

ESTIMATION OF SEDIMENTATION RATE AND FRESH-SALINE ENVIRONMENT IN A COASTAL ALLUVIAL PLAIN, USING BORING CORES OF ALLUVIUM IN THE CENTRAL PART AREA OF SETO INLAND SEA, JAPAN

*Tohru Takeuchi¹, Shin-ichi Onodera², Kazuhiro Yamaguchi³ and Koichi Kitaoka³

¹Fujita Geology co. Ltd., ²Hiroshima University, ³Okayama University of Science

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ABSTRACT: To estimate the sedimentary environment between the last glacial stage and the Holocene epoch of an enclosed sea in the Okayama Plain, which constitutes a portion of the Seto Inland Sea coast, we collected 4 boring cores at depths of 6 to 19 m, performed radiocarbon dating of the organic matter contained in the clay, identified the volcanic glass from the Aira Caldera eruption, and measured the electrical conductivity of the pore water. Based on these dating analyses, it was evident that the Holocene clay layer that is widely distributed throughout the Okayama Plain had already accumulated prior to 10,000 years ago. In addition, the different hardness and the presence of Aira volcanic ash in the clay layer indicated the sedimentation since Pleistocene. Because the sea level at the time was lower than this clay sedimentation level, those facts suggest freshwater lakes existed in the Okayama Plain which was dammed up by the shallower granite basement in the mouth of Kojima Bay. Based on the long clay core and date for the last 30,000 years, the sedimentation rates were estimated to be 0.18 mm/ year before 8,100 years ago and 1.19 mm/year for the last 8,100 years, respectively. In the sea water rising after 7,000 years ago, the sea level exceeded the dam and the bay became a saline condition.

Keywords: Holocene clay, radiocarbon dating, volcanic-ashes analysis, Sea-level change

1. INTRODUCTION

Various studies have revealed that the current Seto Inland Sea, which was a land area with freshwater lakes scattered in the Last Glacial Stage, changed to a sea area after the Holocene glacial retreat [2][6]. Therefore, it can be said that the sediments of the Seto Inland Sea and its coastal areas have recorded and preserved the sedimentary environments from the period when the area was land through to when it was a sea or brackish water area. This is a valuable information source for obtaining findings of environmental changes after the Pleistocene in the southwestern region of the Japanese Archipelago as well as in the Seto Inland Sea region.

Land water brought by rainfall flows out into the Seto Inland Sea in the form of river water or groundwater and plays an important role in characterizing the water quality as a part of the water source in the closed sea area. It is clear that sedimentary strata in the coastal area with low water permeability lowers the velocity of the passage of groundwater but affects not only the quality of the river water and groundwater but also that of the water in the closed sea area [3]. The current coastal zone, where the land and the sea area are in contact, has continued to be a water passage area in the water circulation from the ancient times. So, there is a

possibility that not only the transition of the sedimentary environment from the land area to the sea area (brackish water area) is recorded in the sedimentary strata but also the clay of low permeability retains some water of those days[1][4][5][10].

Based on the chronological values obtained at the time of installation of the observation wells and the age determination obtained in the previous studies, we proved that the old Lake Kojima had existed in the Okayama Plain at the end of the Pleistocene [9]. It turned out that the deposition rate could be assumed to be unique in either age of the Pleistocene and the Holocene by connecting measured chronological values at each observation point. So, we were able to estimate the time of the seawater intrusion into the Okayama Plain and the elevation of the surface of the deposition at that time.

2. ANALYSIS

2.1 OUTLINE OF ANALYSIS

In order for fine grain particles from rivers to be deposited as sediment, water zones with low flow velocities such as lakes and seas are necessary. Sedimentation process is different depending on whether freshwater or seawater is in the water area, and in the water area where river water encounters

seawater, the particles floating until they are more likely to aggregate and precipitate. Agglomeration occurs because the thickness of the electric double layer around the particle decreases in the concentrated solution and the particles tend to

collide and coalesce and the size of the clustered particles increases. Therefore, the rate of sedimentation varies depending on whether the process is in freshwater or in sea water.

