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静岡県掛川地域より産する鮮新－更新世軟体動物化石群集と水塊構造

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主論文

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Plio-Pleistocene molluscan assemblages and the water mass conditions in the Kakegawa area, Shizuoka Prefecture, central Japan

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Abstract. Ten types of molluscan assemblages are recognized in the muddy sand and silt facies of the Plio-Pleistocene in the Kakegawa area, central Japan. Both facies are continuously distributed throughout the Plio-Pleistocene sequence. The depositional environments of the assemblages range from upper sublittoral to bathyal depths. First, the horizontal distributions of the assemblages are examined along several tuff layers and the sedimentary prossesses of the Kakegawa Group are discussed. Secondly, the relationship between the horizontal distributions of molluscan assemblages and nature of water masses (temperature, dissolved oxygen, and trophic conditions) are discussed. The water mass structure in the "paleo-sea of Enshu" was similar to that in the present Kuroshio Current region. A successive changes in molluscan assemblages from the upper sublittoral, coastal water to bathyal, cold intermediate water is typically recognized along the tuff layers. Finally, the temporal distributions of species characteristic of each bathymetric zone are examined. Groups of warm-water species in the upper sublittoral zone disappeared in steps in the early Pleistocene. By contrast, warm-water species in the lower sublittoral zone and Japonic endemic species in all depths occurred throughout the interval of the Plio-Pleistocene. The

cooling effect was restricted to the upper sublittoral zone under the influence of the coastal water. This result is confirmed by comparisons of temporal distributions between taxonomically close species having similar ecological characters such as life habits and feeding-types. The difference in the faunal change between depths reflects fluctuation of the marine thermal structure of the sea off central Japan during Plio-Pleistocene time.

Introduction

The Plio-Pleistocene Kakegawa Group is exposed in the western part of Shizuoka Prefecture, central Japan (Fig.1A). It is one of the standard sequences of the Pliocene to the lowest Pleistocene stratigraphy in Japan. The Kakegawa Group yields abundant marine molluscan fossils. Habitats of the molluscs are various from intertidal to bathyal in an open sea condition. Many paleontological studies have been made since the descriptive works of the molluscan faunas by Yokoyama (1923, 1926) and Makiyama (1927). The molluscan fauna is called "the Kakegawa fauna" (Otuka, 1939) and is well known in Japan as the Pliocene to earliest Pleistocene warm-water fauna of southwestern Japan. The Kakegawa fauna is characterised by warm-water extinct species, such as Amussiopecten praesignis, Venericardia panda, Chlamys satoi, Turritella perterebra and so on. They are abundant in marginal nearshore facies, the Dainichi Formation.

The temporal change of the Kakegawa fauna was outlined by Tsuchi (1961). He showed a stratigraphic range chart of representative species and divided the Kakegawa Group into four stages, the Totomian, Suchian, Kechienjian and Yuzanjian, in ascending order. Many warm-water species are abundant in the Suchian stage. Some of these species declined during the Kechienjian stage and most of them disappeared during the Yuzanjian stage. Moreover, some Japonic endemic genera such as *Suchium* and *Siphonalia* show morphological changes at the subspecific or specific level through the stages (Makiyama, 1925, 1941). Tsuchi (1990) suggested that these faunal changes are related to cooling of the sea water in earliest Pleistocene age. These cooling events were recognized also as temporal changes in the planktonic foraminiferal assemblage of the Kakegawa Group (Ibaraki, 1986b).

In the stratigraphic range chart of molluscan species (Tsuchi, 1961), almost all of the species show their temporal distributions restricted to particular stages. Therefore, it is not clear which species occurred throughout the stages. Moreover, most of the key species for the recognition of the stages occur mainly in shallow, marginal facies such as the Dainichi Formation.

With respect to the deep offshore molluscan fauna, Chinzei (1980) described molluscan associations characteristic of lower sublittoral to upper bathyal depths along an isochronous tuff layer in rocks ascribed to the Kechienjian stage. Paleoecological analyses of the deep offshore fauna, however, have not yet made throughout the whole sequence of the Kakegawa Group, and the temporal change in the deep molluscan fauna has not been studied. Therefore, the earliest Pleistocene cooling effect on marine organisms in lower sublittoral and upper bathyal depths has not been examined previously.

For discussion on the temporal change in the molluscan faunas in each bathymetric depth, it is needed to take into account the water mass conditions. Chinzei and Aoshima (1976) and Aoshima

(1978) showed the Plio-Pleistocene water mass structure in the Kakegawa area based on oxygen isotopic paleotemperature and distributions of foraminiferal assemblages. However, relationship between molluscan assemblages and water mass structures are not clear except for the horizons investigated by Chinzei (1980).

In this paper, I treat fossil molluscan assemblages in the muddy sand to silt beds. These lithofacies are distributed continuously throuth the three stages, namely, the Suchian, Kechienjian, and Yuzanjian stages. First, I examine horizontal distribution of fossil molluscan assemblages along several isochronous tuff layers and discuss sedimentary processes of the upper part of the Kakegawa Group. Secondly, I discuss the relationship between the species composition of each molluscan assemblage and nature of water masses (water temperature, concentration of dissolved oxygen, and trophic conditions). Finally, I compare assemblages of different ages that were deposited at similar depths and with similar bottom characters in order to make clear the relationship between bathymetric depth and the cooling effect on marine organisms. In this paper is shown the temporal change of water mass structure near the Pacific coast of central Japan during the late Pliocene to earliest Pleistocene period.

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Geological setting

The Plio-Pleistocene Kakegawa Group unconformably overlies pre-Middle Miocene basement rocks in the north area and conformably overlies the Middle Miocene to Early Pliocene Sagara Group in the south area (Masuda and Ishibashi, 1991). The Kakegawa Group is overlain in turn by the Pleistocene Ogasa Group. The Kakegawa Group is recognized as a typical basin fill sequence bounded by the sequence boundaries of the unconformities and related conformities mentioned above (Ishibashi, 1989; Masuda and Ishibashi, 1991). According to Ishibashi (1989), its sedimentary environment resembles the present western coast of Suruga Bay, where the Philippine Sea Plate is being subducted under the Eurasian Plate.

Molluscan fossils are abundant in the upper part of the Kakegawa Group. The upper part is ascribed to the Suchian to Yuzanjian stages. The chlonological sequence of the Kakegawa Group has been established on the basis of various data of planktonic foraminiferal biostratigraphy (Saito, 1960; Ibaraki, 1986a,b, and other works), magnetostratigraphy (Yoshida and Niitsuma, 1976), and fission track dating (Nishimura, 1977), compiled in Fig.2. The lithofacies of the upper part of the Kakegawa Group changes laterally and vertically (Figs.1B, 2) and it can be divided into five formations in my investigation area. With respect to the lateral change in the lithofacies, a northwestern shallow-sea facies grades into a southeastern deep-sea facies. The northwestern part consists of the Dainichi Formation (fine to medium-grained sand), the Ukari Formation (fine sand and muddy sand), and the Soga Formation (gravels, fine to medium-grained sand and muddy sand), in ascending order. The fine sand facies of the Ukari Formation is covered by the basal conglomerate facies of the Soga Formation with disconformity. The southeastern part consists of the Horinouchi Formation (alternating beds of sand and silt of turbidite facies), and the Hijikata Formation (massive silt), in ascending order. The vertical change in the lithofacies possibly results from a global eustatic sea-level change during the Plio-Pleistocene (Masuda and Ishibashi, 1991). The middle part of the Ukari Formation is at the climax of the transgression, and the Soga Formation was deposited during the regressive period.

Several tuff layers have been traced through the different lithofacies as key horizons in the Kakegawa Group. Of these, the Hosoya Tuff, the T3 Tuff, and the Soga Tuff are important key beds in the upper part of the Kakegawa Group in ascending order.

The Hosoya Tuff (Tsuchi, 1961) is interbedded in the lower part of the Ukari Formation and the uppermost part of the Horinouchi Formation. An age of 1.9 F.T.Ma was dated for the tuff bed (Nishimura, 1977), and its microbiostratigraphic and magnetostratigraphic position is near the base datum of Globorotalia truncatulinoides and the base of the Olduvai event (Ibaraki, 1986b). Tsuchi (1976) set the boundary between the Suchian and Kechienjian stages at the base of the Hosoya Tuff.

The T3 Tuff (Chinzei and Aoshima, 1976) is interbedded in the middle part of the Ukari Formation and the upper part of the Hijikata Formation. The trace of this tuff layer, however, is different between many studies on the geology of the Kakegawa area because of the limited outcrop conditions. For example, Ibaraki (1986a) recognized the T3 Tuff in the southeastern area as the Kogosho Tuff, which is regarded as a distinct tuff layer from the T3 Tuff in the northwestern area. More detail and subdivisional data of biostratigraphy are called for the strict trace of the tuff layer. But it is beyond the scope of this paper. In this study, I mainly adopt the trace of the T3 Tuff of Chinzei and Aoshima (1976) in order to compare the horizontal distribution of molluscan assemblages along the T3 Tuff shown by Chinzei (1980) with the results along other tuff layers.

The Soga Tuff (Tsuchi, 1961) is intercalated in the middle part of the Soga Formation and the uppermost part of the Hijikata Formation. The deposits of the Yuzanjian stage are the Soga Formation and the correlative uppermost part of the Hijikata Formation. Ibaraki and Tsuchi (1979) set the boundary between the Kechienjian and Yuzanjian stages at the horizon between the Soga Tuff and the T3 Tuff (the Kogosho Tuff) for convenience. According to Ibaraki's (1986b) planktonic foraminiferal biostratigraphy, Datum 23 (the second coiling-direction change in *Pulleniatina* spp. from sinistral to dextral) is clearly placed near the boundary between the Kechienjian and Yuzanjian stages. Ibaraki (1986b) estimated the age of the datum at 1.6 Ma on the basis of correlation to the magnetostratigraphical time scale.

In addition, the tracing of the Soga Tuff in the southeastern area, Tagaya, shown by Nobuhara (1990) is revised in comparison with the tracing of Datum 23. That is, the tuff layer at ST19 in Nobuhara (1990) (at KM8 in this paper) is revised to be the T3 Tuff from the Soga Tuff.

Muddy sand to silt facies are recognized in every stages through the Suchian to Yuzanjian, as shown in Fig.2. My investigation stresses on the molluscan fossil assemblages of these facies, i.e. of the Ukari, Hijikata, and Soga Formations. They yield abundant molluscs that live today in upper sublittoral to bathyal depths. In contrast with these formations, the silt beds of the turbidite Horinouchi Formation yield rare molluscan fossils, but I collected specimens from some localities in the uppermost part of the Horinouchi Formation.

In addition, I obtained abundant molluscan fossils from the uppermost part of the Early Pliocene Tamari Formation. The Tamari Formation is a massive silt facies as an inlier largely surrounded by the alternation facies of the Horinouchi Formation. The biostratigraphic interval of the Tamari Formation corresponds to horizons from the middle of the Sagara Group to the lowest part of the Kakegawa Group, shown by the planktonic foraminiferal biostratigraphy of Ibaraki and Tsuchi (1979) and Ibaraki (1986b). With respect to the localities in the Tamari Formation in this survey, their stratigraphic positions are between Datum 11 (3.7 Ma) and Datum 18 (3.0 Ma) of Ibaraki's (1986b) planktonic foraminiferal biostratigraphy and are in the Totomian stage of Tsuchi's (1961) division based on the molluscan faunal change.

The assemblage of the localities of the Tamari Formation is considered to be the same type of the "Calyptogena" assemblage reported from the Hijikata Formation by Majima et al. (1990). The observation of its mode of occurrence in the Tamari Formation is important to discuss its paleoecology because the localities of the Hijikata Formation are now covered artificially and the mode of occurrences cannot be observed. Therefore, the materials of the Tamari Formation also are taken into consideration in this study.

Description of molluscan assemblages

I obtained 134 molluscan species in 85 genera from 124 localities (Figs.1, 2). They are listed in appendix tables 1-4. Before describing fossil molluscan assemblages, a few remarks should be made concerning modes of fossil occurrence. Kidwell et al. (1986) defined the following terms on fossil occurrences: autochthonous assemblage (composed of specimens derived from the local community and preserved in life position); parautochthonous assemblage (composed of autochthonous specimens that have been reworked to some degree but not transported out of the original life habitat); allochthonous assemblage (composed of specimens transported out of their life habitats and occurring in a foreign substratum). In the open sea such as the "paleo-sea of Enshu", shells can be easily reworked and transported, in particular in upper sublittoral depths under the influence of storms. Consequently, some assemblages may be composed of specimens of different origins. According to Kidwell et al. (1986), they are referred to as mixed autochthonous - parautochthonous, parautochthonous - allochthonous, or autochthonous - allochthonous. It is difficult, however, to recognize autochthonous specimens because most of the species identified in this study are shallow-burrowers or epifauna which are easily reworked. Moreover, if an assemblage contains several species in the same matrix sediment and their habitat depths are distinct each other, it is difficult to decide whether the assemblage is an actual ecotone between the different depths or a mixed one containing shells transported from different depths.

Therefore, I classify modes of occurrence into three types, namely "A-type", "A′-type", and "B-type", for convenience. In the A-type occurrence, shells are randomly distributed in the matrix sediment. Shell clusters are also often found but the shells in the clusters are supported by the sediment which are nearly the same with that around the clusters. The A′-type is a shell bed, in which the matrix sediment supporting shells are nearly the same with that above and below the shell bed. The species composition of the assemblages in the A- and A′-type occurrences are compatible with the sedimentary facies. Most of shells are likely to be parautochthonous, although some might have been transported from different depths. The B-type is shell concentrations in beds, lenses, and clusters but, in contrast with the A- and A′-types, the sediment in them is clearly discriminated from the matrix sediment around them. Moreover, the species composition of the shells is incompatible with the sedimentary facies around them. The assemblages are clearly recognized to be allochthonous.

I classify fossil molluscan assemblages in the A- and A′-type occurrences into ten types on the basis of the occurrence of some dominant species and/or characteristic species (Fig.3). The depositional environments of the assemblages range from an upper sublittoral sandy bottom to a bathyal muddy bottom. Paleobathymetric interpretation is made mainly based on the habitat depths of living species shown by Habe (1977) and Higo (1973). Moreover, the depositional environments of the assemblages are cross-checked by Ishibashi's (1989) study on sedimentary facies in the Kakegawa area, because there is close relationship between the assemblages and the lithofacies. The stratigraphic distributions of the assemblages are shown in Fig.4.

1. Amussiopecten praesignis - Scapharca castellata assemblage (A-type occurrence) (Loc. U9-14A)

This assemblage is found in a slightly muddy, fine sand bed, about 2.5 m thick, at U9-14A. This sand bed is intercalated in muddy sand of the lowermost part of the Ukari Formation. This assemblage is characterized by abundant shells of Amussiopecten praesignis (Yokoyama) and Scapharca castellata (Yokoyama) associated with many other species of shallow sea. Disarticulated shells of A.

praesignis are distributed with their commissure planes parallel to the bedding but the shells do not form a cluster or bed. In contrast, S. castellata are crowded together in large shell clusters, over 10 cm thick and about 50 cm long. The shells of Scapharca are well-preserved and disarticulated or articulated. Some articulated shells are open. Many shells of Crenulilimopsis oblonga (A. Adams) are also found, both in the shell clusters and in the fine sand matrix. Representative associated species are Turritella perterebra Yokoyama, Mizuhopecten tokyoensis hokurikuensis (Masuda), Chlamys satoi (Yokoyama), and Venericardia panda (Yokoyama). They occur also in the clusters and/or in matrix sand.

Except for Crenulilimopsis oblonga, most of the component species live in the upper sublittoral zone and/or are commonly found in shell beds in the Dainichi Formation which corresponds to nearshore facies of Ishibashi (1989). The lithofacies of this bed is slightly muddy and seems to be transitional between nearshore fine sand facies of the Dainichi Formations and offshore massive muddy sand facies of the Ukari Formation. These facts indicate that this assemblage was formed in upper sublittoral depths, mixed with reworked shells such as Scapharca castellata.

2. Paphia schnelliana - Clementia papyracea - Glycymeris rotunda assemblage (A-type occurrence) (representative localities: U10-9B, U12-9, ST8).

This assemblage occurs in muddy sand facies in the lower part of the Ukari Formation and in the Soga Formation. This assemblage is characterized by common articulated shells of Paphia schnelliana (Dunker) and Clementia papyracea Gray. In particular, C. papyracea which lives today in depth of 0-20m (Habe, 1977) frequently shows vertical, posterior-up shell position. *Glycymeris rotunda* (Dunker) also occurs abundantly, with its shells articulated at some localities (U12-9, U10-9B). These species are associated with many species living today only in upper sublittoral depths, and with species found commonly in the shallow-water Dainichi Formation; for example, *Glycymeris albolineata* (Lischke), *Amussiopecten praesignis* (Yokoyama), *Venericardia panda* (Yokoyama), and *Dosinia troscheli* Lischke. These shells are well-preserved and are randomly distributed together with the dominant species. Species living in lower sublittoral depths, such as *Nemocardium samarangae* (Makiyama), also occur at ST8 but only a few specimens have been found.

The species composition and the autochthonous occurrence of *C. papyracea* suggest that this assemblage lived in upper sublittoral depths, or in depths transitional between the upper and lower sublittoral zones.

3. *Crenulilimopsis oblonga* - *Glycymeris rotunda* assemblage (A-type occurrence) (representative localities: U8-13B, U9-14B, U13-1, U14-2A, ST10)

This assemblage occurs in muddy sand facies in the lower part of the Ukari Formation and in the Soga Formation. This assemblage is characterized by the dominant occurrences of *Glycymeris rotunda* (Dunker) and *Crenulilimopsis oblonga* (A. Adams). *Crenulilimopsis oblonga* is rare or absent in the *Paphia schnelliana* - *Clementia papyracea* - *Glycymeris rotunda* assemblage described above. Many articulated and disarticulated shells of the two species are randomly distributed and also form many loose clusters, up to about 15 cm in diameter. This assemblage also includes many species living only in upper sublittoral depths, or those found in the shallow-water Dainichi Formation, just as the *Paphia* - *Clementia* - *Glycymeris* assemblage does. Representative species are *Amussiopecten praesignis* (Yokoyama), *Suchium* species, *Babylonia elata* (Yokoyama), *Turritella perterebra* Yokoyama, *Scapharca* species, *Glycymeris albolineata* (Lischke), *Clementia papyracea* Gray, and *Dosinia troscheli* Lischke. At some localities, some of these shalow species occur commonly enough to be considered subdominant species; for example, *Amussiopecten praesignis* at U8-13B, U13-1, *Suchium suchiense suchiense* (Yokoyama) and *Babylonia elata* at U13-1, and *Suchium suchiense subsuchiense* (Makiyama) at ST10. Except for *Glycymeris rotunda* and *Crenulilimopsis oblonga*, species living in the lower sublittoral zone occur in small numbers in this assemblage: for example, *Cryptopecten vesiculosus* (Dunker) at U13-1 and U14-2A. The shells of associated species are well-preserved and randomly distributed as those of the dominant ones.

The species composition suggests that this assemblage was buried in upper sublittoral depths or in depths transitional between the upper and lower sublittoral zones.

4. *Glycymeris rotunda* - *Ventricolaria foveolata* assemblage (A- and A'-type occurrences)(representative localities: 4I-type; U1-1, U1-2, U1-3. 4II-type; U2-8, U2-10, U6-15A)

This assemblage occurs at many localities in the muddy sand of the Ukari Formation. The offshore facies shown by Ishibashi (1989) is exposed at the localities. Abundant shells of both upper and lower sublittoral elements are randomly distributed with many fist-sized clusters (the A-type occurrence). They often form matrix-supported shell beds up to about 15 cm thick (the A'-type occurrence). This assemblage is characterized by the dominance of Glycymeris rotunda (Dunker) and Ventricolaria foveolata (Sowerby). Commonly associated species are Paphia schnelliana (Dunker), Crassatellites takanabensis Shuto, Nassarius siquijorensis (A. Adams), Cryptopecten vesiculosus (Dunker), Cycladicama cumingii (Hanley), and Nemocardium samarangae (Makiyama). Compared with the three assemblages described above, shells of lower sublittoral species are common in this assemblage. The shells of the dominant species, Glycymeris rotunda and Ventricolaria foveolata, are well-preserved and many articulated specimens are found. The two species are representatives of the lower shelf fauna burrowing in mud at present, at depths greater than 40 m in Sagami Bay (Horikoshi, 1957).

This assemblage is divided into two types. The first type, designated the "4I-type assemblage", includes many species living in upper sublittoral depths as well as those living in lower sublittoral depths. For example, Amussiopecten praesignis (Yokoyama), Clementia papyracea Gray, and Solecurtus divaricatus (Lischke) occurs at U1-1, U1-2 and U1-3. By contrast, the second type, designated the "4II-type assemblage" is associated with species living in shelf-edge depths, such as Yoldia similis Kuroda et Habe at U2-8 and U2-10. At some localities (U2-4, U2-5), however, shells transported from the upper sublittoral depths are mixed into a 4II-type assemblage, and the species composition is transitional between the two types. With respect to the distributions of the two types in the Ukari Formation, the 4I-type assemblage occurs in the uppermost part (earliest regressive phase) whereas the 4II-type assemblage occurs in the middle part (climax of the transgressive phase).

This assemblage corresponds to the *Glycymeris rotunda* - *Venus foveolata* Association of Chinzei (1980) and may correspond to the assemblage which was reported from a muddy bottom in the lower shelf in Sagami Bay by Horikoshi (1957). Chinzei (1980) stated that this association is characteristic of lower sublittoral depths. Moreover, he stated that the association in the most western part of the distribution area (the 4I-type assemblage) is estimated to be a biofacies transitional from the shallower-water assemblage of the Dainichi Formation. It is estimated here that some 4I-type assemblages are parautochthonous assemblages of an ecotone between the upper and lower sublittoral zones. Others, however, probably lived in lower sublittoral depths and include some shallower-water shells transported from upper sublittoral depths.

5. *Nassaria magnifica* assemblage (A-type occurrence) (representative localities: U6-1, U6-11, ST13, MKCW6)

This assemblage occurs in the coarse silt facies of the Hijikata Formation. Well preserved shells of gastropods are disseminated sporadically in the massive silt with random orientation. Many gastropod shells have protoconchs. This assemblage is characterized by gastropod shells markedly exceeding bivalve shells in numbers of both species and individuals.

Nassaria magnifica (Lischke) is dominant, associated with some other gastropods, such as *Parabathytoma luehdorfi* (Lischke), *Makiyamaia coreanica* (Adams et Reeve), *Bathybembix argenteonitens* (Lischke), *Fulgoraria* species, and by many minute unidentified gastropods. Several bivalve species characteristic of deep sea facies, such as *Limopsis tajimae* Sowerby and *Yoldia similis* Kuroda et Habe, also are associated with this assemblage. This assemblage has similar composition of the *Nassaria magnifica* Association of Chinzei (1980).

Dominant species, *Nassaria magnifica*, lives now in depths of 30-200m and some associated gastropods such as *Parabathytoma luehdorfi* also have similar habitat depths (Higo, 1973). This assemblage, however, contains many shelf-edge to bathyal elements such as *Makiyamaia coreanica* and *Limopsis tajimae* in the same matrix silt sediment. Moreover, the localities of this assemblage are distributed in the sedimentary facies of slope and basin plain shown by Ishibashi (1989). Well-preservation of the shells and their random orientation in the matrix sediment indicate that these species are not transported and mixed so far from distinct environments. Therefore, it is reasonable to consider that this assemblage lived in shelf-edge to uppermost bathyal depths.

6. *Limopsis tajimae* assemblage (A-type occurrence) (representative localities: U6-8, U8-3, U11-2, MKCW7)

This assemblage occurs at many localities in silt facies through the Suchian to Yuzanjian stages. It is dominated by *Limopsis tajimae* Sowerby. Abundant individuals of *L. tajimae* are disseminated in silt, with random shell orientation. The shells are well-preserved and many articulated specimens can be found. The assemblage contains some gastropods, such as *Bathybembix argenteonitens* (Lischke), *Makiyamaia coreanica* (Adams et Reeve) and *Fulgoraria mentiens* (Fulton), and also some nuculoid shells, such as *Neilonella coix* Habe. This assemblage corresponds to the *Limopsis tajimae* Association of Chinzei (1980).

Most of the component species extend their habitat depths to the bathyal zone. The sedimentary facies at the localities are those of slope and basin plain shown by Ishibashi (1989), although some gastropods such as *Nassaria magnifica* which live in depths shallower than 200m are included at some localities. Kondo (1989) reported dense population of *Limopsis tajimae* at depths of about 280m in Suruga Bay. Therefore, this assemblage is likely to have lived in upper bathyal depths.

7. nuculoids-dominant assemblage (A-type occurrence) (representative localities: U9-3, U12-5, ST12, ST17, HY1)

This assemblage is characterized by dominant nuculoid bivalves. The shells are scattered sporadically in the massive fine silt of the Hijikata Formation. They are generally well-preserved and many are still articulated. This assemblage has various dominant species at various localities; for example, *Acila* aff. *divaricata* (Hinds) at U12-5, *Ennucula niponica* (Smith) at ST12, *Neilonella coix* Habe at U9-3, and *Neilonella coix* and *N. japonica* Okutani at HY1. Except for ST12, other nuculoids such as *Carinineilo carinifera* (Habe), *Bathymalletia inaequilateralis* Habe, and *Nuculana* spp. commonly occur in association with the nuculoid species mentioned above. At ST12, several sublittoral elements, such as *Paphia schnelliana* and *Glycymeris rotunda*, are rarely found together with deep sea elements such as *Periploma plane* Ozaki and *Nipponoscaphander cumingii* (A. Adams). The constituents of the *Nassaria magnifica* and the *Limopsis tajimae* assemblages (the shelf-edge to upper bathyal assemblages) are also included in this assemblage. For example, several specimens of *Limopsis tajimae* Sowerby are found at some localities such as U9-3. At U12-5 and HY1, this assemblage also contains some gastropod species, such as *Parabathytoma luehdorfi* (Lischke), *Euspira plicispira* (Kuroda), *Makiyamaia coreanica* (Adams et Reeve), Bathybembix argenteonitens cf. hirasei (Taki et Otuka), and Baryspira suavis (Yokoyama). Several unidentified small gastropods are also found at every locality.

