

國立中央大學
2026年10月2日

Ancient Earthquakes and Tsunamis revealed in Coastal Sediments using Diatoms Fossils as Hazard Environmental Indicators

Kaoru Kashima
鹿島 薫
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自己紹介



- 鹿島 薫 Kashima, Kaoru

1956年生 70歳

1979：理学士（東京大）

1981：理学修士（東京大）

1986：理学博士（東京大）

1987-1989: 日本学術振興会特別研究員 Postdoctoral Fellow of JSPS
（東京大）

1989-2022: 九州大学（福岡市） Kyushu University, Fukuoka, Japan

2019-2020：KIGAM (Korea Institute of Geoscience and Mineral Resources), Korea

2022-2023: Turku University, Finland

2023-：国立中正大学（嘉義縣） National Chung Cheng Univ.

自己紹介

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Specialty

Diatom 硅藻
Microfossil 微化石



Diatom analysis, a useful method for paleo-environment and histories of natural hazards; **ancient earthquakes, tsunamis and huge typhoons**,
自然災害、地震、津波、巨大台風

during Pre-History and Boundary of Pre-History and History Periods

Boundary between Geology, Archaeology, History, Biology

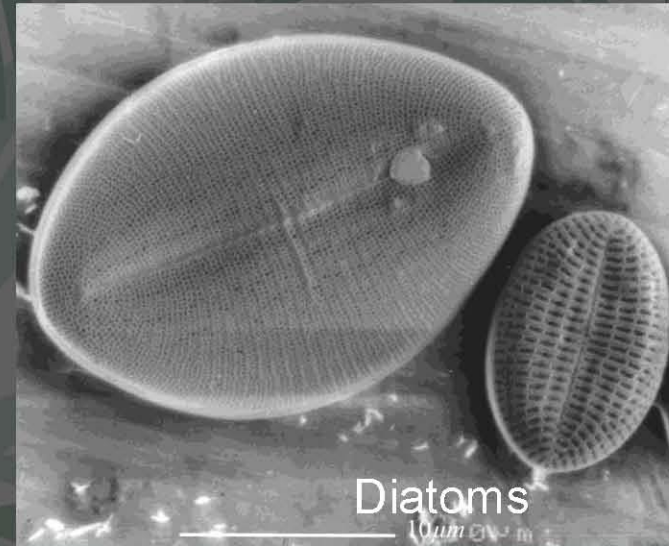
境界領域（地質学、考古学、歴史学、生態学）

The applications to environmental studies using paleo-limnology

Ancient

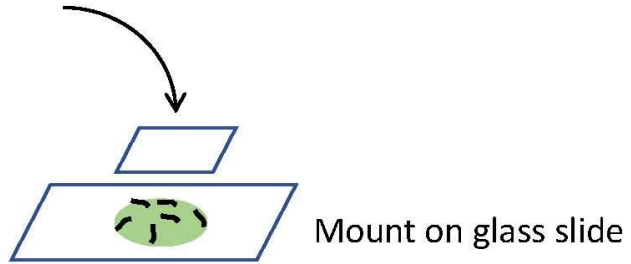
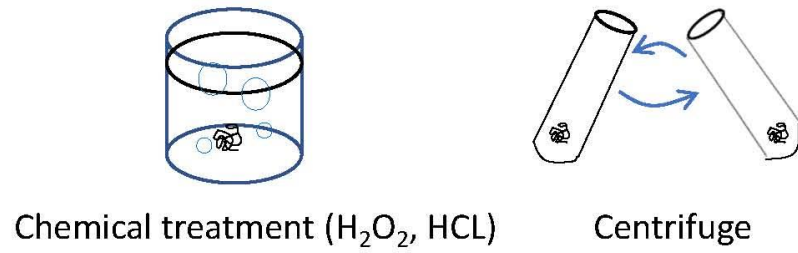
Lake Study

- ❖ Sea level change
- ❖ Climatic Changes and the Global warming
- ❖ Acid rain
- ❖ Earthquake and Tsunami
- ❖ Archeological events
- ❖ Pollutions



10µm

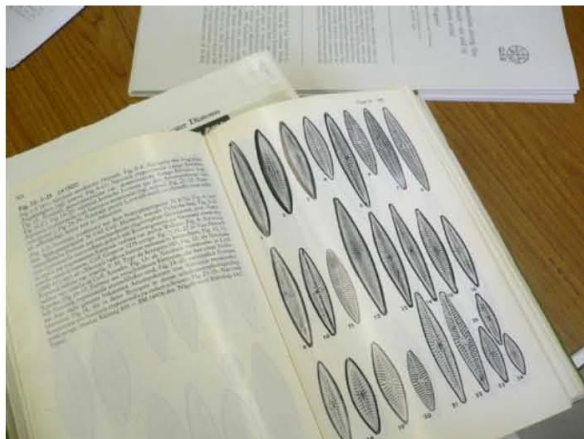
An application to reconstruction of environmental changes using diatoms



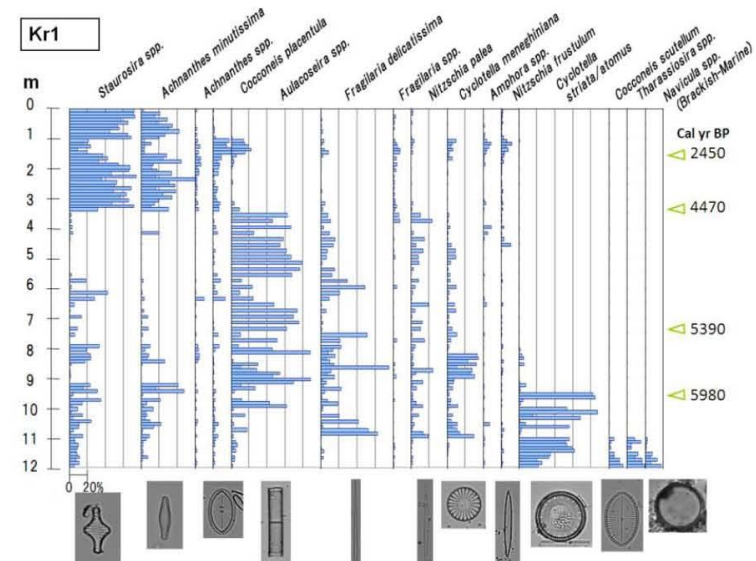
Identify and count
(200-300 valves)
using microscope

A Very Simple Method for the Analysis

Check the ecology of each species
Infer the past environment



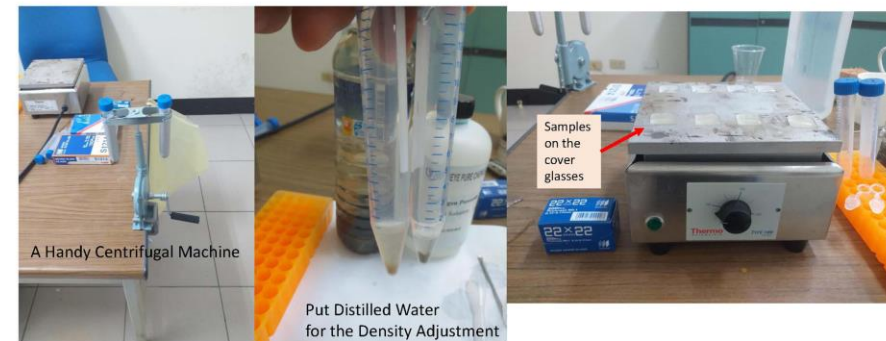
Make a diagram of relative percentage of each taxa



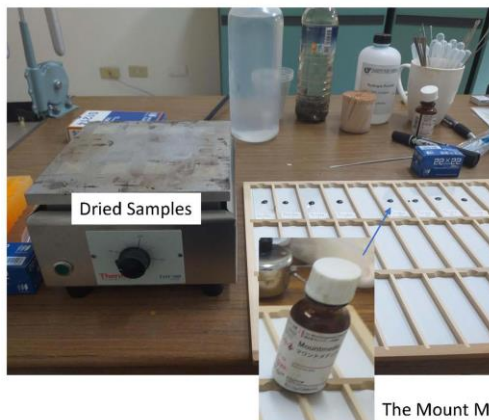
I am working diatoms in the world **with two suitcases**; one is for the microscope and Microscopic Camera, the second one is for the other equipment to make diatom slides.

It is impossible to export and to import **Soil Sediments** without **Special Permissions** in Many Countries.
I usually finish my observations using the Microscope in the evening after the field surveys at my hotels.

Cleaning by a centrifugal machine, three times
Dry the samples on the heater (50-60°C)



Heat the samples with Mounting Material (100-120°C)



The Mount Media (Wako)



Heating Samples

Slides for the Biological Microscope Observation



Ancient Earthquakes and Tsunamis revealed in Coastal Sediments using Diatoms Fossils as Hazard Environmental Indicators

- 2011 Tohoku Earthquake Tsunami and 869 Jogan Earthquake Tsunami

Geologic Supports for the Earthquake Modeling

Dr. Yuki Sawai

Tsunami deposits under different sedimentary conditions

- Tsunami Sands over coastal plains 陸上津波砂層

1611 Keicho Hokkaido Tsunami

2011 Tohoku Earthquake

Dr. Satoshi Ishikawa

Dr. Yoshiki Sato

- Submarine Tsunami Deposits at Kesennuma-Bay 海底津波堆積物

1960 Valdivia (Chilean) Earthquake Tsunami

2011 Tohoku Earthquake

Dr. Yu Fukumoto

- Tsunami Deposits in Coastal Fresh Lakes along the Nankai Trough 沿岸淡水湖沼

1707 Hoei Earthquake

Dr. Ara Cho

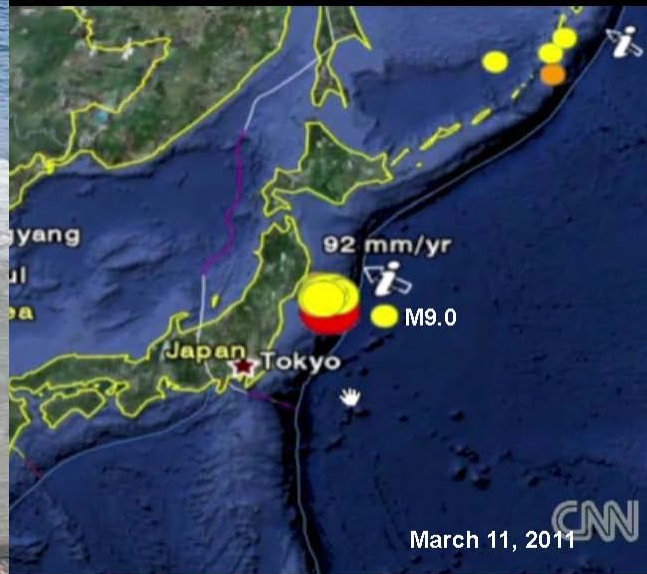
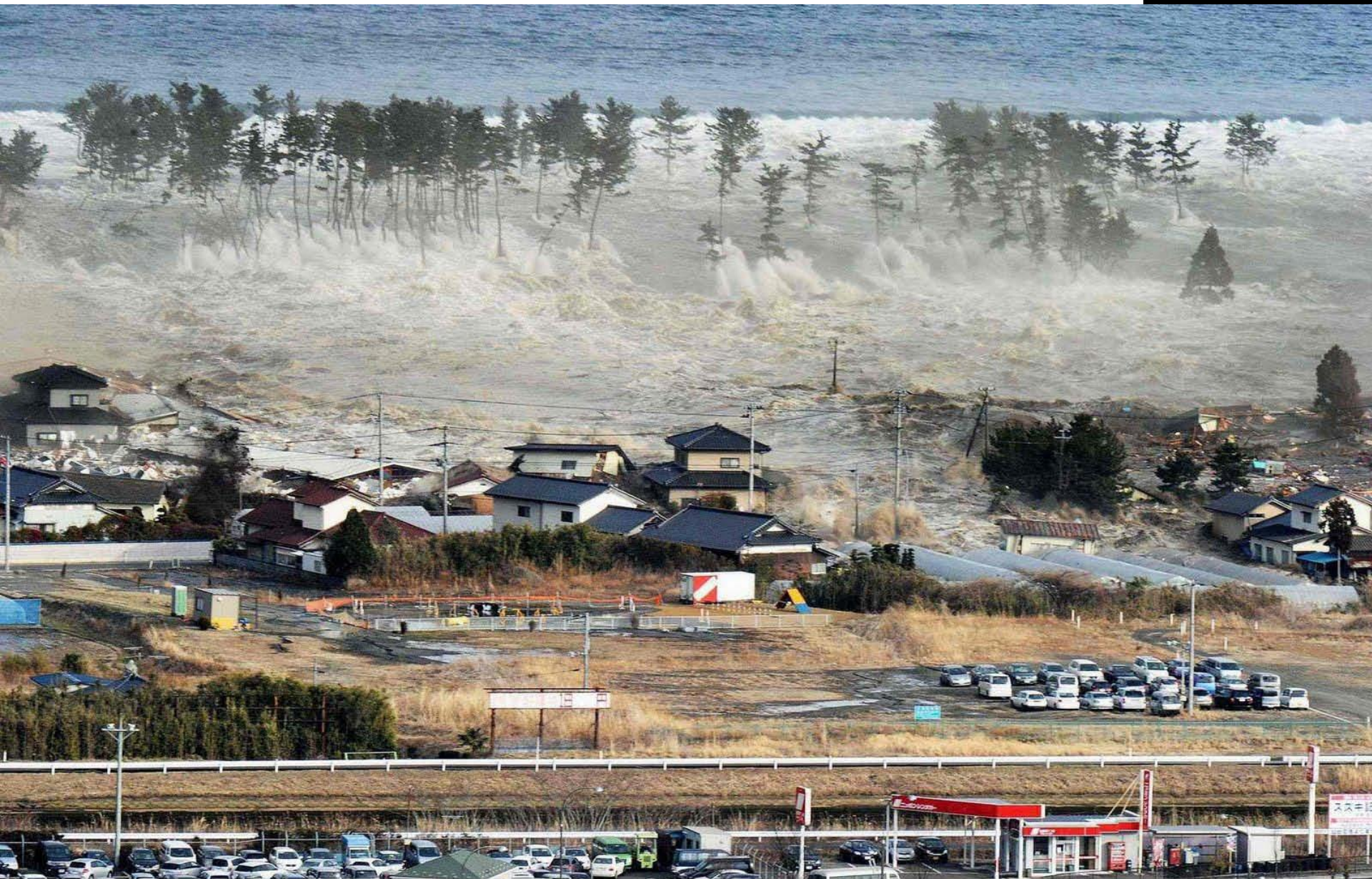
- Tsunami Deposits at Shallow Lagoon along the Nankai Trough 沿岸潟湖

1361 Shohei-Koan Earthquake.

1707 Hoei Earthquake,

1854 Ansei Earthquake.

They were the PhD Students
at Kashima Laboratory



東日本大震災
2011年3月11日

East Japan (Tohoku)
Earthquake
M9.0

March 11,2011
Sendai Airport



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**Sendai International Airport
Just after the Tsunami**

Rice Field

Salinization by Tsunami

平成23年5月18日撮影

18 May, 2011



Just after the Earthquake
11 March 2011



Information Office for Natural Hazard

南三陸町
防災指揮所

16m



May 18, 2011

平成23年5月18日撮影



中央病院

Central Hospital

Hospital

Minami Sanriku Town
宮城県南三陸町

日本三代実録 Nihon Sandai Jitsuroku

(869年5月26日 26 May, 869 AD)

A Huge Earthquake at Tohoku District

廿六日癸未 陸奥國地大震動 流光如晝隱映 頃
之 人民叫呼 伏不能起 或屋仆壓死 或地裂埋殮
馬牛駭奔 或相昇踏 城(郭)倉庫 門櫓墻壁 頽落
顛覆 不知其數 海口哮吼 聲似雷霆 驚濤涌潮
汭洄漲長 忽至城下 去海數十百里 浩々不弁其
涯諸 原野道路 惣為滄溟 乘船不遑 登山難及
溺死者千許 資産苗稼 殆無子遺焉

Thousands people were killed by the Tsunami

A Huge Tsunami attacked coastal areas
of hundreds kilo-meters

Jogan Earthquake Tsunami 貞觀地震津波 AD869

石巻・仙台平野における 869 年貞観津波の数値シミュレーション

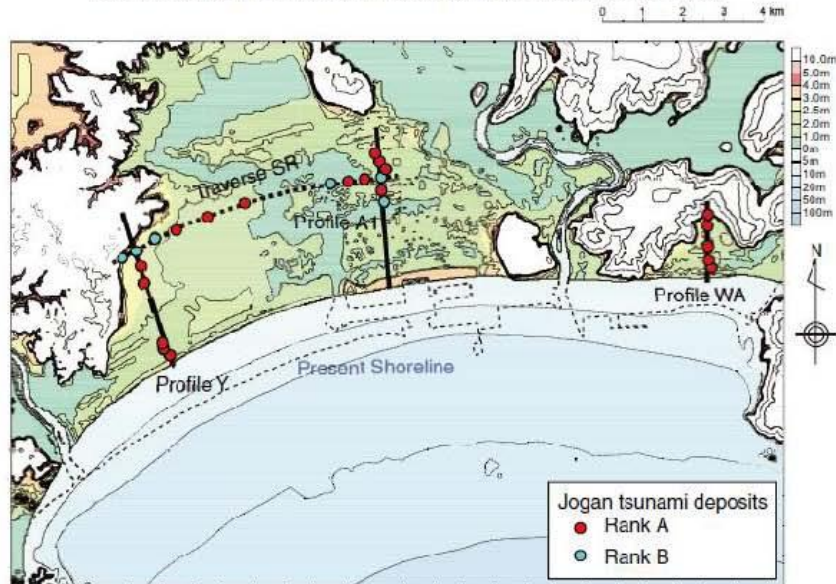
Numerical simulation of the AD 869 Jogan tsunami in Ishinomaki and Sendai plains

佐竹健治¹・行谷佑一²・山本 滋³Kenji Satake¹, Yuichi Namegaya² and Shigeru Yamaki³¹ 活断層研究センター 及び 東京大学地震研究所 (Active Fault Research Center and Earthquake Research Institute, University of Tokyo, satake@eri.u-tokyo.ac.jp)² 活断層研究センター (Active Fault Research Center, GSI/AIST)³ シーマス (Seamus)

Abstract: The AD 869 Jogan earthquake, off Miyagi prefecture along the Japan Trench, produced unusually large tsunami, according to a historical document and tsunami deposits. The document reports that about 1,000 people were drowned from the tsunami in Sendai plain, indicating much larger tsunami than the 1896 or 1933 Sanriku tsunamis. In Ishinomaki plain, the 869 tsunami deposits extend more than 3 km from the estimated coast line, which is about 1-1.5 km inland of the present coast. In Sendai plain, the deposits extend about 1-3 km from the estimated coast, or about 1 km more from the present coast. We computed tsunami inundation in both plains from several types of tsunami source models such as outer-rise normal fault (similar to the 1933 Sanriku tsunami), tsunami earthquake (similar the 1896 Sanriku tsunami), interplate earthquakes with variable fault depth, width, length and slip amounts, and an active fault in Sendai bay. Comparison of the computed inundation areas with the distribution of tsunami deposits indicates that only an interplate earthquake source with 100 km width and more than 7 m slip ($M_w=8.4$) can reproduce the observed distribution of tsunami deposits in the two plains.

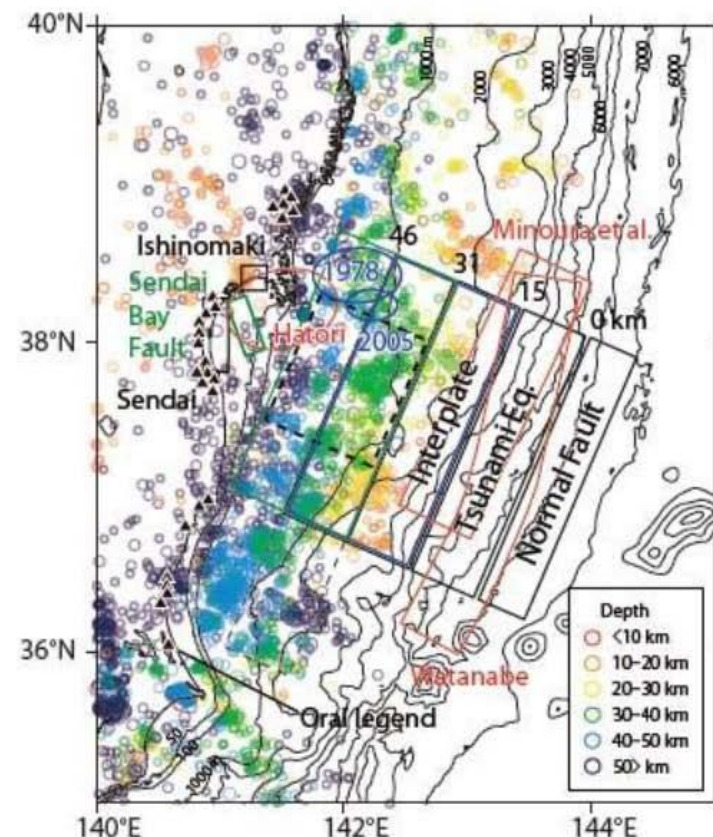
キーワード: 貞観津波, 石巻平野, 仙台平野, 津波堆積物, 津波シミュレーション

Keywords: Jogan tsunami, Ishinomaki plain, Sendai plain, tsunami deposit, tsunami simulation



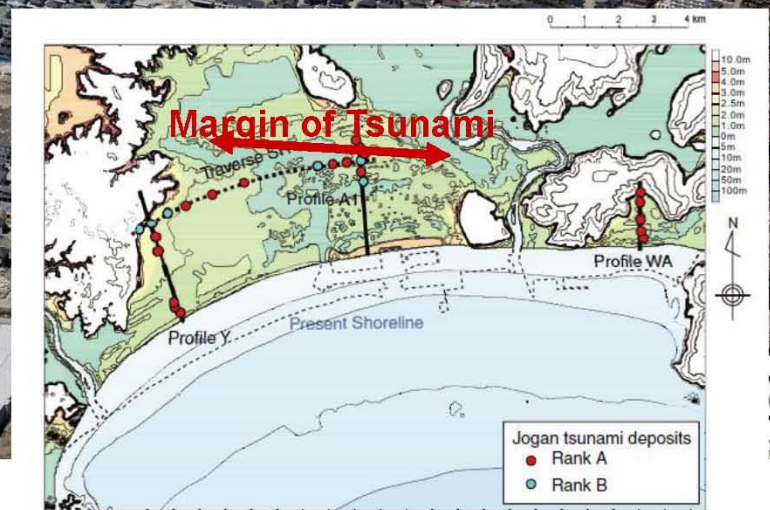
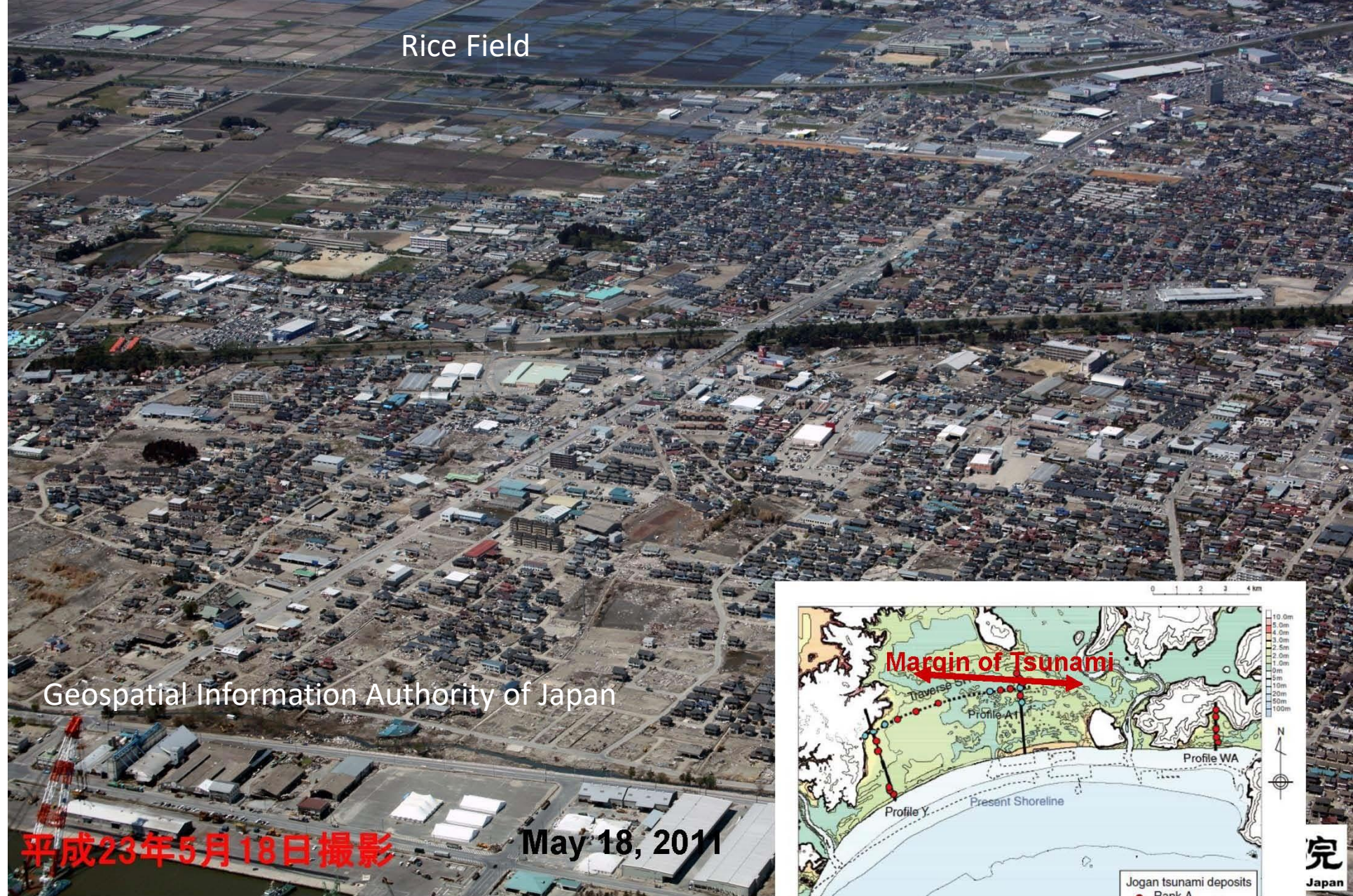
第 4a 図. 石巻平野の貞観当時の推定地形 (格子間隔 25 m). 津波堆積物が見つかった位置 (実倉・他, 2007) ならびに津波シミュレーションと堆積物の比較を行う 3 箇所の位置も示す. 津波堆積物は貞観津波である可能性の高低によりランクを A, B に分けた.

