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BURIED ON FOREIGN SHORES:
Isotope Analysis of the Origin of Human Remains Recovered from a Macassan Site in Arnhem Land

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Abstract

This study uses strontium ($^{87}Sr/^{86}Sr$), oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope analysis of archaeological tooth enamel samples to investigate the origins of human remains from two sites in Arnhem Land, Northern Territory: a coastal Macassan site and an Indigenous rockshelter complex. The study aims to resolve whether two individuals from the Macassan site originate from outside Arnhem Land and, if so, whether their place of origin can be determined. Strontium results confirm the Macassan and Indigenous samples represent two distinct populations. The Indigenous values match the local Arnhem Land geologic strontium signatures, while the Macassan values are outside the local range and more likely to match Indonesian geological signatures. Carbon isotope results are more equivocal, but tend to support the presence of two populations by revealing slightly different dietary backgrounds for each group. Oxygen isotope data introduce more complexity; their geographic signal may be confounded by cultural behaviour. Radiocarbon dating suggests the Macassan Anuru Bay A site is a relatively early contact site. This study shows that even with a small sample set there is potential to discern past human mobility and origin using stable isotope analysis.

Introduction

For centuries, the northern coastline of Australia has witnessed the meeting, trading and cultural exchange of people from vastly different societies. Sailing south out of the centre of what is now Indonesia, fleets of boats called 'praus' visited the coast of northern Australia, arriving on the northwest monsoons in October and November and returning home when the southeast winds blew several months later (Berndt and Berndt 1947:133). They came to collect and process trepang, a marine animal found abundantly on the shallow seabeds off the coast. A prized ingredient in Chinese cuisine, trepang was a major item of commerce (Macknight 1976:1). The archaeological site of Anuru Bay A in northwest Arnhem Land is one of the places Macassans came to process their catch; it is a large trepang processing site with the remains of 21 lines of stone fireplaces for boiling trepang. The site is located on a sheltered peninsula on the eastern side of Anuru Bay, a low-energy sandy bay facing northeast towards the Arafura Sea (Figure 1). Originally excavated by Campbell Macknight in 1966 and 1967, the site is currently the focus of renewed archaeological work.

Macknight recovered two sets of skeletal human remains during his initial work at Anuru Bay A in 1966. The archaeological context and morphology of these remains led Macknight and Thorne (1968) to identify them as Macassan rather than Aboriginal Australian in origin. In this study, strontium, oxygen and carbon stable isotope analyses of tooth enamel from these two 'Macassans' is used as an independent means of assessing whether they originate from outside Arnhem Land and if so, whether their origin may indeed be Macassan. Key to these assessments is a comparison of stable isotope ratios from the skeletons to a local signature for an Arnhem Land population. We therefore also report stable isotope ratios from three human teeth and one faunal tooth recovered from the nearby archaeological site of Malarrak. These are the first reported archaeological stable isotope ratios derived from human remains in Arnhem Land, and are therefore supplemented in the analysis with ratios from geological (Table S1, supplementary information) and hydrological reports.

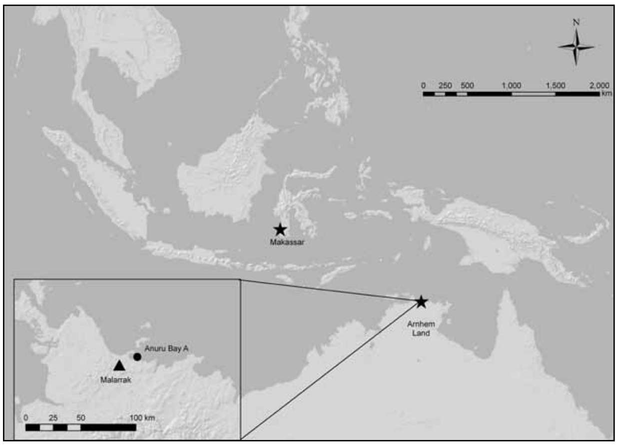

Figure 1 Map showing the study area and the archaeological sites of Anuru Bay A and Malarrak.

Our results confirm that the two people buried at Anuru Bay A were not Aboriginal Australians from Arnhem Land and, when combined with previously reported archaeological and morphological data, analyses strongly support their identification as Macassans. There is also interesting variation within both the Macassan and Aboriginal Australian groups' isotope ratios which points toward the potential for using stable isotope analysis to more precisely identify origin locations for people and fauna recovered from archaeological sites both within Arnhem Land and Island Southeast Asia. In addition, radiocarbon dating of the enamel indicates that Anuru Bay A was occupied relatively early in the Macassan trepang period; in fact, the Anuru Bay A remains are likely to be the earliest known non-Aboriginal human skeletons from anywhere in Australia.

Macassan Trepang Visits to Arnhem Land

Central to the current study is the identity and geographical origin of Macassans. Macknight (1976, 2008) provides an

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overview based on historic sources; for our purposes, the term 'Macassan' refers to a person on the annual fleet of praus to the Northern Territory, rather than to a particular racial, linguistic or cultural group. The crews are known to have consisted predominantly of men from the Macassarese and Bugis cultural groups of southwest Sulawesi. Macknight found that even in the twentieth century, the old men in the city of Makassar remembered the 'Macassan' trepangers as a distinct group with a close association of captains. The direct connection to southwest Sulawesi is also supported linguistically, as the Macassarese language is the most common in words borrowed into Arnhem Land languages. However, the Macassan crews do not appear to have been limited to men from southwest Sulawesi. Macknight (1976) has cited crew lists in which individuals came from various places in Indonesia including New Guinea, Java and Ceram, with further mention of crew members from Buton, Timor, Maluka and Papua. He also notes historical records indicating that, while the majority of praus were of the type from Makassar, a few were made in the styles of other places such as the island of Sumbawa.