Most of the component species live in lower sublittoral to bathyal depths, according to the present data of Habe (1977) and Higo (1973). Hickman (1984), however, suggested that dominance of protobranch bivalve is a characteristics of deep-sea communities. Moreover, this assemblage occur in the sedimentary facies of slope and basin plain shown by Ishibashi (1989). Well-preservation of the shells and their random orientation suggest that they are autochthonous to parautochthonous. These facts indicate that this assemblage lived at bathyal depths.

8. Akebiconcha kawamurai assemblage (A′-type occurrence)
(localities: NK101A,B,C, NK102FC, and NK103)

This assemblage was recognized in the uppermost part of the Tamari Formation (Nobuhara and Tanaka, in press). The assemblage occurs in several shell beds, scattered through the massive silt (A′-type occurrence). The silt between shell beds yields sporadic shells of another molluscan assemblage, the "Empleconia" sp. A - Neilonella coix assemblage described next (Fig.5).

This assemblage is characterized by the dominant ocurrence of Akebiconcha kawamurai Kuroda. Lucinoma aff. acutilineata (Conrad) and Conchocele bisecta (Conrad) are commonly associated. Solemya johnsoni Dall frequently occurs. Sublittoral elements, such as Glycymeris rotunda (Dunker), and some constituents of the "Empleconia" sp. A - Neilonella coix assemblage occur rarely.

Large shells are closely spaced and supported by the matrix of fine silt. Most of the shells lie horizontally with their commissure planes parallel to the bedding. However, within one bedding plane, a dominant orientation of shells is not recognizable. Few individuals preserve their life position, although *Lucinoma* and *Conchocele* are known to be deep-burrowers and might be expected not to have been disturbed from their life position. Most of the shells are disarticulated, but I also observed silt blocks containing many articulated shells. Moreover, I found an open *Akebiconcha* shell, with the valves still connected with the ligament. The shells were poorly sorted; the shell length of *Akebiconcha* ranges from ca. 1cm to over 10cm.

The fossil occurrence described above suggests that the shells underwent excavations from their life position and some transportation, but that the transportation was not so far from their original habitat. This parautochthonous occurrence of large shells with high density suggests that *Akebiconcha kawamurai* formed a large-biomass colony with *Lucinoma* aff. *acutilineata*, *Conchocele bisecta*, and *Solemya johnsoni*.

Recent specimens of *Akebiconcha kawamurai* have been reported from about 200-460m deep near the Pacific coast of central Japan (Kuroda, 1943; Shikama, 1962; Tsuchida, 1986). The depth data are concordant with the results of the sedimentary facies analysis by Ishibashi (1989). In his figure 13, the Tamari Formation corresponds to the slope facies. Except for *A. kawamurai*, this assemblage is very similar to the *Thyasira*-*Lucinoma*-*Solemya* Community of Hickman (1984) in generic composition and the *Thyasira* Association Group of Matsui (1990) in species composition. The *Thyasira*-*Lucinoma*-*Solemya* Community is one of the Cenozoic deep-water faunas (Hickman, 1984). The *Thyasira* Association Group might be restricted to a reducing environment (Matsui, 1990). Therefore, this A. kawamurai assemblage is characteristic to a reducing environment in bathyal depths.

In addition, "Calyptogena" shells were found in the lower part of the Hijikata Formation (Majima et al., 1990; personal communication from Drs. Yasuo Kondo (Kochi University), Hiroshi Kitazato (Shizuoka University) and Mr. Tsumoru Tanabe (Fukuroi City)). Calyptogena species are taxonomically very close to Akebiconcha kawamurai (e.g., Okutani, 1966). Unfortunately, the localities in the Hijikata Formation are covered artificially. According to the personal communication from Dr. Yasuo Kondo, abundant "Calyptogena" shells occurred gregariously in the massive silt. Majima et al. (1990) reported that shells of "Calyptogena" were enclosed by massive fine silt and that they are not considered to have been transported from another place. Majima et al.(1990) postponed the correct identification of the relatively small shells because "Calyptogena" species can change their shell characters along the growth. Shells of various growth stages are needed for correct identification. I compare the figures of Majima's et al (1990) materials with the shells from the Tamari Formation. The shells of Majima et al (1990) are very similar to the young shells of Akebiconcha kawamurai in hinge characters and shape of subumbonal pit. I consider that the "Calyptogena" shells of the Hijikata Formation are Akebiconcha kawamurai as is the shells from the Tamari Formation because of the resemblance of the shell characters and its occurrence from massive silt.

9. "Empleconia" sp. A - Neilonella coix assemblage (A-type occurrence) (localities: NK100U, NK101A-B, NK102)

This assemblage has been recognized only in the Tamari Formation. It occurs in the massive silt between the shell beds of the *Akebiconcha* assemblage described above (Fig.5).

This assemblage is characterized by common occurrences of "*Empleconia*" sp. A, *Neilonella coix* Habe, and *Bathybembix aeola* (Watson). They are associated with *Acila* sp., *Bathymalletsia inaequilateralis* (Habe), and *Neptunea constricta* (Dall). The shells are sporadically scattered in the massive silt and also form small shell clusters. Many closed or open but still articulated specimens of bivalves are found. Gastropod shells commonly preserve their protoconchs. The mode of occurrence is parautochthonous.

The protobranch shells are as abundant as shells of "*Empleconia*" sp. A. This features suggests that this assemblage is deep-sea fauna, as is the case with the 7-type (nuculoids-dominant) assemblage mentioned above. It is supported by the Ishibashi's (1989) sedimentary facies analysis that the facies of the Tamari Formation is slope. Therefore, this assemblage lived on the bathyal muddy bottom. Moreover, the habitat depth of this assemblage is considered to have been deeper than those of the 5-type, *Nassaria magnifica* assemblage and the 6-type, *Limopsis tajimae* assemblage on the basis of the following two facts. 1) The mode of occurrence of *Limopsis tajimae* and *Bathybembix argenteonitens* are allochthonous in this assemblage, whereas they are commonly found in a parautochthonous occurrence in the Hijikata Formation. In the 9-type assemblage in the Tamari Formation, the two species occur in a thin sand layer intercalated in massive silt or occur rarely as fragments in the matrix silt sediments. The shell surfaces are abraded. The massive silt yields abundant shells of another close species, "*Empleconia*" sp. A and *Bathybembix aeola*, with parautochthonous occurrences. 2) The present data show that the habitat depth of *B. aeola* is generally deeper than that of *B. argenteonitens* (e.g., Okutani et al., 1988).

In addition, the constituents of this "*Empleconia*" - *Neilonella* assemblage prefer ordinary oxic bottom environments as the other assemblages from the 1- to 7-type, whereas the 8-type, *Akebiconcha* assemblage, noted above, prefers reducing bottom environments.

10. *Limopsis* cf. *uwadokoi* assemblage (A-type occurrence) (representative localities; TG5, S-N4′, KM14, S-N7, KM14, KM8)

This assemblage occurs in the uppermost part of the Horinouchi Formation and in the lowermost part of the Hijikata Formation in the southeasternmost of the investigation area. In Ishibashi's (1989) figure 13, the sedimentary facies of these localities corresponds to a slope facies. Shells of *Limopsis* cf. *uwadokoi* Oyama are sporadically scattered in the massive silt layer. The density of shells is mich lower than that of the *Limopsis tajimae* assemblage. *Bathybembix aeola* (Watson), minute unidentified gastropods and *Acila* aff. *divaricata* (Hinds) are rarely associated. Shells of *Limopsis* are well-preserved and some are articulated.

At KM14 and KM8, all of *Limopsis* shells are very small, less than 1cm long. The assemblage at KM8 was reported as *Limopsis tajimae* assemblage in Nobuhara (1990). After the publish, large adult shells were obtained around the localities and are identified with *L.* cf. *uwadokoi*, which is distinguished from *L. tajimae* in having coarse radial striae. Comparison between the large and small specimens suggests that the small shells at KM14 and KM8 are also *L.* cf. *uwadokoi*.

The well-preservation of the shells and their random orientations suggest that the shells are autochthonous to parautochthonous ones. Limopsis uwadokoi lives now in the depths of 160-200m in northeastern Japan (Kira, 1959), but this Limopsis assemblage contains some bathyal species such as Bathybembix aeola. Moreover, the sedimentary facies shown by Ishibashi (1989) suggested that the depositional environments of the localities were slope. The parautochthonous occurrence of the bathyal species and the sedimentary facies suggest that this assemblage lived in a muddy bottom in bathyal zone. Moreover, the occurrence of Bathybembix aeola suggests that the living depth of this assemblage is deeper than that of the Limopsis tajimae assemblage which commonly associated with Bathybembix argenteonitens.

All the assemblages described above are plotted on the columnar sections (Figs.6,7) and on schematic stratigraphic cross section (Fig.4). Their distribution is nearly concordant with the change in lithofacies demonstrating the transgressive-regressive cycle described by Ishibashi (1989). In Ishibashi's (1989) figure 13, the Ukari, Hijikata, and Soga Formations correspond to the offshore, slope and basin plain, and submarine channel facies, respectively. However, Aoshima (1978) suggested that foraminiferal assemblages in nearshore conditions are found in the basal and uppermost parts of the Ukari Formation and in the Soga Formation. The distribution of the foraminiferal assemblages nearly corresponds to those of the molluscan assemblages of 1-, 2-, 3-, and 4I-types in Fig.4. These assemblages contain many species living in upper sublittoral depths. Therefore, this cross section (Fig.4) shows the horizontal change in molluscan assemblages along the nearshore - offshore transects from the upper sublittoral to bathyal depths in the respective stages.

Horizontal distribution of fossil molluscan assemblages

In this chapter, I examine horizontal distribution of fossil molluscan assemblages along three key tuff layers and the depositional environments are discussed. In these horizontal traces, the localities are not isochronous in a strict sense. Most of the localities along the key tuff layers are 0 to 5m below the tuff layer or in the tuff layer. Outcrops of the tuff layers, however, are not found in some areas today. Therefore, some localities are judged to be close to the horizon of the tuff layer, from the geological maps of the preceding studies (Makiyama, 1963; Tsuchi, 1976; Chinzei and Aoshima, 1976; Ibaraki, 1986a,b).

1) horizon along the Hosoya Tuff

Along the Hosoya Tuff, the following assemblages occur from northwest to southeast: the 4-, 6-, 7-, 8-, and 10-type assemblages (Figs.4, 6, 8A).

In Ukari, the northwesternmost of the investigation area, the Hosoya Tuff is intercalated in the fine sand to muddy sand facies of the Ukari Formation. In the pumiceous muddy sand bed at U1-10 close to the base of the Hosoya Tuff, some poorly preserved casts of *Glycymeris rotunda* and *Paphia schnelliana* occur. This suggests that sublittoral environments extended in this area.

In Hosoya, the southeast of Ukari, the lithofacies just below the Hosoya Tuff changes southeastward from muddy sand to fine silt. The type of molluscan assemblage changes southeastward in concordant with the change in lithofacies as follows: the 4II-type assemblage (muddy sand bed 3-5m below the base of the tuff at U6-15A); a mixed assemblage of the 4- and 6-types (in a thin shell lens with muddy sand matrix sediments 1.5m below the tuff base at U8-9); the 6-type assemblage (silt about 0.5m below the tuff base at U8-8, and pumiceous sand at the base of the tuff at U9-6). Therefore, the depositional environment changes from lower sublittoral to upper bathyal depths in this area.

In the northwest of Kakegawa (the southeast to Hosoya), the tuff layer is intercalated between massive fine silt yielding the 7-type assemblage (e.g., U10-1 and U12-5). In the south of Kakegawa, many shells of Calyptogena sp. were found in the massive silt (Majima et al., 1990). Moreover, according to personal communication from Drs. Yasuo Kondo (Kochi University), Hiroshi Kitazato (Shizuoka University) and Mr. Tsumoru Tanabe (Fukuroi City), abundant "Calyptogena" shells occurs in massive silt facies in Kamenoko, the south of the Kakegawa. The localities are judged to be near the tuff horizon based on the geological map of Chinzei and Aoshima (1976). As noted before, I consider that the "Calyptogena" assemblages correspond to the 8-type, Akebiconcha assemblage in this paper. A bathyal reducing environment might have existed in this area. In the southeastern part of the studied area, the Hosoya Tuff is unfortunately not found. However, in the southeasternmost area, near Tagaya, I found the 10-type assemblage in the fine silt bed of the Horinouchi Formation at several localities near the Hosoya Tuff horizon (e.g., TG5).

2) horizon along the T3 Tuff

Along the T3 Tuff, the following assemblages are recognized from northwest to southeast: the 4-, 5-, 6-, 7-, and 10-type assemblages (Figs.4, 6, 7, 8B).

In Ukari, the northwestern part of the studied area, the T3 Tuff is intercalated in muddy sand yielding the lower sublittoral 4-type assemblage. For example, at U2-5, the assemblage occurs in a muddy sand bed just above the T3 Tuff. In this area, Chinzei (1980) also confirmed many localities yielding the *Glycymeris rotunda* - *Venus foveolata* Association, which corresponds to the 4-type assemblage in this study, near the tuff horizon. Therefore, the lower shelf extended in this area.

In the south to Kakegawa, the T3 Tuff has been traced southeastward by Chinzei and Aoshima (1976) as follows: Kogosho, Kechienji, Ganshoji, and Kamihijikata (Fig.1B). Chinzei (1980) showed the distributions of molluscan fossils along the tuff as follows: the *Nassaria magnifica* Association (the 5-type assemblage) occurs in the areas of Kogosho to Kechienji; the *Limopsis tajimae* Association (the 6-type assemblage) in the areas of Kechienji, Ganshoji, and Kamihijikata. I recognized similar distribution trend of the shelf-edge to bathyal assemblages in these areas of Kogosho to Ganshoji. For example, the 5- and 6-type assemblages occur in the silt bed close to the tuff horizons at SCC19C and SCC19B, between Kogosho and Kechienji. In Kechienji, the columnar section S7 (Fig.7) shows that the 6-type assemblages is dominant near the tuff horizon, although the 7-type assemblage containing *Limopsis tajimae* temporally occurs about 10m below the tuff. In Ganshoji, the 6-type assemblage occurs in fine silt close to the tuff horizon at W103 and WG8. In the areas south to Ganshoji, in contrast, I recognized commonly the 7-type assemblage at GSJS4 (silt bed just below the tuff) and at MKCE3 (silt bed near the tuff horizon).

Moreover, I traced the T3 Tuff further southward to Shimohijikata (at KM8), and recognized the 10-type assemblage in the massive fine tuff layer. In this area, the 10-type assemblage occurs in the massive fine silt near the tuff horizon at many other localities such as S-N4′ and KM14.

3) horizon along the Soga Tuff

Along the Soga Tuff, the following assemblages occur southeastward: the 2-, 3-, 5-, and 7-type assemblages (Figs.4, 7, 8C).

In the south to Ukari, the northwestern part of the studied area, the fossils are rare. At ST1, however, Scapharca broughtonii which lives now in the depth of 0-20m was found in the middle part of the Soga Tuff (Nobuhara, 1990). The western part of the Soga Formation shows sedimentary facies of shoreface and submarine channel (Ishibashi, 1989).

In Shinoba, the central studied area of the Soga Formation, the allochthonous shell bed was found at the base of the tuff at ST2. The shell composition is the same with the 2-type assemblage. In Kechienji, the southeast to ST2, assemblages including many species living now in the upper sublittoral zone occurs in muddy sand near the base of the tuff (2-type, at ST7, and ST8) and about 10m below the tuff (3-type, at ST9, and ST11). Therefore, the nearshore environment extended in these areas.

About 0.5km southeast to the localities in Kechienji, muddy sand facies of the Soga Formation grades laterally into massive silt facies of the Hijikata Formation. In the silt facies, the shelf-edge to bathyal assemblages occur: the 5-type assemblage (about 25m below the tuff base, at ST13), the 7-type assemblage (about 5m below the tuff base, at ST12). In Kamihijikata and Shimohijikata, the southeasternmost part of the studied area, the bathyal 7-type assemblage occurs in the massive fine silt near the base of the Soga Tuff at ST15, ST16, ST17, and ST18.

It is noted that the 4-type assemblage containing many species living in the lower sublittoral depths is rare not only along this horizon but also in the Soga Formation, although the assemblage commonly occurs in the Ukari Formation. This suggests that the bathymetrical change along the horizon was abrupt from nearshore to shelf-edge and bathyal depths. The lower shelf had few area in this period.

From the results mentioned above, general trend on the horizontal distributions can be recognized along the nearshore - offshore transect. As shown in the cross section Fig.4, the shelf assemblages (the 1- to 4-type), 5-, 6-, 7-, 8-, and 10-type assemblages occur in order from northwest to southeast. Even in the deep-sea bathyal facies, the horizontal distribution shows the regular "5-6-7-8-10 pattern" mentioned above rather than a disorder, "mosaic" of different types. In particular, the horizontal distribution pattern, "5-6-7", is recognized as a general trend in several horizons other than the key tuff horizons mentioned above. For example, as shown in columnar sections in Hosoya and north of Kakegawa (columns U6-U12 in Fig.6), the "5-6-7" or the "6-7" distribution pattern is recognized and the pattern shift landward (northwestward) correspondingly to the transgressive phase suggested by Ishibashi (1989). Moreover, Fig.4 shows that this "5-6-7 pattern" is recognized at least in two horizons above the Soga Tuff, although the horizons are not correlated correctly because of the limited outcrop conditions.

Between the Hosoya Tuff and the T3 Tuff in the southeastern areas, however, investigations of molluscan assemblages has not been examined at so many localities as in the northwestern areas. In the southeastern areas, i.e. south to Kechienji, Chinzei (1980) reported the Limopsis tajimae Association, which corresponds to the 6-type assemblage in this study, at several localities. This occurrence seems to be inconsistent with the "5-6-7 distribution pattern" recognized in the northwest area. The assemblages of deeper facies, such as the 7- to 9-types, are expected to occur in the southeastern area. However, the distribution of the bathyal assemblages might have been influenced by hydrographic conditions controlling their food supply, as discussed later. Therefore, change in hydrographic conditions could have made the suspension-feeding, 6-type assemblage occur temporarily in more seaward and deeper facies. The distribution pattern of bathyal molluscan assemblages in the southeastern area remains to be tested at many localities. In this paper, the "5-6-7 distribution pattern" is regarded as an overall regular trend of change in molluscan assemblages from the shelf-edge to bathyal zone.

The regular horizontal patterns mentioned above are related with the change in some ecological conditions with an increase of bathymetric depth, as discussed later. The regular patterns temporally shift landward or seaward correspondingly to the transgression or regression suggested by Ishibashi (1989), as shown in Figs.4, 6. Therefore, the temporal shift suggests sedimentary processes of the upper part of the Kakegawa Group.

Sedimentary processes of the upper part of the Kakegawa Group

Sedimentary processes of the Kakegawa Group was described by many studies such as traces of planktonic foraminiferal datum planes by Ibaraki (1986b) and sequence stratigraphy by Ishibashi (1989) and by Masuda and Ishibashi (1991). The distributions of molluscan assemblages, however, have not been examined in the relationships to the sedimentary processes.

The vertical change in lithofacies in the upper part of the Kakegawa Group shows transgressive-regressive cycles. According to Ishibashi (1989), the sedimentary facies below the T3 (Kogosho) Tuff horizon shows an overall transgressive sequence and it is succeeded by an overall regressive sequence above the tuff horizon. Ishibashi (1989) noted that the apparent transgressive-regressive cycle is controlled by (1) eustatic changes of sea level, (2) tectonic movements such as subsidence and uplift of a sedimentary basin, and (3) rates of sedimentary supply. Although it is not clear which was the most important cause of the transgressive-regressive cycle in the Kakegawa Group, Masuda and Ishibashi (1991) suggested that the depositional sequence might have been formed during a global eustatic change in the Plio-Pleistocene time. According to them, the sequence cycle can correspond to a long cycle of oxygen isotope curves presented by Williams (1989). Moreover, Ishibashi (1989) stated that the regression phase recognized in rocks ascribed to the Yuzanjian stage (ca.1.6 Ma to ca. 1.0 Ma) was mainly caused by glacial eustasy because of the following two data: 1) Vail's et al.

(1977) chart of the relative sea level changes on a global scale indicated a sea level fall at 1.7 Ma; 2) Ibaraki (1986b) showed that the temperature of the "paleo-sea of Enshu" decreased abruptly at 1.6 Ma on the basis of the ratio of cold water species to total planktonic foraminifera species.

The temporal shift of the horizontal distribution of the molluscan assemblages, as shown in Fig.4, suggests the sedimentary processes and the bathymetric change in the transgressive-regressive cycle, as noted below. In particular, it is noticed that the temporal change in depositional environment is clearly traced into the shelf-edge to bathyal silt facies by the temporal shift.

Below the Hosoya Tuff, the shelf assemblages including upper sublittoral species (the 1- to 3-type assemblages) laterally change to the bathyal 6-type assemblage southeastward. This distribution pattern shifts landward (northwestward) successively as the horizon is closer to the Hosoya Tuff. This landward shift indicates that this sequence was formed during the transgressive phase. The typical lower shelf 4-type assemblage is rare in this sequence. This suggests that, in this transgressive phase, relative rise of sea level was likely so rapid that a wide lower shelf could not be formed by the sedimentary supply.

The 4II-type assemblage firstly occurs just below the Hosoya Tuff horizon in Hosoya and it commonly occurs in the muddy sand facies between the T3 Tuff and the Hosoya Tuff horizons in Ukari. The lower shelf extended in the northwestern areas in this earliest Pleistocene age. Between the tuffs, "the 5-6-7 distribution pattern" shifts landward as in the previous stage, but the landward shift ended in this stage. The transgression might have continued from the previous stage, but relative rise of sea level was likely not so rapid as in the previous stage. Consequently, the lower shelf was formed and the transgressive phase changed into the stationary phase.

Along the T3 Tuff (Fig.8B), the 4-type assemblages occur in Ukari and the lower shelf extended as in the previous stages. The "5-6-7 distribution pattern", however, shifted seaward in this stage compared with the distribution in the previous stage. This seaward shift might have been caused by relative fall of sea level and/or sedimentary progradation. Masuda and Ishibashi (1991) recognized the downlap surface spaced at the just upper horizon of the T3 (Kogosho) Tuff as a maximum flooding surface. They set the sequence boundary between the lower transgressive system and the upper highstand system at this horizon. If the sea level rise lasted by the time of this horizon, sedimentary progradation over the shelf-edge played an important roll in the seaward shift of the bathyal molluscan assemblages and made the topography of sea bottom from the shelf to slope more gradual than that in the previous stages.

This gradual sea bottom topography drastically change to the abrupt one near the boundary between the Ukari and Soga Formations. This boundary horizon corresponds to the horizon at which the ratio of cold water to total planktonic foraminifera species abruptly increased (Ibaraki, 1986b). This cooling event suggests that abrupt eustatic fall of sea level occurred at 1.6 Ma (Ishibashi, 1989).

Below the cooling event horizon, the 4-type assemblage occurs at many localities in the Ukari Formation, and the lower shelf extended in the northwestern area, Ukari. In contrast, the 4-type assemblage is rare in the Soga Formation. Along the Soga Tuff horizon, the 2- and 3-type assemblages including many upper sublittoral species laterally changes to the shelf-edge to bathyal assemblages such as the 5- and 7-types (Fig.8C). The lower shelf was likely remarkably reduced in this stage. This is consistent with Ishibashi's (1989) sedimentary facies analysis along this horizon. He stated that fewer offshore deposits developed in this stage.

The vertical change in molluscan assemblages are observed continuously over the cooling event horizon at 1.6Ma in a columnar section in Kechienji, S7 (Fig.7). The 5-type assemblage changes to the 3-type one over the horizon. This suggests that the paleobathymetry might have changed from the shelf-edge to upper sublittoral depths. If the sea level falls in this scale so abruptly and the sedimentary supply had no time to extend the shelf area, the lower shelf zone was reduced, as shown in Fig.8C. This sea level fall changed the sedimentary system of the northwestern shallow facies. In contrast, the southeastern deep facies shows few change in the sedimentary system. The "5-6-7 distribution pattern" seems to shift seaward successively from the T3 Tuff horizon to the horizons above the Soga Tuff.

As a result, the sedimentary processes of the upper part of the Kakegawa Group is divided mainly into the following three stages: 1) the transgressive phase below the Hosoya Tuff horizon, when the lower shelf was not formed widely and the horizontal distribution pattern, "the shelf assemblages - the bathyal 6-type assemblage," shifted landward; 2) the transition from transgressive to regressive phase between the Hosoya Tuff and the cooling horizon of Ibaraki (1986b), when the lower shelf extended widely and the temporal shift of the "5-6-7 distribution pattern" changed from landward to seaward; 3) the regressive phase above the cooling horizon, when the lower shelf area was reduced and the "5-6-7 distribution pattern" shifted seaward as in the previous stage. The first, second, and third sedimentary process stages corresponds to the Suchian, Kechienjian, and Yuzanjian stages of Tsuchi's (1961) faunal succession, respectively.

The temporal shift of regular distribution pattern such as the "5-6-7" is useful for discussion on the sedimentary processes. In the following chapters, I discuss what environmental factors formed the regular distribution patterns along a nearshore-offshore transect.

The relationship between the molluscan assemblages and water mass conditions

It is certain that the distribution of each molluscan assemblage corresponds to each lithofacies, but the stable pattern of the horizontal distribution mentioned above cannot be explained only by bottom character. For example, several assemblage types are recognized in the same bathyal silt facies. Moreover, the regular horizontal distribution of their bathyal assemblages also are not explained only by the bathymetric depth data of the living species. The regular pattern is likely to have been formed by the composition of various environmental factors. In thie chapter, I note their relationships with nature of water masses (water temperature and seasonal fluctuation, concentration of dissolved oxygen, and trophic conditions).

