FIELD EXCURSION GUIDE

Cretaceous forearc basin siliciclastic successions along the Pacific coast, central Japan: Choshi, Nakaminato and Futaba groups

Hisao Ando, Kenji Kashiwagi, Ren Hirayama and Seiichi Toshimitsu

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“Cretaceous Ecosystems and Their Responses to Paleoenvironmental Changes in Asia and the Western Pacific”
Field Excursion Guide

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Tokyo - Choshi - Tsukuba - Nakaminato - Kitaibaraki - Iwaki - Tokyo

JAPAN

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Itinerary

DAY 1: Sunday, September 7, 2014
8:00  Leave Takadanobaba, Tokyo at 8 a.m. for Inubosaki (small peninsula projected over the Pacific), Choshi City, Chiba Prefecture by chartered bus
Stop 1-1 ---  Kurohae Fishery Port: Cross-stratified conglomerate and conglomeratic sandstone, Ashikajima Formation, bedded chert block of Atagoyama Unit as basement rock
Stop 1-2 ---  Kimigahama: HCS sandstone and bioturbated sandy siltstone, Kimigahama Formation.
Picnic lunch
Stop 1-3 ---  Cape Inubousaki, Geosite of Choshi Geopark, Choshi City: HCS sandstone and wave-formed sedimentary structure, Inubouzaki Formation
Stop 1-4 ---  Cape Nagasakihana, Choshi City: Massive fine sandstone, Nagasakihana Formation, Upper Miocene to Pliocene Naarai Formation, Inubo Gr. and Lower Miocene Senninzuka Fm.
18:00  Arrival at Hotel Sunrise Choshi
19:00  Dinner and welcome party at Café Marina, Chiba Institute of Science near a sunset beach
20:30-21:00  Preliminary meeting and overview lecture

DAY 2: Monday, September 8, 2014
07:30  Breakfast
08:30  Leave Choshi for Kita-Ibaraki through Tsukuba and Nakaminato
Stop 2-1 ---  Geological Museum, Geological Survey of Japan, AIST in Tsukuba City
Lunch at AIST restaurant
Stop 2-2 ---  Wave cut bench along Hiraiso coast, Nakaminato City: Mudstone of Hiraiso Formation
Stop 2-3 ---  “Seijo-seki”, north of Hiraiso coast: Turbidite facies of the lower Isoai Formation
Stop 2-4 ---  north of Hiraiso coast: debris flow deposits of the Isoai Formation (pterosaur locality)
Stop 2-5 ---  Isozaki coast, Nakaminato City: Thick sandstone succession of the upper Isoai Formation
18:00  Arrival and stay at Izura Kanko Hotel Taikanso along sea cliff of Izura Coast, Kitaibaraki City
19:00  Dinner (with fresh seafood and Japanese cuisine)
20:30  Explanatory lecture

DAY 3: Tuesday, September 9, 2014
07:30  Breakfast
08:30  Leave hotel for field along Izura Coast, Kitaibaraki City by foot
Stop 3-1 ---  North of “Rokkakudo”, Oh-izura: Calcareous concretions in Kokozura Fm., late E. Mio.
Stop 3-2 ---  South of “Rokkakudo”, Ko-izura: Stratigraphic relations of late-E. to Mid. Miocene
Stop 3-3 ---  Garden rocks: Calcareous concretion blocks bearing chemosynthetic bivalves
Stop 3-4 ---  “Rokkakudo”, cultural monument, Izura Institute of Art and Culture, Ibaraki University
After North Ibaraki Geopark leave for Iwaki Lunch at Iwaki Coal and Fossil Museum
Stop 3-5 ---  Iwaki Coal and Fossil Museum (“Iwaki Sekitan Kasekikan”): Plesiosaur, dinosaur, coal, etc.
Stop 3-6 ---  Iwaki City Ammonite Center: Ammonite shell bed of Ashizawa Formation, Futaba Group
17:30  Arrival at Hotel Iwaki Shin-Maiko Heights
19:00  Dinner
20:00  Explanatory lecture

DAY 4: Wednesday, September 10, 2014
After visit to the Futaba Group, leave Iwaki for Tokyo
07:30  Breakfast
08:30  Leave hotel for field
Stop 4-2 ---  Large cliff at Kitazawa, Hirono: Kasamatsu & Tamayama F., Futaba Gr., Eoc. Iwaki Fm.
Stop 4-3 ---  “Kairiyu-no-sato” at Irimazawa, Iwaki City: near plesiosaurid locality, Tamayama Fm.
Stop 4-4 ---  Itakizawa, Iwaki C.: Boundary between fluvial and shallow-marine facies of Tamayama Fm., Futaba Gr. and unconformity between Up.Cretaceous Futaba Gr. and Paleogene Shiramizu Gr.
Arrival at Tokyo until 6 p.m.
Cretaceous forearc basin siliciclastic successions along the Pacific coast, central Japan: Choshi, Nakaminato and Futaba groups

Hisao Ando 1), Kenji Kashiwagi 2), Ren Hirayama 3) and Seiichi Toshimitsu 4)

1) Department of Environmental Sciences, Faculty of Science, Ibaraki University, Bunkyo 2-1-1, Mito 310-8512, Japan (ando@mx.ibaraki.ac.jp)
2) Graduate School of Science and Engineering for Research, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan (kasiwagi@sci.u-toyama.ac.jp)
3) School of International Liberal Studies, Waseda University, Nishi-Waseda 1-6-1, Shinjuku-ku, Tokyo 169-8050, Japan (renhirayama@waseda.jp)
4) Geological Museum, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Central 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan (s.toshimitsu@aist.go.jp)

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Introduction

As the Japanese Islands are situated in an active convergent margin, their geologic structure is very complicated in general. The pre-Neogene strata are distributed reflecting a zonal arrangement of several geotectonic provinces on the surface, some of which were intensely modified by post-Paleocene tectonism partly related to the opening of the Japan Sea caused by backarc spreading during the middle Miocene (Fig. 1). On a large scale, the pre-Neogene structure of the Japanese Islands is divided into Southwest Japan and Northeast Japan by the Tanakura Tectonic Line (TTL).

Therefore, the Cretaceous strata had been affected by tectonic movements several times on a large/mid/micro scale. On the basis of lithostratigraphy, facies and sequence stratigraphy and biostratigraphy, over 22 surface and subsurface stratigraphic successions of the Cretaceous and lower Paleogene were correlated from north Honshu to Kanto region. Their distribution and geologic features of the Cretaceous strata are considerably different between the two divisions (Fig. 2).

In Northeast Japan, Upper Cretaceous to Lower Paleocene shallow-marine to non-marine sediments as well as offshore-marine sediments are distributed along the Pacific coast of north Honshu and the offshore Pacific area (Fig. 1). They continue northward toward Sakhalin through central Hokkaido, 1,400 km long in a north-south direction (Ando, 2003, 2005). They have been deposited in an ancient forearc basin along the eastern margin of the paleo-Asian continent, called the Yezo forearc basin.

On the other hand, Southwest Japan had been uplifted by the tectonic movements after the Japan Sea opening, e.g. subduction and transform movements of Pacific and Philippine Sea Plates. As many of Cretaceous forearc sediments had been eroded away and tectonically deformed, their surface distribution is very limited. Therefore, it is not easy to study the sedimentary and faunal successions as well as due to recent vegetation of inland areas. However, since the Nakaminato and Choshi groups are well exposed along the Pacific coastline, their stratigraphic successions can be appropriately traced and established.

Recently the boundary problems between Southwest Japan and Northeast Japan, especially on the differentiation during the pre-Neogene and post-Neogene stages, are well noticed recently (Takahashi, 2006).

Cretaceous Forearc Siliciclastics: Choshi, Nakaminato and Futaba groups

In this excursion we observe forearc siliciclastic successions exposed along the Pacific coast and nearby, central Japan, 100-250 km east to northeast from Tokyo, central Honshu Island (Fig. 3). They include fluvial to offshore turbidite facies through storm-dominated shallow-marine facies occasionally associated with several sedimentary structures and such fossil sites as vertebrate bone beds and bivalves/
Fig. 1. Pre-Neogene geological map and tectonic subdivision of Tohoku to Kanto regions (Ando, 2006). Numbers of the locations refer to those of columnar sections shown in Fig. 2.
Cretaceous forearc basin siliciclastic successions: Choshi, Nakaminato and Futaba groups

Fig. 2. Stratigraphic correlation of Cretaceous to Paleogene sediments from Tohoku to Kanto regions (Ando, 2006).
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The Choshi Group is situated at the eastern margin of Southwest Japan, and also the eastern extremity of Chiba Prefecture facing the Pacific with rocky shore and steep sea cliffs (Figs. 1 and 2, no. 19). The Choshi Group is characterized by moderately consolidated rocks of storm-dominated, shallow-marine sandstone and mudstone less than 950 m thick. Its age is regarded as Barremian-Aptian based on ammonites and foraminifers.

The Nakaminato Group is also located in the eastern margin of Southwest Japan, forming a fault block on the southern extension of the Tanakura Tectonic Line (Figs. 1 and 2, no. 18). This group consists of the sandy turbidite and offshore mudstone facies of late Campanian to early Maastrichtian age. The characteristic heteromorph ammonite occurrence suggests that the Nakaminato Group is the eastern extension of the thick sequence of the Izumi Group in Shikoku and west Honshu 600 to 800 km WSW of the Nakaminato area.

The last Futaba Group lies on the southern margin of Northeast Japan (Figs. 1 and 2, no. 15). It is fluvial to shallow-marine sandstone and mudstone sequences of the Coniacian to lower Santonian. Due to simple geologic structure and low-grade diagenesis, the sediments are not well consolidated. There is even a sand quarry still working. Invertebrate fauna represented by such as ammonites, etc., vertebrate fauna and recently discovered angiosperm flower fossils make possible to reveal the late Cretaceous ecosystem of shallow-sea and land areas nearby.

In the Choshi and Nakaminato areas, there are some geosites of Japanese Geoparks, Choshi Geopark and North Ibaraki Geopark, respectively. Even in the Iwaki area local people are now under investigation for the nomination to the Japanese Geopark Network. We can also know the outline of geopark activities at each geosite.

Furthermore, we visit the Izura Coast Geosite of North Kitaibaraki Geopark, Kitaibaraki City as extra stops. There we can observe the late Early Miocene strata bearing a large amount of calcareous concretions and a chemosynthetic bivalve community of methane seep origin. The striking natural scenery on sea cliff and rocky coast is derived from the wave-resistant rocks of naturally cemented under sea bottom during late Early Miocene.

We can see a few excellent museums and their exhibition facilities highlighting the Cretaceous fossils and geology: Geological Museum of Geological Survey of Japan, Iwaki Coal and Fossil Museum and Iwaki Ammonite Center.

