Movement during the Yayoi Period: An Examination of the Western Burial Area of the Doigahama Site Using Strontium Isotope and Cranial Morphological Analyses

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ABSTRACT
This study aimed to clarify the movement of people during the Yayoi period (c. 800～600 BC–around AD 200) by examining the western burial area of the Doigahama site using strontium (Sr) isotope and morphological analyses. The results of the Sr isotope analysis for incisor, premolar and molar indicated that the $^{87}Sr/^{86}Sr$ *value of the skeletal remains of individuals No. 807 and No. 1305 were distributed outside the range of* $^{87}Sr/^{86}Sr$ *value estimated by the faunal teeth excavated from the Doigahama site. Furthermore, the results of the Sr isotope analysis for No. 1305's third molars indicated that the weighted mean of the third molar crown and root values fell outside the range of* $^{87}Sr/^{86}Sr$ *value of the Doigahama site. These findings suggest that No. 1305 lived in a different area from the isotopic environment around the Doigahama site until the age of complete formation of the third molar. Combining the results of Sr isotope analysis, morphological analysis and archaeological context, the area along the Hibikinada coast adjacent to the Doigahama site is considered to be the most probable area where No. 807 and No. 1305 lived before they moved.*

KEYWORDS: Doigahama site, human skeletal remains, movement of people, morphological analysis, strontium isotope analysis, Yayoi period

1. Introduction

The Doigahama site is a cemetery in the western coastal area of the Honshu (the main island of the Japanese archipelago, Figure 1) from which over 300 skeletal remains dated to the Yayoi period have been excavated. During the Yayoi period (*c*. 800～600 BC–around AD 200, see Mizoguchi 2013), an economic transition from a hunter-gatherer

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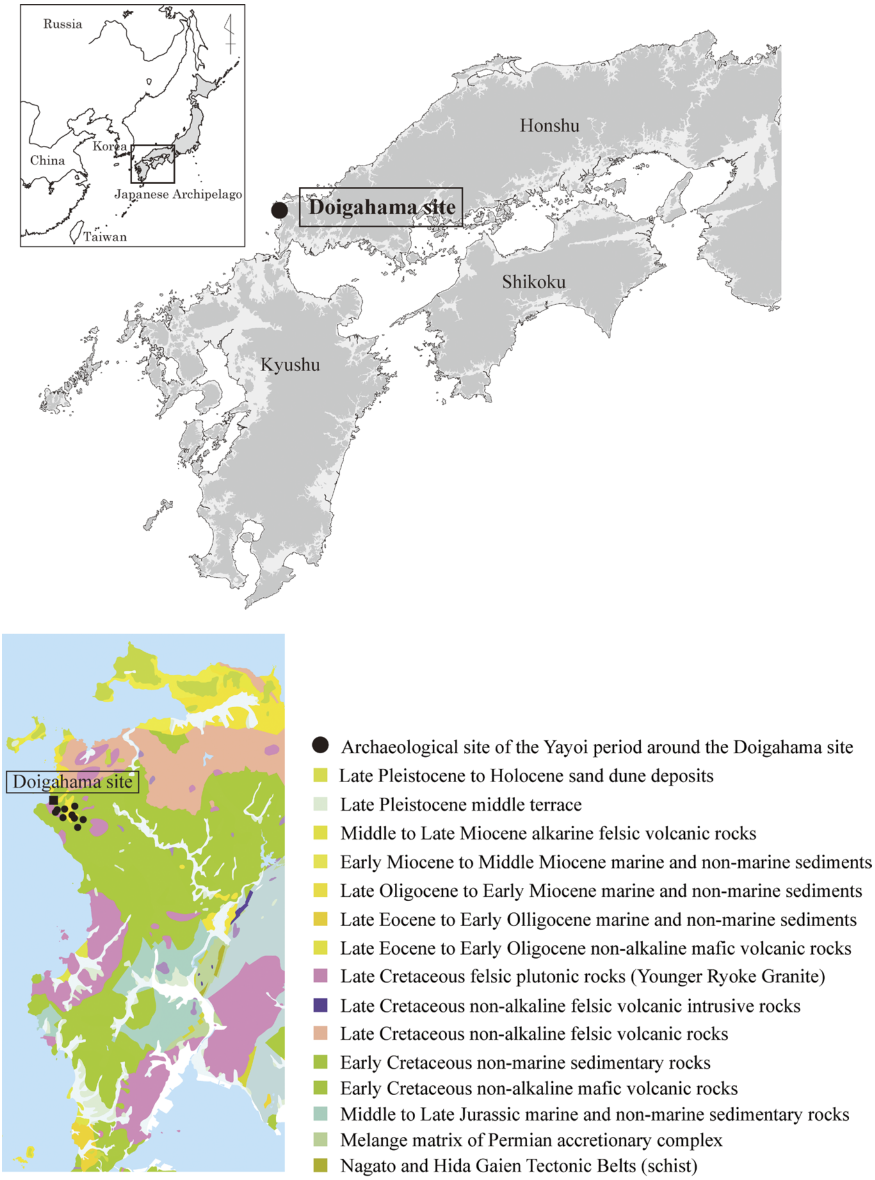


Figure 1. Location of the Doigahama site and the surrounding geological environment. The geological map was retraced by the author using the GIS data from a 1:50,000 geological map (Geological Survey of Japan). (https://gbank.gsj.jp/geonavi/geonavi.php#14,34.28606,130.90103)

economy to a rice paddy agricultural economy occurred when agricultural technology was introduced from the Korean peninsula. In addition to these economic changes, human morphological changes, such as facial form, dental size and shape, limb proportions and stature, occurred from the Jomon period (*c*. 12000 BP– 2300 BP, see Mizoguchi 2013) to the Yayoi period. Many previous studies have suggested that these morphological changes were the result of gene flow following the immigration of peoples from mainland Asia to northern Kyushu (Kanaseki *et al.* 1960; Ikeda 1981, 1998; Brace & Nagai 1982; Yamaguchi 1982; Dodo & Ishida 1988; Mizoguchi 1988; Hanihara 1991; Kim *et al.* 1993; Nakahashi 1993, 2005; Matsumura 1994; Dodo 1995). The results of ancient DNA analysis have also suggested that individuals at the Doigahama site were influenced by the gene flow from mainland Asia (Mizuno *et al.* 2021; Kim *et al.* 2025). Kim *et al.* (2025) sequenced the whole nuclear genome of an individual (No. 1604) excavated from the Doigahama site and reported the following: 1) the Doigahama Yayoi individual had three distinct genetic ancestries: Jomon-related, East Asian-related, and Northeastern Siberian-related; 2) the Korean population exhibited the highest degree of genetic similarity to the Doigahama individual among the non-Japanese populations; and 3) a two-way admixture model, assuming Jomon-related and Korean-related, was supported by the analysis of admixture modelling. Agricultural technology and immigration from mainland Asia occurred first in northern Kyushu, which is the nearest island of the Japanese archipelago to the Korean peninsula. Starting from northern Kyushu, rice cultivation, agricultural technology and gene flow from the mainland Asia spread to the eastern area of the Japanese archipelago. The Doigahama site is located on these routes from Kyushu to Honshu (Figure 1). Archaeological excavations have revealed that the Doigahama site consists of two burial areas: a western and an eastern burial area (Figure 2). The graves in the western burial area are distributed in a linear form, while those in the eastern burial area form clusters. Many previous studies have used archaeological and physical anthropological methods to examine the Doigahama site and attempt to reconstruct its social organisation (Kanaseki 1969; Harunari 1974, 2002; Koumoto 1975; Tanaka *et al*. 1986; Tanaka 2008; Yamada 1997; Funahashi 2000, 2016; Furusho 2001).

