INSULARITY AND ADAPTATION

INVESTIGATING THE ROLE OF EXCHANGE AND INTER-ISLAND INTERACTION IN THE BANDA ISLANDS, INDONESIA

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A dissertation
submitted in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

University of Washington
2015

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Program Authorized to Offer Degree:
Anthropology

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Abstract

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Trade and exchange exerted a powerful force in the historic and protohistoric past of Island Southeast Asian communities. Exchange and interaction are also hypothesized to have played an important role in the spread of new technologies and lifestyles throughout the region during the Neolithic period. Although it is clear that interaction has played an important role in shaping Island Southeast Asian cultures on a regional scale, little is known about local histories and trajectories of exchange in much of the region. This dissertation aims to improve our understanding of the adaptive role played by exchange and interaction through an exploration of change over time in the connectedness of island communities in the Banda Islands, eastern Indonesia.

Connectedness is examined by measuring source diversity for two different types of archaeological materials. Chemical characterization of pottery using LA-ICP-MS allows the identification of geochemically different paste groups within the earthenware assemblages of two Banda Islands sites. Source diversity measures are employed to identify differences in relative connectedness between these sites and changes over time. Similarly, stable and radiogenic isotope ratios (δ^{13}C, δ^{18}O, ^{87}Sr/^{86}Sr, ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, ^{208}Pb/^{204}Pb) are used to identify source groups and quantify source diversity for pigs reared in different locations. Increases in connectedness were expected during periods of increased environmental variability around 3000 BP and 2000 BP, although there is considerable disparity in the timing of these climate shifts based on paleoclimate proxy records from the eastern and western Pacific.

At Banda Islands site PA1, connectedness was relatively high at initial occupation approximately 3500 BP and peaked ~500 years later. A correlation with an increase in El Niño frequency around this time is possible but cannot be confirmed without a well-dated local paleoclimate proxy record. A decline in connectedness as measured by earthenware diversity just after 2300 BP may relate to a change in site use away from permanent occupation. This may be linked with a more dramatic increase in frequency and amplitude of El Niño events and attendant variability in rainfall.

In addition to variation in connectedness over time within the PA1 sequence, there is variability in the connectedness of the two sites in this study. At BN1 there was higher diversity of Banda Islands clay sources but PA1 had higher diversity of non-Banda sources. Despite close proximity these communities appear to have operated within different social landscapes. This result highlights the potential of this approach for studying exchange and interaction to reveal nuances about the social geographies of the past.

ACKNOWLEDGMENTS

Many individuals and organizations have contributed to this research. I want to thank the members of my reading committee, Jim Feathers, Ben Marwick, and especially my chair Peter Lape whose patience, encouragement, and advice have never failed me. Thanks to John Krigbaum, Ben Valentine, George Kamenov, and Jason Curtis for making me part of the extended UF family, providing access to facilities, expert advice, and friendship. I want to thank Laure Dussubieux and the Field Museum, Chicago for welcoming me and guiding me through the LA-ICP-MS analysis.

Some of my fondest memories of graduate school are from time spent in the field in the Banda Islands. This fieldwork was made possible by generous funding from the National Geographic Society and the Henry Luce Foundation. Laboratory analysis was funded through a dissertation fellowship from the American Council of Learned Societies with funding from the Henry Luce Foundation. Many thanks to Kementerian Riset dan Teknologi Republik Indonesia, Lembaga Ilmu Pengetahuan Indonesia, Direktorat Jenderal Sejarah dan Purbakala, Balai Arkeologi Ambon, and Universitas Gadjah Mada. To my Indonesian colleagues and friends: Daud Tanudirjo, Gusti Made Sudarmika, Marlon Ririmasse, Simon Latupupua, Wuri Handoko, Hari Wibowo, Johan Arif, and Unggul Prasetyo Wibowo—Terima Kasih! Thanks also to all the members of the 2007 research team and the students and staff of the 2009 Banda Islands Arcaheology Field School.

I have had the great priviledge of knowing, learning from, and leaning on an amazing group of fellow graduate students at the University of Washington. Special thanks to Jennifer Huff, David Carlson, Erik Gjesfjeld, Shelby Anderson, Jacob Fisher, Chung-Ching Shiung, Amanda Taylor, Becky Kessler, Jack Johnson, Haiying Zhang, and Megan Luce. Finally, I want to thank my family—Mom, Dad, Kristin and Benny, your love and support mean the world to me.

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CHAPTER 1: INTRODUCTION

Beginning as early as 1500 years ago, trade networks connected Island Southeast Asia to Mainland Asia, Southwest Asia, the Arabian Peninsula, and Europe, creating one of the most extensive trading networks in the world. Emerging evidence from archaeology indicates that these trade networks and interregional interactions had their roots thousands of years earlier, during the period between 3500-2000 BP when pottery and domestic animals first became widespread in the region. With more frequent integration of geochemical sourcing methods in archaeological research, evidence is mounting that during this period, often termed the Neolithic, islands within Southeast Asia became linked to each other and to adjacent regions of Mainland Southeast Asia and Near Oceania (Chia 2003; Hung, et al. 2007; Reepmeyer, et al. 2011; Tanudirjo 2001). Some have even suggested that interaction networks may have begun to develop even earlier, in the late Pleistocene and early Holocene (Bulbeck 2008). Interaction and exchange figure prominently in a number of models for Neolithization in Island Southeast Asia and the attendant transformation of the lifeways of people throughout the region. While from these broad regional perspectives it seems clear that interaction has played an important role in shaping Island Southeast Asian history, the degree to which interaction vs. isolation shaped local histories and the relationships between local and regional scale histories are less clear. This research examines this complex interplay between the opposing forces of insularity and interaction in the context of human-environment interactions, and how they defined the social landscapes of the Banda Islands, eastern Indonesia.

The Banda Islands are home to one of very few well-stratified, open, Neolithic period sites in Island Southeast Asia. For this reason they offer a unique opportunity to examine evidence for exchange through well-dated assemblages and identify diachronic change in exchange networks. This dissertation presents the results of elemental and isotopic analyses of materials from this site, PA1 and a slightly later occupation at BN1. Together these sites provide a long sequence stretching from the early Neolithic to the late precolonial period. These data sets are used to address several key questions:

- How varied were sources for exchange items? Were pottery and pigs obtained through exchange and how many different source locations did they come from?
- How did exchange networks change over time? Was exchange intensified over time?
- How did the degree of connectedness, measured through source diversity, vary over time?
- How did exchange help island communities adapt to their isolated environments? Can we establish temporal correlations between climate variability and changes in connectedness?

This dissertation seeks to identify instances where pottery or pigs originated outside the area of the site (from another island in the group or from outside the Banda Islands), quantify the degree of source diversity for these materials, and examine diachronic change in the degree of connectedness of Banda Islands communities in the context of climatic variability.

ISLANDS, ISOLATION, AND EXCHANGE

Isolation is the primary feature that differentiates islands from other environments and has a strong influence on the composition of island biotas because it has implications for both colonization and extinction of island taxa. Based on MacArthur and Wilson’s (1967) model of island biogeography, organisms on more isolated islands are at a greater risk of extinction, especially when these islands are small (Figure 1). With increasing isolation, progressively fewer organisms are able to successfully colonize a landmass. Since more isolated islands are more difficult to colonize, they tend to have lower biodiversity than mainlands and less isolated islands. This biogeographic pattern has been demonstrated for many Pacific Islands (Paulay 1994). Once they arrive, species on isolated islands are more likely to become extinct or extirpated due to the limited genetic variability and adaptive options caused by founders effect and genetic drift (Cox and Moore 1993). The distance effect also means that an isolated population under stress is also less likely to be ‘rescued’ (Grayson 2001; Keegan and Diamond 1987). Human populations on islands face the same challenges as other organisms but human technological abilities make them particularly well-suited to face these adaptive challenges. Technology gives humans the ability to reach the most isolated islands and once there, technology and behavioral adaptations allow humans to minimize the effective isolation of islands. Humans can move between islands and establish networks of social relations that minimize the effects of physical isolation and reduce the likelihood of extinction/extirpation to which other island dwelling species are so prone. In the following discussion a distinction is drawn between geographic isolation, the distance between an island and the mainland or a neighboring island, and social isolation, the extent to which interactions between people living on different islands are limited.

Despite these abilities, not all island societies maintain connections beyond their own shores (Fitzpatrick and Anderson 2008). That humans need not be isolated is clear but there has been little investigation into why some populations choose to maintain isolation while others act to reduce it. In a few cases, like those of Mangareva and Easter Island, declines in voyaging and inter-island exchange networks may be due to raw material constraints on maritime technology

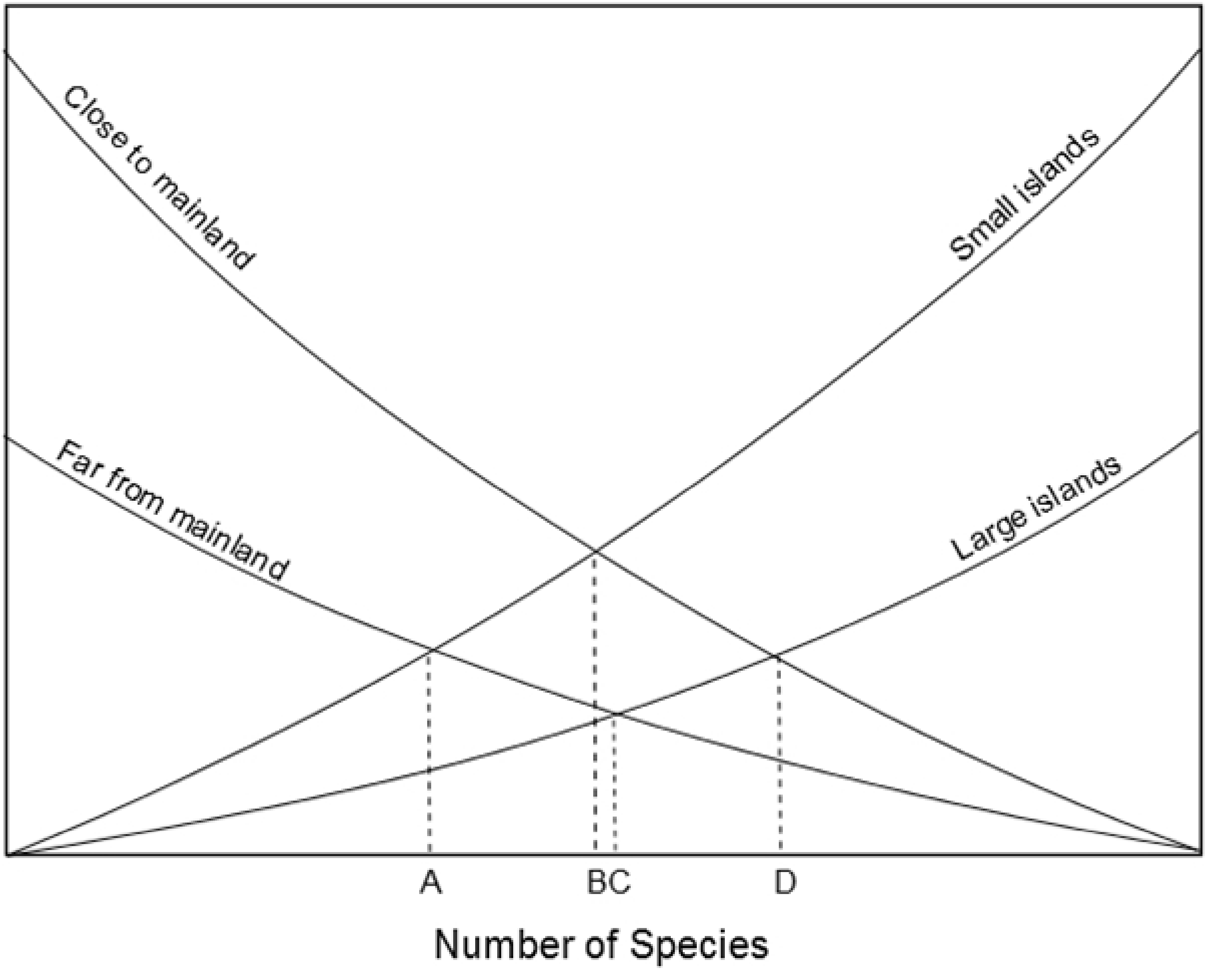

Figure 1.. MacArthur and Wilson's Equilibrium Theory of Island Biogeography (1967)
Models the relationship between island size, isolation, and the relative species richness expected for (A) small and distant islands, (B) small and near islands, (C) large distant islands, (D) large and near islands

as a result of deforestation (Van Tilburg 1994; Weisler 1994). In other areas of the Indo-Pacific, however, intensity of inter-island voyaging and exchange has varied over time with no such obvious cause. For example, the initial Lapita period in Near Oceania was a time of significant interaction with evidence for transport of obsidian and pottery among islands. Most early Lapita sites contain obsidian from multiple sources. Within a few centuries, however, the nature of interisland interaction seems to change and later Lapita sites typically only contain obsidian from the closest source or two (Kirch 1990). At the same time pottery begins to diverge stylistically. Several explanations have been suggested for this contraction of exchange networks including Allen's model of network complexity and fragmentation (J. Allen 1985) and the possibility that early long-distance exchange primarily served to keep new colonists tied to their immediate homeland (Kirch 1988). These hypotheses remain untested but it is apparent that following the initial phase of the Lapita period, communities chose to invest differently in building and maintaining social connections with other islands.

This research investigates one potential cause of variation in exchange and interaction—environmental variability—by employing a simple economic model. In a stable environment, the effects of geographic isolation are minimal. In a perfectly stable environment, geographic isolation would have no effect on survival (although area effects would remain a factor). With increasing environmental variance, isolation effects become more significant and insular populations are at mounting risk of extinction unless isolation can be reduced. Developing social relationship with communities on other islands is one way to reduce effective isolation. While the islands themselves remain physically isolated, participation in exchange networks transforms and enlarges the social landscapes of island communities. Since these interactions frequently involve the exchange of materials, whether through formal trade transactions or informal gift exchange, they often leave an archaeological signature. The utility of developing exchange relationships is greater during periods of increased environmental variability and uncertainty than in more stable environments. Individuals will invest more time and energy in building and maintaining exchange relationships and increasing connectedness in variable environments. In this context, exchange will intensify and diversity of exchange materials will increase.

The choice to pursue exchange relationships can be characterized in terms of the

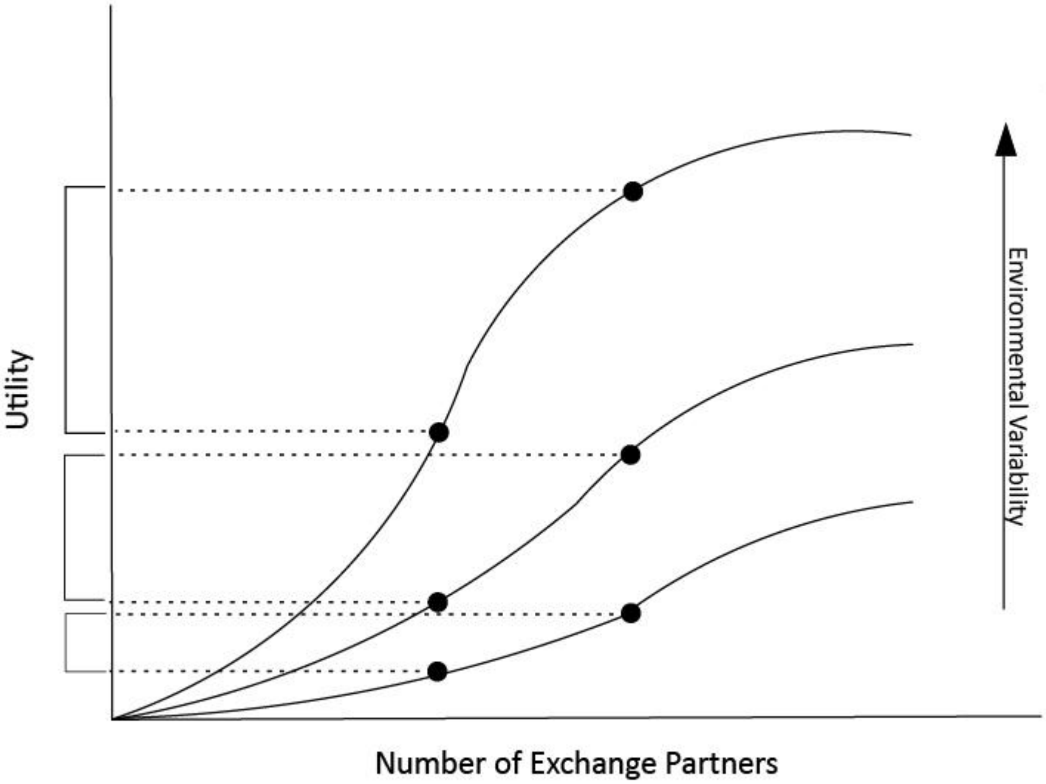

Figure 2. Utility of adding exchange partners in variable environments

associated costs and benefits. Costs associated with exchange include the time and energy required for procuring or producing items for exchange, the allocation of resources to constructing sea-going vessels, a significant risk of death associated with voyaging in small craft on the open-ocean, and the opportunity costs of not pursuing another activity such as foraging. The benefits of exchange activities include access to resources not locally available, prestige within the home community, and as discussed above, the reduction of social isolation. Costs and benefits together comprise utility, or the satisfaction derived from a particular behavior. Utility is a concept from microeconomics that forms the basis for the theory of consumer choice in that discipline. Initially, when the number of exchange partners is low, marginal utility is also low because efficiency is low. Initial costs, like the building of canoes and time spent learning to sail

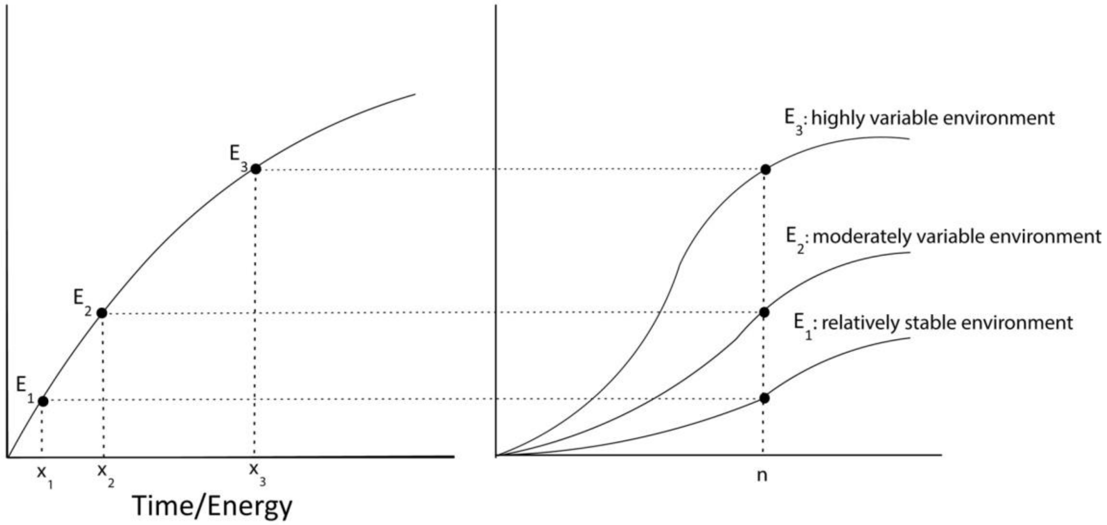

Figure 3. Investment in exchange activity in variable environments

and navigate are the same regardless of whether there are one or two exchange partners. When exchange networks are very small, the costs of participation in exchange networks are high relative to the benefits gained from this behavior. Once exchange networks grow to a certain point, more efficiency is achieved and marginal utility increases. Above a certain level, marginal utility diminishes as the costs associated with maintaining exchange contacts and social relationships begin to outweigh the benefits of expanding networks (Figure 2).

If an important benefit of exchange is that effective isolation is decreased, and the importance of isolation depends on environmental conditions, utility will also vary depending on the environmental context. The utility curve for additional exchange partners is much steeper in a variable environment with considerable extinction risk than in less variable environments. An investment in exchange networks is worth more in highly variable environments than in a more stable environment so individuals should choose to spend more of their time, energy, and resources on building and maintaining exchange relationships (Figure 3).

CHARACTERIZING EXCHANGE NETWORKS

Archaeologists have characterized exchange networks in a number of different ways. Some studies focus on the spatial scale of exchange networks emphasizing long-distance and particular exchange relationships. Others focus on the structure of exchange networks, seeking to differentiate down-the-line vs direct exchange. In this research, the approach taken is to characterize exchange networks in terms of their diversity. The primary goal is to understand how communities reduce social isolation through exchange and interaction. Exchange networks that confer the most connectedness have the most value in this respect. Source diversity of exchange materials is used as a proxy for connectedness. When source diversity is high, a community can be considered more socially connected (and less isolated). Specific source locations do not need to be identified so long as we can group exchange materials from the same locations. This allows the use of underdetermined data that would be excluded from an analysis focused on spatial scale or structure. This approach has the additional advantage of producing data on exchange networks that could be readily compared with similar data from other areas.

CHEMICAL CHARACTERIZATION

In this research chemical characterization techniques were used for two different classes of material that were likely traded in the Banda Islands: pigs, and pottery. Demonstrating exchange through elemental and isotopic analyses requires that there be sufficient geologic and environmental variation to give rise to different geochemical signatures in materials and organisms from different locations. The geologic and environmental variation among the Banda

Islands and across the Banda Arc is examined in Chapter 3.Raw data from LA-ICP-MS and Isotope analyses are archived with ResearchWorks and freely available at: http://hdl.handle.net/1773/27613.

POTTERY

Laser ablation-inductively coupled plasma-mass spectrometry was used for chemical characterization of clay in earthenware ceramics. Similar to digestion mass-spectrometry techniques and neutron activation analysis (INAA), LA-ICP-MS is a chemical characterization method that can be used to identify different compositional groups within a sample (Larson, et al. 2005; Speakman and Neff 2005). Unlike these other bulk analysis techniques, LA-ICP-MS uses laser ablation, allowing small and specific parts of the sample material to be selectively targeted (Cogswell, et al. 2005). For this reason it is less destructive and offers the opportunity to target matrix alone while excluding temper grains or to target temper grains themselves. The potential heterogeneity of clay raw material sources presents a challenge for provenance analysis through chemical characterization. In the Pacific region, many researchers have chosen instead to rely on a petrographic technique for sourcing temper sands, which tend to be more homogenous in a given source location but vary between source locations depending on local geology (Descantes, et al. 2001; Dickinson 2001, 2002, 2005; Dickinson, et al. 2001; Dickinson and Shutler Jr. 1979, 2000; Dickinson, et al. 1996; Dickinson, et al. 1990; Fitzpatrick, et al. 2003; Fitzpatrick, et al. 2006; Intoh and Dickinson 2002; Specht, et al. 2006). This method, however, has significant drawbacks. First, the method requires a very detailed knowledge of local and regional geology. This information is not well developed or readily available for the Banda Islands of Maluku. Second, if pottery is tempered with calcareous material, these sherds cannot be distinguished for different locations (Dickinson 2006). Three of the six main islands in the Banda group are uplifted limestone and likely to have primarily calcareous temper sands.

Additionally, if shell or grog tempers were used these sherds could not be sourced by temper analysis. Finally, the preparation and examination of thin sections is quite time-consuming, limiting sample sizes in studies relying on this technique (Cochrane and Neff 2006). In contrast, LA-ICP-MS requires comparatively little time for preparation and analysis of samples, allowing the larger sample sizes necessary to reliably measure source diversity. Results of LA-ICPMS analysis, source grouping, and source diversity of pottery are discussed in Chapter 4.

PIGS

Chapter 7 provides details on data collection, source group identification, and source diversity based on stable isotope analysis of pig teeth from PA1 and BN1. Pigs are not present on most of these islands today, except for a small feral population on Banda Besar. Indeed, very few domesticated animals are kept on by Banda Islanders. Limited fresh water resources may be one reason why. On Pulau Ay, where there is no accessible groundwater, domesticated animals would be in direct competition with their human keepers for this critical and limited resource. For this reason, it is likely that in the past, as today, the inhabitants of these islands would not have raised many domesticated animals. The prevalence of pig bone in mammal bone assemblages at PA1and BN1 suggests that pigs may have been a trade item in prehistory.

Isotopic analysis of pig teeth and quantitative analysis was used to identify source groups and estimate the source diversity for pigs. Isotopes in bone and tooth enamel can be used to identify the area where an individual animal was born and spent its early years. Isotope studies in Asia and the Pacific can be challenging because soil conditions and the microbial environment usually create a poor environment for bone preservation (Lee-Thorp, et al. 1989; van Klinken 1999). The Banda Islands are no exception. Lape (2000a) attempted to obtain radiocarbon dates on relatively recent (500-1000 years old) bone samples from BN1 but 2 of 3 samples had insufficient collagen. In addition to problems with collagen preservation, even the apatite fraction of bone is subject to isotope contamination in the microbial environments of the tropical Pacific (S. H. Ambrose 1990; S. H. Ambrose and Norr 1997; Krigbaum 2005). Several recent studies however, have successfully measured isotopes in tooth enamel which is more resistant to degredation and contamination due to its denser structure. A recent study of human bone from a cemetery at Teouma used measurement of $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{13}C$ and Ba and Sr concentrations to establish that four of seventeen individuals were not from the local area (Bentley, et al. 2007). Krigbaum (2005) used $\delta^{13}C$ and $\delta^{18}O$ measurements on tooth enamel from burials at Niah Cave, Sarawak, to show diachronic change in diet at the site and several studies have used isotopes to study migration of both humans and pigs from Lapita era sites (Shaw, et al. 2009 2010; 2011).

Isotope analyses included $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{87}Sr/^{86}Sr$, $\delta^{18}O$, and $\delta^{13}C$. None of these analyses alone can effectively measure source diversity without extensive geological sampling and modeling to determine ratios for biologically available Sr and Pb. Additionally, the geology of the region may not be diverse enough to confidently differentiate between source locations based on a single element. Differences in $^{87}Sr/^{86}Sr$ among individuals may differentiate source locations on volcanic islands versus those formed through uplift of reef limestone, but this distinction alone would not be sufficiently fine-grained for estimating source diversity. Like $^{87}Sr/^{86}Sr$, lead ratios in tooth enamel are geologically-derived and have been used for provenance analysis (Turner, et al. 2009; Valentine 2013). However, controls on biologically available Pb are less well understood, making interpretation of results difficult with regards to specific source determination.

$\delta^{18}O$ in tooth enamel is derived from the $\delta^{18}O$ of ingested water. Oxygen isotope variation within an area with similar climatic conditions is not sufficient for source differentiation (Bentley 2006). There are, however, some differences in rainfall for the inner versus the outer islands of the Banda archipelago itself (Lape 2000a). Within the Banda group inhabitants of some islands rely entirely on direct rainwater collection, while others have groundwater resources to draw on, therefore, small differences in $\delta^{18}O$ were expected between sources on inner versus outer islands.

Though $\delta^{13}C$ is tied to the individual's diet and does not, by itself give information about source location, animals raised in the same location are likely to have the same diet and these are likely to vary somewhat between locations, depending on local environment. Some differences may also be tied to the local environment through the canopy effect. Individuals whose diets are derived from forests with dense canopies have more negative $\delta^{13}C$ values than those who have eaten plants grown in more open environments (S. H. Ambrose and Krigbaum 2003; Jackson, et al. 1993; Krigbaum 2003). While each method has limited potential for discriminating sources if applied independently, they can become a powerful tool for measuring source diversity when combined.

CLIMATE AND ENVIRONMENTAL VARIABILITY IN THE INDO-PACIFIC

Chapter 4 examines the mid to late Holocene record of climate change and assesses the relationship between climate change as a source of environmental variability and changing levels of connectedness in the Banda Islands. In the tropics where seasonality pertains mainly to rainfall rather than temperature differences, The El Niño Southern Oscillation is the most significant modern source of interannual environmental variability. Its effects are particularly strong in Island Southeast Asia and Near Oceania. The Indo-Pacific Warm Pool (IPWP) is a major location of atmospheric convection with a strong influence on global climate. In El Niño years, wind-driven currents displace the IPWP eastward, sea surface temperatures (SST) in the eastern Pacific rise and trade winds weaken. This relocation of convection causes a re-arrangement of the Walker Circulation and rainfall anomalies throughout the Indo-Pacific region (Dijkstra 2006). In the southwest Pacific, El Niño periods are characterized by slightly lower sea-surface temperatures (SST) and dramatically reduced rainfall, an occurrence with significant consequences for humans. During the documented El Niño events of 1877-1878, 1982-1983, and 1991-1992, large forest fires and prolonged drought were observed in the islands of Indonesia and elsewhere in the usual range of the warm pool (Tomascik 1997). During the 1997 El Niño, a 4% decline in annual rice-production in Indonesia was attributed to the intense and prolonged El Niño driven rainfall anomalies that year (Fox 2000:179). In Maluku and Irian Jaya, located in the IPWP, rice production fell 32% the same year (Fox 2000). During the 1997-1998 El Niño, drought led to significant wildfires on Gunung Api, a volcanic island in the inner Banda Archipelago, and rainfall was 50% less than an average year (Lape 2000a). Instrumental data indicate that during El Niños Island Southeast Asia experiences 40-60% less rainfall than in average non-El Niño years (Lape and Chao 2008). Rainfall anomalies have also been documented for other moderate to strong ENSO events in both modern instrumental data and in paleoclimate proxy records, including two four hundred year teak tree ring sequences from Java and Sulawesi (Cook, et al. 2000).

Another study, using satellite estimates and historic rain-gauge records to map global ENSO-related rainfall anomalies, places eastern Indonesia in the area with the strongest negative rainfall anomalies during El Niño (Dai and Wigley 2000). Rainfall anomalies in the region are strongest from December through May (Dai and Wigley 2000), eclipsing the December-February wet monsoon, when this region receives the most rain (Lape 2000a). El Niño induced drought and forest fires would have led to crop shortages in the past. On small limestone islands without groundwater sources like Pulau Ay strong El Niños necessitate travelling to a neighboring island for water (Lape 2000a). In addition, El Niño has been associated with dengue fever epidemics, (Gagnon, et al. 2001) and rat infestations (Fox 2000).

ENSO proxy records from the Holocene show variance at the interannual, centennial, and millennial scales. During the early Holocene ENSO events were infrequent and probably low amplitude (Brijker, et al. 2007; Gagan, et al. 2004; McGregor and Gagan 2004; Moy, et al. 2002; Sandweiss, et al. 2001). During the mid-to-late Holocene several episodes of more frequent and intense ENSO events are apparent in paleoclimate proxy records.

The model for the growth and intensification of exchange networks discussed above predicts that there should be more investment in exchange networks when the environment is more variable. Periods of more frequent strong ENSO events represent just such a context. There can be no question that human populations in the western Pacific would experience hardships during severe El Niño events and if they recurred frequently enough they could threaten the populations of at least some small and isolated islands with extirpation.

Paleoclimate proxy records are available from locations throughout the Pacific basin. While these proxy records often yield different results, we can confidently identify patterns in ENSO frequency and hydrology by comparing multiple records. In addition to the Indo-Pacific, proxy data are available from South and Central America (Moy, et al. 2002; Rodbell, et al. 1999; Sandweiss, et al. 1999), the Eastern Pacific (Conroy, et al. 2008; Riedinger, et al. 2002; Woodroffe, et al. 2003; Woodroffe and Gagan 2000), and the Western Pacific (Brijker, et al. 2007; Gagan, et al. 2004; Langton, et al. 2008; McGregor and Gagan 2004; Stott, et al. 2004;

Tudhope, et al. 2001). These and other proxy records are discussed in Chapter 4 and related to the record of changing source diversity among Banda Islands assemblages in Chapter 8.

SUMMARY

The isolation of small islands in the Pacific was once the basis for considering them as laboratories for the study of human cultures (Clark and Terrell 1978; Goodenough 1957). It is now widely appreciated that rather than serving as controlled experiments, different rules apply for islands. One of these rules is that islands are physically isolated and those taxa that inhabit them will be at risk from this isolation unless they can take steps to diminish its effects. Although we may intuitively appreciate that inter-island voyaging, interaction and exchange make insular human populations less vulnerable by reducing social isolation, this recognition does little to explain those cases in which people allowed themselves to become more isolated. While it is widely recognized that exchange and inter-island contacts were important at different times in Indo-Pacific prehistory, our understanding of how and why these systems changed is incomplete. This research uses chemical composition analyses of multiple material types to measure the intensity of exchange networks through source diversity. This research will begin to fill gaps in the record of Neolithic period exchange by more rigorously characterizing exchange networks using multiple archaeological materials, and focusing on an area, eastern Indonesia, where archaeological investigation is just beginning.

CHAPTER 2: THE NEOLITHIC IN ISLAND SOUTHEAST ASIA

This dissertation examines culture change from the early Neolithic to the late prehistoric period in the Banda Islands, Indonesia at a deliberately restricted scale of analysis and interpretation. This is in contrast to much of the research on this period in Island Southeast Asia and the Pacific which has been embedded within a grand narrative framework. Large scale patterning in the distribution of languages and phenotypes across the Pacific Basin coupled has led some researchers to advocate an exclusive focus on large-scale theory and grand narratives (Bellwood 2005). As others have pointed out, approaches overly focused on constructing large scale historical narratives in this way tend to mask or ignore considerable variability that is apparent at more restricted scales of analysis (Swete-Kelly 2008; Szabó and O'Connor 2004) This has been a major problem for the archaeology of the Neolithic in ISEA. For instance, Bellwood (2002:22) argues that migration of Neolithic farmers should produce widespread and homogenous archaeological culture signatures but with “much local variation in language and cultural style.” This argument is set up in such a way that any archaeological patterning observed supports the conclusion that Neolithisation in ISEA was the result of migration. If the archaeological record shows a high-degree of homogeneity in material culture across the region, this confirms Bellwood’s view that language and farming spread through migration. If on the other hand we demonstrate that there is substantial heterogeneity, this pattern also seen as consistent with the farming-language dispersal hypothesis. Ultimately, this grand narrative scheme is a just-so story which has, unfortunately dominated archaeological inquiry in ISEA since the 1980s. In this chapter I will examine some of the most prominent models and hypotheses that have been presented regarding the Island Southeast Asian Neolithic in order to contextualize my research. While testing these models is not a primary goal of this research, we will see that the nature of exchange and interaction through this period has important implications for the process of Neolithisation in ISEA.

PERSPECTIVES ON NEOLITHISATION IN ISLAND SOUTHEAST ASIA

Archaeologists working throughout the Pacific have long recognized that isolation is an important feature of environments in the area and early culture history reconstructions were founded on the assumption that after initial colonization, prehistoric populations in the Pacific became as isolated socially as they were geographically (Rainbird 1999). Although the isolation bias has now largely been rejected by Island Southeast Asian archaeologists its legacy still exerts a strong influence on the field. Much archaeological research on the Neolithic period in Island Southeast Asia has been carried out within a culture historical paradigm dominated by a migrationist perspective on culture change. In large part this bias derives from the integration of historical linguistics at all levels in archaeological research from theory formulation to site interpretation.

The majority of languages spoken in ISEA belong to the Austronesian language family. The distribution of Austronesian languages extends further east to include most of the languages of Near Oceania and all the languages of Remote Oceania and extends to Madagascar in the west. The broad distribution of these closely related languages has led to this enormous region (with the exception of Madagascar) being treated as a culture area and has defined the scale of archaeological theory and explanation. Simply put, the big distribution of the AN family seems to require big explanation. Problematically, the integration of historical linguistics at this level predetermines the kinds of explanation that will be acceptable. A link between languages, pottery distribution, and migration is clear for the Remote Pacific since only Austronesian languages are spoken in this region and there is no record of pre-ceramic human populations in this region. Tracing the AN homeland to Taiwan, the same interrelationship between language, pottery, and migration, has also been applied to explain the distribution of pottery (presumably carried by AN language speakers) throughout Island Southeast Asia as well as Oceania. But the situation in these regions is complicated by the presence of non-Austronesian languages and a pre-ceramic archaeological record stretching back to at least 40 kya. Speakers of the Oceanic branch Austronesian languages of across Remote Oceania share a relatively recent common origin in the vicinity of New Guinea but this fact does not inform the question of when Austronesian languages spread through ISEA and Near Oceania (Oppenheimer 2006). Similarly the fact that pottery and languages spread together in Remote Oceania does not mean that they <u>must</u> have spread together in ISEA and Near Oceania. In fact, it is only the concept of large-scale migration that links the distribution of Neolithic associated material culture items in ISEA to the colonization of Remote Oceania. Distant island groups in the eastern Pacific were colonized 3000 years after pottery and possibly farming (but see discussion of evidence for agriculture below) supposedly spread through migration from Taiwan to the Northern Philippines. Given the difference in timing, there is no reason to assume that these two events are linked to the same process of cultural change. Migration theorists invoke the idea of a “long pause,” a period of over 1000 years between the first appearance of pottery and domesticates in Near Oceania and the first colonization of the Remote Pacific Islands, to maintain the view that the colonization of the Pacific was a single migration event despite the temporal inconsistency between the first appearance of Neolithic technologies in the western versus the eastern Pacific. A similar device is used by Bellwood and Dizon (2008) to explain a gap of at least a millennium between the first dispersal of agriculturalists into Taiwan from a mainland source and the subsequent dispersal of these farmers from Taiwan to the Batanes Islands. We must question the reasonableness of theorizing and explaining such scenarios as single events. As (Campbell 2002:52) points out "telescoping of events resulting in the distribution of the languages into a single spread with a single cause does disservice to the prehistory which we are attempting to understand." If archaeological evidence is considered without regard to linguistic patterning, many different views on Neolithisation are possible.

OUT OF TAIWAN

The dominant narrative for the Neolithisation of the region during the mid-Holocene holds that pottery, domestic animals, agricultural economies, and a number of other traits emerged in Taiwan around 5000 BP and led to an eastward demic expansion (Bellwood 1984-85, 1997, 2005, 2011; Bellwood, et al. 1995; Blust 1995; Diamond 2001; Diamond and Bellwood 2003; Shutler and Marck 1975). According to this model, the social landscape of Island Southeast Asia was transformed through the migration of an ethno-linguistically unified group usually referred to as "Austronesians" through insular Southeast Asia and into the Pacific. "The Austronesians" began to colonize other islands and island groups in Southeast Asia beginning with the nearby Batanes Islands and Northern Philippines around 4200 BP (Bellwood and Dizon 2005, 2008). By about 3000 BP this group had colonized all of Island Southeast Asia and moved into near Oceania where "Austronesian" culture was expressed as the Lapita culture complex (Bellwood and Koon 1989). While Bellwood has regularly refined this out-of-Taiwan (OT) hypothesis to fit emerging evidence, the basic tenets have remained unchanged despite criticism on many different points. This model has set most research agendas relating to the Neolithic period in Island Southeast Asia and limited the kinds of questions that archaeologists have asked.

The model is widely cited by linguists (e.g. Blust 1995) and geneticists (Lipson, et al. 2014; Mirabal, et al. 2013; Trejaut, et al. 2014; Zeng, et al. 2014).

The OT hypothesis is compelling because multiple lines of evidence (historical linguistics, genetics, and archaeology), presented as independent, seem to support the same conclusion. In fact linguistic and archaeological evidence have been tightly intertwined since the 1970s in Island Southeast Asian archaeology. When Bellwood first began promoting the OT hypothesis, historical linguistic reconstruction of the AN family seemed to unequivocally support a large-scale migration. Taiwan was identified as the AN homeland because it had the highest diversity of AN languages. This aspect of the OT hypothesis is still largely supported although some have pointed out that dialect leveling, linked to high degrees of social exchange and interaction, could have erased linguistic diversity that once existed in other parts of ISEA. Meacham (1984-85) has even argued that the preservation of AN linguistic diversity in Taiwan could reflect a higher degree of relative isolation rather than homeland status, going so far as to refer to it as a “cultural backwater”. Recent genetic research on y-chromosome haplogroup distributions provides some support for this view. High degrees of biomolecular differentiation among Taiwanese aboriginal tribal groups indicate that these populations have experienced significant isolation, endogamy, and genetic drift (Mirabal, et al. 2013).

LINGUISTICS

Blust (1984-1985, 1995) identified a sequence of proto-language divergence and depicted a strongly hierarchical, tree-like structure for the language family consistent with a process of linguistic fissioning through population dispersal and subsequent isolation. High order groupings were geographically structured and indicated a directional dispersal from Taiwan (Proto-Austronesian) to western Southeast Asia (Proto-Malayo-Polynesian), Eastern Indonesia (Proto

Central/Eastern-Malayo-Polynesian), the north coast of New Guinea (Proto-Eastern Malayo-Polynesian) and into the Pacific (Proto-Oceanic). This structure was a good fit with a migration narrative in which a single group from Taiwan diverged as they colonized different sub-regions and island groups. More recently, this strongly hierarchical tree has been revised with the recognition that some of the major groupings lack unique shared innovations. For example, the languages comprising the Western Malayo-Polynesian group share many cognates but no innovations that are not also shared by the higher order Malayo-Polynesian group (Donohue and Denham 2010; Pawley and Ross 1993). Revisions have also been proposed to eliminate the CEMP and CMP nodes (Donohue and Grimes 2008) and challenging the status of the the EMP node (Ross 1995). Rather than a strong phylogenetic signal, this rake-like structure suggests the gradual divergence of a large dialect chain. An important implication is that with this flattening of the AN language family tree, the directional signal in Blust's formulation disappears. As Donohue and Denham (2010), point out, this phylogeny, with little-to-no hierarchical structure between Malayo- Polynesian and Oceanic groupings, does not support the model of a structured north-to-south dispersal through migration.

GENETICS

Geneticists have been very active in trying to trace the descent of populations in Island Southeast Asia and Oceania. A substantial body of work including mtDNA, y-chromosome and autosomal DNA studies paints a complex genetic picture for populations in these regions. Just as archaeology and linguistics have not been constructed independently in ISEA, genetic studies often embed the assumption that linguistic groups represent distinct ethnic populations with a common history. Sampling strategies often use linguistic affiliation for data aggregation and comparison and interpretation of results (eg. Mirabal, et al. 2013; Trejaut, et al. 2014; Zeng, et al. 2014). For example, Lipson, et al. (2014) found that a component of ancestry for western ISEA populations and some eastern ISEA groups shows a relationship to groups in Mainland Southeast Asia (MSEA) that speak Austroasiatic languages. They propose that Austronesian speakers moved west through Vietnam and Malaysia before moving into ISEA and mixing with populations there, picking up their genes but not their languages. There seems to be a conviction that languages are fixed and immutable in populations—a biological fact.

What is clear from genetic research is that the population history of the region is more complex than linguistic patterning suggests. Results from mitochondrial DNA show that mtDNA haplogroup E reached ISEA at the beginning of the Holocene but reached Taiwan millennia later, indicating that bidirectional movements of people were occurring long-before pottey use and agriculture (Soares, et al. 2008). The haplogroup ancestral to the 'Polynesian motif' (B4a1) is shared by Polynesians and Taiwanese but the motif itself (B4a1a1a) is absent west of Borneo and rare in ISEA as a whole (Hill, et al. 2007). Based on age estimates for the appearance of this clade in different regions, Soares, et al. (2011) argue that it arose in the Bismarcks around 6500 years ago, spreading westward into ISEA 4000-5000 BP.

Y-chromosome results have tended to show a closer connection between Taiwanese aboriginal populations and living Polynesians. Three Austronesian-speaking groups on Taiwan, the Ami, Saisuat, and Bunun, seem to have a close genetic relationship to some populations in the Solomon Islands and Society Islands (Zeng, et al. 2014). On the other hand the distribution of y-chromosome haplogroups does not show consistent patterning that might be expected from a single migration event. The same study showed that some Solomon Islands populations are more closely related to Southeast Asian groups and others along with Santa Cruz populations have more affinity with SW Chineses and northeast Asians. Zeng, et al. succinctly sum up the current state of affairs in terms of the genetics: "There is no clear geographical or linguistic correlation reflected in the observed phylogenetic partitioning of the Oceanic communities, thus, it is difficult to attribute any historical and/or cultural significance to this partitioning" (2014: 246).

CHRONOLOGY AND THE NEOLITHIC PACKAGE

Regional chronology has also been framed as providing considerable support for the OT hypothesis. A central tenet of the original OT hypothesis was that "Austronesian" migrants carried with them a material culture package by which they could be identified in the archaeological record. This package includes red-slipped pottery, a range of shell artifact types, certain forms of ground stone adzes, domesticated animals, and an agriculture-based subsistence system. Rapid and directional appearance of these attributes at archaeological sites from the vicinity of Taiwan east through ISEA and into the Pacific would support the inference of a highly structured migration by a single Taiwan-based population. Archaeological evidence shows that there is no consistent package, that different elements purported to comprise this package do not appear simultaneously, there is no direct evidence for critical evidence like agriculture, and even the spread of pottery does not show rapid spread or strongly directional patterning.

Evidence for the arrival of an introduced Neolithic package is lacking outside of Taiwan, a fact that many authors have pointed out both in ISEA (O'Connor, et al. 2006) and Near Oceania (Specht et al. 2014). For example, shell artifacts are not present at all Neolithic sites. No shell artifacts have been identified at PA1/ PA12, the only known Neolithic period site in the Banda Islands. Where shell artifacts have been recovered, they are highly variable in form, raw material, and production techniques at contemporaneous sites in different parts of ISEA (Szabo and O'Connor 2004). Some sites have strong evidence for shell artifact manufacture and use prior to the appearance of pottery in the archaeological record and continuity across this transition (Szabo and O'Connor 2004, O'Connor 2006, 2010; Specht et al. 2014). Since his earlier formulations of OT (Bellwood 1984-85, 1985, 1987), Bellwood (2011) has backed-off from the idea of the Neolithic package and now sees it as polythetic in nature. While he is correct in asserting that we need not expect the complete transfer of all material culture items in a migration scenario, what we actually see in the archaeological record is far more variable than the occasional adding or dropping of a component or two. At PA1/ PA12 two typical Neolithic items were present, red-slip pottery and pigs. However, pottery and pigs do not appear to have arrived together. Pottery use began several hundred years before pig bone appears in the archaeological record. The only polished stone adzes from the Banda Islands have been surface finds or from much more recent contexts. Additionally, no shell tools or ornaments have been recovered and we have not yet found the evidence needed to pinpoint the timing of the transition to an economy based on agriculture or horticulture. In short there is nothing resembling a package here—not even a polythetic one. The lag between the appearance of pottery and pigs on Pulau Ay does not support the idea that they arrived with a migrating population. A similar pattern is apparent in Lapita sites in Mussau, the Bismarck Archipelago, Nissan Island, and Vanuatu where early Lapita sites have pottery but pigs appear later (Specht, et al. 2014). Evidence from Watom Island indicates interisland transport of pigs in the Bismarck Archipelago, but not until the Late Lapita period (Shaw, et al. 2010).

SUBSISTENCE ECONOMY

As an explanatory model, an agricultural economy is absolutely essential to Bellwood's hypothesis because demic expansion related to food production is presented as the prime causal factor driving migration. Lexical reconstructions of agriculture related vocabularies are cited as evidence that Austronesian migration was carried out by agriculturalists but archaeological evidence for agriculture is generally lacking outside of Taiwan (Bellwood 2011). The absence of evidence for agriculture should not be taken as conclusive evidence that early pottery-users were not agriculturalists, particularly given that soil and climate conditions are not favorable to the preservation of macrobotanical remains and archaeobotanical sampling techniques have not been consistently employed in archaeological excavations in the region (Castillo and Fuller 2010). The important point here is that the association between pottery and agriculture posited by the OT hypothesis must be demonstrated through the archaeological record. Since historical linguistics cannot provide reliable dates for language spread or divergence, lexical reconstructions do not prove such associations.

A handful of sites have provided information on plant-resource exploitation during the Neolithic period based on macrobotanical remains, starch grain analysis, or isotope analysis. If agriculture spread with AN migrants from Taiwan, rice and foxtail millet would almost certainly have been the most important crops but there is no evidence that these crops successfully spread south and east during the Neolithic. Glover (1986) reported possible foxtail millet at Uai Bobo 2 in East Timor but the single specimen was from a more recent context and could even be modern (Oliveira 2010). A few sites in ISEA, outside Taiwan have provided secure, dated evidence for an association between pottery and rice (Paz 2002). At Gua Sireh, Sarawak rice grains were recovered from site sediments and as pottery temper. One such temper grain has been directly dated to 3850±260 BP [CAMS 725] (Beavitt et al. 1996, Datan and Bellwood 1999). It is worth noting, however, that Gua Sireh pottery does not belong to what Bellwood sees as a red-slipped tradition associated with Austronesian migrants. Charred rice remains from Ulu Leang, South Sulawesi have not been directly dated but Neolithic occupation at the site dates to at least 3800 BP (Spriggs 2007). Rice hull and stem fragments in pottery from Andarayan have been directly dated to 3240±160 BP [SFU-86] (Snow et al 1986). As Paz (2002) points out, rice temper in pottery in absence of other evidence for rice growing or processing cannot be interpreted as evidence for a rice-based agricultural economy.

Oliveira (2008, 2010) recovered and identified macrobotanical remains from several cave sites on the Bacau Plateau of East Timor and found no significant change in plant use in this region across the Neolithic transition period. As Spriggs (2007) points out, there is currently better evidence to support an early spread of domesticates west from New Guinea than east from Taiwan and this may have occurred prior to the appearance of pottery outside Taiwan. Bellwood contends that it is to be expected that Austronesian speaking migrants would adapt to new ecological conditions by shifting from their original cultivars to more viable crops (Bellwood 2011). This position, however, is difficult to reconcile with the idea that agriculture and the resulting demographic growth was the primary driver of colonization (Oppenheimer 2002).

ALTERNATIVE PERSPECTIVES

Since the Austronesian migration hypothesis came to prominence during the 1970s, many have pointed out inconsistencies in the data (Anderson 2005; Donohue and Denham 2010; Szabó and O'Connor 2004), problems with the assumptions about the relationships between material culture and ethnolinguistic identity (Terrell, et al. 2001) Sweete-Kelly 2008), or proposed alternative models for the “spread of the Neolithic” (Donohue and Denham 2010; Solheim, et al. 2006; Tanudirjo 2001). Tanudirjo has proposed a different model that he argues better accounts for the structure of the AN family as we now understand it and the archaeological evidence. Rather than viewing the spread of AN languages as a single event, D. Tanudirjo (2004) argues for a four stage migration model. In the final stage, extensive interaction spheres are formed leading to a process akin to globalization. This model still has a strong migration component but it has the advantage of allowing for more complexity in the process at smaller scales. Cultural exchange and homogenization occur at larger scales but variation in the reproduction of that global culture is apparent at the local scale. This model still has a strong migration component but it has the advantage of allowing for more complexity in the process at smaller scales.

In his most recent review of the state of Southeast Asian Neolithic archaeology, Spriggs (2011) outlines revisions to the Austronesian language family tree and other problems with Bellwood's model for the ISEA Neolithic. But while he argues for a new focus on Neolithisation as identity formation, he suggests that the answer is to return to a descriptive model proposed by Roger Green in 1991. Green's model was developed for the Lapita Culture Complex in the Bismarck Archipelago as an alternative to a Coloniser model that did not account for local innovations and the role of interaction between indigenous populations and new colonisers. These interactions were seen as giving rise to a degree of heterogeneity in artifact assemblages. His model represented a sort of middle ground between those attributing origins of the Lapita cultural complex primarily to intrusion by Southeast Asian colonists (Bellwood 1979; Green 1985) and those arguing for indigenous development (Allen 1984; Allen and White 1989; White and Allen 1980; White, Allen and Specht 1988). Employing the Triple I model involved attributing very specific and well differentiated types to either external sources, mainly in Island Southeast Asia (e.g. certain adze forms), indigenous traditions (e.g. various horticultural products), or innovations (eg. the Lapita design motifs on pottery) (Green 1991).

Employing this model places an emphasis on careful examination of well-defined types within artifact assemblages. At present such research is rare in ISEA where the broad category of red-slipped is often translated directly into ethnolinguistic identity. In the literature on this area there is a tendency to assign "Austronesian" status to any site where red-slipped pottery is observed without more detailed examination (or at least publication) of characteristics of the ceramic assemblage. But whereas the formal and elaborate decorations of Lapita pottery, which are correlated with specific vessel shapes and formation techniques, form the basis for a robust typology, red-slip is too broad a categorization. The presence of red-slips on ceramics is simply not sufficient to define a type, let alone to be considered a marker of a single unified ethnolinguistic group.

Although it allows for local innovation, Green's formulation is still embedded within a migrationist paradigm and is ultimately a descriptive rather than explanatory model. Migration is maintained as a primary cause of culture change but the model does not provide any mechanism for explaining why this migration took place. It is as untestable as the OT hypothesis. In suggesting this as a framework for studying the Neolithic in Island Southeast Asia, Spriggs is distancing himself from the original OT model but while he has dropped the term "Austronesian" in his latest description of the ISEA Neolithic he maintains the notion that populations on far-flung islands in this enormous region shared a unified cultural identity:

> "Neolithisation of ISEA was a new process of identity formation that seized the imagination of a mass of people on hundreds of islands across thousands of kilometers of ocean, spreading like a pulse across ISEA and into the Pacific over a few centuries. It spread through processes both of migration and recruitment in-place" (Spriggs 2011:524).

What is needed is not a single new theory to describe the broad trends throughout Island Southeast Asia. This scale of regional synthesis is premature at this stage in Island Southeast Asian archaeology. We need to build more, detailed local sequences, synthesize data at a more restricted spatial scale, and focus on comparison between sub-regions. Typological analyses, when undertaken, need to be much more fine-grained before they can demonstrate what has been largely assumed in Southeast Asian Archaeology—that artifact similarities spring from common descent. Rather than directly relating the histories of Neolithisation in Taiwan, the Northern Philippines, Western and Eastern Indonesia to build a single super-regional narrative, we need to focus on understanding the processes of culture change as they operated in each area independently, and comparing these histories.

There are several reasons why a single model for Neolithisation is not likely to adequately explain culture change across the entirety of ISEA. First, environmental gradients existing across the region imposed very different sets of constraints on their populations. Variation in island size, rainfall regimes, and terrestrial biodiversity within Island Southeast Asia must have impacted the people inhabiting these islands. In different parts of the super-region people would have experienced different degrees of relative geographic isolation and dealt with different constraints. Therefore, we should expect to see differences in how new technologies as cultural adaptations were made and used in different areas. There is widespread recognition that environmental differences conditioned the development of agricultural/horticultural practices in different parts of the region. For example, while rice-based agriculture may have accompanied the first pottery use in Taiwan and the northern Philippines, this was certainly not the case in eastern Indonesia where islands are too small and dry to support much rice production. The role of such environmental constraints is clear when we consider questions about food production but it is important to explore their impacts on other facets of society that may be less obviously environmentally constrained. This research aims to investigate the relationship between interisland exchange and interaction networks and environmental variability in one part of Island Southeast Asia. While interisland interaction is a complex and fundamentally social behavior, also plays an important adaptive role for people inhabiting small and relatively isolated islands.

EXCHANGE IN THE INDO-PACIFIC

Chemical characterization of various materials to demonstrate exchange and interaction has been successful in many regions of the world and has been particularly productive in Near and Remote Oceania. Numerous studies, based on chemical characterization of obsidian or basalt and petrography of ceramics have demonstrated early long-distance exchange in the Indo-Pacific (W. Ambrose, et al. 2009; Bedford, et al. 2002; Best 1987; Cochrane 2004; Cochrane and Neff 2006; Dickinson 2001, 2002, 2005; Dickinson, et al. 2001; Dickinson and Shutler Jr. 1979; Fitzpatrick, et al. 2003; Green 1987; Hunt 1989; Intoh and Dickinson 2002; Lilley 2002, 2004; Reepmeyer, et al. 2011; Sheppard 1993; Sheppard, et al. 2010; Specht, et al. 2006; Spriggs and Dickinson 2010; Spriggs, et al. 2011; Summerhayes 2003, 2004; Summerhayes and Allen 1993). By the Late Pleistocene people in the Bismarck archipelago were either exchanging materials between islands or directly procuring “exotic” resources not available at their home bases. On New Ireland the bones of cuscus (not native to the island) and obsidian from New Britain appear in sites dating to about 20,000 BP (Leavesley 2005). While these materials may have been procured directly rather than exchanged between groups of people, their presence nevertheless shows that at this early date people were voyaging between islands and redistributing resources among them.

The transport of obsidian continued into the Holocene with Bismarck Islands obsidian reaching its broadest distribution around 3000 years ago, shortly after the appearance of Lapita pottery in the area (W. Ambrose, et al. 2009). During the period when Lapita pottery was being produced, sites throughout Near Oceania tend to have obsidian from a variety of different sources but Talasea obsidian is often the most abundant and is found at sites thousands of kilometers away (W. Ambrose and Green 1972; Sheppard 1993). The spatial distribution of

Talasea obsidian does not fit well with the expectations of simple formalist economic models, which predict fall off with increasing distance (Renfrew 1969). Following the early Lapita period, a time of intense, long-distance exchange, regional exchange in Near Oceania gradually contracts (Kirch 1990, 1991). Within the Bismarck archipelago region there is a tendency for early Lapita sites to contain obsidian from multiple sources but after a few hundred years the closer source comes to dominate (Kirch 1990, 1991). Evidence for long distance exchange is absent after approximately 2000 BP but there is evidence that exchange was quite active over shorter distances and this regionalization has been described as a process of intensification (J. Allen 1985; Kirch 1991).

A similar pattern is also evident in Remote Oceania where provenance studies have focused on basalt (Bedford and Spriggs 2008; Davidson 1977; Di Piazza and Pearthree 2001; Weisler 2002; Weisler and Green 2001; Weisler and Kirch 1996) The earliest archaeological sites often have evidence for long-distance exchange in the form of basalt sourced to distant islands or the presence of pearl shell on islands where it does not naturally occur (Rolett 2002). After 500 BP, this evidence is absent. In contrast to Near Oceania, this seems to have been a general decline of exchange and inter-island interaction and islands became increasingly isolated from each other. This pattern has been observed in the Southern Cook Islands (M. S. Allen 1996), Marquesas (Rolett 1998), and the Pitcairn Mangareva group (Weisler 1995).

The record of early Neolithic exchange in Island Southeast Asia is sparse but evidence from a handful of sites suggests that, as in Near Oceania, trade networks developed early and rapidly in at least some areas. Recent research has shown that exchange networks linking Taiwan with mainland Southeast Asia and the Philippines emerged as early as 4000 BP (Hung, et al. 2007). In Sabah, the site of Bukit Tengkorak has provided evidence for trade links between

Island Southeast Asia and Near Oceania in the form of obsidian from the Talasea source in New Britain, 3000 km away (Chia 2003). Obsidian from another, unidentified source was found at both Bukit Tengkorak and in the Talaud Islands of Eastern Indonesia indicating that exchange networks linked eastern and western Island Southeast Asia although the intensity and extent of these contacts is unclear (Chia 2003). For the Bukit Tengkorak sequence, trade was most active between 3150-2850 BP. In the Talaud Islands a history of changing trade frequency has been demonstrated with significant early exchange interactions until around 2000 BP, when an increasing divergence in artifact styles suggests that interactions across the broader region may have declined and undergone a similar regionalization process to that seen in Near Oceania (Tanudirjo 2001).

At present most provenance analysis on archaeological materials in Island Southeast Asia has focused primarily on identifying inter-island transport of obsidian. Obsidian is ideally suited to chemical characterization for such provenance analyses because sources are geographically discreet, chemically uniform, and chemical signatures exhibit substantial variation between volcanic sources. Sourcing studies of obsidian have identified some of the longest-distance transport of this material anywhere in the ancient world with Bismarck Islands obsidian, chemically matched to the Talasea source, identified at Bukit Tengkorak, Sabah (Bellwood and Koon 1989; Reepmeyer, et al. 2011; Tykot and Chia 1997). In the Philippines, geochemical sourcing using XRF has shown that obsidian artifacts from Ille Cave, Palawan, and Huluga, Mindanao are not derived from any known source in the Philippines and may have originated from two separate sources outside the archipelago (Neri 2007). A second recent study using LA-ICP-MS confirmed these results and showed that the Ille obsidian probably derives from the same unidentified source as specimens from Letigio, Cebu (Reepmeyer, et al. 2011). The Ille obsidian, dated to 11,000-9,400 BP (Lewis, et al. 2008), represents a very early movement of obsidian in ISEA. Obsidian in other Philippines sites included in Neri and Reepmeyer's studies date from the Neolithic to the Early Metal period (Spriggs, et al. 2011).

