Archaeological and Anthropological Sciences (2022) 14: 103
https://doi.org/10.1007/s12520-022-01571-w

ORIGINAL PAPER

Trace element and Pb isotope analyses highlight decentralized inter-island exchange in American Sāmoa (Polynesia)

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Received: 21 February 2022 / Accepted: 28 April 2022 / Published online: 13 May 2022

Abstract
Exchange plays a number of roles within societies, including the provisioning of necessary and prestige resources. The elucidation of these different roles requires documenting how different kinds of material were used and how these resources became distributed. These studies are particularly prominent in Polynesia, especially the Sāmoan archipelago. However, the nature and scale of artifact transfer within and outside the archipelago are debated given deficiencies in the empirical record. Here, we remedy this situation by examining trends in Sāmoan intra-archipelago exchange using geochemical and limited technological analyses of a lithic assemblage from the Manu'a group of the Sāmoan archipelago. Our results indicate that material from multiple basalt sources is present, including several sources outside the Manu'a group. It is apparent that this nonlocal material was used differently than local material as 95% of analyzed adzes were manufactured of the former. However, there is no evidence to suggest that this nonlocal material was differentially distributed or controlled at the scale of the group or site. We argue that this is evidence of decentralized exchange and that imported materials became common pool resources to support community resiliency and sustainability.

Keywords Geochemistry · Common pool resources · Polynesia · Collective action · EDXRF · ICPMS

Introduction

Pacific Islands present unique challenges to persistent human habitation given their limited resource base and higher vulnerability to perturbations relative to continental settings. While there is evidence of settlement discontinuity and abandonment on some islands (Bellwood 1978; Weisler 1996), most communities were able to live in these environments sustainably and resiliently. Populations developed several ways to manage the inherent unpredictability and riskiness of these environments. In many cases, this involved the large-scale construction and modification of landscapes (Huebert and Allen 2020; Quintus and Cochrane 2018), population controls (Firth 1936), and extended social networks (Alkire 1965). The latter is particularly well documented (e.g., Alkire 1965; McCoy et al. 2020; Reepmeyer 2021; Torrence 2016; Weisler 1994).

Social networks facilitated the exchange of needed or desired resources to supplement or enhance existing local resources. Exchange not only provided resources that were locally unavailable, but played important social roles in maintaining alliances, building social friendships, and, at times, mediating political competition (Clark et al. 2014; Fitzpatrick 2008; McAlister and Allen 2017). In essence, the materials exchanged and the patterns of their exchange became key elements of both collective action and political economies (Blanton and Fargher 2008; Carballo and

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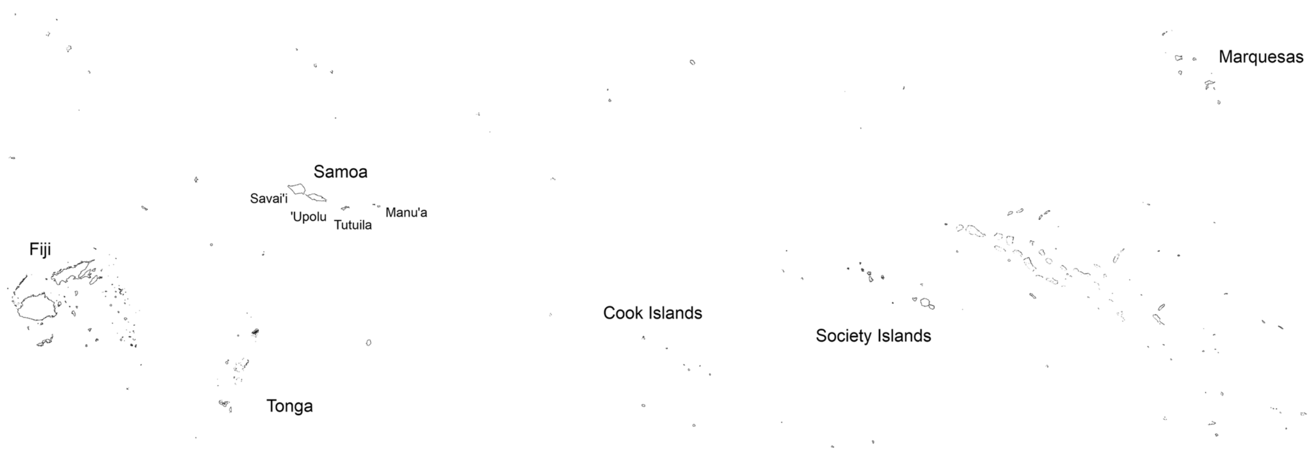

Fig. 1 Map of West Polynesia and Central East Polynesia with major archipelagos mentioned in the text labelled

Feinman 2016; Earle and Spriggs 2015; Furholt et al. 2020). The elucidation of how nonlocal material was used socially once it entered economies requires exploration of the differential use of local and nonlocal material as well as the variable spatial distribution of materials from different sources. Documentation of the differential or similar use of material from different locations implies that these sources were envisaged as economically different or similar products (McAlister and Allen 2017; Mills et al. 2011). Differentiation would denote either the perceived social or economic importance of one material class relative to the other. The value of these items often played a political role, where leaders were able to control a bottleneck in distribution or consumption (Earle and Spriggs 2015). Where this occurred, these items signified social rank and wealth (Kahn et al. 2013; Kirch et al. 2012). However, even if economically prized, the material may have become a broadly distributed resource to support community integration and a collective sense of identity in service of community resiliency (see Blanton and Fargher 2008; Carballo and Feinman 2016). By way of gift exchange, these items circulate to become common pool resources (Putzi et al. 2015), which ensures access to needed materials in a decentralized manner. These dynamics of exchange are often key considerations in the decisions of and negotiations between different social actors who are seeking to enhance prestige, limit autocratic control, gain access to needed resources, and gain compliance (Furholt et al. 2020).

West Polynesia provides a useful case study to evaluate these dynamics of material exchange and use. The transfer of raw material and finished artifacts across West Polynesia is well documented, both archaeologically (Barnes and Hunt 2005; Best et al. 1992; Clark et al. 2014; Weisler and Kirch 1996) and ethnographically (Kaeppler, 1978). Much of the archaeological focus of this research has been placed on the movement of basalts from the islands of the Sāmoan archipelago (Fig. 1) as well as the social role played by those transfers. This focus stems, in part, from ethnographic descriptions of basalt tool production and transfer on Tutuila island that note the prominence of particular quarries (Buck 1930:330). Building on this research, various authors argue that the scale of transfer from some quarries was substantial (Addison 2010; Best et al. 1992; Johnson 2013; Leach and Witter 1987; Winterhoff et al. 2007), which some have linked further to emergent political economies (Winterhoff 2007). These authors argue that both raw material and finished tools were wealth assets (after Earle 1997), and the distribution of these tools was controlled by elites.

Available data does suggest some interesting patterns, specifically highlighting the importance of Tutuila in regional exchange, but what is empirically known is limited (see summary in Cochrane and Rieth 2016). The data that is available suggests that while the material was widely distributed in the last 1000 years, the amount of material transferred from Tutuila is smaller than is often assumed (Cochrane and Rieth 2016). Furthermore, the nature of the material that was transferred (e.g., finished or unfinished tools), how that material was used, and the social significance assigned to the material is largely unknown (but see Clark et al. 2014), stemming from the relatively low quantity of material that has been reported. Because of this, questions about the social and economic importance of basalt distribution in Sāmoa have been raised (Cochrane and Rieth 2016).