Macassan-Indigenous relations were not limited to one-way contact in the form of Macassans visiting northern Australia. There are accounts of Aboriginal people sailing on praus, travelling to Macassar and Singapore, and living abroad for a time (Macknight 1976:86). Such adventures away from Australia were frequent occurrences for young Aboriginal men (and for women occasionally), while Macassans seem to have been less likely to remain in Australia beyond their working season. There are also several accounts of Macassans fathering children with Aboriginal women (Macknight 1976; Warner 1932).

The early chronology of contact is uncertain. Based on written sources, Macknight (1976:97) initially suggested Macassan praus began visiting northern Australia for trepang between AD 1650 and 1750, probably in the last quarter of the seventeenth century. He later revised his estimate to somewhere between early contact in the 1720s when 'the trepang trade in Macassar was still in its infancy' and 1754 when more concrete evidence was available (Macknight 2008:136). Some ethnographic evidence, based on local Aboriginal culture, language, narrative and mythology, suggests an earlier date for the beginnings of the industry, perhaps as early as the first part of the sixteenth century (Berndt and Berndt 1947:133; Taçon *et al.* 2010:7). A recently discovered pottery sherd at Groote Eylandt was found below a date of 930±60 BP (ANU-8984) (Clarke and Frederick 2009 cited in Taçon *et al.* 2010). Another study investigating the minimum age for early rock art depictions of southeast Asian praus in northwest Arnhem Land found one depiction under beeswax dated to before AD 1664 (Taçon *et al.* 2010).

Stable Isotope Analysis

Isotopes are atoms of the same element but with differing weights. That is, they have the same number of protons but differing numbers of neutrons in the nucleus. Unlike radioactive isotopes such as ^{14}C, stable isotopes do not decay over time. The ratio of heavy to light isotopes for a particular element, however, often varies across the landscape. Strontium ratios vary based on the age and composition of the underlying geology while oxygen isotope ratios depend on precipitation source and intensity, and temperature. The isotope ratios of particular places become incorporated into plants growing on the landscape, and are carried up through the food chain until they are incorporated into human tissues. Carbon isotope ratios, on the other hand, depend on the particular photosynthetic pathway utilised by plants and are useful for distinguishing certain aspects of diet including the relative proportions of marine and terrestrial components in the diet. While not frequently applied in Australian and Indonesian archaeological situations, stable isotope analyses have become common in many other regions. A number of recent overviews of archaeological stable isotope analysis are available elsewhere (e.g. Bentley 2006; Lee-Thorp 2008; Tykot 2004). In the Island Southeast Asia-Pacific region, isotope analyses have been used archaeologically as indicators of Lapita migration in the Bismarck Archipelago (Shaw *et al.* 2009, 2010) and remote Oceania (Bentley *et al.* 2007) and in the study of Neolithic groups in Sarawak, Malaysia (Valentine *et al.* 2008).

Strontium

The ratio of heavy and light isotopes of strontium ($^{87}Sr/^{86}Sr$) for a particular place is determined by the ratio in the soil, which may be derived from rocks of different ages and lithologies. Very young rocks such as basalt and reef limestone typically have low ratios (less than 0.704) while very old continental crust rocks such as gneiss, schist and slate can have quite high ratios (well above 0.710) (Bentley 2006; Pye 2004). While geologic processes are the ultimate basis for strontium ratios, interpretation of strontium values in organic specimens by comparison to geologic information can be problematic because the strontium composition of soil and the biosphere does not usually correspond exactly with that of the underlying bedrock. Soils and sediments are products of varying compositions of the source materials from which they are derived, so strontium readings incorporated into the food chain can vary significantly from those of the bedrock beneath. When additional factors such as differential mineral weathering, leaching, seaspray, geological drift and surface additions of dust and rainwater are added to the equation, the strontium found in biological materials can be quite removed from the geological indicators of the region (Eckardt *et al.* 2009; Price *et al.* 2002; Pye 2004). Optimally, archaeologists prefer to use strontium ratios from archaeological faunal remains or humans to determine the local biologically-available strontium ratio signature for an area (Bentley 2006; Bentley *et al.* 2004; Price *et al.* 2002). Unfortunately, no biologically-available strontium ratios have been published from either Arnhem Land or likely Macassan origin islands. As discussed below, we measured strontium ratios in three human and one mammal teeth from an Aboriginal Australian archaeological site to determine the local strontium signature, and supplement this with expectations derived from geological analyses.

Oxygen

Oxygen isotope ratios in mammals are determined by the ratios in water obtained from drinking and consuming food. They are useful for archaeological assessment of location because they are correlated with environmental variables such as temperature during precipitation and precipitation intensity, which can vary significantly between different regions (Bowen *et al.* 2005; Eckardt *et al.* 2009; Luz *et al.* 1984). Human cultural behaviour such as boiling water or using wells to obtain underground water with a different isotopic ratio can also influence oxygen isotope ratios.

Carbon

Carbon isotope analysis is typically used to reconstruct ancient diets. The approach is based on different plant groups having a subtle difference in the fractionation of atmospheric carbon dioxide during photosynthesis (Lee-Thorp 2008; Tykot 2004). The two dominant photosynthetic pathways, C3 and C4 (after the number of carbon atoms fixed in the initial product), result in different ratios of the two stable isotopes of carbon, ^{12}C and ^{13}C.

