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ORIGINAL PAPER

Isotopic analyses of prehistoric human remains from the Flinders Group, Queensland, Australia, support an association between burial practices and status

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Abstract

Isotopic analyses of human remains have the potential to alter our understanding of prehistoric lifeways and migration in Australia, but very few such analyses have been conducted in the country to date. Here, we report the first regional multiproxy isotope study of pre-contact human remains from Australia. We obtained $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen,}$ $\delta^{18}O_{bioapatite}$, $\delta^{13}C_{bioapatite}$ and $^{87}Sr/^{86}Sr$ isotope values from three complex interments and two simple beach burials from the Flinders Group of Islands, Queensland. The study had two goals. One was to assess how the diets of the individuals compared to those of pre-contact populations elsewhere in the region. The other goal was to test the hypothesis that burial type was indicative of local/non-local status. We found that the individuals' diets were diverse and included a relatively high percentage of low trophic level foods. With regard to the difference in burial practices, we found those afforded complex burials had grown up in the Flinders Group, while those given beach burials likely grew up away from the islands. These results highlight the intricacies of the lives of the Indigenous Australians who inhabited the islands and inform our understanding of their pre-contact diet and mobility. The results also suggest that multiproxy isotope studies may be able to aid with the repatriation of unprovenanced remains of Indigenous Australians.

Keywords Indigenous Australians · Cape York · Isotopes · Mobility · Diet · Complex burial · Bundle burial · Social differentiation

Introduction

Over the last 40 years, the analysis of isotope proxies has greatly improved understanding of prehistoric human lifeways (Ambrose and DeNiro 1986; Richards and Trinkaus 2009; King et al. 2020) and aided in the repatriation of unprovenanced human remains (Pate et al. 2002; Watkins et al. 2017). However, this approach has been little used in Australian archaeology, to date. Here, we report the first

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regional multiproxy isotope study focusing on the remains of Indigenous Australians.

The study focused on five pre-contact Indigenous Australian burials from the islands of the Flinders Group in far northern Queensland and involved the extraction and analysis of carbon and nitrogen isotopes from bone collagen ($\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$) and oxygen, carbon and strontium isotopes from dental tissues ($\delta^{18}O_{bioapatite}$, $\delta^{13}C_{bioapatite}$ and $^{87}Sr/^{86}Sr$). We selected these isotopes because previous work has shown that they have the potential to shed light on diets and movements. The study had two goals. First, we were interested in how the diets of the Flinders Group individuals compared to those of pre-contact populations elsewhere in Oceania. Second, we wanted to know how the isotopic variability within the Flinders Group sample relates to the differences in the way the individuals were buried.

The study was carried out as part of a large Australian Research Council-funded project that aimed to shed light on the Indigenous history of Cape York, Queensland, and to improve methods for repatriating unprovenanced remains of Indigenous Australians. Details of the broader project can be found in Collard et al. (2019).

Background

The Flinders Group

The islands of the Flinders Group are located in Princess Charlotte Bay, which is approximately 340 km northwest of the city of Cairns, and are part of the Great Barrier Reef Marine Park. There are seven islands in the group—Flinders (Wurriima), Stanley (Muyu Mali), Blackwood (Wakayi), Maclear, Denham (Inggal Odul), King and Clack (Ngurromo). The human remains analysed in the present study were discovered on Flinders Island and Stanley Island. The locations of these islands, along with those of Blackwood Island and Denham Island, are shown in Fig. 1.

Continental in origin, the islands of the Flinders Group consist of Jurassic-Cretaceous Dalrymple Sandstone and Gilbert River Formation Sandstone. They feature rugged escarpments and sand dunes that are covered by mixed heath woodland, grassland and vine thickets. While the only terrestrial animals are monitor lizards and snakes, the islands are home to many bird species. A fringing reef surrounds the islands and supports a wide range of fish species, as well as dugong and turtles. The climate of the islands is tropical, with monsoonal rains from November to April and frequent cyclones.

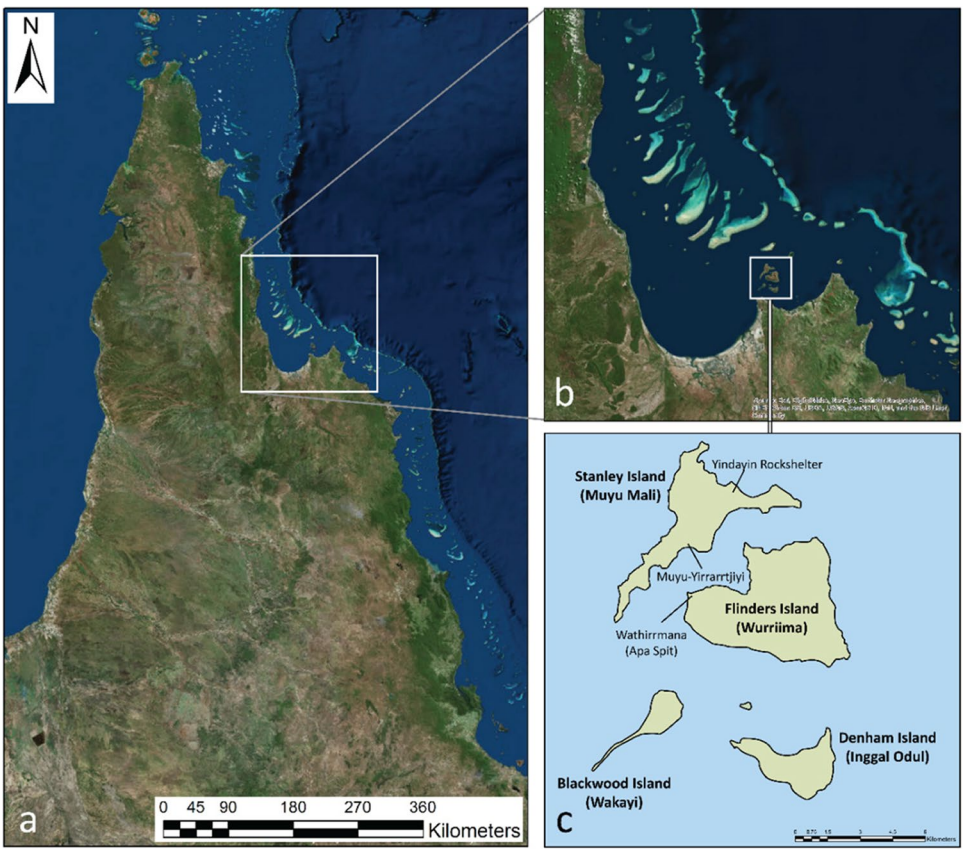

Fig. 1 **a** Cape York Peninsula, north Queensland, Australia; **b** Princess Charlotte Bay; **c** the four main islands of the Flinders Group, with their European and Indigenous names. The human remains analysed in the present study were discovered on Flinders Island and Stanley Island

Early archaeological investigations on Stanley Island suggested that the initial occupation of the Flinders Group was late, at ca. 2200 years ago (Beaton 1985). These dates have recently been revised to ca. 6280 cal BP, indicating a much longer human presence on the islands (Collard et al. 2019). It is important to keep in mind, however, that we still know very little about the history of human occupation of the islands so this new date should be treated with caution. Oral history indicates that the first inhabitants of islands were groups known collectively as the Aba Wurriya—'Aba' means 'people', while 'Wurriya' is the Indigenous name for the islands (Peter Sutton pers. comm 2018).

Ethnographic data indicate that the Aba Wurriya moved seasonally between the islands and mainland and that the islands were regularly visited by groups from over 50 km to the west and south (Sutton et al. 1993). However, it is possible that Aba Wurriya's social network was much larger than these observations suggest. McNiven (2016) has argued that the Coral Sea was an 'interaction sphere' involving cultural diffusion and gene flow between Indigenous Australians and Melanesians from the Torres Strait Islands and New Guinea for thousands of years. A recent review of the available genetic evidence did not support this hypothesis (Wasef et al. 2021), but the authors stressed that their conclusions were tentative due to the small number of relevant aDNA sequences that are available at the moment.

The Flinders Group were an early point of contact between Indigenous Australians and Europeans. The first recorded meeting of the Aba Wurriya and the British took place in 1821, during Captain Philip King's survey of Australia's east coast (King 1827). Subsequently, the islands became an anchorage for ships travelling between Sydney and Asia, before becoming a centre for the pearling trade. These developments greatly impacted the Aba Wurriya. In the late 1890s, the first Northern Protector of Aborigines, Walter Roth, photographed 84 of the islands' Indigenous inhabitants (Roth 1898). By 1935, the number of Aba Wurriya on the islands had dropped to nine (Sutton 2005). In the 1930s and 1940s, the last Aba Wurriya were removed to Hopevale and Palm Island, where their descendants live today (Sutton 2005).

