Outline of the geological survey on the age of Yasuda Layer under Kashiwazaki-Kariwa Nuclear Power Station

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Tokyo Electric Power Company

東京電力

TEPCO

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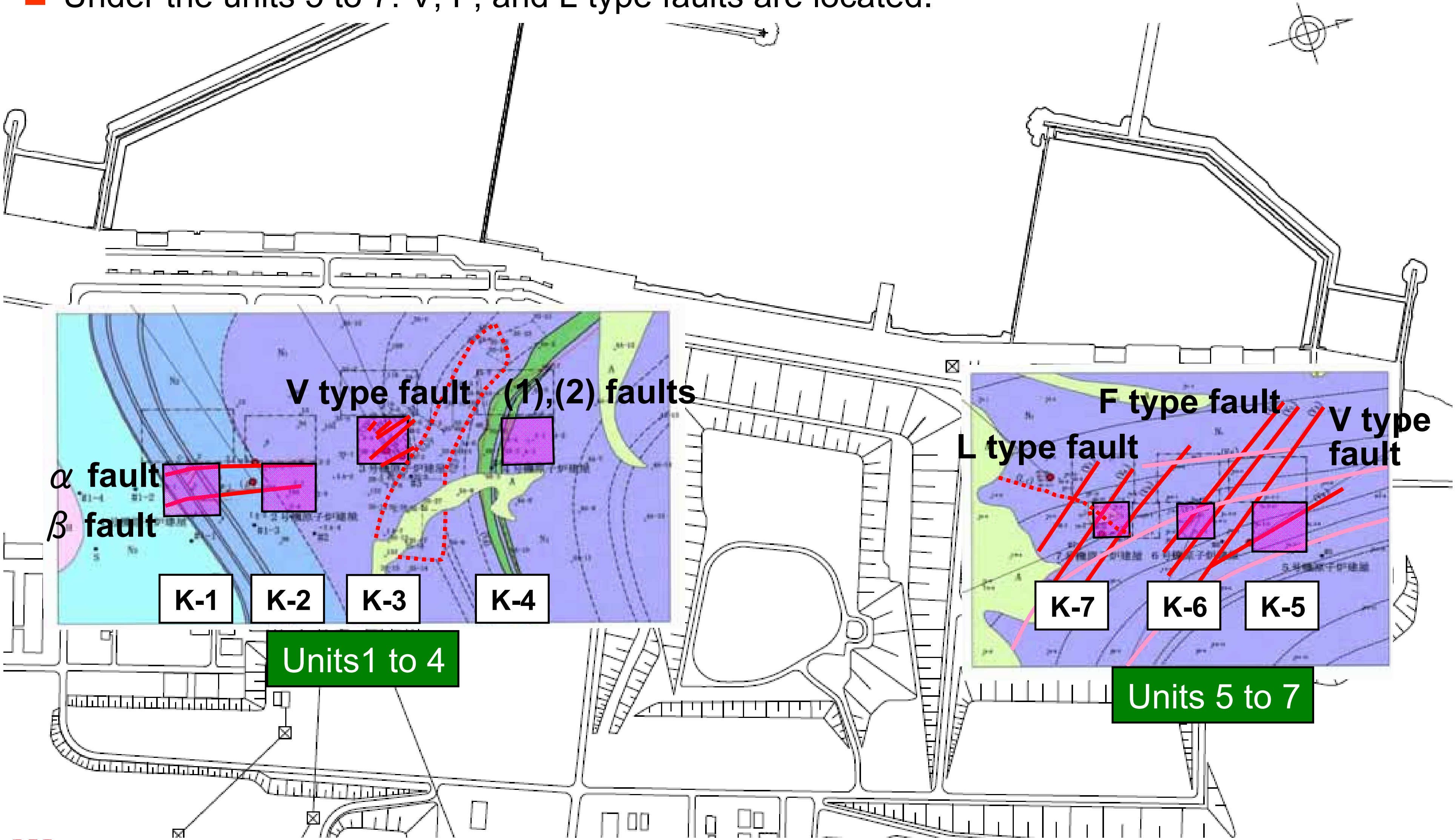
Previous Survey: Location of Faults under the Premises

- Under the units 1 to 4: α, β faults, V type faults, and (1), (2) faults are located.
- Under the units 5 to 7: V, F, and L type faults are located.



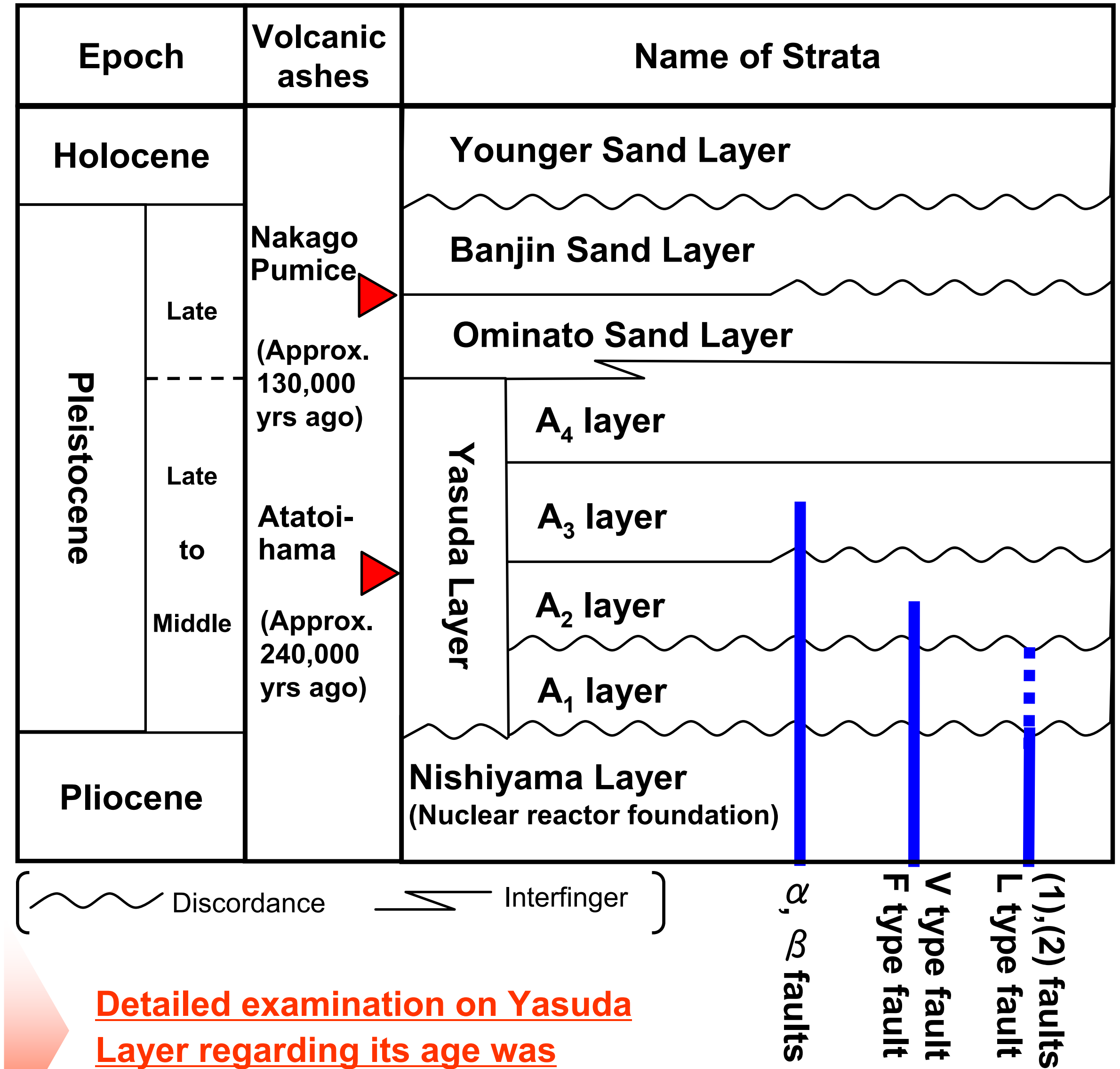
Previous Survey: Assessment of Fault Activity and Opinions from the Hearing

- α, β layer displaced A_3 layer of Yasuda Layer but did not affect the upper layers.
- V and F type faults were active during the same period and the latest activity affected up to A_2 layer.
- L type and (1),(2) faults did not affect Yasuda Layer or at least not A_2 layer.
- Based on the above, the faults are not active as there has been no activity since the accumulation of Yasuda Layer and thus are not a concern in terms of earthquake-resistant designing.