The C3 pathway is typically followed by trees, woody shrubs, herbs and grasses from temperate regions. Domesticated C3 cereals include rice, wheat, barley, and oats while C3 root staples include manioc, yam and potato. The isotope ratio values ($\delta^{13}C$) for C3 plants average about -26.5‰ but range from -24‰ to -36‰ (Lee-Thorp 2008; Tykot 2004). The C4 pathway is commonly utilised by grasses native to hot and arid environments as well as by some sedges. Domesticated C4 plants include maize, sorghum, millet and cane sugar. C4 plant $\delta^{13}C$ values average about -12.5‰ and their range is narrower, between -7‰ and -16‰ (Krigbaum 2005; Lee-Thorp 2008; Tykot 2004). The carbon isotope ratios of marine organisms vary depending on their local ecology, but primary producers such as algae and diatoms are usually enriched in ^{13}C compared to those in terrestrial C3 ecosystems (Lee-Thorp 2008; Tykot 2004), resulting in marine organisms with $\delta^{13}C$ values around -12‰ (Collier and Hobson 1987). While purely marine-food consumers should contrast to those on a terrestrial C3 diet, the difference between marine-food consumers and those on a terrestrial C4 diet is more difficult to distinguish. We are primarily interested in distinguishing the origin of samples rather than determining their diet, so we will focus on differences among groups rather than on assessing dietary components.

Sites and Materials

Anuru Bay A

In the soft sand of the beach dune at the Macassan Anuru Bay A site, about 15m behind the high water mark, two burials were identified and excavated by Macknight in 1966 (Macknight 1976; Macknight and Thorne 1968). Digging underneath a 'rather jumbled spread of stones that had probably once been a rectangular outline' (1976:68), two individuals, buried at different times, were uncovered. A summary of Macknight's (1976) and Macknight and Thorne's (1968) observations and interpretations follows: The first burial (MAC I) consisted of a relatively wide shallow grave into which a person had been laid face downwards, with the head at the northern end. Macknight and Thorne assessed the skeleton as male, 170cm tall and about 32 years old. He had lost 10 teeth over the previous years and the remaining teeth were in poor condition. Probably some years later, a second burial pit was excavated at right angles to the previous trench, cutting across the centre of the first body. The bones from the neck to the knees of the first body were put aside and a second man was laid on his right side with his head to the east. A row of stones was laid behind him. The second person (MAC II) was male, around 160cm tall and died in his early 20s. He had lost only one tooth previously but had chronic gum disease. As the second burial was filled in, the bones of the first burial were heaped into the north side of the trench, in approximately the area from which they had been removed. The cause of death for both men is unknown.

In addition to their proximity to a trepang processing site, Macknight and Thorne viewed several other details as evidence for their final conclusion that the buried individuals were Macassan men. The graves were marked by a rectangle of stones, a feature of Macassan graves in Australia also observed on Winchelsea Island. The second burial had been arranged in Muslim practice, with the body on its right side facing west towards Mecca. Thick deposits of limy calculus around the teeth of both men and black staining of the second man's mouth suggest they chewed lime and betel. Both men also had their teeth filed down, a common custom in the Indonesian archipelago including South Sulawesi.

Today, the skeletal remains of the two men are held by the J.L. Shellshear Museum of Physical Anthropology and Comparative Anatomy at the University of Sydney. For this project, one mandibular premolar was obtained from each skeleton (Table 1).

Malarrak

The teeth used as a local Arnhem Land signature in this study came from two rockshelters excavated by a team led by Daryl Wesley and Sue O'Connor at the Indigenous Malarrak Complex in 2008. Analyses were carried out with prior permission from coauthor RL, senior traditional owner of the lands of the Manganowal traditional owners within the Arnhem Land Aboriginal Land Trust. All Malarrak samples remain the property of the traditional owners. All teeth were isolated finds with no other human skeletal material nearby. The main Malarrak shelter revealed two teeth. A human molar, MG25, was uncovered around 150mm beneath the surface of test pit G25 within a

Table 1 Origin, type and condition of samples.

Sample	Location	Type	Condition
MAC I	Anuru Bay A , Burial I	Human premolar (mandibular)	No wear
MAC II	Anuru Bay A, Burial II	Human premolar (mandibular)	No wear
MG25	Malarrak Main Shelter, Square G25, XU8	Human molar (mandibular)	Heavily worn to dentine; 2 cavities on sides (one deep, one developing)
MK25	Malarrak Main Shelter, Square K25, XU4	Faunal mandible fragment (3 teeth)	
MT4	Malarrak Shelter #4, Trench 1, Square 11, XU4	Human premolar	No wear; one lateral crack
MT6	Malarrak Shelter #4, Trench 1, Square 11, XU6	Human molar	Slightly worn; split laterally; several hairline cracks

hearth-like lens of dense charcoal surrounded by loose sandy sediment (Table 1). A radiocarbon date of 487±26 BP (NZA-32470) was obtained around 50mm above the excavation unit containing MG25 and a date of 577±17 BP (NZA-32455) was obtained around 50mm below the unit. An iron spearhead was excavated just below the excavation unit. The test pit stratigraphy appeared disturbed with possible postholes penetrating from the upper sediment into the Pleistocene sediment starting 350mm below the surface.

A mandible fragment with several teeth of a small mammal, MK25, was recovered from test pit K25, also in the main Malarrak shelter. Located around 80mm beneath the surface in loose sediment, the mandible may have belonged to a possum or rat-kangaroo. No dating information is available for test pit K25.

In Malarrak Rockshelter #4, one test pit was excavated revealing two additional teeth. MT4, a human premolar, was found approximately 80mm beneath the surface in sandy sediment containing large concentrations of charcoal thought to belong to hearth remains. The second tooth in this test pit, human molar MT6, was uncovered approximately 40mm below MT4, also in sandy sediment with dense charcoal concentrations. A fragment of Staffordshire Ware ceramic, possibly from the late eighteenth to early nineteenth century, was found in the excavation unit containing MT4, and a glass fragment was found in the excavation unit containing MT6. This shelter appeared to have well-preserved stratigraphy, suggesting deposition of the teeth occurred within the European contact period.