The burials

Adams et al. (2020) have previously discussed the five individuals. They described the burial practices and outlined the results of in-field osteological analyses of the remains. They also reported a calibrated radiocarbon date for each individual and compared the burial practices to ethnographic data on burial practices in Cape York in the early part of the twentieth century. Additionally, the five individuals have been subjected to ancient DNA (aDNA) analysis by Wright et al. (2018) and Wasef et al. (2020).

Adams et al. (2020) referred to the five individuals as FI1, FI2, B2, B3 and SI1, and we will do the same. FI1, FI2, B2 and B3 were found on Flinders Island, while SI1 was found on Stanley Island (we are withholding the burials' exact locations at the request of the Traditional Owners). FI1 and SI1 were simple beach interments. They were excavated in 2015 because they were at risk of destruction due to erosion. Excavation and reburial were undertaken by traditional owners with archaeologists recording the burials, analysing the remains and taking samples for dating, aDNA extraction and isotope analysis. SI1 was not accompanied by any grave goods. FI1's grave included just a single item: a large rock, which, strikingly, had been placed on the individual's torso. FI2, B2 and B3 are bundle burials that are located in painted rock-shelters. They were assessed and sampled in 2016 as part of an effort to create a baseline for monitoring purposes.

The results of Adams et al.'s (2020) analyses are summarised in Table 1. Their osteoarchaeological analyses indicated that one of the beach burials, FI1, and two of the bundle burials, FI2 and B2, were adult males; the remaining individuals, B3 and SI1, were determined to be adult females. These sex assessments were subsequently confirmed by aDNA analysis (Wright et al. 2018; Wasef et al. 2020). The marine-corrected calibrated radiocarbon dates reported by Adams et al. (2020) indicate that the individuals died between 473 and 147 years before present (BP). This means that all five individuals probably passed away before the first recorded meeting of the Aba Wurriya and Europeans.

Importantly for present purposes, Adams et al. (2020) proposed an explanation for the difference in burial treatment between FI2, B2 and B3 on the one hand, and FI1 and SI1 on the other. Drawing on ethnographic accounts of the burial practices of the Indigenous people of Cape York, Adams et al. (2020) hypothesised that the difference in burial treatment reflected a difference in status. Specifically, they suggested that FI2, B2 and B3 received bundle burials because they were locals, whereas FI1 and SI1 were simply buried in beach sands because they were outsiders.

$\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ analyses

Materials and methods

$\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ are usually analysed together to shed light on sources of dietary protein and the trophic level of species consumed by individuals (Ambrose and DeNiro 1986). $\delta^{13}C_{collagen}$ is calculated by relating the ratio of ^{12}C and ^{13}C to a standard (VPDB) (Peterson and Fry 1987). $\delta^{13}C_{collagen}$ reflects the relative importance of C_3 versus C_4 resources and/or the relative importance of marine versus terrestrial resources (Schoeninger and DeNiro 1984). C_3 plants are isotopically distinct from C_4 plants: C_3 plants

Table 1 Human remains analysed in this study. See Adams et al. (2020) for details of the sex and age-at-death assessments, pathologies and calibrated date ranges. The sex assessments have been confirmed by genetic analyses (Wright et al. 2018; Wasef et al. 2020)

Individual	Island	Burial type	Sex	Age-at-death	Pathologies	Calibrated date range (CE)
FI1	Flinders	Simple beach interment with a large rock on the torso	M	Middle adult	Periodontal disease; periapical lesion; anthesopathy on the right humerus	1589–1802
FI2	Flinders	Complex bundle burial in a painted rock-shelter	M	Young adult	Periosteal lesion on left femora	1490–1640
B2	Flinders	Complex bundle burial in a painted rock-shelter	M	Young adult	Cribra orbitalia; calculus; periodontal disease	1647–1804
B3	Flinders	Complex bundle burial in a painted rock-shelter	F	Young adult	Dental enamel hypoplasia; periodontal disease with alveolar resorption; possible evidence of sepsis on the ilium	1477–1633
SI1	Stanley	Simple beach interment	F	Young adult	Dental enamel hypoplasia; periodontal disease; osteoarthritis in neck and shoulder	1505–1674

generally present $\delta^{13}C$ values of between −33 and −23‰ VPDB (Tokui et al. 2000), while the $\delta^{13}C$ values for C_4 plants usually fall between −16 and −9‰ VPDB (Stantis et al. 2015). $\delta^{13}C$ values for marine and terrestrial species overlap, but in general marine diets result in higher $\delta^{13}C$ values than terrestrial diets. $\delta^{15}N_{collagen}$ is calculated by comparing the ratio of ^{14}N and ^{15}N to a standard (AIR) (Minagawa and Wada 1984). $\delta^{15}N_{collagen}$ fractionation involves a trophic offset of 3–6‰, which makes it possible to reconstruct an individual's trophic position and shed light on their main source(s) of protein (O'Connell et al. 2012).

$\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ measurements were completed on finger bones from FI1, FI2, B3 and SI1 and a rib from B2 at the Australian National University using a Sercon 20–22 mass spectrometer coupled to an ANCA-GSL. Collagen was retrieved using ultrafiltration, and acid and alkali were used to remove exogenous carbonates and humics. The samples were gelatinised before being filtered. Collagen extraction followed the ultrafiltration protocol described by Brock et al. (2010). All samples yielded > 1% collagen. Samples were measured against in-house references and corrected against standards USGS-40, USGS-41 and ANU Sucrose (Fallon et al. 2010). All samples returned a standard error of < 0.2‰.

A $\delta^{13}C_{collagen}$ to $\delta^{13}C_{diet}$ offset for the Flinders Group was calculated based on Fernandes et al.'s (2012) dietary macronutrient model in which $\delta^{13}C_{collagen} = 4.8 + 0.74\ (\delta^{13}C_{protein}) + 0.26\ (\delta^{13}C_{energy})$ ‰. $\delta^{15}N_{collagen}$ was converted to $\delta^{15}N_{diet}$ on the basis of the results of O'Connell et al.'s (2012) controlled feeding experiments. Specifically, we used their most conservative red blood cell-to-collagen result, which was +4.6‰.

To interpret the $\delta^{13}C_{collagen}$ values for the Flinders Group individuals, we compared them to $\delta^{13}C_{collagen}$ data for edible species from the islands and elsewhere in Australia and the Pacific (Supplementary Table 2). Following Kinaston et al. (2014), the comparative data were corrected for pre-industrial atmospheric carbon levels (Suess effect); terrestrial faunal values were increased by 1.5‰ and marine faunal values by 0.86‰. Bone collagen values were converted to flesh values by subtracting 3.7‰ for macropodid and 1.5‰ for dugong. We also compared the data for the Flinders Group individuals to previously published $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ isotope data from human remains recovered at several archaeological sites in Oceania. These data were chosen for comparison because they are the closest geographically and because the sampled tissue and analyses are the same. Details of the comparative samples are given in Supplementary Table 2.

Results

The $\delta^{13}C_{collagen}$ analyses returned a mean of -12.68 ± 1.26‰, while the $\delta^{15}N_{collagen}$ analyses returned a mean of 11.5 ± 0.91‰ (Table 2). These correspond to a mean $\delta^{13}C_{diet}$ of -17.48 ± 1.26‰ and a mean $\delta^{15}N_{diet}$ of 6.9 ± 0.91‰, respectively.

Figure 2 compares the Flinders Group individuals' diet-converted $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values to $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values for edible species from the region. Looking at the $\delta^{13}C_{collagen}$ values, we can see that the Flinders Group individuals' diets straddle C_3 and C_4 plants and are in approximately the same position as freshwater fish, marine turtles and terrestrial fauna from Papua New Guinea and the Pacific Islands. This suggests that the diets of the Flinders Group individuals likely included both terrestrial and marine resources. The $\delta^{15}N_{collagen}$ values for the Flinders Group diet provide some information about the nature of those resources. The values are relatively low, which suggests that the Flinders Group individuals' diets were dominated by lower trophic level sources of protein such as

Table 2 Flinders Group human $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ results

Sample name	Element sampled	Internal ID	Collagen yield (%)	C:N	$\delta^{13}C_{collagen}$ (VPDB)	$\delta^{15}N_{collagen}$ (AIR)
FI1	Finger bone	15,127	1.05	3.2	− 10.8	12
FI2	Finger bone	16,861	6.0	3.1	− 12.2	11.1
SI1	Finger bone	15,128	4.28	3.2	− 13.6	10.2
B2	Rib	16,862	3.0	3.1	− 14.0	11.6
B3	Finger bone	16,863	2.9	3.1	− 12.8	12.6