Fig. 4a. Estimated topography of Ishinomaki plain at the time of AD 869 Jogan tsunami. This area is gridded into 25 m interval for inundation modeling. Locations of the tsunami deposits (Shishikura *et al.*, 2007) and three profiles on which simulation results are compared with the deposits are shown. Ranks A and B refer to probability of the Jogan tsunami deposits.



第 1 図. 貞観津波の断層モデル. 本研究で検討するのは, 正断層モデル, 津波地震モデル, 断層幅 50 km のプレート間地震モデル (黒実線) のほか, プレート間地震の断層の長さを 300 km, 100 km に変えたもの (黒破線), 幅を 100 km に変えたもの (青, 緑) 及び仙台湾の活断層 (赤線). これらのほか, 羽鳥 (1998), Minoura *et al.* (2001), 渡邊 (2000) による推定断層域, 1978 年, 2005 年の宮城県沖地震の震源域も示す. カラーの小さい丸はこの地域の地震活動 (1997 年 10 月~2007 年 3 月: 気象庁一元化震源による) を示す. 各断層の上に書かれた数字 (0 km, 15, 31, および 46) は断層上端の深さを示す. 三角印は貞観地震・津波によるものと推定される伝承が残る場所を示す (渡邊, 2000).

Fig. 1. Fault models of the Jogan tsunami. The fault models tested in this study are the normal fault, tsunami earthquake and interplate earthquake models (widths: 50 km) (shown by black solid lines), interplate models with different fault length (shown by black dashed lines), with different fault widths (green and blue lines), and an active fault in Sendai Bay (dark green). In addition, those proposed by Hatori (1998), Watanabe (2000) and Minoura *et al.* (2001) are shown. The source areas of 1978 and 2005 Miyagi-oki earthquakes are also shown. Color circles indicate seismicity in this region between October 1997 and March 2007, according to Japan Meteorological Agency data. Numerals beside the faults (0 km, 15, 31, and 46) indicate upper depth of the faults. Triangles show locations where oral legends of the 869 Jogan earthquake and tsunami were reported (Watanabe, 2000).



第4a図. 右巻平野の貞観当時の推定地形(格子間隔25m). 津波堆積物が見つかっった位置(矢倉・他, 2007)ならびに津波シミュレーションと地形物の比較を行う3断面の位置も示す. 津波堆積物は貞観津波である可能性の高低によりランクをA, Bに分けた.
 Fig. 4a. Estimated topography of Ichi-no-maki plain at the time of AD 869 Jogan tsunami. This area is gridded into 25 m interval for inundation modeling. Locations of the tsunami deposits (Shishikura et al., 2007) and three profiles on which simulation results are compared with the deposits are shown. Ranks A and B refer to probability of the Jogan tsunami deposits.

The Tsunami areas were very similar
 between Jogan貞観 Tsunami 869AD, and the East Japan Tsunami 2011AD

仙台平野の堆積物に記録された歴史時代の巨大津波 -1611年慶長津波と869年貞観津波の浸水域-

Dr. Yuki Sawai

澤井 祐紀¹⁾・岡村 行信¹⁾・栄倉 正展¹⁾・松浦 旅人¹⁾
Than Tin Aung¹⁾・小松原純子¹⁾・藤井雄士郎²⁾



1. 近年における仙台平野の津波被害

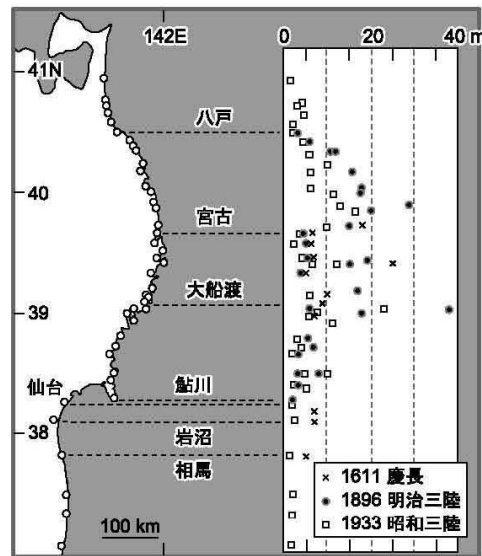
宮城県の仙台平野では、三陸海岸に比べて津波による被害が少ないと考えられている。例えば1933年3月3日の昭和三陸津波の際には、岩手県大船渡市で28m超の津波が観測されたのに対して、仙台平野では山元町磯地域での3.9mが最大だった。1896年明治三陸津波の際も同様に、大船渡市で38.2m(一説には50m以上)の津波が観測されたのに対し、仙台平野では5m以下であった(羽鳥, 1995; 第1図)。また、2005年8月16日に発生した宮城県沖地震の際には、宮城県で最大震度6弱を観測したが、津波は石

巻市鮎川で0.1mなど微弱なものであった。これらの近年における「仙台平野は津波被害が少ない」という認識に反して、歴史記録には巨大な津波が仙台平野を襲ったという記述がある。

2. 歴史記録に残っている巨大津波

2.1 仙台平野を襲った貞観津波の歴史記録

平安時代に編纂された日本三代実録には、貞観十一年五月二十六日(西暦(ユリウス暦)869年7月9日)に関して以下のような記録がある。「陸奥国地大震動。流光如晝隠映。(中略)去海数千里。浩々不辨其涯。俟矣。原野道路。忽為滄溟。乗船不遑。登山難及。溺死者千許。資産苗稼。殆無子遺焉」これは、陸奥の国において大地震が発生し、その後の津波によっ



第1図. 1611年慶長津波, 1896年明治三陸津波, 1933年昭和三陸津波の津波波高。羽鳥(1995)を改変。



第2図. 東北地方の地図。貞観津波に関係する伝承が残されている地域、十和田a火山灰の降下範囲を示した。

The Mega Earthquake with Huge Tsunami

898 AD Jogan Tsunami

713 years ? Interval

1611 AD Keicho Tsunami

400 years ? Interval

2011AD Higashi Nihon Tsunami

Huge Earthquakes have been continuously occurred with 400 – 700 years intervals

Geologic Discussions are required

Diatomist
PhD at Kyushu Univ.

5 years before
2011



図4 ハンディジオスライサーを用いた掘削調査の様子。



図5 石巻平野における貞観地震津波堆積物の分布。

の結果、泥灰層あるいは有機質泥層に挟まれた津波堆積物が最大で7層確認されました。これらの津波堆積物うち、十和田a火山灰直下に分布する貞観津波の津波堆積物は現在の海岸線より約3.0-3.5kmの地点まで観察することができました。観津波襲来当時の海岸線の位置は、現在の海岸線より0.5-1km程度内陸に存在していたと推定されることから、貞観津波の遡上距離は少なくとも2km程度と考えられました(図6)。



図6 仙台平野における貞観地震津波堆積物の分布。



図7 宮城県亘理町鳥の海における湖上での掘削作業の様子。



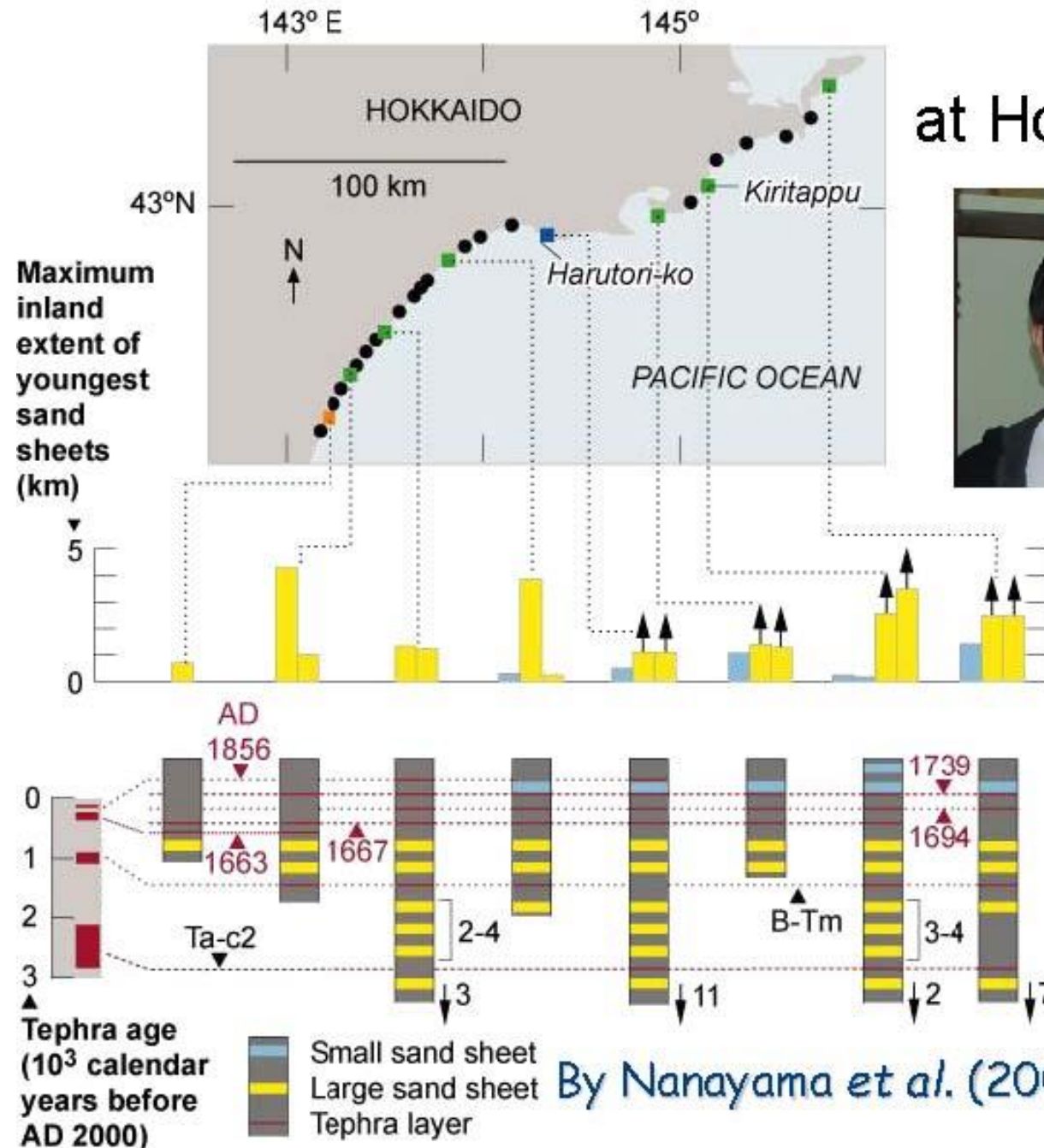
図8 大型ジオスライサーによる掘削調査の様子。

Published on June 2010, 9 month before the earthquake

Tsunami Trace at Hokkaido, North Japan

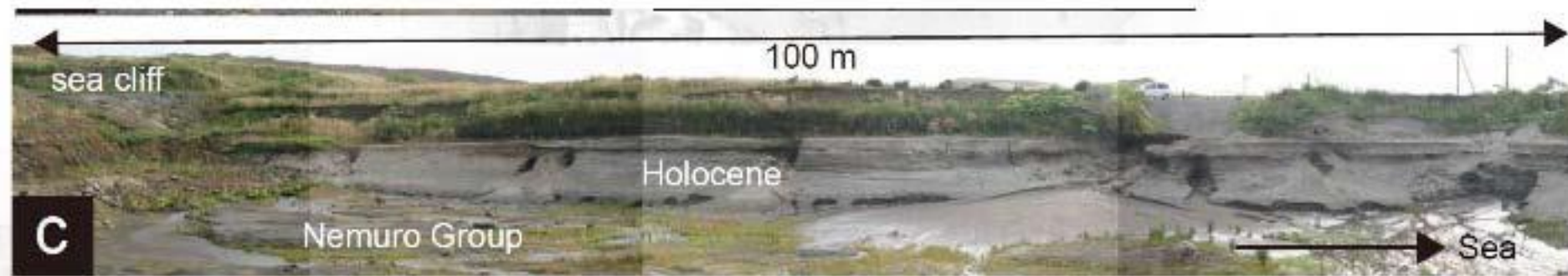


Dr. Satoshi Ishikawa



By Nanayama et al. (2003)

Mega Trench in Nemuro

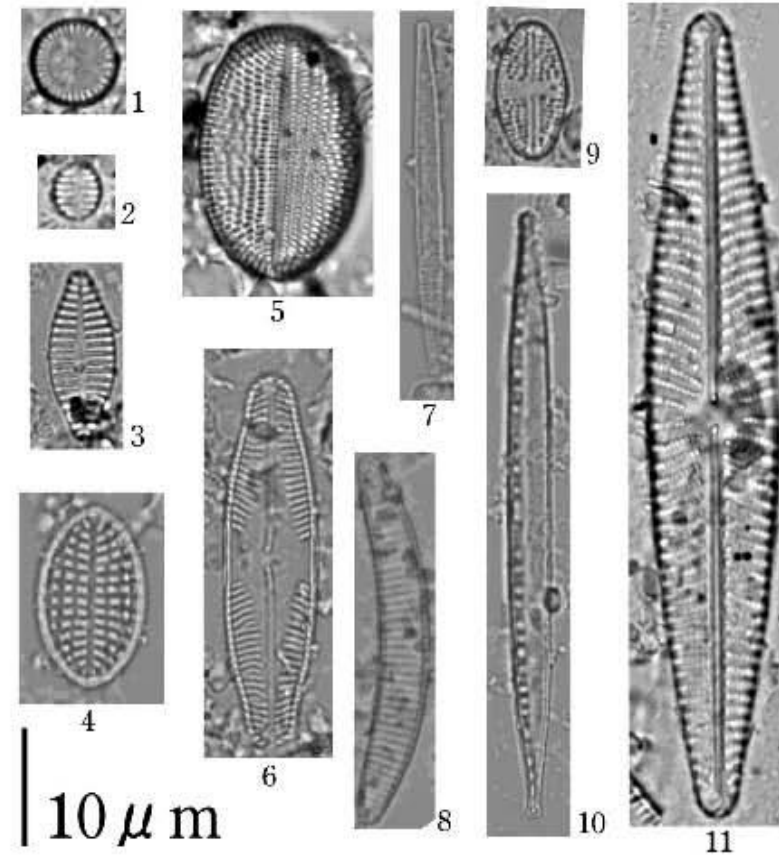


Sand: Tsunami deposit
in 17thC

Peat

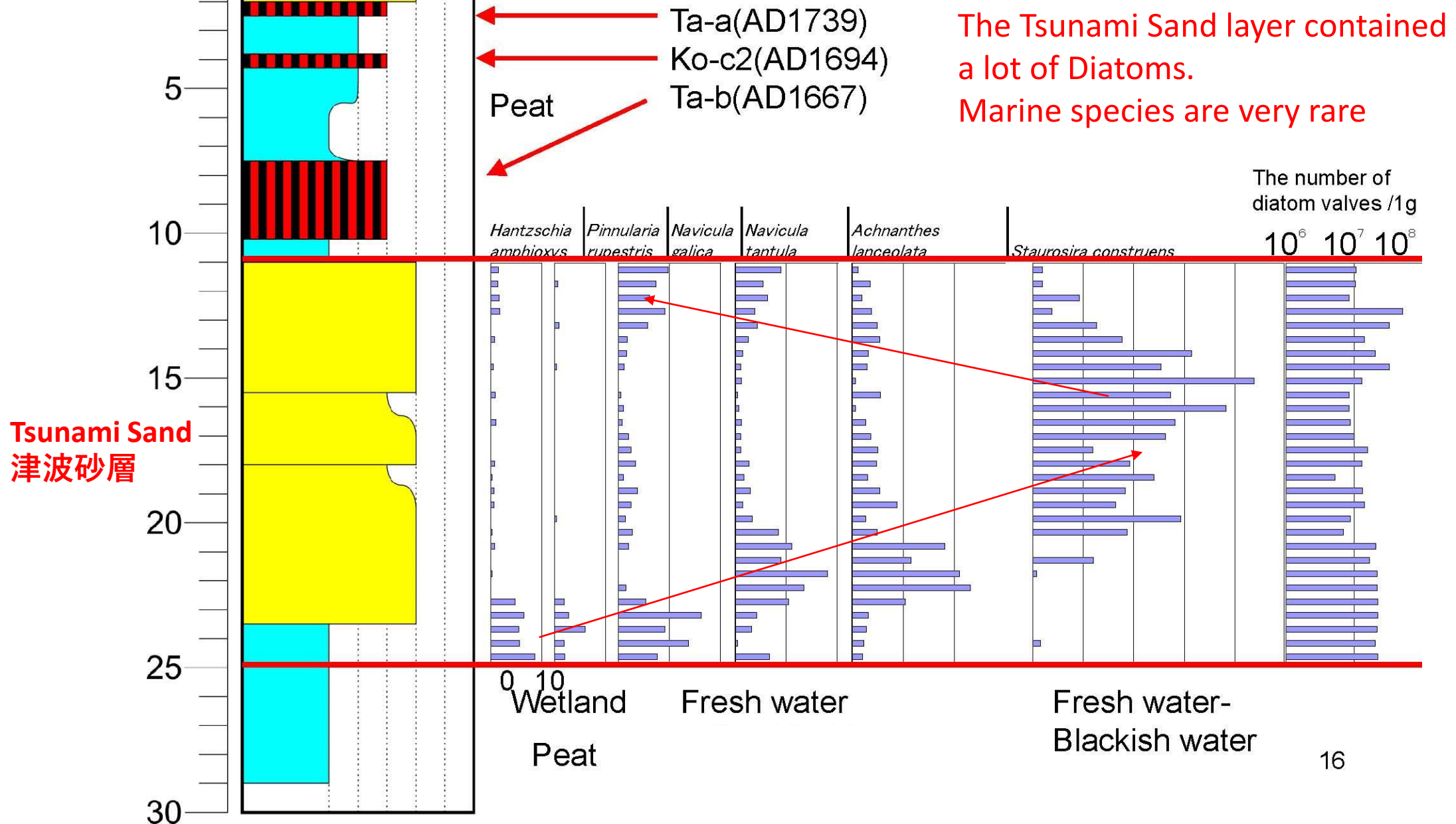
Sand: Tsunami deposit
in 13thC

Peat



Diatom (micro fossil)

17thC tsunami in Nemuro



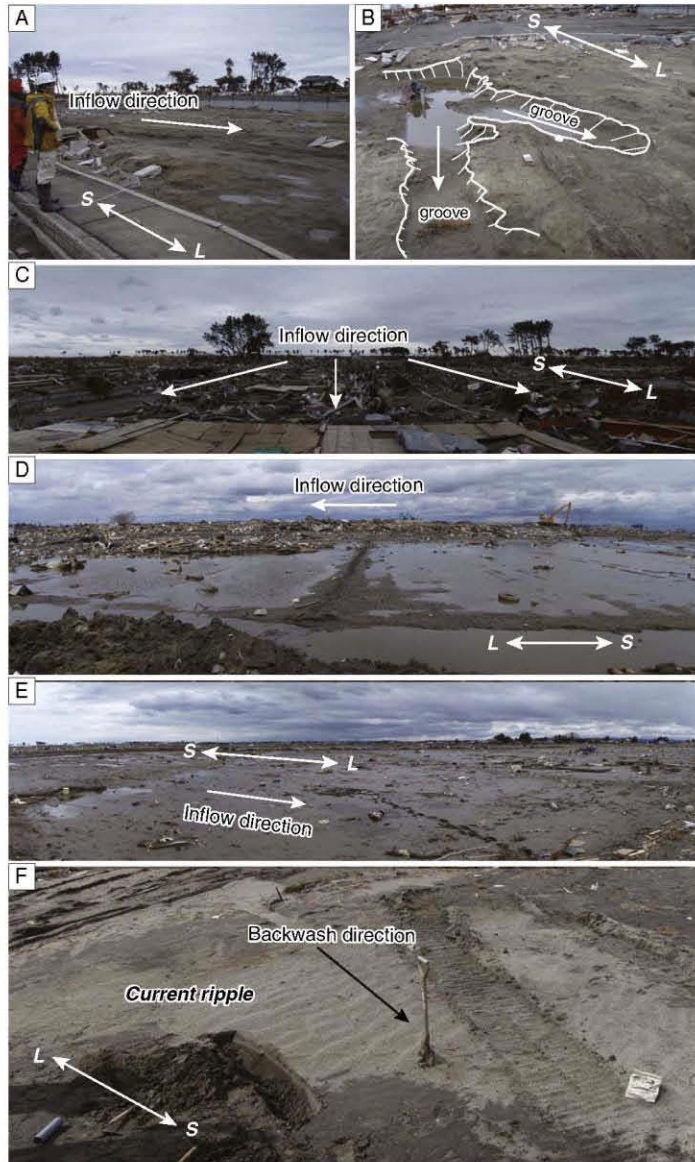


Fig. 5.