The investigation of intra-archipelago exchange is a useful way to explore these issues, and here we use the relationship between Tutuila and the islands of the Manuʻa group as a case study (Figs. 1 and 2). The three islands of the Manuʻa group are all quite small, with the largest, Taʻū, measuring some 36 km^2 while the other two, Ofu and Olosega, are 7 km^2 and 5 km^2, respectively. Little archaeological research on artifact transfers has been conducted in the Manuʻa group, but available data suggests both the general

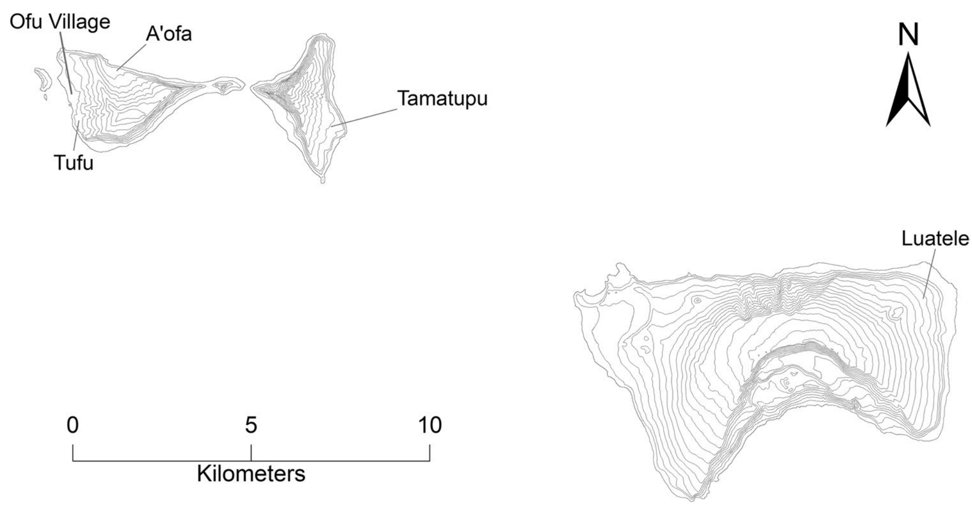

Fig. 2 Map of the Manu'a group with locations of archaeological samples labelled

importance of exchange and the potential social role that it played. Notably, a small number of Manu'a artifacts characterized using EDXRF (energy-dispersive X-ray fluorescence) (Weisler 1993; Weisler and Kirch 1996) suggests that formal tools (i.e., adzes) were manufactured of nonlocal material with local material associated with more expedient tools and waste flakes.

We expand on this initial research by reporting EDXRF and lead (Pb) isotope compositions on an assemblage of basalt debitage and tools recovered from the three islands of the Manu'a Group in American Sāmoa. Using this assemblage, we assess the relative contribution of local and nonlocal sources and explore variation between these two groups of artifacts. In doing so, we seek to assess the scale of artifact transfer to Manu'a, the nature of material use, and, finally, its social significance. These goals can be addressed by testing two expectations. First, we expect that nonlocal and local materials were used differently, implying that these were of differential value. Given the cost of importation, we assume that differential use would reflect the greater value of nonlocal material. Second, we expect nonlocal material to be primarily associated with elite structures, defined on the basis of residential terrace size and location within communities (see Quintus et al. 2022), and local material to be associated with commoner structures. Such a pattern would imply elite preferential access to nonlocal material.

Background

The Sāmoan archipelago is comprised of nine main islands—Savai'i, Apolima, Manono, 'Upolu, Tutuila, Aunu'u, Ofu, Olosega, and Ta'ū that formed through mantle plume activity along a ESE gradient (Hart et al. 2000), just north and east of the andesite line. The first four islands are part of the independent nation of Sāmoa while the remaining five constitute the territory of American Sāmoa. The distribution of surface lava flows is reasonably well mapped across the archipelago (Kear and Wood 1959; Stearns 1944; Stice and McCoy 1968); islands are dominated by alkali olivine basalts (McDougall 2010) with a range of rock types present (Hart and Jackson 2014; Kear and Wood 1959; Stearns 1944). These lavas are geochemically diverse (Hart and Jackson 2014; Jackson et al. 2014; Reinhard et al. 2019), with variation driven by both space and time. Most notably for our purposes, the Manu'a group represents a separate volcanic lineament from other islands in the archipelago "sampling geochemically distinct plums" (Reinhard et al. 2019:1499). Furthermore, the youthful age of Manu'a (less than 1 million years old) has meant that these islands have not yet reached a point in their evolution to capture later components of the Sāmoan hotspot apparent on the western islands (Reinhard et al. 2019). At a smaller spatial scale, archaeologists have documented geochemical variation along specific flows on Tutuila (see Best et al. 1992; Clark et al. 1997; Jackson et al. 2014; Weisler 1993), and more detailed chemical descriptions of archaeologically defined quarry sites have occurred recently (Johnson 2013; Johnson et al. 2007; Winterhoff 2007; Winterhoff et al. 2007). Still, complete geochemical separation at this scale has been a challenge. Similarly, geochemical differentiation of separate surface lava flows in the Manu'a group and the western islands of the archipelago has been difficult and research has been limited (see Clark et al. 2014; Hart and Jackson 2014; Weisler 1993). Given this, we expect to source artifacts to individual islands within the archipelago, though assigning each artifact to a specific quarry or surface flow may be more difficult.

Artifacts analyzed here were recovered from all three islands of the Manu'a group (Fig. 2). These islands were settled around 2700 years ago as part of a population movement from the western Pacific (Clark et al. 2016; Petchey and Kirch

2019). The bulk of residential activities occurred on the coastal flats of the three islands until around 1500 years ago (Kirch and Hunt 1993; Quintus et al. 2015, 2020). More intensive use of the interior uplands occurred in the last 1000 years on all three islands, a time of demographic, social, and political change in the region (Clark et al. 2014; Quintus et al. 2020), manifesting in the construction of expansive landscapes of terracing on which people resided and grew crops (Quintus 2018, 2020; Quintus et al. 2015, 2020). Population seems to have increased substantially across the archipelago after AD 1000 based on both genomic and archaeological data (Harris et al. 2020; Quintus et al. 2020). Social inequality increased over time as well, indicated archaeologically by elaborated residential and corporate architecture (Jennings and Holmer 1980; Quintus et al. 2016; Wallin et al. 2007).

Ethnohistorically and ethnographically, Sāmoan social units were organized by descent. Descent groups possessed titles whose rank was partially determined by genealogical proximity to prominent ancestors (Goldman 1970; Mead 1969; Sahlins 1958), as was typical in Polynesian chiefdoms. Exchange was an important component of status and social participation in Sāmoa, in both formal and informal settings. While abundance was an important marker of fertility and *mana* (Shore 1989), it was in exchange and generosity that such abundance was demonstrated (Goldman 1970; Mead 1969:19). Furthermore, exchange was the means by which groups became integrated, social relationships became formalized, and identity was reinforced; the intersection of aggrandizement and collective negotiation was at the heart of exchange decisions (Linnekin 1991). Exchange was practiced as part of agreements to provide a service (i.e., house construction) (Buck 1930), but also formally during ceremonies when nonlocal goods would likely be transferred, especially marriage ceremonies, where families exchanged different kinds of materials, and *malaga*. These *malaga* were travelling parties during which time feasts and other ceremonial activities occurred. A key component of these activities was and is the transfer of gifts between groups, to show hospitality and thankfulness for that hospitality. However, the time depth of these social activities is not known. Our research expands on this time depth.

Materials and methods

All artifacts analyzed derive from sites dating to the period between AD 1000 and AD 1830. We make use of material from both surface ($n=28$) and subsurface ($n=147$) contexts. Artifacts derive from five locations across these three islands: Ofu Village ($n=5$; 14°10′14″S 169°40′39″W[1]), Tufu ($n=1$; 14°10′45″S 169°40′29″W), and A ‘ofa ($n=4$; 14°10′4 ″ S 169°39′44″W) on Ofu Island (Quintus 2015), Tamatupu ($n=19$; 14°10′39″S 169°36′37 ″W) on Olosega (Quintus and Clark 2016), and Luatele ($n=146$; 14°13′12″ S 169°25′41″W) on Ta‘ū (Quintus et al. 2017). All of these except Ofu Village are agro-residential settlement zones in the interior uplands (see Fig. 2). Those artifacts recovered from the interior derive from residential terraces and are interpreted to reflect domestic activity and refuse. Those artifacts from the coast are not directly associated with residential architecture or domestic use; rather, they likely derive from periodic resource exploitation on the coast. Subsurface deposits in both the interior and coast from which artifacts derive have been dated to the last 1000 years of the Sāmoan sequence (Quintus et al. 2015, 2020), while those from the interior surface are inferred to date from the last 1000 years based on their location on residential terraces known to have been constructed during this time (Quintus 2018; Quintus et al. 2020). While it is highly likely, then, that the analyzed debitage stems from the last 1000 years of Sāmoan history, this does not preclude the manufacture of some of the formal tools analyzed here before this time and the reuse of artifacts over time.

