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Communication

Strontium Isotope Analysis of Prehistoric Faunal Remains Excavated from Fais Island in Micronesia

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1. Introduction

The distribution of prehistoric mammals in Micronesia was very limited. Fais is the only island where a reliable collection of prehistoric mammal bones has been excavated (Intoh and Shigehara, 2004; Intoh, 2008). A set of Southeast Asian domesticated animals brought to Oceania in prehistoric times, dog (*Canis l. familiaris*), pig (*Sus scrofa*), and chicken (*Gallus gallus domesticus*), was found together with many rat (*Rattus rattus*) bones.

It was rather surprising to find a set of these domesticated animal remains spanning the cultural sequence of the island, i.e., from AD 200 to the present. There are no other islands or island groups in Micronesia where a whole set of these animals has been excavated. Considering the coral environment and the small size of Fais Island, there was suspicion that not all of these mammals were locally raised on the island, but were imported from other islands, particularly volcanic islands.

Strontium isotope ratio ($^{87}Sr/^{86}Sr$) is one of the most effective indicators to find an answer to this question. Prehistoric pig remains have been analyzed for Sr isotopes to identify the pig remains as local or non-local (Bentley et al., 2004), because Sr isotopes in dental enamel have recorded those of the geological background on which the pig had been raised. It is particularly useful to differentiate animals raised in coral and volcanic environments (Laffoon et al., 2012; Laffoon et al., in press), and therefore valuable in differentiating local and foreign pigs recovered from prehistoric deposits of Fais Island, which is a coral island.

This paper reports the results of isotope studies on the prehistoric animal remains of Fais

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Island and some comparative analyses on modern plants, using the research question: Were the excavated animal remains from Fais Island local or non-local?

1.1. Geographic and Natural Background

Fais is situated near the western end of the Central Caroline Islands extending from Ulithi to Namonuito. All the islands in the region are coral islands. Volcanic islands are situated farther west and north (Yap, Palau, the Marianas) and farther east (Chuuk, Pohnpei, Kosrae). The island nearest to Fais is Ulithi atoll, lying about 80 km to the west.

Fais is an uplifted coral island (about 20 m above sea level) and is located at 9°46' N and 140°31' E in the Federated States of Micronesia (Figure 1). Fais Island is about 2.7 km in length and about 1.1 km in width, making the land area about 2.8 km^2. The climate of Fais is tropical Oceanic and highly humid (about 83%). The average mean temperature is 27°C and the annual rainfall is about 3,000 mm.

Fais Island is elongated in shape in the direction of northeast to southwest. A narrow fringing reef surrounds the island except for the northeast end and the west sides, where steep cliffs receive the impact of rough waves. There is neither a safe anchorage nor a good landing place on the island. Inside the fringing reef, a narrow sandy beach extends along the coast. The sea bottom between the reef and the coastal beach is covered with fused, old coral, and has little sandy patches. The traditional habitation area is confined to the coastal flat along the southern beach, while the gardening area is distributed mainly on the inland plateau. The flat central plateau is about 20 m above sea level, elevated by a steep slope from the coastal flat. The soil was rich in phosphates, and was mined during the German and Japanese mandate period. The soil is highly porous, and rainwater permeates the ground. The conditions are not suitable for cultivating *Cyrtosperma*, which is the major subsistence crop of the surrounding atolls. The population of Fais in recent history has ranged between about 200 and 300 individuals (Rubinstein, 1979, 1995).

Subsistence crops on Fais consist mainly of the sweet potato, which was introduced from Yap in historic times, taro (*Colocasia esculenta, Alocasia macrorrhiza*), breadfruit (about 10 varieties), banana, and coconut. Pigs, dogs, chickens, and rats were introduced by the first colonizing population around AD 200 (Intoh and Shigehara, 2004).

Currently, pigs are kept around housing properties, in the coastal beach bush, or near gardening areas (usually by having a foreleg tied to a stake) and are fed mainly copra and vegetable scraps. Dogs are allowed to walk around freely on the island and are fed any leftover foods, including fish bones. Chickens are also left free in the village area and fed copra. Rats live mainly on plants and are distributed in the bush. It is very likely that rats are also consumed as a food.