Strontium (Sr) isotope analysis is conducted on human skeletal remains to evaluate prehistoric mobility patterns (e.g. Bentley 2006). Sr is a relatively abundant isotope in rocks, and four main isotopes occur in nature. The Sr isotope ratio ($^{87}Sr/^{86}Sr$) is expressed by the ratio of the amount of ^{86}Sr to ^{87}Sr. In general, ocean floor basalt is homogeneous and has a low $^{87}Sr/^{86}Sr$ value (about 0.703). On the other hand, granite is considered to have a relatively high $^{87}Sr/^{86}Sr$ value because of its high rubidium/Sr ratio (Bentley 2006). The $^{87}Sr/^{86}Sr$ values in the underlying geology are incorporated into the human body, especially teeth and bones, through water and the plants and animals that it consumes. The $^{87}Sr/^{86}Sr$ values of teeth may reflect the $^{87}Sr/^{86}Sr$ values of the area where the teeth formed during

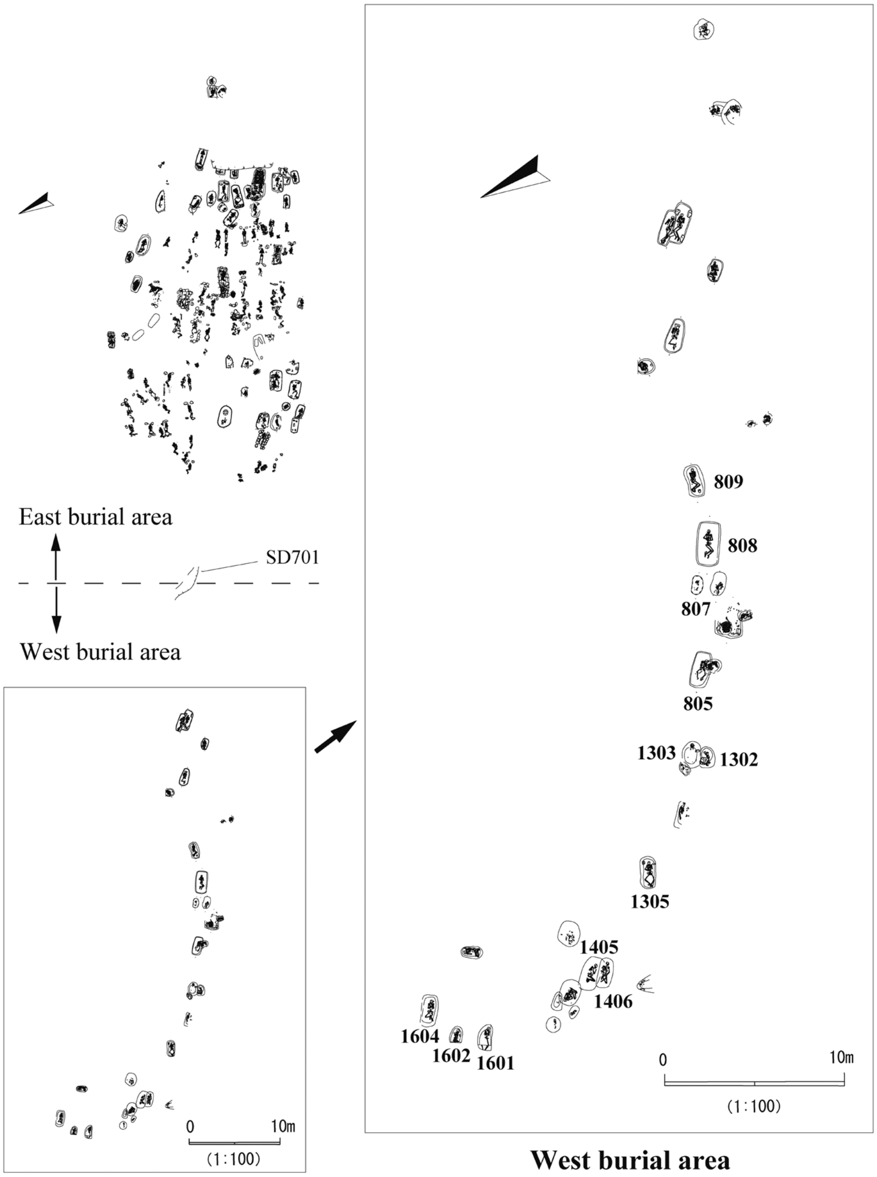


Figure 2. Layout of the remains of the Doigahama site. Left: Overall view of the Doigahama site. Right: Enlarged figure of the western burial area at the Doigahama site. The figure was created by the author using the Doigahama Site Anthropological Museum (ed.) (2014) as a reference.

childhood because teeth are not remodelled once they are formed (Bentley 2006).

Sr isotope analysis has also been conducted in Japan, including in studies using human skeletal remains excavated from shell mounds dating to the Jomon period (Kusaka *et al.* 2008, 2009, 2011, 2012) and faunal remains (Gakuhari & Yoneda 2016). Previous studies have also combined Sr isotope analysis and human dental morphology (Morita *et al.* 2012) and Sr isotope analysis and human bone morphology with archaeological information from the Kofun period (around AD 200–600, see Mizoguchi 2013) (Tanaka *et al.* 2017; Yonemoto *et al.* 2022; Takamuku *et al.* 2024). In the present study, laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS) was used for the Sr isotope analysis, the most important feature of which is that it has a localised and minimal effect on the material being sampled. This is important from the viewpoint of protecting valuable skeletal materials and minimising the negative impact on other research fields such as tooth morphology. In addition, the fact that the negative impact of the analysis on the material is localised makes it possible to analyse multiple locations for the same tooth, and multiple teeth within the same individual. Because the age of tooth formation is determined based on the tooth, the analysis of multiple locations and teeth in the same individual can trace temporal changes in the Sr isotopic ratios of the same individuals, allowing reconstruction of the timing when that individual moved from one location to another. In the present study, we analysed the Sr isotope ratios of teeth with later formation for the same individuals, who were presumed to have moved based on Sr isotope analysis that traced the timing of their relocation to the area around the Doigahama site.

