Part A. Geological setting of echinoid fossil-bearing strata in the northern part of Ibaraki Prefecture

I. Daigo area (Fig. 1-I)

Tertiary deposit in the Daigo area is narrowly distributed along the area between the Pre-Tertiary Yamizo Mountains in the west and the Tanakura Tectonic Line in the east. The early middle Miocene deposit of the Daigo area is composed of followings six formations including two members; Kitatake, Asakawa, Nantaisan, Naeshiroda, Konamase and Uchiono Formations, and the Osawaguchi Tuff Member of the Kitataki Formation and the Daienji Siltstone Member of the Asakawa Formation (Tables 1-2).

Tertiary deposit of Daigo area have been studies from various kind of views of geology and paleontology as followings; Nathorst (1883), Omori (1948, 1958), Oyama (1960), Noda (1966), Ishii *et al.*, (1974), Otsuki (1975), Nikaido and Kikuchi (1983), Noda and Kikuchi (1980), Noda *et.al.* (1989), Takahashi (1984), Takahashi and Amano (1984) and Saito *et al.* (1992).

Echinoid fossils of the studies area were newly occurred from the early middle Miocene Daienji Siltstone Member of the Asakawa Formation, Naeshiroda Formation and the Uchiono Formation by the present study (Tables 1-2).

Table 2. Stratigraphic division and correlation in the area I, Daigo area.

Geologic age	Omori *et al.*, (1953)		Otsuki (1975)	Saito *et al.*, (1992)	Present paper
MIOCENE			Uchiono F.		Uchiono F. ★
	Konamase G.	Konamase F.	Konamase F.	Uchiono F. / Konamase F.	Konamase F.
	Kurosawa G.	Nawashiroda F.	Naeshiroda F.	Nawashiroda F.	Naeshiroda F. ★
		Nantaisan Agglomerate	Nantaisan Volcanic Breccia	Nantaisan Volcanic Breccia	Nantaisan F.
		Takikura F.	Daienji Siltstone Mem.	Asakawa F.	Daienji Siltstone Mem. ★
	Kanazawa G.	Asakawa F.	Asakawa F.		Asakawa F.
		Osawaguchi Tuff	Osawaguchi Tuff Mem.	Osawaguchi Tuff Mem.	Osawaguchi Tuff Mem.
		Kanazawa F.	Kitatake F.	Kitatage F.	Kitatake F.
PRE TERTIARY	Basement Rocks		Basement Rocks	Yamizo Group	Yamizo Group

★; Stratigraphical position of echinoid fossils.

1. Kitatake Formation (defined by Otsuki, 1975)

The Kitatake Formation is corresponding to the Kanazawa Formation (Omori, 1948; Kamiya, 1969), Kanazawa Group (Omori, 1958) and the Kitatake Formation (Takahashi and Amano, 1984; Saito *et al.*, 1992). This formation includes the Osawaguchi Tuff Member.

[Type locality]

Type locality of this formation is exposure along the National Route 118 road at Kitatage, Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 900 meters.

[Lithology]

The Kitatake Formation is mainly composed of andesitic massive coarse grained sandstone, with conglomerate and fine grained white tuff. Lithofacies varies in composition of conglomerate and sandstone from lower part to upper part. The lower part consists of ill-sorted rounded cobble sized conglomerate, cross-laminated pumiceous coarse grained sandstone, granule sized conglomerate and dark gray siltstone. The middle part consists of andesitic sandstone. The upper part consists of tuffaceous coarse grained sandstone with greenish pumice grain and granule sized conglomerate.

[Stratigraphic relationship]

The Kitatake Formation unconformably overlies the basement rocks of Pre-Tertiary Yamizo Group and/or fault contact in part.

[Fossil Occurrence]

Fossils from the Kitatake Formation were reported by Nathorst (1883), Omori (1958), Oyama (1960), Kamiya (1969), Ishii *et al.*, (1974) and Otsuki (1975). The formation yields plant fossils belonging the *Comptonia naumannii-Liquidamber formosana* flora (Otsuki, 1975).

1-A. Osawaguchi Tuff Member (defined by Otsuki, 1975)

The Osawaguchi Tuff Member is occupied the most upper part of Kitatake Formation. This member is corresponding to the upper part of Kanazawa Formation (Omori, 1948; Kamiya, 1968), upper part of the Osawaguchi Tuffaceous Sandstone (Omori, 1958) and the Osawaguchi Tuff Member (Takahshi and Amano, 1984; Saito *et al.*, 1992).

[Type locality]

Type locality of this member is at the quarry of Osawaguchi in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 150 meters.

[Lithology]

The Osawaguchi Tuff Member is mainly composed of white

tuff with accretional lapilli. Lithofacies varies in composition of tuff from lower to upper part. The lower part includes volcanic breccia. The middle part consists of massive tuff with volcanic breccia. The upper part is composed of fine grained white tuff.

[Fossil occurrence]

This member is lacking in fossil record.

2. Asakawa Formation (defined by Otsuki, 1975)

The Asakawa Formation includes the Daienji Siltstone Member is corresponding to such strata as the Asakawa Formation (Otsuki, 1975), and the lower to middle part of Takikura Formation (Omori, 1948, 1958; Kamiya, 1969) and the Asakawa Formation (Takahashi and Amano, 1984; Saito *et al.*, 1992).

[Type locality]

Type locality of this formation is exposure along the roadside at Kawayama to Oenji in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 2,000 meters.

[Lithology]

The Asakawa Formation is mainly composed of coarse to medium grained sandstone, in association with dark greenish tuff and fine grained white tuff.

[Stratigraphic relationship]

The Asakawa Formation conformably overlies the early middle Miocene Kitatake Formation.

[Fossil occurrence]

Fossils from the Asakawa Formation were reported by Shikama and Omori (1952), Omori (1958), Kamiya (1969), Noda (1973), Ishii *et al.*, (1974), Otsuki (1975) and Takahashi and Amano (1984). This formation contains such fossils as *Comptonia naumannii* and *Liquidamber formosana* (plant), molluscs of *Vicarya callosa japonica* and *Anadara* (*Hataiarca*) *kakehataensis*, and other fossils.

2-A. Daienji Siltstone Member (defined by Otsuki, 1975)

The Daienji Siltstone Member is corresponding to the upper part of Takikura Formation (Omori, 1948, 1958; Kamiya, 1969) and the upper part of Asakawa Formation (Takahashi and Amano, 1984; Saito *et al.*, 1992).

[Type locality]

Type locality of this member is at Oenji in Daigo-machi, Kuji-gun, Ibaraki Prefcture.

[Thickness]

The total thickness is about 250 meters.

[Lithology]

The Daienji Siltstone Member consists of dark gray

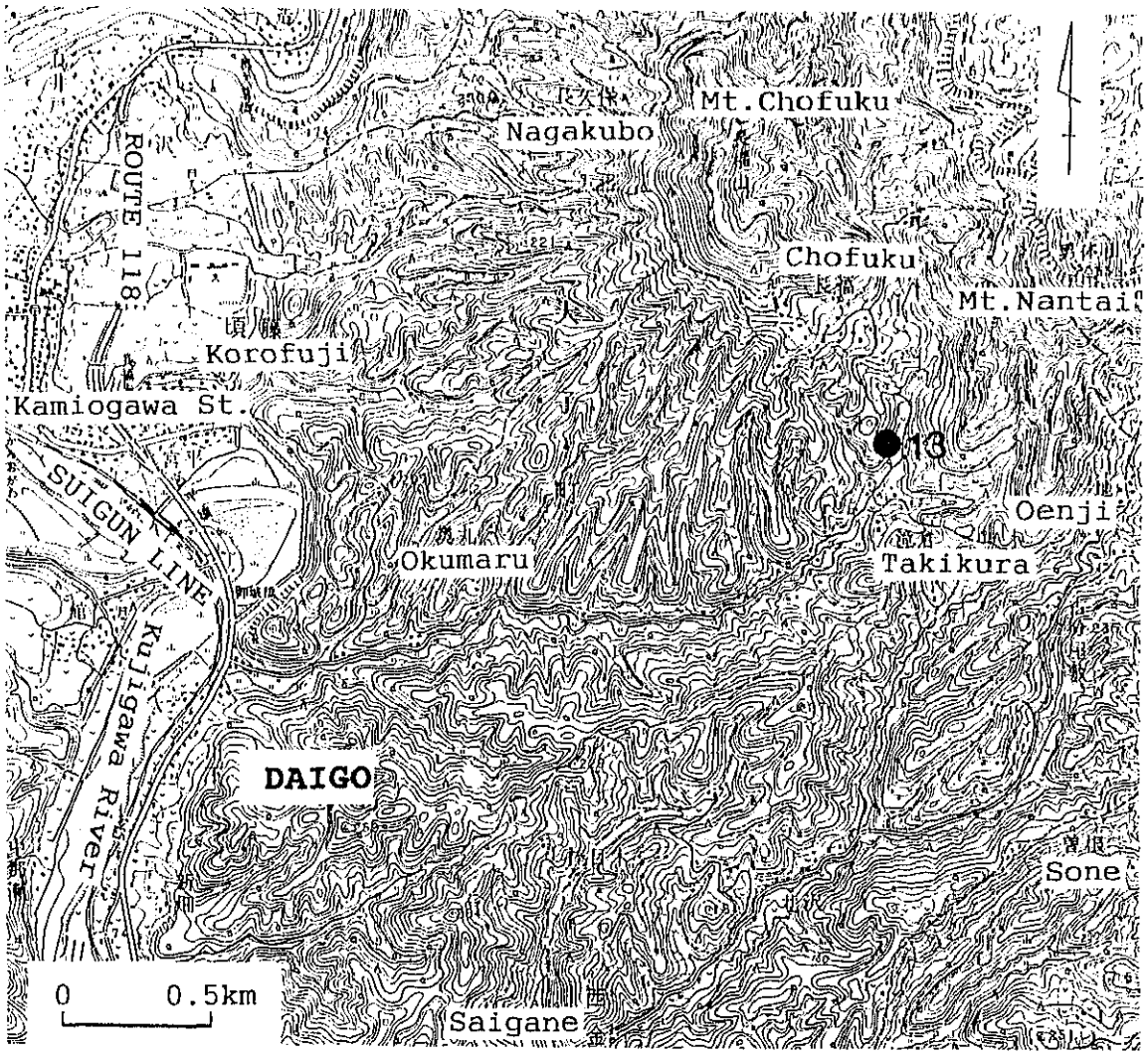

Fig. 3. Locality map of echinoid fossil in the area I, southern part of the Daigo area.
●; Fossil locality.

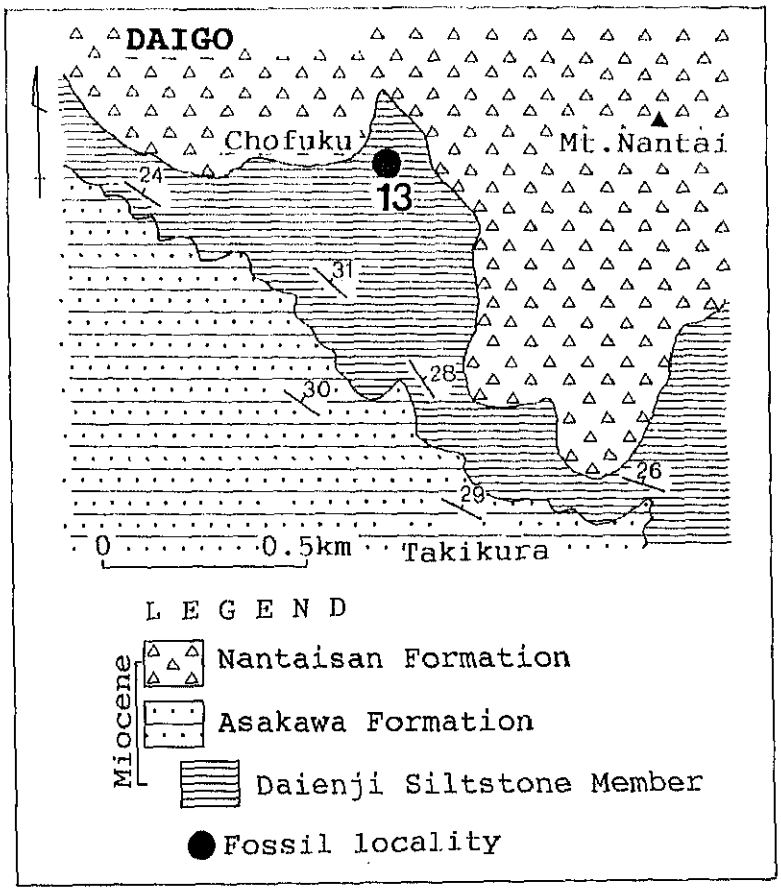

Fig. 4. Geological map and echinoid fossil locality in the area I, southern part of the Daigo area.

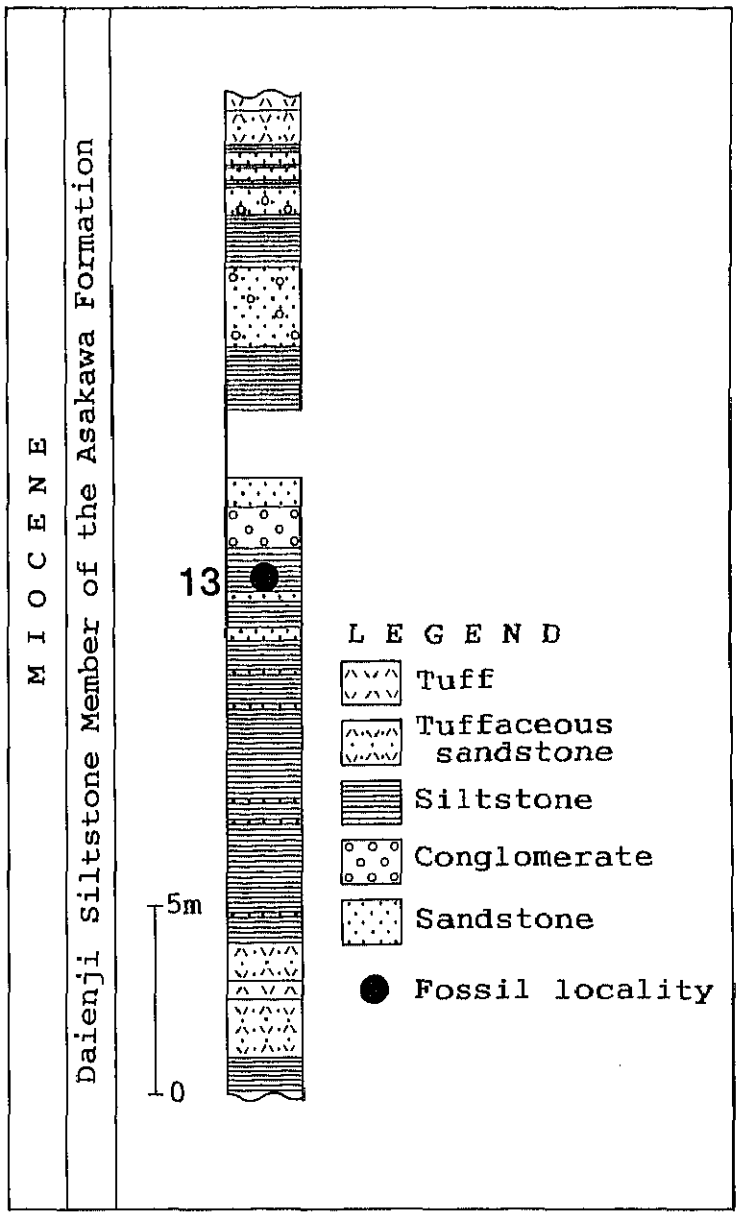

Fig. 5. Columnar section showing stratigraphical position of echinoid fossil in the area I, southern part of the Daigo area.

siltstone, association with thin sandstone and coarse grained thin tuff.

[Fossil occurrence]

The Daienji Siltstone Member yielded such molluscan fossils as *Limopsis* sp., *Natica* sp. and *Donax* sp. (Otsuki, 1975).

The author newly collected such fossils as echinoid of *Brissopsis* sp., Crustacean of *Munidia* sp., and molluscs of *Acila* sp., *Lamellinucula* sp. and *Portlandia watasei* (Figs. 2, 10-12; Tables 1-2, 14).

3. Nantaisan Formation (modified from Otsuki, 1975)

The Nantaisan Formation is correlative the Nantaizan Agglomerate (Omori, 1948, 1958; Kamiya, 1969) and the Nantaisan Volcanic Breccia (Otsuki, 1975; Takahashi and Ikeda, 1984; Saito *et al.*, 1992).

[Type locality]

The type locality of this formation is exposure at Mt. Nantaisan in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The thickness of this formation varies from 0 to 1,000 meters.

[Lithology]

The Nantaisan Formation mainly consists of dacitic

volcanic breccia (Takahashi and Ikeda, 1984), in association with white tuff, sandstone and siltstone.

[Stratigraphic relationship]

The Nantaisan Formation conformably overlies the early middle Miocene Asakawa Formation.

[Fossil occurrence]

Mollusca fossil of *Phanerolepida expansilabrum* (Kuroda) only reported from the formation by Noda and Kikuchi (1980).

4. Naeshiroda Formation (modified from Otsuki, 1975)

The Naeshiroda Formation is corresponding to the Nawashiroda Formation (Omori, 1948; Saito et al., 1992), Shionokusa Sandstone and Shale (Omori, 1958) and the Naeshiroda Formation (Otsuki, 1975).

[Type locality]

Type locality of this formation is exposure at Nawashiroda, Konamase in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 300 meters.

[Distribution]

The Naeshiroda Formation is narrowly distributed along that of the Nantaisan Formation in eastern part of Machizuki, Shimonomiya, Masenokubo, Tatsugami, Nawashiroda, Yazawa,

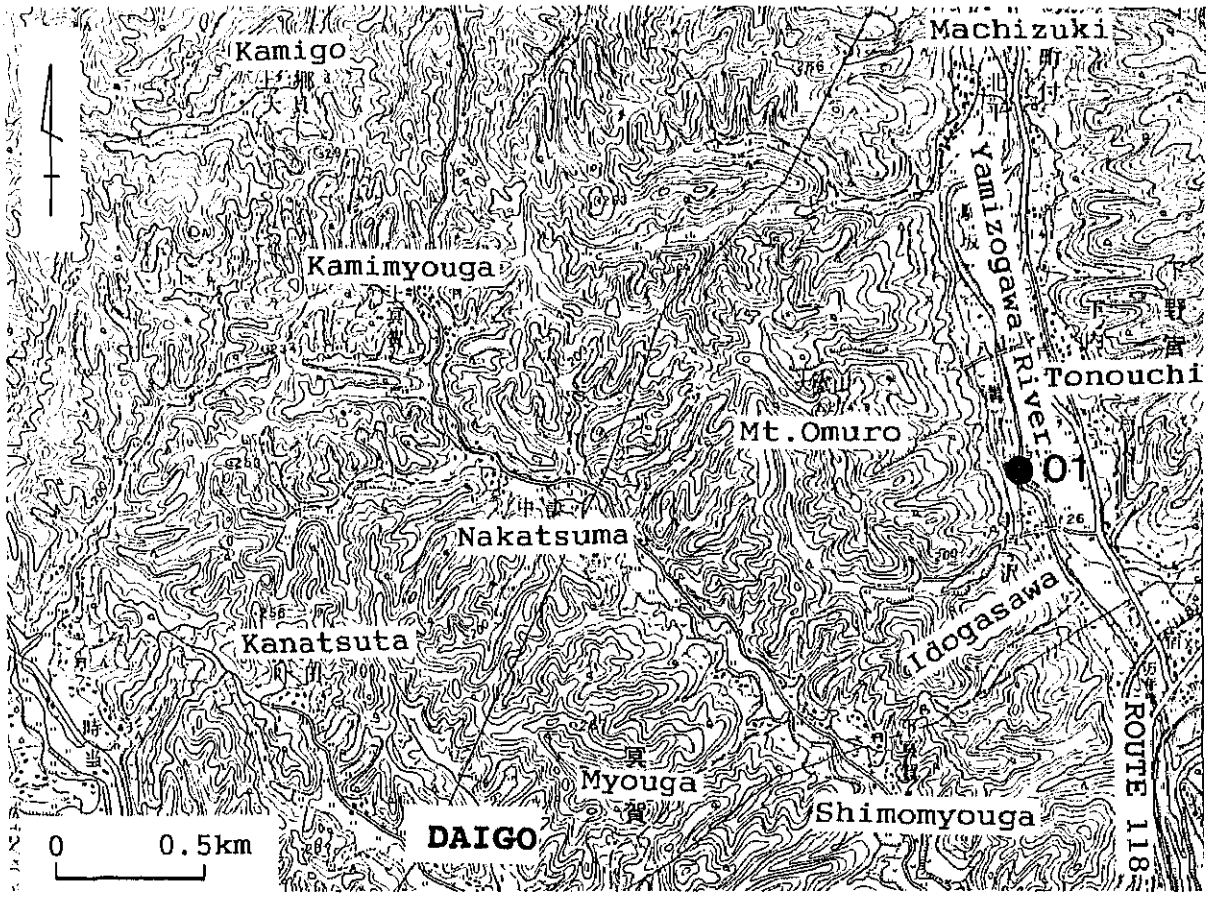

Fig. 6. Locality map of echinoid fossil in the area I, northern part of the Daigo (1).
●; Fossil locality.

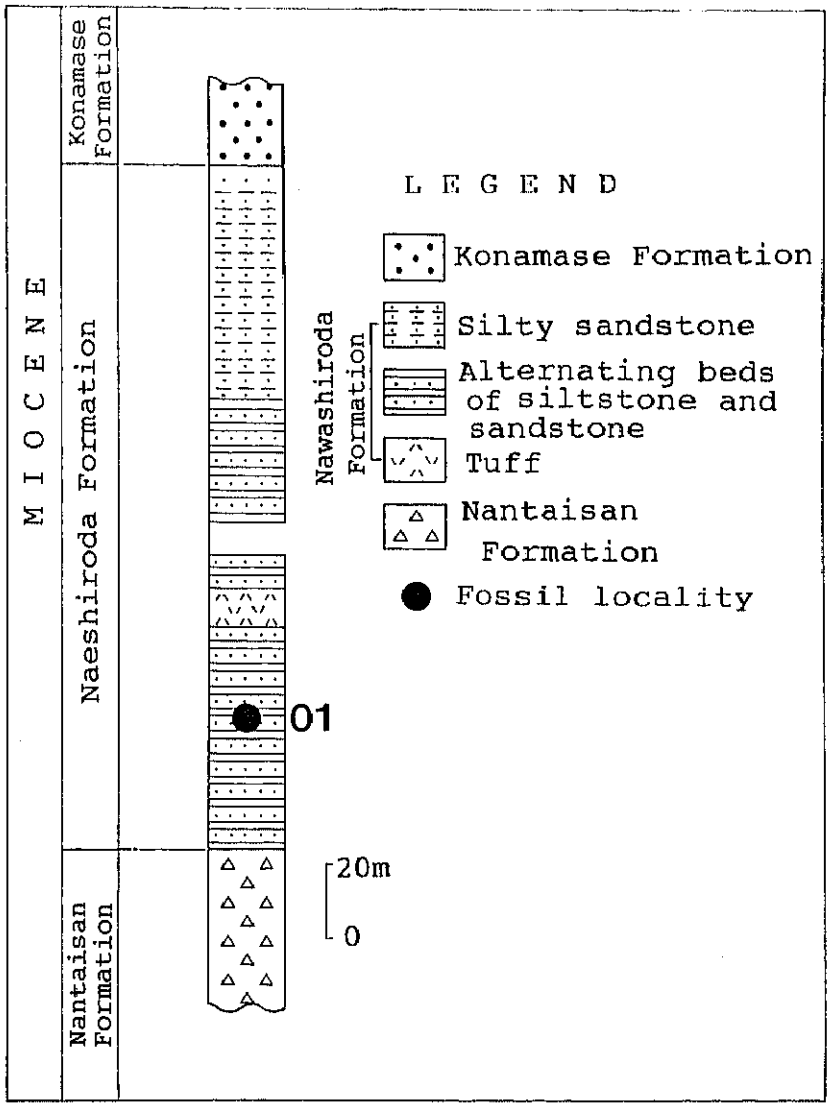

Fig. 7. Columnar section showing stratigraphical position of echinoid fossil in the area I, northern part of the Daigo area (1).

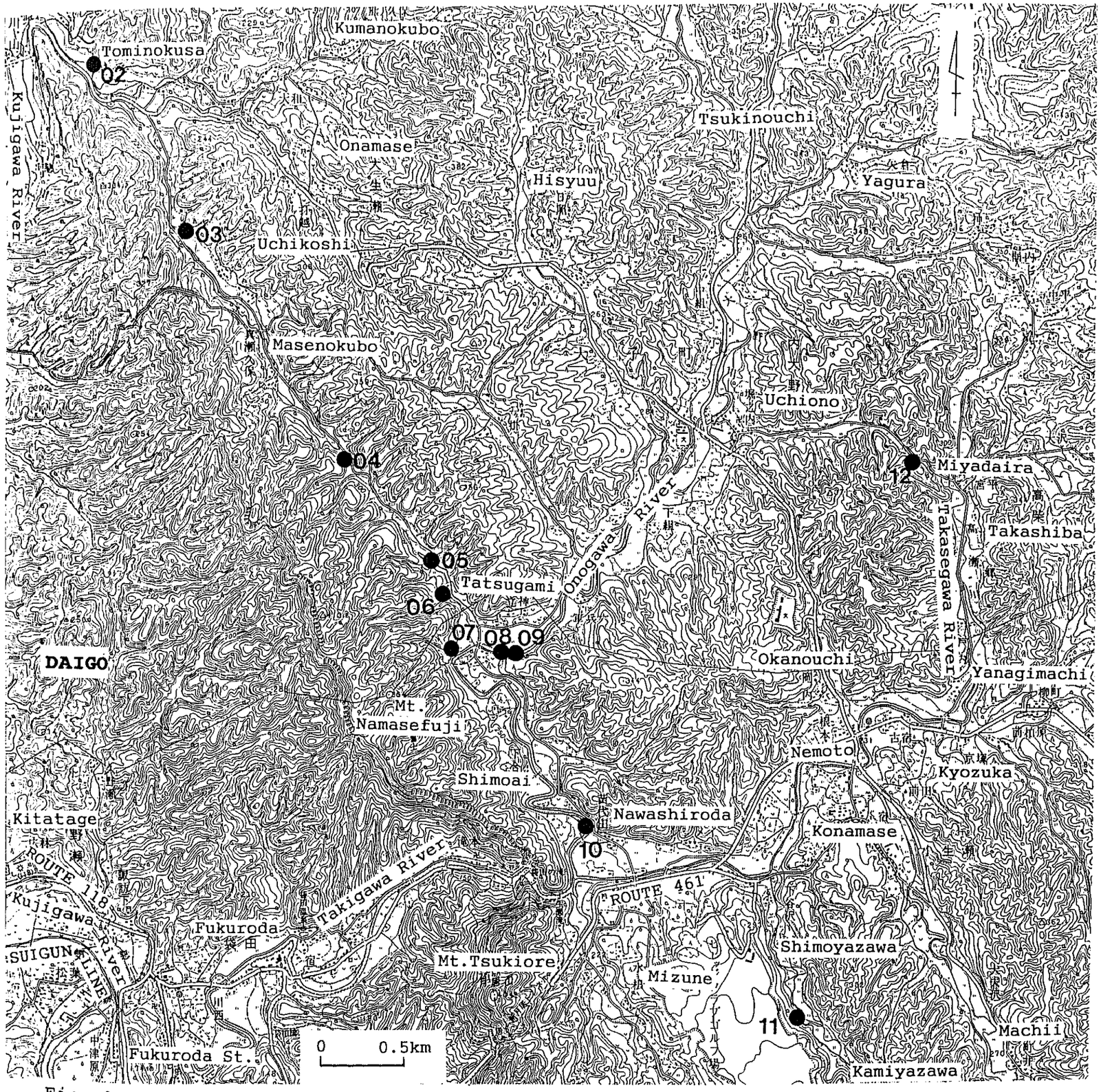

Fig. 8. Locality map of echinoid fossils in the area I, eastern part of the Daigo area (2). ●; Fossil locality.