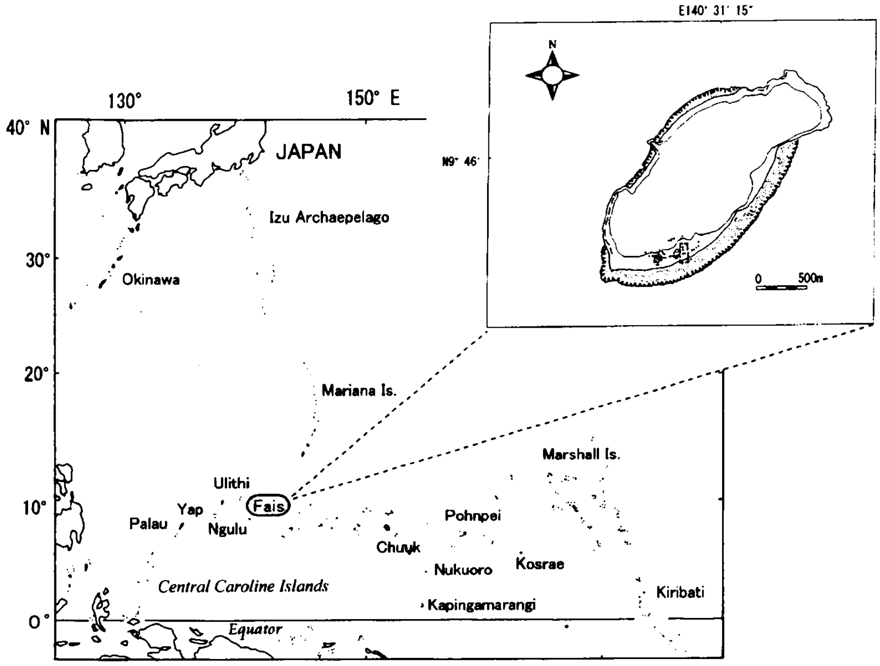

Figure 1. Map of Micronesia and Fais Island

1.2. Historic and Archaeological Background

People on Fais speak a Nuclear Micronesian language. This language group was considered to have dispersed from the southeastern Solomon Islands to most parts of Micronesia except for western Micronesia, including the Marianas, Yap, and mainland Palau. The original colonization of Fais is considered to have been part of this large wave of Nuclear Micronesian migration.

In historic times, there was an exchange system, called *sawei*, between coral atolls in the Central Caroline Islands and Yap Island (Alkire, 1978), in which Fais also participated. This was a kind of safety network for atoll people and a way to obtain natural and cultural resources unobtainable in a coral environment, such as turmeric, red soil, earthen pots, and stones, in exchange for handicrafts such as woven cloth, ropes, and shell beads.

Intoh has conducted archaeological research on Fais Island since 1991 (Intoh, 2008). A rich cultural deposit was unearthed in the southern coastal area, including not only artificial remains, but also a variety of natural remains. The results indicate that Fais has been inhabited by human populations since as early as AD 40.

A number of exotic/foreign materials have been recovered from excavations, such as pottery, trolling lures, and metamorphic stones (Intoh, 1996, 1999). The distribution pattern of these imports demonstrates that continual contact with other islands was fairly constant throughout the habitation history. It is apparent that maintaining external contacts was one of the significant living strategies of the people of such a resource-limited coral island (Intoh, 1996).