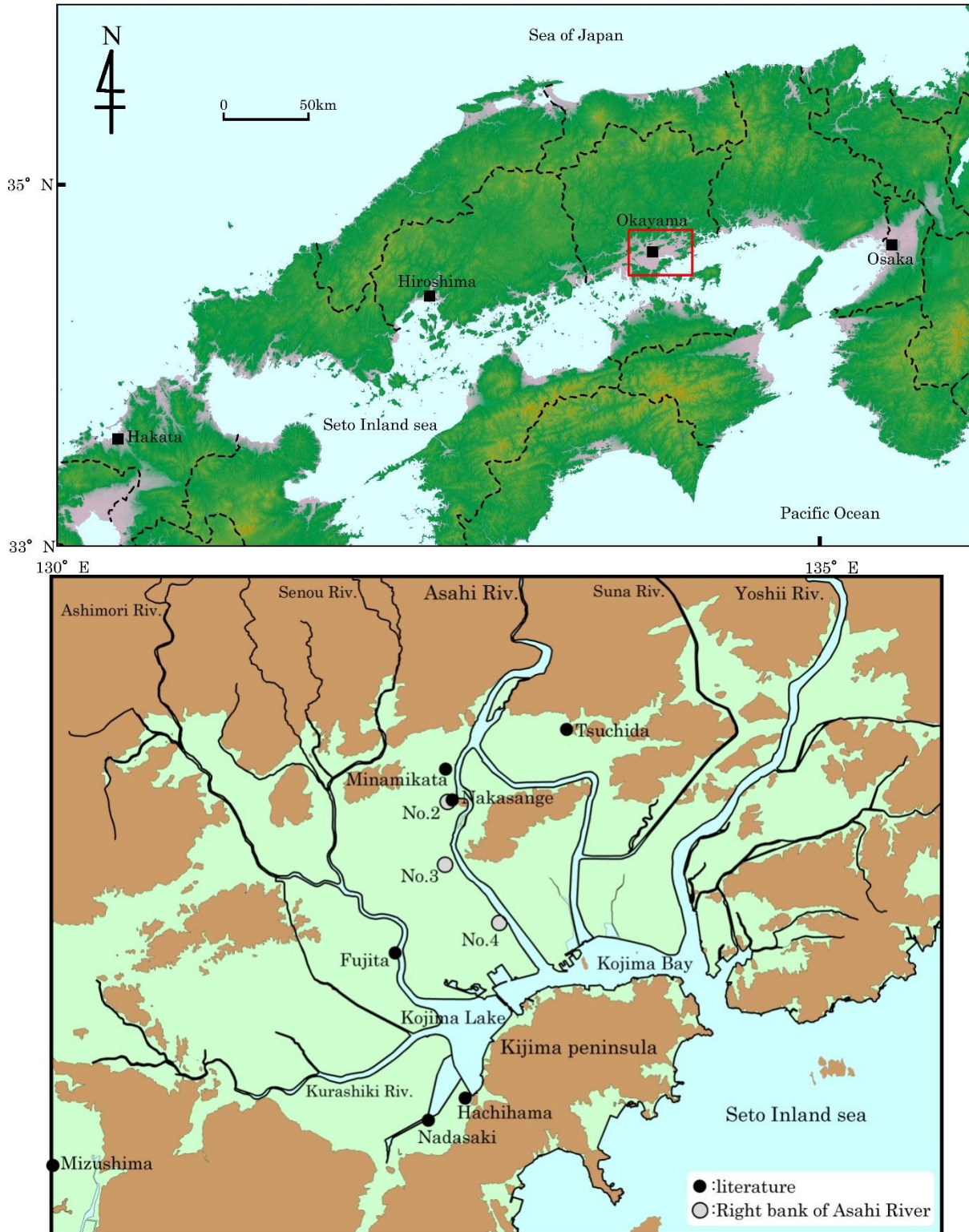


Fig.1 Position diagram of dating measurement sampling

Tabl.1 Radioactive carbon dating result of 2008 and age of volcanic ash

Number	Well No.	Depth (m)	Elevation (m)	Libby Age (yr B.P.)	Calibrated Age (cal B.P.)
IAAA-90200	No.2	6.60- 6.70	- 2.72 ~ - 2.82	6,560±40	7,510 - 7,420
IAAA-90201		8.60- 8.70	- 4.72 ~ - 4.82	9,100±40	10,300 - 10,200
IAAA-90202	No.3	5.60- 5.70	- 3.05 ~ - 3.15	5,620±40	6,480 - 6,310
IAAA-90203		8.00- 8.10	- 5.45 ~ - 5.55	7,600±40	8,460 - 8,350
IAAA-90204	No.4	5.00- 5.10	- 3.67 ~ - 3.77	2,240±30	2,270 - 2,160
IAAA-90205		13.00-13.10	-11.67 ~ -11.77	8,270±40	9,420 - 9,130
AhsType	Well No.	Depth (m)	Elevation (m)	Libby Age (yrBP)	Calibrated Age (calBP)
K-Ah	No.4	11.6	-10.27	6,300	7,300
AT		14.5	-13.17	24,000~25,000	26,000~29,000

Tabl.2 Radioactive carbon dating result by past record of Okayama plain

Number	Place	Elevation (m)	Libby Age (yrBP)	Calibrated Age	
				(calBP)	
GaK-5784	Nadasaki	-14.5	7,920±250	8,876	8,311 - 9,441
GaK-5786		-23.4	24,900 ⁺³⁴⁵⁰ ₋₂₄₅₀	28,808	22,390 - 35,225
No Data	Hachihama	-14.7	10,500±125	12,336	12,021 - 12,650
		-15.9	29,000± 720	33,242	31,685 - 34,799
No Data	Fujita	-11.8	8,150±90	9,130	8,927 - 9,332
		-14.3	21,100± 410	25,212	24,125 - 26,298
No Data	Tuchida	1.8	2,670±70	2,828	2,700 - 2,956
		-1.2	19,270±220	22,975	22,385 - 23,564
Beta-168007	Mizushima	-17	8,230±40	9,189	9,070 - 9,308
No Data	Nakasange	0.7	2,790±110	2,976	2,730 - 3,221
KN-89028	Nakasange	0.1	6,220±95	7,104	6,881 - 7,327
No Data	Minamigata	0.0	3,820±40	4,229	4,140 - 4,317