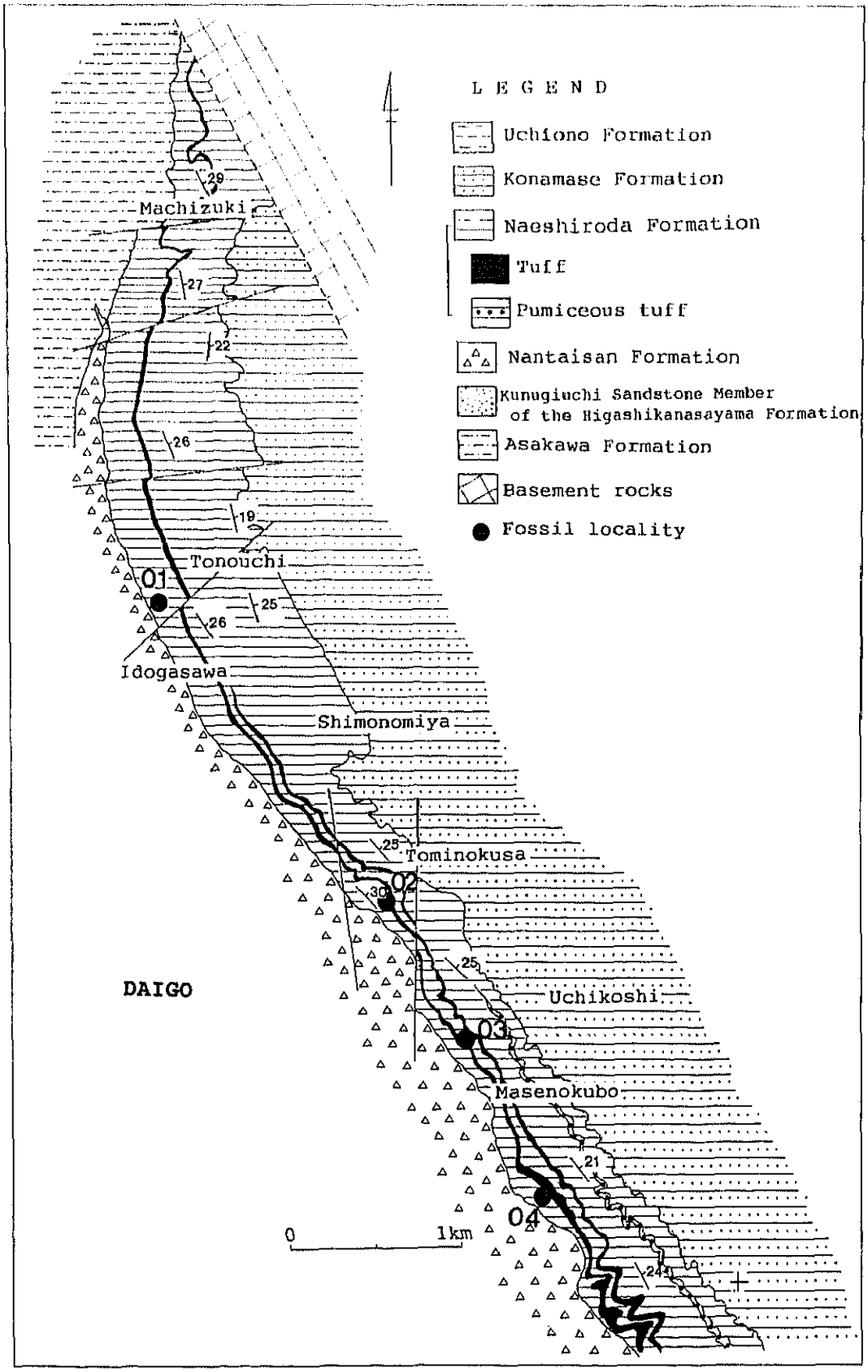

Fig. 9. Geological map and echinoids fossils localities in the area I, Daigo area (1).

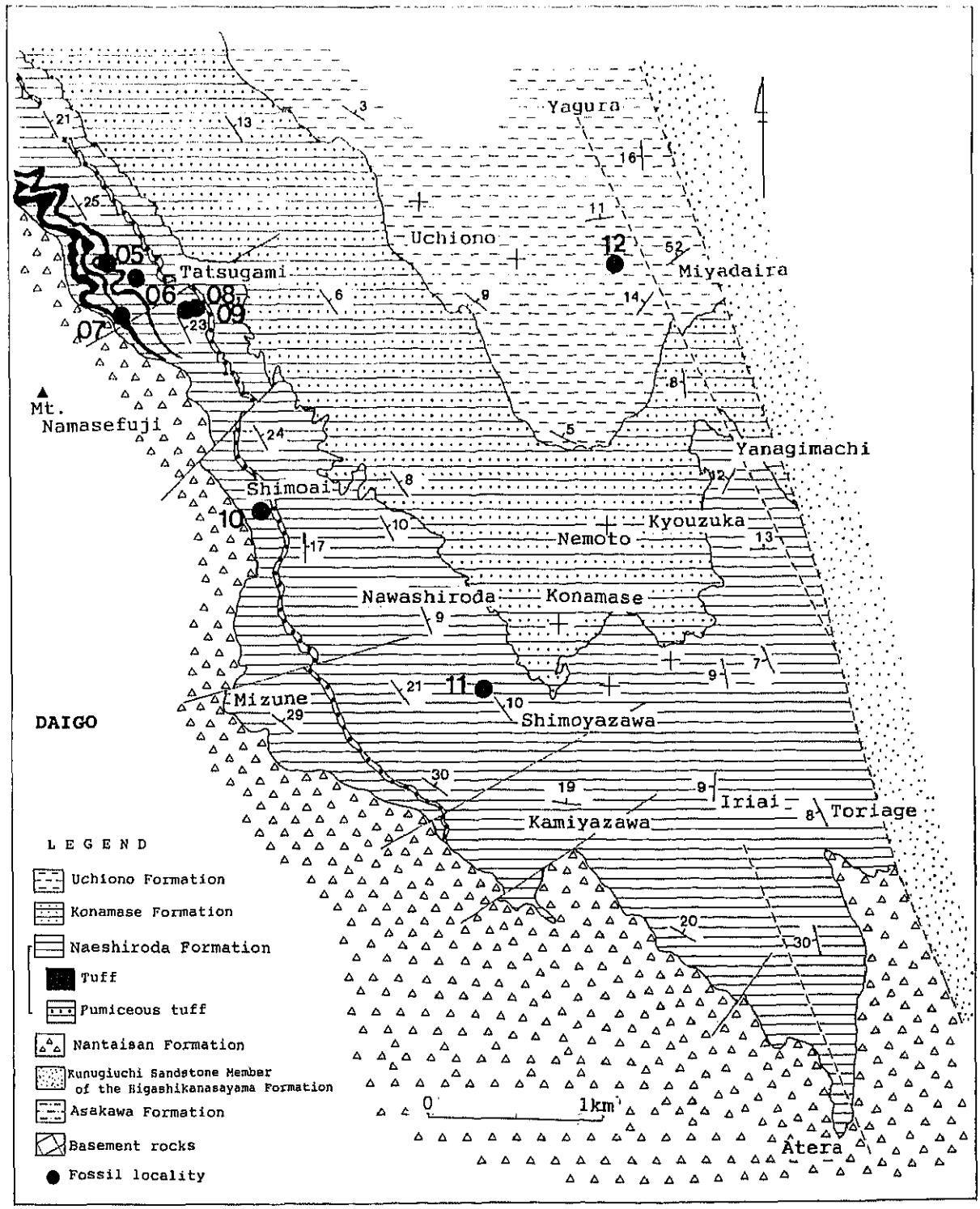

Fig. 10. Geological map and echinoids fossils localities in the area I, Daigo area (2).

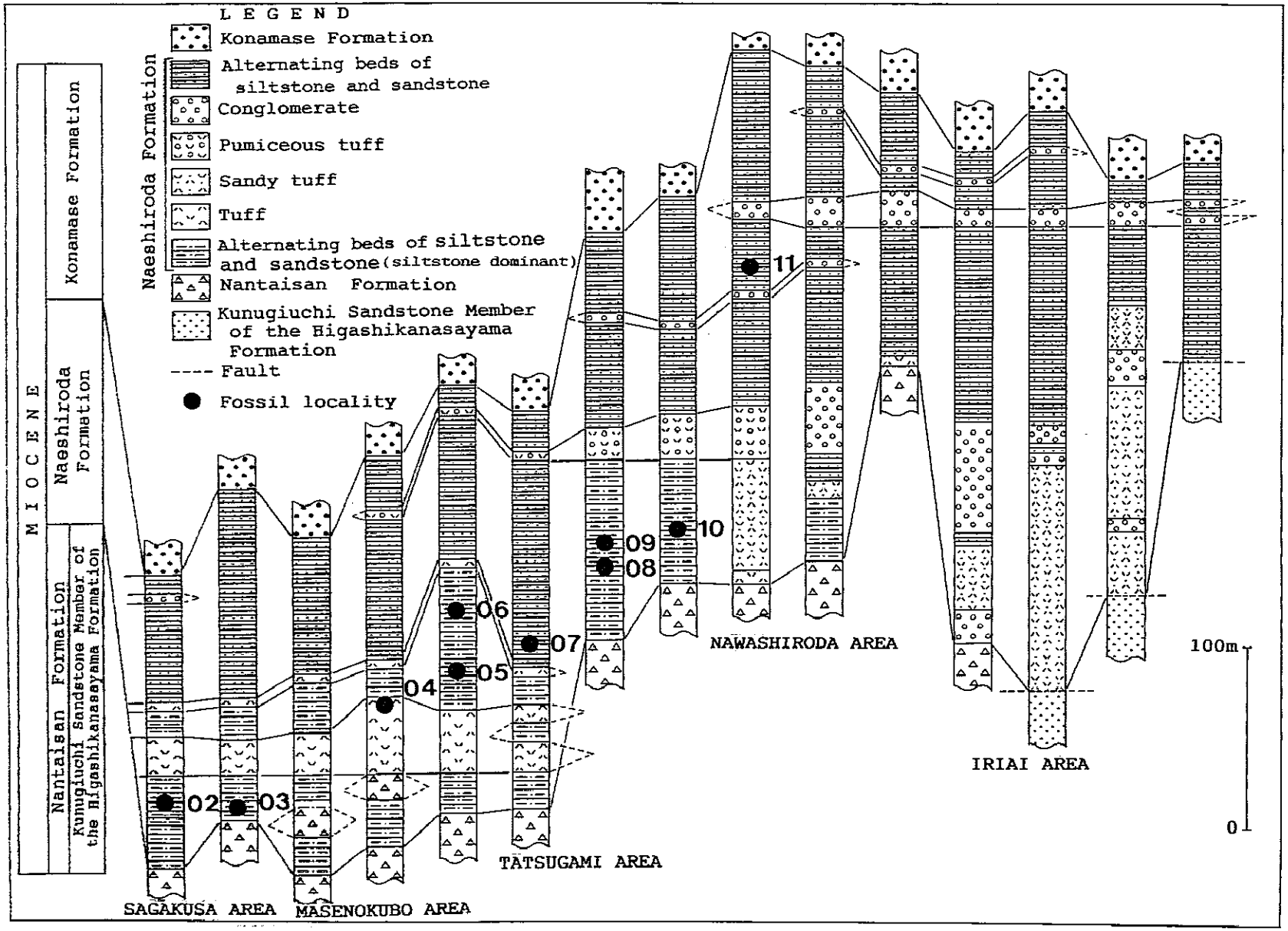

Fig. 11. Columnar section showing stratigraphical position of echinoid fossils in the area I, Daigo area (1-2).

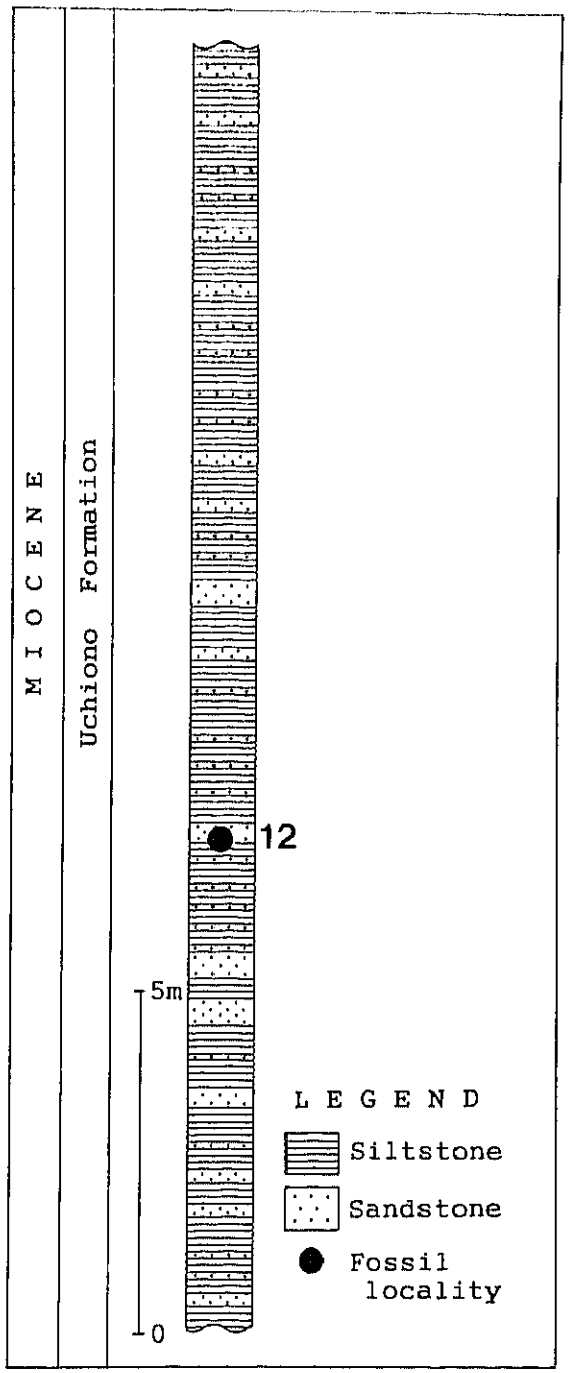

Fig. 12. Columnar section showing stratigraphical position of echinoid fossil in the area I, Daigo area (2).

through, Iriai to Yanagimachi in Daigo district.

[Lithology]

The Naeshiroda Formation consists of massive dark gray siltstone, siltstone dominant alternating beds of dark gray siltstone and sandstone, tuffaceous and sandstone, ill-sorted greenish gray pumiceous tuff, greenish white tuff and conglomerate.

[Stratigraphic relationship]

The Naeshiroda Formation conformably overlies the early middle Miocene Nantaisan Formation.

[Fossil occurrence]

Fossils from the Naeshiroda Formation were reported by Omori (1958), Otsuki (1975), Nikaido and Kikuchi (1983), Takahashi and Amano (1984), Noda *et al.*, (1989), and Kikuchi and Nikaido (1996). This formation contains such fossils as large foraminifera of *Operculina complanata japonica* and *Miogypsina kotoi kotoi*, molluscs of *Acilana tokunagai* and *Propeamussium tateiwai* and holothurians of *Cucumaria igoi* and *Ypsilothuria bitentaculata*, and others (Kikuchi and Nikaido, 1996).

Newly collected fossils by the present study are as follows; echinoid of Echinothuriidae, *Brissopsis daigoensis* n. sp. and *Brissopsis kajiwarai* n. sp., sponge of *Makiyama chitanii*, molluscs of *Portlandia kakimii*, *Bathymalletia* sp.,

Lamellinucula sp., *Conchocele disjuncta*, *Lucinoma* sp., *Phanerolepida expansilabrum*, *Fulgoralia* sp., *Natica* sp. and *Fussidentalium* sp., trace fossils of *Chondrites* isp. and *Zoophycos* isp., and *Comptonia naumanii*, *Liquidamber* sp., *Castane* sp. and *Quercus* sp. of plant fossils (Figs. 2-8; Tables 1-2, 14).

5.Konamase Formation (defined by Otsuki, 1975)

The Konamase Formation is corresponding to the Konamase Formation (Omori, 1948; Otsuki, 1975; Takahashi and Amano, 1984; Saito *et al.*, 1992) and the Okado Sandstone (Omori, 1958).

[Type locality]

Type locality of this formation is exposure along a roadside, as at Nemoto connecting Konamase and Uchiono in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 300 meters.

[Lithology]

The Konamase Formation is mainly composed of coarse grained sandstone and conglomerate. Lithofacies varies in composition of this formation from lower to upper part. The lower part consists of mica-rich, medium grained sandstone to bolder conglomerate with laminated coarse grained sandstone. The middle to upper part consists of coarse grained sandstone

with siltstone, medium grained sandstone and conglomerate.

[Stratigraphic relationship]

The Konamase Formation conformably overlies the early middle Miocene Naeshiroda Formation.

[Fossil occurrence]

The Konamase Formation is lacking in fossil record.

6.Uchiono Formation (defined by Otsuki, 1975)

The Uchiono Formation is corresponding to the Konamase Formation (Omori, 1948) and the Zuiryu Shale (Omori, 1958).

[Type locality]

Type locality of this formation is exposure along a roadside at Uchiono to Sotoono in Daigo-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is a more than 400 meters.

[Lithology]

The Uchiono Formation mainly consists of medium to coarse grained sandstone, fine grained sandstone and siltstone with conglomerate.

[Stratigraphic relationship]

The Uchiono Formation conformably overlies the early middle Miocene Konamase Formation.

[Fossil occurrence]

Table 3. Stratigraphic division and correlation in the area II, Yamagata to Suifu area.

Geologic age	Otsuki (1975)	Saito *et al.*, (1992)	Present paper
MIOCENE	Nishizome F.	Nishizome F.	Nishizome F.
	Oginokubo Siltstone Mem.		Oginokubo ★ Sandstone Mem.
	Nantaisan Volcanic Breccia	Nantaisan Volcanic Breccia	Nantaisan F.
	Daienji Siltstone Mem.	Asakawa F.	Daienji Siltstone Mem.
	Asakawa F.		Asakawa F.
	Nakazawa Sandstone Mem.		
	Osawaguchi Tuff Mem.	Osawaguchi Tuff Mem.	Osawaguchi Tuff Mem.
	Kitatake F.	Kitatage F.	Kitatake F.
PRE TERTIARY	Yamizo Group	Yamizo Group	Yamizo Group

★; Stratigraphical position of echinoid fossil.

Newly collected fossils are following; echinoid fossil of Schizasteridae gen. et sp. indet, and sponge fossil of *Makiyama chitanii* (Figs. 2, 5, 7, 9; Tables 1-2, 14).

II. Yamagata area (Fig.1-II)

Tertiary deposit in the Yamagata area is widely distributed between the Pre-Tertiary Yamizo Group in the west and the Tanakura Tectonic Line in the east. The early middle Miocene deposit in the Yamagata to Suifu area can be divided into the following four formations: the Kitatake, Asakawa, Nantaisan and Nishizome Formations, in ascending order (Tables 1, 3).

Geological and paleontological studies have been done by Saito (1952), Omori (1958), Kamiya (1968), Otsuki (1975), Saito *et al.* (1992) and Nakashima (1993 MS).

Echinoid fossil is collected from the Oginokubo Siltstone Member of the Nishizome Formation (Tables 1, 3).

1. Kitatake Formation (defined by Otsuki, 1975)

The Kitatake Formation includes the Osawaguchi Tuff Member is corresponding to the Nishinouchi Formation and the Tashiro Formation (Saito, 1952), Kanazawa Group (Omori, 1958), Kanazawa Formation (Kamiya, 1969), Kitatake Formation (Otsuki,

1975) and the Kitatage Formation (Saito *et al.*, 1992; Nakashima, 1993 MS).

[Fossil occurrence]

Saito (1952) and Nakashima (1993MS) reported plant fossils from the Kitatake Formation.

1-A. Osawaguchi Tuff Member (defined by Otsuki, 1975)

The Osawaguchi Tuff Member is correlative to such strata as the Nanatsugane Formation (Saito, 1952), upper part of the Nishinouchi Tuff (Omori, 1958), Osawaguchi Tuff Formation (Kamiya, 1969) and the Osawaguchi Tuff Member (Takahashi and Amano, 1984; Saito *et al.*, 1992; Nakashima, 1993 MS).

2. Asakawa Formation (defined by Otsuki, 1975)

The Asakawa Formation is corresponding to the Seki Formation (Saito, 1952), Seki and Takikura Formations (Omori, 1958), Takikura Formation (Kamiya, 1969), Tashiro and Toya Formations (Takahashi and Amano, 1984), Asakawa Formation (Otsuki, 1975; Saito *et al.*, 1992) and the middle part of Asakawa Formation (Nakashima, 1993 MS).

[Fossil occurrence]

Fossils from the Asakawa Formation were reported by Kamiya (1969) and Nakashima (1993 MS). The Asakawa Formation of this area contains intertidal to shallow-water molluscs such

as *Vicarya yokoyamai*, *Vicaryell ishiian*, *Anadara kakehataensis* and *Apolymetis takaii*. These fossils are represented the tropical and subtropical molluscs in the early middle Miocene in the Japanese Islands.

3. Nanataisan Formation

The Nantaisan Formation is corresponding to the Nantaizan Agglomerate (Omori, 1948, 1958; Kamiya, 1969) and the Nantaisan Volcanic Breccia (Otsuki, 1975; Takahashi and Amano, 1984; Saito *et al.*, 1992).

4. Nishizome Formation (defined by Otsuki, 1975)

The Nishizome Formation is corresponding to the Shionokusa Formation (Saito, 1952), Shionokusa Sandstone and Shale (Omori, 1958) and the Nishizome Formation (Saito *et al.*, 1992; Nakashima, 1993 MS). The Nishizome Formation includes the Oginokubo Siltstone Member.

[Type locality]

Type locality of this formation is exposure along the roadside at Takinoue in Suifu-mura to Atojuku in Kanasago-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 100 meters.

[Lithology]

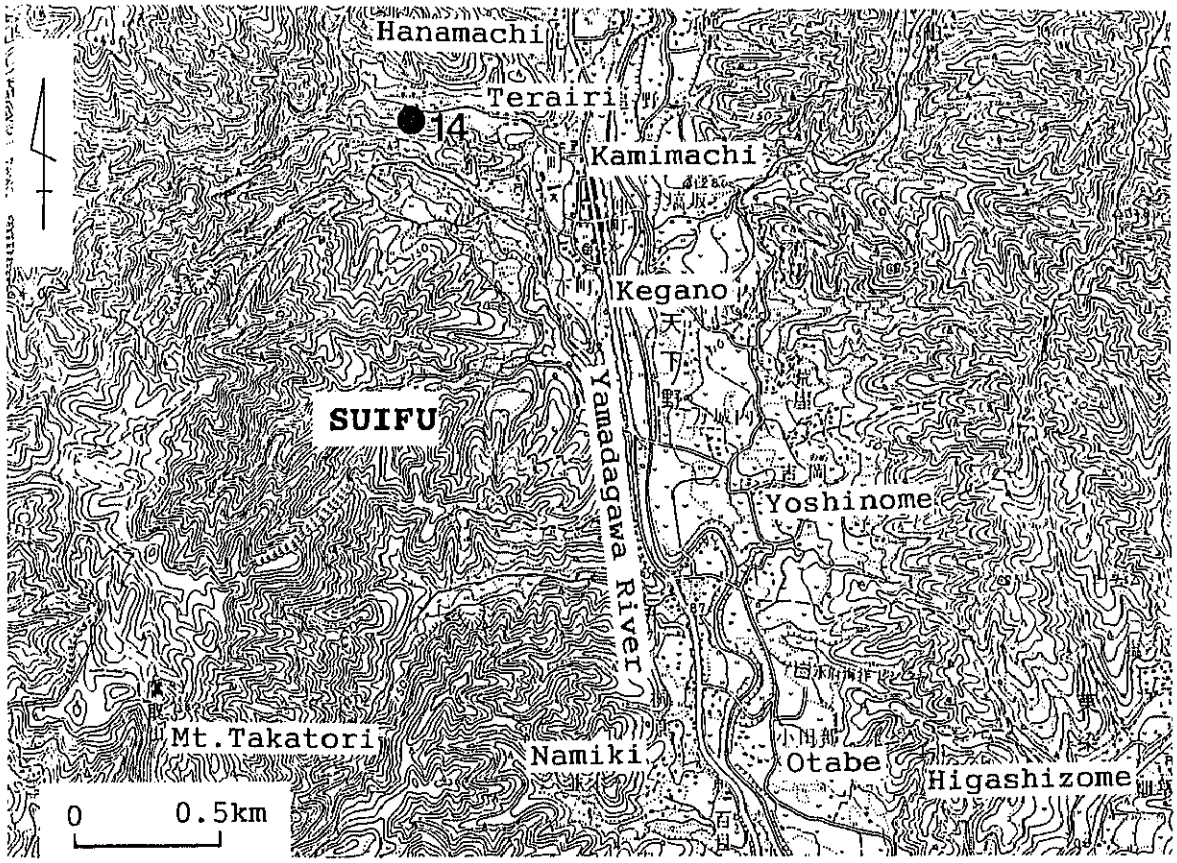

Fig. 13. Locality map of echinoids fossil in the area II, northwestern part of the Suifu area.

● ; Fossil locality.

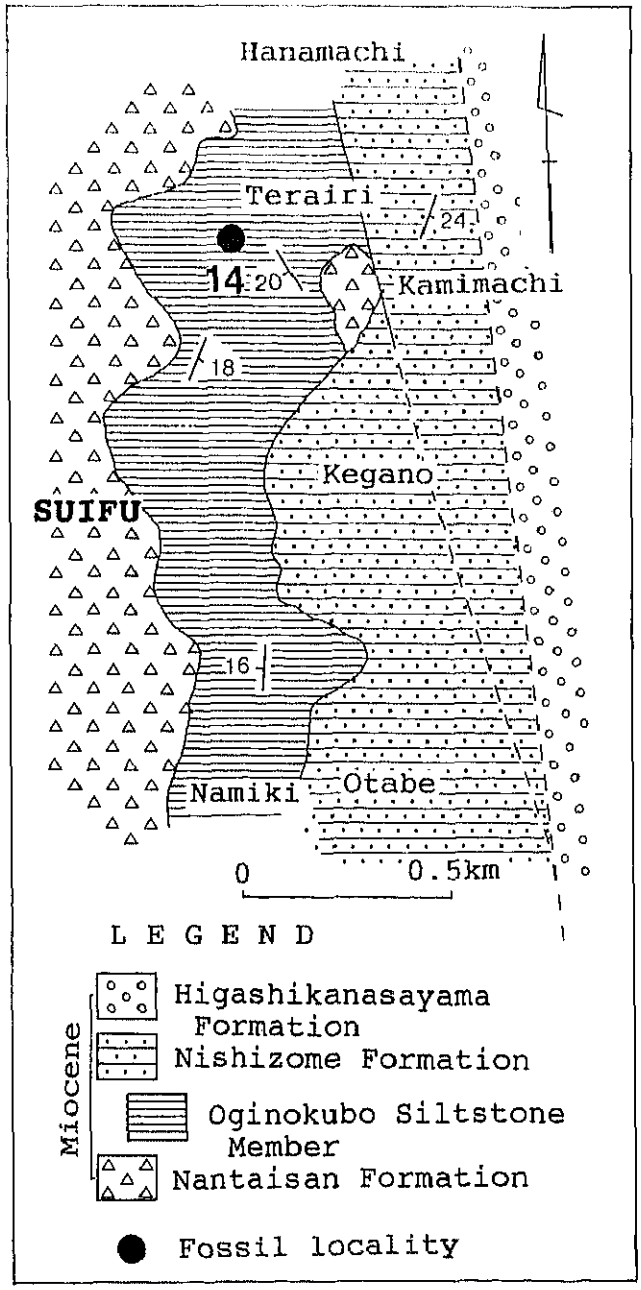

Fig. 14. Geological map and echinoid fossil locality in the area II, northwestern part of the Suifu area.

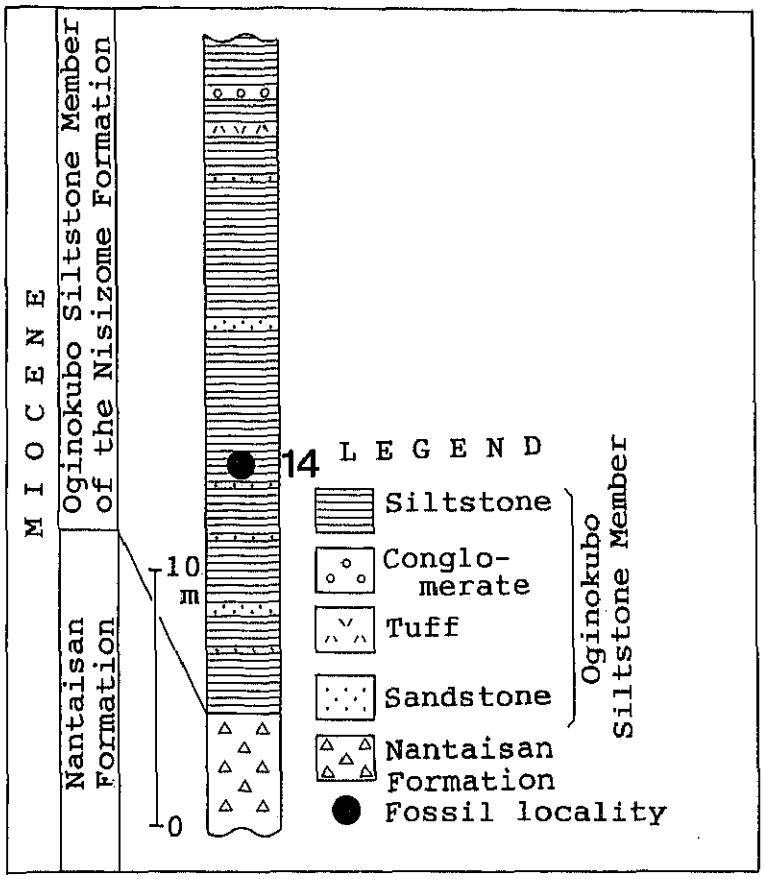

Fig. 15. Columnar section showing stratigraphical position of echinoid fossil in the area II, northwestern part of the Suifu area.

The Nishizome Formation mainly consists of dark gray siltstone, and siltstone dominant alternating beds of siltstone and sandstone with massive coarse grained sandstone and conglomerate.

[Stratigraphic relationship]

The Nishizome Formation conformably overlies the early middle Miocene Nantaisan and Asakawa Formations.

[Fossil occurrence]

This formation is lacking in fossil record.