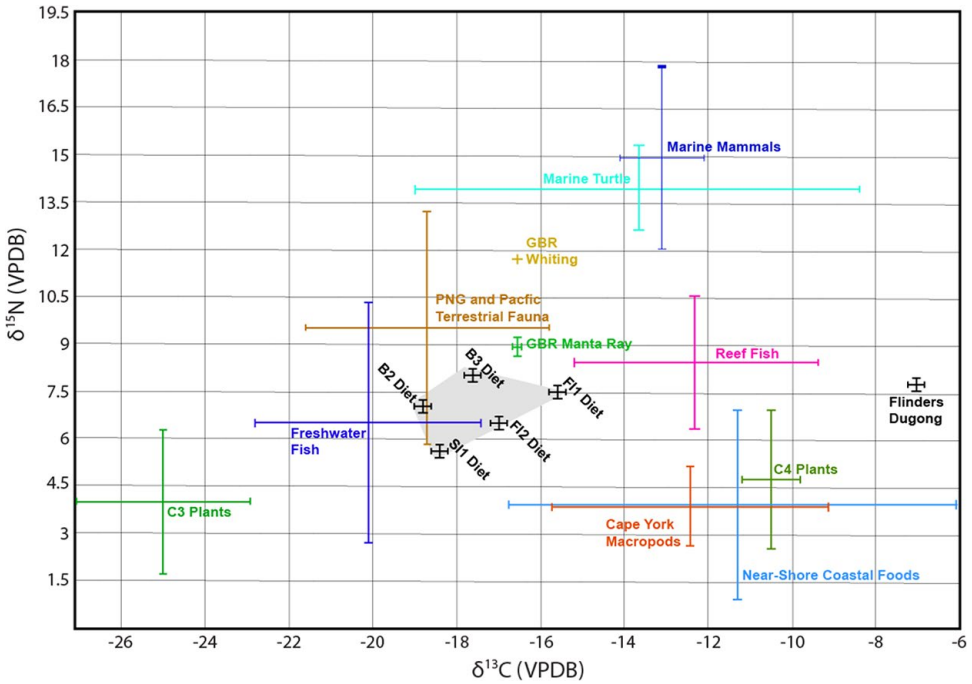

Fig. 2 Comparison of Flinders Group burials' diet-converted $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values to $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values for edible species from the region. Human $\delta^{13}C$ and $\delta^{15}N$ collagen values converted to dietary protein values following Fernandes et al. (2012) and O'Connell et al. (2012). Modern faunal $\delta^{13}C$ and $\delta^{15}N$ values were obtained from Murphy and Bowman (2006), Revill et al. (2009) and Couturier et al. (2013). Other Pacific Islands regional $\delta^{13}C$ and $\delta^{15}N$ results were compiled and reported in Herrscher et al. (2018), Fry et al. (1983), Collier and Hobson (1987), Keegan and DeNiro (1988), Leach et al. (1996), Ambrose et al. (1997), Yoneda et al. (2004), Valentin et al. (2006), Beavan Athfield et al. (2008), Field et al. (2009), Allen and Craig (2009), Jones and Quinn (2009), Richards et al. (2009), White et al. (2010), Valentin et al. (2010), Storey et al. (2010) and Kinaston et al. (2014). PNG refers to Papua New Guinea and GBR refers to the Great Barrier Reef. Archaeological dugong material obtained from an undated midden on Flinders Island in 2016 (ID: 456,965)

macropods and shellfish rather than by higher trophic level species like marine turtles and marine mammals.

These findings are consistent with ethnographic observations about the diets of the Aba Wurriya. Hale and Tindale (1934) reported that the Aba Wurriya fished for mullet, rock cod, groper, shark, oysters and rock-lobster. Three species of macropod were also eaten: *Macropus agilis*, *Macropus antilopinus* and *Petrogale coenensis*. So were grubs, land snails, green ants, honey, frogs, varanids and birds. In addition, Hale and Tindale (1934) stressed the contribution of plants in the Aba Wurriya's diet. Yams and other rhizomes were plentiful, while pandanus and mangroves were exploited during lean periods.

Figure 3 plots the $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values for the Flinders Group individuals alongside comparable data from archaeological sites elsewhere in Oceania. The Flinders Group individuals are closest to the samples of human remains from Lake Alexandrina and the Coorong, both of which are in South Australia. Lake Alexandrina is a large freshwater system at the termination of the Murray River. Located due south of Lake Alexandrina, the Coorong is a wetland featuring freshwater, estuarine and hypersaline waterbodies. The human remains from the two sites were

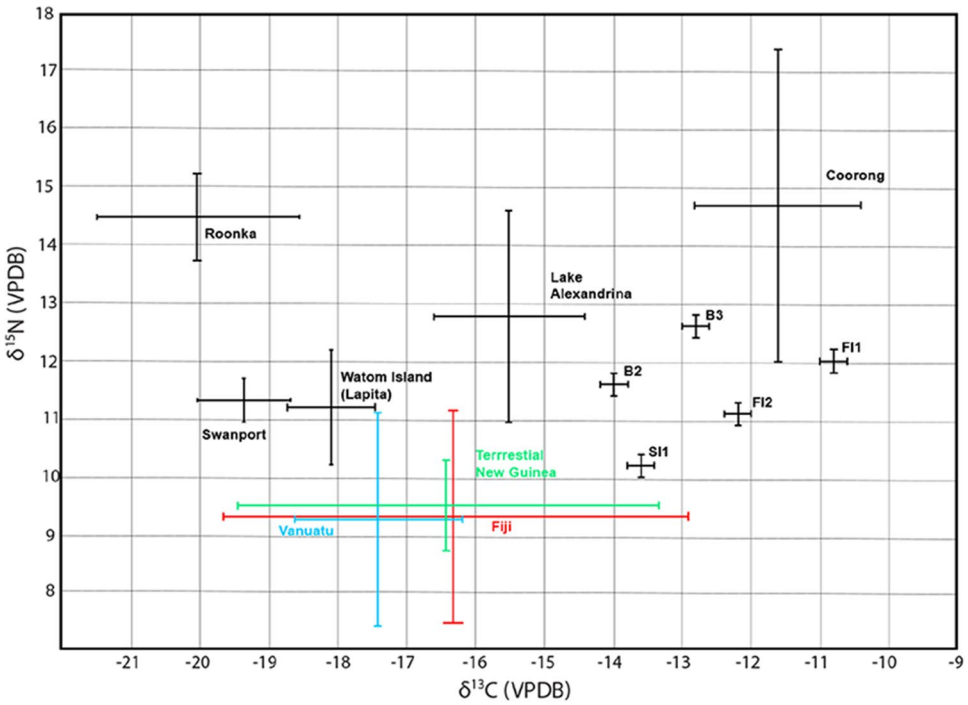

Fig. 3 Comparison of Flinders Group burials' $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values with comparable data from human skeletons from archaeological sites elsewhere in Oceania. Terrestrial New Guinea values were reported in Kinaston et al. (2014). Watom Island Lapita values were reported in Jones and Quinn (2009). Vanuatu values were reported in Kinaston et al. (2014). Values for Australian Aboriginal populations reported in Pate and Owen (2014). Roonka and Swanport are on the inland Murray River, while the Coorong and Lake Alexandria are in the estuary reaches of the Murray. Vanuatu, Fiji and New Guinea are coloured to allow the reader to visualise the different ranges

recovered from Holocene burial grounds (Pate 1998; Pate et al. 2002). Pate (1998) interpreted the isotope results for the Lake Alexandrina individuals as reflecting a C_3/terrestrial diet, and the higher $\delta^{15}N_{collagen}$ values for the Coorong human remains as indicating a larger proportion of dietary protein (Pate 1998). The Flinders Group individuals' $\delta^{13}C_{collagen}$ values are either in line with or slightly lower than those of the Coorong remains, while the Flinders Group individuals' $\delta^{15}N_{collagen}$ values are in line with, or slightly lower than, those of the Lake Alexandria remains. This also suggests that the diets of the Flinders Group individuals most likely consisted predominantly of C_4 plants and/or C_4 plant-eating herbivores and low trophic level marine foods.

The two individuals who received simple burials (FI1 and SI1) can be distinguished from the three individuals who were accorded complex burials (FI2, B2 and B3). While FI1's $\delta^{15}N_{collagen}$ value is in line with those for FI2, B2 and B3, his $\delta^{13}C_{collagen}$ value is markedly higher than those of FI2, B2 and B3, which suggests that he ate more C_4 and/or marine species than did FI2, B2 and B3. SI1 departs from FI2, B2 and B3 in a different direction. Her $\delta^{13}C_{collagen}$ value is in line with those of FI2, B2 and B3, but her $\delta^{15}N_{collagen}$ value is substantially lower than those of FI2, B2 and B3, suggesting that she was even more dependent on lower trophic level sources of protein; a plant- and shellfish-dominated diet would seem to be a reasonable interpretation of her $\delta^{15}N_{collagen}$ value. That the individuals who received simple burials appear to have had different diets from those who were given complex burials is consistent with Adams et al.'s (2020) hypothesis that FI1 and SI1 were outsiders while FI2, B2 and B3 were locals.