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Fig. 3. Distribution of isolated Cretaceous to Paleogene strata around the Kanto Region.
Choshi Group: Shallow-marine storm-dominated sandstone facies

The Choshi Group, extending ca. 4 km in a north-south direction along the eastern coastline of Choshi Peninsula, is Barremian-Aptian in age, approximately 935 m thick, and is made up of terrigenous siliciclastic rocks (Fig. 4). The Choshi Group is bounded by inferred faults with the pre-Cretaceous basement rocks, which are possibly the equivalent strata of the Jurassic accretionary complexes. The Choshi Group is unconformably overlain by the upper Miocene to Pliocene Naarai Formation at Inubousaki, west of Toriakeura, Nagasakihana and Tokawa (Obata et al., 1975; Takahashi et al., 2003).

Geologic Setting of the Choshi area

Quaternary Terrace Geomorphology

The Choshi area situated in the eastern extremity of the Kanto Plain geomorphologically forms the western Iioka (about 50m high) and eastern Choshi (about 30 m) terraces (Figs. 4 and 5). The two terraces had been formed during post-Middle Quaternary glacioeustatic sea-level changes, MIS (marine isotopic stage) 5e (ca. 130-115 ka) and 5a (ca. 85-80ka), respectively (Sugihara, 2000).

Pre-Neogene tectonic block

Below the Pleistocene unconsolidated sediments the older rocks such as the Cretaceous Choshi Group and pre-Cretaceous basement rocks are distributed only in the Choshi Peninsula projected over the Pacific. The Choshi area represents a tectonic high of the eastern margin of Kanto basin formed by the large-scale tectonic movement related to plate motion.

According to Takahashi et al. (2003), the pre-Neogene basement rocks of the Choshi Peninsula are distributed only on the east side of the NE-SW trending Metogahana-Kayakarijima fault. This basement area is subdivided into two areas by the NNE-SSW trending Kurouhae-Togawa fault. Here, we name the two as the western Atagoyama block and the eastern Inubousaki block.

The Atagoyama block is characterized by the sporadically and isolatedly distributed the Takagami Conglomerate and the Atagoyama Unit (Takahashi, 2008; Figs. 4 and 6). This block forms a horst-like highland.

In the Inubousaki block the Cretaceous Choshi Group crops out along the N-S trending Pacific coast. Furthermore, as this block is subdivided into a few blocks by other smaller-scale faults crossing the Kurouhae-Togawa Fault, the stratigraphy of the Choshi Group is difficult to be established (Obata et al., 1975, 1982, etc.). The Choshi Group may be in fault contact with the pre-Cretaceous basement rocks, Atagagoyama Unit.

"Byobugaura", steep coastal cliff of Plio-Pleistocene Inubo Group

In the Iioka Terrace, the Plio-Middle Pleistocene Inubo Group is distributed NE strike and dip gently northwestward at less than 10 degree. Especially, the lower to middle parts (Naarai, Kasuga and Obama formations) are exposed along the steep Pacific coastal cliff 40 to 50 meter high called "Byobugaura" (means folding screen in Japanese) 9 km long from west Cape Gyobu to east Naarai (Fig. 6). It is somewhat similar to White Cliff of Dover. This is also a Geosite highlighting Choshi Geopark.

Pleistocene marine sand cover

The Late Pleistocene Katori Formation is mainly composed of unconsolidated marine sand and unconformably covers the older strata distributed both in the Iioka and Choshi terraces (Fig. 4, S2).

Pre-Cretaceous basement rocks

Pre–Cretaceous basement rocks have been described as the Atagoyama Formation (Ozaki, 1959) or the Atagoyama Group (Shikama and Suzuki, 1972; Takahashi, 1990). Although small, discontinuous outcrops and lacking of fossils indicative of sedimentary age make it difficult to establish the precise correlation and age determination. In the last ten years, Pre–Cretaceous basements have been tectonically and stratigraphically subdivided into 2 systems: the Kurohae Formation and the Atagoyama Formation (Tazawa and Hasegawa, 2007); the Atagoyama Unit and the Takagami Conglomerate (Takahashi, 2008). Here we follow Takahashi’s (2008) criteria (Figs.6, 7).

The Takagami Conglomerate crops out northwest and west of Atagoyama hill and northwest of Nagasakihana, and is mainly composed of sandstone and conglomerate. Intraformational conglomerate beds within thick sandstone show polymictic gravel composition: limestone, plutonic and volcanic rocks, sandstone, slate and so on (Kano, 1958; Ozaki, 1959). A fusulinoidae fauna including Lepidolina shiraiwensis and Yabeina columbiana obtained from the limestone clasts indicates that the age of the
Fig. 4. Geological map of the Choshi area. After Geological Map, 1:200,000, Chiba, Unozawa et al. (1983).
A: Atagoyama Unit (Jurassic); C: Choshi Group (Cretaceous); Me: Metogahana Fm. (Mio.); K1: Naarai Fm. (Plio.); K2: Iioka Fm. (Plio.); S1: lower Shimosa Gr. (Pleist.); S2: Katori Fm. of upper Shimosa Gr. (Pleist.)

Fig. 5. Satellite image of the Choshi Peninsula. After Google Earth.
Takagami Conglomerate is late Permian (Tazawa and Hasegawa, 2007).

The Atagoyama Unit crops out isolatedly in the north and south of the Atagoyama block. Bedded chert at Kurohæ in the northeastern part of the block yields Middle to Late Triassic conodont genera such
as Neogondolella, Epigondolella and Parvigondolella (Kunihiro et al., 1984). The Atagoyama Unit at northwest of Nagasakihana in the southern part consists of sandstone, sandstone-mudstone alternations and pebbly mudstone including lots of sandstone and small amounts of greenish tuff and chert (Takahashi, 1990). Due to the broken mixture of various lithologies, the Atagoyama Unit is possibly interpreted as a part of Jurassic accretionary complexes (Tazawa and Hasegawa, 2007; Takahashi, 2008).

### Stratigraphy of the Choshi Group

Owing to the block fault structure, restricted outcrops to the sea cliff and lacking of continuous strata overall, the stratigraphy of the Choshi Group has not yet reached a united opinion, although many researchers have accepted Obata’s et al. (1982) stratigraphic scheme.

The Choshi Group consists of five formations based on their lithofacies and ammonoid ages: the Ashikajima, Kimigahama, Inubouzaki, Toriakeura, and Nagasakihana formations in ascending order (Figs. 7-10) (Obata et al., 1982; Obata and Matsukawa, 2009a). Explanations for its each formation below are referred to their works.

The Ashikajima Formation forms the base of the Choshi Group, and is composed of cross-stratified very coarse to fine sandstone and conglomerate. Clasts within the conglomerate are dominated by chert with minor sandstone, shale, limestone and porphyry (Obata et al., 1975).

The main part of the formation shows upward-fining facies changes from the lower conglomerate into coarse to medium sandstone gradually, in general. Macrofossils are rare, but belemnite and petrified wood fragments were reported by Obata et al. (1975).
The Kimigahama Formation consists of medium to fine sandstone and bioturbated mudstone alternations. On the basis of ammonoids and foraminiferal biostratigraphy, the Kimigahama Formation is safely assigned to the Barremian.

The Inubouzaki Formation is characterized by amalgamated hummocky cross-stratified fine sandstone, and alternated HCS fine sandstone and mudstone. Ripple marks, trace fossils and plant fragments are abundant. The facies changes from the Kimigahama to Inubouzaki formations are abrupt. From the occurrence of five Aptian ammonite genera,
the Inubouzaki Formation is surely deposited in the Early Aptian age, although foraminifers are not known from the formation.

The Toriakeura Formation shows a general upward-fining trend from alternating sandstone and mudstone in the lower half to more muddy alternating beds facies in the upper. From the ammonites and foraminifers occurrences, the formation is referred to be the Upper Aptian.

The Nagasakihana Formation is comprised of mostly amalgamated, thick-bedded to massive, medium to fine sandstone. Obata and Matsukawa (2009a) assumed the formation as the lower Albian.

**Sedimentary facies and environments of the Choshi Group**

Katsura et al. (1984) conducted detailed sedimentological analyses of sedimentary successions in the Choshi Group, and revealed its depositional environmental changes. The Choshi Group was deposited in storm-dominated shallow marine environments as below (Figs. 10, 11):

- Nagasakihana Fm. Offshore (turbidite)
- Toriakeura Fm. Inner to outer shelf
- Inubouzaki Fm. Lower shelf
- Kimigahama Fm. Lower shelf-inner shelf
- Ashikajima Fm. Up. Upper – lower shoreface
- Ashikajima Fm. Low. Upper shoreface

**Macrofauna of the Choshi Group**

The Choshi Group has also been well known for abundant occurrences of macrofossils: ammonoids, bivalves, gastropods, brachiopods, echinoids, shark teeth, plant fossils (petrified woods and ambers) and so on (e.g., Shikama and Suzuki, 1972; Hayami and Oji, 1980; Kase and Maeda, 1980; Obata et al., 1982; Saiki et al., 1991; Obata and Matsukawa, 2007, 2009a, b). In particular, ammonoid fossils have been studied precisely as important age diagnostic taxa in a series of Obata and Matsukawa’s researches (Obata et al., 1975, 1982; Obata and Matsukawa, 2005, 2007, 2009a, b), and have contributed the precise age controls of the Choshi Group as Barremian to early Albian.

**Microfossils of the Choshi Group**

Radiolarians have been firstly extracted from 3 horizons of the Choshi Group: chert gravels in the Ashikajima Formation; sandy shell bed intercalated in the Kimigahama Formation; calcareous nodule within the Toriakeura Formation. Here we introduce some radiolarian occurrences as below (Fig. 12).

Several chert pebbles and cobbles within conglomerate beds of the Ashikajima Formation sometimes contain abundant radiolarian fossils. Sample 12072301-03 contains poorly- to moderately-preserved Bajocian to early Callovian (Middle Jurassic) radiolarians: *Eucyrtidiellum* sp., *Hsuum* sp., *Striatojaponocapsa* sp. (identified as *Striatojaponocapsa conexa* or *Striatojaponocapsa plicarum*), *Syringocapsa* sp. and *Williriedellum* sp.

Also sample 12072301-06 indicates a Permian age for the presence of *Pseudoalbailella* spp. Chert gravels in the Ashikajima Formation have been probably derived from the Jurassic accretionary complex.
The Kimigahama Formation (middle Barremian to earliest Aptian) contains a scarce and poorly preserved radiolarian fauna in the sandy shell bed intercalation within the sandstone–mudstone alternations. Most of radiolarians show spherical to subspherical outline of test, and 180–380 μm in length/diameter of test due to sorting by size and shape during deposition. Only two forms were...
identified: *Praeconosphaera* sp. and *Sethocapsa*? *orca* Foreman. The radiolaria-bearing shell bed indicates early Hauterivian to early Aptian or later based on the presence of *Sethocapsa*? *orca*.

The Toriakeura Formation (early late Aptian) contains radiolaria-bearing calcareous nodules in the muddy facies. The radiolarian assemblage shows a high diversification, and is listed as follows: *Archaeodictyomitra mitra* Dumitrica, *Dictyomitra pseudoscalaris* (Tan) sensu Schaaf, *Holocryptocanium* sp. as nassellarians, and *Angulobracchia* sp., *Cenosphaera* sp., *Orbiculiforma* sp. and *Triactoma* sp. as spumellarians. A radiolaria-bearing calcareous nodule indicates an age interval of late Valanginian to early Aptian or later due to the coexistence of *Archaeodictyomitra mitra* and *Dictyomitra pseudoscalaris*.