4-A. Oginokubo Siltstone Member (Otsuki, 1975)

The Oginokubo Siltstone Member develops in the lower part of Nishizome Formation. This member is corresponding to the lower part of Shionokusa Sandstone and Shale (Omori, 1958) and the lower part of Nishizome Formation (Saito *et al.*, 1992).

[Type locality]

Type locality of this member is exposure at entrance to the tope of a valley at the northern part of Kanasago-machi, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 300 meters.

[Lithology]

The Oginokubo Siltstone Member is composed mainly of

Table 4. Stratigraphic division and correlation in the area III, central sheared zone at eastern part of the Suifu area.

Geologic age	Otsuki (1975)	Present paper
MIOCENE	Tatsukuroiso Mudstone Mem. Higashikanasayama Conglomerate Hosokusa Sandstone Mem.	Tatsukuroiso Mudstone Mem.★ Higashikanasayama Formation

★;Stratigraphical position of echinoid fossil.

massive dark gray siltstone, and siltstone dominant alternating beds of siltstone and sandstone.

[Stratigraphic relationship]

The Oginokubo Siltstone Member conformably overlies the early Middle Miocene Nantaisan Formation.

[Fossil occurrence]

Fossils from the Oginokubo Siltstone Member were reported by Otsuki (1975) and Nakashima (1993MS). This member contains deep-water molluscs such as *Acilana tokunagai* and *Preopeamussium tateiwai*. The newly collected echinoid fossil is *Brissopsis* sp. (Figs. 2, 13-15; Tables 1, 3, 14).

III. Central Sheared Zone in southern part of Suifu area (Fig. 1-III)

The Tertiary deposit of this area is widely distributed between the west marginal fault and east marginal fault of the Tanakura Tectonic Line. The early middle to middle Miocene deposit of the area constitute the following one formation and two members; the Higashikanasayama Formation, Hosokusa Sandstone Member and the Tatsukuroiso Mudstone Member in ascending order (Tables 1, 4).

The Tertiary deposit of the southern part of Suifu area have been studied by Omori (1948, 1958), Koizumi (1973), Otsuki

(1975), Kikuchi and Nikaido (1985) and Saito *et al.* (1992).

Echinoids fossils were collected from the middle Miocene Tatsukuroiso Mudstone Member of the Higashikanasayama Formation by the present study.

1. Higashikanasayama Formation (defined by Saito et al., 1992)

The Higashikanasayama Formation of the study area is divided into the Hosokusa Sandstone and Tatsukuroiso Mudstone Members. This formation is correlative the Nanamagari Conglomerate, Maji Conglomerate, Shimotakakura Subgroup, Yamada Conglomerate or Shirokanezawa Conglomerate (Omori, 1958) and the Higashikanasayama Conglomerate (Otsuki, 1975)

[Type locality]

Type locality of the Higashikanasayama Formation is exposure around the Mt. Higashikanasayama in Suifu-mura, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 1,200 meters.

[Lithology]

The Higashikanasayama Formation is mainly composed of boulder to cobble sized conglomerate of granitic and metamorphic rocks.

[Stratigraphic relationship]

The Higashikanasayama Formation conformably overlies

the early middle Miocene Asakawa and Nantaisan Formations, and is interfingering the middle Miocene Genjigawa Formations.

[Fossil Occurrence]

Foraminifera fossils from the Higashikanasayama Formation reported by Otsuki (1975).

1-A. Hosokusa Sandstone Member (defined by Otsuki, 1975)

The Hosokusa Sandstone Member is corresponding to the some part of Zuiryu Shale (Omori, 1958), alternating beds of sandstone and siltstone portion of the Higashikanasayama Conglomerate in the eastern part of Suifu district (Saito *et al.*, 1992) and the Hosokusa Sandstone Member (Nakashima, 1993 MS).

[Type locality]

Type locality of this member is exposure along the ridge at Nakazome to Kunigakusa in Suifu-mura, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The lithofacies of Hosokusa Sandstone Member varies in composition from the lower part to upper part. The lower part consists of sandstone dominant alternating beds of sandstone and siltstone with conglomerate. The upper part consists of coarse grained sandstone, in association with conglomerate.

[Stratigraphic relationship]

The Hosokusa Sandstone Member is interfingering the Higashikanasayama Formation.

[Fossil occurrence]

This member is lacking in fossil record.

1-B. Tatsukuroiso Mudstone Member (modified from Otsuki, 1975)

The Tstsukuroiso Mudstone Member is corresponding to the lower part of Zuiryu Shale (Omori, 1958), some portion of the alternating beds of fine grained sandstone and the siltstone of the Higashikanasayama Conglomerate (Saito *et al.*, 1992) and the Tatsukuroiso Mudstone Member (Otsuki, 1975).

[Type locality]

Type locality of this member is exposure along the roadside at Tatsukuroiso, Suifu-mura, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The thickness of this member varies 0 to 300 meters.

[Distribution]

The Tatsukuroiso Mudstone Member distributes at Tatsukuroiso and marginal area of Tatsukuroiso in the southeastern part of Suifu district.

[Lithology]

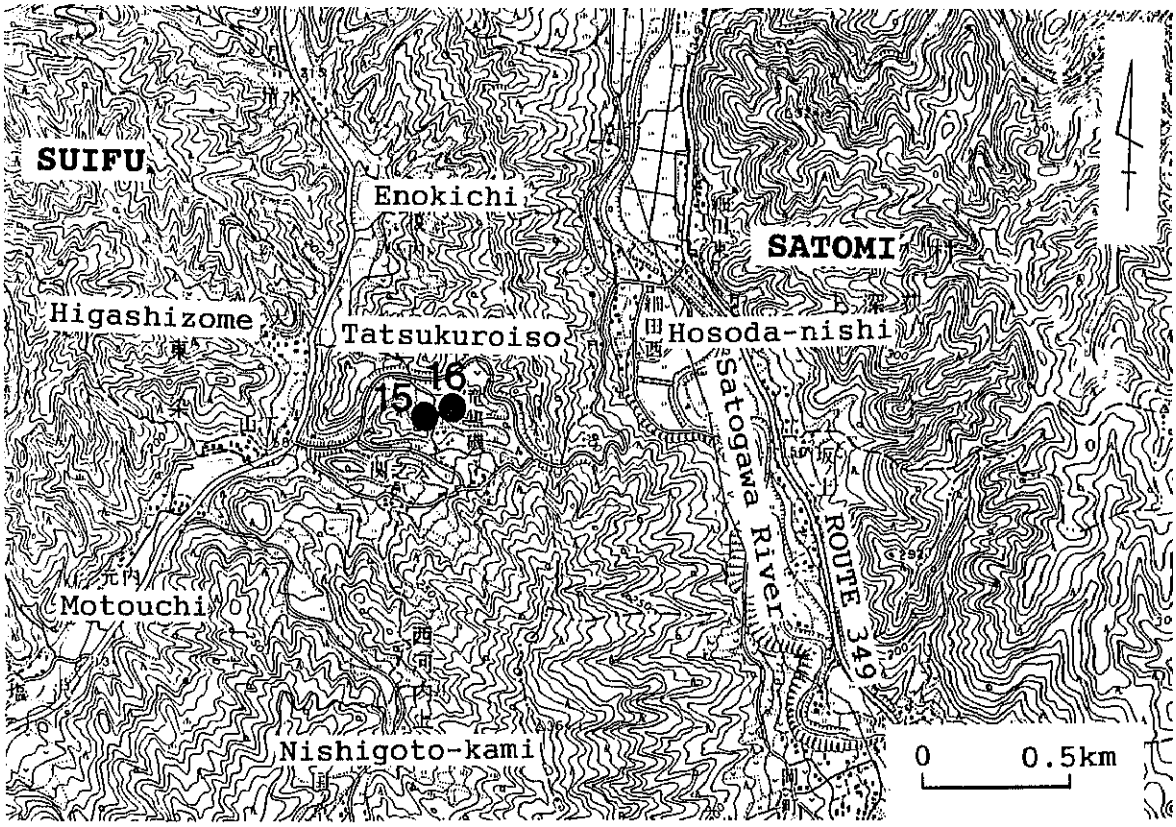

Fig. 16. Locality map of echinoid fossil in the area III, eastern part of the Suifu area.
● ; Fossil locality.

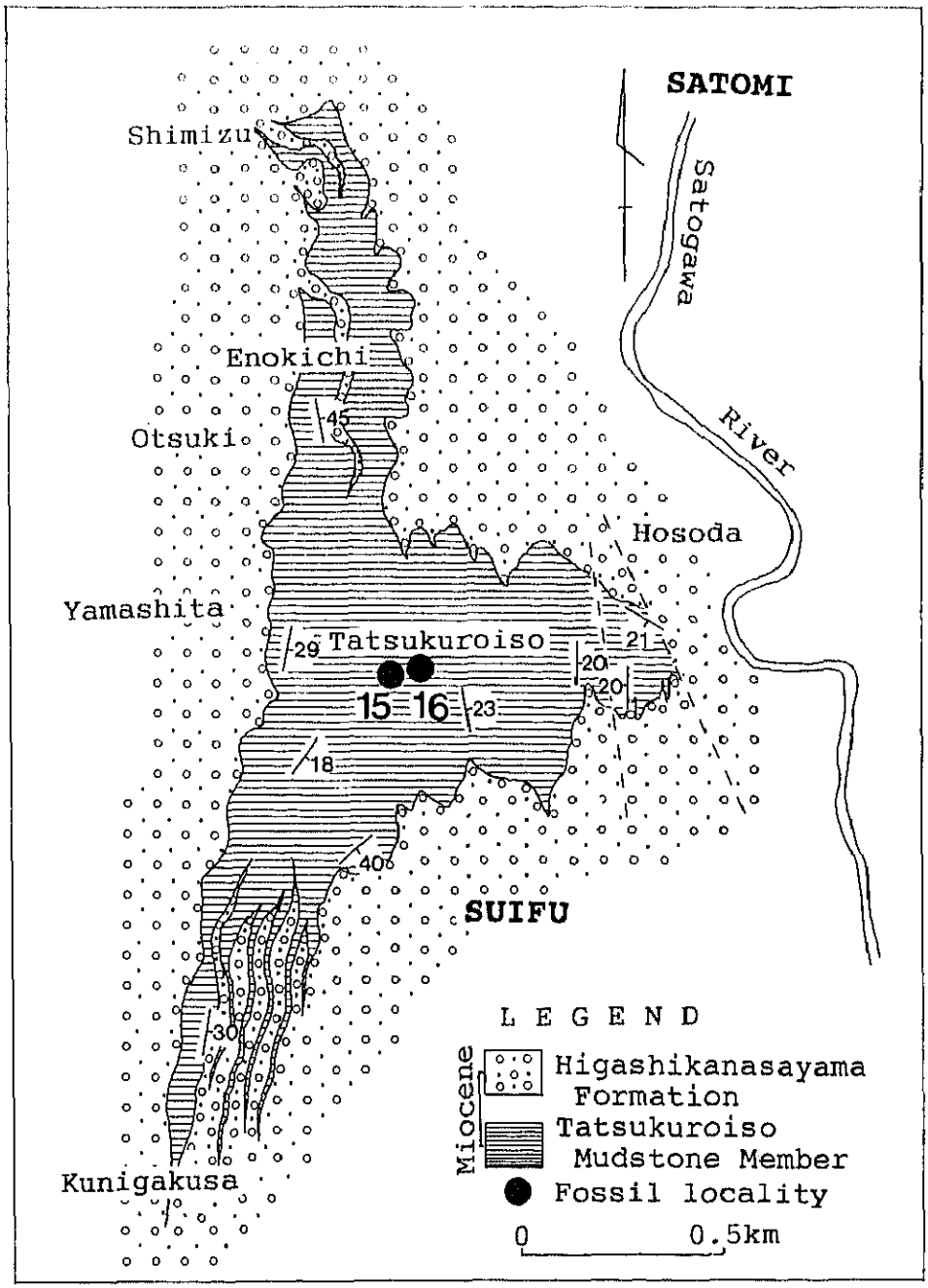

Fig. 17. Geological map and echinoid fossils localities in the area III, eastern part of the Suifu area.

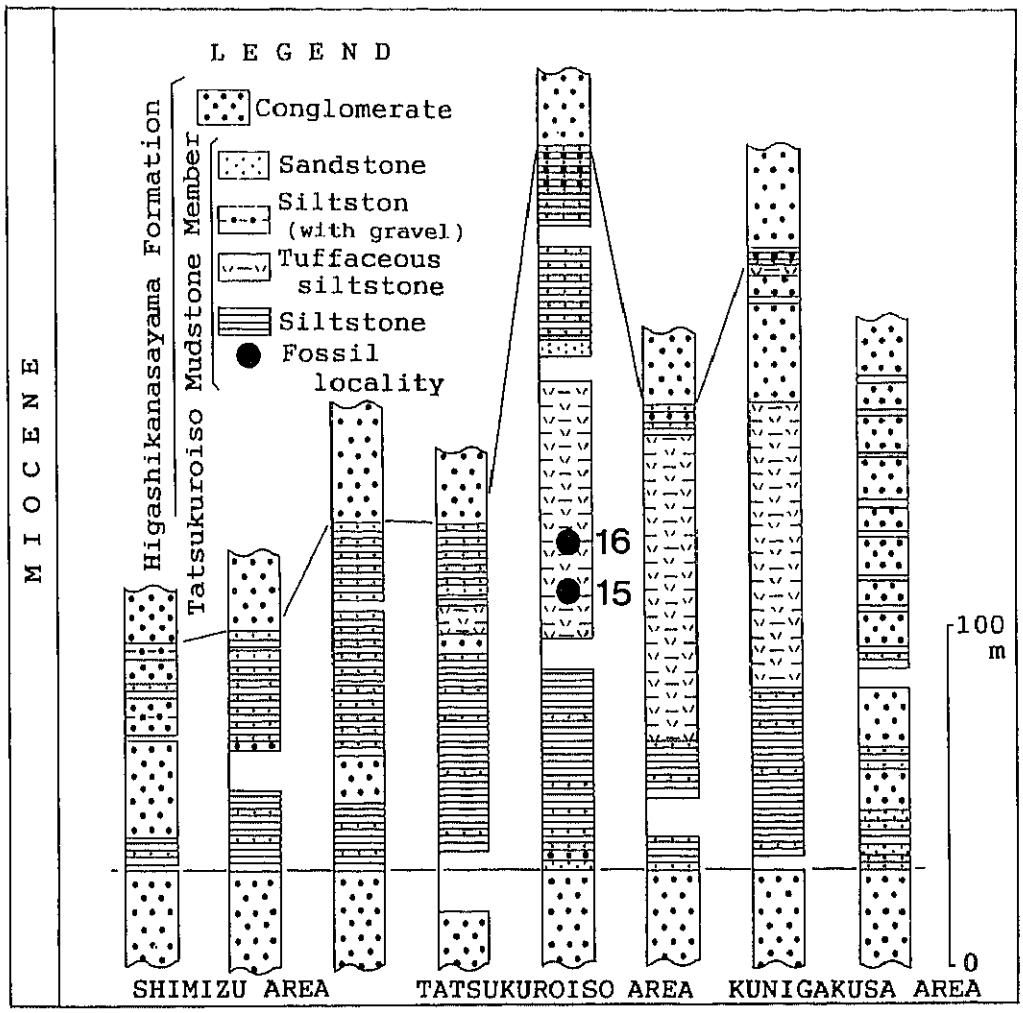

Fig. 18. Columnar section showing stratigraphical position of echinoid fossils in the area III, eastern part of the Suifu area.

The Tatsukuroiso Mudstone Member mainly consists of tuffaceous mudstone with coarse grained sandstone and granitic conglomerate. Lithofacies of the member varies in composition from the lower to upper part. The lower part mainly consists of pale gray to gray tuffaceous siltstone with conglomerate. The upper part consists of the alternating beds of coarse grained sandstone and siltstone with many mica grains.

[Stratigraphic relationship]

The Tatsukuroiso Mudstone Member is included the Higashikanasayama Formation.

[Fossil occurrence]

Fossils from the Tatsukuroiso Mudstone Member were reported by Koizumi (1973), Otsuki (1975), Kikuchi and Nikaido (1985).

Koizumi (1973) and Otsuki (1975) reported diatom fossil of *Denticula lauta* from the member.

The Tatsukuroiso Mudstone Member of the Higashikanasayama Formation contains deep-water echinoid and molluscs, and other fossils, such as echinoid of *Pourtalesia* sp., molluscs of *Solemya tokunagai* and *Delectopecten peckhami*, and *Denticulopsis* lauta of diatom fossil.

Newly collected fossils by the present study are as following;

echinoid fossils of *Pourtalesia kusachii* n. sp., and *Aceste* sp.; molluscan fossils of *Bathyarca* sp., *Acila* sp., *Neilonella* sp., *Chlamys nipponica*, *Cavolina* sp. and *Dentalium* sp.; plant fossils of *Cunninghamia* sp., *Taiwania* sp. and *Fagus* sp. (Figs.2, 13-18; Tables 1, 4, 14).

IV. Omiya area (Fig. 1-IV)

The Tertiary deposit of the Omiya area is widely distributed in the Yamizo Mountains. It is well exposed along the Kujigawa River of the southwestern part of Yamagata area. The early Middle Miocene deposits of Omiya area are composed of the following seven formations: the Boji, Kuniosa, Ogaino, Sakuramoto, Tamagawa and Sakachi Formations, in ascending order (Tables 1, 5).

Geological and paleontological studies has been done by Akutsu (1952), Omori (1958), Ohyama and Sakurai (1966), Kamei and Kamiah (1981), Takahashi and Amano (1984), Amano *et al.* (1989), Yanagisawa (1990), Saito *et al.* (1992), Noda *et al.* (1994) and Kodak *et al.*, (2003).

Echinoid fossil is newly collected from the early middle

Table 5. Stratigraphic division and correlation in the area IV, Omiya area.

Geologic age	Akutsu (1952)	Ohyama and Sakurai (1966)	Saito *et al.*, (1992)	Noda *et al.*, (1994)	Prsent Paper
PLEISTO-CENE	Terrace Deposite				
MIOCENE	Urizura F.	Urizura F.			
	?				
	Araya F.	Araya F.	Araya F.		
	Sakachi F.	Sakachi F.	Sakachi F.	Sakachi F.	Sakachi F.
	Tamagawa F.	Tamagawa F.	Tamagawa F.	Tamagawa F.	Tamagawa F.★
	Sakuramoto F.	Sakuramoto F.	Sakuramoto F	Sakuramoto F.	Sakuramoto F.
	Ogaino F.	Ogaino F.	Ogaino F.	Ogaino F.	Ogaino F.
	Kuniosa F.	Kuniosa F.			
	Boji F.	Boji F.			
PRE TERTIARY	Yamizo Group	Yamizo Group	Yamizo Group	Yamizo Group	Yamizo Group

★;Stratigraphical position of echinoid fossil.

Miocene Tamagawa Formation by this study.

1. Boji Formation (defined by Akutsu, 1952)

The early middle Miocene Boji Formation is stratigraphically situated in the lower most part of this area, and is correlative the lower part of Kanazawa Subgroup (Omori, 1958), Boji Formation (Ohyama and Sakurai, 1966) and the Boji Conglomerate (Takahashi and Amano, 1984; Saito *et al.*, 1992).

[Type locality]

Type locality of this formation is outcrop at Boji in Ogawa-mura, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 150 meters.

[Lithology]

The Boji Formation mainly consists of cobble to boulder sized conglomerate.

[Stratigraphic relationship]

The Boji Formation unconformably overlies the Pre-Tertiary basement rocks of the Yamizo Group.

[Fossil occurrence]

This formation is lacking in fossil record.

2. Kuniosa Formation (defined by Akutsu, 1952)

The early middle Miocene Kuniosa Formation is corresponding to the Kanazawa Subgroup (Omori, 1958) and the Kuniosa Formation (Ohyama and Sakurai, 1966; Takahashi and Amano, 1984; Amano *et al.*, 1989; Saito *et al.*, 1992).

[Type locality]

Type locality of this formation is outcrop at Kuniosa in Ogawa-mura, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is a more than 300 meters.

[Lithology]

The Kuniosa Formation is mainly composed of dark gray siltstone, pale gray tuffaceous sandstone with brecciated tuff and andesitic pyroclastics with lignite beds.

[Stratigraphic relationship]

The Kuniosa Formation conformably overlies the early middle Miocene Boji Formation, and also unconformably overlies the Pre-Tertiary basement rocks of the Yamizo Group in part.

[Fossil occurrence]

Some plant fossils were reported from the Kuniosa Formation by Akutsu (1952) and Ohyama and Sakurai (1966).

3. Ogaino Formation (defined by Akutsu, 1952)

The early Middle Miocene Ogaino Formation is correlative the Shiraiwa-Toge Tuff and the Asakawa Formation (Omori, 1958), Kokaino Formation (Takahashi and Amano, 1984), Ogaino Formation (Amano *et al.*, 1989; Saito *et al.*, 1992; Noda *et al.*, 1994) and the Osawaguchi Tuff Member of the Asakawa Formation (Takahashi and Amano, 1984).

[Type locality]

Type locality of this formation is outcrop at Ogaino, Kita-Shiogo in Omiya-machi, Naka-gun, Ibaraki Prefcture.

[Thickness]

The total thickness is about 700 meters.

[Lithology]

The Ogaino Formation mainly consists of fine to coarse grained white tuff, tuffaceous sandstone with siltstone, conglomerate and lignite beds.

[Stratigraphic relationship]

The Ogaino Formation conformably overlies the early middle Miocene Kuniosa Formation.

[Fossil occurrence]

Fossils from the Ogaino Formation were reported by Akutsu (1952), and Kamei and Kamiya (1981) such as proboscidean of *Eostegodon pseudolatidens*.

4. Sakuramoto Formation (modified from Akutsu, 1952)

The early middle Miocene Sakuramoto Formation is corresponding to the upper part of Kanazawa Group and lower to middle part of the Asakawa Formation (Omori, 1958), and the Sakuramoto Formation (Ohyama and Sakurai, 1966; Takahashi and Amano, 1984; Amano *et al.*, 1989; Saito *et al.*, 1992; Noda *et al.*, 1994).

[Type locality]

Type locality of this formation is exposure along the Nakago to Sakuramoto in Ogawa-mura, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 400 meters.

[Lithology]

The Sakuramoto Formation is mainly composed of tuffaceous sandstone and siltstone with lignite beds. Lithofacies varies in composition from lower to upper part. The lower part consists of the alternating beds of the medium grained tuffaceous sandstone and

siltstone with greenish tuff. The middle to upper part consists of the pumiceous medium to coarse grained, greenish tuff with siltstone.

[Stratigraphic relationship]

The Sakuramoto Formation conformably overlies the early middle Miocene Ogaino Formation.

[Fossil occurrence]

Proboscidea and plant fossils from the Sakuramoto Formation were reported by Akutsu (1952) and Koda *et al.*, (2003).

5. Tamagawa Formation (defined by Noda *et al.*, 1994)

The early middle Miocene Tamagawa Formation is corresponding to the Tamagawa Formation (Akutsu, 1952; Ohyama and Sakurai, 1966; Takahashi and Amano, 1984; Amano *et al.*, 1989), Tamagawa Formation except for upper part (Saito *et al.*, 1992), Takikura Formation and the lower part of Shionokusa Formation (Omori, 1958).

[Type locality]

Type locality of this formation is exposure along the Tamagawa River in Omiya-machi, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total is about 800 meters.

[Lithology]

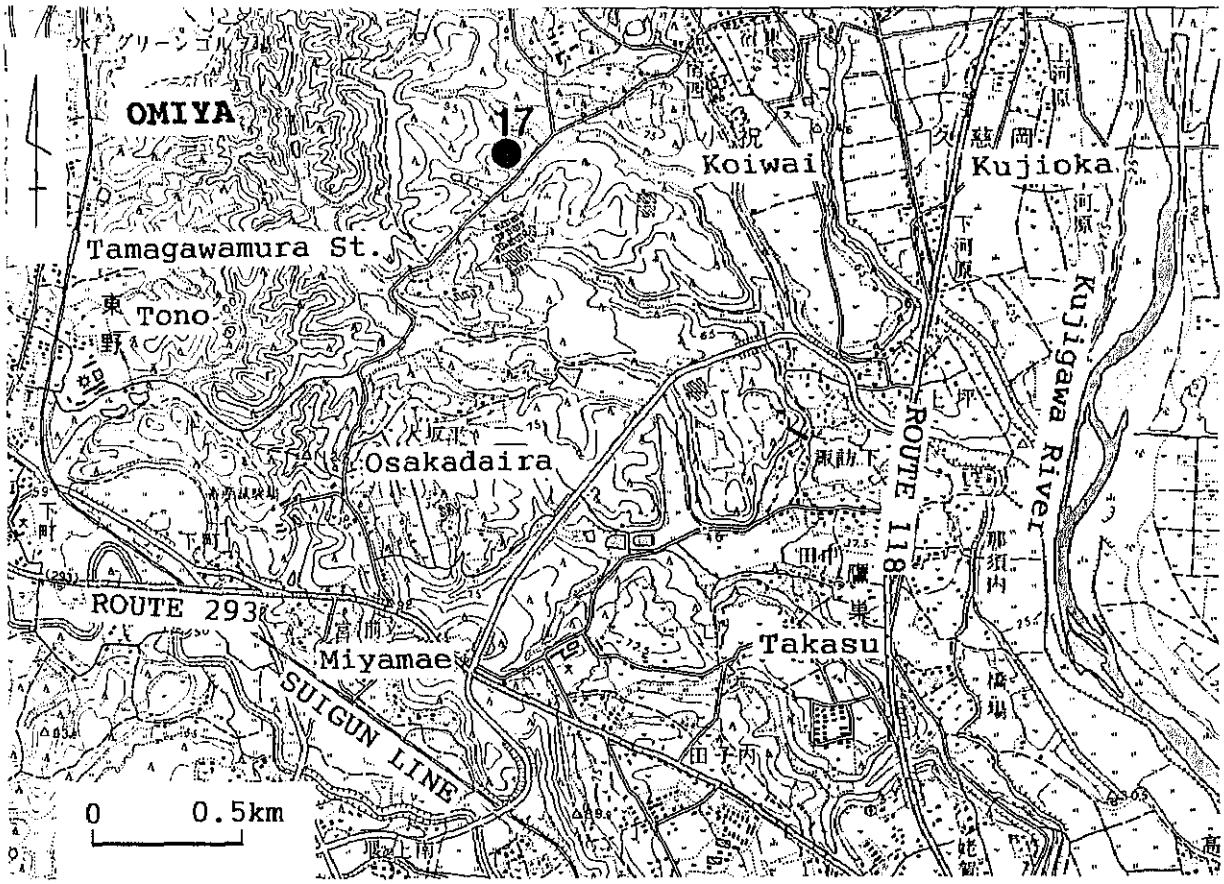

Fig. 19. Locality map of echinoid fossil in the area IV, Omiya area. ●; Fossil locality.

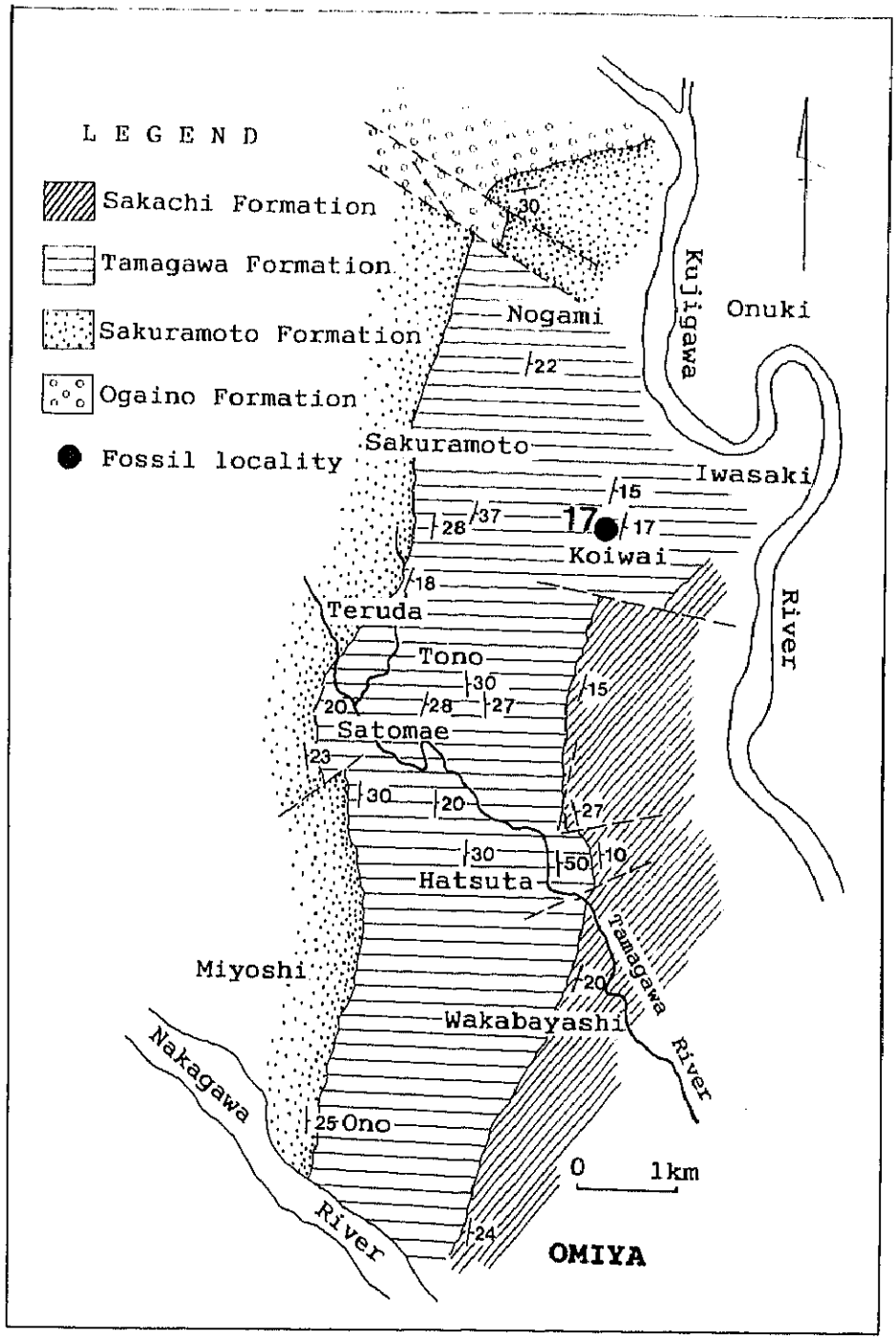

Fig. 20. Geological map and echinoid fossil locality in the area IV, Omiya area (modified from Noda *et al.*, 1994).