$\delta^{13}C_{bioapatite}$ and $\delta^{18}O_{bioapatite}$ analyses

Materials and methods

$\delta^{18}O_{bioapatite}$ and $\delta^{13}C_{bioapatite}$ are also usually analysed in tandem. $\delta^{18}O_{bioapatite}$ isotopes in tooth enamel provide insights into drinking water during the period of tooth development, while $\delta^{13}C_{bioapatite}$ allows childhood diet to be compared between individuals and/or between different points in dental development (de Laeter et al. 2003). $\delta^{13}C_{bioapatite}$ is precipitated from blood plasma bicarbonate with carbon dioxide expired from diet and metabolism (Faure 1986; Passey et al. 2005; Turner et al. 2009; Gerling 2015:126, Fernandes et al. 2012) and can be used to estimate dietary input if metabolic fractionation is taken into account. Fernandes et al. (2012) arrived at a robust model for calculating omnivore dietary carbon routing in bioapatite after they took body size effects into account: $\delta^{13}C_{bioapatite} = 11.3 + \delta^{13}C_{diet}‰$ (Fernandes et al. 2012).

$\delta^{18}O_{bioapatite}$ reflects drinking and food water $\delta^{18}O$. However, it can become enriched through meteoric and metabolic processes (fractionation). The isotopic composition of meteoric water is dependent upon altitude, temperature and amount effects that alter the relative abundance of ^{16}O to ^{18}O in water (Lachniet and Patterson 2009). While the lighter ^{16}O is preferentially lost through evaporation and

transpiration, ^{18}O becomes concentrated in evaporated water bodies. In contrast, ^{18}O is preferentially lost from atmospheric water during precipitation (Dansgaard 1954). Heavier ^{18}O isotopes are higher in abundance in areas of higher rainfall, warmer climate and closer to the coast due to the amount effect (Gerling 2015:125). While Longinelli (1984) and Smits et al. (2010) noted that a difference of as little as 1‰ can indicate a different drinking water source, this can be easily confounded.

$\delta^{13}C_{bioapatite}$ and $\delta^{18}O_{bioapatite}$ results are usually analysed together because oxygen and carbon isotopes are incorporated into dental enamel at the same time (Britton 2019). While one might expect $\delta^{13}C_{bioapatite}$ to be analysed alongside $\delta^{13}C_{collagen}$, there is a good reason why this is not normally done. $\delta^{13}C_{bioapatite}$ reflects childhood macronutrient sources of protein, carbohydrates and lipids, whereas $\delta^{13}C_{collagen}$ represents dietary protein during the 10–15 years prior to death (de Laeter et al. 2003; Hedges et al. 2007). The differences in formation period and error margins associated with fractionation calculations also make it difficult to compare $\delta^{13}C_{bioapatite}$ and $\delta^{13}C_{collagen}$ values.

We sampled the lower left first molar of FI1, the lower right fourth premolar of FI2 and the upper left first incisor of B3. For B2 and SI1, we sampled the upper right second incisor. A portion of tooth enamel was removed from the occlusal surface (~2 mm × 2 mm) to measure $\delta^{13}C_{bioapatite}$ and $\delta^{18}O_{bioapatite}$. It is important to note that this bulk sample approach provides an average of isotopic input during tooth formation and cannot be used to observe isotopic change during tooth formation.

Each tooth enamel sample was ground into a fine powder using a mortar and pestle. The powder was placed in an ultra-cleaned Teflon tube and covered in 0.1 M acetic acid (CH_3COOH), before sonication for 15 min. This was followed by a further 15 min of reaction. The solution was centrifuged at 4000 rpm for 15 min and acetic acid was removed. The sample was rinsed three times with Milli-Q ultrapure water (18.2 Ω at 25 °C), centrifuging between steps. Excess Milli-Q ultrapure water was evaporated at 40 °C. Analyses were run on a Finnigan MAT 251 and Kiel carbonate device. The working gas used was 2009–2, and the resulting values were corrected for ^{17}O interference using Santrock et al.'s (1985) formula: $R_{17} = k\ (R_{18})^a$. Raw ions were converted to delta values for analysis, and Vienna Pee Dee Belemnite (VPDB) was used as the standard for both $\delta^{18}O$ and $\delta^{13}C$ measurements.

All samples returned a standard deviation of less than 0.04. Drinking water $\delta^{18}O$ values were calculated using the equation in Chenery et al. (2012), based on Daux et al.'s (2008) equation: $\delta^{18}O_C$ ($\delta^{18}O_{DW} = 1.590 \times \delta^{18}O_C - 48.634$) to compare the Flinders Group $\delta^{18}O_{bioapatite}$ results to predicted drinking water $\delta^{18}O$ values. VPDB values were converted to Vienna Standard Mean Ocean Water (VSMOW) with the following equation: VSMOW‰ = (1.03092 × VPDB‰) + 30.92 (Coplen et al. 1983).

Unfortunately, we currently lack $\delta^{13}C_{bioapatite}$ results from other Cape York archaeological investigations with which to compare the values for the Flinders Group individuals. The most suitable alternatives are macropodid $\delta^{13}C_{bioapatite}$ results reported by Murphy et al. (2007b). These authors sampled specimens from nine sites between − 12.7° and − 15.4° latitude in the Cape. They found that eight of the samples yielded $\delta^{13}C_{bioapatite}$ between − 13.89 and − 6.85‰ (VPDB), with a mean of − 8.94‰ (VPDB).

Two isoscapes predicting $\delta^{18}O$ in Cape York precipitation have been produced (Bowen et al. 2005; Hollins et al. 2018). However, no measurement sites are located within 1000 km of Princess Charlotte Bay and none at all on the coast of Queensland above − 27°. Therefore, these models can only be used as rough guides. The Bowen et al. (2005) model predicts modern annual $\delta^{18}O$ values for the Princess Charlotte Bay region between − 6.6 and − 5‰ (SMOW), with lower predicted $\delta^{18}O$ results of − 7.4 to − 6.6‰ (SMOW) in the more temperate hinterland rainforest region south of Princess Charlotte Bay. The Hollins et al. (2018) model predicts − 6 to − 5‰ (SMOW) throughout all of Princess Charlotte Bay and ~ 100 km south and inland of Cape York. Murphy et al. (2007a) sampled macropodid $\delta^{18}O_{bioapatite}$ throughout Cape York and their results give us the only direct assessment of $\delta^{18}O_{bioapatite}$ variability. Between − 12.7° and − 15.4° latitude, within Cape York, Murphy et al. (2007a) collected nine enamel apatite $\delta^{18}O$ samples and measured a range of − 1.40 to 2.09‰ (VPDB). This indicates that the combined annual isoscape predicted range of − 7.4 to − 5‰ (SMOW) (Bowen et al. 2005; Hollins et al. 2018) should be used as a rough annual estimation only.

Results

The $\delta^{13}C_{bioapatite}$ results for the five burials returned a range of − 12.59 to − 7.8‰ (VPDB). In the $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ analyses, we hypothesised that the adult diets of FI1, FI2, B2 and B3 probably included a relatively large amount of lower trophic level sources of protein such as macropods and shellfish, while SI1's adult diet was dominated by even lower trophic level foods such as plants. The $\delta^{13}C_{bioapatite}$ values paint a somewhat different picture vis-à-vis the individuals' childhood diets (Table 3). The $\delta^{13}C_{bioapatite}$ values for FI2, B2 and B3 fall within a narrow range of − 10.55 to − 9.66‰ (VPDB). This range is close to the higher end of $\delta^{13}C_{bioapatite}$ results reported for Vanuatu and Bali. $\delta^{13}C_{bioapatite}$ values for FI1 are higher than those for FI2, B2 and B3. When converted to diet using the diet-carbonate $\delta^{13}C$ offset (− 11.3‰), FI1's results indicate a childhood diet value of − 19.10‰ (VPDB), suggesting that he ate more higher trophic level marine resources, C_4

Table 3 Flinders Group $\delta^{18}O_{bioapatite}$ and $\delta^{13}C_{bioapatite}$ results

Burial	Tooth Sampled	Enamel carbonate $\delta^{18}O$ VPDB	Enamel carbonate $\delta^{18}O$ VSMOW	Drinking water $\delta^{18}O$ VSMOW	$\delta^{13}C_{bioapatite}$ (VPDB)	$\delta^{13}C_{bioapatite}$ Diet (VPDB)
FI1	LM_1	−1.46	29.42	−1.86	−7.80	−19.10
FI2	RP_4	−3.43	27.38	−5.09	−9.66	−20.96
B2	RI^2	−0.15	30.77	0.28	−10.19	−21.49
B3	LI^1	−2.68	28.16	−3.86	−10.55	−21.85
SI1	RI^2	−4.49	26.29	−6.83	−12.59	−23.89

vegetation and/or C_4 vegetation-consumers than the other individuals. Interestingly, he also appears to have eaten more higher trophic level marine resources, C_4 vegetation and/or C_4 vegetation-consumers than any of the individuals in the comparative sample (Fig. 4). SI1's childhood diet also appears to have been different from those of the other four individuals, but it shifts closer to the diets of FI2, B2 and B3 in maturity. In Fig. 4, her $\delta^{13}C_{bioapatite}$ value plots within the range of $\delta^{13}C_{bioapatite}$ results from Arnhem Land, Vanuatu and Bali implying a distinct diet from the Flinders Group bundle burials. Thus, the $\delta^{13}C_{bioapatite}$ values support the hypothesis that the differences in burial practices reflect differences in insider/outsider status with FI2, B2 and B3 having been locals and FI1 and SI1 outsiders.