From Public Hearing:

TEPCO claims that there has been no activity among the faults affecting the upper part of Yasuda Layer after the late Pleistocene, but the method of Yasuda Layer's stratigraphic division is not clear. The division and the age of each layer need to be re-evaluated.

The public hearings on earthquake and tsunami (geology and tectonics) (5th NISA 08/10/2012)



Detailed examination on Yasuda Layer regarding its age was conducted.

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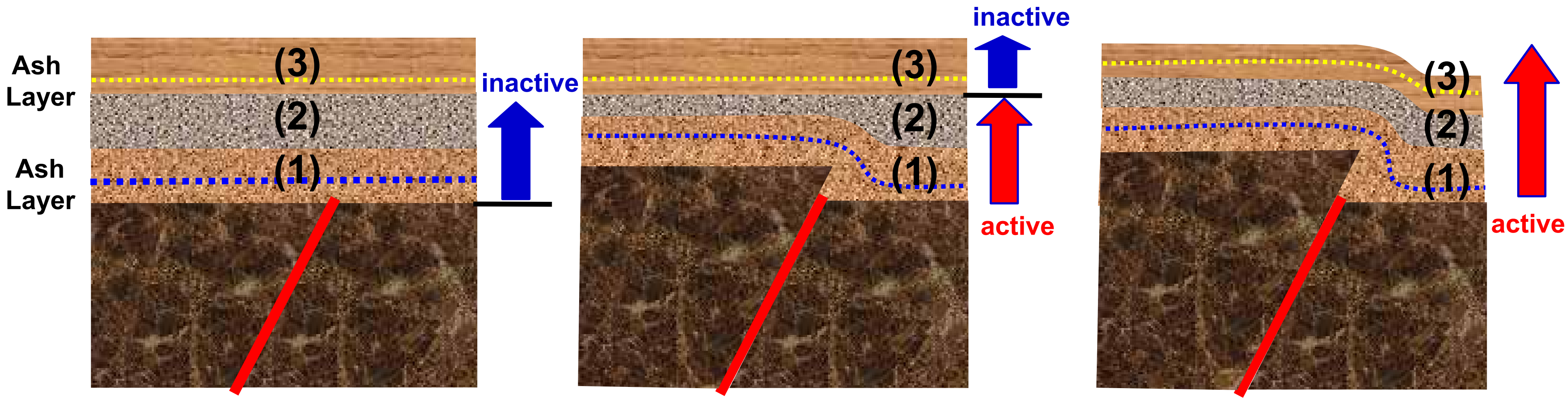
Commentary: Why Assess the Age of Strata above Faults?

The activity of faults are assessed based on the presence dislocation and deformation in the strata deposited on top of the faults (i.e. upper strata). For example, if there is no dislocation or deformation in the upper strata and volcanic ash layers within the strata, it can be concluded that there was no activity in the fault after the upper strata deposited. On the other hand, if there is dislocation and/or deformation, the faults were active after the deposition. Thus, it is critical to know the age of the upper strata when estimating the active period of the faults.



No activity after the deposition of (1).

There is no dislocation in (3): there was no movement after (3) it deposited.

All layers including (3) are dislocated: the fault was active after (3) it deposited.

An Approach to Estimate Yasuda Layer's Age

There are several tephra (e.g. volcanic ash) layers within Yasuda Layer and one of them is comparable to Atatoihama Tephra (approx. 240,000 yrs ago). Nakago Pumice stones (130,000 yrs ago) were found between Ominato and Banjin Sand Layers. Based on the location and the age of the tephra layers, microfossils are used to determine the past climate and aquatic environment and to estimate the strata's age.

Geological Observation → **Determine the strata distribution**

Tephra Analysis → **Determine the age**

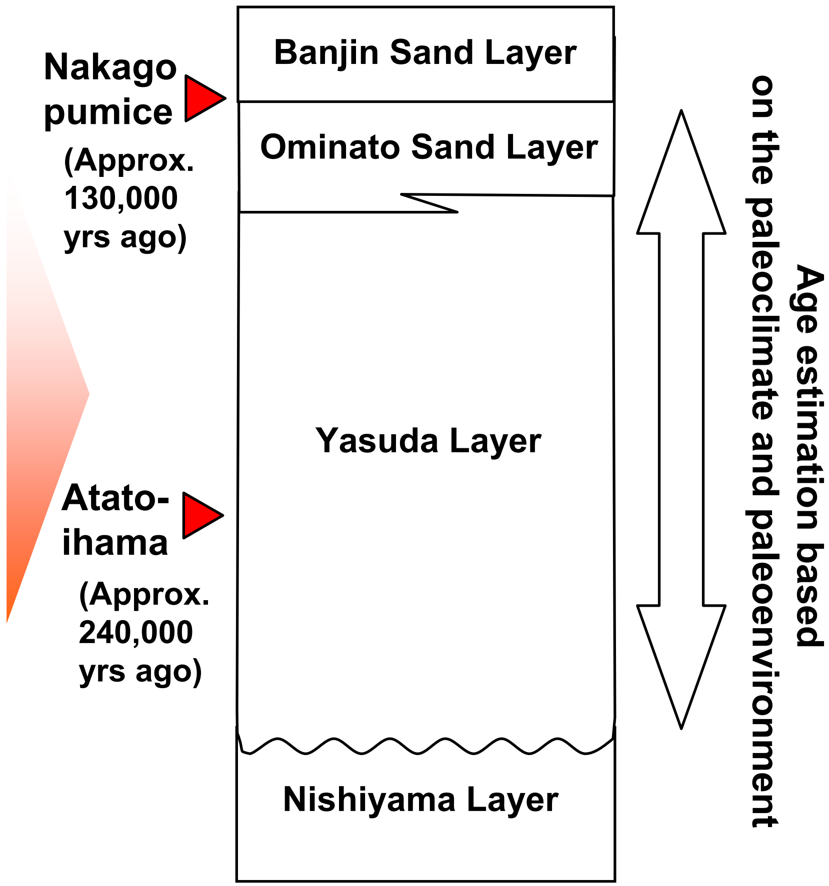
Microfossil Analysis (pollen, diatom) → **Determine the past climate and aquatic environment**

↓

Estimate the age of the strata from the stratigraph and chronology of the layers.

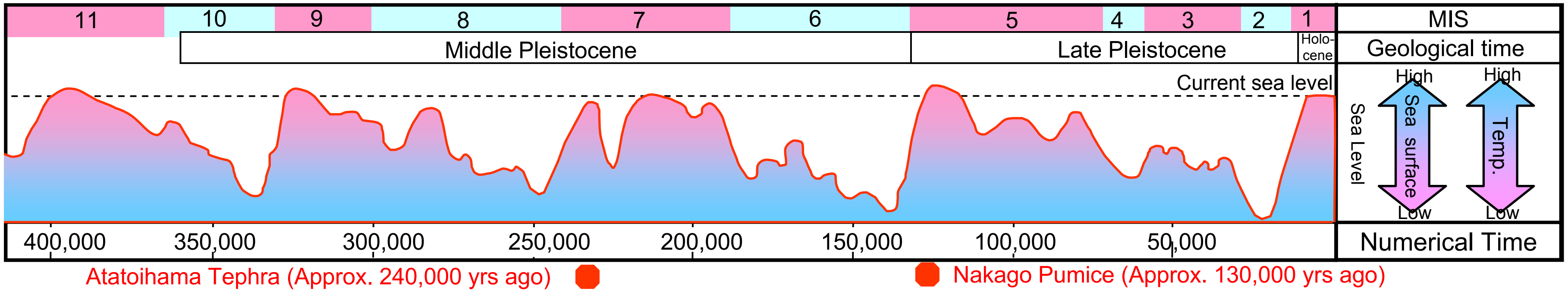
↓

Estimate the active period of the faults under the premises.