Previous studies have shown that a combination of Sr isotope analysis, morphological analysis, and archaeological evidence is crucial to maximise the accuracy of the interpretations (Tanaka *et al.* 2017; Yonemoto *et al.* 2022; Takamuku *et al.* 2024). In the complex geological environment of the Japanese archipelago, several regions have the same Sr isotope ratio values; therefore, the place of origin cannot be narrowed down by the Sr isotope ratio alone. The integration of morphological analyses on skeletal remains and archaeological information may provide a better understanding of mobility patterns based on the genetic and cultural phylogenetic relationships among the population studied. Given this background, using Sr isotope ratio analysis, the present study aimed to clarify mobility patterns during the Yayoi period by examining cranial morphological data along with archaeological information, such as funerary objects, for individuals presumed to have changed where they lived during the Yayoi period.

2. Materials and methods

2-1. Skeletal samples

The human skeletal remains used in this study were excavated from the western burial area of the Doigahama site (Figure 2), which is separated from the eastern burial area by an open space (about 20 m wide) and ditches (SD701). The tombs are distributed in a row around the ridge of a sand dune, and a total of 28 tombs have been found. Of the human skeletal remains used in this study, the ^{14}C age of the No. 1604 sample was 2305±20 years, and the calibrated ages (95.4% probability) were in the range of 405–361 cal BC (90.7%), 275–263 cal BC (3.1%), and 243–235 cal BC (1.7%) (Kim *et al.* 2025). Other samples are dated to the Yayoi period based on archaeological context, such as soil layers, burial facilities, and burial accessories.

The total number of samples for which Sr isotope analysis was available was 13 (three males, six females, and four nonadults). The teeth for Sr isotope analysis were mainly incisors, but if the incisors of the individual being analyzed were not present, then premolars or molars were used. For individuals that showed a different Sr isotope ratio from the Doigahama site area on isotope analysis, additional analysis was conducted. Specifically, Sr isotope ratio analysis of teeth (e.g., third molars) that form later than the teeth analyzed first was performed, and the Sr isotope ratio values were compared among multiple tooth types. For example, if the Sr isotope ratio of the third molar differed from the Sr isotope ratio of the tooth used in the initial analysis (incisor, premolar, or molar), but was the same as the Sr isotope ratio of the area around the Doigahama site, it could be estimated that the individual moved to the area around the Doigahama site from another region before the age at which the third molar was formed. Alternatively, if the Sr isotope ratio of the third molar was the same as the Sr isotope ratio of the tooth in the initial analysis, it could be assumed that the individual moved to the area around the Doigahama site after the formation of the third molar.

To estimate the range of Sr isotope ratios in the area around the Doigahama site, the faunal teeth excavated from the Doigahama site were used in this study. A total of six faunal samples, consisting of deer (three samples), a raccoon dog (one sample), a dog (one sample) and a mole (one sample), were used for the analysis. All faunal samples were excavated from the soil layers of the Doigahama site dated from the Yayoi to the early modern period.

2-2. Sex and age determination of human skeletal remains

Sex was assessed based on morphological features of the hip bone, such as the greater sciatic notch, subpubic angle and ischiopubic proportion, with reference to Phenice (1969) and Bruzek (2002). When the hip bone was unavailable, assessment of sex followed a metric assessment of the postcranial bones (Nakahashi & Nagai 1986) and cranial features (Buikstra & Ubelaker 1994). Age at death was estimated based on age-related changes in the pubic symphysis (Todd 1920; Sakaue 2006) and the morphology of the auricular surface (Lovejoy *et al.* 1985; Buckberry & Chamberlain 2002; Igarashi *et al.* 2005). In addition, if the hip bone was not preserved, age was estimated based on an evaluation of the degree of obliteration of cranial sutures (Meindl & Lovejoy 1985; Sakaue 2015).

For development of the teeth (I1, P2, M1, M3) used in the Sr isotope ratio analysis, this study referred to Ubelaker (1989), The Japanese Society of Pedodontics (1988), and Masutomi *et al.* (2019). In this study, the completeness of each tooth crown was determined to be the stage at which the tooth crown is complete and the formation of the tooth root begins. In Ubelaker (1989), which used data from Native Americans, the completeness of each tooth crown used in this study was shown as follows: incisors (beginning of formation: 6±3 months, completion: 4±1 years), second premolars (beginning of formation: 3±1 years, completion: 6±2 years), first molars (beginning of formation: birth, completion: 3±1 years), and third molars (beginning of formation: 9±3 years, completion: 15±3 years). The Japanese Society of Pediatric Dentistry (1988) used Japanese data and found the following: incisors (beginning of formation: 6 months, completion: 4 years), second premolars (beginning of formation: 3 years, completion: 7 years), first molars (beginning of formation: birth, completion: 4 years), and third molars (beginning of formation: 9 years, completion: 15 years). Masutomi *et al.* (2019), who examined the stage of formation of the third molar using Japanese data, reported that the median age of completion of the third molar's crown was 16.9 years. Based on previous research on the stage of tooth crown formation, the age range for tooth crown formation in this study was defined as follows, including the error range (upper and lower limits): incisors (3 months to 5 years old), second premolars (2 to 8 years old), first molars (birth to 4 years old), and third molars (6 to 18 years old).

2-3. Sr isotope analysis

We used an LA-MC-ICP-MS instrument (Neptune Plus; Thermo Fisher Scientific, Waltham, MA, USA) combined with an LA system (Analyte G2 Excimer; Photon Machines, Inc., Redmond, WA, USA) installed at Kyushu University, Japan. First, the condition of the analysis part was observed using an optical microscope to find the most suitable, non-weathered location for analysis. The surface of the teeth was polished from 3 mm to 7 mm using a dental engine to make a flat plane and obtain a stable signal. Second, we performed isotopic analyses using LA-MC-ICP-MS. Briefly, 50 measurements per line (150 μm wide and 4 mm in total length) were made, the weighted mean value of these 50 measurements was taken as the value of the line, and the weighted mean value of the result for five lines was taken as the value of the sample. Isotopic ratios were corrected based on the protocols described by Horstwood *et al.* (2008). Sea Shell, which has $^{87}Sr/^{86}Sr$ ratio of 0.70917 as determined using thermal ionization mass spectrometry installed at Kyushu University, was used for the calibration standard. Two types of modern human teeth and natural apatite (Durango apatite; McFarlane & McCulloch 2008) were used for doublycharged rare earth elements and Ca dimer corrections. Finally, the analysis traces were observed using a scanning electron microscope (VHX-D500; Keyence, Osaka, Japan). The analysis was carried out for more than five lines for each tooth; these values were then used to calculate the weighted means of the $^{87}Sr/^{86}Sr$ ratios to check for deviations from the obtained data.