**Naarai Formation: Upper Miocene-Pliocene bearing Cretaceous reworked ammonites**

The Cenozoic Naarai Formation, the base of the Inubo Group, consists of the basal conglomerate (probably Late Miocene to Early Pliocene) and the overlying tuffaceous sandstone beds (probably Pliocene to Pleistocene). It is estimated to 80–100 m in total thickness (Ozaki, 1958; Matoba, 1967).

The basal conglomerate less than several meters thick is composed of various gravel consisting of Paleozoic rocks, Cretaceous sandstone and calcareous rocks, lower Miocene volcanic rocks, etc. within tuffaceous silty matrix (Ozaki, 1958; Matoba, 1967). It overlies the probably Jurassic Atagoyama Unit, the Lower Cretaceous Choshi Group and the Lower Miocene Metogahama Formation with a distinct angular unconformity (Ozaki, 1954, 1958). At present, these unconformity outcrops had been artificially covered by reclaimed land for building a fishery port.

The overlying tuffaceous sandstone beds crop out continuously along the Byobugaura Sea-Cliff, and contain pumice and glauconite with many intercalations of pumice and silty tuff (Ozaki, 1958; Matoba, 1967; Sakai, 1990). The stratigraphic relationship between the tuffaceous sandstone and the underlying basal conglomerate has been unknown due to lacking of outcrops showing their contact horizon.

**Macro- and micro-fossils and depositional age**

In the basal conglomerate, various fossils are included: 62 species of gastropods, 51 species of pelecypods, 26 species of brachiopods, 70 species of benthonic foraminifers, 8 species of planktonic foraminifers and other taxa (barnacles, corals, echinoids, ophiuroids, bryozoans, teeth of shark, otolith of whales, mammalian bones and plant leaves.

**Fig. 13.** Some microfossils from the calcareous rocks in the basal conglomerate of the Naarai Formation. 1-2. *Holocryptocanium barbii*; 3ab. *Cryptamphorella* sp.; 4. spumellarian radiolaria; 5. multisegmented tower-like nassellaria; 6-8. fragmental pieces of ichthyoliths.
Also many microfossils occur in the tuffaceous sandstone: foraminifers (Matoba, 1967; Ishikawa and Hatta, 1984), nannoplankton (Nishida, 1980), and radiolarians (Sakai, 1990). (Fig. 13)

The basal conglomerate was firstly assigned to the upper Pliocene based on the molluscan similarity with the Zushi Formation, Miura Peninsula, Kanagawa Prefecture (Ozaki, 1954a, b). And then Matoba (1967) regarded the basal conglomerate as the upper Miocene owing to the presence of some planktonic foraminifera (*Globigerina nepenthes*, *Globorotalia menardii miocenica*, *Sphaeroindellopsis seminulina*). On the other hand the tuffaceous sandstone intercalates with some Pleistocene tuff beds (2.2-2.3 Ma, ca. 2.5 Ma and 2.65 Ma tuff beds) (Tamura et al., 2010). Thus the stratigraphic relationship between the basal conglomerate and the overlying tuffaceous sandstone have been a matter of debate.

An interesting fact is that several ammonoids have been discovered sporadically in the basal conglomerate of the Naarai Formation: Albian *Mortoniceras* sp. and *Puzosia subcorbarica* (Obata et al., 1975, 1982), and Tithonian *Virgatosphinctes* sp. and *Usseliceras* (*Usseliceras*) sp. (Obata and Matsukawa, 2005). These ammonoids are interpreted as derived fossils from unexposed Cretaceous and Jurassic formations.

Some calcareous rocks in the basal conglomerate yield abundant radiolarians and foraminifers with rare ichthyoliths. Kashiwagi et al. (2013) reported latest Late Jurassic to early Late Cretaceous radiolarian assemblage (e.g., *Holocryptocanium barbui* Dumitrca, *Cryptamphorella* spp., etc.) from vertebrate bone fragment-bearing calcareous rock (Fig. 13).

**Choshi Geopark**

The Choshi Geopark approved by Japan Geopark Network in November 2012, covers the Choshi Peninsula and nearby in Choshi City, Chiba Prefecture. There are major four geosites, 1) Kurohane, Metogahana and Houman, 2) Inubousaki, 3) Atagoyama, Senga iwa and Inuiwa and 4) Byobugaura. In this excursion, we visit and observe 1) and 2).
DESCRIPTION OF DAY 1

Stop 1-1 Kurohae Fishery Port, Choshi City: Cross-stratified conglomerate and conglomeratic sandstone, Ashikajima Formation

Conglomerate and interbedded coarse to medium sandstone of the lower part of the Ashikajima Formation can be observed in the Kurohae Fishery Port (Fig. 14). Conglomerate consists of round and subround, pebble to cobble of chert, sandstone, slate, granite, etc. first three of which seem to have been derived from the pre-Cretaceous Atagoyama Formation. Trough cross-stratification common in sandstone and conglomerate suggests the deposition on upper shoreface of wave-dominated environments.

In the fishery port, a few rocky reefs of andesite massive lava and its volcanic breccia of the Miocene Senninzuka Formation are sporadically distributed, though the contact with the Choshi Group cannot be detected on outcrops.

A bedded chert block is isolatedly exposed in reclaimed land near the Kurohae Port (Fig. 15). This chert is redefined as the Atagoyama Unit by Takahashi (2008). The stratigraphic relation with the Choshi Group is thought to be in fault contact. (Kurohae-Tokawa Fault; Fig. 6).

Stop 1-2 Kimigahama, Choshi City: HCS sandstone and bioturbated sandy siltstone, lower part of Kimigahama Formation

Along a rocky to sandy beach, north of Kimigahama, we can observe the facies changes from the Ashikajima to Kimigahama Formation. The upper part of the Ashikajima Formation is composed of amalgamated hummocky cross-stratified (HCS) sandstone. The lower part of the Kimigahama Formation changes into alternated HCS sandstone and bioturbated sandy siltstone facies (Fig. 16).

In the sandstone part, there are wave-formed structure such as HCS and wave-ripples. Several kinds of vertical and horizontal burrows filled with dark gray muddy matrix are also common. Molluscan shells mostly of bivalves such as trigoniids, etc. are included as basal lags of beds, intervening lamina or scattering fragments.

Mudstone is much mottled and homogenized by heavy bioturbation of benthic organisms. Initial sedimentary structures were considerably destroyed.

Stop 1-3 Cape Inoubousaki, Geosite of Choshi Geopark, Choshi City: HCS sandstone and wave-formed sedimentary structure, Inubouzaki Formation

This stop is the Inoubousaki Geosite, a highlight of the Choshi Geopark. It was also selected as one of Japan's Top 100 Geological Features in 2007.

It is also a sightseeing spot where a small cape.

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Fig. 14. Conglomerate of the Ashikajima Formation at Stop 1-1, Kurohae Fishery Port.

Fig. 15. A bedded chert block at Stop 1-1, Kurohae Fishery Port.

Fig. 16. Sandstone-dominated, alternating HCS fine sandstone and bioturbated sandy mudstone of the Ashikajima Formation at Stop 1-2, Kimigahama Formation, Kimigahama coast.
Cretaceous forearc basin siliciclastic successions: Choshi, Nakaminato and Futaba groups

projects over the Pacific from the Choshi Peninsula.

Shallow-marine sandy deposits of the Inubouzaki Formation, the middle of the Lower Cretaceous Choshi Group, crop out on large outcrops along a sea cliff, forming a gentle anticline with an eastward plunging E-W axis. In comparison with both of the northern and southern coasts, the harder lithology of apparently massive sandstone of the Inubouzaki Formation makes resistant geomorphology of the steep coastal cliff against wave erosion.

The Inubouzaki Formation is characterized by HCS fine sandstone and occasionally associated with sandy siltstone (Fig. 17). On the coastal cliff and rocky shore, several kinds of sedimentary structure are observable as follows: the most frequent HCS and amalgamated and thickly stacked HCS, flat/parallel lamination, wave ripples as top marks or in cross section, planar cross-stratification (PCS), trough cross-stratification (TCS) and several kinds of trace fossils. Ammonites, tritonymid bivalves, amber, plant remains (fern, conifer and cycad, etc.) rarely occurs from certain horizons (Obata et al., 1982; Hayami and Oji, 1980; Kase and Maeda, 1981 etc.).

Hummocky cross-stratification is well known to be indicative of storm-dominated sandy shallow-marine environments (e.g., Duke, 1985; Walker, 1992). Ishigaki and Ito (2000) suggested that HCS might be formed by combined flows with dominant oscillatory flows on the basis of the log normal distribution of HCS wave length with a mode at 300 cm detected in this formation. They also pointed out that HCS size decreases in offshore finer facies reflecting the relation among substrate grain size, wave energy and water depth.

The Inubouzaki Formation seems to have been deposited on the storm-dominated lower shoreface sandy bottom of open-sea shallow shelf.

The strata has been designated a natural monument in Japan as “Cretaceous shallow-marine sediments at Inubousaki” in 2000 (Fig. 17). We can see some familiar figures and photo for geologists and sedimentologists on the explanatory board.

Stop 1-4 Cape Nagasaki-hana, Choshi City: Massive fine sandstone, Nagasakihana Formation and overlying Upper Miocene to Pliocene Naarai Formation, Inubo Group and Lower Miocene Senninzuka Formation

The uppermost Nagasakihana Formation of the Choshi Group can be observable only here (Figs. 6, 8). This formation is composed of thick, mostly massive and slightly laminated, medium to fine sandstone considerably different from other sandy formations. While convolute structure is common (Fig. 8), bioturbated traces are rare, suggesting high sedimentation rate. The sediments seem to be gravity flow deposits, though not typical turbidite. Outer shelf to upper slope is a reasonable candidate for the sedimentary environments.

No fossils are found except plant fragments. Owing to no good index fossils, the age determination is difficult. In terms of the geologic structure, the formation has been regarded as the uppermost stratigraphic position in the Choshi Group (Obata et al., 1982).

Fig. 17. Amalgamated HCS fine sandstone of the Inubouzaki Formation at Stop 1-3, Cape Inubousaki. The right-side stone monument marks “Cretaceous shallow-marine sediments at Inubousaki” in Japanese as a natural monument in Japan.

Fig. 18. Convolute structure observed in massive medium sandstone of the Nagasakihana Formation at Stop 1-4, Nagasakihana coast.
Senninzuka Formation: Miocene andesite

On rocky reefs northeast of the Nagasakihana lighthouse, the Miocene Senninzuka Formation is composed of cross-stratified tuffaceous sandstone and the overlying bronzite andesite lava according to Takahashi et al. (2003).