Methods

Enamel was collected and pretreated to remove adhering contaminants following procedures adapted from Koch *et al.* (1998) and detailed in Fenner (2007:175-178). Briefly, teeth were mechanically cleaned and enamel powder collected using a drill. Samples were immersed in 2% NaOCl for 24 hours, rinsed, then immersed in 0.1N C_2H_4O for four hours. Strontium isotope composition was determined by Geochron Laboratories, Massachusetts using TIMS. NIST 987 standard samples run simultaneously produced a value of 0.710240±0.000012 (2σ error). Oxygen and carbon isotope in enamel carbonate was determined at the Australian National University Research School of Earth Sciences on a Finnigan MAT 251 IRMS. Sample MAC I did not contain quite enough enamel to balance against the reference gas during the measurement, but the laboratory is confident the result is accurate. Results are reported using the VPDB standard. When compared with precipitation, $\delta^{18}O$ values are converted to the SMOW standard and adjusted for fractionation during incorporation into enamel apatite using the equations in Coplen *et al.* (1983), Bryant *et al.* (1996:5147) and Daux *et al.* (2008).

Due to low sample size, all statistical tests were performed using the unequal variance *t*-test (Ruxton 2006). A metric analysis of Anuru Bay A skull morphology for geographic assignment using the FORDISC and CRANID tools was performed but results were inconclusive (Watson 2011). Both programmes were unable to confidently assign the skulls to any group, presumably due to the lack of Indonesian data in the FORDISC and CRANID comparative database. Radiocarbon dating was performed on enamel from each Anuru Bay A sample using AMS at the Australian National University Radiocarbon Dating Laboratory.

Results

Stable isotope ratio analysis results are shown in Table 2 and Figure 2. The strontium isotope data show a large range and clear grouping. The Anuru Bay A and Malarrak samples are significantly different (t=10.970, p=0.007, df=2.106), with the Anuru Bay A samples much lower than the Malarrak samples. Within each location, there is substantial strontium isotope variation: 0.0018 for the two samples from Anuru Bay A and 0.0031 for the four samples from Malarrak. Excluding the faunal sample as potentially reflecting a different geographic range from the human samples, the Malarrak samples still have a fairly large strontium isotope range of 0.0012.

The $\delta^{18}O$ values range from -5.91‰ to -0.42‰. Daux *et al.* (2008:1144-1145) suggest that 'at any given place, the water ingested by human beings via solid foods, whether it is raw or cooked, should not be richer in ^{18}O than is the total water ingested by herbivorous animals of the same place whose diet is composed of raw plants (tree-leaves, fruits, and grass)'. The faunal sample in this study, MK25, is indeed an outlier in the sample set, with an isotopic value far more enriched than the human samples and also well outside the expected range of modern Arnhem Land precipitation $\delta^{18}O$ values (discussed below). It may be that this animal obtained most of its water from different sources than did the humans; it may have used water derived from plants rather than drinking water, or sipped water from partially evaporated puddles. To avoid distortion of comparative human enamel results the oxygen isotope signature of MK25 is excluded in the statistical analyses. We note however that including the faunal sample in the Malarrak values does not materially alter the results (data not shown).

Excluding the faunal sample, the Anuru Bay A and Malarrak $\delta^{18}O$ values are not significantly different (t=0.085, p=0.943, df=1.441). Figure 2 shows that in fact the two Anuru Bay oxygen isotope values are at opposite extremes of the total human range, while the Malarrak values are spaced (widely) in between.

As with $\delta^{18}O$, the faunal sample is omitted from $\delta^{13}C$ statistical comparisons with human samples because its diet is probably different from a human diet in the same region. The Anuru Bay A samples are on average 0.9‰ more positive than the Malarrak human samples (Table 2, Figure 2). A ranked *t*-test indicates the two populations are statistically different (t=3.536, p=0.046, df=2.667) while an unranked test does not reach statistical significance (t=4.110, p=0.1425, df=1.056). This uncertainty is likely to be a reflection of the small sample size.

Interestingly, the human $\delta^{13}C$ values are strongly linearly correlated with the $^{87}Sr/^{86}Sr$ values (two-tailed r=-0.98, p=0.004; Spearman's ρ=-0.98, p=0.005). This suggests the $\delta^{13}C$ values at the base of food chains vary systematically with geographical variation evident in the strontium data. While this could reflect either causal or coincidental geological interaction with plant communities such that plants growing on older rocks tend to be depleted in heavy carbon isotopes, it seems more likely to involve human dietary behaviour. Perhaps younger geology with low strontium isotope ratio values tends to be located closer to the sea, and people living closer to the sea eat more marine food with relatively low $\delta^{13}C$ values. A larger sample will be needed to test this hypothesis.

Table 2 Strontium, oxygen and carbon isotope ratio results. Note: $\delta^{18}O_{SW}$ is the estimated isotope ratio of source water calculated from $\delta^{18}O$ using equations in Coplen *et al.* (1983), Bryant *et al.* (1996:5147) and Daux *et al.* (2008). $\delta^{18}O_{SW}$ uses the VSMOW standard; $\delta^{18}O$ and $\delta^{13}C$ use the VPDB standard.

				Strontium		Oxygen (‰)		Carbon (‰)
Sample	**Site**	**Type**	**Lab. No.**	$^{87}Sr/^{86}Sr$	2σ error	$\delta^{18}O$	$\delta^{18}O_{SW}$	$\delta^{13}C$
MAC I	Anuru Bay A	Human	SS-119887	0.70628	0.000007	-3.4	-4.8	-12.1
MAC II	Anuru Bay A	Human	SS-119888	0.70807	0.000008	-5.9	-8.8	-12.5
	Anuru Bay A mean values			*0.70718*		*-4.7*	*-6.8*	*-12.3*
MG25	Malarrak Main	Human	SS-119890	0.71786	0.000011	-3.5	-5.0	-13.1
MK25	Malarrak Main	Faunal	SS-119889	0.72097	0.000009	-0.4	-0.2	-12.7
MT4	Malarrak #4	Human	SS-119891	0.71910	0.000012	-4.6	-6.7	-13.2
MT6	Malarrak #4	Human	SS-119892	0.71909	0.000012	-5.5	-8.1	-13.1
	Malarrak mean values			*0.71926*		*-3.5*	*-5.0*	*-13.0*

Table 3 Enamel radiocarbon dates. Dates calibrated using the SHCAL04 curve (McCormac *et al.* 2004) in the BCal tool (Buck *et al.* 1999). The $\delta^{13}C$ values are due to fractionation occurring in the ion source and are not directly comparable to apatite values.