Horikoshi (1957) and Okutani (1968) showed the relationship between the water mass conditions and the living molluscan faunas in Sagami Bay. The living faunas have similar species composition to those of the fossil assemblages in the Kakegawa Group. Some molluscan faunas in different bathymetric depths in Sagami Bay are under the influence of different water masses, such as coastal water, oceanic Kuroshio water, and intermediate water. This reflects that the distribution of molluscs are controlled mainly by marine thermal structures. I compare the fossil assemblages in the Kakegawa Group with these living faunas in Sagami Bay to discuss the relationship between the fossil molluscan assemblages and water mass conditions. Moreover, the stratigraphic distribution of each molluscan assemblage is compared with those of the Aoshima's (1978) foraminiferal assemblages (compiled in Fig.9). He made clear characteristics of the living foraminiferal assemblages along the Pacific coast of Southwest Japan and applied the data in the present sea to the fossil foraminiferal assemblage in the Kakegawa Group. Therefore, water mass conditions suggested by the molluscan assemblages are cross-checked by Aoshima's (1978) data. Terminology on water mass follows that of Aoshima (1978).

The 1- to 4I-type assemblages include many species living in upper sublittoral depths. Some of them (e.g., Suchium giganteum, Glycymeris nakamurai, Callista chinensis, and Tonna luteostoma) are the components of the molluscan associations in coastal water region shown by Matsushima (1984). They occur in the nearshore coastal water region in Sagami Bay (Horikoshi, 1957). According to Aoshima (1978), coastal water is distinguished from the offshore waters by its low salinity. Coastal water is formed by the influx of fresh water from the land during summer, when the water masses are strongly stratificated, and covers bottoms of the inner shelf area (Horikoshi, 1987). The 1- to 4I-type assemblages are distributed in the lowermost and uppermost parts of the Ukari Formation and in the Soga Formation. This distribution nearly corresponds to that of the foraminiferal assemblages under the influence of the coastal water shown by Aoshima (1978). He suggested that the foraminiferal assemblages in the coastal water show low percentage of planktonic foraminifera and low species diversity. These indicators of coastal water are recognized also in the assemblages in the Dainichi Formation (Aoshima, 1978). The upper sublittoral species in these molluscan assemblages (the 1- to 4I-types) are likely to have been under the influence of coastal water.

The 4-type assemblage includes many species living now in the lower sublittoral zone, such as *Nemocardium samarangae*, *Ventricolaria foveolata*, and *Cryptopecten vesiculosus*. Most of them have been found in the lower shelf in Sagami Bay (Kuroda et al., 1971). Moreover, the dominant species of the 4-type assemblage, *Glycymeris rotunda* and *Ventricolaria foveolata*, are the representatives of the muddy bottom assemblage in the lower shelf in Sagami Bay, as shown by Horikoshi (1957). Horikoshi (1957) stated that the lower shelf fauna in Sagami Bay is under the influence of the offshore warm Kuroshio water. The 4-type assemblage occurs commonly in the Ukari Formation. The distribution corresponds to that of the Aoshima's (1978) foraminiferal assemblage 1 which has the same composition with that living now in the surface water. The surface water occupies the upper 100 to 200m of the offshore water and it is characterized by seasonal changes of the temperature and salinity (Aoshima, 1978).

The 5-, 6-, and 7-type assemblages occur in the silt facies of slope and basin plain shown by Ishibashi (1989). Their relationships with water mass conditions are inferred from the geographic distributions of the component species. The assemblages contain many species whose geographic distributions are restricted in southwestern Japan, such as *Limopsis tajimae*, *Carinineilo* carinifera, and Baryspira suavis, but contain few north elements whose distributions are restricted in the north to Choshi. These facts suggest that the 5- to 7-type assemblages are under the influence of the Kuroshio water which occupies the depths of 0-300m in Sagami Bay (Horikoshi, 1957). The stratigraphic distributions of the 5-type assemblage corresponds to that of the Aoshima's (1978) foraminiferal assemblage 2 (upper water assemblage). The stratigraphic distributions of the 6- and 7-type assemblages correspond to those of the foraminiferal assemblage 2 (upper water) and 3 (intermediate water). The upper water lies directly under the surface water, characterized by little seasonal variation of temperature and salinity, and the intermediate water exists under the upper water, characterized by the minimum salinity (Aoshima, 1978).

By contrast with the 5- to 7-type assemblages, the 8-, 9-, and 10-type assemblages contain some cold water species. For example, the 9-type assemblage contains Neptunea constricta which lives now in Kashima-Nada north up to Hokkaido and Japan Sea, 50-300m deep, at present (Higo, 1973). The 8-type assemblage contains Solemya johnsoni which lives off Chosi north to Bering Sea and off California (Habe, 1977). Moreover, subdominant species of the assemblage, Lucinoma acutilineata and Conchocele bisecta, are considered to have their main distributions in northern sea areas, although they extends their distributions into sea areas to the south of Chosi (Habe, 1977; Okutani and Habe, 1975). Noda(1992) compiled the temporal and spatial distributions of the two species to be the Oligocene to Recent of North America and North Pacific region. The dominant Limopsis species in the 10-type assemblage resembles Limopsis uwadokoi which lives in depths of 100-200m in northeastern Japan (Kira, 1959). According to personal communication from Dr. Hiroshi Kitazato (Shizuoka University), benthic foraminiferas now living in about 1000m deep, such as Melonis barleanus, were obtained from the silt in which the 8- and the 9-type assemblages occur. With respect to the 10-type assemblage, its stratigraphic distribution corresponds to that of the Aoshima's (1978) foraminiferal assemblage 3 which lived in the intermediate water. The molluscan fauna of the intermediate water (600-800m) of Sagami Bay has some cold water elements as do the Kakegawa fossil assemblages. Okutani (1968) reported that some species characteristic to the cold Oyashio water, such as Macoma calcarea (Gmelin) and Euspira pallida (Broderip et Sowerby), occur in the depths of Sagami Bay. Therefore these three fossil assemblages are considered to have been under the influence of the cold intermediate water.

As mentioned above, the molluscan faunas in the Kakegawa Group are under the similar water mass conditions to those in Sagami Bay. This is concordant with the results of Chinzei and Aoshima's (1976) isotopic analysis that marine thermal structure of the "paleo-sea of Enshu" was quite similar to that of the present-day warm Kuroshio water. Each molluscan fauna is correspondingly in the influence of each water mass: the 1- to 4I type assemblages (the coastal water), the 4-type assemblages (the surface water), the 5- to 7-type assemblages (the upper to intermediate water), and the 8- to 10-type assemblages (the intermediate water).

The distribution of the molluscs in the "paleo-sea of Enshu" was controlled mainly by the marine thermal structures, as are the case of the living faunas in Sagami Bay. In the following two chapters, I discuss the other environmental factors, i.e., concentration of dissolved oxygen and trophic conditions. The factors might have caused the difference of molluscan assemblage in the same massive silt facies of slope and basin plain.

Dissolved oxygen in water masses

The constituents of the 8-type assemblage prefer a reducing environment, whereas the other assemblages prefer an ordinary oxic condition. The distribution of the 8-type, *Akebiconcha kawamurai* assemblage is considered to have been related with the minimum dissolved oxygen layer in bathyal water mass, as noted below.

The parautochthonous fossil occurrence of the 8-type assemblage suggests that the dominant species, *Akebiconcha kawamurai*, formed a large-biomass colony with *Lucinoma* aff. *acutilineata*, *Conchocele bisecta*, and *Solemya johnsoni*. Many species of genera *Lucinoma*, *Solemya*, *Thyasira* (close to *Conchocele*), and *Calyptogena* (close to *Akebiconcha*) have been confirmed to prefer a reducing environment and possess endosymbiotic sulphide-oxidising bacteria as their nutrition strategy (e.g., Reid, 1980; Felbeck et al., 1981; Cavanaugh, 1983).

Calyptogena colonies have been found in various environments such as deep-sea hydrothermal vents off the Galápagos Islands (Arp et al., 1984), cold-seepage regions in Sagami Bay (Okutani and Egawa, 1985), oil and gas seepage regions on the Louisiana continental slope (Kennicutt II et al., 1985), and so on. They often are associated with *Lucinoma* and *Conchocele*. The *Calyptogena* colonies are supported by sulphide-rich water being discharged from the hydrothermal vent (Arp et al., 1984) or by cold-seepage water from the subduction zone (Masuzawa et al. 1992). The Tamari and Hijikata Formations were deposited in a forearc basin situated where the Philippine Sea Plate was being subducted under the Eurasian Plate. The tectonic setting implies that the Akebiconcha colony in the Tamari Formation is the latter cold-seepage type.

The 8-type assemblage, however, is enclosed in the massive fine silt with low permeability. This is inconsistent with the fact that the living Calyptogena colonies supported by cold-seepage water occur in coarser sandy sediments with high permeability (e.g., Hashimoto et al., 1988, 1989). Sakai et al.(1987) suggested that high-density Calyptogena colonies may be unable to occur in sediments with a thick surface silty layer. This is probably because the seepage supporting the colonies depends on the high permeability of the sandy layer. If fine silty sediments covered the surface thickly, the clams could not utilize methane and dissolved organic carbon supplied by seepage to the sediment surface.

Moreover, we cannot find any geologic structures suggesting the presence of seepage, such as a fault, at the localities in the Tamari Formation. Therefore, we do not think that this fossil Akebiconcha colony was supported by cold seepage. The silt sediments themselves must be enriched in sulphide at the burrowing depth inhabited by the symbiont-bearing bivalves.

In general oxic water mass condition, the surface sediments are oxidised by the overlying oxygenated waters. Underneath the surface oxidised layer, the sediments remain to be in an anaerobic condition, where anaerobic bacteria reduce sulphate to decompose the organic matter, and sulphide occurs as a by-product in this layer. The depth of the interface between the surface oxidised layer and the underlying anaerobic layer is controlled by the concentration of dissolved oxygen in the overlying sea water, by the quantity of organic matter in the sediments, and by bioturbation.

Lucinoma and Conchocele are deep-burrowers, and their burrows are apt to be near, or below, the top of the reduced sediment zone. They obtain sulphide from the reduced sediment zone, and oxygen from the overlying oxygenated sea water through their agglutinated inhalant muscus tube. By contrast, Akebiconcha kawamurai is expected to be a shallow burrower from the direct observation of the close Calyptogena species (Hashimoto et al., 1988, 1989). Moreover, the colony in the Tamari Formation includes small individuals (ca. 1cm long). Therefore, the oxidised surface layer of the Akebiconcha colony was probably thin, so that the small individuals could utilize the reducing, sulphide-rich layer below the oxidised surface layer (Fig.10). This reducing environment is related to the hypoxic bathyal water which could hardly oxydise the sediment surface.

In bathyal depths, the water mass with the minimum dissolved oxygen occurs, because light is too weak for phototrophs and oxygen is only consumed by the respiration of organisms. At the localities of the 8-type assemblage in the Tamari Formation, the silt contains many large plant remains. This suggests that much organic matter was supplied from the land area. In these depositional conditions, the dissolved oxygen is apt to be exhausted by the decomposition of organic matters and the water mass overlying the bottom becomes hypoxic. The 8-type assemblage suggests that such a hypoxic condition occurred in the intermediate water.

Moreover, the 8-type assemblage alternates with the ordinary, oxic bathyal 9-type assemblage (the "Empleconia" sp. A - Neilonella coix assemblage) in the vertical sequence observed in the outcrops in the Tamari Formation (Fig.5). This sequential change indicates that the intermediate water alternate intermittently between the hypoxic and oxic conditions.

Trophic conditions

The 5-, 6-, and 7-type assemblages occur in the similar silt facies and are considered to have been under the influence of the upper to intermediate water, as noted above. Their distribution pattern along a horizon, however, seems to be regular: the 5-, 6-, and 7-type assemblages occur in order southeastward (seaward). This distribution pattern likely reflects change in some paleoenvironmental factors along the shelf-edge to bathyal depths within the similar water temperature.

The remarkable difference between these assemblages is feeding characters of the major component species. The 5-type, Nassaria magnifica assemblage is characterized by abundant gastropods markedly exceeding bivalves. The common species, such as Nassaria magnifica, Parabathytoma luehdorfi, and Makiyamaia coreanica, are Buccinidae or Turridae species. The representative feeding characters of the families are carnivorous and/or saprophagous (Okutani et al., 1986). The dominant species of the 6-type assemblage, Limopsis tajimae, is a suspension-feeding, non-siphonate bivalves. By contrast with the 6-type, the 7-type assemblage is composed mainly of deposit-feeding nuculoid bivalves. Therefore, the horizontal change in the molluscan assemblage, the "5-6-7 distribution pattern", suggests some change in trophic conditions from the shelf-edge to bathyal zone.

The trophic conditions on shelf-edge to bathyal bottoms in present seas have not been made clear. However, I consider that the bottom trophic conditions may be related with not only the hydrographic conditions of the water just above the bottom but also with the surface water conditions. For example, surface water at shelf-edge areas is noted by many oceanographers, because it is the position of highly productive fisheries (e.g., the sea areas from the Grand Banks off Newfoundland, south to Cape Hatteras). The "paleo-sea of Enshu" is considered to have been under a similar condition to that of the highly productive fisheries areas in the eastern seaboard of North America. That is, the westward intensified warm current such as Kuroshio Current and North Atlantic Current runs off the coast. Mann and Lazier (1991) noted that, in the eastern seaboard of North America in winter, a front straddles the shelf break, making the transition between the colder and fresher shelf water mass and the warmer and more saline slope waters. In spring, the front becomes weak but, on the deeper part of the shelf below the thermocline, a parcel of water of reduced salinity with a temperature less than about 10°C is isolated from the warmer, shallower waters inshore and from the more saline waters offshore. The parcel maintains the front below the thermocline, even through the period of summer stratification. There have been various observations of nutrient enrichment and/or enhanced phytoplankton and zooplankton biomass associated with the shelf-break fronts (Mann and Lazier, 1991). This intensified biological production at shelf-break fronts is possible to have been related with the occurrence of the carnivorous and/or saprophagous gastropods assemblages (the 5-type assemblage) at the shelf-edge facies in the Kakegawa Group. Moreover, the hydrographic conditions in the vicinity of the shelf-break front, such as surface water convergence and vertical mixing, could have been related with the horizontal change from the suspension-feeding, 6-type assemblage to the deposit-feeding, 7-type one, because the hydrographic conditions controls the amount of organic matter in suspension and the rate of sedimentation.

The shelf-edge to bathyal faunas in the present sea have been surveyed mainly with dredges and trawls. Therefore, living "assemblages" correlative to these fossil ones are difficult to be recognized, except for some box core sampling of populations of *Limopsis tajimae* (e.g., Kondo, 1989). However, if the trophic conditions are related with water mass structure such as shelf-break front, the "5-6-7 distribution pattern" is considered to occur along shelf-edge to bathyal depths also in the present sea, because the molluscan faunas in the Kakegawa Group are considered to have been under the similar water mass conditions to those in present Sagami Bay, as mentioned above.

The horizontal change in molluscan assemblages and its relationship with water mass conditions are schematically compiled in Fig.11. The lateral distribution pattern of the assemblages presents one of typical faunal changes along depths from the upper sublittoral to bathyal zone in the sea areas under the influence of the westward intensified warm current such as Kuroshio.

Temporal distribution of species characteristic of each bathymetric depth zone

As discussed in the previous chapters, the water mass structure in the "paleo-sea of Enshu" was similar to that of the present Kuroshio region such as Sagami bay. The molluscan assemblages in each water mass except for the intermediate water occur through the Suchian to Yuzanjian stages (Fig.4). Therefore, the distribution of water masses is considered to have shown no remarkable change through the Plio-Pleistocene period, although the cooling in water temperature occurred in the earliest Pleistocene as suggested by Ibaraki's (1986b) study on planktonic foraminifera. Tsuchi (1990) suggested that the molluscan faunal changes during the Suchian to Yuzanjian stages was related with the cooling. What bathymetrical depth the cooling effects reached in the structural frame of water masses? In this chapter, the relationship between bathymetric depth and the cooling effect on molluscs is examined.

As mentioned above, the shelf to bathyal assemblages are recognized through the Suchian to Yuzanjian stages, except for the 8- to 10-type assemblages under the influence of intermediate water (Fig.4). An assemblage composed only of the upper sublittoral elements is not recognized. However, the 1- to 4I-type assemblages contains many species living in the upper sublittoral zone. In addition, some assemblages in the allochthonous B-type occurrence also contain the shallow species. Therefore, as shown in this figure, I obtained material of component species representing the upper sublittoral to bathyal faunas in each of the Suchian to Yuzanjian stages. Using this material, I can trace the temporal distributions of species characteristic of each depth zone.

In order to clarify the relationship between bathymetric depth and the cooling effect on molluscs, I pay attention to the relationship between the temporal distribution of species and their habitat (geographical distribution and bathymetric depth).

The geographical distribution of each species reflects its tolerance for sea water temperature. For species that are still living, I use the following terms for water regimes, based on the data on their geographical distributions along the Pacific side of

Japan (Habe, 1977; Higo, 1973; Kuroda and Habe, 1952): "Kuroshio" (0° - 34°N), "Kuroshio-Japonic" (0° - 35°N), "Southwestern Japonic" (31°N - 35°N), and "Japonic" (31°N - 42°N) (shown in Fig.12). In this paper, the species occupying the first two regimes are called "warm-water elements" and those occupying the last two are called "Japonic endemic elements". For extinct species, "warm-water elements" is defined as taxa whose distributions extend to tropical regions such as Taiwan and Okinawa Island (e.g., *Amussiopecten praesignis*, *Venericardia panda*), and "Japonic elements" is defined as taxa whose distributions are restricted to Japan (e.g., *Mizuhopecten tokyoensis*).

The habitat depths are inferred mainly from the data of living species (Habe, 1977; Higo, 1973). The data, however, are synthesized from various reports in the sea around Japan and some species are possible to have narrower depth range in the local "paleo-sea of Enshu". Moreover, some species are extinct ones. Therefore, the interpretations on habitat depths are supplemented by the depositional environments of the assemblages in which the species occurs. In order to avoid a vicious circle, the depositional environments are cross-checked by the results of the sedimentary facies analysis (Ishibashi, 1989) and of the study on foraminiferal assemblages (Aoshima, 1978), as noted before. The species whose habitat depths are cross-checked by these data are marked with "#" in Fig.13.

Fig.13 shows examples of the temporal distribution of characteristic species in each bathymetric depth at representative localities.

As noted in the introduction to this paper, the temporal change in the Kakegawa fauna is defined partly by the stepwise disappearance of warm-water species, and almost all of those are found commonly in the shallowest facies such as the Dainichi Formation. In the Kechienjian and Yuzanjian stages, however, muddy sand to silt facies are the dominant fossiliferous lithofacies, in contrast with shallow-water sandy facies such as the Dainichi Formation in the Suchian stage. In order to confirm that the stepwise disappearance is caused by cooling, I compare the temporal distributions of many species within the same muddy sand facies in each stage, depositional conditions being nearly equal.

From each stage, Suchian to Yuzanjian, I collected species assigned to the assemblages which are considered to have lived on a muddy sand bottom in the upper sublittoral zone, or in transitional depths between the upper and lower sublittoral zones. They are the 1- to 4-type assemblages. The localities of these assemblages nearly correspond to the distribution of the nearshore foraminiferal assemblages shown by Aoshima (1978). I trace the temporal distributions of species that live now in upper sublittoral depths or, whose occurrences are restricted in the four assemblages and in the Dainichi Formation. They can be assumed to have been upper sublittoral species.

The assemblages in rocks of the Suchian stage include many warm-water elements such as *Amussiopecten praesignis*, *Venericardia panda*, *Paphia amabilis*, *Placamen* spp., *Oblimopa japonica*, and so on. *A. praesignis* and *V. panda* are found at most of the localities representing the Suchian stage. In particular, *Amussiopecten praesignis* is abundant at some localities (e.g., U10-9B, U13-1). Some warm-water elements such as *Nassarius dorsatus*, *Anisocorbula scaphoides*, and *Dendostera? crenulifera* are found only at U10-9B, but many individuals of these species occur at this locality.

In rocks of the Kechienjian stage, some of the warm-water species listed above are not present. For example, the 4I-type assemblage at U1-1 contains many species living in upper sublittoral depths and abundant shells of *Amussiopecten praesignis*, whereas other warm-water elements such as *Venericardia panda* and *Oblimopa japonica* are absent. This is possibly due to the slight difference in depositional environments between the 4I-type assemblage and the other assemblages of the 1-, 2-, and 3-type in the Suchian stage. At U2-11, however, an allochthonous assemblage transported from the upper sublittoral or shallower depths is present in the B-type occurrence, but it contains no shells of *Venericardia panda* or *Oblimopa japonica*.

In rocks of the Yuzanjian stage, the 2- and 3-type assemblages occur. The dominant species are the same between the Sucian and Yuzanjian stages. However, the warm-water Suchian species that are absent from the previous Kechienjian stage also are not found in these shallow Yuzanjian assemblages. *Amussiopecten praesignis* occurs in this stage but only rarely, as a fragment, whereas its well-preserved shells are abundant in the Suchian and Kechienjian assemblages.

As noted above, some warm-water elements in the upper sublittoral zone disappeared in steps. In contrast to this, some Kuroshio-Japonic species survived in the upper sublittoral zone through three stages. They are *Clementia papyracea*, *Solecurtus divaricatus*, *Saccella confusa* and *Tonna luteostoma*. *S. divaricatus* was not found in Suchian rocks in this survey, but Yoshida (1981) reported the species from the Dainichi Formation. Japonic endemic elements such as *Dosinia troscheli* also survived in the upper sublittoral zone through all three stages.

With respect to species living in upper to lower sublittoral depths (or which live now in the lower sublittoral and the deeper zones but also occur abundantly in fossil assemblages of the 1-, 2-, and 3-types), both the warm-water and the Japonic endemic elements also occur through all three stages, as shown in Fig.13.

This continuous occurrence is true of species living in lower sublittoral to bathyal depths. Warm-water elements living in lower sublittoral depths, such as *Cryptopecten vesiculosus*, are found in all three stages. Japonic endemic elements also occur throughout the three stages. Besides the species cited as examples in Fig.13, many other Japonic elements in these depth zones are found throughout the three stages, such as *Yoldia similis* and *Fulgoraria mentiens*. Chinzei (1980) studied the deep offshore fossil molluscan fauna in rocks of the Kechienjian stage and stated that it mostly is composed of species living now in waters off central Japan. These deep-water faunas seem to have been poor in warm-water elements throughout the sequence, including the Suchian stage, as shown in Fig.13. Some of the Southwestern Japonic living species, however, for example *Makiyamaia coreanica*, have been reported from the Shinzato Formation of Okinawa Island by Noda (1980). It appears likely that their geographical distributions in Pliocene age were very similar to those of the fossil warm-water elements. Whether the species are warm-water elements or not, the species compositions of the deep assemblages seem to have been stable throughout the three stages.

Thus, the effects of cooling on faunal change seem to have been restricted to the upper sublittoral zone. Some problems, however, remain. First, the deep assemblages contain many minute unidentified gastropods whose temporal distributions are not clear.

Secondly, the effect of cooling on organisms possibly differs not only with habitat depth, but also with other ecological parameters such as food source and whether they are infaunal or epifaunal. Therefore, in order to confirm the effect of cooling in each bathymetric zone, I compare the temporal distributions of some taxonomically close species that have similar ecological characters (life habits, food sources) but lived at different depths and/or in different water regimes. The comparisons reveal which bathymetric zone and which water regime the disappearing species lived in, all other ecological characters being nearly equal. The result can be regarded as a typical faunal change for a cooling event, which can be applied to all faunal components.

Figs.14a-d show four examples of the comparison of temporal distributions at all 124 localities in this survey. Life habit of each example species has not been confirmed except for life positions of some species. Superfamilies of bivalves, however, have tended to remain constant with regard to feeding types throughout their histories (Stanley, 1968). Therefore, the feeding types of the following four species groups are mainly inferred based on the feeding categories of Stanley (1968, 1970).

1) "Limopsis" species (non-siphonate suspension feeders) (Fig.14a)

Three living species, Oblimopa japonica (a Kuroshio-Japonic element), Crenulilimopsis oblonga (a Japonic element) and Limopsis tajimae (a Southwestern Japonic element) occur abundantly at the localities where each species is found. Kondo (1987) showed that these three species are semi-infauna (partly exposed) and/or shallow burrowers (2-3 cm beneath the surface).

Oblimopa japonica occurs in the Kakegawa Group only in the 3-type assemblage containing many upper sublittoral species, although Recent Oblimopa japonica has been recorded from depths of 10-400m (Habe, 1977). Therefore, it is reasonably inferred that Oblimopa japonica lived in the upper sublittoral zone and did not live in the deeper zones in the Pliocene "paleo-sea of Enshu." Crenulilimopsis oblonga lives today in depths of 50-2000m (Habe, 1977). The fossils of this species occur widely in sublittoral to bathyal facies. In particular, the species is one of the dominant species of the 3-type assemblage. Limopsis tajimae lives in depths of 100-800m (Habe, 1977), and fossils correspondingly occur in shelf-edge to bathyal assemblages of the 5- to 7-type assemblages.

Comparison of the temporal distributions of these three species indicates that Oblimopa japonica disappeared near the base of the Kechienjian stage but that the other two "Limopsis" occurred throughout the three stages. That is, the warm-water element in the upper sublittoral zone disappeared, whereas the Japonic endemic elements in the deeper zones survived.

2) Paphia species (infaunal siphonate suspension feeders) (Fig.14b)

The temporal distributions of two living species, Paphia amabilis (a Kuroshio-Japonic element) and P. schnelliana (a Southwestern Japonic element), are compared in Fig.14b. Their actual life habits have not been observed. It is, however, most likely that they are shallow burrowers, because their shell outlines and pallial sinuses resemble those of Ruditapes philippinarum (Adams et Reeve) which has been confirmed to be an active shallow burrowers by Kondo (1987).