Depositions
of Tsunami
Sands at
2011 Tohoku
Earthquake

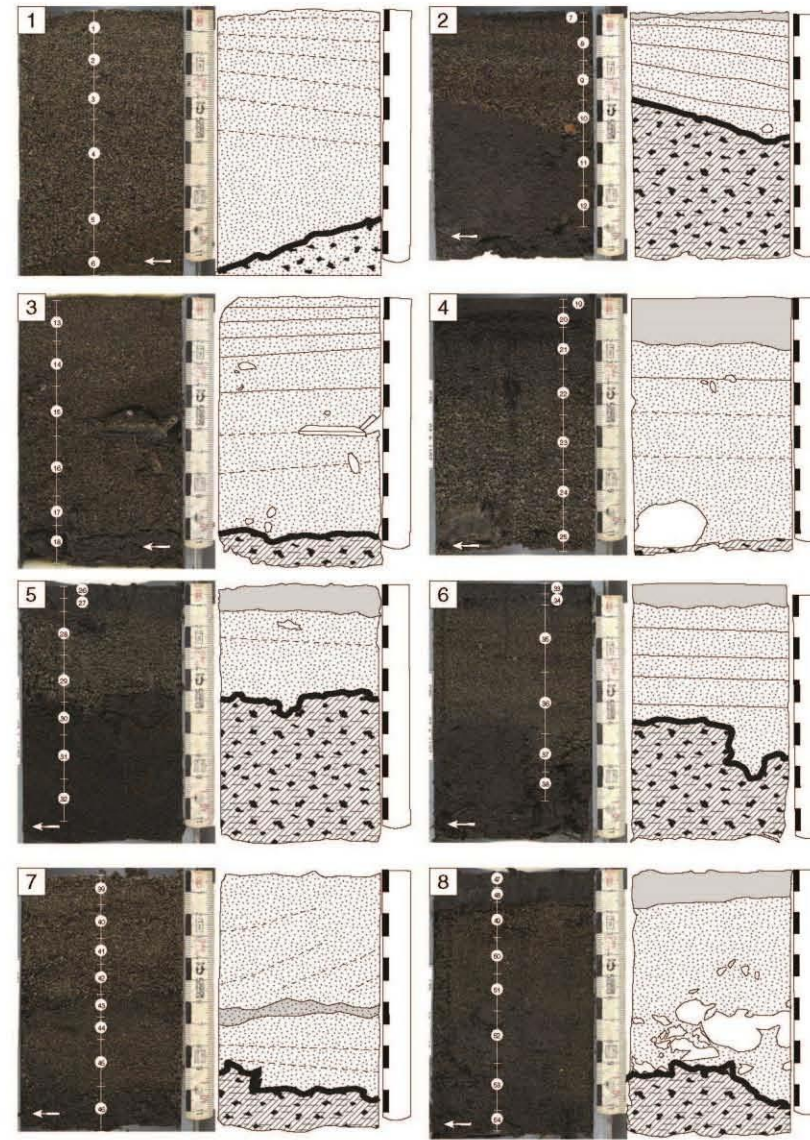


Fig. 4. Photographs and sketches of the oriented undisturbed tsunami deposit at each survey site. The number on the upper left corner of each photograph indicates the site name along the survey line in Fig. 2. White-colored circles with numbers indicate the sampling horizons for diatom analysis. The arrows show the seaward direction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Block Sampling
of Tsunami Sands

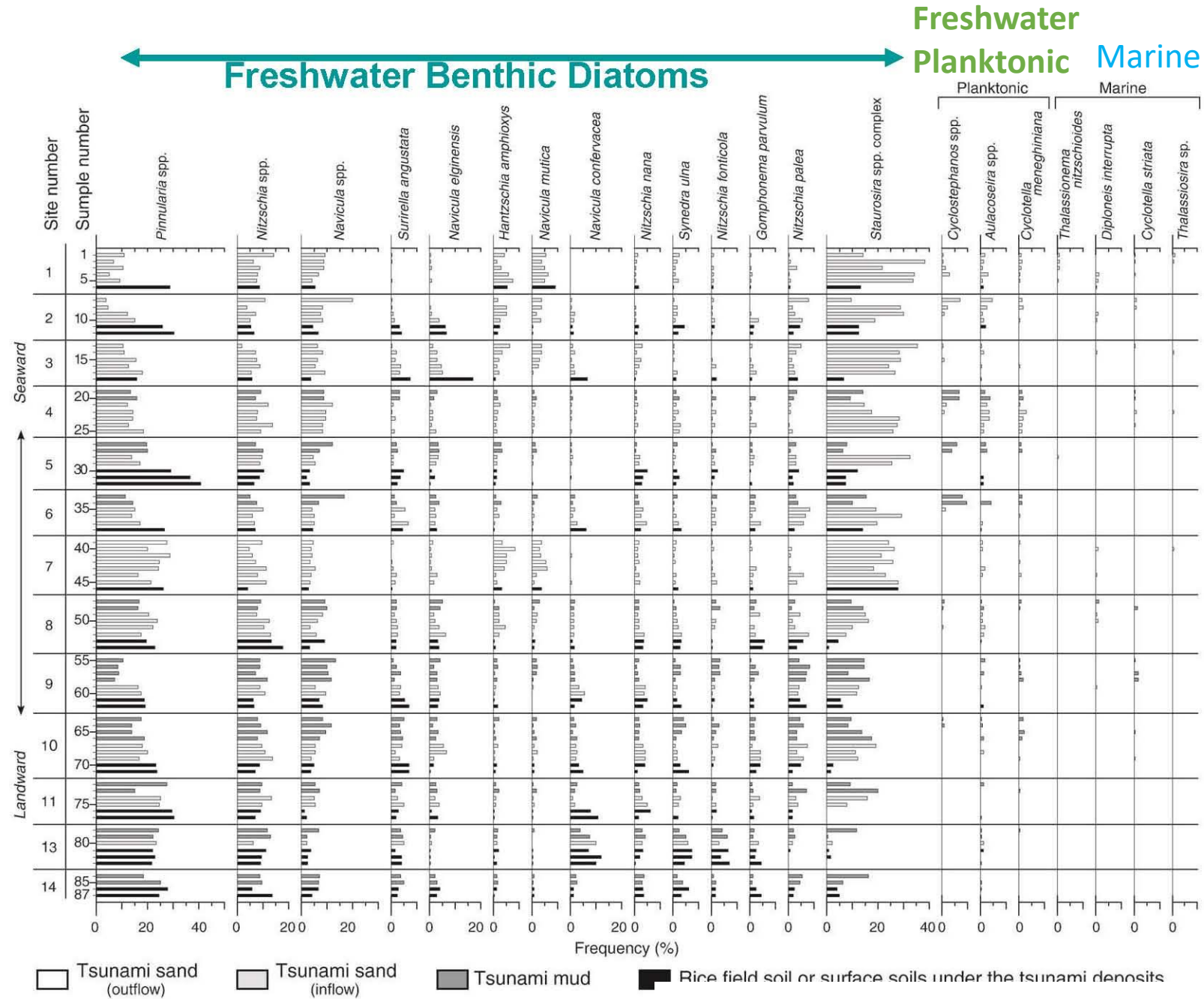


Fig. 9. Relative abundance of main diatom species in the underlying rice field soil and tsunami deposit at sites 1–11, 13 and 14 all correspond to sample numbers in Fig. 4. Subsamples are divided into backwash parts of tsunami sand layers, inflow parts of tl

The Tsunami Sand layer contained a lot of Diatoms.
Marine species are very rare

Submarine Tsunami Deposits 浅海津波堆積物

Diatom Assemblages as the Indicators for Huge Tsunami
Sedimentations and Recover Processes of Environment
at Kesennuma Bay, Tohoku, Japan

Kaoru Kashima^{1*}, Ryozi Shiomi², Yu Fukumoto³ and Tsuyoshi Haraguchi²

鹿島 薫^{1*}, 塩見良三², 福本侑³, 原口強²

¹ Faculty of Science, Kyushu University, Fukuoka, Japan

² Faculty of Science, Osaka City University, Osaka Japan

³ Ritsumeikan University, Kyoto, Japan

*Correspondence: kashima@geo.kyushu-u.ac.jp



Dr. Yu Fukumoto



Kesennuma March11, 2011



Kesennuma March12, 2011

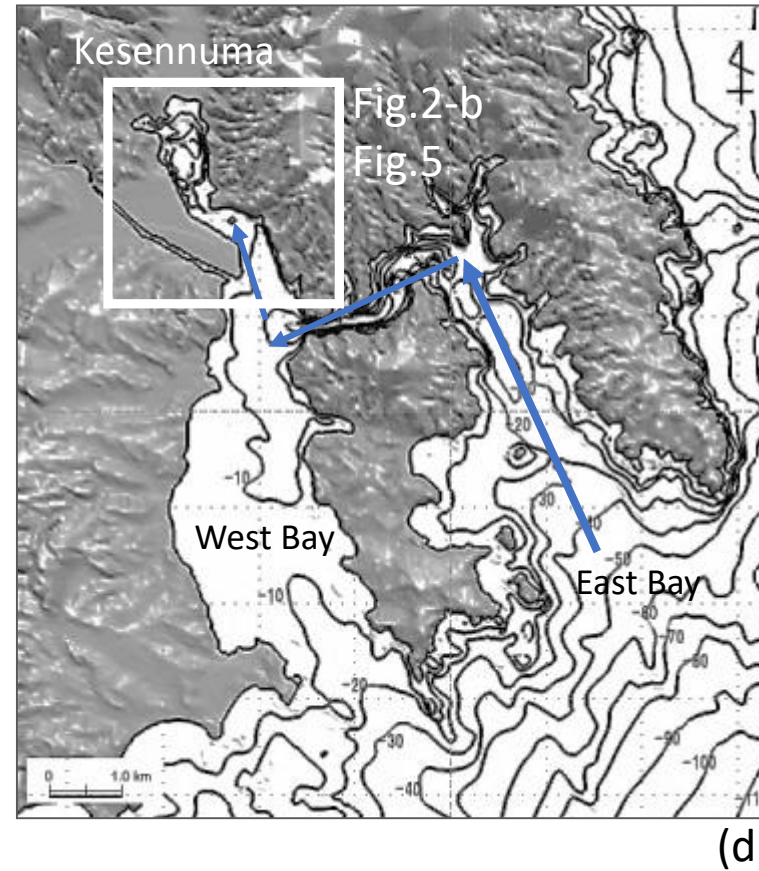
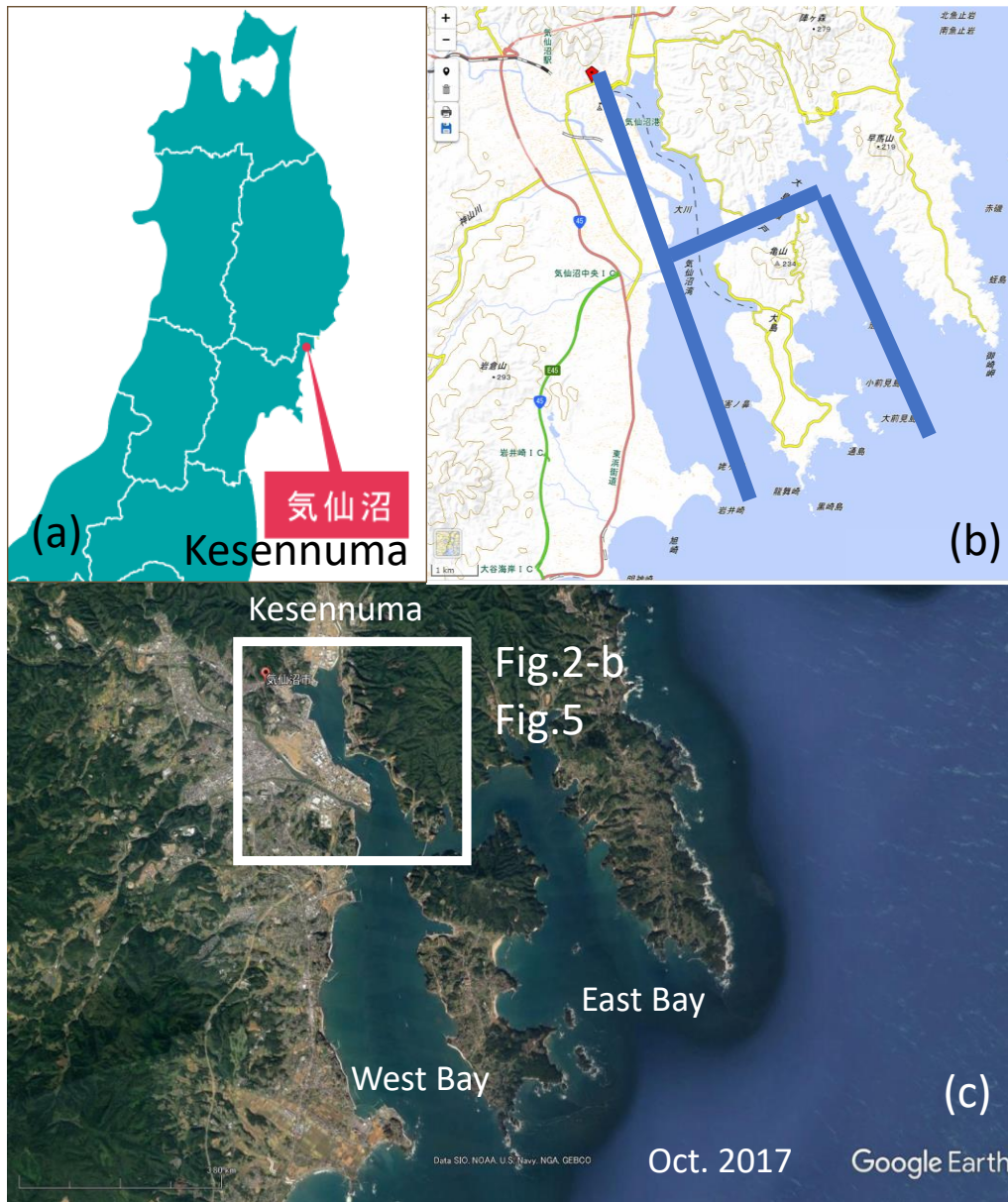
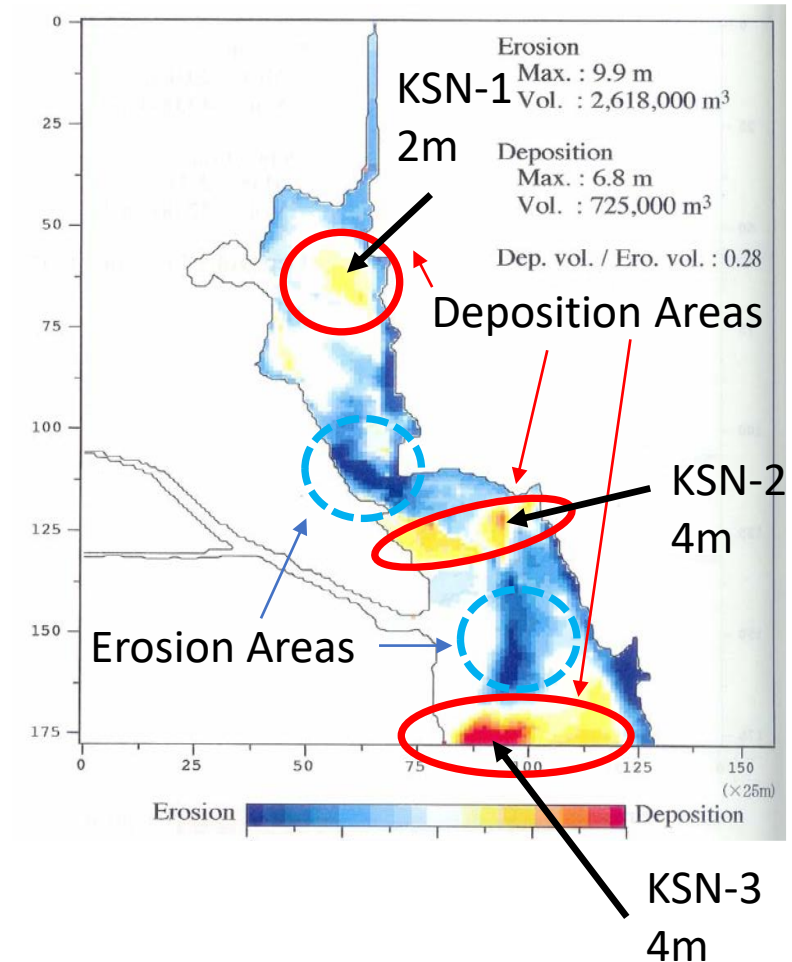


Figure 1 Location of Kesennuma, Tohoku Area, Japan
 (a) Location map, (b) detail location map
 (c) Satellite view by Google Earth
 (d) Submarine topographic map of the bay

1960 Valdivia (Chilean) Earthquake Tsunami on May 23-24, 1960



(a)



(b)

Figure 2 The tsunami hazards by 1960 Valdivia (Chilean) Earthquake on May 23-24, 1960

(a) photos of the tsunami hazard in 1960 (Kesennuma Tsunami Field Museum)

(b) Submarine topographic change by the tsunami currents

after Takahashi *et al.* (1991) KSN1, KSN2, KSN3: Coring sites of submarine deposits in 2009

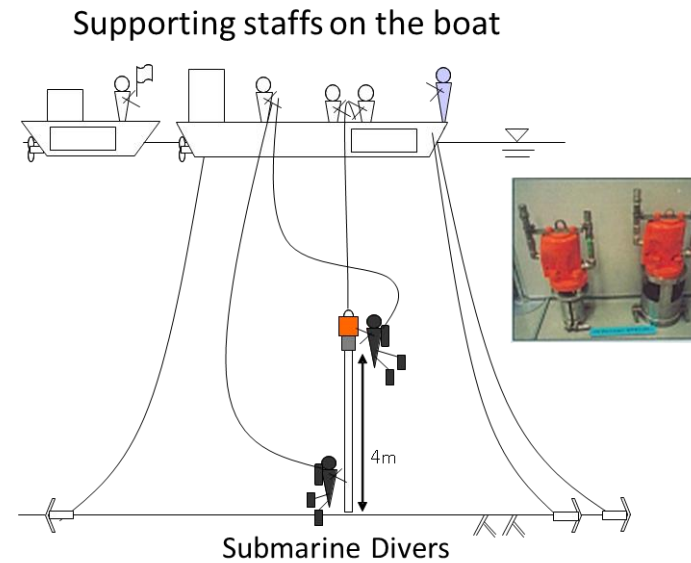
The tsunami of the 2011 earthquake off the Pacific coast of Tohoku (March 11, 2011)



Figure 4 The tsunami of the 2011 earthquake off the Pacific coast of Tohoku (March 11, 2011)
(a), (b) Fishery port and aquaculture industries along the coast one month before the tsunami hazard, and our filed survey on the boat (by Mr. Shiomi, Feb.11, 2011)
(c) The fire after the tsunami attacks (by Mr.Onodera, March 11, 2011)
(d) The next morning of the bay. The fire had still continued (by Mr. Onodera, March 12,2011)
(e)The fired cost along the bay (By Prof. Haraguchi, March 29, 2011)
(f) The ship was derived to the land (By Prof. Haraguchi, March 29, 2011)



(a)



(b)

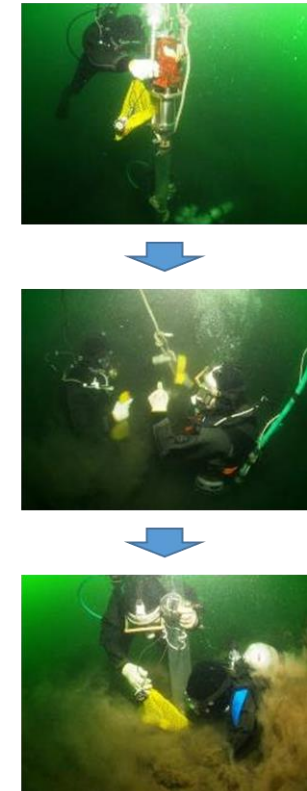


Fig.5 Emergency Survey just after the 2011 Tsunami (by Prof. Haraguchi)
 (a) Submarine topography measurement,
 (b) Submarine coring of the sea bottom sediments by tsunami deposition

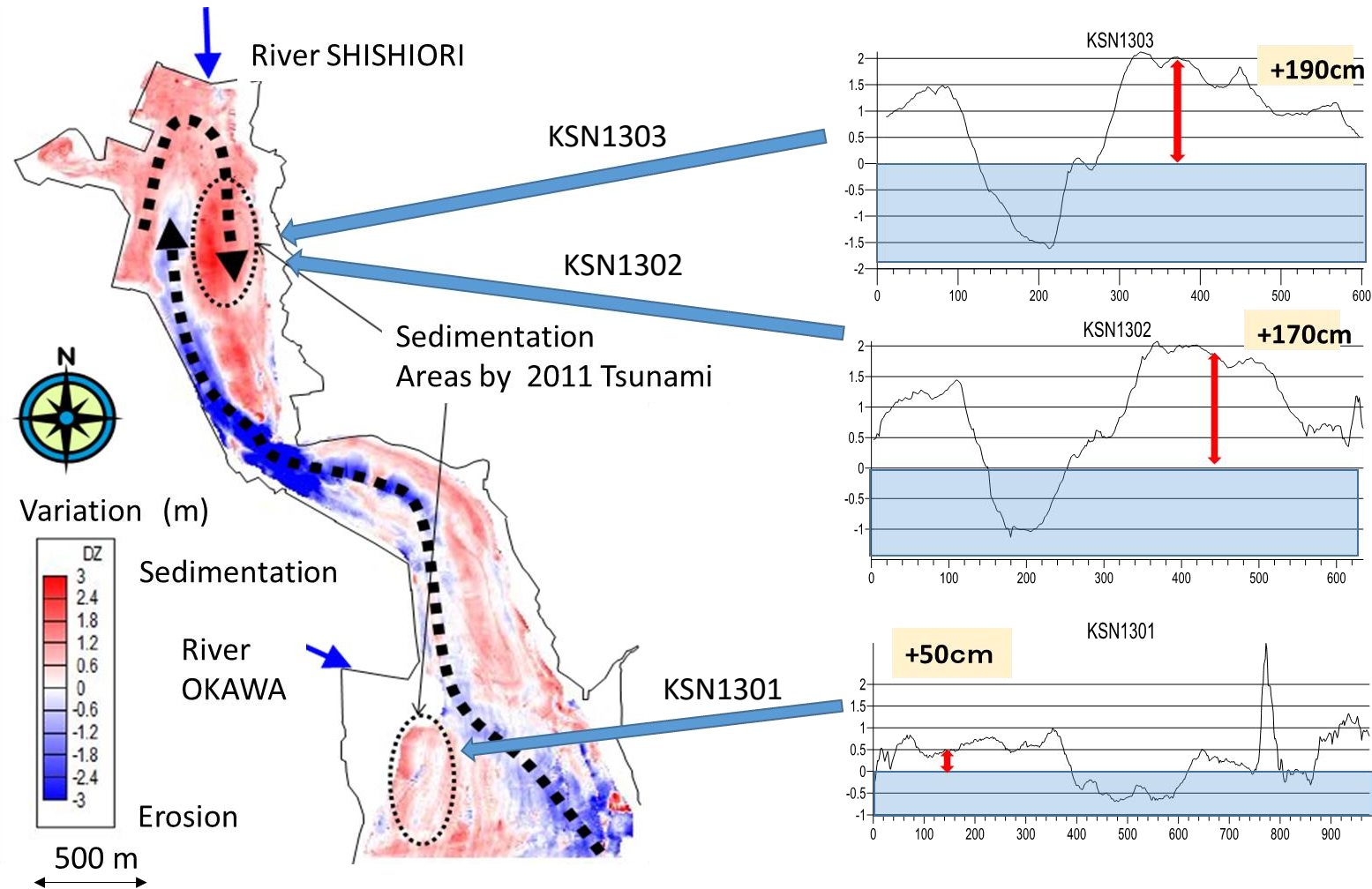


Fig.6 Submarine variations at Kesennuma bay after the 2011 Tsunami (by Prof. Haraguchi)
 The coring of the submarine deposits at three sites on the submarine mounds which were caused by tsunami currents on March 11, 2011