The distribution pattern of the excavated artifacts indicates that the island was consecutively

Table 1. Cultural Phases in Fais Island

Cultural phase	Age	FSPO* site	FSFA* site
IV	AD 1400–historic	Layers 1-4	Layer 1
III	AD 800–1400	Layers 5-6	Layers 2-3
II	AD 400–800	Layers 7-11	Layer 4
I	AD 1–400	Layer 12	Layers 5-6

(modified from Ono and Intoh 2011)
* FSPO and FSFA are excavation units on the coastal area in Fais Island (Intoh and Shigehara 2004)

inhabited (Intoh, 1993, 2008). Four cultural phases were set out based on the excavated materials and associated radiocarbon dates. Phases I (AD 40–400) through III (AD 800–1400) are prehistoric, and Phase IV (after AD 1400) is the post-contact period. A series of ^{14}C dates obtained from Fais excavations was published by Ono and Intoh (2011), and a summary table of dates and their correlation to the cultural phases is shown in Table 1.

Large amounts of faunal remains were obtained in excavations, including mollusks, crustaceans, fish, mammals (pig, dog, rat, and dolphin), and birds (Steadman and Intoh, 1994; Intoh and Shigehara, 2004; Ono and Intoh, 2011). Of these, a total of over 500 g of bones were from terrestrial mammals, including dogs, pigs, and rats. The number of dog and pig bones increases from Phase I to Phase IV. Only 2.3% were from Phase I, while 37.2% were from Phase II, and 60.5% were from Phases III and IV. The existence of dogs and pigs during Phase II is secure, but the possibility that they were first introduced during Phase I is also conceivable (Ono and Intoh, 2011).

1.3. Strontium Isotope Analysis of Faunal Remains

Strontium resembles calcium in chemical behavior and is absorbed in bones and teeth. Isotope of strontium constitutes ^{88}Sr, ^{87}Sr, ^{86}Sr, and ^{84}Sr in its natural state. The strontium isotope ratio generally represents the ratio between ^{87}Sr and ^{86}Sr in geology, since natural abundance of ^{86}Sr is similar to that of ^{87}Sr (Faure and Mensing, 2005).

The strontium isotope ratio of a certain natural environment varies according to the bedrock in the area (Faure and Mensing, 2005; Hess et al., 1986; Bentley, 2006). Continental bedrock with a high Rb/Sr ratio has a higher average $^{87}Sr/^{86}Sr$ of 0.716, while oceanic basalt with a low Rb/Sr ratio has a lower average $^{87}Sr/^{86}Sr$ of 0.703–0.706, because ^{87}Sr is originated from the decay of ^{87}Rb. Phanerozoic marine limestone has intermediate $^{87}Sr/^{86}Sr$ values between 0.707 and 0.709, reflecting the composition of the ocean during their deposition. Living organisms take in strontium from bedrocks through their diet and drinking water. Because Sr isotopic ratios do not change through a food chain, plants and animals including humans will show similar Sr isotopic ratios in an ecosystem (Åberg, 1995; Blum et al., 2000; Capo et al., 1998). Applying this nature of strontium isotope ratio, $^{87}Sr/^{86}Sr$ has been used in a number of studies for estimating the original place of archaeological faunal remains (Bentley, 2006).

Samples for strontium isotope analysis are often extracted from tooth enamel rather than from bone. The possibility of contamination from the surrounding soil and the diagenesis alteration of enamel occurring post-mortem is very low compared with compact bone, because the crystal size distribution of enamel is larger than that of non-biogenic carbonate formed with diagenesis alteration (Sillen, 1986). As post-mortem contamination can be removed by leaching with a weak acid (Price et al., 1994; Budd et al., 2000; Hoppe et al., 2003), the strontium isotope analysis of mammal tooth enamel has been widely used in archaeological research.

The strontium isotope ratios in plants and/or small mammals are good proxies for evaluating the range of $^{87}Sr/^{86}Sr$ in local organisms. This is called the "bio-available strontium isotope ratio" (Price et al., 2002). For example, rabbits, dogs, and pigs are suggested as good indicators for the bio-available strontium isotope ratio (Knudson et al., 2004), although possible Sr intake from the marine ecosystem should be considered in the case of omnivores. Furthermore, the strontium isotope ratio of modern plants was consistent with those of local mammals (Kusaka et al., 2009). Local mammals and plants were good indicators for differentiation of local or non-local individuals. Therefore, if the $^{87}Sr/^{86}Sr$ values of human and faunal remains and modern local plants do not match the bio-available strontium isotope ratios of the island, these individuals were likely brought in from outside the island.