In contrast with the other northern rocky and sandy coasts along Choshi Peninsula, the Nagasakihana coast is dark-colored gravel beach due to abundant black-colored andesite beach gravel derived from the Miocene Senninzuka Formation. The gravel is derived also from the basal conglomerate of the Upper Miocene to Pliocene Naarai Formation described below and the Cretaceous Nagasakihana Formation.

Naari Formation, Inubo Group: Pliocene bearing Cretaceous ammonites and radiolarian-bearing pebbles

Owing to the recent gravel beach, the basal conglomerate of the Naarai Formation crops out intermittently (Fig.19). It shows poorly sorted, matrix- or clast-supported, angular to subround gravel facies with tuffaceous matrices.

Various macrofossils occur from the basal conglomerate and its reworked gravel on the recent gravel beach. So Nagasakihana is one of the well-known fossil localities in the Choshi area where many fossil hunters have visited to collect fossils. You can also gather microfossil-bearing calcareous gravel with round to subround shape and much-bored surfaces by recent boring shells.

Outcrop observations of the basal conglomerate and collecting fossils depend on the ebb tide and wave condition on 7th September (ebb tide at 8:43; flood tide at 15:36 by tidal forecasts of the Japan Meteorological Agency).

At Café Marina, Chiba Institute of Science, we can observe the excellent fossil collections by a local fossil collector.

Fig. 19. Field view at Nagasakihana, Stop 1-4. 1) Panoramic view of Nagasakihana. 2) The basal conglomerate of the Naarai Formation. Black arrow indicates an angular cobble of microfossil-bearing calcareous rock. 3-4) Boulders of microfossil-bearing calcareous rocks washed out from the basal conglomerate of the Naarai Formation.
Nakaminato Group: Offshore-marine mudstone and turbidite facies

Along the Pacific coastline about 80 km north of the Choshi Peninsula, a thick deep-marine sequence (at least 1,500 m thick) of sandstone, mudstone and subordinate conglomerate is narrowly exposed near the left river-mouth side of the Naka River. This Nakaminato Group forms a northeast dipping (30-40°) homoclinal structure with WNW-NW strike (Fig. 20).

Stratigraphy and sedimentary facies changes

According to Tanaka (1970) and Sakamoto et al. (1972), the Nakaminato Group is divided into three formations, the Hiraiso and Isoai and Chikko formation. Though the Chikko Formation about 30 meter thick is distributed as a small isolated block in fault contact with the Paleogene Oarai Formation and covered by the Miocene Toneyama Formation with angular unconformity, it is now not exposed due to the fishery port and town artificial cover.

We can observe the Hiraiso and Isoai formations in upward sequence along the Hiraiso to Isozaki coast, Hitachinaka City (Fig. 20 right).

1. Hiraiso Formation
The Hiraiso Formation about 600 meter thick is mainly dark gray siltstone frequently intercalated with thin fine to very fine sandstone layers and occasionally thick massive sandstone with sharp erosional base. The upper part of the formation is frequent in alternated sandstone and mudstone.

2. Isoai Formation
The Isoai Formation constitutes sandstone-dominated, interbedded sandstone and mudstone, though their various thicknesses and proportions, occasionally intercalated with conglomerate several centi- to decimeters thick. Pebbly mudstone layers of debris flow deposits and chaotically mixed and deformed beds of slump deposits both less than a few meters are intercalated in several levels throughout the group.

Fig. 20. Left: Geological Map of the southernmost part of the Tanakura Tectonic Line between Northeast Japan and Southwest Japan (base map after Yoshioka et al., 2001). Right: Geological map of the Nakaminato Group and Oarai Formation (Sakamoto et al., 1972 and Sakamoto, 1974).
3. Sedimentary facies changes
The facies changes from the Hiraiso to Isoai formations were inferred as the basin-plain to lower submarine-fan mudstone and turbidite facies to the mid to upper submarine-fan coarser turbidite facies by Masuda and Katsura (1978) and Katsura and Masuda (1978).

Macrofauna and depositional age
The Hiraiso Formation occasionally contains helicoid heteromorph ammonite Didymoceras awajiense, U-shaped heteromorph Polyptychoceras sp., planispiral ammonite (Pachydiscus sp.), Inoceramus cf. balticus, some small bivalves and echinoids (Saito, 1958, 1959, 1961, 1962; Sakamoto et al., 1972). The Isoai Formation very rarely contains some inoceramids as Inoceramus cf. shikotanensis and Inoceramus kusiroensis in a few horizons (Sakamoto et al., 1972; Ando, 2006). The late Campanian to early Maastrichtian age is inferred for the Hiraiso and Isoai formations respectively, on the basis of those inoceramid and ammonite occurrences. This age is nearly equivalent to that of the Izumi Group (Morozumi, 1985) in Southwest Japan and the Hakobuchi Group in the Sorachi-Yezo Belt of Hokkaido (Toshimitsu et al., 1995; Ando, 2003).

Microfossils from the Hiraiso Formation
A calcareous nodule collected from massive mudstone facies of the Hiraiso Formation on 7th March 2014 yields abundant diatoms with rare radiolarians and foraminifera (Fig. 21). Radiolarians show various preservation states, although they don’t contribute to the age assignment due to lacking in age-determinable species. Extracted diatom specimens have circular disc-like tests, and are almost filled by framoidal pyrite in their inner side.

As late Cretaceous diatom fossils occurred from as follows: Santonian Omagari Formation (Shimada et al., 2013) and lower Campanian Osoushinai Formation (Iwata et al., 1998) of the Yezo Group in Hokkaido, and Upper Campanian to Lower
Maastrichtian Shoya Formation in the Kanto Region (Takahashi et al., 1999). Therefore, the diatom occurrence from the Hiraiso Formation is the fourth case in the pre-Cenozoic strata in Japan.

Tectonic Setting

In terms of the lithofacies similarity and macrofossil biostratigraphy, the Nakaminato Group is thought to be a part of the eastern extension of the Izumi Group that is widely distributed along the Median Tectonic Line in Shikoku and western Honshu of Southwest Japan, 600 to 800 km WSW of the Nakaminato area. In Northeast Japan, there are no equivalent contemporaneous strata similar in lithofacies and biofacies (Fig. 2). During the latest Cretaceous, a wide forearc (or strike-slip) basin seems to have been distributed in Southwest Japan facing the Paleo-Asian continent.

The stratigraphic relations of the Nakaminato Group with the underlying and overlying strata are unknown due to an inferred fault block distribution and the Quaternary sediment cover. Taking the large geologic structure and the geographic distribution into account, the Nakaminato Group seem to be a large tectonic block within the southern extension of the Tanakura Tectonic Line (Fig. 20).

Paleogene Oarai Formation

To the south of the Nakaminto Group, the possibly Paleogene Oarai Formation is distributed from river mouth side of the Naka River to the Oarai coast southward (Fig. 20). The Oarai Formation (Oyama, 1960; Saito, 1961) dominated by very thick, gravel-supported, pebble to cobble conglomerate, apparently underlies the Nakaminato Group on the basis of its dip and strike, though there is no exposure of the contact. Its thickness reaches 1,000 m.

Since plant macrofossils and pollen fossils occur from intervening sandstone layers, the Oarai Formation was uncertainly interpreted to be late Cretaceous in age ("Oarai flora": Oyama, 1960, 1961), and fluvial sediments (Saito, 1961). Because of bad preservation of the fossils (specimens' repository: Ibaraki Univ.) and lacking of index taxa, a reliable age assignment was difficult (Sakamoto et al., 1972).

According to Saiki and Miyahashi (2005), most of the specimens of the Oarai flora do not show any characteristics of Cretaceous plant elements such as Bennettitales. They concluded the Oarai Formation as the Cenozoic strata, but they did not find any good evidence to discriminate the Paleogene or Neogene. On the other hand, Ono (2000) reported 64.2 Ma K-Ar age of granitic rock gravel from conglomerate in addition to the older different gravel ages. Judging from these circumstances and the geologic setting nearby, the Oarai Formation is possibly regarded as the late Paleocene in age.

The Oarai Formation may represent marine channel facies deposited at high sedimentation rate and derived from gravelly river, taking the extremely large thickness (over 1,000m), the relatively monotonous conglomeratic lithofacies and no clear evidence of fluvial origin (Ando, 2006) into account.

The Nakaminato Group and Oarai Formation are recognized as geologic elements of Southwest Japan on the basis of the geographic distribution of the equivalent contemporaneous strata.

North Ibaraki Geopark

North Ibaraki Geopark approved by Japanese Geopark Network in 2011, covers the northern half of Ibaraki Prefecture 100 to 180 km north of Tokyo. It includes 1) Abukuma mountains composed of Paleozoic sediments (Cambrian and Carboniferous to Permian), their metamorphic rocks during early Cretaceous and granitic rocks intruded during early to mid-Cretaceous, 2) Yamizo Mountains of Jurassic to early Cretaceous accretional complexes, 3) Pacific side hilly area of Abukuma Mountains composed of Eocene to Pliocene sediments (Joban forearc basin), 4) Kuji Mountains and the southern hilly area of Miocene to Pliocene sediments (Tanakura basin formed by strike-slip movements of Tanakura Tectonic Line, and 5) northern part of Hitachi Terrace of Pleistocene shallow-marine sand deposits.

Among 15 selected major geosites, the Hiraiso Coast Geosite is characterized by the Upper Cretaceous Nakaminato Group and its exposed rocky shore and wave cut benches. Offshore marine sediments of 76 to 70 Ma attract the public imagination on the Late Cretaceous world with heteromorph ammonite swimming ocean and pterosaur-flying sky. At Stop 2-3 an explanatory board was recently set up for the Geopark tourism.
DESCRIPTION OF DAY 2

Stop 2-1 Geological Museum of Geological Survey of Japan, AIST: Excellent geological collections

The Geological Museum of Geological Survey of Japan, AIST (National Institute of Advanced Industrial Science and Technology) was established in 1980 in Tsukuba Science City (Fig. 22). Its main purpose is to exhibit and keep large amounts of geological specimens collected by many GSJ geologists over a number of years, and extend research processes and fruits of GSJ to the general public.

The exhibition areas of the Geological Museum are divided into four major display rooms themed on 1) History of earth and life, and geology of the Japanese Islands, 2) Human life and mineral resources, 3) Geological hazards, such as earthquakes and volcanic eruptions and 4) Systematic exhibitions of minerals, rocks and fossils. A total of exhibition areas including the entrance hall reach 1500m² in the museum building. The remarkable highlights of major exhibits are as follows:

**Entrance hall:**
1. Distribution patterns of earthquakes beneath the Japanese Islands on the ceiling of the entrance hall.
2. Peeling cast of the Jogan tsunami deposits (A.D. 869) collected from Sendai City, Miyagi Prefecture, Northeast Japan.
3. Replica of folded Jurassic strata from the Ojika Peninsula, Miyagi Prefecture, NE Japan (Fig. 23).

**1st display room:**
4. Schematic 3-D geological map of the Japanese Islands.
5. Reconstructed whole skeleton model of a Miocene extinct mammal *Desmostylus* from Hokkaido, Northern Japan (Fig. 24).