KSN1301 CT

Tsunami Deposit
in 2011

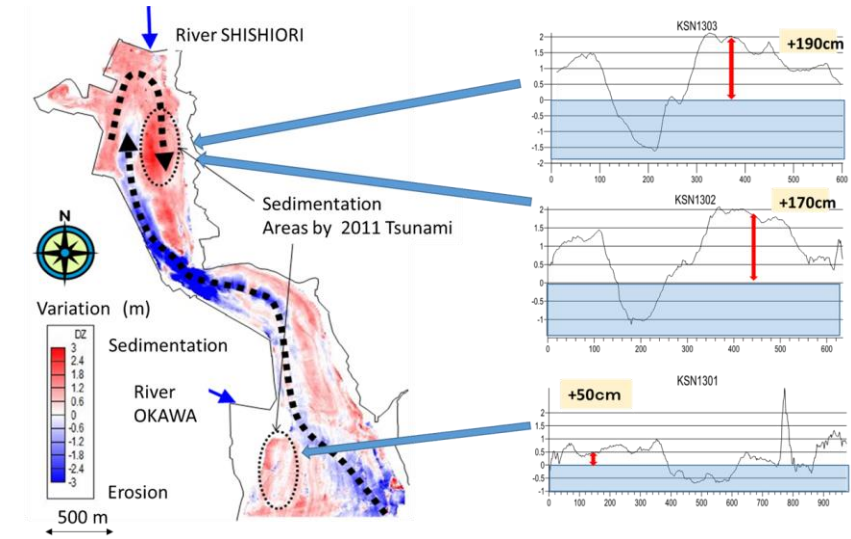
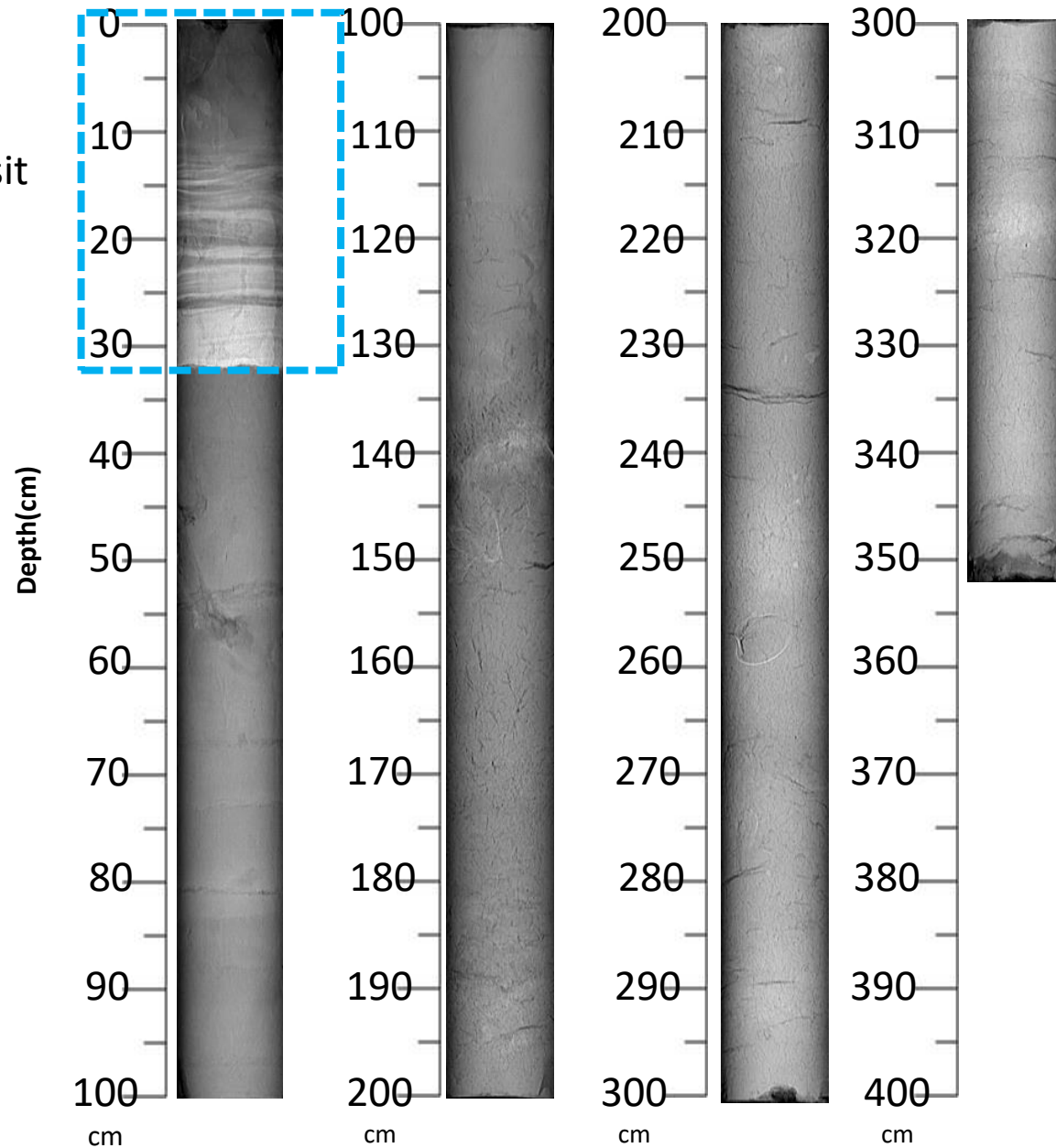


Fig.7 KSN 1301 core
The core was 3.5m long. Top 32cm was
the tsunami deposit in 2011

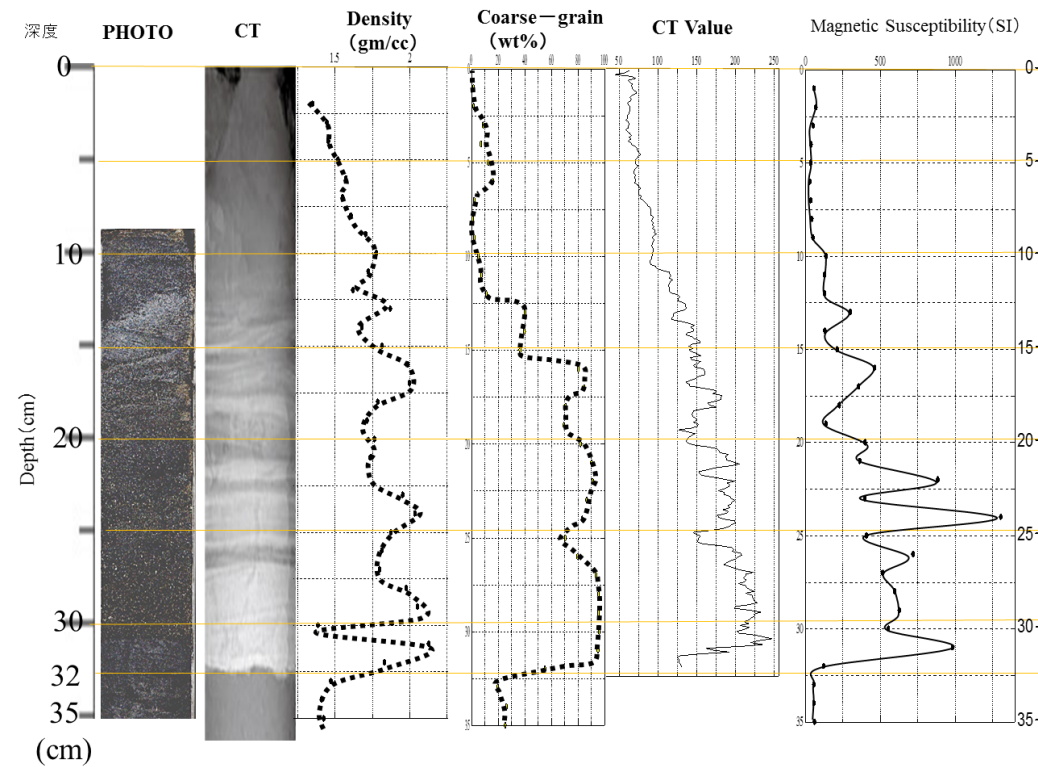


Figure 8 Top 32 cm of KSN1301 core
CT photo, Density, Grainsize, CT value and Magnetic Susceptibility were shown.

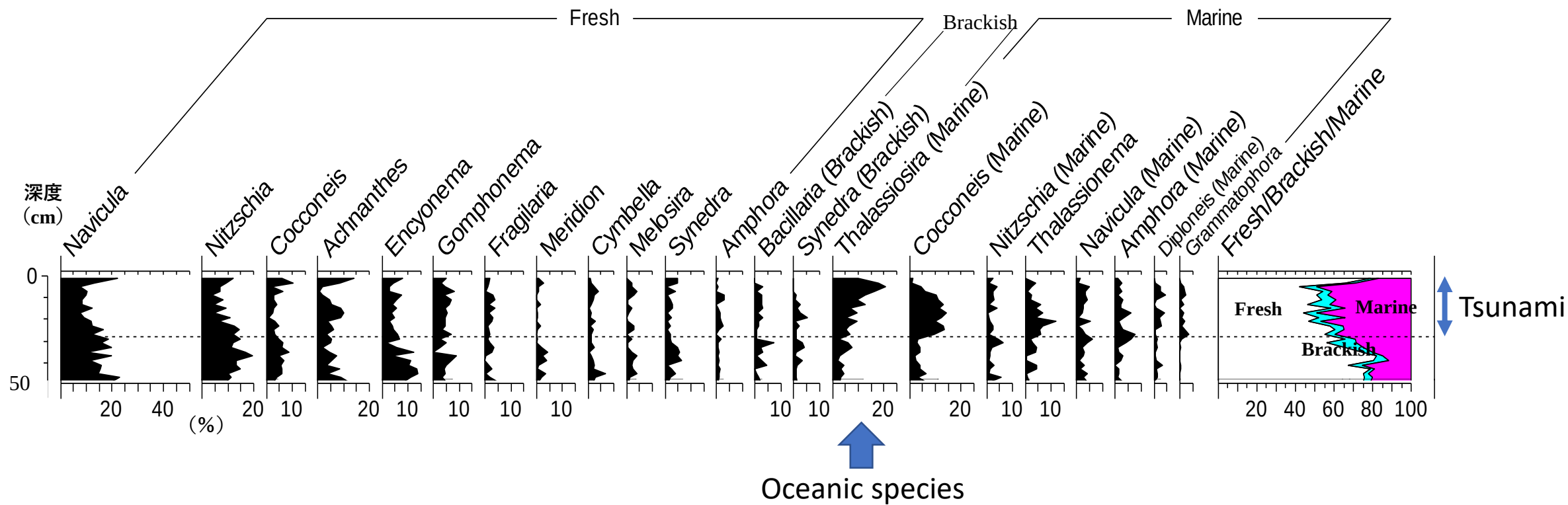
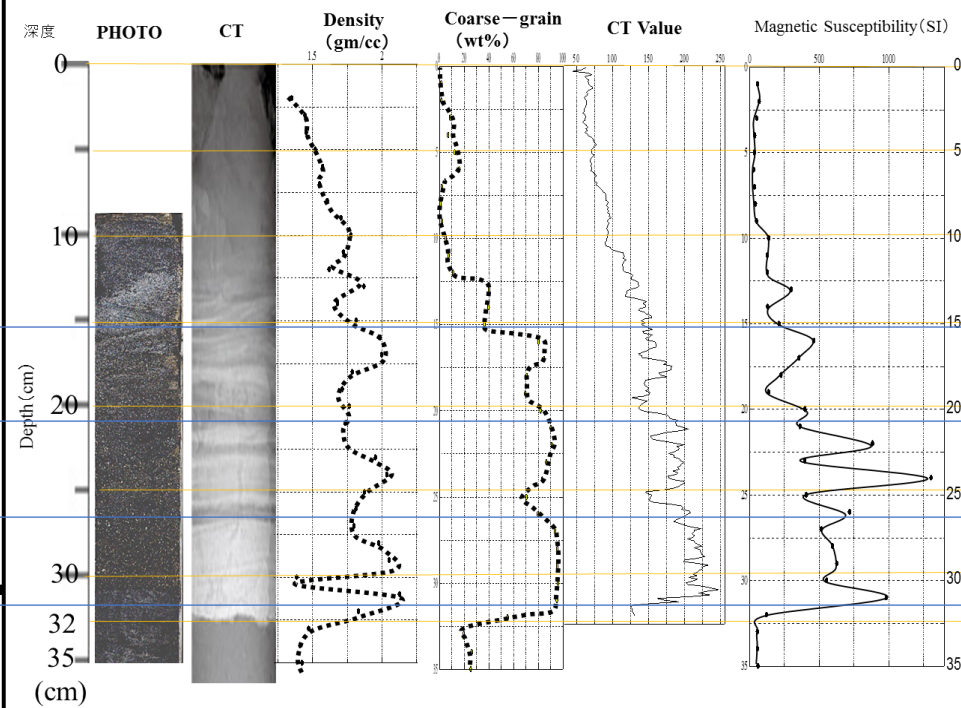
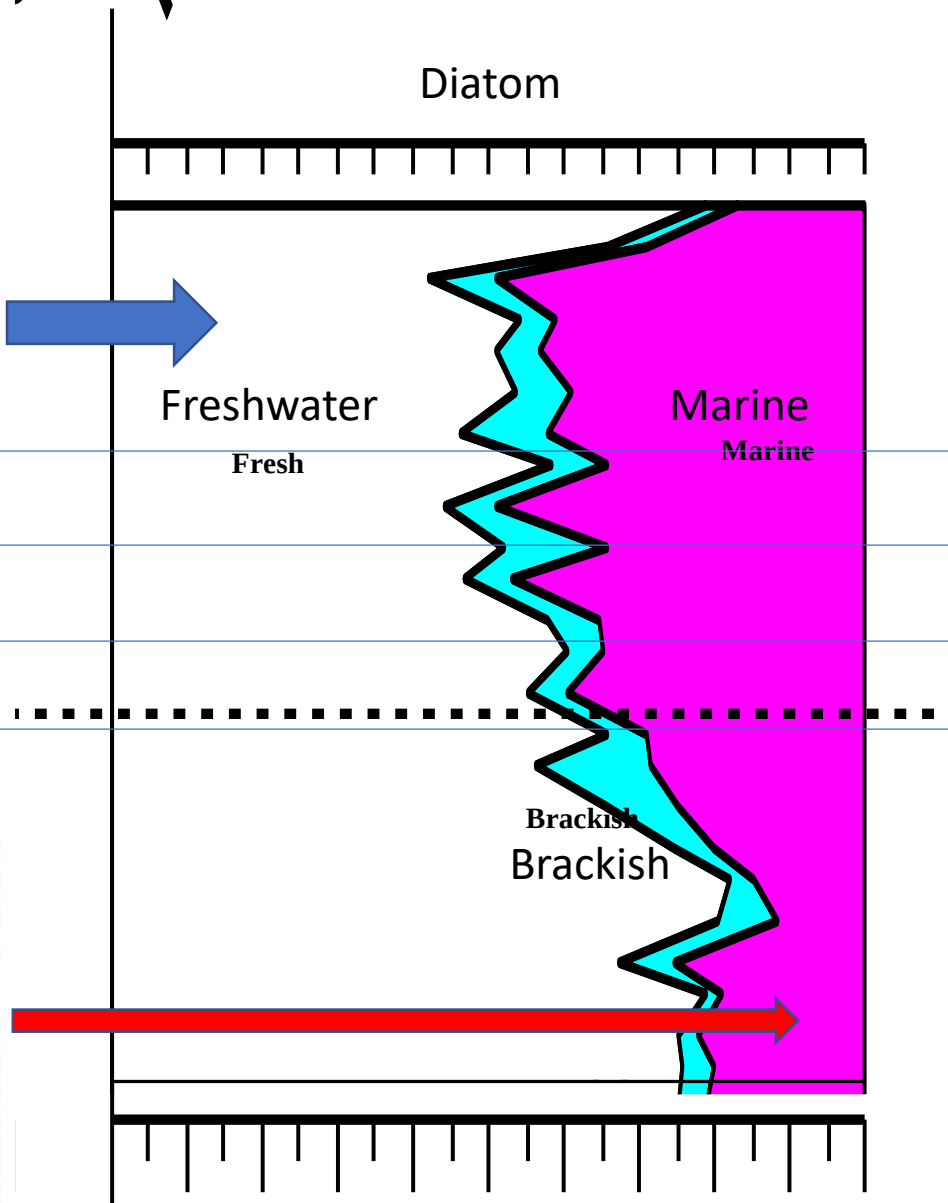
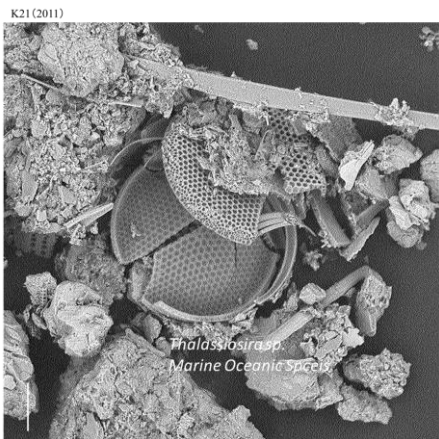
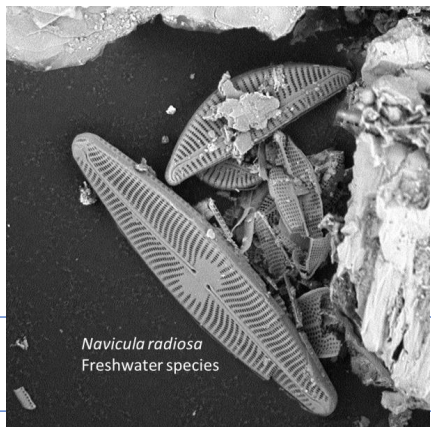


Figure 9 Diatom assemblages of 0- 50 cm layer of KSN1301 core



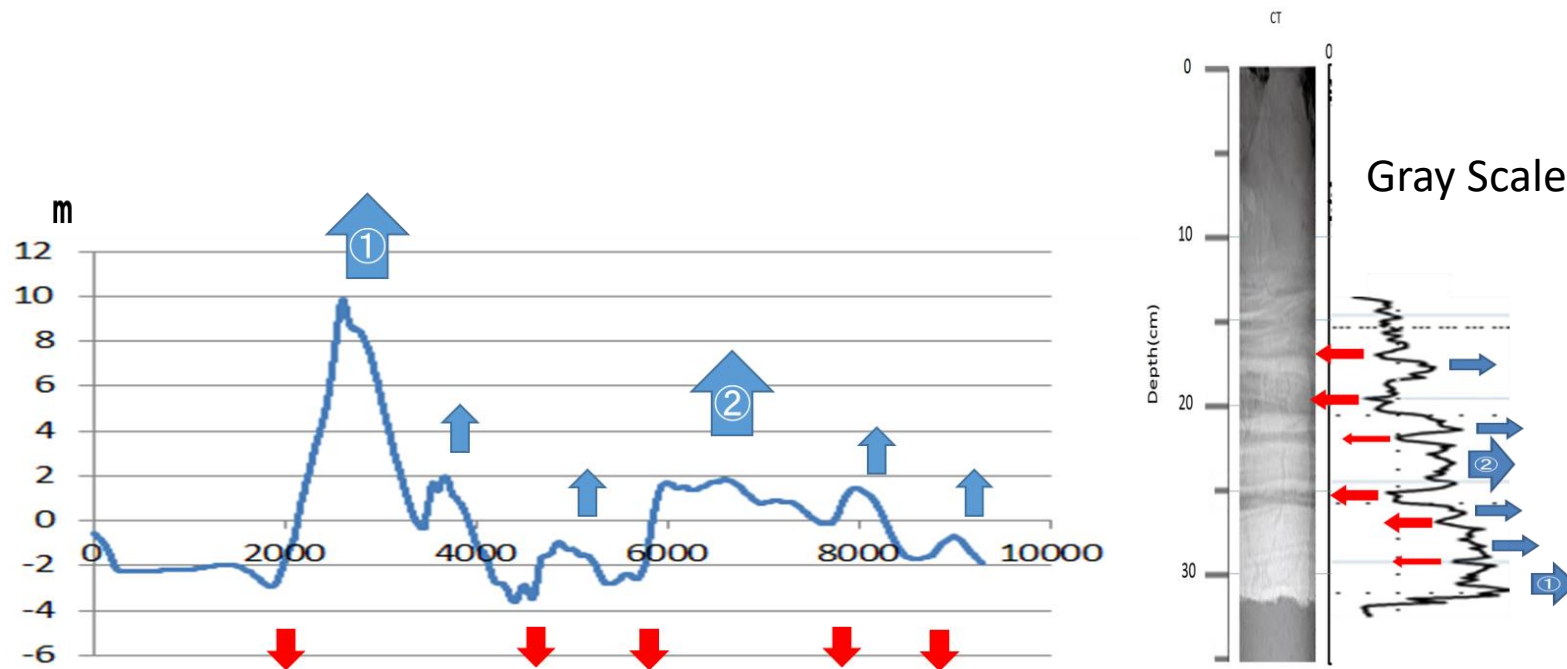


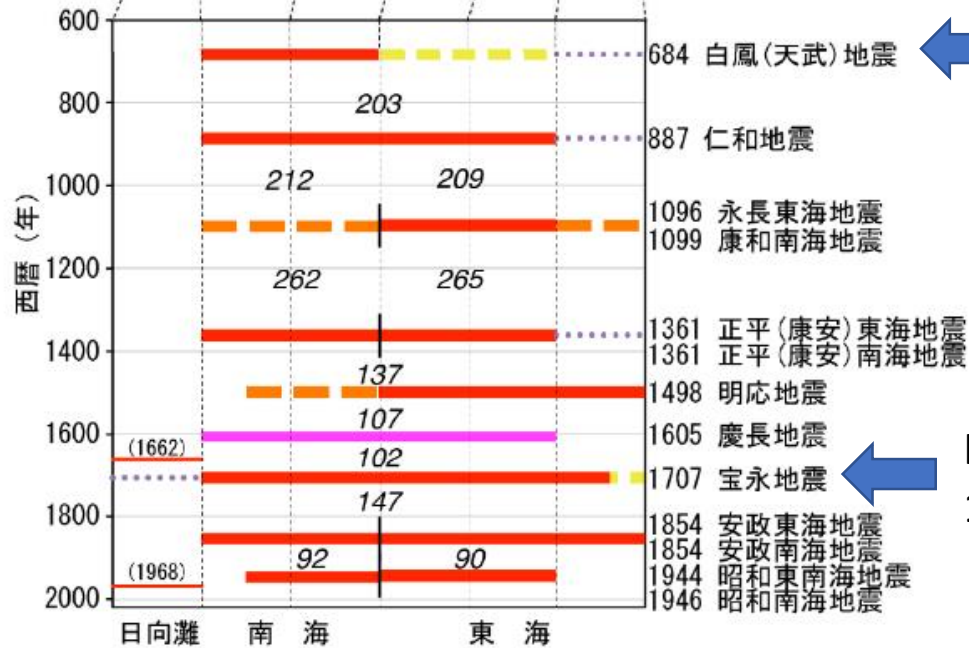
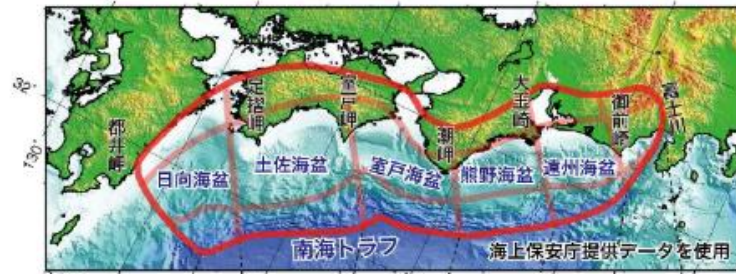
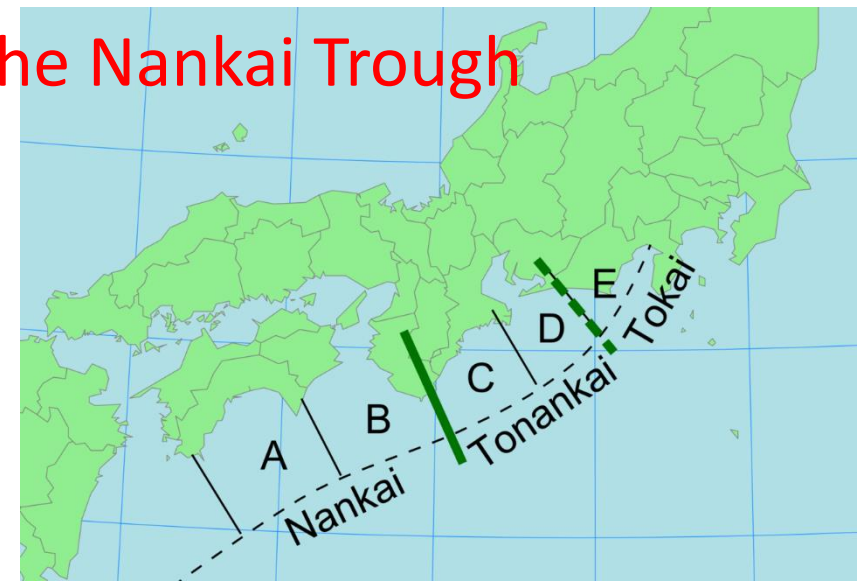
Figure 10

(a) Tide level changes at the 2011 tsunami (by Sugahara and Haraguchi)

(b) Lamination pattern (Gray Scale) of the core.