Sample	Lab. No.	$\delta^{13}C$‰	^{14}C Age (years BP)	Calibrated Age (cal years AD)
MAC I	ANU-19410	-11.3	295±50	1496 to 1691, 1727 to 1804
MAC II	ANU-19411	-12.4	255±55	1505 to 1594, 1615 to 1710, 1718 to 1811

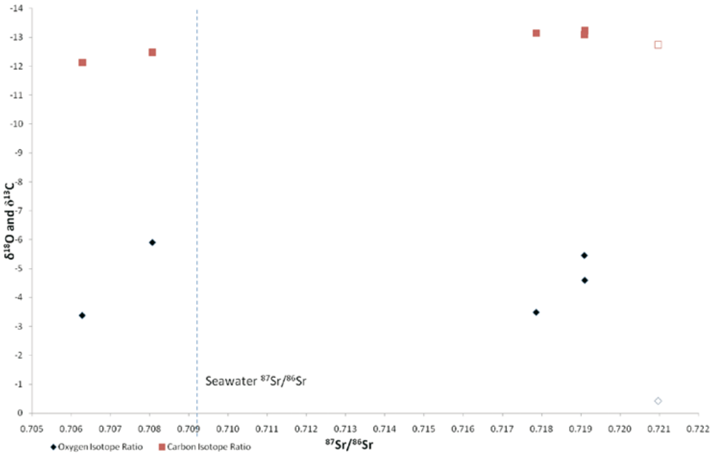

Figure 2 Strontium, oxygen and carbon isotope ratios. Also shown is the strontium isotope value of modern seawater (0.7092). Samples left of the seawater line are from Anuru Bay A; those to the right are from Malarrak. Filled markers are human samples; outlined markers are from the faunal sample.

Radiocarbon Results

As is common for radiocarbon dates from after AD 1500, the Anuru Bay A calibrated dates span a fairly long timeframe (Table 3). The posterior probability distributions are uneven, however, and tend to be weighted towards the earlier dates within the range. MAC I, for instance, has a 72% chance of being earlier than AD 1700 and only a 12% chance of being later than AD 1770. Enamel does not remodel during life so the radiocarbon method dates when the enamel formed, rather than when the person died. Human adult premolar enamel forms between ages 2 and 8 (Bass 1995:304). Macknight and Thorne (1968:219) estimate that MAC I was in his early 30s when he died so the radiocarbon-based dates pre-date the burial by 20 to 30 years. Thus MAC I most likely died in the first half of the eighteenth century. MAC II has a 40% chance of being earlier than AD 1700 and a 13% chance of being later than AD 1780. MAC II was assessed as being in his early 20s (1968:220) so the radiocarbon dates for that skeleton pre-date the burial by 10 to 20 years, and MAC II most probably died in the mid-to-late eighteenth century.

The archaeological context of the burials indicates the MAC II burial disturbed the MAC I burial and therefore occurred later in time than MAC I (Macknight and Thorne 1968:218). Incorporating this information into the date calibration (and ignoring for the moment the 10-year difference in age at death) increases the probability that MAC I was earlier than AD 1700 to 84%. Adding in his age at death, there is thus an 84% chance that he died (and Anuru Bay A was occupied) before approximately AD 1730.

Discussion

Strontium Isotopes

The strontium and carbon isotope results indicate the Anuru Bay A and Malarrak samples have significantly different means and thus probably come from different populations. The next task is to determine which (if any) of the two populations is the local group. The archaeological evidence strongly links the Anuru Bay A skeletons to a Macassan site, placing them as the best candidates for non-local people. Meanwhile, the Malarrak remains are associated with an Aboriginal Australian rockshelter and are therefore likely to be representative of a local population. We can evaluate this proposition using only isotopic data. First, our one small mammal sample would be considered *a priori* as the most likely 'local' candidate. Its strontium isotope value exceeds but is close to the human Malarrak samples, and greatly exceeds the Anuru Bay A samples. This points to the Malarrak humans being the local population.

We can also compare our results to geological strontium isotope data. As noted above, geological strontium values can vary substantially from biologically available strontium values, but can provide a rough gauge of likely values within a region.

Geological strontium isotope ratios from around the Australia and Island Southeast Asia region are shown in Table S1. It is clear from these data that Australian values are generally high (exceeding 0.710) while Island Southeast Asian values are relatively low (usually below seawater's value of 0.709). This is as expected because Australia in general and Arnhem Land in particular are known to have very old rock formations while Island Southeast Asia is largely of relatively recent volcanic or sedimentary origin. Our Malarrak samples have values exceeding 0.710 while the Anuru Bay A samples are below 0.709; this once again points to the Malarrak samples as the local population and the Anuru Bay samples as the non-local population. In sum, between the isotopic data and the archaeological contexts, there is no reasonable doubt the Anuru Bay A remains are from Macassans and the Malarrak remains are from Australian Aboriginal people.

The strontium variation within each group is also interesting. The two samples from Malarrak Shelter #4, MT4 and MT6, have almost identical strontium signatures. MG25 differs by about 0.0012, still within one standard deviation from MT4 and MT6. Given the likely variation of geological strontium isotope values in the area (Table S1), this difference could simply be the result of an individual obtaining his or her nutrients from a slightly different resource composition or location. The lower signature of MG25 could, for example, reflect an increased exploitation of estuarine or marine resources. The Malarrak teeth are all quite recent, probably less than 500 years old, but even so, the difference between them may also reflect a shift in resource use over time. A larger human and/or faunal sample size from northwest Arnhem Land would allow for more certain interpretations of any variation within the data.