2-4. Morphological analysis

To analyse the cranial morphology, a total of nine measurements (MCL: maximum cranial length, MCB: maximum cranial breadth, BBH: basion–bregma height, BB: bizygomatic breadth, UFH: upper facial height, OB: orbital breadth, OH: orbital height, NB: nasal breadth, NH: nasal height) were taken, in accordance with Martin & Saller (1957) and Baba (1991). As comparative samples for cranial morphological analysis, skeletal remains excavated from the site dating to both the Jomon and Yayoi periods were used (Table 1). To assess cranial morphological differences between the Jomon and Yayoi samples and summarise the data sets, a principal component analysis (PCA) based on covariance matrices was performed using all nine measurements. The data set used for the PCA was collected from complete individual value sets, and any individuals with missing data were excluded. Before performing the PCA, each individual variable was generated to a "log-shape" variable based on the method of Mosimann and colleagues (Darroch & Mosimann 1985; Jungers *et al*. 1995; Mosimann & James 1979). Log-shape variables are used to adjust size and are calculated by dividing each of the original individual variables by the geometric mean of all variables for that individual. For the principal components (PCs) calculated by the PCA, only those with eigenvalues greater than 1.0 were used. All

Table 1. Comparative samples for cranial morphological analysis in this study

Group	Era	Sample size	Site
Jomon	Late-Final[a)]	12	(Aichi prefecture) Yoshigo[a)] (Okayama prefecture) Tsukumo[b)] (Fukuoka prefecture) Yamaga, Nagainumaru, Kuwabaruhigushi
Yayoi	Early-Middle[b)]	81	(Shimane prefecture) Koura (Yamaguchi prefecture) Doigahama, Nakanohama (Fukuoka prefecture) Kanenokuma, Hakugen, Nishihiratsuka, Monden, Dojoyama, Kuma, Nagaoka, Kumanishioda, Okubo, Kiridoshi, Mitsu, Asahikita

a) c. 4000 to 2300 BP (Mizoguchi 2013)
b) c. 400 ～200 BC to around AD 1 (Mizoguchi 2013)

statistical analyses were carried out using SPSS Statistics 20 (IBM Corp., Armonk, NY, USA) and Microsoft Office Excel 2020 (Microsoft Inc., Redmond, WA, USA).

3. Results

3-1. Sr isotopic analysis

Isotopic data obtained from the human and faunal tooth enamel are shown in Table 2 and Figure 3. In the faunal tooth enamel, the $^{87}Sr/^{86}Sr$ values of large mammals such as dogs, deer, raccoon dogs, and moles exhibited wide $^{87}Sr/^{86}Sr$ values, while the values of small mammals such as moles yielded a narrow range. This is considered the result of differences in the behavioural range of each animal. Excluding dogs, the range of each modern animal is 16.3～43.7 ha for deer (Ishizuka *et al.* 2007), 280 ha for raccoon dogs (Saeki *et al.* 2007) and an average of 0.0724 ha for moles (Imaizumi 1983). The weighted mean $^{87}Sr/^{86}Sr$ value for all faunal tooth enamels was 0.70955 and the 2 σ value fell between 0.70938 and 0.70972 (Table 2 and Figure 3). These values likely affected the $^{87}Sr/^{86}Sr$ values around the Doigahama site because they included a sample of animals with a narrow range of behaviour (moles).

In the isotopic data of human tooth enamel, most $^{87}Sr/^{86}Sr$ data were within this value range (Figure 3). However, the $^{87}Sr/^{86}Sr$ value of skeletal remain No. 807 (weighted means of $^{87}Sr/^{86}Sr=0.70903$, $2\sigma=\pm0.00026$) and No. 1305 (weighted means of $^{87}Sr/^{86}Sr=0.70880$, $2\sigma=\pm0.00025$) was distributed outside the $^{87}Sr/^{86}Sr$ value range around the Doigahama site estimated from the faunal remains (Figure 3). This result suggests that No. 1305 (♀) moved from a different isotopic environment around the Doigahama site by the age of enamel formation of the central incisor crown, and that No. 807 (immature human skeletal remain) moved from a different isotopic environment around the Doigahama site by the age of enamel formation of the first molar crown. Moreover, to evaluate the timing of these moves, we analysed the third molar of No. 1305 (Table 2 and Figure 4). Due to the poor preservation of other permanent teeth and the lack of formation of some permanent teeth, no additional analysis could be done on No. 807. The weighted means of the $^{87}Sr/^{86}Sr$ values in both tooth crowns (upper part: analysis No. 1–5 in Figure 4, lower part: analysis No. 6–7 in Figure 4) and roots (analysis No. 8–12 in Figure 4) of No.1305 were almost the same as the $^{87}Sr/^{86}Sr$ value of the incisor (Figure 4). This result suggests that No. 1305 moved from a different isotopic environment around the Doigahama site after completion of the third molar's crown and root.

3-2. Morphological analysis

Next, we examined the cranial morphology of No. 1305, who was considered to move from a different isotopic environment around the Doigahama site based on Sr isotope ratio

Table 2. Results of the Sr isotope analyses on teeth and context information about the samples

Sample type	Burial No.	Sex	Age (y)	Faunal	Tooth sample	$^{87}Sr/^{86}Sr$	
						Weighted mean	Error (2 σ)
Human	801	♀	20–39	—	I1	0.70972	0.00026
Human	805	♀	40–59	—	I1	0.70994	0.00063
Human	807	—	2–4	—	M1	0.70903	0.00026
Human	808	♂	40–59	—	I1	0.70958	0.00029
Human	809	♀	40–59	—	I1	0.70933	0.00016
Human	1302	—	1–6	—	I1	0.70958	0.00011
Human	1303	—	1–6	—	M1	0.70959	0.00022
Human	1305	♀	30–39	—	I1	0.70880	0.00025
Human	1305	♀	30–39	—	M3	0.70895	0.00011
Human	1405	♀	45–59	—	I1	0.70928	0.00013
Human	1406	♂	40–59	—	I1	0.70953	0.00052
Human	1601	♀	50–59	—	P2	0.70939	0.00011
Human	1602	—	1–6	—	M	0.70968	0.00014
Human	1604	♀	20–39	—	I1	0.70938	0.00012
Faunal	—	—	—	Deer (Ce1)	M	0.70974	0.00009
Faunal	—	—	—	Deer (Ce2)	M	0.70983	0.00022
Faunal	—	—	—	Deer (Ce3)	M	0.70930	0.00024
Faunal	—	—	—	Raccoon dog (Np)	M	0.70944	0.00018
Faunal	—	—	—	Dog (Ca)	M	0.70945	0.00013
Faunal	—	—	—	Mole (Ta)	M	0.70947	0.00007

Teeth: M (molar), P (premolar), I (incisor tooth)

analysis. Table 3 shows the results of the PCA, and Figure 5 shows a two-dimensional scatterplot of the PC scores. Regarding the results of the PCA, the first PC (PC1; factor loading=1.767, contribution rate=19.635) showed high positive values for MCB and BB, and high negative values for UFH and NH. Therefore, it can be said that PC1 is a factor that indicates the width of the neurocranium and the ratio of the width and height of the face. It can also be said that the higher the PC1 score, the wider the neurocranium and the stronger the tendency to have a low face (characterized by a shorter (vertically lower) and broader face, leading to a relatively wider facial aspect), whereas the lower the PC1 score, the smaller the width of the neurocranium and the stronger the tendency to have