It was similar to the tidal level changes

Tsunami Hazards along the Nankai Trough



日本書紀地震

Hoei Tsunami
1707

- 確実な震源域
- 確実視されている震源域
- 可能性のある震源域
- 説がある震源域
- 津波地震の可能性が高い地震
- 日向灘のプレート間地震(M7クラス)

過去に発生した南海トラフ地震の震源域の時空間分布

「南海トラフの地震活動の長期評価（第二版）」（地震調査研究推進本部）

南海トラフの地震の発生領域（見直し後） [54][注 4]

	Z	A	B	C	D	E	地震サイクルの再来間隔	
	日向海盆	土佐海盆	室戸海盆	熊野海盆	遠州海盆	駿河湾	南海道沖	東海道沖
古村(2015)による 発生領域 ■: 確実 ■: 可能性がある	684年 白鳳地震						-	
	887年 仁和地震						203年	203年
	1096年 永長地震						474年	209年
	1361年 正平(康安)地震							265年
	1498年 明応地震						346年	137年
	1707年 宝永地震						209年	209年
	1854年 安政地震						147年	147年
	1944/1946年 昭和地震						92年	90年

A pair of the earthquakes segments of Philippine Sea Plate, occurred at 100-200 years interval at more than eight times.

The Next ones would be occurred soon.

RESEARCH ARTICLE

Fossil diatom assemblage changes due to paleoenvironment change, tsunami, and typhoon in southern Japan

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Abstract

Tracking paleoenvironmental change and past event deposits is very important to evaluate the natural hazard spatially. This paper presents how the environment changes and implies the event deposit depending on the diatom assemblage change. To investigate paleoenvironmental change and identify the difference between tsunami and typhoon deposits, we analyze diatoms from the sediments in two coastal lakes in southern Japan where flood deposits have been linked to historical typhoon and tsunami events (Lakes Kawahara and Ryuo). The sediment cores extend from B.C.E. 500 to approximately C.E. 1000 and the downcore variation in diatom assemblages indicates a series of transitions from saline to fresher conditions in both Lake Kawahara and Lake Ryuo between approximately C.E. 500 and 1700. We observe an obvious deviation in diatom assemblages in event deposits previously identified to be either of tsunami or typhoon in origin. For the most prominent event deposit preserved in Lake Ryuo by the Hoei tsunami of C.E. 1707, the deposition of marine diatoms serves as evidence of marine flooding, while the subsequent deposition of soil and freshwater diatoms indicates the mobilization of terrigenous sediment during returning seaward flows. In contrast, the most prominent event deposit in Lake Kawahara is associated with freshwater flooding by the Kamikaze typhoon of C.E. 1281 and contains very low diatom abundances and a peak of freshwater taxa, followed by a peak in diatom counts potentially due to greater biological activity induced by a resultant influx of nutrients and re-oxygenation during the event.

KEYWORDS

diatom assemblage, Holocene, paleoenvironment, tsunami, typhoon

1 | INTRODUCTION

Reconstructing environmental histories along Japan's coastlines is complex due to its location within the prolific northwest Pacific tropical cyclone basin and at the convergence of major tectonic plate boundaries. Extreme flooding from both tsunamis and typhoons impact Japan, with coastal sediments often containing depositional evidence of both. For example, Nanayama et al. (2000) describe deposition from both tsunamis and typhoons in southwestern Hokkaido,

Japan. They identify distinct units within tsunami deposits from landward transport by incoming flows and seaward transport by return flows. In contrast, only marine sediments were evident within a typhoon deposit, and the bedding in this storm layer was consistent with strictly sea-to-land transport. In contrast to the tsunami deposition observations by Nanayama et al. (2000), Komatsubara et al. (2008) found little sedimentary evidence of return flows within tsunami deposits preserved along the Pacific Coast of southeastern Japan in the Tokai region. Instead, Tokai tsunami deposits were

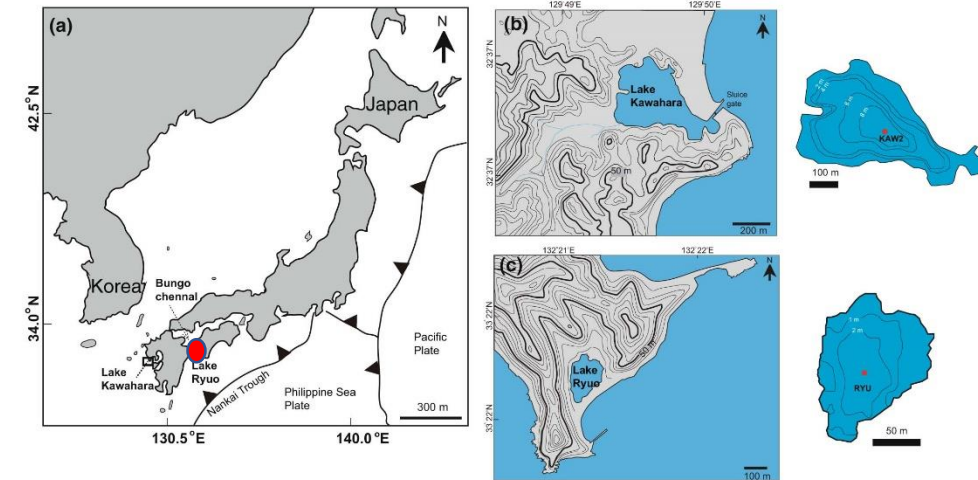


FIGURE 1 Study locations, with monthly average precipitation and temperature: (a) map of study site location. (b). Core site (KAW2) at Lake Kawahara. (c). Core site (RYU) at Lake Ryuo

average high tide elevation of 137.3 cm and a low tide elevation of -162.6 cm relative to mean sea level (MSL) (Japan Meteorological Agency, 2020). A small tributary with a watershed area of 1.74 km^2 drains into the southwestern side of the lake (Hossain et al., 2013). Bedrock within the watershed of Lake Kawahara is mainly composed of Cretaceous metamorphic schist, bordered by ultramafic rocks (Geological Survey of Japan, 2020). Compared with other locations in Japan, the southwestern coastline of Kyushu, where Lake Kawahara is located, is considered relatively stable tectonically (Fukumoto, 2011; Nakada et al., 1994; Okuno et al., 2014). However, the site is more vulnerable to typhoon flooding because typhoons usually come from the southwest and make their first landfall in western Japan by westerly winds (e.g., Elsner & Liu, 2003). RSL was at a high stand 1 m above present sea level at 5500 year. B.P. and has likely decreased until present on the west coast of Kyushu based on the limited data available over the past 2000 years (Yokoyama et al., 1996).

At present, the lake is freshwater with eutrophic conditions, with a distinct thermocline between February and October each year (Furumoto et al., 1999). Lake Kawahara was historically brackish until 1974, when saltwater was pumped from the hypolimnion, followed by the construction of a sluice gate across the lagoon's ocean inlet completed in 1979 (Figure 1b) (Hossain et al., 2013).

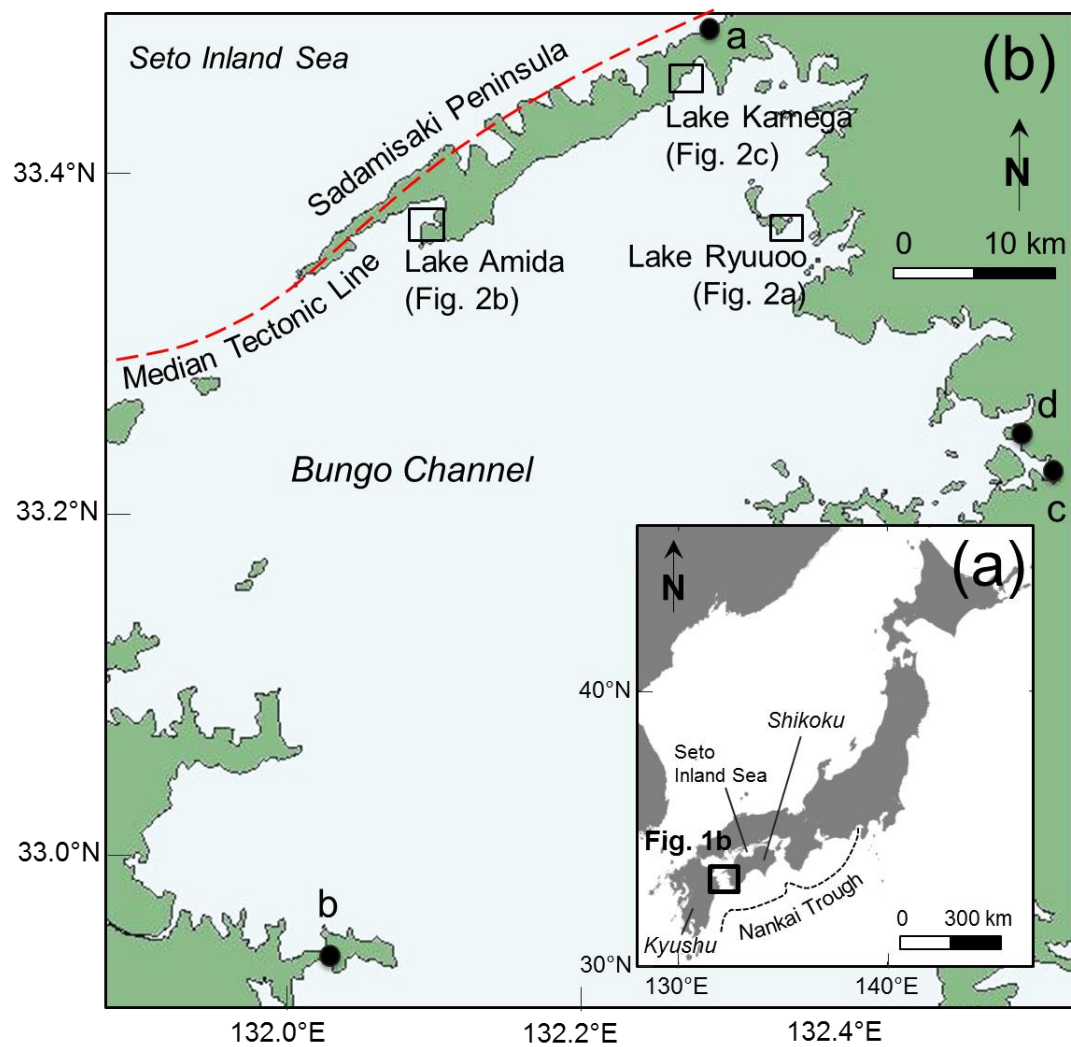
2.2 | Lake Ryuo

Lake Ryuo lies on a small island at the northern end of the Bungo Channel, which separates the mainland islands of Shikoku and Kyushu

(Figure 1a). The lake is housed within a drowned river valley and is separated from the sea by a cobble and sand barrier beach that is 200 m long, 40 m wide, and 3–4 m above MSL. Lake Ryuo is relatively shallow, reaching a maximum of 2 m depth at its center (Figure 1c). The regional tide range is ~ 230 cm, with an average high tide elevation of 105 cm and a low tide elevation of -126.4 cm relative to MSL (Japan Meteorological Agency, 2020). The bedrock in the Lake Ryuo watershed is primarily Cretaceous sandstone (Geological Survey of Japan, 2020). Change in RSL is associated with rapid uplift and subsidence linked with Nankai Trough subduction zone earthquake occurrences offshore to the southeast (Figure 1a) (e.g., Baranes et al., 2018; Furumura et al., 2011) and local seismicity along the Japan Median Tectonic Line to the northwest (Okada, 1973, 1980; Research Group for Active Faults of Japan, 1991). Anthropogenic alterations to Lake Ryuo include a 2-m sea wall built along the barrier beach in 1964, a small jetty built offshore in 1980, and a small underground pipe installed in the mid-1900s primarily to allow drainage to the sea following high freshwater run-off events (Baranes et al., 2016).

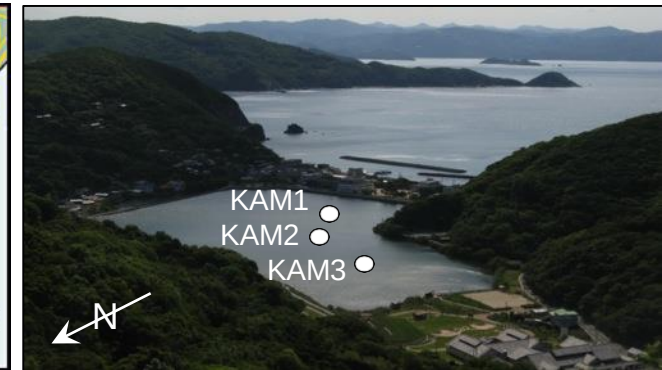
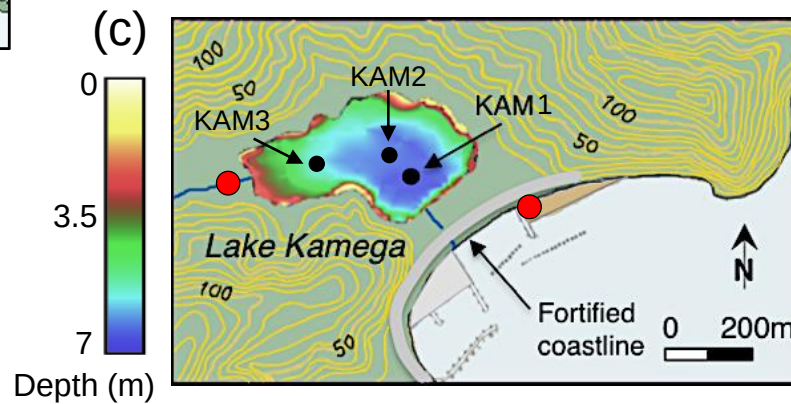
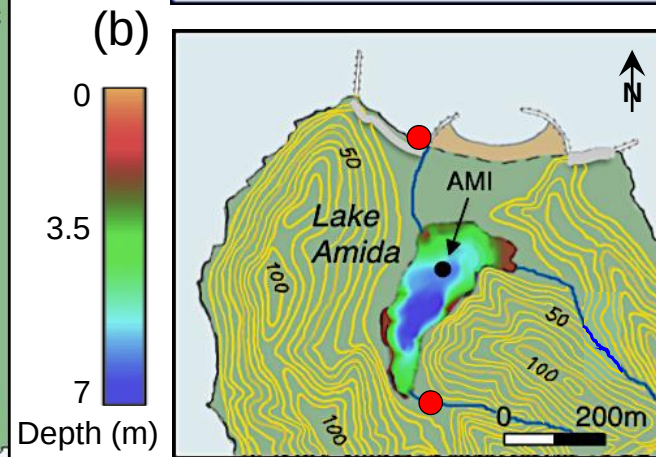
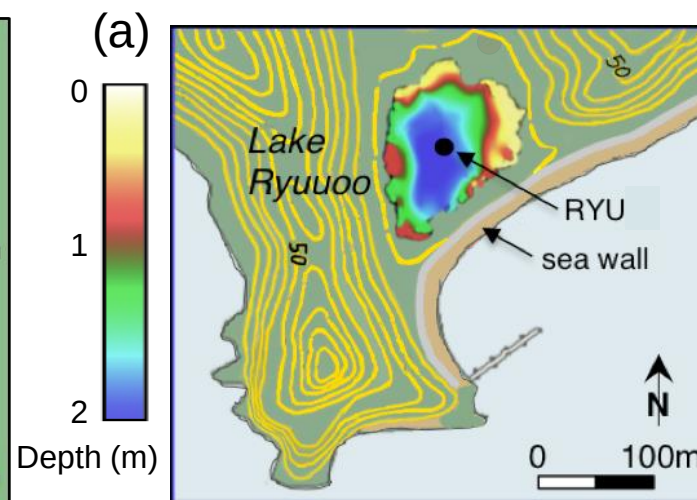
3 | MATERIAL AND METHODS

Diatom assemblages were analyzed at the primary core sites from Lake Kawahara and Lake Ryuo. KAW2 (32.62334°N , 129.83264°E) core was collected from Lake Kawahara in November 2010, and RYU core (33.37238°N , 132.36°E) was collected from Lake Ryuo in May 2012. The depth-to-age models, lithological descriptions, elemental abundance depth profiles from ITRAX X-ray fluorescence (XRF), and

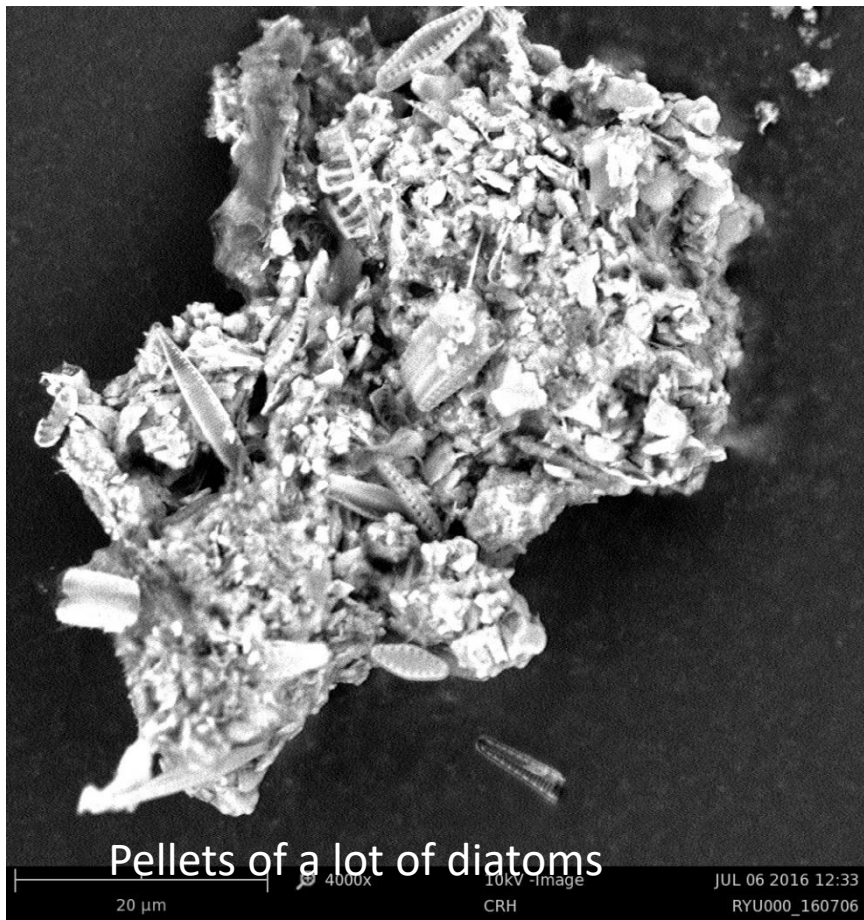


Baranes *et al.*, 2016

These lakes are suitable to presume the environmental changes and hazard histories.