Our assemblage consists of 22 adzes and adze fragments, seven flake tools, one core, and 145 flakes and pieces of shatter. Additionally, we also analyzed six geological samples to supplement existing source data. We conducted nondestructive geochemical analysis of all material using a Thermo Scientific Quant’X EDXRF spectrometer at the Geoarchaeology Laboratory at the University of Hawai‘i at Hilo. Compositional data were acquired for 24 elements using methods described in Lundblad et al. (2008); the elements Rb, Sr, Y, Zr, and Nb display the highest analytical precision with EDXRF. We analyzed all artifacts with a maximum dimension over 10 mm^2. The full range of elemental data are available for 140 artifacts (Online Resource 1), four geological samples from Ta‘ū, and two source samples from Fagasa on Tutuila. Only mid-Z elemental data (Cu, Zn, Rb, Sr, Y, Zr, Nb, Mo, and Pb) were collected for 35 artifacts that were especially small (Online Resource 2). We consider both a conservative dataset, constituted by artifacts for which we have full elemental data, and an expanded dataset that includes the smaller artifacts. While EDXRF provides data on a smaller set of elements and at lower analytical precision than partially destructive and more expensive methods (e.g., ICPMS), it has proven effective at discriminating quarries within the Sāmoan archipelago (Johnson 2013) and it allowed us to analyze a large set of artifacts in a nondestructive manner.

The pairing of lower precision but highly efficient techniques with the more limited application of high precision but less efficient techniques has proven useful for improving confidence of source decisions across Polynesia while

[1] These personally collected coordinates reflect the center of each archaeological site sampled during this project.

Table 1 Mean values for relevant trace elements associated with artifacts and sources (full dataset is provided in Supplementary Material)

	Local	Local (partial)	Tutuila	Tutuila (partial)	Manu'a (source)	Tutuila (source)	Sāmoa (source)	BHVO-2 average values	BHVO-2 published value
RB	29.32	21.04	49.87	43.98	24.99	46.75	33.05	12	10
SR	448.26	389.89	725.29	719.49	512.24	712.90	530.92	404	389
Y	29.44	27.42	44.56	44.63	34.11	48.32	25.56	28	26
ZR	277.22	251.63	424.88	416.78	273.98	434.95	223.05	178	172
NB	43.15	38.13	52.31	51.94	45.14	48.04	45.25	19	18

maintaining the benefits of large sample sizes (Clark et al. 2014; DiVito et al. 2020; Kahn et al. 2013; McAlister and Allen 2017). Here, source decisions were refined and confirmed using Pb isotope ratios of eight artifacts from geochemical groups defined using the EDXRF data. Pb isotope compositions have been used successfully to discriminate sources between archipelagos in Polynesia (Weisler and Woodhead 1995) and geological data suggests separation of Pb isotope ratios between islands of Sāmoa (Hart and Jackson 2014; Jackson et al. 2014; Reinhard et al. 2019). Artifacts were analyzed for Pb isotope compositions at the University of Hawai'i at Mānoa Isotope Lab, following the methods of Konter and Storm (2014). Artifact surfaces were first cleaned with ultra-clean methanol and acetone (Fisher brand, OPTIMA grade). After rinsing artifacts with 18 MOhm water and drying, they were crushed to a sand-sized fraction. Prior to dissolution, samples were acid-leached (double distilled reagents) to remove any remaining surface contamination. After column separation and purification of the Pb, sample Pb isotope compositions were determined by multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS). Samples were measured in dry mode, using an APEX introduction system, monitoring fractionation with a Tl spike (NIST SRM 997), and standard-sample bracketing against Pb reference standard NIST SRM 981 (values of Todt et al. 1996). Pb blanks using this procedure are < 75 pg, and a measurement of the USGS BCR-2 rock standard gave $^{206}Pb/^{204}Pb$ of 18.7465 ± 4, $^{207}Pb/^{204}Pb$ of 15.6079 ± 4, and $^{208}Pb/^{204}Pb$ of 38.6840 ± 10, during the same analytical period.

Our expectation is that artifacts used in Manu'a derive largely from local sources in Manu'a or from sources on the island of Tutuila (roughly 130 km away). As such, we largely compared our data to sources in these locations but supplemented these data with reference samples from a series of islands in West Polynesia analyzed by Clark et al. (2014) and Best et al. (1993). While source data are available for several documented quarries on Tutuila (Best et al. 1992; Collerson and Weisler 2007; Johnson 2013; Sinton and Sinoto 1997; Weisler 1993; Winterhoff 2007), no quarries are known for Manu'a (but see Weisler 1993). Therefore, we include geological samples from Manu'a reported in Hart and Jackson (2014). Slight but well-documented inter-laboratory variability of EDXRF values and differences in calibration between instruments can make direct quantitative comparison with source data defined by other laboratories difficult (Charleux et al. 2014), especially when those source data were characterized several decades ago. In particular, we note higher values for some elements in our own data relative to analyzed USGS rock standards (Table 1). However, these are still in the acceptable range and do not impact our results. We also included in our source data samples derived from both Ta'ū and Tutuila, and analyzed at the University of Hawai'i at Hilo, including four new geological samples from Luatele, Ta'ū, and two new archaeological samples that serve as source samples from Fagasa (14°17′22″S 170°43′15″W). Finally, the University of Hawai'i at Hilo geochemical data on tools reported in Rieth and Cochrane (2012) from Tutuila and samples from Fagasa and Tataga Matau are also used. In total, we have trace element source data from Tonga ($n = 4$), Rotuma ($n = 6$), 'Uvea ($n = 7$), Sāmoa ($n = 21$), Tutuila ($n = 133$), and Manu'a ($n = 45$); all source data with their associated citations can be found in Online Resource 3.

Pb isotopic compositions are reasonably well documented across the Sāmoan archipelago (Hart and Jackson et al. 2014; Jackson et al. 2007, 2010, 2014; Konter and Jackson 2012, Konter et al. 2016; Reinhard et al. 2019; Workman et al. 2004). We supplemented our Sāmoan comparative samples with reference data from the Cooks/Australs (Hanyu et al. 2011; Jackson et al. 2020; Lassiter et al., 2003; Miyazaki et al. 2018; Schiano et al. 2001), the Society Islands (Blais et al. 2002; Cordier et al. 2016; Jackson et al. 2007; White and Duncan 1996), the Marquesas (Castillo et al. 2007; Chauvel et al. 2012; Legendre et al. 2005a, b), and a series of locations in Fiji/West Polynesia reported by Price et al. (2017).

All artifacts were classified as local or nonlocal. The classification of materials using these terms can be arbitrary in some contexts, but we use established ethnographic boundaries. Groups in Manu'a thought of themselves as socially distinct and set apart from the rest of the Sāmoan archipelago (Mead 1969). Given the high rate of interaction and the proximity

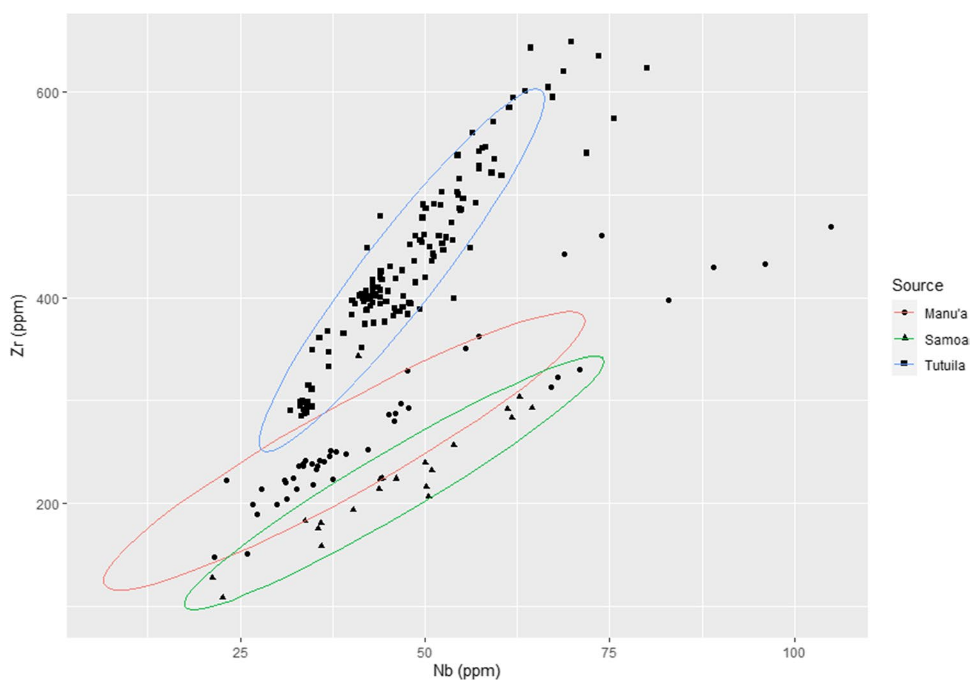

Fig. 3 Bivariate plot of Nb and Zr and 95% confidence ellipses for source samples across Sāmoa. Note the separation between island groups

among the three islands, we classify material from the entire Manuʻa group as local. Artifacts that do not source to Manuʻa are classified as nonlocal. While the island of Tutuila is only 130 km away, travel between Tutuila and Manuʻa was far less frequent than travel among the islands in Manuʻa. Furthermore, Tutuila was politically aligned with the western islands of the archipelago, at least in the late precontact period, with Manuʻa forming a separate political entity (Goldman 1970). Thus, artifacts from Tutuila are classified as nonlocal. In the following, we use Sāmoa (nation) to refer collectively to the islands of ʻUpolu and Savaiʻi while we use Sāmoa (archipelago) to refer to the island group as a whole.