While it is clear that inter-island exchange of obsidian occurred in several parts of ISEA from at least the early Holocene it is not clear whether this movement of obsidian was the result of regular participation in established exchange networks or a more sporadic occurrence. The attributes that make obsidian ideally suited for chemical sourcing make it less than ideal for fully characterizing prehistoric exchange networks. Obsidian sources are discreet and not distributed homogenously across the region so its distribution in archaeological sites can only partially represent the range of potential exchange interactions in the past. Additionally, obsidian occurs in low numbers relative to other materials in most archaeological sites, so these studies tend to have small sample sizes. For example, at PA12 in the Banda Islands only 11 of 577 lithics recovered from two 2-x-1 meter units were obsidian. These artifacts are all extremely small flakes suggesting that if larger pieces were ever present they were used to exhaustion. The rarity of obsidian and the small size of the few recovered specimens indicate that it was not an important resource for Neolithic and later populations in the Banda Islands either because they did not have regular access to the raw material or because other materials were preferred for tool manufacture. Reepmeyer, et al. (2011) analyzed the 15 obsidian flakes recovered at PA1 and found that they all originated from a single source that was most likely not located in the Banda Islands or even in Maluku.

CHAPTER 3: GEOLOGY AND ENVIRONMENT OF THE BANDA ISLANDS

INTRODUCTION

This chapter describes the geologic history and natural environment of the Banda Islands. Such context is important for this research for several reasons. A discussion of local geology of both the Bandas and the rest of the Banda arc is necessary for interpretation of isotope and trace element data for pottery and pigs presented in chapters 5 and 6. Isotopic and chemical characterization methods can only be applied to demonstrate the movement of materials in the past if it can be established that different sources within an area can be expected to have different chemical signatures. The complex processes that have created the inner and outer Banda arc have led to patterns of geochemical variation which do support this assertion and with which we can compare the results of chemical analyses of archaeological materials.

Geological history of islands also has biogeographic implications in that it constrains the range of resources available on these islands. As will be shown below, the Banda Islands do not represent a resource rich environment in most respects and I argue that because of these limitations, people in these islands would have been dependent on exchange with islands outside the group in order to provision themselves. Even during periods of relative climate stability, the Banda Islands could probably only have produced enough to meet the caloric needs of a small population. Even a slight decline of productivity due to hydrologic variation may have put inhabitants at risk of serious resource shortfall. For this reason exchange contacts with other islands would always have been important and there should have been a large increase in utility for growing these networks at times of climatic instability, whether such changes were predictable or not.

GEOLOGY

The Banda islands are located in Eastern Indonesia approximately 100 km south of southeast Seram. Geologically they are part of the Banda arc system where the convergence of the Eurasian, Pacific, Philippines Sea and Indo-Australian Plates gives rise to a complex orogeny. Before collision with the Australian continental margin, subduction of oceanic crust in the vicinity of Timor created an island-arc (Von Der Borch 1979). The Australian continental crust then collided with this island-arc in the Pliocene (Carter, et al. 1976). Subsequent subduction of continental crust along the Timor-Tanimbar trench has created an outer arc including the islands of Timor, Leti, Sermata, Babar, Tanimbar, Kei, Tayandu, Kur, Watubela, Gorom, and Seram Laut and an inner volcanic arc including the island groups stretching from Alor and Wetar in the Southwest to Ambon in the Northeast as well as submarine volcanism (Figures 4 & 5). The southeastern most portion of the inner arc (Alor, Wetar, and Romang) is no longer volcanically active. Volcanism occurred in this segment from 12—3 mya (Abbot and Chamaulan 1981). Northeast of this segment four volcanic islands (Manuk, Serua, Nila, Teun) sit atop a ridge between the Weber Deep and the Banda Sea floor (Vroon 1992). The Banda Islands are usually considered to be the most northerly, actively volcanic part of this inner arc but Ŝpičák, et al. (2013), dividing the inner Banda arc into two distinct systems, consider them to be the southern terminus of the Ambon arc as distinct from the Banda arc (the component running

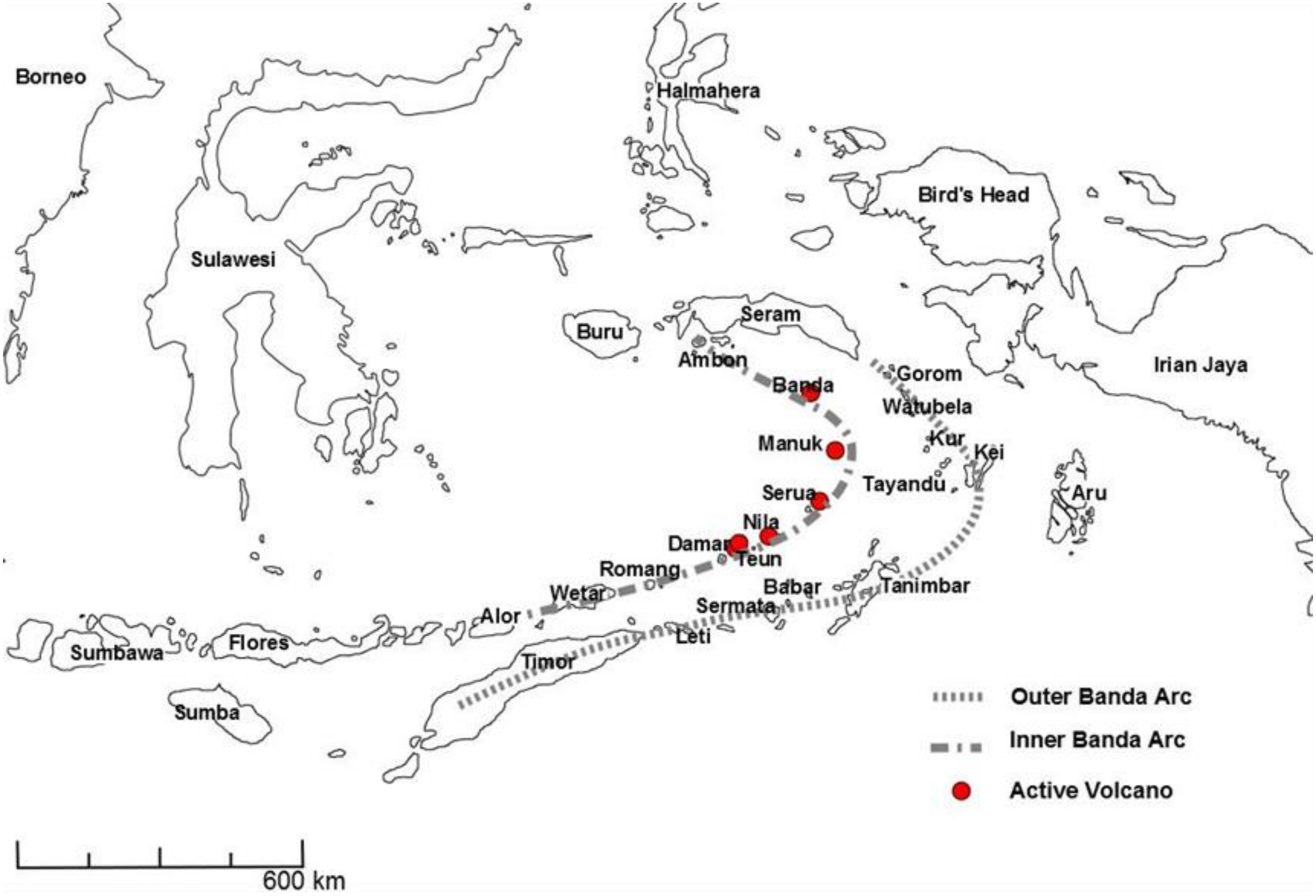

Figure 4. Map of Maluku showing inner and outer Banda Arc

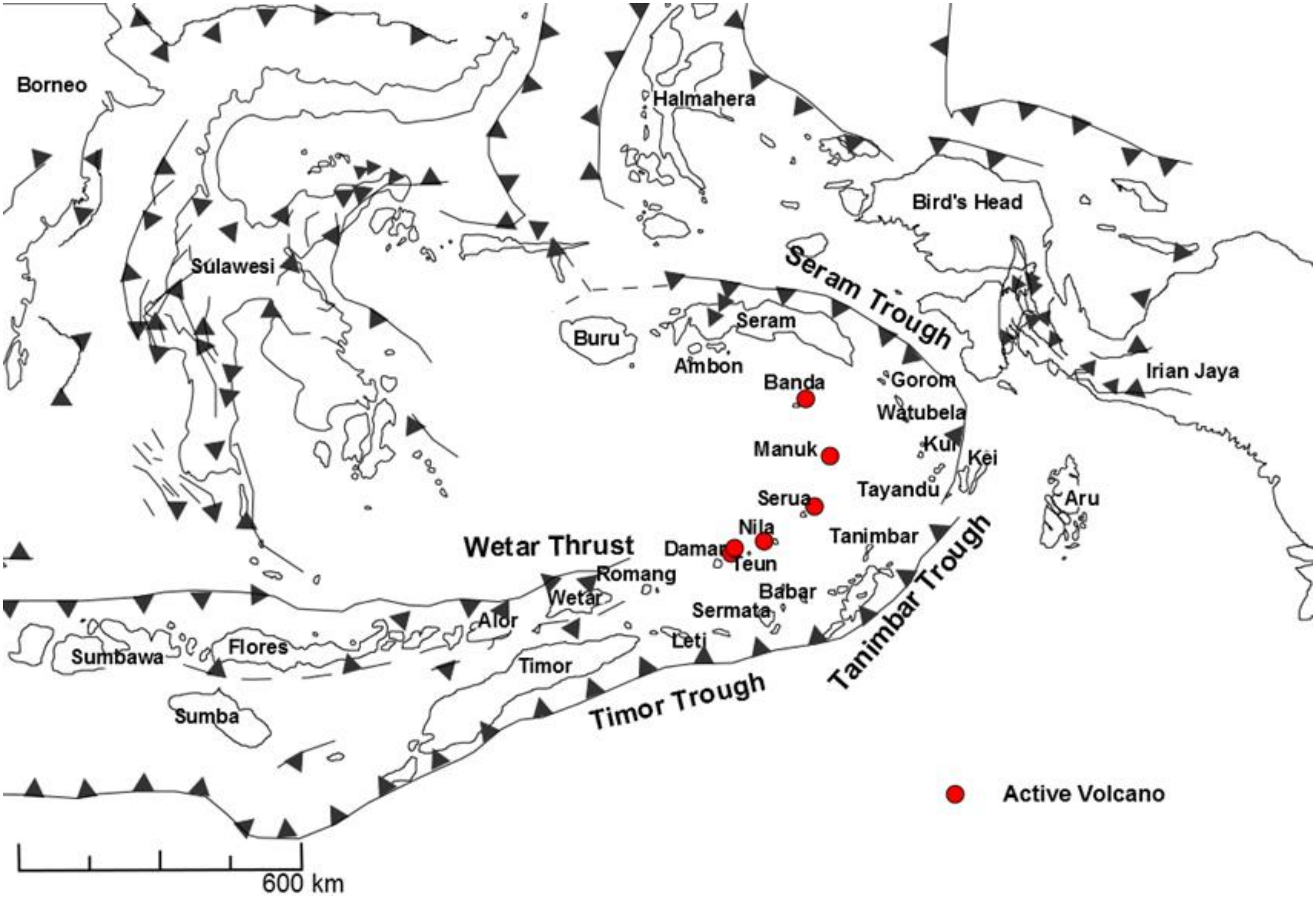

Figure 5. Map of Maluku showing plate movements in and around the Banda Arc

from Alor to Serua). North of Banda, Ambon also has volcanic origins but active volcanism of this island ceased around the same time as it did at the southeast terminus of the arc (circa 3 mya) (Abbot and Chamalaun 1981).

Unique features of the Banda Arc include the 180° curvature of the island arc, the deep subduction of continental lithosphere (Fichtner, et al. 2010), and the presence of a number of Australian crustal fragments throughout the region since prior to the collision of the island arc and continental margin (Hall and Sevastjanova 2012). Since the mid-seventies a number of different models to explain these and other characteristics of the system have been proposed and debated among geologists. In early plate tectonic models the Banda arc was seen as essentially contiguous with the Sunda-arc, originally trending east-west until the Plio-Pleistocene when westward thrust of the Sorong fault and Pacific Plate in combination with the northward movement of the Australian continent transformed the arc to its present loop-shape (Katili 1971, 1975). This model was challenged by Audley-Charles (1975), who argued that there was a major discontinuity between the Sumatra-Java and Timor-Tanimbar trenches in the vicinity of Sumba based on negative gravity anomalies, earthquake patterning, and submarine features. Bowin, et al. (1980) modified this model, recognizing that there were already continental crustal blocks in the Banda Arc when the arc-continent collision occurred 3-5 ma and that the continental margin was subducted beneath an accretionary wedge of the Banda arc. At present there is no consensus model to explain the unique features of the Banda arc and the field is still divided between those who argue for the subduction of a single, contorted plate and those who espouse Cardwell and Isacks' (1978) model of two subducting slabs. Recent breakthroughs in understanding the orogeny of the Banda arc have come with recognition for the role of subduction rollback in causing the extreme curvature of the Banda arc, an explanation argued to better account for x, y, z (Hall 2011; Hall, et al. 2011; Hall and Sevastjanova 2012).

The Banda group itself can be divided into geologically distinct inner and outer groups. The inner islands, Banda Neira, Banda Besar, Pulau Pisang, Pulau Karaka, and Batu Kapal, are what remains of an ancient volcano and encircle the currently active volcanic cone: Gunung Api. The outer islands, Pulau Ay, Pulau Rhun, Pulau Nailakka, Pulau Manukan and Pulau Hatta, are non-volcanic, formed through uplift of reef limestones. The inner islands have sources of fresh groundwater that are lacking on the outer islands (Lape 2000a). Even so groundwater here is primarily tapped through deep wells except for a few natural springs on Banda Besar.

PATTERNS OF GEOCHEMICAL VARIATION

A variety of geochemical analyses of the ridges of the Banda Sea and both inactive and active volcanic islands have revealed evidence for systematic patterning in element and isotope concentrations across the arc. Whitford and Jezek (1979) attributed these variations to three factors: the involvement of two subducting slabs intersecting in the vicinity of Serua as proposed by Cardwell and Isacks (1978); the continental origins of the Ambon crustal fragment; and magma genesis involving both melting of sialic material and a mantle-derived component. The role of subducted continental material in magma genesis was later modeled by Vroon (1992).

The diagram in (Figure 6) shows the major element systematics for the Banda Arc. Based on these systematics, Whitford and Jezek (1979a) and Vroon (1992) have demonstrated that the active Banda arc from the Banda group to Damar can be divided into three segments. In the northern part of the arc, lavas are predominantly tholeiitic but calc-alkaline to high-K calc-alkaline suites predominate south of the Banda group (Whitford and Jezek 1979). The Banda

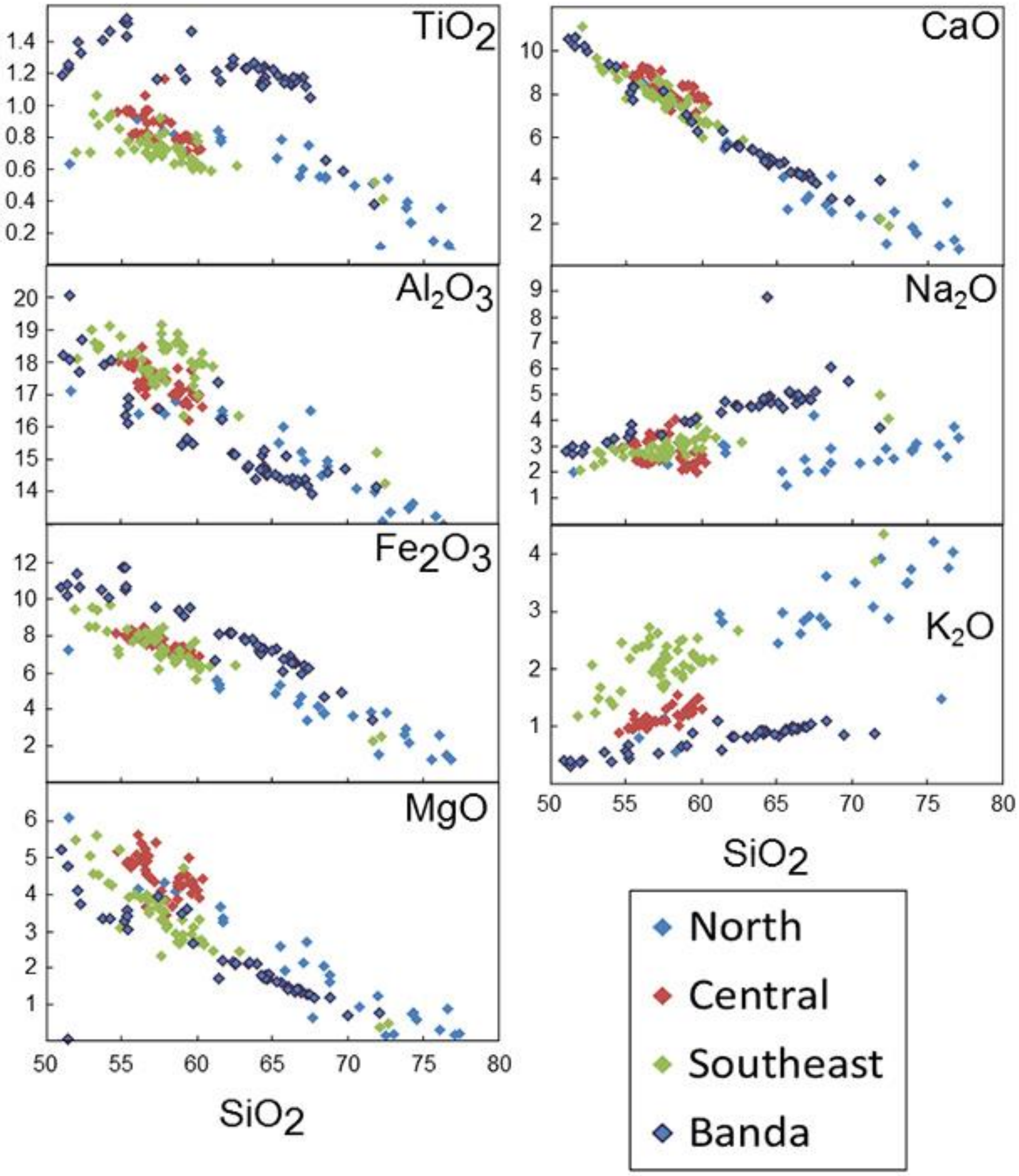

Figure 6. Harker diagram showing major oxide systematics for segments of the Banda arc. North: Ambon, Haruku, Saparua, Seram, Kelang, and Ambelau; Central : Manuk and Serua; South: Nila, Teun, Damar, and Romang. Data from Vroon (1992) and Honthaas (1999).

archipelago itself has a MORB-like profile with low K (K57.5=.60), variable SiO2, the highest Fe2O3 and the lowest Al2O3 concentrations across the arc. Manuk and Serua, in the central arc comprise a group with mid-range K concentrations (K57.5=1.14-1.15) and less variable SiO2.

The Southwestern islands of Nila, Teun, and Damar are more potassic (K57.5=1.89-2.43) with higher Al2O3 concentrations and lower TiO2 than the other groups (Vroon 1992).

Honthaas, et al. (1998) measured major and trace element concentrations in samples from the summit of Banda Api as well as various volcanic suites from Ambon, Saparua, Haruku, Seram, and Ambelau islands in the northeast, extinct segment of the arc. Their Banda samples are described as low-K dacites and rhyolites with slight enrichment of the large ion lithophile elements (LILE) relative to high field strength elements (HFSE) and negative Ti and Nb anomalies. Similar low-K volcanics are also found in Ambon and Seram but a high-K calc-alkaline suite is more prevalent and can be attributed to the presence of continental crust fragments in this area (Honthaas, et al. 1998). The LILEs increase from NE to SW along the arc (Vroon 1992; Whitford and Jezek 1979). The heavy rare earth elements (HREE) display a relatively flat profile along the arc but light rare earth elements (LREE) are progressively enriched relative to HREEs from NE to SW. This systematic geochemical variation across the Banda arc enables us to make a few predictions for how clay raw materials from different portions of the arc may differ. Predictions are summarized in Table 1.

Along with these major and trace element trends, various isotopic ratios have been shown to display along-arc patterning. Isotopic patterning is thought to arise primarily from subduction of continental derived sediments with strongly radiogenic “continental” signatures. This is primarily apparent in the comparison of Pb ratios and the negative correlation of Pb ratios and Sr ratios. As with the trace element variation, this patterning is thought to result from variation in the contributions of subducted continental material along the arc. Since continental sediments are older, and thus more radiogenic, more radiogenic isotope signatures are thought to derive from relatively greater amounts of SRM mixing (Vroon 1992). Measured Pb and Sr ratio ranges from

		Northeast arc		Central arc		Southern arc
		Ambon	Banda Islands	Manuk	Serua	(Nila, Teon, Damar)
Major elements	K_2O	-	Low	Medium	Medium	High
	Fe_2O_3	-	High	-	-	-
	TiO_2	Low	Low	Low	-	Low
	Al_2O_3	-	Low	-	-	High
LILE	Rb	High	Lower	Med	Med	High
	Sr	Low	Lower	Med	Med	High
	Ba	High	Low	Med	Med	High
HFSE	Nb	Low	Low	Med	Med	High
	Th	High	Low	Med	Med	High
REE	Ce (LREE)	High	Low	Medium	Medium	High
	Yb (HREE)		High	High	High	High
	Eu		Moderate anomalies	Small anomalies	Small anomalies	Deep anomalies
	REE conc.		Low	Med	Med	High
	LREE:HREE ([La/Yb]n)		No enrichment	Slight enrichment	Slight enrichment	Strong enrichment

Table 1. Geochemical patterning across the Banda Arc.

Vroon are presented in Table 2 and Figures 7-8 show linear relationships among ^{87}Sr/^{86}Sr, ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, ^{208}Pb/^{204}Pb. The only available baseline data for isotopes come from whole rock volcanic samples. Limestone islands in the Bandas and elsewhere will likely have very different signatures, particularly for Sr isotopes since Sr in seawater is relatively stable at a global scale. Marine carbonates should have a signature similar to this value (0.70916). This

	$^{87}Sr/^{86}Sr$		$^{206}Pb/^{204}Pb$	
Island	Range	Mean	Range	Mean
Ambon*	0.7042-0.7175	0.7093	18.670-18.901	18.778
Banda	0.7045-0.7048	0.7047	18.650-18.798	18.690
Manuk	0.7051-0.7055	0.7052	18.744-18.764	18.753
Serua	0.7075-0.7095	0.7084	19.018-19.092	19.042
Nila	0.7071-0.7078	0.7076	19.313-19.418	19.360
Teun	0.7073-0.7094	0.7080	19.399-19.434	19.421
Damar	0.7065-0.7070	0.7066	19.28-19.369	19.344
Romang	0.7085-0.7093	0.7090	19.147-19.185	19.166

	$^{207}Pb/^{204}Pb$		$^{208}Pb/^{204}Pb$	
Island	Range	Mean	Range	Mean
Ambon*	15.637-15.716	15.672	38.862-39.279	38.860
Banda	15.618-15.697	15.638	38.182-38.991	38.896
Manuk	15.636-15.676	15.649	38.921-39.007	39.013
Serua	15.676-15.706	15.692	39.190-39.341	39.278
Nila	15.720-15.749	15.733	39.514-39.661	39.585
Teun	15.708-15.743	15.726	39.611-39.713	39.660
Damar	15.709-15.742	15.727	39.628-39.748	39.471
Romang	15.688-15.700	15.694	39.511-39.552	39.552

Table 2. Stable isotope ratios from Banda Arc volcanics.
Data from Vroon (1992), Morris (1984), and Whitford and Jezek (1979). *Ambon range includes both enriched cordierite-bearing lavas (Ambonites) and basalts.

would constitute a bedrock signature only. Soils and sediments will also contain a component of volcanic material, at least in Banda, where limestone islands are close enough to Banda Api for the deposition of volcanic ash and pumice during some eruptions in the past. Biologically available Sr then will derive from a combination of these two materials.

It is important to note that, for both clay and apatite, absolute correspondence between trace element and isotope measurements on whole rock and archaeological samples is unlikely. These data are presented here not to serve as specific predictions of absolute abundances and ratios that may be expected in the archaeological materials but to demonstrate that there is

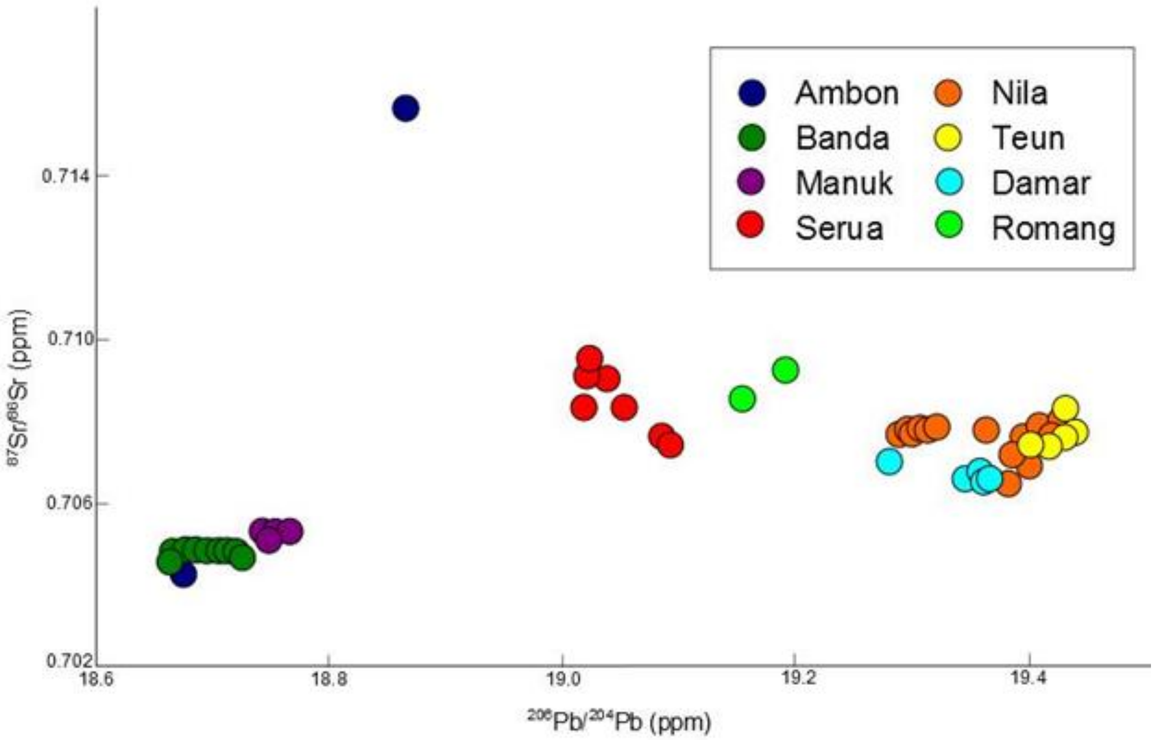

Figure 7. Biplot showing relationship between Sr and Pb isotope ratios across the Banda Arc. Data from Vroon (1992), Whitford and Jezek 1979, and Morris (1984).

significant variation in element concentrations and isotope ratios in the bedrock materials of islands across the arc that we can expect sources to be differentiable. In addition, since variation across the arc is strongly patterned from the NE to the SW, we may expect these gradients to appear in clays derived from these bedrocks and in apatite isotope ratios ultimately derived from bedrock sources. Specific provenance determinations are not the goal of the material analyses in this research but where several correspondences with known across-arc-patterning are apparent between different source grouping we will be able to tentatively suggest a possible area of origin for future testing. Additionally, since it would be likely that most clay and pig sources would come from the Banda arc, identification of similar patterns of variation between source groups can serve as an empirical check on the groupings obtained. If source-groups identified solely

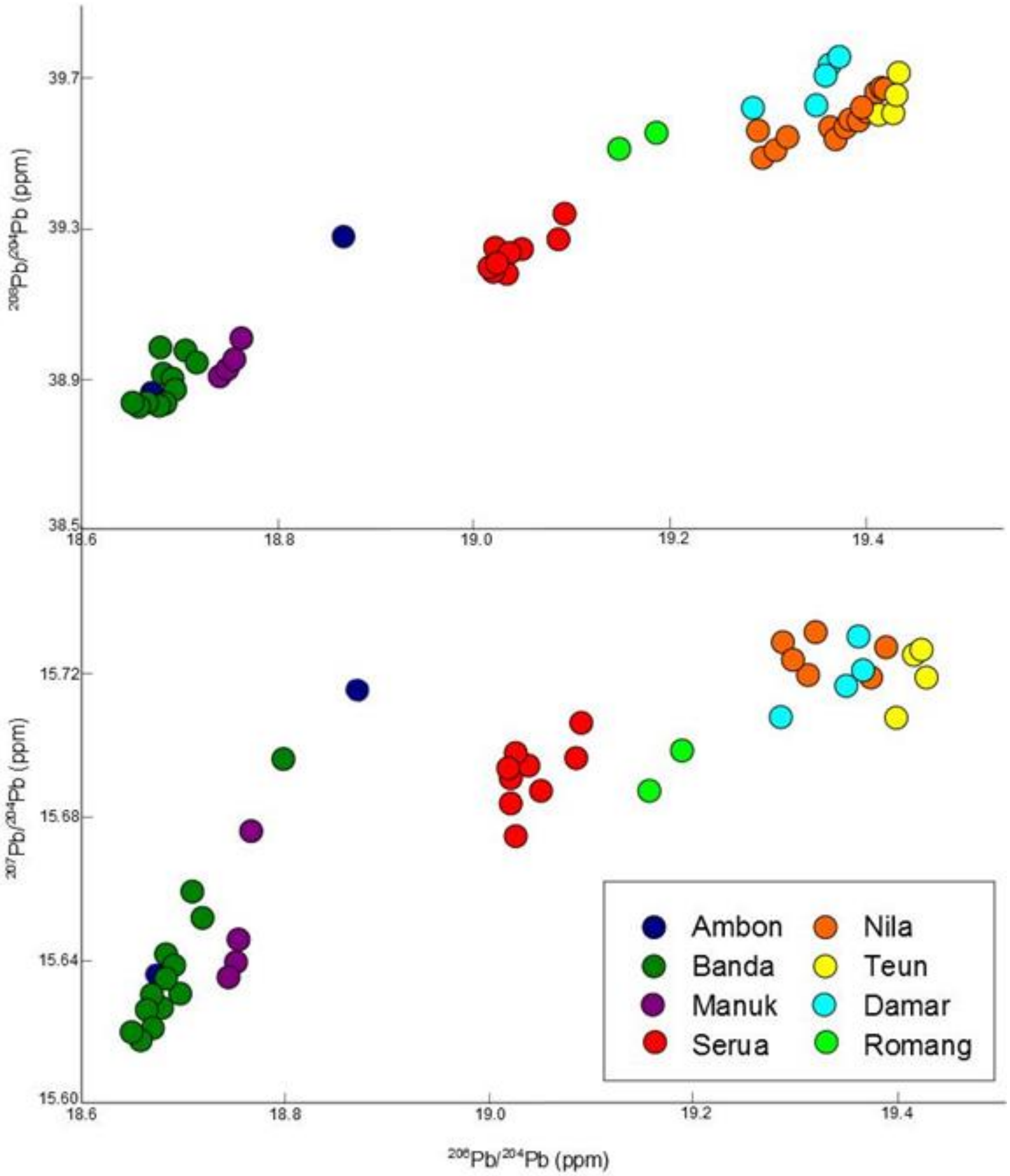

Figure 8. Biplot showing relationship among Pb isotope ratios across the Banda Arc. Data from Vroon (1992), Whitford and Jezek 1979, and Morris (1984).

based on their element constituents happen to display patterns with real-world geological significance, we can be more confident that the source groups identified represent real groupings.

ENVIRONMENT

The geological history discussed in the preceding has implications for the environment of the Banda Islands and the distribution of resources that would have been important for early human populations. The Bandas display depauperate terrestrial fauna and flora typical of Wallacean islands, which have never been connected either to Mainland Southeast Asia or to Australia. This general biogeographic trend may be further amplified in the case of Banda since they are among both the youngest and smallest islands in the Banda arc and eastern Indonesia in general. The nearest large islands that could serve as sources for colonizing biota are Southeast Seram, 110 km to the northeast and Ambon 150 km to the north. The Birds Head area of New Guinea is the closest landmass on the Sahul continental shelf and is 300 km to the east.

The fauna and flora of Banda are not well studied but are clearly not very diverse. Today terrestrial fauna are limited to a cuscus (Phalanger sp.), a small monitor lizard (Varanus sp.), and small rodents, plus a suite of domesticates brought to the islands by humans since 3500 BP. Pigs (*Sus scrofa*) were probably the first species introduced as they were present by at least 3000 BP (Lape et al. In Prep). It is unclear, however, how long the cuscus has been in Banda. In some parts of ISEA and Melanesia, *Phalanger orientalis* was introduced from a New Guinea source during the Pleistocene or early Holocene. In Island Southeast Asia the earliest conclusive evidence for translocation of *P. orientalis* is from the island of Timor where the cuscus was translocated from Sahul by the early Holocene (O'Connor 2006). In New Ireland *P. orientalis* was a much earlier transplant, brought to the island by 20,000 BP (Allen and Gosden 1989;

Leavesley 2005). It is possible that this species was brought to Banda quite early but on current evidence this seems unlikely. Cuscus bones have not been identified in the best studied archaeological faunas despite their presence on Pulau Ay and the inner islands today. According to Pulau Rhun locals, efforts to translocate the cuscus to that island from the inner Bandas have failed repeatedly and they have never managed to establish a breeding population there. Domesticated dogs (*Canis familiaris*) were also brought to Banda by people, probably around the same time as *Sus scrofa*. Later introductions include goat, deer and cow.

Paleontological studies have not been undertaken on Banda itself so it is possible that some terrestrial fauna disappeared with the arrival of humans on these islands. The example of the cuscus illustrates just how difficult it is to make a living on the landscapes of the Bandas and it would be expected that the additional stress on a population from human predation would easily and rapidly lead to the extinction of endemic taxa following initial human colonization.

This phenomenon has been documented for other much larger Wallacean islands, including Timor, where giant Murids quickly went extinct after humans first arrived (Glover 1986). However, it has also been argued that the levels of human-induced extinction and extirpation were much lower in Island Southeast Asia than in the eastern Pacific (O'Connor and Aplin 2007). I will return to this point below. The modern distribution of pigs provides an example of the tenuousness of survival for terrestrial fauna on the islands of the Banda group. People may have brought *Sus Scrofa* to the Bandas as early as 3500 BP but at first their bones are very scarce in archaeological assemblages. Around 3000 years ago they become significantly more abundant in archaeological assemblages and remain the most abundant mammalian taxon in all archaeological assemblages from Pulau Ay, Banda Besar, and Banda Neira until around 500 BP when Islam was introduced and pig-eating was abandoned by converted communities

(Lape 2005). On Banda Besar, the largest island in the Banda group a small feral pig population persists today but no they are absent from all other islands. Pigs have been extirpated from Pulau Ay and Banda Neira, where they probably could never have survived without human management due to water constraints. Giovas (2006) has demonstrated that a basic island biogeographic model predicts survival vs. extirpation in most cases for Remote Oceania, where pigs were extirpated after initially successful introduction. She found that there were statistically significant relationships between island size and elevation and pig survivorship. The Banda case, where pigs have only endured on the largest and highest of the islands in the group accords well with her model.

In the Remote Pacific initial colonization by humans is generally accompanied by extinction of endemic faunas due to a combination of predation by humans and their commensals and environmental disturbances attributed to human behavior (Anderson 1997, 2002; Burney 1997; Martin and Steadman 1999; Steadman 1997, 2006; Weisler 2001; Weisler and Gargett 1993). However, this pattern is much less pronounced in Island Southeast Asia (O'Connor and Aplin 2007). This may be because human populations were small and relied more on marine shellfish and fish than on terrestrial resources. While terrestrial island faunas in Wallacea have low biodiversity and high rates of endemism, coral reefs in the region are among the most diverse ecological communities in the world and would have been more resilient, particularly if human populations were small and dispersed.

As with fauna, the pre-human flora of the Banda islands has not been extensively studied. The modern landscape has been transformed through the establishment of large nutmeg plantations by the Dutch during the colonial period and the introduction of many non-native cultivars. Cassava and corn are the most important staples grown on the islands today but these have only been in Banda since the colonial period along with important fruits like papaya. Other non-native plants were probably introduced much earlier including domesticated banana, ultimately of New Guinea origin, and mango, which could have been brought by Indian traders. Economically important native plants include nutmeg, kenari (Canarium), taro, and, pandanus. Several attempts have been made to better describe the pre-human flora of the Bandas but with little success. Lape (2000a) tested soil samples from sites on Pulau Ay and Banda Neira for macrobotanicals, pollen and phytoliths. However, the humid and microbial conditions of Banda soils make a poor environment for plant preservation and there are no wetlands for pollen coring. None of Lape's samples had preserved macrobotanicals or pollen. Phytoliths were recovered but, since comparative specimens were not available for many species, few could be identified to family or better. During fieldwork in 2007 and 2009 we sampled each level for botanical remains through flotation. Although charcoal was recovered it was too small or too poorly preserved for identification (Lape et al. in prep).

In contrast to the depauperate terrestrial flora and fauna, the marine fauna of the Bandas is extremely diverse and abundant. In fact, this part of Indonesia falls within the Coral Triangle with over 1600 reef species (G. R. Allen 2008). During the Pleistocene, eustatic sea-level change led to a restricted range for various coral and coral-reef dwelling species in the Indo-Pacific as continental shelves emerged, straits narrowed, and some areas experienced increased upwelling of colder water. These changes may have created barriers to dispersal of marine organisms and led to increased speciation as populations were isolated from each other (Hoeksma 2007). Following the stabilization of sea-levels around 6000 years ago corals and coral-reef dwelling species recolonized vast areas of the Indo-Pacific. Banda Islands coral reefs are both extremely diverse and highly resilient to localized disturbances. The last eruption of the active central volcano, Gunung Api in 1988, provided scientists the opportunity to study colonization by corals and successional dynamics. During the eruption, lavas covered about 70,000 m^2 of the fringing reef (Casadevall, et al. 1989). Within 5 years the andesitic lavas had been re-colonized by 124 species (Tomascik, et al. 1996).

In addition to near shore marine resources concentrated on the reef, the Banda Islands are a productive area for pelagic fisheries and today most people in the Banda islands rely heavily on locally caught tuna for subsistence. Species diversity for such large pelagic species has been shown to peak at slightly higher latitudes (20-30° N and S) but diversity hotspots are also linked to proximity to productive reefs. All Banda Islands sites for which fauna have been studied show heavy reliance on marine fishes in the past. While species and family level identifications of marine faunal assemblages have yet not been undertaken, there does appear to some variability between sites in the types of species represented. For example at PA1, fish bone is more abundant than mammal bone in all layers and the taxa represented are predominantly smaller sized. These may include both reef-dwelling and pelagic species to some extent. At BN1 both small and large sized fishbone is present and abundant and there is reason to believe a greater proportion of the large fish bone is from pelagic species than at PA1. Specifically, the presence of Dolphin vertebra, sea turtle shell, and shark teeth in common with very large fish bones suggests that people here were spending considerable time foraging beyond the reefs.

CHAPTER 4. CLIMATE

INTRODUCTION

A primary goal of this research is to investigate temporal correlations between shifting levels of environmental variability and changing levels of connectedness in order to contextualize these changes in terms of human-environment interaction. Located as they are in the tropical Western Pacific, rainfall (rather than temperature) is the primary driver of environmental variability in the Banda Islands. In eastern Indonesia, temperatures are relatively constant through the year but the region does experience moderate seasonal variability in precipitation with wet and dry seasons driven by Australian and Asian summer monsoons. Various climate researchers have divided the Maritime Continent of Indonesia into three (Aldrian and Dwi Susanto 2003) or four (Hamada, et al. 2002) climate regions that vary in terms of the degree of seasonal variation and the timing of peak monsoonal precipitation. In eastern Indonesia, the wet monsoon generally occurs during Boreal winter with increased rainfall Dec-Feb. During the dry monsoon (Jun-Aug), precipitation is decreased and strong southeasterly winds lead to higher surf and difficult sailing conditions. Rainfall data from Ambon indicate a reversal of this pattern, probably due to orographic effects with peak rainfall during Boreal summer (Figure 9). Rainfall data have only been collected from the airport at Banda Neira since 1986 but these also show an Ambon-like departure from the prevailing pattern for eastern Indonesia.

The intensity of the monsoons and seasonal rainfall is influenced by several different larger ocean and atmosphere systems including the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), the Indonesian Throughflow (IT), and shifts in the locations of the

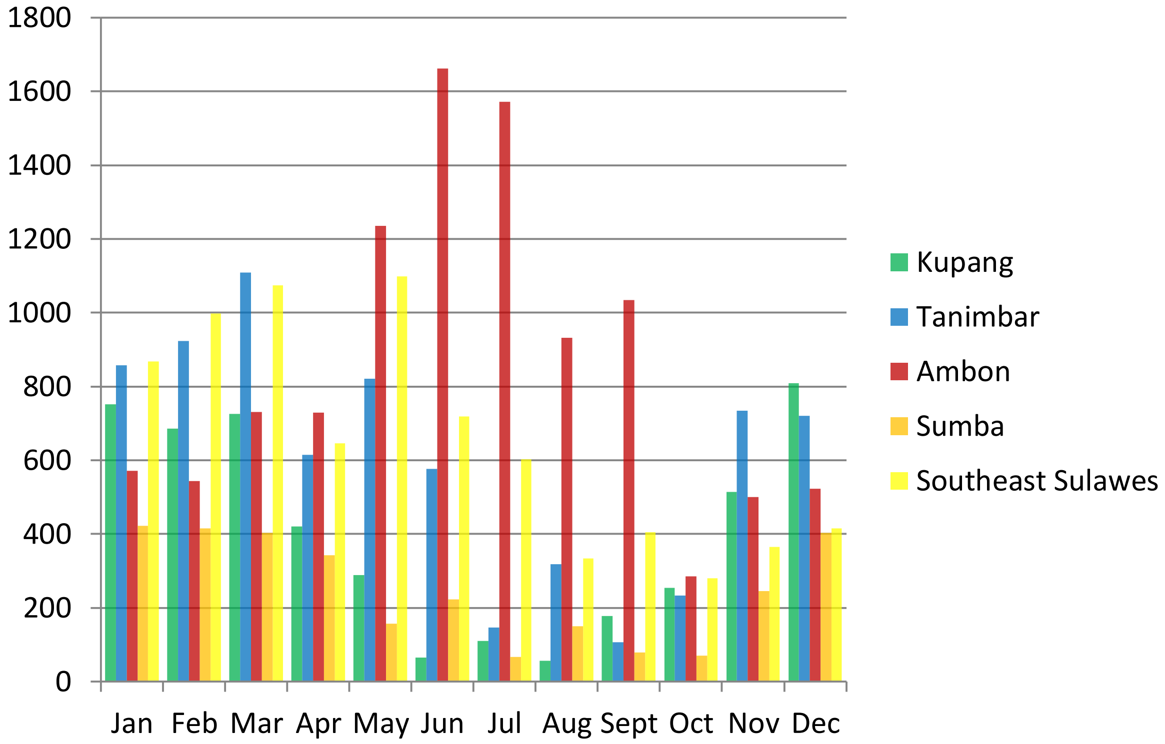

Figure 9. Average total monthly precipitation for locations in eastern Indonesia. Data from Menne et al., (2012) Global Historical Climatology Network Daily (GHCN-Daily), Version 3, NOAA National Climatic Data Center. http://doi.org/10.7289/V5D21VHZ

Inter Tropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ). Of these, ENSO is currently the best understood. Although there remains much debate over the long-term forcing mechanisms, the effects across the Pacific basin, especially in the warm phase, are well established. During El Niño years, the warm, low-density waters of the Indo Pacific Warm Pool (IPWP) are displaced eastward into the central Pacific, relocating this important locus of atmospheric convection (McPhaden and Picaut 1990). Sea surface temperature and rainfall increase over the eastern equatorial Pacific and decrease over the western tropical Pacific. The El Niño phase of the ENSO cycle lasts 9-12 months but the strongest effects occur during the normal wet monsoon season in eastern Indonesia so that the arrival of seasonal rains is

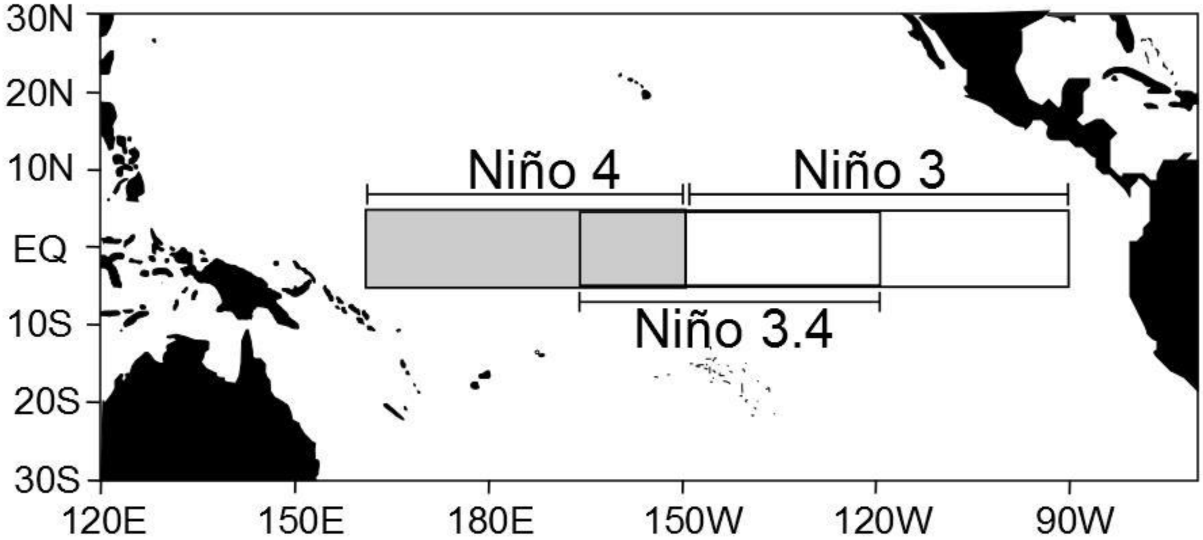

Figure 10. Niño index zones

delayed. In extreme cases, these islands receive no rainfall at all during what are normally the wettest months. Although the wettest months are later in the year in the Banda Islands than elsewhere in eastern Indonesia, El Niño induced drought can be severe. During the strong El Niño event of 1997-98 no rainfall was recorded from August-September and the total annual rainfall, which had averaged 2361 mm over the three preceding years, was <1000 mm.

The frequency and magnitude of El Niño events and their impacts can be highly variable. At present, El Niño occurs with a 2-7 year periodicity but the frequency of warm events has varied through the Holocene. Proxy records from Lake Pallcacocha, Ecuador (Moy, et al. 2002; Rodbell, et al. 1999) and El Junco, Galapagos (Conroy, et al. 2008) show that these events were rare in the early Holocene with increases in the frequency and intensity of El Niño events in the mid-to-late Holocene.

Recent research has shown that the magnitude of El Niño associated rainfall anomalies is strongly influenced by the location of maximum positive SST anomalies. El Niño events can be classified as Eastern Pacific El Niños (EPEs), with the greatest SST variation in the NINO 4 region or Central Pacific El Niños (CPEs), which have the greatest SST variations in the NINO 3 region (Figure 10). An intermediate form also exists with the greatest SST variations in the NINO 3.4 region. Instrumental data suggest that EPEs occur less often but have the strongest impacts on rainfall and wind patterns both in terms of the scale of its influence and the intensity of effects (Murphy, et al. 2014). El Niño frequency/intensity is an important dimension of environmental variability because of its tendency to disrupt normally predictable seasonal rainfall patterns. This would wreak havoc with planting cycles and if sufficiently prolonged could render the outlying limestone islands of Ay, Rhun, and Hatta uninhabitable. Because ENSO events involve sea surface temperature (SST) anomalies in both the eastern (positive anomalies) and western (negative anomalies) Pacific, long-term ENSO histories can be reconstructed through paleoclimate proxies from both regions.

PALEOCLIMATE PROXIES

Concern over global warming and modern climate change in recent years has led to a surge in research into long-term patterns of climate change. With the goal of building better climate models that can predict future climate change and its impacts, climate researchers engaged in paleoclimate research, focusing on patterns of past climate variability at a different scales. In order to look at climate variability on timescales longer than the instrumental record, researchers have turned to paleoclimate proxies. Different types of proxies exist, each with advantages and disadvantages for paleoclimate research. For understanding rainfall variability in the tropical Pacific, the relevant proxies include sea surface temperature (SST) and salinity (SSS) archives from corals, marine foraminifera, speleothems, lake sediments, and tree rings and paleohyrology records from marine and lake cores. These proxies are reviewed briefly below and currently available records for the Indo-Pacific Warm Pool are described.

CORAL

Corals are marine organisms that build skeletons of aragonite ($CaCO_3$). These aragonite skeletons have annual banding with more and less dense layers. Like tree rings, the annual banding allows for good chronological control and high resolution paleoclimate records. For recent corals this can often be tied to the instrumental record, providing calendar ages for the rings. In fossil corals, individual rings can be dated using ^{14}C or $^{230}Th/^{234}U$. Individual Porites corals (the most commonly used taxon) can live for up to 1000 years (Correge 2006). Corals are one of the only proxy records with annual resolution, enabling examination of climate variability from interannual to centennial scales.

Since corals incorporate oxygen from their shallow marine environment, and since stable oxygen isotope ratios are temperature sensitive, $\delta^{18}O$ in the coral skeleton represents an archive of local SST at the time when it was formed. The $\delta^{18}O$ of sea water also influences $\delta^{18}O$ of coral aragonite, reflecting variation in evaporation, precipitation, and runoff (Felis and Pätzold 2004). Since oxygen isotope ratios record both changes in SST and salinity, it can be difficult to disentangle these two effects in order to reconstruct past climate from corals. Other proxy biochemical measurements like Sr/Ca and Mg/Ca are increasingly being used in combination with oxygen isotopes to separate the SST and SSS signals.

Sr/Ca in corals (and other biogenic carbonates) is dependent on the seawater temperature at the time of skeletal formation. Strontium and calcium are both incorporated in the aragonitic coral skeleton in ratios moderated by seawater temperature (Beck, et al. 1992). Unlike stable oxygen isotope ratios, Sr/Ca is not sensitive to variations in SSS. This is also the case for Mg/Ca, a more recent method of thermometry based on similar principles (Mitsuguchi, et al. 1996). When used effectively in combination, δ^{18}O and Sr/Ca or Mg/Ca can provide reliable SST reconstructions based on the thermometry and a record of salinity changes based on δ^{18}O with the SST signal removed (Correge 2006). Salinity records of this sort in the tropics are directly related to the hydrologic balance between rainfall and evaporation and thus provide valuable information on the kinds of environmental variability that would most impact the human occupants of the region.

When available, corals provide high-quality paleoclimate proxy data with high resolution and good chronological control. Unfortunately, these records are rare even for the recent past because of the expense of coring and analysis and the relative rarity of the corals themselves. Fossil corals are even rarer and most sequences are <200 years long. In some cases long-term records of past climate have been derived by coring multiple fossil corals of different age in the same colony, but the existence of appropriate corals is fortuitous and these longer-term records generally have significant data gaps.

SEDIMENT CORES

Marine sediment cores have provided similar types of proxy data based on oxygen and hydrogen isotope ratios on planktonic foraminifera and various specific compounds from plant material. Many paleoclimate reconstructions have been based on marine cores. Unlike corals, these often cover long-periods of time but they lack the resolution of annually banded corals. Occasionally, higher resolution proxy records have been obtained from lakes with laminated sediments. Another problem with sediment cores is that they lack data for the recent past because gravity corers, a common recovery method, disturb the uppermost sediments in the column.

Multi-corers are increasingly being used to remedy this problem and allow tie-ins to the instrumental record, an important step in verifying the interpretation of results from biochemical analyses.

The majority of marine sediment core proxies reconstruct SST/SSS from $\delta^{18}O$, often in combination with Sr/Ca and Mg/Ca as discussed above. Compared to corals, however, interpretation of $\delta^{18}O$ in foraminifera is further complicated by temporal and spatial variation in the seasonal behavior of the organisms involved (Oppo, et al. 2009).

The deuterium/hydrogen ratio (expressed as δD in relation to a mean ocean water standard) in plant material has been shown to be a sensitive indicator of past regional hydrology (Craig 1961; Gat 1996; Sachse, et al. 2012). Like stable oxygen isotopes, the hydrogen in water undergoes fractionation during phase changes (e.g. vapor to liquid), with the lighter isotope preferentially evaporating. While many factors influence the fractionation of hydrogen isotopes the general pattern is for freshwater to be depleted in deuterium while surface waters subjected to evaporation are enriched in this isotope (Gat 1996). Hydrologic shifts, often corresponding with increased or decreased precipitation, lead to changes in the hydrogen isotope ratios of both seawater and groundwater (Tierney, et al. 2010). In plant materials, lipid δD is highly correlated with the organism's water source, whether aquatic or terrestrial (Sachse, et al. 2012; Schwab and Sachs 2009).

Hydrogen isotope studies of lipids from cores across the Pacific are providing important information about hydrologic variability in the past. Tierney, et al. (2010) measured δD of terrestrial plant waxes in marine sediment cores from southwest Sulawesi. Comparison with instrumental records back to 1960 showed good correspondence indicating that δD_{wax} from these cores accurately tracks local hydrologic variability. This study showed that the Indonesian

Monsoon was typically strong over the last 2000 years but with enriched δD during two periods: 1000-1300 AD and 0-400 AD (Tierney, et al. 2010). Comparison with other proxy records from the Eastern Pacific suggests that El Niño frequency may have been higher during these periods (Tierney, et al. 2010).

WESTERN PACIFIC PALEOCLIMATE PROXIES

The ideal climate proxy with which to compare the archaeological record of exchange and interaction would be a high resolution, long-term, local record. Unfortunately, at present this record does not exist. Within the Western Pacific Warm Pool, the available proxies for the mid-to-late Holocene are mostly low-resolution marine cores with a few fragmentary coral records. The complex interaction of several ocean-atmosphere phenomena impacting local conditions in combination with the lack of long-term, high resolution proxy records present a major challenge for reconstructing environmental variability in the past. The approach taken here is to build a picture of mid-to-late Holocene variability by combining information from those proxies that are available within eastern Indonesia and comparing with higher-resolution long-term proxies available from the Eastern Equatorial Pacific. Since ENSO has the strongest influence on rainfall variability in the region (Dai and Wigley 2000) and since the El Nino events with the strongest impacts are marked by strong SST and rainfall anomalies in the NINO3 region, these records are, at present, the best indication of past environmental variability in the Bandas. Relevant paleoclimate proxy records from the WPWP (see Figure 5 for locations) are described below.

The only lake record at all comparable to those from the EEP is from Lake Logung, East Java. This core records several multidecadal to centennial scale El Nino linked droughts during the last 2000 years (Rodysill, et al. 2012). Calcite layers within the lake sediments are thought to

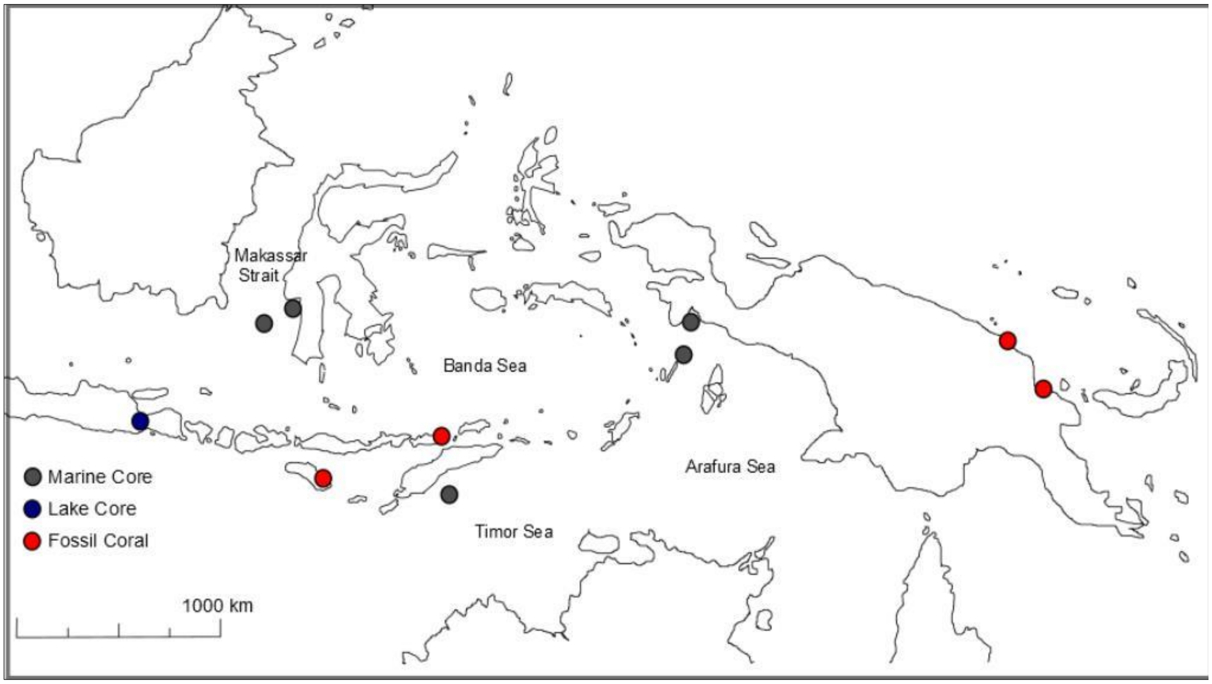

Figure 11. Locations of WPWP paleoclimate proxies

result from salinity increases due to shifts in the evaporation-precipitation balance during prolonged drought. Most of this record post-dates the periods represented at PA1 and BN1 but severe drought from 930-1130 indicates a weak Monsoon during this period. This finding is supported by results from marine core proxy records.

Tierney, et al. (2010) analyzed δD of terrestrial leaf wax in two sediment cores from the vicinity of southwest Sulawesi. The study included both a gravity core and a multi core, allowing hydrologic reconstruction from 2300- present. In this study low δD_{wax} during several periods in the last 2300 years indicates drier conditions resulting from a weakened monsoon. Two periods of reduced hydrologic intensity overlap with the archaeological records of PA1 and BN1. From 2000-1550 BP and 950-650 BP δD_{wax} was enriched in both cores (Tierney, et al. 2010). $\delta^{18}O_{sw}$

based on planktonic foraminifera from Makassar Strait marine cores is also enriched during these periods indicating increased salinity due to reduced precipitation (Oppo, et al. 2009).

Another set of marine cores from eastern Indonesia provides a record with more time depth. Stott, et al. (2004) analyzed Mg/Ca and δ^{18}O of surface dwelling foraminifera in cores MD-76, collected near the Bird's Head of New Guinea and MD-70, located near Timor. These two measurements were used to derive δ^{18}O of surface waters ($\delta^{18}O_{sw}$) as a proxy for salinity. While they were focused on very long term trends occurring over the last 10,000 years, close examination of their data for the last 4000 years shows elevated $\delta^{18}O_{sw}$, indicating more saline conditions from 3000-2750 BP and 1750-1250 BP (Stott, et al. 2004). Since salinity is primarily controlled by freshwater flux in the region, higher SSS was likely caused by reduced precipitation. Brijker, et al. (2007) measured δ^{18}O on another marine core from the Seram Trough very close to MD-76. They observed heavier δ^{18}O values at 1900 BP, 2100 BP, 2700BP, 3300BP, and 3700 BP which they interpret as periods of increased ENSO variability, particularly increased frequency and intensity of the El Niño phase (Brijker, et al. 2007).