An Approach to Estimate Yasuda Layer's Age

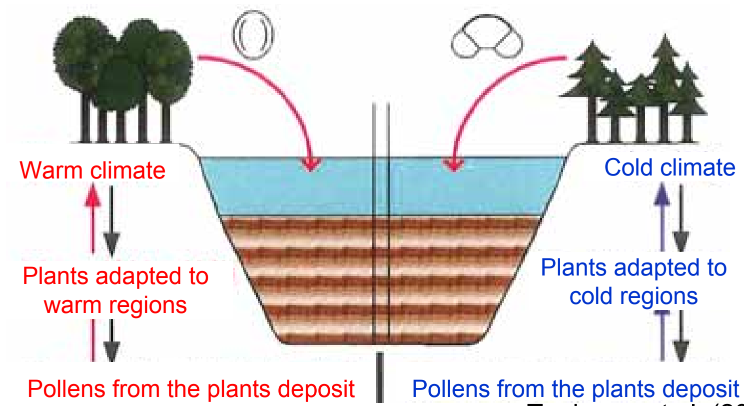
The global climate is known to change periodically and as the change occurs, the vegetation and sea level change as well. The variation trends of climate and aquatic environment can be determined by analyzing microfossils such as pollen and diatom.



Sea level change based on marine-oxygen isotope

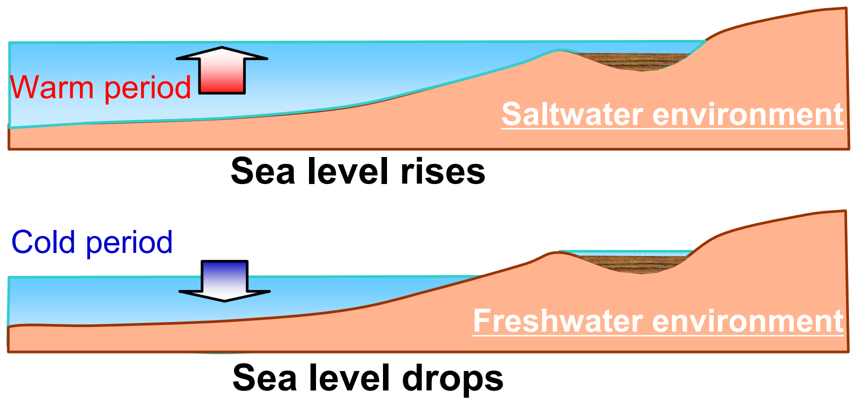
Created based on Ota et al. (2010)

Vegetation changes based on the climate



Tanimura et al. (2012)

Aquatic environment changes based on the sea level



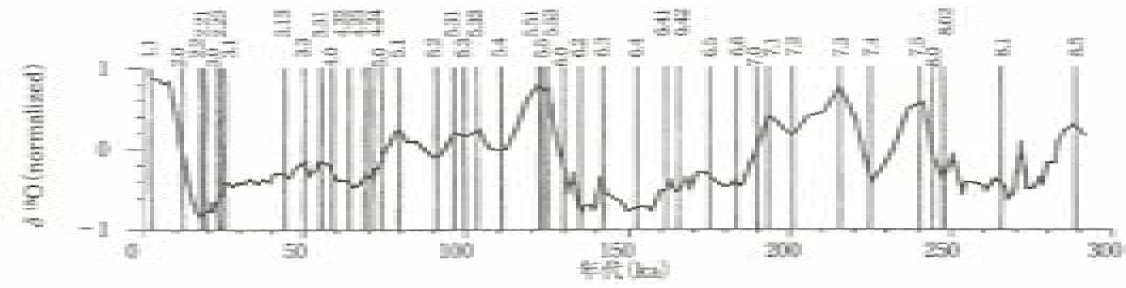
Analysis of pollen fossils in the strata

Analysis of diatom fossils in the strata

Commentary: Marine-Oxygen Isotope Stage (MIS)

- The ratio between ^{16}O in the ocean and its isotope*, ^{18}O, depends on the quantity of continental ice sheet, which is affected by the global climate change.
- Thus, the ratio of calcium carbonate ($CaCO_3$) and its oxygen isotope is also known to vary along with the climate change. Calcium carbonate is contained in the shells of foraminifer in the ocean.
- From previous studies on the oxygen isotope ratio in deep sea core samples, it is understood that glacial and interglacial periods alternate and repeat over time.
- Marine isotope stage (MIS) organizes the periodic repeat of glacial and interglacial periods by assigning them numbers: odd numbers to glacial periods starting from the latest and even number to interglacial periods.

* Same atom but differs in its mass number as its number of neutrons in the nucleus is different.



Oxygen isotope record for the past 290,000 years. (Martinson et al. 1987)

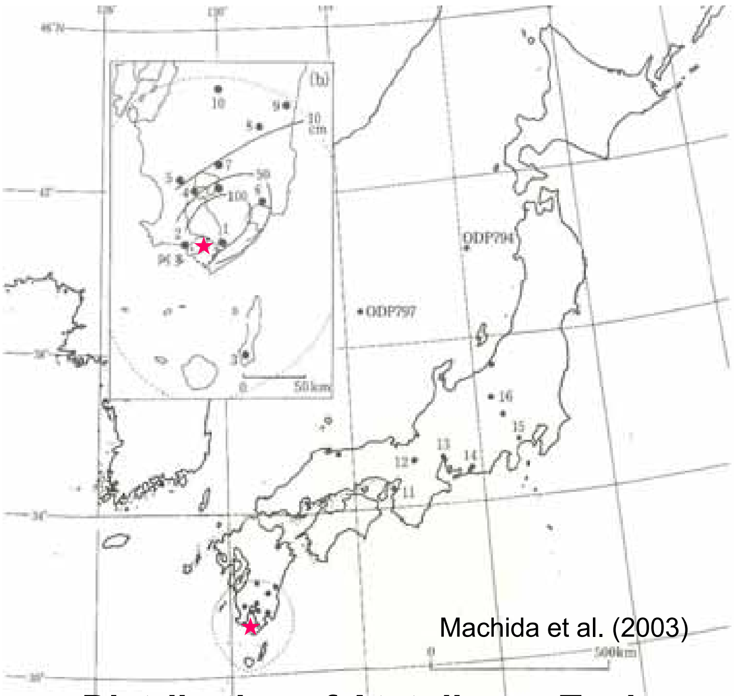
Estimated MIS

MIS	Time (10,000 yrs ago)*	Glacial/Interglacial period
5	7-13	Interglacial (warm)
6	13-19	Glacial (cold)
7	19-24	Interglacial (warm)
8	24-30	Glacial (cold)
9	30-33	Interglacial (warm)

*The ages were taken from Martinson et al. (1987) and Ota et al. (2010).

Commentary: Tephra Analysis

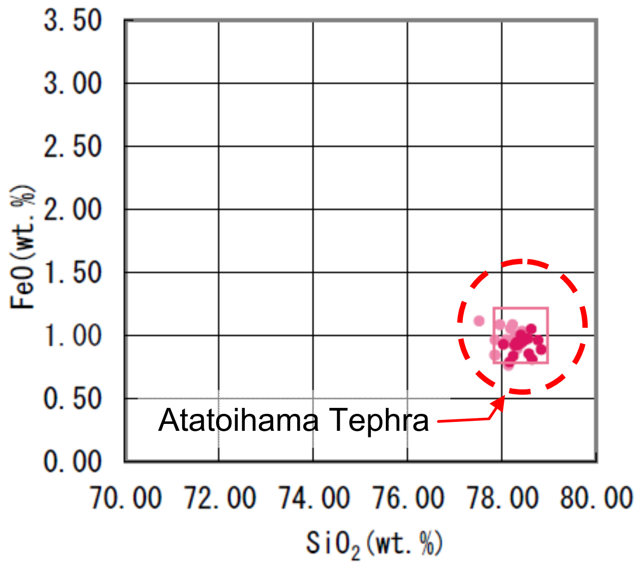
- Tephra (volcanic ash, etc.) is produced by a volcanic eruption and falls over a wide range of areas within a short period of time.
- Therefore, strata far from the volcano is considered to be formed during the same period when the same tephra is found in the strata.
- This kind of tephra strata is found in multiple places in Japan and their ages were accurately measured in recent studies (e.g. Machida et al. 2003). Each tephra has specific characteristics such as volcanic glass and types of minerals and these can be analyzed and compared with the already existing tephra data for identification.



