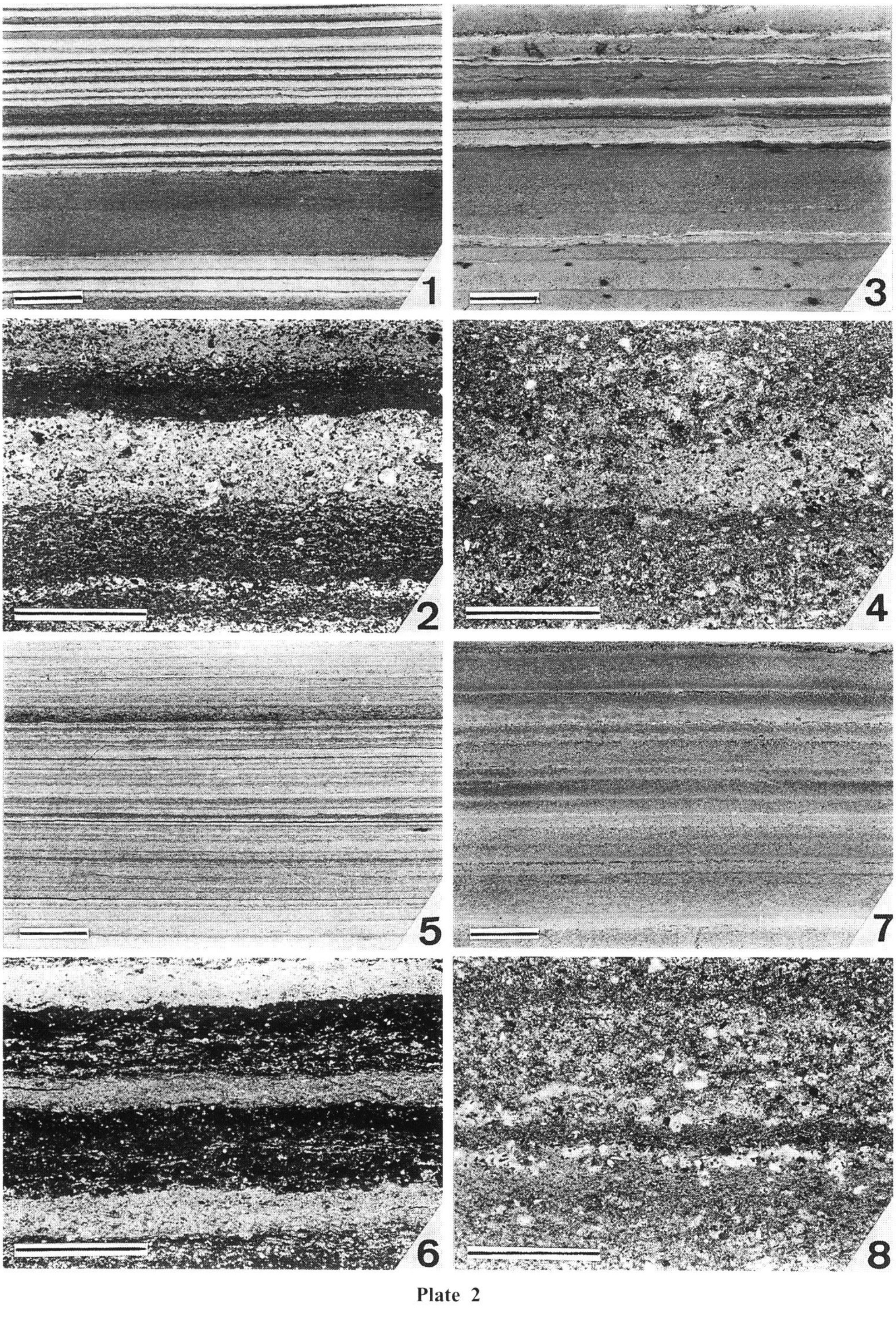


**Plate 2**

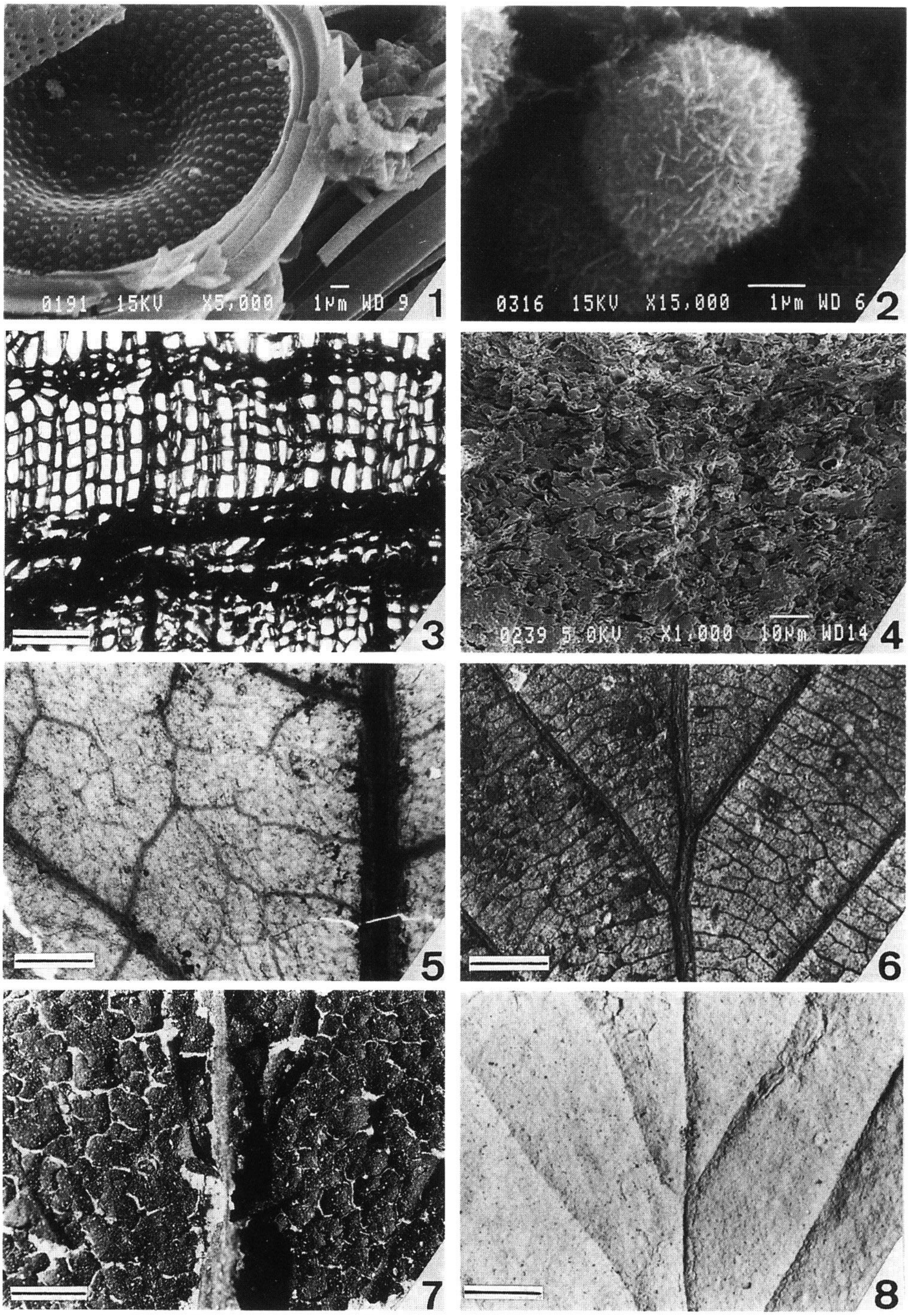

0191 15KV X5,000 1µm WD 9
1
0316 15KV X15,000 1µm WD 6
2
3
0239 5.0KV X1,000 10µm WD14
4
5
6
7
8

Plate 3