Tudhope, et al. (2001) analyzed fossil Porites from uplifted terraces on the Huon Peninsula, Papua New Guinea. Each provides just a short window on past SST and rainfall variability in the past. Two samples from this study cover a period ~2,000-3,000 years ago. These show similar ENSO variance to modern records and a higher incidence of high amplitude events than the early Holocene coral record (~6,500 BP). The increase in El Niño activity through the Holocene and high amplitude events around 3000 years ago are both in evidence in other Holocene records from the western equatorial pacific.

Gagan, et al. (2004) studied the connections between ENSO and IPWP conditions throughout the Holocene based on multiple climate proxies including coral records from

Vanuatu, Papua New Guinea, the Great Barrier Reef, Alor, and Sumba. These along with proxy records from marine cores show that IPWP SSTs were cooler at the LGM but warmed rapidly and reached modern levels by the early Holocene. El Niño events occurred less frequently at that time but reached approximately modern periodicities by 5000 years ago (Gagan et al 2004). This finding is supported by the EEP proxy records discussed below. The magnitude of events was also lower in the past but increased about 3000 BP (Gagan et al., 2004). McGregor and Gagan (2004) identified higher incidence of El Niño events from 2500-1700 BP in corals from Muschu and Koil Islands, Papua New Guinea. These records included evidence for a prolonged, 7-year El Nino period around 2000 BP. If drought persisted for this entire period, an event of this magnitude would have been devastating for the inhabitants of the Banda Islands.

EASTERN PACIFIC EL NIÑO PROXY RECORDS

Several well-dated, high resolution proxy records exist for the Eastern Equatorial Pacific (EEP) including lake cores and coral-based records. Lower resolution marine core data are also available. Although these locations are distant from the Banda Islands they are a valuable source of information about ENSO related environmental variability there because of the teleconnections between the two areas. As noted above, those El Niño events which record the greatest SST anomalies in the NINO3 and NINO 3.4 regions have been shown to cause the most significant rainfall anomalies in the western Pacific. Therefore proxy records for El Niño frequency and intensity from this core ENSO region also inform the frequency and intensity of El Niño related drought in the WPWP.

Laguna Pallcacocha, Ecuador, has yielded two of the longest, high resolution, ENSO-related data sets available for the Pacific Basin. A 9 meter core contains laminated sediments

Figure 12. Locations of Eastern Equatorial Pacific ENSO proxies

spanning the last 15,000 years. The onset of El Niño along the coast of Ecuador is typified by abrupt rise in SST and deep convection leading to extreme rainfall and flooding even at significant distances from the coast. These periods of extreme rainfall and flooding are recorded in the Laguna Pallcacocha sediments as light-colored inorganic clastic sediment layers interbedded with organic-rich sediments. Comparison between this core and the historical record for El Niño from 1800-1976, showed precise correlation with strong El Niño events and strong correlation with moderate El Niños (Rodbell, et al. 1999). Grey-scale analysis of the Laguna Pallcacocha core revealed long-term trends in the periodicity of ENSO since 15,000BP, reaching modern periodicities by 5000 BP (Rodbell, et al. 1999). Red-color intensity was analyzed in a second study by Moy. et al. (2002). Like the earlier study, Moy, et al. found that strong El Niño events occurred less frequently during the early Holocone. Strong El Niño events occur more frequently after 2000 BP with a peak around 1200 BP.

Another lake-record from El Junco, Galapagos Islands at the eastern edge of the NINO-3 region, (Figure 12), also shows low ENSO variance from 4000 to 3200 BP followed by a two-step increase at 3200 BP and 2000 BP. Lake levels at El Junco respond strongly to ENSO. A 3.5 meter-long core provided a 9000 year record of fluctuating lake levels through grain size distribution and C/N ratios (Conroy, et al. 2008). Abundance of clay and silt size grains are inversely correlated and reflect overall precipitation with higher percentages of silt (lower %clay) indicating more precipitation. Abundance of sand size grains is not strongly correlated with silt and clay percentages showing differences in the intensity of rainfall rather than overall precipitation. The period from 2000-1500 has the highest percentage of sand in the El Junco sequence suggesting more frequent intense rainfall events during this period. It also has a high percentage of silt relative to the abundance of clay showing that this period was typified by higher lake levels due to greater overall precipitation.

The sedimentary record of another Galapagos has also been examined for evidence of past El Niño frequency and intensity. A 4.2 meter core from Bainbridge crater lake contained lamina whose formation is linked to El Niño related precipitation changes. Carbonate laminae are thought to result when increased rainfall from moderate El Niño events lowers salinity in the normally hypersaline crater lake, promoting carbonate precipitation. Siliciclastic lamina are also present and attributed to erosion of the crater walls during episodes of extreme rainfall during strong to very strong El Niño events (Riedinger, et al. 2002). Warm ENSO events occur throughout the 6100 year sequence but are infrequent before 4000 BP. At 3000 BP there is an increase in the frequency and intensity of El Niño events.

EXCHANGE AND INTERACTION IN ENVIRONMENTAL CONTEXT

Numerous proxies from the Eastern Equatorial Pacific and the Western Pacific Warm Pool record periods of increased El Niño frequency and intensity or decreases in precipitation in the WPWP during the Holocene. While no two proxies agree completely, careful comparison of multiple proxies indicate two periods when climatic conditions would have led to increased environmental variability in the Banda Islands. We can expect to see increases in source diversity for exchange materials during these times.

First data from both the EEP and the WPWP reveal that ENSO variance increased sometime around 3000 BP. The exact timing of this increase varies between proxies. Moy et al's (2002) Laguna Pallcacocha record shows a slight increase in the number of warm ENSO events per century 3400-2800 BP. Compared to later periods El Niño frequency was relatively low in this period, ranging from 5-10 events per century. However, in the preceding six centuries only 1-5 El Niño events per century were recorded. The increase would be noticeable over the course of an individual's lifetime. The El Junco record from the Galapagos (Conroy, et al. 2006), shows an abrupt change to higher lake levels in the same time period. The Bainbridge crater lake record also shows an increase in El Niño frequency and intensity around 3000 years ago (Riedinger et al. 2002). Around the same time a marine core from the Seram Trough in eastern Indonesia shows increased δ^{18}O centered on 3300 and 2700 BP indicating lower SST and higher salinity due to decreased rainfall (Brijker et al. 2007). Finally, a marine core from the Banda Sea, located approximately 400 km east of the Banda Islands also shows a decrease in SST and an increase in salinity based on Mg/Ca and δ^{18}O of planktonic foraminifera around this time (Stott, et al. 2004).

Another, more extreme increase in the frequency of El Niño events and drier conditions in the western Pacific is also recorded in proxy records from both the EEP and the WPWP. In the

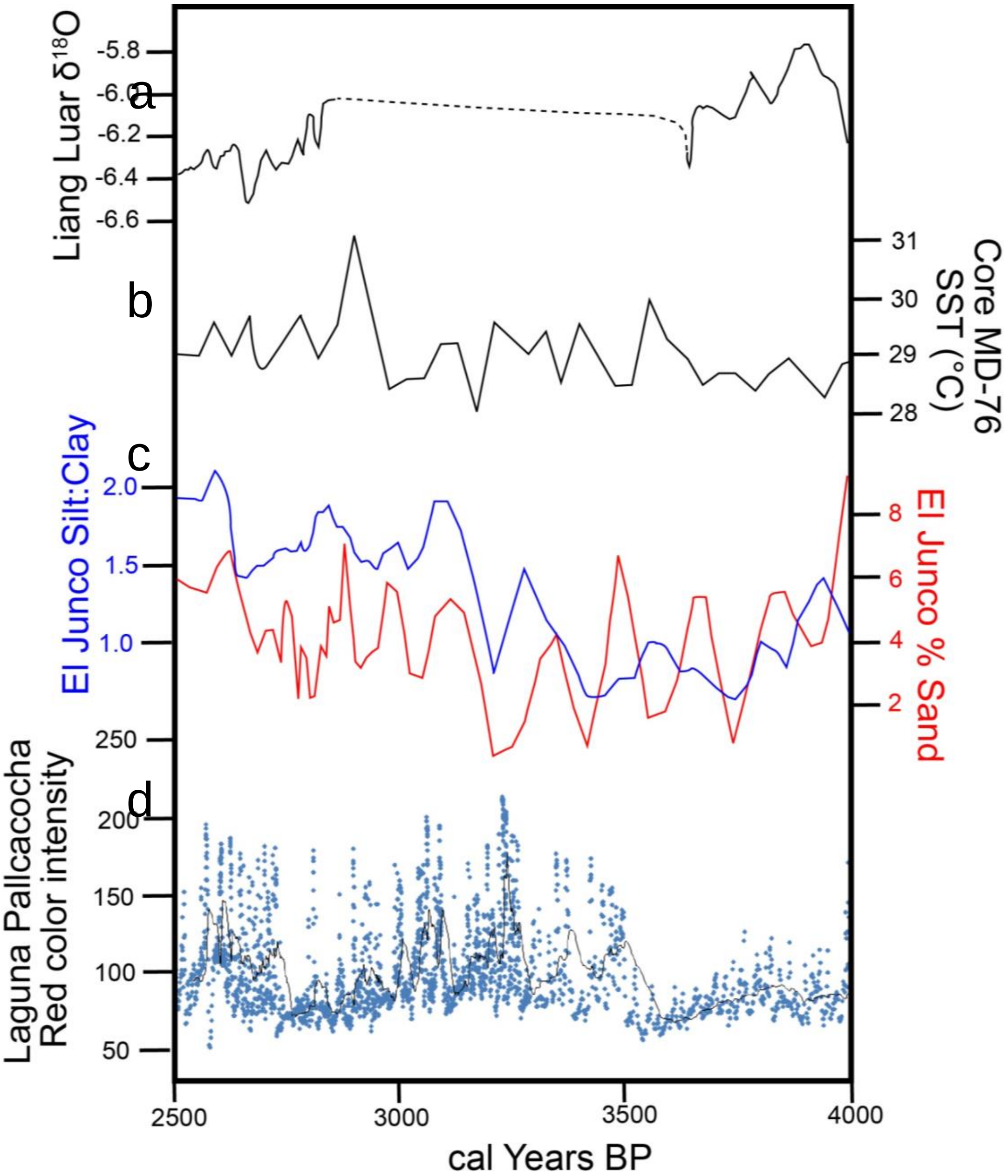

Figure 13. Comparison of paleoclimate proxy records from around the Pacific, 4000-2500 cal BP (a) δ18O (‰ VPDB) for Liang Luar , Flores stalagmites LR06-B1 and LR06-B3 (Griffiths et al., 2009); (b) Reconstructed SST from MG/Ca of planktonic foraminifera from marine core MD-76 (Stott, et al. 2004);(c) Silt:Clay and % sand from El Junco, Galapagos Island (Conroy, et al. 2008); (d) Red color intensity from Laguna Pallcacocha, Ecuador (Moy, et al. 2002).

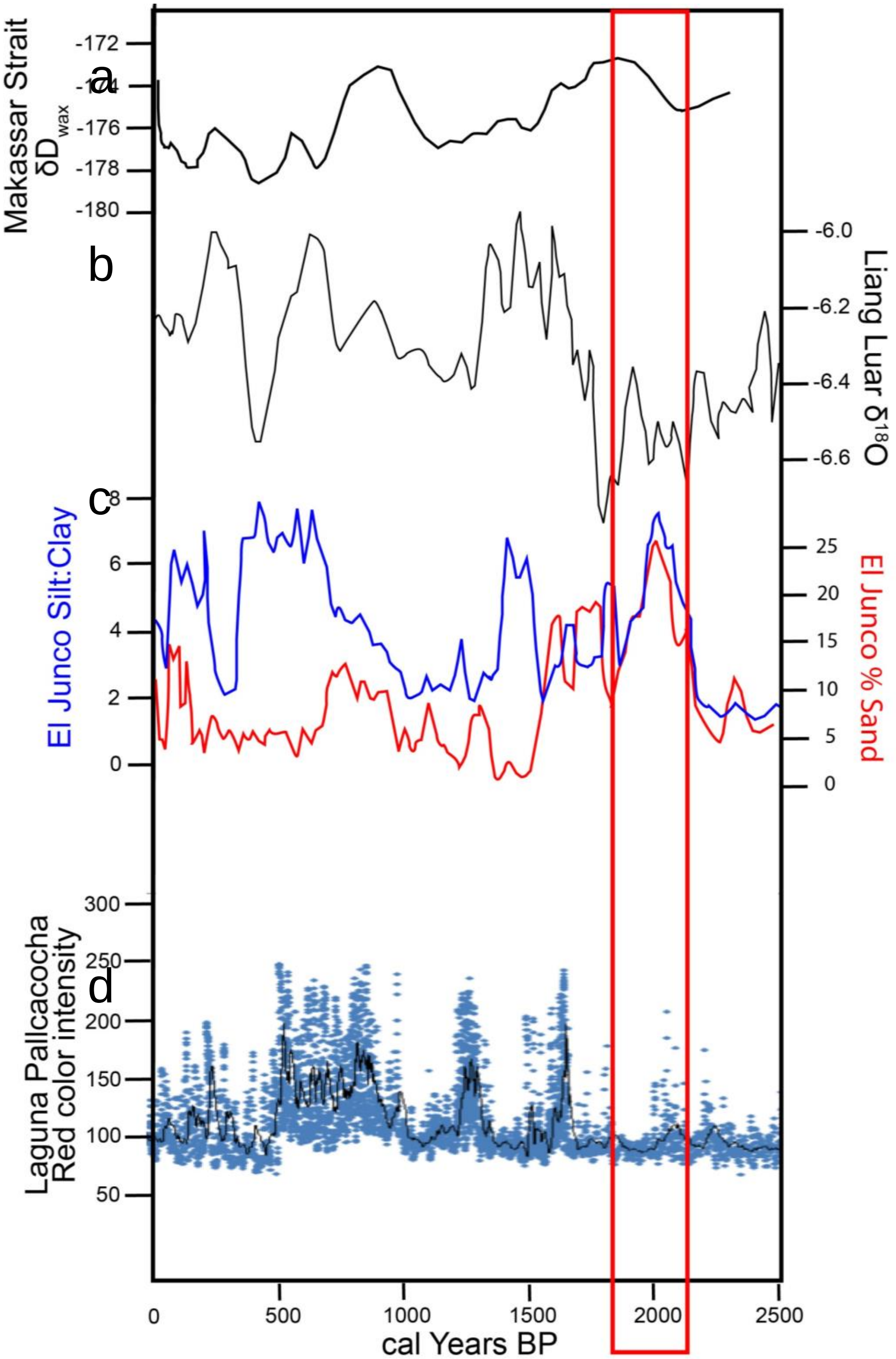

Figure 14. Comparison of paleoclimate proxy records from around the Pacific, 2500 cal BP-present

(a)δD$_{wax}$ of leaf wax from marine cores 31MC and 34GGC (Tierney et al., 2010); (b) δ^{18}O (‰ VPDB) for stalagmites LR06-B1 and LR06-B3 (Griffiths et al., 2009); (c) Silt:Clay and % sand from El Junco, Galapagos Island (Conroy, et al. 2008); (d) Red color intensity from Laguna Pallcacocha, Ecuador (Moy, et al. 2002).

Laguna Pallcacocha record the highest El Niño frequency of the entire sequence occurs from 1600-1200 BP with an average of over 15 events per century and a maximum of 31 (Moy et al 2002). This increase is also apparent at El Junco in the Galapagos where the highest percentage of sand, linked to very strong El Nino events, occurs from 2000-1500 BP. Several proxy records from the WPWP also reveal periods of decreased rainfall approximately 2000-1500 years ago. These include Tierney et al.'s hydrogen isotope record from the Makassar Strait and available oxygen isotope reconstructions of SSS in eastern Indonesia (Brijker et al. 2007; Stott et al. 2004). Corals from both the western and eastern Pacific offer a higher-resolution glimpse of part of this period. A record from Papua New Guinea shows a 7 year period of El Niño like conditions around 2000 BP and generally higher El Niño frequency 2500-1700 BP compared with conditions earlier in the Holocene(McGregor and Gagan 2004). Corals from Christmas Island in the central Pacific also show an increase in ENSO amplitude around 2,000 BP (Woodroffe, et al. 2003).

CHAPTER 5: ARCHAEOLOGICAL SITES

PULAU AY

The Banda Islands, in eastern Indonesia are home to one of very few, well-stratified, open settlements dating to the Neolithic period. PA1 on Pulau Ay is a pottery bearing open settlement site with ~3 meters of stratified archaeological deposits located on an uplifted limestone terrace near the southern tip of Pulau Ay (Figure 15). The site was first identified by Peter Lape in 1997. Initial site recording at that time included intensive surface survey and excavation of a shovel test unit and 1x1 meter excavation units. The shovel test extended to sterile layers about 320 cm below the surface, and the two 1 x 1 m units were excavated to 120 cm. Two AMS radiocarbon dates on pig bone indicated that the site was occupied by at least 3000 cal BP.

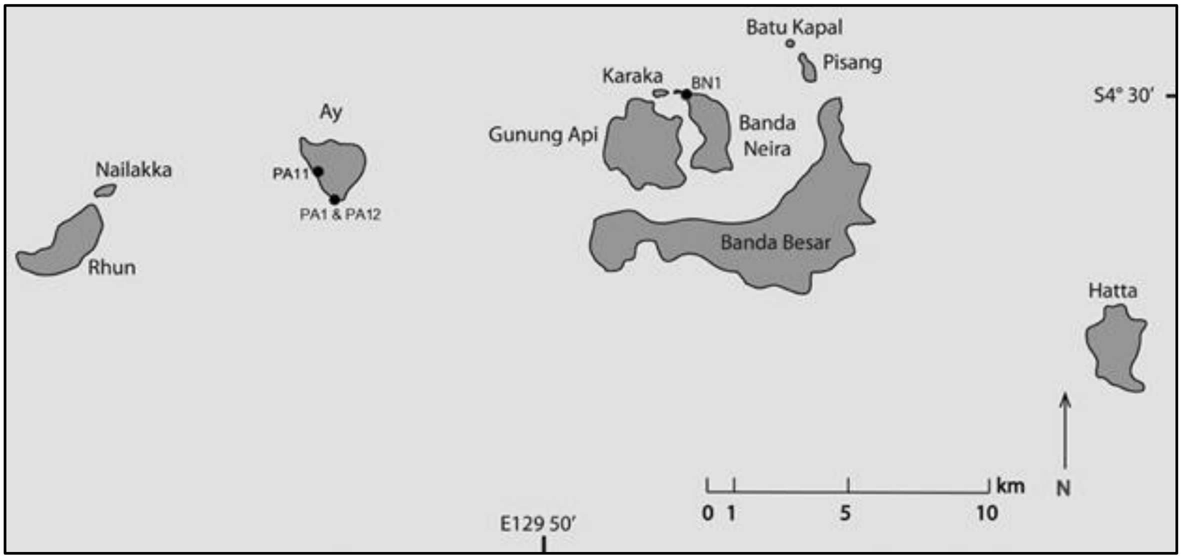

Figure 15. Location of Banda Islands sites mentioned in the text

In 2007, we returned with an international research team to excavate a larger 2 x 2 unit (Unit 3) down to culturally sterile layers. In 2009, a joint University of Washington-Universitas Gadjah Mada field school returned and excavated two more 1 x 2 m units nearby at PA12. This was initially designated as a separate site from PA1 despite its close proximity (~ 100m; Figure 17) because there was a break in surface artifact distribution. However, the 2009 excavations showed stratigraphic continuity with PA1 deposits and subsequent dating showed that the two sites were in use at the same time. The break in surface artifact distribution is most likely the result of recent gardening activity in the area rather than reflecting actual site boundaries in the past. Here the two are treated as a single site. The laboratory analyses discussed in later chapters only pertain to materials recovered from PA1 because at the time of sample selection radiocarbon dates had not yet been obtained from PA12.

Figure 16. Photo of PA1 Unit 3 location prior to excavation

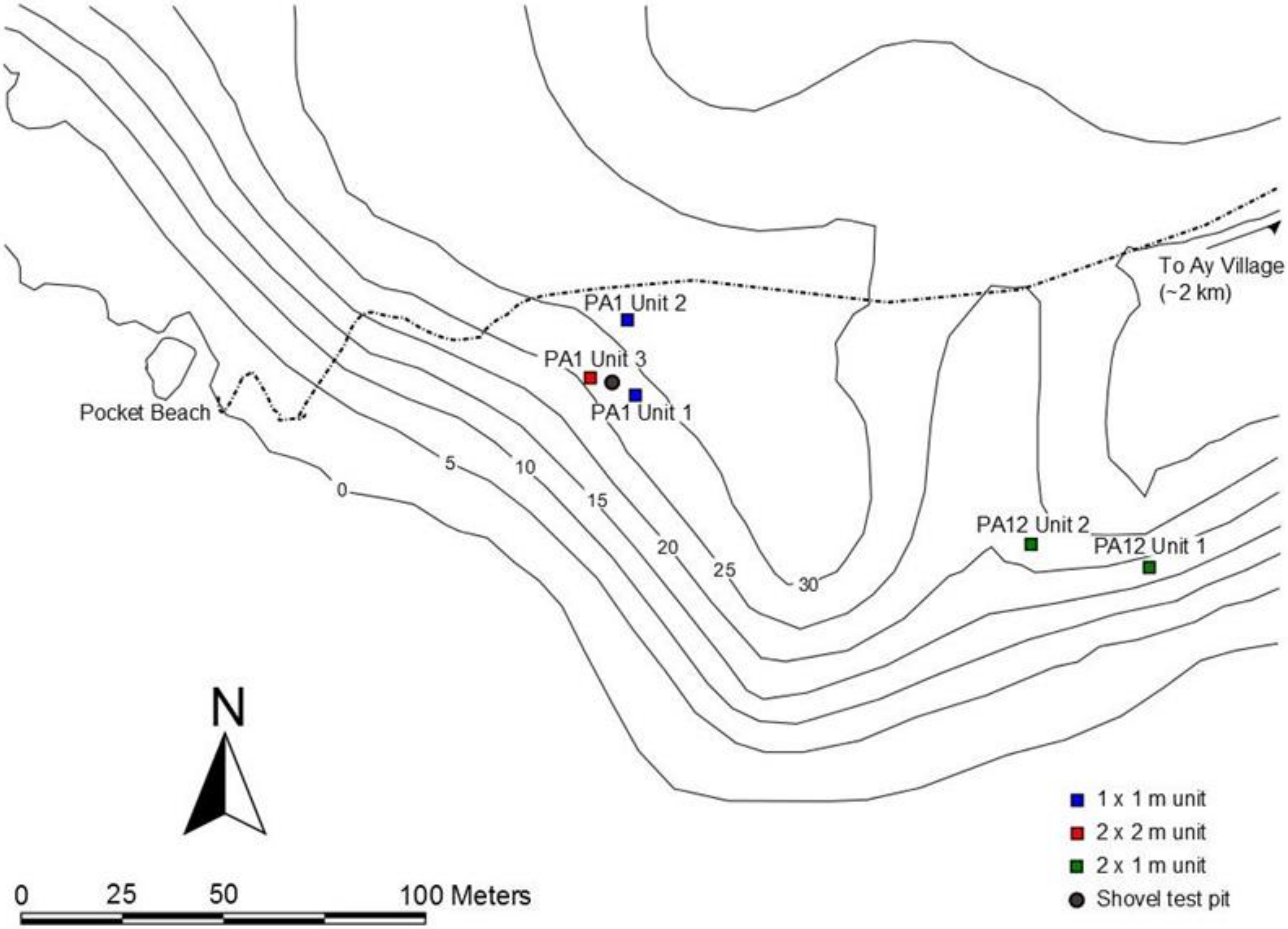

Figure 17. PA1/PA12 site map

Excavations followed natural strata (represented by the number in the level designation), subdivided into 5 or 10 cm increments (represented by the letter in the level designation). At PA1 Unit 3, excavated sediments were screened through 6mm mesh with samples from each level and feature collected for flotation and then screened through 2 mm mesh. At PA12 2mm screens were used throughout excavation and samples from each level were also taken for flotation.

PA1UNIT 3 STRATIGRAPHY

Layer 1, 0-50 cmbd

Layer one was excavated in five 10 cm arbitrary levels. It consists of well mixed topsoil containing many roots, charcoal, and pieces of cassava. The unit was located in a fallow cassava field (Figure 16) and has clearly been disturbed by tilling and other garden modifications. Artifacts included small earthenware sherds (many showing signs of wear from plowing), small chert flakes, and one historic lead bullet.

Layer 2, 50-88 cmbd

Layer 2 was excavated in four 10 cm arbitrary levels. Sediments were brown sandy silt with fewer roots and charcoal fragments than in Layer 1. Artifacts found included earthenware, chert flakes, mammal and fish bone, and a volcanic groundstone adze recovered in the screen from level 2C (70-80 cmbd). In addition to textural differences in sediments, the transition from Layer 1 to Layer 2 was marked by many large coral cobbles (>10cm diameter). These were particularly concentrated in the northwest quadrant of the excavation unit. Four post holes, averaging 14 cm in diameter, also appeared in this layer (Table 3). Earthenware sherds were larger and showed less wear than in Layer 1. Layer 2 appears to be undisturbed by the tilling of the cassava field.

Layer 3, 88-175 cmbd

Layer 3 was excavated in nine10-cm arbitrary levels. It consists of greyish brown, fine clayey silt with some fine-grained sand. Four post holes which first appeared in Layer 2D continued into Layer 3 to depths up to 170-180 cmbd. Additional postholes appeared and terminated in Layer 3 (Table 3). Artifacts from this layer included obsidian and chert flakes as well as medium-grained volcanic flakes, earthenware, mammal and fish bone, and a single bone point. A single dentate and circle stamped sherd similar to pottery from Sulawesi and the Philippines and with some affinity to Lapita pottery was recovered in situ in Level 3C at 170 cmbd (Figure 18).

Layer 4, 175-200 cmbd

Layer four was excavated in three 10 cm arbitrary levels. Sediments were yellowish brown clayey silt with some fine-grained sand and many small gravels, particularly as

Post hole	First appeared	Terminated
1	70-80 cmbd	150-160 cmbd
2	70-80 cmbd	170-180 cmbd
3	70-80 cmbd	170-180 cmbd
4	70-80 cmbd	150-160 cmbd
5	80-90 cmbd	170-180 cmbd
6	80-90 cmbd	110-120 cmbd
7	90-100 cmbd	110-120 cmbd
8	90-100 cmbd	160-170 cmbd
9	90-100 cmbd	110-120 cmbd
10	100-110 cmbd	110-120 cmbd
11	100-110 cmbd	110-120 cmbd
12	100-110 cmbd	110-120 cmbd
13	100-110 cmbd	110-120 cmbd
14	100-110 cmbd	110-120 cmbd

Table 3. PA1 Post hole depths

Figure 18. Dentate and circle stamped sherd from PA1 Unit 3

it transitioned to Layer 5. Artifacts included obsidian flakes and other lithics, earthenware, and mammal and fish bone. This layer was undisturbed by post holes.

Layer 5, 200-230 cmbd

Layer 5 was not subdivided into arbitrary levels because it was culturally sterile. This layer consisted of loose pumice pebbles and cobbles. Although the sediments are unconsolidated there is a sharp boundary with both Layer 4 above and Layer 6 below (Figure 19). This layer represents a single event and probably accumulated very rapidly during an eruption of Gunung Api in the central Bandas.

Layer 6, 230-259 cmbd

Layer 6 was excavated in three 5 cm arbitrary levels. Sediments were yellowish brown clayey silt. The upper boundary of layer six represents an ancient surface that was suddenly buried during a volcanic event. Immediately below the Layer 5 pumice, this surface was strewn with many large earthenware sherds. In total 46 sherds were recorded resting on this surface. A few marine shells were also recorded in layer 6, whereas marine shell was not preserved in any subsequent deposit in Unit 3. Mammal and fishbone, charcoal, obsidian and other lithic flakes, and additional earthenware sherds were also recovered from Layer 6. Artifacts were sparse in layer 6C so a 50-x-50-cm area was excavated until the next natural stratigraphic transition was encountered approximately 340 cmbd. The unit was culturally sterile below 259 cmbd.

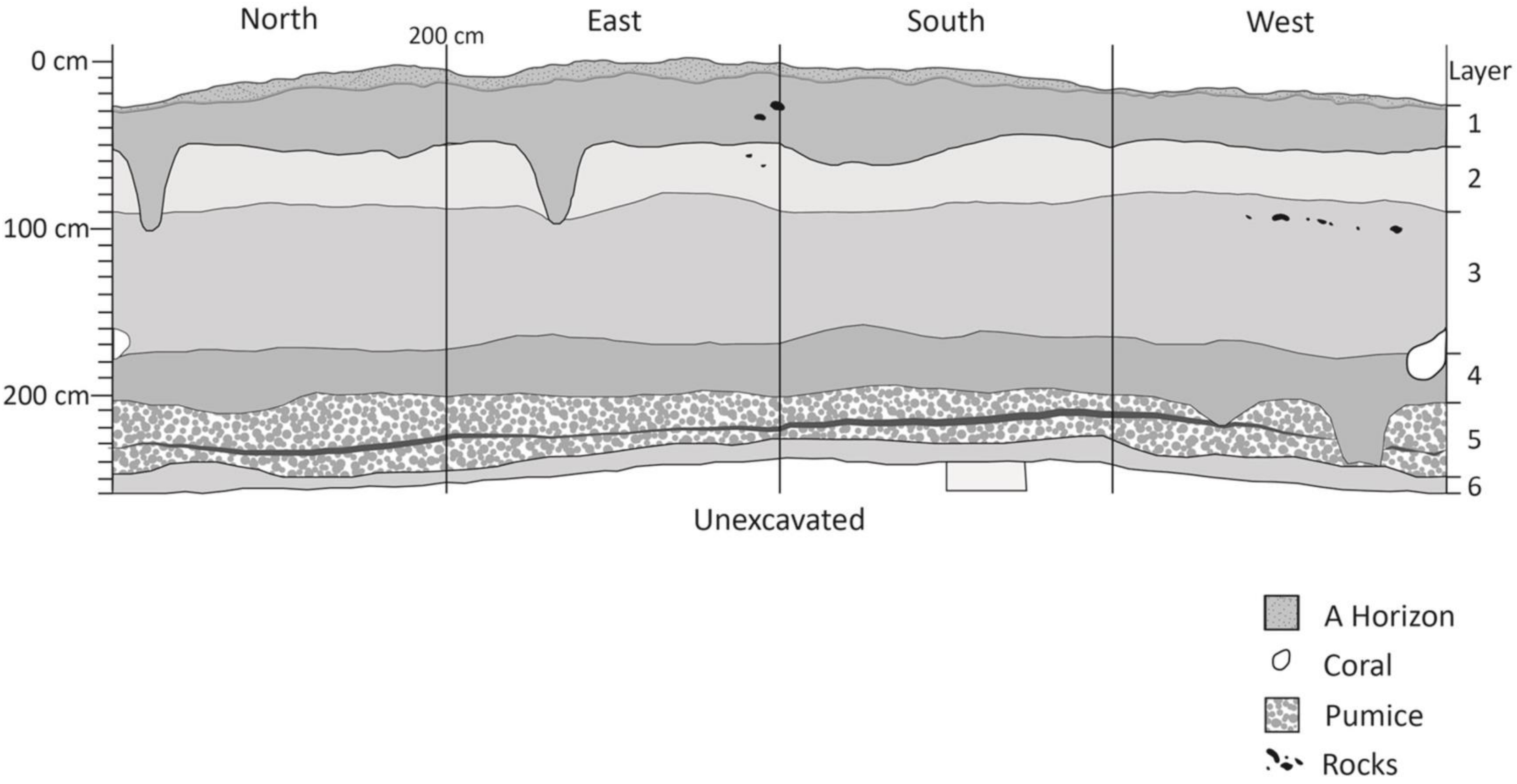

Figure 19. PA1 Unit 3 Stratigraphy

PA12 UNIT 1 STRATIGRAPHY

Stratigraphy at PA12 was generally similar to that of PA1 but the upper layers were more compressed and the pumice layer was encountered at a shallower depth. At PA12, the pumice layer was only 120-150 cmbd. The character of the pumice layer itself was also different between PA1 and PA12. At PA1 it was composed of loose, large pumice stones with very little mixing at the layer interfaces and was culturally sterile. The pumice layer at PA12 was composed of smaller pumice stones with significant mixing at layer interfaces and contained sparse cultural material. These differences made it unclear during excavation whether they really derived from the same depositional event. However, despite their different characteristics, overlap in the 2σ ranges of AMS radiocarbon dates bracketing pumice layers at PA1 and PA12 show that they are contemporary (Figure 20).

Another significant difference between the two sites was the presence of shell throughout the PA12 deposits whereas it was confined to the layer below the pumice at PA1. This difference could reflect different activity areas within the site, but more likely derives from differences in post-depositional processes in the two areas. PA12 unit 1 was located much closer to the escarpment of the upper limestone terrace and this area may have been more sheltered from chemical weathering.

From an archaeological perspective the most significant difference between the PA1 and PA12 deposits is the continuation of cultural material for approximately 100 cm below the pumice layer in the latter, whereas at PA1 cultural material was only found to a depth of 30 cm below the pumice.. In contrast, cultural materials were only present for about 20 cm below the pumice deposit. Pottery was very sparse below 180 cm (Layer 8) and there was no pottery at all in the last 10 cm of the cultural deposit. In contrast, all layers containing cultural materials at PA1 also contained pottery.

PA1 AND PA12 CHRONOLOGY

A total of ten radiocarbon dates have been obtained for PA1. Lape (2000a) dated two pieces of animal bone from PA1, Unit 1. These dates suggested a Neolithic age for the site. Eight charcoal samples from different layers of PA1 Unit 3 and three marine shell samples from PA12 were dated using AMS radiocarbon. In absence of a local marine carbon curve to correct for reservoir effects, charcoal was the preferred material for dating. At PA12, however, little charcoal was recovered during excavation and the only charcoal available from the level relevant to the target events were collected from the screens. Since exact provenience within the unit was not available for these samples, shells collected as field specimens were used instead. All radiocarbon dates were in stratigraphic sequence with acceptable error terms except for the date from PA1 Unit 3 Level 2D. Comparing radiocarbon determinations for marine carbonates and terrestrial samples is problematic when the local marine reservoir effect is unknown and cannot be corrected. This is the case for the Banda Islands. ΔR values from locations on the adjacent Sunda Shelf average -13 (Southon, et al. 2002) and those from the Australian continental shelf average 50 (Bowman 1985; Chappell 1976; Gillespie 1979; O'Connor 2010; Rhodes 1980;Southon, et al. 2002). However, conditions in the deep Banda Sea contributing to marine reservoir effects would be quite different from those on neighboring continental shelves. No ΔR values are available from the Banda Sea region.

Although marine shell dates presented here cannot be corrected, the close correspondence of dates bracketing the pumice layer suggest that the ΔR is not large. Based on bracketing dates from both PA1 and PA 12, deposition of this pumice layer occurred circa 3200 BP. The event

	Lab No.	Unit	Layer	2σ calibrated date range	Material
PA1	AA-33117	1		3827-2887 BP	Animal bone
	AA-33116	1		3172-2850 BP	Animal bone
	Beta-269220	3	Layer 2B	1174-960 BP	Charcoal
	Beta-277826	3	Layer 2D	2845-2726 BP	Charcoal
	Beta-235454	3	Layer 3C	2710-2364 BP	Charcoal
	Beta-302404	3	Layer 3E	2953-2793 BP	Charcoal
	Beta-302405	3	Layer 3I	3141-2888 BP	Charcoal
	Beta-240738	3	Layer 4B	3341-3072 BP	Charcoal
	Beta-240739	3	Layer 6A	3550-3274 BP	Charcoal
	Beta-235453	3	Layer 6B	3341-3072 BP	Charcoal
PA12	D-AMS 006797	1	Layer 4B	3293-3079 BP	Marine Shell
	D-AMS-006796	1	Layer 6A	3399-3236 BP	Marine Shell
	D-AMS-006795	1	Layer 8A	3635-3452 BP	Marine Shell

Table 4. Radiocarbon determinations from PA1/PA12
Calibrated with OxCal v.2.4 Bronk Ramsey (2013). Charcoal dates:IntCal13 atmospheric curve (Reimer et al., 2013). Shell dates: Marine13 marine curve (Reimer et al., 2013).

does not appear to have had a lasting impact on the site. Radiocarbon dates show no significant hiatus in occupation following pumice deposition and no major change in the kinds of artifacts deposited before and after the eruption. Using the pumice layer as a chronological indicator, it appears that the area of the site designated as PA12 may have been occupied slightly earlier than that designated as PA1. As previously mentioned, PA12 is located slightly further inland, sheltered at the foot of an upper limestone terrace. This location was targeted for excavation in 2009 in part because this setting is typical of the earliest Neolithic occupations elsewhere in Eastern Indonesia (Tanudirjo pers. comm). At PA1 all layers with cultural material also contained pottery so it was clear the site was not in use until after this technology had been adopted in the Banda Islands and therefore data from the site could be used to investigate the Neolithic period itself but was less relevant for addressing questions about how and why the Neolithic transition came about. It was hoped that deposits dating to this critical period of transition would be present at PA12. Another site, PA11, shows that Pulau Ay was occupied before pottery was being produced or used locally. This rockshelter site contained preceramic cultural deposits AMS radiocarbon dated to 7930-8320 cal BP. Although pottery was also present in more recent levels at PA11, the compressed stratigraphy in this rockshelter makes it difficult to precisely date its first appearance. To date, PA12 is the only open site with evidence for the initial adoption of pottery in the Banda Islands.

The oldest pottery in PA12, Unit 1 occurs in layer 8, but only 14 sherds were recovered in this natural stratum and none were recovered below 200 cm (Level 8C). In layers 1-7 pottery counts range from 90-1334 (excluding the nearly sterile pumice layer in 5A). These few sherds, may be intrusive from upper layers. While there are also fewer bones and shells in layer 8 than in younger layers, faunal remains were recovered to 230 cmbs, including 125 bone fragments and 91 shell fragments. It is clear that deposition for all cultural materials increased from level 8D to level 7C , but while the increase appears gradual for fish and shellfish, it is abrupt for pottery. If the 14 sherds in layer 8 really do reflect primary deposition this pattern could indicate that there was some initial resistance to the adoption of this new technology. Pottery may have occasionally been transported to the site through exchange but was probably not produced locally. It certainly was not being used and discarded intensively in a way that would suggest the arrival of a group of migrants for whom pottery-use was an established part of daily life. In this respect, the PA12 record is inconsistent with the view, discussed in Chapter 2, that Neolithic technologies spread across ISEA primarily through migration. An AMS radiocarbon date was obtained on shell recovered from Layer 8A at a depth of 197 cmbs with a 2 sigma calibrated age of 3635-3452 cal BP. This date is slightly older than the earliest date from nearby PA1 (excluding Lape's (2001) date on animal bone which is likely too old), but they do overlap at 2σ (3550-3341 cal BP). This result confirms that pottery first appeared in the Banda Islands around 3500 years ago

As mentioned above, there is some question of whether the charcoal date obtained for layer 2D accurately dates the deposition of that layer. Dates from 2B and 2D indicate that just 20 cm of deposit accumulated over a period of 1552-1885 years. If this is correct, it represents a dramatically reduced rate of accumulation at the site considering that from 3550-2364 (a period of 1186 years), over 150 cms accumulated. A rough calculation of accumulation rates shows that, if the date from 2D is correct, Layers 2B, 2C, and 2D accumulated at a rate of only 1.16 cm/100 years while the lower strata of the site accumulated at approximately 15.61 cm/100 years. The charcoal sample from 2D is problematic in that it is out of sequence with the date from 3C. Although it was collected in situ as a field specimen, the sample was in the vicinity of post hole #8 and may therefore have been displaced from deeper in the site when that post hole was dug. However, even if we discount this date, accumulation rates were lower during the later stage of site occupation. If the date from 2D is excluded the accumulation rate for the upper 105 cm of the site is still only 2.99 cm/100 years—considerably slower than the lower part of the deposit.

This difference has several possible explanations. First there might have been a change in site use beginning 2500-2000 BP. For example the site may still have been occupied but the area where PA1 Unit 3 was located was no longer a focus of activity. In this case we might see a

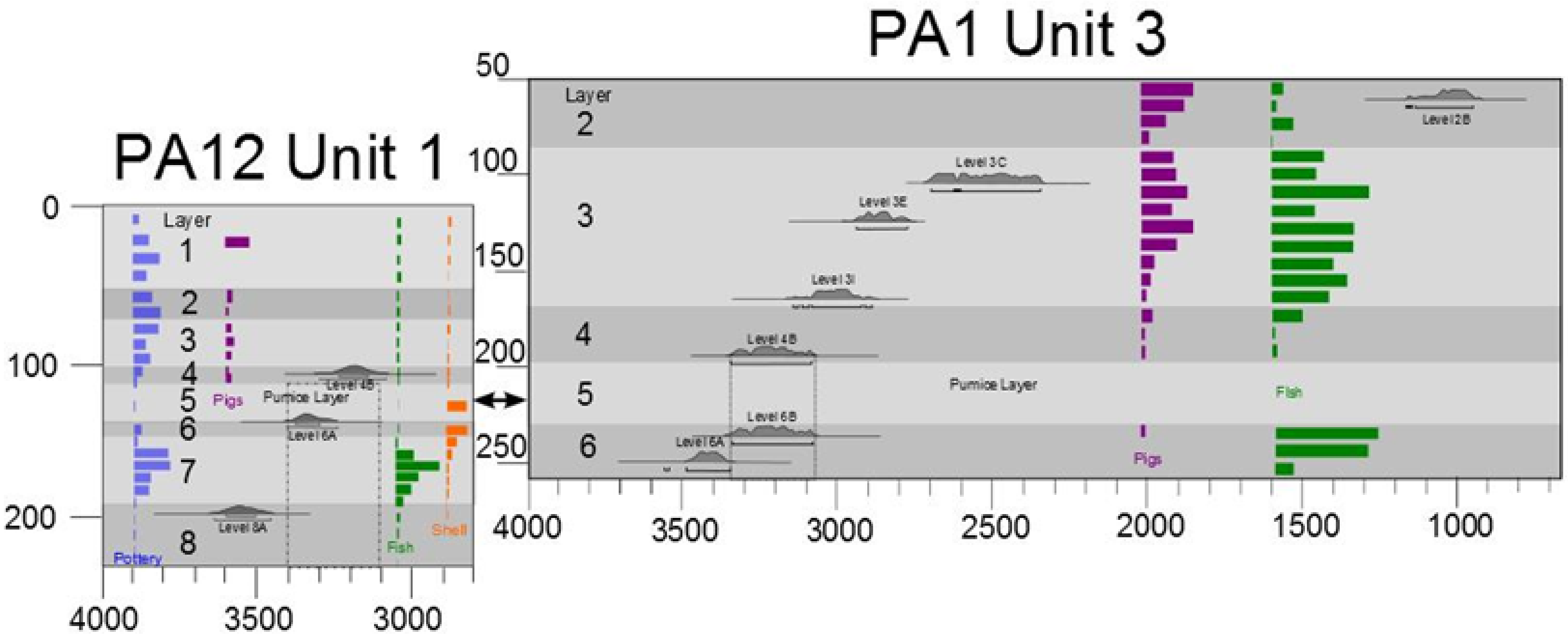

Figure 20. Comparison of site chronology between PA12 and PA1
Calibrated with OxCal v.2.4 Bronk Ramsey (2013). Charcoal dates:IntCal13 atmospheric curve (Reimer et al., 2013). Shell dates: Marine13 marine curve (Reimer et al., 2013).

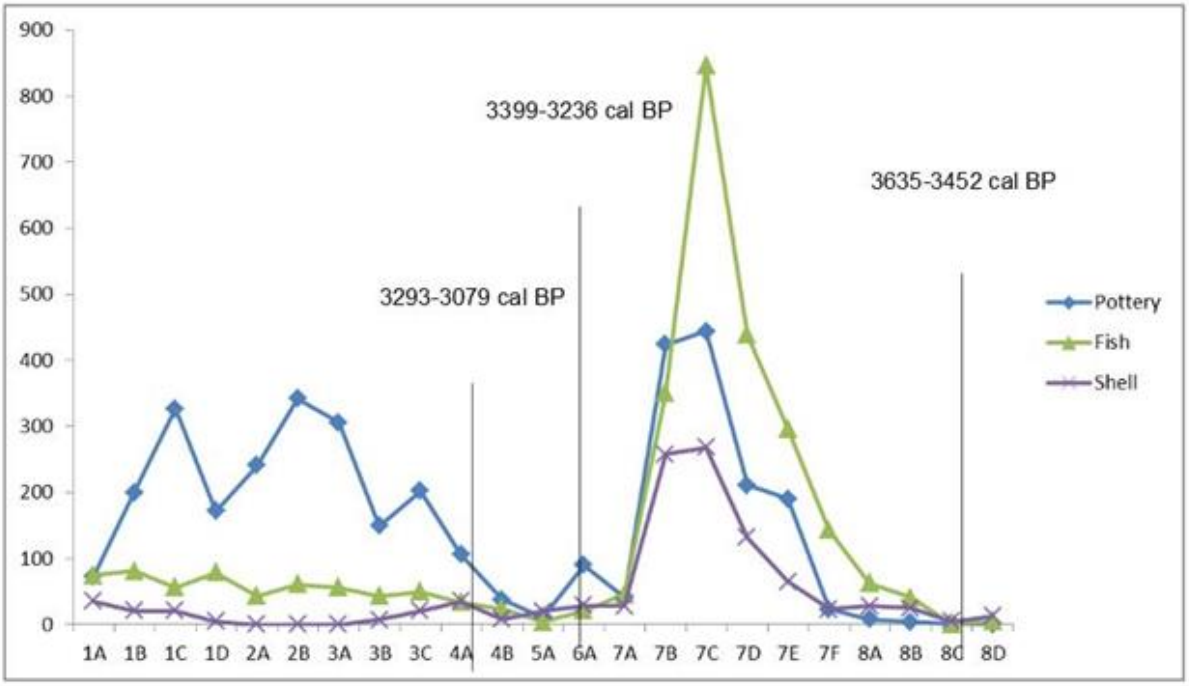

Figure 21. Cultural deposition at PA12 Unit 1

decline in deposition like that shown by the site chronology. If this were true we would not expect the same pattern to be manifested in PA12 Unit 1. Unfortunately, the three radiocarbon dates thus far obtained for that unit are insufficient for even a rough approximation of accumulation rates. Based on artifact counts, there does appear to be a slight decline in deposition in this unit as well but it may not be on the same order of magnitude with that in PA1 Unit 3 (Figures 19-20).Alternatively, permanent occupation at the site may have ceased but with people returning periodically for short stays while they foraged on the productive reefs. In this case we might expect to see a change in the composition of faunal assemblages concurrent with the change in accumulation. Specifically, given the paucity of terrestrial fauna beyond domesticated populations kept by people, if the site came to be used as a fishing camp we should see marine taxa dominating the faunal record. This is not the case. Instead, NISPs for marine taxa decrease from layer 3 to Layer 2 while the abundance of pig bone increases in the PA1 Unit 3 assemblage (Figure 21). Marine fauna are also more abundant in the early layers in PA12 Unit 1 than in more recent layers. Faunal assemblages are described and discussed in more detail below.

The final, scenario is that PA1/PA12 was completely abandoned for an extended period beginning around 2000 BP and then briefly reoccupied. The period of abandonment could have lasted for 500-1000 years, with very little accumulation. The absence of a culturally sterile layer in either of the units described here argues against this explanation. It is unlikely that both anthropogenic and non-anthropogenic deposition would cease simultaneously for this extended period of time. The possibility of an extended period of site abandonment is discussed further in Chapter 8.

SUBSISTENCE AT PA1/PA12

BONE

In total 14,338 animal bone fragments were recovered from PA1 Unit 3. All bone and teeth fragments from both the 6mm excavation screens and the heavy fraction from flotation (>2mm) were examined and classified as mammal, fish, or bird. Further identification (element and taxon) was attempted for all mammal bone and teeth fragments. Although organic preservation at PA1 was better than is often found in Southeast Asian sites, the faunal assemblage was highly fragmentary. Only 15% percent of the 3,590 mammal bone fragments could be identified to genus or better.

A total of 3231 animal bone fragments were recovered from PA12 Unit 1, a 2 x 1 m excavation unit. This faunal assemblage was less fragmented with 54% of mammalian specimens

(N=339) identifiable to family level or better. Taxonomic identification of fishbone was not attempted in this study as suitable comparative collections were not available.

Fish bone, mostly very small-sized and recovered from the 2mm screens, is more abundant than mammal bone in both units. At PA1 it comprises 75% of the total assemblage and at PA12 89% of bone and teeth was marine fish. Only a handful of bird bone was recovered (PA1:0.1%, PA12: <0.5%). Although fish bone dominates these assemblages overall, it is not

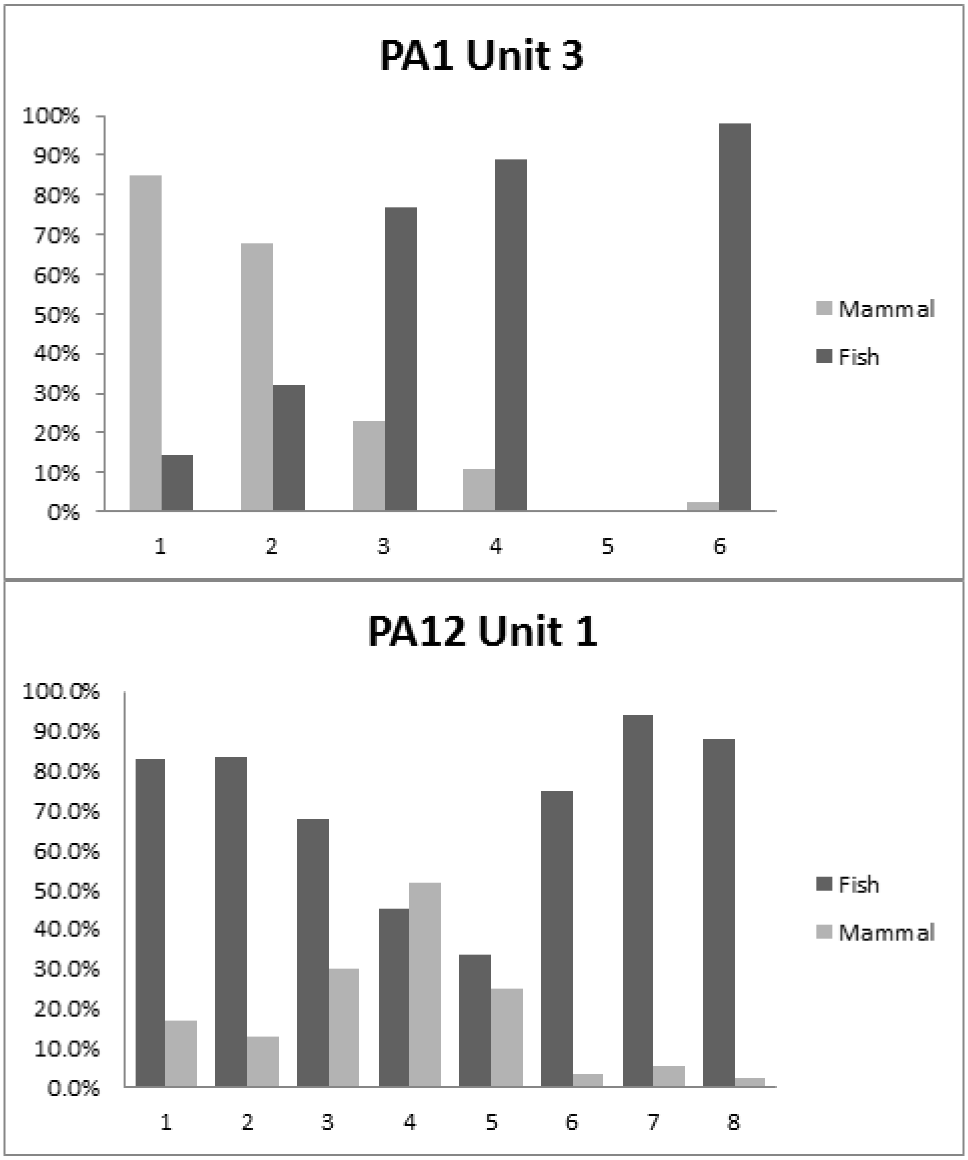

Figure 22. Percentage of specimens identified as mammal vs. fish at PA1 and PA12

evenly distributed among excavated layers in either unit. Figure 21 shows the percentage of mammal and fish, revealing a clear change in the composition of the PA1 assemblage over time. In the earliest Neolithic levels (6A-C), mammal bone is all but absent but beginning slightly later, mammal bone becomes increasingly abundant while fish bone makes up an ever smaller part of the assemblage.

The faunal record of the earliest occupation at PA1 shows a focus on marine resources for subsistence with a gradual shift toward domesticated animals beginning in Layer 3. *Sus Scrofa* abundance mirrors that of the mammalian fauna overall, as this is the most abundant species (Figure 22). Below layer 3F they are present in decreasing frequencies, indicating they were not a significant subsistence resource at PA1 during at least the first 500 years of occupation. Beginning with layer 3, *Sus* scrofa abundance increases. The maximum difference in cumulative distributions for fish vs. mammal bone occurs in layer 3D, dating to just after 3000 BP (see Table 4 for dates bracketing this level).

Of the three domesticates thought to have been carried by Neolithic colonists in ISEA, only *Sus scrofa* and *Canis familiaris* are present at PA1 but these two species account for nearly all of the identifiable mammal bone. This is not surprising given the island's impoverished terrestrial fauna—aside from domesticates, Pulau Ay would only have had a few native species, possibly including *Phalanger orientalis* (as it does today), a small varanid lizard, and several species of bat. However, none of these were identified in the PA1 assemblage. Domesticated dog, while present, is not at all abundant with a total NISP of 14 nearly all of which were recovered from between layers 4A and 3C. Domesticated pig, while present in very small quantities as early as layer 6A, becomes much more abundant in layers 2 and 3. Additionally, Murid rodents are present in the faunal record of the site. Like *Sus Scrofa* and *Canis familiaris*

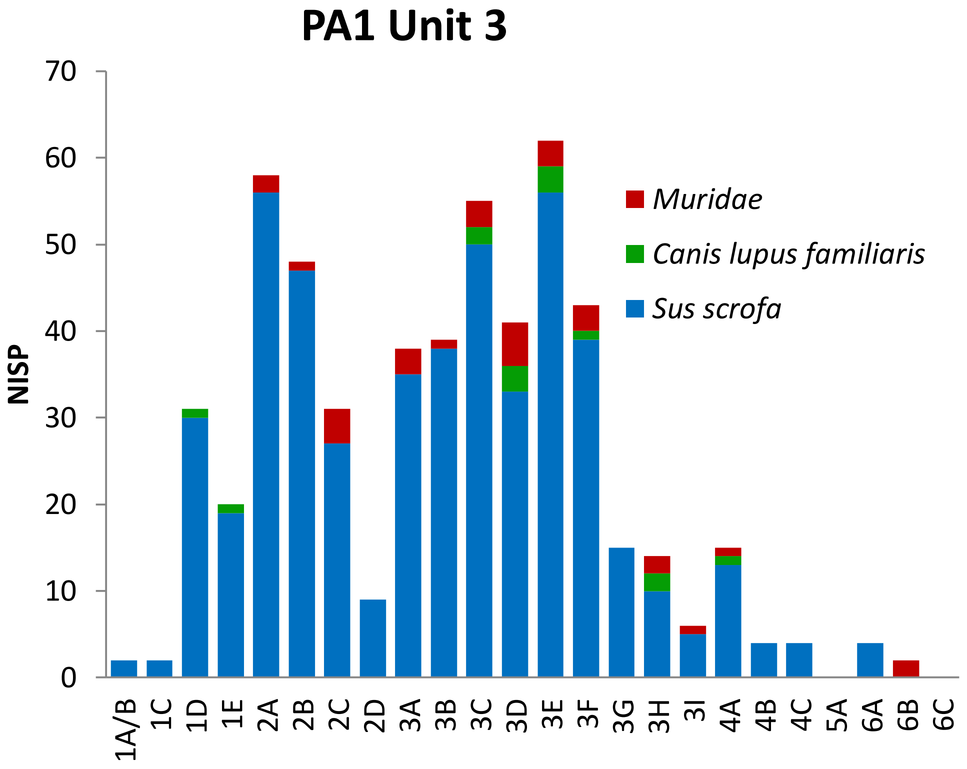

Figure 23. Domesticated and commensal species at PA1

Muridae sp. are very rare during the early period of site occupation. Muridae NISP for layers 4 and 6 is only 3, while 28 specimens, primarily teeth, were identified from layers 2 and 3. Nearly all identifiable Muridae specimens were from the heavy fraction (>2mm) of flotation samples, highlighting the importance of screen size for recovering small mammal remains as well as fishbone. Screening all sediments through 2mm mesh would likely have resulted in larger NISP for this taxon.

Patterning in the faunal assemblage from PA1 clearly indicates a shift from a subsistence regime strongly oriented toward marine resource exploitation to one increasingly incorporating domesticated animals. Whereas some elements of the Neolithic "package" are present throughout the site (pottery), some appear to be a slightly later introduction (pigs), and others like shell material culture items and groundstone adzes are altogether absent. The PA1 fauna show a process of change occurring at the site over the course of at least several hundred years. This could be construed as representing a learning curve as new colonists got to know the environment of their new home and how to successfully maintain a breeding stock of pigs there. But it could just as likely indicate a resident local population adopting some new technologies more readily than others.

The early focus on marine subsistence is also in evidence in the PA12 assemblage with fishbone accounting for 95% of the animal bone recovered in Layers 6, 7 and 8. As discussed below, most of the marine shell from the site was also recovered in these early levels. Fishbone is more abundant than mammal bone in all layers except 4, directly overlaying the pumice layer. This is in contrast to PA1 where mammal bone is more abundant than fishbone in the two uppermost layers (Figure 22). At PA12 mammal bone abundance peaks in layer 4, dated to 3399-3236 cal BP and then declines again through the uppermost layers.

At PA12 the identified mammalian taxa include Muridae sp., Chiroptera, *Sus Scrofa*, and *Canis familiaris*. Murid rodents are the most common of identified taxa accounting for 43% of the mammal bone recovered (Figure 23). *Sus Scrofa* is the next most abundant taxon (7% of mammal bone), and other taxa represent less than 5% of recovered mammal bone. This is another deviation from what was found at PA1 where *Sus Scrofa* was the most abundant of identified mammal taxa (14% of recovered mammal bone). Other identified taxa accounted for <1% each of the recovered mammal bone). This difference may relate more to taphonomy and recovery methods than to meaningful differences in the importance of *Sus scrofa* between PA1 and PA12 Although they are fairly close together and positioned on the same landform,

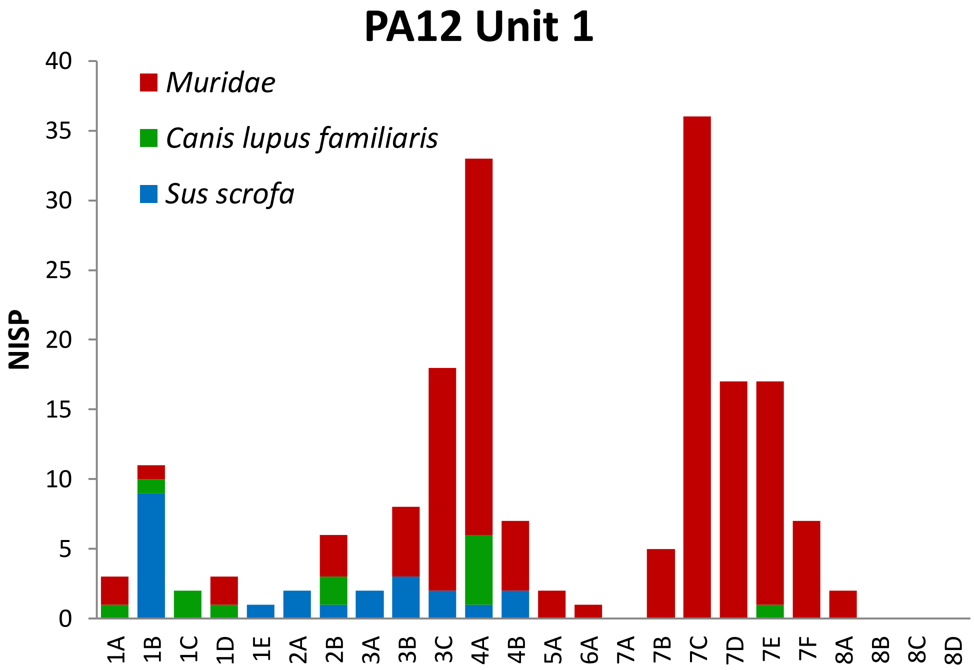

Figure 24. Domesticated and commensal species at PA12

taphonomic processes seem to have differed significantly between PA1 and PA12. This is most apparent in the different representation of shell at the sites, discussed below. In addition, different screen sizes were used during excavations at the two sites.