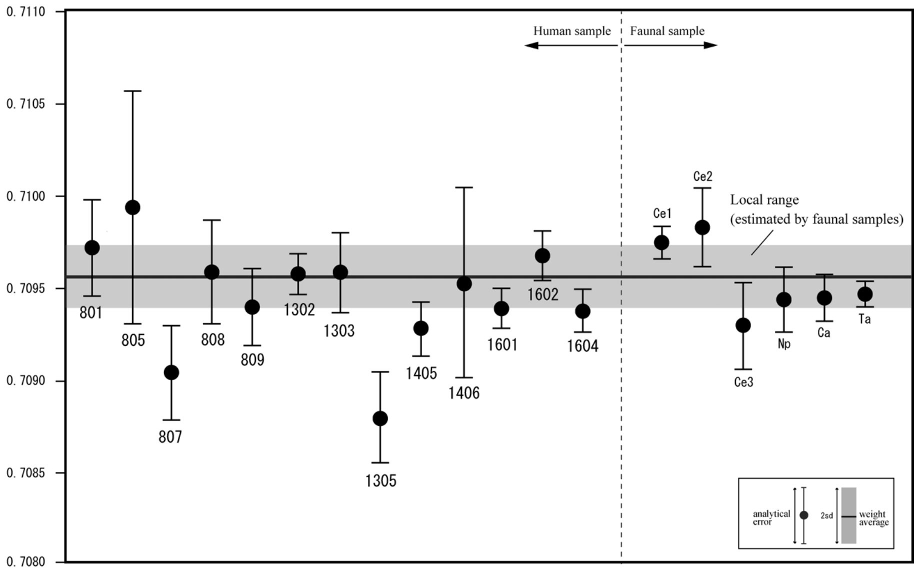


Figure 3. Results of the Sr isotope analysis for human and faunal teeth excavated from the Doigahama site. Ce: Deer, Np: Racoon dog, Ca: Dog, Ta: Mole.

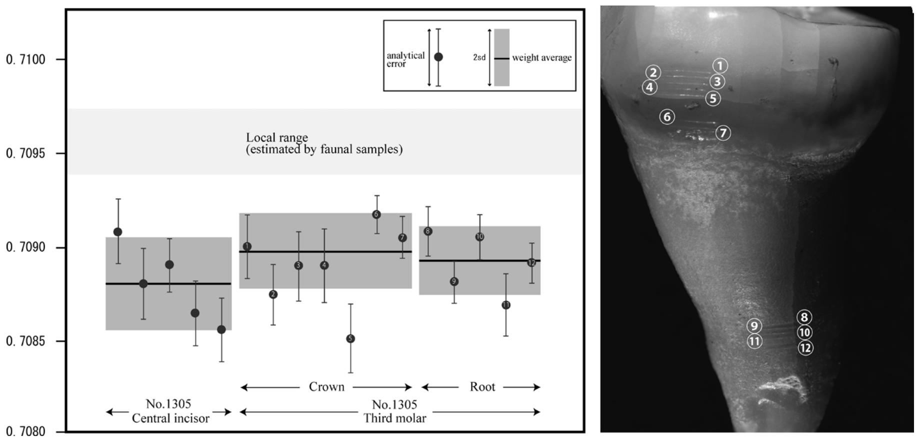


Figure 4. Results of the Sr isotope analysis for No. 1305 and analysis points (numbers enclosed in circles) of the third molar in No. 1305

a high face (characterized by a longer (vertically higher) and narrower face, leading to a relatively slimmer appearance). The second PC (PC2; factor loading=1.350, contribution rate=14.998) showed positive values with high BBH and MCB, and can be said to be a factor indicating the width and height of the neurocranium. The higher the PC2 score, the larger the height and width the neurocranium, and the lower the PC2 score, the smaller

Table 3. Factor loadings of the principal component analysis

		PC1	PC2	PC3
MCL	Maximum cranial length	0.209	− 0.083	0.942
MCB	Maximum cranial breadth	0.789	0.474	− 0.067
BBH	Basion–bregma height	− 0.041	0.920	0.327
BB	Bizygomatic breadth	0.784	− 0.092	0.109
UFH	Upper facial height	− 0.452	− 0.327	− 0.374
OB	Orbital breadth	0.089	0.019	0.136
OH	Orbital height	0.006	− 0.062	− 0.179
NB	Nasal breadth	− 0.099	− 0.382	0.018
NH	Nasal height	− 0.512	− 0.075	− 0.266
	Eigenvalue	1.767	1.350	1.273
	Contribution	19.635	14.998	14.139

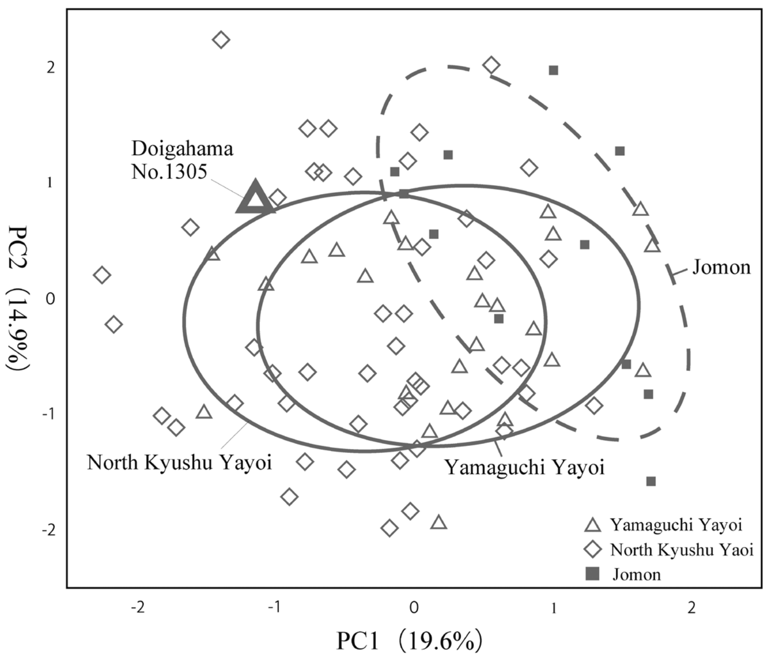


Figure 5. Scatterplot of individual PC1 and PC2 scores estimated by principal component analysis using nine cranial measurements. Circles show the confidence ellipse (68.27%) in each population.

the height and width of the neurocranium. The third PC (PC3; factor loading=1.273, contribution rate=14.139) showed positive MCL values, and can be said to be a factor indicating the length of the neurocranium. Since the factor loading of PC3 was largely biased to one measurement item (MCL), the analysis was performed using PC1 and PC2.

Figure 5 shows the PC1 and PC2 scores of each individual developed in two dimensions. The PC1 score (x-axis) differed between the Jomon and Yayoi populations. The Jomon group had higher PC1 scores, wider neurocraniums and a stronger tendency for a low face. The Yayoi group had lower PC1 scores, narrower neurocraniums and a stronger tendency for a high face. Since many previous studies have pointed out differences in facial proportions between the Jomon and Yayoi populations (Kanaseki *et al.* 1960; Ikeda 1981, 1998; Yamaguchi 1982; Mizoguchi 1988; Hanihara 1991; Nakahashi 1993), the results of the PCA conducted in the present study represent the differences in the trait characteristics between the two groups. In Figure 5, individual No. 1305, who was estimated to have moved from a different isotopic environment around the Doigahama site based on the Sr isotope ratio analysis, is located closer to the Doigahama site and the Yayoi group in northern Kyushu than to the Jomon group.