2. Materials

A total of 10 teeth, each representing a unique prehistoric sample, were selected for the isotope analysis: 4 pigs, 2 dogs, and 4 rats. The excavation details and estimated cultural phase for each sample are shown in Table 2.

Also, some additional modern samples of various kinds were added for the analysis (Table 3). In order to characterize the isotope value for animals and plants grown on Fais, a modern pig tooth and some plant materials (banana fiber, coconut husk rope, and dried tobacco leaf) that were undoubtedly grown on Fais were added. Also, two modern pig tusks from Yap Island (metamorphic high island) and one pig tusk from Pohnpei Island (volcanic island) were analyzed for comparative purposes. Yap Island is about 260 km west of Fais, and Pohnpei Island is about 2,000 km to the east. Although the sample number is small to clarify the bio-available strontium isotope ratio in volcanic environments, as a preliminary study, these samples should allow us to discuss the differences in values of 87Sr/86Sr between coral and volcanic environments.

Table 2. Description of Prehistoric Teeth Samples Analyzed in This Study

Sample ID	Material	Cultural phase	Excavation square	Layer
TG111301	*Sus scrofa* (pig)	I	FSFA-2	5
TG111302	*Sus scrofa* (pig)	III	FSPO-2	11
TG111303	*Sus scrofa* (pig)	III	FSFA-2	3
TG111304	*Sus scrofa* (pig)	IV	FSFA-1	1
TG111305	*Canis l. familiaris* (dog)	II	FSFA-1	3
TG111307	*Canis l. familiaris* (dog)	IV	FSFA-1	1
TG111308	*Rattus rattus* (rat)	I	FSFA-2	6
TG111309	*Rattus rattus* (rat)	II	FSFA-2	4
TG111310	*Rattus rattus* (rat)	III	FSFA-2	3
TG111311	*Rattus rattus* (rat)	IV	FSFA-2	1

Table 3. Description of Modern Samples for Comparative Analysis

Sample ID	Material	Island
TG111312	Modern pig	Fais
TG120501	Modern pig	Yap
TG120502	Modern pig	Yap
TG120503	Modern pig	Pohnpei
TG120402	Dried tobacco plant	Fais
TG120403	Banana fiber	Fais
TG120404	Coconut rope	Fais

3. Method

3.1. Sampling Procedure

The enamel was sampled in batches of approximately 5 mg taken from prehistoric remains. After removal of the surface of the tooth enamel (depth: >0.1 mm), the enamel powder was sampled using a tungsten carbide drill. To avoid the risk of cross contamination, a new drill bit was used for each sample. The pretreatment and purification of enamel powder was carried out in the clean room (class 1000) of the Research Institute for Humanity and Nature (RIHN).

3.2. Strontium Isotope Measurement

To remove the influence of diagenetic alteration in enamel samples, the enamel powder was reacted in 0.1 M acetic acid buffer for 24 hours. The pretreated sample was dissolved in 6 M nitric acid and dried in an oven. Plants were combusted into ash by a microwave ashing tool, and the strontium in the ash samples was purified by the same method used for the enamel samples. The strontium of dried samples was purified and extracted using a column filled with cation exchange resin (Muromachi Technos). After purification of the strontium, the samples were loaded onto tungsten filaments.

Measurements of strontium isotope ratios were carried out using the thermal ionization mass spectrometer (TRITON, Thermo Fisher Scientific) at RIHN. The strontium isotope ratio ($^{87}Sr/^{86}Sr$)

was normalized by $^{88}Sr/^{86}Sr$ to natural abundance, and $^{87}Sr/^{86}Sr$ was corrected by NBS987, an international standard for strontium isotope ratio (certified value: $^{87}Sr/^{86}Sr$=0.710250). The internal measurement error (standard error) was 3.66 ppm (n=12) in this study.