At PA1 most of the assemblage was screened through 6mm mesh. Samples from each quadrant of the unit for each level were taken for flotation and bone from the heavy fraction (2mm screen) was included in analysis of faunal remains. In contrast, all sediments were screened through 2x4 mm mesh at PA12. The use of a finer mesh for all sediments may account for the much higher proportion of small mammal bones at PA12 vs. PA1.

Analysis of faunal assemblages at PA1 showed that although pottery was present in all layers containing cultural material, pigs were rare-to-absent before about 3000 BP. This is also true for PA12 where there are no pigs in evidence before layer 4. The delay of several centuries between the first appearance of pottery and the arrival of pigs is significant in relation to dominant historical narrative for Neolithization in Island Southeast Asia which ties the spread of pottery and domesticates including pigs to the migration of Austronesia language speakers. Pottery, pigs, shell artifacts, and certain adze forms are considered to comprise a Neolithic package the first appearance of which signals the arrival of Austronesian speaking colonists. The fact that pigs appeared several hundred years after pottery and the other components of the so called package (shell artifacts, quadrangular adzes) have never been found in situ in the Banda Islands does not represent a material signal of migration. Even if the Neolithic package is seen as polythetic the gradual nature of the appearance of pottery and pigs inconsistent with the idea that Neolithization was a single event.

MARINE SHELL

The shell at PA1 was very poorly preserved and often disintegrated on contact. Those shells that remained sufficiently intact for recovery were not identifiable beyond classification as medium-sized gastropods. Marine shell was recovered from all layers in PA12 Unit 1 except layer 2 (Figure 25). All shell in this layer belonged to land snails and has not been included in this analysis. In general shell was highly fragmented with only 35% of specimens retaining characteristics to allow identification to the family level or better. Preservation was not uniform between layers with some layers, most notably layer seven, containing larger, more complete specimens than other. The pumice deposit in layers 5 and 6 appear to have provided more favorable conditions for shell preservation in lower levels. The sudden deposition of approximately 30 cm of pumice may have protected the shell at and near the surface at that time from being tramped and crushed. In this context of differential preservation among strata,

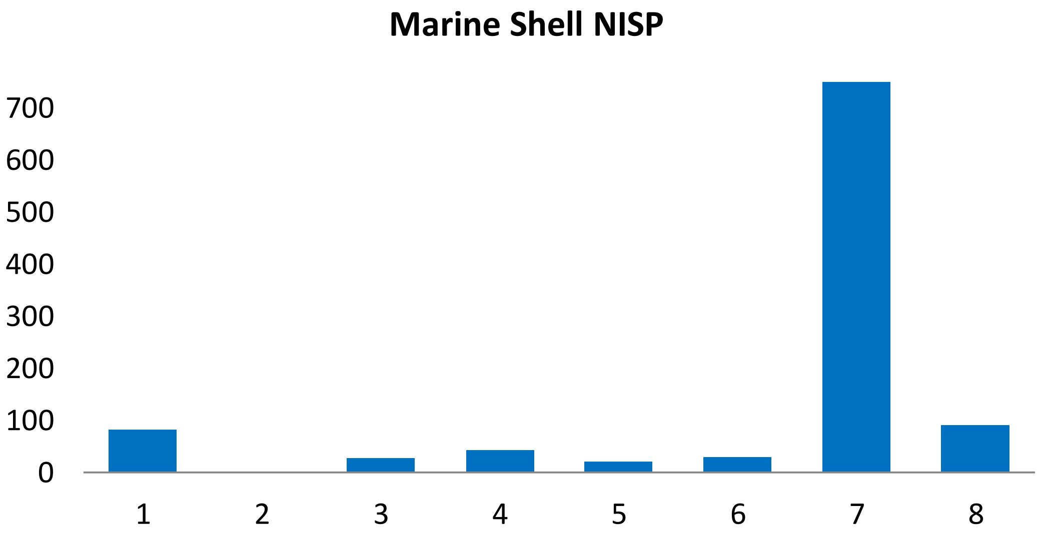

Figure 25. Marine shell NISP by stratigraphic layer at PA12.
Calibrated with OxCal v.2.4 Bronk Ramsey (2013). Charcoal dates:IntCal13 atmospheric curve (Reimer et al., 2013).

data on taxonomic abundance, richness, and diversity must be taken with a grain of salt. Layer seven had largest NISP and the highest richness and evenness values of any strata. This may be a relic of preservation bias rather than a pattern illustrative of human subsistence change.

The marine shell assemblage from PA12 is composed primarily of small to medium sized, shallow-water, reef-dwelling taxa. In total 17 different taxa were identified. Eight families account for at least 1% of the total identifiable specimens. In order of abundance these are: Conus, Muricidae, Turbo, Cypraea , Trochus,Tridacnidae, Neritidae, and Angariidae.

As noted above, marine shell was by far most abundant in layer 7 where 774 specimens were recovered (281 identifiable). The next greatest abundance was in layer 8 with 91 specimens (21 identifiable). The marine shell assemblage demonstrates the same pattern as the animal bone assemblage with the marine taxa far more abundant in layer 7 than in any other stratum.

Each marine shell specimen was carefully examined for signs of human modification including flaking, grinding, and perforation. Of the 1067 shells examined, none showed signs of potential modification. Unlike pottery-using populations elsewhere in Island Southeast Asia and Near Oceania, the people who inhabited PA12 and PA1 during the Neolithic do not appear to have produced or traded for shell tools and ornaments. Shell material culture has long been considered an important hallmark of "Austronesian" populations and has often been described as a key component in the so-called Neolithic package that immigrants are supposed to have brought with them as the colonized Island Southeast Asia and the Pacific (Bellwood 1997, 2002, O'Connor 2006; Spriggs 2011; Szabo 2002,). This is not the case for PA12. Shellfish may have been an important subsistence resource during the early Neolithic but they do not seem to have been an important tool resource or artistic medium on Pulau Ay.

BN1

The BN1 site is located on the island of Banda Neira in the central Banda Islands near Lautaka village. The site was first recorded and investigated by Lape in 1997 who identified it as the historic village called Labetacca. Two shovel test pits were excavated to expose soil profiles and four 1 x 1 excavation units were placed to establish site chronology and investigate the process of Islamization in the Banda Islands (2000a). The site was found to be occupied from around 1400 BP and into the colonial era based on radiocarbon dating and diagnostic Asian tradewares (Lape 2000a). In 2009, additional excavations were undertaken to further examine the occupation history of the site and to determine the age of a tumbled stone wall located along the beach berm. Two units were excavated. Unit 5 was a 1-x-4 meter trench intersecting the beach berm for the purpose of exposing the base of the wall and dating its construction. Unit 6 was a 2-x-2 meter unit placed in the vicinity of BN1 Unit 3. Pottery and pig teeth recovered from the

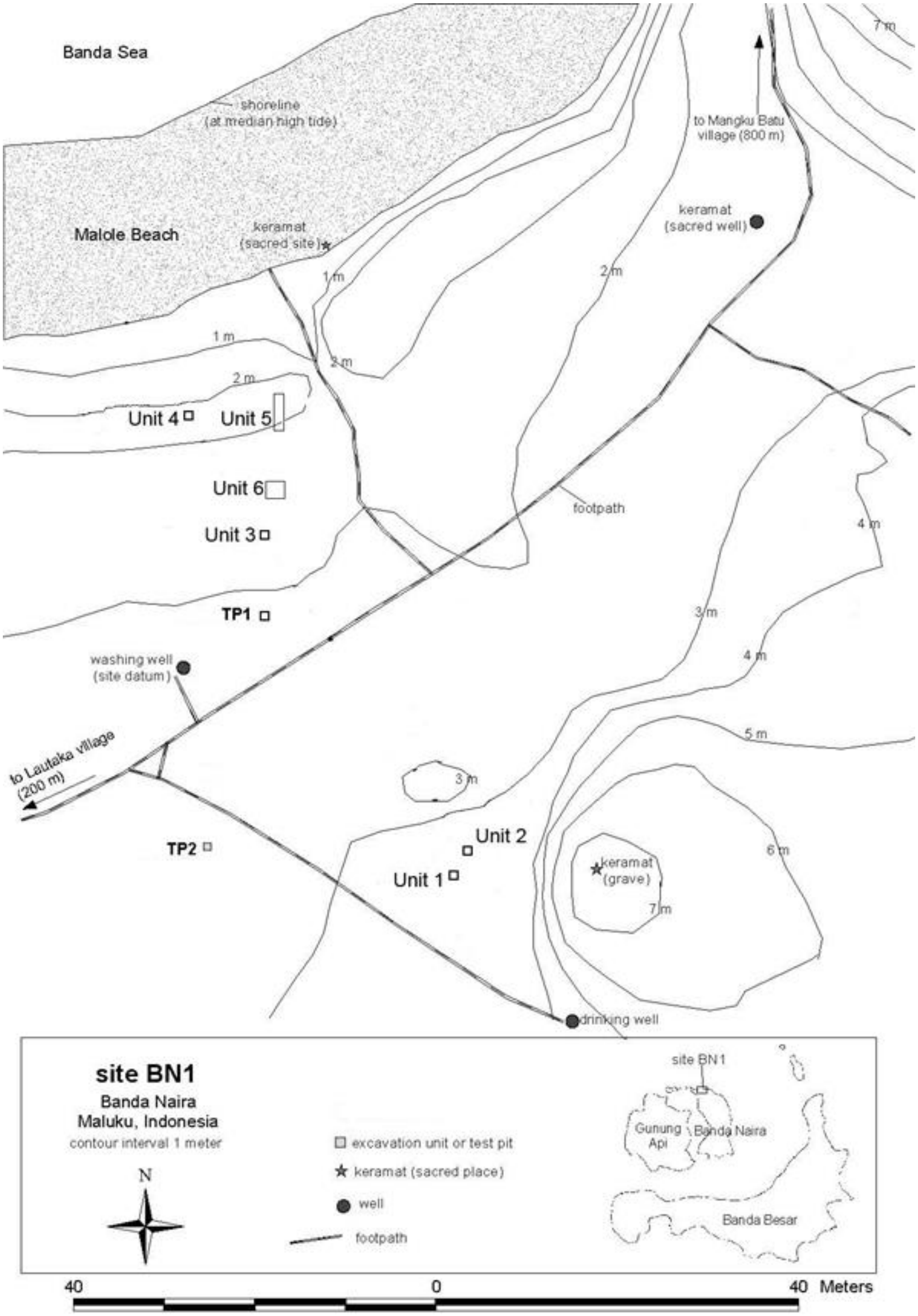

Figure 26. BN1 site map

Lab No.	Unit	Level	2σ calibrated date range	Material
AA-33114	3		1385-1180 BP	Animal bone
Beta-298969	6	9B	1267-1058 BP	Charcoal
Beta-269219	6	10E	1230-981 BP	Charcoal

Table 5. Radiocarbon determinations from BN1.

early levels of the latter were included in this study both to allow comparison of exchange histories at two different locations within the Banda Islands and to extend the sequence from PA1

BN1 UNIT 6 STRATIGRAPHY

Layer 1, 0-30 cmbd

This layer was excavated as a single unit to a depth of 30 cm because it was heavily disturbed through tilling (the unit is located in a cassava field presently under cultivation) and bioturbation by ants (the unit contained a large ant's nest). Sediments were loose, dark brown topsoil with many rootlets throughout.

Layer 2, 30-130 cmbd

Layer 2 sediments were brown, fine sandy silt with many pebbles. Artifacts include many plain and decorated earthenware sherds, bone, and a small red glass bead. The pottery, along with some lithics and charcoal were not evenly distributed but occurred in two concentrations. Feature 1 was a concentration near the center of the east wall. A second concentration (Feature 2) was recorded in the southeast quadrant of Unit 6. Layer 2 sediments were uniformly distributed across the unit to a depth of about 45 cm. Below this layer 2 sediments appear to have filled in three large pits dug through the lower layers.

Human remains were found in all three pits, including a skull with a coin placed in the eye socket at the bottom of the easternmost pit. Text on one side of the coin read “1808”—presumably the date the coin was produced and a minimum date for the burial. Although these burials was uncovered during excavation, human remains found in situ were not removed and bone from these pits found in the screens was kept separate for reburial.

Layer 3, 50-70 cmbd

Sediments in this layer were grey laminated ash and clay with many thin black charcoal lenses and a thin pumice lens at the interface with Layer 2. Artifacts from layer 3 were limited to a small number of fishbones and pottery sherds around 70 cmbd—the interface with Layer 4. This layer is essentially culturally sterile.

Layer 4, 70-80 cmbd

Layer 4 sediments were blackish brown fine sandy silt. The black color is due to a large amount of charcoal in this layer. Artifacts included earthenware and one small sherd of white porcelain tradeware.

Layer 5, 80-85 cmbd

Layer 5 sediments were brown, fine sandy silt. Animal bone, charcoal, earthenware, small beads, Chinese coins, lithics, and Asian tradeware were recovered in this layer.

Layer 6, 85-100 cmbd

Layer 6 sediments were reddish brown fine sandy silt. Animal bone, shell, charcoal, earthenware, tradeware, lithics, beads, and metal fragments were recovered from this layer.

Layer 7, 100-110 cmbd

Layer 7 sediments were greyish brown fine silty sand with many small pieces of pumice. Artifacts were similar to those in Layer 6 including animal bone, shell, charcoal, earthenware, tradeware, lithics, beads, and metal.

Layer 8, 110-140 cmbd

This layer was excavated in five 10-cm arbitrary levels. Sediments were clayey silts containing small pumice pebbles. The lower boundary was undulating at depths ranging from 140-150 cmbd. Excavation in the NE and NW quadrant ceased at this depth to minimize disturbance to the burials so this and subsequent layers were only excavated in the SE and SW quadrants. Artifacts included animal bone, shell, charcoal, earthenware, tradeware, beads, lithics, and metal.

Layer 9, 140-170 cmbd

Layer 9 was excavated in four 10-cm arbitrary levels. Sediments were similar to those in Layer 8 but with a softer texture and more gravel. Many large coral cobbles (up to 20 cm diameter) were encountered within the first ten centimeters. Artifact content was similar to Layer 8 including bone, shell, charcoal, earthenware, tradeware, beads, lithics (some obsidian), and metal.

Layer 10, 170-220 cmbd

Layer 10 was excavated in five 10-cm arbitrary levels. Sediments were dark brown sandy clay with pumice pebbles. Distinctive sculpted earthenware was found in this layer and only one small piece of greyish colored tradeware was recovered. Other cultural materials included bone, lithics (chert and obsidian), shell, and human teeth.

SUBSISTENCE AT BN1

The faunal material recovered from BN1 Unit 6 has not been fully analyzed but materials from layers 8-10 were sorted and identified as preliminary to selecting pig tooth samples for the isotope analysis. Materials from layers 3-7 were only sorted into mammal, fish, and bird categories and checked for pig teeth. Only two small pig tooth fragments were identified from these layers. As suggested by Lape (2000a) the absence of pig remains in more recent layers may relate to the arrival of Islam in the Bandas and the cessation of pig-eating with conversion of the villagers. Archaeological evidence from other Banda Islands sites suggests Islamization may have begun as early as 750 BP but, if presence of pig bones is a reliable indicator, the village at BN1 did not convert until around 500 BP.

CHAPTER 6: CHEMICAL CHARACTERIZATION OF POTTERY FROM THE BANDA ISLANDS INDONESIA

INTRODUCTION

Pottery is ubiquitous in Banda Islands archaeological sites. Only two sites, the PA11 rockshelter and PA12, an open site, have aceramic levels. The oldest known pottery in the islands occurs in the basal layers of PA1 (dated to 3550-3274 BP) and PA12 (dated to 3635-3452 cal BP). This pottery was described in detail by Chung Ching Shiung (2011) in his analysis of earthenware from various Banda Islands sites, a study that included 682 rim sherds from PA1. The early ceramics consist of relatively thin-walled earthenware sherds often red-slipped either on both surfaces or on the interior surface alone. The majority have oxidized exteriors and reduced interior firing cores, indicating they were most likely fired in an open environment for a short period of time (Shiung 2011). Although Shiung identified some change over time in ceramic assemblages, most notably in rim style, wall thickness, and application of red-slips, the earthenware assemblage at PA1 was overall relatively homogenous with few decorated sherds. Plain earthenwares are prevalent in all prehistoric sites in Banda and these simple vessels continued to be used and discarded long after the introduction of Asian tradewares from the west.

EVIDENCE OF EARTHENWARE EXCHANGE IN THE BANDA ISLANDS

There is substantial evidence that the Banda Islands were involved in exchange networks that transported earthenware throughout the Banda Sea region. Pottery from Banda has been found on other islands and non-local pottery has been found in Banda Islands sites. Shiung (2011) notes that several sherds from BN1 displayed the distinctive foraminiferal tempers characteristic of pottery produced on Saparua in the Ambon-Lease group. Additionally, mineralogical analyses have shown transport of ceramic materials between the Banda group and Seram and Gorom to the North, and with the Aru islands in the South (Spriggs and Dickinson 2010). Dickinson's petrographic study of a small sample of sherds from late prehistoric sites around Maluku Tengah identified 6 sherds (of 15 analyzed) recovered at Gorom sites with volcanic sand tempers originating in the Banda group. One of the five Seram sherds analyzed was also attributed to a Banda source (Spriggs and Dickinson 2010). In a previous study several Aru sherds from Wangil Midden and Karkur in the Aru islands were also sourced to the Banda group (Dickinson 2006). At least one of these is 700 years old (Veth, et al. 2005). Additionally, of ten Banda sherds submitted to Dickinson for analysis, two could be conclusively identified as exotic based on the presence of hornblende mineral grains, which do not occur in Banda. The specific source of the hornblende mineral temper is still unknown but based on Indonesian Geological maps a potential source could be Pulau Kur, a small outlying island approximately 100 km west of the northern tip of Kei Besar (Achdan and Turkandi 1994). While all of the sherds investigated by mineralogical analysis are from later periods than those selected for this study, the presence of exotic sherds in Banda islands sites and of Banda sherds in other island groups shows that ceramic materials were transferred through exchange prior to the earliest documented arrival of foreign traders from the West.

The success of petrographic techniques shows that there is sufficient geologic variability across the Banda Arc to expect that clays from different areas may also be geochemically distinct. While Dickinson's petrographic examination focused on identifying the mineral characteristics of temper sands, he also noted that the Banda sherds had distinctive pastes containing vitroclastic volcanic ash. Dickinson (2006) observed that, these tiny shards of volcanic glass are unbroken but more evenly distributed than temper inclusions. He concluded

Island	Location	Bedrock type	Distance from Gunung Api
Banda Neira	Inner group	Volcanic	2-3 km
Banda Besar	Inner Group	Volcanic	2-9 km
Pulau Pisang	Inner Group	Uplifted Limestone	6.5-7 km
Pulau Ay	Outer Group	Uplifted Limestone	10.5-13 km
Pulau Rhun	Outer Group	Uplifted Limestone	20-23 km
Pulau Hatta	Outer Group	Uplifted Limestone	17-20 km

Table 6. Distance of islands from the central volcano (Gunung Api)

that, since the degree of working required to obtain this distribution would have broken the shards, the ash was incorporated in the clay raw material rather than being a later additive in the production process (2006). If this is a pervasive characteristic of local clays within the Bandas, they should be chemically distinct from other source areas. Indeed, Dickinson, who has personally done most of the petrography on archaeological samples in Island Southeast Asia and Oceania, considers this characteristic of Banda clay paste to be unique in the broader Pacific region (2005:117).

There is also a strong likelihood of being able to differentiate source groups within the archipelago. Since the different clay sources within the Banda group are located at different distances from the central volcano, some on uplifted limestone islands others in the central volcanic islands (Table 6), clays from different locations can be expected to vary in their chemical composition. The Banda sherds examined by Dickinson were tempered with volcanic sand derived from reworked ash suggesting that these sherds were most likely produced in the inner Banda group where volcanic bedrock predominates. If this pottery were produced on Pulau

Ay, Pulau Rhun, or Pulau Hatta, one would expect calcareous sand tempers since these islands are uplifted limestone and located between 10 and 20 km from the central volcano. The presence of a sterile pumice layer (5a) at PA1 clearly indicates that Pulau Ay, at least, is close enough that it sometimes receives volcanic products during eruptions but this volcanic material is not the primary constituent of beach sands. Clays themselves on these islands could be marine deposits or may derive from in situ weathering of both volcanic sediments and limestone bedrock. Since they are located at different distances and in different directions from the central volcanic islands, eolian sediments will not be uniformly distributed amongst the islands.

SAMPLE SELECTION

Samples were selected from each natural stratum at PA1 and from the older levels at BN1. At the latter site Asian tradeware appears later in the sequence. Since the participation of Banda in proto- to early historic global trading systems was not the focus of this study, levels with significant quantities of tradeware were excluded from the analysis. In total 200 samples were analyzed by LA-ICP-MS including 76 from BN1, 122 from PA1 and a single contemporary waste sherd from a pottery workshop at Ouw Village in Saparua. At present no pottery is produced in the Banda Islands and Ouw village is the only significant pottery-producing locale in the region. Earthenware produced there is made from a single large clay source in the forest near the village and the clay paste is tempered with a distinctive foraminiferal temper, easily identifiable as dense small white rounded inclusions. The contemporaneous sherd was included for comparative purposes. The goal of this analysis was to obtain a sample that would represent differences between sources. Rather than a simple random sample, excavation levels were used as sampling strata and within these sherds were selected based on macroscopic observation of thickness, color, and temper to reduce the likelihood of selecting multiple sherds from the same vessel.

LAB METHODS

LA-ICP-MS analysis was conducted at the Chicago Field Museum Elemental Analysis Facility (EAF) on a Varian quadropole inductively coupled plasma mass spectrometer, equivalent to the Varian 810. A New Wave UP213 (helium carrier gas, 213 nm laser operated at 0.2 mJ and a pulse frequency of 15 Hz) laser was used for sample induction. Samples were first prepared for the analysis by sawing off a small portion of each sherd to produce a sample small enough to fit easily in the instrument's induction chamber. This preparation also allowed the fabric to be targeted with the laser, reducing the possibility of contamination from the weathered outer surfaces of sherds. For each sherd 58 elements were measured at ten different ablation sites with a spot size of 100 microns. Samples were run in batches of four to five with NIST standards n610 (Glass) and n679 (Brick Clay), and New Ohio Red Clay as well as blank measurements between batches to correct for instrumental drift over the course of the analysis. Concentrations were calculated using 29Si as an internal standard following the methods described by Gratuze et al (1999).

RELIABILITY OF METHOD

In total, 59 runs of Ohio Red clay were conducted over the course of the analysis, each including nine replicates of 5 different ablation sites. Data for this reference material were not used for calculating element concentrations in the archaeological samples. Instead, Ohio Red data serve as a control for the analysis allowing the assessment of precision and accuracy of the method. Comparison of calculated concentration values between runs of Ohio Red gives an

	Mean (‰)	S.D.	RSD
Li	149.58	11.89	8%
Be	3.45	0.35	10%
B	129.47	17.61	14%
P	232.46	27.80	12%
Cl	257.70	82.73	32%
Sc	18.50	1.05	6%
V	210.80	11.98	6%
Cr	92.15	4.61	5%
Mn	268.34	26.69	10%
Co	23.52	1.46	6%
Ni	79.07	4.05	5%
Cu	32.42	3.16	10%
Zn	131.66	11.41	9%
As	6.86	3.68	54%
Rb	208.85	13.72	7%
Sr	62.87	5.76	9%

	Mean (‰)	S.D.	RSD
Y	28.35	4.73	17%
Zr	178.10	47.74	27%
Nb	26.48	2.05	8%
Mo	1.27	0.11	9%
Ag	0.32	0.10	32%
In	0.09	0.01	14%
Sn	4.39	0.39	9%
Sb	1.64	0.24	14%
Cs	10.97	1.04	9%
Ba	569.86	44.14	8%
La	37.62	6.77	18%
Ce	94.82	16.21	17%
Pr	9.92	1.72	17%
Nd	34.09	5.48	16%
Sm	6.71	1.03	15%
Eu	1.39	0.19	14%

	Mean (‰)	S.D.	RSD
Gd	5.82	1.00	17%
Tb	0.93	0.20	21%
Dy	5.51	1.34	24%
Ho	1.16	0.26	23%
Er	3.42	0.75	22%
Tm	0.49	0.10	20%
Yb	3.44	0.67	20%
Lu	0.54	0.12	21%
Hf	5.96	1.57	26%
Ta	2.28	0.36	16%
W	2.89	0.33	11%
Au	0.10	0.05	51%
Pb	14.19	1.79	13%
Bi	4.37	1.99	46%
Th	13.02	2.23	17%
U	2.97	0.51	17%

Table 7. Mean concentration, standard deviation and RSD for minor and trace elements in New Ohio Red Clay

	Mean	S.D.	RSD
SiO_2	65.12%	1.35	2%
Na_2O	0.41%	0.05	12%
MgO	1.58%	0.07	5%
Al_2O_3	19.02%	0.91	5%
K_2O	4.19%	0.22	5%
CaO	0.31%	0.11	37%
Fe_2O_3	8.04%	0.64	8%
TiO_2	1.12%	8.86	1%

Table 8. Concentration (%) and RSD for major element in New Ohio Red Clay

indication of the precision of the method. Table 7 present relative standard deviations (RSD) for each of the 58 elements measured using LA-ICP-MS and their associated mean values and RSD. Five elements (Cl, As, Ag, Au, and Bi) have RSD values over 30%. Two elements with poor precision ICP-MS measurements, As and Cl, are subject to both isobaric and polyatomic interferences. Isobaric interferences, when isotopes of different elements have overlapping masses, were avoided by selecting non-conflicting analytes (Pollard 2007). Polyatomic interferences result when molecular ions with the same mass to charge ratios form during analysis (May and Wiedmeyer 1998). The high temperature of the plasma disassociates atoms but they can then recombine in the region between the torch and the magnetic sector (Pollard 2007). Cl is poorly measured by ICP-MS because it prefers to form negative ions and $^{75}As^{+}$ is subject to interference from $^{40}Ar^{35}Cl^{+}$ (Evans and Giglio 1993). The relatively high variation displayed by Ag, Au, and Bi may be the result of low abundances in the sample matrix.Twenty-two trace elements have RSD values <15% and twenty have values from 15-26%. These values are consistent with variation arising from sample heterogeneity in ceramics and are generally comparable with RSD values obtained on New Ohio Red for similar studies at the Field Museum (eg. Sharratt, et al. 2009). Accuracy of the method can be assessed by comparing the mean concentration values obtained in this study with published data for New Ohio Red clay. Such comparisons show that most elemental concentrations for New Ohio Red obtained in this analysis overlap at 1-2 standard deviations with those from large NAA data sets from Glascock cited in Kuleff and Pernicka 2002:140) and Bishop (cited in Munita, et al. 2001:194).

GROUP IDENTIFICATION

Source groups were identified quantitatively using cluster analysis and principle components analysis (PCA). An initial PCA was run for all elements except the five with RSDs > 30% in Ohio Red Clay (Cl, As, Ag, Au, Bi), to identify the elements with the highest loadings and reduce noise in the data set. In this initial run the first 10 principle components describe 90.06% of the variance, excluding major elements in the next PCA improved this to 92.32%. Element loadings were examined in scree plots to identify the best elements for differentiating source groups and revealing structure in the data set. Scree plots display the loading factors for each element in a given PC and allow the identification of extreme values, both high and low, and visual assessment of the differences in magnitude for these element loading scores. This process was repeated three times to define the element set explaining the most variation in the least number of principle components. The cumulative variance explained by each element set is reported in Table 9.

Initial inspection of PC biplots suggested that there were three main point clusters. Based on visual inspection of the PCA biplots and dendrograms from hierarchical clustering, each data point was assigned to one of three groups. These were then refined by examining probabilities for group membership based on Mahalanobois distance. Since probabilities of group membership based on Mahalanobis distance require large group size, the method is ineffective for identifying small point clusters. After each round of reassignment, biplots for the first three principle components were reexamined for the presence of any small point clusters and qualitatively assess the goodness of fit of group assignments. Twenty four samples could not be assigned conclusively to any group. Samples that switched group membership depending on the element set used and samples with < 1% probability for membership in any group were left unassigned. Most unassigned samples fall in or near the overlap between 90% confidence intervals for MG1 and MG3 but one data point consistently plots as an outlier (Figures 27-28). After identifying the three macrogroups, the process was repeated to examine within-group structure for the two large groups (MG1 and MG3) and identify subgroups. PCA and HCA analyses were performed using MURRAP statistical routines v 8.8 with the Gauss v8.0 runtime environment. The program is freely available at http://archaeometry.missouri.edu.

MACROGROUP 1

MG 1 is the largest with 107 members, representing 54% of the total assemblage. MG1 can be further divided into three subgroups which differ in 12-22 elemental concentrations. The least distinct subgroup is 1d which only differs from 1b in two elements (B, Mo) and nine of the fourteen REEs. Mean concentrations for all other subgroup pairings differ significantly in at least seventeen of 42 trace elements.

At PA1, 34% of pottery is from group 1a but other MG1 samples only account for another 6%. Additionally, MG1 sherds are not equally represented over time at this site. In the two oldest layers, 26% or less of pottery belongs to this source group. In layer three, macrogroups one and three are balanced, representing 36% and 40% of the total sample respectively. In the most recent stratigraphic layer, MG1 dominates (82% of all sherds). At BN1, 43% of samples were identified as group 1b and an additional 36% of samples belong to other

% variance explained

		PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	Elements
1	Variance	44.82	15.78	10.06	7.46	3.60	2.68	1.89	1.59	1.46	1.34	SiO2, Na2O, MgO, Al2O3, P2O3, K2O, CaO, Fe2O3, TiO2, Li, Be, B, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo, In, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
	Cumulative		60.60	70.66	78.12	81.72	84.40	86.29	87.88	89.34	90.68	
2	Variance	47.79	15.98	9.23	7.23	2.98	2.72	2.05	1.76	1.45	1.20	Li, Be, B, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo, In, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pb, Th, U
	Cumulative		63.77	73.00	80.23	83.21	85.93	87.98	89.74	91.19	92.39	
3	Variance	44.65	15.06	10.29	7.45	4.03	3.30	2.40	2.13	1.80	1.49	Li, Be, Sc, V, Cr, Mn, Co, Ni, Zn, Rb, Sr, Y, Zr, Nb, Mo, Sb, Cs, Ba, La, Ce, Pr, Nd, Ta, W, Pb, Th, U
	Cumulative		59.71	70.00	77.45	81.48	84.78	87.18	89.31	91.11	92.60	
4	Variance	34.28	23.13	12.31	7.92	4.74	4.36	3.36	2.63	1.74	1.35	Li, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Mo, Sb, Cs, U
	Cumulative		57.41	69.72	77.64	82.38	86.74	90.1	92.73	94.47	95.82	

Table 9. Variance explained by different element sets in PCA

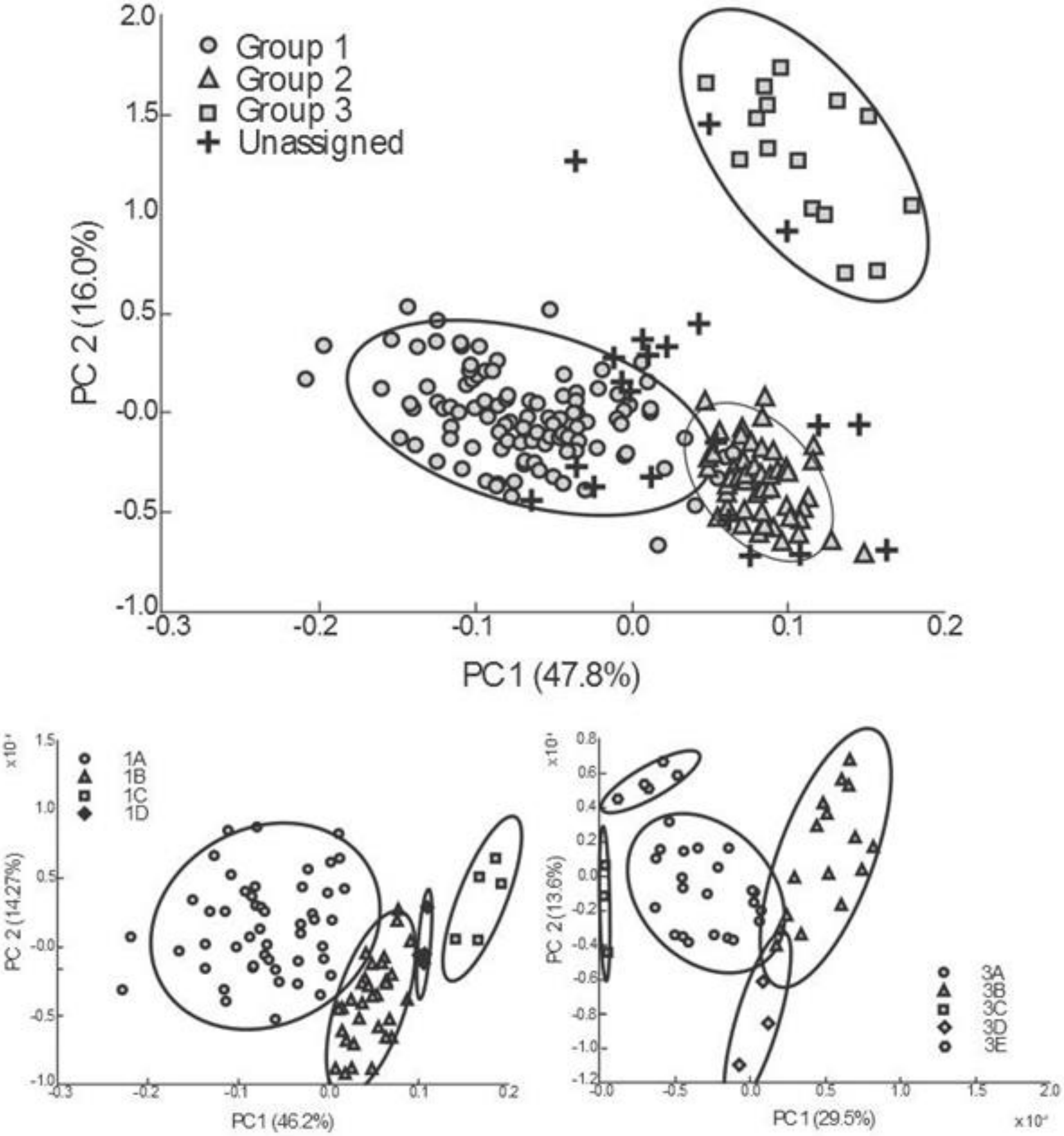

Figure 27. Plots showing macgrogroups and subgroups. Elipses represent 90% confidence intervals.

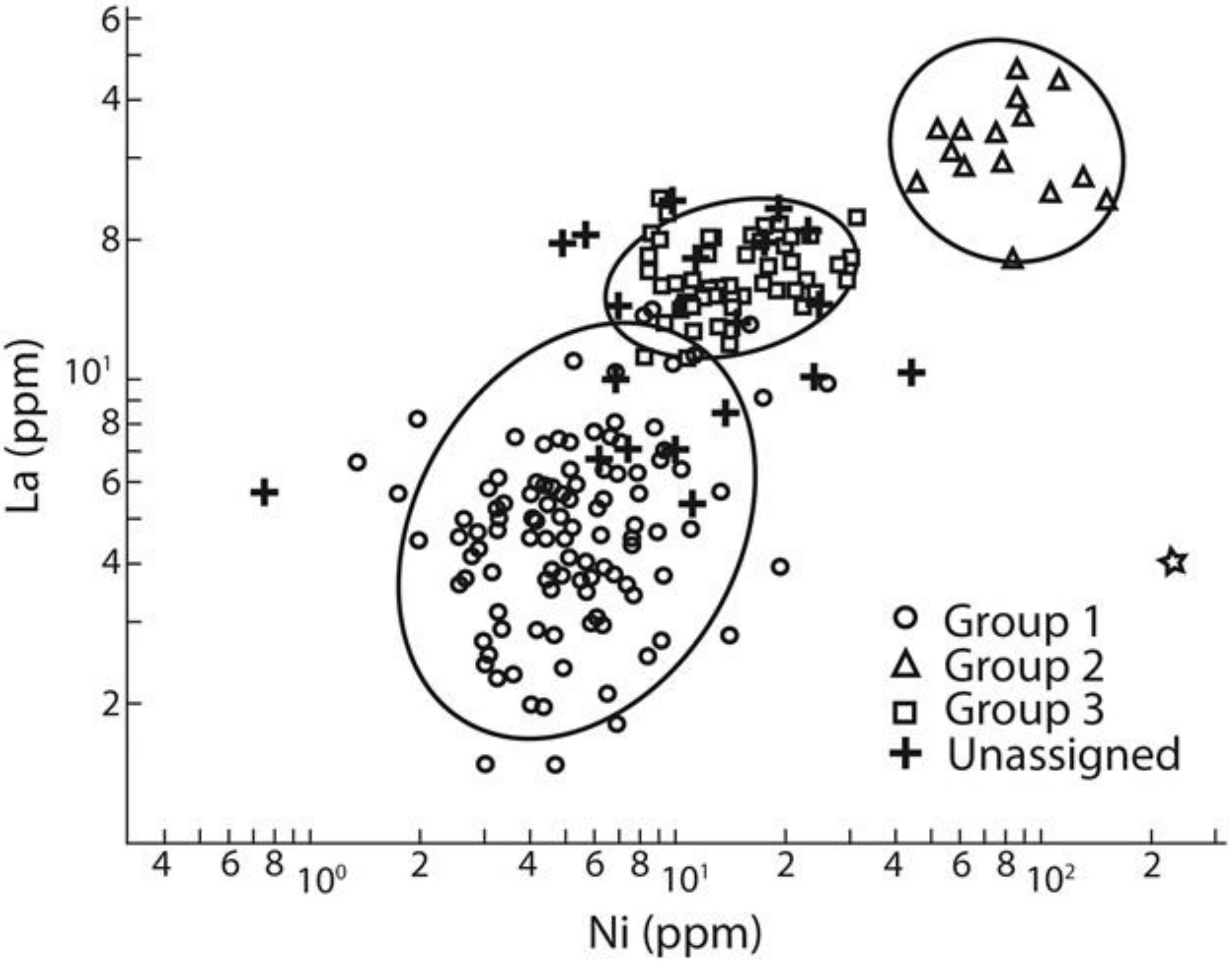

Figure 28. Biplot showing Macrogroups, unassigned samples, and outlier. Elipses represent 90% confidence intervals.

MG1 subgroups. Group 1b is the most abundant in all layers sampled ranging from 33-56% of the assemblage. In the absence of well characterized reference materials for all potential source groups it is not possible to determine the spatial scale at which subgroups represent different clay raw material sources. They may represent clay sources in different island groups, on different islands within a group, different clay sources on a single island.

MACROGROUP 2

MG 2 includes 15 archaeological samples plus one modern sherd produced at Ouw, Saparua. Sherds from this group are more abundant at BN1 (17%) than at PA1 (2%). Over time, MG2 sherds increase in frequency, peaking in Layer 10 at BN1 and then declining again. SiO2 concentration is similar to MG1 but it is relatively enriched in K_2O and most of the trace elements. Three elements (Rb, Cs, Ba,) are of particular interest. Whitford and Jezek (1979) found that cordierite bearing lavas in Ambon are enriched in these elements, a pattern they interpret, along with differences in $^{87}Sr/^{86}Sr$ ratios as the result mixing of mantle material and acrustal component. Due to the complex nature of clay deposit formation, we cannot expect exact agreement between trace element concentrations in bedrock material and clay deposits. However, since bedrock will constitute the main parent material for clays, when this material displays meaningful patterning in trace element abundances across the region of interest, clays should also mirror this patterning. The Ambon-like enrichment in these elements is consistent with an origin in the Ambon-Lease group. Furthermore, the single modern sherd, collected at Ouh village on Saparua and produced using clay from a local deposit plots within this group. Earthenware pottery produced at Ouw is known for the use of a distinctive and readily identifiable foraminiferous temper. All group two sherds have this temper type and it is not present in sherds from the other macrogroups.

MACROGROUP 3

A total of 54 sherds belong to MG 3. All come from PA1 where they account for 43% of all sherds in the sample. MG3 is the dominant group in the earlier layers of the site shifting abruptly from an average frequency of 63% below layer 3d to an average of 9% in more recent layers. MG 3 clays have the lowest SiO2 concentration of all groups but are enriched in Al_2O_3 and the incompatible trace elements Sr, Zr, Sm, Eu, Gd, Tb, Dy, Ho, Er, and Hf. The high

		1A	1B	1C	1D	2	3A	3B	3C	3D	3E
BN1	L8	12%	56%	8%	0%	8%	0%	0%	0%	0%	0%
	L9	4%	33%	8%	13%	17%	0%	0%	0%	0%	0%
	L10	8%	38%	0%	4%	23%	0%	0%	0%	0%	0%
PA1	L2	74%	0%	4%	0%	0%	4%	0%	0%	0%	0%
	L3	29%	0%	0%	0%	2%	19%	12%	0%	2%	2%
	L4	14%	0%	0%	0%	4%	36%	7%	11%	4%	0%
	L6	26%	0%	0%	0%	0%	48%	19%	0%	0%	0%
	n	49	32	5	4	14	32	12	3	2	1

Table 10. Relative abundance of source groups by site and layer.

concentration of Sr particularly stands out at 2-4 times the concentrations found in MG1 or MG3. While ^{87}Sr/^{86}Sr vary significantly in the volcanic across the Banda arc, Sr concentrations do not display this variation (see Vroon, et al. 1993). Two larger subgroups and two smaller groupings of samples can be distinguished in Macrogroup 3. These may represent different sources on the same island or sources on different islands with similar geological characteristics like Pulau Ay and Pulau Rhun to the north.

SOURCE GROUP PROVENANCE

Applying the criterion of abundance, it can be inferred that the samples comprising MG1 are made from clays local to the Banda Islands. In the absence of well characterized reference materials for all potential source groups it is not possible to determine the spatial scale at which MG1 subgroups represent different clay raw material sources. They may represent clay sources on different islands within the group, different clay sources on a single island, or different parts of a large single clay source. But comparison with known patterns of geochemical variation permits some speculation. In the central islands clays will derive primarily from the weathering of volcanic bedrock and deposition of volcanic ash with eruptions. Clays on outer islands will also contain this airborne material but because their bedrock is marine carbonate, they should differ in some elements. Most notably, different rare earth element (REE) profiles can be expected for limestone vs volcanic islands because marine carbonates tend to incorporate REEs in proportion to their concentration in seawater. In addition, REE profiles from different volcanoes across the Banda arc display variation that permits speculation as to the provenance of source groups.

The REEs are present in seawater at very low concentrations as particulates. REEs have a residence time much shorter than ocean mixing time, so they are heterogeneously distributed in seawater (McLennan 1989). Seawater chondrite or shale normalized REE profiles display a characteristic negative Ce anomaly. This is thought to be because while the Lanthanides are primarily trivalent, Ce^{3+} can be oxidized to Ce $^{4+}$. Biogenic carbonates formed in equilibrium with seawater preserve the seawater REE profile including this negative Ce anomaly. Ce/Ce*is a measure of the strength of the anomaly calculated as:

$$\mathrm{Ce/Ce^*}=\frac{Ce_N}{\sqrt{(La_N\times Pr_N}}$$

Likewise the strength of Eu anomalies is given by:

$$\mathrm{Eu/Eu^*}=\frac{Eu_N}{\sqrt{(Sm_N \times Gd_N)}}$$

In addition to negative Ce anomalies, biogenic carbonates tend to be enriched in the heavy rare earth elements (HREE) relative to the light rare earth elements (LREE) because the former are less readily scavenged in the formation of manganese nodules (Brookins 1989). Clays formed primarily from weathering of volcanic material should have a very different REE profile from those originating in marine environments. Vroon (1992) showed that across the active

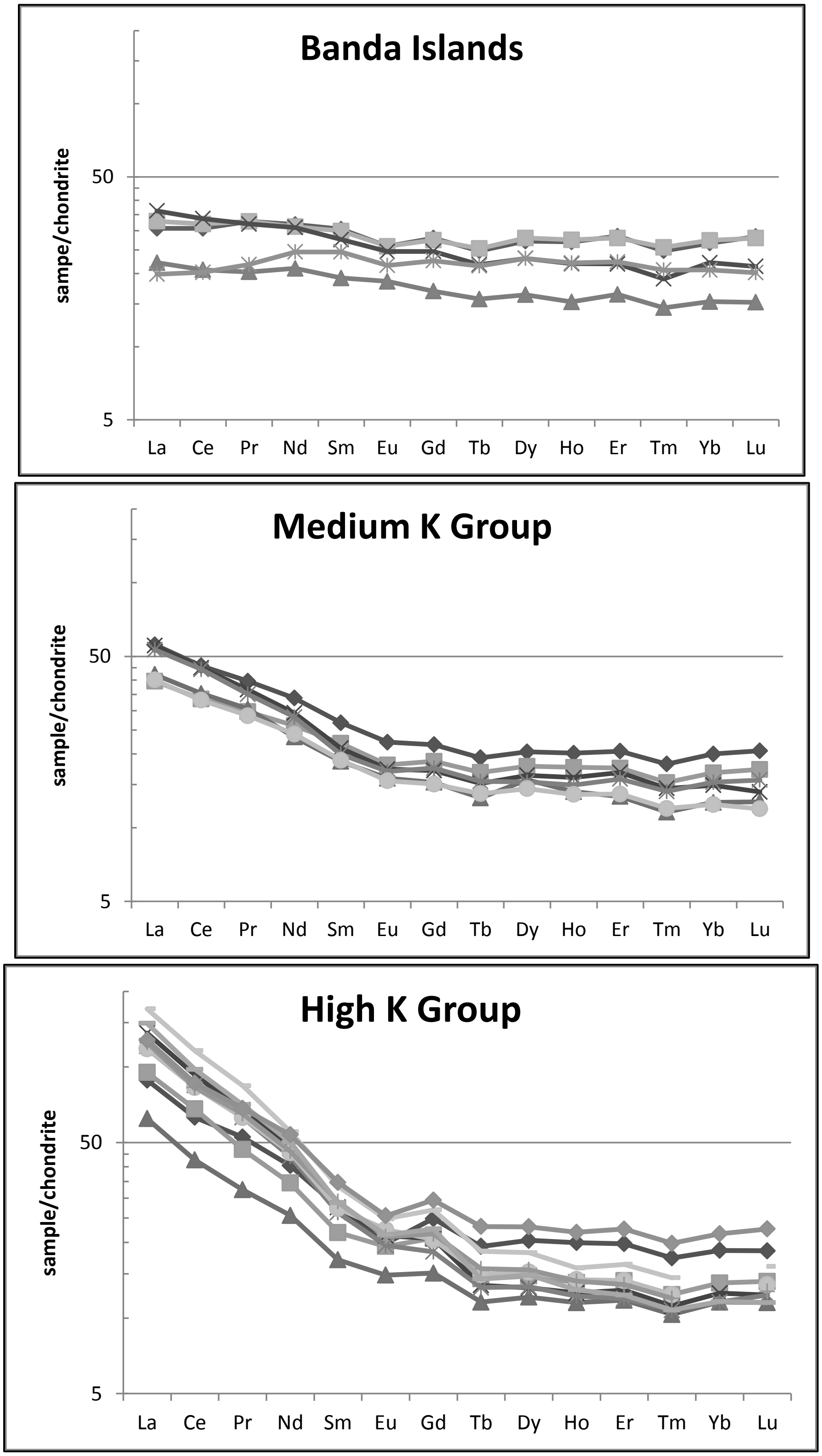

Figure 29. Chondrite normalized REE plots for Banda Islands volcanics.
Medium-K group includes Manuk and Serua, High-K group includes Nila, Teun, and Damar.REE concentrations (‰) from Vroon (1992) are normalized to C1 chondrite values from Anders and Grevesse (1989:Table 1).

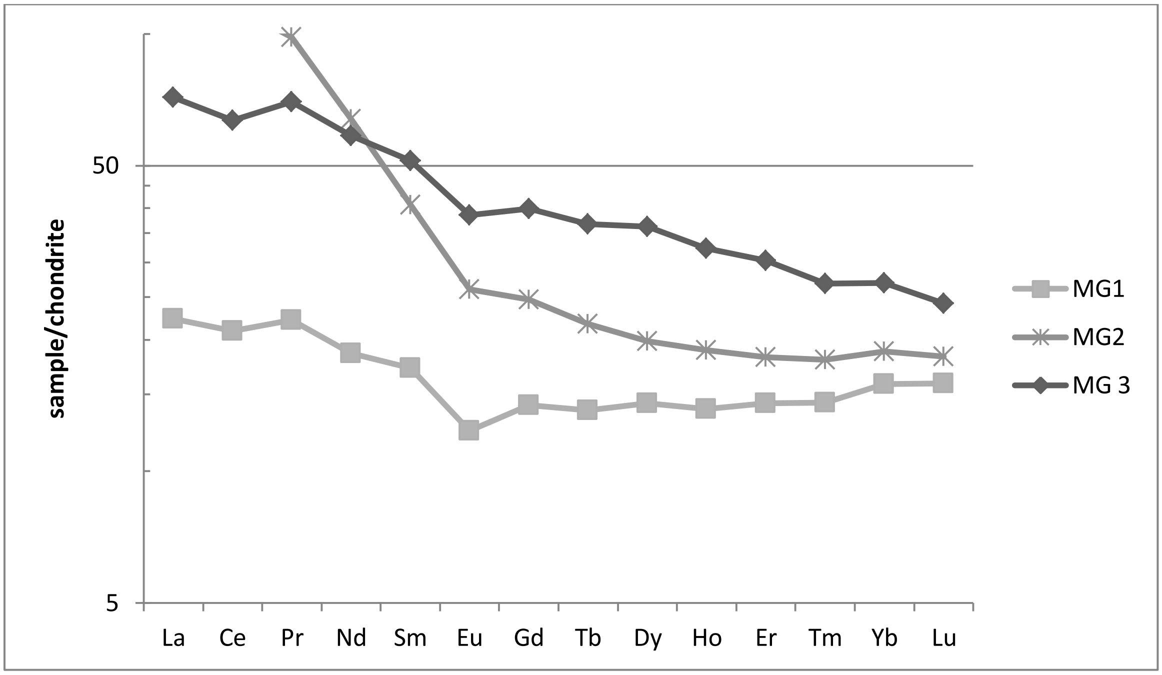

Figure 30. Average chondrite normalized REEs for archaeological samples. C1 chondrite values from Anders and Gervesse (1989: Table 1).

portion of the Banda Arc LREE of volcanic rock and sediments are enriched relative to HREE and the degree of enrichment increased from NE to SW (Figure 29).

Average REE profiles for source groups and Banda arc volcanics are presented in Figure 25. MG1 shows a flat REE profile ([La/Yb]N 0.66-2.97) with slight negative Eu anomalies (Eu/Eu*=0.62-1.62). Within group 1 subgroups show slight variation in profiles. Subgroups vary in the abundance of REEs; 1a has the lowest and most variable REE abundances (ΣREE=57.56-252.17), the smoothest curve, no apparent Ce anomaly and only a slight Eu anomaly (Ce/Ce*= 0.49-1.87; Eu/Eu*=0.65-1.62). Subgroups 1c and 1d have higher REE abundances (ΣREE= 466.71-620.09 ppm and 346.65-369.27 ppm respectively), exhibit stronger Eu anomalies (Eu/Eu*=0.77-0.81 and 0.62-0.78 respectively), and display slight negative Ce anomalies (Ce/Ce*=0.74-0.84 and 0.82-0.96 respectively).

All subgroups within MG3 show a very different REE profile from those in MG1. LREE are strongly enriched relative to HREE ([La/Yb]N=1.47-6.13) and REE are more concentrated (ΣREE=606.73 ppm). This profile mirrors those of the High K segment of the arc. Two subgroups, 3b and 3e also show slight negative Ce anomalies (Ce/Ce*=0.60-0.95 and 0.68 respectively) suggesting a point of origin on a marine limestone island.

The flat REE profiles and slight negative Eu anomalies of MG1 are consistent with a Banda Islands origin for MG1 clays. Within the active Banda arc, only the Banda group itself has such flat profiles with groups to the SW having increasingly enriched LREEs. The distribution of samples between the two sites in this study is also consistent with MG1 representing sources from within the Banda Islands. This macrogroup is the only one that is represented at both sites and in every level. Within MG1, subgroup 1A is the most abundant at PA1 but is relatively scarce at BN1. Subgroup 1B is more common at BN1 and completely absent from PA1. It seems reasonable to conclude that 1A may derive from local sources on Pulau Ay while group 1B is from a source on Banda Neira or Banda Besar.

MG2 and 3 have much steeper REE profiles indicating they are most likely exotic to the Banda group. As discussed above, a probably point of origin for MG2 is Saparua island or a nearby island based on the fact that a modern Saparua sherd plots with this macrogroup and the presence of a distinctive temper type in many of these sherds. This cannot be confirmed with REE profiles as these elements were not measured in previous geochemical studies of the Ambon Lease islands. MG3 REE profiles are most similar in shape to those of the medium-K group of Banda arc volcanics (Manuk and Serua). In absolute terms REE are more abundant in the archaeological samples than in volcanic rock but this would be expected as clays tend to concentrate REEs. However, since they do so without any known fractionation, the similar profile is suggestive. Since geochemical data comparable to that for the active Banda arc are not available for other parts of Central and South Maluku, Seram, Kei and other island groups cannot be excluded as sources for MG3. Based on REE profiles, however, it is unlikely that these are from the Banda group itself and the source area for MG3 seems to include both limestone and volcanic islands since some MG3 subgroups display a moderate negative Ce anomaly.

SOURCE DIVERSITY MEASUREMENT AND RESULTS

Source diversity is an easily measured variable, which can be used to quantify the degree of connectedness in an exchange system. Diversity encompasses two dimensions of variability: richness (the number of sources represented in an assemblage and evenness (the distribution of samples across classes). Richness is a simple and straightforward count of the number of sources represented but evenness (and therefore diversity) can be measured in several different ways. Both Simpson's Index and Shannon index are calculated here and presented in Table 10 for Macrogroups only, and Table 11 for all groupings.

There is good agreement between richness and diversity measures, all of which show that the greatest source diversity occurs at PA1 in Layer 4. Layer 3 also has high richness and evenness values compared to the earliest and latest parts of the sequence. It is important to note that the sample sizes for PA1 layer 3 is greater than for most other layers. Richness and evenness measures are both susceptible to sample size effects but the data show only a weak correlation between sample size and richness (See Figure 26).

The diversity measures show that the exchange networks linking the people of the Banda Islands to each other and to populations in other island groups were not static in prehistory. Layer 6 at PA1 is the earliest evidence of Neolithic occupation in Central Maluku. This layer

Site	Layer	Richness	Simpsons Index (D)*	Simpsons Index of Diversity (1-D)	Simpson's Reciprocal Index (1/D)	Shannon Index (H')	Shannon Evenness (EH)
BN1	8	2	0.834	0.166	1.199	0.128	0.426
	9	2	0.700	0.300	1.429	0.201	0.666
	10	2	0.584	0.416	1.711	0.255	0.845
PA1	2	2	0.920	0.080	1.087	0.073	0.242
	3	3	0.456	0.544	2.191	0.350	0.734
	4	3	0.591	0.409	1.693	0.293	0.614
	6	2	0.580	0.420	1.724	0.258	0.855

Table 11. Richness, Evenness and Diversity for Macrogroups

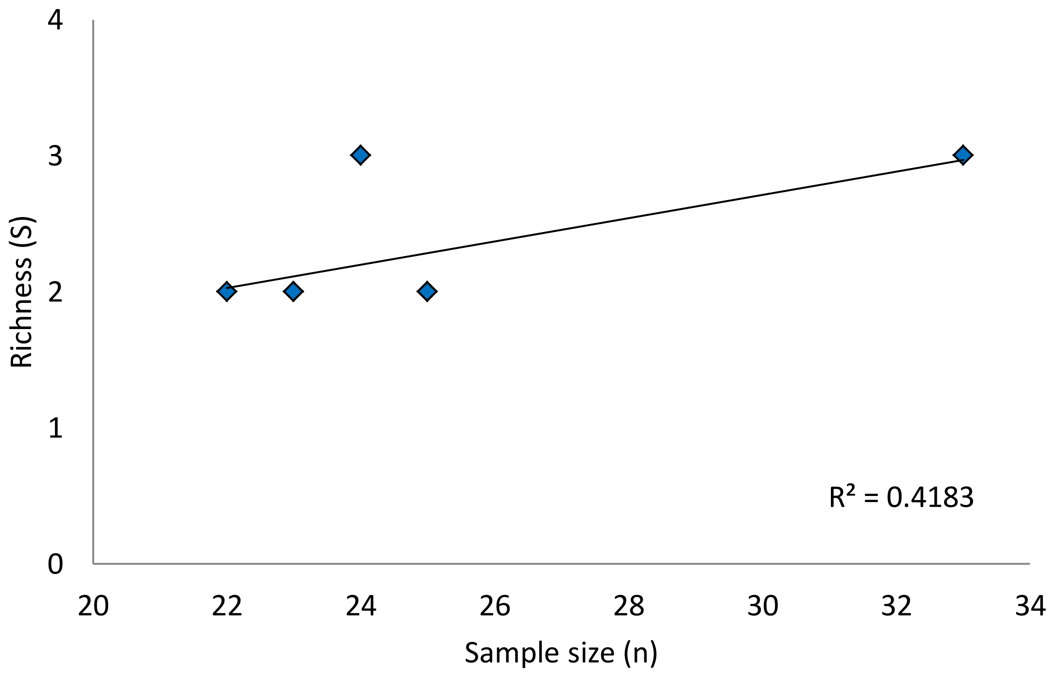

Figure 31.Richness and sample size for macrogroups

provided dates from 3078-3550 cal BP. During this initial occupation of the site, pottery from three different sources was used and discarded. While this study cannot conclusively assign these sources to specific locations, they most likely include a single Banda Islands source, probably on Pulau Ay, and two related sources located somewhere outside the Banda Islands. Richness is lower in this layer than later in the sequence but the sources are represented more evenly than in any other layer at PA1 so diversity is moderate.

Richness and diversity increase in subsequent layers at PA1 while evenness declines slightly. In layer 4, pottery from 6 different clay sources was made and used. This included sherds from the probably local Pulau Ay source, a single sherd tentatively sourced to a location in the Ambon-Lease Islands to the Northeast, and four unknown sources interpreted as outside the Banda Islands. Diversity is significantly higher in layer 4 than in layer 6 ($t=2.369$, $\nu=30$, $P=0.025$).

Layer 3 is similar to layer 4 with a small amount of local pottery, a single sherd from Ambon-Lease, and four unknown sources from outside the Banda group. Three of these four are the same as represented in Layer 4. These two layers were deposited between 3078 and 2370 cal BP. There is no significant difference between diversity (Shannon-Weaver) for these two layers ($t=0.342$, $\nu=44$, $P=0.734$).

At the end of the PA1 sequence (layer 2) only 3 source groups are represented. All but one sample are from MG1 subgroups and 74% of samples are from group 1A, the likely Pulau Ay source. Diversity is significantly lower than in layer 3 ($t=-4.399$,$\nu=44$, $P=.000068$). In fact, this layer has the lowest diversity and evenness of any tested.