The transition from the Pleistocene to the Holocene is generally supposed to have begun with the seawater intrusion into the land area due to the rise in sea level caused by global warming after the Last Glacial Stage [2].

It is presumed that the difference in the sedimentation rate before and after the seawater intrusion has been recorded and preserved in the formation.

2.2 MATERIALS FOR ANALYSIS

By means of radiocarbon dating and identification of volcanic glass, eight sets of data of chronological values were obtained from cores collected from the right bank of the Asahi river (Tabl.1) [9]. In addition, 12 sets of data were obtained from the materials of the previous studies

in the Okayama Plain (Tabl.2) [7][8]. The points where the chronological values were obtained are shown in Fig.1.

Fig. 2 shows the relationship between the elevation of the sampling points and the measured ages. As a whole, although the samples obtained at the lower elevation tend to be older, the correlation between the data does not appear to be high. The low correlation is presumed to be mainly due to the fact that the elevation of the sedimentary surfaces varies depending on the location, even if their ages are identical.

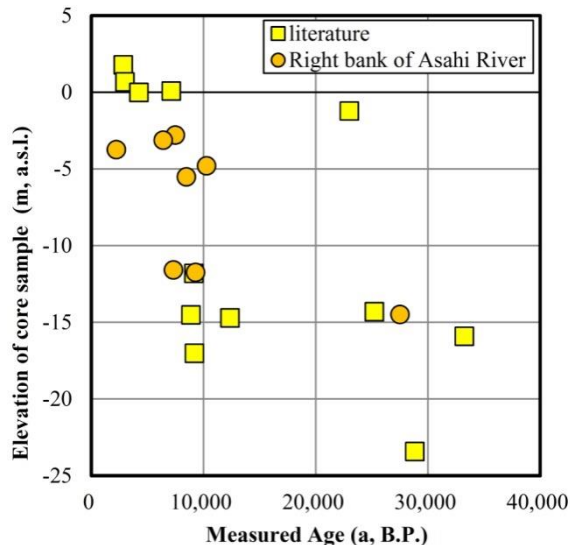


Fig. 2 Relation between age value and altitude

It is clear that not only the Holocene but the Pleistocene is also included in the sedimentary layer of the Okayama Plain, as the samples cover the range period of 2,000 to 30,000 calibrated BP. Therefore, sediments before and after the seawater intrusion are mixed in the measurement samples.