When converted to ingested water values, the Flinders Group individuals show a range of −6.83 to 0.28‰ SMOW (Table 3). $\delta^{18}O$ precipitation models for the Princess Charlotte Bay region produce an estimated annual average of −5 to −6.6‰ SMOW (Bowen et al. 2005; Hollins et al. 2018), meaning that FI2 and SI1 are the only individuals that are close to the modelled results. FI1, B2 and B3's $\delta^{18}O_{bioapatite}$ results are much higher at a drinking water range of −3.86 to 0.28 SMOW. Australian surface and meteoric waters are known to be enriched in ^{18}O due to evaporation and amount effects (Ayliffe and Chivas 1990; Hollins et al. 2018), and local macropodid field data confirms that regional $\delta^{18}O$ values are generally elevated to 1.40–2.09‰ VPDB (Murphy et al. 2007a).

The unconverted $\delta^{18}O_{bioapatite}$ results for the five Flinders Groups individuals are plotted in Fig. 4. The results are consistent with the hypothesis that the female beach burial, SI1, was an outsider to the Flingers Group. Her $\delta^{18}O_{bioapatite}$ results align with published annual modelled results, but they are lower than the range of the three bundle burials—FI2, B2 and B3—and instead align closely with the values for Arnhem Land humans and humans from Vanuatu and Bali (Fig. 4). In contrast, the $\delta^{18}O_{bioapatite}$ results for FI1 are not in line with the predictions of the hypothesis that he was an outsider to the Flinders Group, because his $\delta^{18}O_{bioapatite}$ value is within the range of the three bundle burials. The implication of this is that, if FI1 was an outsider, he spent his childhood in an area with drinking water of a similar isotopic composition to that of the Flinders Group.

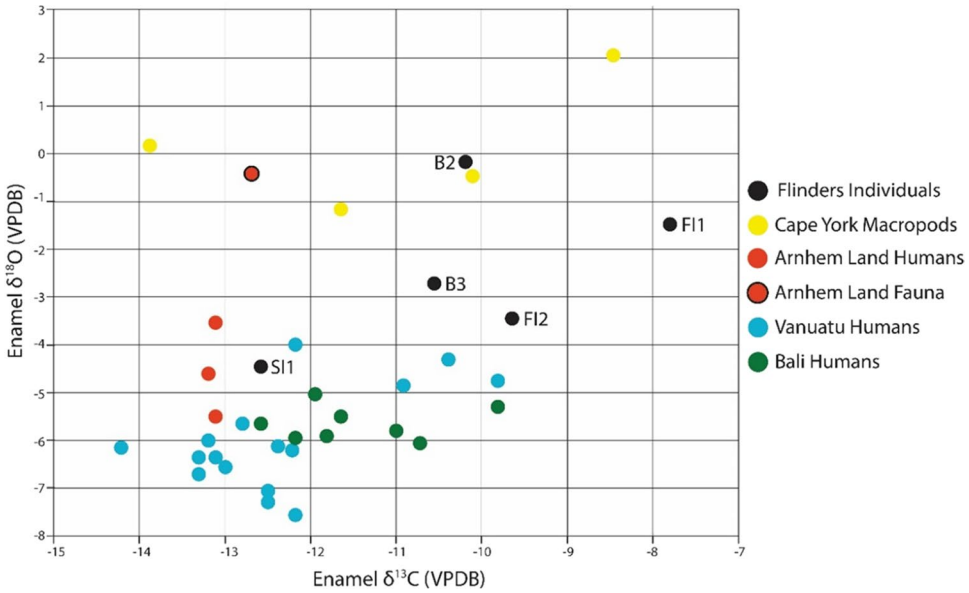

Fig. 4 Flinders Group human $\delta^{18}O_{bioapatite}$ and $\delta^{13}C_{bioapatite}$ results compared to regional faunal and human results. Samples from north Australia at Cape York and Arnhem Land are plotted in red and yellow. The values in question were taken from Theden-Ringl et al. (2011) and Murphy et al. (2007a, b). Historical results from Vanuatu and Bali are plotted in blue and green. These values were obtained from Bentley et al. (2007) and Fenner et al. (2016). Individual results can be viewed in Supplementary Item 4

$^{87}Sr/^{86}Sr$ analyses

Human skeletal tissues exhibit the geological $^{87}Sr/^{86}Sr$ value of the area occupied during the formation of the tissues. The reason for this is that as rock weathers, the bedrock Sr signal is transported into the hydrological system and then incorporated into the tissues of local biota (Faure 1986; Hodell et al. 2004). The Sr in question is known as 'bioavailable Sr' (Price et al. 2002). The fact that bioavailable Sr is incorporated into human skeletal tissues means that Sr values from human remains can be compared to landscape Sr values in order to determine the remains' provenance (Budd et al. 2000).

Dental enamel and dentine are usually sampled in archaeological $^{87}Sr/^{86}S$ research because they do not remodel (e.g. Ross et al. 2006; Goldberg et al. 2011; Radhakrishnan 2011). Dental enamel is resistant to diagenesis. In contrast, once dentine is buried, it can become diagenetically altered, taking on the $^{87}Sr/^{86}Sr$ signature of the area in which the body was buried (Budd et al. 2000). Therefore, by comparing enamel and dentine results, it is possible to discern whether or not an individual was buried in the geographic area in which the enamel of the sampled tooth stopped forming and therefore shed light on whether s/he grew up in the area or moved there as an adult (Budd et al. 2000; Montgomery 2010).

Before $^{87}Sr/^{86}Sr$ can be used to determine whether an individual was a local or non-local, an understanding of landscape $^{87}Sr/^{86}Sr$ in the region is required. Thus, we will first outline our landscape $^{87}Sr/^{86}Sr$ analyses and then describe the $^{87}Sr/^{86}Sr$ analyses of the five burials.

Landscape $^{87}Sr/^{86}Sr$ materials and methods

Our approach was to combine published soil, vegetation and water $^{87}Sr/^{86}Sr$ values for Princess Charlotte Bay (Adams et al. 2019) with measurements from soil and plant samples from Flinders and Stanley Island that were collected specifically for this study.

Processing of the soil, plant and water samples that we collected in the Flinders Group was conducted at the University of Queensland's Radio Isotope Facility. Sampling was completed under Permit WITK16288415.

Plant samples consisted of ~ 10–20 leaves from the species *Corymbia intermedia*. Plant sample digestion followed the method described in Yu et al. (2007). Samples were washed with Milli-Q ultrapure water (18.2 Ω at 25 °C) to remove exogenous dust and placed into 50-ml quartz ultra-cleaned crucibles. They were then ashed at 450 °C for 12 h in a muffle furnace. Subsequently, a 10 mg aliquot was collected and digested in 2 ml 7 N ultrapure concentrated nitric acid (HNO_3) for 48 h at 140 °C. The resulting solution was then evaporated overnight at 90 °C before being redissolved in 3 ml 2 N ultrapure concentrated nitric acid (HNO_3) for column chemistry.

Soil samples were first dried overnight at 60 °C before a 100 mg aliquot was leached in 4 ml ultrapure 1 M acetic acid (CH_3COOH) for 30 min before 15 min of sonication. Each sample was centrifuged at 4000 rpm for 15 min, and then, the supernatant was removed. The supernatant was evaporated overnight at 90 °C. The sample was redissolved in 1 ml 7 N ultrapure HNO_3 and evaporated overnight at 90 °C. The solute was redissolved in 2 ml 2 N ultrapure HNO_3 on a hotplate at 120 °C for at least 2 h.

Ion-exchange chromatography was used to isolate Sr from other elements in the soil, plant and water samples (Yu et al. 2007). Columns were filled with 3.8 ml Eichrom Sr Specific Resin in 1.5 N ultrapure HNO_3 and capped at either end. Columns were loaded with the concentrated solute in 2 N ultrapure HNO_3 and the final Sr solution was collected for analyses. The samples were screened in 2% ultrapure HNO_3 with a 10 ppb Indium internal standard on an Agilent 7900 quadrupole inductively coupled plasma mass spectrometer. Once screened, the samples were diluted and Sr isotope ratios were analysed on a multi-collector inductively coupled plasma mass spectrometer.