Both species live today in sublittoral depths (*P. amabilis*, 10-70m; *P. schnelliana*, 10-100m) (Habe, 1977). Fossil *P. schnelliana* is commonly found in every sublittoral assemblage and its fossil occurrence agrees with its living depth range. By contrast, fossil *P. amabilis* are found only in assemblages containing many upper sublittoral species (in the 1- and 3-type assemblages, and some allochthonous assemblages). *P. amabilis* also occurs in the Dainichi Formation (Yoshida, 1981). This occurrence indicates that *P. amabilis* lived only at upper sublittoral depths in the Kakegawa area during the Pliocene.

The temporal distributions of these species indicate that *P. amabilis* disappeared near the base of the Kechienjian stage but that *P. schnelliana* occurred throughout the three stages. That is, the warm-water element in the upper sublittoral zone disappeared, whereas the Japonic endemic elements occurred throughout the stages.

3) "*Chlamys*" species (epifaunal suspension feeders) (Fig.14c)

The temporal distributions of two species, *Chlamys satoi* (a fossil species) and *Cryptopecten vesiculosus* (a living species) are compared in Fig.14c. *Chlamys* species are generally considered to be sessiles with byssuses (Hayami, 1990).

Both species, *Chlamys satoi* and *Cryptopecten vesiculosus*, are warm-water elements. According to Masuda (1962), *Chlamys satoi* occurs in Neogene rocks in the Miyazaki area in Kyushu, at Miyako Island in Okinawa, and in Taiwan, as well as in the Kakegawa area. *Cryptopecten vesiculosus* lives now at 50-600m in the Kuroshio-Japonic water regime (Habe, 1977). Its fossil geographical distribution extends from the Neogene of Boso Peninsula southward to the Sumagui Formation in the Philippine Islands (Masuda, 1962).

Therefore, both species lived in nearly the same water regime during the Pliocene. However, their fossil occurrences confirm that their habitat depths were different in the Kakegawa area during Pliocene time. Chlamys satoi occurs only in upper sublittoral facies (in the 1- and 2-type assemblages). By contrast, Cryptopecten vesiculosus is common in lower sublittoral facies (the 4-type assemblage) and occurs rarely in the transitional facies between the upper and lower sublittoral zones (the 3-type assemblage).

With respect to the temporal distributions in the Kakegawa Group, Chlamys satoi disappeared near the base of the Kechienjian stage but that Cryptopecten vesiculosus occurred throughout the three stages. Although the occurrence of C. vesiculosus in the Yuzanjian stage is the allochthonous B-type, the abundance and the good preservation of the shells indicate that the species lived near the deposition site during the Yuzanjian stage. Thus, of these two Chlamydinae, only the upper sublittoral species disappeared near the base of the Kechienjian stage, although both species are warm-water elements.

4) Species of Amussiopecten and Mizuhopecten (epifaunal suspension feeders) (Fig.14d)

Amussiopecten praesignis, Mizuhopecten tokyoensis (s.s.) and Mizuhopecten tokyoensis hokurikuensis occur at many localities.

Masuda's (1962) data on the geographical distribution of these species suggested that Amussiopecten praesignis is a warm-water element and that Mizuhopecten tokyoensis (s.s.) and M. tokyoensis hokurikuensis are Japonic endemic elements. The water regimes of these species are different but their living depths are estimated to have been the same (in the upper sublittoral zone) on the basis of their fossil occurrences. That is, these species occur in assemblages containing many upper sublittoral species (the 1- to 4I-type assemblages). Co-occurrence of *Amussiopecten* and *Mizuhopecten* was observed at many localities (U1-3, U1-5, U2-11, U8-13B, U9-14A, U12-6B, and U12-8A).

Amussiopecten praesignis commonly occur in rocks of the Suchian and Kechienjian stages. In rocks of the Yuzanjian stage, however, only one small fragment of the species was found in the 5-type assemblage at MKCW6. By contrast, *Mizuhopecten tokyoensis hokurikuensis* occurs at many localities in rocks of the Suchian and Kechienjian stages and many disarticulated specimens were obtained at ST10 (in rocks of the Yuzanjian stage). *Mizuhopecten tokyoensis* (s.s.) rarely occurs in rocks of the Kechienjian and Yuzanjian stages. Masuda (1962) suggested that *Mizuhopecten tokyoensis hokurikuensis* is an ancestral form of *M. tokyoensis* (s.s.). Therefore, in the upper sublittoral zone, Japonic endemic elements survived through all three stages, whereas the warm-water element is likely to have disappeared early in Yuzanjian time.

The common pattern recognized in these four examples is that the warm-water elements living in the upper sublittoral zone disappeared near the base of the Kechienjian stage or early in the Yuzanjian stage. By contrast, other species, such as the warm-water elements in the lower sublittoral zone and Japonic endemic elements in all depth zones, survived through all three stages.

These examples therefore demonstrate that the cooling effect of the sea water on the fauna in the Kakegawa area is restricted to the upper sublittoral zone.

Water mass fluctuation causing the faunal change

The faunal changes mentioned above seem to have occurred correspondingly to the stationary to regressive phases of sedimentary process. It is most likely that the fluctuation of sea water temperature associated with eustatic sea-level change caused the faunal change. The results noted above, however, suggest that the cooling effect was restricted to the upper sublittoral zone and that the thermal change in the deeper zones was too small to cause marked faunal change.

The molluscs in the "paleo-sea of Enshu", except for those living in the cold intermediate water, was under the control of the "paleo-Kuroshio Warm Current" in the same way as present southwestern Japanese marine fauna is controlled by the Kuroshio Warm Current. It cannot be considered that the warm-water current vanished and was replaced by a cool current, because the Kuroshio-Japonic species, such as Clementia papyracea, Nassarius siquijorensis and Cryptopecten vesiculosus, continuously occurred through the three stages from Suchian to Yuzanjian, as shown in Fig.13. The difference in the faunal change between depths is most likely to have been related with water thermal structure in the nearshore-offshore area under the influence of the "paleo-Kuroshio Warm Current". Chinzei and Aoshima's (1976) isotopic analysis along tuff layers in the Kechienjian stage showed that the water thermal structure at the earliest Pleistocene was quite similar to that of the present-day Kuroshio water. Almost all of the localities for their analysis, however, yields molluscan assemblages only under the influence of offshore, oceanic water. Therefore, conditions of water masses in the nearshore sea are needed to be considered for discussion on this selective faunal change.

As noted before, the nearshore molluscan assemblages were under the influence of coastal water. Its influence on nearshore organisms is recognized during both the Suchian and Yuzanjian stages, as reported by Aoshima (1978). According to him, foraminiferal indicators for coastal water mass, such as a low percentage of planktonic foraminifera and low species diversity, can be recognized in the Dainichi Formation, in the basal and uppermost parts of the Ukari Formation, and in the Soga Formation. The localities indicating the influence of coastal water nearly correspond to the localities yielding upper sublittoral species in this survey. By contrast, lower sublittoral and bathyal species were under the influence of oceanic Kuroshio water.

According to Horikoshi (1987), coastal water is formed by the influx of fresh water from the land during summer, when the water masses are strongly stratificated. Horikoshi (1987) stated that coastal water covers the inner shelf in the summer, but that it disappears in winter, when the sea surface is cooled and the water conditions are convectional. Conditions of coastal water are controlled by various factors such as terrestrial climate (atmospheric temperature and amount of precipitation), and topography of coastline (embayment, gulf, or open sea). Changes in such factors could have intensified the effect of cooling associated with eustatic sea-level change and could have caused the difference of the faunal change between depths.

For example, Japanese terrestrial climate deteriorated from a warm temperate to a more arctic one with severe winters during the interval of late Pliocene to early Pleistocene age, as shown in the terrestrial floral change in Osaka, Aizu, and Niigata areas by Suzuki and Nasu (1988). During the interval, the Tertiary type plants, such as Metasequoia and Glyptostrobus, disappeared in steps, and some boreal elements, such as Pinus koraiensis and Picea jezoensis, appeared for the first time. Some problems still remain unsolved in correlations between marine sediments and terrestrial (and fresh water) ones, as noted by Nakagawa (1988). The terrestrial floral succession, however, leads to one of the possible scenarios to explain the selective fluctuation of water masses, as follows.

During the Suchian stage (late Pliocene), the terrestrial climate was warm-temperate throughout the year. That is, the winter climate was mild and the annual temperature range was relatively small. Thus, winter convectional conditions were difficult to initiate, and warm coastal water is estimated to have covered the nearshore area all year round.

By contrast, during the Kechienjian and Yuzanjian stages (earliest Pleistocene), the winter terrestrial climate became more severe than in the Suchian stage. As a result, winter convectional conditions occurred in the nearshore sea and warm coastal water disappeared during the winter. This change in the water seasonality seems likely to have had a more severe effect on organisms in the upper sublittoral zone than on those in the lower sublittoral zone, because upper sublittoral species had lived in the warm coastal water stratified throughout the year during the Suchian stage, whereas lower sublittoral species were under the influence of offshore Kuroshio water all year round, as they previously had been. This intensified seasonality caused the faunal change in the nearshore area.

This scenario mentioned above focuses on conditions of coastal water. On the contrary, it is possible to consider that physical factors of the oceanic Kuroshio water, such as current intensity, primarily controlled the nearshore faunal change. At a global scale, the current intensity is related to heat transport to the latitude. At a local scale, more directly influenced by the oceanic water current, an upper shelf fauna contains more warm-water species, as suggested in Sagami Bay by Horikoshi (1957). Therefore, changes of the current course also could have influenced the faunal change.

At present it cannot be specified what is the trigger leading to the disappearance of warm-water species only in the upper sublittoral zone. More studies and investigations are needed, in particular on the interaction of the terrestrial climate and marine climate in each depth zone and on thermal structural change in the Kuroshio Current along the vertical (depth) and horizontal (latitude) axes. The results of this paper on faunal change, however, enable a start to be made in understanding the fluctuation of the water mass structure associated with eustatic sea-level change over a period near the Pliocene/Pleistocene boundary.

Conclusions

1) Ten types of molluscan assemblages are recognized in muddy sand to silt facies of the upper part of the Kakegawa Group and the Tamari Formation. Their depositional environments range from a muddy sand bottom in the upper sublittoral zone to a silt bottom in the bathyal zone, as shown in Fig.3.

2) The horizontal distributions of the molluscan assemblages are examined along three key tuff layers. A general trend on the horizontal distributions are recognized. The shelf fauna (the 1- to 4-types), 5-, 6-, 7-, 8-, and 10-type assemblages occur in order

from northwest to southeast. Even in the deep-sea, massive silt facies, their distributions seems to show a stable "5-6-7" pattern in every stages rather than a disorder, "mosaic" of different types. The distribution pattern temporally shifted landward or seaward correspondingly to the transgression or regression (Fig.4). The temporal change of the distribution pattern reflects the sedimentary processes as follows: 1) the transgressive phase in the latest Pliocene (narrow lower shelf and landward shift of the horizontal distribution pattern of the shelf - bathyal assemblages); 2) the transitional phase from transgression to regression in the earliest Pleistocene (widely extended lower shelf and seaward shift of the "5-6-7 distribution pattern"); 3) the regressive phase after the early Pleistocene cooling event at 1.6 Ma (reduced lower shelf area and seaward shift of the "5-6-7 distribution pattern").

3) The species composition of the molluscan assemblages and their horizontal distributions suggest that the water mass structure in the "paleo-sea of Enshu" was similar to that in the present Kuroshio Current region. The horizontal distribution pattern presents one of typical faunal changes on the level of "assemblage" along depths in the Kuroshio Current region, from the upper sublittoral zone under the influence of the coastal water to the bathyal zone in the cold intermediate water. The regular distribution pattern of the assemblages was likely formed by the composition of various nature of water masses (water temperature and seasonal fluctuation, concentration of dissolved oxygen, and trophic conditions), as shown in Fig.11. The latter two factors might have made an important role on the distribution of the 5- to 9-type assemblages in the similar silt facies of slope and basins.

4) I traced the temporal distributions of species characteristic of each bathymetric depth zone. Some warm-water elements in the upper sublittoral zone disappeared in step in the early Pleistocene. By contrast, warm-water elements in the lower sublittoral zone and Japonic endemic elements in all depths occurred throughout the period during the late Pliocene to the earliest Pleistocene. This result is supported by the comparisons of the temporal distributions between taxonomically close species, ecological characters such as life habits and feeding-types being similar. The cooling effect on faunal change was restricted to the upper sublittoral zone.

5) The difference in the faunal change between depths probably is related with water thermal structure in the nearshore-offshore area. One of the models explaining the selective faunal change between depths is as follows. The seasonal fluctuation of the coastal water was intensified by the cooling of the land climate in the early Pleistocene. This intensified seasonality caused the faunal change in the upper sublittoral zone, whereas the fluctuation was too weak to caused marked faunal change in the deeper zones under the influence of offshore Kuroshio water all year round. The results on the faunal change give clues to the understanding of the fluctuation of water mass structure associated with eustatic sea-level change over a period near the Pliocene/Pleistocene boundary.

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Captions of Figure and Tables

Fig.1. (A) Index map of the Kakegawa area. (B) Geological map of the studied area, showing sampling localities. (C1)-(C5) Enlargement map showing locations of columnar sections and sampling localities near Ukari, Hosoya, Kakegawa, Kogosho to Ganshoji, and Kamihijikata to Shimohijikata.

Fig.2. Schematic stratigraphic section of the upper part of the Kakegawa Group, showing the distribution of the sampling localities. The time scale was compiled from the data of magnetostratigraphy (Yoshida and Niitsuma, 1976), fission track age (Nishimura, 1977) and planktonic foraminiferal biostratigraphy (Ibaraki, 1986b).

Fig.3. Molluscan fossil assemblages in the A- and A′-type occurrence and their depositional environments. Square: schematic occurrence mode in vertical sections normal to the bedding plane.

Fig.4. Distribution of the molluscan assemblages.

Fig.5. Columnar section showing the alternation of the 8- and 9-type assemblages.

Fig.6. Columnar sections plotted with assemblage types in the Ukari Formation.

Fig.7. Columnar sections plotted with assemblage types along the Soga Tuff horizon.

Fig.8. Depositional environments inferred from the distribution of molluscan assemblages along the key tuff layers. A= horizon along the Hosoya Tuff; B= horizon along the T3 Tuff; C= horizon along the Soga Tuff.

Fig.9. Relationship between the molluscan assemblages and water masses, cross-checked by correlation of their stratigraphic

distributions with those of Aoshima's (1978) foraminiferal assemblages. *; Fossil benthic foramniferas living in about 1000m deep were obtained from silt at NK100U, NK101C, NK102, NK102FB, and NK103 (personal communication from Dr. H. Kitazato).

Fig.10. Model of the environmental changes envisaged to form the alternation of reducing and oxic fossil assemblages. A= *Akebiconcha kawamurai*; L= *Lucinoma*; C= *Conchocele*; S= *Solemya*. (after Nobuhara and Tanaka, in press)

Fig.11. Schematic concept on change in molluscan assemblages along depths in the "paleo-sea of Enshu" and the relationship with water mass conditions. 1= *Amussiopecten praesignis*; 2= *Clementia papyracea*; 3= *Scapharca castellata*; 4= *Paphia schnelliana*; 5= *Glycymeris rotunda*; 6= *Ventricolaria foveolata*; 7= *Parabathytoma luedorfi*; 8= *Nassaria magnifica*; 9= *Makiyamaia coreanica*; 10= *Limopsis tajimae*; 11= *Carinineilo carinifera*; 12= *Neilonella coix*; 13= "*Empleconia*" sp. A; 14= *Bathybembix aeola*; 15= *Akebiconcha kawamurai*; 16= *Conchocele bisecta*; 17= *Lucinoma* aff. *acutilineata*; 18= *Limopsis* cf. *uwadokoi*.

Fig.12. Terminology of the water regimes (based on geographic distribution) of molluscs living now on the Pacific side of Japan. Courses on ocean currents are compiled after Natural Astronomical Observatory (1992).

Fig.13. Temporal distributions of the species characteristic of each bathymetric depth. Supplementary interpretation on habitat depths: #1= species which commonly occur in the Dainichi Fm. and whose occurrences are restricted in the assemblages of 1- to 4I-types in Fig.3; #2= species which now live in lower sublittoral depths and the deeper zones but also occur abundantly in the assemblages of 1- to 3-types; #3=

species which now lives on shelf but also occur abundantly in the assemblages of 5- to 7-types. Water regime for living species: K, KJ, SJ, J (see Fig.12); that for extinct species: *W= warm-water; *J= Japonic. Fossil occurrence: circle= A- and A′-type; triangle = B-type.

Fig.14. Comparison of the distributions of taxonomically close species.

Fig.14a. Distributions of "*Limopsis*" species.

Fig.14b. Distributions of *Paphia* species.

Fig.14c. Distributions of "*Chlamys*" species.

Fig.14d. Distributions of *Amussiopecten* and *Mizuhopecten*.

Appendix tables 1-4. List of molluscan fossils at representative localities. R=1-2, F=3-4, C=5-9, A=10-19, VA=20-, in number of specimens.

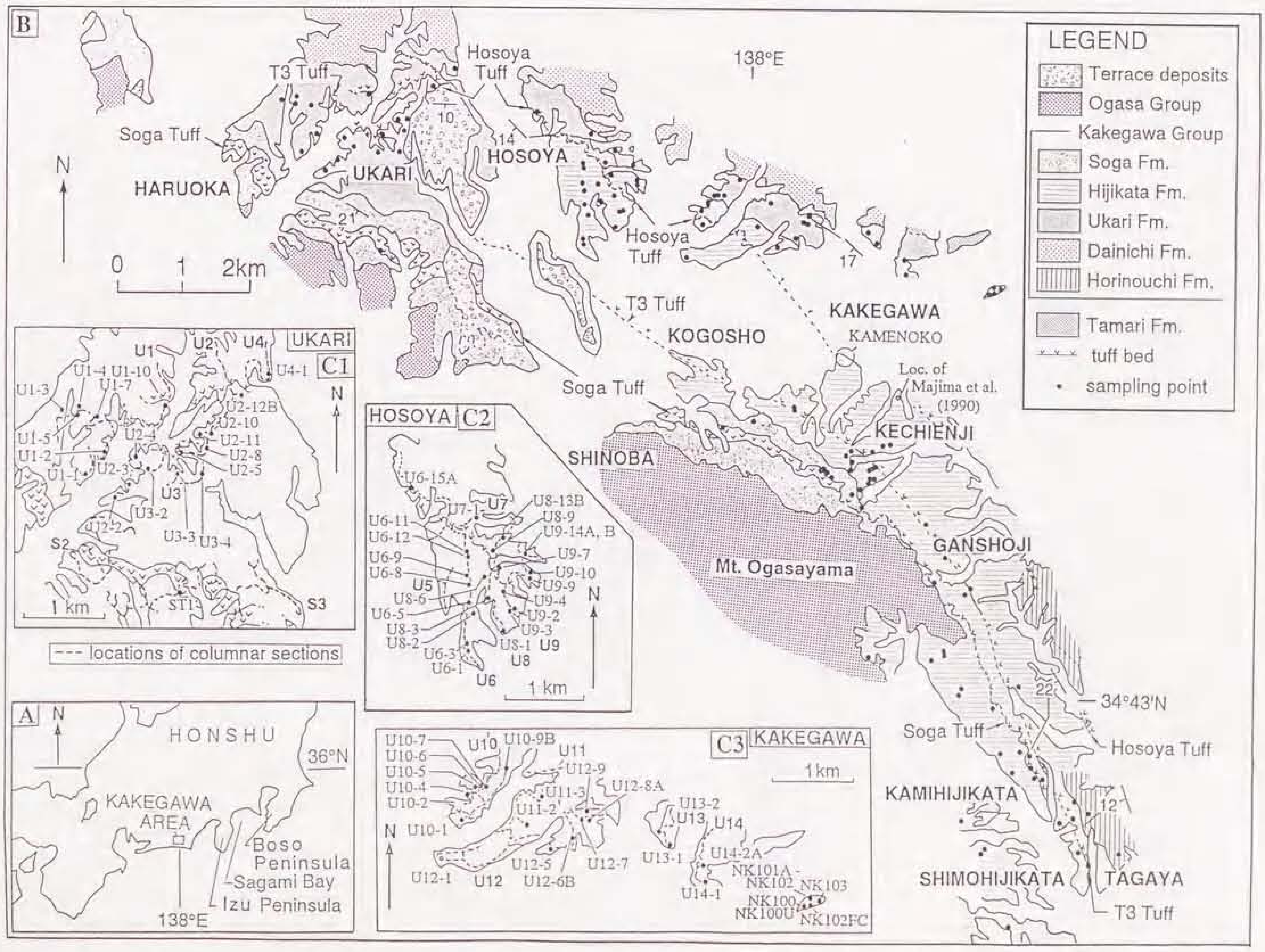
Plates. Representative species of each molluscan assemblage.

Pl.1. Characteristic species of each bathymetric depth (1). upper sublittoral depths. 1a,b, *Nassarius dorsatus* (Röding), X1, ESN 50013, Loc. U10-9B; 2, *Venericardia panda* (Yokoyama), X0.75, ESN 50020, Loc. U13-1; 3, *Clementia papyracea* Gray, X1, ESN 50016, Loc. ST8; 4, *Scapharca castellata* (Yokoyama), X1, ESN 50043, Loc. U1-4; 5, *Cucullaea labiosa granulosa* Jonas, X0.65, ESN 50018, Loc. U8-13B; 6a,b, *Oblimopa japonica* (A. Adams), X1.7, ESN 50014, Loc. U13-2; 7, *Chlamys satoi* (Yokoyama), X0.8, ESN 50019, Loc. U9-14A; 8, *Paphia amabilis* (Philippi), X0.75, ESN 50015, Loc. U9-14B; 9, *Anisocorbula scaphoides* (Hinds), X1, ESN 50017, Loc. U10-9B; 10, *Mizuhopecten tokyoensis hokurikuensis* (Masuda), X0.83, ESN 50022, Loc. U12-6B; 11, *Amussiopecten praesignis* (Yokoyama), X0.75, ESN 50021, Loc. U8-13B.

Pl.2 Characteristic species of each bathymetric depth (2). 1a-5, 9, upper to lower sublittoral depths; 6-8, lower sublittoral depths; 10-21b, shelf-edge to bathyal depths. 1a,b, *Nassarius siquijorensis* (A. Adams), X1, ESN 50023, Loc. U3-4; 2a,b, *Crenulilimopsis oblonga* (A. Adams), X1.7, ESN 50024, Loc. U10-5; 3, *Paphia schnelliana* (Dunker), X0.9, ESN 50025, Loc. U6-15A; 4a,b, *Glycymeris rotunda* (Dunker), X0.9, ESN 50027, Loc. U1-3;5, *Cycladicama cumingii* (Hanley), X1, ESN 50026, Loc. U2-3; 6, *Nemocardium samarangae* (Makiyama), X1, ESN 50031, Loc. U1-3; 7, *Cryptopecten vesiculosus* (Dunker), X1, ESN 50029, Loc. U2-10; 8, *Ventricolaria foveolata* (Sowerby), X1, ESN 50030, Loc. U1-3; 9, *Onustus exutus* (Reeve), X1.2, ESN 50028, Loc. Ogz1; 10, *Nassaria magnifica* (Lischke), X1, ESN 50033, Loc. MKCW6; 11, *Parabathytoma luedorfi* (Lischke), X1, ESN 50044, Loc. MKCW7; 12, *Makiyamaia coreanica* (Adams et Reeve), X1, ESN 50035, Loc. MKCW6; 13, *Baryspira suavis* (Yokoyama), X1, ESN 50034, Loc. MKCW7; 14, *Bathybembix argenteonitens* (Lischke), X1, ESN 50038, Loc. MKCW6; 15, *Yoldia similis* Kuroda et Habe, X1, ESN 50045, Loc. KHO24; 16a,b, *Limopsis tajimae* Sowerby, X1, ESN 50032, Loc. U6-12; 17, *Ennucula niponica* (Smith), X1.3, ESN 50036, Loc. ST12; 18, *Bathymalletia inaequilateralis* Habe, X1.7, ESN 50046, Loc. KHO21; 19a,b, *Carinineilo carinifera* (Habe), X1.3, ESN 50047, Loc. U9-3; 20, *Neilonella coix* Habe, X1.7, ESN 50037, Loc. U9-3; 21a,b, *Neilonella japonica* Okutani, X1.7, ESN 50048, Loc. HY1.

Pl.3 Characteristic species of each bathymetric depth (3). bathyal species under the influence of the cold water mass. 1a,b, "*Empleconia*" sp. A, X1, ESN 50001, Loc. NK100U; 2, *Neilonella coix* Habe, X2, ESN 50003, Loc. NK100U; 3, *Bathybembix aeola* (Watson), X1, ESN 50002, Loc. NK101A-B; 4, *"Rectiplanes"* sp., X1, ESN 50042, Loc. NK10? (float); 5a,b, *Limopsis* cf. *uwadokoi* Oyama, X1, ESN 500049, Loc. S-N4’; 6, *Conchocele bisecta* (Conrad), X1, ESN 50006, Loc. NK103; 7a,b, *Neptunea constricta* (Dall), X0.7, ESN 50039, Loc. NK102; 8, *Akebiconcha kawamurai* Kuroda, X0.9, ESN 50012, Loc. NK103; 9, *Lucinoma* aff. *acutilineata* (Conrad), X1, ESN 50005, Loc. NK103; 10, *Akebiconcha kawamurai* Kuroda, X1, ESN 50011, Loc. NK100U; 11, *Solemya* (*Acharax*) *johnsoni* Dall, X1, ESN 50007, Loc. NK103.