Discrimination of sources was based on a set of bivariate plots and a linear discriminant analysis of log-transformed Rb, Sr, Y, Zr, and Nb values undertaken in R (R Core Team 2022) using the MASS package (Venables and Ripley 2002). Qualitative and quantitative attributes were also recorded for each artifact, including weight, length, width, thickness, artifact class/type, presence or absence of polish, and presence or absence of cortex. Furthermore, the context of these artifacts was recorded, specifically noting the size of terraces on which these artifacts were found and their spatial distribution as a proxy for status (see Quintus et al. 2022). Statistical analyses of these attributes were undertaken in PAST4 (Hammer et al. 2001).

Results

All data produced in this study can be found in Online Resources 1–8 (see also Table 1). A simple Nb and Zr bivariate plot effectively separates sources in Manuʻa from Tutuila and those in the western islands with almost no overlap (Fig. 3); values of this ratio are highly correlated to different stages of the evolution of Sāmoan volcanoes (Reinhard et al. 2019). As such, we used these elements to initially group artifacts. Furthermore, we used a linear discriminant analysis (LDA) to independently classify artifacts using five mid-Z elements (Rb, Sr, Y, Zr, and Nb) (Fig. 4). The LDA correctly classified 93.52% of source specimen (96.6% of between-group variation explained by the first two functions), with the notable misclassification of six source samples from Manuʻa (out of 41). Four of these were misclassified as coming from Sāmoa (nation), one from Tutuila, and one from ʻUvea. No source sample from Tutuila was misclassified ($n = 133$).

All artifacts in the conservative dataset fall within the expected geochemical range of alkali basalts using classifications described in Richards (2019), and all but one artifact are within the expected range of Sāmoan (archipelago) sources. Apart from this artifact and one other that falls within the expected range of Sāmoan (archipelago) basalts but outside the rest of the assemblage, all artifacts cluster in two broad geochemical groups: Group 1 ($n = 22$) and Group 2 ($n = 116$) (Fig. 5). A Nb and Zr bivariate plot combined with the Pb isotopic compositions of seven artifacts within these two groups supports the affiliation of Group 1 with Manuʻa and Group 2 with Tutuila. The result of the mid-Z elemental LDA is largely consistent with those derived from the Nb and Zr bivariate grouping (Fig. 6), with 99.3% sharing the same classification (excluding artifact 46–3). The lone difference is one artifact that groups with Manuʻa in the bivariate plot but was classified as coming from Sāmoa (nation) in the LDA. Based on this broad grouping, artifacts

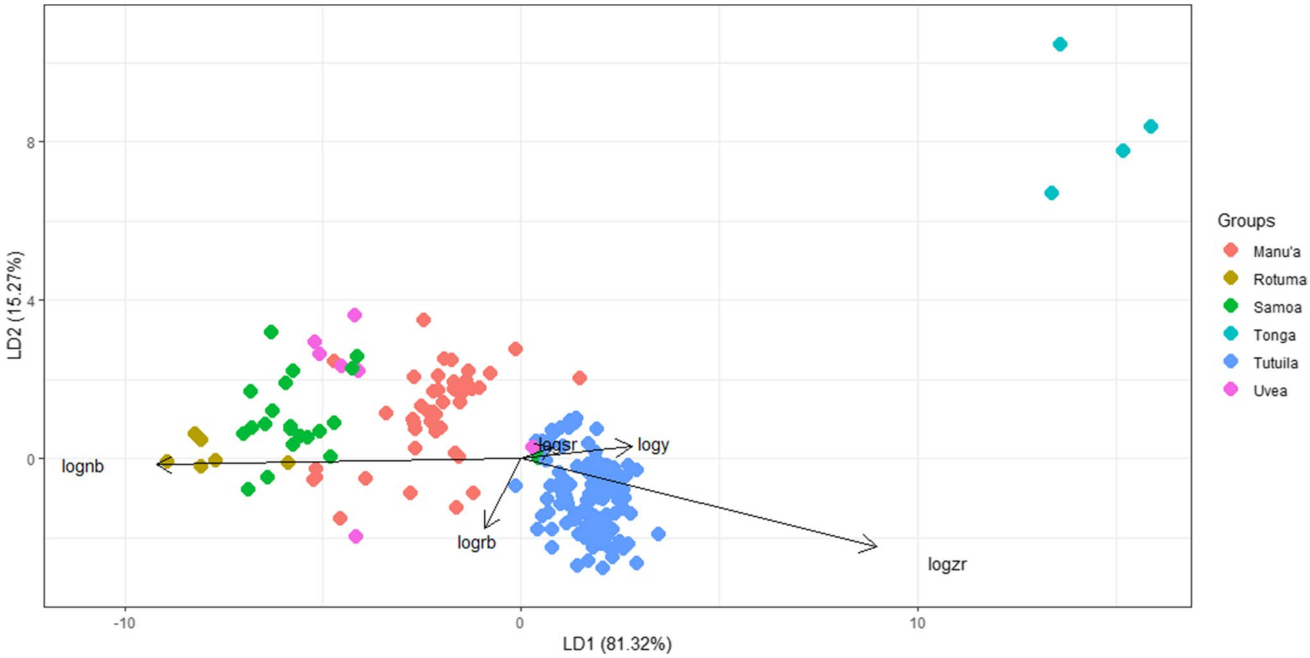

Fig. 4 Bivariate plot of the first two functions of a linear discriminant analysis of mid-Z elements for source material (constructed using the ggord R package, Beck 2017)

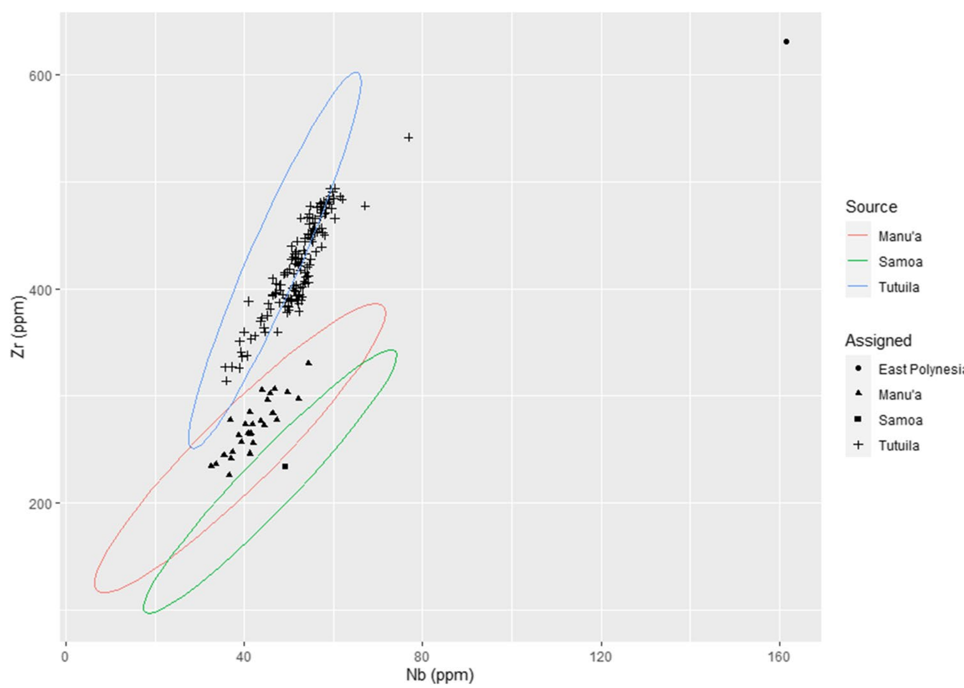

Fig. 5 Bivariate plot of artifact Nb and Zr values with 95% confidence ellipses derived from Sāmoan sources described above. Note the clear clustering of artifacts and the one clear outlier. The offset between the confidence ellipse for Tutuila and archaeological samples is assumed to reflect differential calibration between laboratories. Group 1 includes those artifacts assigned as Manuʻa and Group 2 includes artifacts assigned as Tutuila. The single artifact assigned as Sāmoa is Taʻū 16 while the artifact assigned as East Polynesia is Taʻū 46–3 described further below

assigned to a source from Manuʻa account for 13.9% of the artifacts in the conservative dataset.