4. Discussion

The results of the Sr isotopic analysis conducted in the present study suggest that No. 807 moved from the isotopic environment around the Doigahama site until the age of formation of the first molar crown. The age at which the crown of the first molar forms ranges from birth to 4 years. The age of death of No. 807 was estimated to be 2–4 years (Table 2), based on the complete formation of the deciduous teeth and formation of the crowns of the first molars. The results of the Sr isotopic analysis and estimated age of death based on the state of permanent tooth formation suggest that No. 807 most likely died shortly after moving to around the Doigahama site from a different area. Because it is difficult to move alone and settle in a remote residential group without being accompanied by adults at this age, it is most likely that No. 807 moved to the Doigahama site accompanied by an adult. The results of the Sr isotopic analysis also suggest that No. 1305 moved from a different area after the age of formation of the third molar crown and root. As Masutomi *et al.* (2019) reported that formation of the Japanese third molar's root ranges from 16.9 to 24 years, including individual differences, these results suggest that No. 1305 (age of death: 30–39 years, see Table 2) moved to around the Doigahama site from an isotopically different area after age 16.9 to 24 years.

Regarding archaeological information such as grave goods, No. 807 had no burial accessories and No. 1305 was buried wearing a shell bracelet made of *Anadara satowi* (Figure 6). At the Doigahama site, shell bracelets are major grave goods, and are divided

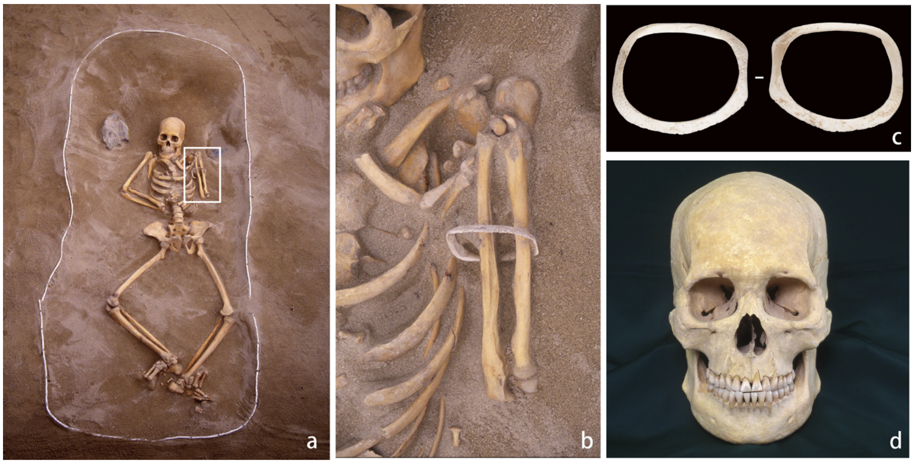
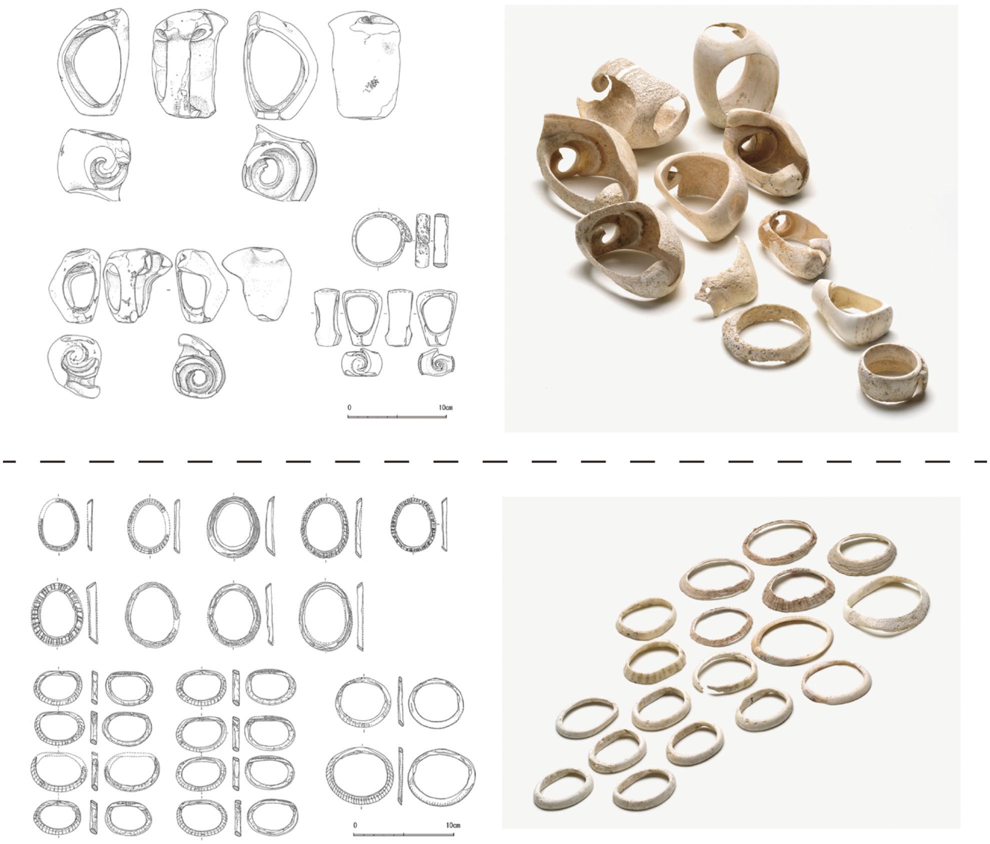


Figure 6. Archaeological information for No. 1305 excavated from the Doigahama site. a, b: excavation condition. c: shell bracelet, d: cranium

into two types based on the kind of sea shell used (Figure 7). The first type is made by large scallops inhabiting the Nansei Islands of the Japanese archipelago, such as *Strombus latissimus* and *Conus leopardus* or *Conus litteratus Linnaeus*. The second type is made by clams inhabiting areas near the Doigahama site. The shell bracelets found with human skeletal remains at the Doigahama site are distinguished as follows: the first type, which were made from large scallops inhabiting the Nansei Islands, was mainly for adults, whereas the second type, which were made from clams inhabiting areas near the Doigahama site, was for juveniles. Twenty-four inshore shell bracelets have been excavated from the Doigahama site, and there have been only two cases in which an inshore sea shell bracelet was excavated together with adult human skeletal remains. In those two cases, No. 1305 was the only adult wearing an inshore shell bracelet, which suggests that No. 1305 is a rare case from the perspective of shell bracelet customs among adults at the Doigahama site. In western Japan, the use of two-piece shell rings flourished during the Jomon period, and adult females were the overwhelming majority of wearers; many of the cases of shell rings being worn were on the left arm (Watanabe 1969). The fact that No. 1305 also wore a bracelet on the left arm reflects the custom of wearing shell rings since the Jomon period.