Fig. 1


B
N
HARUOKA
Soga Tuff
T3 Tuff
UKARI
HOSOYA
Hosoya Tuff
10
14
21
0 1 2km
138°E
Hosoya Tuff
17
T3 Tuff
KOGOSHO
KAKEGAWA
KAMENOKO
Soga Tuff
Loc. of Majima et al. (1990)
SHINOBA
KECHIENJI
Mt. Ogasayama
GANSHOJI
34°43'N
Soga Tuff
Hosoya Tuff
KAMIHIJIKATA
22
12
SHIMOHIJIKATA
TAGAYA
T3 Tuff
LEGEND
Terrace deposits
Ogasa Group
Kakegawa Group
Soga Fm.
Hijikata Fm.
Ukari Fm.
Dainichi Fm.
Horinouchi Fm.
Tamari Fm.
tuff bed
sampling point
UKARI C1
U1 U2 U4 U4-1
U1-3 U1-4 U1-10 U1-7
U1-5 U1-2 U1-1 U2-4 U2-3
U2-12B U2-10 U2-11 U2-8 U2-5
U3 U3-2 U3-3 U3-4 U2-2
S2 ST1 S3
N
1 km
--- locations of columnar sections
HOSOYA C2
U6-15A U7 U7-1
U8-13B U8-9 U9-14A, B
U6-11 U6-12 U6-9 U6-8 U6-5
U5 U8-6 U8-3 U8-2 U6-3 U6-1 U6
U9-7 U9-10 U9-9 U9-4 U9-2 U9-3 U8-1 U9 U8
N
1 km
A N
HONSHU
36°N
KAKEGAWA AREA
Boso Peninsula
Sagami Bay
Izu Peninsula
138°E
C3 KAKEGAWA
1km
U10-7 U10-6 U10-5 U10-4 U10-2 U10-1
U10 U10-9B U11 U12-9
U11-3 U11-2 U12-8A
U12-1 U12 U12-5 U12-6B U12-7
U13-2 U13 U14 U13-1 U14-1 U14-2A
NK101A NK102 NK103 NK100 NK100U NK102FC
N

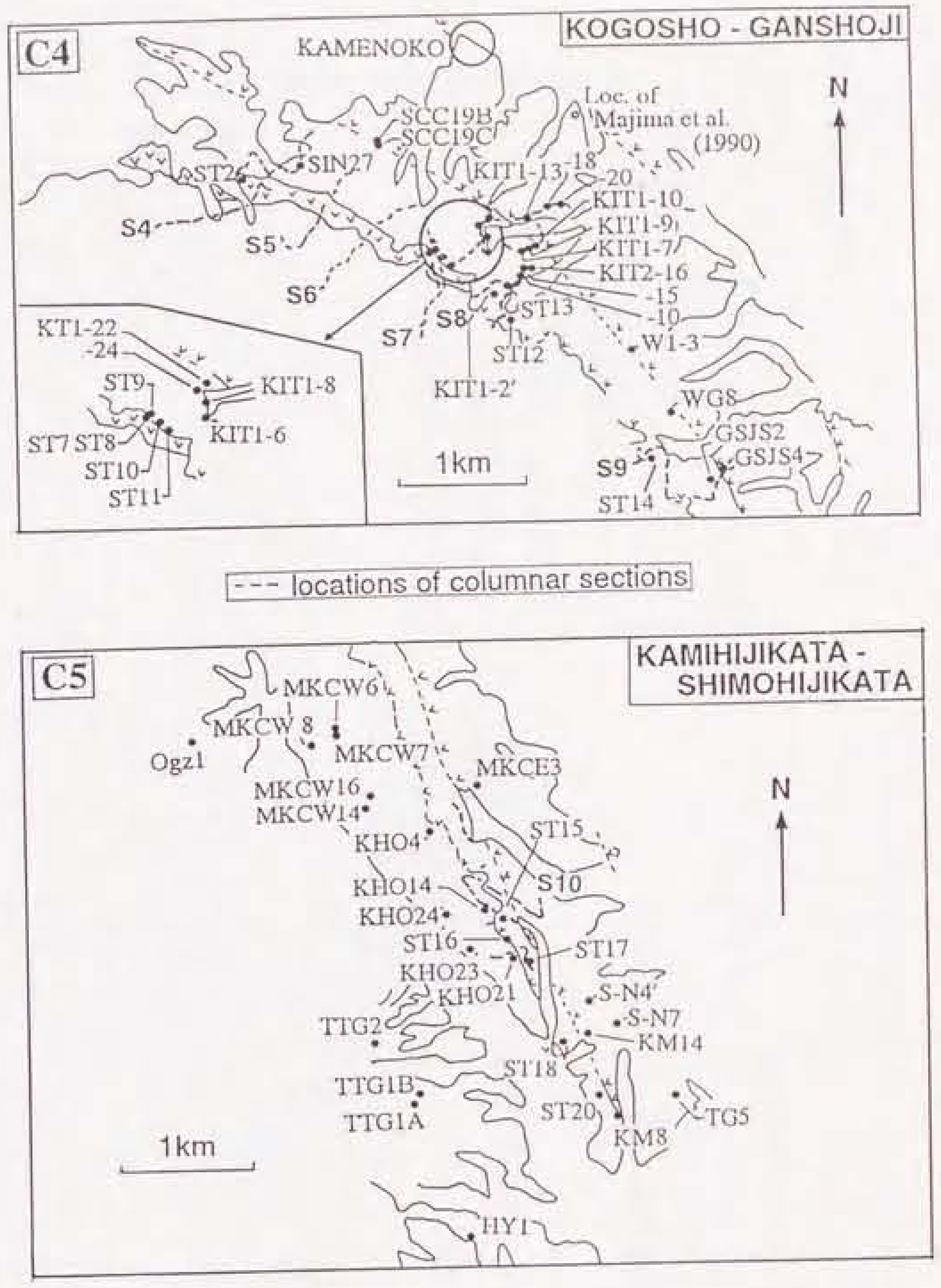

C4
KOGOSHO - GANSHOJI
KAMENOKO
N
SCC19B
SCC19C
Loc. of Majima et al. (1990)
ST26
SIN27
KIT1-13
-18
-20
KIT1-10
KIT1-9
KIT1-7
KIT2-16
-15
-10
S4
S5'
S6
S7
S8
ST13
ST12
W1-3
KIT1-2'
KT1-22
-24
ST9
KIT1-8
KIT1-6
ST7 ST8
ST10
ST11
1km
WG8
GSJS2
GSJS4
S9
ST14
--- locations of columnar sections
C5
KAMIHIJIKATA - SHIMOHIJIKATA
MKCW6
MKCW 8
Ogz1
MKCW7
MKCE3
MKCW16
MKCW14
N
KHO4
ST15
KHO14
S10
KHO24
ST16
ST17
KHO23
KHO21
S-N4'
S-N7
TTG2
KM14
ST18
TTG1B
TTG1A
ST20
KM8
TG5
1km
HY1

Fig. 1

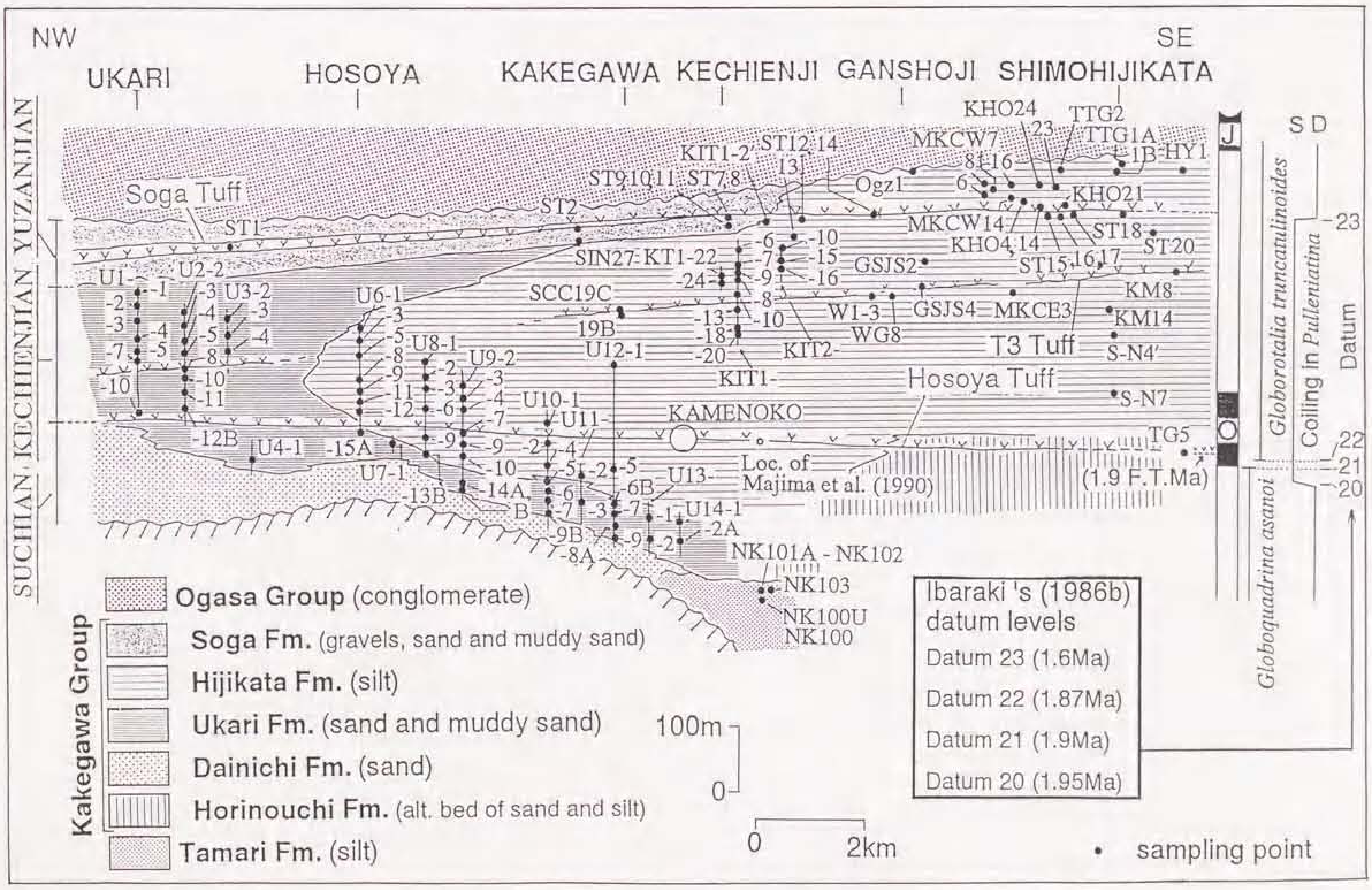
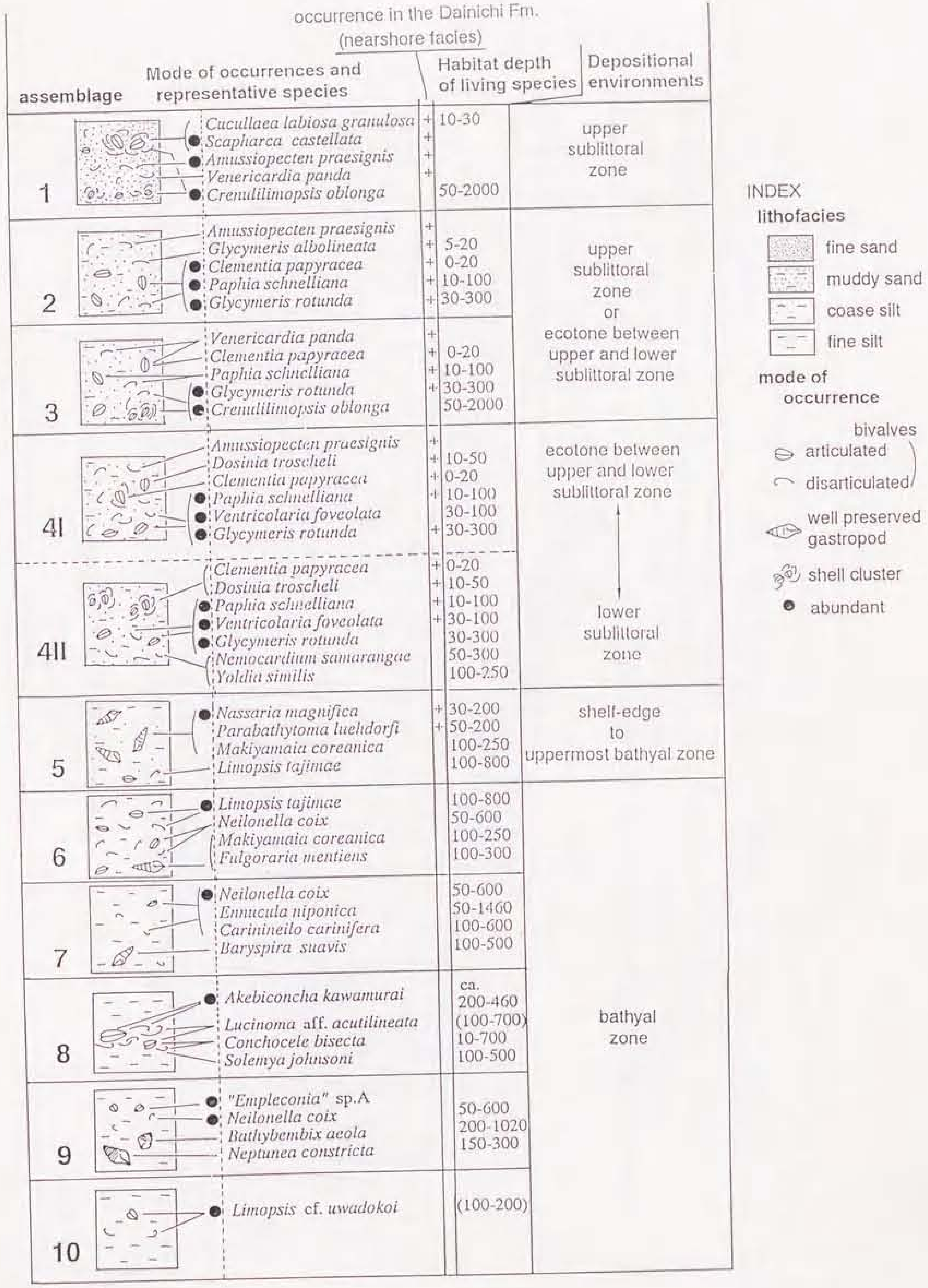

NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
SUCHIAN
KECHIENJIAN
YUZANJIAN
Soga Tuff
T3 Tuff
Hosoya Tuff
KAMENOKO
Loc. of Majima et al. (1990)
(1.9 F.T.Ma)
J
O
S D
Globorotalia truncatulinoides
Globoquadrina asanoi
Coiling in Pulleniatina
Datum
23
22
21
20
Kakegawa Group
Ogasa Group (conglomerate)
Soga Fm. (gravels, sand and muddy sand)
Hijikata Fm. (silt)
Ukari Fm. (sand and muddy sand)
Dainichi Fm. (sand)
Horinouchi Fm. (alt. bed of sand and silt)
Tamari Fm. (silt)
100m
0
0
2km
Ibaraki 's (1986b) datum levels
Datum 23 (1.6Ma)
Datum 22 (1.87Ma)
Datum 21 (1.9Ma)
Datum 20 (1.95Ma)
• sampling point

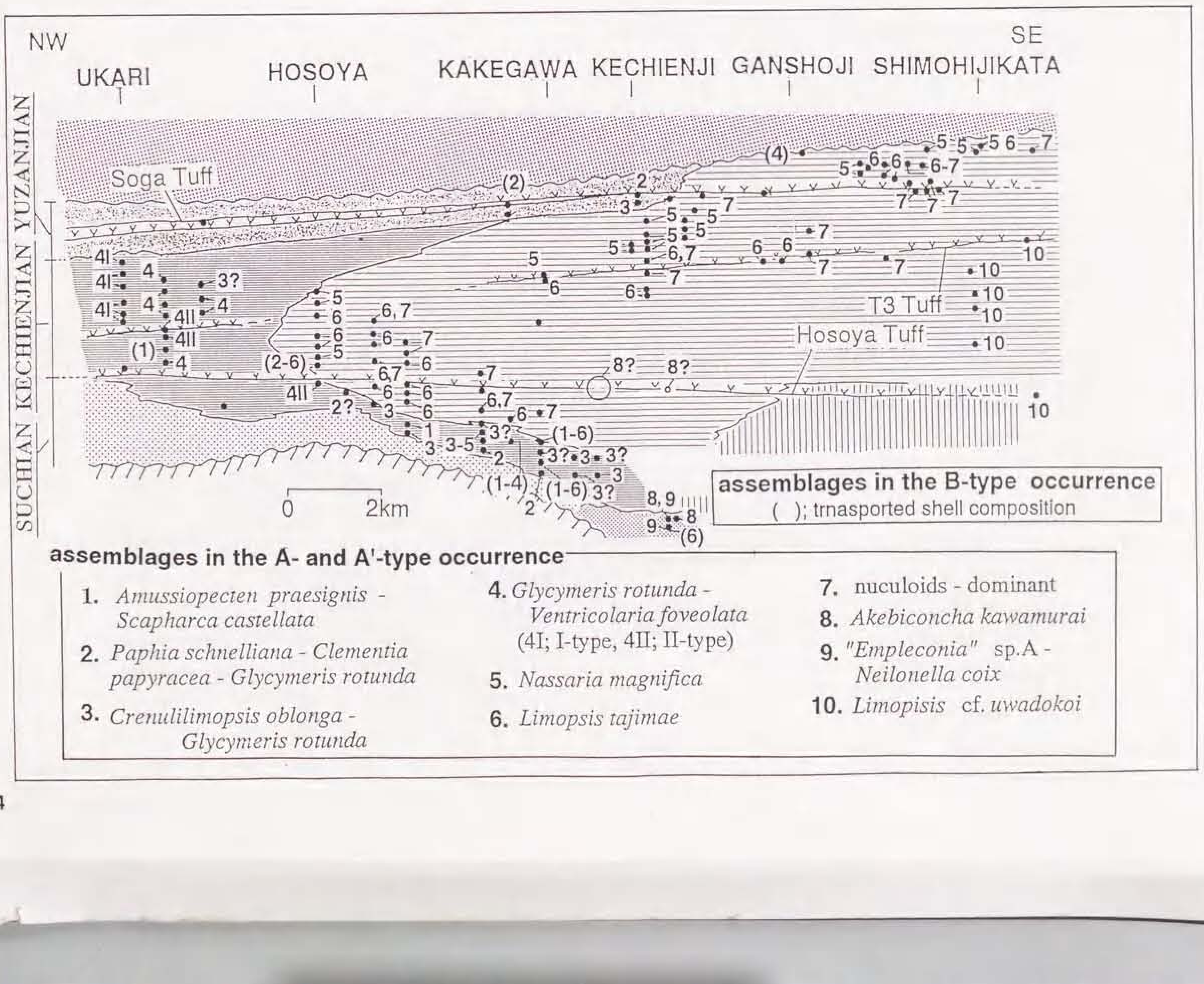
Fig. 2



assemblage	Mode of occurrences and representative species	occurrence in the Dainichi Fm. (nearshore facies)	Habitat depth of living species	Depositional environments
1	*Cucullaea labiosa granulosa*	+	10-30	upper sublittoral zone
	● *Scapharca castellata*	+		
	● *Amussiopecten praesignis*	+		
	Venericardia panda	+		
	● *Crenulilimopsis oblonga*		50-2000	
2	*Amussiopecten praesignis*	+		upper sublittoral zone or ecotone between upper and lower sublittoral zone
	Glycymeris albolineata	+	5-20	
	● *Clementia papyracea*	+	0-20	
	● *Paphia schnelliana*	+	10-100	
	● *Glycymeris rotunda*	+	30-300	
3	*Venericardia panda*	+		
	Clementia papyracea	+	0-20	
	Paphia schnelliana	+	10-100	
	● *Glycymeris rotunda*	+	30-300	
	● *Crenulilimopsis oblonga*		50-2000	
4I	*Amussiopecten praesignis*	+		ecotone between upper and lower sublittoral zone ↕ lower sublittoral zone
	Dosinia troscheli	+	10-50	
	Clementia papyracea	+	0-20	
	● *Paphia schnelliana*	+	10-100	
	● *Ventricolaria foveolata*		30-100	
	● *Glycymeris rotunda*	+	30-300	
4II	*Clementia papyracea*	+	0-20	
	Dosinia troscheli	+	10-50	
	● *Paphia schnelliana*	+	10-100	
	● *Ventricolaria foveolata*	+	30-100	
	● *Glycymeris rotunda*		30-300	
	Nemocardium samarangae		50-300	
	Yoldia similis		100-250	
5	● *Nassaria magnifica*	+	30-200	shelf-edge to uppermost bathyal zone
	Parabathytoma luehdorfi	+	50-200	
	Makiyamaia coreanica		100-250	
	Limopsis tajimae		100-800	
6	● *Limopsis tajimae*		100-800	bathyal zone
	Neilonella coix		50-600	
	Makiyamaia coreanica		100-250	
	Fulgoraria mentiens		100-300	
7	● *Neilonella coix*		50-600	
	Ennucula niponica		50-1460	
	Carinineilo carinifera		100-600	
	Baryspira suavis		100-500	
8	● *Akebiconcha kawamurai*		ca. 200-460	
	Lucinoma aff. *acutilineata*		(100-700)	
	Conchocele bisecta		10-700	
	Solemya johnsoni		100-500	
9	● "*Empleconia*" sp.A			
	● *Neilonella coix*		50-600	
	Bathybembix aeola		200-1020	
	Neptunea constricta		150-300	
10	● *Limopsis* cf. *uwadokoi*		(100-200)	

Fig. 3

Fig. 4



NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
YUZANJIAN
KECHIENJIAN
SUCHIAN
Soga Tuff
T3 Tuff
Hosoya Tuff
0
2km
assemblages in the B-type occurrence
( ); trnasported shell composition
assemblages in the A- and A'-type occurrence
1. Amussiopecten praesignis - Scapharca castellata
2. Paphia schnelliana - Clementia papyracea - Glycymeris rotunda
3. Crenulilimopsis oblonga - Glycymeris rotunda
4. Glycymeris rotunda - Ventricolaria foveolata (4I; I-type, 4II; II-type)
5. Nassaria magnifica
6. Limopsis tajimae
7. nuculoids - dominant
8. Akebiconcha kawamurai
9. "Empleconia" sp.A - Neilonella coix
10. Limopisis cf. uwadokoi

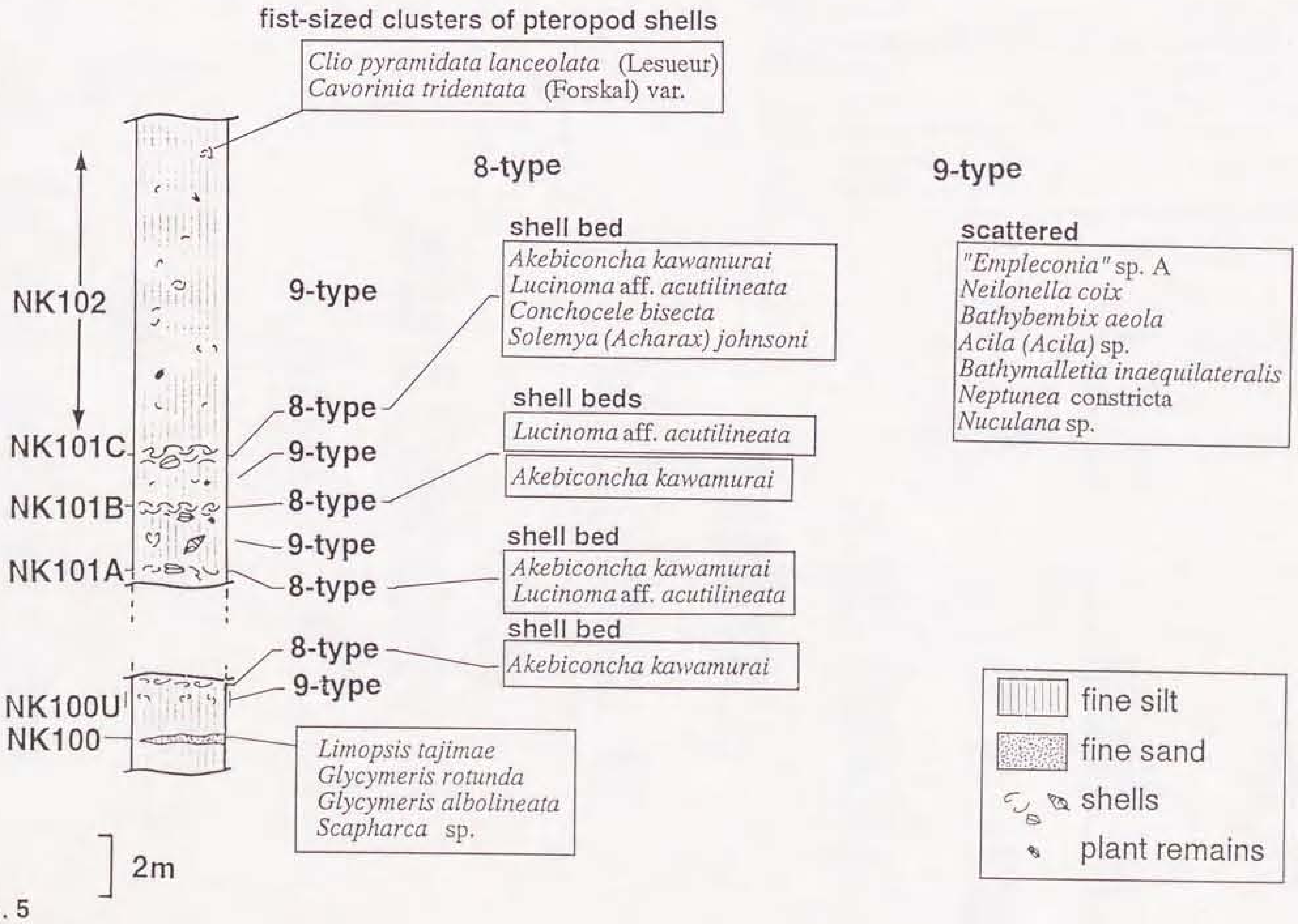

fist-sized clusters of pteropod shells
Clio pyramidata lanceolata (Lesueur)
Cavorinia tridentata (Forskal) var.
8-type
9-type
NK102
9-type
shell bed
Akebiconcha kawamurai
Lucinoma aff. *acutilineata*
Conchocele bisecta
Solemya (Acharax) johnsoni
scattered
"*Empleconia*" sp. A
Neilonella coix
Bathybembix aeola
Acila (Acila) sp.
Bathymalletia inaequilateralis
Neptunea constricta
Nuculana sp.
NK101C
8-type
9-type
shell beds
Lucinoma aff. *acutilineata*
Akebiconcha kawamurai
NK101B
8-type
9-type
NK101A
8-type
shell bed
Akebiconcha kawamurai
Lucinoma aff. *acutilineata*
8-type
9-type
shell bed
Akebiconcha kawamurai
NK100U
NK100
Limopsis tajimae
Glycymeris rotunda
Glycymeris albolineata
Scapharca sp.
2m
fine silt
fine sand
shells
plant remains