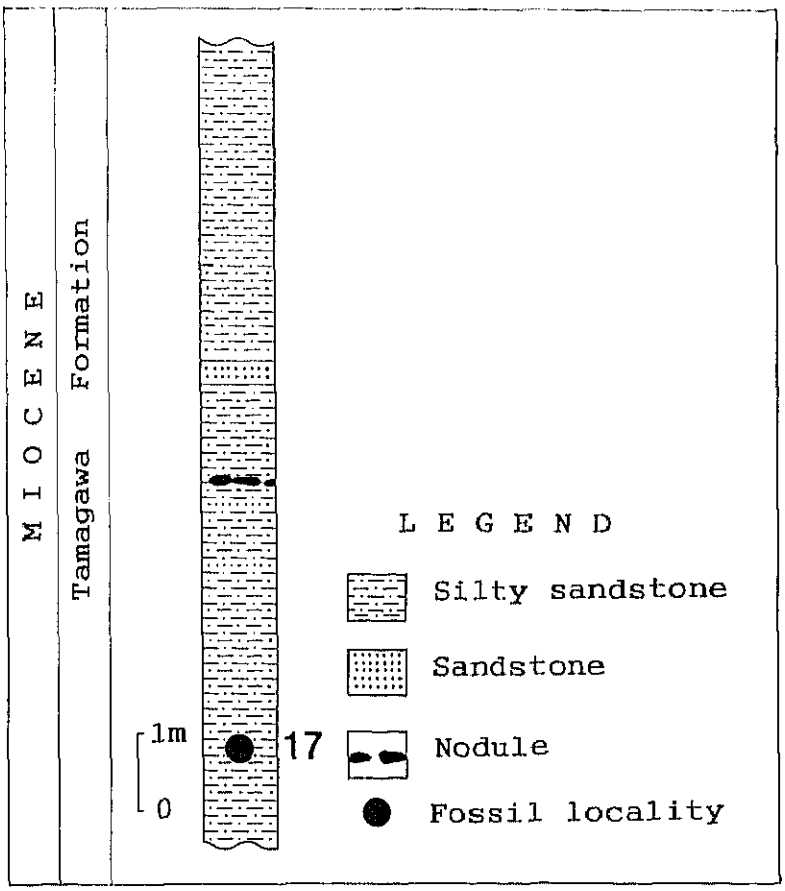

Fig. 21. Columnar section showing stratigraphical position of echinoid fossil in the area IV, Omiya area.

The Tamagawa Formation mainly consists of medium grained tuffaceous sandstone, white tuff and siltstone.

[Stratigraphic relationship]

The Tamagawa Formation conformably overlies the early middle Miocene Sakuramoto Formation.

[Occurrence fossil]

Fossils from the Tamagawa Formation were reported by Akutsu (1952), Ohyama and Sakurai (1966), Takahashi and Amano (1984), Amano *et al.* (1989) and Noda *et al.* (1994).

The Tamagawa Formation contains shallow-water molluscs, trace and other fossils, including molluscs of *Vicarya yokoyamai*, *Vicaryella ishiian*, *Tateiwaia tateiwai*, *Anadara kakehataensis*, *Dosinia nomurai* and *Cultellus izumoensis*. These fossils regarded the Arcid-Potamid Fauna of Tsuda (1959) flourished intertidal to shallow-water environment under tropical and subtropical-water condition by comparison with the modern molluscs of the Western Pacific.

New collected echinoid fossil is Schizasteridae gen. et sp. indet. by this study (Figs. 2, 19-21; Tables 1, 5, 14).

6. Sakachi Formation (modified from Noda *et al.*, 1994)

The early middle Miocene Sakachi Formation is correlative the Shionokusa Sandstone and Shale, the part of the Okado Sandstone (Omori, 1958) and the Sakachi Formation (Akutsu, 1952; Ohyama and Sakurai, 1966; Takahashi and Amano, 1984; Amano *et al.*, 1989; Saito *et al.*, 1992).

[Type locality]

Type locality of this formation is outcrop along a road between Sakachi and Oba in Omiya-machi, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 400 meters.

[Lithology]

The Sakachi Formation mainly consists of massive gray siltstone with fine sandstone.

[Stratigraphic relationship]

The Sakachi Formation conformably overlies the early middle Miocene Tamagawa Formation.

[Fossil occurrence]

Fossils from the Sakachi Formation were reported by Akutsu (1952) and Ohyama and Sakurai (1966) as the molluscan fossils of *Argonata* cf. *tokunagai*, *Izumonauta* sp. and plant fossils. These

Argonata fossils are regarded as the index of the middle Miocene in age (Yanagisawa, 1990).

Newly collected fossils are as following: sponge of *Aphrocallistes* sp. and *Makiyama chitanii*, molluscs of *Propeamussium tateiwai* and *Lucinoma* sp., and *Zoophycos* isp. and *Chondrites* isp. of trace fossils.

V. Naka area (Fig. 1-V)

The middle Miocene and Pliocene deposits are narrowly distributed along the valley of west side of Kujigawa River in the Naka area (Figs. 22-23). These deposit of Naka area are composed of the following two formations: the middle Miocene Urizura Formation, and the Pliocene Kume Formation, in ascending order (Tables 1, 6).

Geological and paleontological studies of these strata have been done by Akutsu (1952), Omori (1958), Ohyama and Suzuki (1966), Sakamoto *et al.*, (1973), Koizumi and Terunuma (1985) and Amano *et al.*, (1989).

Echinoid fossil first yielded from the Pliocene Kume Formation by present study.

Table 6. Stratigraphic division and correlation in the area V, Naka area.

Geologic age	Koizumi and Terunuma (1985)	Present paper
PLEISTO-CENE		Terrace Deposite
PLIOCENE		Kume F. ★
MIOCENE	Taga F.	Urizura F.

★; Stratigraphical position of echinoid fossil.

1. Urizura Formation

The late to latest middle Miocene Urizura Formation is corresponding to the Urizura Formation (Akutsu, 1952) and the Taga Group (Sakamoto *et al.*, 1972; Koizumi and Terunuma, 1985).

[Type locality]

Type locality of this formation is outcrop along the valley side at Kadobe in Urizura-machi, Naka-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is more than 100 meters.

[Lithology]

The Urizura Formation mainly consists of massive blue gray siltstone, fine grained white tuff, fine grained sandstone and coarse grained pumiceous tuff.

[Stratigraphic relationship]

The Urizura Formation may conformably overlies the middle Miocene Araya Formation.

[Fossil occurrence]

Fossils from the Urizura Formation were reported by Akutsu (1952), Ohyama and Sakurai (1966) and Koizumi and Terunuma (1985). These fossils are as follow: diatom of *Denticulopsis hustedtii, Denticulopsis nicobarica, Denticulopsis lauta* and *Denticulopsis,*

etc., molluscs of *Delectopecten tairanus* , and *Carcharodon megarodon* of shark teeth.

Newly collected fossils by the present study are as following; shark teeth of *Isurus hastalis*, and molluscs of *Delectopecten peckhamii* and *Lucinoma* sp.

2. Kume Formation

This stratum is isolated and very narrowly developed at the Nagai in the Nukada-Togo district. Geological and paleontological studies are very few. This formation of the Nagai area seems to be represented marginal facies of the Pliocene Kume Formation.

[Thickness]

The total thickness is about 30 meters in this area.

[Lithology]

This Kume Formation consists mainly of massive bleu gray sandy siltstone, in association with many calcareous nodules.

[Stratigraphic relationship]

This formation unconformably overlies the middle Miocene Urizura Formation (Pl. 2, figs. 1ab).

[Fossil occurrence]

Many molluscan fossils were newly collected from the

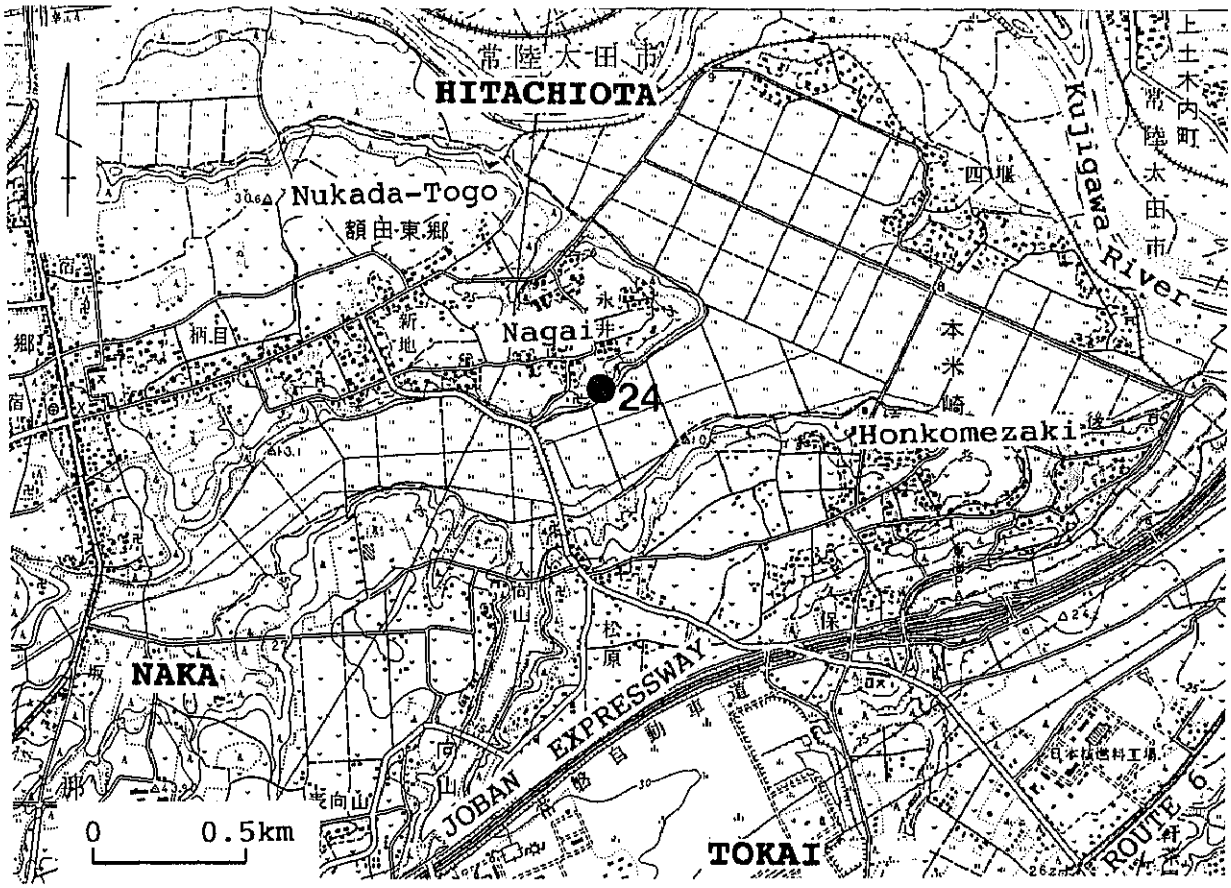

Fig. 22. Locality map of echinoid fossil in the area V, Naka area. ●; Fossil locality.

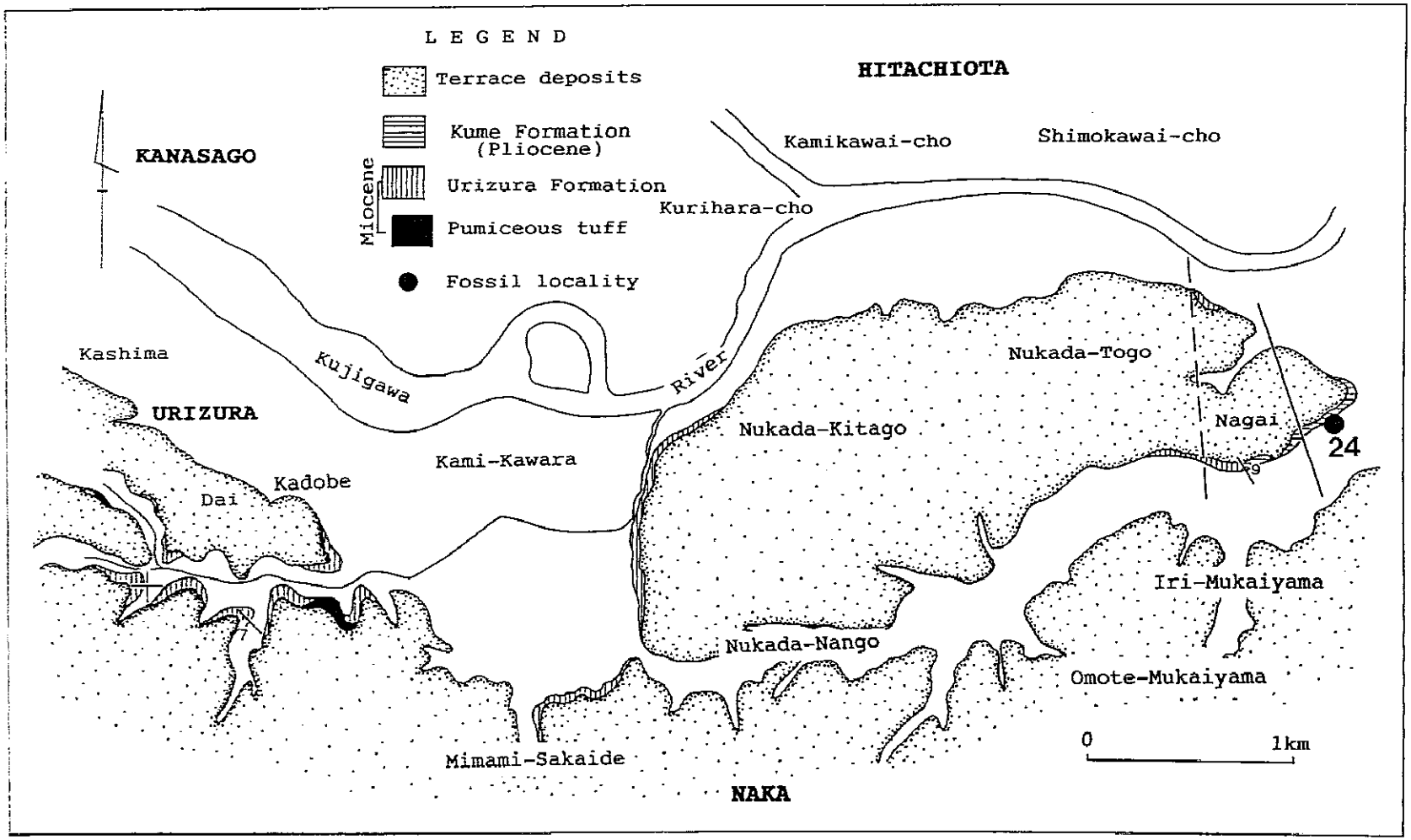

Fig. 23. Geological map and echinoid fossil locality in the area V, Naka area.

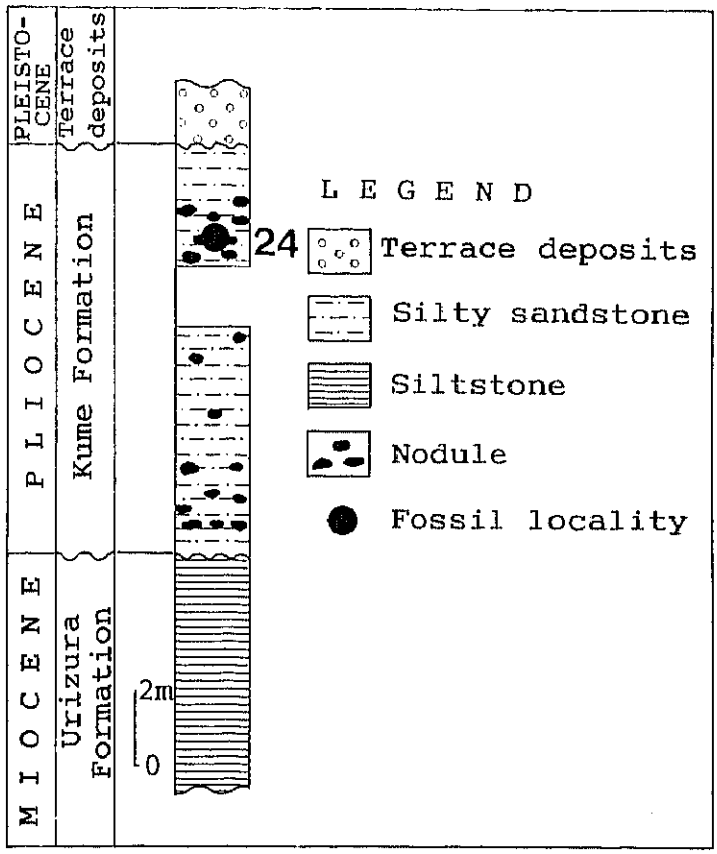

Fig. 24. Columnar section showing stratigraphical position of echinoid fossil in the area V, Naka area.

formation by the present author such as molluscs of *Acila divaricata submirabilis*, *Anadara amicula elongata*, *Cyclocardia ferruginea*, *Lucinoma* sp., *Mizuhopecten ibaragiensis*, *Buccinum* sp. and Shizasteridae gen. et sp. indet. of echinoid fossil (Figs. 2, 22-24; Tables 1, 6, 14).

This molluscan assemblage is correlative to that of the Kume Formation in Kanasago and Hitachiota districts.

VI. Kanasago to Hitachiota area (Fig. 1-VI)

Tertiary deposits widely distributed in the area between the Kujigawa River and Satogawa River in Kanasago to Hitachiota area can be divided into the following five formations, in ascending order; the early middle Miocene to middle Miocene Higashikanasayama Formation, early middle Miocene Okado Formation, early middle Miocene Zuiryu Formation, middle Miocene Genjigawa Formation, and the Pliocene Kume (Tables 1, 7).

Many geological and paleontological studies have been done in this area such as Kinoshita (1935), Omori (1948, 1958), Suzuki and Omori (1953), Saito (1952), Ozaki and Saito (1954), Ishii *et al.* (1974), Otsuki (1975), Noda and Amano (1977), Maruyama (1984),

Table 7. Stratigraphic division and correlation in the area VI, Kanasago to Hitachiota area.

Geologic age	Omori (1952)	Suzuki and Omori (1953)	Suzuki (1954)	Ozaki and Saito (1954)	Omori (1956)	Otsuki (1975)	Maruyama (1984)	Saito et al., (1992)	Present paper
PLEISTOCENE									Terrace Deposite
PLIOCENE	Kume G.	Hanareyama Tuff Kume Sandy Shale	Genjigawa G. Hitachi G. Kume Sandy Shale	Kume F.	Kume Sandy Shale	Kume F.	Kume F.	Kume F.	Kume F. ★
MIOCENE	Genjigawa G.	Genjigawa G.	Tawatari Mudstone Baba Sandstone	Genjigawa F.	Genjigawa G.	Genjigawa F.	Genjigawa F.	Genjigawa F.	Genjigawa F.
	Ota G. Zuiryu F.	Zuiryu Shale	Zuiryu Shale	Zuiryu F.	Zuiryu Shale	Zuiryu F.	Zuiryu F.	Zuiryu F.	Zuiryu F.
	Okado F.	Okado Sandstone	Ota G. Okado Sandstone	Okado F.	Okado Sandstone	*Okado F.*	*Okado F.*	*Okado F.*	*Okado F.*
	Somewada Conglomerate	Somewada Conglomerate	Somewada Conglomerate	Somewada F.	Yamada *Conglomerate*	Higashikanasa-*yama* Conglomerate	Somewada F.	Higashikanasa-*yama* Conglomerate F.	Higashikanasa-*yama F.*

★; Stratigraphical position of echinoid fossil.

Takahashi (1986), Kikuchi and Nikaido (1987), Amano *et al.* (1989), Noda *et al.* (1989), Kikuchi *et al.* (1991), Saito *et al.* (1992), Nakashima (1993 MS) and Noda *et al.* (1993, 1995).

Echinoid fossils are newly collected from the middle Miocene Genjigawa Formation and Pliocene Kume Formation.

1. Higashikanasayama Formation

The early middle to middle Miocene Higashikanasayama Formation is corresponding to the Machiya Conglomerate (Kinoshita, 1935), Machiya Conglomerate (Omori, 1958), Somewada Conglomerate (Omori, 1948; Ozaki and Saito, 1954) and the Higashikanasayama Conglomerate (Saito *et al.*, 1992) in this area.

2. Okado Formation (defined by Otsuki, 1975)

The early middle Miocene Okado Formation is correlatives to the Okado Sandstone (Kinoshita, 1935; Suzuki and Omori, 1953; Omori, 1958), Okado coarse grained Sandstone (Ozaki and Saito, 1954) and the Okado Formation (Omori, 1948; Saito, 1952; Takahashi, 1986; Amano *et al.*, 1989; Saito *et al.*, 1992; Nakashima, 1993MS).

[Type locality]

Type locality of this formation is exposure along the valley

at the Okado to Nagao in Hitachiota City, Ibaraki prefecture.

[Thickness]

The total thickness is about 550 m.

[Lithology]

The Okado Formation mainly consists of dark gray siltstone, siltstone dominated alternating beds of siltstone and sandstone with white tuff.

[Stratigraphic relationship]

The Okado Formation conformably overlies and also interfinging lower part of the Higashikanasayama Formation.

[Occurrence fossil]

Noda *et al.* (1995) reported such molluscs from the formation as *Aturia cubaensis* and *Conchoele disjuncta*, and also sponge fossil of *Makiyama chitanii*.

3. Zuiryu Formation (defined by Otsuki, 1975)

The early Middle Miocene Zuiryu Formation is corresponding to such strata as the Zuiryu Shale (Kinoshita, 1935; Suzuki and Omori, 1953; Omori, 1958), Zuiryu Hard Shale (Ozaki and Saito, 1954) and the Zuiryu Formation (Omori, 1948; Saito, 1952; Takahashi, 1986; Amano *et al.*, 1989; Saito *et al.*, 1992).

[Type locality]

Type locality of this formation is exposure of Moto-Zuiryu in Hitachiota City, Ibaraki Prefecture.

[Thickness]

The total thickness is about 200 meters.

[Lithology]

The Zuiryu Formation is mainly composed of dark gray siliceous siltstone, alternating beds of sandstone and siltstone, associated with medium grained pumiceous gray tuff.

[Stratigraphic relationship]

The Zuiryu Formation conformably overlies the early middle Miocene Okado Formation.

[Occurrence fossil]

Diatom and foraminifera fossils from the Zuiryu Formation were reported by Saito (1952) and Ozaki and Saito (1954).

4. Genijigawa Formation (modified from Otsuki, 1975)

The middle Miocene Genjigawa Formation is correlative to the part of Nishiyama Tuffaceous Sandy Shale and Hatasome Tuffaceous Sandy Shale (Kinoshita, 1935), Ota Formation (Saito, 1952), Genjigawa Group (Suzuki and Omori, 1953), Genjigawa Tuffaceous

Mudstone (Ozaki and Saito, 1954) and the Genjigawa Tuffaceous Mudstone (Omori, 1948, 1958; Maruyama, 1984; Takahashi, 1986, Amano *et al.*, 1992; Nakashima, 1993MS).

[Type locality]

Type locality of this formation is the outcrop along the Genjigawa River in Hitachiota City, Iabaraki Prefecture.

[Thickness]

The total thickness is about 800 m.

[Lithology]

The Genjigawa Formation mainly consists of the massive diatomaceous siltstone and sandy siltstone with coarse grained pumiceous tuff.

[Stratigraphic relationship]

The Genjigawa Formation conformably overlies the early middle Miocene Zuiryu Formation.

[Fossil occurrence]

Diatom and other fossils from the Genjigawa Formation were reported by Saito (1952), Ozaki and Saito (1954), Omori (1958), Otsuki (1975) and Maruyama (1984).

In addition to above fossils, some newly collected fossils by the author are following; mollusca of *Portlandia* sp., sponge

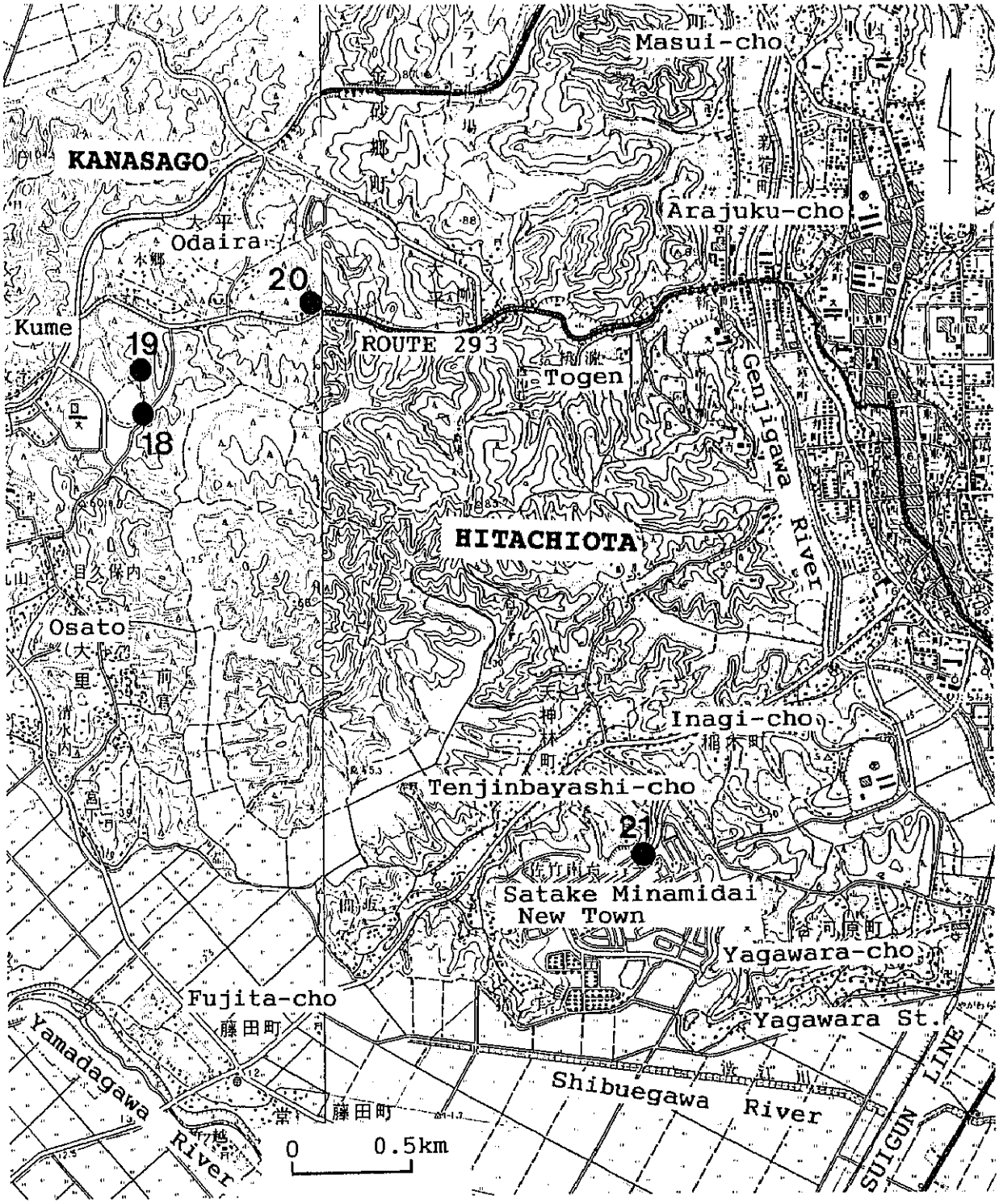

Fig. 25. Locality map of echinoid fossils in the area VI, Kanasago to Hitachiota area. ●; Fossil locality.