Moreover, at the Doigahama site, 78.5% of adults showed tooth ablation (Matsushita & Matsushita 2014), but not No. 1305. Regarding the social meaning of the custom of tooth ablation at the Doigahama site, some previous studies have suggested that it was a rite of passage among the Yayoi people at the Doigahama site. Nakahashi (1990) and Funahashi (2000) suggested that the Yayoi people at the Doigahama site first showed

Shell bracelet
(shells inhabited in the south east islands)



Inshore sea shell bracelet
(shells inhabited near the sea)

Figure 7. Two types of shell bracelets excavated from the Doigahama site. The figure was created by the author using materials from the Doigahama Site Anthropological Museum (ed.) (2014) as a reference.

tooth ablation at age 12 to 13 years based on an analysis of the attrition of the opposing tooth, and that one of the explanations for tooth ablation at the Doigahama site was that it formed part of coming-of-age ceremonies (Nakahashi 1990; Funahashi 2000). The results of the present study suggested that No. 1305, who showed no tooth ablation, moved from a different isotopic environment around the Doigahama site after age 24 years. This finding offers one hypothesis about tooth extraction customs at the Doigahama site. The group of individuals who had no tooth ablation at the Doigahama site included people who moved to the Doigahama site from an isotopically different area. In order to verify this hypothesis, it will be necessary to increase the number of cases of analysis of Sr isotope ratios of other individuals who had no tooth ablation at the Doigahama site. Depending on whether No. 1305 was an isolated case or a common case in the group of individuals who had no missing teeth, our understanding of the tooth ablation custom at the Doigahama site (in particular the group of individuals with no missing teeth) would differ greatly.

Based on the above, the results of this study suggest that No. 1305 might be interpreted as a person who moved from an area that differed from the social and cultural customs recognised at the Doigahama site. So where did No. 807 and No. 1305 come from? In the complex geological environment of the Japanese archipelago, there are multiple regions with the same Sr isotope ratios, so it is not possible to determine the source of the Sr isotope ratio values based on the Sr isotope ratio values alone. In previous studies, maps of the Sr isotope ratios of the Japanese archipelago have been presented for groundwater and rocks (Nakano *et al.* 2020) and vegetables (Aoyama *et al.* 2017). Referring to these Sr isotope ratio maps, the Sr isotope ratio values for the area around the Doigahama site are 0.7096–0.7104 for groundwater, 0.710–0.716 for rocks, and 0.7090–0.7095 for vegetables. The analysis values for animal bones in this study were 0.70938–0.70972, which are close to the values for groundwater and vegetables. However, these values can be seen in multiple locations across the Japanese archipelago (Aoyama *et al.* 2017; Nakano *et al.* 2020). It has been pointed out that the Sr isotope ratio is affected by the consumption of marine food by individuals, and that individuals with high consumption of marine food have low Sr isotope ratios (Lahtinen *et al.* 2021). The values of the carbon and nitrogen isotope ratios reported by Yoneda (2014) indicated that the carbon isotope ratio (δ^{13}C: −18.0 ‰) and nitrogen isotope ratio (δ^{15}N: 11.0 ‰) of No. 1305 are not significantly different from the average values (δ^{13}C: −18.9 ‰, δ^{15}N: 10.9 ‰) for the other individuals at the Doigahama site. However, as Yoneda's research (2014) analysed bone samples, the carbon isotope ratio and nitrogen isotope ratio of No. 1305 do not strictly reflect the diet of the age of the teeth used in this study. Therefore, the relationship between Sr isotope ratios and diet at the Doigahama site will need to be discussed in the future. Furthermore, as we consider the possibility that the Sr isotope ratio values of humans might fluctuate due to short-term or seasonal movement of individuals, it is difficult to determine from Sr isotope ratio values alone where the individuals who migrated to the Doigahama site from different isotopic environments came from. Therefore, we would like to consider local movement around the Doigahama site from the perspective of the archaeological context and the morphological characteristics of human skeletal remains.

Pottery excavated from the Doigahama site has included local pottery as well as pottery influenced by neighbouring (Nagato area) or remote areas such as the Setouchi and north Kyushu areas (Noriyasu 2014) (Figure 8). Local pottery, which applied patterns such as leaves, wings and double arcs, was shared on the Hibikinada coast area, and some sites from the same periods as the Doigahama site have been confirmed in the Toyoura and Ayaragi areas (Figure 8). Regarding the composition of the pottery at the Doigahama site, some was influenced by the Nagato area. As for that influenced by the Setouchi area, pottery with a comb pattern and polygonal ridge has also been excavated from the Doigahama site. Pottery with these characteristics has widely been seen in the Setouchi area, and Noriyasu (2014) suggested that it flowed into the Doigahama site through the eastern area of Yamaguchi. Regarding pottery from northern Kyushu, Itazuke-type and red-painted pottery (with unidentified Pigment) have been excavated from the Doigahama site. Among these, Itazuke-type pottery dates to the early Yayoi period, indicating that it was influenced by northern Kyushu during the formation period of the Doigahama site. In addition, the amount of pottery from northern Kyushu increased in the middle stage of the Yayoi period, indicating that the influence from northern Kyushu continued to flow in (Noriyasu 2014). Bronze wares excavated from the Doigahama site include small bronze mirrors and copper iron, and the amount of bronze wares excavated from the Doigahama site has been reported to be smaller than that of other Yayoi burial sites along the Hibikinada coast (Kobayashi 2011). Among these wares, it has been pointed out that small mirrors were manufactured in northern Kyushu. Regarding the ornaments excavated from the Doigahama site, the shell ornaments mentioned above indicate exchanges with the Nansei Islands. In addition to shell ornaments, stone ornaments have been excavated, including jasper tube balls, jade magatama and small amazonite balls. Most of the jasper used for tube balls was produced in the Hokuriku region, according to fluorescent X-ray analysis (Warashina 2014). The jade used for the magatama is estimated to be from Itoigawa and Oumi in Toyama Prefecture (Warashina 2014). The stone ornaments excavated from the Doigahama site reveal interactions with the Hokuriku region. From the archaeological materials excavated from the Doigahama site, it is possible to infer interaction with other areas. There is a high degree of commonality with the plains along the Hibikinada coast near the Doigahama site, such as the Toyoura and Ayaragi areas. In these areas, human skeletal remains and animal bone materials were excavated dating to the same time as the Doigahama site, so Sr isotope analysis will need to be performed on these materials in future research. On the other hand, there was interaction with the Doigahama site in remote areas such as the Setouchi area, northern Kyushu area, Hokuriku area and Nansei Islands. With regard to the exchange of archaeological artifacts at the Doigahama Site, Kobayashi (2011) evaluated the Yayoi people of the Doigahama as a group that was engaged in rice cultivation in paddy fields (which requires a sedentary lifestyle) but was also actively engaged in mutual interaction by sea.