Site	Layer	Richness	Simpsons Index (D)*	Simpsons Index of Diversity (1-D)	Simpson's Reciprocal Index (1/D)	Shannon Index (H')	Shannon Evenness (E_H)
BN1	8	4	0.457	0.543	2.188	0.433	0.719
	9	5	0.341	0.659	2.935	0.652	0.933
	10	4	0.399	0.601	2.508	0.477	0.791
PA1	2	3	0.823	0.177	1.216	0.160	0.335
	3	6	0.275	0.725	3.635	0.602	0.773
	4	6	0.262	0.738	3.818	0.635	0.816
	6	3	0.363	0.637	2.752	0.442	0.927

Table 12. Richness, Evenness, and Diversity including subgroup divisions

At BN1, the oldest stratigraphic layer (layer 10) has been AMS radiocarbon dated to 1180-970 BP. Four different raw material sources were identified in this layer. These include three from MG1 and MG2. Most of the MG1 samples are from subgroup 1B which, as noted above, is well represented in all BN1 layers and completely absent at PA1. This most likely represents a source used for local manufacture located on Banda Neira or across the sheltered harbor on Banda Besar. Sherds from MG2, the Ambon-Lease source group, are more abundant in layer 10 than in any other context. Source diversity in this layer is moderate (H'=0.477) with a similar level of diversity to PA1 layer 6. In fact there is no significant difference in the Shannon-Weaver index between these two layers despite their being separated by over 2000 years ($t=0.443$, $\nu=29$, $P=0.661$).

In layer 9 richness, evenness, and diversity are all higher than in layer 10. Five different source groups are represented including all four MG1 subgroups and MG2. The Shannon-Weaver diversity index is not significantly different between layer 9 and layer 10 (t=-1.458, ν=37, P=0.153).

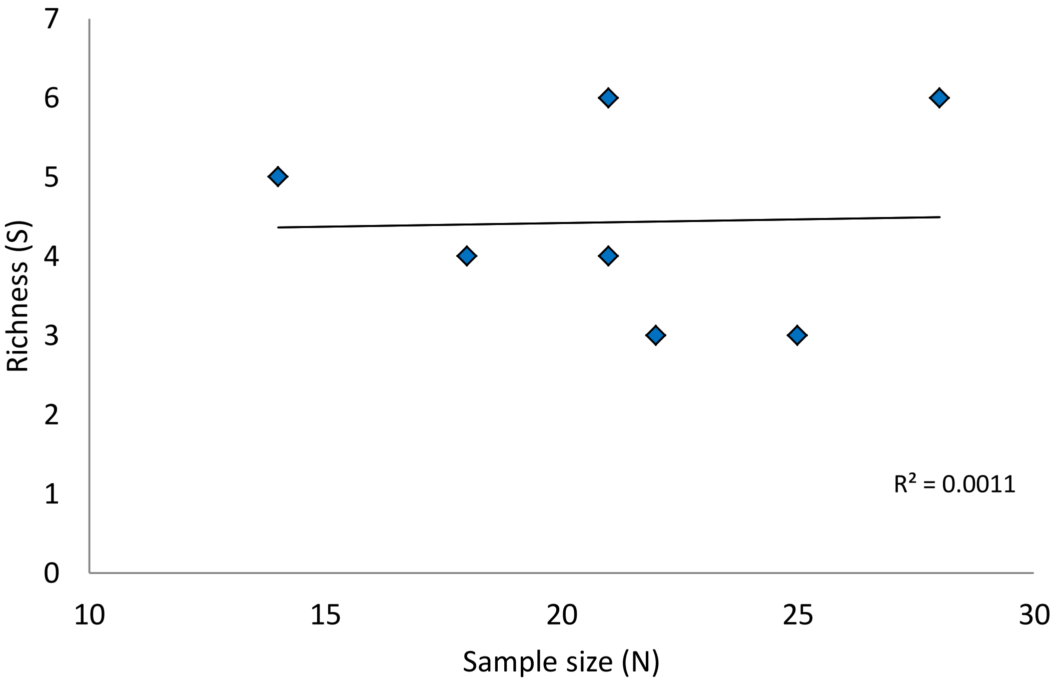

Figure 32. Richness and sample size for all groupings

SUMMARY

Statistical analysis of LA-ICP-MS results was used to identify source groups for clay raw materials of earthenware ceramics from Banda Islands archaeological sites. Three Macrogroups were identified and the two larger groups can be further separated into several subgroups. The largest macrogroup (MG3)is consistent with Banda Islands clays both by the criterion of abundance and by analysis of its geochemical properties in comparison to local volcanic bedrocks. The least abundant source group (MG2) is likely from the vicinity of Saparua Island to the north. Provenance of the remaining source group (MG3) remains undetermined but could be located further South along the Banda Arc.

The distribution of source groups varies between the two sites examined here. BN1 has no sherds from MG3, more subgroups of MG1 are represented, and MG2 sherds are more abundant. Incontrast, only a single MG1 subgroup is represented at PA1, MG2 sherds are rare, and MG3 sherds are very abundant, especially in the earlier levels of the site. These early layers have the greatest source diversity. Initially diversity increases at PA1 peaking around 3300-3000 BP. Around 2000 BP source diversity declines and MG3 sherds become scare after 2710-2364 BP. At BN1, where diversity is driven primarily by the representation of local MG1 subgroups, diversity is less variable over time.

CHAPTER 7. STABLE ISOTOPE ANALYSIS

INTRODUCTION

Sus Scrofa are the most prevalent mammalian fauna in Banda Islands archaeological sites from the pre-Islamic period. Domesticated pigs appear across ISEA and the Pacific beginning around 3500 BP and they have traditionally been considered a major component of either a "Neolithic package" or a "portmanteau biota" in these regions. Ethnographically, pigs often played an important role in ritual exchange systems linking, for example, the New Guinea highlands and the coast (Rappaport 1968). One aim of this study was to investigate whether pigs in the Banda Islands were a locally raised subsistence item or a significant exchange item. To address this question, stable isotope analysis of pig teeth was used to differentiate source groups and examine change over time in source diversity.

Isotopes are different species of an element that can be radioactive, stable, or radiogenic. Archaeological applications of radioactive isotopes relate to dating and will not be discussed here but both stable and radiogenic isotopes can be sensitive indicators of one or another aspect of the environment in which an individual lived and these signatures leave traces in bones and tooth enamel. These methods are relatively new in archaeology but since the 1990s they have been extremely productive for reconstructing aspects of individual behavior in the past and the environmental contexts in which they took place.

Isotope analysis of pig teeth was employed in this research to discriminate between source groups for pigs to enable measurement of source diversity over time. Because they can vary depending on different environmental parameters, it was expected that combining isotopic ratios, using the methodologies frequently employed for artifact provenance through trace element analysis, could potentially discriminate pig source groups. In this chapter I review the principles behind isotope analysis, focusing especially on provenance analysis and diet reconstruction, present the results of heavy (Sr, Pb) and light (C, O) isotope analyses in this project, and discuss the implications of these results. Since stable (C, O) and radiogenic (Sr, Pb) isotope analyses have different foundations, these methods will be discussed separately below.

PRINCIPLES AND APPLICATIONS OF STABLE ISOTOPE ANALYSIS IN ARCHAEOLOGY

Stable isotope analyses have been employed by archaeologists in the Pacific and around the world for climate reconstruction (see Chapter 4 for discussion), diet reconstruction (S. H. Ambrose, et al. 2003; 1997; S. H. Ambrose and Norr 1997; Bosl, et al. 2006; Jones and Quinn 2009; Krigbaum 2005; Pate, et al. 2001; Pechenkina, et al. 2005; Valentin, et al. 2006; Valentin, et al. 2010), and to study mobility and human migration (Bentley, et al. 2005; 2007; Shaw, et al. 2010; 2011). Different isotopes of a given element contain different numbers of neutrons in their nuclei such that they have the same atomic number but different atomic masses. Most chemical properties of isotopes remain similar but because of mass differences they vary with regard to the strength of bonds they form and their reactivity (Schoeller 1999). Lighter isotopes form weaker bonds and react more readily than heavier isotopes, leading to mass fractionation in physical processes like evaporation and during chemical reactions, including those involved in photosynthesis and metabolic processes. When the controls on fractionation are well understood, isotopic abundances can be used to reconstruct details about those processes and reactions that have archaeological significance.

For the most common elements (H, C, N and O) the lighter isotope is far more abundant than the heavier so changes in absolute abundance of these isotopes created by mass fractionation are very small. For ease of measurement and comparison, ratios rather than abundances are used and these ratios are quantified as variation from a known standard and calculated as:

$$\delta(‰) = \left[\frac{R_{sample}}{R_{std}} - 1\right] \text{x}\, 1000$$

Where R_{sample} is the isotopic ratio of interest in the sample, and R_{std} is the isotopic ratio of the reference material. Carbon ratios are reported relative to the Vienna Pee Dee Belemnite standard (VPDB) and $^{18}O/^{16}O$ relative to either standard mean ocean water (SMOW) or VPDB. In the discussion below $\delta^{18}O$ values reference the VPDB standard but data tables provide $\delta^{18}O$ relative to both VPDB and SMOW to facilitate comparison with other studies. Values were initially calculated relative to VPDB and $\delta^{18}O$ vs. SMOW was derived using the conversion provided by Coplen et al. (1983:237):

$$\delta^{18}O_{SMOW} = 1.03091 \times \delta^{18}O_{VPDB} + 30.91$$

Bone apatite, bone collagen, and tooth enamel all record stable isotope signatures relevant to individual life histories and many studies make use of all of these materials. There are, however, some important differences. First, tooth enamel and bone preserve isotopic signatures reflecting different periods of an individual's life. Tooth enamel forms early, beginning before birth for fast developing mammals like pigs and is not subsequently remodeled. Therefore, isotopic ratios in individual teeth present a snapshot of the diet and environment during this brief period of early life. In contrast, the body repairs bone tissues throughout an individual's life, so isotopic ratios in bone apatite and collagen reflect a more time averaged isotopic signature, reflecting the diet and environment in which they spent their last few years of life. These differences in the period of life represented by tooth and bone isotopes can be exploited to build a detailed picture of individual life history. For example, comparison of tooth enamel and bone signatures from the same individual can lead to the identification of instances of migration and in humans has allowed the demonstration of matrilocal residence patterns (Bentley, et al. 2005; Ericson 1985). Since human tooth development is relatively slow, comparison of different teeth from the same individual can give an even more detailed picture of changes in diet or location over the course of the first 18 years or so of a person's life.

A second important difference between isotopic signatures in collagen and apatite pertains to diet reconstruction. Collagen preferentially incorporates carbon from proteins in the diet whereas apatite records whole diet signatures. Measurement of both collagen and apatite can be used to model the relative contributions of different types of food to the diet as well as different types of plants in a wide range of contexts (e.g. Eerkens, et al. 2013; Pechenkina, et al. 2005; Roberts, et al. 2013; Sullivan and Krueger 1983), allowing quantitative analysis of past diets not possible through traditional faunal analysis.

CARBON ISOTOPES

Carbon isotopes, often in combination with nitrogen isotopes, have seen widespread use in diet reconstruction since the 1980s. The foundation of stable isotope analysis for diet reconstruction is the simple fact that different dietary resources systematically vary in the ratios of certain stable isotopes and this variation is passed on to (and preserved in the tissues of) consumers. Carbon enters the foodchain when CO_2 is absorbed by plants and used in photosynthesis. Plants use one of three different photosynthesis pathways to fix carbon in their cells: C_3, C_4, or crassulacean acid metabolism (CAM). In these chemical reactions the lighter carbon (^{12}C) always reacts more readily than the heavier (^{13}C), but the reactions involved in forming the C_3 vs C_4 molecules discriminate against the heavy isotope to different degrees. Therefore each photosynthetic pathway results in different ranges of $\delta^{13}C$ values in plant tissues. C_3 plants have lower $\delta^{13}C$ values, averaging -26.5‰ globally, compared to an average of -12.5‰ for C_4 plants (van der Merwe and Vogel 1978). C_3 plants also have a greater range of variation than C_4 plants. These ratios are then passed along to consumers but fractionation due to metabolic processes must be accounted for by applying an offset (fractionation factor) for the tissue of interest (S. H. Ambrose and Krigbaum 2003). Offsets vary between carnivores, omnivores, and herbivores and controlled feeding experiments have shown some variation between species within these groups that may relate to microorganisms in the digestive track (Cerling and Harris 1999). Experimental data have demonstrated that *Sus Scrofa* tooth enamel is enriched by 13.3-12.3‰ relative to diet (Passey, et al. 2005).

The majority of terrestrial and aquatic plants use the C_3 pathway whereas a smaller range of arid adapted plants use the C_4 pathway (Krigbaum 2003). In tropical Island Southeast Asia, nearly all endemic flora belong to the C_3 group but some variation in $\delta^{13}C$ values can still be expected depending on the consumption of marine foods and the relative density of forest cover. Although most are C_3 plants, marine flora $\delta^{13}C$ values are enriched compared to terrestrial C_3 plants, averaging -19‰ (vs. -26.5‰), because carbon in this environment derives from dissolved bicarbonates rather than an atmospheric sources (S. H. Ambrose, et al. 1997). Diets with a significant marine food component tend to have less negative $\delta^{13}C$ values than those without (S. H. Ambrose 1993). This may be especially true for diet incorporating seagrasses, frequently collected today on beaches adjacent to BN1 and a short distance from PA1. Seagrasses have been shown to have $\delta^{13}C$ values at the high end of the C_3 range (S. H. Ambrose, et al. 1997).

In tropical forests, the canopy effect may also lead to differences in $\delta^{13}C$. Carbon ratios vary at different levels within a dense forest because of differential inputs of atmospheric CO_2 vs. biogenic carbonates and different levels of irradiance (Krigbaum 2003). In these environments $\delta^{13}C$ decreases along a gradient from the upper canopy to ground level and plants in closed forest environments have more negative $\delta^{13}C$ values than those in more open, cleared environments. Therefore, when a primarily C_3-based diet can be assumed, variation in $\delta^{13}C$ can indicate environmental changes in the area where consumers fed. For example, in Borneo, Krigbaum (2001) demonstrated that C_3 plants collected from environments with these different conditions varied in their carbon isotope ratios. Since it is unlikely that C_4 resources played a significant role in human diet in this environment, increasing $\delta^{13}C$ of humans from Niah cave burial contexts from the pre-Neolithic to Neolithic period probably reflect a change in the forest conditions in which plant foods grew from closed to a more open canopy (Krigbaum 2001, 2003).

OXYGEN ISOTOPES

The most widespread application of oxygen isotopes has been in paleoclimate reconstruction but $\delta^{18}O$ of human bones and teeth have also been used to identify instances of migration and mobility (Eerkens, et al. 2014; Laffoon, et al. 2014; Laffoon, et al. 2013; Price, et al. 2014; Turner, et al. 2009; Wright 2012). These applications are based on the fact that mass-dependent fractionation of oxygen occurs during phase transitions such that vapor $\delta^{18}O$ is depleted relative to liquid or solid phases. This is the case because isotopically light water evaporates more quickly, while isotopically heavier water condenses more readily. Therefore as condensation proceeds, liquid water is progressively enriched in 18O and water vapor is increasingly depleted in ^{18}O. In teeth, $\delta^{18}O$ records a history of the isotopic composition of water ingested by an individual during the time of enamel formation. If there is geographic patterning in $\delta^{18}O$ within the region of interest, measurement of $\delta^{18}O$ in teeth and bones can provide information about the location of origin of different individuals. In the tropical Pacific variation in $\delta^{18}O$ is low, but slight differences have been observed with changes in elevation and distance from the coast. Some variation may also be expected if drinking water in different areas comes from different sources (lakes, streams, wells, rainwater collection).

STRONTIUM ISOTOPES

Stronium (Sr) is a pervasive element found in sedimentary, metamorphic, and igneous rocks, groundwater, seawater, rainwater, soils, plants, and animals. It has three stable, naturally occurring isotopes ^{84}Sr (~0.56%), ^{86}Sr (~9.87%) and ^{88}Sr (~82.53%). A fourth, naturally occurring isotope, ^{87}Sr (7.04%) is radiogenic, formed as the product of β-decay of ^{87}Rb. The ratio of the radiogenic isotope to a non-radiogenic isotope (^{86}Sr is used) in geological materials varies as a function of $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ in the mantle source and the age of the material.

Since it has an ionic radius (1.32 Å) similar to that of calcium (1.18 Å), Sr substitutes readily for this element during mineral formation. In bone or tooth enamel, $^{87}Sr/^{86}Sr$ ratios reflect the average of the ratios found the environmental reservoir where the individual lived during the period of apatite formation. In bone, this period corresponds to the last few years of the individual's life since bone continually remodels. Tooth enamel, however, does not remodel so Sr isotope ratios in teeth represent the early life of an individual. For *Sus Scrofa* tooth formation begins before birth and both crowns and roots are formed within the first year (Hillson 1986). Gingival eruption of deciduous teeth occurs within the first three months of life and permanent teeth erupt from 4-22 months old (Hillson 1986).

LEAD ISOTOPES

Lead isotope analysis for provenance involves measurement of four different naturally occurring isotopes. Three, ^{206}Pb, ^{207}Pb and ^{208}Pb, are the products of decay chains (^{238}U, ^{235}U, and ^{232}Th respectively) while the fourth, ^{204}Pb, is non-radiogenic. Like strontium, ratios of radiogenic and non-radiogenic isotopes of lead can be measured to provide information on geographic origins because lead in tooth enamel derives from the geological environment occupied during the period of tooth formation. Lead (Pb^{2+}) ingested in food and water is incorporated in the hydroxyapatite structure of skeletal tissues where it substitutes for calcium (Ca^{2+}). Like Sr, the ionic radius of Pb (1.06 Å) is similar to that of Ca (1.18 Å). Lead concentrations tend to be higher in dentine and bone that maintain equilibrium through blood exchange throughout an individual's life. In contrast, enamel is formed during early childhood and does not change during the individual's life. Enamel apatite crystals are also larger than bone apatite, making it is less prone to diagenetic alteration. Isotopic measurements on ancient tooth enamel samples are more likely to be representative of in vivo ratios (Chiaradia, et al. 2003).

In more recent periods, Pb isotope ratios in skeletal tissue are not solely related to local geology because metallurgy, use of leaded gasoline, and other environmental pollutants have led to increased lead exposure for humans and the animals sharing their environments (Budda, et al. 1999; Jaric 2004). The latest occupation at PA1 and the early occupation of BN1 fall within the Metal Age for ISEA but metal artifacts have only been recovered from colonial period contexts in the Banda Islands and these are imports rather than locally produced metals. No significant problems with contamination were anticipated.

EXPECTED ISOTOPIC VARIATION IN THE BANDA ARC

CARBON

Within the Banda group, there is unlikely to be significant variation in $\delta^{13}C$ due to either C_4 plant consumption or the canopy effect between populations on different islands since there are no known systematic differences in canopy density between islands. Slight variation could occur if pigs in some areas fed more on marine plant material like agar-agar, a seaweed often harvested by people in shallow water. If pigs were exchanged from other island groups, however, more significant variation might be expected. For example, pigs raised on the New Guinea could have had access to sugar cane, a C_4 plant and this would result in higher $\delta^{13}C$. A study comparing pigs feeding in three different habitats in Northern Queensland showed that those feeding in sugarcane habitats and interface zones between sugarcane fields and rainforest had more variable $\delta^{13}C$ than those feeding in the rainforest (Wurster et al 2012). Individuals with access to sugarcane showed higher mean $\delta^{13}C$ values (~ -19.5 ‰) than rainforest feeders (~ -24‰) (Wurster, et al. 2012: Fig. 3). The $\delta^{13}C$ for sugarcane is -12.3 ‰ (Spain and Le Feuvre 1997), close to the mean value for C_4 plants (-12.5 ‰). Variation in $\delta^{13}C$ values could also be expected over time if C_4 cultivars were introduced or if there was significant forest clearance following the introduction of metal tools or commencement of the spice trade in later periods.

OXYGEN

Although islands within the Banda group vary somewhat with regard to elevation, these differences are not likely significant enough to lead to different $\delta^{18}O$ values among islands. However, there may be some variation due to differences in drinking water sources. As discussed in Chapter 2, groundwater is available on the larger inner islands of the Banda group (Banda Neira and Banda Besar), accessed by residents through wells and springs. In contrast the modern residents of Pulau Ay rely entirely on rainwater collection in cisterns for their drinking water

Island	Max elevation	Island	Max elevation
Banda Api	640 meters	Manuk	280 meters
Banda Besar	500 meters	Serua	640 meters
Banda Neira	200 meters	Nila	780 meters
Pulau Rhun	170 meters	Teun	655 meters
Pulau Ay	100 meters	Seram	3000 meters
Pulau Hatta	150 meters	Ambon	1225 meters
Pulau Pisang	40 meters	New Guinea Bird's Head	2290 meters

Table 13. Maximum elevation of islands in the Banda Arc and the Bird's head of New Guinea

because this small limestone island lacks groundwater sources (Lape 2000a). We could expect slight variation between pigs reared locally at PA1 and BN1 $\delta^{18}O$ if water stored on the surface in open cisterns or other containers at PA1. Deeper groundwater sources would less subject to evaporation and this would have lower $\delta^{18}O$.

Pigs from sources on larger islands outside the Banda group, with mountainous interiors may have significantly different oxygen isotope ratios from pigs raised in Banda. The Banda islands and the islands of the southern part of the inner Banda Arc are not large enough to have a clear division between coast and inland and the highest elevations are around only 800 meters. The larger islands of Seram, Ambon, and the Bird's Head of New Guinea, however, are both larger and reach higher elevations (Table 12). Pigs raised in the interiors of these islands could be expected to have significantly different $\delta^{18}O$ values from local Banda pigs because ^{18}O is progressively depleted moving inland from the coast.

STRONTIUM AND LEAD

Successful interpretation of heavy stable and radiogenic isotope ratios in biogenic material depends on good information about regional geology and geochemistry. First, whether the goal is specific sourcing or compositional grouping, provenance analysis based on these ratios requires that there be sufficient natural variation in the geology of the region of interest. Second, when geology and geochemistry are well understood, these methods become more powerful tools, allowing not only identification of different signatures but also contextual interpretation of the results. For specific source designation, it is necessary to model biologically available strontium and lead in the environment. Geological ratios are often poor indicators of biologically available strontium and lead because in addition to in situ weathering of bedrock, soils may contain windblown dust particles from geologically different locations. In coastal areas, sea spray inputs can also alter isotope ratios. In addition, diet can impact the $^{87}Sr/^{86}Sr$ in an individual's teeth in certain contexts, such as when marine foods play a significant role.

The Banda Islands are part of the Banda Arc, a subduction zone where the Pacific, Eurasian, and Indian-Australian plates are converging, creating a highly complex orogeny. This convergence of plates forms an island arc enclosing the Banda Sea and bordered by continental lithosphere to the south and east (Vroon, et al. 1993). The arc is typically divided into three parts: the Wetar segment in the Southwest and the Ambon segment in the Northeast are areas where volcanism ceased around 3 million years ago (Abbott and Chamalaun 1978, 1981) while the portion from Damar to the Banda Islands is still volcanically active. In addition to differences in the age of volcanic activity in these segments, there are well-documented geochemical variations in the lavas extruded. In the Bandas and southern Ambon, they are tholeiitic with progressive K enrichment moving southwest along the arc. Manuk and Serua are calc-alkaline and Nila, Teun, and Damar are High-K calc-alkaline (Whitford and Jezek 1979). This patterning is mirrored in lead isotope ratios which increase along a Northeast to Southwest gradient (Vroon, et al. 1993).

Strontium isotope ratios are complexly patterned, ranging from 0.7042-0.7175 (Vroon, et al. 1993;Whitford and Jezek 1979). Published whole rock $^{87}Sr/^{86}Sr$ values for the Banda arc are presented in Table 2. Published $^{87}Sr/^{86}Sr$ values for Ambon Island include both the highest and lowest values for the Banda arc, although the sample size for Ambon is very small. Whitford and Jezek (1979) measured trace elements and $^{87}Sr/^{86}Sr$ in two young basalt samples from Leitimor in the south and two samples of cordierite-bearing andesite (also known as ambonites) from the vicinity of Hifa in the north. The Leitimor samples had values similar to those of the Banda group, while ambonites had significantly higher values than are found elsewhere in the Banda Arc. (Whitford and Jezek 1979) interpret the high ambonite values as evidence for a continental crust contribution in magma genesis.

South of Ambon the arc has values ranging from 0.7045 in Banda to 0.7095 on Serua. Tholeiitic lavas in Banda display the lowest ratios, the calc-alkaline lavas of Manuk and Serua are characterized by high ratios, and among the high-K calc-alkaline islands there is a north to south decrease (Whitford and Jezek 1979). Like Sr, Pb isotopes are also spatially patterned with increasingly radiogenic values (lower ratios) from northeast to southwest. In general, the Banda Arc has more radiogenic values than other intra-oceanic arcs (Morris 1977). Whitford and Jezek’s study (1979) did not measure lead isotopes but Morris (1977) did conduct lead isotope analysis on a subset of their samples and Vroon, et al. (1993) obtained lead isotope ratios for a larger sample collected during the 1984-85 Snellius II expedition (1993). All available Pb reference values are plotted in Table 2 and Figure 7,**Error! Reference source not found.** showing that the three segments of the Banda Arc are geochemically distinct in their lead ratios as well as strontium.

For both Pb and Sr, published isotope data for Banda are only available from the three inner islands comprising the volcanic center of the archipelago: Banda Besar, Banda Neira, and the currently active Gunung Api. No whole rock values are available for the outer limestone islands but since they derive from uplifted coral reefs they would be expected to have higher Sr ratios. Likely the bedrock of these islands would have ratios approaching that of modern seawater at 0.70916. When plotted against $^{206}Pb/^{204}Pb$, whole rock Sr ratios for the Banda Arc appear to separate into three groups. Banda and Manuk plot together at the low end of the scale for both ratios. Serua and Romang plot together with relatively high Sr ratios and middle-range Pb ratios. Nila, Teun, and Damar have the highest Pb ratios and middle-range Sr ratios. These groups align well with Whitford and Jezek's (1979) division of the arc into tholeitic lavas in the northern arc, calc-alkaline lavas in the central arc, and high-K calc-alkaline lavas in the southern portion of the arc but there are two discrepancies between their classification and the biplot grouping shown in Figure 8. First, Manuk is placed in the calc-alkaline group and would be expected to plot with Serua rather than Banda. Second, Romang, which was not included in the Whitford and Jezek study, plots with Serua despite its location at the southwestern end on the Banda Arc.

Because Sr and Pb ratios are patterned across the Banda Arc, we can expect to see variation in both Sr and Pb ratios if pigs were traded between Banda and other areas within this geological province. Positive identification of specific sources at the island level would be complicated by overlapping ranges within the different segments of the arc as well as the expectation that biologically available ratios will not exactly match whole rock references. It is clear, however, that pigs from the northern, central, and southern segments should have significantly different signatures. While there is no reason to expect that heavy stable isotope ratios in biogenic material will exactly match the ratios found in local geography, we can expect that the distribution of biogenic isotope ratios will mirror the distribution of geological ratios. Unfortunately, no isotope data are available for comparison from the large island of Seram, a likely source for pigs if they were traded. However, since Seram is older with a more complex geological history than the Banda Arc, it can be assumed that it would have a different isotopic signature.

METHODS

Sus Scrofa tooth enamel was sampled from 50 specimens recovered at PA1 on Pulau Ay and BN1 on Banda Neira during excavations in 2007 and 2009. For each site, samples were selected from with a single excavation unit by natural strata so as to permit diachronic comparison. Nearly all well-preserved adult teeth were selected with a preference for second and third molars when possible. Ideally, in a large assemblage, samples would be collected only from a single tooth (e.g. only upper left permanent third molars), to eliminate the possibility of selecting two samples from the same individual. Since well-preserved teeth were not abundant in either site this sampling strategy was not viable for this study. Where very similar ratios were obtained on two samples from different dental positions, the likelihood of their belonging to a single individual was assessed by looking at the stratigraphic positions of the teeth and the approximate age of the individual (permanent vs. deciduous teeth, degree of wear).

For sample preparation, a portion of enamel was removed using a dental drill with a carbide bit under 10x magnification, all surfaces were then abraded with a diamond bit to remove dentine and contaminants. Each sample was then ground in an agate mortar and pestle and subdivided for light and heavy stable isotope analyses.

Samples for light isotope analysis (δ18O, δ13C) were soaked in 2% NaOCl to remove organic material, and rinsed to neutral in dH20. This was followed by soaking in a 0.2% acetic acid solution to remove carbonates and other contaminants (Garvie-Lok et al. 2004). Isotopic measurements were conducted on a Finnigan-MAT 252 isotope ratio mass spectrometer using a Kiel III carbonate prep device with a ConFlo II interface in the Department of Geological Sciences, University of Florida. Using the Kiel III carbonate device, each pretreated enamel sample was loaded into a pyrex reaction vessel and reacted with 100% phosphoric acid at 70 °C. Evolved CO2 gas was then measured using a Finnigan-MAT 252 isotope ratio mass spectrometer. Results are reported in standard delta notation relative to Vienna Pee Dee Belemnite (VPDB). Analytical precision of NBS-19 standard was0.056 for , δ13C and 0.103 for , δ18O.

Sample aliquots for heavy isotope analysis (87Sr/86Sr, 206Pb/204Pb, 207Pb/204Pb, 208Pb/204Pb) were processed in a clean lab at the University of Florida, Department of Geological Sciences. Samples were pretreated with 5% Optima acetic acid for 30 minutes, rinsed, and then dissolved in 50% HNO3. Sr and Pb were separated from each aliquot using ion chromatography. First lead was separated with Dowex 1X-8 resin. These washes were collected, redissolved and Sr was separated with Sr-spec resin (Eichro, Technologies, Inc.). Sr and Pb isotopic analyses were conducted on a Nu-Plasma multiple-collector inductively-coupled-plasma mass spectrometer (MC-ICP-MS) following Kamenov et al. (2006) for Sr and Kamenov et al.

(2004) for Pb (also described in Valentine 2008). Samples were run in batches of five and standard measurements of NBS-987 for Sr and NBS-981 for Pb were repeated between each batch. 87Sr/86Sr results were corrected by normalizing to the standard and a Tl normalization technique was used for the lead isotope analyses. The long-term reproducibility of TRA-measured 87Sr/86Sr of NBS 987 is 0.71024±0.00005.

RESULTS

CARBON AND OXYGEN

The results of light stable isotope analyses are presented in Tables 14-15. The average measured $\delta^{13}C$ values for all Banda pigs was -13.02 ‰, with a range of -11.53‰ to -14.31‰, similar to average apatite $\delta^{13}C$ values from studies elsewhere in ISEA and Oceania. There is no significant difference in $\delta^{13}C$ between PA1 and BN1 (two-sample t (42)=1.274, p=0.105) and all BN1 samples fall within two standard deviations from the PA1 mean. Three samples have $\delta^{13}C$ values falling outside the 2σ range for the overall assemblage suggesting these individuals had

Catalog Number	Site	$\delta^{13}C$ ‰ (VPDB)	$\delta^{18}O$ ‰ (VPDB)	$\delta^{18}O$ ‰ (SMOW)
608B0L02B3	BN1	-12.38	***-1.82***	***28.52***
608C0L02B1	BN1	-13.17	-3.80	25.93
608E0L02B1	BN1	-12.80	-5.37	23.88
608E0F01B1	BN1	-12.04	-4.00	25.68
609B0L02B1	BN1	-12.48	-3.48	26.36
609B0L02B1	BN1	-12.87	-3.62	26.17
609D0L02B1	BN1	-13.28	-2.60	27.51
610A2F20B1	BN1	-12.58	-4.85	24.56
610B0F37B1	BN1	-12.64	***-6.83***	***21.96***
610D0F03B1	BN1	-13.58	-3.64	26.14

Table 14. Carbon and Oxygen isotope ratios for Pig's teeth from BN1

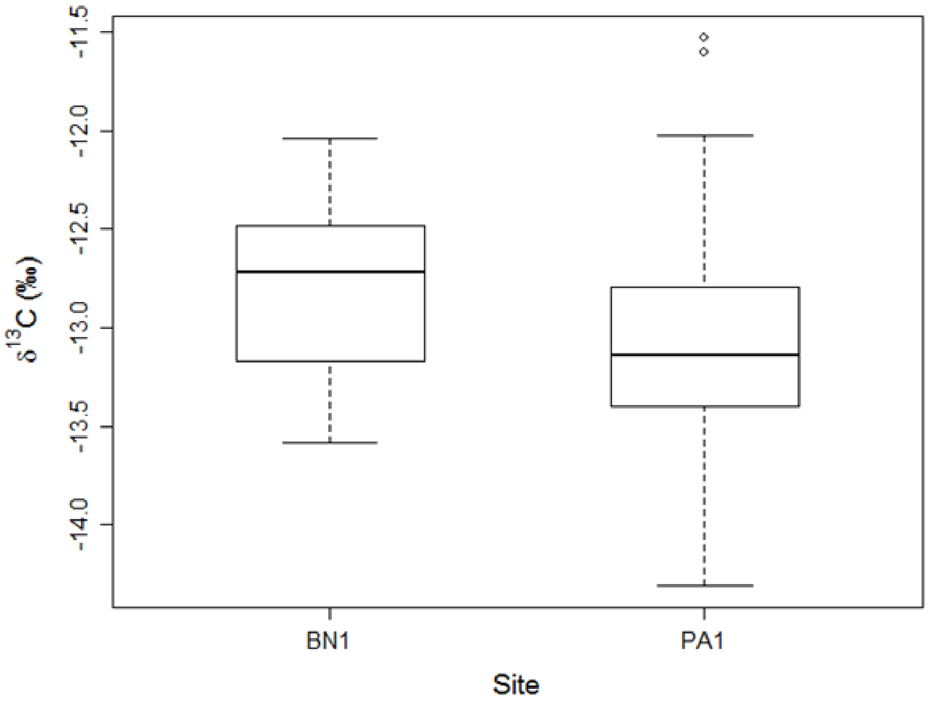

Figure 33. Boxplot showing distribution of $\delta^{13}C$ values by site.

different diets. Two are enriched compared to other samples (-11.53‰ and -11.6‰), possibly suggesting more consumption of marine foods or C_4 plants for these individuals. The third has lower $\delta^{13}C$ (-14.31‰) potentially resulting from feeding in a more closed canopy environment. All, however, plot within group A in the Pb-based grouping, so these dietary differences are not the result of these individuals originating in geologically distinct locations. he only economically significant C_4 cultivar in prehistoric Island Southeast Asia was sugarcane, an indigenous New Guinea domesticate (S. H. Ambrose and Krigbaum 2003).

Sugarcane was probably domesticated by approximately 6000-5500 BP in the New Guinea Highlands (Daniels and Daniels 1993). $\delta^{13}C$ values for locally grown plants are not available but Table 15 shows values for relevant species from a variety of locations around the

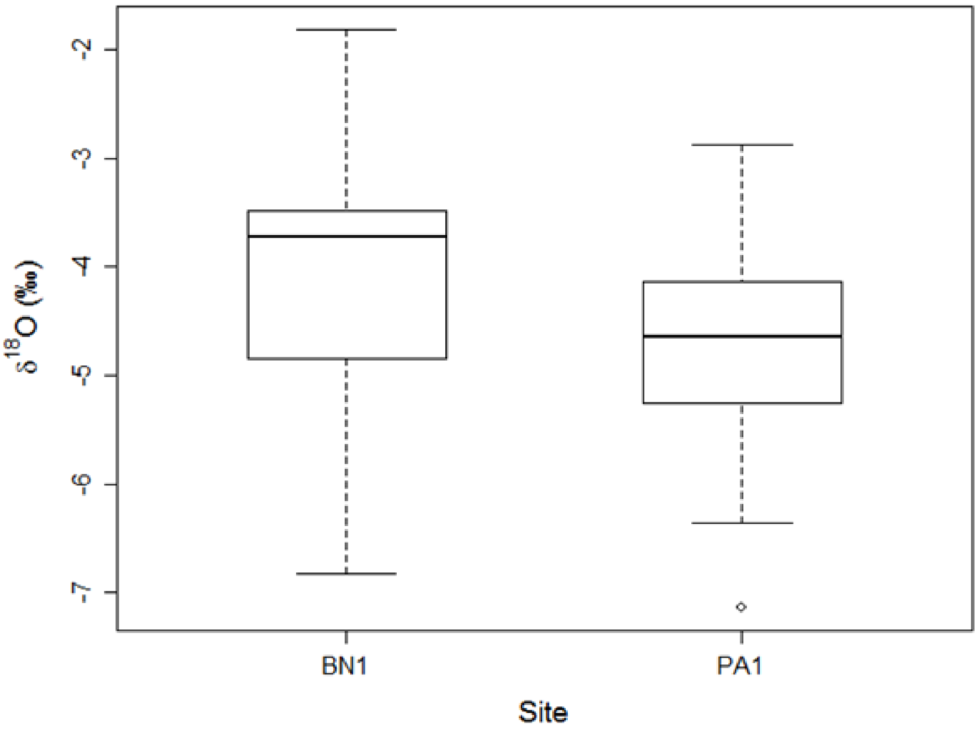

Figure 34. Boxplot showing distribution of δ^{18}O by site.

tropical Pacific. Very few δ^{13}C values for *Sus Scrofa* have been published in the tropical Pacific, but bone collagen from six samples in Fiji ranged from -20.5 to -16.1‰ (Field et al. 2009) bone collagen from six samples in Fiji ranged from -20.5 to -16.1‰ (Field et al. 2009) and 18 collagen samples from the Cook Islands had values between -18.8 and -14.3‰ (Allen and Craig 2009). Since apatite offsets are much larger than those for collagen, these somewhat more negative values are expected but comparison between collagen and apatite δ^{13}C values is further complicated by the fact that apatite values tend to reflect the whole diet while collagen values are derived primarily from proteins.

There is some difference between the two sites: δ^{13}C for PA1 samples averaged -13.1‰, slightly depleted compared to the BN1 mean of -12.8‰ but this is not significant (two sample

Catalog Number	Site	δ^{13}C ‰ (VPDB)	δ^{18}O ‰ (VPDB)	δ^{18}O ‰ (SMOW)
32A0L06B1	PA1	-11.53	-5.44	23.79
32A0L06B1	PA1	-13.16	-5.26	24.02
32C0L06B1	PA1	-12.89	-5.17	24.15
32B0L06B1	PA1	-14.31	-4.30	25.28
32B0L06B1	PA1	-13.67	-5.37	23.87
32A0H03B1	PA1	-13.14	-7.14	21.57
32C0L06B1	PA1	-13.76	-5.43	23.81
32A1H07B1	PA1	-13.24	-4.99	24.38
32A0L06B1	PA1	-12.90	-4.26	25.33
32B0L06B1	PA1	-13.23	-6.21	22.78
32A0L02B1	PA1	-13.58	-3.91	25.80
32A0L06B1	PA1	-13.18	-4.42	25.12
33C1L06B1	PA1	-12.73	-4.50	25.01
33B0L06B2	PA1	-12.99	-4.89	24.51
33D0L06B1	PA1	-11.60	-4.83	24.59
33C1L06B1	PA1	-12.02	-4.24	25.36
33E0L06B1	PA1	-12.98	-3.60	26.20
33F0L06B1	PA1	-13.70	-5.14	24.19
33I0F01B1	PA1	-14.12	-3.38	26.48
33B0L06B1	PA1	-13.93	-4.43	25.12
33D0F03B1	PA1	-13.29	-4.44	25.10
33C1L06B1	PA1	-12.14	-3.69	26.08
33A0L06B1	PA1	-14.13	-3.73	26.03
33C0L06B1	PA1	-12.92	-2.88	27.14
33I0L06B1	PA1	-13.10	-5.42	23.81
33D0L06B1	PA1	-13.12	-4.15	25.48
33C0H25B1	PA1	-12.79	-5.02	24.34
33C0L06B1	PA1	-13.40	-4.64	24.83
33A1H17B1	PA1	-12.78	-4.13	25.51
33C0L06B1	PA1	-13.56	-5.25	24.04
33B0L06B1	PA1	-13.15	-5.16	24.15
33D0L06B1	PA1	-12.74	-3.39	26.48
33E0L06B1	PA1	-12.95	-6.10	22.93
33D0L06B1	PA1	-13.30	-3.29	26.60
33F0L06B1	PA1	-12.45	-3.76	25.99
33D0L06B1	PA1	-12.54	-4.91	24.48
33B0L06B1	PA1	-13.25	-6.36	22.58

Table 15. Carbon and Oxygen isotope ratios for Pig's teeth from PA1

Common name	Species	δ^{13}C	Reference
Banana	*Musa X paradisiaca*	-23.2	Beavan-Athfield, et al. 2008
Banana	*Musa* sp.	-24.8	Ambrose, et al. 1997
Banana	*Musa* sp.	-24.8	Ambrose, et al. 1997
Banana	*Musa* sp.	-25.8	Ambrose, et al. 1997
Breadfruit	*Artocarpus altilis*	-28.1	Ambrose, et al. 1997
Breadfruit	*Artocarpus altilis*	-28.1	Ambrose, et al. 1997
Breadfruit	*Artocarpus altilis*	-27	Ambrose, et al. 1997
Coconut palm	*Cocos nucifera*	-24.9	Leach, et al. 2003
Coconut palm	*Cocos nucifera*	-22.4	Beavan-Athfield, et al. 2008
Dryland taro	*Colocasia* sp.	-25.5	Beavan-Athfield, et al. 2008
Dryland taro	*Colocasia* sp.	-24.7	Beavan-Athfield, et al. 2008
Giant swamp taro	*Cyrtosperma chamissonis*	-26.9	Ambrose, et al. 1997
Malay apple	*S. malaccensis*	-28.3	Beavan-Athfield, et al. 2008
Pacific arrowroot	*T. leontopetaloides*	-23.7	Beavan-Athfield et al. 2008
Sour sop	*Annona squamosa*	-29.2	Ambrose et al. 1997
Sweet potato	*Ipomoea batatas*	-26.8	Beavan-Athfield et al. 2008
Sweet potato	*Ipomoea batatas*	-28.4	Ambrose et al. 1997
Sweet potato	*Ipomoea batatas*	-28.4	Ambrose et al. 1997
Sweet potato	*Ipomoea batatas*	-25.5	Ambrose et al. 1997
Sweet potato	*Ipomoea batatas*	-27.4	Ambrose et al. 1997
Taro	*Colocasia esculenta*	-27.7	Leach et al. 2003
Taro	*Colocasia esculenta*	-27.4	Leach et al. 2003
Taro	*Colocasia esculenta*	-26.8	Leach et al. 2003
Taro	*Colocasia esculenta*	-31.1	Ambrose et al. 1997
Yam	*Dioscorea alata*	-26.9	Ambrose et al. 1997
Yam	*Dioscorea alata*	-27.8	Ambrose et al. 1997
Yam	*Dioscorea esculenta*	-27.2	Ambrose et al. 1997
Yam	*Dioscorea esculenta*	-26.8	Ambrose et al. 1997
Yam	*Dioscorea aculeata*	-29.3	Ambrose et al. 1997
Yam	*Dioscorea aculeata*	-27.2	Ambrose et al. 1997
Yam	*Dioscorea aculeata*	-30.7	Ambrose et al. 1997
	mean	-26.86	
	adjusted for apatite offset (12.3‰ to 13.3‰)	-14.56 to -13.56	

Table 16. δ^{13}C for tropical Pacific terrestrial plant foods

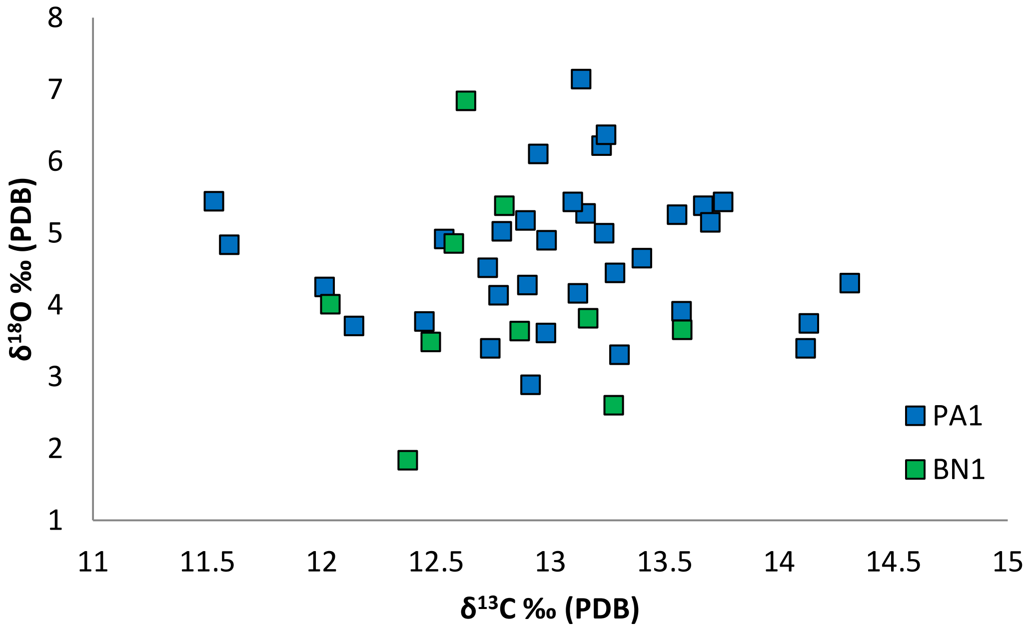

Figure 35. **δ18O and δ13C at PA1 and BN1**

t(12)=1.429, P=0.089). The average δ^{18}O value was 4.54‰ with values ranging from 1.82 to 7.14‰. Three samples have δ^{18}O values outside the 2σ range for the assemblage. These are not the same three samples mentioned for δ^{13}C. One is enriched compared to the mean and was assigned to group B in the Pb-based grouping. The other two members of this group, however, have δ^{18}O values falling very close to the mean so the cause of this anomalously enriched measurement is unclear. A biplot of δ^{18}O and δ^{13}C (Figure 35) shows the lack of correlation between these variable and the lack of differentiation between pigs from PA1 and BN1 with regard to light stable isotope ratios.

STRONTIUM AND LEAD

Strontium isotope ratios were obtained for all 50 samples and display a very narrow range of values from 0.7081-0.7094 and an average of 0.7086. In the absence of extensive sampling of the environment to model biologically-available Sr, one approach for identifying local vs. non-local

	PA1	BN1	All
$\delta^{13}C$ (‰ VPDB)			
N	37	11	47
Mean	-13.1	-12.8	-13.0
SD	0.6	0.46	0.61
Range	-14.3 to -11.5	-13.6 to -12	-14.3 to -11.5
$\delta^{18}O$ (‰ VPDB)			
N	37	11	47
Mean	-4.6	-4.2	-4.5
SD	1.07	1.52	1.07
Range	-7.1 to -1.8	-6.8 to -1.8	-7.1 to -1.8
$\delta^{18}O$ (‰ SMOW)			
N	37	11	47
Mean	24.8	25.4	25.0
SD	1.40	1.99	1.40
Range	21.6 to 28.5	22 to 28.5	21.6 to 28.5

Table 17. Summary data for $\delta^{13}C$ and $\delta^{18}O$ by site

individuals is to calculate a two standard deviation range for the assemblage and take this as an estimate for the local range of variation (Price, et al. 2002; Shaw, et al. 2011; Slovak, et al. 2009; Turner, et al. 2009). Outliers falling more than two standard deviations from the mean are identified as non-local. In this case the sample mean is 0.7086 and the two standard deviation range is 0.7082-0.7091. Two samples fall outside of this range, one lower and one is higher. Both are from PA1. Using this method, we could conclude that all but two individuals are local but in this case there is a problem with using Sr ratios in this way. First, while there is little variability in Sr ratios among archaeological samples, the same is not true for the other isotope ratios, suggesting that Sr ratios may not directly represent the geological signature of source areas for pigs. Second, comparison between Sr ratios from archaeological samples and published

Catalog Number	Site	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb	^{87}Sr/^{86}Sr
32A0L06B1	PA1	18.642	15.624	38.589	0.70868
32A0L06B1	PA1	18.528	15.629	38.492	0.70872
32C0L06B1	PA1	18.537	15.632	38.385	0.70872
32B0L06B1	PA1	18.443	15.623	38.367	0.70824
32B0L06B1	PA1	18.570	15.623	38.545	0.70852
32A0H03B1	PA1	19.346	15.704	38.883	0.70876
32C0L06B1	PA1	18.573	15.621	38.577	0.70860
32A1H07B1	PA1	19.187	15.687	38.844	0.70874
32A0L06B1	PA1	18.518	15.621	38.395	0.70862
32B0L06B1	PA1	18.528	15.617	38.534	0.70870
32A0L02B1	PA1	18.384	15.611	38.315	0.70870
32A0L06B1	PA1	18.553	15.625	38.532	0.70881
33B0L06B2	PA1	18.608	15.616	38.465	0.70880
33D0L06B1	PA1	18.604	15.628	38.481	0.70835
33C1L06B1	PA1	18.467	15.614	38.406	0.70877
33E0L06B1	PA1	19.075	15.678	38.755	0.70887
33F0L06B1	PA1	18.664	15.622	38.491	0.70873
33I0F01B1	PA1	18.474	15.612	38.373	0.70865
33B0L06B1	PA1	18.608	15.641	38.498	0.70844
33C1L06B1	PA1	18.491	15.625	38.400	0.70845
33A0L06B1	PA1	18.702	15.640	38.707	0.70945
33C0L06B1	PA1	18.714	15.640	38.593	0.70842
33I0L06B1	PA1	18.348	15.608	38.220	0.70868
33D0L06B1	PA1	18.628	15.623	38.620	0.70869
33C0H25B1	PA1	18.494	15.635	38.408	0.70850
33C0L06B1	PA1	18.793	15.662	38.947	0.70879
33A1H17B1	PA1	18.547	15.636	38.376	0.70838
33C0L06B1	PA1	20.071	15.770	39.382	0.70860
33B0L06B1	PA1	18.464	15.618	38.298	0.70855
33E0L06B1	PA1	18.670	15.636	38.582	0.70859
33D0L06B1	PA1	18.748	15.643	38.432	0.70834
33F0L06B1	PA1	18.493	15.622	38.371	0.70810
33D0L06B1	PA1	18.594	15.634	38.442	0.70868
33B0L06B1	PA1	18.464	15.637	38.329	0.70883

Table 18. Pb and Sr isotope results for PA1

Catalog Number	Site	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb	^{87}Sr/^{86}Sr
608B0L02B3	BN1	18.603	15.647	38.456	0.70872
608C0L02B1	BN1	18.552	15.643	38.581	0.70883
608E0L02B1	BN1	18.309	15.620	38.250	0.70877
608E0F01B1	BN1	18.585	15.654	38.608	0.70874
609B0L02B1	BN1	18.574	15.658	38.676	0.70845
609B0L02B1	BN1	18.564	15.658	38.626	0.70864
609D0L02B1	BN1	18.127	15.585	38.062	0.70856
610A2F20B1	BN1	18.141	15.592	38.115	0.70824
610B0F37B1	BN1	18.583	15.651	38.655	0.70826
610D0F03B1	BN1	18.589	15.668	38.690	0.70840

Table 19. Pb and Sr isotope results for BN1

geological values shows that the above 2sd range is not similar to the local range for the Banda Islands (0.7045-0.7050). Within the Banda Arc, similar values have been obtained from Serua (0.7071-0.7098), Teun (0.7068-0.7091) and Romang (0.7083-0.7096). With such a discrepancy between the archaeological samples and Banda bedrock ^{87}Sr/^{86}Sr, it is tempting to conclude that all of the individuals sampled were non-local, spending their first 3 months to a year on one of several islands to the southwest of Banda. Although this would be a parsimonious explanation for the observed Sr values it is unlikely to be correct. As mentioned above, there is little reason to expect biologically available Sr values for a reservoir to match bedrock Sr values. In addition, the criterion of abundance, often invoked in provenance analyses for other materials, tells us that if there is a local source, it should be the most abundant compositional group. A population of feral pigs is present on Banda Besar today (Lape 2000b) indicating that they were successfully introduced to this island at some time in the past. After conversion to Islam, around 500 BP pigs disappeared from the archaeological record (Lape 2000a), so it is unlikely that they were a more recent introduction to the Bandas. Given these facts, it is unlikely that there would be no locally raised pigs in Banda.

There are several possible explanations for how pigs reared within the Banda Islands could have enamel $^{87}Sr/^{86}Sr$ values so much higher than local geological signatures. First, the pigs could have come from a number of different places but have common diet with a substantial marine component. Such a diet could lead to $^{87}Sr/^{86}Sr$ approaching that of seawater (0.7092). Seawater has a more or less homogenous $^{87}Sr/^{86}Sr$, which represents a global average of Sr ratios for continental crust (Bentley 2006). This average is representative of the environment of marine flora and fauna and, when consumed in large quantities, the seawater ratio will make a large contribution to the overall environmental reservoir value for the consumer. Pigs foraging on the beach and consuming seagrasses and reef-flat-dwelling organisms could have Sr ratios higher than the native bedrock. Pig diets often overlap human diets and the faunal assemblages at both PA1 and BN1 indicate a heavy reliance on marine fish.

Second, even if the diet does not contain large quantities of marine flora and fauna, the soils, groundwater, and plants in coastal areas can be influenced by seawater Sr through inputs from seaspray or rainwater influenced by $^{87}Sr/^{86}Sr$ of evaporated seawater (Bentley, Tayles, et al. 2007; Whipkey, et al. 2000). Since all of the Banda Islands are relatively small, and none has an interior that could be considered far enough from the coast to be free of this influence, individuals from any island in the group could have a more radiogenic signature than would be expected from $^{87}Sr/^{86}Sr$ of bedrock alone. If the pigs all originated on small islands, including but not limited to the Bandas, we could expect seawater-like $^{87}Sr/^{86}Sr$.

Finally, as mentioned previously, the outer islands of the Banda group are non-volcanic, uplifted marine sediments. Such phanerozoic marine limestones have $^{87}Sr/^{86}Sr$ in the range of

0.707-0.709, which reflect the seawater ratio at the time when they formed (Bentley 2006). The archaeological samples all fall within this range. Human teeth from Lifafaesing, located on a small limestone island in the Bismarck Archipelago, showed a similar limited range of $^{87}Sr/^{86}Sr$, also within the range for marine limestones (Shaw et al. 2010). The pigs in this study could all come from limestone islands.

Finally, Whitford, et al. (1977) and Whitford and Jezek (1979) report Sr isotope ratios as high as 0.7175 in Ambon and Vroon, et al. (1993) measured values over 0.709 in Serua and Romang. These high values are attributed to the subduction of sea-floor sediments or continental crust that are then incorporated in magma genesis (Whitford and Jezek 1979). A point of origin in one of these areas would account for the high $^{87}Sr/^{86}Sr$ of the archaeological samples.

As mentioned previously lead isotope ratios exhibit more variation than $^{87}Sr/^{86}Sr$. Lead is less abundant than strontium and four samples with high errors are probably the result of not having purified enough lead in the column chemistry for isotopic measurement. Three samples had particularly large errors (≥ 0.24 for $^{206}Pb/^{204}Pb$, $\geq 0.088$for $^{207}Pb/^{204}Pb$, and ≥ 0.099 for $^{208}Pb/^{204}Pb$) and were excluded from further analysis. A fourth with errors at the high end of the acceptable range was also excluded because values for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ were anomalous falling 16 and six standard deviations below the mean respectively. The remaining 46 samples ranged between 18.127-20.071 for $^{206}Pb/^{204}Pb$, 15.585-15.770 for $^{207}Pb/^{204}Pb$, and 38.062-38.486 for $^{208}Pb/^{204}Pb$.

Three samples have at least one lead ratio falling outside the two standard deviation ranges of 18.000-19.222 for $^{206}Pb/^{204}Pb$, 15.576-15.697 for $^{207}Pb/^{204}Pb$, and 38.067-38.959 for $^{208}Pb/^{204}Pb$. The archaeological samples are, on average, less radiogenic than published geological values. Excluding the unlikely possibility that nearly all pigs in Banda Islands archaeological sites are exotic, not only to the Banda Islands but to the entire Banda Arc, one possible explanation is that the majority of pigs come from limestone islands. As discussed above, no geochemical studies have undertaken sampling of limestone islands in the Banda Arc.

Unlike $^{87}Sr/^{86}Sr$, which varies over time in seawater but not over space, lead isotope ratios are variable in space (Komárek, et al. 2008) and with depth in seawater (Reuer, et al. 2003). Lead isotopes in marine carbonate are controlled by a combination of sediments entering the seawater from nearby landmasses, and airblown dust particles that settle in the ocean. Additionally, following uplift, the lead ratios of sediments may continue to be influenced by the deposition of windblown dust. In Banda this means that while the erosion from the inner volcanic islands will have been one source of lead, submarine hydrothermal outputs may also introduce “mantle Pb” to seawater columns (Jahn and Cuvellier 1994). And, in addition to windblown volcanic material from within the Banda group, windblown dust from larger landmasses like Australia and New Guinea are also possible.

GROUP DETERMINATION

The isotope dataset proved much less tractable to attempts at identify source groups than the pottery dataset discussed in Chapter 6. Initially, groups were identified through a combination of hierarchical cluster analysis and principal components. Due to the small sample size (and hence small group sizes), Mahalanobois distance could not be used to assess probability of group membership as it was for pottery. Hierarchical cluster analysis using all six isotope ratios was used to divide the dataset into preliminary groups based on the position of samples in the dendrogram (Figure 36).