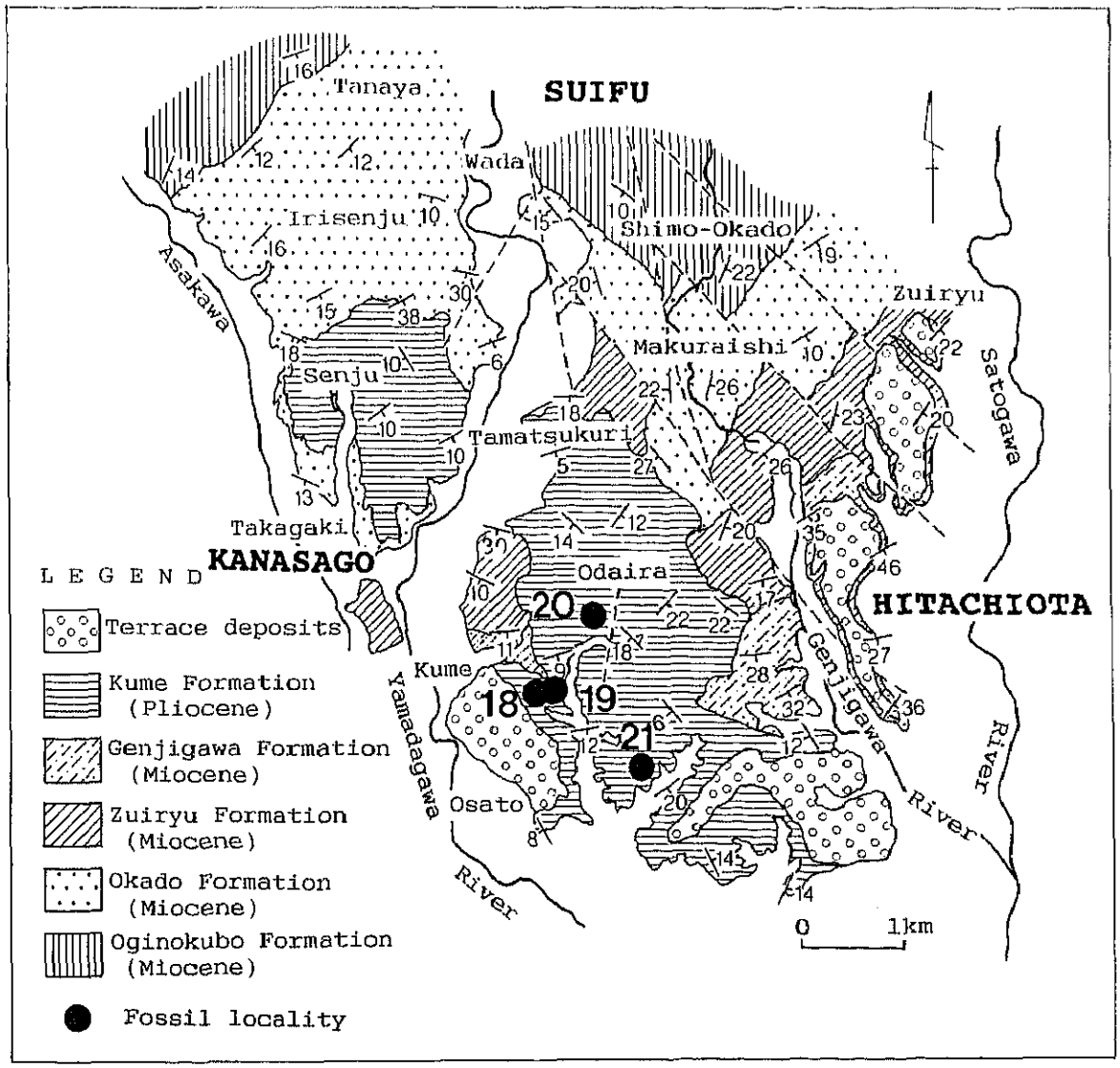

Fig. 26. Geological map and echinoid fossils localities in the area VI, Kanasago to Hitachiota area (modified from Takahashi, 1986).

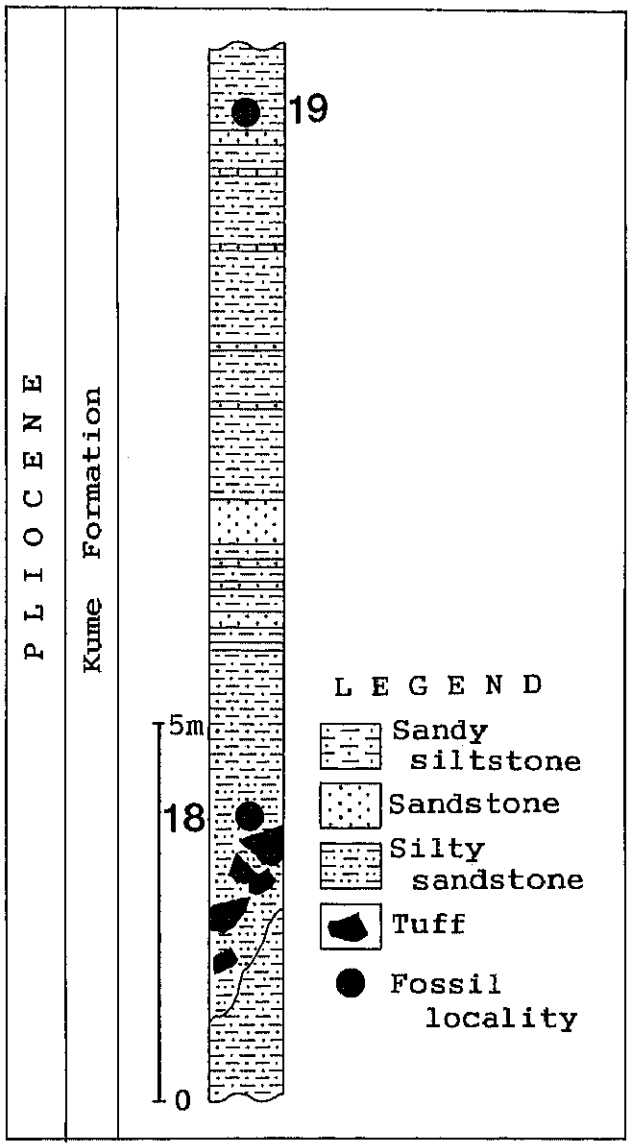

Fig. 27. Columnar section showing stratigraphical position of echinoid fossils in the area VI, Kanasago to Hitachiota area (1).

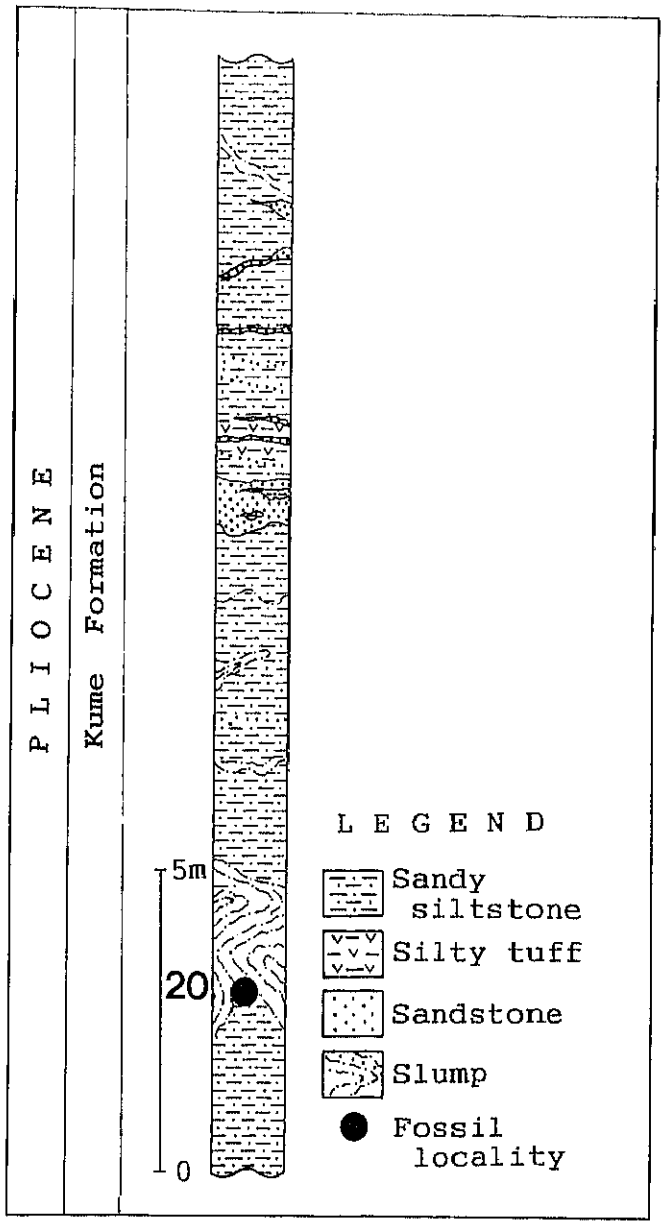

Fig. 28. Columnar section showing stratigraphical position of echinoid fossil in the area VI, Kanasago to Hitachiota area (2).

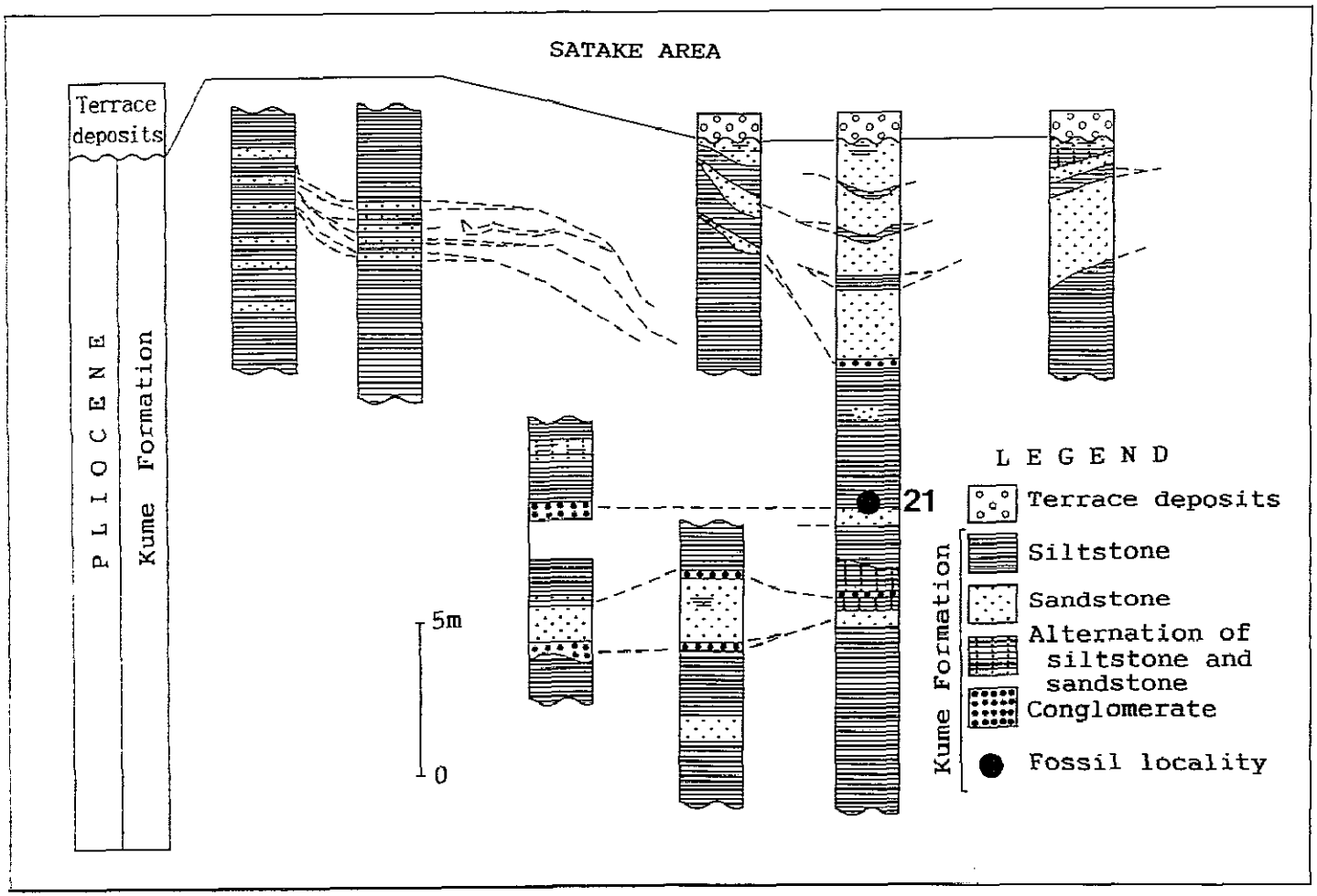

Fig. 29. Columnar section showing stratigraphical position of echinoid fossil in the area VI, Kanasago to Hitachiota area (3) (modified from Noda *et al.*, 1993).

fossils of *Aphrocallistes* sp. and *Makiyama chitanii*, and undetermined echinoid.

5. Kume Formation (defined by Otsuki, 1975)

The Pliocene Kume Formation is corresponded to the part of Nishiyama Tuffaceous Sandy Shale and Hatasome Tuffaceous Sandy Shale (Kinoshita, 1935), Kume Group (Omori, 1948), Kume Sandy Shale (Suzuki and Omori, 1953; Omori, 1958), Kume Fine Sandstone (Ozaki and Saito, 1954) and the Kume Formation (Noda and Amano, 1977; Takahashi, 1986; Kikuchi and Nikaido, 1987; Noda *et al.*, 1989, 1993; Amano *et al.*, 1989; Saito *et al.*, 1992, *etc.*).

[Type locality]

Type locality of this formation is exposure along the roadside of Omiya to Hitachiota, in Ibaraki Prefecture.

[Thickness]

The total thickness is about 300 meters.

[Lithology]

The Kume Formation consists of massive dark gray sandy siltstone with sandstone, white tuff and conglomerate. This formation commonly exhibits slumping structure.

[Occurrence fossil]

Fossils form the Kume Formation were reported by Saito (1952), Suzuki and Omori (1953), Ozaki and Saito (1954), Omori (1958), Ishii *et al.* (1974), Otsuki (1975), Noda and Amano (1977), Takahashi (1986), Kikuchi and Nikaido (1987), Noda *et al.* (1989, 1993) and Kikuchi *et al.* (1991).

This formation contains shallow to deep-water molluscs, echinoid and other fossils, such as *Anadara amicula elongata*, *Glycymeris* (*Glycymeris*) *nakamurai*, *Nemocardium* (*Keenea*) *smarangae*, *Cuspidaria* (*Cuspidaria*) *nobilis*, *Turritella* (*Neohaustator*) *nipponica nipponica*, and echinoid of *Linthia tokunagai*. These molluscan fossils include tow different type of element of cold-temperate and warm waters.

Newly collected fossils by this study are echinoid of *Linthia nipponica*, *Linthia tokunagai*, *Linthia* sp. and *Lutetiaster ogasawarai* n. sp. and also sharks of *Hexanchus* sp., *Cetorhinus maximus*, *Carcharodon carcharias* and *Odontaspis* sp. (Figs. 2, 25-29; Tables 1, 14).

Ⅶ. Southern part of Kanasago area (Fig. 1-Ⅷ)

Tertiary deposit narrowly distributes in the area between

Table 8. Stratigraphic division and correlation in the area VIII, southern part of the Kanasago area.

Geologic age	Present paper
MIOCENE	Urizura F.
	Genjigawa F. ★
	Zuiryu F.

★; Stratigraphical position of echinoid fossil.

Kujigawa - Asagawa and Yamadagawa Rivers in the southern part of Kanasago area (Figs. 30-31). Tertiary deposit of the southern part of Kanasago area is composed of the following three formations; the Formation and the late to latest middle Miocene Urizura Formation, in ascending order (Tables 1, 8).

Geological studied had been carried out only by Omori (1958) and Yoshioka *et al.*, (2001).

Echinoid fossil yielded from the middle Miocene Genjigawa Formation.

1. Zuiryu Formation

The early middle Miocene Zuiryu Formation is very narrowly distributed at Hanabusa in the middle part of Kanasago area.

2. Genjigawa Formation

The middle Miocene Genjigawa Formation of this area is correlative to the Mito Tuffaceous Mudstone and the Kume Sandy Shale by Omori (1958), and also the Genjigawa Formation by Yoshioka *et al.*, (2001).

[Thickness]

The total thickness is about 60 meters.

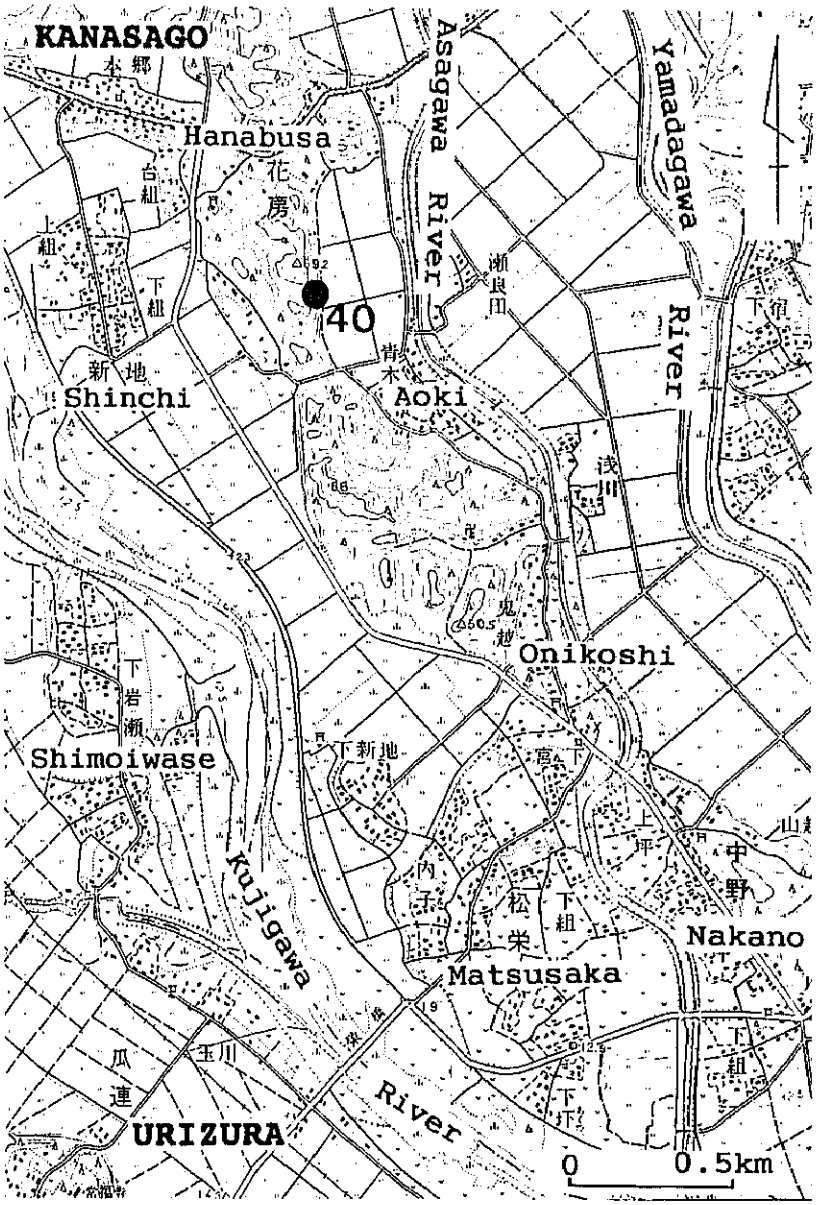

Fig. 30. Locality map of echinoid fossil in the area VIII, southern part of the Kanasago area.
●; Fossil locality.

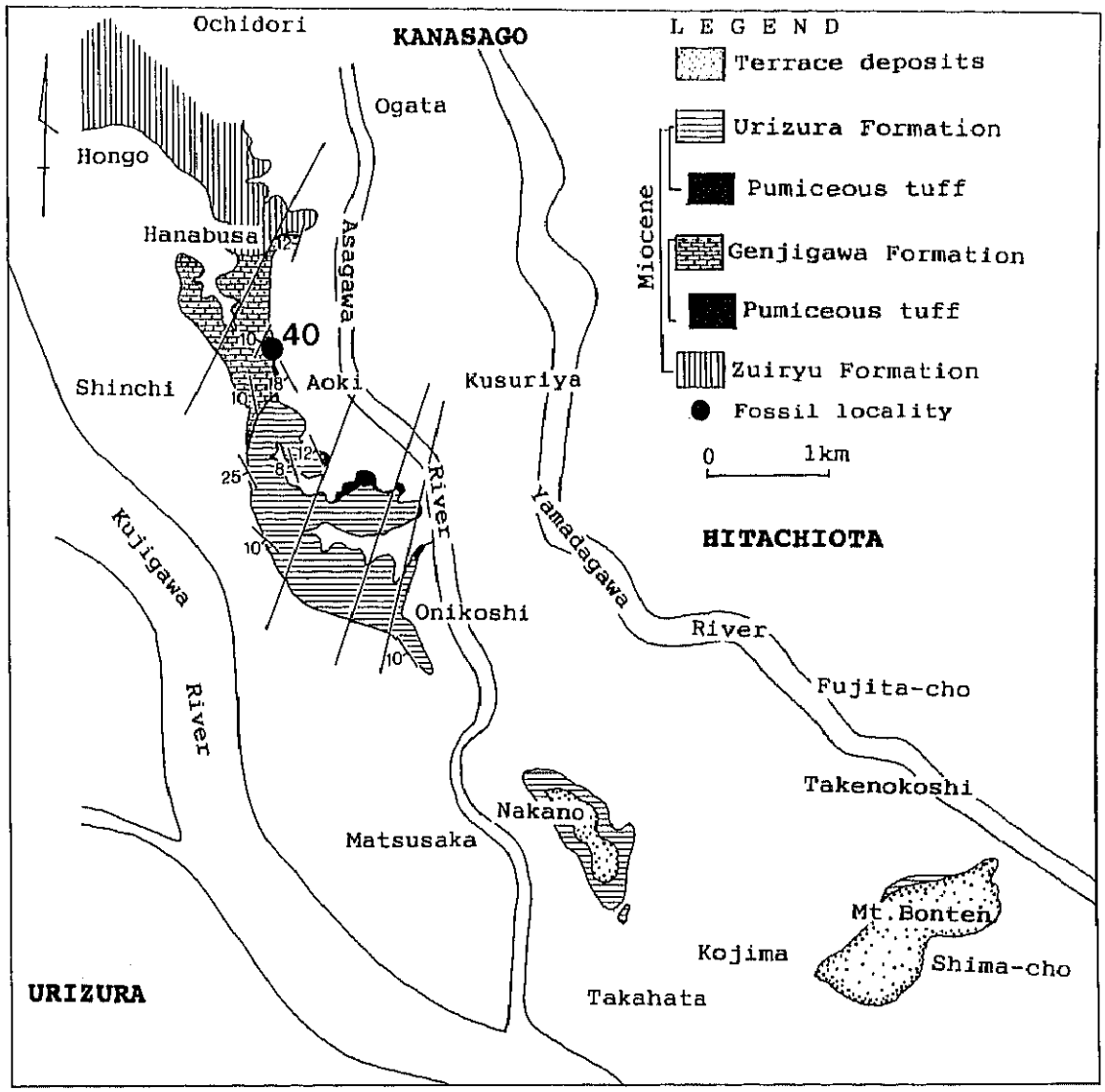

Fig. 31. Geological map and echinoid fossil locality in the area VIII, southern part of the Kanasago area.

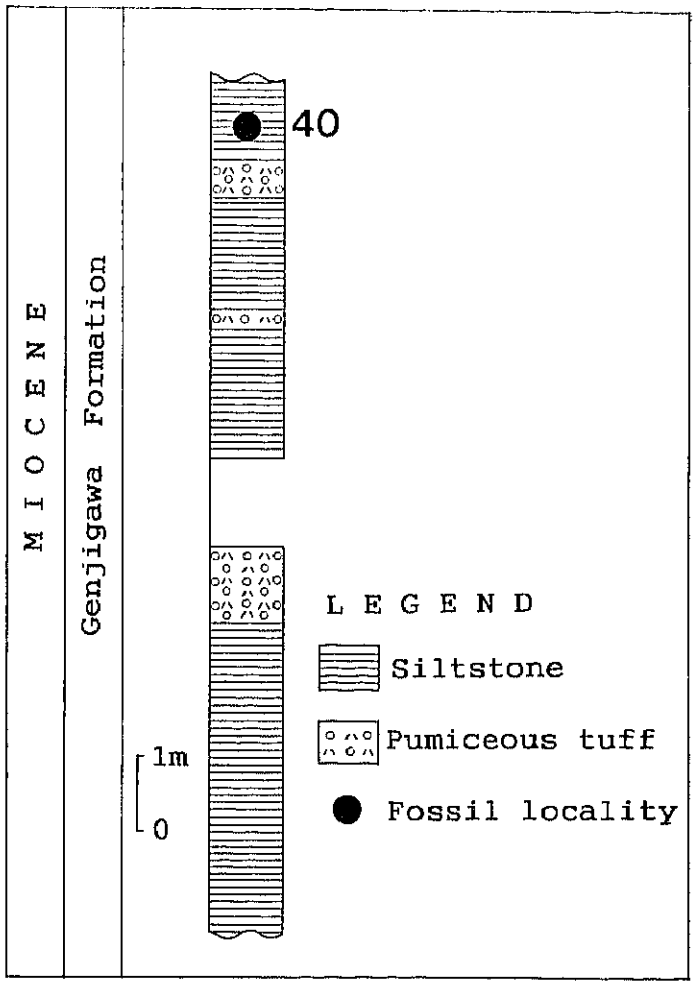

Fig. 32. Columnar section showing stratigraphical position of echinoid fossil in the area VIII, southern part of the Kanasago area.

[Distribution]

The Genjigawa Formation is distributed along the margin of hill at Hanabusa to Aoki in the southern part of Kanasago area.

[Lithology]

The Genjigawa Formation mainly consists of massive gray siltstone and is including disordered blocks of siltstone and coarse grained pumice.

[Stratigraphic relationship]

The Genjigawa Formation conformably overlies and/or fault contact with the early middle Miocene Zuiryu Formation (Pl. 1, fig. 6).

[Fossil occurrence]

Some fossils are newly collected from the Genjigawa Formation; molluscs of *Portlandia* cf. *kakimii*, *Solemya tokunagai*, *Macoma* sp. and *Lucinoma* sp., sponge of *Makiyama*, and Shizasteridae gen. et sp. indet. of echinoid (Figs. 2, 30-32; Tables 1, 8, 14).

3. Urizura Formation

The late middle Miocene Urizura Formation of this area is correlative with the Mito Tuffaceous Mudstone and the Kume Sandy Shale by Omori (1958), and also the diatomaceous mudstone of the Taga

Group by Yoshioka *et al.*, (2001).

[Thickness]

The total thickness is about 100 meters.

[Distribution]

The Urizura Formation is distributed along the margin hill of Aoki, Onikoshi and Nakano to the Mt. Bontenyama in southern part of Kanasago area.

[Lithology]

The Urizura Formation consists of massive gray siltstone, massive medium to coarse grained pumiceous tuff, and is including disordered blocks of siltstone and coarse grained pumice (Pl. 5, fig. 6).

[Stratigraphic relationship]

The Urizura Formation conformably overlies the middle Miocene Genjigawa Formation.

[Fossil occurrence]

Fossil is only collected from the Urizura Formation as siliceous sponge of *Makiyama chitanii*.

VIII. Eastern part of Hitachiota area (Fig. 1-Ⅷ)

Table 9. Stratigraphic division and correlation in the area VII, eastern part of the Hitachiota area.

Geologic age	Suzuki (1954)		Ozaki and Saito (1954)	Otsuki (1975)	Maruyama (1984)	Saito *et al.*, (1992)	Present paper
PLIOCENE	Hitachi G.	Kume Sandy Shale	Kume F.	Kume F.	Kume F.	Kume F.	Kume F. ★
MIOCENE	Taga G.	Tawatari Mudstone	Genjigawa F.	Genjigawa F.	Hase F.	Hase F.	Hase F.
PRE TERTIARY	Hitachi Metamorphic Rocks		Abukuma Metamorphic Rocks	Basment Rocks	Basment Rocks	Basment Rocks	Hitachi Metamorphic Rocks

★; Stratigraphical position of echinoid fossil.

Tertiary deposit is narrowly distributed in the area between the Satogawa River and the Abukuma Mountains, eastern part of Hitachiota area (Figs. 33-34). Tertiary deposit of the area is composed of the following two formations as the late Miocene Hase Formation and the Pliocene Kume Formation, in ascending order (Tables 1, 9).

Geological and paleontological studies have been done by Kinoshita (1935), Saito (1952), Suzuki (1954b), Ozaki and Saito (1954), Otsuki (1975), Takahashi and Amano (1986), Amano et al. (1989), Saito *et al.* (1992) and Yoshioka (2001).

Echinoid fossils newly yielded from the Pliocene Kume Formation.

1. Hase Formation (modified from Amano and Takahashi, 1986)

The late middle Miocene Hase Formation (Amano and Takahashi, 1986; Yanagisawa *et al.*, 1989) of this area is correlative with the Ota Formation (Saito, 1952), Genjigawa Group (Suzuki and Omori, 1953; Omori *et al.*, 1953; Omori, 1958), Genjigawa Tuffaceous Mudstone (Ozaki and Saito, 1954), Tawatari Mudstone in Genjigawa Group (Suzuki, 1954b), Genjigawa Formation (Otsuki, 1975), and the Hase Formation (Amano and Takahashi, 1986; Amano *et al.*, 1989; Yanagisawa et al.,

1989; Saito *et al.*, 1992; Yoshioka, 2001).

[Thickness]

The total thickness is about 300 meters.