4. Results

To evaluate the strontium isotope range of the modern biosphere in Fais Island, $^{87}Sr/^{86}Sr$ was measured in several plant samples and a modern domesticated pig sample (Table 4). Our results show that Sr ratios in modern plants and the domesticated pig were generally consistent with those of the marine limestone in the Quaternary period (0.709165–0.709181; Ando et al. 2010). On the other hand, we found that Sr isotope ratios of modern pigs living in volcanic islands (Yap and Pohnpei) are significantly lower than those of the modern plants and a pig from Fais (Z=2.12, P=0.03). It is highly possible that this difference between Fais and volcanic islands was caused by the difference in their geological backgrounds.

On the other hand, Sr isotope ratios of prehistoric animals (dogs, pigs, and rats) from Fais are similar to those of the modern plants and pigs in Fais and clearly different from pigs in volcanic islands (Table 5). This result indicates that the strontium isotope ratios of prehistoric animals were affected by seawater and/or the marine limestone in the Quaternary period, as well as in the modern one, as was reported by previous researchers (Evans et al., 2009; Evans et al., 2010). As a result, it is possible that prehistoric pigs inhabited an ecological niche similar to the modern pig on Fais. The mean difference among modern plants, a modern pig, and prehistoric rats was tested by a Mann-Whitney U test, indicating no significant difference among them (Z=1.73, P=0.08; see Figure 2). Given the hypothesis that most prehistoric rats were local, it is possible that the Sr isotope range of terrestrial biosphere on Fais in prehistoric time was similar to the modern one. Hence, based on the results in modern plants, a modern pig, and prehistoric rats, a range between 0.709166 and 0.709176 is assigned to the bio-available Sr isotope ratio on Fais Island.

Table 4. Strontium Isotope Ratios in Faunal Remains from Fais Island

Sample ID	Material	Cultural phase	$^{87}Sr/^{86}Sr$	StdErr (abs)
TG111301	*Sus scrofa* (pig)	I	0.709177	0.000005
TG111302	*Sus scrofa* (pig)	III	0.709179	0.000005
TG111303	*Sus scrofa* (pig)	III	0.709176	0.000006
TG111304	*Sus scrofa* (pig)	IV	0.709174	0.000005
TG111305	*Canis l. familiaris* (dog)	II	0.709185	0.000006
TG111307	*Canis l. familiaris* (dog)	IV	0.709177	0.000005
TG111308	*Rattus rattus* (rat)	I	0.709171	0.000005
TG111309	*Rattus rattus* (rat)	II	0.709171	0.000005
TG111310	*Rattus rattus* (rat)	III	0.709167	0.000005
TG111311	*Rattus rattus* (rat)	IV	0.709166	0.000006

Table 5. Strontium Isotope Ratios in Modern Samples

Sample ID	Material	Island	$^{87}Sr/^{86}Sr$	StdErr (abs)
TG120402	Nicotiana sp. (tobacco)	Fais	0.709173	0.000004
TG120403	Musa spp. (banana)	Fais	0.709176	0.000005
TG120404	Cocos nucifera (coconut)	Fais	0.709169	0.000005
TG111312	Sus scrofa (pig)	Fais	0.709176	0.000005
TG120501	Sus scrofa (pig)	Yap	0.708970	0.000005
TG120502	Sus scrofa (pig)	Yap	0.709028	0.000005
TG120503	Sus scrofa (pig)	Pohnpei	0.708501	0.000005