**2nd display room:**
7. 3-D topographic map of the Pacific Ocean floor.

**3rd display room:**
8. 3-D geological map of Fuji and Hakone volcanoes, central Japan.

**4th display room:**
9. Over 1000 geological specimens, such as minerals, rocks and fossils (Fig. 25).
Cretaceous forearc basin siliciclastic successions: Choshī, Nakaminato and Futaba groups

Stop 2-2: Wave cut bench along Hiraiso Coast, Nakaminato City: Basin plain mudstone facies of the Hiraiso Formation

Only during low spring tides from March to August, the Hiraiso Formation is well exposed on a wide wave cut bench 100 to 150 meter long in a seaward direction (Fig. 26). This rocky shore consists of dominant dark gray mudstone and often intercalated thin layers of fine sandstone (distal turbidite). They seem to have deposited in an offshore deep-sea environment. A few very thick (> 5 m) layers of medium sandstone (possibly high density turbidite) can be observed as rock reefs projected on a flat bench reflecting high resistance against wave erosion. The strata were often cut and translated by minor faults in several ways and offset lengths due to tectonic movements after deposition.

There sporadically contains calcareous concretions of various size and occasionally forms nodular layers. Spiral heteromorph ammonite, *Didymoceras awajiense* rarely occurs from the concretions and mother rocks.

Stop 2-3: “Seijo-seki”, north of Hiraiso Coast, Nakaminato City: Turbidite facies of alternated sandstone and mudstone in the lower part of the Isoai Formation

Rocks at this stop were named as “Seijo-seki” that means pure stone in Japanese, by Mitsukuni Tokugawa, the second lord of the domain of Mito (now nearly Ibaraki Prefecture) in 17th century. Here rhythmically alternated sandstone and mudstone of the lower part of the Isoai Formation is exposed on a wave cut bench narrower than Stop 2-2 (Fig. 27). The thickness of the sandstone and mudstone couplets ranges a few tens centimeter to 1.5 meters. Reflecting differential resistance of each bed against wave erosion, alternated resistant sandstone and depressed mudstone form small-scale, serrated high and low relief like a washboard.

This turbidite succession shows various sedimentary structures as grading, parallel/cross lamination, dish, convolute and load structures, burrowing traces by benthos as well as flute and groove casts as sole marks.

Fig. 26. Dark gray mudstone facies of the Hiraiso Formation, Nakaminato Group exposed on a wide wave cut bench at the low tide in the spring tide during summer. A left rocky reef represents thick massive medium sandstone projected on the flat bench.

Fig. 27. Alternated sandstone and mudstone in the lower part of the Isoai Formation, Nakaminato Group, north of Hiraiso coast.
Stop 2-4: North of Hiraiso Coast, Nakaminato City: Debris flow deposits as pebbly sandstone in the Isoai Formation (pterosaur locality)

In the rocky shore 300 m north of Stop 2-3, pebbly sandstone is intercalated in a thick succession of sandstone-dominated, interbedded sandstone and mudstone (Fig. 28). Poorly sorted gravel scattered within a large amount of massive sand matrix indicates of subaqueous debris-flow origin. Beds of granule to pebble conglomerate and conglomeratic sandstone are also occasionally intercalated. A pterosaur bone and a few kinds of bivalve shells (articulated *Opis* and inoceramid fragments) were discovered from the pebbly sandstone. Only a piece of mosasaurid caudal vertebra was recently found from a conglomerate layer.

![Fig. 28. Pebbly sandstone of debris flow deposit in the lower part of the Isoai Formation, Nakaminato Group, north of Hiraiso coast. A pterosaur bone was recently discovered from the central portion.](image)

To 150 m northward, there are southward dipping strata forming rocky reefs within the NNE dipping Isoai Formation, locally called “Chikusho-iwa” (dump animal rock in Japanese) (Fig. 29). This seems to be a large-scale slump block, possibly tilted by submarine sliding.

![Fig. 29. Reversely inclined strata regarded as slump block due to submarine sliding in the lower part of the Isoai Formation, Nakaminato Group, north of Hiraiso coast.](image)

Stop 2-5: Isozaki Coast, Nakaminato City: Thick sandstone succession of the upper part of the Isoai Formation

Along cobble to boulder gravel beach, thick sandstone-dominated succession typical in the upper part of the Isoai Formation is exposed with NNE dip (40°) and WNW strike (Fig. 30).

Beach gravel is mostly eroded and reworked sandstone of the Isoai Formation. Rarely some Miocene calcareous mudstone gravel bearing bivalves fragments can be collected. This may be derived from the some Miocene strata nearby already eroded away.

The white-walled building here on the late middle Pleistocene terrace about 20 meters high from sea level is a beautiful hotel called “Hakuaki-so”. “Hakuaki” and “so” mean Cretaceous System and inn/hotel/apartment house in Japanese, respectively.

![Fig. 30. Thick sandstone facies in the upper part of the Isoai Formation, Nakaminato Group, Isozaki coast.](image)
Cretaceous forearc basin siliciclastic successions: Choshi, Nakaminato and Futaba groups

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**Fig. 31.** Stratigraphy of the Upper Cretaceous to Neogene sequence in the Joban area (Ando et al., 2011).
DESCRIPTION OF DAY 3

Stop 3-1 North of “Rokkakudo”, Ohizura, Izura coast, Kitaibaraki City: Calcareous concretions in Kokozura Formation, Takaku Group (late Early Miocene)

The Izura coast is one of highlights of North Ibaraki Geopark in culturally and geologically striking features.

We can see a large amount of calcareous concretions of various shapes are included in the late Early Miocene Kokozura Formation, Takaku Group along the Izura (five inlet in Japanese) coast forming five small inlets of rocky shore (Figs. 32, 33). The Kokozura Formation is mainly composed of tuffaceous, intensely bioturbated, very fine silty sandstone to sandy siltstone, which may have been deposited on inner shelf of the Miocene forearc basin. Bivalve shells occur scatteringly or somewhat gregariously often in articulated life position.

Ueda et al. (2005) described the mode of occurrence of calcareous concretions and fossil shells on the cliff and rocky reef section less than ten meter thick. They detected six morphotypes of calcareous concretions on the basis of their shapes, sizes and modes of occurrence, and defined three stratigraphic units. Judging from carbon and oxygen isotopic ratios in carbonate concretions as well as mode of fossil (Lucinoma acutilineatum) occurrences, these concretions seem to have been formed in a methane seepage zone associated with chemosynthetic community on a shallow shelf environment.

Kohda et al. (2007) discovered the shark teeth aggregation of Carcharodon megalodon, the largest shark species during the Earth history.

Fig. 32. Geological map of the Hirakata-Otsu area, Kitaibaraki City showing Paleogene to Neogene strata. The Kokozura Formation is generally equivalent to the Numanouchi Formation, Takaku Group in Fig. 31. The overlying Taga Group indicates the submarine channel-fill deposits composed of several sedimentary units of different ages (Ando et al., 2011).
Stop 3-2 South of “Rokkakudo”, Koizura, Izura coast, Kitaibaraki City: Stratigraphic relations between Kokozura Formation, Takaku Group (late Early Miocene) and Taga Group (latest Early-Middle Miocene)

In the small inlet called “Koizura” (=small inlet in Japanese), we can observe the complicated unconformable relations between the Kokozura Formation, Takaku Group and the Taga Group. On the basis of the detailed diatom biostratigraphy, outcrop observations and wide-areal geological mapping, three stratigraphic units were described as
follows (Ando et al., 2011; Fig. 34):

1) Ot3: Ohtsu submarine channel-fill unit 3
   (Late Miocene: ca. 10-10.5 Ma)
2) Ot2: Ohtsu submarine channel-fill unit 2
   (Late Early Miocene: ca. 16.3-16.5 Ma)
3) Kokozura Formation (late Early Miocene)
   (Late Early Miocene: ca. 16.7 Ma)

Though all of the three strata are apparently similar to each other in lithology, erosional surfaces (unconformity) as submarine channel bases can be detected on the outcrop surfaces.

In the Ot3, Izura Tuff (Yanagisawa, 2000) is intercalated within thick and massive diatomaceous siltstone. This marker bed is characterized by coarse mica, quartz and pumice grains. The F-T age dating for the correlated Ayukawa Tuff in the Hitachi area 40 km south resulted in 11.1±0.5 Ma a little older than the estimated position of the uppermost NPD 5c (North Pacific Diatom Zone 5c) in Ot3 (Figs. 31, 34).

Stop 3-3 Garden rocks on a marine terrace above Stop 3-2: Calcareous concretions bearing chemosynthetic bivalves

There are many blocks of calcareous concretions in a garden on a marine terrace above Stop 3-2 (Fig. 35). These occurred from the ground of Izura Kanko Hotel Taikanso (north of Stop 3-1) during construction works. The stratigraphic horizon may be equivalent to the lower unit of Ueda et al. (2005) at Stop 3-1.

Of dark/light gray-colored concretions, light gray ones contain a large amount of chemosynthetic bivalves as *Adulomya* sp., *Conchocele bisecta*, *Lucinoma acutilineatum*, *Acharax yokosukensis*, *Nipponothracia*? sp. The predatory gastropod species such as *Cryptonatica clausa* and *Megasurcula yokoyamai* are also associated to a small extent. Amano and Ando (2011) described a specimen about 30 cm long of *Acharax yokosukensis*, the largest as the genus.

Stop 3-4 Izura Institute of Art and Culture, Ibaraki University: “Rokkakudo”, a small hexagonal cottage on calcareous concretions

“Rokkakudo” a red-walled small hexagonal cottage stands on a narrow cliff step in the Izura Institute of Art and Culture, Ibaraki University (Fig. 36).

The institute was established in 1955, after the houses, Rokkakudo and an entrance gate built during late Meiji Period by Mr. Tenshin Okakura, a pioneering Japanese artist, were donated to Ibaraki University, a regional national university. Around here the Japanese-style modern painting art movement occurred during late Meiji to early Taisho Period, early 1900s to 1910s by Mr. Okakura his following painters. Here is one of highlights of North Ibaraki Geopark and sightseeing of Kitaibaraki City.
Cretaceous forearc basin siliciclastic successions: Choshi, Nakaminato and Futaba groups

Futaba Group: Western marginal facies of the Yezo Basin

The Upper Cretaceous Futaba Group is narrowly distributed 2 to 3 km from east to west and about 15 km from north to south along the foot area of the Abukuma Mountains parallel to the Pacific coast, covering the southernmost Naraha and Hirono towns and the northern part of Iwaki City (Fig. 37).

This area is tectonically regarded as the Abukuma Belt, Northeast Japan. The Futaba Group overlies the Lower Cretaceous Abukuma granitic rock mass (Ohisagawa Granodiorite) with nonconformity in the western margin, and the Permian Takakurayama Group with angular unconformity in the southwestern margin (Fig. 37). In the eastern margin it underlies the upper Eocene-lower Oligocene Shiramizu Group with gentle angular unconformity. In the southern margin, the group is truncated by the Futatsuya Fault and is not distributed southward. However, the equivalent strata were detected underground southward by the coal exploration drilling (Eguchi et

Fig. 37. Geological map of the Futaba Group (Ando et al., 1995).
Hisao Ando, Kenji Kashiwagi, Ren Hirayama and Seiichi Toshimitsu

al., 1959) and the sea-bottom dredge survey (Sugai et al., 1957). Its correlatives are also distributed under the sea bottom off Soma to Joban in the Pacific (Ando, 2003).