[Distribution]

The Hase Formation is distributed along the Abukuma Mountains, mainly from Chinone-cho, Tawatari-cho, east of Takanuki-cho through east of Kamezaku-cho to north of Omori-cho, eastern part of Hitachiota area.

[Lithology]

The Hase Formation mainly consists of greenish blue gray siltstone with massive pumiceous tuff, fine grained white tuff and coarse grained sandstone.

[Stratigraphic relationship]

The Hase Formation unconformably overlies the Pre-Tertiary igneous and metamorphic rocks of the Abukuma Mountains (Pl. 1, fig. 5).

[Fossil occurrence]

Fossils from the Hase Formation were reported by Suzuki and Omori (1953), Ozaki and Saito (1954), Otsuki (1975).

Some fossils are newly collected from the Hase Formation such as molluscs of *Solemya tokunagai*, *Delectopecten* sp., *Lucinoma* sp.,

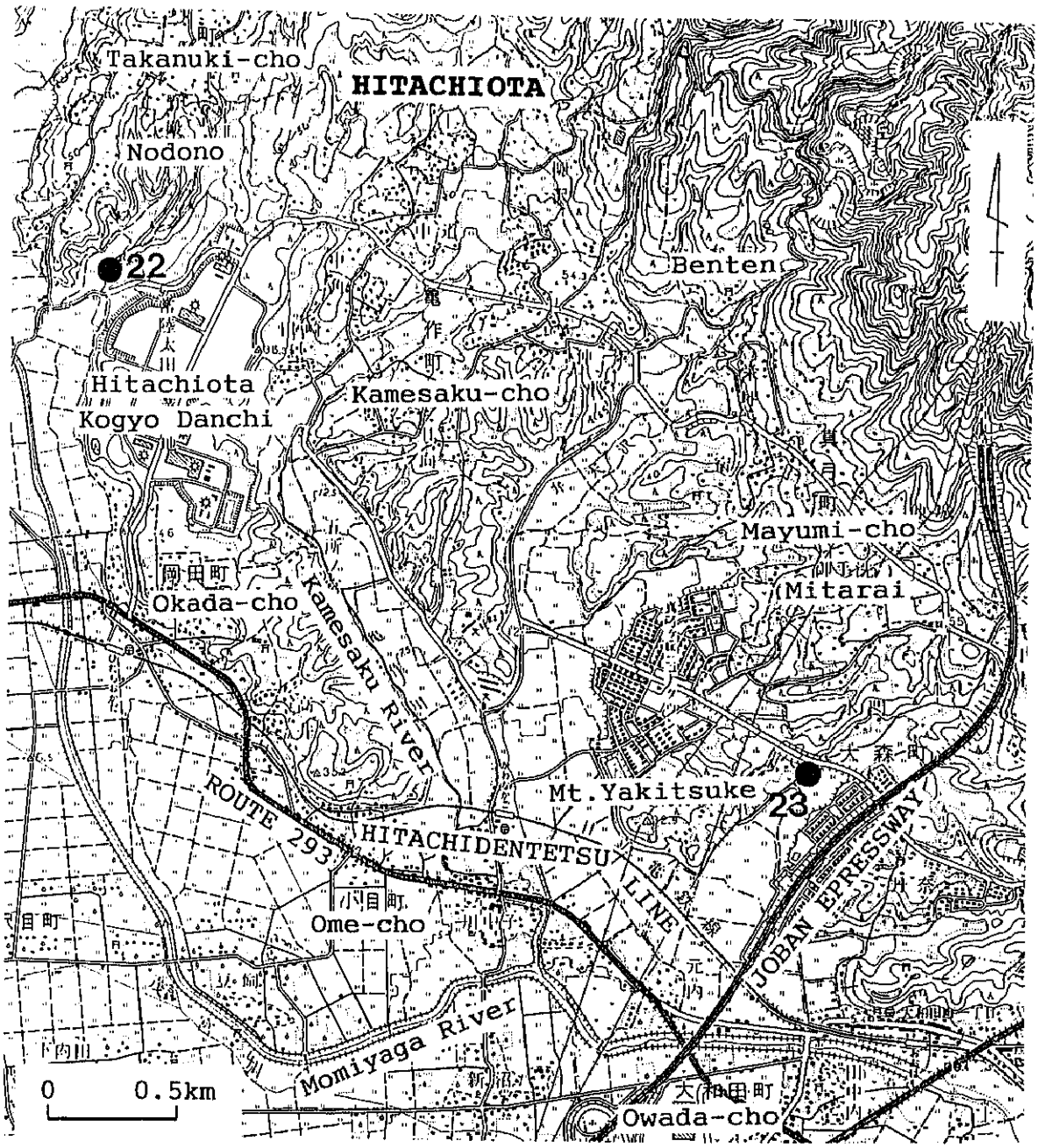

Fig. 33. Locality map of echinoid fossils in the area VII, eastern part of the Hitachiota area.
●; Fossil locality.

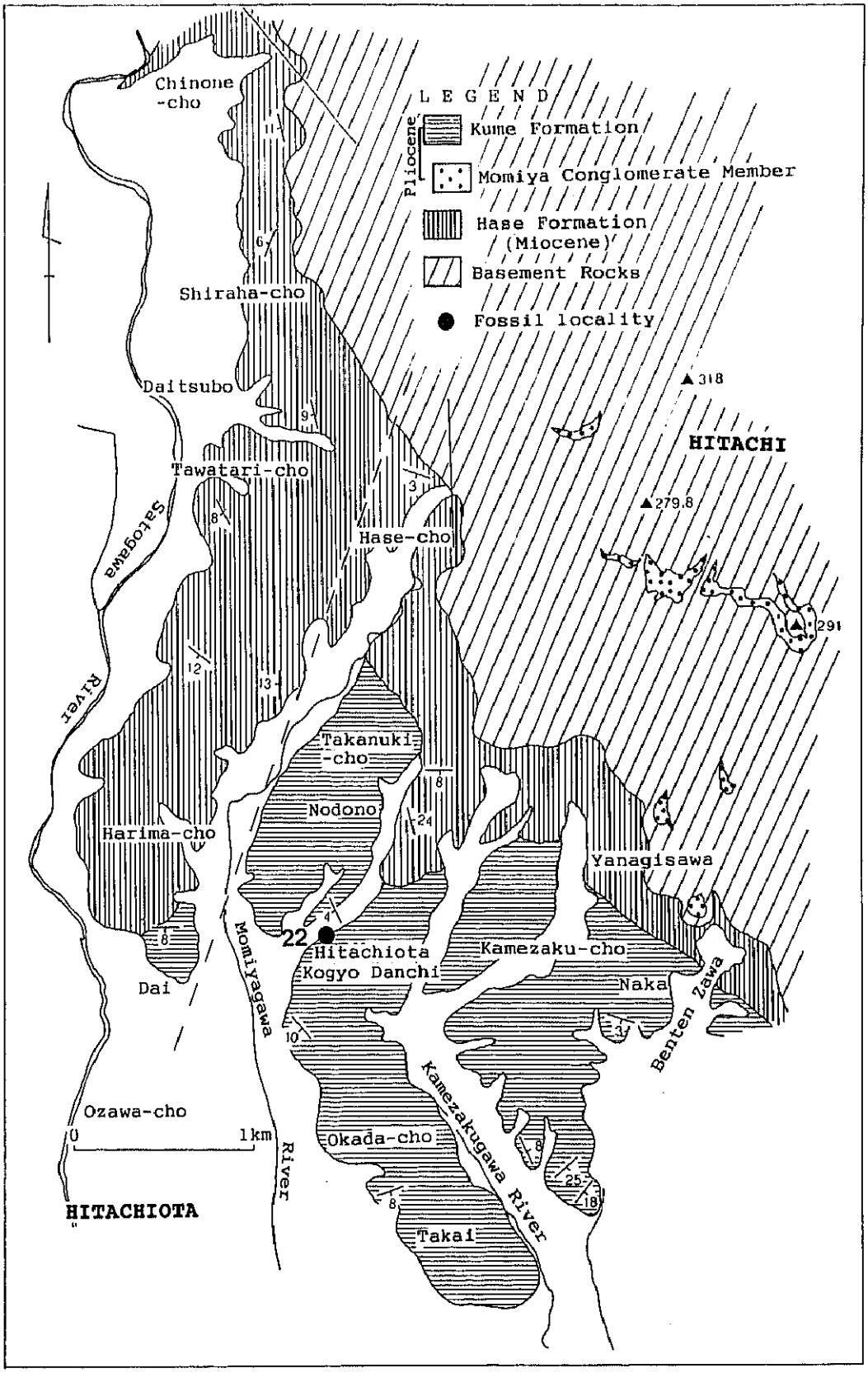

Fig. 34. Geological map and echinoid fossil locality in the area VII, eastern part of the Hitachiota area (1).

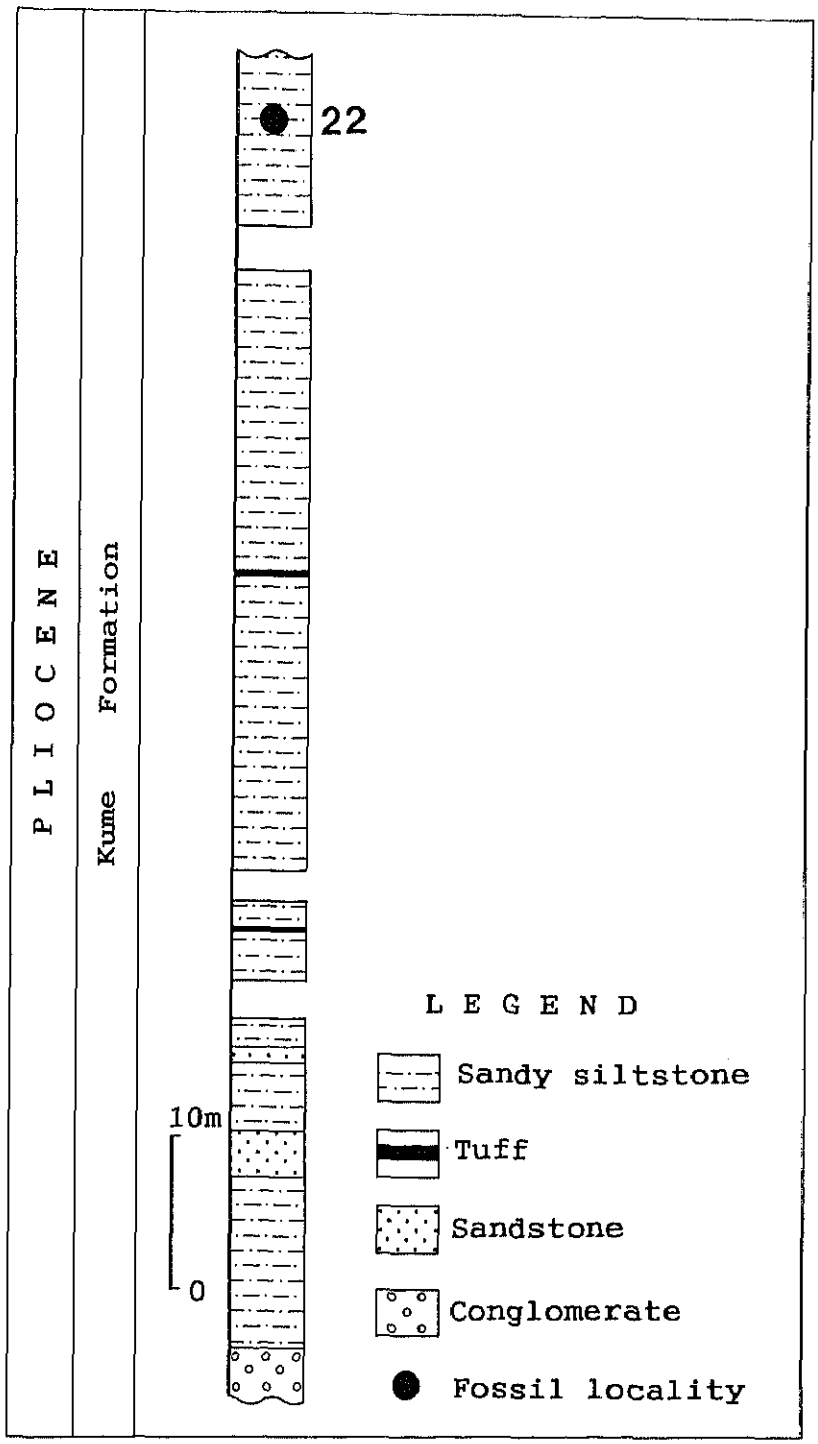

Fig. 35. Columnar section showing stratigraphical position of echinoid fossil in the area VII, eastern part of the Hitachiota area (1).

Conchocele bisecta, and *Makiyama chitanii* of sponge.

2. Kume Formation (modified from Otsuki, 1975)

The Pliocene Kume Formation of this area is corresponding to the Nishiyama and Hatasome Tuffaceous Sandy Shale (Kinoshita, 1935), Kume Sandy Shale (Omori *et al.*, 1953; Suzuki and Omori, 1953; Suzuki, 1954b; Omori, (1958), Kume Fine Sandstone (Ozaki and Saito, 1954) and the Kume Formation (Otsuki, 1975; Takahashi and Amano, 1986; Amano *et al.*, 1989; Saito *et al.*, 1992).

[Thickness]

The total thickness is about 200 meters.

[Distribution]

The Kume Formation is distributed along those of the middle Miocene Genjigawa Formation, such location as Dai at Harima-cho, Okada-cho, Omori-cho in Hitachiota City, through the Momiya-cho, Hanareyama at Kuji-cho in Hitachi City.

[Lithology]

The Kume Formation mainly consists of massive greenish blue gray sandy siltstone with fine grained white tuff and fine to coarse grained sandstone with conglomerate.

[Stratigraphic relationship]

The Kume Formation unconformably overlies the middle Miocene Genjigawa Formation (Pl. 1, figs. 1-3).

[Fossil occurrence]

The Kume Formation in this area has been known as lacking in fossil record.

However, following fossils are newly collected by this study; echinoid of *Lutetiaster owasawarai* n. sp. and Schizasteride gen. et sp. indet., molluscs of *Acila* (*Acila*) *divaricata submirabilis*, *Acilana matsuoi*, *Portlandia* (*Portlandella*) *lischkei*, *Glycymeris* sp., *Chlamys* (*Chlamys*) *iwakianus*, *Chlamys* cf. *nipponensis*, *Aequipecten veciculosa*, *Mizuhopecten ibaragiensis*, *Cyclocardia ferruginea*, *Nemocardium* (*Keenaea*) *samarangae* and *Turritella* (*Neohaustator*) *nipponica nipponica*, shark teeth of *Isurus hastalis*, bone of whales?, and *Makiyama chitanii* of sponge fossil (Figs. 2, 33-37, Tables 1, 9, 14).

IX. Ishinazaka area, southern part of Hitachi area (Fig. 1-IX)

Table 10. Stratigraphic division and correlation in the area IX-X, eastern part of Hitachiota to shoutern part of the Hitachi area.

Geologic age	Omori and Suzuki (1950)	Suzuki (1954)	Present paper
PLEISTO-CENE			Narita F.
PLIOCENE	Hatsuzaki G.	Hatsuzaki G.	
	Hitachi G. / Hanareyama Tuff ? Hitachi Sandy Shale	Hitachi G. / Hanareyama F. / Sukegawa F.	Hanareyama Tuff Mem. / Kume F. / Momiya Conglomerate Mem.
MIOCENE		Genji-gawa G. / Ayukawa F. / Namekawa F.	Hase F. / Kawarago F.
PRE TERTIARY	Basment Rocks	Basement Rocks	Hitachi Metamorphic Rocks

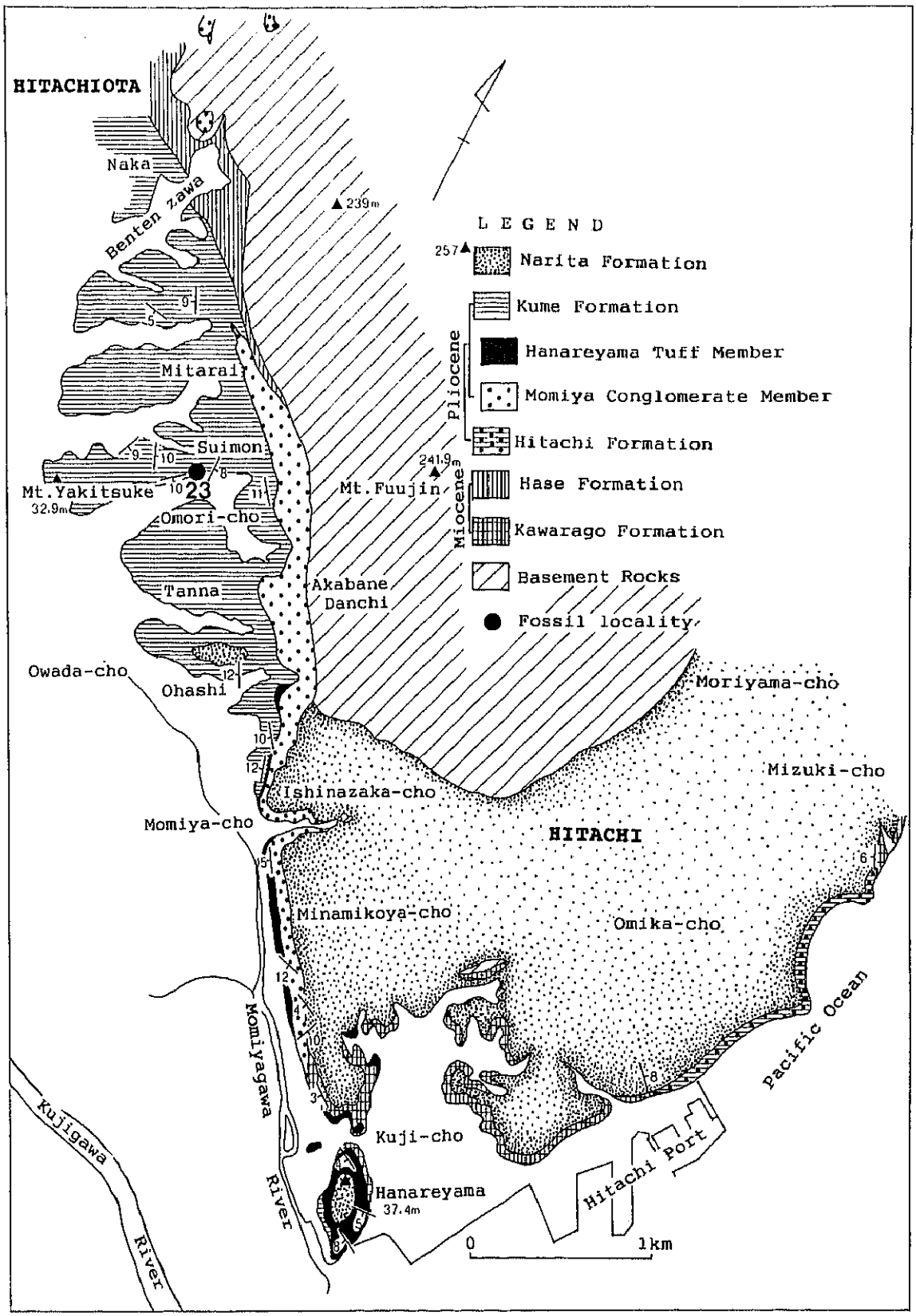

Fig. 36. Geological map and echinoid fossil locality in the area IX-X, eastern part of Hitachiota to southern part of the Hitachi area (2).

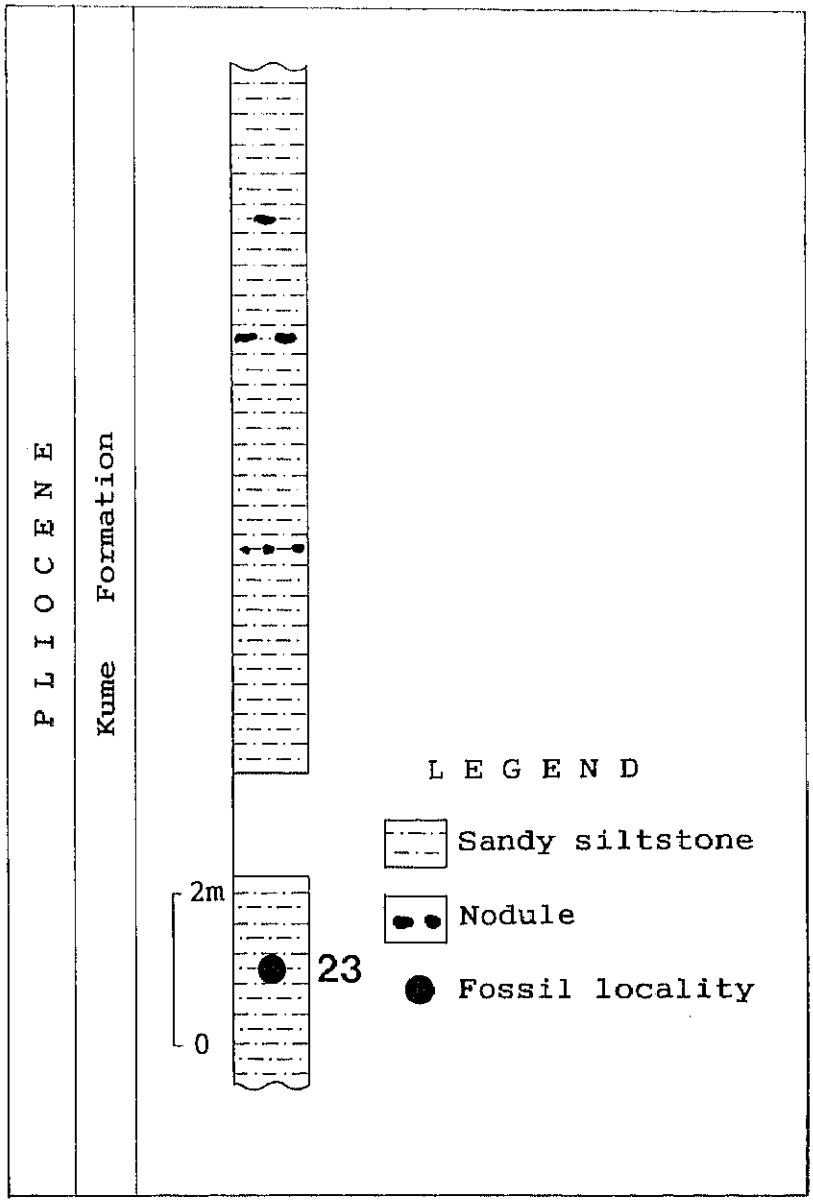

Fig. 37. Columnar section showing stratigraphical position of echinoid fossil in the area IX-X, eastern part of Hitachiota to southern part of the Hitachi area (2).

Tertiary deposit of the Ishinazaka area is narrowly distributed along the southwestern margin of the Abukuma Mountains in the southern part of Hitachi area (Fig. 36). It is composed of the following one formation which is including two members; the Pliocene Kume Formation, Momiya Conglomerate and the Hanareyama Tuff Members of the Kume Formation (Tables 1, 10).

Geological and paleontological studies in this area have been done by Kinoshita (1935), Suzuki and Omori (1953), Ozaki and Saito (1954), Suzuki (1954b) and Kikuchi *et al.* (1992).

1. Kume Formation

The Pliocene Kume Formation includes the Momiya Conglomerate Member and the Hanareyama Tuff Member.

[Thickness]

The thickness of this formation varies from 0 to 20 meters.

[Distribution]

The Kume Formation is narrowly distributed at southern side of the Hanareyama and Minami-Koya in Kuji-cho, Hitachi City, Ibaraki Prefecture.

[Lithology]

The Kume Formation is mainly composed of massive gray

calcareous sandy siltstone, which includes glauconite-like grains, massive sandy siltstone and conglomerate.

[Stratigraphic relationship]

The Kume Formation unconformably overlies the middle Miocene Genjigawa Formation and is interfingering the Momiya Conglomerate Member (Pl. 4, fig. 6).

[Fossil occurrence]

The Kume Formation is lacking in fossil record in this area, in general. However, following fossils are newly collected by the present study; molluscs of *Acila* (*Acila*) *divaricata, Propeamussium* sp. and *Dentalium* sp., and *Makiyama chitanii* of sponge fossil.

1-A. Momiya Conglomerate Member

The Pliocene Momiya Conglomerate Member consists of the basal portion of Kume Formation, and is corresponding to the basal conglomerate of Kume Formation (Ozaki and Saito, 1954) and the Mayumi Gravel (Omori and Owada, 1985).

[Type locality]

Type locality of this member is outcrop of the northeast of Momiya Station of the Hitachi-Dentetsu Railway in Hitachi City, Ibaraki Prefecture (Pl. 3, figs. 1-2).

[Thickness]

The thickness of this member varies from 0 to 50 meters.

[Distribution]

The Momiya Conglomerate Member is distributed along the southwestern margin of the Abukuma Mountains as mainly near peak to foot at the Yanagisawa in Kamezaku-cho and Mitarai, Omori-cho in Hitachiota City, Akabane-cho, Ishinazaka-cho through Momiya-cho to Minamikoya-cho in Hitachi City. This member is thinning out at the Mitarai in Omori-cho in Hitachiota City and Minamikoya-cho in Hitachi City.

[Lithology]

The gravels of Momiya Conglomerate Member consists varies kinds of rocks such as white marble, dark gray limestone, green schist, graphite schist, gneiss, shale, sandstone and so on. These gravels exhibit irregular shaped from angular to round, and various sizes from granule to boulder. The matrix is composed mainly of two types. One is the fine to coarse grained sandstone, and the another is calcite cemented without any kinds of clastic sediments (Pl. 3, figs. 5-6; Pl. 4, figs. 1-6).

[Stratigraphic relationship]

The Momiya Conglomerate Member unconformably overlies the

Pre-Tertiary basement rocks of the Abukuma Mountains (Pl. 3, figs. 3-6).

[Fossil occurrence]

This member yielded trace fossil of boring-shell which is preserved in gravels.

Fossils from the matrix of conglomerate are occurred as molluscan fossils of *Monia* sp., *Chlamys* cf. *iwakianus* and boring shell "*Pholadidea*" sp., and also *Balanus* sp. of crustacean.

X. Kuji area, southern part of Hitachi area (Fig. 1-X)

Tertiary deposit is distributed along the southwestern margin of the Abukuma Mountains and is also narrowly distributed in southern part of Hitachi area (Fig. 36). These deposits are composed of two formations including on member; the middle Miocene Kawarago Formation, Pliocene Kume Formation and the Pliocene Hanareyama Tuff Member of the Kume Formation, in ascending order (Tables 1, 10).

Geological and paleontological studies of the Kuji area have been done by Kato (1914), Tokunaga (1972ab), Omori and Suzuki (1950), Yabe (1950), Suzuki and Omori (1953), Suzuki (1954b), Omori (1958) and Kikuchi *et al.* (1992). However, echinoid fossil is not known from

Table 11. Stratigraphic division and correlation in the area XI, Hitachi area.

Geologic age	Hatai (1936)	Hatai (1940)	Omori and Suzuki (1950)	Suzuki (1954)	Maruyama(1984)	Noda *et al.*, (1995)	Present Paper
PLEISTO-CENE	Terrace Deposite	Terrace Deposite	Terrace Deposite			Terrace Deposits / Narita F.	Terrace Deposits / Narita F.
PLIOCENE	Hatsuzaki G.	Hatsuzaki G.	Hatsuzaki G.	Hatsuzaki G.	Htsuzaki G.	Hatsuzako Sandstone Mem.	Hatsuzaki Sandstone Mem.★
	Sukegawa Bed	Sukegawa Brachiopods Bed	Hitachi G. Hanareyama Tuff	Hitachi G. Hanareyama Tuff	Hanareyama F.	Hitachi F.	Hitachi F.
			? Hitachi Sandy shale	Sukegawa Sandy shale	? Hitachi F.		
MIOCENE			Taga G. Kawarago F.	Taga G. Ayukawa Mudstone	Mizuki F.	Kawarago F.	Kawarago F
				Namekawa Sandstone	? Kokubu F.		
PRE TERTIARY	Basment Rocks	Basment Rocks	Basment Rocks	Basement Rocks	Basement Rocks	Hitachi Metamor-phic Rocks / Abukuma Granitic Rocks	Hitachi Metamor-phic Rocks / Abukuma Granitic Rocks

★; Stratigraphical position of echinoid fossil.

the area.

1. Kawarago Formation (modified from Omori and Suzuki, 1950)

The late middle Miocene Kawarago Formation is corresponding to the Kawarago Formation (Omori and Suzuki, 1950; Kikuchi *et al.*, 1992), Genjigawa Formation of the Genjigawa Group (Suzuki and Omori, 1953), Ayukawa Mudstone of the Taga Group (Suzuki, 1954a; Omori, 1958) and the Kokubu Formation (Maruyama, 1984; Yanagisawa *et al.*, 1986).

[Lithology]

The Kawarago Formation mainly consists of massive gray siltstone with coarse grained pumiceous tuff, fine grained white tuff and pebble gravels. Upper part of this formation occasionally exhibits slumping structure.

[Stratigraphic relationship]

This formation unconformably overlies the Pre-Tertiary basement rocks of the Abukuma Mountains (Pl. 1, fig. 4).

[Fossil occurrence]

Fossils are very few, however, *Glycymeris* sp. of mollusca and *Makiyama chitanii* of sponge fossil yielded from this formation by the present study.