While the two Anuru Bay A samples are quite convincingly non-local, their actual origin is unclear. MAC I and MAC II did not necessarily share a common childhood origin, with their signatures differing by 0.0018. This range is surprisingly large for only two samples, and suggests they did not grow up on the same geologic substrate. Of course, the complex geologically-derived ^{87}Sr/^{86}Sr values of Indonesia caution that the difference in ^{87}Sr/^{86}Sr values between MAC I and MAC II do not necessarily exclude a common place of origin either. Differences may be accounted for by variations of resource use, higher values for example being obtained by farming on limestone lowlands common on islands and lower values obtained through acquisition of resources from young volcanic soils. Both extremes of the geological strontium isotope range found in Indonesia occur on Sulawesi alone, the most likely place of origin of the Macassans based on historical information. The lower signature of MAC I, for example, could indicate a childhood predominantly located on young volcanic rocks, while the higher signature of MAC II could indicate influencing factors such as marine and coastal resources.

It is unlikely the homeland of the Macassan men can be determined with certainty based on isotope analysis alone. With comparative biological samples from various possible locations in Indonesia, however, it may become possible to exclude certain places and thus narrow down the number of potential places of origin. Incorporation of other geologically-determined isotope ratios, such as those of lead, could also help narrow the number of potential homelands.

Oxygen Isotopes

The relationship between oxygen isotope ratios in modern meteoric precipitation and latitude and altitude has been globally modelled based on information from the International Energy Association/World Meteorological Organization Global Network of Isotopes in Precipitation. Estimates of δ^{18}O in various locations are provided according to an algorithm developed by Bowen and Wilkinson (2002) (and refined by Bowen and Revenaugh 2003 and Bowen *et al.* 2005) called the Online Isotopes in Precipitation Calculator (OIPC version 2.2). According to this online calculator, Darwin and most of the Northern Territory sit in an area with δ^{18}O precipitation values expected around -5 to -5.9‰, while most of Indonesia expects values from -4 to -9.9‰.

A specific query considering latitude, longitude and altitude, provides an estimated δ^{18}O precipitation value of -5.2‰ for Anuru Bay at sea-level, an estimate of -5.3‰ at 100m elevation approximately 50km inland (directly south) from Anuru Bay, and an estimate of -5.8‰ at 350m elevation approximately 150km inland (directly south) from Anuru Bay.

Precipitation estimates vary further in the more mountainous island environments of Indonesia. For example, an estimated δ^{18}O precipitation of -5.6‰ at sea-level for Makassar on Sulawesi decreases to -6.7‰ as the land rises to 500m elevation southeast of Makassar, and decreases further to -8.1‰ at 1200m elevation in the mountain ranges 50km east of Makassar. This is a difference of 2.5‰ within 50km. Another example of wide δ^{18}O range is found in Papua New Guinea, where δ^{18}O precipitation increases from -7.4‰ at Port Moresby (sea-level) to -12.7‰ in the mountain range to the north (2700m altitude), a difference of 5.3‰ within 150km. There is little difference in estimated δ^{18}O precipitation between Makassar and Port Moresby (both on west-facing coastlines) and their respective coastal sites on the east of each island.

These predictive patterns are consistent with the model that precipitation becomes more depleted of heavier ^{18}O isotopes as water vapour moves farther from the ocean and elevation increases. As oxygen isotopes in the human body are primarily derived from ingested drinking water (Eckardt *et al.* 2009), an isotopic similarity between the oxygen isotopes in the human body and those in local meteoric water exists, especially in archaeological populations where water would have been sourced locally and consumption of imported drink and foodstuffs was limited (Pye 2004).

A complicating factor is that both Australia's north coast and Indonesia are in the tropics within the Indo-Australian monsoon region, characterised by high temperatures, high humidity and abundant rain (van Bemmelen 1949). This may reduce the potential for applying oxygen isotope forensics, as the most distinct results are obtained in mid- to high-latitude continental regions where strong spatial isotope gradients exist (Bowen *et al.* 2005). Furthermore, comparing precipitation δ^{18}O data with δ^{18}O recovered from human remains rests on the assumption that δ^{18}O of ingested water is relatively unaltered from its source precipitation. Shallow groundwater often has a close association with precipitation, unless evaporation has enriched water through loss of lighter isotopes (Pye 2004). Conversely, deep groundwater and surface waters fed from artesian sources may be different from modern precipitation values because of water-rock interaction and the effects of climatic change (Pye 2004). River water, too, could introduce a precipitation value representative of an area upstream. Thus, by the time it is ingested, drinking water can be quite different from mean δ^{18}O of rainfall. We suggest this explains the non-patterned but large δ^{18}O variation found in our samples. Daux *et al.* (2008:1146) indicate that ideally, confidence in the validity of the interpretation can only be obtained through a 'full understanding of the hydrological factors at the local scale', which is currently unavailable for both Arnhem Land and Indonesia.

Carbon Isotopes

As previously discussed, the carbon isotope ratios provide weak support for a difference between the Anuru Bay and Malarrak human samples, with one statistical test achieving significance while another does not. This uncertainty is probably a result of the small sample size. It is interesting, however, that all samples (including the faunal sample) fall in a small range between -12.1 and -13.2‰. Given a diet-to-enamel offset of at least 9‰ (Tykot *et al.* 2009), all samples represent diets below -21‰ and therefore show strong C3 signatures. The Macassans probably had a rice-dominated diet (Macknight 1976) so a C3 signature would be expected for them. The past Indigenous Australian diet within Arnhem Land is more difficult to characterise. Grasses within Arnhem Land are predominantly C4 (Hattersley 1983) and seven modern *Macropus* samples from southeast Arnhem Land showed substantial C4 influence with enamel values averaging -7.5±1.2‰ (Murphy *et al.* 2007). Nevertheless, our human and faunal samples from Malarrak indicate a predominantly C3-based terrestrial diet. This suggests either that people emphasised non-grass based resources such as tubers, nuts, fruits and forest mammals (including the small mammal in our faunal sample) or that C3 grasses were more common at that time in northernmost Arnhem Land than they are today in southeast Arnhem Land. It also appears that marine fish and mammals did not comprise a large portion of the diet during childhood when enamel was forming. A larger archaeological human and faunal sample which includes collagen-based isotope analyses will be needed to investigate this further.