$^{87}Sr/^{86}Sr$ values for soil and plant samples for a given site were combined because, on average, they exhibited a difference of only 0.0001.

Landscape $^{87}Sr/^{86}Sr$ results

Environmental results for Princess Charlotte Bay and the Flinders Group sit between 0.70959–0.74042 (Fig. 5) and can be divided into four groups:

1. The Flinders Group: Combined soil and plant $^{87}Sr/^{86}Sr$ results from the Jurassic-Cretaceous alluvial and marine sandstone/limestone of the Flinders Group (sites 8 and 9) sit close to the modern marine Sr signature. Stanley Island samples returned 0.71087, while Flinders Island samples returned a value of 0.70961 (Fig. 5c, d). This suggests that the input of exogenous marine $^{87}Sr/^{86}Sr$ has influenced the surficial geology and brought the $^{87}Sr/^{86}Sr$ ratio closer to the modern marine value of ~ 0.70920 (Hodell et al. 2004).
2. Coastal Princess Charlotte Bay: Coastal sites in Princess Charlotte Bay consist of Quaternary marine sands and Jurassic-Cretaceous alluvial and marine sandstone/limestone at Bathurst Head (sites 1, 5 and 7) sitting between 0.71210 and 0.71430 (Fig. 5c, d).
3. Cape Melville: Results from Carboniferous-Permian granite at Cape Melville (sites 10, 11 and 12) sit between 0.71617 and 0.71854 (Fig. 5c, d).

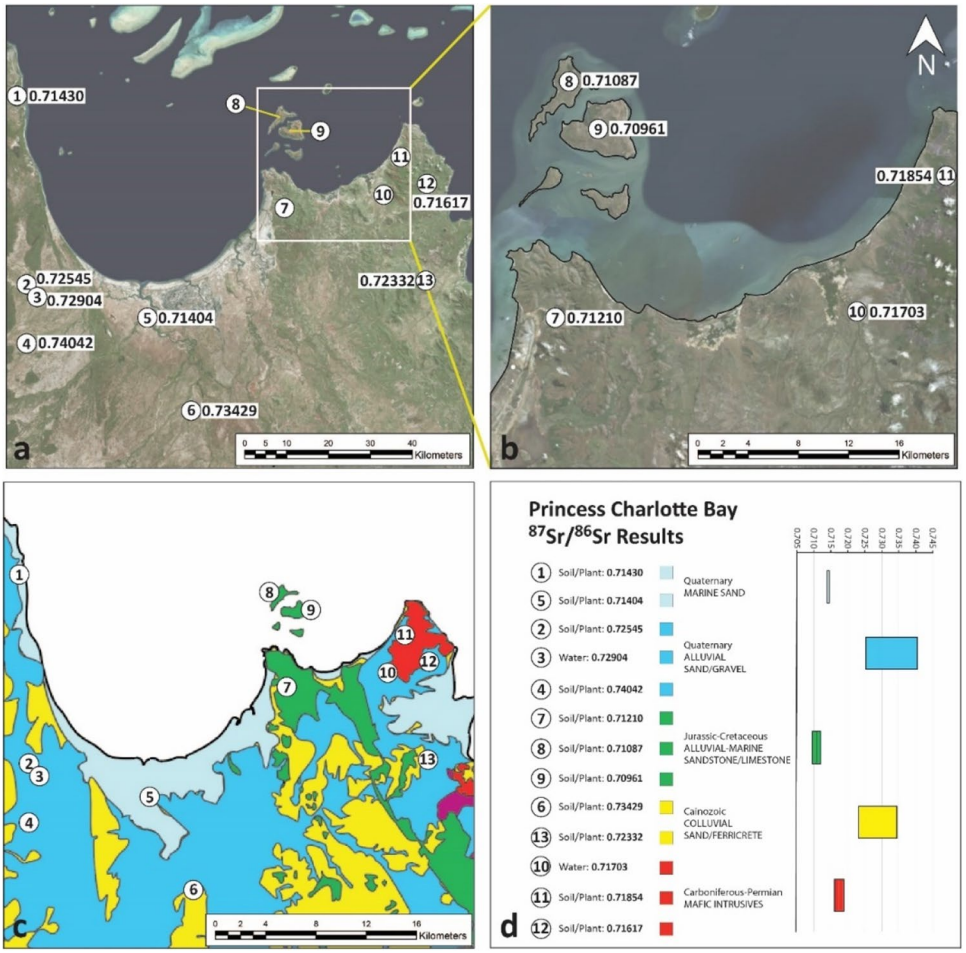

Fig. 5 Summary of landscape $^{87}Sr/^{86}Sr$ values. Results from Adams et al. (2019) and this study—see Landscape $^{87}Sr/^{86}Sr$ materials and methods for details. **a** Princess Charlotte Bay $^{87}Sr/^{86}Sr$. **b** Bathurst Bay and Flinders Group $^{87}Sr/^{86}Sr$ results. **c** Princess Charlotte Bay $^{87}Sr/^{86}Sr$ results over lithologies. **d** Princess Charlotte Bay lithological units and associated $^{87}Sr/^{86}Sr$ ranges

4. Inland alluvial regions: The most elevated $^{87}Sr/^{86}Sr$ results come from Cainozoic colluvial material over 10 km from the coast (sites 2, 3, 4, 6 and 13), sitting between 0.72332 and 0.74042 (Fig. 5c, d).

Human $^{87}Sr/^{86}Sr$ materials and methods

We sampled the lower left first molar of FI1, the lower right premolar of FI2, the upper left first incisor of B3 and the upper right second incisors of B2 and SI1. The incisors were bisected from the incisal surface to the apex of the root, while the molars were cut diagonally from the buccal edge of the occlusal surface to the lingual root apices. Tooth sections were mounted into aluminum holders using modelling clay with the exposed surface facing upwards.

We used a Finnigan MAT Neptune Varian 820 laser ablation system to sample across the bisected surface of the dental tissue. This system utilises a 25 × 8-mm beam exciting laser that is projected and demagnified via a long-working distance triplet lens. At a wave length of 193 nm, the laser delivers fluence of 10 J/cm^3 (Grün et al. 2014). Ablation at 205 µm was used to clean the exposed surface of exogenous material. This was followed by 120-s analyses with 30 s pre- and post-ablation at 10 Hz using 160-µm spot size.

The laser ablation system was configured to run three measurements: 10-s whole mass recording, 1-s half-mass recording and 1-s recording mass 71. The latter was measured to track polyatomics that stems from the high levels of phosphorous in teeth, which can lead to the polyatomic compounds $^{40}Ar + ^{31}P + ^{16}O$ and $^{40}Ca + ^{31}P + ^{16}O$ on mass 87 (Horstwood et al. 2008, Simonetti et al. 2008). Willmes et al. (2016) developed tuning techniques to lower oxide production to minimise this interference. This procedure was carried out by adding 8 cc/min nitrogen to the plasma to drop the gas flow rate and increase particle residence time. A previously recovered *Dugong dugon* tooth was utilised to standardise all Sr measurements. Rare earth elements were also recorded to assess the likelihood of enamel diagenesis (Willmes et al. 2016).

Enamel was analysed at three locations between the dento-enamel junction and the crown. Dentine was analysed at two locations from the pulp to the dento-enamel junction. Spot analysis results from the different locations were combined to provide bulk averages for the enamel and dentine.

The individual spot values can be found in Supplementary Table 6. It is important to note that because of the way the teeth were sectioned, the individual spot values should not be interpreted as a linear age sequence.

Human $^{87}Sr/^{86}Sr$ results

The $^{87}Sr/^{86}Sr$ results for the Flinders Group individuals vary substantially (Table 4). These are bulk results from the individual laser ablation spot analyses, which can be found in Supplementary Table 6.

The enamel $^{87}Sr/^{86}Sr$ value for FI2 (0.71036) is close to the averaged Stanley Island value of 0.71086, aligning with a local origin (Fig. 6). FI2's dentine tissue value of 0.71025 is very similar to the enamel value. This indicates limited diagenetic alteration and implies that FI2 was resident in the Flinders Group until at least the cessation of premolar dentine formation, which occurs between 7 and 10 years of age (Dean and Scandrett 1996).

B2's and B3's enamel apatite values (0.70992 and 0.70979, respectively) are close to the values returned by soil and plant samples from Flinders Island, which suggests that they lived in the Flinders Group or a similar setting during enamel formation. However, their dentine values (0.71775 and 0.71581, respectively) are the highest values recorded in the sample. This may suggest that they moved to a geological setting distinct from the Flinders Group following cessation of enamel formation but while dentine tissue was still forming. Given what we know about the formation of the enamel and dentine of the incisors (Dean and Scandrett 1996), B2 and B3 would have been between 3.5 and 10 years of age when they relocated to the mainland. The Carboniferous-Permian granite geology of Cape Melville yields $^{87}Sr/^{86}Sr$ values of 0.71617 to 0.71854 (Fig. 5), which aligns well with the dentine values for B2 and B3 and therefore makes Cape Melville a potential area of residence for these individuals when their dentine stopped forming. Consistent with this, Hale and Tindale (1934) recorded that the Aba Wurriya regularly visited Cape Melville.