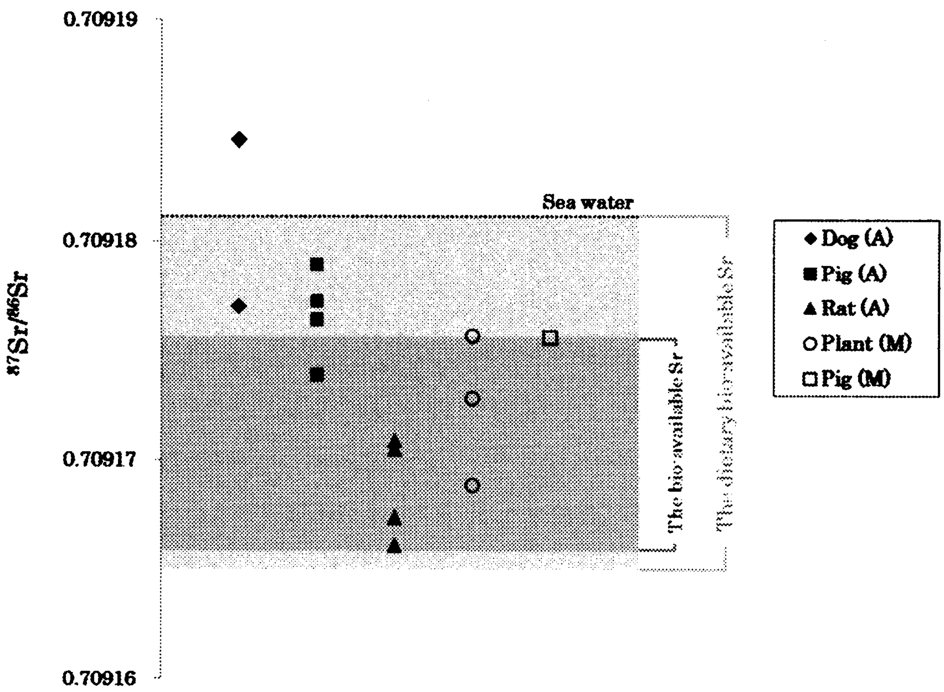

Figure 2. Comparison of Strontium Isotope Ratios between Prehistoric and Modern Samples in Fais Island (A: Archaeological Remains; M: Modern Samples)

Comparing the means of Sr isotope ratios among prehistoric dogs, pigs, and rats by a Mann-Whitney *U* test, those of prehistoric pigs and dogs show significantly higher ratios than those of prehistoric rats (Z=2.56, P=0.01). This tendency did not correlate with the cultural phase. As a result, it was indicated that prehistoric pigs and dogs used other Sr resources different from the terrestrial biosphere on Fais Island.

5. Discussion

There are a number of examples in Polynesia in which pigs were introduced by prehistoric people, but were extirpated afterwards. It has been suggested that animal husbandry was simply less feasible on resource-impoverished islands (Anderson, 2002; Kirch, 2000, etc.). Among the various factors affecting pig survivorship in an island environment, island size was shown to be the most significant factor in Polynesia (Giovas, 2006).

From this viewpoint, Fais is an island where pigs cannot survive because of its small size. However, archaeological excavations conducted on Fais have shown that pigs were kept throughout its history, for about 1,800 years. The following discussion will demonstrate that the excavated pigs were likely to have been raised on Fais and not extirpated as they were on other small islands in Polynesia.

First, we compared the bio-available strontium isotope of Fais Island with those of the other islands in Polynesia reported in previous studies. Shaw et al. (2009) showed that the means of bio-available strontium isotopic ratios on a number of volcanic islands in Polynesia ranged between 0.705 and 0.707 based on the teeth from prehistoric omnivore mammals. Those of two islands (Teouma and Kamgot) were higher than 0.708 (Bentley et al., 2007; Shaw et al., 2009; Shaw et al., 2010). In our research, it was shown that the strontium isotopic ratios obtained from modern pigs living in Pohnpei and Yap—volcanic islands—fit well within the range of volcanic islands reported in the previous studies and did not fall within the range of Fais characterized by the narrow range of bio-available strontium isotope. This result clearly indicates that the prehistoric Fais pigs were not likely introduced from volcanic islands.