Distribution of Atatoihama Tephra (Approx. 240,000 years ago)

Tephra from a volcano in Kyusyu is found in multiple places in Japan.

Volcanic ash found during the survey (Atatoihama Tephra)



Example of PCA (principal component analysis)

Atatoihama Tephra found in the premises. It (●●) matches with the past analysis (□).

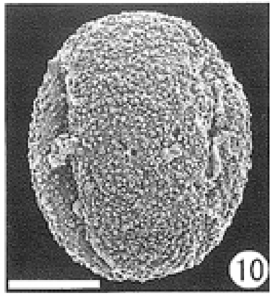
Commentary: Microfossil Analysis

Microfossil samples taken at about every 50 cm of core samples.

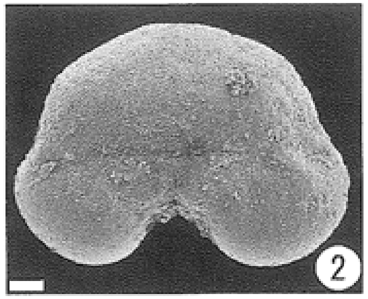
Pollen Fossil Analysis

Vegetation types depend on the climate

Identification of pollen fossil → indicator of paleoclimate (warm/cold)



Quercus microfossil



Picea microfossil

Photos from Tanimura et al. (2012). The scale is 10 μm.

Diatom Fossil Analysis

Diatom types depend on the aquatic environment

Identification of diatom fossil → indicator of paleoenvironment (sea water, brackish water, or freshwater)

Sea water species
(Nitzschia granulata Grunow)
Witkowski et al.(2000)

Brackish water species
(Diploneis suborbicularis (Greg.) Cleve)
Witkowski et al.(2000)

Freshwater species
(Navicula spp.)
Krammer et al.(1986)

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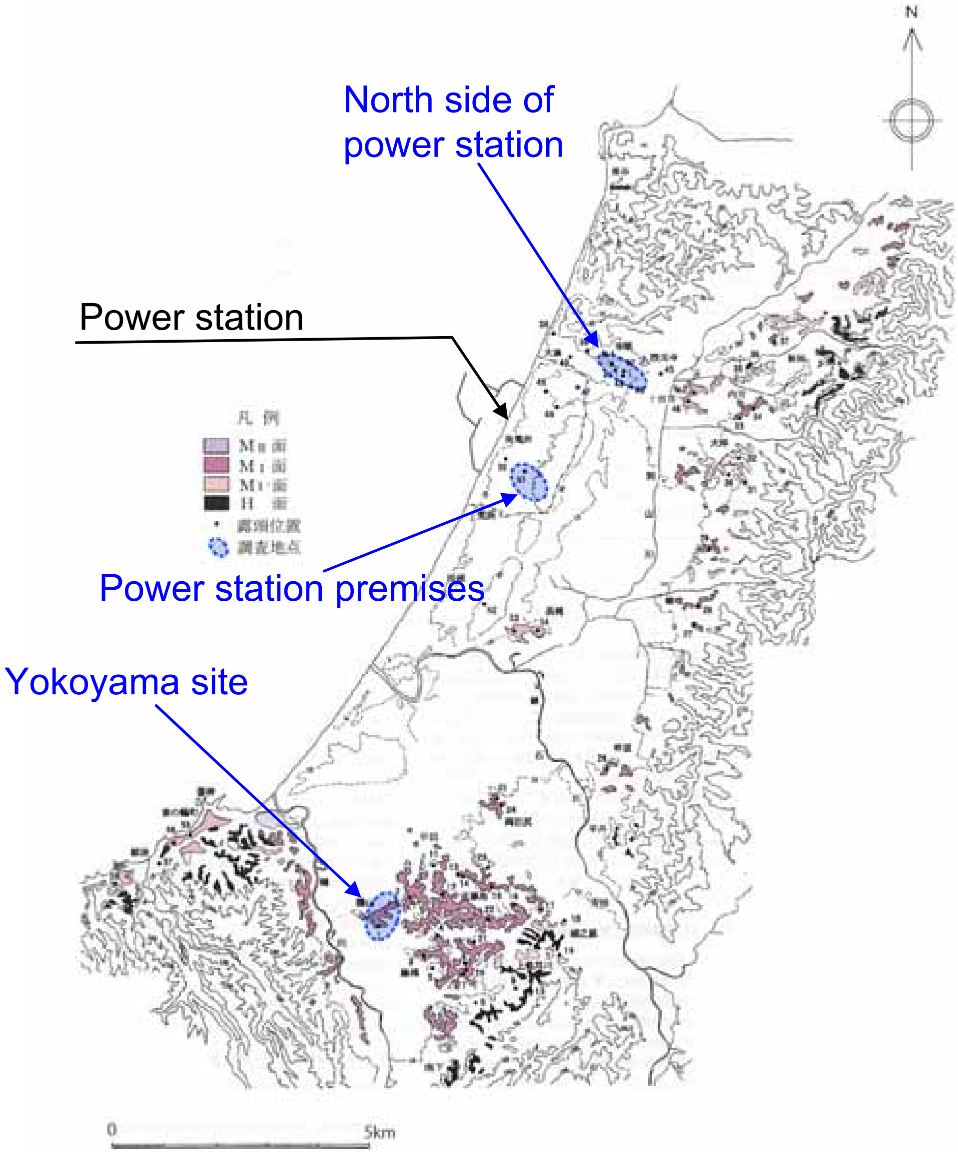
Geological Survey Location Map



Geological survey was completed at the following three areas and boring investigation, tephra analysis and microfossil analysis were conducted.

<u>Within the Power Station Premises</u>

The age of Yasuda Layer under the premises was investigated.

<u>North Side of Power Station</u>

The ages of Yasuda Layer of the site and under the premises were compared. Boring investigation was previously performed at the site after the Chuetsu Offshore Earthquake in 2007.

<u>Yokoyama Site</u>

Yasuda Layer was first defined at this site by the Kashiwazaki Hirano Research Group (1966). The age was compared with the other two sites.

Samples Taken from Geological Survey

- Sample numbers

Site	Boring	Tephra analysis	Pollen fossil analysis	Diatom fossil analysis
Within the premises	3 locations Approx. 150 m	4 samples	Approx. 210 samples	Approx. 210 samples
North side of power station	2 locations Approx. 120 m	3 samples	Approx. 140 samples	Approx. 140 samples
Yokoyama site	2 locations Approx. 110 m	3 samples	Approx. 80 samples	Approx. 80 samples
Total	**7 locations Approx. 380 m**	**10 samples**	**Approx. 430 samples**	**Approx. 430 samples**