All artifacts within the small size dataset fall within the known range of geological sources in the Sāmoan archipelago and all can be placed into the two broad groups defined above (Figs. 3, 4): Group 1 ($n=6$) and Group 2 ($n=29$). This geochemical distribution is not significantly different to that of the larger dataset (χ^2 *with Yates Correction*$=0.03$, $n=173$; $p=0.86$). The LDA classification was consistent with this grouping (Fig. 6).

Local group ($n=28$)

Eighteen artifacts form a relatively distinct group with generally low Sr, Zr, Nb, Rb, and Y values. These values compare

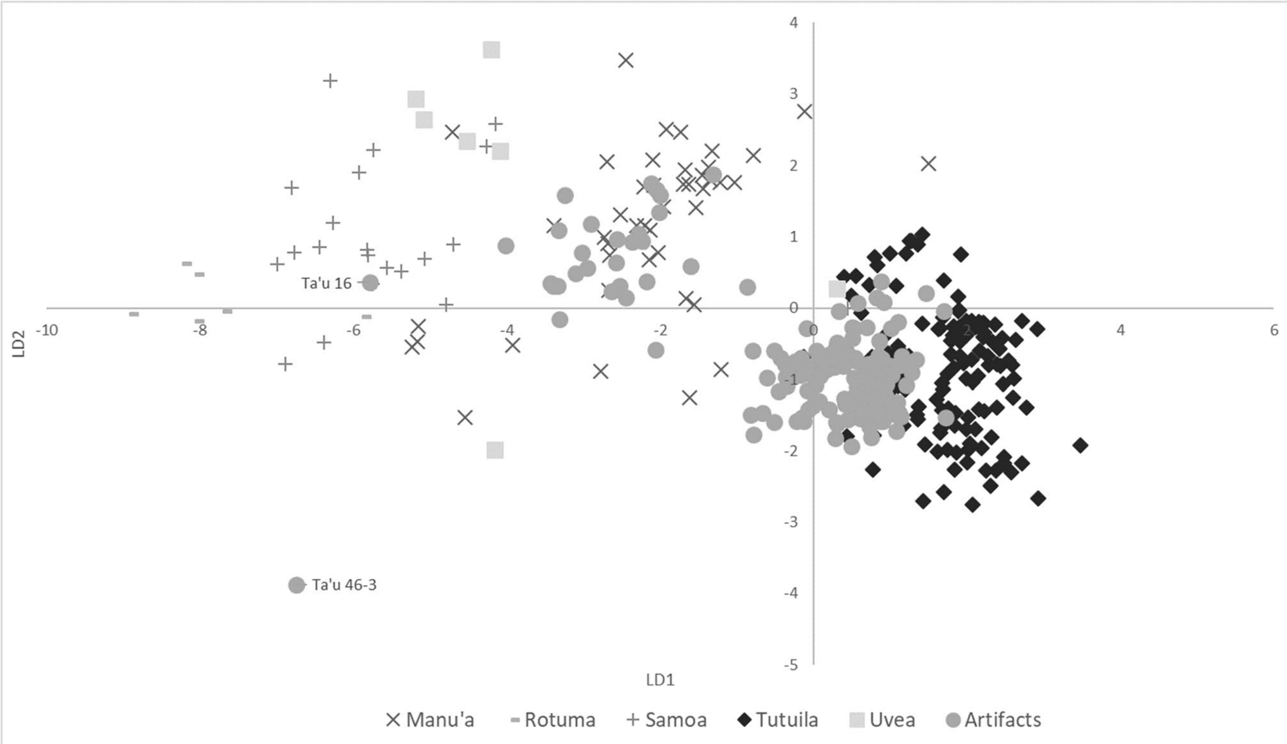

Fig. 6 Bivariate plot of the first two functions of a linear discriminant analysis of mid-Z elements for sources and artifacts. Tongan sources are not included given their dissimilarity with artifacts and other sources. If they were included, they would be positioned to the far upper right of the plot

well to published sources in Manuʻa, though results with our calibration tend to possess higher values of Zr, Rb, and Nb. This may also reflect the well-documented impact of weathering (i.e., Rb) and sample shape (all other elements) on EDXRF-derived values (see Lundblad et al. 2008). One artifact included in this group was classified as deriving from Samoa (nation) in the LDA. However, this artifact falls within the distribution of source specimens from Manuʻa on the LDA and various bivariate plots. The posterior probability produced by the LDA (27%) also highlights the plausibility of this artifact originating in Manuʻa. Because of this, we argue, based on parsimony, the artifact derives from Manuʻa. Four artifacts possess distinctly higher Sr and Zr values relative to the rest of the group, though they fall within the broader group defined by the Nb and Zr bivariate plot, overlap with published source data from Manuʻa, and fall outside the range of published source data from Tutuila. Two of these artifacts, both tools, fall closer to sources on Tutuila in several bivariate plots but are classified by the LDA as originating in Manuʻa. Their association with a source in Manuʻa is considered more tenuous. Finally, six small artifacts are assigned to this broad group based on a Nb and Zr bivariate plot and the results of the LDA.

Pb isotopic composition of three artifacts from this group (Figs. 7, 8) supports the use of at least two sources in Manuʻa along the Vai trend isotopic group (Jackson et al. 2014). At least one of these sources was on Taʻū (see Hart and Jackson 2014), but our data do not allow further discrimination of the source of the other two artifacts.

Nonlocal-Tutuila (*n* = 145)

One hundred artifacts are assigned to a general Tutuila geochemical group. Artifacts from this group fall within the geochemical range of source material derived from several quarries, including Tataga Matau and Fagasa. Twelve additional artifacts fall within the range of Tutuila basalt on a Nb and Zr bivariate plot, though they possess lower Sr and Zr values relative to most other artifacts and sources from Tutuila. This group is similar to some geological samples from Malaeloa valley on Tutuila (Winterhoff 2007), but some major oxide values, like TiO_2, are dissimilar. Furthermore, four artifacts have higher TiO_2 wt% values relative to other artifacts and geological sources, though they generally cluster closely to the twelve artifacts described above in other measures. The LDA classified all artifacts in this group as deriving from Tutuila. Twenty-nine small artifacts cluster with the nonlocal group in various bivariate plots and the LDA, and these artifacts represent much of the variation apparent in the conservative dataset.