A British Origin?

Given the fairly wide range of calibrated radiocarbon dates and the presence of European artefacts within the apparently disturbed contexts of the Malarrak units, it is possible that our human samples are neither locals nor neighbours; they could potentially be from Britain. The strontium isotope ratios of the Malarrak individuals, however, are strongly suggestive of the diverse geological range of the greater Arnhem Land region, exceed the range found in the British Isles other than in several small Scottish regions (Evans *et al.* 2010), and are compatible with the presumably local small mammal faunal sample. Additionally, the remote location of the Malarrak shelter and its significance as an important Indigenous site render it unlikely the samples derive from non-Indigenous individuals.

A European origin for the Anuru Bay individuals can be dismissed based on the archaeological and morphological evidence. Tooth filing on both men, teeth stained by lime and betel, and Muslim burial practices are indicative of a southeast Asian, rather than a European, origin.

Conclusions

Stable isotope ratio data obtained from human tooth enamel at two sites in northwest Arnhem Land – Anuru Bay A and Malarrak – support three main points. The first is that each site clearly represents a distinct population in terms of childhood origin. The second is that geologic strontium information combined with a faunal sample can be successfully used to distinguish the non-local (Anuru Bay A) from the local (Malarrak) population. These two points support the archaeological and ethnographic evidence for both sites, confirming one as a Macassan burial site and the other as an Indigenous site. Furthermore, our radiocarbon data indicate that Anuru Bay A was a relatively early Macassan site, with at least one of its occupations probably occurring before AD 1730.

The third point is that there is potential in the isotope data to identify trends on an individual scale, especially through the combined patterns revealed by the strontium and carbon isotope analyses. So while the current data are insufficient to determine the precise origins of the Macassan men, for example, they do reveal subtle information pertaining to the men's origins, such as the unlikelihood they spent their childhoods in the same area. Similarly, the large variation within the data suggests that all the Indigenous individuals from Malarrak may not have originated in the same locality either.

With strong results regarding provenance obtained even from a very small sample set – five humans and one small mammal – our study shows potential for further isotope research in north Australian archaeology. With a larger sample size, for example, a dataset could be built from which to define a local population more accurately and in which to firmly position the current findings. In particular, a large sample of biogenic strontium isotope ratios from various locations in Arnhem Land and at potential places of Macassan origin in Indonesia would reduce uncertainty surrounding the origin of these individuals as well as others who may be studied in the future. The substantial strontium isotope ratio variation predicted by the geology of Arnhem Land and confirmed in our small sample from Malarrak promises to be of great use in studies of pre-European Aboriginal Australian movement and may also assist in resolving issues of repatriation or geographic association of human skeletal material.

Supplementary Information

Supplementary information for this article is available online at www.australianarchaeologicalassociation.com.au.

Acknowledgements

We would like to thank Denise Donlan and the J.L. Shellshear Museum of Physical Anthropology and Comparative Anatomy at the University of Sydney for allowing us to take samples from the Anuru Bay teeth. Thanks also to Lindsay Watson for performing the metric analysis of the Anuru Bay skulls and creating casts of the Anuru Bay teeth, and to Marc Oxenham for helping with cast creation. Funding for this project was provided by ARC Linkage Project *Baijini, Macassans, Balanda, and Bininj: Defining the Indigenous past of Arnhem Land through Culture Contact* awarded to Daryl Wesley and Sue O'Connor.

References

Bass, W.M. 1995 *Human Osteology: A Laboratory and Field Manual*. Columbia: Missouri Archaeological Society.

Bentley, R.A. 2006 Strontium isotopes from the earth to the archaeological skeleton: A review. *Journal of Archaeological Method and Theory* 13(3):135-187.

Bentley, R.A., H.R. Buckley, M. Spriggs, S. Bedford, C.J. Ottley, G.M. Nowell, C.G. Macpherson and D.G. Pearson 2007 Lapita migrants in the Pacific's oldest cemetery: Isotopic analysis at Teouma, Vanuatu. *American Antiquity* 72(4):645-656.

Bentley, R.A., T.D. Price and E. Stephan 2004 Determining the 'local' ^{87}Sr/^{86}Sr range for archaeological skeletons: A case study from Neolithic Europe. *Journal of Archaeological Science* 31:365-375.

Berndt, R.M. and C.H. Berndt 1947 Discovery of pottery in north-eastern Arnhem Land. *The Journal of the Royal Institute of Great Britain and Ireland* 77(2):133-138.

Bowen G.J. and J. Revenaugh 2003 Interpolating the isotopic composition of modern meteoric precipitation. *Water Resources Research* 39(10):1299.

Bowen, G.J., L.I. Wassenaar and K.A. Hobson 2005 Global application of stable hydrogen and oxygen isotopes to wildlife forensics. *Oecologia* 143:337-348.

Bowen G.J. and B. Wilkinson 2002 Spatial distribution of δ^{18}O in meteoric precipitation. *Geology* 30(4):315-318.

Bryant, J.D., P.L. Koch, P.N. Froelich, W.J. Showers and B.J. Genna 1996 Oxygen isotope partitioning between phosphate and carbonate in mammalian apatite. *Geochimica et Cosmochimica Acta* 60(25):5145-5148.