Example of Geological Survey Results

- Core sample from geological survey within the premises

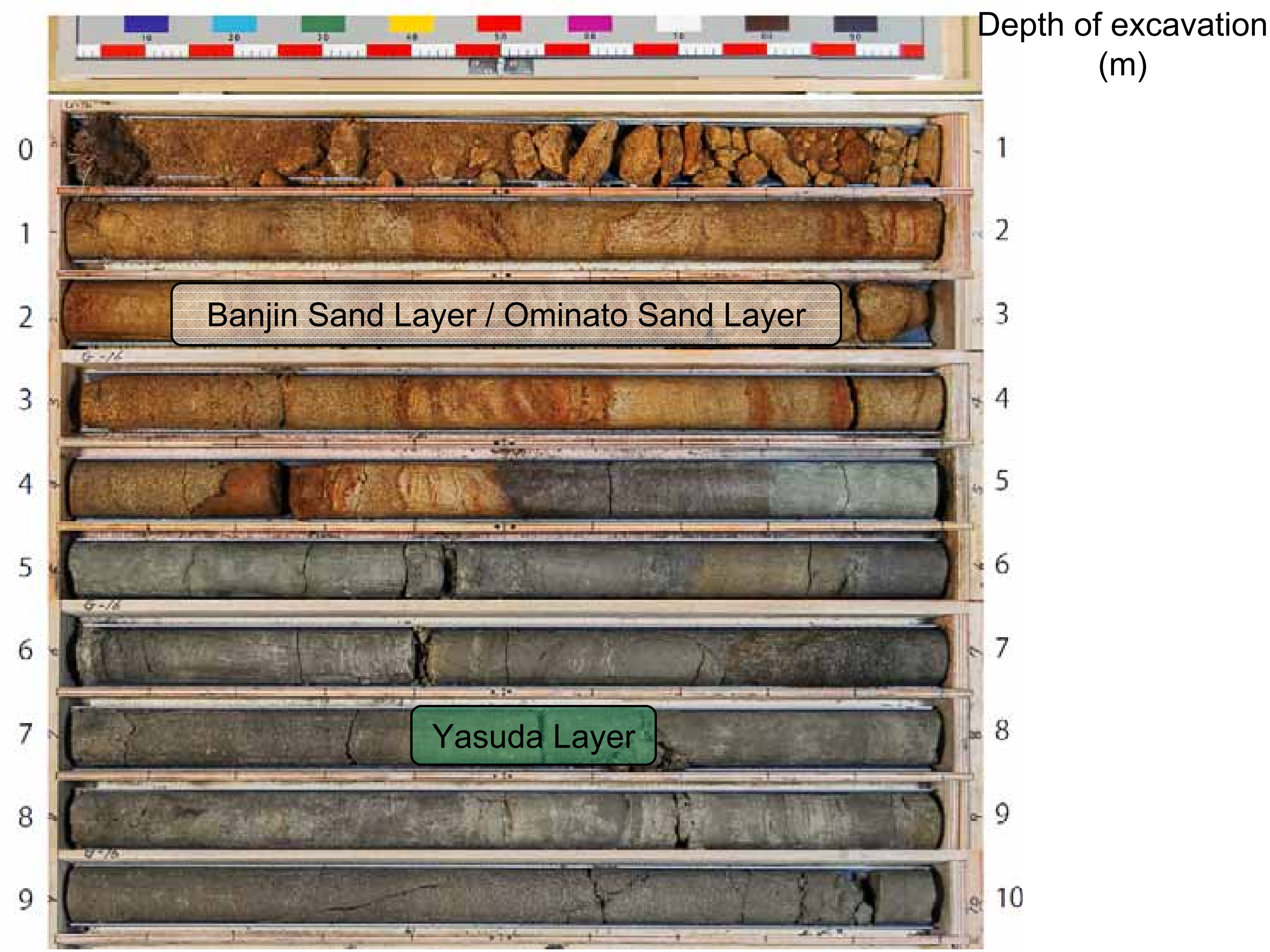


Photo: core sample (G-16)

Example of Geological Survey Results

■ Geological survey within the premises

(1) Volcanic ash sampling

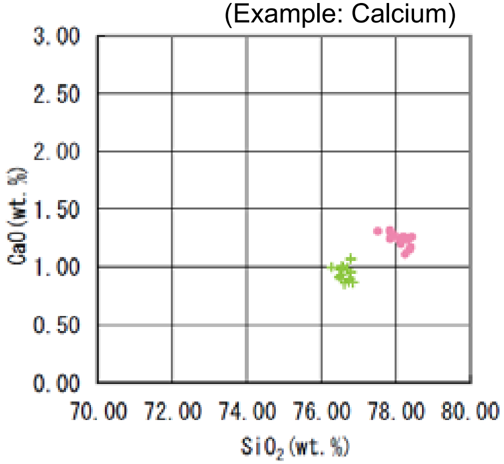
●G-16 （Altitude -10.48m）

＋G-18 （Altitude -30.2m）

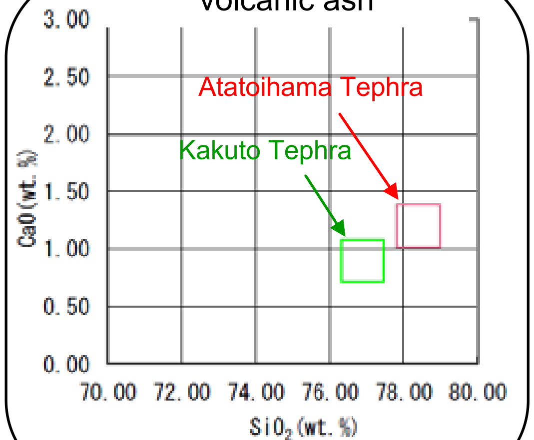
Examples of tephra analysis (Atatoihama Tephra, Kakuto Tephra)

(2) Principal component analysis of volcanic ash

(Example: Calcium)

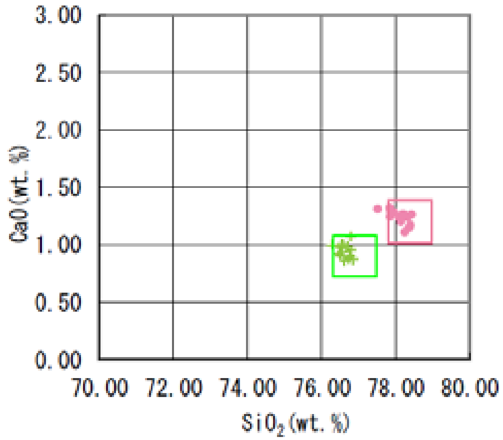


(3) Existing results of volcanic ash



Machida et al. (2003)

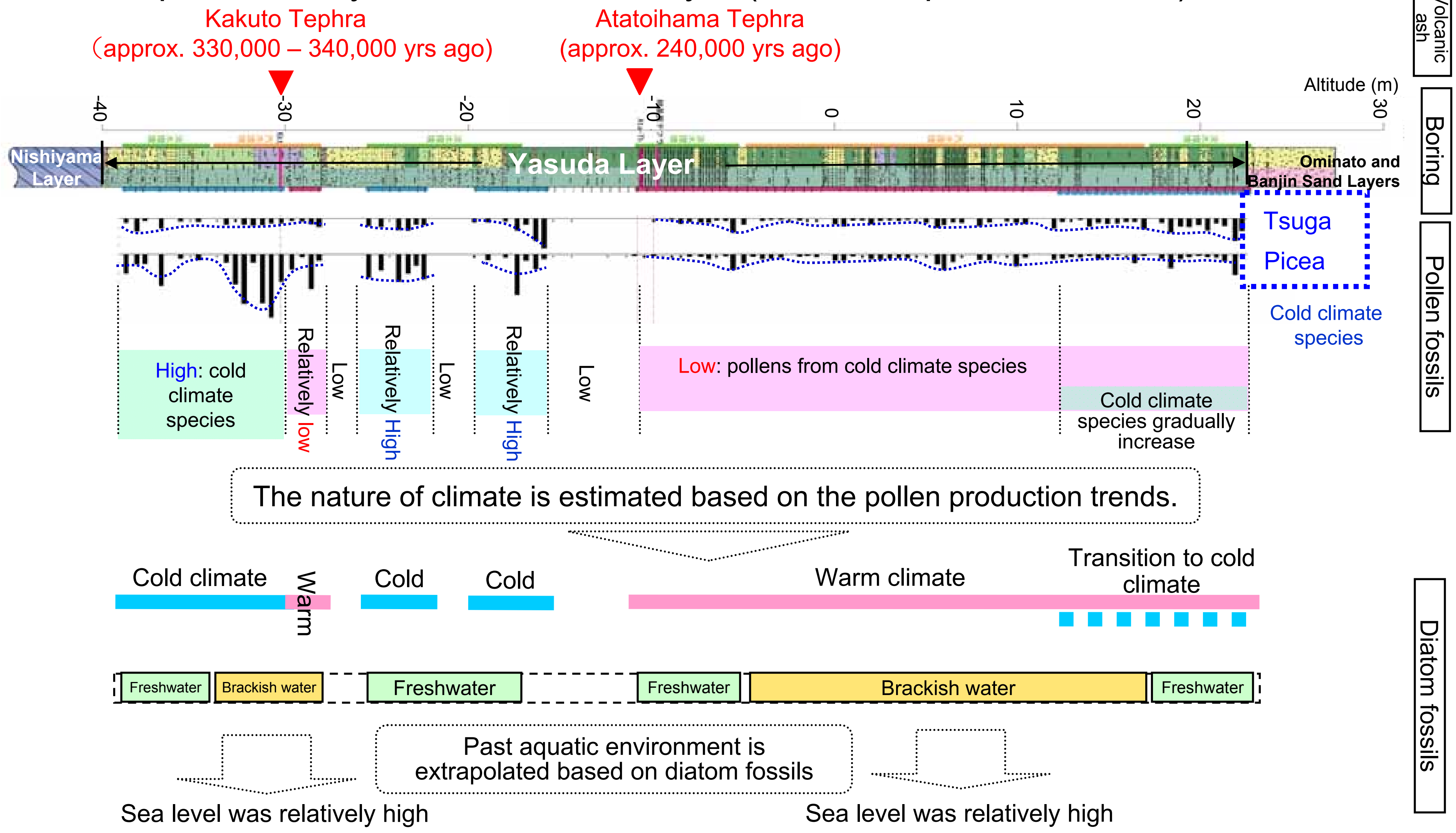
(4) Comparison of the results



As a result of tephra analysis, Atatoihama Tephra (approx. 240,000 yrs ago) and Kakuto Tephra (approx. 330,000 to 340,000 yrs ago) were found.