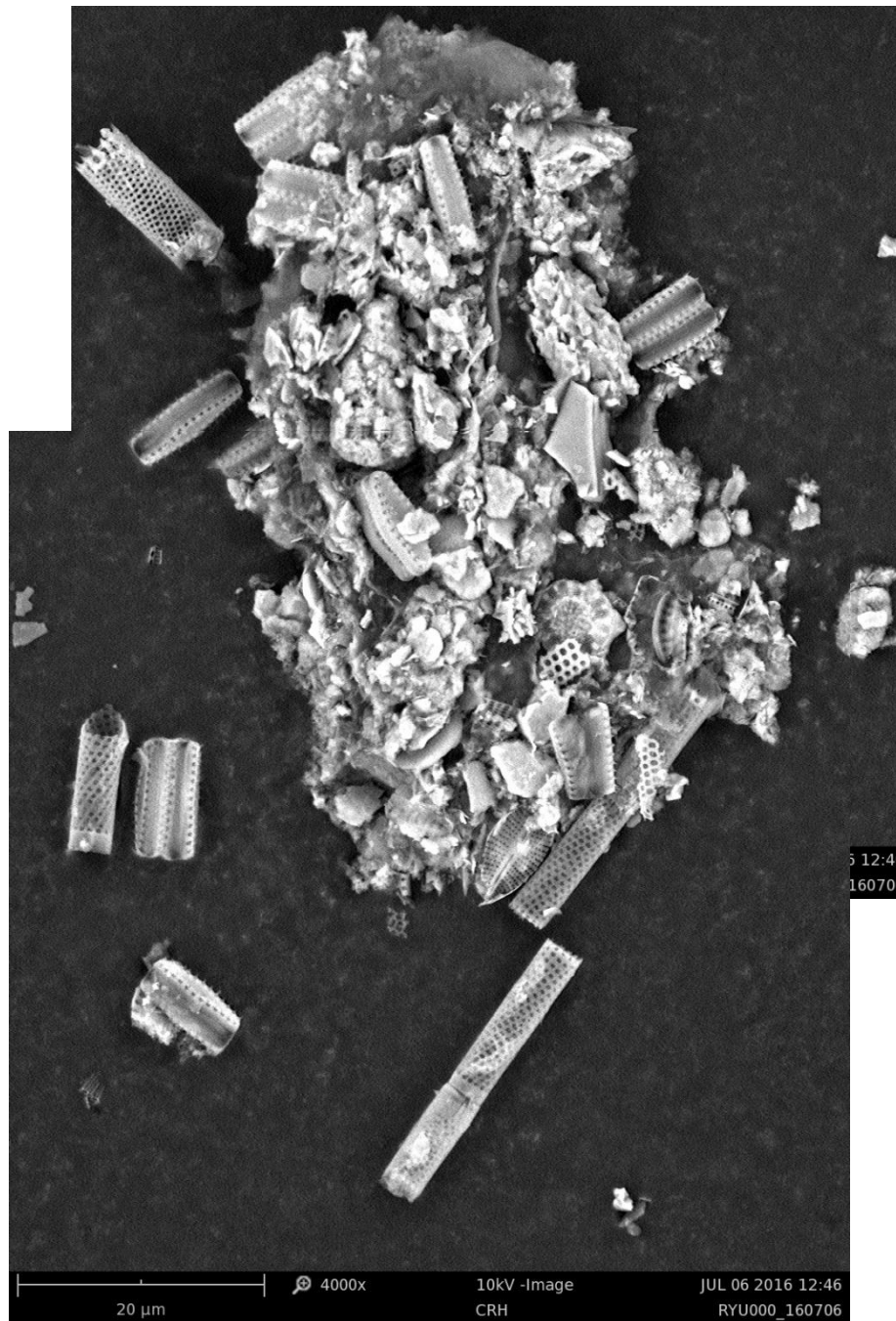


● Surface sample locations

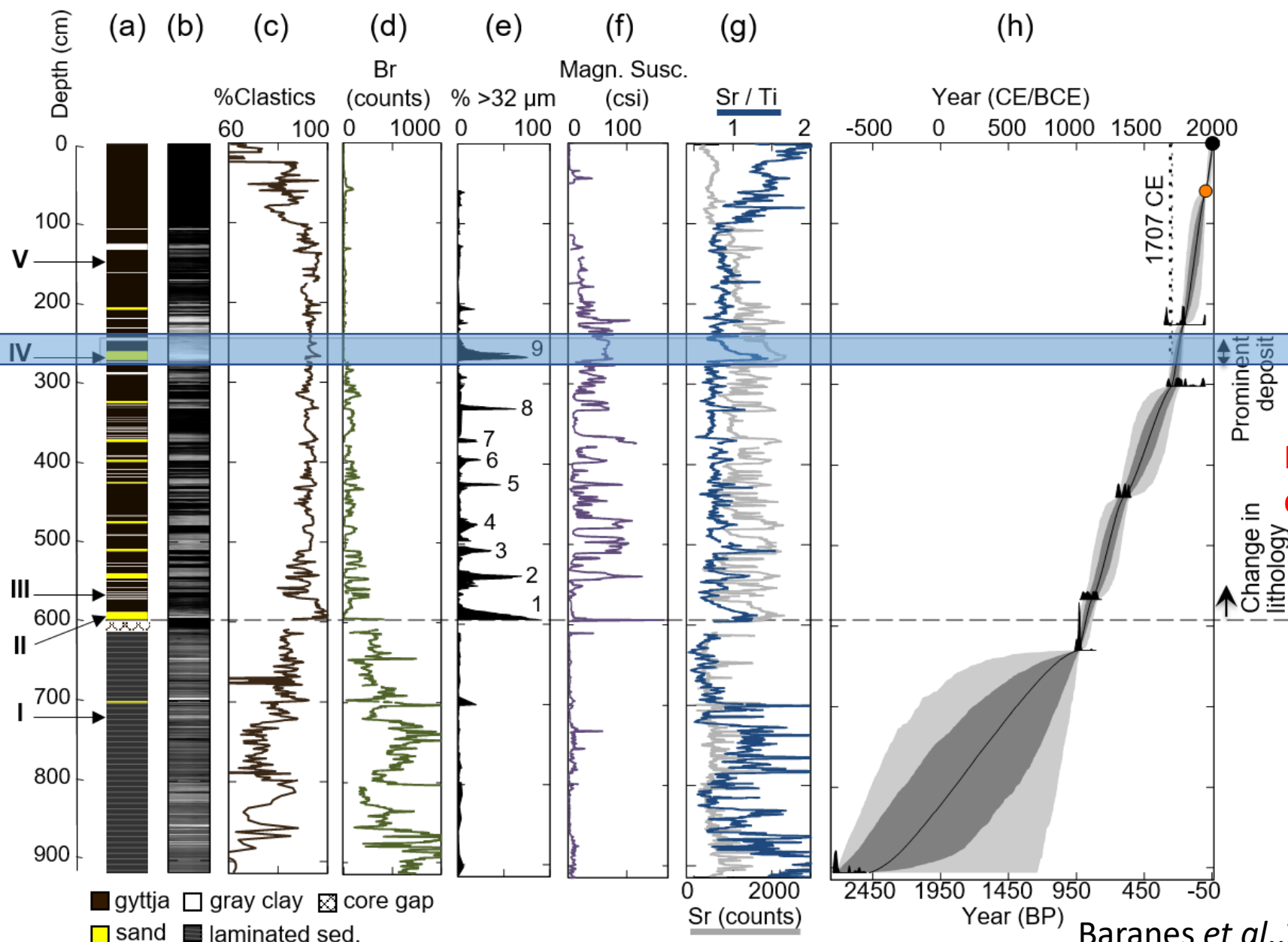


SEM photos at Surface deposit of
Lake Ryuo 龍王池

More than 10,000 diatoms were
observed in 1mg deposits



Bromine 臭素

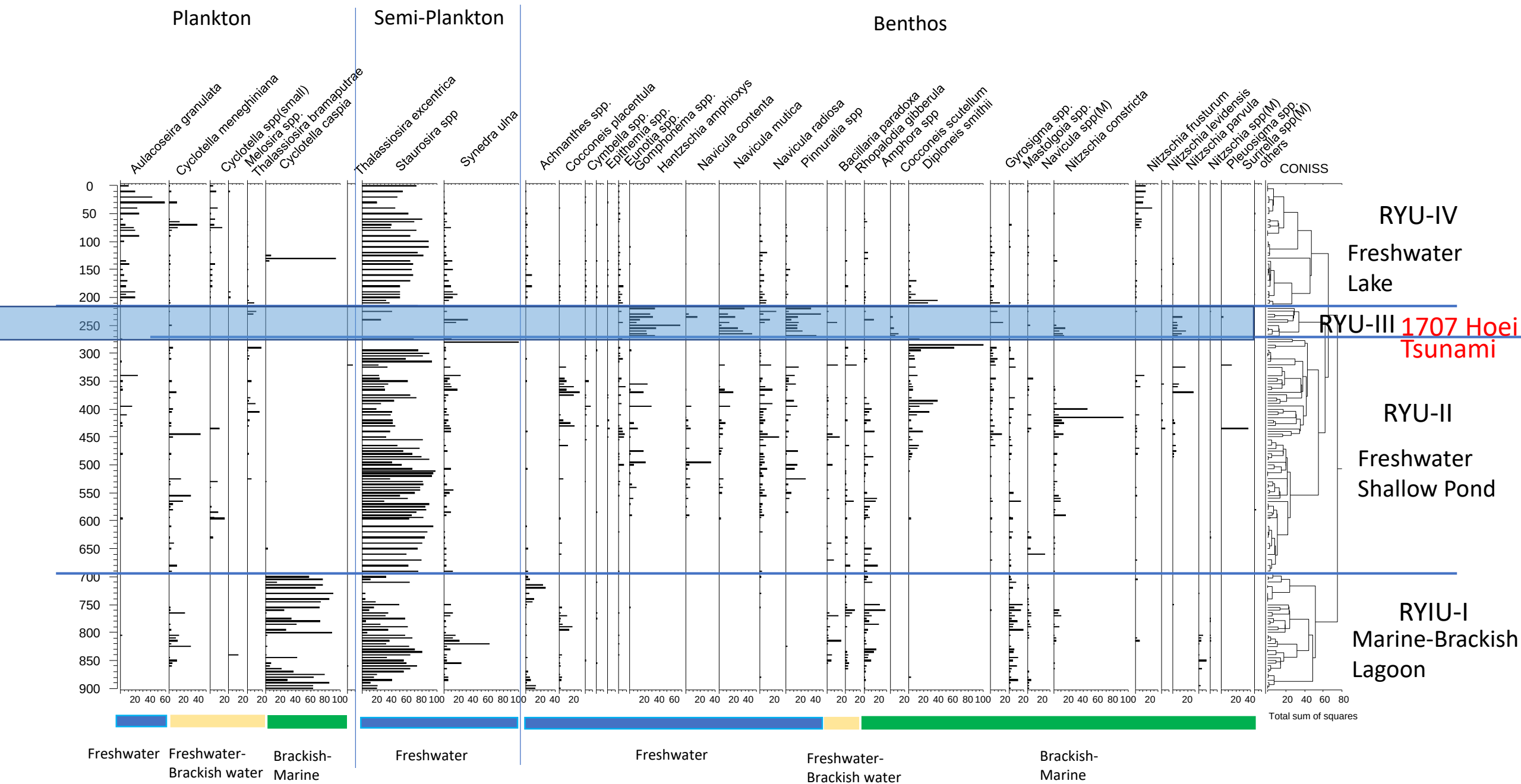


Lake Ryuo 龍王池

Hoei Tsunami (1707) 宝永津波
270 cm depth

Nine times of Sand sedimentation
during 250-600 cm depth

Baranes *et al.*, 2016



0 – 300 cm

Plankton

Semi-Plankton

Benthos

Marine



1707AD tsunami unit
Hoei Tsunami
宝永津波



Marine coast

Freshwater
Freshwater-
Brackish water
Brackish-
Marine

Freshwater

Freshwater

Freshwater-
Brackish water

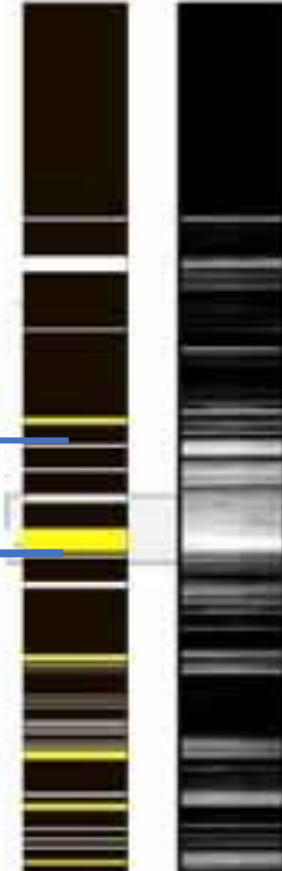
Brackish-
Marine

Peat and wet soil surrounding the lake

Depth (cm)

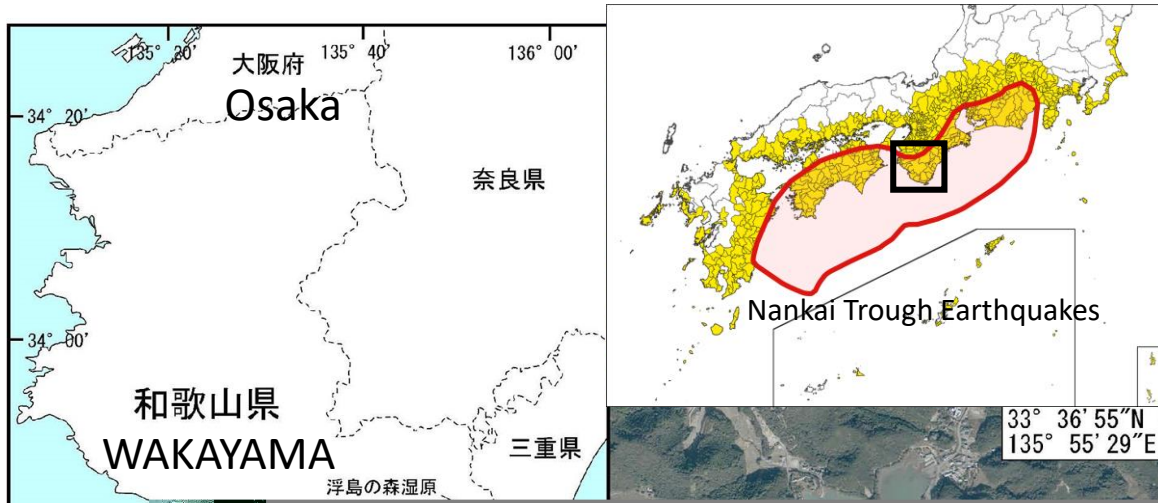
(a) (b)

0
100
200
300
400



Yukashi-Gata Lagoon, a shallow lagoon, along the Nankai Trough and Tsunami Deposits

調査研究場所



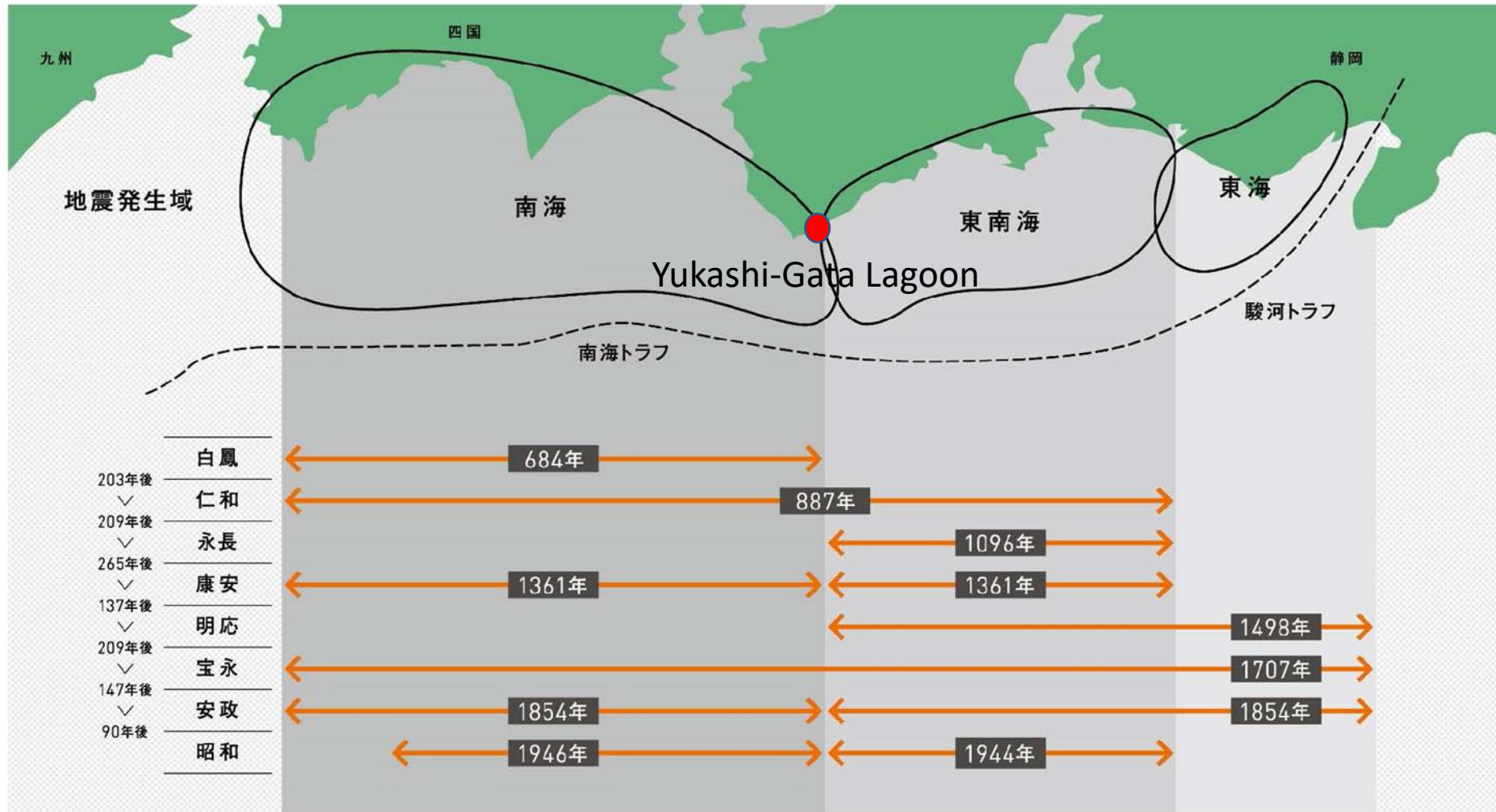
掘削調査 (2023.8.20)



Yukashi-Gata Lagoon

Shallow Lagoon sediments ⇒ Diatom valves, Diatom Pellets are destroyed by high magnitude tidal currents which cause huge physical and chemical stresses to diatom valves.

南海トラフ地震津波の周期



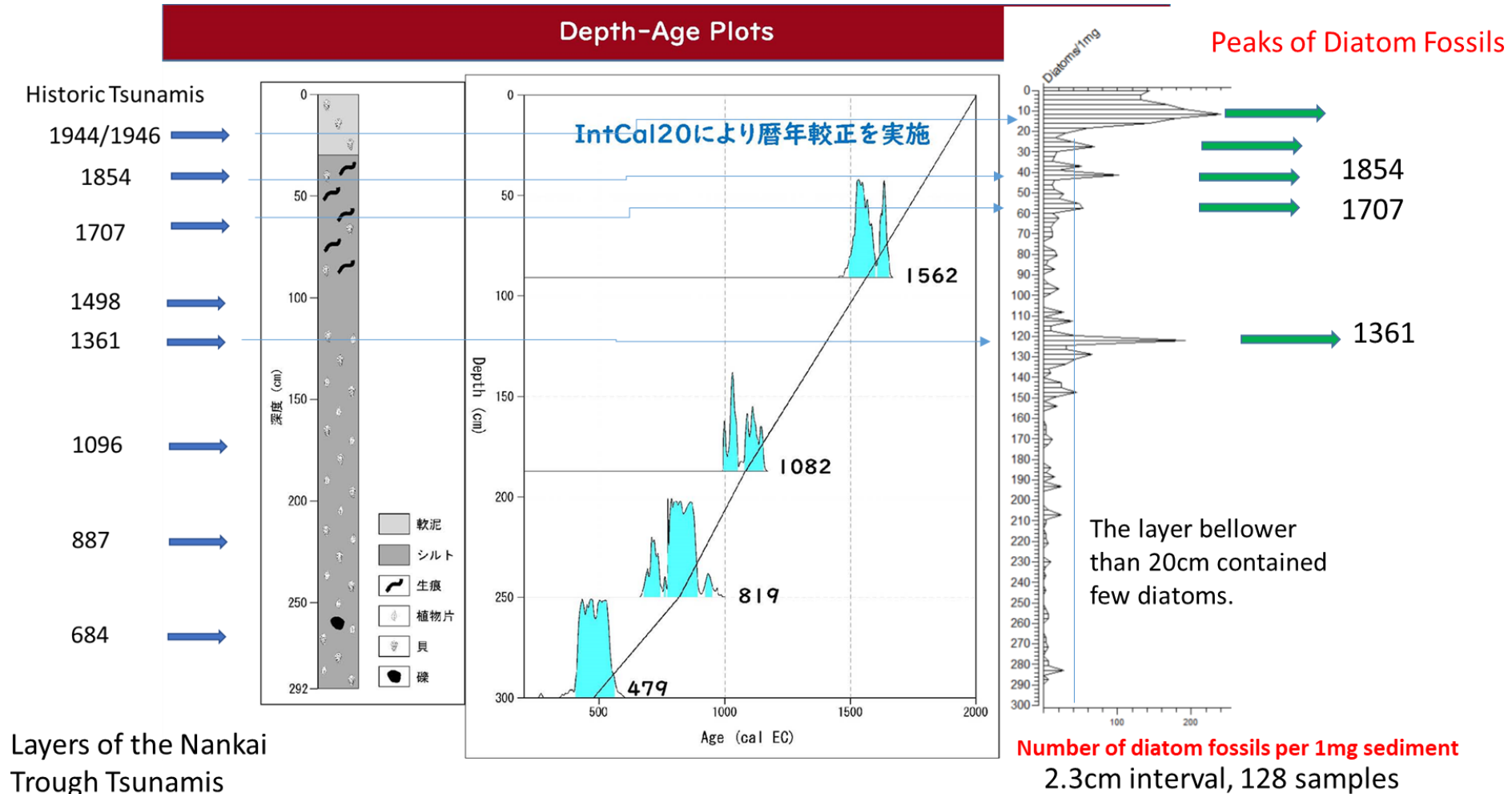
コアの層相



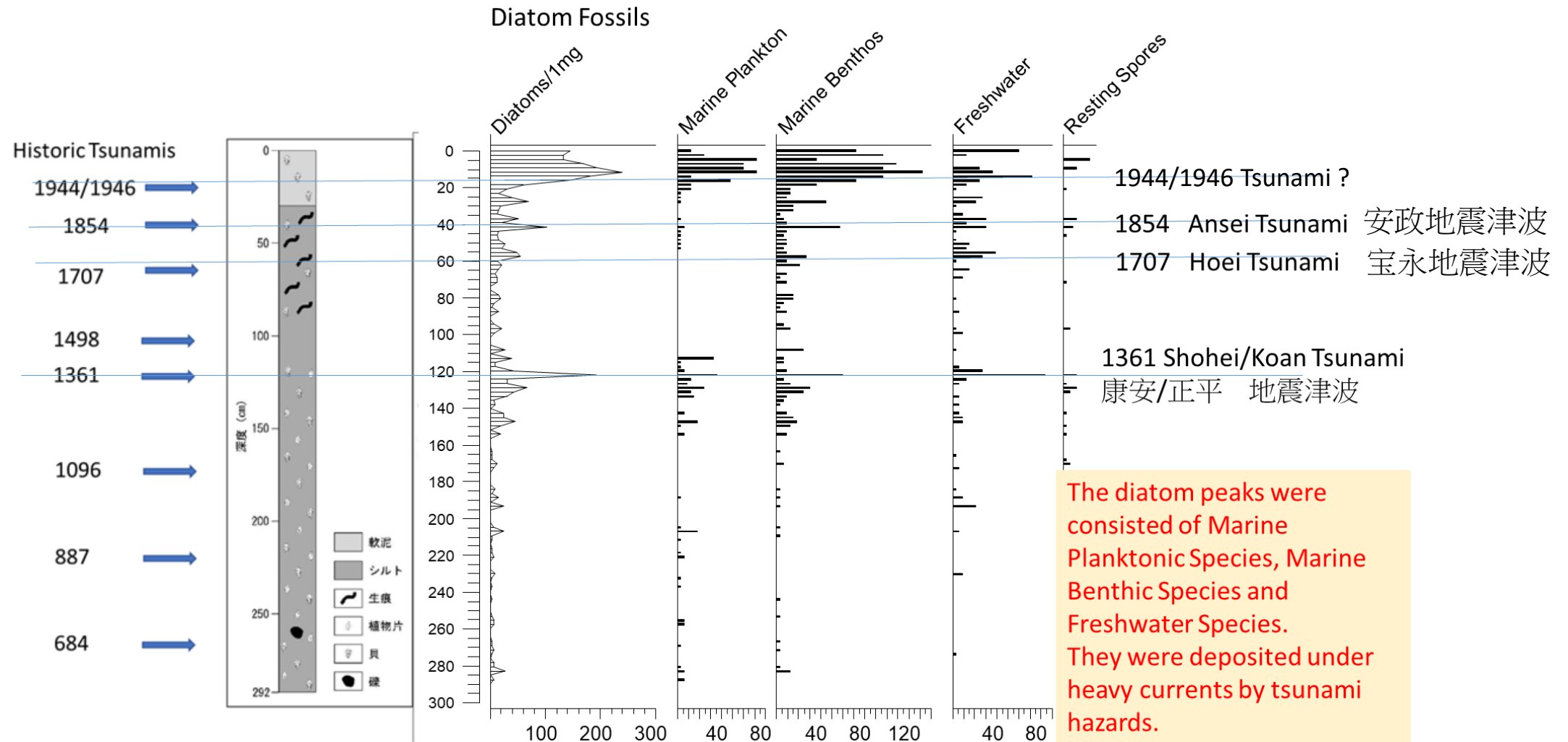
The core was Massive. We could not observe Tsunami deposits such as the Sand Layers.