2. Kume Formation (defined by Kikuchi *et al.*, 1992)

The Pliocene Kume Formation is corresponding to the Hitachi Sandy Shale (Omori and Suzuki, 1950), Kume Sandy Shale (Omori and Suzuki, 1950; Suzuki, 1954a) and the Kume Formation (Kikuchi *et al.*, 1992). This formation includes the Hanareyama Tuff Member.

[Distribution]

The Kume Formation is narrowly distributed in Minami-Koya to Kuji area at the southern part of Hanareyama in Kuji-cho, Hitachi City.

[Thickness]

The total thickness is about 10 meters.

[Lithology]

The Kume Formation is mainly composed of massive greenish gray siltstone, silty sandstone with glauconite-like grain and quartz, and pumice dominant tuff with gravels.

[Stratigraphic relationship]

This formation unconformably overlies the Pre-Tertiary basement rocks of the Abukuma Mountains and the middle Miocene Kawarago Formation (Pl. 2, fig. 5).

[Fossil occurrence]

Kikuchi *et* al., (1992) reported such fossils as molluscs

of *Propeamssium* sp., *Acesta* sp. and *Teredo* sp., and also *Makiyama chitanii* of sponge fossil.

2-A. Hanareyama Tuff Member (modified from Kikuchi *et al.*, 1992)

The Pliocene Hanareyama Tuff Member of the Kume Formation is corresponding to the Hanareyama Tuff of the Taga Group (Omori and Suzuki, 1950), Hanareyama Tuff of the Hitachi Group (Suzuki, 1954a) and the Hanareyama Formation (Kikuchi *et al.*, 1992).

[Type locality]

Type locality of this member is the backside cliff of the Chinone Hospital in Kuji-cho, Hitachi City, Ibaraki Prefecture.

[Distribution]

The Hanareyama Tuff Member is narrower distributed in the area from Hanareyama through Minami-Koya to a small valley of the south of Kuji-Tetsuko Danchi of Ishinazaka-cho, Hitachi City.

[Thickness]

The thickness of this member is various from 0 to 10 meters.

[Lithology]

The Hanareyama Tuff Member mainly consists of felsic tuff, and tuffaceous silty sandstone with accretional lapilli and conglomerate. These tuff and tuffaceous facies sometime exhibit

convolute lamination.

[Stratigraphic relationship]

This member occupies upper portion of the Pliocene Kume Formation or Momiya Conglomerate, and unconformably overlies the middle Miocene Kawarago Formation (Pl. 2, fig. 3).

[Fossil occurrence]

Kato (1914) reported *Mastodon* cf. *latidense* Clift from the member.

XI. Hitachi area (Fig. 1-XI)

Tertiary deposit is narrowly distributed along the Abukuma Mountains and along coast side of the Pacific Ocean in Hitachi area (Figs. 38-40). Tertiary deposit of the area is composed of the following two formations and one member; the middle Miocene Kawarago Formation, Pliocene Hitachi Formation and the Hatsuzaki Sandstone Member of the Hitachi Formation, in ascending order (Tables 1, 11).

Many geological and paleontological studies from the Hitachi area has been done by such works as Kochibe (1882), Tokunaga (1927ab), Hatai (1936, 1940), Omori and Suzuki (1950), Masuda (1953), Suzuki (1954b), Ishii *et al.* (1974), Noda (1975), Tomida and Itoigawa,

(1984), Maruyama (1984), Watanabe (1993 MS) and Noda *et al.* (1995) and others.

Echinoid fossils are newly collected from the Pliocene Hatsuzaki Sandstone Member of the Hitachi Formation by this study.

1. Kawarago Formation (modified from Watanabe, 1993 MS and Noda *et al.*, 1995)

The late middle Miocene Kawarago Formation is corresponding to the Kawarago Formation (Omori and Suzuki, 1950; Watanabe, 1993 MS; Noda *et al.*, 1995), Ayukawa Formation, Namekawa Sandstone of the Taga Group (Suzuki, 1954ab) and the Kokubu Formation (Maruyama, 1984; Yanagisawa *et al.*, 1986; Yoshioka *et al.*, 2001).

[Thickness]

The total thickness is about 300 meters.

[Lithology]

The Kawarago Formation is mainly composed of massive greenish gray siltstone. Lithofacies varies in composition from the lower to upper part. The lower part exhibits cross-lamination and consists of conglomerate with coarse grained sandstone. The upper part consists of massive greenish gray siltstone with sandy pumice, pumiceous tuff and many accretional lapilli (Pl. 5, fig. 5).

[Distribution]

The Kawarago Formation is widely distributed along the Abukuma Mountains. For example, well exposures are recognized along coast side of the Pacific Ocean, mainly at, Hanareyama, Kawarago, Ose, and Asahi through Tajiri-cho in Hitachi City to Juo-machi in Taga-gun, Ibaraki Prefecture.

[Stratigraphic relationship]

This formation unconformably overlies the Pre-Tertiary basement rocks of the Abukuma Mountains.

[Fossil occurrence]

Fossils from the Kawarago Formation were reported by Omori and Suzuki (1950), Maruyama (1984) and Watanabe (1993 MS).

They are diatom of *Coscinodiscus yabei*, *Denticulopsis lauta* and *Denticulopsis nicobarica*, and molluscs of *Epitonium* sp., *Portlandia* sp., *Delectopecten peckhami* and so on.

2. Hitachi Formation (modified from Watanabe, 1993 MS; Noda *et al.*, 1995)

The Pliocene Hitachi Formation is corresponding to such strata as the Sukegawa Bed (Hatai, 1936), Sukegawa Brachiopoda Bed (Hatai, 1940), Hitachi Sandy Shale of the Taga Group (Omori and

Suzuki, 1950), Sukegawa Sandy Shale (Suzuki, 1954ab), Sukegawa Formation (Masuda, 1953; Noda, 1974) and the Hitachi Formation (Maruyama, 1984; Watanabe, 1993 MS; Noda *et al.*, 1995). This formation includes the Hatsuzaki Sandstone Member.

[Type locality]

Type locality of this formation is cliff at the north of Tsurushimisaki Cape in Hitachi City, Ibaraki Prefecture.

[Thickness]

The total thickness is about 100 meters.

[Lithology]

The Hitachi Formation is mainly composed of massive greenish gray sandy siltstone with tuffaceous fine to medium grained sandstone, fine grained white tuff and pumiceous tuff.

[Distribution]

The Hitachi Formation is irregularly distributed along the Pacific coast side, mainly, north of Hitachi Port to south of Mizuki-cho, south of the Kawarago Beach to south of Kokubu-cho, Hatsuzaki, stream valley in the Miyatagawa River, eastern part of the Miyatagawa River to east of Namekawa-cho and Takaiso to Kawajiri-cho in Hitachi City, Ibaraki Prefecture.

[Stratigraphic relationship]

This formation unconformably overlies the middle Miocene Kawarago Formation.

[Fossil occurrence]

Fossils from the Hitachi Formation were reported by many works such as Kochibe (1882), Yoshiwara (1899), Tokunaga (1903, 1927ab), Hatai (1936, 1940), Omori and Suzuki (1950), Masuda (1953), Suzuki (1954ab), Ishii *et al.* (1974), Noda (1975), Watanabe (1993 MS) and Noda *et al.*, (1995).

The Hitachi Formation contains shallow to deep-water molluscs, brachiopods, asteroid and other fossils. They are molluscs of *Tugari gigas, Ennucula niponica, Acilana matsuoi, Mizuhopecten ibaragiensis, Conchocele nipponica, Cardiomya* (*Cardiomya*) *septentrionalis*, brachiopods of *Terebratulia kiiensis, Coptothyris gray,* and asteroid of *Pseudrachiaster* sp.

2-A. Hatsuzaki Sandstone Member (modified from Watanabe, 1993 MS and Noda *et al.*, 1995)

The Pliocene Hatsuzaki Sandstone Member of the Hitachi Formation is corresponding to the Diluvium (Tokunaga, 1903), Hatsuzaki Group (Omori and Suzuki, 1950; Suzuki, 1954ab), Hatsuzaki Formation (Maruyama, 1984) and the Hatsuzaki Sandstone Member of the

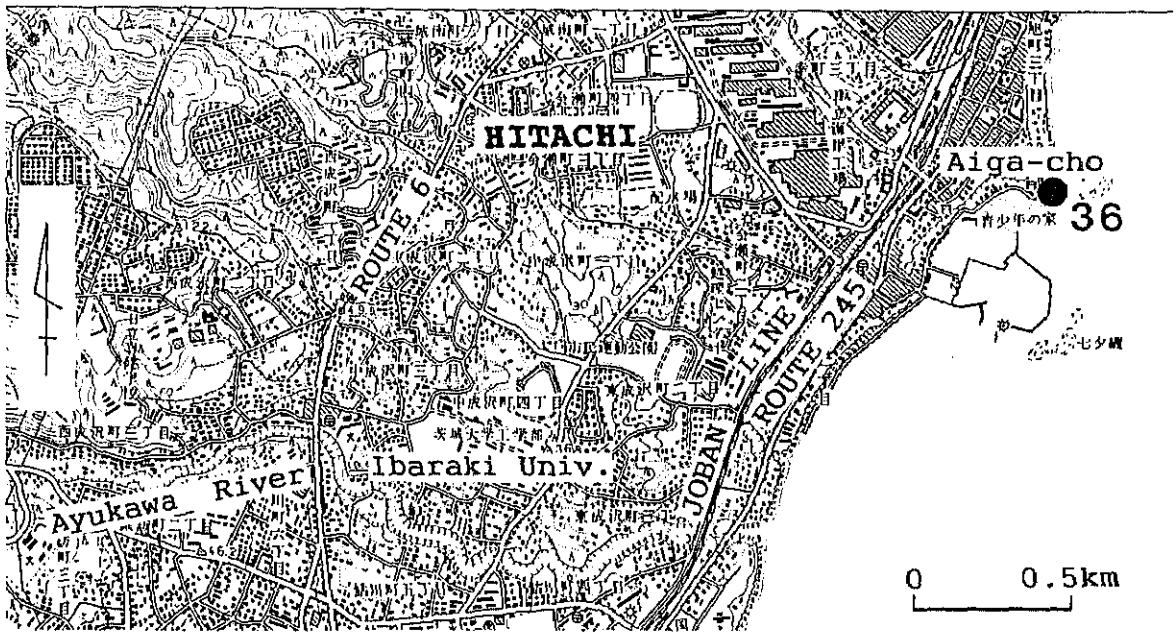

Fig. 38. Locality map of echinoid fossil in the area XI, Hitachi area (1). ●; Fossil locality.

Fig. 39. Locality map of echinoid fossils in the area XI, Hitachi area (2). ●; Fossil locality.

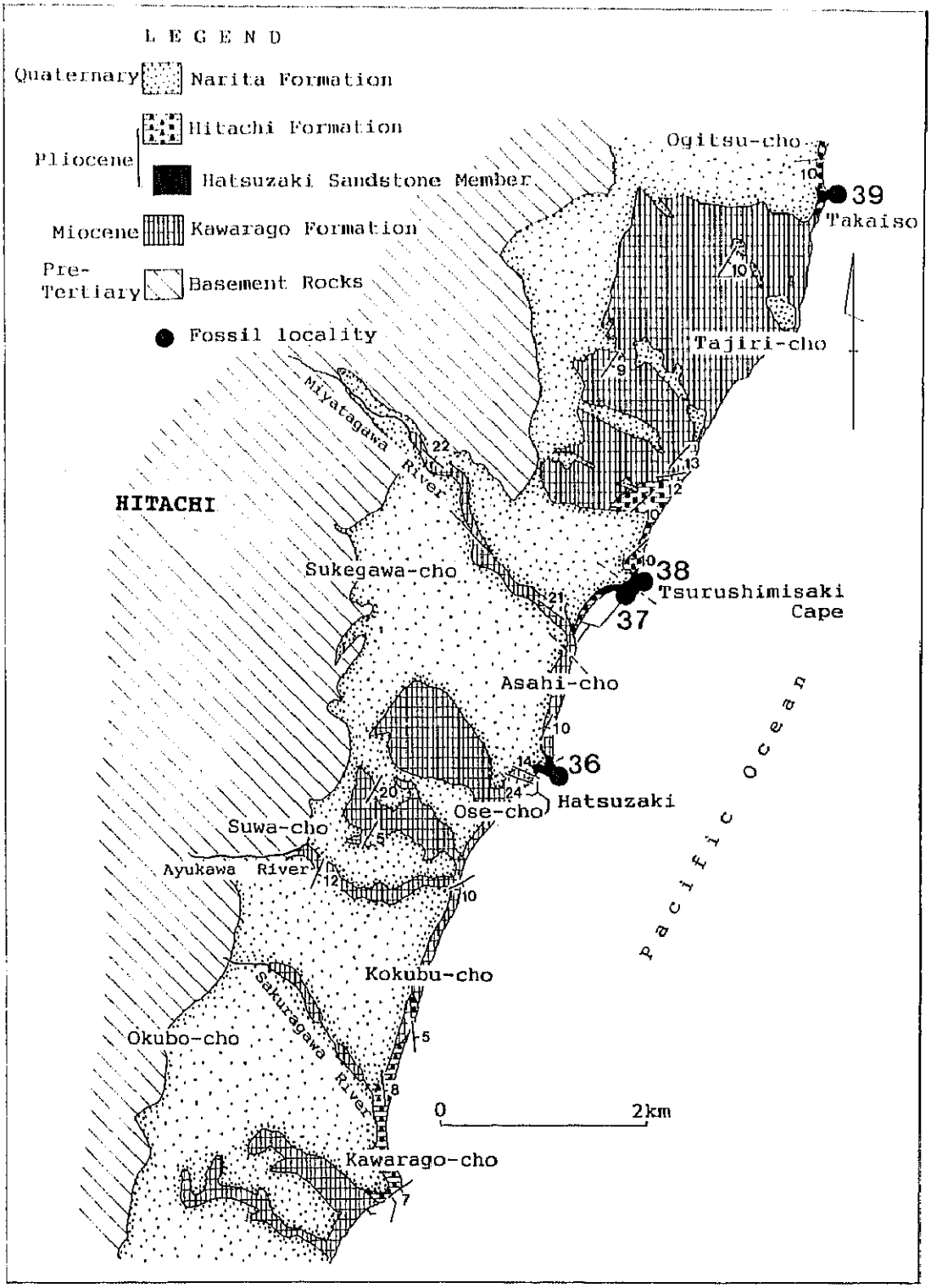

Fig. 40. Geological map and echinoid fossils localities in the area XI, Hitachi area (modified from Noda *et al.*, 1995).

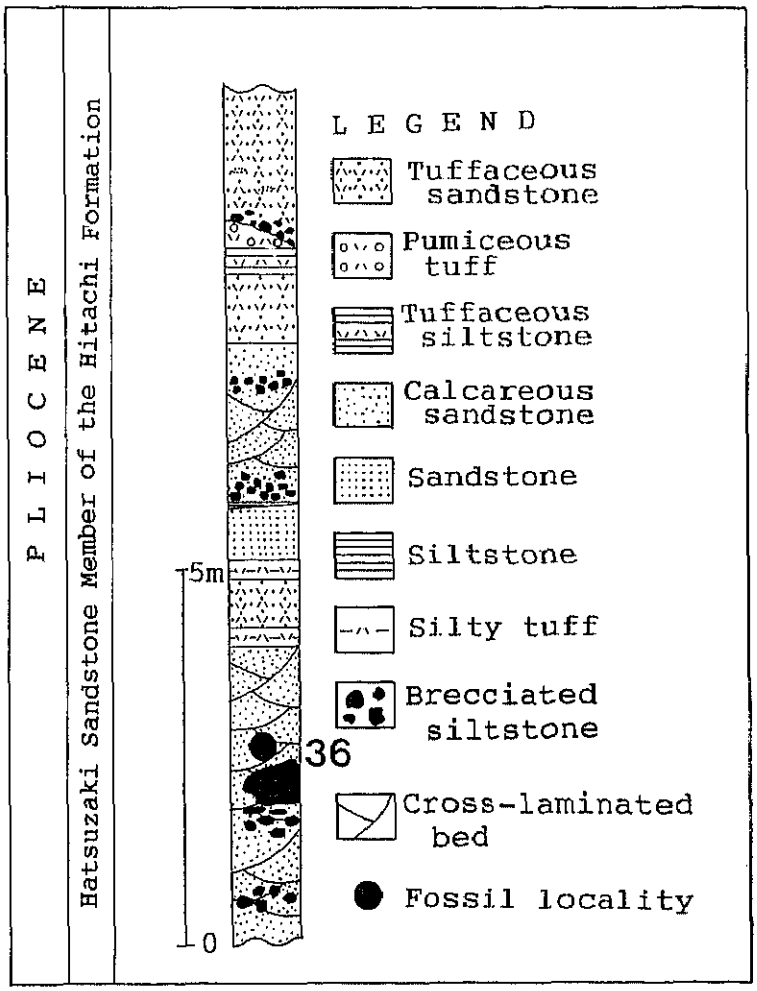

Fig. 41. Columnar section showing stratigraphical position of echinoid fossil in the area XI, Hitachi area (1).

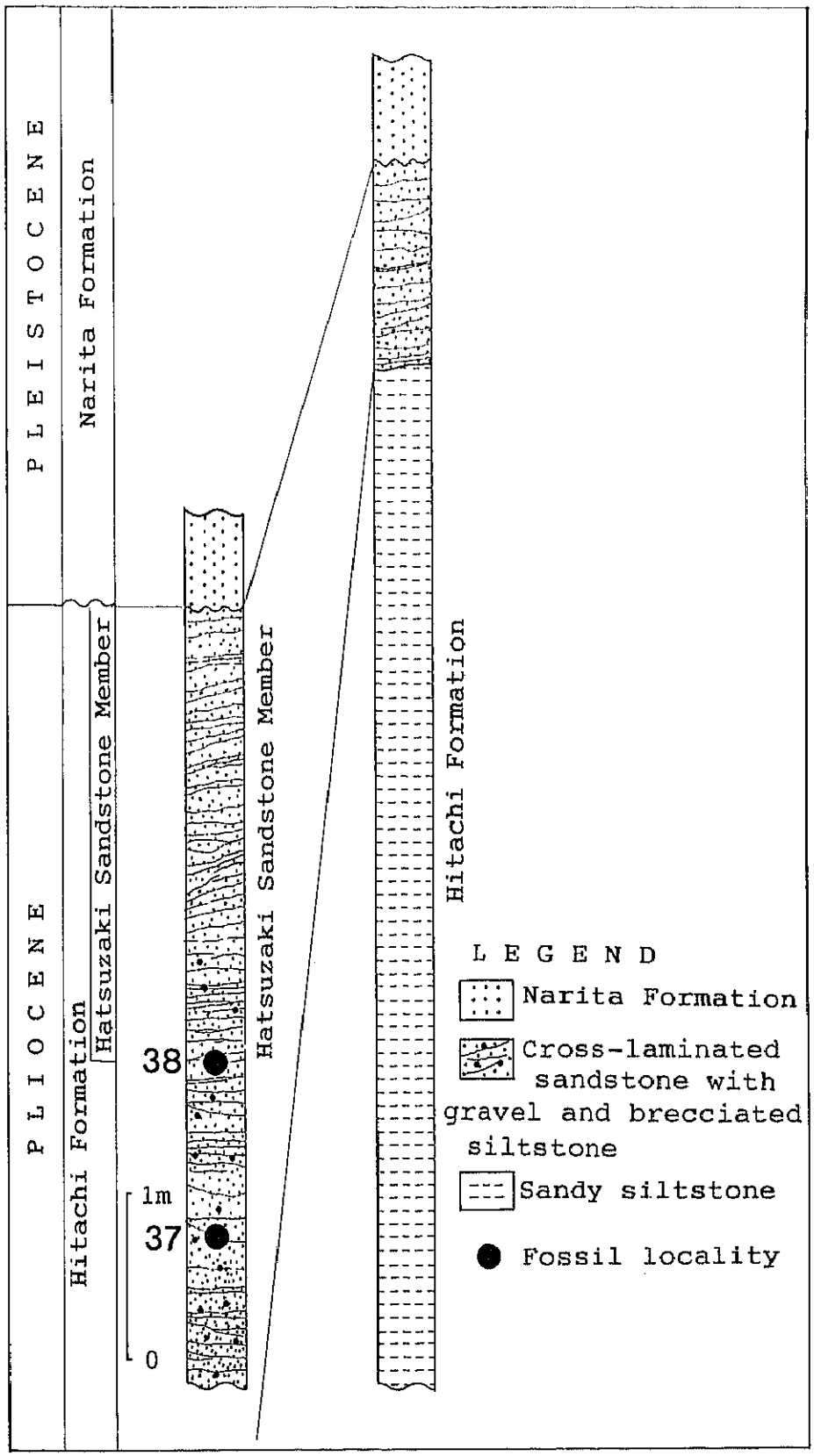

Fig. 42. Columnar section showing stratigraphical position of echinoid fossils in the area XI, Hitachi area (2).

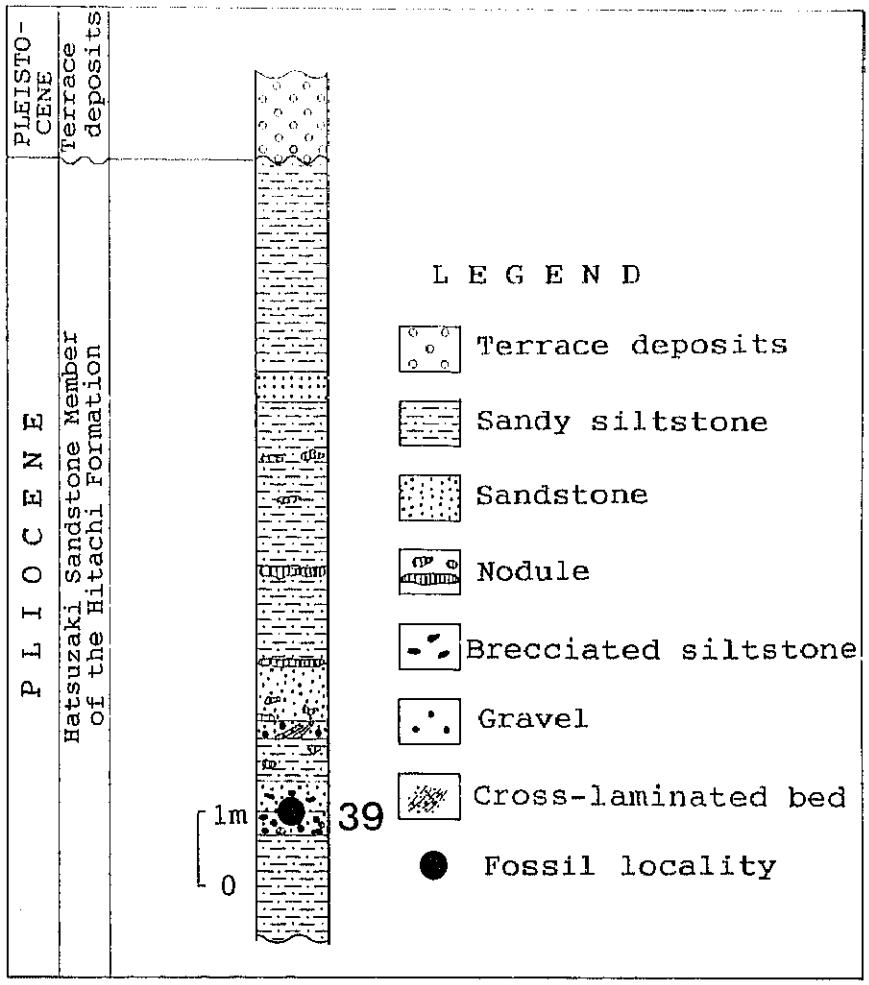

Fig. 43. Columnar section showing stratigraphical position of echinoid fossil in the area XI, Hitachi area (3).

Hitachi Formation (Watanabe, 1993 MS; Noda *et al.* 1995).

[Type locality]

Type locality of this member is cliff at the bluff of Hatsuzaki Coast in Aiga-cho, Hitachi City, Ibaraki Prefecture.

[Thickness]

The total thickness is about 30 meters.

[Lithology]

The Hatsuzaki Sandstone Member mainly consists of massive medium to coarse grained sandstone with tuff and siltstone. This formation is well developing cross-lamination in locally.

[Distribution]

The Hatsuzaki Sandstone Member is narrowly distributed at Hatsuzaki, Turushimisaki Cape at south of the Hitachi Chemical Company, and at Takaiso in Hitachi City. The Hatsuzaki Sandstone Member is corresponding to upper part of the Hanareyama Tuff Member which is distributed southern part of Hitachi district.

[Stratigraphic relationship]

This member is interfingering the Pliocene Hitachi Formation.

[Fossil occurrence]

Fossils from the Hatsuzaki Sandstone Member were reported

by Kochibe (1883), Yoshiwara (1899), Otsuki (1901), Tokunaga (1903, 1927ab), Omori and Suzuki (1950), Suzuki (1954ab), Tomida and Itoigawa (1984), Watanabe (1993 MS) and Noda *et al.* (1995).

This member contains shallow to deep-water many molluscs, echinoid and other fossils such as molluscs of *Haliotis kochibei*, *Hartungia japonica*, *Turbo* (*Batillus*) *cornutus*, *Turritella* (*Neohaustator*) *nipponica nipponica*, *Fusitriton oregonensis*, *Olivella* (*Olivella*) *fulgurata*, *Fulgoraria* (*Nipponomelon*) *prevostiana magna*, *Solemya* (*Acharax*) cf. *tokunagai*, *Arca* (*Arca*) *boucardi*, *Hawaiarca uwaensis*, *Anadara* (*Anadara*) cf. *amicula elongata*, *Cryptopecten vesiculosus*, *Anomia chinensis* and *Akebiconcha kawamurai*, echinoid of *Echinocyamus crisupus* and *Linthia nipponica*. These molluscan fossils can be divided into two different types that are cold-water and warm-water origins.

Newly collected fossils by the present study are echinoid of *Temnotrema rubrum*, *Echinocyamus crispus*, *Scaphechinus* cf. *mirabilis*, *Linthia tokunagi* and *Nodaster watanabei* n. gen. et n. sp., and molluscs of *Acilana matsuoi* and *Epitonium* sp. (Figs. 2, 38-43; Tables 1, 11, 14).

XII. Tokai area (Fig. 1-XII)

Table 12. Stratigraphic division and correlation in the area XII, Tokai area.

Geologic Age	Present paper
PLEISTOCENE	Terrace deposits
	Narita F.
PLIOCENE	Muramatsu F.★
MIOCENE	Shinkawa F.

★ ; Stratigraphical position of echinoid fossil.

Tertiary deposit is narrowly distributed along the margin of hills in Toka area. Tertiary deposits of the area composed of following two formations: the late middle Miocene Shinkawa Formation and the Pliocene Muramatsu Formation, in ascending order. The echinoid fossils were first collected from the Pliocene Muramatsu Formation by this study (Tables 1, 12).

1. Shinkawa Formation

The late middle Miocene Shinkawa Formation is corresponding to the Urizura Formation (Akutsu, 1952), Hase Formation (Takahashi and Amano, 1986; Amano *et al.*, 1989; Yanagisawa *et al.*, 1989; Saito *et al.*, 1992), Kawarago Formation (Noda *et al.*, 1995), Kokubu Formation (Maruyama, 1984; Yanagisawa *et al.*, 1989), Isozaki Formation (Maruyama, 1984; Yanagisawa *et al.*, 1989; Takada, 1999MS) and the Hitachinaka Formation (present paper).

[Type locality]

Type locality of this formation is exposure of hill slope along the Shinkawa River in Tokai-mura, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is a more than 150 meters.

[Lithology]

The Shinkawa Formation mainly consists of massive bluish gray siltstone with pumice dominant tuff, fine grained white tuff, and interbedding thin layers of medium to coarse grained sandstone. This formation exhibits slumping structure in upper part.

[Distribution]

The Shinkawa Formation is narrowly distributed hill slope along the Shinkawa River area, mainly at the Sawa-Kashiwano Danchi in Hitachinaka City to west of Kawane in Tokai-mura.

[Stratigraphic relationship]

The beneath of this formation is not recognize in Tokai area.

[Fossil occurrence]

Molluscan fossils of *Delectopecten peckhami*, *Thyasira* cf. *tokunagai* and *Solemya* cf. *tokunagai*, and sponge fossil of *Makiyama chitanii* are newly yielded from the formation.

2. Muramatsu Formation

The Pliocene Muramatsu Formation is correlative to the Kume Formation (Otsuki, 1975; Takahashi, 1986; Noda et *al.*, 1993) and the Hitachi Formation (Yoshioka *et al.*, 2001).