Another plausible scenario for the divergence between the enamel and dentine results for B2 and B3 involves mortuary

Table 4 Flinders Group human $^{87}Sr/^{86}Sr$ results

Burial	Element sampled	Enamel $^{87}Sr/^{86}Sr$	2 se	Dentine $^{87}Sr/^{86}Sr$	2 se
FI1	LM_1	0.71012	0.00004	0.70953	0.00003
FI2	RP_4	0.71036	0.00007	0.71025	0.00008
B2	RI^2	0.70993	0.00012	0.71776	0.00016
B3	LI^1	0.70979	0.00012	0.71581	0.00026
SI1	RI^2	0.71171	0.00013	0.71179	0.00009

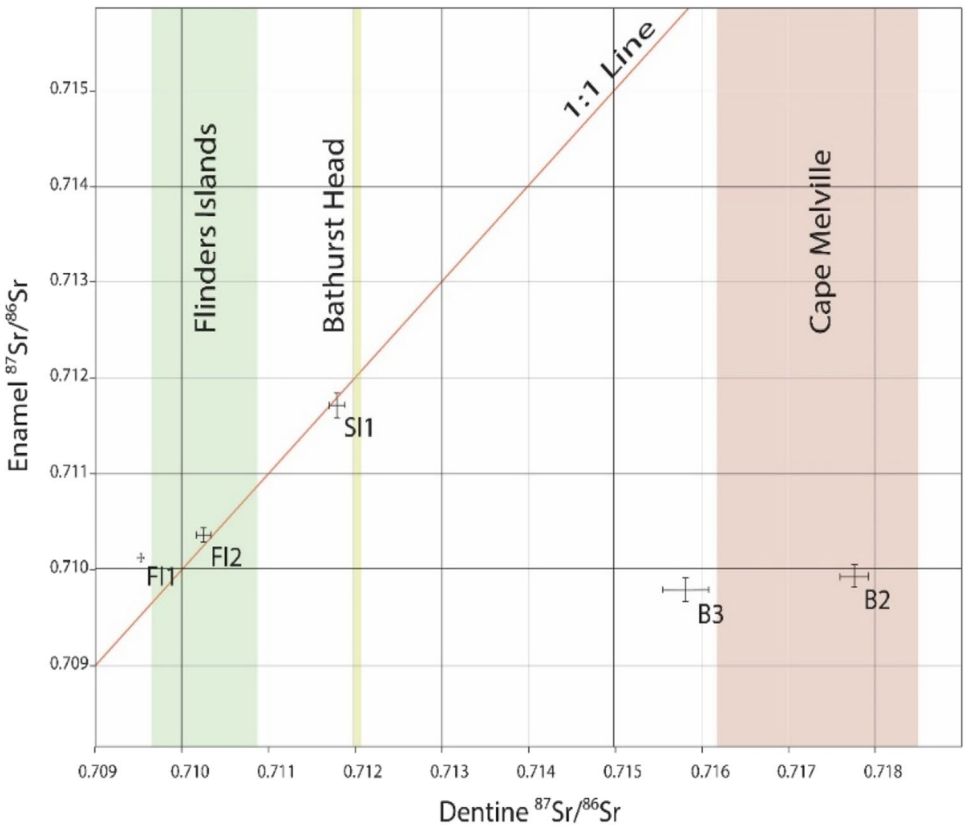

Fig. 6 Flinders Group burials' enamel and dentine $^{87}Sr/^{86}Sr$ results compared to local soil, plant and water result ranges. 1:1 line in red shows where the results would be placed if the enamel and dentine results were the same and thus no diagenetic overprinting had occurred

treatment. To reiterate, B2 and B3 were found bundled in a rock-shelter on Flinders Island (Adams et al. 2020). Because the rock-shelter is dry, it is unlikely that their dentine was diagenetically imprinted while they were in it. However, ethnographic records from Cape York mention the use of maceration techniques following death to assist the transfer of skeletal elements before bundling and secretion (Hale and Tindale 1934). One such maceration technique was a burial for a lengthy period of time (Roth 1907:380–384). If B2 and B3 had been buried in Cape Melville for the purposes of maceration, it may have led them to have elevated dentine $^{87}Sr/^{86}Sr$ results. Thus, it is also possible that B2 and B3 were adult Aba Wurriya who died while visiting Cape Melville. This is consistent with the aforementioned ethnographic evidence for the Aba Wurriya visiting Cape Melville on a regular basis (Hale and Tindale 1934).

SI1's enamel (0.71171) and dentine (0.71179) values are both higher than those observed in the environmental samples from the Flinders Group, suggesting she was not living in the islands at the time of enamel or dentine formation (Fig. 6). SI1 was buried in beach sands so it would be reasonable to expect her dentine values to express a partial or full diagenetic overprint from marine water, like FI1. However, SI1's enamel and dentine values align well and do not reflect the modern marine $^{87}Sr/^{86}Sr$ value. This is consistent with the hypothesis that SI1 was not local to the islands. SI1's $^{87}Sr/^{86}Sr$ results are close to that measured for the Jurassic-Cretaceous alluvial and marine sandstone/limestone of Bathurst Head (0.71210). Hence, it is possible that she spent her childhood up to the age of about ten in the Bathurst Head area, before moving to the islands of the Flinders Group.

The enamel $^{87}Sr/^{86}Sr$ values for FI1 (0.71012) are also close to the averaged Stanley Island value, but his dentine tissue value of 0.70952 diverges from the enamel value. There would seem to be three hypotheses that can potentially explain this pattern. One is that the dentine value reflects diagenetic replacement from sea water due to burial in beach sands. If this were the case, FI1 could have spent his whole life in the Flinders Group. The second possibility is that he grew up in the Flinders Group, moved to another area before the cessation of dentine formation at about age 10 and was then returned to the Flinders Group after his death. The third potential explanation is that FI1 spent his childhood in a location with a similar $^{87}Sr/^{86}Sr$ signal to the Flinders Group, moved to another location prior to age 10 and then died on a visit to the Flinders Group.

Thus, the $^{87}Sr/^{86}Sr$ values generally support Adams et al.'s (2020) hypothesis that the differences in burial practices reflect differences in local/outsider status with respect to FI2, B2, B3 and SI1. The individuals from three complex rock-shelter burials all appear to have spent their early childhood in the Flinders Group, while SI1 seems to have spent her early childhood elsewhere. Unfortunately, the $^{87}Sr/^{86}Sr$ values are more ambiguous with regard to FI1. They are consistent with him having been an outsider but there is also a scenario involving diagenesis in which he was a local.

Discussion

In the study reported here, we examined $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$, $\delta^{13}C_{bioapatite}$, $\delta^{18}O_{bioapatite}$ and $^{87}Sr/^{86}Sr$ in the remains of five prehistoric Indigenous Australians from the islands of the Flinders Group in Australia's far north-east. We used the isotopes to compare the individuals' diets with each other and with pre-contact populations elsewhere in Australia and the Pacific. We also investigated whether the isotopic data were consistent with an association between burial practices and status proposed by Adams et al. (2020). Three of the individuals—FI2, B2 and B3—were given complex bundle burials in painted rock-shelters, while the other two individuals—FI1 and SI1—received simple beach burials. Drawing on ethnographic data, Adams et al. (2020) hypothesised that the difference in mortuary treatment was a consequence of FI2, B2 and B3 having been considered of higher social standing than FI1 and SI1 due to age, health or local/outsider status. Given that the isotope ratios we measured can potentially shed light on an individual's movements, we wanted to know whether the isotope results of the bundle burials and simple burials were consistent with them being locals and outsiders, respectively.

The dietary isotopes—$\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$ and $\delta^{13}C_{bioapatite}$—suggested that the Flinders Group humans consumed both terrestrial and marine resources and that the resources in question were mainly lower trophic level species such as plants, macropods and shellfish rather than higher trophic levels species like marine turtles and marine mammals. This is consistent with observations about the diets of the Aba Wurriya that were recorded in the early part of the twentieth century (Hale and Tindale 1934). When the $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$ and $\delta^{13}C_{bioapatite}$ values of the Flinders Group individuals were compared to those obtained from populations elsewhere in Oceania, they were found to be closest to values obtained from human remains unearthed at two pre-contact burial grounds in the state of South Australia. Both of the burial grounds were located close to large bodies of water that would have had plenty of aquatic resources. This also suggests that the diets of the Flinders Group individuals most likely consisted predominantly of C_4 plants and/or C_4 plant-eating herbivores and low trophic level marine foods. The differences among the individuals' $\delta^{13}C_{collagen}$ and $\delta^{15}N_{collagen}$ values are consistent with Adams et al.'s (2020) conclusion that the Flinders Group burials show that the link between burial type and

status documented by ethnographers in the early twentieth century extended into prehistory.