The Futaba Group represents sandy and subordinately silty and gravelly, fluvial to shallow-marine siliciclastics deposited on the western margin of a matured forearc basin during the Coniacian to Santonian. It is characterized by simple geologic structure with NNE-SSW strike and isoclinally eastward dip of 10 to 20 degrees. The group ranges 350m in thickness at maximum, but pinches out northward by the angular unconformity with the overlying late Eocene Shiramizu Group containing coal measures (Figs. 31, 38).

<table>
<thead>
<tr>
<th>Age</th>
<th>Stratigraphy</th>
<th>Columnar section</th>
<th>Lithology</th>
<th>Descriptions</th>
<th>Paleoenvironments</th>
<th>Sequence</th>
<th>Paleodepth</th>
<th>Paleogeographic reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eocene</td>
<td>Shiramizu G</td>
<td>Width</td>
<td>12</td>
<td>64.6</td>
<td>Massive to tough cross-stratified, round to subround pebble to cobbly conglomerate</td>
<td>Braided river</td>
<td>SB4</td>
<td>LST</td>
</tr>
<tr>
<td>Lower Santonian</td>
<td>Kasamatsu G</td>
<td>Width</td>
<td>16</td>
<td>47.5</td>
<td>Stratified massive fine sandstone with calcareous pebbles, common Ophiomorpha burrows</td>
<td>Inner shelf</td>
<td>RS2</td>
<td>LST</td>
</tr>
<tr>
<td>Lower Santonian</td>
<td>Futaba G</td>
<td>Width</td>
<td>15</td>
<td>46.6</td>
<td>Interstratified sandy sandstone and dark grey sandy siltstone</td>
<td>Lower shoreface</td>
<td>SB3</td>
<td>LST</td>
</tr>
<tr>
<td>Lower Santonian</td>
<td>Kasamatsu G</td>
<td>Width</td>
<td>14</td>
<td>54.6</td>
<td>White algal tuff</td>
<td>Meandering &gt; braided river</td>
<td>SB2</td>
<td>LST</td>
</tr>
<tr>
<td>Lower Santonian</td>
<td>Kasamatsu G</td>
<td>Width</td>
<td>13</td>
<td>44.6</td>
<td>Massive or TCS m-f.s. with pebble layers and calcareous pebbly conglomerite</td>
<td>Upper - lower shoreface</td>
<td>S1</td>
<td>LST</td>
</tr>
</tbody>
</table>

Fig. 38. Synthesized stratigraphic column, and depositional model and history of the Upper Cretaceous Futaba Group. As: Asamigawa Member, Ashizawa Formation, Ob: Obisagawa Member, Ashizawa Formation, Km: Kasamatsu Formation, Tm: Kohisagawa Member, Tamayama Formation, Tu: Irimazawa Member, Tamayama Formation. Modified from Ando et al. (1995).
Stratigraphy and Sedimentary facies

The Futaba Group is divided into three formations, the Ashizawa (the Asamigawa and Obisagawa members), Kasamatsu and Tamayama (the Kohisagawa and Irimazawa members) formations in upward sequence (Figs. 31, 38; Saito, 1961, 1962; Ando et al., 1995; Kubo et al., 2002, etc.). Sedimentary facies and their spatial distribution were analyzed in detail by Ando et al. (1995) and Kubo et al. (2002). According to Ando et al. (1995), fifteen depositional facies were discriminated based on their lithology, sedimentary structure, etc. (Fig. 39). The group includes talus, alluvial fan, meandering river, braided river, transgressive lag, upper shoreface to inner shelf sediments.

1. Asamigawa Member, Ashizawa Formation

This member is represented by basal conglomerate and interbedded often cross-stratified coarse to medium arkosic sandstone and sandy mudstone indicative of upper to lower alluvial fan environment.

<table>
<thead>
<tr>
<th>No.</th>
<th>Column</th>
<th>Facies</th>
<th>Descriptions</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Column</td>
<td>Poorly-sorted, angular conglomerate</td>
<td>Poorly-sorted, angular to subangular, pebble to cobble, massive conglomerate, matrix-supported to partly gravel-supported; medium to coarse sand matrix</td>
<td>Talus / upper alluvial fan</td>
</tr>
<tr>
<td>2</td>
<td>Column</td>
<td>Poorly-sorted, subangular to subrounded conglomerate</td>
<td>Poorly-sorted, subangular to subrounded, cobble to boulder gravel; matrix-supported to partly gravel-supported; medium- to very coarse-grained sand matrix, more or less bedded and trough cross-stratified</td>
<td>Upper - middle alluvial fan</td>
</tr>
<tr>
<td>3</td>
<td>Column</td>
<td>Cross-stratified, coarse to medium sandstone</td>
<td>Moderately to poorly-sorted, medium to coarse sandstone; middle to large-scale, trough and planar cross-stratified, rarely containing coaly wood fragments</td>
<td>Braided river</td>
</tr>
<tr>
<td>4</td>
<td>Column</td>
<td>Graded, cross-stratified very coarse to fine sandstone</td>
<td>Poorly-sorted, graded very coarse to fine sandstone; middle-scale trough cross-stratified, mostly interbedded with faces 6; base conspicuously loaded; rarely containing coaly wood fragments</td>
<td>Braided - meandering river (channel - point bar)</td>
</tr>
<tr>
<td>5</td>
<td>Column</td>
<td>Reverse-graded, fine to medium sandstone</td>
<td>Moderately-sorted, reverse-graded, fine to medium sandstone intervening within facies 4 or 5</td>
<td>Flood plain / natural levee</td>
</tr>
<tr>
<td>6</td>
<td>Column</td>
<td>Carbonaceous siltstone</td>
<td>Carbonaceous and partly coaly, black sandy siltstone to fine sandstone; mostly interbedded with faces 4; flame and dewatering structure above faces 4</td>
<td>Flood plain</td>
</tr>
<tr>
<td>7</td>
<td>Column</td>
<td>Massive, subrounded to round, thick conglomerate</td>
<td>Moderately-sorted, subrounded to round, pebble to cobble conglomerate, gravel- to partly matrix-supported; very coarse to medium sand matrix</td>
<td>Upper - lower shoreface / transgressive lag</td>
</tr>
<tr>
<td>8</td>
<td>Column</td>
<td>Calcareous round conglomerate</td>
<td>Well-sorted, round, cobble to granule conglomerate layer intervening within faces 10; gravel- to partly matrix-supported; medium to fine calcareous sand matrix; containing swarmed disarticulated shells of shallow-marine bivalves</td>
<td>Upper shoreface</td>
</tr>
<tr>
<td>9</td>
<td>Column</td>
<td>Intervening round conglomerate</td>
<td>Massive, moderately-sorted, matrix supported, round to subrounded, pebble conglomerate overlying facies 10 and underlying facies 13 or 14</td>
<td>Upper - lower shoreface</td>
</tr>
<tr>
<td>10</td>
<td>Column</td>
<td>Massive, well-sorted, medium sandstone</td>
<td>Massive and thick-bedded, well-sorted, medium to coarse sandstone; sometimes trough cross-stratified</td>
<td>Upper shoreface</td>
</tr>
<tr>
<td>11</td>
<td>Column</td>
<td>Parallel-laminated sandstone</td>
<td>Well-sorted, parallel-laminated medium sandstone</td>
<td>Upper shoreface</td>
</tr>
<tr>
<td>12</td>
<td>Column</td>
<td>Hummocky cross-stratified sandstone</td>
<td>Well-sorted, hummocky cross-stratified fine sandstone</td>
<td>Lower shoreface</td>
</tr>
<tr>
<td>13</td>
<td>Column</td>
<td>Massive fine sandstone</td>
<td>Well-sorted, fine to medium sandstone containing calcareous nodules; often parallel laminated or bioturbated</td>
<td>Upper - lower shoreface</td>
</tr>
<tr>
<td>14</td>
<td>Column</td>
<td>Bioturbated fine sandstone</td>
<td>Well-sorted, but bioturbated fine to very fine sandstone; often containing calcareous nodules sometimes containing such moluscan fossils as bivalves, gastropods, ammonites and others</td>
<td>Lower shoreface - inner shelf</td>
</tr>
<tr>
<td>15</td>
<td>Column</td>
<td>Fine tuff</td>
<td>Monotonous, light gray to greenish light gray, fine tuff</td>
<td></td>
</tr>
</tbody>
</table>
The basal conglomerate contains pebbles to boulders mainly of granite rocks and subordinately of shale and sandstone, amphibolite, schist, chert derived from the basement. In the southern periphery of the distributed area, it includes talus or upper fan conglomerate composed of angular gravel of basement rocks as black shale, chert, granite, etc. In the northern part the sandstone unconformably covers the granitic basement without basal conglomerate. The thickness of this member varies from less than 30 to a few meters depending upon the undulated basal unconformity. A variety of mesofossils of plants including angiosperm flowers, pollen and spores have been found from the lower part of the member at Kamikitaba, Hirono Town, and reported in several papers (e. g., Takahashi et al., 2014) since Takahashi et al. (1999a, b).

2. Ohisagawa Member, Ashizawa Formation

The Ohisagawa Member 60 to 150 meters thick is dominated by the upper to lower shoreface fine sandstone and inner shelf sandy siltstone above the basal transgressive conglomerate of subround to round pebble to cobble traceable over the area. The lowest part is generally coarser and contains medium to coarse, partly cross-stratified sandstone intercalated with pebble to granule conglomeratic layers and conglomerate. A few layers of intercalated calcareous pebbley sandstone form coquina beds of trigonid, glycimerid and other bivalves.

The main part of the Ohisagawa Member is mainly composed of much bioturbated very fine to fine sandstone, but rarely hummocky cross-stratified in fine sandstone. Calcareous concretions are common, though their size and shape are variable. There are several fossiliferous horizons and layers mainly of molluscs such as bivalves including inoceramids, gastropods, scaphopods and ammonites, though their stratigraphic positions are different by area. Furthermore, shark teeth, turtle bone, and dinosaur bone and teeth rarely occur from a few different localities. The ammonite shell bed observed at the Iwaki Ammonite Center is stratigraphically equivalent to the lower one third of this member. One of common fossils, *Inoceramus uwajimensis* indicated the Early to Middle Coniacian age.

3. Kasamatsu Formation

The Kasamatsu Formation about 120 meter thick is characterized by fluvial upward-finining units composed of cross-stratified coarse- to medium-grained, channel sandstone and flood-plain grayish-black bituminous siltstone containing coaly seams and plant remains. The uppermost part indicates the lagoonal environments locally, judging from common bioturbated and burrowed sedimentary structures. The repetitive sandstone and mudstone couplets form five to six, higher-order upward-finining/thinning units 5 to 20 meter thick. The ratio and thickness of sandstone/mudstone show the northward fining and thickening of mudstone suggesting the northward distal/down-stream trend.