Fig. 5

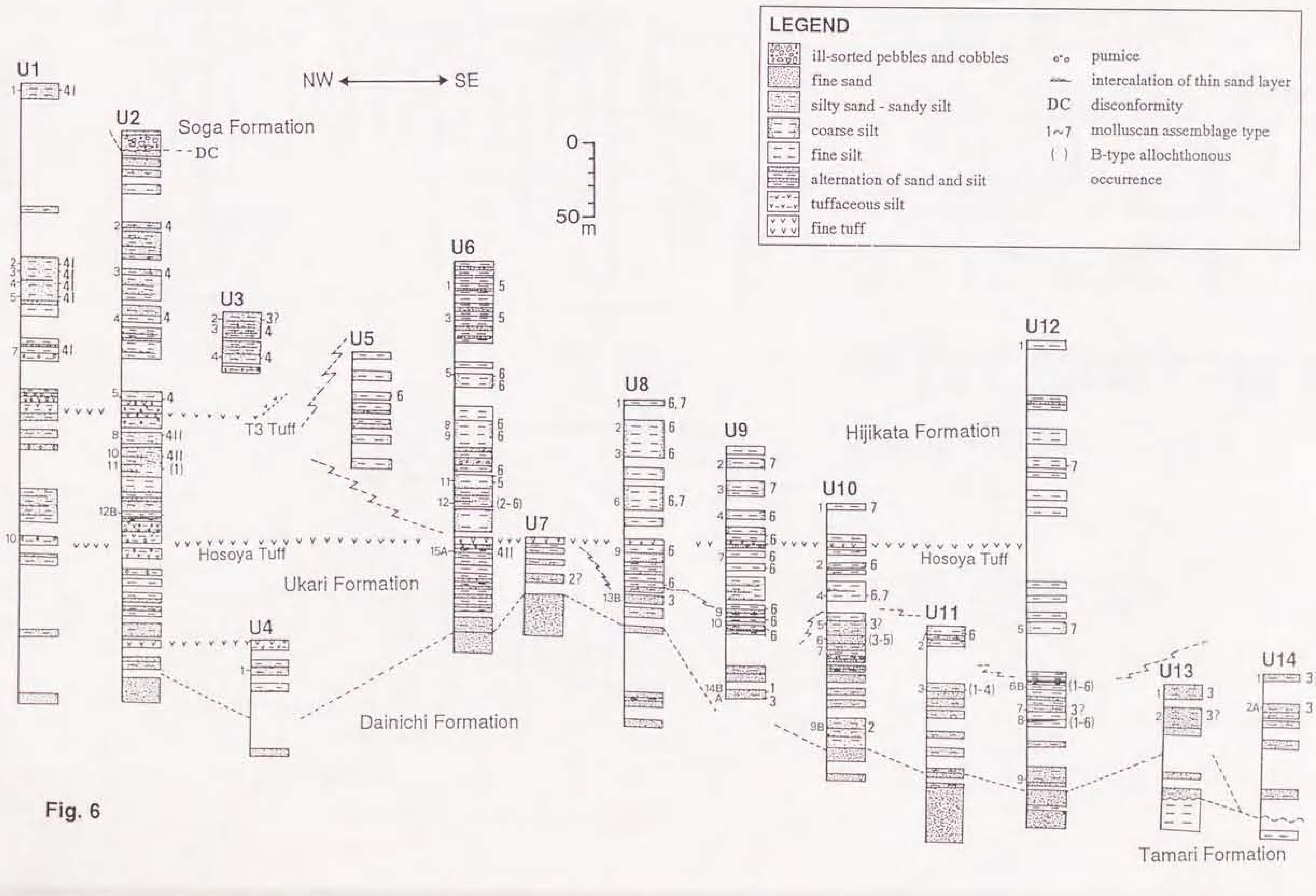

LEGEND
ill-sorted pebbles and cobbles
fine sand
silty sand - sandy silt
coarse silt
fine silt
alternation of sand and silt
tuffaceous silt
fine tuff
pumice
intercalation of thin sand layer
DC disconformity
1~7 molluscan assemblage type
( ) B-type allochthonous occurrence
NW SE
0
50 m
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
U12
U13
U14
Soga Formation
DC
T3 Tuff
Hosoya Tuff
Ukari Formation
Dainichi Formation
Hijikata Formation
Hosoya Tuff
Tamari Formation

Fig. 6

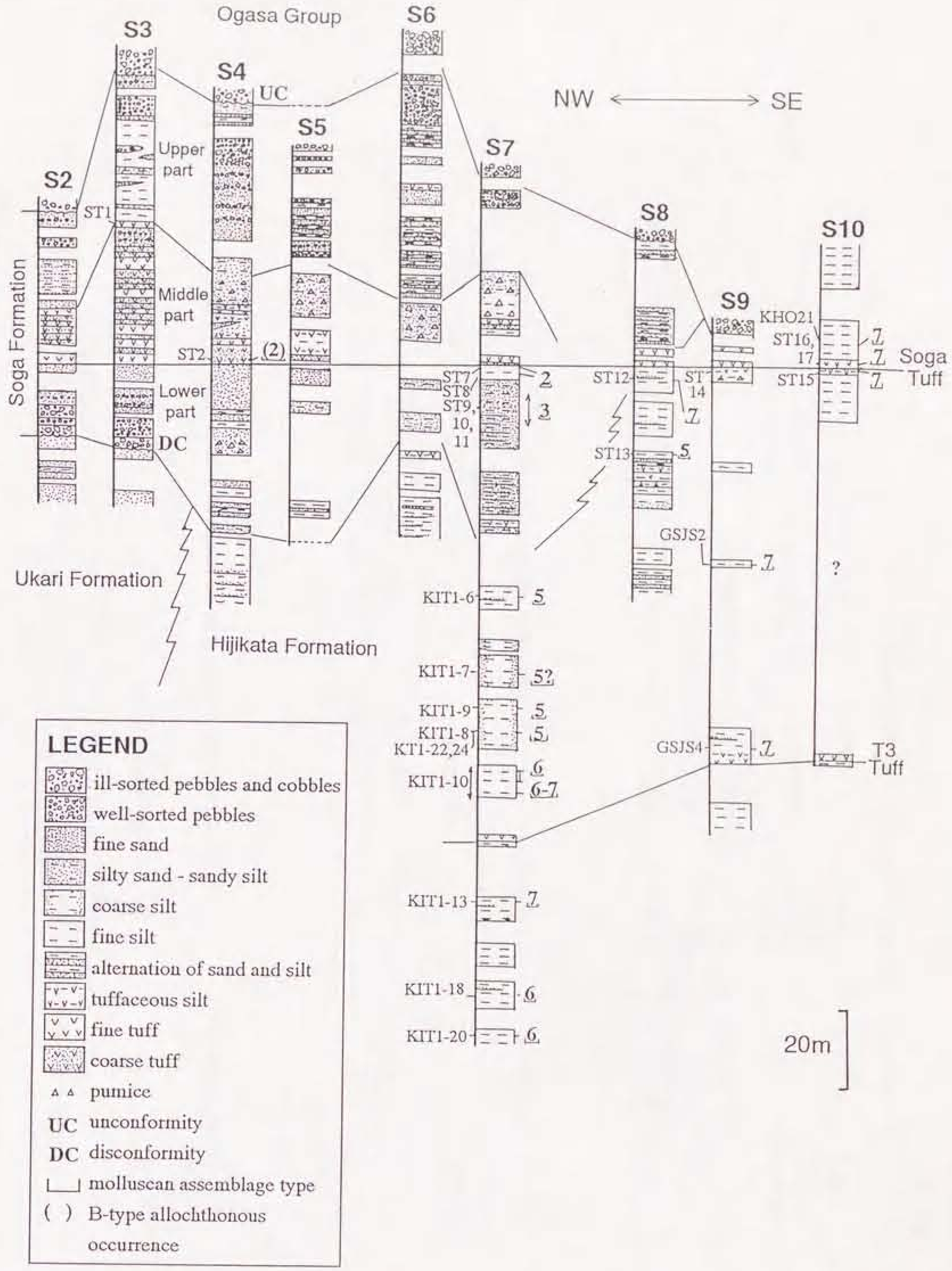

Ogasa Group
S2
S3
S4
S5
S6
S7
S8
S9
S10
NW ⟷ SE
UC
Upper part
Middle part
Lower part
DC
ST1
ST2
(2)
Soga Formation
ST7, ST8, ST9, 10, 11
2
3
ST12
ST 14
ST13
5
7
KHO21
ST16, 17
ST15
Soga Tuff
GSJS2
?
Ukari Formation
Hijikata Formation
KIT1-6
5
KIT1-7
5?
KIT1-9
5
KIT1-8
KT1-22,24
5
KIT1-10
6
6-7
GSJS4
T3 Tuff
KIT1-13
7
KIT1-18
6
KIT1-20
6
20m
LEGEND
ill-sorted pebbles and cobbles
well-sorted pebbles
fine sand
silty sand - sandy silt
coarse silt
fine silt
alternation of sand and silt
tuffaceous silt
fine tuff
coarse tuff
pumice
UC unconformity
DC disconformity
molluscan assemblage type
( ) B-type allochthonous occurrence

Fig. 7

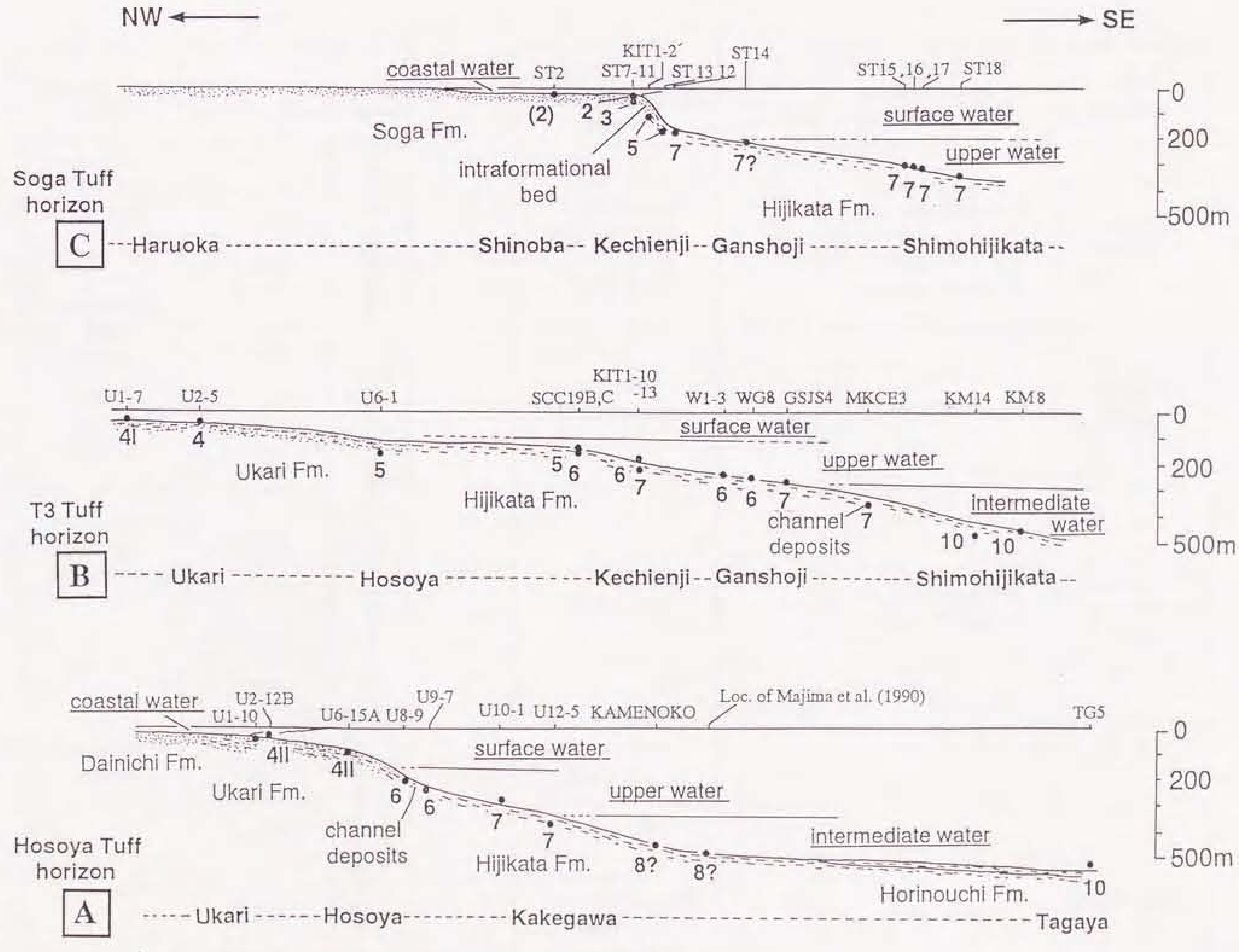
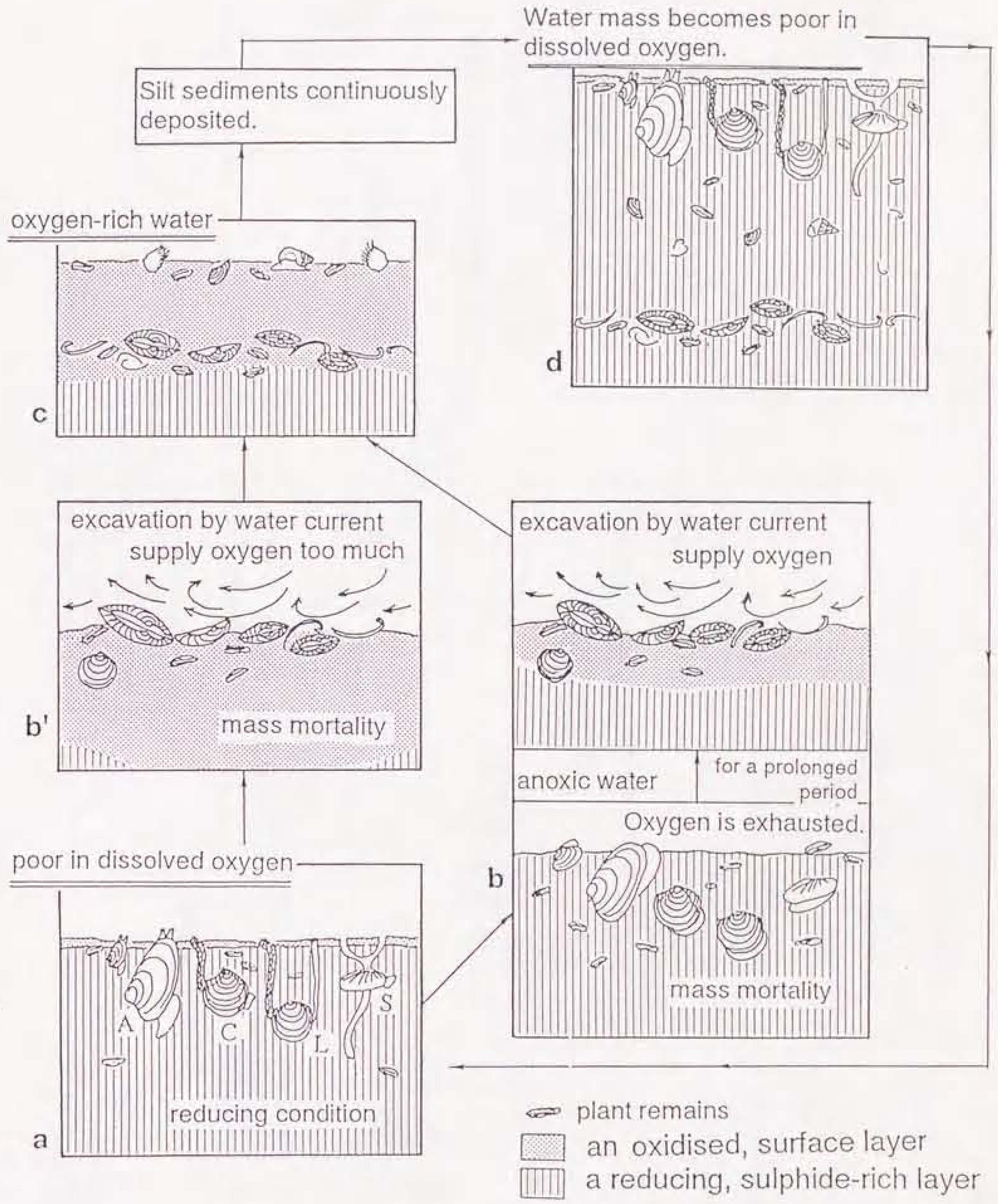

NW
SE
coastal water
ST2
KIT1-2′
ST7-11
ST 13 12
ST14
ST15,16,17
ST18
Soga Fm.
(2)
2
3
5
7
7?
7 7 7
7
surface water
upper water
intraformational bed
Hijikata Fm.
Soga Tuff horizon
C
Haruoka
Shinoba
Kechienji
Ganshoji
Shimohijikata
0
200
500m
U1-7
U2-5
U6-1
KIT1-10
SCC19B,C
-13
W1-3
WG8
GSJS4
MKCE3
KM14
KM8
4l
4
5
5
6
6
7
6
6
7
7
10
10
Ukari Fm.
Hijikata Fm.
surface water
upper water
intermediate water
channel deposits
T3 Tuff horizon
B
Ukari
Hosoya
Kechienji
Ganshoji
Shimohijikata
0
200
500m
coastal water
U2-12B
U1-10
U6-15A
U8-9
U9-7
U10-1
U12-5
KAMENOKO
Loc. of Majima et al. (1990)
TG5
Dainichi Fm.
4ll
4ll
Ukari Fm.
6
6
7
7
8?
8?
10
surface water
upper water
intermediate water
channel deposits
Hijikata Fm.
Horinouchi Fm.
Hosoya Tuff horizon
A
Ukari
Hosoya
Kakegawa
Tagaya
0
200
500m
0
10km

Fig. 8

bathymetric depth	molluscan assemblages	water masses	distributions in the stratigraphic section	foraminiferal assemblages of Aoshima (1978)	water masses
upper sublittoral zone	1-type	coastal water	Ukari Fm. (uppermost and lowermost parts) Soga Fm.	assemblage 1 (low percentage of planktonic foraminiferas: low species diversity)	coastal water
upper to lower sublittoral zone	2-type 3-type				
lower sublittoral zone	4I-type 4II-type	oceanic Kuroshio water	Ukari Fm. (middle part)	assemblage 1	surface water
shelf-edge to uppermost bathyal zone	5-type		Hijikata Fm.	assemblage 2 to assemblage 3	upper to intermediate water
bathyal zone	6-type 7-type				
	8-type	cold intermediate water	Tamari Fm. Hijikata Fm. (?)	*	intermediate water
	9-type		Tamari Fm.		
	10-type		Horinouchi Fm. (uppermost part) Hijikata Fm. (lower part)	assemblage 3	

Fig. 9



after Nobuhara and Tanaka (in press)

Fig. 10

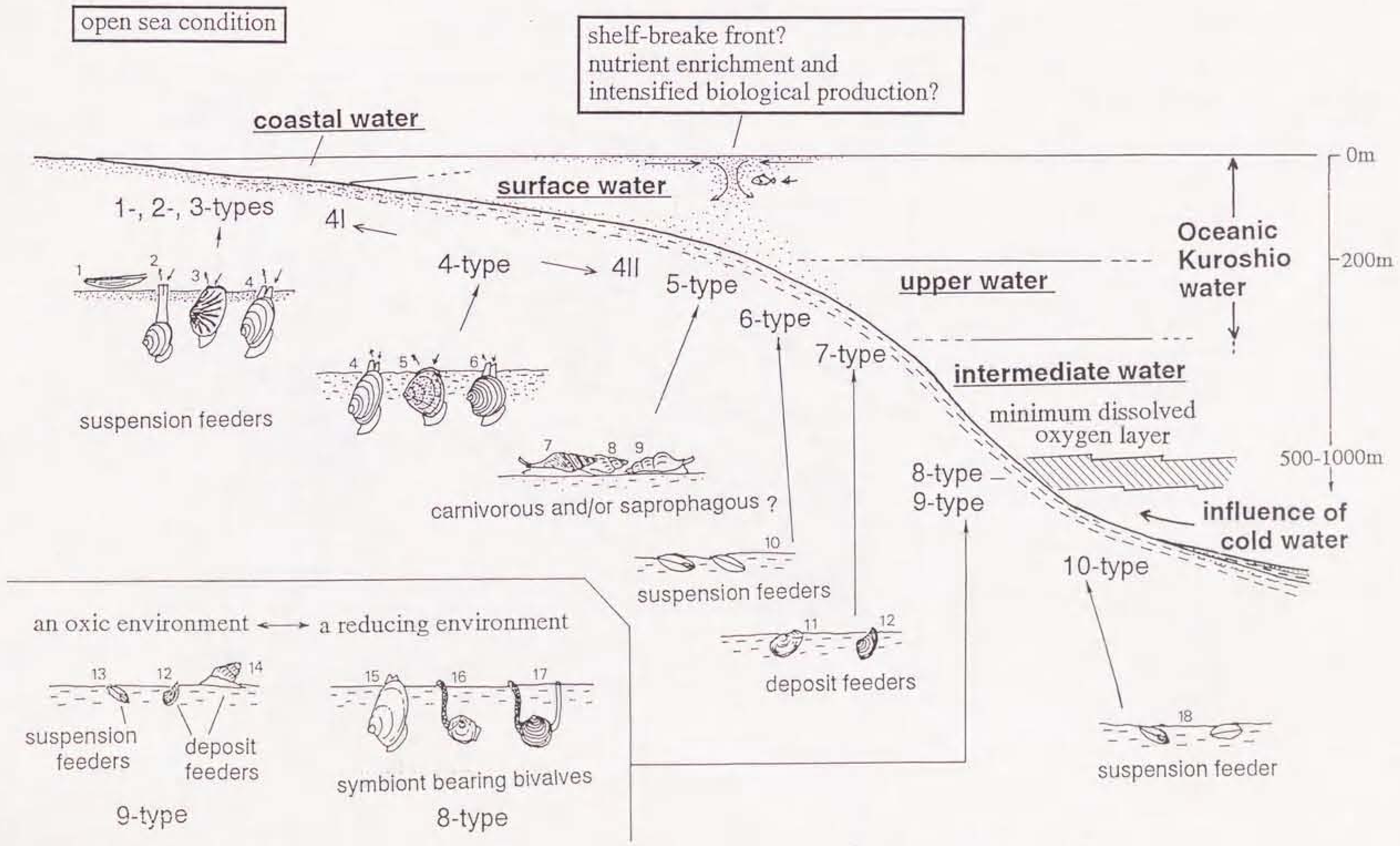

open sea condition
shelf-breake front?
nutrient enrichment and
intensified biological production?
coastal water
surface water
0m
200m
500-1000m
Oceanic
Kuroshio
water
upper water
intermediate water
minimum dissolved
oxygen layer
influence of
cold water
1-, 2-, 3-types
4I
4-type
4II
5-type
6-type
7-type
8-type
9-type
10-type
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
suspension feeders
carnivorous and/or saprophagous ?
suspension feeders
deposit feeders
suspension feeder
an oxic environment ←→ a reducing environment
suspension
feeders
deposit
feeders
9-type
symbiont bearing bivalves
8-type

Fig. 11

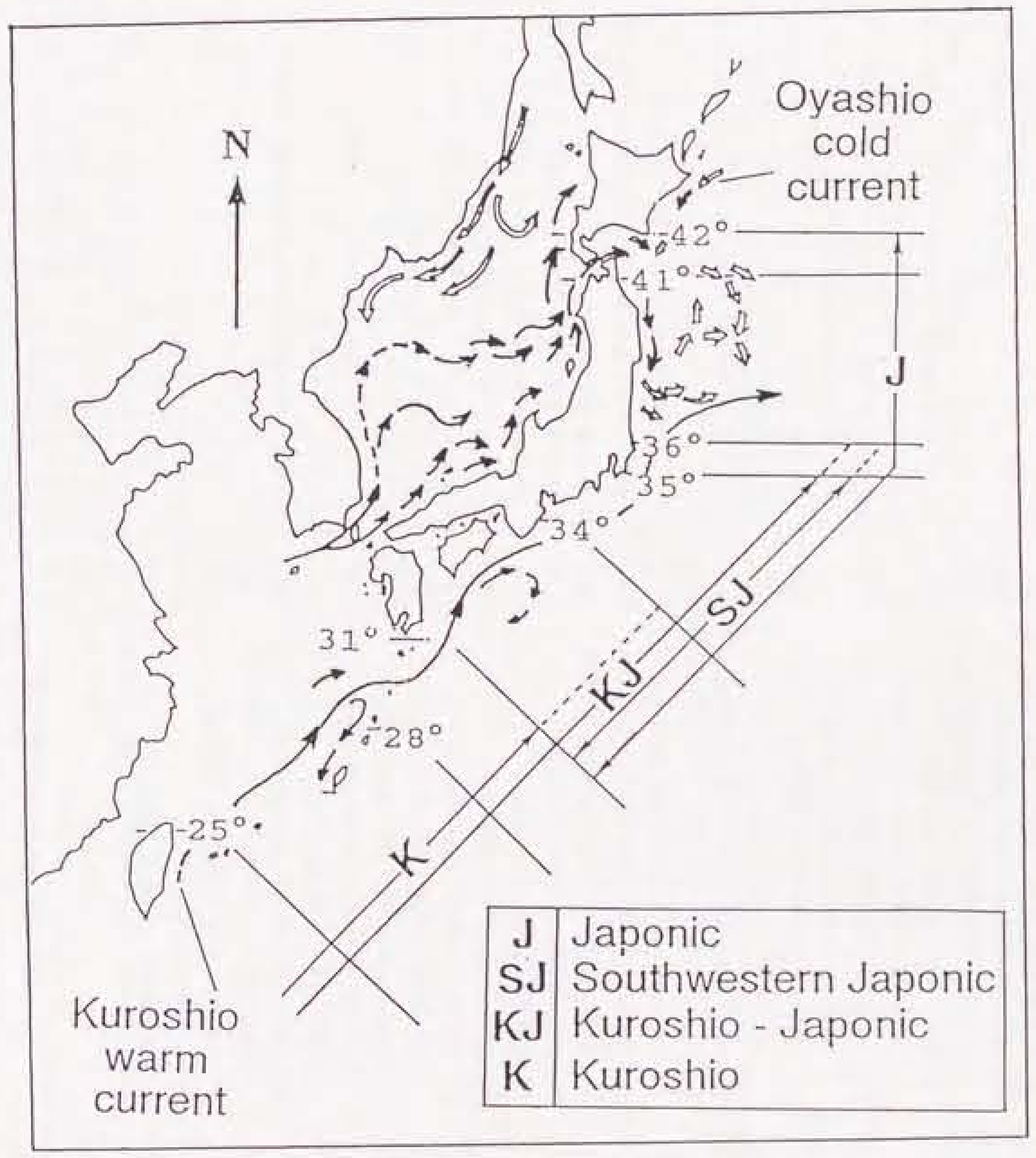

N
Oyashio cold current
42°
41°
J
36°
35°
34°
SJ
KJ
31°
28°
K
25°
Kuroshio warm current
J Japonic
SJ Southwestern Japonic
KJ Kuroshio - Japonic
K Kuroshio