Second, the results from prehistoric dogs (n=2) and pigs (n=4) were compared with the isotope range of dietary Sr estimated below (Figure 2). Considering the intake of marine Sr through diet, we estimate the possible dietary Sr for domesticated animals on Fais had an isotopic range between 0.709166 (minimum of terrestrial value) and 0.709181 (maximum of marine isotopic value reported in Ando et al., 2010). As a result, the Sr isotope ratios of the dogs and pigs are mostly consistent with the estimation of dietary strontium isotope range on Fais Island. Because those values are very different from Sr ratios observed in the modern pigs raised on Yap and Pohnpei Islands (Figure 3), it is unlikely that these prehistoric pigs and dogs were grown in a volcanic environment, and it is quite possible that these animals were raised on coral islands including Fais Island. Considering the very limited evidence of prehistoric pigs in Micronesia and nearby atolls to date (Intoh, 1986; Masse et al., 2006), however, it is highly probable that these prehistoric mammals were raised on Fais.

In addition, we detected higher Sr ratios in one prehistoric dog and three prehistoric pigs, indicating intake of marine Sr with higher isotope ratio. In the future, human strontium isotope data, in conjunction with carbon and nitrogen data from human bone collagen, will demonstrate the effect of human diet on those animals.

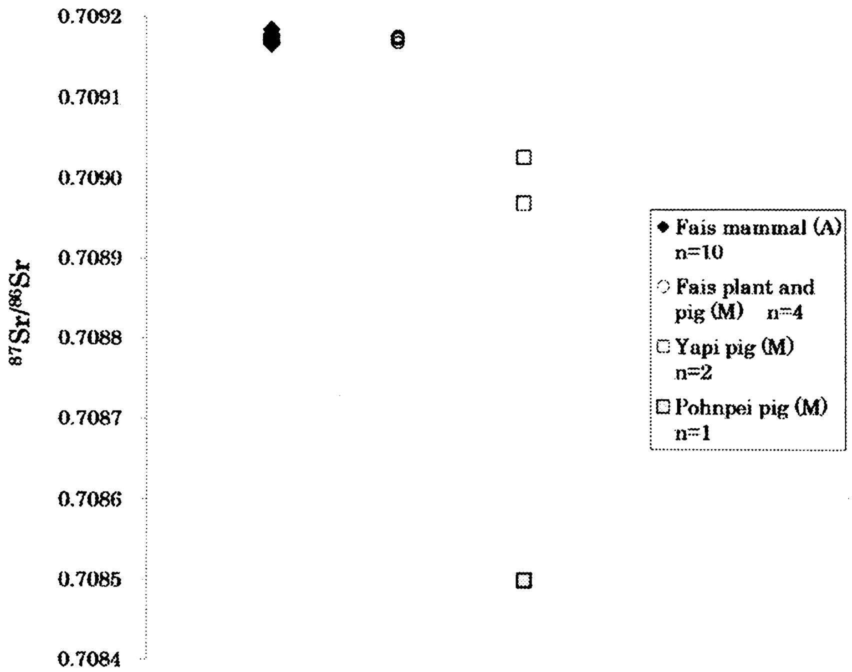

Figure 3. Comparison of Strontium Isotope Ratios among Prehistoric Mammals, Modern Plants, and a Pig in Fais Island and Modern Pigs in Yap and Pohnpei Island (A: Archaeological Remains; M: Modern Samples)

6. Conclusion

The bio-available strontium isotope ratio on Fais Island was estimated at 0.709166—0.709176 based on the $^{87}Sr/^{86}Sr$ values of modern plants and prehistoric rats. Given the evidence of feeding domesticated mammals with some marine food, the range of dietary strontium isotope on Fais Island is estimated to be between 0.709166 and 0.709181. This represents the integrated $^{87}Sr/^{86}Sr$ values of modern plants, prehistoric rats, and prehistoric seawater. The strontium isotope ratios of most prehistoric remains, including those of dogs and pigs, are consistent with the isotopic range of dietary strontium on Fais Island. Although there was a traditional exchange relation between Fais and Yap Island, the $^{87}Sr/^{86}Sr$ values of the modern pigs of Yap as well as the other volcanic island (Pohnpei) are clearly lower than those of prehistoric dogs and pigs from Fais Island. These prehistoric individuals were probably not introduced from outside, but were raised on Fais Island.

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