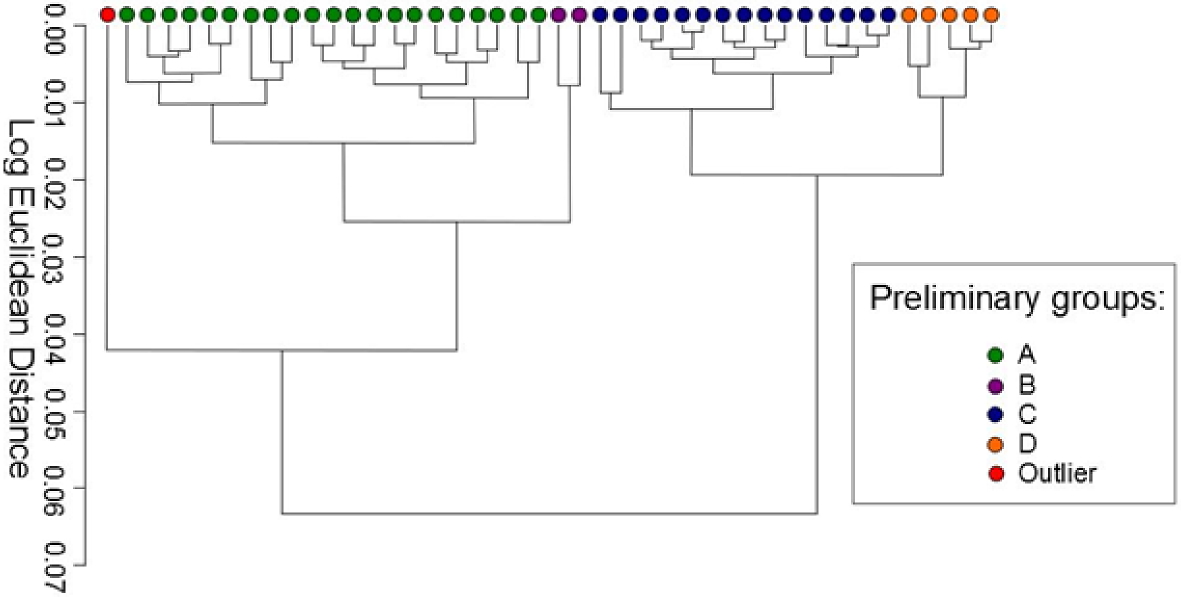

Figure 36. Dendrogram produced by hierarchical cluster analysis using all isotope ratios

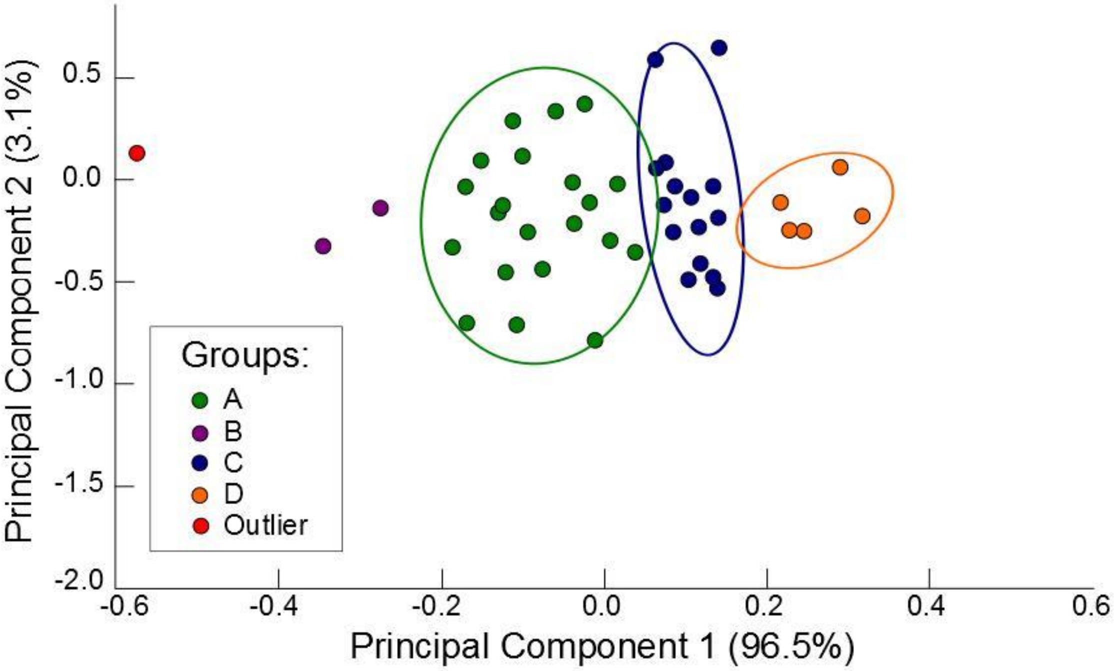

Figure 37. PCA Plot of preliminary grouping using all isotopes

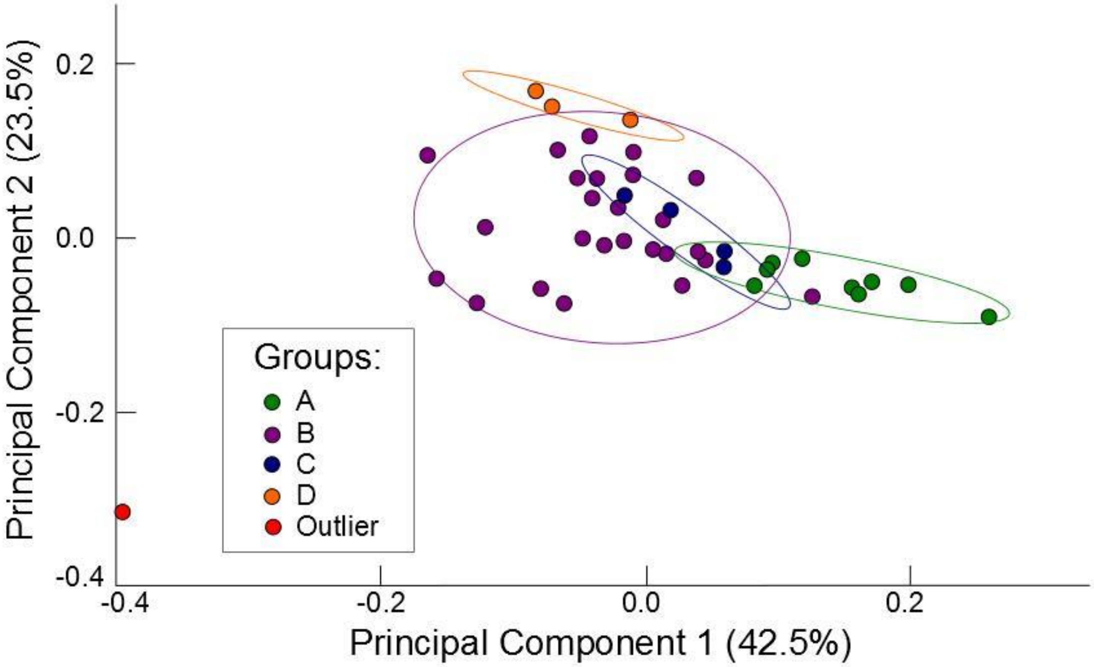

Figure 38. PCA Plot of groups using standard z- scores for all isotopes except ^{87}Sr/^{86}Sr

Four clusters and one outlier were identified at this stage. These groups were then examined in biplots and PCA plots. The cluster analysis showed identical results whether ^{87}Sr/^{86}Sr was included or not. The preliminary groups were well defined in PCA plots based on all isotopes with 99.6% of variation explained by the first two components (Figure). Analysis of variance (ANOVA) was used to test whether these groups had significantly different means for each isotope ratio. Differences between means were not significant for any isotope except δ^{18}O [F(3,39) = 111.938, p = 3.31E-19]. When δ^{18}O is not included in the principal component analysis, the preliminary groups are no longer discriminated, confirming the dominance of δ^{18}O in discriminating preliminary groups. δ^{18}O drives these results because it is the smallest of the isotope values measured. When the same procedure is repeated using standardized values the groups defined by HCA are not well differentiated in the PC plot or element biplots. The first

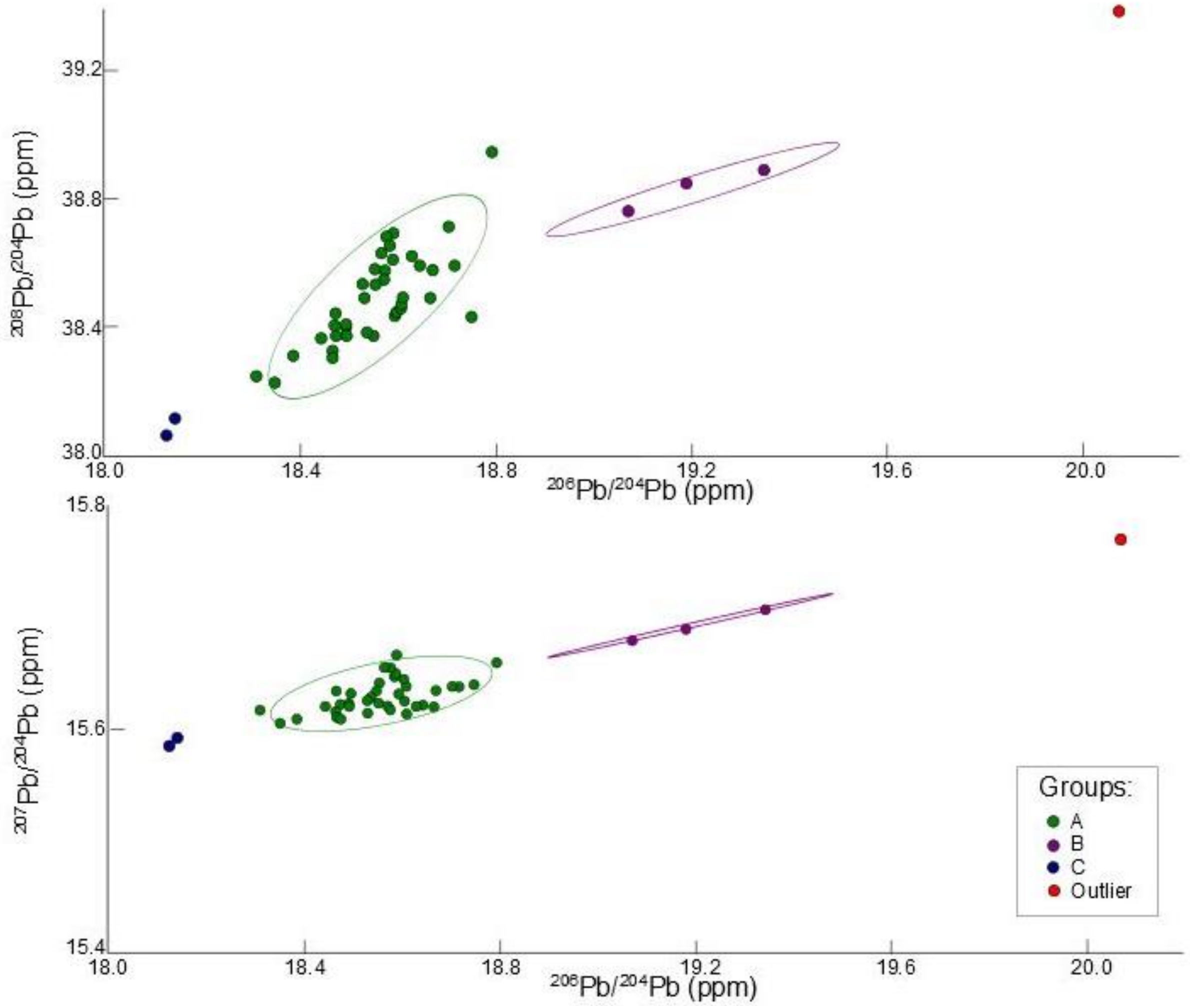

Figure 39. . Biplots Pb isotope groupings for archaeological samples.

two components of the PCA describe only 58.6% of variation using all isotopes or 66% of variation when Sr is excluded (Figures 37-38).

An entirely different grouping solution is possible if only the lead isotopes are used. As discussed previously, Pb isotope ratios exhibit spatial patterning across the Banda Arc, so if it can be assumed that most pigs obtained through exchange by Banda Islanders would have come

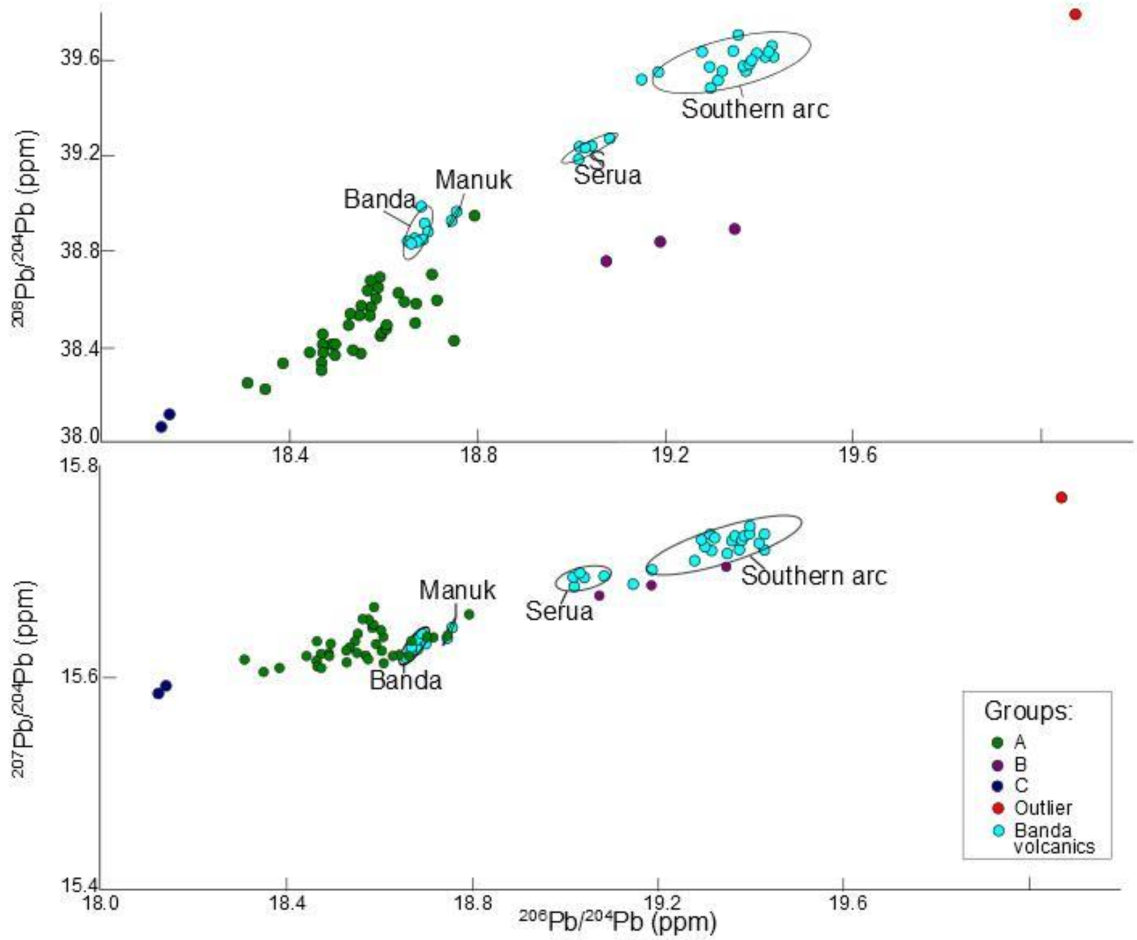

Figure 40. Pb biplot showing relationship between archaeological samples and Banda Arc volcanics

from islands in the Banda arc, this is an appropriate strategy. The Pb-only grouping yields three groups and one outlier. The majority of samples (38 of 44) belong to a single large group most likely to represent the Banda Islands themselves. A cluster of two samples has lower values for all three Pb isotope ratios and a grouping of three has higher values (Figure 39). One-way ANOVA was conducted to determine whether differences in mean isotope ratios for between groups were significant. As expected, significant differences were found for ^{206}Pb/^{204}Pb [F(3,39) = 73.756, p = 2.81E-14], ^{207}Pb/^{204}Pb [F(3,39) = 30.730, p = 8.23E-09], and ^{208}Pb/^{204}Pb

Site/Layer	A	B	C	D	n	Richness	Simpson D	Simpsons Index of Diversity (1-D)	Shannon Index (H')
PA1/2	9	2	0	0	11	2	0.673	0.327	0.206
PA1/3	21	1	0	1	23	3	0.830	0.170	0.155
BN1/8	4	0	0	0	4	1	1.000	0.000	0.000
BN1/9	1	0	2	0	3	2	0.333	0.667	0.276
BN1/10	3	0	0	0	3	1	1.000	0.000	0.000

Table 20. Diversity measures for pigs at PA1 and BN1

[F(3.39) = 16.718, p = 5.28E-06]. The grouping solution produced using Pb isotope ratios alone, produces consistent results and given the across arc patterning in Pb ratios, these are more likely to reflect spatially distinct sources for pigs. Figure 39 compares the distribution of Pb isotopes in archaeological samples with those for Banda arc volcanics. There is relatively close correspondence between the largest source group (A) and volcanics from the Banda Islands. Group B is enriched in the radiogenic isotopes relative to Group A just as the islands of the southern Banda Arc are enriched relative to the Banda Islands and Manuk.

DIVERSITY OVER TIME

Because few source groups could be discriminated, diversity measures are less informative for the pig data than they were for pottery. Richness values range from 1 to 3 and are highest at PA1 in layer 3 (Table 20). This is also the layer with the largest sample size, and this is likely what drives the higher richness. The greatest diversity is at BN1 in layer 9. Only 3 samples were successfully analyzed from this layer and only 1 is from Group 1, most likely the local pig population. Both of the other samples are from Group C and these constitute the entirety of that group. These two samples are a third premolar from level 9B and a first molar from level 9D.

Since they are from different teeth it is possible they are from the same individual but this is considered unlikely because they differ in their light isotope ratios. Likewise the three samples in Group B are all from PA1 where they occur in 2 layers (2A and 3C). Each is from a different tooth but they display enough variation in light isotope ratios to make it unlikely they come from the same individual.

SUMMARY

An attempt was made to identify source groups for pigs using statistical analysis of six isotope ratios. Three of the six ratios used ($\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$) were not useful in identifying sourcegroups because they did not exhibit sufficient variability. Tentative source groups have been identified using only the Pb ratios. Most of the 50 pig teeth sampled belong to a single group but three other small groups can be discriminated. The large group most likely represents pigs native to Banda but the points of origin of the other groups are unknown. There is little patterning in diversity over time for the pigs. Pigs do not appear to have been an important exchange item in the Banda Islands.

Several factors have limited the utility of this approach for identifying source groups and assessing changes in diversity over time. Sample size is a major limitation in this study. All viable specimens available were included in the study but after excluding samples with high errors, only 44 samples could be included in the grouping and diversity analysis. This has led to uneven sample sizes for each excavation layer and small source group size. Three of the four groups distinguished through their Pb isotope signatures are very small with three or fewer members. It is likely that with greater sample size, more groups could be differentiated and differences in diversity among excavation levels would be more apparent.

The lack of variation in Sr isotope ratios and the lack of patterning in light isotope ratios are also limiting factors. Additional research would be necessary to determine the cause of the limited range for $^{87}Sr/^{86}Sr$. Analysis of paired bone and tooth samples and the incorporation of more specific diet reconstruction would be a very useful approach to resolve this issue. This would require a site with good bone preservation and analysis of a range of local plants and both terrestrial and marine fauna. In this study, all that can be said is that pig $\delta^{13}C$ of pigs is consistent with a terrestrial plant based diet but could include a significant proportion of marine foods. Incorporating bone in the study would enable us to determine the role of marine-based foods in determining Sr ratios.

CHAPTER 8. CONCLUSION

Trade and exchange have waned as a focus of archaeological inquiry since the late 1980's. As Bauer and Doonan (2002) point out, the number of publications focused on trade and exchange in the 1990's was markedly lower than the preceding two decades. In recent years, methodological advancements for provenance analysis have stimulated a resurgence of research tracing the movement of materials in the past but there remains little theoretical development regarding trade and exchange. The waning of interest in the subject of trade may be linked to general theoretical developments in archaeology at large; positivist methodological approaches were of little interest to postprocessual archaeologists (Bauer and Agbe-Davies 2010). The study of artifact distributions to demonstrate exchange tends to ignore the social landscape, which both formed the setting of and was conditioned by these interactions. Provenance studies have tended to situate exchange geographically rather than productively examining evidence for past interactions among communities as a process integral to creating the social landscapes that those communities inhabited. Viewed in this light, exchange and interaction studies are an avenue for discovering social landscapes and boundaries in the past that may not align closely with the geographic world.

This research has used non-specific provenance analysis to differentiate between material sources and quantify connectedness of Banda Islands communities. Connectedness, the inverse of social isolation, and its measurement represent a way to define past social boundaries. Each link in an exchange network tying a given community to others increases the connectedness of that community and decreases its social isolation. Approaching exchange and interaction using the concept of connectedness has many advantages over more traditional approaches to provenance analysis and interaction studies. This chapter discusses the advantages of this approach to exchange and interaction and how they have played out in this research, returns to the questions posed at the beginning of this dissertation, and discusses future avenues for studying exchange and interaction.

MEASURING SOCIAL ISOLATION

Traditional approaches to provenance analysis focus on reconstructing exchange systems by matching the chemical signatures of artifact raw materials to specific source locations. Such studies typically result in distribution maps showing past network connections. Such maps contain useful information but also have major limitations in terms of testing explanatory hypotheses. Interaction maps are useful for composing narratives about the history of interaction at particular times and places but they are poor tools for measurement for several reasons.

In some cases interaction maps can distort data in ways that either give the impression of patterning where none exists or obscure patterned structure that may be historically significant. Connections between discreet locales demonstrated through provenance analysis or inferred from artifact distributions are represented by arrows or lines on maps. These connections appear equal when in reality these links may represent exchange relationships of varying frequency and intensity. Not all interaction links are equal in their effect—isolated instances of contact or occasional exchange activity will not result in strong relationships between communities that significantly reduce social isolation. These nuances—the importance of the frequency and intensity of contact rather than its mere presence or absence—cannot be readily shown on interaction maps. This also complicates comparison between locations. Interaction maps are particular to a certain site, area, or region and unless the two records to be compared are extremely different, one cannot draw conclusions about the relative degrees of interaction represented.

Similarly, interaction maps are not a useful tool for examining diachronic change in exchange and interaction. Time is collapsed with interaction maps, presenting either a synchronic or phased view of interaction between places. An example is Bulbeck's (2008) analysis of prehistoric maritime interaction spheres across ISEA, which presents a series of interaction maps, each representing a large slice of time. Spriggs (2011: 523) argues that Bulbeck's aggregation of evidence for interaction from a period spanning thousands of years creates a "mirage of interaction" for the period preceding the Neolithic. The material record of interactions at a given site already represents a cumulative palimpsest as described by Bailey (2007). In terms of interaction, this can give the impression that a group was more socially connected than was actually the case at any given moment in time. Scaling data up to draw a map of regional interaction risks greatly overestimating the degree of interaction between peoples and places in the past and will tend to obscure diachronic variation in interaction networks. Using source richness, evenness and diversity measures to quantify connectedness avoids some of these pitfalls. In particular, diversity and evenness measures are sensitive to variations in frequency and intensity. In terms of capturing diachronic variation in connectedness, care must be taken in sampling for provenance analysis and when aggregating data as sample size can drive differences in richness so that uneven sampling between data sets could create the impression of significantly different richness and diversity when it does not in fact exist. Unlike traditional approaches, however, one can determine whether observed patterning in richness and diversity is dependent on sample size through simple regression of richness and sample size. So long as the relationship between sample size and richness/diversity is taken into account, diversity measures provide a means for unambiguous comparison of relative social isolation between places and through time that is not possible with particularistic interaction maps.

A further advantage of this approach is that it makes use of data from provenance analysis that is too underdetermined to incorporate in explicit reconstruction. When all possible raw material sources have not been characterized, provenance studies often identify groups of artifacts from the same source but fail to identify that source's location. These results cannot be integrated with fully determined source designations in interpretation and these data go unutilized. For example, Reepmeyer, et al. (2011) assayed 101 obsidian artifacts from Island Southeast Asia but could only match 16 to specific known obsidian sources. Data about the remaining artifacts cannot be shown on interaction maps, but they can be incorporated in measures of source diversity.

GEOGRAPHIC VS. SOCIAL ISOLATION

Employing the concept of connectedness and measures of source diversity in this study has allowed the explicit consideration of social isolation as a driving factor in interaction and exchange networks. Isolation is widely recognized as a critical variable in island environments but geographic isolation is typically taken to also reflect social isolation. This is not always the case. Relative geographic isolation is easily measured using distance as a proxy, but social isolation may not always correlate with geographic isolation. Of the two sites examined in this research, PA1 is the more geographically isolated but it had a greater degree of connectedness than BN1. In this case geographic isolation is not a reliable predictor of social isolation. Whether this is the exception or the rule in Island Southeast Asian prehistory is a question that must be answered through careful testing.

One important outstanding question is whether the difference in connectedness between PA1 and BN1 is reflective of diachronic change or differences in the connectedness of different Banda Islands sites. A priority for future testing is to conduct similar research quantifying connectedness through source diversity for more sites on different islands in the Banda Sea region. An expanded dataset will provide the context to elucidate whether observed differences in source diversity reflect diachronic change in exchange networks at a larger scale, different social positioning among sites, or both.

HOW VARIED WERE SOURCES FOR EXCHANGE ITEMS?

As discussed in Chapters 5 and 6, both pottery and pigs had local and non-local sources. Three to ten different sources for pottery were identified. The more conservative count is based on the three macrogroups observed in the data but multiple subgroupings can be differentiated for two of these. Further research involving raw material source surveys and sampling for ICP-MS or a similar characterization method could determine the specific geographic locations of clay sources and better define the groups observed in this research. What is clear at present is that macroscopically similar plain earthenware from different sources were present at both PA1 and BN1. Two explanations are possible for this exchange in functionally and stylistically similar pottery. First, the pottery itself may not have been the primary exchange item; perhaps it was the contents of ceramic vessels that people sought through exchange. Pottery may have contained food items that could not be grown in the Banda Islands, like sago, an important staple in many parts of Maluku that requires wetter conditions than are found in Banda. Alternatively, the fact that Banda Islanders went to the trouble of obtaining functionally and stylistically similar pottery from varied sources suggests that some exchange behavior may not have been driven by provisioning considerations. Ceramic vessels from non-Banda sources may have been procured through gift-exchange rather than more formal types of exchange and may have functioned primarily as a symbolic marker of social relationships.

HOW DID EXCHANGE NETWORKS CHANGE OVER TIME?

One of the most interesting results of this research is that the majority of early Neolithic pottery at PA1 is made from clays originating outside the Banda Islands. Local production accounts for less than 25% of pottery during for the first several hundred years of occupation on Pulau Ay. This result, especially coupled with the delay between the inception of pottery-use and pig rearing described in Chapter 5, is at odds with the dominant narrative for the Neolithization of ISEA. If a significant population of pottery producing horticulturalists settled at PA1 we would expect to see simultaneous arrival of pottery and pigs and significant local production of the former. Instead the archaeological record from Pulau Ay suggests a gradual transition from a hunting-fishing-gathering lifestyle, probably with relatively high mobility, to food production involving domesticated pigs and probably yam horticulture. Pottery-use with low-level local production was an initial step and may have catalyzed the shift in subsistence strategy.

Fresh water is a major constraint on settlement and subsistence in the Tropical Pacific. It appears likely that there were no long-term settlements on Pulau Ay until pottery was in use and lack of permanent accessible water resources may be the reason. The PA11 rockshelter provides evidence that people were spending time on Pulau Ay at least 8000 years ago but fairly low density deposits suggest the site may have been used repeatedly as a temporary fishing camp. The Banda Islands have extremely productive reefs that may have drawn foragers from larger islands to the north where stream runoff tends to inhibit reef growth and productivity to some extent. Permanent settlement of the Bandas, especially the dry outer islands, may not have been possible until a better technology for collecting and storing rainwater was available. In order to survive on Pualu Ay through the dry season people would have needed to be able to store enough fresh rainwater to sustain them and their domesticates for several weeks at a time. Bamboo is the most likely candidate for water storage technology prior to the advent of pottery in the region. It is unclear whether low-fired earthenware pottery would have been a substantial improvement in terms of water storage efficiency but this could be determined in the future with an experimental study. Shiung (2011) suggests that two of the more abundant rim forms in the lower layers of PA1, everted, straight rims with rounded lips and everted, straight rims with pointed lips, could have been designed to store and transport liquid. Once better water storage technology was available, the rich coral reef ecosystems provided a strong pull for more permanent settlement. PA1 is a defensible position with easy access to good reefs and to the upper terrace commanding a view of the inner islands. It is possible that the desire for territorial control drove permanent settlement. While reefs would have provided ample proteins to support permanent settlement, the small inland forest may not have initially provided sufficient starchy foods to support a growing population. Initially, people may have procured starchy plant foods, stored in earthenware pots, from other islands through exchange, accounting for the high-proportion of non-local MG3 pottery in the lower levels of PA1. Relative abundance of MG3 sherds declines shortly after pig bone abundance increases (level 3d for the former, level 3e for the latter). If the first animal husbandry and horticulture were contemporary, as generally assumed for the ISEA Neolithic, this decline may signal the time when local food production became adequate to the needs of the local population. Residue analyses, to determine whether MG3 pottery was used to store starchy plant foods, would provide a partial test of this hypothesis.

HOW DID EXCHANGE HELP ISLAND COMMUNITIES ADAPT TO THEIR ISOLATED ENVIRONMENTS?

It is clear from this study that exchange was an important part of life on Pulau Ay from at least 3500 years ago but it is not possible to draw conclusions about the ways that this exchange may have functioned as an adaptive strategy in contexts of climatic change. Such conclusions must await a long-term, well-dated, high resolution paleoclimate proxy from the vicinity of the Banda Islands. While precise temporal correlation is not possible due to the chronological uncertainties associated with each record and with the dating of the archaeological sites, it is worth noting that the greatest source diversity in PA1 ceramic raw materials occurs around 3000 BP. Source richness and diversity (measured through both Simpson and Shannon indices) is highest in Layer 4 dated to 3341-3072 BP. As described in Chapter 4, multiple paleoclimate proxy records from the eastern and western Pacific show an increase in El Niño-like conditions around this time. Bandanese exchange networks may have increased to include more exchange partners when environmental variability linked to ENSO increased. This layer also has the first evidence for at least sporadic contact with the Ambon-Lease islands. This may be significant because Ambon is a larger, higher, and wetter island and while it would also be affected by ENSO drought, the impacts would not likely have been so severe as in the Banda Islands in general and Pulau Ay in particular.

A clearer and more extreme increase in the frequency and amplitude of El Niño occurred about a millennium later but the Banda Islands archaeological record provides little evidence regarding exchange and interaction from 2000-1000 BP. In fact this period is notably absent in the Banda Islands sites. PA1 is the only site with dates eclipsing this period. Although this site has provided dates ranging from 3550-960 BP, there is clearly a change in deposition late in the sequence that suggests site abandonment just after 2300 BP. If AMS radiocarbon dates obtained from layers 2B and 2D are valid, sediments and artifacts accumulated at a rate of only 1.16 cm/100 years during this time. As discussed in Chapter 5, the radiocarbon sample from layer 2D may have been redeposited when postholes were dug. However, even if we exclude this problematic date, accumulation rates are markedly different in the earlier and later portions of the site. The uppermost 105 cm accumulated at a rate of just 2.99 cm/100 years while the lower portion accumulated at approximately 15.61 cm/ 100 years. One possible explanation is that the site was abandoned for a significant period of time. In light of the paleoclimate proxy evidence, this scenario seems likely. Severe prolonged drought of the type recorded in the fossil coral from Papua New Guinea (McGregor and Gagan 2004) would have made Pulau Ay and other outlying limestone islands uninhabitable. Indeed, no other sites on Pulau Ay are dated to this period.

An attempt to locate an open site occupied 2000-1500 years ago was made during the 2009 field season. PA10 was identified based on the presence of surface pottery that appeared similar to sculpted earthenware found at BN1 and dated to approximately 1300 BP (Lape 2000a). Two shovel probes were dug but no subsurface archaeological deposits were present. Further survey and testing was also unsuccessful. Since a complete systematic survey has not been carried out we cannot conclusively say that these sites do not exist but based on this negative evidence is suggestive of a period when permanent occupation of the island was abandoned approximately 2000-1500 BP.

Archaeologists have suggested a correlation between high ENSO variance and increasing conflict across the Pacific with the onset of the Little Ice Age. Climate change has been proposed as an explanation for the dramatic increase in fortified settlements on islands throughout the Pacific Basin, from East Timor (Lape and Chao 2008) to Fiji (Field 2004) to Palau (Clark and Reepmeyer 2012). If this is a general trend in Pacific prehistory, increased conflict could also contribute to this change in settlement. PA1 is a relatively defensible location but perhaps increased conflict in the region prompted the inhabitants to relocate closer to their allies.

The earliest occupation at BN1 has been dated to 1300-1400 BP (Lape 2000a). The earliest date for BN1 Unit 6 (the source of materials for this research) was slightly later at 1140-940 BP. Source diversity for pottery in this layer was much lower compared to the earlier layers at PA1 and the non-local macrogroup which dominated the PA1 assemblage is entirely absent. This appears to be a climatically more stable period in many of the proxy records although there is considerable inconsistency between EEP and WPWP proxies. The Laguna Pallcacocha and El Junco data sets show relatively low frequency and intensity of El Niño for a period of several centuries centered on 1000 BP. In contrast, the hydrogen isotope sequence from the Makassar Strait indicates that the region was drier from 950-650 BP. If the latter is correct, this climatic change did not lead to significant changes in source diversity at BN1. It could be significant that all of the non-local pottery at BN1 belongs to the source group attributed to Ambon-Lease. As discussed above, this area may have been somewhat insulated from droughts caused by El Nino conditions which peak Nov-Dec, while Ambon tends to receive the most rainfall in June and July. Another possibility is that the focus of exchange activities shifted from pots (and/or their contents) to less archaeologically visible goods. Occupation at BN1 post-dates the beginning of the Metal Age in ISEA. Little is known about this period in eastern Indonesia but it was a period when maritime trade and interaction increased across much of ISEA and this may have presented new opportunities for exchange and trade. The Bandanese may have traded less archaeologically visible materials, like nutmeg, rather than simple earthenware.

CONCLUSION

It is challenging to draw conclusions about the relationship between exchange and environmental variability at present. This is mainly because there is as yet no long-term, well-dated, high resolution proxy from the vicinity of the Banda Islands. The proxy records available from the WPWP are low-resolution marine cores or broken sequences from coral and these often yield inconsistent results, especially in regard to the timing of climatic change. Well-dated, high-resolution proxies from the EEP offer the best information about ENSO variability through the Holocene but it is unclear whether the teleconnections linking SST anomalies in the EEP and hydrologic variability in the WPWP have been stable over the long-term. Obtaining a high quality proxy record for rainfall in central Maluku is a major priority for future research into human-environment interaction in this area.

Assessment of the existing proxy records suggests that, consistent with the model tested here, source diversity in exchange networks in the Banda Islands may have increased during a period of increased ENSO variance and associated reduced rainfall. This conclusion is tentative at best because of significant temporal inconsistencies and differences in resolution between proxy records place the climatic shift anywhere from 3400 BP to 2700 BP. This range encompasses most of the PA1 sequence so it is unclear whether this shift came before or after the increase in source diversity.

Around 2000 years ago, extreme drought conditions linked to El Nino may have led to a complete abandonment of dry limestone islands. At minimum there was a change in site use at PA1 leading to no deposition in the portion of the site that has been tested. While exchange may function to reduce the risks associated with isolation in period of high environmental variability it would not be sufficient if that variability crossed a certain threshold. Again the temporal vagaries associated with paleoclimate proxies make it impossible to state with any certainty that the period of high ENSO variance co-occurs with the change at PA1 at present. Obtaining such a record is a high priority for future research on human-environment interactions in this region. This outstanding question is an important one that will require collaborative research between archaeologists and paleoclimate scientists.

Extreme drought conditions linked to El Nino may have a role in the change in site use observed at PA1 around 2000 years ago. This climatic change may have been so severe that the inhabitants of small, dry, isolated, limestone islands were forced to abandon their homes. More research in the Banda Islands and elsewhere in Maluku will be necessary to test this hypothesis. Coupled with the problems of extreme drought, El Nino also creates more favorable voyaging conditions in the Banda Sea. While full-time occupation of Pulau Ay would have been very difficult with frequent intense El Nino conditions, calmer seas would have allowed people to more easily travel there to procure reef resources. Perhaps the once full-time inhabitants of PA1 abandoned permanent settlement during a period of extreme water stress settling in a more hospitable location and frequently returning to their old village sites to fish and forage on the reefs.

Paleoclimate research is needed to determine if the effects in the Banda Sea region were as severe as suggested by the coral record from Papua New Guinea. Paleoclimate proxy data from the Banda Sea region, particularly well-dated, hydrogen isotope-based paleohydrology proxies, are needed to confirm that El Nino frequency and amplitude had the expected effect in the Banda Sea area. If this is the case, pollen records could help to document actual changes within the island landscape that resulted from more frequent severe droughts. Archaeological research at other open sites occupied around this time could help to answer several important questions: Was there a widespread abandonment of sites on small, remote, and dry islands around the same time? Were sites on larger/less remote islands with more reliable water resources occupied continuously or were the effects of the climatic shift strong enough to lead to a demographic collapse?

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APPENDIX A: LA-ICP-MS RESULTS

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
1	PA1	L2b01	2	b	62.27%	0.80%	0.76%	22.99%	0.65%	0.31%	2.78%	8.01%	1.35%
2	PA1	L2b02	2	b	62.87%	1.13%	0.88%	22.35%	0.75%	0.95%	2.41%	7.43%	1.09%
3	PA1	L2b03	2	b	67.74%	1.61%	0.64%	21.05%	0.95%	0.29%	3.25%	3.78%	0.55%
4	PA1	L2b04	2	b	62.67%	0.79%	1.36%	24.90%	0.75%	0.37%	3.05%	5.37%	0.64%
5	PA1	L2b05	2	b	62.29%	1.48%	0.57%	26.51%	0.55%	0.21%	2.65%	4.93%	0.72%
6	PA1	L2b06	2	b	64.10%	0.98%	1.03%	24.67%	0.61%	0.36%	2.63%	4.83%	0.67%
7	PA1	L2b07	2	b	60.96%	1.97%	0.93%	22.13%	0.98%	0.76%	2.95%	8.43%	0.67%
8	PA1	L2b08	2	b	62.68%	1.44%	2.32%	20.33%	1.52%	1.07%	2.35%	7.67%	0.49%
9	PA1	L2b09	2	b	63.70%	0.81%	0.96%	22.67%	1.43%	0.21%	2.83%	6.72%	0.54%
10	PA1	L2c01	2	c	60.61%	1.10%	0.78%	24.16%	1.58%	0.28%	3.31%	7.45%	0.62%
11	PA1	L2c02	2	c	61.34%	1.02%	0.89%	24.06%	1.46%	0.48%	2.70%	7.37%	0.58%
12	PA1	L2c03	2	c	62.40%	1.35%	0.69%	22.79%	1.59%	0.32%	2.58%	7.56%	0.63%
13	PA1	L2c04	2	c	62.52%	1.23%	1.09%	22.25%	1.25%	0.47%	2.72%	7.76%	0.60%
14	PA1	L2c05	2	c	65.98%	1.28%	0.74%	21.10%	0.75%	0.71%	1.80%	7.02%	0.54%
15	PA1	L2c06	2	c	60.56%	0.88%	1.38%	23.59%	1.56%	0.49%	2.60%	8.22%	0.62%
16	PA1	L2c07	2	c	64.08%	1.42%	0.64%	22.36%	1.06%	0.24%	2.68%	6.87%	0.58%
17	PA1	L2c08	2	c	59.63%	0.59%	1.02%	23.33%	1.32%	0.20%	2.44%	10.55%	0.77%
18	PA1	L2c10	2	c	67.00%	1.57%	0.64%	20.61%	0.83%	0.16%	2.99%	5.67%	0.46%
19	PA1	L2d01	2	d	68.02%	1.23%	0.52%	18.04%	1.57%	0.21%	3.04%	6.62%	0.66%
20	PA1	L2d02	2	d	55.04%	0.91%	1.55%	25.61%	3.50%	0.24%	4.24%	8.18%	0.63%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
21	PA1	L2d03	2	d	68.94%	1.65%	0.44%	20.51%	0.94%	0.18%	2.88%	4.00%	0.40%
22	PA1	L2d04	2	d	60.88%	1.17%	1.58%	23.47%	1.31%	0.26%	2.82%	7.81%	0.57%
23	PA1	L2d05	2	d	61.28%	1.34%	0.99%	24.52%	0.84%	0.32%	2.98%	7.03%	0.62%
24	PA1	L2d06	2	d	60.78%	0.93%	0.65%	26.74%	1.15%	0.15%	2.70%	6.35%	0.47%
25	PA1	L2d07	2	d	67.74%	0.94%	0.74%	22.51%	0.50%	0.21%	2.19%	4.74%	0.38%
26	PA1	L2d08	2	d	62.48%	1.18%	0.91%	24.92%	0.71%	0.26%	3.21%	5.75%	0.52%
27	PA1	L2d10	2	d	61.67%	0.76%	2.63%	15.99%	1.42%	0.24%	3.13%	13.11%	0.84%
28	PA1	L3a01	3	a	59.22%	1.17%	1.50%	21.44%	2.01%	0.26%	4.01%	9.30%	0.93%
29	PA1	L3a02	3	a	66.24%	1.71%	1.00%	21.27%	0.72%	0.29%	2.69%	5.42%	0.56%
30	PA1	L3a03	3	a	68.09%	1.68%	1.34%	17.90%	0.44%	0.68%	1.72%	7.45%	0.57%
31	PA1	L3a04	3	a	58.35%	0.91%	1.27%	24.85%	1.42%	0.39%	2.81%	8.93%	0.96%
32	PA1	L3a05	3	a	62.90%	0.58%	0.54%	22.56%	1.54%	0.14%	2.21%	8.61%	0.79%
33	PA1	L3b01	3	b	63.89%	1.11%	0.77%	23.23%	1.31%	0.25%	2.88%	5.89%	0.59%
34	PA1	L3b02	3	b	64.01%	1.19%	0.85%	23.12%	0.86%	0.23%	2.65%	6.36%	0.63%
35	PA1	L3b04	3	b	68.03%	1.66%	0.68%	22.21%	1.05%	1.97%	1.69%	2.45%	0.13%
36	PA1	L3b05	3	b	68.68%	1.10%	1.43%	19.05%	0.77%	0.35%	2.45%	5.55%	0.52%
37	PA1	L3c01	3	c	58.19%	0.68%	1.19%	25.70%	2.06%	0.31%	3.73%	7.38%	0.62%
38	PA1	L3c02	3	c	55.66%	0.59%	1.08%	26.21%	4.44%	0.43%	3.78%	7.13%	0.55%
39	PA1	L3c03	3	c	65.07%	0.60%	1.17%	20.21%	1.12%	1.37%	1.67%	8.04%	0.67%
40	PA1	L3c04	3	c	59.33%	1.69%	1.22%	24.48%	1.12%	0.42%	3.05%	7.95%	0.64%
41	PA1	L3c05	3	c	60.01%	0.64%	1.12%	24.97%	0.90%	0.50%	2.73%	8.33%	0.67%
42	PA1	L3d01	3	d	59.38%	0.96%	1.49%	25.61%	0.91%	0.26%	3.15%	7.57%	0.59%
43	PA1	L3d02	3	d	58.72%	1.12%	1.00%	24.96%	2.29%	0.33%	3.47%	7.44%	0.57%
44	PA1	L3d03	3	d	69.79%	1.65%	0.69%	19.60%	0.43%	0.53%	1.76%	5.11%	0.39%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
45	PA1	L3d04	3	d	59.57%	0.63%	1.39%	25.42%	1.52%	0.30%	2.95%	7.51%	0.63%
46	PA1	L3D05	3	d	69.12%	1.33%	1.21%	16.93%	0.62%	0.43%	2.70%	7.02%	0.57%
47	PA1	L3e01	3	e	51.93%	0.87%	1.73%	26.63%	5.66%	0.42%	4.20%	7.84%	0.58%
48	PA1	L3e02	3	e	60.54%	0.82%	1.48%	24.51%	0.80%	0.33%	2.91%	7.86%	0.66%
49	PA1	L3e03	3	e	60.81%	1.29%	1.08%	24.03%	1.40%	0.28%	2.47%	7.96%	0.58%
50	PA1	L3e04	3	e	62.53%	0.58%	1.45%	22.75%	1.50%	0.30%	3.25%	6.99%	0.56%
51	PA1	L3e05	3	e	57.36%	0.59%	1.40%	25.16%	2.45%	0.26%	3.71%	8.24%	0.62%
52	PA1	L3f01	3	f	60.94%	0.57%	1.56%	23.59%	0.39%	0.19%	2.24%	9.60%	0.85%
53	PA1	L3f03	3	f	63.66%	2.66%	1.73%	20.46%	0.25%	0.48%	1.84%	8.28%	0.60%
54	PA1	L3f04	3	f	63.17%	0.82%	1.49%	21.18%	1.29%	0.30%	3.63%	7.46%	0.59%
55	PA1	L3f05	3	f	57.14%	1.50%	1.68%	24.05%	1.66%	0.65%	3.44%	9.04%	0.74%
56	PA1	L3g01	3	g	52.34%	0.63%	0.93%	29.72%	3.86%	0.30%	4.04%	7.52%	0.57%
57	PA1	L3g02	3	g	58.22%	0.63%	1.24%	24.17%	3.76%	0.23%	3.59%	7.43%	0.61%
58	PA1	L3g03	3	g	54.10%	1.31%	0.82%	28.03%	3.29%	0.32%	3.23%	8.24%	0.57%
59	PA1	L3g04	3	g	60.15%	0.94%	1.06%	25.59%	0.87%	0.25%	3.17%	7.23%	0.58%
60	PA1	L3g05	3	g	62.05%	1.08%	1.34%	23.01%	0.44%	0.33%	2.58%	8.37%	0.74%
61	PA1	L3h01	3	h	63.04%	1.10%	0.70%	20.51%	0.84%	0.21%	2.72%	9.94%	0.87%
62	PA1	L3h02	3	h	55.89%	0.89%	1.31%	25.54%	3.74%	0.19%	4.13%	7.62%	0.61%
63	PA1	L3h03	3	h	57.68%	0.93%	1.09%	26.17%	1.67%	0.23%	2.86%	8.65%	0.64%
64	PA1	L3h04	3	h	54.79%	1.40%	1.30%	25.19%	1.33%	0.59%	5.92%	8.73%	0.64%
65	PA1	L3h05	3	h	60.06%	0.61%	1.07%	24.02%	0.38%	0.16%	2.42%	10.39%	0.81%
66	PA1	L3i01	3	i	53.67%	0.78%	1.14%	26.74%	4.23%	0.19%	3.62%	8.96%	0.59%
67	PA1	L3i03	3	i	60.96%	1.36%	1.48%	24.03%	1.00%	0.41%	2.87%	7.31%	0.52%
68	PA1	L3i04	3	i	59.02%	1.01%	1.27%	21.99%	3.95%	0.24%	3.69%	8.03%	0.62%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
69	PA1	L3i05	3	i	60.68%	0.64%	2.05%	23.49%	1.29%	0.46%	2.78%	7.92%	0.53%
70	PA1	L4a01	4	a	55.75%	1.44%	1.51%	24.84%	2.55%	0.58%	4.33%	8.18%	0.71%
71	PA1	L4a02	4	a	61.39%	1.14%	2.51%	21.95%	1.34%	0.50%	3.72%	6.75%	0.49%
72	PA1	L4a03	4	a	57.45%	1.02%	1.48%	26.24%	1.65%	0.34%	4.25%	6.94%	0.56%
73	PA1	L4a04	4	a	61.12%	0.99%	1.02%	24.64%	0.69%	0.22%	2.91%	7.77%	0.59%
74	PA1	L4a05	4	a	57.49%	1.07%	1.18%	24.66%	2.99%	0.30%	3.79%	7.80%	0.64%
75	PA1	L4a06	4	a	66.38%	1.63%	1.45%	18.66%	0.24%	0.67%	2.20%	7.95%	0.68%
76	PA1	L4a07	4	a	56.03%	0.93%	1.43%	27.75%	0.80%	0.24%	2.96%	9.03%	0.75%
77	PA1	L4a09	4	a	53.16%	1.03%	1.38%	29.85%	2.54%	0.08%	3.17%	7.99%	0.65%
78	PA1	L4a10	4	a	51.64%	0.51%	1.31%	27.48%	5.70%	0.23%	4.97%	7.48%	0.58%
79	PA1	L4b01	4	b	58.09%	1.07%	1.55%	25.37%	1.67%	0.34%	3.43%	7.76%	0.61%
80	PA1	L4b02	4	b	57.37%	1.01%	1.52%	25.60%	2.12%	0.33%	3.60%	7.73%	0.60%
81	PA1	L4b03	4	b	57.11%	0.98%	1.53%	25.73%	2.18%	0.33%	3.65%	7.77%	0.61%
82	PA1	L4b04	4	b	56.80%	1.02%	1.48%	25.92%	2.26%	0.31%	3.73%	7.75%	0.62%
83	PA1	L4b05	4	b	56.79%	0.88%	1.71%	23.14%	3.77%	0.36%	5.07%	7.57%	0.62%
84	PA1	L4b06	4	b	59.43%	1.58%	1.26%	24.12%	1.06%	0.47%	2.50%	8.73%	0.76%
85	PA1	L4b07	4	b	60.04%	1.16%	1.47%	22.16%	1.69%	0.28%	4.09%	8.27%	0.69%
86	PA1	L4b08	4	b	53.24%	0.79%	0.97%	29.43%	3.28%	0.21%	3.45%	7.77%	0.76%
87	PA1	L4b10	4	b	52.23%	0.97%	1.28%	26.98%	6.23%	0.21%	3.88%	7.44%	0.57%
88	PA1	L4c01	4	c	58.79%	1.31%	2.06%	20.76%	0.26%	1.56%	3.81%	10.40%	0.81%
89	PA1	L4c02	4	c	61.72%	0.91%	1.37%	22.65%	0.37%	0.24%	2.38%	9.35%	0.89%
90	PA1	L4c03	4	c	57.48%	0.90%	1.56%	26.30%	2.42%	0.31%	3.09%	7.26%	0.62%
91	PA1	L4c04	4	c	55.93%	0.71%	0.75%	26.42%	3.12%	0.23%	3.49%	8.50%	0.77%
92	PA1	L4c05	4	c	64.56%	1.22%	1.60%	24.74%	0.70%	0.83%	3.50%	1.85%	0.69%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
93	PA1	L4c06	4	c	55.62%	0.91%	1.01%	26.13%	4.53%	0.26%	3.69%	7.04%	0.65%
94	PA1	L4c07	4	c	56.06%	2.28%	2.26%	21.01%	1.36%	0.85%	5.20%	8.75%	0.71%
95	PA1	L4c08	4	c	53.96%	0.57%	0.95%	27.66%	2.60%	0.20%	4.49%	8.88%	0.61%
96	PA1	L4c09	4	c	59.25%	0.69%	1.07%	28.01%	4.61%	0.23%	3.74%	1.56%	0.73%
97	PA1	L4c10	4	c	61.55%	0.45%	1.29%	24.56%	0.39%	0.19%	2.75%	8.04%	0.74%
98	PA1	L6a01	6	a	61.82%	0.89%	1.32%	21.03%	0.19%	0.45%	2.76%	10.45%	1.02%
99	PA1	L6a02	6	a	58.85%	0.74%	1.15%	24.90%	2.42%	0.21%	3.70%	7.38%	0.55%
100	PA1	L6a04	6	a	61.78%	1.36%	2.03%	18.16%	0.70%	0.29%	4.73%	9.79%	1.02%
101	PA1	L6a05	6	a	56.44%	0.76%	0.81%	27.70%	1.73%	0.22%	3.75%	7.86%	0.68%
102	PA1	L6a06	6	a	52.54%	0.70%	0.99%	28.68%	3.97%	0.28%	4.11%	8.10%	0.55%
103	PA1	L6a07	6	a	54.49%	0.86%	1.14%	28.31%	2.98%	0.30%	3.75%	7.47%	0.62%
104	PA1	L6a09	6	a	56.65%	1.07%	1.70%	24.89%	3.26%	0.33%	4.17%	7.26%	0.58%
105	PA1	L6a10	6	a	59.38%	0.95%	0.92%	24.23%	0.75%	0.32%	3.30%	9.00%	1.09%
106	PA1	L6a12	6	a	66.48%	0.70%	1.16%	19.69%	0.51%	0.23%	2.47%	7.93%	0.78%
107	PA1	L6a13	6	a	58.58%	1.85%	4.99%	17.77%	0.10%	0.14%	3.44%	11.97%	0.97%
108	PA1	L6b01	6	b	55.45%	1.00%	1.09%	27.90%	1.52%	0.29%	3.62%	8.30%	0.74%
109	PA1	L6b02	6	b	56.50%	0.96%	1.03%	27.16%	1.33%	0.27%	4.40%	7.64%	0.66%
110	PA1	L6b03	6	b	51.80%	0.74%	1.02%	28.70%	3.36%	0.27%	4.95%	8.37%	0.70%
111	PA1	L6b04	6	b	58.34%	3.12%	0.99%	25.58%	0.86%	0.23%	4.32%	5.94%	0.56%
112	PA1	L6b05	6	b	55.24%	0.79%	1.81%	23.83%	0.70%	0.28%	4.24%	11.80%	1.21%
113	PA1	L6b06	6	b	58.94%	1.11%	1.30%	23.18%	1.14%	0.38%	4.41%	8.66%	0.76%
114	PA1	L6b07	6	b	56.51%	0.65%	1.03%	24.80%	4.26%	0.34%	4.55%	7.17%	0.56%
115	PA1	L6b08	6	b	57.66%	0.98%	0.81%	26.18%	2.07%	0.23%	3.49%	7.89%	0.60%
116	PA1	L6b09	6	b	51.51%	0.77%	1.12%	24.62%	3.29%	0.30%	10.67%	6.97%	0.65%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
117	PA1	L6c01	6	c	65.71%	0.79%	1.09%	21.18%	0.21%	0.20%	2.63%	7.52%	0.62%
118	PA1	L6c02	6	c	59.43%	0.97%	1.05%	23.44%	2.62%	0.26%	3.21%	8.22%	0.70%
119	PA1	L6c03	6	c	55.05%	1.14%	1.15%	26.31%	3.62%	0.22%	3.67%	7.96%	0.80%
120	PA1	L6c04	6	c	58.78%	1.18%	1.70%	23.62%	2.12%	0.32%	4.64%	6.92%	0.61%
121	PA1	L6c05	6	c	56.83%	1.21%	1.74%	23.38%	4.26%	0.33%	4.34%	7.20%	0.59%
122	PA1	L6c06	6	c	62.54%	1.05%	1.50%	21.71%	0.25%	0.38%	2.40%	9.30%	0.82%
123	PA1	L6c07	6	c	52.05%	0.75%	1.12%	24.92%	5.87%	0.25%	6.00%	8.30%	0.60%
124	PA1	L6c08	6	c	57.13%	0.86%	1.51%	25.36%	1.90%	0.27%	3.92%	8.32%	0.67%
125	BN1	L8a01	8	a	67.14%	2.10%	0.58%	18.88%	1.41%	0.59%	1.32%	7.27%	0.58%
126	BN1	L8a02	8	a	66.02%	1.94%	0.56%	17.95%	1.15%	0.67%	1.42%	7.23%	0.68%
127	BN1	L8a03	8	a	60.77%	0.89%	0.78%	23.44%	1.28%	0.31%	1.28%	10.18%	0.99%
128	BN1	L8a04	8	a	67.25%	1.22%	0.89%	18.36%	1.60%	1.61%	1.10%	7.35%	0.51%
129	BN1	L8a06	8	a	59.19%	1.43%	0.45%	22.34%	3.09%	0.51%	1.72%	10.16%	0.97%
130	BN1	L8b01	8	b	65.84%	0.91%	0.66%	17.31%	0.75%	3.78%	1.58%	8.23%	0.80%
131	BN1	L8b02	8	b	69.94%	1.72%	0.64%	17.22%	1.72%	0.53%	1.53%	5.95%	0.64%
132	BN1	L8b04	8	b	64.46%	1.79%	0.42%	19.70%	2.41%	0.56%	1.72%	8.18%	0.64%
133	BN1	L8b05	8	b	63.15%	2.27%	0.37%	18.72%	2.98%	0.70%	1.65%	9.22%	0.84%
134	BN1	L8b06	8	b	63.82%	1.77%	0.97%	19.20%	1.59%	0.77%	1.48%	9.37%	0.90%
135	BN1	L8c01	8	c	65.58%	1.57%	0.47%	19.56%	1.80%	0.46%	1.84%	7.96%	0.68%
136	BN1	L8c02	8	c	65.14%	1.14%	0.60%	19.94%	0.59%	2.29%	1.65%	8.02%	0.53%
137	BN1	L8c03	8	c	62.62%	1.83%	0.33%	20.72%	2.14%	0.57%	1.76%	9.07%	0.85%
138	BN1	L8c04	8	c	68.43%	1.95%	1.03%	17.58%	0.10%	0.58%	1.17%	8.31%	0.78%
139	BN1	L8c05	8	c	61.74%	1.62%	0.35%	20.25%	2.48%	0.51%	1.76%	10.21%	0.96%
140	BN1	L8d01	8	d	60.90%	1.12%	0.54%	21.62%	2.04%	0.88%	2.08%	9.77%	0.97%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
141	BN1	L8d02	8	d	54.58%	0.86%	0.56%	21.15%	5.00%	0.51%	2.70%	13.15%	1.37%
142	BN1	L8d03	8	d	65.97%	1.59%	0.61%	19.02%	1.30%	0.60%	1.70%	8.30%	0.83%
143	BN1	L8d04	8	d	63.04%	1.39%	0.52%	19.54%	2.79%	0.59%	2.33%	8.81%	0.89%
144	BN1	L8d06	8	d	59.77%	1.36%	0.36%	22.92%	2.33%	0.38%	1.82%	9.80%	1.18%
145	BN1	L8e02	8	e	64.70%	1.20%	0.63%	20.03%	2.54%	0.46%	1.99%	7.68%	0.67%
146	BN1	L8e03	8	e	59.70%	0.92%	1.06%	18.58%	2.12%	0.67%	2.10%	13.12%	1.66%
147	BN1	L8e04	8	e	58.07%	0.71%	0.34%	23.74%	1.84%	0.33%	2.62%	11.21%	1.08%
148	BN1	L8e05	8	e	66.89%	1.55%	1.22%	19.51%	0.59%	1.85%	1.82%	6.06%	0.43%
149	BN1	L8e06	8	e	59.97%	0.32%	1.33%	24.43%	0.55%	0.69%	1.92%	9.74%	0.94%
150	BN1	L9a02	9	a	64.86%	2.64%	1.23%	19.33%	0.38%	0.74%	1.36%	8.54%	0.82%
151	BN1	L9a03	9	a	64.86%	2.64%	1.23%	19.33%	0.38%	0.74%	1.36%	8.54%	0.82%
152	BN1	L9a04	9	a	64.26%	1.73%	0.67%	18.49%	1.42%	0.43%	1.86%	10.03%	0.91%
153	BN1	L9a05	9	a	57.81%	1.37%	0.41%	23.46%	2.41%	0.52%	1.91%	11.04%	0.99%
154	BN1	L9a06	9	a	64.80%	2.04%	0.87%	19.49%	0.61%	1.50%	1.64%	8.19%	0.73%
155	BN1	L9a07	9	a	63.78%	2.45%	0.93%	19.66%	0.65%	1.21%	1.30%	9.02%	0.84%
156	BN1	L9a09	9	a	67.48%	1.32%	0.47%	18.81%	1.16%	0.56%	1.78%	7.69%	0.64%
157	BN1	L9a10	9	a	68.31%	1.48%	0.55%	18.81%	1.24%	0.54%	1.72%	6.59%	0.70%
158	BN1	L9b01	9	b	61.25%	1.17%	0.41%	22.19%	0.31%	0.31%	1.00%	12.03%	1.26%
159	BN1	L9b04	9	b	57.45%	0.80%	0.61%	21.55%	2.05%	1.37%	2.07%	12.96%	1.05%
160	BN1	L9b05	9	b	66.96%	1.89%	0.46%	18.15%	1.60%	0.65%	2.05%	7.44%	0.70%
161	BN1	L9b06	9	b	62.18%	1.17%	1.89%	17.85%	0.81%	1.98%	5.61%	7.64%	0.66%
162	BN1	L9b07	9	b	65.45%	1.64%	0.38%	19.74%	0.70%	0.46%	2.17%	8.63%	0.76%
163	BN1	L9b08	9	b	70.77%	1.56%	0.66%	16.08%	0.26%	0.68%	1.76%	7.33%	0.83%
164	BN1	L9b09	9	b	58.65%	1.08%	0.69%	20.57%	3.11%	0.49%	2.63%	11.55%	1.12%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
165	BN1	L9b10	9	b	60.27%	0.73%	0.64%	22.27%	4.13%	0.71%	3.45%	7.23%	0.47%
166	BN1	L9c02	9	c	67.24%	1.55%	0.55%	18.43%	0.75%	0.46%	2.21%	7.79%	0.92%
167	BN1	L9c03	9	c	60.29%	0.89%	2.13%	17.79%	1.06%	1.70%	7.72%	7.51%	0.65%
168	BN1	L9c04	9	c	65.89%	2.02%	0.69%	16.11%	1.26%	0.76%	2.04%	9.91%	1.18%
169	BN1	L9c05	9	c	61.68%	1.50%	0.41%	21.30%	1.91%	0.47%	2.27%	9.43%	0.93%
170	BN1	L9c06	9	c	69.31%	0.90%	0.66%	17.49%	1.04%	1.48%	1.55%	6.89%	0.62%
171	BN1	L9c07	9	c	69.56%	1.01%	1.64%	21.62%	1.05%	0.95%	1.88%	1.49%	0.61%
172	BN1	L9c08	9	c	56.20%	0.82%	0.53%	23.95%	5.18%	0.52%	3.13%	8.84%	0.72%
173	BN1	L9c09	9	c	56.30%	0.32%	0.90%	22.19%	3.29%	0.99%	8.60%	6.70%	0.56%
174	BN1	L10a01	10	a	58.62%	0.71%	0.52%	22.79%	2.93%	0.33%	2.66%	10.23%	1.13%
175	BN1	L10a02	10	a	67.01%	1.23%	0.67%	18.51%	0.86%	0.41%	1.90%	8.57%	0.77%
176	BN1	L10a04	10	a	63.27%	0.75%	1.29%	17.62%	1.52%	1.36%	4.34%	9.21%	0.56%
177	BN1	L10a05	10	a	59.43%	1.06%	0.43%	29.92%	2.96%	0.84%	2.62%	2.52%	0.14%
178	BN1	L10a06	10	a	57.36%	1.28%	3.78%	15.52%	1.62%	1.78%	10.68%	7.27%	0.52%
179	BN1	L10b01	10	b	62.22%	1.05%	0.42%	20.01%	2.42%	0.40%	2.27%	10.22%	0.91%
180	BN1	L10b02	10	b	65.09%	1.33%	0.40%	19.09%	1.89%	0.65%	2.31%	8.20%	0.95%
181	BN1	L10b03	10	b	59.93%	0.98%	2.09%	17.14%	1.24%	1.62%	8.26%	7.98%	0.61%
182	BN1	L10b04	10	b	68.98%	1.86%	0.72%	17.13%	0.86%	0.44%	1.84%	7.43%	0.65%
183	BN1	L10b05	10	b	47.98%	1.00%	0.49%	27.70%	7.34%	1.44%	3.83%	9.41%	0.70%
184	BN1	L10c01	10	c	57.16%	0.70%	0.74%	23.04%	3.75%	0.34%	2.79%	10.25%	1.15%
185	BN1	L10c02	10	c	57.54%	1.07%	1.24%	18.84%	2.50%	0.77%	10.64%	6.40%	0.88%
186	BN1	L10c03	10	c	56.91%	0.97%	0.57%	24.77%	3.07%	0.35%	2.81%	9.57%	0.88%
187	BN1	L10c05	10	c	62.37%	0.76%	0.62%	21.22%	3.09%	0.27%	2.23%	8.63%	0.74%
188	BN1	L10C06	10	c	68.77%	0.75%	1.67%	14.83%	0.37%	3.79%	2.59%	6.56%	0.56%