Fig. 12

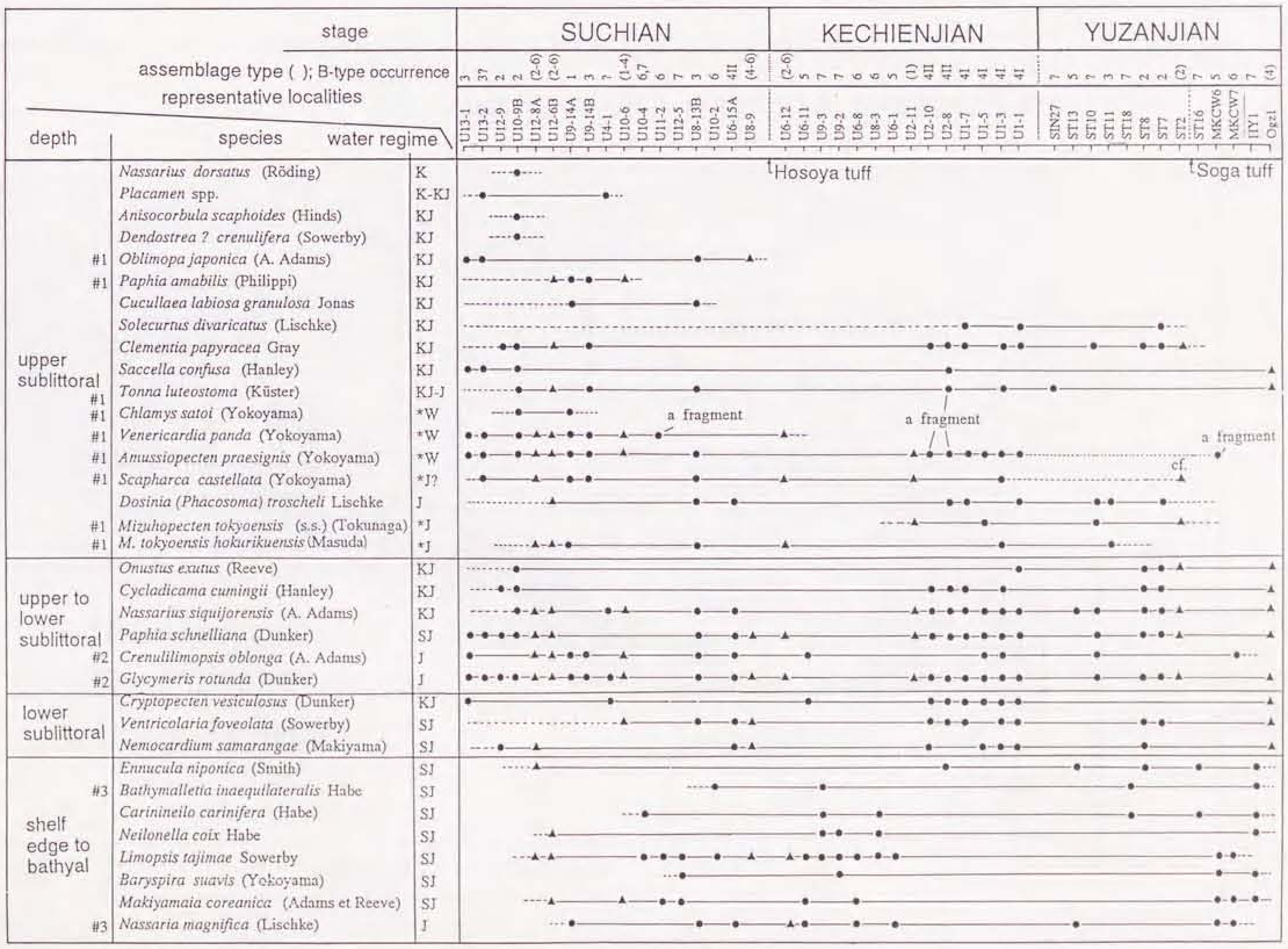

stage
SUCHIAN
KECHIENJIAN
YUZANJIAN
assemblage type ( ); B-type occurrence
representative localities
depth
species
water regime
U13-1 3
U13-2 3?
U12-9 2
U10-9B 2
U12-8A (2-6)
U12-6B (2-6)
U9-14A 1
U9-14B 3
U4-1 7
U10-6 (1-4)
U10-4 6,7
U11-2 6
U12-5 7
U8-13B 3
U10-2 6
U6-15A 4II
U8-9 (4-6)
U6-12 (2-6)
U6-11 5
U9-3 7
U9-2 7
U6-8 6
U8-3 6
U6-1 5
U2-11 (1)
U2-10 4II
U2-8 4II
U1-7 4I
U1-5 4I
U1-3 4I
U1-1 4I
SIN27 7
ST13 5
ST10 7
ST11 3
ST18 7
ST8 2
ST7 2
ST2 (2)
ST16 7
MKCW6 5
MKCW7 6
IIY1 7
Ogz1 (4)
Hosoya tuff
Soga tuff
upper sublittoral
Nassarius dorsatus (Röding) K
Placamen spp. K-KJ
Anisocorbula scaphoides (Hinds) KJ
Dendostrea ? crenulifera (Sowerby) KJ
#1 Oblimopa japonica (A. Adams) KJ
#1 Paphia amabilis (Philippi) KJ
Cucullaea labiosa granulosa Jonas KJ
Solecurtus divaricatus (Lischke) KJ
Clementia papyracea Gray KJ
Saccella confusa (Hanley) KJ
#1 Tonna luteostoma (Küster) KJ-J
#1 Chlamys satoi (Yokoyama) *W
#1 Venericardia panda (Yokoyama) *W
#1 Amussiopecten praesignis (Yokoyama) *W
#1 Scapharca castellata (Yokoyama) *J?
Dosinia (Phacosoma) troscheli Lischke J
#1 Mizuhopecten tokyoensis (s.s.) (Tokunaga) *J
#1 M. tokyoensis hokurikuensis (Masuda) *J
upper to lower sublittoral
Onustus exutus (Reeve) KJ
Cycladicama cumingii (Hanley) KJ
Nassarius siquijorensis (A. Adams) KJ
Paphia schnelliana (Dunker) SJ
#2 Crenulilimopsis oblonga (A. Adams) J
#2 Glycymeris rotunda (Dunker) J
lower sublittoral
Cryptopecten vesiculosus (Dunker) KJ
Ventricolaria foveolata (Sowerby) SJ
Nemocardium samarangae (Makiyama) SJ
shelf edge to bathyal
Ennucula niponica (Smith) SJ
#3 Bathymalletia inaequilateralis Habe SJ
Carinineilo carinifera (Habe) SJ
Neilonella coix Habe SJ
Limopsis tajimae Sowerby SJ
Baryspira suavis (Yokoyama) SJ
Makiyamaia coreanica (Adams et Reeve) SJ
#3 Nassaria magnifica (Lischke) J
a fragment
a fragment
a fragment
cf.

Fig. 13

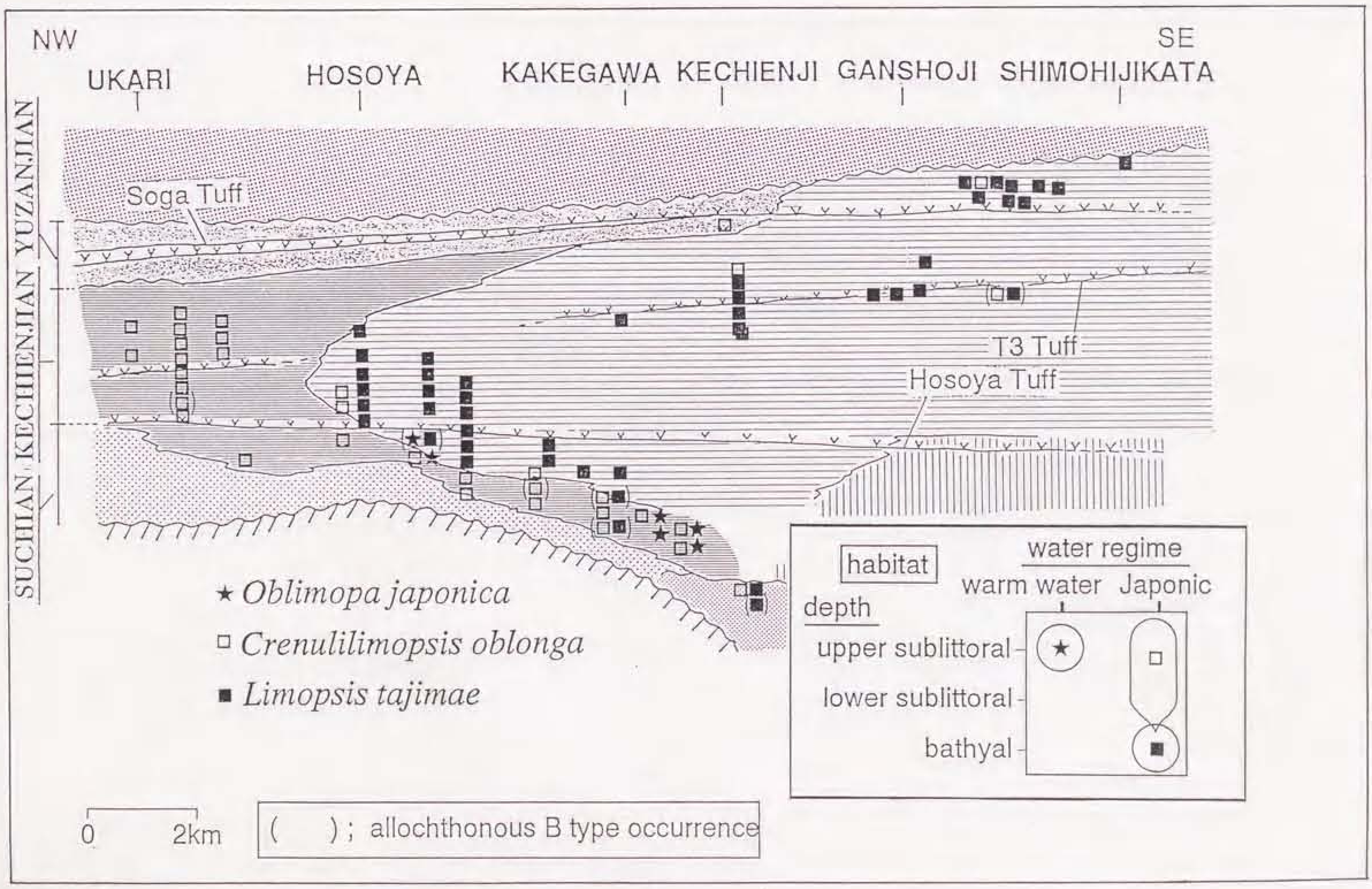

NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
SUCHIAN
KECHIENJIAN
YUZANJIAN
Soga Tuff
T3 Tuff
Hosoya Tuff
★ Oblimopa japonica
□ Crenulilimopsis oblonga
■ Limopsis tajimae
habitat
depth
water regime
warm water
Japonic
upper sublittoral
lower sublittoral
bathyal
0
2km
( ) ; allochthonous B type occurrence

Fig. 14a

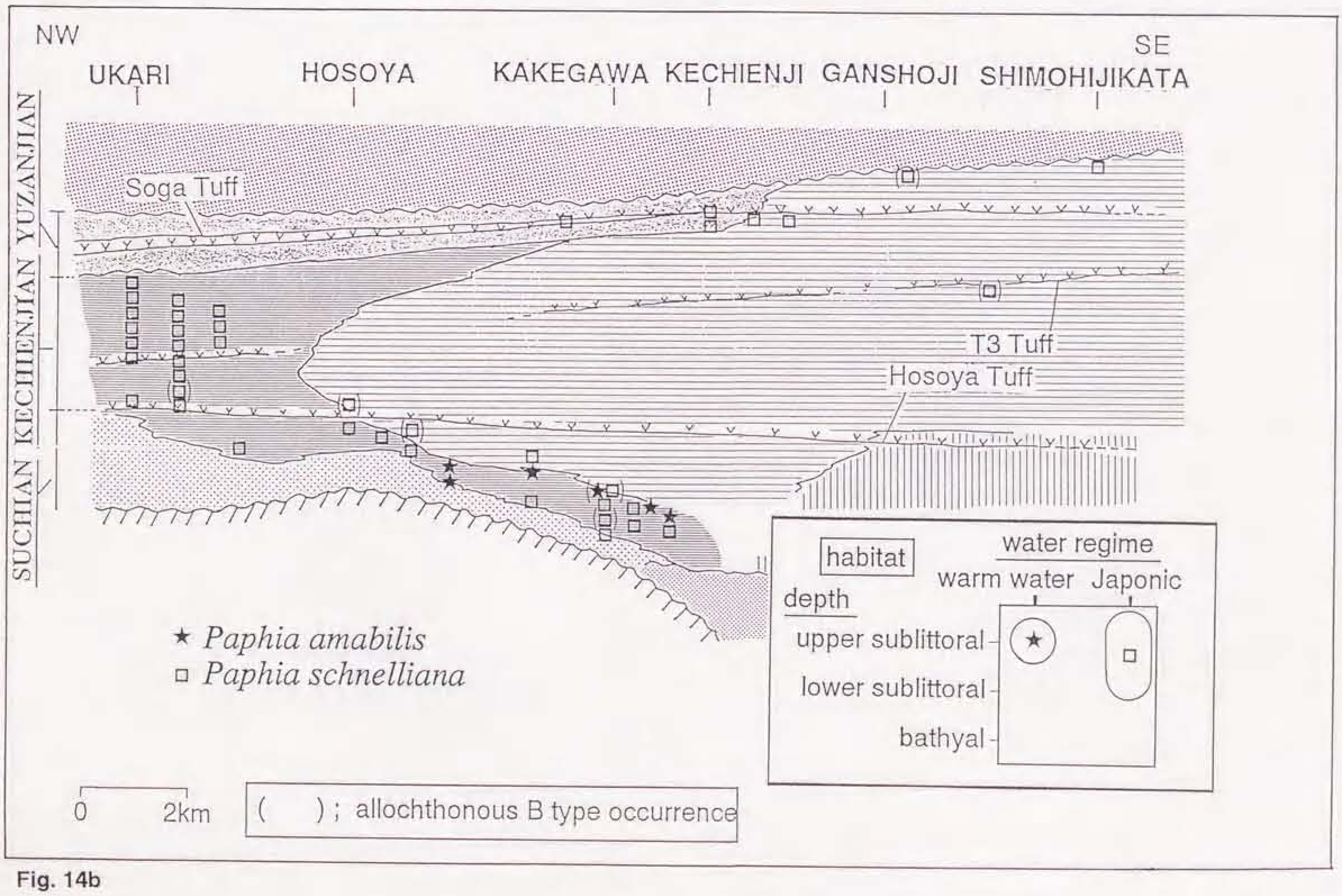

NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
SUCHIAN
KECHIENJIAN
YUZANJIAN
Soga Tuff
T3 Tuff
Hosoya Tuff
★ Paphia amabilis
□ Paphia schnelliana
habitat
water regime
warm water
Japonic
depth
upper sublittoral
lower sublittoral
bathyal
0
2km
( ) ; allochthonous B type occurrence

Fig. 14b

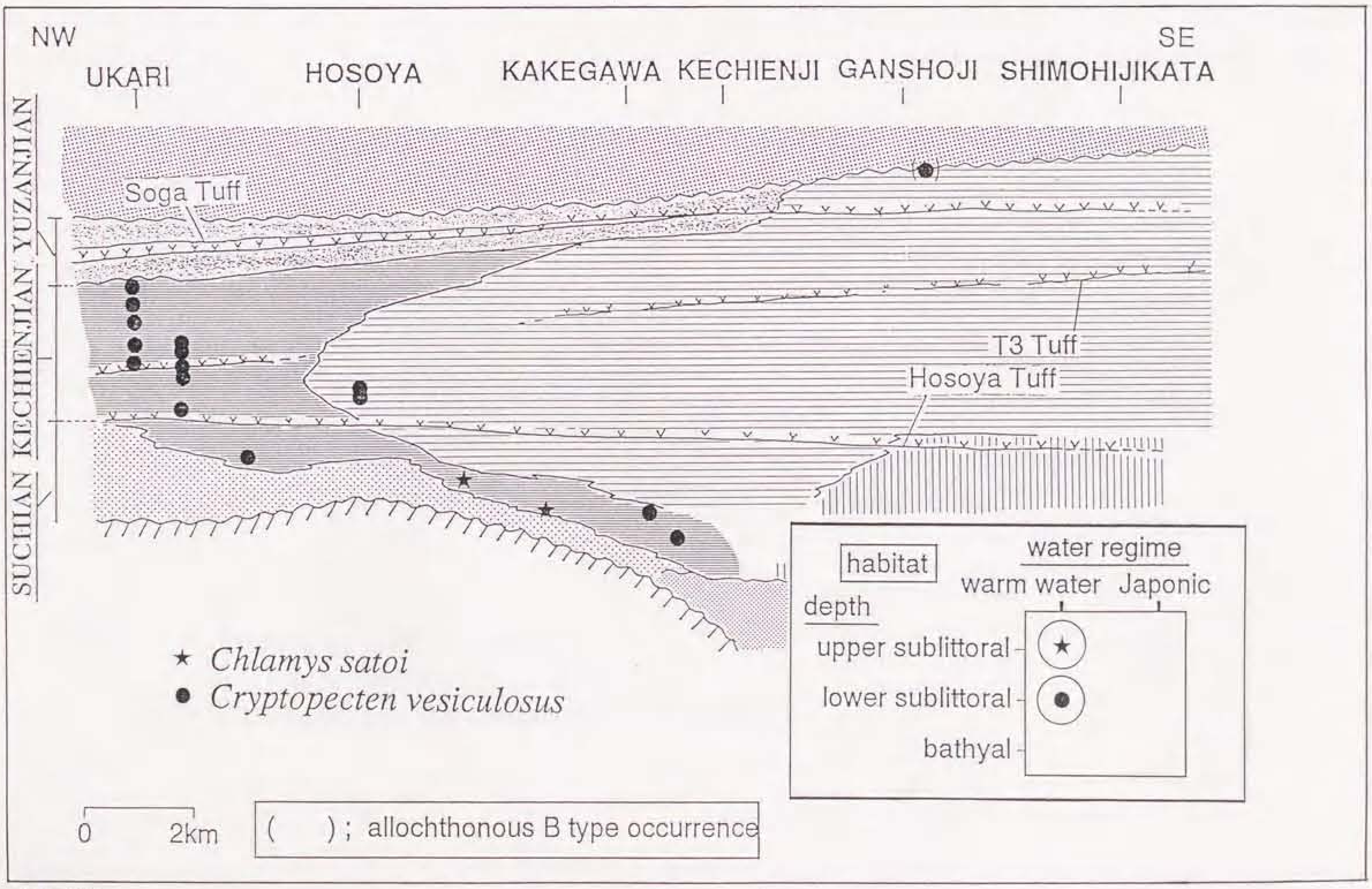

NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
SUCHIAN
KECHIENJIAN
YUZANJIAN
Soga Tuff
T3 Tuff
Hosoya Tuff
★ Chlamys satoi
● Cryptopecten vesiculosus
habitat
depth
water regime
warm water
Japonic
upper sublittoral
lower sublittoral
bathyal
0
2km
( ) ; allochthonous B type occurrence

Fig. 14c

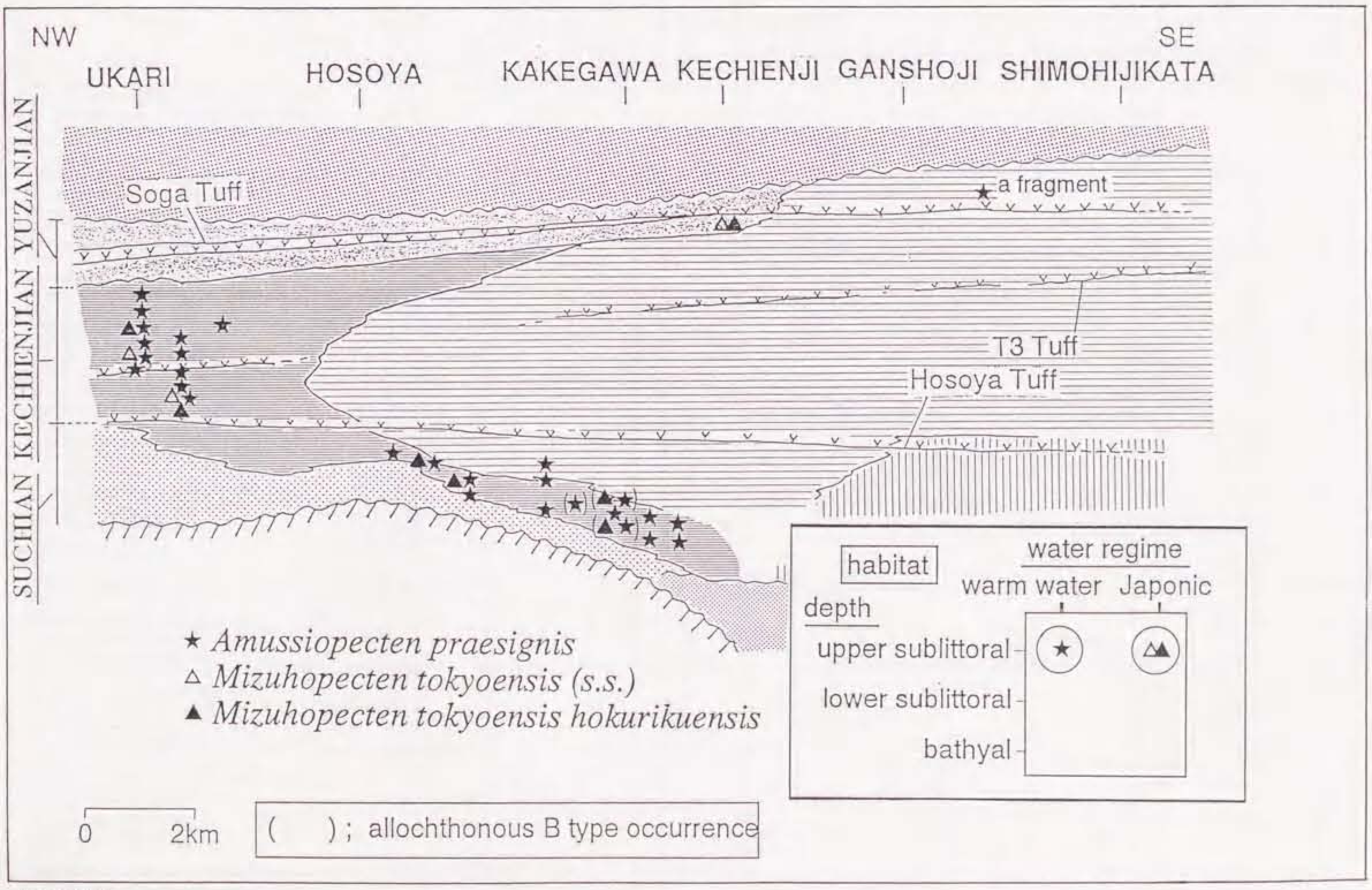

NW
SE
UKARI
HOSOYA
KAKEGAWA
KECHIENJI
GANSHOJI
SHIMOHIJIKATA
YUZANJIAN
KECHIENJIAN
SUCHIAN
Soga Tuff
a fragment
T3 Tuff
Hosoya Tuff
★ Amussiopecten praesignis
△ Mizuhopecten tokyoensis (s.s.)
▲ Mizuhopecten tokyoensis hokurikuensis
habitat
water regime
warm water
Japonic
depth
upper sublittoral
lower sublittoral
bathyal
0
2km
( ) ; allochthonous B type occurrence