4. Kohisagawa Member, Tamayama Fm.

The Kohisagawa Member, the lower to middle parts about 200 meter thick of the Tamayama Formation is braided river sediments characterized by generally monotonous, medium to large-scale trough cross-stratified, arkosic, coarse to medium sandstone. Coaly plant fragments are rarely contained in sandstone. The uppermost part is locally intercalated with coaly and carbonaceous mudstone layers and occasionally bioturbated and vertically burrowed, suggesting the lagoonal environments.

Amber, pollen and spore and angiosperm flower occur from intercalated coaly mudstone in the upper part (Miki, 1977; Takahashi, 1988; Takahashi et al., 1999). Dinosaur bones and teeth are also found from the same coaly mudstone facies.

5. Irizawa Member, Tamayama Fm.

The Irizawa Member less than 60 meter thick exposed, of the Tamayama Formation forms lower shoreface to inner shelf fine sandstone facies above a pebble conglomerate layer overlying lagoonal deposits of the uppermost part of the Kohisagawa Member. The basal conglomerate can be regarded as transgressive lag deposits diachronously formed by shoreface erosion during transgression. Fine sandstone of the lowest part shows low-angle cross-stratification or hummocky cross-stratification, but the middle to upper parts are generally bioturbated and massive, and occasionally contain lenticular calcareous-concretion layers. Marine molluscs, fish and marine reptile (plesiosaurid: *Futabasaurus suzukii* Sato et al., 2006) occurred from a few horizons. An inoceramid fossil as *Inoceramus (Platyceramus) amakusensis* indicates this member as the Lower Santonian.
Cretaceous forearc basin siliciclastic successions: Choshi, Nakaminato and Futaba groups

Fig. 40. Correlated columnar sections of the Futaba Group showing facies distribution and successions (Ando et al., 1995)
**Sequence Stratigraphy and Depositional History**

The nearly shore-parallel facies distribution schematized from correlated columnar sections (Figs. 39, 40 and 41) enables us to interpret sequence stratigraphy. A thick acidic tuff layer recognized in the upper part of the Kasamatsu Formation provides only a good time marker horizon. Each formation of the Futaba Group consists of a third-order depositional sequence (DS) during 4 to 4.5 m.y.

The lowest sequence boundary (SB1) is equal to the nonconformity or angular unconformity with basement rocks. The first depositional sequence (DS1) has an LST as the main part of the Asamigawa Member distributed in the northern half of the area. It is lithologically characterized by upper alluvial fan conglomerate and mid to lower fan sandstone. In the southern periphery of the distributed area the member contains talus or upper fan angular conglomerate.

The basal conglomerate of the Obisagawa Member distributed over the area is interpreted to be transgressive conglomerate with a sharp base called a ravinement surface (RS1) that was formed by transgressive shoreface erosion during transgression. The overlying thick sandstone of the Obisagawa Member shows a gently upward-finining trend from medium, fine to very fine sandstone, suggesting the wide and prolonged development of sandy shallow shelf and the environmental changes from upper shoreface to inner shelf. Therefore, this member can be regarded as transgressive systems tract (TST).

A sharp erosional surface between the Obisagawa Member and the Kasamatsu Formation appears an unconformity (SB2) showing sea-level fall and subaerial erosion. Five to six upward-finining successions composed of channel sandstone and flood-plain siltstone couplets in the Kasamatsu Formation, shows large-scale river channel shifts by periodic changes of the fluvial system or relative sea-level changes.

The sudden lithofacies changes from the Kasamatsu into the Tamayama Formations imply some large-scale changes in fluvial systems by sea-level fall, possibly meandering to braided river, though an erosional base is not observable. Because a sequence boundary (SB3) is expected at the base of the Tamayama Formation or nearby, the Kasamatsu Formation seems to form a depositional sequence (DS2) as TST due to thick aggradational successions of fluvial plain deposits and the uppermost subordinant lagoonal deposits.

The third sequence (DS3) is characterized by LST of thick braided river sediments of the Kohisagawa Member of the Tamayama Formation.

The basal conglomerate of the Irimazawa Member of the Tamayama Formation is interpreted as transgressive lags just above a ravinement surface (RS2). The Irimazawa Member exposed about 50 m thick only in the central area, shows the slight upward-finining/deepening trend from upper shoreface fine to inner shelf very fine sandstone. The member may represent thick TST of DS3. The upper sequence boundary (SB4) of DS3 shows the conspicuous angular unconformity with the Paleogene Shiramizu Group.

In summary, each formation of the Futaba Group forms a depositional sequence. They may have formed in the small-scale fan delta, coastal plain to shallow shelf on the foot area of the Early Cretaceous granitic basements by three relative sea-level changes.
Judging from the time duration of Early Coniacian to Early Santonian (89.8-85.5: Gradstein et al., 2012), these sequences are regarded as third-order ones.

Coniacian to Early Santonian Fauna and Flora detected from the Futaba Group

Futaba Fauna

1. Molluscan fauna
   A variety of molluscs as ammonites and shallow-marine, fine sandy-bottom dwelling bivalves, gastropods and scaphopods occur from the Obisagawa Member of the Ashizawa Formation gregariously or sporadically. The abundance of the benthos and the common burrowing trace fossils in the bioturbated massive sandstone facies suggest that a shallow-marine benthic ecosystem during Coniacian were prolific in biomass and active in substrate mixing, though not so many in deep burrowing bivalves.

   The bivalves fauna is characterized by Yaadia, kimurai (thick-shelled large trigonid), Loxo and Glycymeris in occasionally pebbly, fine to medium calcareous sandstone, and by Apiotrigonia (small trigonid), Inoceramus uwajimensis, Eryphyla, Nanonavis, etc. in fine to very sandstone, reflecting the substrate characteristics.

   Though ammonites generally occur from some certain horizons and localities sporadically, the peculiar ammonite shell bed is observable at the Iwaki Ammonite Center. A few tens huge ammonites mainly of Mesopuzosia yubarensis, the middle-sized Anagaudriceras limatum and other species including heteromorphs are swarmed and associated with common bivalves and gastropods on a bedding plane. Shark, rays and teleost teeth, plesiosaurid bones and amber are also rarely found. In comparison with the Yezo Group of Hokkaido well known in well preserved diverse ammonite fossils, the ammonite preservation of the Futaba Group is not so good. However, their species composition is similar, suggesting the same ammonite fauna within the Northwest Pacific region.

   Furthermore, a small amount of molluscs rarely occur also from the Irimazawa Member, Tamayama Formation, but their detail is only briefly reported by Obata and Suzuki (1969). The member was regarded as the lower Santonian due to the occurrence of Inoceramus amakusensis.

2. Vertebrate fauna
   Since plesiosaurid fossils were discovered in 1968 and subsequently excavated during a few years (Obata et al., 1970), the specimens called “Futaba Suzuki Ryu” and the Futaba Group as the vertebrate fossil-bearing Cretaceous strata have been well known to the Japanese public. According to Goto et al. (1996), Saegusa and Tomida (2011), Sato et al. (2006, 2012) and Shimada et al. (2010), the Futaba Group includes the following vertebrate fossils: 1) partial shells of a terrestrial turtle, family Nanhansiuchelyidae (Order Testudines), 2) tooth of Mosasauridae (Order Squamata), 3) vertebra of Elasmosauridae and 4) isolated teeth of Polycotylidae? (Order Sauropterygia) from the Ashizawa Formation of Hirono Town and Iwaki City (Tomunaga and Shimizu, 1926; Sato et al., 2012); 5) isolated shark teeth such as Scapanorhynchus mophiadon Agassiz, ?Paranamotodon angustidens, and Cretolamina appendiculata, 6) a rostral spine of an osteichthyan fish, Ischyrida iwaiakensis, 7) vertebra of Mosasauridae (Order Squamata), 8) a well preserved skeleton of famous marine reptile, Futabasaurus suzuki Sato, Hasegawa and Manabe, 2006 (Order Sauropterygia), and 8) teeth of titanosaurian sauropod (Order Saurischia) from the Tamayama Formation of Iwaki City. Several taxa of dinosaurs and turtles from the Futaba Group are remained unpublished.

Futaba Flora (Kamikitaba Mesofossil Flora)

Takahashi et al. (1999a, b) found new assemblages of well-preserved plant fossils from poorly consolidated, carbonaceous, black, poorly-sorted, sandy siltstone of the lower Asamigawa Member, Ashizawa Formation and the upper part of the Kohisagawa Member, Tamayama Formation. The former prolific assemblage was named as Kamikitaba mesofossil flora. The fossils basically extracted by water washing and sieving, are generally small, three-dimensional and charcalified or lignitized (mesofossils) and yield elaborate structural details when observed with SEM. This flora importantly extends current knowledge of Coniacian plant evolution and biogeography in Asia. The Kamikitaba assemblage contains well-preserved angiosperm flowers, fruits, seeds, leaf fragments and wood, as well as shoots, leaves, pollen cones, cone scales and seeds of confer. They include a variety of angiosperm taxa such as Lauraceae (ツツジ目), Hamamelidaceae (マンサク科), Fagaceae (ブナ科), Cornales (ブナ科), Combreaceae (シクサ科), and probably Ericales (ツツジ目), Magnoliaceae (モクレン目), Nymphaeales (スイレン目) and
Taxodiaceae (スギ科). Besides, leaf and rachis fragments of ferns, sporangia with in situ spores, and megaspores also document the presence of Selaginellaceae (イワヒバ科) and Schizaeaceae (フサシダ科). Several new taxa (mostly new genera and species) were described as follows: *Esgueiria futabensis* Takahashi et al., 1999b (Combretaceae flower); *Lauranthus futabensis* Takahashi et al., 2001 (Lauraceae flower); *Hironoia fusiformis* Takahashi et al., 2002 (Cornalean fruit); *Symphanale futabensis* Takahashi et al., 2007 (Annonaceae seed); *Archaefagacea futabensis* Takahashi et al., 2008a (Fagales flower); *Futabanthusa samigawaensis* Takahashi et al., 2008b (Annonaceae flower); *Microlaurus perigynus* Takahashi et al., 2014 (Lauraceous flower).

In comparison with the palynofloral analyses of the Ashizawa Formation by Miki (1977), Takahashi et al. (1999a) concluded that the early Coniacian vegetation represented by the Futaba Group was probably dominated, in terms of abundance, by both conifers and angiosperms, with angiosperms probably more diverse in terms of species. The charcoalified preservation of many plant fossils from the Futaba Group suggests that the vegetation was periodically subjected to fire.
**DESCRIPTION OF DAYS 3 AND 4**

**DAY 3**

*Stop 3-5: Iwaki Coal and Fossil Museum ("Iwaki Sekitan Kasekikan")*

Exhibitions on Upper Cretaceous plesiosaur, dinosaur and several molluscan fossils occurred from the Futaba Group, including Paleogene coal mine facilities

The Iwaki Coal Fossil Museum was opened in October 1984 a few years after the closing of all coal mines, near the hot spring town Iwaki-Yumoto (Fig. 42). The purpose of this museum is to explain the 125 years history of the Joban Coal Field in Iwaki City and exhibit the various and valuable fossils specimens mainly occurred around the city. The exhibition of the museum now consist of four sections: 1) Paleozoic to Cenozoic major fossils occurred from Iwaki City and the surrounding, 2) natural history of Iwaki City including coal, rocks and geology, 3) the history of the Joban Coal Field, by using a underground simulated mine equipped with archived coal-mining facilities and machineries and 4) life in coal mines and city as well as coal mining customs, apartment houses and local community.