The $\delta^{13}C$ results for the three complex burials clustered together for childhood ($\delta^{13}C_{bioapatite}$) and adult diet ($\delta^{13}C_{collagen}$), suggesting a similar diet throughout life. However, the $\delta^{13}C$ results for the simple beach burials diverged from those of the complex burials. FI1's $\delta^{13}C_{bioapatite}$ and $\delta^{13}C_{collagen}$ results indicated that, throughout his life, he consumed a diet higher in marine and/or C_4 species than the three complex burials. SI1's dietary isotope values also differed from the complex burials' values but in a different way than FI1's. SI1's $\delta^{13}C_{bioapatite}$ value indicated that her childhood diet contained far less marine and/or C_4 food than the diets of FI2, B3 and B3. The isotope values pertaining to SI1's adult diet indicate that it was more similar to those of FI2, B2 and B3 in terms of the amount of marine and/or C_4 food it contained, but the species she consumed were from lower trophic levels. That the diets of FI1 and SI1 differed from those of FI2, B2 and B3 in important ways is consistent with the hypothesis that the three individuals who received complex burials were locals, whereas the two individuals who were given simple burials were outsiders.

Interpreting the $\delta^{18}O$ results for the Flinders Group individuals is not straightforward because of confounding factors such as the amount effect. Nevertheless, it is clear that SI1 grew up drinking water from a different source to the three bundle burials: FI2, B2 and B3. Her $\delta^{18}O$ value aligns closely with those for populations from Arnhem Land, Vanuatu and Bali (Fig. 4). This is once again consistent with the hypothesis that SI1 was an outsider to the Flinders Group. The $\delta^{18}O$ value for the male beach burial, FI1, is not different from those of FI2, B2 and B3, which suggests that, if FI1 was an outsider, as the hypothesis suggests, he grew up in area where drinking water had a similar isotopic composition to that of the Flinders Group.

The $^{87}Sr/^{86}Sr$ results for the three individuals who received complex mortuary treatment—FI2, B2 and B3—were consistent with them spending their early childhood in the Flinders Group, while their dentine values suggest they had different patterns of mobility later in life. Specifically, FI2's dentine values suggest that she lived her whole life on the islands, whereas the dentine values for B2 and B3 imply that they moved from the Flinders Group to an area of elevated $^{87}Sr/^{86}Sr$ between 3.5 and 10 years of age, before returning to the islands as adults or being transported back to them after death. The enamel and dentine $^{87}Sr/^{86}Sr$ results for the female who was given a simple burial, SI1, may indicate that she grew up away from the islands and moved to them as an adult. The $^{87}Sr/^{86}Sr$ results for FI1 are more ambiguous. They are consistent with him having been an outsider but there is also a scenario involving diagenesis in which he was local. Thus, the $^{87}Sr/^{86}Sr$ results generally support the hypothesis that the two types of burial treatment reflect social status, but there is some uncertainty regarding FI1.

Taken together, the Flinders Group isotope results support the hypothesis that the way the five individuals were treated after death was based on their status. The $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$, $\delta^{13}C_{bioapatite}$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for the three individuals who were given complex burials—FI2, B2 and B3—indicate that they spent their early years in the Flinders Group, which is consistent with them being regarded as locals by the people who buried them. The $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$, $\delta^{13}C_{bioapatite}$, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for the female who was buried on the beach, SI1, are equally clear-cut in indicating that she spent her early years elsewhere and did not move to the islands until she was at least ten. Needless to say, this is consistent with her being regarded as an outsider by those who buried her. The $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ results for the male who was buried on the beach, FI1, are equivocal, but his $\delta^{13}C_{collagen}$, $\delta^{15}N_{collagen}$ and $\delta^{13}C_{bioapatite}$ values indicate that his diet was very different from those of the putative locals: FI2, B2 and B3. This implies that he may not have been local to the Flinders Group and therefore is consistent with him having been viewed as an outsider by the people who buried him.

Recently, Wasef et al. (2020) reported analyses of mitochondrial (mtDNA) sequence data recovered from the five Flinders Group individuals. They also extracted Y-chromosome data from two of the three males but were unable to analyse the data adequately due to the small size of the current Y-chromosome database for Indigenous Australians. Wasef et al. (2020) found that the three bundle burials—FI2, B2 and B3—were not related to each other at the level of kin but had close mtDNA relationships with contemporary Cape York Aboriginal communities. SI1 was found to share an mtDNA lineage with FI2 and therefore was also determined to be closely related to contemporary Cape York Aboriginal communities. The mtDNA results for the fifth individual, FI1, were strikingly different. FI1's mtDNA haplotype was not found among any of the Cape York Aboriginal individuals included in Wasef et al.'s (2020) study. Instead, his mtDNA data suggested that he or his maternal ancestors came from much further south. The individuals in Wasef et al.'s (2020) sample to whom FI1 was most closely related were from central Queensland, New South Wales and South Australia. Thus, Wasef et al.'s (2020) results are consistent with the isotope data reported here in supporting the hypothesis that FI2, B2 and B3 were locals. Their results are also consistent with the isotope data reported here in supporting the hypothesis that FI1 was an outsider. With regard to SI1, when Wasef et al.'s (2020) mtDNA data and the isotope data are taken together, it appears that SI1 was indeed an outsider to the Flinders Group, but most probably she grew up somewhere else in Cape York rather than another region of Australia, before moving to the Flinders Group as a young

woman. It is worth noting in connection with this that Sutton et al. (1993) recorded histories detailing regular intermarriage between the Aba Wurriya and people of the hinterland of Princess Charlotte Bay. Environmental samples from the hinterland region south of the bay returned similar $^{87}Sr/^{86}Sr$ results to SI1. Because the area in question is rainforest, it would likely exhibit less evaporative hydrological processes and lower trophic level foods. This is consistent with SI1's $\delta^{18}O$ and $\delta^{13}C_{bioapatite}$ results, which makes the area a good candidate for SI1's childhood home. Interestingly, the area includes the town of Hopevale, which is where the majority of the Aba Wurriya live today.

Lastly, it is worth noting that the present study has implications for repatriation efforts in Australia. Australia's colonial past included the removal of thousands of Indigenous human remains, many of which now reside within institutions with scant details of their origin. The results we have reported here suggest that it may be possible to narrow down the likely place of origin and/or death of many of the Indigenous Australians whose remains are held by institutions, by analysing carbon, nitrogen, oxygen and strontium isotopes from small samples of teeth and bones, and by comparing the results of such analyses to regional $^{87}Sr/^{86}Sr$ isoscapes. Combining such analyses with aDNA analyses may improve results further (Collard et al. 2019).

Conclusions

In the study reported here, we extracted and analysed carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes from bone collagen and oxygen ($\delta^{18}O$), carbon ($\delta^{13}C$) and strontium ($^{87}Sr/^{86}Sr$), isotopes from dental tissues from three late prehistoric ceremonial rock-shelter burials and two similarly dated simple beach interments in the Flinders Group of islands in far northern Queensland, Australia.

The study had two goals. One was to assess how the diets of the Flinders Group individuals compared to those of pre-contact populations elsewhere in Australia and the Pacific. With respect to this goal, we found that the pre-contact Indigenous diet in the Flinders Group was diverse and included a relatively large degree of low trophic level foods and was distinct from other regional communities.

The study's other goal was to test Adams et al.'s (2020) hypothesis that the difference in burial practices reflects a difference in status between the individuals who were buried in the rock-shelters and the individuals who were buried on the beach. Specifically, we tested the hypothesis that the three rock-shelter individuals were locals, while the two beach burials were outsiders. Taken together, the isotope results support this hypothesis: the isotope values for the three rock-shelter burials were consistent with them having grown up in the Flinders Group, while those for the two beach burials point to them having grown up away from the islands.

When isotope results are combined with the results of recently completed analyses of mtDNA from the five individuals (Wright et al. 2018; Wasef et al. 2020), it appears that the three individuals who received complex burials were local to the Flinders Group and that the woman who was buried on the beach grew up elsewhere in Cape York. When the isotope and mtDNA results are taken together, there are grounds for thinking that the man who was buried on the beach was an outsider who potentially originated from south of Cape York.

The isotope results reported here point to the existence of a complex pattern of mobility among the inhabitants of northeast Australia prior to the arrival of Europeans, as well as to the presence of social differentiation based on insider/outsider status. More generally, this study demonstrates that isotopic analyses of ancient human remains have the potential to yield insights into the lives of ancient Indigenous Australians, especially when combined with aDNA analyses. This has important implications for understanding the history of Australia prior to the arrival of Europeans and for the repatriation of the remains of Indigenous Australians that are held in museums and other institutions.

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