Fig. 14d

mode of occuerrence	A-type																															B-type								
assemblage type	1	2			3					4I			4II			5				6				7									→2	→4			→4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	U8-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogz1	U12-6B	U6-12	U8-6	U12-8A
species / stage	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Bathybembix argenteonitens (s.s.) (Lischke)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. argenteonitens cf. *hirasei* (Taki et Otuka)	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·	·	·	·	·	·	·
B. argenteonitens forma *convexiusculus* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
"Tristichotrochus" sp.	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Suchium suchiense suchiense (Yokoyama)	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	C	·	·	·
S. suchiense subsuchiense (Makiyama)	·	·	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. giganteum (Lesson)	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. cf. *mysticum* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
S. obsoletum arenarium (Makiyama)	·	·	·	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Turritella perterebra Yokoyama	F	·	·	·	R	R	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·
T. perterebra var.	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Orectospira aff. *excelsa* (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
O. sp.A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Onustus exutus (Reeve)	·	F	·	R	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	R	·	·	·	C	·	·	·	·
Volva volva habei Oyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Euspira plicispira (Kuroda)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	R	·	·	·	·	·	·	·	·	F	·	·	·	·	·	R	·	·	·
Tonna luteostoma (Küster)	·	R	·	·	·	R	·	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	R	·	·	·
Neptunea kuroshio Oyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Babylonia elata (Yokoyama)	·	·	·	·	R	R	A	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R
B. elata var.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Siphonalia declivis declivis Yokoyama	·	·	·	·	F	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	C	·	·	·
S. declivis biconica Makiyama	·	·	R	·	·	·	A	·	·	F	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
S. declivis subsp.	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. tonohamaensis totomiensis Makiyama	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	R	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. mikado Melvill	·	·	·	·	R	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·
S. modificata (Reeve)	·	F	·	·	·	·	R	R	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	F	·	·	·
S. spadicea (Reeve)	·	·	·	R	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
S. trochula (Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	C	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·
S. spp.	·	·	·	·	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Nassaria magnifica (Lischke)	R	·	·	·	R	·	·	·	·	·	·	·	F	·	·	A	VA	F	VA	·	A	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·
N. sp.	·	·	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nassarius (Zeuxis) siquijorensis (A. Adams)	·	R	·	C	R	·	·	·	R	C	C	R	F	F	C	·	·	R	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	C	F	R	C	R	·	·	R
N. (Z.) dorsatus (Röding)	·	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Granulifusus cf. *nipponicus* (Smith)	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·
G. kiranus Shuto	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
Uromitra nakamurai Makiyama	·	A	F	·	·	·	F	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Baryspira albocallosa (Lischke)	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
B. urashima Kira	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	A	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
B. suavis (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	C	R	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·
B. sp.	·	R	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·
Fulgoraria totomiensis Makiyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·
F. prevostiana (Crosse)	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
F. mentiens (Fulton)	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	R	F	·	R	R	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	R
F. concinna (Broderip)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
F. cf. *hirasei* (Sowerby)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
F. spp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R
Marginella (Stazzania) flaccida (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	R	·	R	·	·	·	C	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·
Makiyamaia coreanica (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	A	R	R	·	A	R	·	·	·	·	·	·	·	F	·	R	·	·	·	R	·	·	·
M. subdeclivis (Yokoyama)	·	·	C	·	R	·	R	C	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·

Appendix Table 1

mode of occuerrence	A-type																																B-type								
assemblage type	1	2			3					4I			4II			5				6				7									→2	→4			→4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	US-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogz1	U12-6B	U6-12	U8-6	U12-8A
species / stage	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Solamen spectabilis (A. Adams)	·	·	·	·	·	·	·	·	·	R	·	R	·	·	·	R	·	·	R	·	R	·	R	·	·	·	·	·	R	·	·	·	·	·	·	·	A	·	·	R	·
Ctenamusium clancularium (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Bathyamussium jeffreysi (Smith)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
Chlamys satoi (Yokoyama)	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
C. cf. *asperulata* Adams et Reeve	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Cryptopecten vesiculosus (Dunker)	·	·	·	·	·	·	R	R	·	F	R	F	·	R	F	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Amussiopecten praesignis (Yokoyama)	VA	VA	·	·	A	F	A	R	·	A	R	F	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	C	·	F	·	·	A
Mizuhopecten tokyoensis (s.s.) (Tokunaga)	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·	·
M. tokyoensis hokurikuensis Masuda	F	·	·	·	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	R
Yabepecten tokunagai (Yokoyama)	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·
Anomia chinensis Philippi	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Acesta goliath (Sowerby)	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Limatula vladivostokensis Scarlato	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·
Dendostrea ? crenulifera (Sowerby)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Lucinoma annulata (Reeve)	·	·	·	C	·	·	·	·	A	F	·	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	F	·	·	·	·
Cycladicama cumingii (Hanley)	·	F	R	F	·	·	·	·	·	·	·	R	·	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Venericardia panda (Yokoyama)	R	C	·	·	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	C	R	·	R
V. ferruginosa (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Pleuromeris pygmaea Kuroda et Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Indocrassatella oblongata (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Crassatellites takanabensis Shuto	R	·	·	·	A	A	·	·	·	·	C	C	A	·	C	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	C	A	·	R	R
C. uchidanus (Yokoyama)	·	·	·	·	·	·	C	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nemocardium samarangae (Makiyama)	·	·	R	R	·	·	·	·	·	F	R	R	F	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	R	R
Lutraria maxima Jonas	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Angulus vestalioides (Yokoyama)	·	·	·	F	·	·	·	·	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Abra maxima Sowerby	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
A. soyoae Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
A. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Gari anomala (Deshayes)	·	·	·	·	·	·	·	·	·	F	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sibogai Prashad	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sp.	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Solecurtus divaricatus (Lischke)	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. sp.	·	·	·	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solen gordonis Yokoyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
"*Cultellus*" sp.	·	R	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Meiocardia tetragona (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·
Ventricolaria foveolata (Sowerby)	·	·	·	R	R	·	·	·	·	A	A	A	A	C	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	A	·	·	·	·
Mercenaria yokoyamai (Makiyama)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·
Pitar sp.	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Dosinia (*Phacosoma*) *japonica* (Reeve)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. (*P.*) *troscheli* Lischke	·	·	·	·	R	·	·	·	F	R	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. sp.	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Paphia amabilis (Philippi)	R	·	·	·	·	F	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·
P. schnelliana (Dunker)	·	A	C	C	A	·	R	R	F	A	A	F	A	F	A	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	·	·	R	R	A	R	·	R
Callista chinensis (Holten)	·	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R
Clementia papyracea Gray	·	A	A	F	·	R	·	·	R	R	F	R	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	R	·	·	·
Anisocorbula scaphoides (Hinds)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solidicorbula erythrodon (Lamarck)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Panopea japonica A. Adams	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·
Periploma plane Ozaki	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·

Appendix Table 2

mode of occuerrence	A-type																																B-type								
assemblage type	1	2			3					4I			4II			5				6				7									→2	→4			→4	→6?			→7
localities	U9-14A	U10-9B	U12-9	ST8	U8-13B	U9-14B	U13-1	U14-2	ST10	U1-1	U1-2	U1-3	U6-15A	U2-8	U2-10	U6-1	U6-11	ST13	MKCW6	U11-2	U6-8	U8-3	MKCW7	U12-5	U9-2	U9-3	U10-1	ST12	ST15	ST16	ST17	HY1	ST2	U10-6	U11-3B	U2-11	Ogz1	U12-6B	U6-12	U8-6	U12-8A
species / stage	S	S	S	Y	S	S	S	S	Y	K	K	K	S	K	K	K	K	Y	Y	S	K	K	Y	S	K	K	K	Y	Y	Y	Y	Y	Y	S	S	K	Y	S	K	K	S
Solamen spectabilis (A. Adams)	·	·	·	·	·	·	·	·	·	R	·	R	·	·	·	R	·	·	R	·	R	·	R	·	·	·	·	·	R	·	·	·	·	·	·	·	A	·	·	R	·
Ctenamusium clanculаrium (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Bathyamussium jeffreysi (Smith)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
Chlamys satoi (Yokoyama)	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
C. cf. *asperulata* Adams et Reeve	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Cryptopecten vesiculosus (Dunker)	·	·	·	·	·	·	R	R	·	F	R	F	·	R	F	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Amussiopecten praesignis (Yokoyama)	VA	VA	·	·	A	F	A	R	·	A	R	F	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	C	·	F	·	·	A
Mizuhopecten tokyoensis (s.s.) (Tokunaga)	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	R	·	·	·	·	·
M. tokyoensis hokurikuensis Masuda	F	·	·	·	R	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	R
Yabepecten tokunagai (Yokoyama)	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·
Anomia chinensis Philippi	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Acesta goliath (Sowerby)	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Limatula vladivostokensis Scarlato	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·
Dendostrea ? crenulifera (Sowerby)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Lucinoma annulata (Reeve)	·	·	·	C	·	·	·	·	A	F	·	·	R	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	F	·	·	·	·
Cycladicama cumingii (Hanley)	·	F	R	F	·	·	·	·	·	·	·	R	·	F	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·
Venericardia panda (Yokoyama)	R	C	·	·	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	R	R	·	·	C	R	·	R
V. ferruginosa (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Pleuromeris pygmaea Kuroda et Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·
Indocrassatella oblongata (Yokoyama)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Crassatellites takanabensis Shuto	R	·	·	·	A	A	·	·	·	·	C	C	A	·	C	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	C	A	·	R	R
C. uchidanus (Yokoyama)	·	·	·	·	·	·	C	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Nemocardium samarangae (Makiyama)	·	·	R	R	·	·	·	·	·	F	R	R	F	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	VA	·	·	R	R
Lutraria maxima Jonas	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Angulus vestalioides (Yokoyama)	·	·	·	F	·	·	·	·	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Abra maxima Sowerby	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·	·	·	·	·	·
A. soyoae Habe	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·
A. sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·
Gari anomala (Deshayes)	·	·	·	·	·	·	·	·	·	F	R	C	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sibogai Prashad	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
G. sp.	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
Solecurtus divaricatus (Lischke)	·	·	·	·	·	·	·	·	·	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. sp.	·	·	·	·	·	·	·	·	·	·	R	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solen gordonis Yokoyama	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·
"Cultellus" sp.	·	R	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Meiocardia tetragona (Adams et Reeve)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	C	·	·	·	·
Ventricolaria foveolata (Sowerby)	·	·	·	R	R	·	·	·	·	A	A	A	A	C	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	A	·	·	·	·
Mercenaria yokoyamai (Makiyama)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	A	·	·	·
Pitar sp.	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Dosinia (Phacosoma) japonica (Reeve)	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. (P.) troscheli Lischke	·	·	·	·	R	·	·	·	F	R	·	·	R	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·
D. sp.	·	·	·	·	·	R	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Paphia amabilis (Philippi)	R	·	·	·	·	F	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	F	·	·	·
P. schnelliana (Dunker)	·	A	C	C	A	·	R	R	F	A	A	F	A	F	A	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	F	·	·	R	R	A	R	·	R
Callista chinensis (Holten)	·	·	·	·	·	R	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	R
Clementia papyracea Gray	·	A	A	F	·	R	·	·	R	R	F	R	·	R	F	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	F	·	·	·	·	R	·	·	·
Anisocorbula scaphoides (Hinds)	·	A	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Solidicorbula erythrodon (Lamarck)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·
Panopea japonica A. Adams	·	·	·	·	·	·	R	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·
Periploma plane Ozaki	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	R	·	·	·	·	·	·	·	·	·	·	·	·	·

Appendix Table 3

mode of occuerrence	B-type	A'-type					A-type			?	A-type		
assemblage type	6	8					9			8-9	10		
localities	NK100	NK101A	NK101B	NK101C	NK102FC	NK103	NK100U	NK101A-B	NK102	NK10? (float)	S-N4'	KM8	KM14
species / stage	Y-T	Y-T	Y-T	Y-T	Y-T	Y-T	Y-T	Y-T	Y-T	Y-T	K	K	K
Bathybembix aeola (Watson)	•	•	•	R	R	R	•	C	C	R	R	•	•
B. argenteonitens (Lischke)	•	•	•	R	•	•	•	•	•	•	•	•	R
Phanerolepida cf. *pseudotransenna* Ozaki	•	•	•	•	•	R	•	•	•	R	•	•	•
Neptunea constricta (Dall)	•	•	•	R	•	•	•	R	R	R	•	•	•
Fulgoraria sp.	R	•	•	•	•	•	•	•	•	•	•	•	•
"Rectiplanes" sp.	•	•		•	•	•	•	•	•	R	•	•	•
Thatcheria sp.	•	•	•	•	•	•	•	•	•	R	•	•	•
Fissidentalium yokoyamai Makiyama	•	•	•	R	•	•	•	•	•	•	•	•	•
Solemya (Acharax) johnsoni Dall	•	•	•	F	•	R	•	•	•	F	•	•	•
Lamellinucula tokyoensia (Yokoyama)	•	•	•	•	•	R	F	•	•	•	•	•	•
Acila sp.	•	•	•	R	•	R	•	R	R	R	•	•	R
Bathymalletia inaequilateralis Habe	•	•	•	•	•	•	R	•	R	R	•	•	•
Carinineilo carinifera (Habe)	•	•	•	•	•	•	F	•	•	•	•	•	•
Neilonella coix Habe	•	•	•	F	•	•	F	C	R	C	•	•	•
Nuculana acinacea Habe	•	•	•	•	•	•	R	•	R	•	•	•	•
N. sp.	•	•	•	•	•	•	•	•	R	•	•	•	•
Yoldia similis Kuroda et Habe	•	•	•	•	•	•	•	•	•	•	•	•	•
Scapharca sp.	R	•	•	•	•	•	•	•	•	•	•	•	•
Glycymeris albolineata (Lischke)	R	•	•	•	•	•	•	•	•		•	•	•
G. rotunda (Dunker)	R	•	•	R	•	•	•	•	•	•	•	•	•
Limopsis tajimae Sowerby	R	•	•	R	•	•	R	•	•	•	•	•	•
L. cf. *uwadokoi* Oyama	•	•	•	•	•	•	•	•	•	•	C	C	A
"Empleconia" sp.A	•	•	•	C	R	R	VA	C	VA	VA	•	•	•
Crenulilimopsis oblonga (A. Adams)	•	•	•	R	•	•	•	•	•	•	•	•	•
Limatula vladivostokensis Scarlato	•	•	•	•	•	•	R	•	R	R	•	•	•
Lucinoma aff. *acutilineata* (Conrad)	•	R	C	VA	C	A	•	•	•	A	•	•	•
Conchocele bisecta (Conrad)	•	•	•	C	•	VA	•	•	•	R	•	•	•
Abra spp.	•	•	•	•	•	•	F	•	•	•	•	•	•
Akebiconcha kawamurai Kuroda	•	C	C	VA	VA	VA	R	•	R	VA	•	•	•
Paphia sp.	•	•	•	•	•	•	•	•	•	R	•	•	•
Callista chinensis (Holten)	R	•	•	•	•	•	•	•	•	•	•	•	•

Appendix Table 4

Plate 1

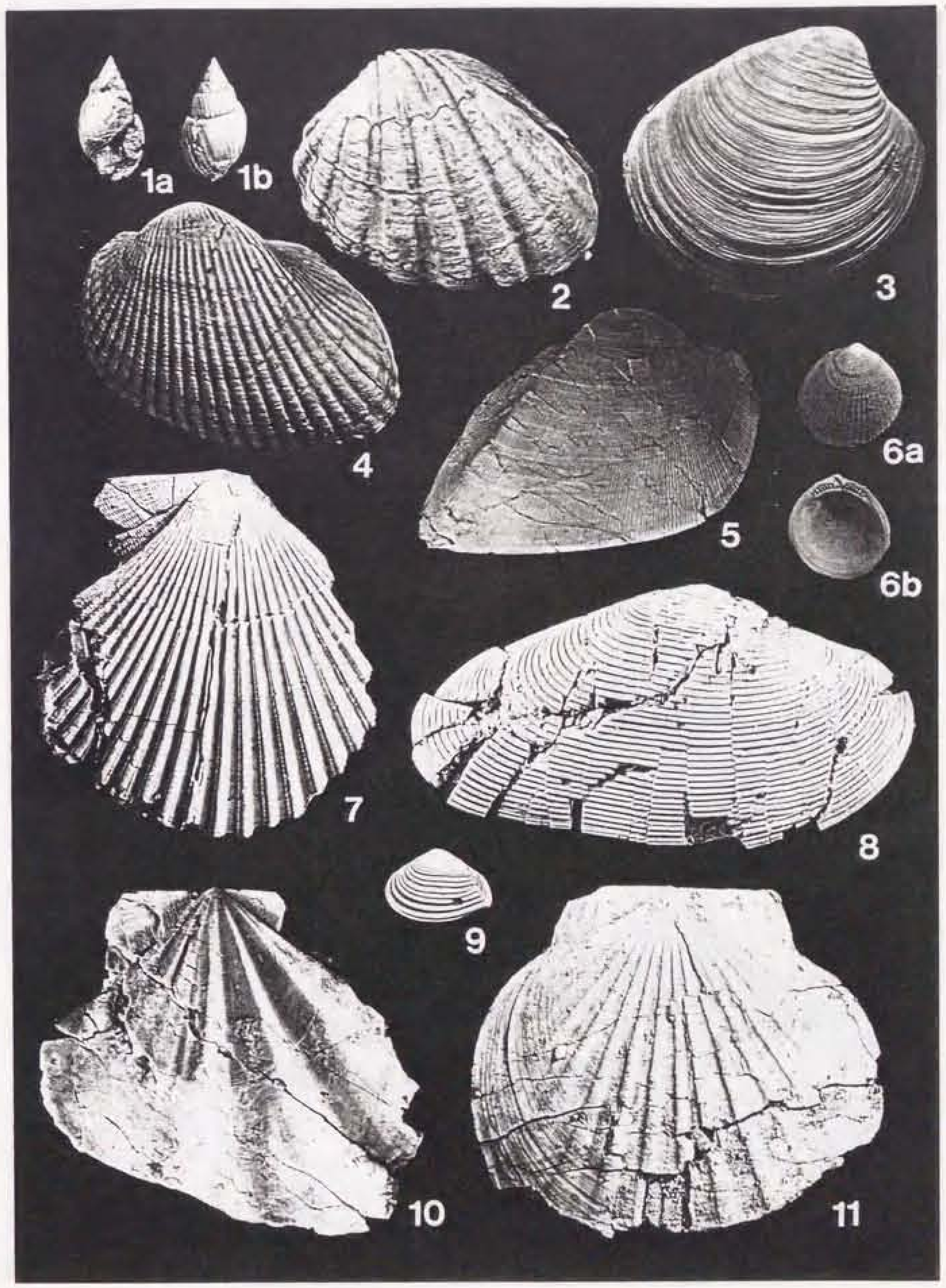


Plate 2

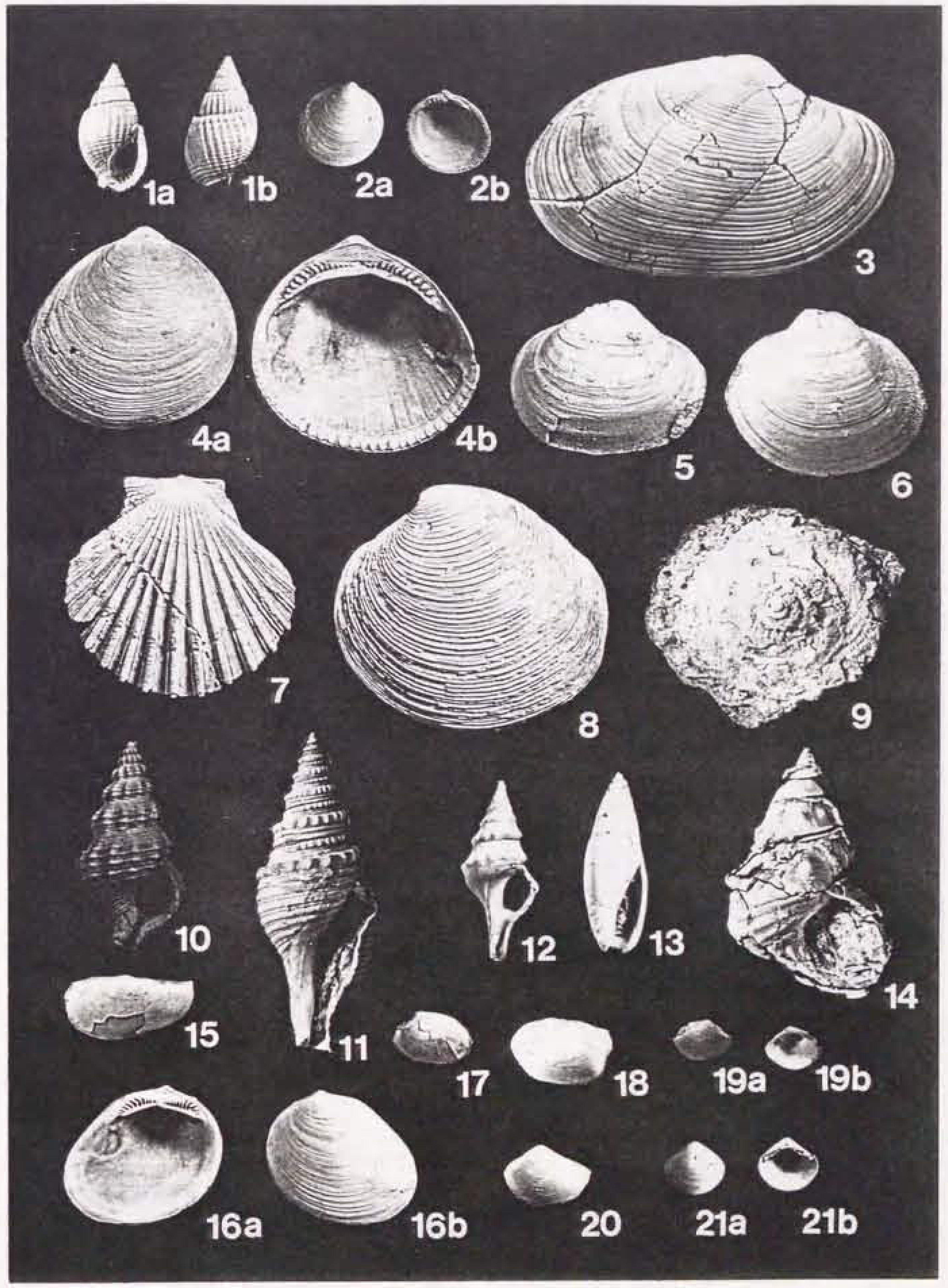
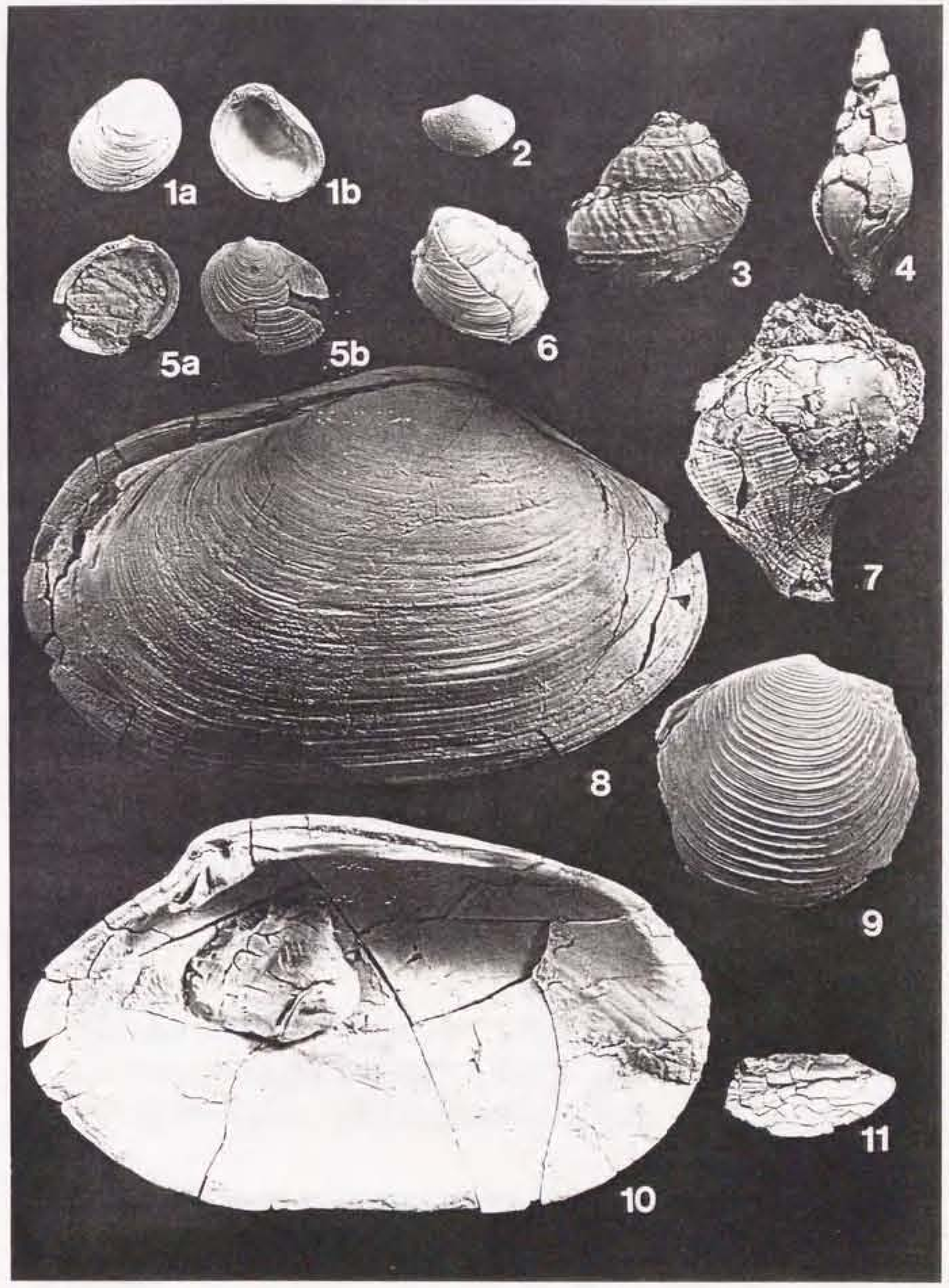

1a
1b
2a
2b
3
4a
4b
5
6
7
8
9
10
11
12
13
14
15
16a
16b
17
18
19a
19b
20
21a
21b

Plate 3



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