Based on the cranial morphology analysis in this study, No. 1305 was similar to the Yayoi period group on the Hibikinada coast such as the Doigahama site or the Yayoi period

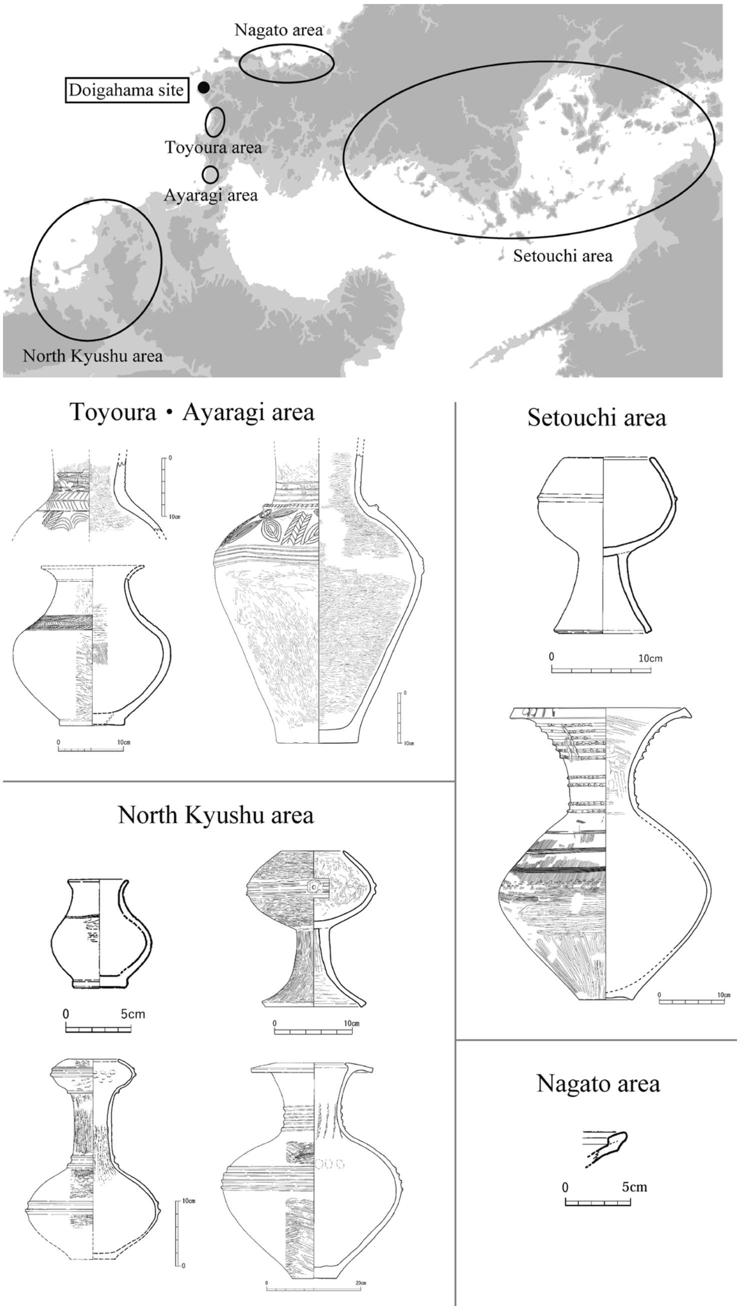


Figure 8. Pottery excavated from the Doigahama site and the area related to the Doigahama site from the perspective of pottery. The figure above was created by the author using the Doigahama Site Anthropological Museum (ed.) (2014) as a reference.

group in northern Kyushu. Previous studies have pointed out that the Yayoi group on the Hibikinada coast and in northern Kyushu were genetically influenced by migrants from the continent. In addition, the genetic influence of migrants from the continent is linked to the spread of Yayoi culture based on paddy rice farming, and the greater the geographical distance from northern Kyushu, the weaker the genetic influence of migrants (Doi & Tanaka 1987). Based on the cranial morphological analysis carried out in this study and the results of previous research, it is highly possible that the residential area of No. 1305 before the move was strongly influenced by the genetic influence of migrants from the mainland Asia. Among the remote areas that interacted with the Doigahama site based on material culture, northern Kyushu is the area most affected by the genetic influence of migrants from the mainland Asia. Yoneda *et al.* (2011) reported that the Sr isotope ratio of the Hakata site on the Fukuoka Plain in northern Kyushu was 0.707–0.708, and that of the southern area of the Fukuoka Plain, where many Yayoi period sites are located, was 0.705–0.706. As this was lower than the Sr isotopic ratio of No. 807 and No. 1305 at the Doigahama site, it suggests that the Fukuoka Plain was unlikely to be the residence area of No. 807 and No. 1305 before they moved to Doigahama. In the Setouchi and Hokuriku regions, few cases of excavated human skeletal remains from the Yayoi period have been reported. On the Nansei Islands of the Japanese archipelago, the number of skeletal remains from the same period as the Doigahama site is limited, but human skeletal remains dated from the end of the Yayoi period to the Kofun period have been excavated at the Hirota site in Tanegashima. A previous study suggested that these remains have more traditional Jomon morphological characteristics than do the Yayoi people in northern Kyushu and the Doigahama site (Nakahashi 2003). Moreover, based on an analysis of ancient mtDNA, Shinoda *et al.* (2020) suggested that no outside influx would have changed the genetic composition of the population in the late shell mound period, which is chronologically consistent with the Yayoi period in the Honshu area. Considering the findings of those previous studies, it is unlikely that No. 1305 moved directly from the Nansei Islands.

Combining the results of the Sr isotope analysis, morphological analysis, and archaeological context, the area along the Hibikinada coast adjacent to the Doigahama site is considered to be the most probable area where No. 807 and No. 1305 were before they moved to Doigahama. However, at this point, the possibility of other regions cannot be denied. It will therefore be necessary to collect more Sr isotope ratio data from the western burial area of the Doigahama site and surrounding Yayoi sites.

5. Conclusion

This study examined the moves of individuals from the western burial area of the Doigahama site based on Sr isotope and cranial morphological analyses. The results of the Sr isotope analysis suggested that the $^{87}Sr/^{86}Sr$ value of No. 1305 and No. 807 was distributed outside the $^{87}Sr/^{86}Sr$ value range of the Doigahama site estimated by faunal teeth. Furthermore, Sr isotope analysis for No. 1305's third molars with a later age of complete formation suggested that the weighted means of No. 1305's crown and root values for the third molars were outside the $^{87}Sr/^{86}Sr$ value range of the Doigahama site estimated by faunal teeth. These results suggest that No. 1305 most likely lived in an area different from the isotopic environment around the Doigahama site until the age of complete formation of the third molar. In the cranial morphological analysis, PCA based on nine cranial measurements suggested that the trait characteristics of No. 1305 were more similar to the Yayoi population, which was genetically influenced by the migrants from mainland Asia, than to the Jomon population. Combining the results of Sr isotope analysis, morphological analysis and archaeological context, the area along the Hibikinada coast adjacent to the Doigahama site is considered to be the most probable area where No. 807 and No. 1305 originated.

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