2.3 ANALYSIS METHOD

The elevation distribution of the chronological measurement is considered to include the event of seawater intrusion and the number of fine particles in the river water can be influenced by the weather and hydrological conditions of the upstream area. However, it is presumed that no significant changes will occur in the long-term average hydrological climate of the catchment basin, so we can assume that the amount of fine grain soil particles transported from the upstream is almost invariant. Therefore, the sedimentation rate of the lake bottom is largely dependent on whether the lake water is freshwater or brackish water. For the sake of convenience, we call the point at which seawater intrusion occurred the “transition year” and the hypotheses for analysis are set as follows.

1. The sedimentation rate is unique for either period (the Holocene and the

Pleistocene) before and after the transition year.

2. The relationship between elevation and age at a sampling site can be represented by two straight lines with different inclinations before and after the transition year.
3. In order to correlate geographically widespread data, it is assumed that there was a lake vast enough to include the sampling sites.
4. The sedimentation rate was identical over the most area in the vast lake.

By making the above assumptions, mutual parallel relationships between elevations and ages are formed among points of different elevation of the sedimentary level (at the lake bottom). This means that we can arrange all the data on a single straight line by shifting the elevation of the sample at each point upward or downward. By applying the least-squares method, a regression line representing the average elevation of the sedimentation surface for each point is obtained, and the sedimentation rate and the shift amount for each point can also be estimated.

When the material covers the periods both before and after the transition year, two regression lines with different inclinations are required. In that case, the intersection of the two straight lines represents the transition year and the average elevation of the sedimentation surface at that time.

First, we consider the case where all the material is from the Holocene. With the shift amount (adjustment amount) for each observation well as a parameter, we estimate the value of this parameter so that the entire line becomes a single straight line. Therefore, the regression line is set to $y=ax+b$, and the coefficients a and b are also included in the parameters and are also estimated. Here, y represents the average elevation of the sedimentary surface (at lake bottom) when setting to a single straight line, while x represents the measured age of the material, and a represents the average sedimentation rate.

We will name the measured elevation of each material to which shift amount has been added the “adjusted elevation”. This method is aimed to obtain a regression line between adjusted elevation and measured age. In other words, we can obtain the shift amount at each point and the most probable value of the coefficients of the regression line that would minimize the mean square deviation from the regression line of the adjusted elevation of each material. Once the coefficients of the regression line and the shift amount for each point are obtained, the shift amount for each point is subtracted from the regression line. Also, the elevation of the sedimentary surface at x , a certain point of time (age), can be obtained by subtracting

the shift amount from y , the adjusted elevation calculated with the regression line $y=ax+b$.

In the same way, we assume that the regression line $y=cx+d$ and the shift amount at each point are also obtained in the Pleistocene stratum, too. Here, the coefficient c represents the sedimentation rate of the Pleistocene.

When applying the least-squares method, an initial value is given to the transition year, while samples from the ages later than the transition year are to be assumed as those of the Holocene layers, and older samples are to be assumed as those of Pleistocene layers. Then, we obtain the optimal parameters that would minimize the mean square deviation by giving some initial value to the elevation shift amount for each point and to the parameters of the coefficients of the two regression lines.

The x -coordinate of the intersection of the two straight lines thus obtained is called the “crossover transition year”. When the crossover transition year obtained deviates from the initial value of the transition year, the optimum value is to be recalculated with this crossover transition year as a new initial value. By repeating this process, the final optimum value can be obtained.

3. RESULTS AND DISCUSSION

The optimum value 8,078 calibrated BP of the crossover transition year obtained by means of regression with two straight lines of the Holocene and Pleistocene is shown (Fig. 3).