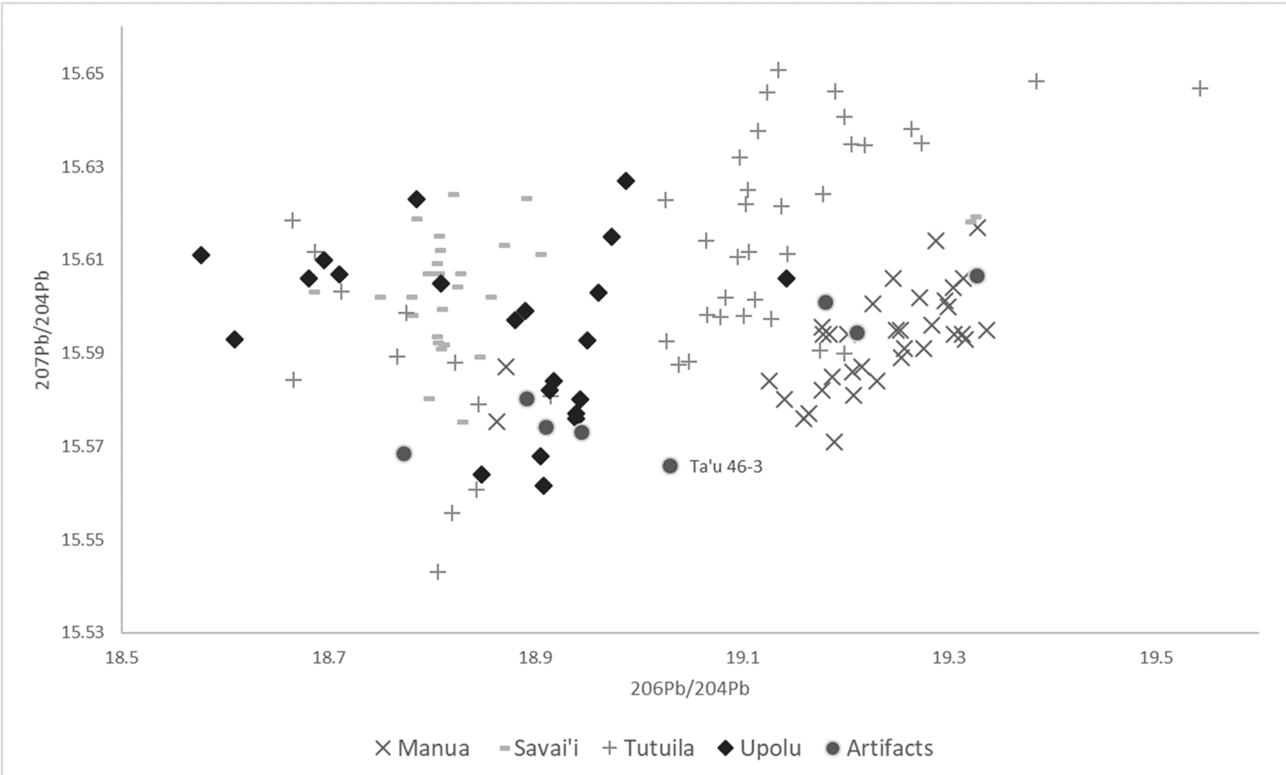

Fig. 7 Bivariate plot of isotope ratios for archaeological and Sāmoan geological samples. Note the proximity of three artifacts with geological samples from Manu'a with the other five artifacts falling outside the range of geological material in the group

Pb isotopic compositions for four artifacts that cover variation represented by the above subgroups, including one that was part of the high TiO_2 wt% set, are consistent with an origin on Tutuila (Figs. 7, 8), though they overlap with isotopic compositions of geological samples from 'Upolu and all are part of the 'Upolu trend isotopic group (Jackson et al. 2014). The spread of the isotopic signatures indicates that multiple sources were used, again consistent with the elemental data. However, the combination of the lack of reference Pb data for known quarries on Tutuila and the size of standard errors for those reference data that are available (e.g., Collerson and Weisler 2007) make allocation to individual quarries difficult at present.

Nonlocal-outliers (*n* = 2)

Two artifacts were classified as outliers relative to the two major groups described above. One of these (Ta'ū 16) falls outside source data from Manu'a and Tutuila in a Nb and Zr bivariate plot. It does, however, fall within the range of source data from Sāmoa (nation) and we argue that it originates from the western islands of the archipelago based on the results of the LDA (Figs. 5, 6).

The other artifact (Ta'u 46–3), a nondiagnostic piece of fine-grained basalt shatter, exhibits a substantially different geochemical signature relative to others in the assemblage, with high Sr, Zr, Rb, Nb, and Ba values (Figs. 5; Online Resource 1). Element ratios are also substantially different than those noted for Sāmoan (archipelago) sources. As such, the EDXRF data suggests that this artifact may stem from an archipelago to the east of Sāmoa. The Pb isotopic composition of the artifact supports this hypothesis (Figs. 7, 8) and highlights its origin in Central East Polynesia (Fig. 9). This Pb isotopic composition is somewhat common in the region, found in the Marquesas and the Society Islands. However, the artifact's Pb isotopic composition falls especially close to geological material from the Society Islands, specifically Bora Bora and Tahiti (Fig. 9).

Characteristics of local and nonlocal artifacts

All but two formal tools (*n* = 29; 93%)—including all but one adze (*n* = 22; 95%)—are from nonlocal sources. Rejuvenation and reshaping are apparent on several of these nonlocal tools (Fig. 10), while the potentially local adze is the largest in the assemblage. The one core and 25 pieces of debitage cluster with local sources. By weight, artifacts from local sources account for around 17% of the assemblage (sum = 2902 g; local (*n* = 28) = 485 g, mean = 17.32 g;

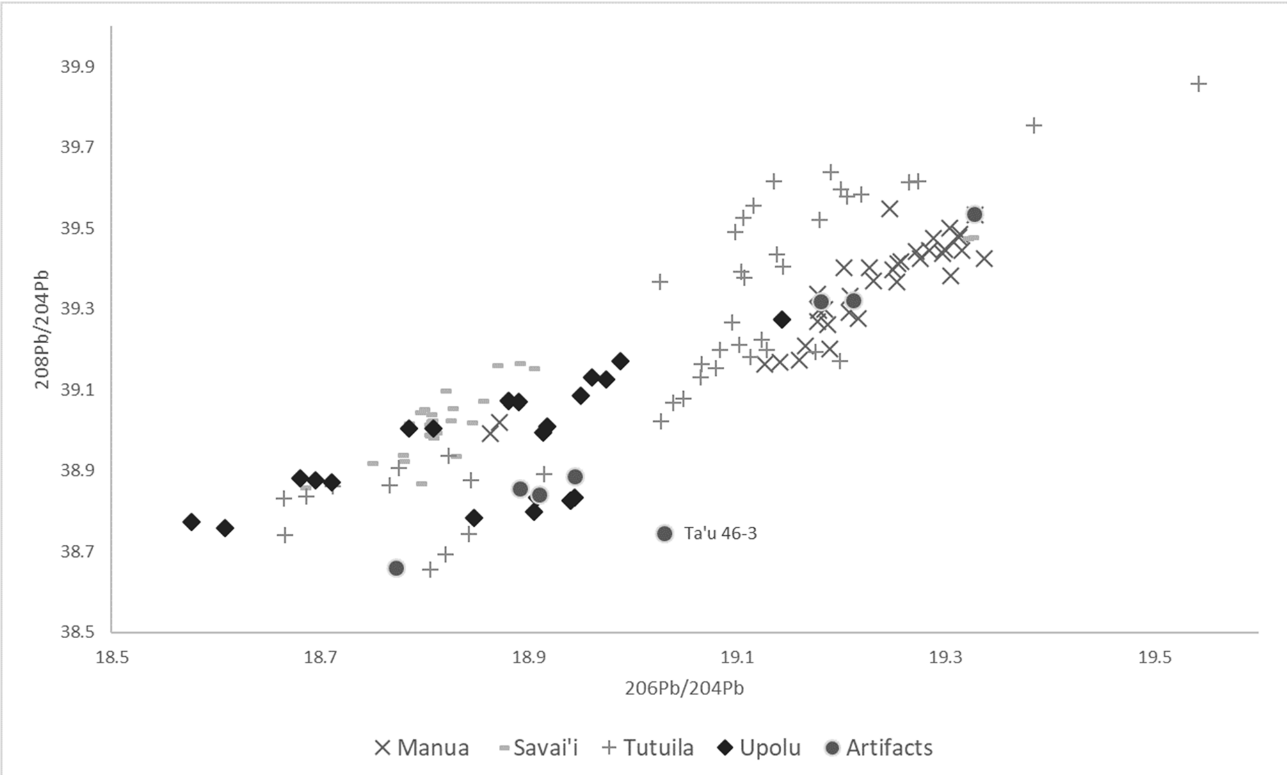

Fig. 8 Bivariate plot of isotope ratios for archaeological and Sāmoan geological samples. Note the proximity of three artifacts with geological samples from Manuʻa, four falling inside the distribution of geological sources on Tutuila, and one falling outside the range of the geological data from Sāmoa

nonlocal ($n=144$) = 2417 g, mean = 16.44 g). When restricting the analysis to only debitage, the median weight of local and nonlocal artifacts is the same (0.9 g). The median maximum dimension of local debitage (18.1 mm) is slightly larger than that of nonlocal debitage (17.5 mm), though this is not statistically different (Mann–Whitney test; $U=1488$; $z=0.06$; $p=0.95$). In fact, the maximum dimension of only five pieces of debitage in the entire assemblage is over 40 mm. Polish was unambiguously identified on 51 pieces of debitage (34%; polish was ambiguous on one artifact). Cortex was relatively rare, unambiguously identified on 18 pieces of debitage (12.4%), and most of this was cobble cortex.