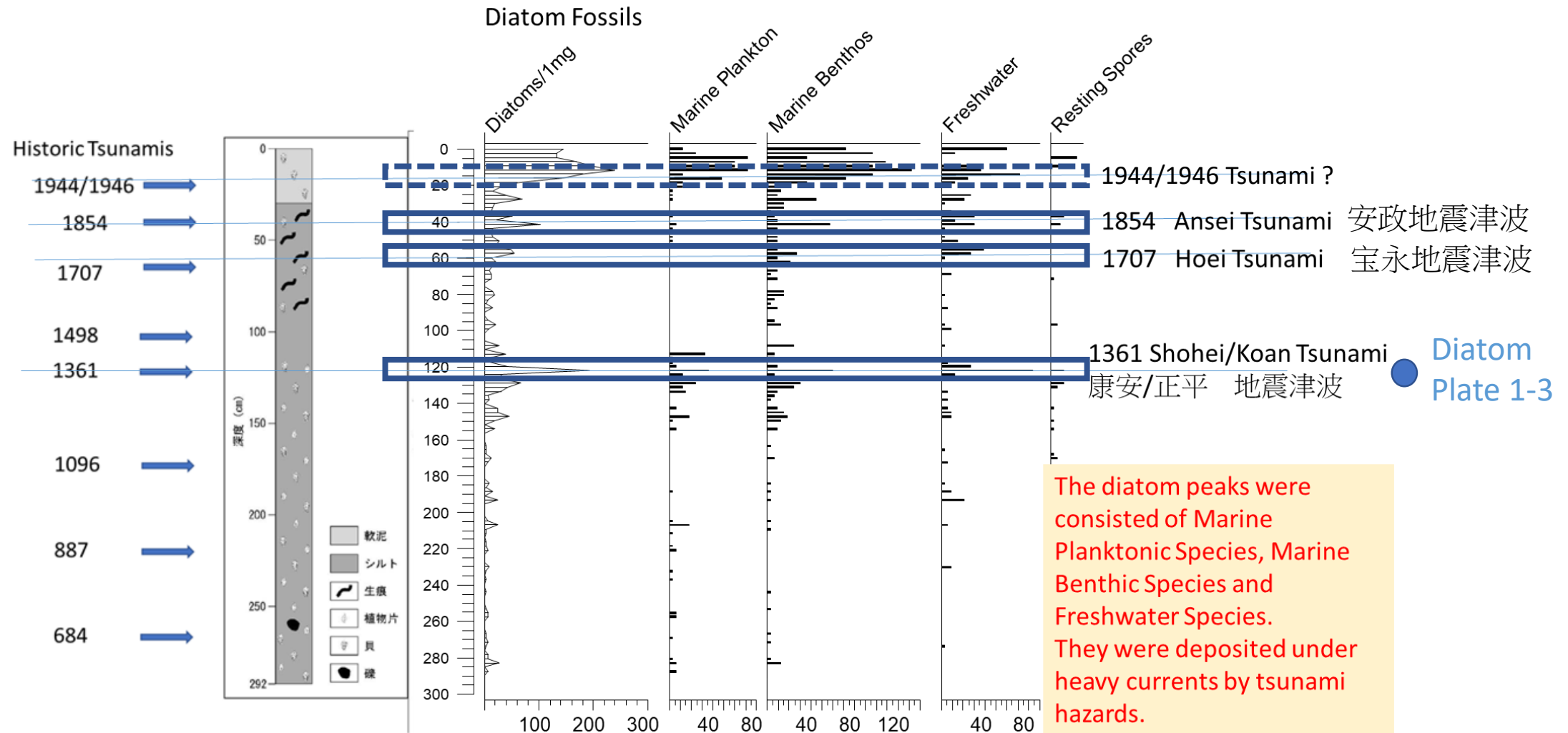
(2)Yukashi-Gata Lagoon, a shallow lagoon, along the Nankai Trough and Tsunami Deposits

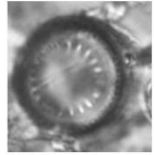
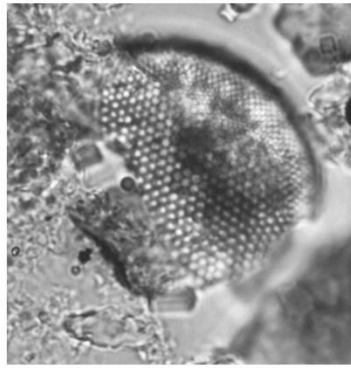
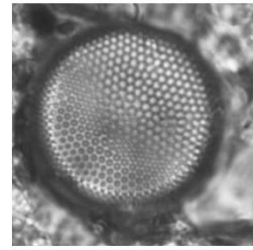
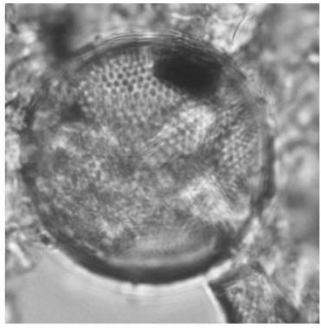


(2)Yukashi-Gata Lagoon, a shallow lagoon, along the Nankai Trough and Tsunami Deposits



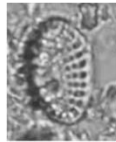
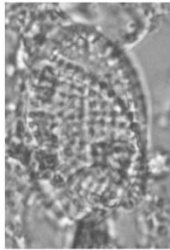
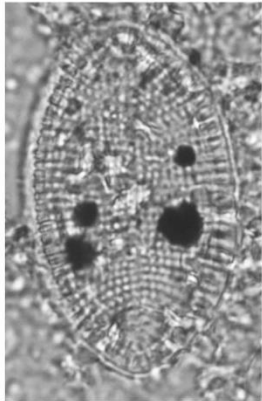
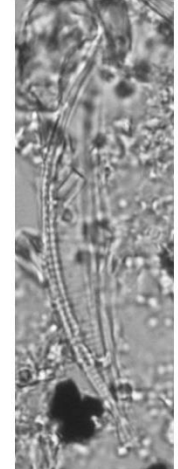
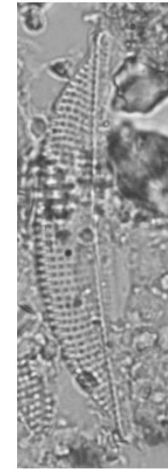
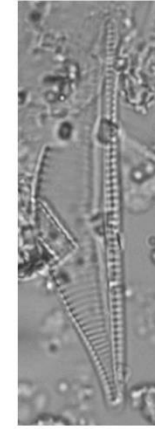
(2)Yukashi-Gata Lagoon, a shallow lagoon, along the Nankai Trough and Tsunami Deposits





Oceanic Species
Not Shallow Lagoon Species

Plate 1



Shallow Lagoon Species

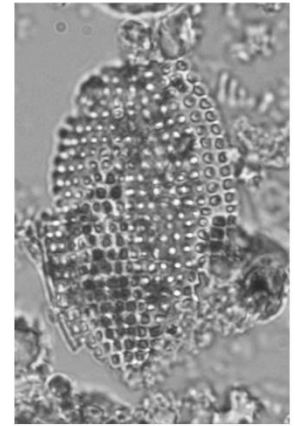
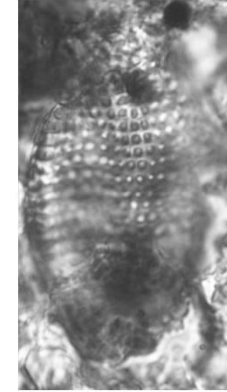


Plate2-1

Yukashi-Gata

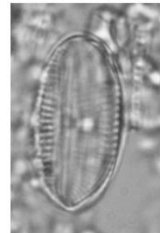
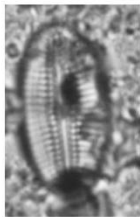
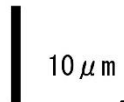
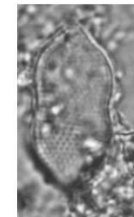
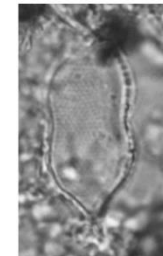
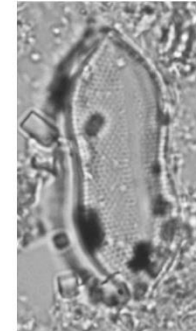
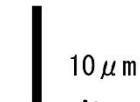
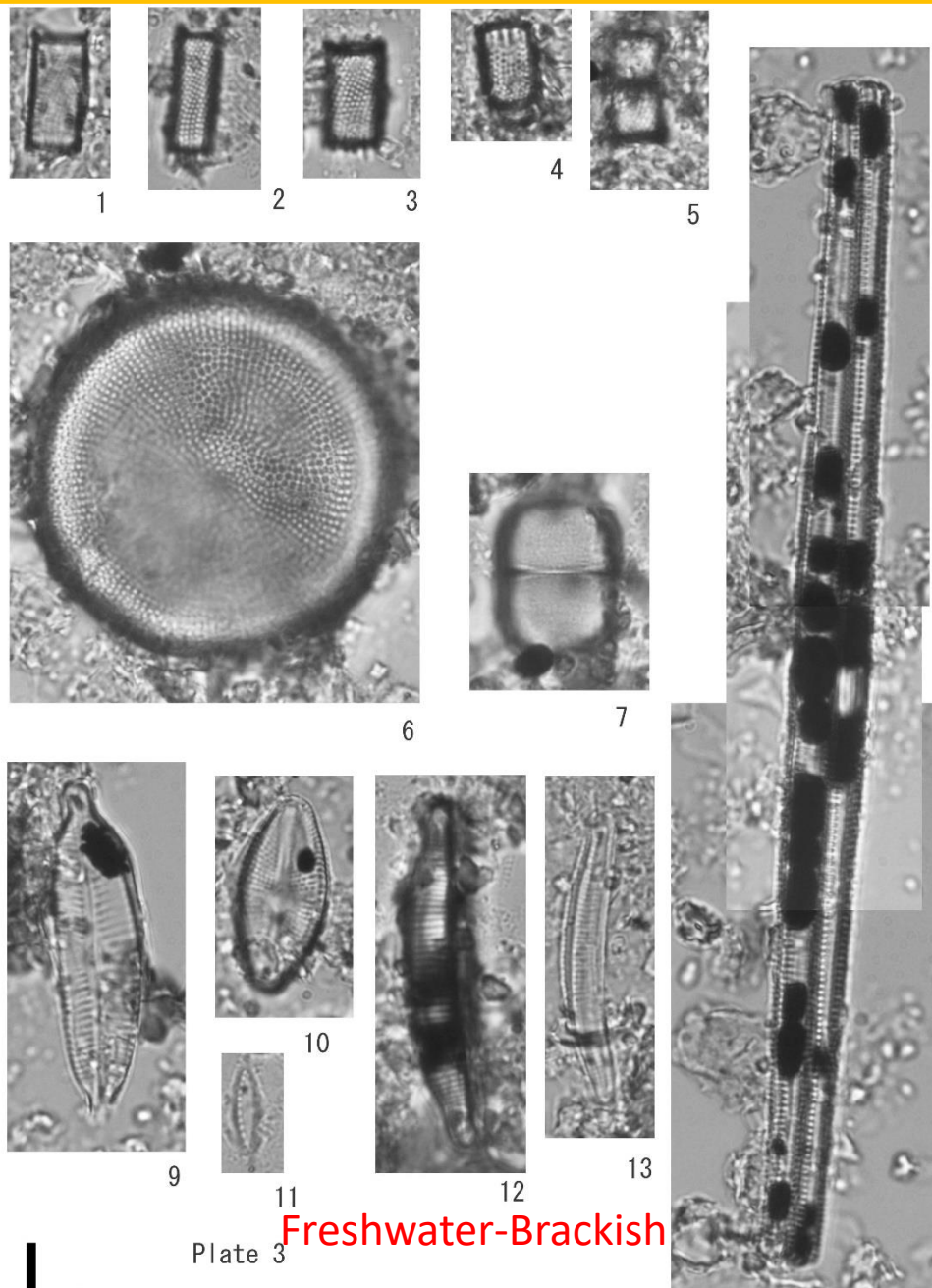


Plate 2-2

Yukashi-Gata





Diatom Catalog from the Shohei-Koan Tsunami (AD1361) Deposits at Yukashi-Gata Lagoon

Plate 1 (Marine Plankton)

1-3: *Thalassiosira* sp.

Thalassiosira eccentrica (Ehrenberg) Cleve 1904

4: *Paralia sulcata* (Ehrenberg) Cleve 1873

Plate 2-1 (Marine Benthos)

1-4: *Cocconeis scutellum* Ehrenberg 1838

5-8: *Diploneis pseudovalis* Hustedt 1930

Plate 2-2 (Marine Benthos)

1-5: *Amphora* sp.

Amphora coffeaeformis (C.Agardh) Kützing, 1844

Amphora coffeiformis (C.Agardh) Kützing 1844

(*Halamphora coffeiformis* (C.Agardh) Levkov 2009)

5-7: *Nitzschia punctata* (W.Smith) Grunow 1878 (*Tryblionella punctata* W.Smith 1853)

8-10: *Nitzschia panduriformis* W.Gregory 1857

(*Psammodictyon panduriforme* (W.Gregory) D.G.Mann 1990)

11: *Nitzschia lanceola* Grunow 1880

Plate 3 (Freshwater –Brackish)

1-5: *Aulacoseira ambigua* (Grunow) Simonsen 1979

6: *Thalassiosira bramaputrae* (Ehrenberg) Håkansson & Locker 1981

7: *Melosira varians* C.Agardh 1827

8: *Synedra ulna* (Nitzsch) Ehrenberg 1832 (*Ulnaria ulna* (Nitzsch) Compère 2001)

9: *Cymbella naviculiformis* Auerswald ex Heiberg 1863

(*Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer 2003)

10: *Navicula mutica* Kützing 1844 (*Luticola mutica* (Kützing) D.G.Mann 1990)

11: *Nitzschia inconspicua* Grunow 1862

12-13: *Eunotia pectinalis* (Kützing) Rabenhorst 1864

Plate 3

Yukashi-Gata

10 μm

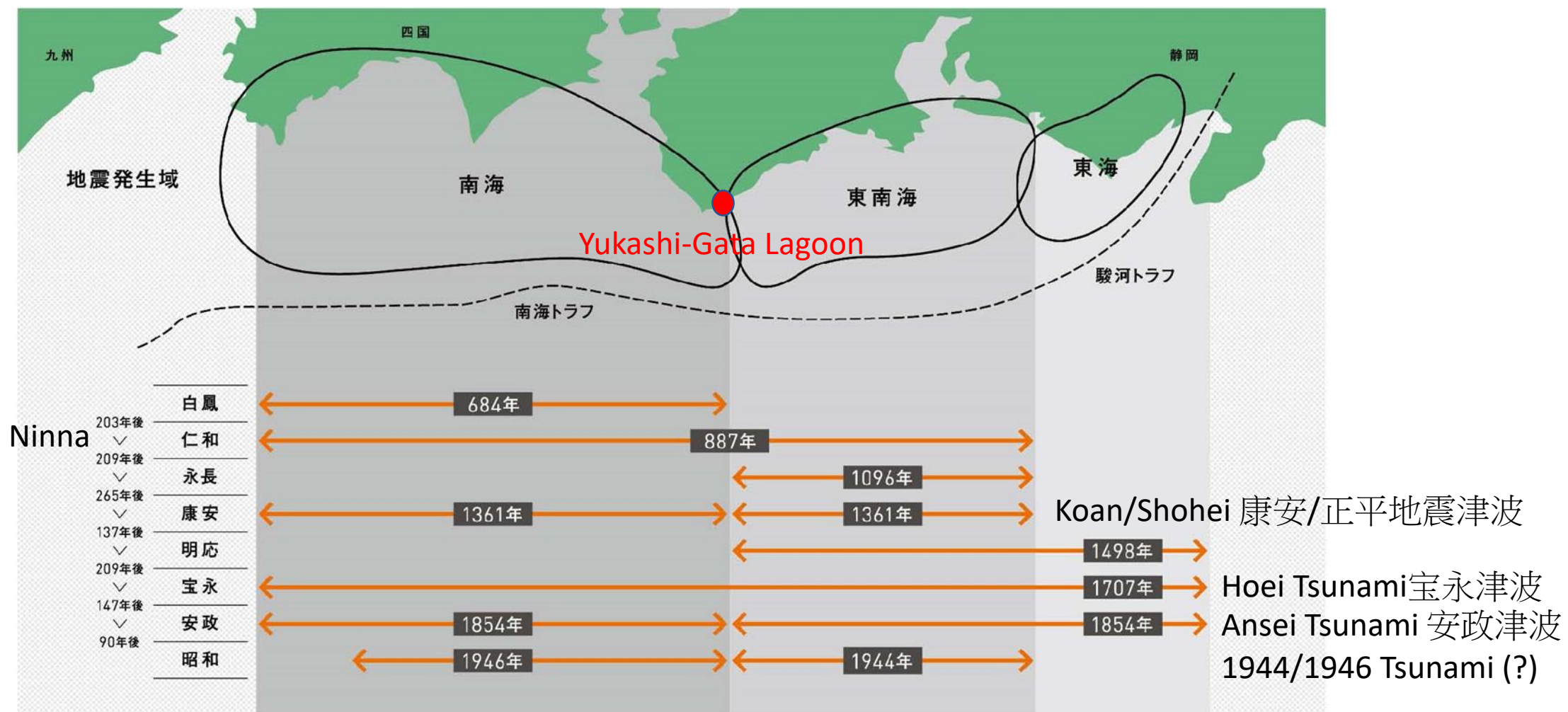
Freshwater-Brackish

Impossible to Live at Lagoons 8

Yukashi-Gata Lagoon, a shallow lagoon, along the Nankai Trough and Tsunami Deposits

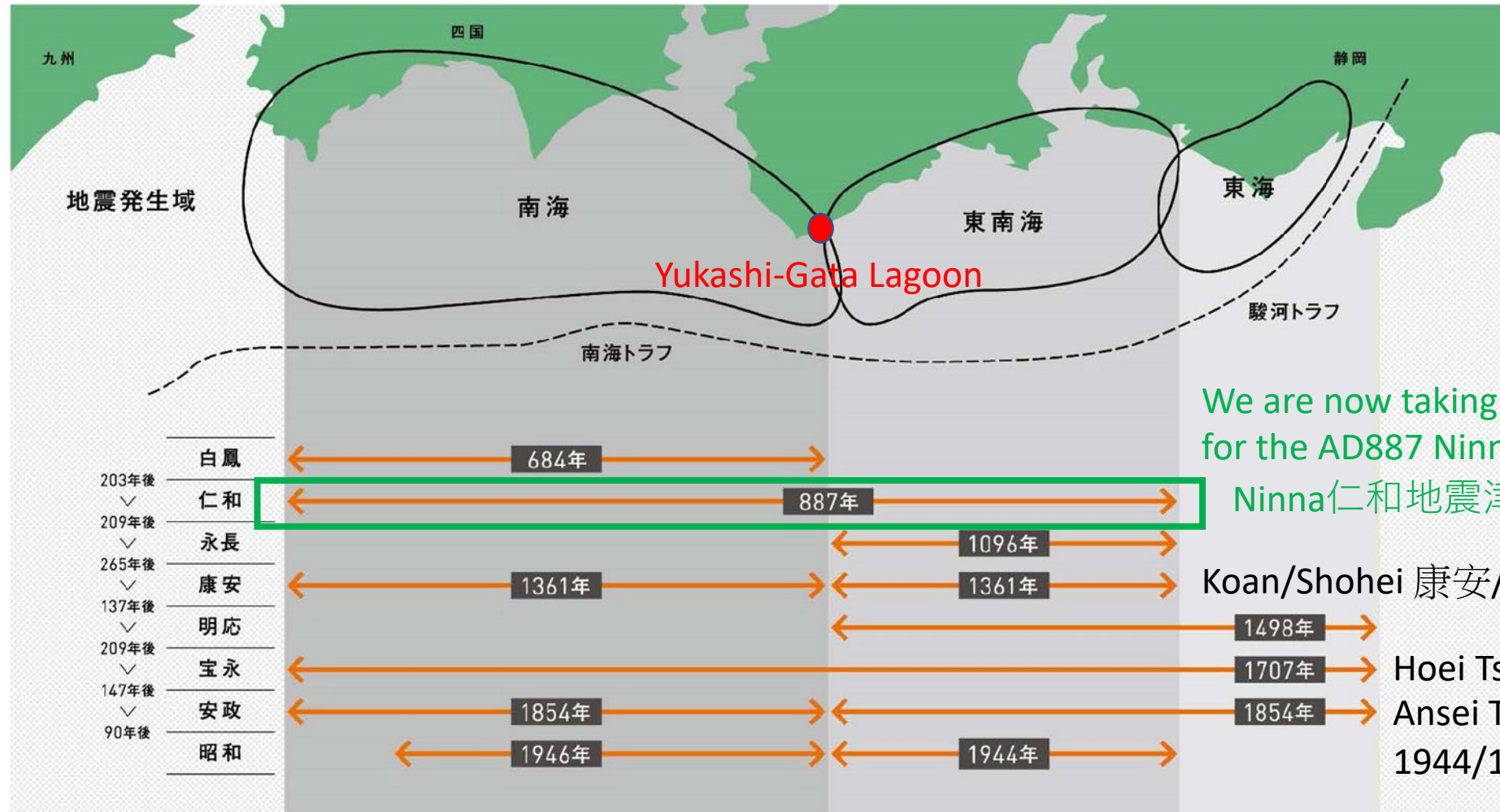
- Diatom Valves (Diatom Pellets) were easily broken by the strong tidal currents, and were hardly preserved in the sediment at the **gentle sedimentation** (the Inter-Earthquake stage).
- However an **Anomalous** (非日常的) **deposits** were occurred by the Tsunami Currents, and Diatom Valves with Freshwater species, Marine benthic species, Marine Planktonic species, were deposited together in the Lagoon floor.

南海トラフ地震津波の周期



Historic Earthquakes and Tsunamis along the Nankai Trough

南海トラフ地震津波の周期



Historic Earthquakes and Tsunamis along the Nankai Trough

仁和Ninna地震（AD887年）日本三代実録

The Nankai Trough Earthquake

- 卅日辛丑、申時、地大震動、經歷數剋震猶不止、天皇出仁寿殿、御紫宸殿南庭、命大藏省、立七丈幄二、為御在所、諸司倉屋及東西京廬舍、往往顛覆、壓殺者衆、或有失神頓死者、亥時又震三度、**五畿内七道**諸国、同日大震、官舍多損、**海潮漲陸、溺死者不可勝計**、其中摂津国尤甚、夜中東西有声、如雷者二、
（AD887年8月22日）
- 五畿内 大和、山城、和泉、河内、摂津五か国 近畿地方
- 七道 東海道、東山道、北陸道、山陽道、山陰道、南海道、西海道（日本全域）

17 Years later from the Jogan Earthquake in 869

2026 is 15 Years later from the Tohoku Earthquake in 2011

Legend of Heian Sand Layer 平安砂層

- 仁和三年七月三十日 (**AD887.08.22**) の仁和地震によって、北八ヶ岳の一角の天狗岳が大きく崩れて、流れ下った土砂が千曲川をせき止めて湖をつくった。その湖は、翌年の梅雨時の五月八日 (**AD888.06.20**) に決壊して下流に洪水を引き起こした (石橋、1999、2000)。



Prof. Katsuhiko ISHIBASHI 石橋克彦



Huge Earthquake(Ninna Earthquake in 887) made a temporal lake along the mountain valley. The lake crushed next year (in 888), and occurred a huge Flooding.