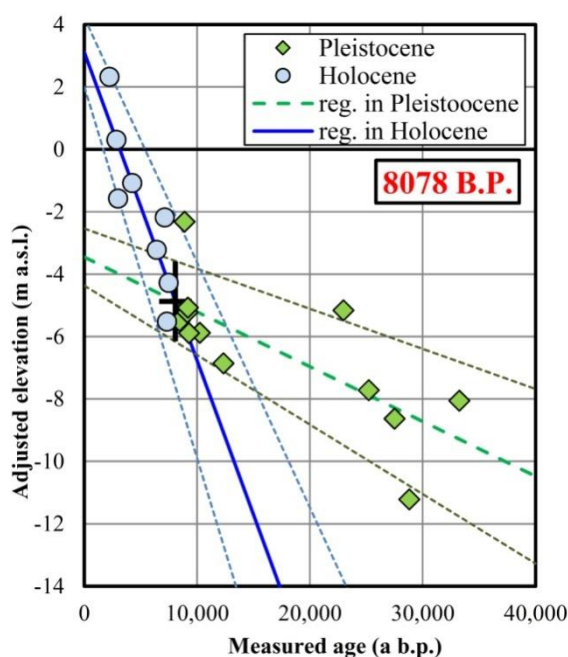


Fig.3 Relationship between adjusted altitude and measured age

The decorrelation of the data is remarkable, and the mean square deviation around the regression line, of which the range is indicated with the dotted line, is large. Estimated deviation of the transition year is $\pm 1,200$ years. This significant deviation is presumed to be due to radiocarbon dating performed in different ways.

Analyses only on the basis of the material from the right bank of the Asahi river show that the transition year was 8,100 calibrated BP, which is fairly accurate with the deviation only ± 0.003 years. The deviation of the elevation (y -coordinate) in the transition year, which is the intersection of the two straight lines, is 0.005 mm.

It is noteworthy that the transition year $8,080 \pm 1,200$ calibrated BP obtained from wide area samples and the transition year $8,100 \pm 0.003$ calibrated BP obtained from the samples along the Asahi river have a high identity in terms of the mean value. This suggests that the assumption of the unique sedimentation rate applied in this method is not so far from reality.

The sedimentation rate observed in the entire Okayama Plain is 1.0 ± 0.2 mm/y in the Holocene, and 0.18 ± 0.05 mm/y in the Pleistocene stratum, which is considered to be the average value observed in the vast area of the Okayama Plain.

Thus, it appears to be clear under certain assumptions that the seawater intrusion into the Okayama Plain occurred in 8,100 calibrated BP, while the sedimentation surface at the transition year can be described as 8.89 meters below sea level.

Therefore, it is generally considered that if there are about ten chronological materials available including those of the Holocene and Pleistocene, accurate estimation of the transition year will be made possible by means of this method.

On the basis of the distribution of Jomon ruins, we can estimate that the surface of the brackish lake formed after the seawater intrusion was several meters higher than the current sea level. It is considered that the alluvial clay layer of the Okayama Plain developed in the warm weather of this Jomon Transgression.

4. CONCLUDING REMARKS

We found out that, given the condition that the sedimentation rate was unique either in the Holocene or Pleistocene era, the chronological data could be arranged on a single straight line by shifting the elevation of the observation points upward or downward in either of the periods. By doing so, the chronological data of sediments obtained by measurements at different locations were related to each other, and

It was possible to estimate that the sedimentation rate was almost unique over a vast area at either of the periods.

1. It was possible to estimate the average sedimentation rate either in the Holocene or Pleistocene.
2. It was possible to estimate the time of seawater intrusion from the point of intersection of the two straight lines.
3. It was possible to estimate the elevation of the sedimentary surface when the seawater intrusion occurred at each observation well.

As a result, seawater intrusion into the Okayama Plain is considered to have occurred in 8,100 calibrated BP with the elevation of the sedimentary surface 8.89 meters below sea level. The sedimentation rate proved to have been 1.19 mm/y in the Holocene, and 0.18 mm/y in the Pleistocene.

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