The debitage assemblage from Luatele provides an opportunity to understand the use of local and nonlocal materials in more detail. Both local and nonlocal materials exhibited cortex, but at markedly different rates. Cortex was observed on the surface of 14 local artifacts (out of 25; 56%) and four nonlocal artifacts (out of 115; 3.6%), which is a significant difference (χ^2 *with Yates' correction* = 45.98, $n=140$, $p<0.001$). The cortex present on local artifacts is largely consistent with waterworn cobbles while both water-rounded and primary geological cortexes were present in the nonlocal assemblage. Polish, indicative of adze use or maintenance, was also observed on several artifacts. Four (16%) local artifacts possess some polish (adze flakes) compared to 42 (37%) nonlocal artifacts; this difference is marginally significant (χ^2 *with Yates' correction* = 3.14, $n=139$, $p=0.077$).

Nonlocal artifacts are present on all three islands, while local artifacts are found on Taʻū and Olosega. The island-scale differences reflect the size and nature of each sample. Not only is the Taʻū sample larger, but it includes a substantial amount of debitage. In contrast, much of the sample from Ofu and Olosega stems from formal tools or adze flakes. That local artifacts were used on Ofu is indicated by results in Weisler (1993), though no formal tool analyzed by Weisler was manufactured of local material.

The larger sample from Luatele allows us to evaluate the spatial distribution of sources more systematically. The distribution of residential terraces (i.e., house platforms) across the site reflects some level of social inequality (Quintus et al. 2022), with larger residential terracing reflecting high status found in the center of the site. Large terracing is also found in the northwest with smaller terraces found in the southeast. Artifacts in both broad geochemical groups are found across the extent of the site. While the proportion of artifacts in these groups is different across the site, with a slightly higher proportion of nonlocal artifacts in the northwest

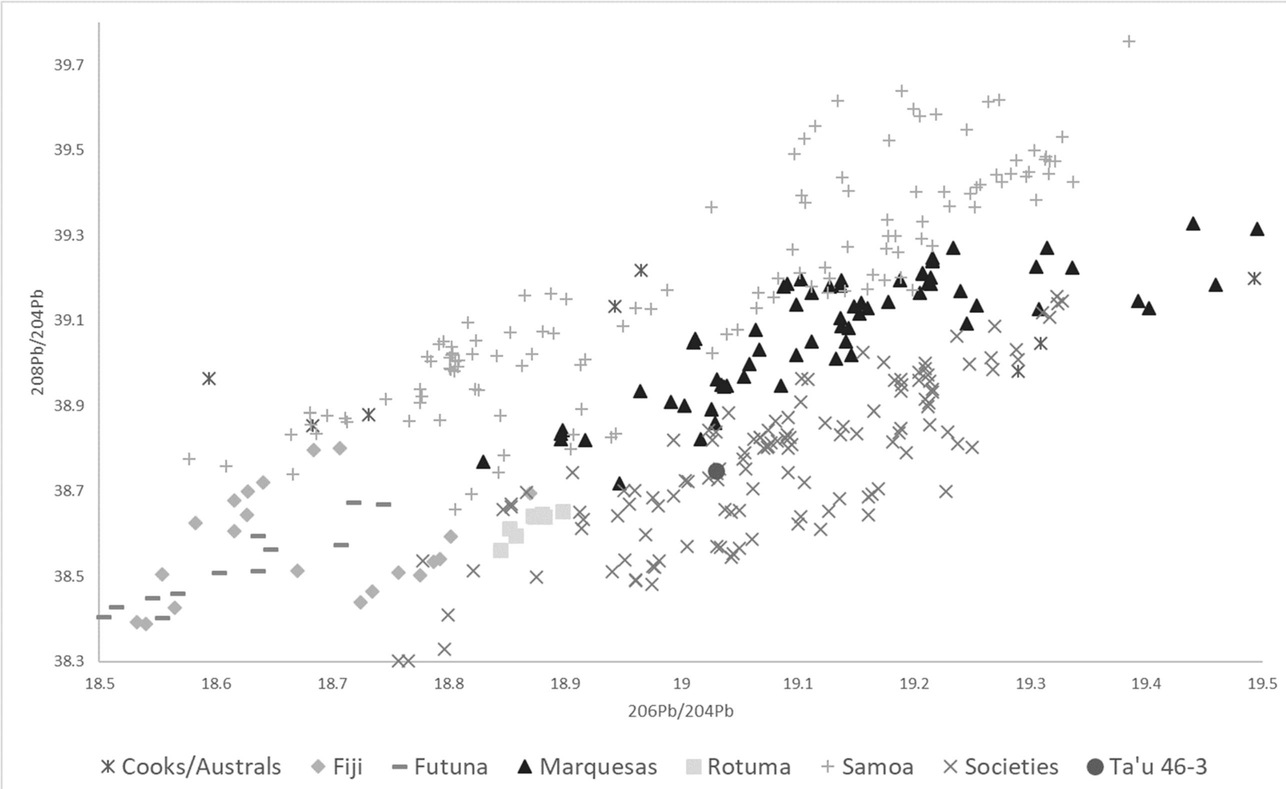

Fig. 9 Comparison of the Pb isotopic compositions of 46–3 with islands and island groups in the central Pacific. The artifact overlaps with geological material from the Society Islands

(86.2%; 75 of 87) relative to the southeast (73.3%; 22 of 30) or center (79.3%; 23 of 29), the sample size from the latter two locations is small and this difference is not statistically significant ($\chi^2 = 2.73$, df = 2, $n = 146$, $p = 0.255$). The size of terraces on which these artifacts were found, a proxy for resident status, does not correlate closely to the proportion of nonlocal goods ($\chi^2 = 2.08$, df = 2, $n = 146$, $p = 0.353$). There is also no correlation between the temporal period during which the terrace was built, defined using data in Quintus et al. (2022), and the proportion of nonlocal basalt (χ^2 *with Yates' correction* = 0.01, df = 1, $n = 143$, $p = 0.92$) (Table 2). In summary, we have no evidence that spatial position, status, or temporal period contributes to the distribution of nonlocal material.

Discussion

Our results demonstrate substantial artifact transfer within the Sāmoan archipelago. Based on the chronology of the sites with which our assemblages were associated, these patterns were in place by at least 1000 years ago. Though communities in Manu‘a used both local and nonlocal materials, the use of these materials was different. Stone from Tutuila appears to be largely associated with formal tools or waste material from the use or maintenance of those formal tools. In contrast, stone from Manu‘a was largely waste flakes with limited evidence of formal tool development or maintenance. These results are broadly consistent with those in Weisler (1993) and Weisler and Kirch (1996).

The presence of an artifact of East Polynesian origin highlights connections between those islands and West Polynesia (cf. Barnes and Hunt 2005; Kramer 1902-3), consistent with earlier work (Weisler et al. 2016), and our results unambiguously document at least some two-way voyaging between East and West Polynesia (see also Clark et al. 2014). The nature of the artifact is perplexing in this regard; a piece of shatter does not meet most expectations of artifact exchange over such distances (over 2000 km). Instead, we would expect a completed formal tool. It may be that this piece of debitage was part of a larger artifact transferred to Ta‘ū and further modified once it reached the island. Furthermore, the nature of artifact transfer is unknown. Given documented connections between Tonga and East Polynesia (Clark et al. 2014), it is possible that the stone on Ta‘ū was transported to the Sāmoan archipelago through Tonga. Alternatively, the artifact of East Polynesian origin in Tonga may have first been transferred

Fig. 10 Examples of adzes and adze fragments from Olosega Island. **A** Adze fragment reshaped into an end scraper (87–1). **B** Small adze with evidence of bevel resharpening (86–4). **C** Adze fragment with no visible evidence of rejuvenation (86–3). **D** Rejuvenated adze (187–2). **E** Adze fragment with incipient tang (93–2). **F** Reshaped adze fragment (187–1)

Table 2 Distribution of nonlocal basalt by associate terrace size (top) and temporal period (bottom) in Luatele

	Proportion of nonlocal basalt	# of terraces (# of artifacts)
Moderate (101–200 M^2)	0.76	5 (33)
Large (201–300 M^2)	0.88	3 (43)
Very large (301 M^2+)	0.81	2 (70)
Early (pre-1400)	0.82	5 (73)
Late (post-1400)	0.81	2 (70)

to Sāmoa given the well-documented exchange of lithic material from Sāmoa to Tonga (Clark et al. 2014).