Assessment of Geological Survey

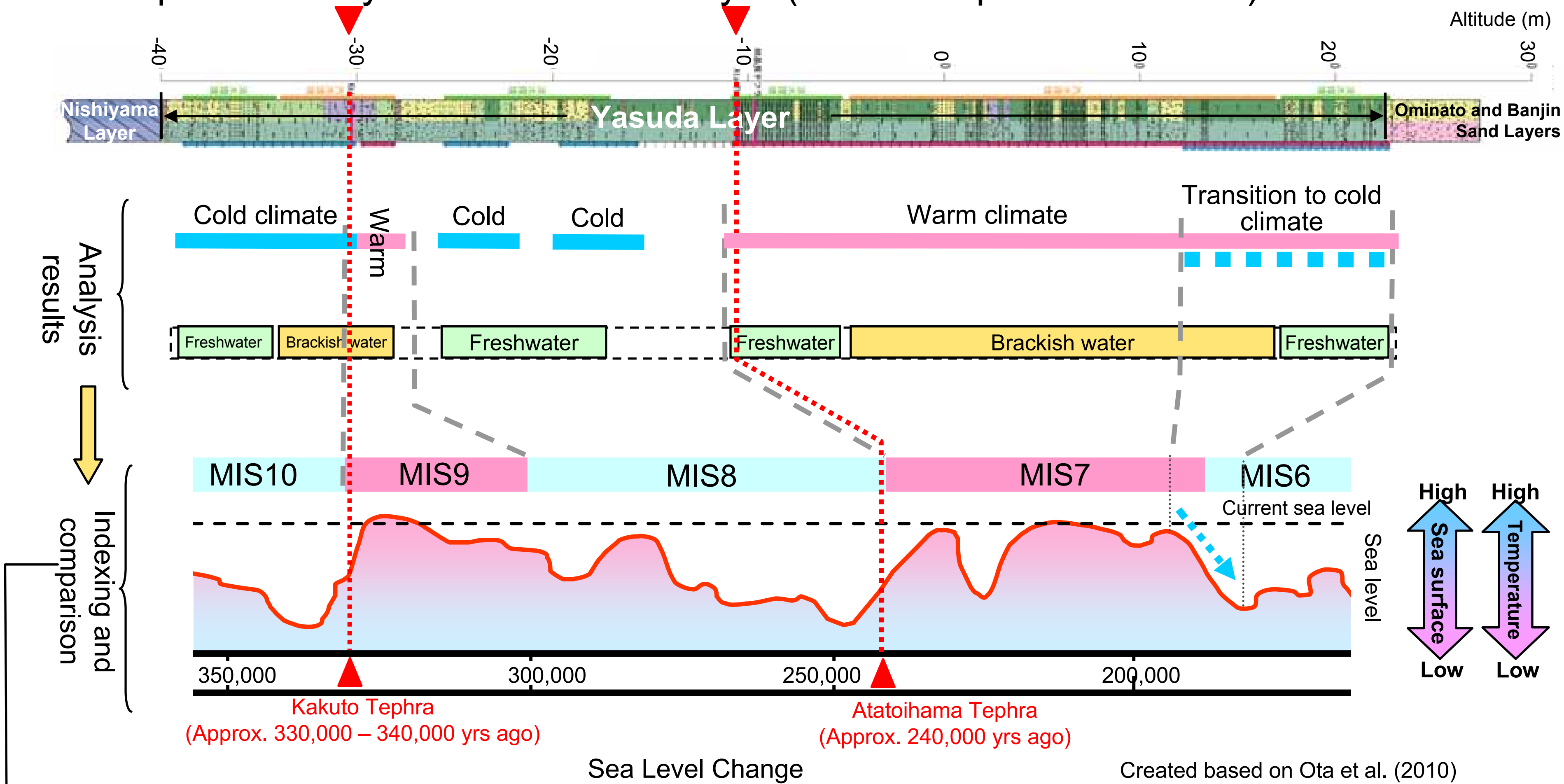
- Example of survey results: Yasuda Layer (within the premises: G-16)



The periodic sea level and climate changes are estimated from the microfossil analysis

Assessment of Geological Survey

■ Example of survey results: Yasuda Layer (within the premises: G-16)

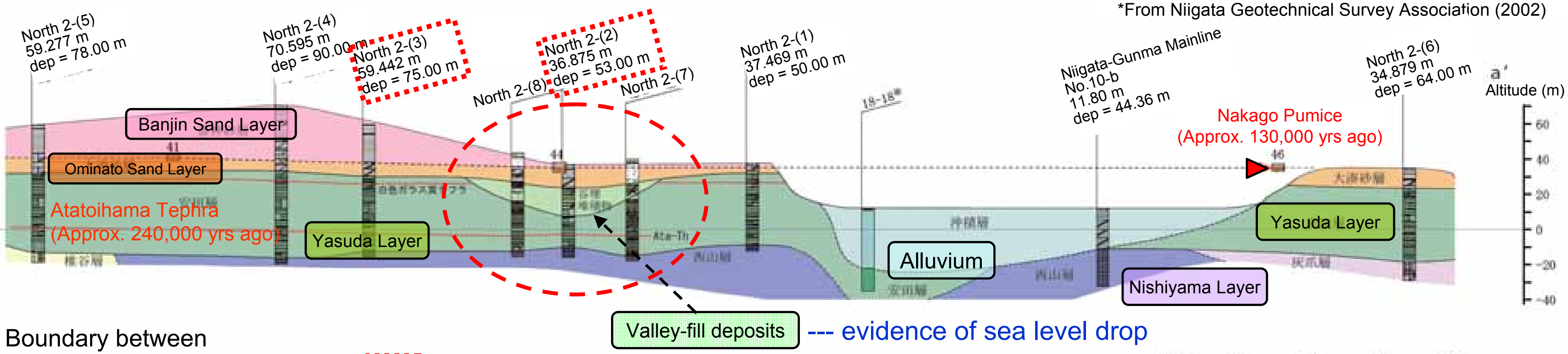


Based on the locations and ages of Kakuto Tephra (approx. 330,000 – 340,000 years ago) and Atatoihama Tephra (approx. 240,000 years ago) found from the boring investigation, the past environment was extrapolated by analyzing the microfossils contained in strata around the tephra layers. The matching of the results and the changes in the past environment is broadly acceptable, and it is believed that Yasuda Layer under the premises was formed during the middle Pleistocene: sedimentation occurred during MIS10 to MIS7/6 when the sea level gradually decreased.