#	Site	Sample ID	Layer	Level	SiO2	Na2O	MgO	Al2O3	P2O3	K2O	CaO	Fe2O3	TiO2
189	BN1	L10d01	10	d	65.01%	1.30%	0.66%	17.91%	1.67%	0.53%	2.44%	9.37%	0.99%
190	BN1	L10d02	10	d	69.31%	1.14%	0.59%	17.84%	2.01%	0.46%	2.21%	5.87%	0.51%
191	BN1	L10d03	10	d	60.10%	1.14%	0.79%	21.85%	3.59%	0.78%	2.76%	8.29%	0.61%
192	BN1	L10d04	10	d	62.49%	1.22%	0.64%	18.95%	1.32%	0.42%	2.06%	11.61%	1.20%
193	BN1	L10d05	10	d	64.64%	1.26%	1.08%	19.12%	0.70%	1.27%	1.46%	9.62%	0.78%
194	BN1	L10d06	10	d	60.71%	1.36%	0.40%	20.77%	3.50%	0.55%	2.87%	8.75%	1.00%
195	BN1	L10e01	10	e	59.95%	1.00%	0.50%	22.32%	3.30%	0.34%	2.70%	8.88%	0.90%
196	BN1	L10e03	10	e	67.20%	1.43%	0.40%	19.20%	1.44%	0.55%	1.86%	6.96%	0.90%
197	BN1	L10e04	10	e	65.42%	0.97%	0.89%	23.46%	1.42%	2.16%	2.21%	2.26%	1.12%
198	BN1	L10e05	10	e	54.24%	0.43%	0.96%	26.24%	3.37%	0.76%	5.77%	7.00%	0.48%
199	BN1	L10e06	10	e	65.38%	0.61%	1.44%	20.00%	1.75%	1.29%	7.30%	1.53%	0.60%
200	Ouh	Sa01	na	na	64.15%	0.37%	1.47%	17.27%	0.07%	2.67%	3.88%	9.23%	0.76%

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
1	PA1	L2b01	6.937	0.583	8.594	38.929	174.986	5.536	167.734	3.34	4.647	31.094
2	PA1	L2b02	4.498	0.642	6.746	30.899	130.89	4.108	337.9	4.176	10.447	32.572
3	PA1	L2b03	10.731	0.971	7.316	21.633	22.402	3.919	382.312	2.548	4.084	19.616
4	PA1	L2b04	8.958	1.122	7.243	32.741	56.034	46.892	167.005	15.996	3.571	34.292
5	PA1	L2b05	10.357	0.62	10.395	21.6	54.365	5.511	126.901	3.604	2.874	9.713
6	PA1	L2b06	16.77	1.311	8.682	27.64	50.444	67.195	260.389	17.316	4.798	34.587
7	PA1	L2b07	11.858	1.752	6.506	26.389	62.639	25.82	1021.559	13.662	10.448	16.278
8	PA1	L2b08	15.392	1.505	14.378	25.968	54.843	12.366	394.839	7.078	5.433	39.22
9	PA1	L2b09	4.523	1.179	7.844	25.21	46.714	8.87	423.205	5.267	5.467	43.764
10	PA1	L2c01	8.583	0.691	7.752	28.763	71.479	13.534	257.936	5.995	3.691	22.939
11	PA1	L2c02	7.682	0.938	7.683	27.017	44.828	10.035	188.536	5.514	4.072	56.373
12	PA1	L2c03	12.824	0.719	9.97	26.267	75.201	19.079	204.853	6.603	2.258	22.517
13	PA1	L2c04	4.903	0.647	8.746	26.144	65.228	18.949	211.839	6.776	4.272	43.037
14	PA1	L2c05	8.216	0.932	12.009	23.702	62.961	38.75	203.597	11.021	2.814	17.917
15	PA1	L2c06	14.691	0.686	9.638	29.112	64.938	7.237	218.626	5.112	5.936	28.933
16	PA1	L2c07	11.596	0.414	8.304	17.341	47.059	3.735	110.676	3.016	1.854	15.412
17	PA1	L2c08	7.302	0.813	6.193	28.984	108.241	3.911	471.459	2.866	9.52	24.401
18	PA1	L2c10	9.315	0.713	8.765	17.597	34.848	5.927	109.374	3.144	1.927	17.191
19	PA1	L2d01	8.735	0.853	7.091	19.671	57.776	9.019	237.612	3.251	3.271	26.556
20	PA1	L2d02	13.913	1.114	10.132	31.313	64.372	30.556	131.804	9.462	3.423	15.66
21	PA1	L2d03	18.915	0.763	10.379	15.423	25.303	3.852	87.674	2.976	1.117	17.815
22	PA1	L2d04	11.771	0.603	8.451	23.685	51.484	8.787	288.279	6.289	4.907	27.479
23	PA1	L2d05	6.764	0.79	10.375	27.882	83.823	15.836	123.002	4.586	3.777	9.228
24	PA1	L2d06	6.667	1.854	7.773	22.218	48.445	15.339	214.846	7.851	4.304	14.401

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
25	PA1	L2d07	24.005	0.671	12.657	18.755	13.224	2.821	101.997	3.08	1.17	16.739
26	PA1	L2d08	12.355	0.798	11.618	24.557	44.119	22.227	79.738	7.574	3.095	14.744
27	PA1	L2d10	4.383	0.417	7.614	28.316	240.902	16.953	918.527	7.411	22.277	23.747
28	PA1	L3a01	11.954	0.697	10.488	32.678	143.116	7.707	655.173	4.557	10.417	41.439
29	PA1	L3a02	13.486	0.698	11.103	16.463	33.932	4.755	308.553	5.703	4.386	35.927
30	PA1	L3a03	59.681	2.1	19.875	13.112	106.233	34.755	482.413	44.215	18.963	28.423
31	PA1	L3a04	8.177	1.806	10.973	39.033	137.511	29.95	245.561	5.666	6.282	31.949
32	PA1	L3a05	11.16	1.18	8.281	27.049	82.851	13.611	525.738	4.9	9.169	9.222
33	PA1	L3b01	8.747	0.503	8.625	19.273	40.091	3.688	168.83	2.567	2.033	14.713
34	PA1	L3b02	12.819	1.004	8.697	21.305	51.472	8.382	270.25	3.382	4.718	20.868
35	PA1	L3b04	64.262	2.756	104.28	9.098	18.827	32.661	332.415	23.913	2.523	27.011
36	PA1	L3b05	10.167	0.622	11.236	20.923	23.962	6.309	205.362	1.985	4.737	31.498
37	PA1	L3c01	23.027	1.772	12.142	26.829	65.144	29.813	501.556	23.023	9.665	16.084
38	PA1	L3c02	14.77	1.326	19.348	22.451	48.981	41.032	268.734	15.588	4.839	24.96
39	PA1	L3c03	43.861	1.302	59.924	14.677	183.881	127.786	50.193	45.553	9.015	34.063
40	PA1	L3c04	8.249	0.535	10.968	26.617	62.916	12.592	220.614	6.897	8.49	25.831
41	PA1	L3c05	8.249	0.918	11.372	27.5	64.093	26.134	297.887	24.685	12.938	49.788
42	PA1	L3d01	26.438	1.673	15.585	24.764	76.543	35.688	192.648	29.985	6.842	19.637
43	PA1	L3d02	13.905	0.927	10.952	26.189	50.075	21.949	160.781	16.984	5.009	19.213
44	PA1	L3d03	5.591	0.759	12.532	16.896	30.328	3.05	72.936	3.006	1.307	8.15
45	PA1	L3d04	18.992	1.127	10.716	27.593	67.582	15.072	105.675	8.6	3	24.405
46	PA1	L3D05	8.819	0.41	8.165	24.54	58.768	18.033	110.02	5.682	2.713	24.154
47	PA1	L3e01	11.723	1.569	30.357	27.293	56.234	31.994	276.079	13.065	4.806	37.897
48	PA1	L3e02	11.827	1.517	9.589	29.282	66.97	20.81	344.592	9.33	8.021	15.333

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
49	PA1	L3e03	21.506	1.032	15.408	26.677	61.434	27.927	225.617	26.047	4.987	25.736
50	PA1	L3e04	15.414	0.897	10.109	25.723	50.33	26.911	151.612	16.073	3.425	17.682
51	PA1	L3e05	7.713	2.904	12.215	28.678	75.632	18.924	651.488	9.781	12.756	12.796
52	PA1	L3f01	13.645	0.506	12.488	30.008	117.766	13.168	163.562	8.344	4.935	25.931
53	PA1	L3f03	11.265	0.52	17.285	25.564	81.401	20.409	157.813	19.289	4.371	14.261
54	PA1	L3f04	18.652	0.812	10.557	26.493	52.034	24.354	143.602	19.3	4.479	10.275
55	PA1	L3f05	16.28	1.256	24.42	29.614	63.826	28.359	162.033	31.157	4.265	19.418
56	PA1	L3g01	8.77	1.609	10.442	29.577	56.568	21.082	83.668	17.873	2.606	12.575
57	PA1	L3g02	10.885	1.769	11.729	29.464	52.161	29.763	248.272	9.02	7.023	14.082
58	PA1	L3g03	13.678	1.363	17.024	25.916	70.469	27.44	164.838	29.403	4.703	11.339
59	PA1	L3g04	11.477	1.415	8.813	29.398	58.628	19.636	621.895	10.764	9.562	12.608
60	PA1	L3g05	7.159	0.46	11.908	28.071	91.791	14.476	102.742	4.846	3.656	8.76
61	PA1	L3h01	4.731	0.524	5.989	25.463	99.349	3.912	124.342	4.937	5.061	37.891
62	PA1	L3h02	9.953	1.155	11.709	29.246	62.804	29.935	164.954	8.583	4.154	9.963
63	PA1	L3h03	18.417	1.811	12.11	28.446	71.669	26.987	275.303	27.872	11.762	13.73
64	PA1	L3h04	18.18	1.103	15.703	27.852	65.654	19.303	305.613	22.185	6.555	11.268
65	PA1	L3h05	4.098	0.422	10.18	28.313	80.922	29.654	259.778	14.246	5.092	31.59
66	PA1	L3i01	9.111	1.314	13.839	29.981	75.525	17.047	124.558	10.989	5.051	9.73
67	PA1	L3i03	20.812	1.128	19.497	20.747	58.535	26.046	200.202	9.109	4.367	12.765
68	PA1	L3i04	6.36	1.053	13.416	25.451	72.026	21.159	270.979	8.985	4.255	9.288
69	PA1	L3i05	10.461	1.044	9.928	23.919	98.154	20.077	344.586	8.425	5.996	13.958
70	PA1	L4a01	7.832	1.47	17.376	29.394	98.854	15.397	389.776	17.34	7.838	17.614
71	PA1	L4a02	13.759	1.156	15.317	21.545	77.555	19.109	675.1	8.427	5.7	23.168

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
72	PA1	L4a03	16.663	1.171	16.133	25.699	63.828	15.939	86.206	12.411	3.358	10.858
73	PA1	L4a04	6.708	0.529	7.753	29.724	80.388	14.885	92.281	6.237	3.025	12.41
74	PA1	L4a05	7.812	1.237	12.679	26.353	64.747	21.177	230.388	14.045	5.147	17.835
75	PA1	L4a06	5.467	0.661	9.507	29.995	103.65	9.587	637.67	7.704	9.065	16.951
76	PA1	L4a07	17.543	2.008	12.9	33.776	60.485	21.185	394.913	6.973	7.407	6.625
77	PA1	L4a09	26.626	2.077	17.075	34.134	53.196	16.262	773.443	12.041	15.061	8.022
78	PA1	L4a10	11.468	1.522	14.729	29.349	62.3	26.849	132.737	9.968	3.893	21.533
79	PA1	L4b01	14.381	1.332	14.356	27.43	72.593	18.84	358.663	10.649	6.564	13.581
80	PA1	L4b02	14.057	1.353	14.398	27.643	71.449	19.73	333.563	10.573	6.267	14.465
81	PA1	L4b03	13.456	1.372	13.916	28.268	72.772	19.051	348.524	10.718	6.474	14.537
82	PA1	L4b04	13.796	1.401	14.337	28.613	70.265	19.022	347.411	10.918	6.498	14.584
83	PA1	L4b05	13.544	1.371	14.591	27.075	69.049	22.101	116.071	19.84	4.365	30.535
84	PA1	L4b06	9.663	0.999	12.655	31.003	81.46	25.294	168.809	17.478	4.468	8.992
85	PA1	L4b07	9.733	1.014	9.242	29.593	109.859	18.661	544.777	17.497	10.993	17.327
86	PA1	L4b08	15.447	1.456	20.88	27.421	115.437	23.232	213.218	22.721	4.637	10.649
87	PA1	L4b10	9.313	1.762	24.212	22.889	70.45	26.471	660.482	8.212	9.279	15.6
88	PA1	L4c01	9.878	0.671	16.345	27.358	127.388	13.072	1086.182	9.123	9.827	43.104
89	PA1	L4c02	7.435	0.642	11.769	29.502	116.144	8.87	516.819	5.849	6.146	23.457
90	PA1	L4c03	15.494	1.253	20.763	26.049	51.466	17.93	101.36	13.94	2.888	23.439
91	PA1	L4c04	7.636	1.346	11.569	26.754	69.52	16.414	165.094	11.076	3.274	8.703
92	PA1	L4c05	29.133	2.394	29.173	18.833	154.913	91.764	1450.236	75.527	15.032	55.924
93	PA1	L4c06	13.878	1.645	16.167	22.521	58.052	16.789	507.606	10.755	6.443	9.464
94	PA1	L4c07	14.126	0.915	18.347	26.252	137.99	19.807	8889.126	11.11	202.694	40.658

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
95	PA1	L4c08	8.459	1.089	13.81	31.529	73.482	20.605	210.95	24.044	5.513	8.998
96	PA1	L4c09	8.079	1.353	11.898	29.65	57.755	17.215	181.257	12.213	4.052	10.456
97	PA1	L4c10	13.962	0.535	8.037	27.72	82.467	11.881	97.632	4.348	3.938	36.821
98	PA1	L6a01	5.109	0.395	10.065	29.506	234.38	7.966	327.793	4.036	7.471	20.243
99	PA1	L6a02	7.281	1.172	9.095	30.265	46.565	18.014	166.297	12.603	4.273	19.466
100	PA1	L6a04	4.726	0.334	9.032	31.024	245.942	8.467	532.947	2.769	9.021	53.696
101	PA1	L6a05	12.553	1.653	13.354	30.701	70.141	18.195	131.818	21.248	5.775	14.923
102	PA1	L6a06	9.878	1.582	14.968	31.994	56.823	23.631	254.904	11.191	4.94	11.11
103	PA1	L6a07	7.891	1.417	14.919	29.685	60.966	17.723	219.383	12.713	4.519	24.525
104	PA1	L6a09	12.2	1.23	16.113	25.761	65.586	21.85	209.319	10.523	4.774	33.472
105	PA1	L6a10	6.835	0.662	8.988	30.485	113.721	16.794	218.317	6.49	2.99	23.105
106	PA1	L6a12	4.891	0.53	18.97	31.7	152.976	17.804	113.513	4.864	3.99	41.787
107	PA1	L6a13	5.733	1.059	3.464	41.931	239.673	499.127	1208.886	233.959	30.408	76.502
108	PA1	L6b01	8.629	1.421	11.776	32.389	82.285	23.527	163.4	14.098	5.01	20.769
109	PA1	L6b02	11.746	1.359	12.793	29.405	73.823	24.888	168.081	20.661	5.453	16.205
110	PA1	L6b03	9.136	1.441	12.884	34.559	72.931	22.526	140.982	20.545	3.819	16.62
111	PA1	L6b04	11.873	1.245	9.755	22.565	55.882	18.935	167.754	14.709	4.356	13.739
112	PA1	L6b05	5.338	0.812	7.037	53.537	159.658	20.22	412.922	7.359	6.547	35.302
113	PA1	L6b06	13.139	1.509	9.338	36.371	95.798	15.231	500.495	15.186	9.39	17.173
114	PA1	L6b07	8.537	1.726	11.003	26.681	48.618	28.621	281.697	12.432	5.535	17.02
115	PA1	L6b08	10.476	1.229	12.522	27.488	67.926	17.875	336.064	14.086	5.623	18.578
116	PA1	L6b09	8.557	1.191	26.021	28.593	54.691	17.842	225.146	10.318	3.85	11.36
117	PA1	L6c01	5.587	0.529	8.938	29.839	64.99	13.851	88.368	4.697	2.609	19.975

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
118	PA1	L6c02	12.195	1.528	14.798	27.055	75.266	19.945	312.088	18.809	7.577	17.324
119	PA1	L6c03	12.023	1.444	19.55	28.825	68.605	21.6	170.516	11.902	4.442	9.046
120	PA1	L6c04	8.246	1.17	18.249	25.11	60.208	13.907	274.075	9.15	4.058	20.25
121	PA1	L6c05	14.785	1.355	16.133	24.055	84.555	26.071	298.354	13.025	8.511	30.903
122	PA1	L6c06	5.841	0.515	11.468	33.429	190.317	9.265	127.341	3.246	4.137	17.88
123	PA1	L6c07	10.382	1.777	15.44	31.921	74.482	24.881	399.194	14.788	8.294	14.175
124	PA1	L6c08	9.365	1.503	14.056	34.157	92.238	28.221	205.772	23.231	6.832	21.264
125	BN1	L8a01	9.928	0.746	11.547	23.684	93.004	1.211	403.223	3.262	4.071	46.39
126	BN1	L8a02	13.022	1.038	13.986	27.941	72.424	6.64	13573.572	9.993	21.835	55.943
127	BN1	L8a03	13.961	1.024	9.41	27.512	136.72	21.346	304.84	13.273	11.016	44.862
128	BN1	L8a04	3.269	0.477	11.824	24.86	75.596	1.316	378.131	2.658	6.524	37.448
129	BN1	L8a06	18.084	1.493	10.815	31.809	83.162	19.198	431.935	11.272	11.083	40.186
130	BN1	L8b01	12.391	0.759	19.42	26.933	95.574	9.27	531.697	6.149	5.145	40.476
131	BN1	L8b02	6.078	0.708	9.772	17.191	61.967	1.582	280.833	2.895	2.64	30.75
132	BN1	L8b04	8.15	0.755	11.132	29.908	127.289	8.067	279.466	4.885	3.307	30.145
133	BN1	L8b05	6.982	0.638	13.48	28.522	133.063	4.645	273.538	4.064	2.433	36.553
134	BN1	L8b06	13.316	0.768	12.315	32.09	89.565	16.264	458.99	7.925	6.22	51.684
135	BN1	L8c01	7.18	0.979	10.633	27.518	123.386	10.581	297.079	5.334	3.717	31.101
136	BN1	L8c02	4.876	0.685	19.476	24.836	113.875	2.046	278.577	3.281	3.386	25.788
137	BN1	L8c03	9.038	0.869	12.003	24.64	59	4.466	316.481	3.072	2.714	25.733
138	BN1	L8c04	13.703	0.714	16.937	28.787	123.72	15.761	323.152	8.917	7.164	29.584
139	BN1	L8c05	8.722	0.755	10.36	26.703	124.991	3.991	305.957	4.464	3.212	35.589
140	BN1	L8d01	7.187	0.807	10.828	34.61	124.73	4.42	270.76	4.435	3.102	33.414

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
141	BN1	L8d02	4.334	0.614	7.802	41.412	246.053	13.483	274.805	6.091	6.916	46.278
142	BN1	L8d03	5.648	1.141	10.698	34.067	97.791	10.441	302.17	6.831	5.273	30.477
143	BN1	L8d04	6.311	0.743	9.694	32.007	105.504	4.381	238.805	4.415	3.052	35.122
144	BN1	L8d06	5.819	0.946	9.927	32.361	129.863	5.312	200.07	3.262	2.006	55.502
145	BN1	L8e02	12.089	0.838	11.68	24.253	108.496	7.92	275.709	6.094	5.454	39.899
146	BN1	L8e03	3.759	0.713	6.762	47.372	228.735	3.078	144.334	3.251	5.177	85.205
147	BN1	L8e04	4.695	0.719	10.781	36.874	156.322	4.703	190.842	3.992	2.643	29.038
148	BN1	L8e05	48.044	2.933	51.463	14.579	96.271	78.329	265.325	83.514	10.578	22.27
149	BN1	L8e06	51.283	2.431	29.994	27.48	155.867	128.946	330.443	130.35	15.873	44.118
150	BN1	L9a02	7.998	0.798	11.509	29.723	114.292	27.357	415.549	8.746	5.321	27.493
151	BN1	L9a03	7.998	0.798	11.508	29.721	114.284	27.355	463.835	8.746	6.08	27.492
152	BN1	L9a04	8.548	1.004	11.546	31.368	119.077	9.179	934.801	6.164	16.516	80.386
153	BN1	L9a05	4.755	0.858	15.716	34.065	122.925	5.447	244.554	4.95	2.723	43.023
154	BN1	L9a06	11.56	1.586	20.904	30.039	84.767	16.488	580.113	9.83	9.107	18.36
155	BN1	L9a07	18.516	1.522	15.533	28.498	136.652	10.926	777.938	9.072	8.069	18.677
156	BN1	L9a09	6.819	1.292	18.792	26.585	147.524	8.683	316.499	5.148	3.596	20.465
157	BN1	L9a10	10.789	0.714	13.231	28.589	187.77	9.672	219.802	3.645	1.571	29.804
158	BN1	L9b01	20.62	1.028	13.825	31.036	136.052	5.507	271.31	7.659	4.019	47.859
159	BN1	L9b04	7.263	0.915	10.38	35.155	179.19	4.344	165.953	5.889	4.232	30.919
160	BN1	L9b05	9.43	1.235	13.506	26.29	83.938	2.019	365.499	5.164	2.874	39.903
161	BN1	L9b06	72.483	2.716	70.156	17.6	200.129	135.748	167.97	76.963	15.69	40.794
162	BN1	L9b07	6.904	1.026	11.302	31.699	121.585	3.091	254.251	4.371	2.521	28.05
163	BN1	L9b08	8.591	1.018	19.043	24.49	102.077	1.857	326.463	6.888	3.616	50.768

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
164	BN1	L9b09	9.09	1.158	10.012	35.456	128.531	9.3	345.616	7.596	5.953	46.564
165	BN1	L9b10	4.017	2.464	9.573	11.395	47.758	11.153	336.957	11.315	6.99	20.108
166	BN1	L9c02	8.877	0.546	13.129	26.448	77.012	6.178	311.727	4.495	2.618	36.984
167	BN1	L9c03	71.471	3.064	60.395	18.172	194.914	128.684	409.202	89.136	21.448	49.337
168	BN1	L9c04	8.536	0.965	11.809	32.308	74.952	3.242	607.311	4.35	7.099	66.045
169	BN1	L9c05	15.518	1.482	13.012	33.105	90.332	18.789	251.92	9.326	6.021	27.057
170	BN1	L9c06	6.301	0.46	21.169	23.448	127.635	14.792	241.097	6.345	4.697	11.404
171	BN1	L9c07	51.376	1.902	29.869	17.679	99.617	69.95	754.782	105.83	16.658	65.324
172	BN1	L9c08	7.808	1.128	7.632	30.897	100.982	10.966	256.824	8.189	3.797	23.215
173	BN1	L9c09	34.56	2.153	43.993	18.01	113.741	142.008	209.132	111.641	11.206	46.111
174	BN1	L10a01	5.161	0.419	7.828	38.086	111.178	2.159	123.147	4.641	2.769	44.086
175	BN1	L10a02	6.733	0.687	10.501	26.847	81.567	4.344	268.489	4.127	4.674	17.738
176	BN1	L10a04	38.263	1.866	47.334	14.289	119.062	96.917	175.497	56.742	11.055	54.961
177	BN1	L10a05	29.035	5.494	20.393	8.825	11.442	19.351	92.366	21.792	1.686	18.88
178	BN1	L10a06	46.765	2.254	38.737	15.549	137.89	95.055	243.302	60.628	11.152	59.917
179	BN1	L10b01	5.044	0.397	8.85	31.648	103.116	4.127	195.471	4.18	3.321	29.107
180	BN1	L10b02	3.449	0.507	11.493	29.227	81.962	7.279	266.605	1.332	3.149	19.959
181	BN1	L10b03	58.364	2.255	61.965	16.092	168.766	111.217	323.932	61.558	15.606	34.737
182	BN1	L10b04	7.755	0.606	11.463	21.403	62.888	10.554	326.245	5.119	4.413	14.139
183	BN1	L10b05	15.355	1.716	14.708	34.181	73.315	27.93	358.05	19.087	5.883	7.103
184	BN1	L10c01	12.433	1.711	10.034	35.075	123.556	16.213	215.928	9.309	4.785	34.641
185	BN1	L10c02	38.779	2.029	36.976	20.909	115.373	103.076	534.71	85.152	11.98	37.174
186	BN1	L10c03	8.627	0.883	9.099	31.724	80.33	19.296	395.627	10.343	5.143	20.089

#	Site	Sample ID	Li	Be	B	Sc	V	Cr	Mn	Ni	Co	Cu
187	BN1	L10c05	3.749	0.512	6.863	29.498	89.819	1.679	189.778	2.629	3.251	32.097
188	BN1	L10C06	13.209	0.515	19.894	21.643	56.811	24.636	327.663	6.857	6.442	19.709
189	BN1	L10d01	7.952	0.598	13.05	30.142	90.037	11.583	335.13	4.785	4.714	21.848
190	BN1	L10d02	7.066	0.391	11.529	15.191	69.894	3.922	224.804	0.752	2.317	11.174
191	BN1	L10d03	2.511	0.543	18.941	34.891	146.074	13.04	266.621	6.823	4.693	46.036
192	BN1	L10d04	4.983	0.455	8.331	37.513	126.518	5.391	276.856	1.724	4.833	30.06
193	BN1	L10d05	5.753	0.479	11.835	28.667	103.39	8.061	191.44	6.337	4.803	24.221
194	BN1	L10d06	7.147	1.195	9.602	35.169	119.756	2.949	248.976	4.001	3.036	31.256
195	BN1	L10e01	8.732	0.483	9.963	33.356	89.172	5.049	218.467	5.197	3.162	38.391
196	BN1	L10e03	2.253	0.375	11.599	24.77	66.377	4.642	184.422	1.977	2.589	16.978
197	BN1	L10e04	3.462	0.551	9.316	38.198	123.37	12.074	230.445	6.351	4.795	33.68
198	BN1	L10e05	27.477	3.574	21.76	19.673	58.788	59.524	4045.64	85.642	24.024	36.886
199	BN1	L10e06	30.221	1.554	51.25	15.2	127.48	99.963	203.678	52.128	8.705	55.034
200	Ouh	Sa01	57.818	2.671	72.044	17.409	184.323	164.621	537.575	150.64	18.179	63.613

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
1	PA1	L2b01	101.622	37.168	354.158	146.966	3.972	0.119	1.53	0.505	2.164	326.535
2	PA1	L2b02	155.743	50.429	324.99	149.142	3.864	0.129	1.776	0.41	1.625	336.256
3	PA1	L2b03	164.064	42.278	383.816	185.45	4.938	0.125	1.957	0.324	3.205	372.169
4	PA1	L2b04	214.232	47.269	376.231	161.755	3.929	0.157	1.863	0.548	2.673	401.358
5	PA1	L2b05	124.495	36.683	343.062	156.579	4.533	0.154	2.137	0.333	2.328	308.591
6	PA1	L2b06	156.191	47.351	321.91	145.468	3.94	0.136	2.067	0.695	2.21	388.693
7	PA1	L2b07	138.561	28.966	325.82	136.286	3.288	0.123	1.897	0.353	1.002	362.432
8	PA1	L2b08	205.533	48.936	321.225	120.035	2.605	0.119	1.498	0.785	2.859	398.642
9	PA1	L2b09	127.888	42.799	395.077	182.395	4.317	0.136	1.948	0.415	2.447	350.832
10	PA1	L2c01	140.198	43.174	386.323	191.492	4.455	0.151	2.049	0.512	2.399	386.328
11	PA1	L2c02	198.086	39.113	313.064	136.555	3.023	0.127	1.687	0.328	2.915	372.634
12	PA1	L2c03	109.728	27.725	299.868	158.421	3.751	0.121	1.756	0.428	1.34	321.566
13	PA1	L2c04	149.676	35.972	365.005	122.841	3.307	0.125	1.695	0.308	1.462	358.677
14	PA1	L2c05	126.465	40.239	203.538	150.257	4.18	0.122	1.943	0.502	1.808	289.557
15	PA1	L2c06	215.526	50.221	303.744	116.153	2.74	0.132	1.574	0.435	2.399	360.646
16	PA1	L2c07	115.043	40.838	291.198	134.787	3.753	0.134	2.045	0.176	3.609	358.569
17	PA1	L2c08	125.095	38.61	303.807	130.372	3.379	0.131	1.668	0.151	2.963	387.4
18	PA1	L2c10	143.811	30.294	311.554	131.844	3.392	0.107	1.569	0.239	2.771	251.924
19	PA1	L2d01	124.066	21.977	332.7	137.917	4.386	0.115	1.806	0.135	1.339	345.98
20	PA1	L2d02	211.229	38.527	1901.639	172.749	5.968	0.175	2.309	0.234	1.671	485.009
21	PA1	L2d03	101.486	34.022	336.824	158.036	4.223	0.122	1.98	0.155	1.682	303.531
22	PA1	L2d04	262.808	35.099	341.794	149.725	4.453	0.182	2.152	0.214	3.962	396.571
23	PA1	L2d05	76.99	59.132	426.322	135.295	4.582	0.119	1.507	0.216	1.629	360.996
24	PA1	L2d06	142.233	27.55	411.413	136.075	3.551	0.13	1.734	0.328	1.331	357.596
25	PA1	L2d07	164.706	35.763	240.422	193.592	4.13	0.146	2.151	0.314	2.325	199.335
26	PA1	L2d08	143.118	46.188	437.645	137.761	5.566	0.132	1.877	0.273	2.121	341.009
27	PA1	L2d10	166.905	20.338	266.427	83.733	2.318	0.156	1.368	0.245	1.333	279.889
28	PA1	L3a01	193.846	44.713	365.265	88.07	2.362	0.113	1.33	0.534	3.998	394.516

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
29	PA1	L3a02	157.69	58.27	331.995	143.118	4.295	0.137	1.864	0.268	3.174	291.566
30	PA1	L3a03	241.508	31.934	242.405	97.059	6.014	0.044	2.723	0.397	2.311	118.997
31	PA1	L3a04	147.889	38.852	494.312	201.444	7.396	0.162	2.363	0.321	2.091	456.753
32	PA1	L3a05	93.015	16.661	296.749	180.778	5.817	0.17	2.051	0.679	0.793	309.448
33	PA1	L3b01	122.916	35.656	327.62	153.129	3.99	0.141	1.896	0.258	2.707	347.659
34	PA1	L3b02	167.839	33.921	315.1	157.523	4.708	0.141	2.097	0.306	2.421	324.961
35	PA1	L3b04	303.501	192.745	261.965	31.758	14.877	0.173	15.27	1.532	26.05	223.384
36	PA1	L3b05	158.864	39.895	305.395	196.039	5.206	0.154	2.214	0.415	3.5	340.071
37	PA1	L3c01	147.234	49.552	1144.97	148.733	5.97	0.179	2.558	0.565	2.466	507.271
38	PA1	L3c02	158.713	73.151	3124.428	122.322	5.001	0.183	2.443	0.301	3.264	661.492
39	PA1	L3c03	182.187	130.988	359.18	100.617	12.626	0.114	3.392	0.837	8.966	435.398
40	PA1	L3c04	123.926	43.065	470.026	84.842	2.47	0.119	1.433	0.39	1.453	435.508
41	PA1	L3c05	112.861	69.35	511.17	156.002	6.402	0.171	2.195	0.449	2.85	395.4
42	PA1	L3d01	183.67	23.44	595.591	118.169	5.611	0.182	2.289	0.537	1.161	297.443
43	PA1	L3d02	163.098	39.61	1693.997	143.925	5.24	0.182	2.309	0.359	1.813	460.606
44	PA1	L3d03	77.506	35.544	228.99	138.465	3.589	0.115	1.897	0.292	1.31	265.492
45	PA1	L3d04	160.541	49.3	370.305	126.149	4.394	0.124	1.536	0.386	2.465	325.729
46	PA1	L3D05	146.388	41.044	313.468	128.529	4.112	0.137	1.766	0.313	1.764	277.601
47	PA1	L3e01	193.425	31.665	3182.974	143.615	5.529	0.161	2.07	0.366	1.485	622.186
48	PA1	L3e02	80.123	25.076	463.33	142.253	5.215	0.156	1.88	0.32	1.539	280.428
49	PA1	L3e03	204.007	45.225	380.517	91.927	3.997	0.151	1.792	0.337	1.69	317.676
50	PA1	L3e04	161.4	38.969	667.438	135.183	5.706	0.161	2.058	0.366	2.145	318.828
51	PA1	L3e05	318.524	33.095	1102.432	174.728	5.557	0.147	1.822	1.105	1.895	536.705
52	PA1	L3f01	147.639	27.513	212.948	107.799	4.343	0.147	1.628	0.286	2.24	167.272
53	PA1	L3f03	100.653	11.048	231.367	91.131	3.627	0.132	1.627	0.241	0.951	86.207
54	PA1	L3f04	144.886	47.313	656.342	142.194	5.252	0.164	2.131	0.544	2.474	329.881
55	PA1	L3f05	177.303	27.564	1375.43	149.779	7.605	0.166	2.369	0.408	2.226	366.389
56	PA1	L3g01	94.145	23.766	2599.553	164.316	5.13	0.17	2.113	0.243	1.108	407.551

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
57	PA1	L3g02	108.788	33.808	2633.557	172.682	5.32	0.178	2.237	0.473	1.696	496.821
58	PA1	L3g03	99.681	21.611	2385.823	134.063	4.812	0.184	2.253	0.487	0.876	305.528
59	PA1	L3g04	55.265	37.099	413.365	128.178	5.595	0.137	1.868	0.227	2.221	312.18
60	PA1	L3g05	48.569	38.662	365.344	115.886	4.448	0.136	1.709	0.24	1.713	218.831
61	PA1	L3h01	73.501	28.903	352.388	103.448	2.999	0.122	1.492	0.174	1.982	222.605
62	PA1	L3h02	92.958	27.502	1733.987	172.069	5.473	0.174	2.176	0.358	1.932	381.331
63	PA1	L3h03	82.373	22.627	596.971	142.231	5.506	0.173	2.129	0.467	1.398	268.745
64	PA1	L3h04	95.131	46.573	1296.629	123.807	4.917	0.153	1.95	0.391	2.357	299.623
65	PA1	L3h05	125.659	23.934	370.224	132.859	3.984	0.165	1.808	0.562	1.113	156.348
66	PA1	L3i01	126.629	20.496	2552.2	135.265	4.148	0.161	2.043	0.333	0.958	336.341
67	PA1	L3i03	101.3	28.372	469.966	113.956	5.346	0.182	2.137	0.336	1.228	181.097
68	PA1	L3i04	348.911	27.626	2872.849	156.774	5.216	0.145	1.867	1.663	1.859	697.507
69	PA1	L3i05	624.376	44.825	847.962	113.223	6.315	0.1	1.412	1.315	2.158	347.674
70	PA1	L4a01	100.304	42.666	2610.131	145.523	5.417	0.078	1.47	0.302	1.738	334.294
71	PA1	L4a02	633.055	49.762	731.316	102.225	5.307	0.097	1.409	1.618	2.416	304.284
72	PA1	L4a03	68.742	42.757	875.894	134.056	5.169	0.165	2.012	0.342	1.493	233.842
73	PA1	L4a04	116.454	34.171	408.007	104.269	2.814	0.125	1.281	0.589	1.265	176.958
74	PA1	L4a05	147.561	36.495	2065.741	126.87	4.878	0.173	2.184	0.368	1.27	339.282
75	PA1	L4a06	113.813	33.63	278.255	114.136	4.262	0.078	0.918	0.292	1.207	202.903
76	PA1	L4a07	96.327	11.019	893.602	157.189	4.914	0.169	1.843	0.414	0.655	151.601
77	PA1	L4a09	104.541	6.282	3659.018	151.883	5.23	0.139	1.844	0.291	0.885	198.891
78	PA1	L4a10	131.108	37.844	3993.938	140.978	4.741	0.161	1.953	0.169	2.604	483.109
79	PA1	L4b01	215.69	32.485	1439.658	128.57	5.05	0.137	1.738	0.605	1.442	251.513
80	PA1	L4b02	206.294	33.08	1723.43	129.948	5.015	0.139	1.762	0.557	1.571	277.243
81	PA1	L4b03	217.053	33.463	1812.956	131.311	4.988	0.135	1.724	0.582	1.59	283.72
82	PA1	L4b04	177.863	32.361	1894.417	132.869	4.866	0.139	1.757	0.511	1.535	277.093
83	PA1	L4b05	147.624	55.718	2222.966	142.901	5.422	0.169	2.299	0.533	2.638	451.853
84	PA1	L4b06	95.687	28.546	1509.241	171.71	7.15	0.167	2.473	0.447	1.661	326.974

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
85	PA1	L4b07	91.236	35.202	1217.564	140.734	4.806	0.137	1.65	0.32	1.411	331.464
86	PA1	L4b08	78.459	34.663	1807.048	150.895	4.874	0.138	1.796	0.177	1.037	255.067
87	PA1	L4b10	210.12	26.195	2298.245	90.561	3.925	0.155	1.655	0.322	1.037	465.195
88	PA1	L4c01	130.019	71.607	457.36	59.768	1.745	0.082	0.959	0.592	2.457	200.527
89	PA1	L4c02	78.652	35.953	267.552	79.426	2.319	0.096	1.159	0.33	1.319	147.071
90	PA1	L4c03	109.412	30.747	996.028	127.529	4.488	0.139	1.809	0.191	1.514	259.496
91	PA1	L4c04	90.42	25.896	1499.359	132.186	5.012	0.129	1.693	0.136	1.03	305.079
92	PA1	L4c05	138.044	114.09	646.802	89.626	14.439	0.156	3.397	0.799	9.495	368.066
93	PA1	L4c06	137.35	34.604	2184.034	107.792	3.828	0.127	1.688	0.146	1.081	272.126
94	PA1	L4c07	146.451	39.047	947.813	62.082	1.798	0.101	1.074	0.382	1.109	289.557
95	PA1	L4c08	75.229	39.698	2232.656	139.186	4.699	0.145	1.722	0.347	1.022	286.565
96	PA1	L4c09	205.948	37.857	3675.881	167.384	5.736	0.183	2.323	0.26	1.543	436.735
97	PA1	L4c10	110.442	33.967	323.777	97.905	2.588	0.098	1.142	0.401	2.376	171.461
98	PA1	L6a01	76.809	40.699	265.294	97.055	1.956	0.083	0.956	0.389	1.011	143.6
99	PA1	L6a02	143.728	42.118	1948.547	162.687	5.516	0.178	2.161	0.41	1.186	310.819
100	PA1	L6a04	123.262	41.217	383.269	96.347	2.595	0.098	1.103	0.246	1.4	177.859
101	PA1	L6a05	69.998	29.296	1263.059	149.188	5.368	0.146	1.835	0.315	0.886	227.569
102	PA1	L6a06	128.215	34.833	2657.893	149.356	4.714	0.174	1.967	0.347	0.987	308.8
103	PA1	L6a07	133.84	38.76	2384.304	141.261	4.81	0.181	1.89	0.383	0.89	277.156
104	PA1	L6a09	161.999	39.834	2251.999	119.447	4.502	0.188	1.989	0.409	1.315	299.26
105	PA1	L6a10	139.7	50.513	448.994	124.975	4.317	0.169	1.711	0.433	1.571	207.496
106	PA1	L6a12	125.967	32.616	278.669	73.858	1.797	0.139	1.728	0.495	0.97	124.12
107	PA1	L6a13	114.076	4.105	64.529	25.3	3.577	0.097	0.985	0.17	0.138	34.186
108	PA1	L6b01	87.883	36.886	1346.713	161.602	5.341	0.192	2.157	0.46	0.933	300.251
109	PA1	L6b02	66.33	28.287	941.767	132.292	5.4	0.16	2.015	0.453	0.689	204.803
110	PA1	L6b03	117.383	39.628	2864	156.535	6.085	0.168	2.002	0.48	1.198	325.147
111	PA1	L6b04	65.873	22.257	810.501	107.933	4.417	0.123	1.478	0.314	0.527	171.168
112	PA1	L6b05	145.951	34.31	432.13	91.768	2.761	0.149	1.271	4.083	0.605	167.739

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
113	PA1	L6b06	101.632	42.437	766.37	137.698	4.717	0.141	1.698	0.391	1.449	253.074
114	PA1	L6b07	173.064	62.511	3165.998	170.58	5.646	0.186	2.256	0.337	1.645	583.216
115	PA1	L6b08	88.53	29.307	1724.882	125.556	4.775	0.135	1.658	0.299	0.91	258.707
116	PA1	L6b09	112.801	55.658	3513.602	133.611	4.368	0.136	1.897	0.365	1.042	342.236
117	PA1	L6c01	89.367	45.153	338.171	125.194	3.774	0.128	1.536	0.291	1.334	134.054
118	PA1	L6c02	131.25	35.841	1496.76	146.008	5.925	0.172	2.141	0.347	1.793	270.936
119	PA1	L6c03	126.685	18.38	2977.954	137.979	5.875	0.16	2.151	0.477	0.964	307.007
120	PA1	L6c04	133.118	28.692	2052.483	131.424	4.947	0.181	1.752	0.432	0.897	305.801
121	PA1	L6c05	177.512	51.335	2197.078	101.363	4.417	0.152	2.035	0.366	1.133	334.926
122	PA1	L6c06	82.706	50.452	329.509	87.586	2.219	0.113	1.296	0.334	0.949	139.592
123	PA1	L6c07	162.042	45.335	4679.735	129.797	4.767	0.178	2.007	0.319	1.041	361.589
124	PA1	L6c08	83.487	46.651	943.448	165.105	6.113	0.205	2.396	0.41	1.015	250.677
125	BN1	L8a01	117.96	34.797	166.807	112.152	2.838	0.107	1.814	0.332	5.585	195.273
126	BN1	L8a02	120.176	59.132	215.658	133.669	3.311	0.112	1.622	0.634	5.813	666.795
127	BN1	L8a03	148.545	37.347	164.207	77.853	2.664	0.125	1.335	1.52	4.105	111.273
128	BN1	L8a04	99.615	78.948	184.491	79.164	2.14	0.098	1.486	0.225	7.284	180.823
129	BN1	L8a06	143.199	51.969	387.727	119.559	3.738	0.147	1.836	0.583	5.329	282.324
130	BN1	L8b01	91.864	235.404	340.782	125.716	3.595	0.11	1.708	0.426	11.124	317.417
131	BN1	L8b02	115.431	46.61	320.128	104.389	2.684	0.079	1.592	0.218	5.638	254.548
132	BN1	L8b04	104.801	40.874	376.165	114.453	2.854	0.118	1.584	0.352	6.238	352.317
133	BN1	L8b05	108.589	46.908	382.177	113.11	3.399	0.16	1.869	0.359	4.939	368.754
134	BN1	L8b06	123.687	56.746	267.105	115.484	3.197	0.112	1.702	0.393	9.183	256.222
135	BN1	L8c01	84.132	49.329	454.077	134.516	3.298	0.119	1.469	0.159	5.413	243.188
136	BN1	L8c02	93.144	167.774	451.026	98.247	2.557	0.13	1.733	0.341	13.205	210.209
137	BN1	L8c03	75.527	38.339	463.182	123.605	3.427	0.153	2.007	0.311	4.134	303.372
138	BN1	L8c04	93.455	22.824	54.74	104.336	3.207	0.126	1.937	0.376	1.706	98.555
139	BN1	L8c05	111.72	37.895	519.709	126.307	3.896	0.143	1.844	0.408	6.114	394.612
140	BN1	L8d01	107.049	83.07	505.88	117.96	3.37	0.121	1.612	0.186	11.009	264.383

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
141	BN1	L8d02	155.029	70.827	858.017	113.23	3.341	0.145	1.6	0.194	6.842	498.452
142	BN1	L8d03	107.557	55.468	287.536	105.85	3.139	0.112	1.436	0.202	7.935	284.635
143	BN1	L8d04	128.731	89.39	655.034	114.017	3.136	0.109	1.653	0.086	10.334	305.558
144	BN1	L8d06	105.526	40.855	488.62	124.947	3.979	0.145	1.671	0.14	5.216	261.721
145	BN1	L8e02	122.28	65.524	466.443	85.121	2.724	0.104	1.398	0.204	11.264	360.677
146	BN1	L8e03	126.361	94.574	526.26	125.051	3.569	0.154	1.423	0.113	14.086	172.498
147	BN1	L8e04	78.494	46.516	821.927	126.769	3.548	0.138	1.715	0.133	5.93	213.515
148	BN1	L8e05	149.311	189.215	276.591	63.848	13.222	0.081	5.052	0.737	13.905	277.581
149	BN1	L8e06	312.97	68.676	344.436	161.812	11.363	0.275	3.819	0.747	7.505	164.639
150	BN1	L9a02	113.501	48.237	241.713	129.811	3.663	0.115	1.556	0.489	4.371	196.985
151	BN1	L9a03	113.494	48.234	241.697	129.802	3.663	0.115	1.556	0.489	4.371	196.972
152	BN1	L9a04	139.152	44.66	356.403	113.898	3.667	0.129	1.762	0.175	11.046	366.856
153	BN1	L9a05	103.304	40.888	382.295	131.874	4.007	0.155	2.104	0.225	4.922	344.008
154	BN1	L9a06	98.242	80.809	248.647	131.912	3.839	0.141	1.876	0.438	6.421	236.049
155	BN1	L9a07	128.555	48.387	178.429	99.199	3.66	0.13	2.026	0.61	2.806	230.762
156	BN1	L9a09	71.113	58.072	400.589	110.094	2.942	0.112	2.293	0.348	6.537	248.63
157	BN1	L9a10	88.483	47.697	303.13	123.275	2.772	0.091	2.112	0.584	6.546	216.445
158	BN1	L9b01	165.72	17.716	93.673	124.133	4.678	0.174	2.219	0.357	3.574	105.756
159	BN1	L9b04	132.415	126.038	660.386	105.492	3.411	0.147	1.736	0.192	18.834	224.392
160	BN1	L9b05	124.422	61.221	462.517	123.15	3.459	0.128	1.643	0.178	12.903	328.042
161	BN1	L9b06	274.74	152.781	417.336	92.243	12.705	0.127	3.775	1.004	17.272	1026.101
162	BN1	L9b07	93.987	50.066	551.221	120.253	3.09	0.11	1.386	0.151	6.076	239.41
163	BN1	L9b08	109.451	57.898	206.879	117.735	3.52	0.105	1.521	0.21	16.922	212.497
164	BN1	L9b09	140.673	70.723	868.479	126.052	3.729	0.15	1.763	0.177	10.778	381.475
165	BN1	L9b10	141.311	181.86	1097.982	243.37	18.099	0.062	5.199	1.142	22.543	392.877
166	BN1	L9c02	83.861	52.815	607.741	128.584	3.377	0.116	1.532	0.306	10.712	249.635
167	BN1	L9c03	363.394	133.757	642.399	93.504	12.182	0.185	4.668	1.263	13.956	1153.871
168	BN1	L9c04	155.46	53.255	240.548	134.054	4.754	0.122	2.09	0.301	12.457	279.292

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
169	BN1	L9c05	107.119	51.508	516.717	129.645	3.891	0.145	1.947	0.385	10.267	366.745
170	BN1	L9c06	56.154	95.366	521.024	104.181	2.24	0.107	1.977	0.439	10.092	138.637
171	BN1	L9c07	288.774	66.764	503.648	87.54	6.492	0.34	4.365	0.916	7.015	221.979
172	BN1	L9c08	113.338	69.681	1619.2	150.033	4.128	0.154	1.966	0.235	9.329	455.075
173	BN1	L9c09	237.554	147.13	1992.26	88.124	16.293	0.158	7.45	2.561	29.368	548.598
174	BN1	L10a01	115.415	63.814	916.354	114.817	3.183	0.135	1.678	0.237	11.144	358.697
175	BN1	L10a02	76.434	63.634	546.65	110.952	3	0.133	1.457	0.44	9.919	216.697
176	BN1	L10a04	123.189	174.659	810.897	83.856	15.894	0.154	4.007	0.8	24.974	298.616
177	BN1	L10a05	109.38	111.238	876.5	101.749	21.36	0.069	5.838	0.487	16.792	361.901
178	BN1	L10a06	276.776	118.667	1083.106	90.23	9.12	0.084	4.105	0.945	10.988	965.842
179	BN1	L10b01	251.668	58.18	837.746	102.602	2.996	0.121	1.456	0.243	5.854	172.783
180	BN1	L10b02	104.255	58.419	710.453	124.995	3.322	0.123	1.784	0.316	5.704	318.949
181	BN1	L10b03	243.14	114.743	591.867	85.642	10.569	0.112	3.075	0.998	11.277	619.56
182	BN1	L10b04	94.721	44.82	411.137	115.103	3.55	0.126	1.676	0.474	5.704	237.963
183	BN1	L10b05	119.697	95.769	5399.834	189.52	6.007	0.204	2.549	0.416	8.617	527.727
184	BN1	L10c01	137.36	70.033	867.706	119.981	4.161	0.207	1.915	3.653	7.903	237.324
185	BN1	L10c02	188.037	116.185	1252.409	150.881	11.296	0.143	2.855	0.479	12.493	266.759
186	BN1	L10c03	116.767	57.314	1089.857	159.065	4.74	0.162	1.924	0.384	7.379	305.687
187	BN1	L10c05	84.382	56.331	696.367	125.564	3.013	0.107	1.245	0.21	8.896	339.264
188	BN1	L10C06	95.475	310.097	763.942	101.238	2.319	0.094	1.218	0.81	14.252	313.547
189	BN1	L10d01	184.463	69.786	654.364	146.008	3.555	0.128	1.623	0.539	8.539	295.669
190	BN1	L10d02	107.166	64.023	564.724	90.036	2.039	0.077	1.047	1.263	5.339	181.476
191	BN1	L10d03	105.915	88.645	954.04	123.378	2.429	0.134	2.079	0.384	7.407	314.7
192	BN1	L10d04	114.875	51.52	491.177	125.745	3.245	0.124	1.575	0.347	6.338	320.955
193	BN1	L10d05	88.669	120.526	351.857	104.682	3.017	0.119	1.848	0.492	15.476	161.958
194	BN1	L10d06	121.743	61.529	916.666	136.866	3.761	0.16	1.87	0.183	8.637	392.277
195	BN1	L10e01	119.352	59.388	893.717	121.054	3.278	0.13	1.631	0.289	11.386	343.674
196	BN1	L10e03	74.179	46.494	472.509	123.919	3.112	0.106	1.613	0.505	5.879	240.297

#	Site	Sample ID	Zn	Rb	Sr	Zr	Nb	In	Sn	Sb	Cs	Ba
197	BN1	L10e04	126.429	142.406	745.586	138.632	3.368	0.13	1.6	0.423	13.614	245.091
198	BN1	L10e05	172.154	155.912	1755.555	156.537	14.829	0.15	6.233	1.295	28.888	328.658
199	BN1	L10e06	144.059	142.807	1098.157	95.437	16.051	0.146	3.953	0.972	15.396	268.74
200	Ouh	Sa01	183.154	170.661	107.026	76.606	14.51	0.105	3.45	2.941	11.02	316.261

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
1	PA1	L2b01	2.89	7.977	1.076	0.247	12.244	6.458	0.819	0.794	0.899	4.368
2	PA1	L2b02	2.884	10.295	1.149	0.258	12.646	9.907	0.795	0.995	0.78	4.728
3	PA1	L2b03	4.577	20.7	1.538	0.342	13.524	15.691	0.559	1.051	0.552	5.827
4	PA1	L2b04	13.094	19.603	3.868	0.295	25.511	15.387	0.746	0.98	0.514	14.898
5	PA1	L2b05	2.315	10.43	0.809	0.35	4.397	20.827	0.542	1.175	0.889	3.065
6	PA1	L2b06	9.133	18.983	2.988	0.304	20.992	18.071	0.642	1.185	0.52	11.497
7	PA1	L2b07	8.447	19.321	4.074	0.228	75.666	11.847	0.551	0.763	1.003	19.162
8	PA1	L2b08	7.32	15.089	3.222	0.187	83.613	6.98	1.11	0.806	0.742	14.836
9	PA1	L2b09	10.953	28.432	4.22	0.29	53.402	12.136	0.084	1.19	0.708	17.838
10	PA1	L2c01	7.694	16.264	2.461	0.292	19.927	13.05	1.281	1.118	0.719	10.435
11	PA1	L2c02	3.678	8.959	1.337	0.263	17.379	8.089	1.089	0.844	0.821	5.75
12	PA1	L2c03	7.543	14.013	2.469	0.286	18.625	13.501	1.194	1.012	0.845	10.056
13	PA1	L2c04	3.788	7.494	1.227	0.232	9.414	13.041	0.842	0.822	0.703	4.949
14	PA1	L2c05	4.761	10.634	1.936	0.314	20.976	15.485	0.967	1.194	1.037	8.146
15	PA1	L2c06	4.12	9.198	1.765	0.247	17.779	9.523	1.144	0.844	0.53	7.861
16	PA1	L2c07	2.442	4.088	0.922	0.29	9.008	16.55	0.616	1.05	0.847	4.13
17	PA1	L2c08	4.679	16.16	2.141	0.295	12.794	11.044	0.684	0.831	0.47	9.435
18	PA1	L2c10	3.826	10.171	1.423	0.209	14.191	10.536	0.145	0.842	0.627	5.38
19	PA1	L2d01	5.27	14.911	1.952	0.31	15.697	14.615	0.801	1.185	0.593	7.988
20	PA1	L2d02	22.711	49.967	9.218	0.464	43.685	25.343	1.866	1.282	0.214	40.556
21	PA1	L2d03	2.719	6.366	0.877	0.36	7.319	17.769	0.523	1.14	0.461	3.619
22	PA1	L2d04	2.948	8.177	1.036	0.355	9.035	18.87	0.686	1.3	0.802	4.544
23	PA1	L2d05	3.877	8.162	1.373	0.299	12.273	12.286	0.757	0.853	0.414	5.632

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
24	PA1	L2d06	6.258	15.05	1.985	0.251	12.932	12.674	0.436	0.89	0.427	8.013
25	PA1	L2d07	2.548	9.411	0.986	0.298	13.502	13.563	0.378	1.037	0.478	4.554
26	PA1	L2d08	4.553	12.688	1.288	0.374	8.689	17.902	0.608	1.023	0.26	4.845
27	PA1	L2d10	7.055	17.784	2.619	0.159	23.655	7.73	0.829	0.713	0.854	10.46
28	PA1	L3a01	3.521	8.707	1.454	0.172	15.739	8.347	0.707	1.03	1.188	6.536
29	PA1	L3a02	3.491	8.124	1.224	0.291	12.558	17.588	0.704	1.101	0.786	5.286
30	PA1	L3a03	10.344	48.432	3.902	0.346	24.212	22.04	1.514	0.571	0.497	15.077
31	PA1	L3a04	20.418	36.813	6.081	0.538	26.763	21.44	0.964	1.363	0.343	23.44
32	PA1	L3a05	19.633	48.179	6.727	0.404	27.145	21.86	1.078	1.507	0.68	25.179
33	PA1	L3b01	3.617	7.346	1.322	0.321	14.089	15.082	0.611	1.077	0.787	5.979
34	PA1	L3b02	5.378	16.902	1.748	0.369	13.377	20.583	0.889	1.321	0.789	7.009
35	PA1	L3b04	10.106	24.842	3.246	2.208	21.763	112.742	4.992	7.074	0.442	11.165
36	PA1	L3b05	8.246	22.303	3.035	0.344	21.676	14.172	0.971	1.703	0.854	12.559
37	PA1	L3c01	20.943	50.5	7.715	0.453	42.707	30.44	2.548	1.773	0.614	33.26
38	PA1	L3c02	18.56	51.003	7.789	0.401	46.603	31.419	1.825	1.42	0.541	33.296
39	PA1	L3c03	26.257	57.087	6.287	0.873	13.26	22.18	5.744	2.176	12.245	18.996
40	PA1	L3c04	1.806	4.536	0.702	0.231	8.014	8.734	1.156	0.733	0.457	2.89
41	PA1	L3c05	14.507	29.212	4.173	0.49	21.833	22.752	0.718	1.459	1.635	14.599
42	PA1	L3d01	18.252	29.952	6.038	0.446	28.443	31.677	1.494	1.834	0.398	23.267
43	PA1	L3d02	19.827	47.279	7.517	0.407	27.368	29.121	1.779	1.65	0.427	30.078
44	PA1	L3d03	1.482	5.698	0.583	0.282	4.027	8.877	0.36	1.08	0.719	2.249
45	PA1	L3d04	14.159	33.137	5.266	0.312	27.928	13.929	3.009	0.959	0.357	22.435
46	PA1	L3D05	4.043	10.597	1.345	0.317	7.332	14.13	0.809	1.001	0.377	5.213