Buck, C.E., A. J. Christen and G. N. James 1999 BCal: An online Bayesian radiocarbon calibration tool. *Internet Archaeology* 7.

Collier, S. and K.A. Hobson 1987 The importance of marine protein in the diet of coastal Australian Aborigines. *Current Anthropology* 28(4):559-564.

Coplen, T.B, C. Kendall and J. Hopple 1983 Comparison of stable isotope reference samples. *Nature* 302:236-238.

Daux, V., C. Lécuyer, M. Héran, R. Amiot, L. Simon, F. Fourel, F. Martineau, N. Lynnerup, H. Reychler and G. Escarguel 2008 Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution* 55(6):1138-1147.

Eckardt, H., C. Chenery, P. Booth, J.A. Evans, A. Lamb and G. Müldner 2009 Oxygen and strontium isotope evidence for mobility in Roman Winchester. *Journal of Archaeological Science* 36(12):2816-2825.

Evans, J.A., J. Montgomery, G. Wildman, and N. Boulton 2010 Spatial variations in biosphere ^{87}Sr/^{86}Sr in Britain. *Journal of the Geological Society* 167(1):1-4.

Fenner, J.N. 2007 Prehistoric Hunting on the Range where the Antelope Play: Archaeological Pronghorn Bonebed Formation Analysis. Unpublished PhD thesis, Department of Anthropology, University of Wyoming.

Hattersley, P.W. 1983 The distribution of C3 and C4 grasses in Australia in relation to climate. *Oecologia* 57:113-128.

Koch, P.L., K.A. Hoppe and S.D. Webb. 1998 The isotopic ecology of late Pleistocene mammals in North America: Part 1. Florida. *Chemical Geology* 152:119-138.

Krigbaum, J. 2005 Reconstructing human subsistence in the West Mouth (Niah Cave, Sarawak) burial sites using stable isotopes of carbon. *Asian Perspectives* 44:73-89.

Lee-Thorp, J.A. 2008 On isotopes and old bones. *Archaeometry* 50:925-950.

Luz, B., Y. Kolodny and M. Horowitz 1984 Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. *Geochimica et Cosmochima Acta* 48:1689-1693.

Macknight, C.C. 1976 *The Voyage to Marege': Macassan Trepangers in Northern Australia*. Melbourne: Melbourne University Press.

Macknight, C.C. 2008 Harvesting the memory: Open beaches in Makassar and Arnhem Land. In P. Veth, P. Sutton and M. Neale (eds), *Strangers on the Shore: Early Coastal Contacts in Australia*, pp.133-147. Canberra: National Museum of Australia Press.

Macknight, C.C. and A.G. Thorne 1968 Two Macassan burials in Arnhem Land. *Archaeology and Physical Anthropology in Oceania* 3(3):216-222.

McCormac, F.G., A.G. Hogg, P.G. Blackwell, C.E. Buck, T.F.G. Higham and P.J. Reimer 2004 SHCal04 Southern Hemisphere calibration, 0-11.0 cal kyr BP. *Radiocarbon* 46:1087-1092.

Murphy, B.P., D.M.J.S. Bowman and M.K. Gagan 2007 Sources of carbon isotope variation in kangaroo bone collagen and tooth enamel. *Geochimica Et Cosmochimica Acta* 71:3847-3858.

Price, T.D., J.H. Burton and R.A. Bentley 2002 The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44(1):117-135.

Pye, K. 2004 Isotope and trace element analysis of human teeth and bones for forensic purposes. In K. Pye and D.J. Croft (eds), *Forensic Geoscience: Principals, Techniques and Applications*, pp.215-236. Special Publications 232. London: Geological Society.

Ruxton, G.D. 2006 The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. *Behavioral Ecology* 17:699-690.

Shaw, B.J., H. Buckley, G.R Summerhayes, D. Anson, S. Garling, F. Valentin, H. Mandui, C. Stirling and M. Reid 2010 Migration and mobility at the Late Lapita site of Reber-Rakival (SAC), Watom Island using isotope and trace element analysis: A new insight into Lapita interaction in the Bismarck Archipelago. *Journal of Archaeological Science* 37(3):605-613.

Shaw, B.J., G.R. Summerhayes, H.R. Buckley and J.A. Baker 2009 The use of strontium isotopes as an indicator of migration in human and pig Lapita populations in the Bismarck Archipelago, Papua New Guinea. *Journal of Archaeological Science* 36:1079-1091.

Taçon, P.S.C, S.K. May, S.J. Fallon, M. Travers, D. Wesley and R. Lamilami 2010 A minimum age for early depictions of Southeast Asian praus in the rock art of Arnhem Land, Northern Territory. *Australian Archaeology* 71:1-10.

Tykot, R.H. 2004 Stable isotopes and diet: You are what you eat. In *Physics Methods in Archaeometry: Proceedings of the International School of Physics* 114:433-444. Amsterdam: IOS Press.

Tykot, R.H., F. Falabella, M.T. Planella, E. Aspillaga, L. Sanhueza and C. Becker 2009 Stable isotopes and archaeology in central Chile: Methodological problems for dietary reconstruction. *Journal of Osteoarchaeology* 19:156-170.

Valentine, B., G.D. Kamenov and J. Krigbaum 2008 Reconstructing Neolithic groups in Sarawak, Malaysia through lead and strontium isotope analysis. *Journal of Archaeological Science* 35:1463-1473.

Van Bemmelen, R.W. 1949 *The Geology of Indonesia, Vol. IA General Geology*. The Hague: Government Printing Office.

Warner, W.L. 1932 Malay influence on the Aboriginal culture of northeastern Arnhem Land. *Oceania* 20:476-495.

Watson, L. 2011 Ancestral Analysis of Two Crania from the Shellshear Museum. Unpublished report to School of Anthropology and Archaeology, The Australian National University.