Example of the Geological Survey Result Assessment

■ Example of survey results: Yasuda Layer and valley-fill deposits (north side of power station)

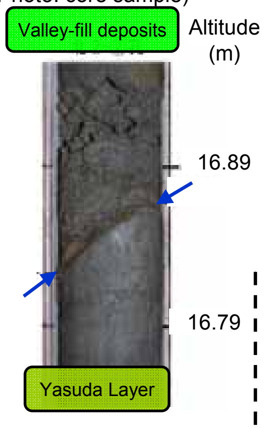
*From Niigata Geotechnical Survey Association (2002)



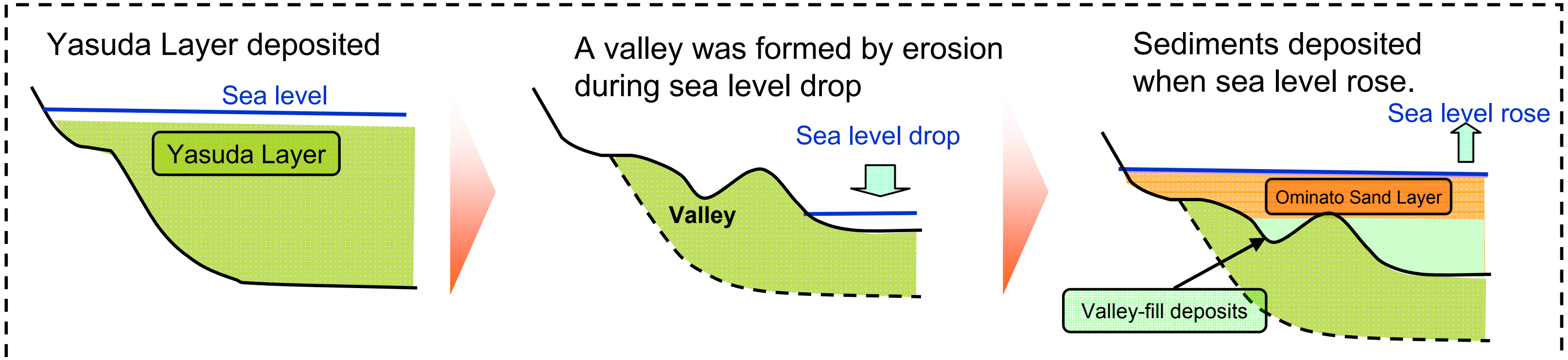
: boring investigation for microfossil analysis

Boundary between valley-fill deposits and Yasuda Layer

(Photo: core sample)



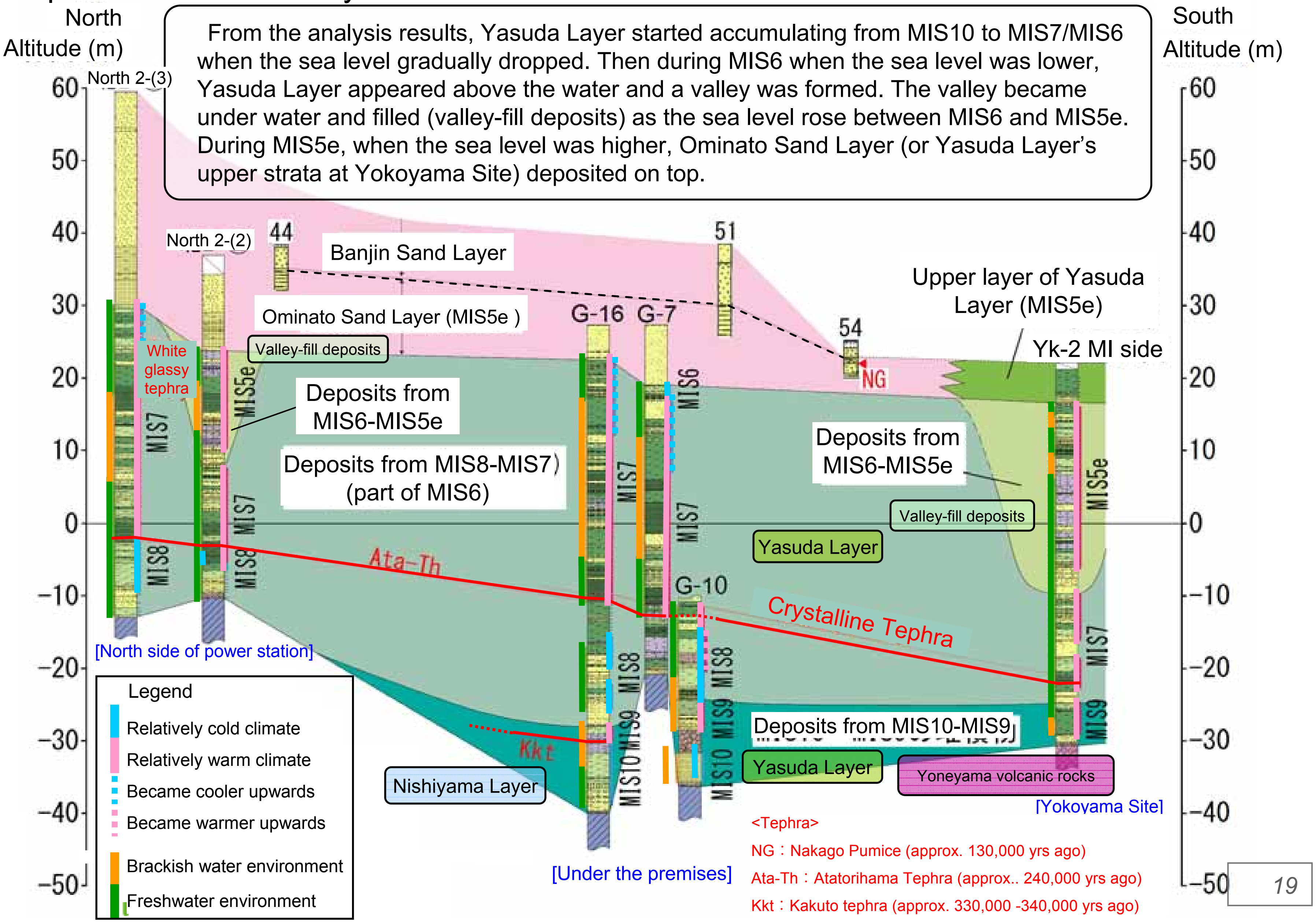
- Valley-fill deposits were found in Yasuda Layer under the north side of the power station.
- Based on the tephra and microfossil analysis, it is believed that this part of Yasuda Layer deposited during MIS8 to MIS7. Nakago pumice (approx. 130,000 years ago) from MIS5e was found in Ominato Sand Layer on top of the valley-fill deposits.
- The valley was formed due to erosion during the MIS6 period when the sea level was lower. Then sedimentation occurred as the sea level rose during MIS5e: Ominato Sand Layer deposited on top of the valley during MIS5e, when the sea level became higher.