The low level of cortex, higher levels of polish, and small size of flakes that source to Tutuila suggest that most stages of tool manufacturing are not represented in the assemblage. We infer from these data that most stones from Tutuila were imported as tools in finished or almost finished form. The presence of small amounts of cobble cortex on nonlocal stone may suggest that cortex remained on the surface of some finished tools or a small amount of raw material were imported on occasion. These results are consistent with expectations of limited or no direct access to quarries by those in Manu‘a. The presence of multiple quarries from Tutuila in our assemblage hints that interaction between Manu‘a and Tutuila was decentralized, not restricted to one area, or at least those interacting with populations from Manu‘a had access to varied sources of material or tools made of stone from across Tutuila. The high degree of adze maintenance associated with this nonlocal material, indicated by a high ratio of polished flakes and evidence of adze rejuvenation, suggests that access to adzes was either unpredictable or relatively infrequent. The fact that the largest adze in the assemblage may be of local origin further suggests some constraints to access of nonlocal material.

Higher levels of cortex on flakes sourced to Manu‘a suggest that the community had more direct access to these sources of stone, though the generally small sizes of flakes in the assemblage indicate little tool manufacturing on the terraces excavated or surveyed. No definitive quarry sites or manufacturing areas have been identified in Manu‘a. The presence of cobble cortex, including on a small core, indicates that the source of much of the material was local streambeds. The lack of formal quarries is not surprising given that streambeds were a common source of high-quality basalt in Polynesia (Kahn et al. 2013). The presence of a small number of polished flakes, an adze, and a nonpolished flake tool that source to Manu'a indicates that some formal tools were manufactured from this material, consistent with the presence of polishing facets (*fo'aga*) in the island group, though it is also clear that populations in Manu'a preferred stone from Tutuila for this purpose.

When considered within a regional context, these results highlight that adzes were moving away from Tutuila to supplement economies with markedly different social systems. Tonga, to the south, and Manu'a, to the east, act as end members of sorts in how these materials were used when they entered local economies. In Manu'a, while our spatial data are somewhat limited, it is apparent that nonlocal stone in the group was widely distributed, found on each island and across each island. These data do not support the restricted distribution and consumption of nonlocal stone at the site, island, or island-group scale, as has been suggested for highly hierarchical societies of East Polynesia (Kahn et al. 2013; Kirch et al. 2012). This seems to contrast with the situation in Tonga where a large percentage of imported materials is associated with emergent elite centers (Clark et al. 2014), though results from outside elite centers also demonstrate a substantial, albeit lower, proportion of nonlocal basalt (Connaughton 2014).

A comparison with the low-hierarchy polities of the Marquesas may be useful. There, the broad distribution of lithic sources and tools is interpreted to reflect gift exchange between elites and commoners (McAlister and Allen 2017). This model of material movement may be apt for Manu'a given evidence of social inequality but a corporate model of political action, wherein leaders sought consensus and group integration (Quintus 2020; Quintus and Clark 2019). Leaders in Polynesia are expected to provide for their people, as mediators with the divine, and such connection to the divine is demonstrated through fertility and productivity (Shore 1989). Because of this, it is the continuous exchange of items rather than the accumulation of them that met social expectations of leadership in Sāmoa, specifically, and Polynesia, generally (Goldman 1970; Marcus 1989). The wide distribution of basalt tools and lack of control over that distribution may have functioned as a mechanism for leaders at multiple scales (e.g., descent group, village, island, group) to maintain community cooperation and loyalty, while at the same time legitimizing their leadership.

Rather than seeing this as a manifestation of top-down patron-client relations, however, we hypothesize that the wide distribution of imported adzes across Manu'a stems from a form of collective action and negotiation; a tool of social integration that both resisted autocratic consolidation and enhanced political stability (see Blanton and Fargher 2008; Furholt et al. 2020). The imported materials became, in effect, common pool resources whose distribution may have supported compliance as well as community well-being. The conceptualization of adzes as a common pool resource was important as the importation of adzes into Manu'a likely had substantial utilitarian importance. Patterns of local and nonlocal material use mirror those found in some Hawaiian contexts, notably Kahalu'u in the Kona District (Mills et al. 2011). As was the case in Kona, our results highlight the lack of economic self-sufficiency of populations in Manu'a, at least for some resources. Formal tools from Tutuila were essential for a variety of daily tasks (e.g., house construction, agriculture, canoe making). Interaction with Tutuila played a role in this small-island environment by expanding the diversity of resources that could be exploited and consumed by those in Manu'a. Given the apparent economic need of imported adzes in Manu'a, the incorporation of these imported adzes as common pool resources is logical from both the social top and bottom, as failure to do so reduces the economic output of the collective, thereby potentially harming a leader's source of legitimacy (i.e., production). Because commoners were the source of power for the leader, those commoners were in a position to demand concessions from the leader (see Fargher et al. 2011). Leaders may have benefited in other ways, though, especially if they were involved in the procurement of the adzes from Tutuila. Gift exchange creates and reinforces social relationships, and gift exchange among descent groups was a politically important activity historically in the archipelago (Linnekin 1991). While the adzes that helped forge those relationships may have become common pool resources once they entered into the local economy, it is plausible that the social relationships and alliances created by the exchange were largely the purview of the elites.

Conclusions

The paring of extensive nondestructive EDXRF analysis with a small set of isotopic analyses can successfully discriminate between basalt sources on several islands across West Polynesia, including within the Sāmoan archipelago. This is significant as far more samples can be run through EDXRF analysis, providing a better opportunity to characterize economic decisions and patterns. Our results also highlight the importance of characterizing both debitage and formal tools, as analysis of both kinds of artifacts can illustrate important patterns; in this case, we demonstrate the differential use of local and nonlocal materials.

The islands of Manu'a acquired a substantial amount of their lithic material, including most of their formal tools, from Tutuila. The geochemical variability of lithic material from Tutuila indicates that multiple sources were exploited for export, highlighting that no single quarry or group had sole control of basalt exportation on the island. While this does not preclude the possibility that basalt was an important resource in the political economy of Tutuila, as the presence of fortifications guarding some quarries (Best 1993) and the lack of direct access to quarries by groups from Manuʻa suggest a degree of control, it does indicate that exchange tended to be decentralized at the island scale (see also Johnson 2013). We do not have any evidence that the distribution or consumption of nonlocal stones was controlled in Manuʻa. The decentralized distribution of adzes in our study area highlights the cooperative social dynamics in the group and the reciprocal nature of relationships between members of integrated Sāmoan hierarchies and descent groups (Goldman 1970; Tcherkezoff 2009). We posit that this was a mechanism of negotiation between leaders and nonleaders that legitimized those leaders, gained compliance, enhanced community integration, and served the public good. It is in this way that apparently decentralized exchange can still meet political ends and benefit elites.

Inter-island interaction is a fundamental risk management device across Oceania. Today and historically, interaction is critically important for the long-term sustainability of settlement in the Manuʻa group. Our results confirm that such connections have a deeper temporal span and demonstrate that such interaction was a substantial contributor to daily life in Manuʻa. The expansion of resource bases through exchange and the wide distribution of those imported resources once they enter local economies were key adaptations in these small islands in the past. Instead of seeing such "dependence" as a negative characteristic of settlement in small-island environments, as is often the case today (see Hauʻofa 1994), the deep-time patterning of these interactions highlights the need to see them as part of cultural heritage and important strategies of long-term adaptations in support of regional well-being.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-022-01571-w.

Acknowledgements We thank and recognize the population of Manuʻa, including all those with whom we worked. We thank especially Eseta Kese and Pastor Fred Scanlan for hosting and assisting us during our research. We thank Logoleo Feagai Logoleo for permission to work in Luatele. We wish also to recognize the contributions of Jennifer Huebert, Jaratnapa Surinlert, Tiffany Lee, Darby Filimoehala, Malone Ieti, Princecharles Faleagafulu, Christina Fuʻafuʻa, Tafa Fuafua, Paulo Paulo, Oceana Teʻi, Arthur Sega, Fafetaʻi Lauofo, Joshua Fuʻafuʻa, Falani Masunu, Visa Vaivai Tiapusua, Brian Vivao, Faʻafutai Lauofo, Fauato Aukuso, Taumakai Atautia, Jonathon Mauga, Leonard Vivao, Lawrence Fautua, Robert Mauga, J. J. Tanielu, and Achilles Tevasea to the success of this research. We appreciate the helpful comments of Robert DiNapoli on a draft version of this manuscript as well as the laboratory support of Aaron Pietruszka. Finally, we thank the American Samoa Historic Preservation Office, specifically Letitia Peau-Folau, Teleai Christian Ausage, and Lancelot Leutuʻutuofiti Teʻi, for archaeological and logistical support. Logistical assistance was provided by the National Park of American Samoa under permit NPSA-2019-SCI-0001.

Funding This work was supported by the National Science Foundation through grant no. BCS-1732360.

Declarations

Conflict of interest The authors declare no competing interests.

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