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
47	PA1	L3e01	15.824	39.596	6	0.375	46.996	22.678	2.551	1.101	0.242	26.095
48	PA1	L3e02	13.2	33.727	5.096	0.381	38.908	19.331	0.908	1.036	0.215	22.124
49	PA1	L3e03	9.8	21.679	3.26	0.337	18.279	23.896	1.583	1.294	0.528	12.805
50	PA1	L3e04	20.417	34.972	6.415	0.346	31.448	20.656	1.108	1.255	0.446	24.43
51	PA1	L3e05	24.243	54.686	8.523	0.38	143.304	42.446	2.367	1.271	0.239	35.227
52	PA1	L3f01	2.537	10.055	0.812	0.322	4.285	13.805	0.833	1.039	0.59	3.262
53	PA1	L3f03	3.93	6.397	1.208	0.335	8.814	13.51	1.042	0.964	0.38	4.991
54	PA1	L3f04	21.551	36.523	7.401	0.375	29.287	23.625	1.203	1.532	0.484	27.768
55	PA1	L3f05	22.349	32.536	7.551	0.537	27.491	29.266	1.447	2.135	0.611	30.371
56	PA1	L3g01	17.48	41.208	6.827	0.433	53.428	25.662	2.696	1.106	0.519	31.296
57	PA1	L3g02	24.498	53.598	9.428	0.4	83.259	26.883	2.203	1.161	0.197	41.179
58	PA1	L3g03	16.311	41.339	6.455	0.386	35.175	27.303	2.065	1.446	0.532	27.067
59	PA1	L3g04	13.956	39	4.823	0.447	31.67	24.336	0.9	1.29	0.359	20.33
60	PA1	L3g05	5.042	5.681	1.503	0.377	11.53	15.941	1.149	1.046	0.517	6.382
61	PA1	L3h01	2.385	3.301	0.752	0.251	9.471	10.62	0.626	0.911	0.481	3.36
62	PA1	L3h02	20.652	46.97	7.337	0.366	62.138	21.439	0.596	1.024	0.258	30.084
63	PA1	L3h03	17.624	34.968	6.094	0.456	37.846	27.364	1.343	1.619	0.476	24.821
64	PA1	L3h04	14.292	27.843	4.733	0.37	21.303	27.939	1.429	1.611	0.692	18.953
65	PA1	L3h05	2.809	5.684	0.846	0.257	8.117	9.781	1.099	0.712	1.089	3.125
66	PA1	L3i01	14.588	36.909	5.734	0.365	40.919	25.025	3.04	1.332	0.385	25.473
67	PA1	L3i03	13.545	29.702	4.398	0.302	13.596	21.427	1.103	1.271	0.601	15.922
68	PA1	L3i04	20.031	48.189	6.926	0.356	44.105	28.919	3.484	1.704	0.615	28.21
69	PA1	L3i05	18.494	35.862	5.477	0.4	20.334	87.216	1.331	1.294	0.39	21.181

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
70	PA1	L4a01	16.123	36.63	6.155	0.36	55.056	18.073	1.177	1.293	1.124	27.67
71	PA1	L4a02	17.102	35.957	5.216	0.348	20.24	91.887	1.736	1.37	0.386	20.754
72	PA1	L4a03	15.67	36.259	6.004	0.313	24.698	21.71	1.246	1.27	0.708	25.52
73	PA1	L4a04	4.601	6.856	1.4	0.221	10.312	11.579	1.274	0.763	0.923	5.88
74	PA1	L4a05	15.901	42.761	6.556	0.343	37.602	26.284	2.548	1.323	0.765	27.723
75	PA1	L4a06	4.849	13.261	1.46	0.343	10.526	8.142	0.538	0.862	2.139	5.056
76	PA1	L4a07	14.361	33.508	5.117	0.372	44.813	18.38	1.049	0.908	0.315	22.213
77	PA1	L4a09	15.147	36.477	5.834	0.423	54.499	18.878	1.787	1.169	0.278	26.172
78	PA1	L4a10	16.149	38.943	6.409	0.353	50.526	22.528	3.326	1.069	0.222	28.72
79	PA1	L4b01	14.591	32.868	5.166	0.344	31.97	34.322	1.476	1.184	0.609	21.662
80	PA1	L4b02	14.764	33.543	5.304	0.345	34.031	33.011	1.681	1.172	0.566	22.446
81	PA1	L4b03	14.862	33.837	5.375	0.349	35.743	34.226	1.715	1.163	0.567	22.98
82	PA1	L4b04	14.512	33.618	5.358	0.344	37.015	29.145	1.748	1.152	0.583	23.096
83	PA1	L4b05	19.427	49.346	7.819	0.39	58.149	23.603	2.548	1.458	0.67	33.7
84	PA1	L4b06	21.434	44.247	7.281	0.592	24.628	25.085	1.081	1.744	0.902	28.846
85	PA1	L4b07	19.761	41.204	6.99	0.297	42.022	16.076	0.073	1.171	0.757	26.531
86	PA1	L4b08	16.279	35.893	6.077	0.342	36.105	20.623	1.067	1.134	0.482	26.358
87	PA1	L4b10	11.176	29.186	4.529	0.297	35.566	22.585	1.762	1.034	0.334	19.643
88	PA1	L4c01	2.739	6.457	0.987	0.136	7.038	6.67	0.885	1.372	1.726	3.903
89	PA1	L4c02	3.742	5.452	1.055	0.193	10.585	6.472	0.583	1.068	1.496	4.433
90	PA1	L4c03	11.838	31.856	4.898	0.361	31.952	17.589	1.732	1.134	0.601	20.981
91	PA1	L4c04	16.399	33.177	6.24	0.358	30.62	19.228	1.297	1.217	0.546	26.255
92	PA1	L4c05	33.995	48.92	9.156	0.817	36.004	34.647	2.583	2.353	1.137	30.535

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
93	PA1	L4c06	11.101	30.443	4.835	0.283	50.603	20.863	1.948	1.096	0.377	21.566
94	PA1	L4c07	5.398	33.324	2.111	0.143	15.088	11.637	1.953	0.911	1.261	9.104
95	PA1	L4c08	15.321	36.008	5.58	0.285	32.357	18.635	1.299	1.143	0.787	24.224
96	PA1	L4c09	18.682	45.583	6.738	0.345	60.941	25.395	3.063	1.122	0.426	27.598
97	PA1	L4c10	1.963	2.965	0.72	0.173	8.519	5.517	0.64	0.61	0.606	3.123
98	PA1	L6a01	1.987	5.027	0.983	0.161	13.999	7.364	0.512	0.706	1.168	4.726
99	PA1	L6a02	20.244	44.761	7.258	0.367	51.985	20.577	1.26	1.108	0.196	29.915
100	PA1	L6a04	4.156	10.106	1.581	0.162	20.321	8.554	0.374	0.623	0.903	6.482
101	PA1	L6a05	15.562	35.807	5.784	0.384	31.276	20.949	1.152	1.3	0.663	25.171
102	PA1	L6a06	12.678	32.753	5.127	0.311	54.929	20.071	1.251	1.083	0.418	23.056
103	PA1	L6a07	15.18	37.434	5.687	0.337	39.01	20.416	1.353	0.976	0.287	24.984
104	PA1	L6a09	14.278	37.721	5.595	0.298	40.984	20.535	2.594	1.076	0.593	25.013
105	PA1	L6a10	2.107	6.184	0.715	0.282	6.714	13.21	0.683	1.006	1.224	3.128
106	PA1	L6a12	3.77	11.364	1.568	0.138	17.049	13.771	0.949	0.872	0.847	6.731
107	PA1	L6a13	4.01	9.708	1.818	0.169	25.683	3.185	0.145	0.163	0.182	8.54
108	PA1	L6b01	14.936	35.419	5.39	0.394	36.614	21.999	1.85	1.18	0.482	22.957
109	PA1	L6b02	17.858	30.446	5.64	0.37	25.783	22.943	1.323	1.428	0.45	22.086
110	PA1	L6b03	20.203	45.45	7.75	0.399	60.99	25.167	1.681	1.506	0.84	33.774
111	PA1	L6b04	13.2	22.618	4.134	0.304	19.944	17.349	1.163	0.969	0.351	16.73
112	PA1	L6b05	3.602	5.867	1.032	0.204	10.005	8.616	1.484	1.408	0.902	4.376
113	PA1	L6b06	15.146	34.143	5.66	0.369	36.124	18.231	1.038	1.224	0.848	24.513
114	PA1	L6b07	20.262	48.279	7.619	0.362	97.559	21.562	1.023	1.19	0.349	31.482
115	PA1	L6b08	14.31	35.166	5.808	0.308	32.255	21.304	1.274	1.224	0.549	25.56

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
116	PA1	L6b09	14.157	36.816	5.549	0.292	41.257	23.557	2.581	1.383	0.719	25.305
117	PA1	L6c01	1.476	3.185	0.496	0.222	4.654	9.506	0.516	1.054	0.707	2.141
118	PA1	L6c02	15.502	39.338	6.245	0.35	54.873	18.587	1.331	1.415	0.692	28.099
119	PA1	L6c03	14.954	39.375	5.653	0.408	41.324	24.25	2.192	1.501	0.807	25.054
120	PA1	L6c04	15.904	41.429	6.306	0.348	33.807	20.144	2.418	1.049	0.595	29.014
121	PA1	L6c05	12.927	34.154	5.297	0.26	44.661	18.546	2.594	1.163	0.561	23.235
122	PA1	L6c06	2.266	5.214	0.898	0.17	11.017	7.202	0.459	0.744	1.026	4.161
123	PA1	L6c07	15.115	36.643	5.902	0.296	68.746	19.089	2.452	1.275	0.401	26.521
124	PA1	L6c08	20.47	36.139	6.616	0.403	34.128	23.159	2.022	1.411	0.525	26.26
125	BN1	L8a01	6.126	16.444	2.584	0.282	28.666	10.696	0.755	0.974	1.164	11.29
126	BN1	L8a02	7.048	23.352	2.948	0.421	29.779	9.574	0.77	17.592	4.872	13.332
127	BN1	L8a03	5.725	11.805	2.465	0.201	30.583	9.311	1.488	0.717	1.8	10.957
128	BN1	L8a04	3.715	9.771	1.562	0.238	23.143	7.264	0.604	0.708	1.067	7.396
129	BN1	L8a06	11.296	25.632	4.834	0.341	58.342	12.394	0.865	1.095	0.844	21.977
130	BN1	L8b01	6.711	17.306	2.611	0.353	32.048	11.561	0.845	1.63	6.801	11.633
131	BN1	L8b02	4.294	11.352	1.804	0.26	25.616	7.401	0.597	0.734	0.852	8.186
132	BN1	L8b04	5.641	16.29	2.253	0.337	25.51	9.754	0.977	0.973	1.116	10.026
133	BN1	L8b05	5.015	14.263	2.031	0.33	22.609	10.782	0.997	1.157	1.199	9.005
134	BN1	L8b06	5.649	16.534	2.343	0.289	26.653	9.874	0.898	1.124	1.191	10.707
135	BN1	L8c01	5.942	13.839	2.439	0.273	31.112	8.75	0.686	0.894	1.365	11.356
136	BN1	L8c02	5.023	12.673	2.085	0.212	22.298	7.975	0.565	0.875	2.887	9.288
137	BN1	L8c03	5.832	15.014	2.562	0.316	28.486	9.334	0.759	1.034	1.089	11.626
138	BN1	L8c04	4.671	9.421	1.826	0.193	24.28	8.542	0.948	0.756	1.137	7.768

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
139	BN1	L8c05	5.374	12.502	2.15	0.375	23.276	8.618	0.967	1.086	1.204	9.371
140	BN1	L8d01	3.692	8.623	1.626	0.241	20.553	7.737	0.738	0.794	1.244	7.558
141	BN1	L8d02	3.052	7.474	1.241	0.248	13.607	9.867	1.099	0.83	1.358	5.374
142	BN1	L8d03	10.396	21.174	3.784	0.272	41.227	11.366	2.102	0.78	0.804	17.182
143	BN1	L8d04	4.528	10.847	1.79	0.237	21.246	8.154	0.815	0.866	0.735	8.033
144	BN1	L8d06	3.16	7.356	1.172	0.295	12.822	9.698	0.774	0.815	1.01	4.971
145	BN1	L8e02	5.297	35.438	2.218	0.226	22.503	8.873	1.073	0.759	1.735	9.942
146	BN1	L8e03	4.716	11.723	1.877	0.241	19.358	8.337	0.66	0.807	1.213	8.438
147	BN1	L8e04	4.541	8.815	1.649	0.266	16.097	10.13	0.701	0.823	0.962	7.301
148	BN1	L8e05	17.962	40.451	4.907	1.188	24.947	33.103	2.274	2.28	0.504	16.488
149	BN1	L8e06	26.947	54.547	7.85	0.662	34.72	32.344	2.69	1.416	1.795	27.122
150	BN1	L9a02	7.861	17.112	2.85	0.302	30.7	11.973	1.283	0.97	1.11	12.734
151	BN1	L9a03	7.861	17.11	2.85	0.302	30.698	11.972	1.283	0.916	1.11	12.734
152	BN1	L9a04	5.29	19.935	1.998	0.313	18.368	13.623	0.668	1.672	1	8.02
153	BN1	L9a05	4.526	9.803	1.812	0.348	16.837	12.858	1.102	1.263	1.238	7.912
154	BN1	L9a06	10.824	25.393	5.057	0.303	53.745	12.218	0.783	1.019	1.363	22.986
155	BN1	L9a07	6.713	15.271	2.71	0.298	25.859	8.788	1.471	1.127	4.367	10.909
156	BN1	L9a09	6.366	15.271	2.815	0.265	35.309	15.44	0.995	1.034	1.381	12.643
157	BN1	L9a10	7.496	15.544	2.348	0.231	23.254	13.324	0.689	1.004	1.14	10.083
158	BN1	L9b01	3.424	9.299	1.405	0.32	15.336	12.732	0.853	0.863	1.165	6.175
159	BN1	L9b04	2.982	6.588	1.133	0.274	12.842	8.721	0.791	0.841	3.666	4.948
160	BN1	L9b05	7.3	14.29	2.653	0.301	25.156	10.162	0.851	0.947	1.228	11.349
161	BN1	L9b06	28.896	71.241	7.851	0.759	17.525	26	7.717	1.704	9.731	27.681

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
162	BN1	L9b07	5.94	12.825	2.264	0.26	23.582	9.133	0.72	0.74	0.878	10.139
163	BN1	L9b08	6.259	15.009	2.409	0.275	26.248	9.283	0.89	0.816	1.048	9.746
164	BN1	L9b09	4.385	11.811	1.796	0.268	19.585	11.259	1.064	0.831	1.068	8.211
165	BN1	L9b10	18.195	23.573	2.776	1.344	9.822	46.209	3.716	2.435	0.992	7.292
166	BN1	L9c02	5.924	15.147	2.278	0.223	25.066	7.936	0.871	1.087	1.089	9.227
167	BN1	L9c03	36.837	85.685	10.317	0.754	25.273	28.176	8.051	1.794	6.019	35.988
168	BN1	L9c04	7.253	18.559	2.658	0.275	32.109	9.454	0.94	0.865	0.925	10.678
169	BN1	L9c05	7.053	15.704	3.001	0.347	34.33	11.951	0.86	1.035	0.944	13.412
170	BN1	L9c06	6.386	16.51	2.685	0.174	36.643	17.853	0.926	0.945	4.873	11.259
171	BN1	L9c07	25.06	87.076	11.356	0.372	36.555	22.728	2.345	1.085	0.818	40.706
172	BN1	L9c08	13.751	28.949	4.845	0.269	55.841	15.661	1.842	1.092	0.61	20.946
173	BN1	L9c09	43.87	91.283	11.494	1.483	36.907	58.634	6.312	5.587	1.164	35.289
174	BN1	L10a01	2.804	6.716	1.226	0.201	15.842	7.644	0.91	0.747	0.63	5.033
175	BN1	L10a02	4.974	11.378	1.909	0.19	20.569	10.417	0.756	0.82	0.809	7.529
176	BN1	L10a04	30.647	84.145	7.084	0.96	20.178	30.239	3.354	2.921	1.191	20.816
177	BN1	L10a05	43.16	66.348	8.792	2.127	36.977	58.749	3.416	1.857	2.608	25.171
178	BN1	L10a06	34.056	68.935	9.221	0.609	26.529	18.989	9.345	1.315	2.019	29.15
179	BN1	L10b01	5.975	12.151	2.098	0.184	22.546	8.411	0.777	0.776	0.788	8.195
180	BN1	L10b02	6.588	15.797	2.53	0.243	23.437	10.809	0.97	1.07	0.889	10.371
181	BN1	L10b03	28.512	69.811	7.534	0.588	19.929	23.752	9.467	1.571	7.191	24.284
182	BN1	L10b04	5.525	15.165	2.065	0.209	20.874	12.105	0.825	0.939	0.679	7.938
183	BN1	L10b05	23.325	57.413	8.261	0.393	82.989	27.888	5.758	1.609	4.648	33.044
184	BN1	L10c01	3.785	8.028	1.443	0.286	13.563	13.612	1.405	1.725	1.587	6.067

#	Site	Sample ID	La	Ce	Pr	Ta	Y	Pb	U	W	Mo	Nd
185	BN1	L10c02	40.331	77.333	11.695	0.689	54.735	28.759	3.542	1.645	0.471	40.257
186	BN1	L10c03	6.389	17.661	2.614	0.302	25.895	12.023	1.096	1.134	1.395	10.494
187	BN1	L10c05	5.004	10.357	1.889	0.214	19.704	7.691	0.888	0.775	0.561	7.426
188	BN1	L10C06	10.031	20.138	3.563	0.173	29.425	8.853	1.266	1.243	14.045	14.072
189	BN1	L10d01	7.453	16.414	2.993	0.258	27.885	11.115	1.286	1.097	1.239	12.454
190	BN1	L10d02	5.728	11.64	2.384	0.155	24.101	8.88	0.969	0.913	0.816	9.676
191	BN1	L10d03	8.062	18.045	2.998	0.178	39.083	13.865	1.016	0.889	1.089	12.015
192	BN1	L10d04	5.681	12.814	2.269	0.219	21.84	9.352	0.869	0.838	0.901	9.372
193	BN1	L10d05	3.933	10.125	1.541	0.209	15.941	9.52	0.916	0.87	1.093	5.993
194	BN1	L10d06	5.669	12.64	2.316	0.297	22.579	10.561	1.09	1.007	1.263	10.059
195	BN1	L10e01	4.794	11.078	1.641	0.23	16.324	8.68	0.923	0.857	0.715	6.415
196	BN1	L10e03	4.502	10.892	1.84	0.246	20.137	9.189	0.937	0.98	0.828	7.734
197	BN1	L10e04	5.513	10.722	2.278	0.208	26.469	9.309	1.15	0.869	1.112	9.609
198	BN1	L10e05	46.346	92.396	11.889	1.258	60.877	53.336	4.258	3.898	2.285	39.614
199	BN1	L10e06	34.208	75.508	8.093	0.955	23.175	23.481	2.939	2.62	1.479	24.804
200	Ouh	Sa01	24.138	44.449	6.422	0.81	21.963	28.832	3.225	2.289	0.541	20.897

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
1	PA1	L2b01	1.283	0.338	1.394	0.26	1.934	0.417	1.241	0.188	1.403	0.204	4.103	2.726
2	PA1	L2b02	1.446	0.4	1.564	0.291	2.099	0.467	1.298	0.2	1.513	0.221	4.293	2.599
3	PA1	L2b03	1.703	0.614	1.804	0.337	2.277	0.518	1.538	0.239	1.839	0.289	5.517	3.663
4	PA1	L2b04	3.831	0.961	3.857	0.661	4.409	0.963	2.815	0.417	3.082	0.48	5.53	3.013
5	PA1	L2b05	0.861	0.442	0.799	0.141	0.988	0.21	0.645	0.102	0.74	0.111	5.422	4.184
6	PA1	L2b06	3.252	0.937	3.434	0.65	4.447	0.959	2.893	0.44	3.353	0.483	5.216	3.115
7	PA1	L2b07	6.423	2.11	8.017	1.388	10.039	2.267	6.673	0.933	6.677	0.977	3.978	2.128
8	PA1	L2b08	5.63	1.714	7.678	1.47	10.988	2.531	7.364	1.059	7.722	1.072	3.446	1.836
9	PA1	L2b09	5.444	1.257	6.345	1.144	7.526	1.803	5.187	0.82	5.883	0.951	5.719	1.865
10	PA1	L2c01	2.972	0.807	2.977	0.479	3.182	0.698	1.997	0.29	2.118	0.304	5.315	3.015
11	PA1	L2c02	1.752	0.458	1.959	0.357	2.558	0.578	1.759	0.266	1.999	0.293	4.02	2.027
12	PA1	L2c03	2.749	0.743	2.856	0.501	3.541	0.756	2.312	0.323	2.483	0.369	5.073	3.088
13	PA1	L2c04	1.392	0.404	1.398	0.253	1.835	0.389	1.19	0.176	1.367	0.195	3.845	2.322
14	PA1	L2c05	2.439	0.567	2.668	0.49	3.7	0.843	2.484	0.394	2.768	0.415	4.626	3.123
15	PA1	L2c06	2.452	0.608	2.633	0.466	3.413	0.742	2.222	0.361	2.656	0.395	3.921	1.875
16	PA1	L2c07	1.289	0.449	1.368	0.225	1.577	0.352	1.135	0.15	1.238	0.187	4.613	3.09
17	PA1	L2c08	2.697	0.732	2.662	0.426	3.025	0.696	1.921	0.29	2.23	0.322	4.792	2.895
18	PA1	L2c10	1.606	0.657	1.709	0.347	2.315	0.527	1.519	0.251	1.819	0.276	3.858	1.792
19	PA1	L2d01	2.33	0.691	2.37	0.421	2.979	0.665	2.022	0.287	2.295	0.328	4.76	3.384
20	PA1	L2d02	11.238	2.855	11.125	1.849	11.873	2.259	5.697	0.718	4.537	0.564	6.14	5.332
21	PA1	L2d03	1.015	0.528	1.164	0.198	1.426	0.322	0.943	0.137	1.074	0.161	5.662	3.744
22	PA1	L2d04	1.318	0.443	1.333	0.218	1.652	0.367	1.109	0.161	1.238	0.188	5.333	3.832
23	PA1	L2d05	1.627	0.53	1.619	0.297	2.044	0.443	1.297	0.2	1.542	0.222	3.851	3.097
24	PA1	L2d06	2.332	0.714	2.239	0.39	2.71	0.568	1.7	0.256	2.101	0.29	4.13	2.169

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
25	PA1	L2d07	1.428	0.438	1.729	0.295	2.082	0.478	1.466	0.225	1.619	0.269	6.051	3.006
26	PA1	L2d08	1.158	0.509	1.142	0.195	1.325	0.302	0.92	0.139	1.129	0.163	4.396	4.246
27	PA1	L2d10	3.128	0.933	3.461	0.619	4.095	0.865	2.363	0.373	2.472	0.363	2.933	2.007
28	PA1	L3a01	1.989	0.592	2.221	0.404	2.85	0.639	1.863	0.273	2.013	0.29	3.034	1.738
29	PA1	L3a02	1.504	0.628	1.531	0.264	1.902	0.361	1.119	0.157	1.263	0.189	4.471	2.982
30	PA1	L3a03	4.297	1.297	3.938	0.682	4.544	0.951	2.71	0.419	2.98	0.42	3.874	3.095
31	PA1	L3a04	6.219	1.651	6.263	1.045	6.946	1.263	3.256	0.586	3.438	0.463	6.346	6.164
32	PA1	L3a05	6.257	1.738	5.956	1.006	6.215	1.251	3.257	0.456	3.227	0.449	5.786	4.421
33	PA1	L3b01	1.714	0.555	1.971	0.349	2.457	0.531	1.58	0.242	1.748	0.268	5.157	3.257
34	PA1	L3b02	2.039	0.656	2.023	0.393	2.552	0.558	1.706	0.262	2.158	0.348	5.357	3.523
35	PA1	L3b04	3.42	0.525	3.192	0.616	3.927	0.777	2.094	0.311	2.311	0.311	1.907	6.103
36	PA1	L3b05	3.421	0.99	3.6	0.624	4.273	0.962	2.763	0.432	3.323	0.546	6.689	4.549
37	PA1	L3c01	9.217	2.609	9.265	1.575	10.456	2.098	5.817	0.8	5.809	0.804	5.499	4.557
38	PA1	L3c02	9.581	2.759	9.447	1.636	10.864	2.279	6.032	0.797	5.217	0.631	5.057	4.027
39	PA1	L3c03	3.294	0.701	2.128	0.336	2.157	0.517	1.52	0.256	1.8	0.243	3.446	11.736
40	PA1	L3c04	0.912	0.299	1.117	0.213	1.612	0.38	1.181	0.188	1.78	0.23	3.627	1.603
41	PA1	L3c05	3.859	1.099	3.662	0.662	4.15	0.91	2.406	0.392	2.703	0.393	5.353	5.291
42	PA1	L3d01	6.515	1.831	6.197	1.117	7.52	1.55	4.47	0.651	4.953	0.692	4.737	4.743
43	PA1	L3d02	8.344	2.383	7.81	1.322	8.248	1.424	3.667	0.482	3.164	0.414	5.847	4.718
44	PA1	L3d03	0.649	0.239	0.599	0.118	0.77	0.169	0.472	0.075	0.557	0.08	4.26	2.215
45	PA1	L3d04	6.035	1.62	5.608	0.912	5.827	1.144	3.141	0.449	3.304	0.455	4.093	2.993
46	PA1	L3D05	1.459	0.517	1.267	0.262	1.757	0.39	1.137	0.175	1.278	0.201	4.425	4.258
47	PA1	L3e01	7.816	2.204	8.165	1.416	9.555	1.986	5.323	0.716	4.764	0.611	4.823	3.902
48	PA1	L3e02	6.541	1.718	6.657	1.163	7.974	1.757	5.218	0.78	5.828	0.876	4.742	4.262

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
49	PA1	L3e03	3.353	1.16	3.112	0.522	3.519	0.728	2.082	0.352	2.491	0.349	3.587	3.071
50	PA1	L3e04	6.47	1.67	6.513	1.102	6.594	1.358	3.201	0.428	2.735	0.378	4.584	4.765
51	PA1	L3e05	10.696	3.284	14.078	2.779	19.637	5.042	14.885	2.402	16.778	2.681	5.151	6.968
52	PA1	L3f01	0.934	0.3	0.814	0.151	1.073	0.226	0.681	0.11	0.923	0.16	3.889	3.276
53	PA1	L3f03	1.298	0.439	1.435	0.234	1.583	0.351	1.038	0.18	1.069	0.16	3.241	3.243
54	PA1	L3f04	7.398	1.935	6.87	1.135	7.067	1.391	3.679	0.529	3.634	0.501	4.931	4.814
55	PA1	L3f05	8.016	1.933	7.207	1.15	7.103	1.305	3.484	0.462	3.187	0.42	5.432	5.627
56	PA1	L3g01	9.441	2.8	10.627	1.84	12.36	2.57	6.734	0.867	5.533	0.708	6.258	4.282
57	PA1	L3g02	12.267	3.393	14.444	2.499	17.042	3.713	10.276	1.482	10.373	1.503	6.321	5.983
58	PA1	L3g03	7.879	2.317	7.534	1.275	8.318	1.679	4.412	0.594	4.118	0.543	4.91	3.843
59	PA1	L3g04	5.631	1.591	5.713	0.986	7.022	1.481	4.344	0.666	4.813	0.726	5.065	5.151
60	PA1	L3g05	1.669	0.462	1.854	0.285	2.005	0.446	1.258	0.171	1.205	0.182	4.448	4.16
61	PA1	L3h01	0.967	0.35	1.106	0.263	1.81	0.42	1.248	0.187	1.423	0.213	4.135	2.592
62	PA1	L3h02	8.603	2.464	9.819	1.774	11.35	2.444	6.138	0.873	5.491	0.761	5.53	4.046
63	PA1	L3h03	7.001	1.991	7.154	1.266	8.664	1.857	5.405	0.784	5.95	0.872	5.467	4.554
64	PA1	L3h04	5.081	1.515	4.749	0.793	5.148	1.075	2.875	0.424	3.17	0.443	4.867	4.307
65	PA1	L3h05	0.867	0.274	0.956	0.183	1.344	0.326	0.954	0.163	1.247	0.191	4.55	2.976
66	PA1	L3i01	7.635	2.238	8.381	1.419	9.741	2.001	5.569	0.723	5.147	0.676	5.255	3.761
67	PA1	L3i03	4.119	1.163	3.678	0.524	3.186	0.633	1.54	0.231	1.666	0.239	3.74	2.7
68	PA1	L3i04	7.796	2.396	8.736	1.466	9.72	1.998	5.126	0.66	3.975	0.492	4.758	5.452
69	PA1	L3i05	5.022	1.377	4.517	0.692	4.268	0.822	2.172	0.301	2.087	0.311	3.33	5.708
70	PA1	L4a01	8.301	2.294	9.003	1.557	10.596	2.146	5.858	0.742	4.862	0.627	4.624	4.018
71	PA1	L4a02	5.082	1.467	4.782	0.768	4.737	0.806	2.099	0.335	2.224	0.302	3.355	5.58
72	PA1	L4a03	7.188	2.063	7.09	1.171	7.329	1.211	3.156	0.389	2.69	0.348	4.707	3.422

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
73	PA1	L4a04	1.582	0.548	1.5	0.284	1.862	0.387	1.277	0.179	1.425	0.226	3.518	1.835
74	PA1	L4a05	8.093	2.409	8.293	1.39	9.023	1.762	4.496	0.565	3.605	0.469	4.352	3.357
75	PA1	L4a06	1.356	0.333	1.368	0.237	1.611	0.378	1.09	0.18	1.416	0.225	3.805	5.638
76	PA1	L4a07	6.684	1.934	7.184	1.327	9.229	2.012	6.057	0.95	7.258	1.125	5.744	3.902
77	PA1	L4a09	8.182	2.355	9.328	1.598	11.241	2.47	7.055	0.917	6.493	1.084	5.413	3.904
78	PA1	L4a10	8.469	2.545	9.11	1.573	10.578	2.211	5.981	0.805	5.087	0.661	4.985	4.028
79	PA1	L4b01	6.112	1.758	6.261	1.054	6.977	1.394	3.842	0.524	3.677	0.54	4.346	3.824
80	PA1	L4b02	6.374	1.846	6.578	1.112	7.377	1.485	4.079	0.556	3.834	0.553	4.417	3.846
81	PA1	L4b03	6.56	1.901	6.818	1.162	7.73	1.556	4.294	0.583	4.022	0.581	4.474	3.951
82	PA1	L4b04	6.685	1.945	7.01	1.201	8.02	1.617	4.471	0.607	4.184	0.604	4.575	3.777
83	PA1	L4b05	9.948	2.833	10.598	1.82	12.19	2.512	6.789	0.862	5.685	0.709	5.201	3.971
84	PA1	L4b06	7.678	2.031	7.035	1.134	6.868	1.252	3.096	0.399	2.624	0.36	6.241	5.015
85	PA1	L4b07	7.075	1.945	7.192	1.263	7.739	1.591	4.146	0.586	3.995	0.555	5.391	1.318
86	PA1	L4b08	7.303	2.097	7.533	1.245	7.963	1.523	3.987	0.501	3.431	0.436	4.832	2.976
87	PA1	L4b10	5.628	1.759	6.26	1.035	7.169	1.559	4.19	0.569	3.895	0.434	3.315	2.392
88	PA1	L4c01	1.15	0.35	1.167	0.217	1.526	0.324	0.997	0.153	1.254	0.171	2.253	1.378
89	PA1	L4c02	1.364	0.363	1.55	0.272	2.026	0.459	1.322	0.206	1.556	0.239	2.824	1.592
90	PA1	L4c03	6.283	1.942	6.644	1.136	7.482	1.51	3.815	0.494	3.121	0.384	4.414	2.67
91	PA1	L4c04	7.322	2.125	7.255	1.226	7.711	1.495	3.779	0.461	2.983	0.369	4.599	2.782
92	PA1	L4c05	6.43	1.668	5.654	1.064	6.258	1.312	3.663	0.53	3.699	0.519	2.718	11.682
93	PA1	L4c06	6.277	1.887	7.133	1.249	8.615	1.911	5.324	0.748	5.227	0.71	3.923	2.367
94	PA1	L4c07	2.952	1.01	2.882	0.535	3.758	0.77	2.281	0.318	2.477	0.341	2.403	1.53
95	PA1	L4c08	6.811	1.965	6.86	1.108	6.816	1.325	3.31	0.404	2.683	0.357	3.996	2.612
96	PA1	L4c09	7.656	2.437	8.8	1.619	10.576	2.314	5.992	0.817	5.242	0.666	5.237	3.811

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
97	PA1	L4c10	0.989	0.238	1.037	0.209	1.466	0.323	0.987	0.155	1.165	0.179	2.971	1.164
98	PA1	L6a01	1.643	0.475	1.908	0.341	2.418	0.533	1.576	0.23	1.766	0.267	2.795	1.236
99	PA1	L6a02	8.436	2.405	8.997	1.602	9.976	2.093	5.277	0.76	4.622	0.665	5.263	4.172
100	PA1	L6a04	2.123	0.615	2.503	0.488	3.224	0.776	2.104	0.357	2.338	0.344	3.081	1.8
101	PA1	L6a05	7.062	1.994	6.853	1.12	7.097	1.396	3.776	0.529	3.753	0.506	4.646	2.877
102	PA1	L6a06	7.098	2.2	7.942	1.332	9.431	2.076	6	0.848	5.764	0.798	4.899	2.647
103	PA1	L6a07	7.383	2.062	7.723	1.281	8.621	1.757	4.546	0.593	3.95	0.506	4.812	3.128
104	PA1	L6a09	7.105	2.212	7.618	1.28	8.595	1.761	4.613	0.598	3.746	0.487	4.112	2.646
105	PA1	L6a10	1.004	0.31	1.003	0.186	1.309	0.305	0.893	0.14	1.095	0.173	4.159	2.273
106	PA1	L6a12	1.977	0.551	2.138	0.421	2.841	0.649	1.887	0.293	2.183	0.341	2.57	1.324
107	PA1	L6a13	3.148	1.035	4.022	0.692	4.562	0.989	2.869	0.399	2.862	0.431	0.933	0.506
108	PA1	L6b01	6.49	1.852	6.851	1.134	7.665	1.573	4.306	0.619	4.406	0.641	5.242	3.578
109	PA1	L6b02	5.766	1.583	5.526	0.881	5.781	1.117	3.215	0.423	3.105	0.443	4.595	3.304
110	PA1	L6b03	9.826	2.797	10.619	1.821	12.227	2.468	6.572	0.813	5.277	0.677	5.384	3.949
111	PA1	L6b04	4.337	1.565	3.964	0.666	4.309	0.876	2.349	0.332	2.403	0.338	3.676	2.708
112	PA1	L6b05	1.366	0.359	1.441	0.284	1.926	0.447	1.295	0.205	1.428	0.224	3.129	1.725
113	PA1	L6b06	7.255	2.028	7.219	1.273	8.267	1.675	4.521	0.597	4.161	0.581	4.887	3.582
114	PA1	L6b07	9.326	2.784	10.925	2.047	13.635	3.252	9.083	1.357	9.325	1.333	5.515	3.897
115	PA1	L6b08	7.293	2.089	7.14	1.184	7.582	1.521	3.78	0.491	3.161	0.389	4.337	2.99
116	PA1	L6b09	7.427	2.25	8.146	1.32	8.921	1.828	4.892	0.645	4.384	0.497	4.707	3.684
117	PA1	L6c01	0.637	0.191	0.631	0.106	0.781	0.183	0.529	0.088	0.704	0.098	3.521	2.481
118	PA1	L6c02	8.297	2.302	8.841	1.484	10.145	2.045	5.384	0.688	4.584	0.563	4.481	2.777
119	PA1	L6c03	7.476	2.188	7.681	1.327	9.048	1.811	4.8	0.631	3.987	0.517	4.838	3.614
120	PA1	L6c04	8.318	2.349	8.614	1.474	9.907	2.064	5.498	0.745	4.812	0.652	5.187	4.078

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
121	PA1	L6c05	6.912	2.179	7.737	1.302	8.884	1.855	5.321	0.639	4.099	0.498	3.322	1.961
122	PA1	L6c06	1.369	0.41	1.671	0.262	1.834	0.422	1.191	0.188	1.404	0.202	2.824	1.184
123	PA1	L6c07	8.103	2.414	8.842	1.501	10.817	2.364	6.952	1.001	6.832	0.918	4.255	2.699
124	PA1	L6c08	6.835	1.838	6.793	1.116	7.133	1.43	3.924	0.549	3.974	0.559	5.544	3.358
125	BN1	L8a01	3.372	0.813	3.912	0.689	4.867	1.088	3.215	0.481	3.505	0.536	3.944	1.857
126	BN1	L8a02	4.157	0.989	4.277	0.817	5.487	1.202	3.545	0.533	4.09	0.608	4.847	2.118
127	BN1	L8a03	3.62	1.222	4.322	0.808	5.673	1.128	3.764	0.543	4.013	0.561	2.719	1.151
128	BN1	L8a04	2.419	0.633	2.999	0.544	4.023	0.871	2.622	0.387	3.081	0.458	2.817	1.505
129	BN1	L8a06	6.86	1.9	8.007	1.414	9.91	2.195	6.149	0.975	7.146	1.052	4.177	2.237
130	BN1	L8b01	3.507	0.871	4.04	0.753	5.249	1.184	3.564	0.556	4.065	0.602	4.55	2.621
131	BN1	L8b02	2.517	0.655	3.181	0.55	4	0.907	2.762	0.426	2.998	0.475	3.55	1.571
132	BN1	L8b04	3.175	0.743	3.658	0.667	4.556	0.995	2.983	0.475	3.484	0.507	4.318	2.025
133	BN1	L8b05	2.745	0.695	3.081	0.549	3.854	0.875	2.617	0.394	2.973	0.45	3.932	2.164
134	BN1	L8b06	3.216	0.857	3.553	0.65	4.711	1.01	3.082	0.462	3.447	0.524	3.973	2.005
135	BN1	L8c01	3.437	0.76	3.796	0.62	4.278	0.922	2.805	0.426	3.027	0.456	3.601	1.994
136	BN1	L8c02	2.784	0.776	3.222	0.558	3.676	0.868	2.433	0.371	2.706	0.413	3.367	1.412
137	BN1	L8c03	3.674	0.925	4.067	0.717	5.221	1.117	3.437	0.518	3.939	0.593	4.1	1.858
138	BN1	L8c04	2.432	0.566	2.836	0.452	3.231	0.717	2.208	0.338	2.45	0.368	2.811	1.687
139	BN1	L8c05	2.912	0.713	3.148	0.578	3.951	0.871	2.6	0.42	3.025	0.469	4.078	2.177
140	BN1	L8d01	2.51	0.578	2.612	0.466	3.194	0.707	2.129	0.319	2.426	0.351	3.354	1.842
141	BN1	L8d02	1.711	0.418	1.822	0.322	2.282	0.488	1.415	0.218	1.633	0.236	3.315	1.866
142	BN1	L8d03	5.497	1.534	6.105	1.095	7.489	1.599	4.725	0.691	4.951	0.79	3.502	2.402
143	BN1	L8d04	2.474	0.562	2.684	0.481	3.354	0.736	2.231	0.333	2.442	0.364	3.658	2.072
144	BN1	L8d06	1.436	0.369	1.69	0.302	2.06	0.463	1.353	0.2	1.571	0.25	3.728	2.259

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
145	BN1	L8e02	2.938	0.893	3.164	0.571	3.854	0.839	2.555	0.381	3.047	0.426	2.688	1.389
146	BN1	L8e03	2.506	0.547	2.81	0.481	3.261	0.721	2.002	0.291	2.08	0.309	3.865	2.247
147	BN1	L8e04	1.983	0.539	2.305	0.406	2.912	0.627	1.883	0.282	2.207	0.328	4.285	2.481
148	BN1	L8e05	3.77	0.909	3.341	0.531	3.437	0.763	2.262	0.352	2.755	0.437	2.258	6.348
149	BN1	L8e06	6.112	1.441	5.141	0.845	5.434	1.227	3.599	0.549	4.016	0.619	4.688	6.881
150	BN1	L9a02	3.729	0.896	4.017	0.716	4.853	1.091	3.237	0.506	3.757	0.562	4.236	2.226
151	BN1	L9a03	3.728	0.896	4.017	0.716	4.853	1.091	3.236	0.506	3.757	0.562	4.236	2.226
152	BN1	L9a04	2.826	0.681	2.684	0.494	3.611	0.727	2.224	0.342	2.512	0.374	3.918	1.927
153	BN1	L9a05	2.416	0.605	2.55	0.451	3.269	0.688	2.037	0.32	2.501	0.37	4.225	2.072
154	BN1	L9a06	7.347	2.055	8.004	1.41	10.149	2.199	6.572	1.012	7.709	1.121	3.954	1.845
155	BN1	L9a07	3.118	0.989	3.223	0.567	4.232	0.901	2.754	0.391	3.008	0.457	3.115	1.658
156	BN1	L9a09	4.173	0.963	5.041	0.865	6.381	1.394	4.234	0.616	4.876	0.699	3.586	1.93
157	BN1	L9a10	3.291	0.761	3.21	0.553	3.651	0.844	2.486	0.353	2.674	0.399	3.805	2.063
158	BN1	L9b01	1.803	0.451	2.094	0.345	2.715	0.534	1.745	0.255	1.948	0.279	3.77	1.799
159	BN1	L9b04	1.599	0.415	1.706	0.312	2.309	0.51	1.575	0.221	1.559	0.234	3.399	1.904
160	BN1	L9b05	3.308	0.853	3.683	0.602	4.056	0.918	2.738	0.41	3.185	0.472	4.015	1.986
161	BN1	L9b06	5.259	1.212	3.537	0.535	3.345	0.678	1.932	0.297	2.017	0.307	3.062	9.602
162	BN1	L9b07	2.93	0.669	3.088	0.515	3.618	0.813	2.501	0.366	2.631	0.393	3.634	1.905
163	BN1	L9b08	2.842	0.736	3.113	0.563	4.035	0.924	2.791	0.4	3.055	0.532	3.51	1.463
164	BN1	L9b09	2.685	0.729	2.888	0.476	4.364	0.789	2.268	0.341	2.605	0.372	4.015	1.995
165	BN1	L9b10	1.307	0.251	1.103	0.192	1.225	0.293	0.862	0.148	1.092	0.179	6.392	18.79
166	BN1	L9c02	2.779	0.683	3.192	0.606	4.086	0.962	2.692	0.43	3.096	0.475	4.454	2.598
167	BN1	L9c03	6.882	1.848	5.153	0.716	4.287	0.891	2.557	0.353	2.968	0.385	3.105	10.116
168	BN1	L9c04	3.391	0.919	3.801	0.72	4.65	1.075	3.034	0.476	3.295	0.505	3.872	2.951

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
169	BN1	L9c05	4.27	1.14	4.582	0.814	5.768	1.269	3.867	0.578	4.482	0.657	3.986	2.138
170	BN1	L9c06	3.581	0.861	4.368	0.86	5.85	1.387	3.912	0.615	4.193	0.645	3.613	2.382
171	BN1	L9c07	9.311	2.658	7.942	1.287	8.004	1.669	4.539	0.651	4.484	0.626	2.791	5.547
172	BN1	L9c08	6.049	1.665	7.119	1.279	8.462	1.817	5.174	0.762	5.014	0.715	4.679	3.487
173	BN1	L9c09	7.053	1.488	5.518	0.911	5.257	1.087	2.966	0.42	2.551	0.362	3.13	12.319
174	BN1	L10a01	1.545	0.416	1.785	0.344	2.096	0.555	1.439	0.248	1.622	0.252	3.6	2.044
175	BN1	L10a02	2.342	0.642	2.536	0.507	3.373	0.794	2.328	0.404	2.751	0.425	3.893	2.198
176	BN1	L10a04	4.049	0.879	3.027	0.472	2.915	0.68	1.927	0.302	2.16	0.313	2.598	13.808
177	BN1	L10a05	5.527	0.668	5.104	0.889	5.325	1.179	3.126	0.49	3.394	0.502	4.216	35.409
178	BN1	L10a06	5.838	1.443	4.405	0.696	3.857	0.836	2.295	0.346	2.399	0.357	2.878	9.403
179	BN1	L10b01	2.42	0.621	2.682	0.491	3.278	0.781	2.183	0.341	2.408	0.351	3.222	2.162
180	BN1	L10b02	2.974	0.844	3.423	0.611	4.232	0.95	2.768	0.418	3.114	0.478	4.403	2.969
181	BN1	L10b03	4.628	1.134	3.486	0.533	3.096	0.67	1.817	0.283	1.964	0.28	2.597	8.816
182	BN1	L10b04	2.317	0.708	2.462	0.491	3.305	0.769	2.229	0.351	2.594	0.388	3.649	2.399
183	BN1	L10b05	9.497	2.773	10.487	1.96	12.466	2.927	7.916	1.228	8.455	1.209	6.318	4.998
184	BN1	L10c01	2.151	0.557	2.193	0.378	2.58	0.602	1.693	0.266	2.074	0.309	3.969	1.99
185	BN1	L10c02	9.071	2.399	8.14	1.365	8.223	1.851	4.794	0.723	4.868	0.735	4.728	9.958
186	BN1	L10c03	3.063	1.013	3.659	0.707	4.33	1.021	2.879	0.471	3.638	0.55	5.168	3.348
187	BN1	L10c05	2.181	0.653	2.428	0.469	3.148	0.754	2.129	0.341	2.354	0.36	4.178	2.156
188	BN1	L10C06	3.774	1.007	4.23	0.744	5.197	1.192	3.528	0.547	3.901	0.583	3.691	2.461
189	BN1	L10d01	3.625	0.85	4.081	0.752	5.246	1.184	3.43	0.545	3.899	0.6	5.073	3.252
190	BN1	L10d02	2.904	0.713	3.19	0.6	4.174	0.942	2.834	0.426	3.084	0.474	3.539	1.957
191	BN1	L10d03	3.812	0.852	4.492	0.908	5.822	1.353	3.843	0.6	4.083	0.635	4.027	2.263
192	BN1	L10d04	2.698	0.688	3.101	0.569	3.878	0.885	2.615	0.397	2.851	0.449	4.485	2.637

#	Site	Sample ID	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
193	BN1	L10d05	1.845	0.469	2.012	0.383	2.524	0.62	1.706	0.273	1.963	0.298	3.63	2.249
194	BN1	L10d06	3.115	0.747	3.324	0.587	4.084	0.934	2.86	0.444	3.119	0.454	4.801	2.822
195	BN1	L10e01	1.851	0.464	2.014	0.389	2.512	0.613	1.695	0.279	1.919	0.289	4.106	2.942
196	BN1	L10e03	2.381	0.567	2.857	0.525	3.633	0.841	2.479	0.37	2.834	0.424	4.542	2.459
197	BN1	L10e04	2.901	0.751	3.275	0.619	4.264	0.962	2.828	0.454	3.279	0.492	4.531	2.554
198	BN1	L10e05	9.005	2.008	8.574	1.438	9.326	2.074	5.489	0.834	5.791	0.823	5.333	17.598
199	BN1	L10e06	4.437	0.941	3.51	0.551	3.36	0.747	2.077	0.327	2.233	0.334	2.852	14.616
200	Ouh	Sa01	4.425	1.123	3.356	0.546	3.271	0.76	1.961	0.306	2.115	0.322	2.268	8.619

APPENDIXB: STABLE ISOTOPE RESULTS

Catalog Number	Sample #	Site	Level	Tooth	Sample weight	$\delta^{13}C$ (‰, VPDB)	$\delta^{18}O$ (‰, VPDB)
32A0H03B1	A-10-662	PA1	2A	I1	0.01127	-13.14	-7.14
32A0L02B1	A-10-663	PA1	2A	P3	0.01114	lost	lost
32A0L02B1	A-10-702	PA1	2A	M2	0.0104	-13.58	-3.91
32A0L06B1	A-10-658	PA1	2A	M3	0.01012	-11.53	-5.44
32A0L06B1	A-10-700	PA1	2A	M3	0.01131	-13.16	-5.26
32A0L06B1	A-10-667	PA1	2A	I1	0.01141	-12.9	-4.26
32A0L06B1	A-10-703	PA1	2A	I1	0.01154	-13.18	-4.42
32A1H07B1	A-10-665	PA1	2A	P4	0.01044	-13.24	-4.99
32B0L06B1	A-10-660	PA1	2B	M1	0.01073	-14.31	-4.3
32B0L06B1	A-10-661	PA1	2B	M1 or M2	0.01065	-13.67	-5.37
32B0L06B1	A-10-666	PA1	2B	I1	0.01076	lost	lost
32B0L06B1	A-10-701	PA1	2B	P2 or P3	0.01084	-13.23	-6.21
32C0L06B1	A-10-659	PA1	2C	M3	0.01054	-12.89	-5.17
32C0L06B1	A-10-664	PA1	2C	DP4	0.01013	-13.76	-5.43
33A0L06B1	A-10-678	PA1	3A	M2	0.01089	-14.13	-3.73
33A1H17B1	A-10-684	PA1	3A	C	0.01099	-12.78	-4.13
33B0L06B1	A-10-675	PA1	3B	M2	0.0115	-13.93	-4.43
33B0L06B1	A-10-686	PA1	3B	P3	0.01087	-13.15	-5.16
33B0L06B1	A-10-704	PA1	3B	P3	0.01025	-13.25	-6.36
33B0L06B2	A-10-669	PA1	3B	M2	0.01097	-12.99	-4.89
33C0H25B1	A-10-682	PA1	3C	M3	0.01017	-12.79	-5.02
33C0L06B1	A-10-679	PA1	3C	M1	0.01056	-12.92	-2.88
33C0L06B1	A-10-683	PA1	3C	M1	0.01187	-13.4	-4.64
33C0L06B1	A-10-685	PA1	3C	M1	0.01132	-13.56	-5.25
33C1L06B1	A-10-668	PA1	3C	M3	0.01108	-12.73	-4.5
33C1L06B1	A-10-671	PA1	3C	P3	0.01033	-12.02	-4.24
33C1L06B1	A-10-677	PA1	3C	M3	0.01054	-12.14	-3.69
33D0F03B1	A-10-676	PA1	3D	M2	0.01079	-13.29	-4.44
33D0L06B1	A-10-670	PA1	3D	M2	0.01094	-11.6	-4.83
33D0L06B1	A-10-681	PA1	3D	P3	0.01141	-13.12	-4.15
33D0L06B1	A-10-687	PA1	3D	P3	0.01007	-12.74	-3.39
33D0L06B1	A-10-689	PA1	3D	I1	0.01121	-13.3	-3.29
33D0L06B1	A-10-691	PA1	3D	P3	0.01061	-12.54	-4.91
33E0L06B1	A-10-672	PA1	3E	P2	0.01094	-12.98	-3.6
33E0L06B1	A-10-688	PA1	3E	I1	0.01096	-12.95	-6.1
33F0L06B1	A-10-673	PA1	3F	M3	0.0112	-13.7	-5.14

Catalog Number	Sample #	Site	Level	Tooth	Sample weight	$\delta^{13}C$ (‰, VPDB)	$\delta^{18}O$ (‰, VPDB)
33F0L06B1	A-10-690	PA1	3F	M3	0.01034	-12.45	-3.76
33I0F01B1	A-10-674	PA1	3I	M1	0.01072	-14.12	-3.38
33I0L06B1	A-10-680	PA1	3I	M3	0.01084	-13.1	-5.42
608B0L02B3	A-10-692	BN1	8B	M1	0.01066	-12.38	-1.82
608C0L02B1	A-10-705	BN1	8C	M1 or M2	0.01028	-13.17	-3.8
608E0F01B1	A-10-693	BN1	8E	M1	0.01015	-12.04	-4
608E0L02B1	A-10-706	BN1	8E	P2	0.01187	-12.8	-5.37
609B0L02B1	A-10-694	BN1	9B	P2	0.01071	-12.48	-3.48
609B0L02B1	A-10-707	BN1	9B	P3	0.01129	-12.87	-3.62
609D0L02B1	A-10-695	BN1	9D	M1	0.01125	-13.28	-2.6
610A2F20B1	A-10-696	BN1	10A	M3	0.01176	-12.58	-4.85
610B0F37B1	A-10-697	BN1	10B	M1	0.01073	-12.64	-6.83
610D0F03B1	A-10-698	BN1	10D	M1	0.01022	-13.58	-3.64
610E0F05B1	A-10-699	BN1	10E	M3	0.01091	-0.03	0.01

APPENDIX C: RADIOGENIC ISOTOPE RESULTS

Catalog Number	Sample #	Site	Level	Tooth	Sample weight (mg)	87/86Sr (‰)	87/86 Sr error	206/204 Pb (‰)	206/204Pb error	207/204 Pb (‰)	207/204Pb error	208/204Pb (‰)	208/204 Pb error
32A0L06B1	2.01	PA1	2A	M3	34.83	0.70868	1E-05	18.6423	0.002	15.6239	0.0017	38.589	0.0047
32A0L06B1	2.02	PA1	2A	M3	28.12	0.70872	1E-05	18.5284	0.003	15.6285	0.0023	38.492	0.0055
32C0L06B1	2.03	PA1	2C	M3	43.25	0.70872	9E-06	18.5368	0.003	15.6317	0.0021	38.3849	0.0052
32B0L06B1	2.05	PA1	2B	M1	31.26	0.70824	1E-05	18.4433	0.002	15.6232	0.0018	38.3667	0.0044
32B0L06B1	2.06	PA1	2B	M1 /2	30.58	0.70852	2E-05	18.5699	0.003	15.6232	0.0025	38.5448	0.0063
32A0H03B1	2.07	PA1	2A	I1	31.74	0.70876	1E-05	19.3464	0.001	15.7044	0.0012	38.8832	0.003
32A0L02B1	2.08	PA1	2A	P3	31.09	0.70876	2E-05	41.6071	2.300	34.4152	1.9	87.2397	4.9
32C0L06B1	2.09	PA1	2C	DP4	22.15	0.70860	2E-05	18.5729	0.001	15.6209	0.00084	38.5765	0.0022
32A1H07B1	2.1	PA1	2A	P4	36.84	0.70874	1E-05	19.1867	0.001	15.6873	0.0012	38.8437	0.0032
32B0L06B1	2.11	PA1	2B	I1	31.89	0.70862	1E-05	18.5175	0.002	15.6205	0.0012	38.3952	0.003
32A0L06B1	2.12	PA1	2A	I1	29.85	0.70870	1E-05	18.5284	0.001	15.6173	0.0011	38.5335	0.0031
32B0L06B1	2.13	PA1	2B	P2 /3	29.73	0.70870	9E-06	18.3835	0.003	15.6111	0.0014	38.3149	0.0049
32A0L02B1	2.14	PA1	2A	M2	34.68	0.70881	2E-05	18.5527	0.003	15.6254	0.0023	38.5324	0.0055
32A0L06B1	2.15	PA1	2A	I1	31.58	0.70879	1E-05	18.9829	0.088	16.1185	0.17	40.2015	0.68
33C1L06B1	3.01	PA1	3C	M3	34.62	0.70880	2E-05	18.6078	0.002	15.6163	0.0016	38.4654	0.0037
33B0L06B2	3.02	PA1	3B	M2	39.71	0.70850	1E-05	18.6042	0.003	15.6284	0.002	38.4814	0.0049
33D0L06B1	3.03	PA1	3D	M2	32.4	0.70877	2E-05	18.4674	0.005	15.6138	0.0026	38.4055	0.0078
33C1L06B1	3.04	PA1	3C	P3	31.74	0.70887	8E-06	19.0747	0.001	15.6775	0.00092	38.7549	0.0023

Catalog Number	Sample #	Site	Level	Tooth	Sample weight (mg)	87/86Sr (‰)	87/86 Sr error	206/204 Pb (‰)	206/204Pb error	207/204 Pb (‰)	207/204Pb error	208/204Pb (‰)	208/204 Pb error
33E0L06B1	3.05	PA1	3E	P2	37.77	0.70873	1E-05	18.6642	0.003	15.6216	0.0025	38.4911	0.0067
33F0L06B1	3.06	PA1	3F	M3	33.81	0.70865	8E-06	18.4736	0.003	15.612	0.0027	38.3728	0.0067
33I0F01B1	3.07	PA1	3I	M1	30.68	0.70844	1E-05	18.608	0.007	15.641	0.0045	38.4975	0.012
33B0L06B1	3.08	PA1	3B	M2	31.51	0.70845	1E-05	18.2559	0.110	15.7786	0.099	38.5106	0.24
33D0F03B1	3.09	PA1	3D	M2	37.31	0.70835	1E-05	18.4907	0.003	15.6249	0.0024	38.4004	0.006
33C1L06B1	3.1	PA1	3C	M3	36.49	0.70945	2E-05	18.7023	0.003	15.6403	0.0018	38.7074	0.0052
33A0L06B1	3.11	PA1	3A	M2	36.3	0.70842	2E-05	18.7139	0.002	15.6402	0.0015	38.5931	0.0036
33C0L06B1	3.13	PA1	3C	M1	30.89	0.70868	2E-05	18.3479	0.001	15.6077	0.00096	38.2202	0.0024
33I0L06B1	3.14	PA1	3I	M3	35.7	0.70869	1E-05	18.6277	0.002	15.6229	0.0021	38.6204	0.0049
33D0L06B1	3.15	PA1	3D	P3	31.39	0.70850	2E-05	18.4939	0.003	15.6351	0.0023	38.4079	0.0057
33C0H25B1	3.16	PA1	3C	M3	32.53	0.70879	9E-06	18.7931	0.002	15.6616	0.0012	38.9467	0.0034
33C0L06B1	3.17	PA1	3C	M1	28.2	0.70838	1E-05	18.5466	0.002	15.6359	0.0017	38.3759	0.0044
33A1H17B1	3.18	PA1	3A	C	35.58	0.70859	1E-05	20.0712	0.001	15.77	0.00057	39.3815	0.0019
33C0L06B1	3.19	PA1	3C	M1	27.27	0.70855	1E-05	18.4644	0.004	15.6181	0.003	38.2981	0.0072
33B0L06B1	3.2	PA1	3B	P3	34.66	0.70884	9E-06	18.4618	0.005	15.2622	0.004	37.8709	0.012
33D0L06B1	3.21	PA1	3D	P3	34.73	0.70881	8E-06	18.6703	0.003	15.6363	0.0021	38.5823	0.0051
33E0L06B1	3.22	PA1	3E	I1	30.86	0.70834	9E-06	18.748	0.002	15.6426	0.0016	38.432	0.0039
33D0L06B1	3.23	PA1	3D	I1	29.85	0.70860	7E-06	18.4926	0.003	15.6218	0.0024	38.3709	0.0058
33F0L06B1	3.24	PA1	3F	M3	29.13	0.70868	9E-06	18.5937	0.002	15.6343	0.0011	38.4418	0.0027
33D0L06B1	3.25	PA1	3D	P3	30.58	0.70883	1E-05	18.4643	0.004	15.6372	0.0029	38.3286	0.0072
33B0L06B1	3.26	PA1	3B	P3	33.58	0.70872	1E-05	18.6033	0.004	15.6473	0.0037	38.4564	0.0091

Catalog Number	Sample #	Site	Level	Tooth	Sample weight (mg)	87/86Sr (‰)	87/86 Sr error	206/204 Pb (‰)	206/204Pb error	207/204 Pb (‰)	207/204Pb error	208/204Pb (‰)	208/204 Pb error
608B0L02B3	8.02	BN1	8B	M1	34.95	0.70883	1E-05	18.5524	0.002	15.6434	0.0017	38.5805	0.0046
608C0L02B1	8.03	BN1	8C	M1/2	36.2	0.70877	1E-05	18.3086	0.004	15.6204	0.0038	38.2503	0.0089
608E0L02B1	8.1	BN1	8E	P2	29.63	0.70874	2E-05	18.5854	0.002	15.6539	0.0013	38.6082	0.0035
608E0F01B1	8.12	BN1	8E	M1	31.76	0.70845	1E-05	18.5742	0.001	15.6577	0.0011	38.6756	0.0024
609B0L02B1	9.04	BN1	9B	P2	35.11	0.70864	2E-05	18.5643	0.002	15.6576	0.0015	38.6264	0.0037
609B0L02B1	9.05	BN1	9B	P3	32.54	0.70856	1E-05	18.1268	0.003	15.5852	0.003	38.0622	0.007
609D0L02B1	9.08	BN1	9D	M1	28.56	0.70824	1E-05	18.1414	0.001	15.5915	0.00079	38.1153	0.0018
610A2F20B1	10.03	BN1	10A	M3	31.44	0.70826	2E-05	18.5825	0.002	15.6505	0.0012	38.6547	0.0033
610B0F37B1	10.06	BN1	10B	M1	31.05	0.70840	1E-05	18.5888	0.001	15.6684	0.00092	38.6903	0.0022
610D0F03B1	10.11	BN1	10D	M1	32.42	0.70836	2E-05	18.4724	0.001	15.6243	0.0013	38.4422	0.003
610E0F05B1	10.16	BN1	10E	M3	36.52	0.70815	2E-05	18.4857	0.001	15.622	0.0011	38.4208	0.0031