[Type locality]

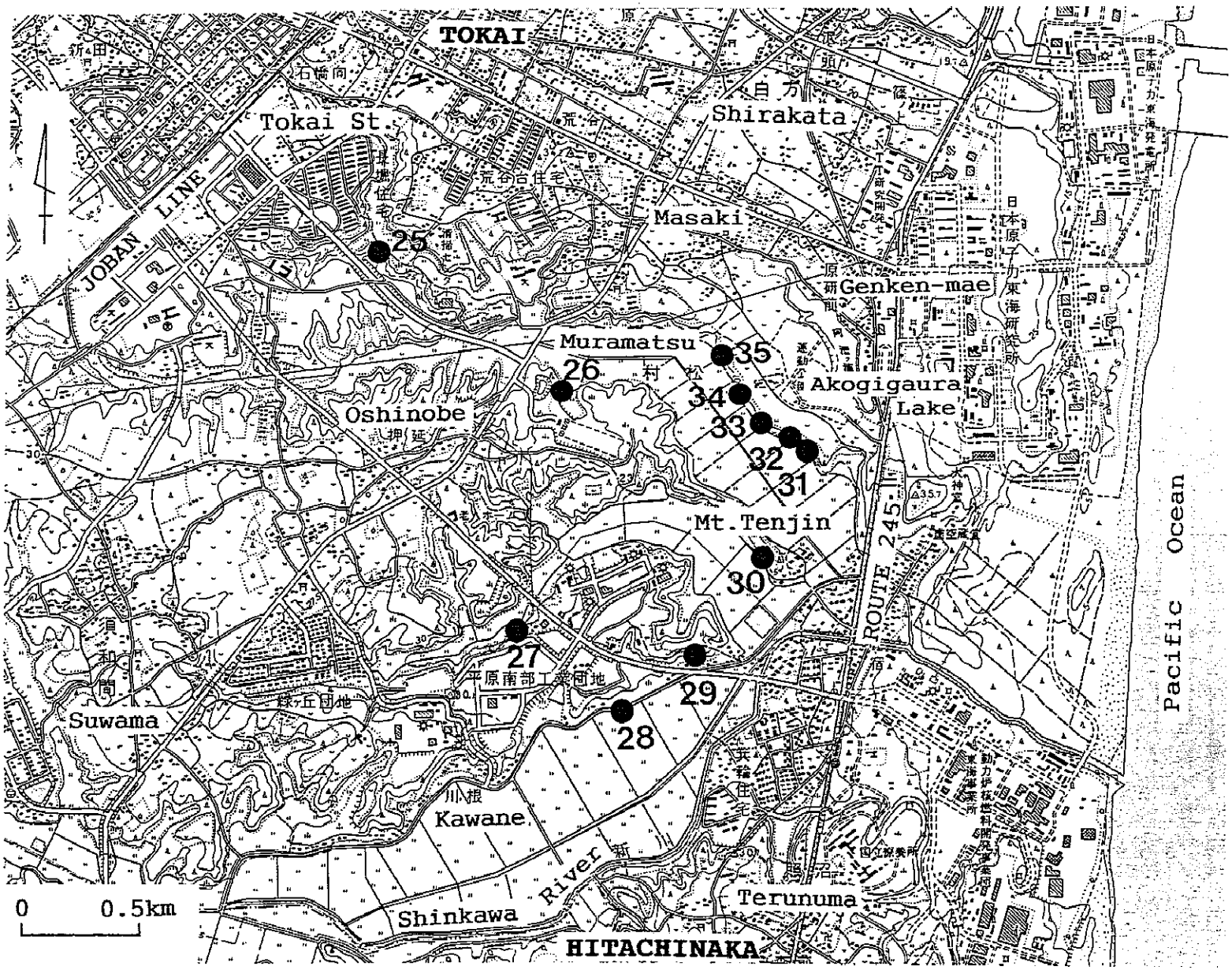

Fig. 44. Locality map of echinoid fossils in the area XII, Tokai area. ●; Fossil locality.

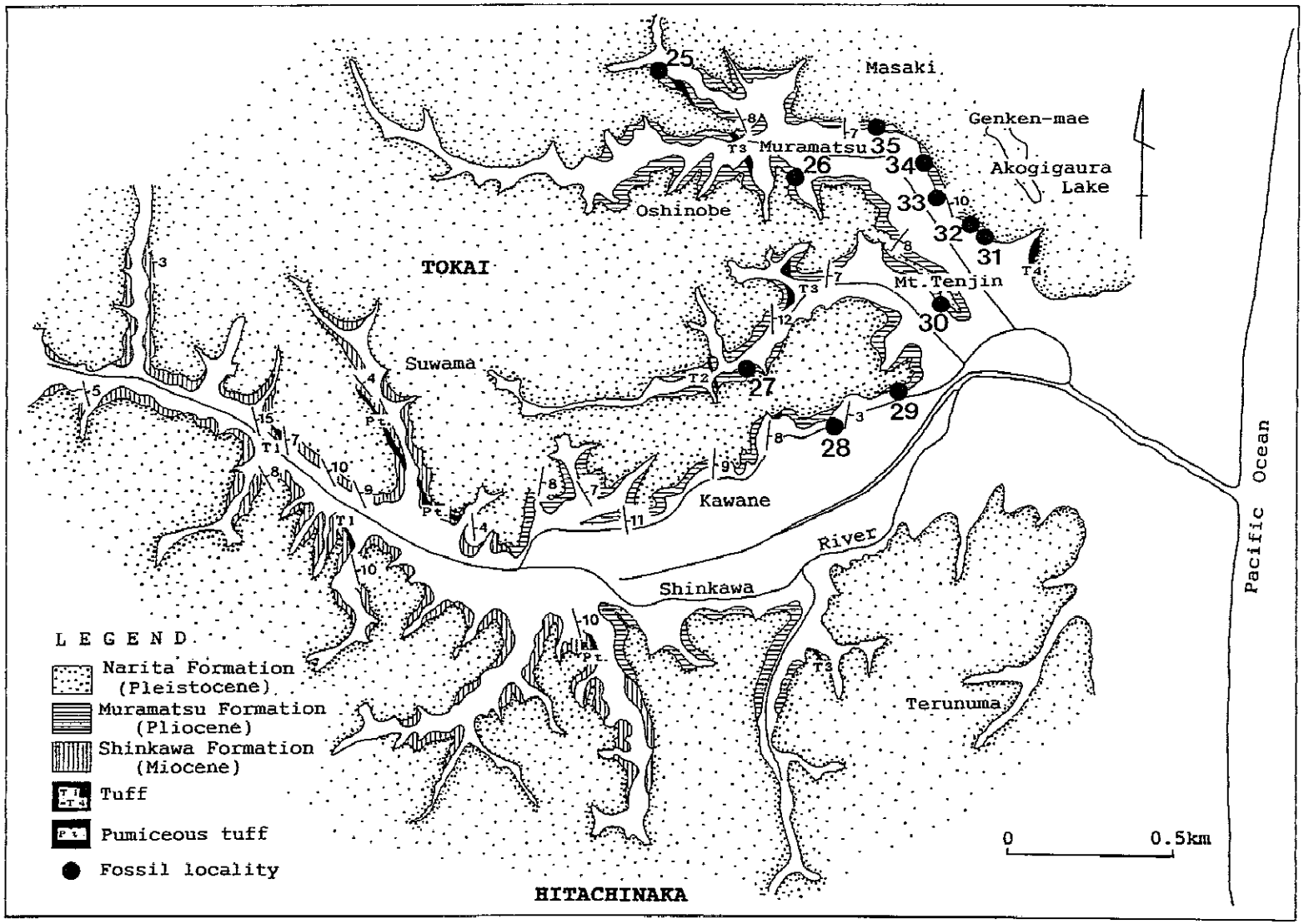

Fig. 45. Geological map and echinoid fossils localities in the area XII, Tokai area.

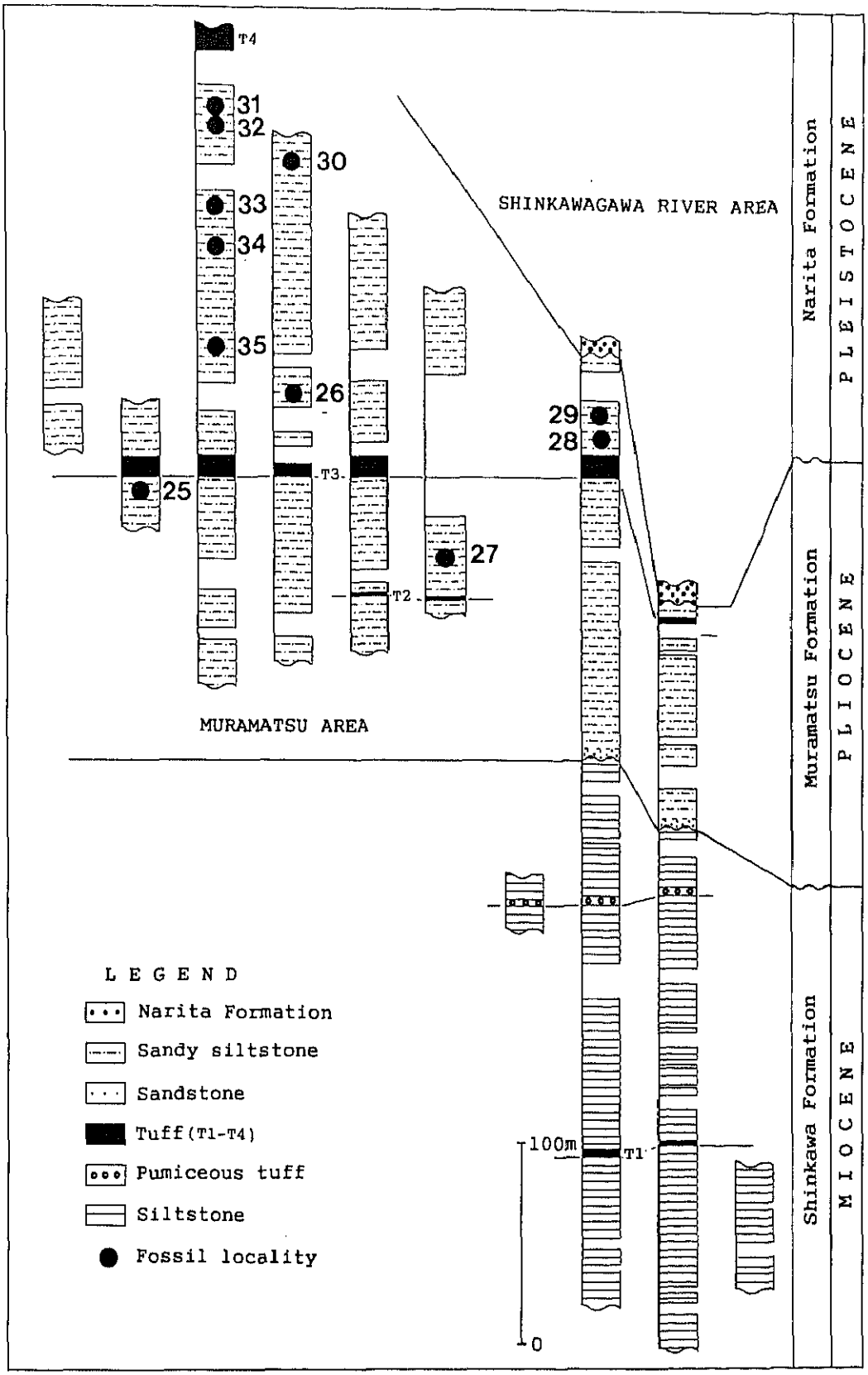

Fig. 46. Columnar section showing stratigraphical position of echinoid fossils in the area XII, Tokai area.

Type locality of this formation is exposure of hill slope along the valley in Muramastu, Tokai-mura, Kuji-gun, Ibaraki Prefecture.

[Thickness]

The total thickness is about 200 meters.

[Lithology]

The Muramatsu Formation is mainly composed of massive greenish gray sandy siltstone with fine grained white tuff and tuffaceous medium grained sandstone.

[Distribution]

The Muramatsu Formation is rather narrowly distributed at hill slope along the valley in Muramatsu area and the Shinkawa River area such as south of Tokai Station of the Joban Railway, Oshinobe, Muramatsu through south of the Akogigaura Lake to Kawane in Tokai-mura.

[Stratigraphic relationship]

This formation unconformably overlies the late middle Miocene Shinkawa Formation (Pl. 2, fig. 4).

[Fossil occurrence]

Many echinoid and molluscan fossils are first recognized from the formation by the present study. Echinoid fossils are

Table 13. Stratigraphic division and correlation in the area XIII, Hitachinaka area.

Geologic age	Suzuki (1954)		Omori (1958)	Ozaki and Saito (1956)	Oyama (1960)		Maruyama (1984)	Present paper
PLEISTOCENE	Terrace deposits			Uwaichi Sand and Gravel	Terrace Gravel		Terrace deposits	Terrace deposits / Narita F.
PLIOCENE	Isozaki Tuff F.	Hetano Mem.	Ajigaura Tuff F.	Ajigaura F.	Ajigaura F.		Hetano F.	
		Ajigaura Mem.						
MIOCENE	Mito G.	Tokiwa Mudstone	Isozaki Sandy Shale F.	Isozaki F.	Isozaki F.		Isozaki F.	Hetano Tuff Mem. / Hitachinaka F.
	Minato G.	Isoai Sandstone						
		Hiraiso Mudstone	Tonoyama Mudstone F.	Tonoyama F.	Tonoyama F.		Katsuta F. / Tonoyama F	
		Ushikubo Sandstone						
		Oharai Conglomerate						
PRE TERTIARY	Isohama G.		Basement Rocks	Nakaminato F.	Naka G.	Nakaminato F.	Nakaminato F.	Basement Rocks
				Oharai F.		Oharai F.	Oarai F.	

Anthocidaris sp., *Palaeopneustes psoidoperiodus*, *Linthia nipponica*, *Linthia* sp., *Lutetiaster ogasawarai* sp., *Brisaster owstoni*, *Brissopatagus* sp., *Nikaidoster tokaiensis* n. gen. et n. sp., *Nodaster watanabei* n. gen. et n. sp. and *Anametalia* sp.. Following molluscan and other mega-fossils yielded; *Solemya tokunagai*, *Portlandia* (*Portlandella*) *lischkei*, *Limopsis tokaiensis*, *Mizuhopecten ibaragiensis*, *Lucinoma annulata*, *Conchocele bisecta*, *Panomya gigath*, *Cardiomya septentrionalis*, *Periploma plane*, *Suchium suchiense subsuchiense*, *Turritella nipponica nipponica*, *Turucicula sukegawaense*, *Fulgoraria* sp., and *crustacean* fossil of *Coronula diadema*, and sharks of *Isurus* sp., *Carcharodon carcharias*, *Cetorhinus maximus* and *Carcharhinus* sp. (Figs. 2, 44-46, Tables 1, 12, 14).

XIII. Hitachinaka area (Fig. 1-XIII)

Tertiary deposit is distributed at hill slope along the Nakagawa River, and cliff at the south margin of the Ajigaura Beach in Hitachinaka area (Figs. 47-48). Tertiary deposit of the area is composed of the following one formation including one member: the middle Miocene Hitachinaka Formation and the Hetano Tuff Member

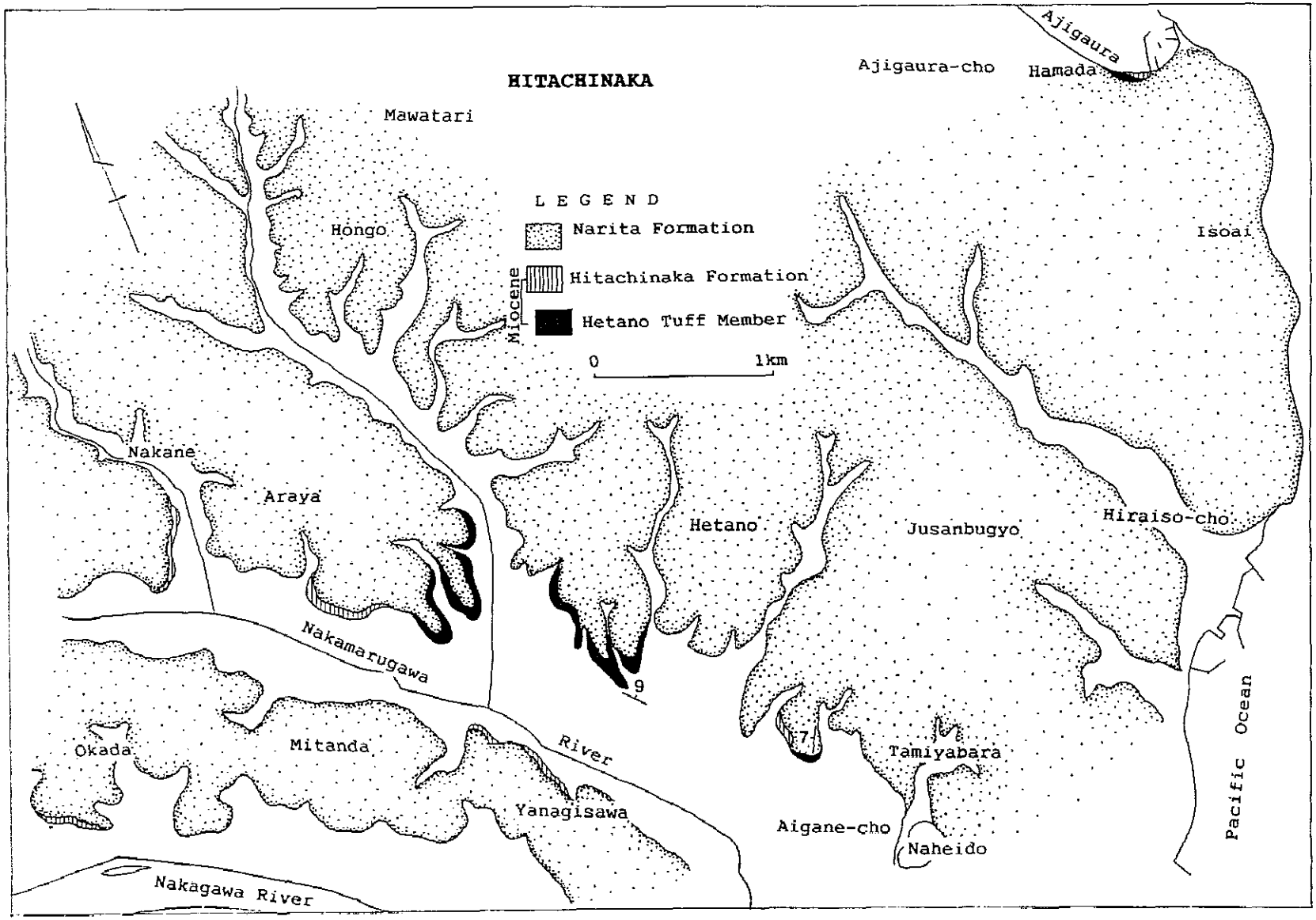

Fig. 47. Geological map in the area XIII, Hitachinak area.

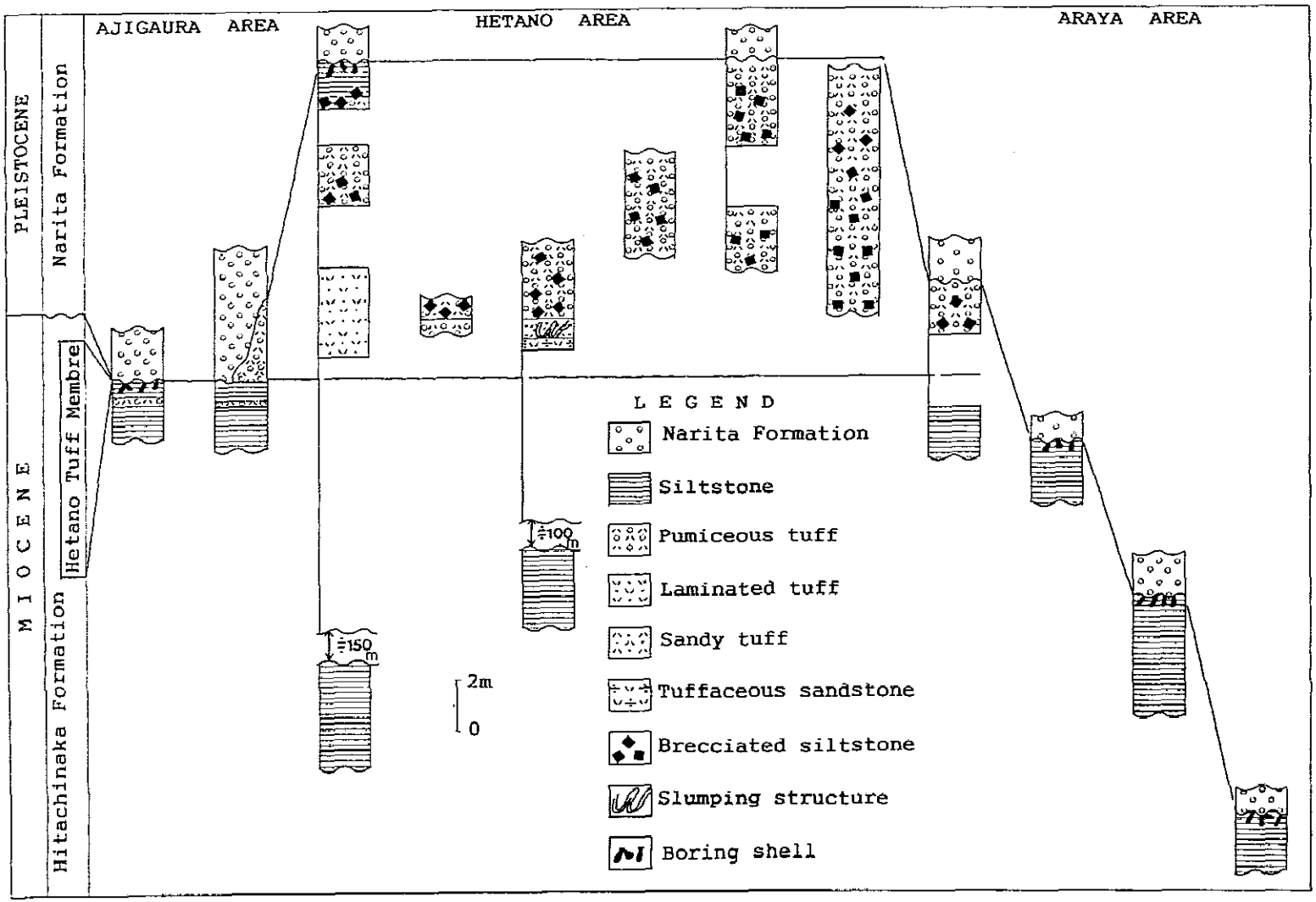

Fig. 48. Columnar section of the area XIII, Hitachinaka area.

(Tables 1, 13).

Geological and paleontological studies of the area have been carried out by Suzuki (1954b), Ozaki and Saito (1955), Saito (1956, 1958, 1959, 1961), Oyama (1960b, 1961), Sakamoto et al. (1972), Ishii *et al.* (1974), Maruyama (1984), Yanagisawa *et al.*, (1989), Takada (1999 MS) and Yoshioka (2001). However, echinoid fossil is not known from the area.

1. Hitachinaka Formation

The late middle Miocene Hitachinaka Formation is corresponding to the Tokiwa Formation of the Tokiwa Group (Suzuki, 1954a), Isozaki Formation (Ozaki and Saito, 1955; Saito, 1961), Isozaki Formation (Maruyama, 1984; Takada, 1999MS; Yoshioka *et al.*, 2001), Hase Formation (Takahashi and Amano, 1986; Amano *et al.*, 1989; Yanagisawa *et al.*, 1989; Saito *et al.*, 1992), Kawarago Formation (Noda *et al.*, 1995), Kokubu Formation (Maruyama, 1984; Yanagisawa *et al.*, 1989) and the Shinkawa Formation (present paper).

[Type locality]

Type locality of this formation is cliff of the south margin of the Ajigaura Beach in Hitachinaka City, Ibaraki Prefecture.

[Thickness]

The total thickness is a more than 400 meters.

[Lithology]

The Hitachinaka Formation mainly consists of massive blue gray siltstone with pumice dominant tuff and tuffaceous sandstone.

[Distribution]

The Hitachinaka Formation is narrowly distributed in south margin of the Ajigaura Beach, and such hill slope along the Nakamarugawa River, Yanagisawa, south of Araya, through south of Nakane to southwest of Okada in Hitachinaka City.

[Stratigraphic relationship]

This formation unconformably overlies the basement Pre-Tertiary rocks.

[Occurrence fossil]

Fossils from the Hitachinaka Formation were reported by Saito (1961), Ishii *et al.*, (1974) and Maruyama (1984).

This formation yielded such diatom, molluscs and other fossils as molluscs of *Nuculana* sp., *Lucinoma acutilineata* and *Lucinoma spectabils*, and diatom of *Cosinodiscus yabei, Denticulopsis hyaline, Denticulopsis lauta, Denticulopsis miocenica, Denticulopsis lauta* and so on.

1-A. Hetano Tuff Member

The late middle Miocene Hetano Tuff Member is correlative to the Pliocene Hetano Member and the Ajigaura Member of the Isozaki Tuff Formation (Suzuki, 1954a), Pliocene Ajigaura Formation (Ozaki and Saito, 1955; Saito, 1961), Pliocene Hetano Formation (Maruyama, 1984), the pumiceous tuff beds of the Urizura Formation at Kadobe in Urizura-machi, tuff beds of the Urizura Formation at Aoki in Kanasago-machi and Pumiceous tuff beds of the Shinkawa Formation at Suwama in Tokai-mura.

[Type locality]

Type locality of this member is cliff in and around the Kamaage-jinja Shrine, Hitachinaka City, Ibaraki Prefecture (Pl. 5, fig. 1).

[Thickness]

The total thickness is a more than 50 meters.

[Lithology]

The Hetano Tuff Member is composed mainly of massive granule to coarse grained pumice dominant tuff with many brecciated siltstone blocks (Pl. 5, fig. 2). This member is thin out at cliff of south margin of the Ajigaura Beach (Pl. 5, fig. 3).

[Distribution]

The Hetano Tuff Member is narrowly distributed in southern margin of the Ajigaura Beach, east slope of hill of Nakamarugawa River area, southeast of Araya, through the Kamaage-jinja Shrine to west of Tamiyabara in Hitachinaka City.

[Stratigraphic relationship]

The Hetano Tuff Member conformably overlies the late middle Miocene Hitachinaka Formation (Pl. 5, fig. 4).

[Fossil occurrence]

Fossil not yielded from the member.

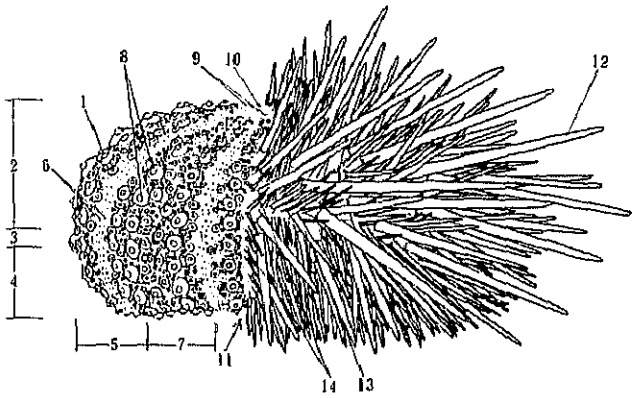

Fig. 49. General morphological feature of the test of a regular echinoid (modified from Shigei, 1986).

1. test, 2. aboral side, 3. ambitus, 4. Oral side, 5. ambulacrum, 6. pore pair, 7. interambulacrum, 8. tubercle, 9.apical system, 10. periproct, 11. peristome, 12. primary spine, 13. secondary spine, 14. military spine.

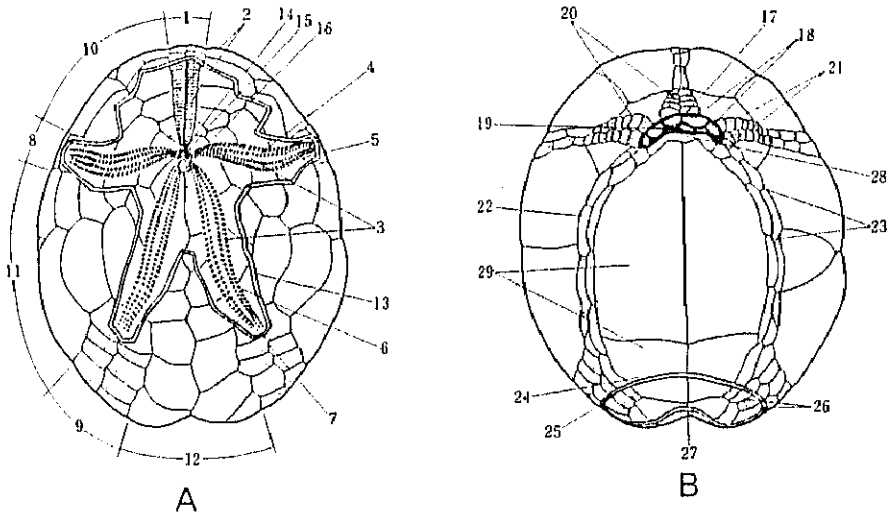

Fig. 50. General morphological feature of the test of a irregular echinoid (modified from Shigei, 1986).

1. frontal ambulacrum, 2. pore-series of frontal ambulacrum, 3. petals, 4.anterior pore-series of anterior petal, 5.posterior pore-series of posterior petal, 6. anterior pore-series of posterior petal, 7. posterior pore-series of posterior petal, 8. antero -lateral ambulacrum, 9. postero-lateral ambulacrum, 10. antero-lateralinterambulacrum,11.postero-lateral interambulacrum, 12. posterior interambulacrum, 13. peripetalous fasciole, 14. apical system, 15. genital pore, 16. madreporite, 17. peristome, 18. peristomial plates, 19. mouth, 20. phyllodes, 21. pores of phyllodes, 22. posterior ambulacrum, 23. pores of posterior ambulacrm, 24. subanal fasciole, 25. subanal region, 26. subanal pore pairs, 27. periproct, 28. labrum, 29. sternal system.