イ)「類聚三代格」(平安中期) ……去年(仁和三年)七月卅日，坤德失静，地震成災，八月廿日亦有大風洪水之沴，前後遭重害者卅州有餘国，或海水泛溢，人民婦魚鼈国，或邑野陷没，廨宇變蛟竜之家，呼嗟猪沢之功未成，象耕之期奄至，願念辺氓，誠軫中懷，朕忝以滂德，丕承洪基，内纏陟岵之慟，多惕臨谷之危，重今月(仁和四年五月)八日，信濃国山頽河溢，唐突六郡，城廬扞地而流漂，戸口随波而没溺，百姓何辜，頻罹此禍，徒癸亥(沈力)首之歎，……

ロ)「扶桑略記」(平安後期) 仁和三年，七月卅日辛丑，申時，地大震，数刻不止，天皇出仁寿殿，御紫宸殿南庭，命大藏省，立七丈幄二，為御在所，諸司舍屋，及東西京廬舍，往々顛覆，压殺者衆，或有失神頓死者，同日亥時，又震三度，五畿七道諸国，同日大振，官舍多損，海潮漲陸，溺死者不可勝計，其中摂津国尤甚，信乃国，大山頽崩，巨河溢流，六郡城廬扞地漂流，牛馬男女流死成丘，

ハ)「日本紀略」(平安末期) (仁和四年)五月八日，信濃国大水，山頽河溢，

Huge Earthquake(Ninna Earthquake in 887)
The Mountain Collapse occurred a huge lake

One year 303 days

Huge Flooding in 888 at 信濃国(Olde name of Nagano)

仁和3年7月30日 ⇒ AD887, August 22

仁和4年5月8日 ⇒ AD888, June 20



Tshibashi Model

887AD Ninna Earthquake

Nankai Trough



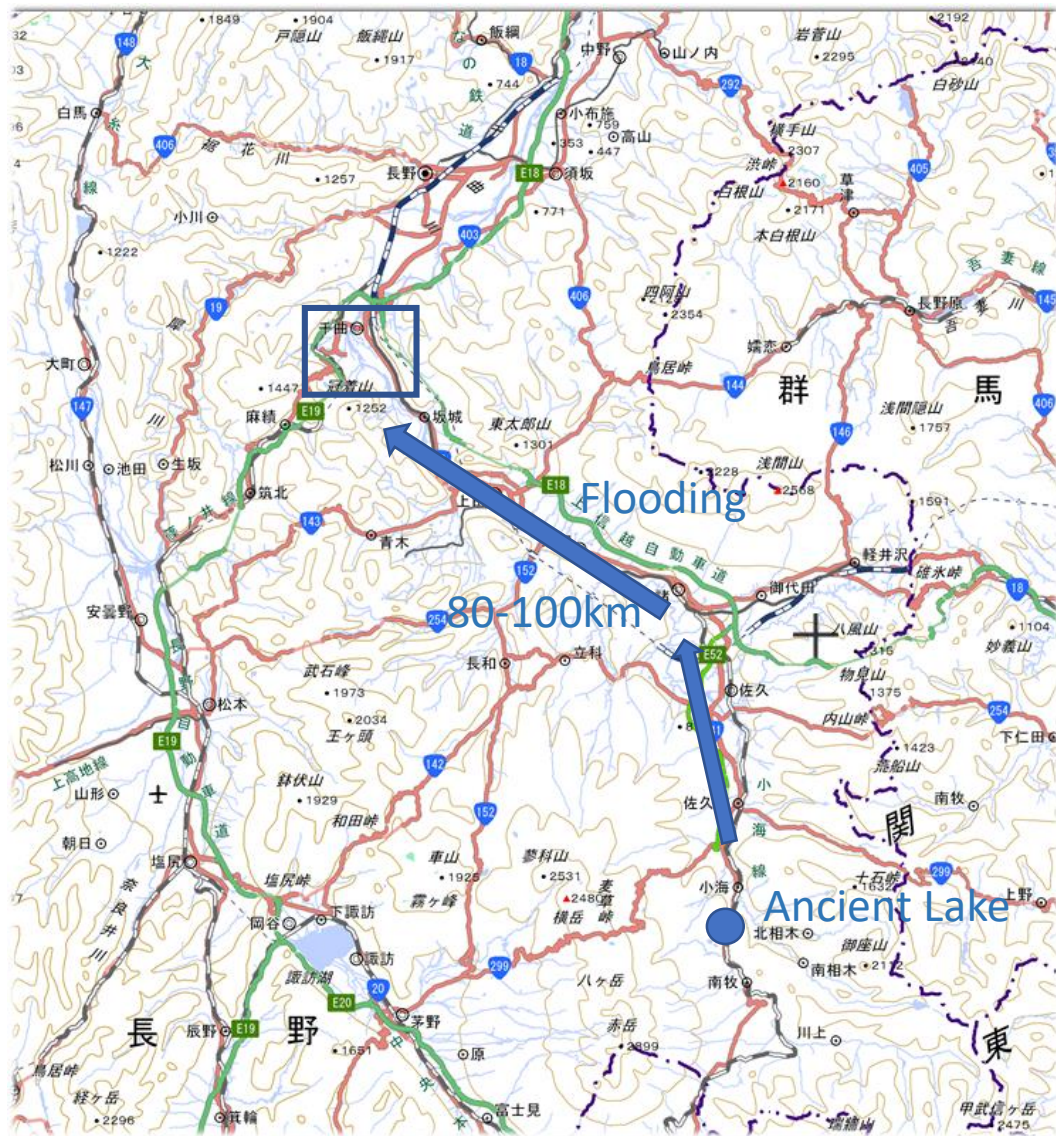


図9 本誓寺遺跡の位置
＜拡大表示＞

(千曲市教育委員会説明資料)



写真5 洪水砂の堆積状況

試料については、緯度経度に「*」を付記：¹⁴C年代測定結果のうち、典型試料の測定値はベータ線計測法、その他は加速器質量分析法（AMS）による値：δ¹³Cは、AMS装置により測定した試料炭素の¹³C濃度を基準試料からのずれとして表した値（記載がない場合は「—」とする）

<https://isabou.net/knowhow/colum-rekishi/colum73.asp>

Huge Earthquake

酸素同位体比年輪年代法

Tree ring dating using oxygen isotopes

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Institute for Earth Science and
Disaster Resilience, NIED）

1 year or seasons determination of
the tree falling year.

Yamada et al.(2019) presumed
that it occurred at spring season in
888

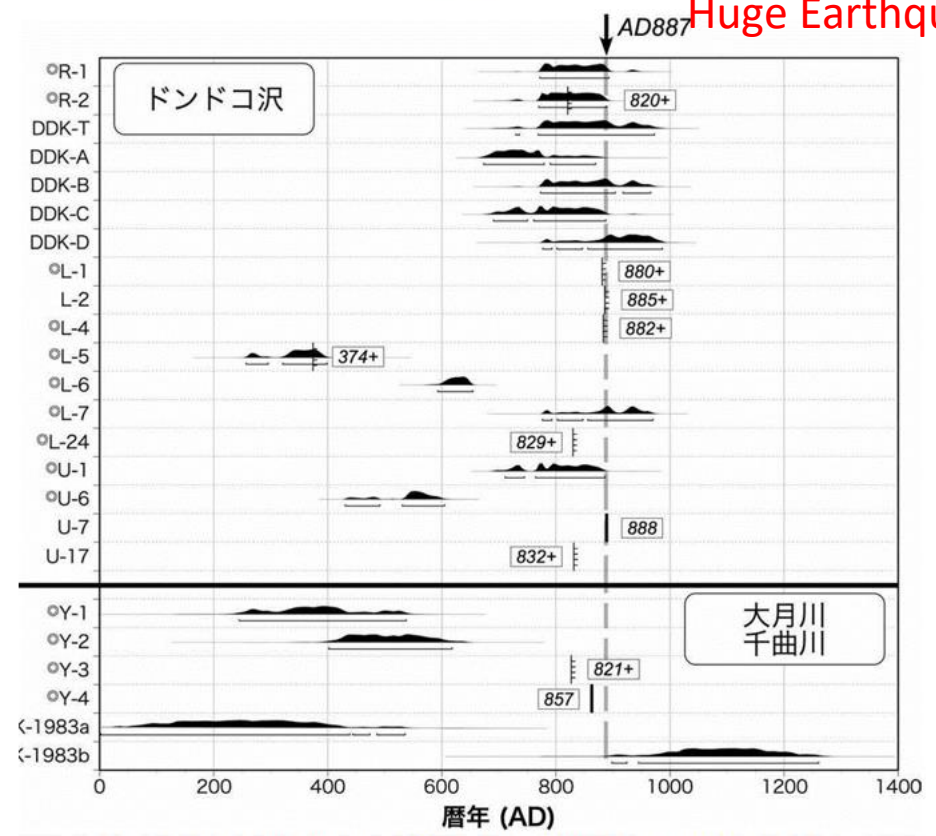


図8 暦年校正した¹⁴C年代範囲の確率分布とδ180年輪年代測定結果（山田ほか，2021a）

C14 dating from 平安砂層

以上の年代測定結果などをまとめると、以下ようになります。
ハケ岳地域では、千曲川沿いに分布するODA堆積物中から出土した樹皮を確認できる倒伏樹幹の枯死年はAD857年であり、大月川沿いで出土した倒伏樹幹はAD821年以降であることが明らかになりました。
一方、新たな2つの¹⁴C年代測定結果（Y-1：244-537calAD, Y2：401-617）は200年以上も古く、先行研究の結果やこれらの樹幹試料の枯死年とは必ずしも一致せず、ODAの発生年代との関連は明らかではありません。しかしながら、現在千曲川沿いは護岸工が施されて露頭がほとんど残っておらず、堆積物層序や倒伏樹木の再調査は困難です。ODA堆積物の年代測定がまだ行われていない崩壊発生源の詳細な調査を

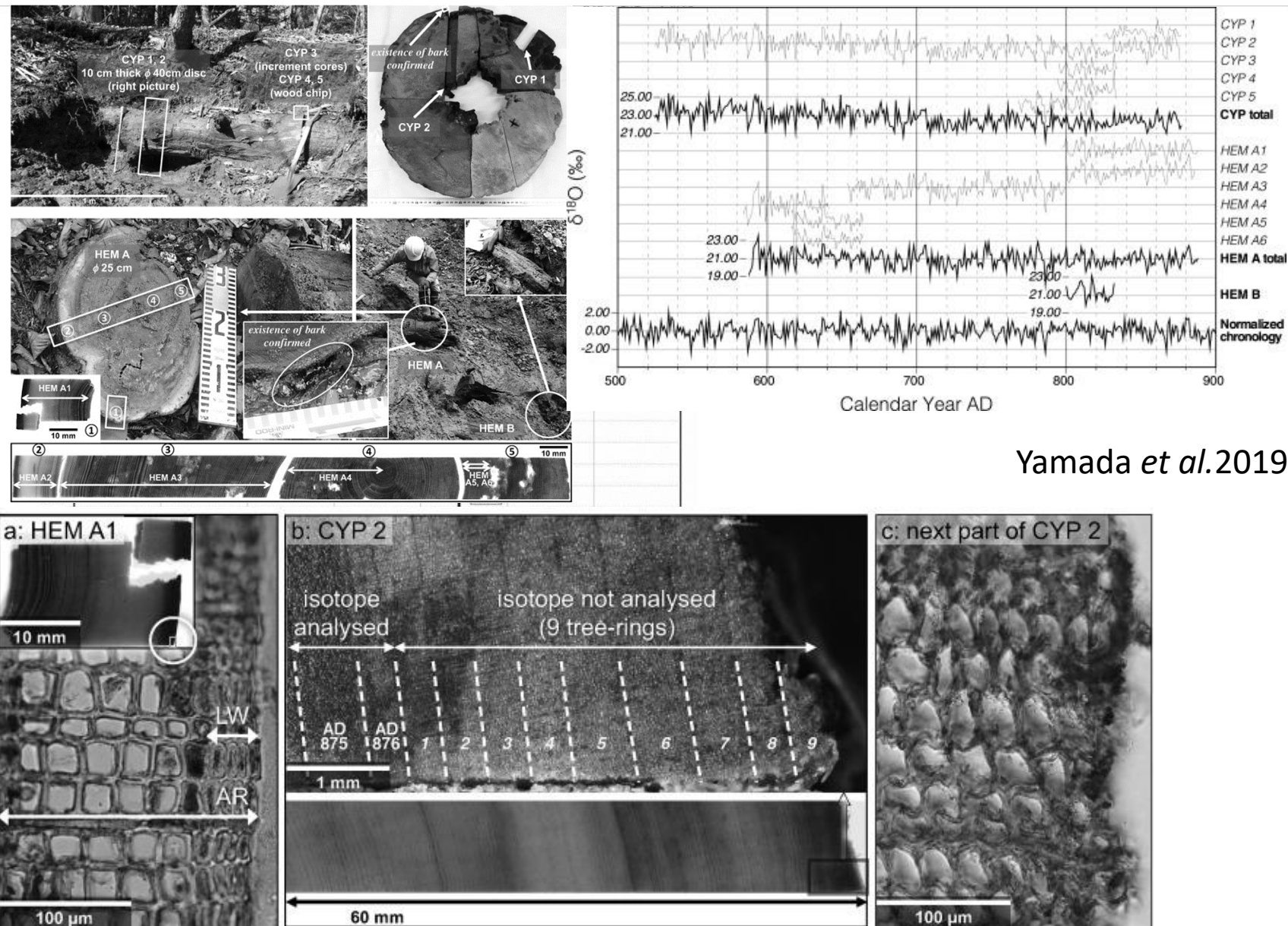
酸素同位体比年輪年代法

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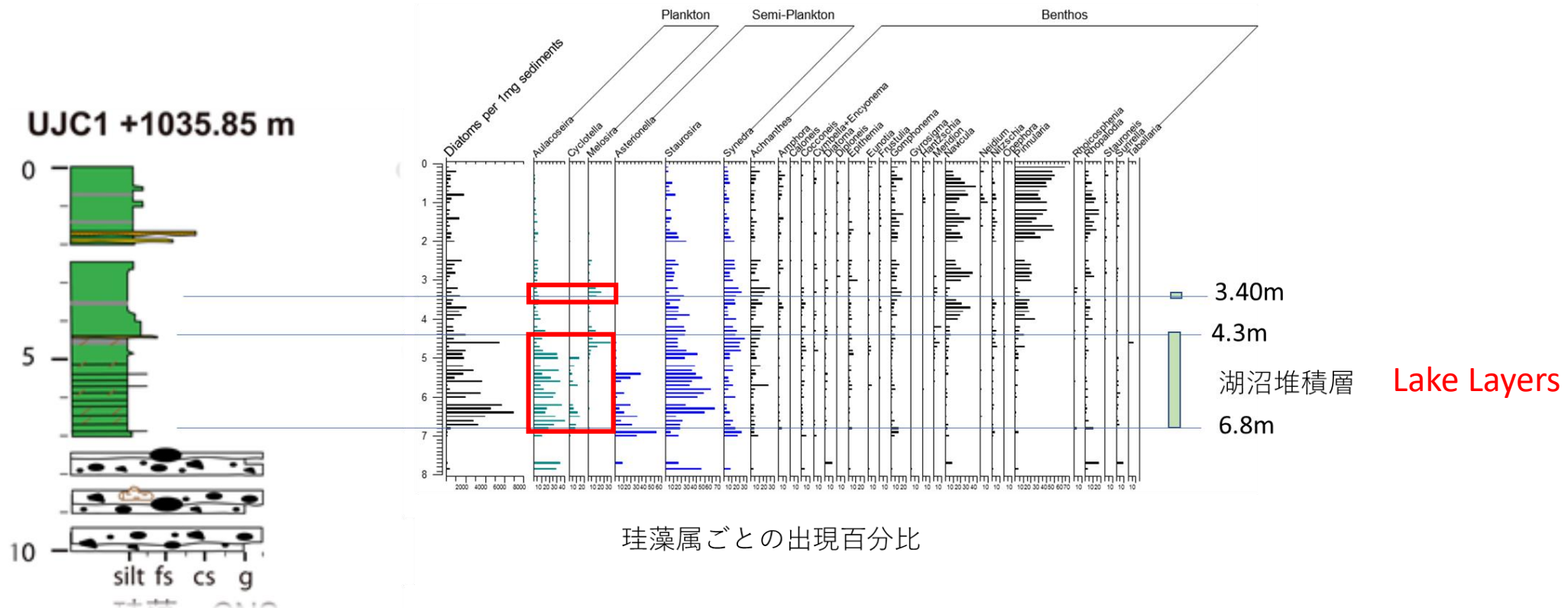


Yamada *et al.* 2019

Drilling surveys at the Ancient Lake area in 2025

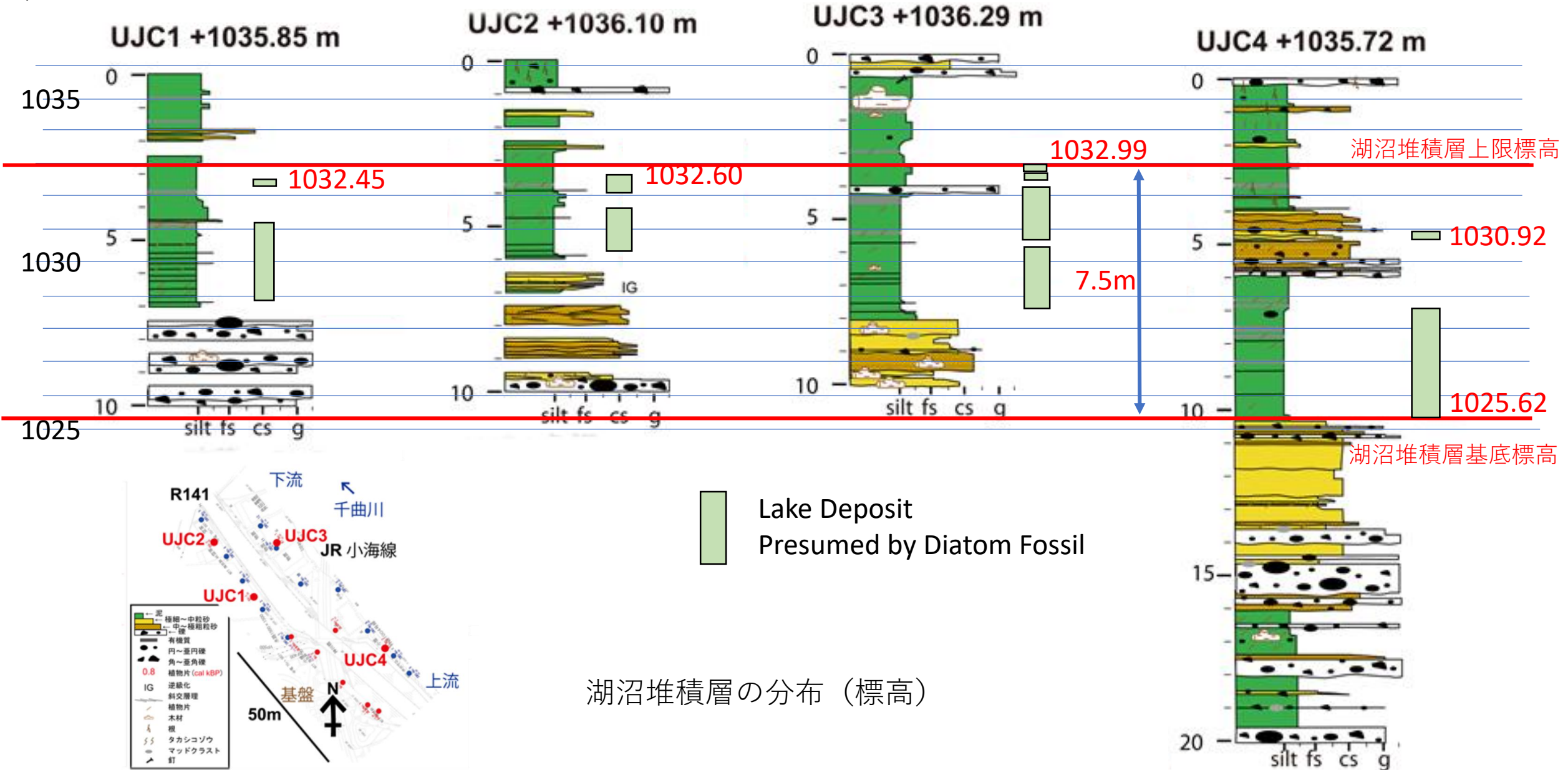
- Four all core drillings at the ancient lake area were done in 2025.

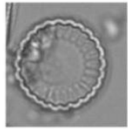
UJC-1



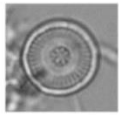
総合図 2
標高

Drilling Surveys for the Ancient Lake Deposit in 887-888 AD





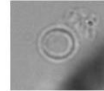
1



2



3



4



5



6



7



8



9



10



11

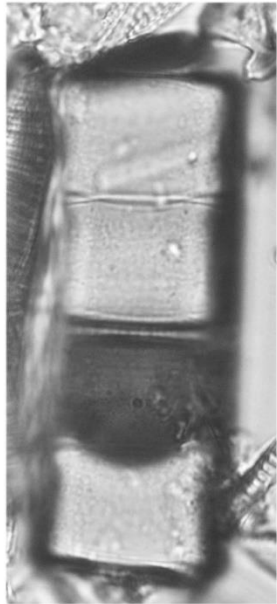


12

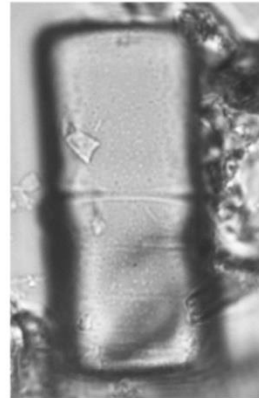
C.meneghiniana *C.stelligera* *C.comta*

4-12 *C.sp. (species is unknown)*

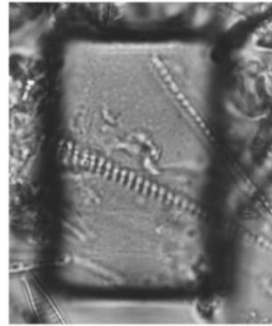
Cyclotella



13



14



15

M.varians

Melosira

UJC-3

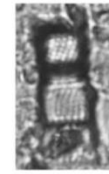
470cm

10 μ m

Plate 01



1



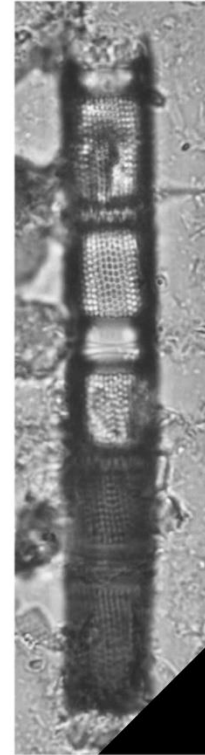
2



3



4



5



6



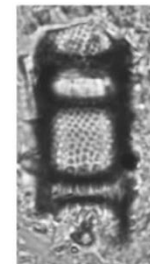
7



8



9



10

UJC-4

1020cm

10 μ m

_Plate 02

A. ambigua

Aulacoseira

- The huge lake was formed by the huge landslides in 887 Ninna Earthquake, and was crushed 308 days later by the historic documents.
- The areas of the ancient lake was presumed by the four all-core drillings.
- New age determination with the Tree ring dating using oxygen isotopes is starting now.
- Questions:
 - The Lake occurred only one time or several times?
 - It was caused by the 887 Ninna Earthquake?
 - The lake was crushed on June 888? It is the heavy rain season 梅雨 in Japan.