The remarkable highlight is a reconstructed plesiosaur described as *Futabasaurus suzukii* Sato et al., 2006, displayed in the entrance hall (Fig. 43). Its specimens was firstly found from the Cretaceous Futaba Group distributed in the northern part of Iwaki City, by a local high school student Mr. Suzuki in 1968, and subsequently excavated during a few years (Obata et al., 1970). This finding and excavation has long attracted not only visitors of the museum but also young generation in Japan to paleontology and vertebrate fossils including dinosaurs.

**Fig. 42.** Large statue of plesiosaurid on a frontal yard of the Iwaki Coal and Fossil Museum. Red-colored iron tower is a facility of the underground simulated mine.

**Fig. 43.** Reconstructed *Futabasaurus suzukii* Sato, Hasegawa and Manabe, 2006 in the entrance hall of the Iwaki Coal and Fossil Museum.

The Iwaki Coal and Fossil Museum was recently renovated in 2010 and nicknamed “Horuru” which means an abbreviated Japanese word “horu” (= excavate) two times: excavate coal and fossils. Many kinds of large attractive fossils mainly of the Mesozoic and Cenozoic have been sophisticatedly exhibited in a renewed large hall (Fig. 44): some Cretaceous huge ammonite such as *Mesopuzosia*, several Cretaceous dinosaur, pterosaurid, turtles, pliosaurid and shark teeth, as well as Cenozoic mammals such as elephant, whales, and fin-footed mammals, and Oligocene protopterygid bird similar to penguin. Other common and paleontologically important fossils from Iwaki City are also displayed sophisticatedly.

**Fig. 44.** Main exhibition hall of the Iwaki Coal and Fossil Museum.
Stop 3-6: Iwaki City Ammonite Center (Ammonite shell bed: shallow-marine fine sandstone facies of Ashizawa Formation, Futaba Group)

Around Stop 3-6, bioturbated, gray massive silty fine to very fine sandstone about 10 m thick of the Ohisagawa Member, Ashizawa Formation of the Futaba Group, are exposed and inclined eastward at 15 to 20 degrees. The main building of the Iwaki Ammonite Center was founded on an inclined bedding surface to observe an ammonite shell bed and associated fossils (Fig. 45). A few tens of ammonites (Mesopusosia yubarensis) larger than a few tens cm in diameter, the smaller planospiral and heteromorph ammonites and other molluscan fossils such as inoceramids (Inoceramus uwajimensis), trigonid bivalves (Yaadia kimurai, Apiotrigonia minor), other bivalves, gastropods, shark teeth, plant remains, etc. are sporadically and irregularly swarmed within less than a meter thick horizon. Many of large ammonites are preserved within carbonate concretions of sandstone, though the central inner whorls of shells were mostly dissolved away. Some external molds of Mesopusosia less than 20 cm in diameter also occur even in less calcified mother rocks. Small patches a few cm thick and in diameter composed of swarmed and poorly preserved fragmentary shells are often scattered. Anyway, taphonomically interesting mode of fossil occurrence can be observed on the bedding surface of the ammonite bed.

At an exposure outside for experimental fossil excavations, the irregularly scattered patchy mode of shell occurrence can be also well observed in massive silty fine sandstone facies. Though shell preservation state is not so good, articulated bivalves are not rare, and thin-shelled bivalves as inoceramid and Didymotis in butterfly position rarely occurred. There is no evidence for secondary distant transportation of these shell fossils after initial deposition. Judging from these taphonomical characteristics as well as the stratigraphic succession of depositional facies, the ammonite shell bed may have formed on Early Coniacian fine sandy inner shelf bottom by storm waves or storm-induced strong currents (or perhaps tsunami?). After deposition, intensive bioturbation by prolific benthic organisms homogenized the shell concentrations and physical sedimentary structures.

DAY 4

Stop 4-1: Kotakidaira near Asami River, Hirono Town: Unconformity between Lower Cretaceous Abukuma granitic rock basement and Upper Cretaceous Futaba Group

Stop 4-1 is a small outcrop where the Upper Cretaceous Futaba Group unconformably overlies a granitic rock mass of Lower Cretaceous Abukuma Granitic Rocks (Ohisagawa Granodiorite in this case: Kubo et al., 2002) with an undulated erosional surface. The basal part of the group, the Asamigawa Member, Ashizawa Formation is inclined eastward at 15 to 20 degree, and composed of gravel-supported round to subround, pebble to cobble conglomerate with arkosic coarse sand matrix. Some lenticular layers of coarse sandstone with cross-stratification are intercalated with sharp facies boundary. Gravel contains mainly granitic rocks derived from the basement, but siliceous older rocks are also common. This conglomerate shows the oldest strata exposed in the Joban subbasin and the beginning of the sedimentation in the western margin of the Joban subbasin, Yezo forearc basin.

Stop 4-2: Large cliff next to a solar power plant at Kitazawa, Hirono Town: Kasamatsu and Tamayama formations, Futaba Group and unconformity with Eocene Iwaki Formation, Shiramizu Group

This large outcrop about 50 m high next to a recently established solar power plant shows the fluvial facies of the (1) Kasamatsu (the upper two third 50 m thick) and (2) Tamayama (the lowest a few m thick) formations, Futaba Group (upper Coniacian) and the alluvial-fan conglomerate facies of the upper Eocene (3) Iwaki Formation, Shiramizu Group (Fig. 46).

The lowest Kasamatsu Formation forms alternating beds of dominant, cross-stratified, poorly to medium-sorted, arkosic medium to fine sandstone and subordinate dark gray to grayish black carbonaceous mudstone. The thickness of sandstone...
and mudstone couplets is less than a few meters. The basal surfaces of sandstone layers sometimes show shallow scour-and-fill structure associated with some load casts. Furthermore, a few to ten sandstone-mudstone couplets form the higher-order, upward fining and thinning units five to ten meters thick. Four to five units at least can be detected over the area. The basal parts of the higher-order units consist of gravelly very coarse sandstone with undulated erosional bases. These higher-order facies successions seem to reflect river channel shifting of a meandering river system.

As there are common in three dimensional network burrows filled with sand within sandy siltstone of the uppermost part of the Kasamatsu Formation, the fluvial system seems to have changed into tide-influenced estuary due to a transgression or marine incursion.

The overlying massive and medium-sorted, arkosic coarse to medium sandstone a few meters thick represents the lowest part of the Tamayama Formation. The facies changes between the two formations are relatively sharp. Grayish black mudstone clasts derived from the underlying Kasamatsu Formation are included at the base of the sandstone. Due to the unconformity with the Iwaki Formation, Shiramizu Group, the most of the Tamayama Formation at Stop 4-2 was eroded away, though nearly 150 m thick of the formation is exposed at the fossil locality of plesiosaur, Futabasaurus, Irimazawa (Stop 4-5) about 5 km southward. The sandstone facies shows the braided river environments.

The lowest part of the late Eocene Iwaki Formation, Shiramizu Group is composed mainly of well- to moderate-sorted gravel-supported conglomerate dominant in subround chert pebble to cobble. The conglomerate is partly cross-stratified and higher in sorting and maturity than conglomerate in the Futaba Group. Large-scale forest cross bedding is well observed, suggesting gravel bar progradation on mid alluvial fan. Lenticular gravelly coarse to medium sandstone is also intercalated.

**Stop 4-3:** “Kairyu-no-sato” at Irimazawa, Ohisa-cho, Iwaki City: Near the fossil locality of plesiosaurid from the Irimazawa Member of the Tamayama Formation, Futaba Group

A small exhibition hall and rest lounge was built in 1991 to provide a tourist spot for the fossil locality of plesiosaurid from the shallow-marine fine sandstone facies of the Irimazawa Member of the Tamayama Formation, Futaba Group.

**Stop 4-4:** Itakizawa, Ohisa-cho, Iwaki City: Boundary between fluvial and shallow-marine facies of Tamayama Formation, Futaba Group and unconformity between Upper Cretaceous Futaba Group and Paleogene Shiramizu Group

The facies transition of the 1) Kohisagawa to 2) Irimazawa members of the Tamayama Formation, Upper Cretaceous Futaba Group and the unconformably-overlying conglomerate of the Eocene 3) Iwaki Formation, Shiramizu Group can be observed in this outcrop near a small village (Fig. 47). All strata dip eastward at 15 to 25 degree in general. 1) The uppermost part of Kohisagawa Member, Tamayama Formation, Futaba Group

The lowest part of the outcrop consists of apparently massive, but somewhat cross-stratified coarse to medium sandstone about 7 to 8 m thick and intercalated grayish black sandy siltstone 1 m thick,
showing sandy braided river environment (Ando et al., 1995). Some vertical burrows observed in the siltstone suggest marine water influence under estuary environments.

2) Irimazawa Member, Tamayama Formation, Futaba Group

The Irimazawa Member thins westward (leftward) from 10 to 4 meters and seems to pinch out further westward due to an unconformity with the Eocene Iwaki Formation. The boundary with the underlying Kohisagawa Member forms a flat westward onlapping surface where the basal transgressive conglomerate and overlying hummocky cross-stratified (HCS) fine sandstone obliquely cover the Kohisagawa Member with low angle less than 10 degree. Cross-lamina planes developed in conglomerate also cross the onlap surface at less than 10 degree and laterally continued into HCS on the other side (eastward). Therefore, the basal conglomerate layer shows interfingered lateral facies changes within the outcrop. These facies distributions suggest transgressive lags and the following storm fine sand layers diachronously deposited above a ravinement surface gently inclined seaward formed by shoreface erosion during transgression.

The fossil horizons of plesiosaurid Futabasaurus suzukii Sato, Hasegawa and Manabe, 2006 discovered along two river-floor exposures at Irimazawa about 200 and 400 m southeast seem to be stratigraphically situated a few tens meter upper than this stop.

3) Iwaki Formation, Shiramizu Group

Gravel-supported, subround pebble to cobble conglomerate of the lowest part of the Eocene Iwaki Formation covers the Irimazawa Member of the Futaba Group with a relatively gentle angular unconformity. As the unconformity eroded the lower horizon westward, the Irimazawa Member pinches out westward and the Iwaki Formation covers the lower Kohisagawa Member. At Stop 4-2, Kitazawa about 5 km northward, only a few meters thick of the
lowest part of the Kohisagawa Member is exposed below the unconformity. The conglomerate of the Iwaki Formation here is partly cross-stratified and shows some imbricate structure (Fig. 47C), though it is generally massive in lithofacies.

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