The Age and Distribution of Yasuda Layer under the Power Station

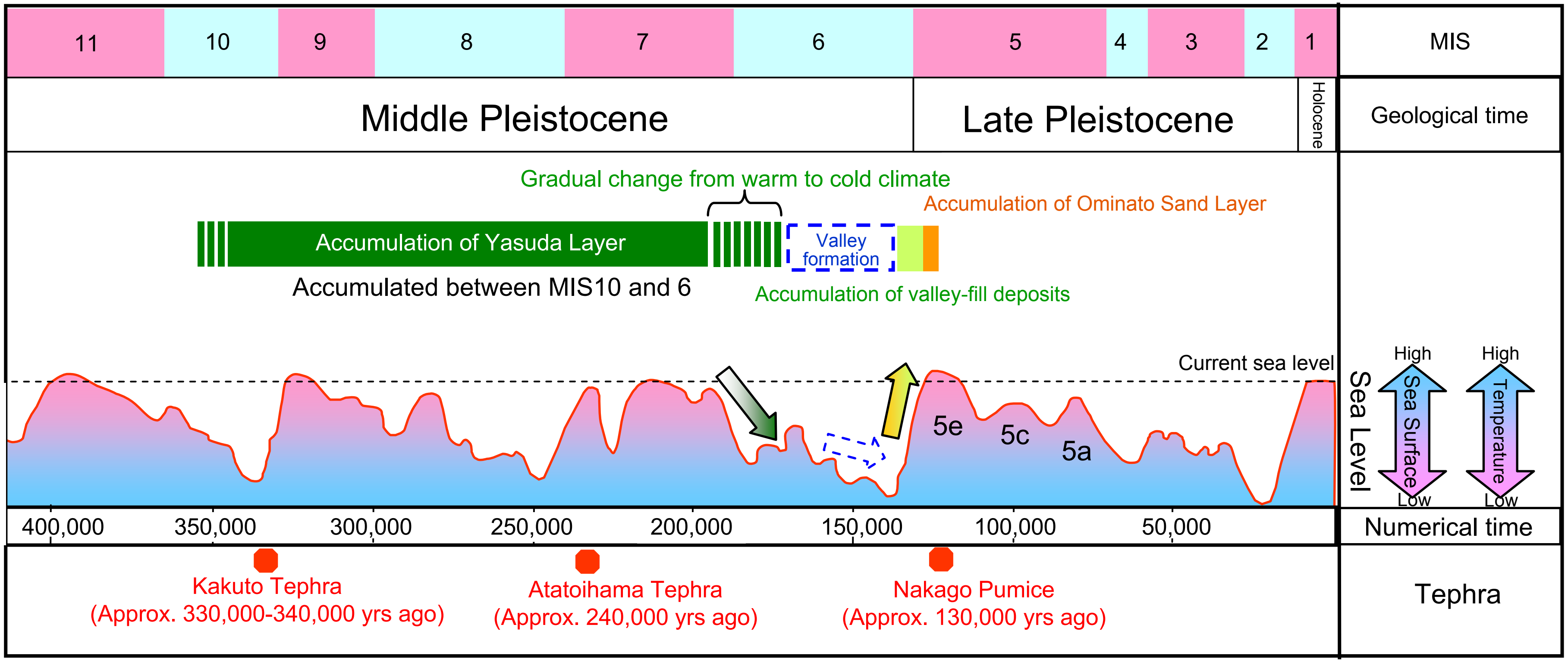
Comparison of Yasuda Layers

From the analysis results, Yasuda Layer started accumulating from MIS10 to MIS7/MIS6 when the sea level gradually dropped. Then during MIS6 when the sea level was lower, Yasuda Layer appeared above the water and a valley was formed. The valley became under water and filled (valley-fill deposits) as the sea level rose between MIS6 and MIS5e. During MIS5e, when the sea level was higher, Ominato Sand Layer (or Yasuda Layer's upper strata at Yokoyama Site) deposited on top.



Summary of Yasuda Layer's Age

■ The accumulation period of Yasuda Layer sediments



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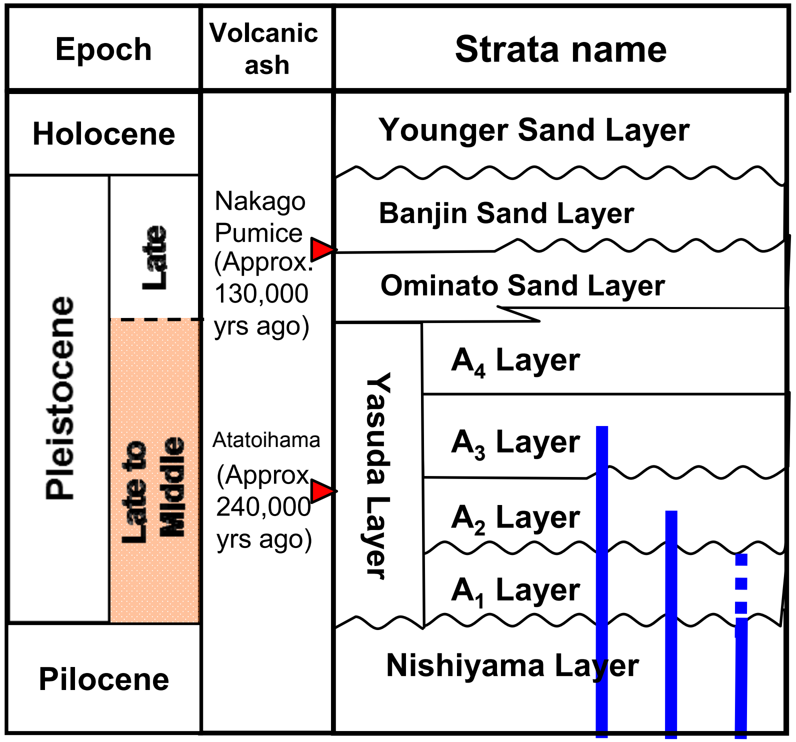
Assessment of Fault Activities under the Premises

- The period of fault activities under the premises

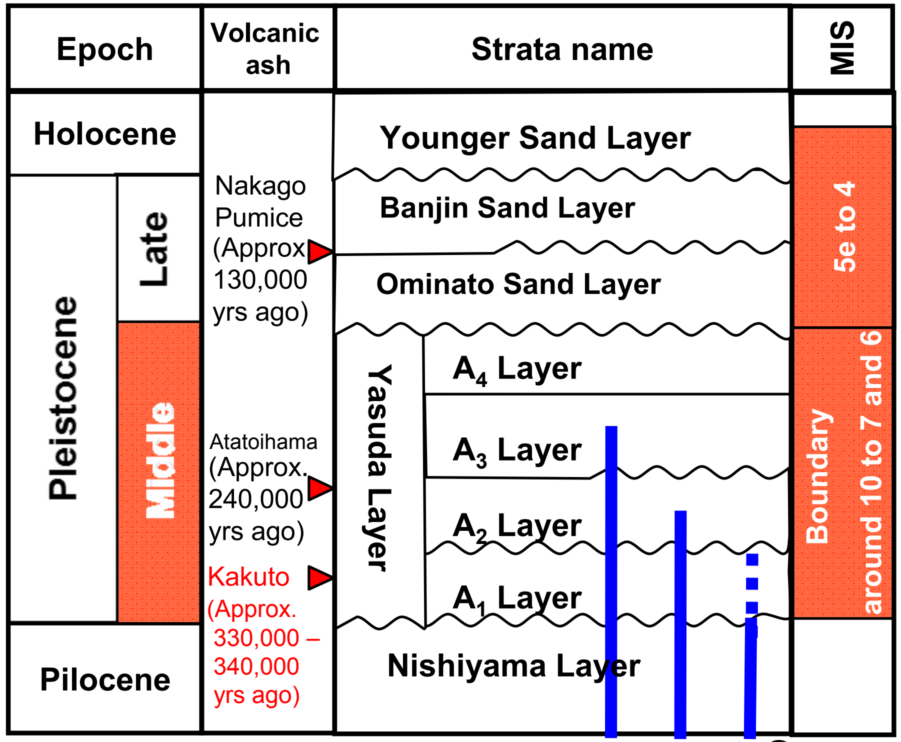
(Discordance Interfinger)

Existing assessment



- It was believed that the upper layer of Yasuda Layer accumulated around the late Pleistocene.

New assessment



- It was confirmed that Yasuda Layer accumulated during the middle Pleistocene.

Yasuda Layer under the premises deposited around the boundaries of MIS10 to MIS7 and MIS6. No activity is recognized after approximately 200,000 years ago, which is after Yasuda Layer deposited as the faults under the premises end inside Yasuda Layer.

Conclusions

- The geological survey was conducted in order to assess the fault activities under the premises by evaluating the age of Yasuda Layer more accurately.
- As a result, it was confirmed that Yasuda Layer under the premises was formed during the middle Pleistocene and its accumulation started in MIS10 until MIS7/MIS6 when the sea level gradually decreased (200,000 years ago). It does not contain sediments from MIS5e and is inconsistently covered by Ominato Sand Layer that has Nakago Pumice Layer in its upper strata.

Conclusions

- Moreover, the following was confirmed based on the survey and the assessment of the fault activities under the premises:

1. The faults under the premises end inside of Yasuda Layer and there has been no activity for the past 200,000 years after Yasuda Layer deposited.
2. The active folds around the Kashiwazaki Plain moved from west to east on land and east to west under the sea. There has been no active movement in the vicinity of the premises since approximately 1.5 million years ago.
3. There is no seismic activity associated with the Chuetsu Offshore Earthquake as the faults under the premises did not affect the upper macadam and asphalt, based on the results from the site investigation conducted after the earthquake.
4. The faults under the premises such as α and β are not affected by seismic forces by Basic Earthquake Ground Motion Ss, according to the seismic stability evaluation of the foundation ground.

Conclusions

- This report is a summary of the latest assessment and we will continue more investigations and analyses as necessary. The Japanese government is currently establishing standards for active fault evaluation and once the standards are set, the results will be re-examined for more appropriate assessments.

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