Title
Cook Island artifact geochemistry demonstrates spatial and temporal extent of pre-European interarchipelago voyaging in East Polynesia

Journal
Proceedings of the National Academy of Sciences of the United States of America, 113(29)

ISSN
0027-8424

Authors
Weisler, Marshall I
Bolhar, Robert
Ma, Jinlong
et al.

Publication Date
2016-07-19

DOI
10.1073/pnas.1608130113

Peer reviewed

Cook Island artifact geochemistry demonstrates spatial and temporal extent of pre-European interarchipelago voyaging in East Polynesia

Marshall I. Weisler[a,1], Robert Bolhar[a,b], Jinlong Ma[c,d], Emma St Pierre[a], Peter Sheppard[e], Richard K. Walter[f], Yuexing Feng[d], Jian-xin Zhao[d], and Patrick V. Kirch[g,1]

[a]School of Social Science, University of Queensland, St. Lucia, QLD 4072, Australia; [b]School of Geosciences, University of the Witwatersrand, WITS 2050, South Africa; [c]State Key Laboratory of Isotope Geochronology and Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China; [d]School of Earth Sciences, University of Queensland, St Lucia, QLD 4072, Australia; [e]Department of Anthropology, University of Auckland, Auckland 1010, New Zealand; [f]Department of Anthropology and Archaeology, University of Otago, Dunedin 9054, New Zealand; and [g]Department of Anthropology, University of California, Berkeley, CA 94720

Contributed by Patrick V. Kirch, May 25, 2016 (sent for review May 14, 2016; reviewed by Geoffrey R. Clark and Barry Rolett)

The Cook Islands are considered the "gateway" for human colonization of East Polynesia, the final chapter of Oceanic settlement and the last major region occupied on Earth. Indeed, East Polynesia witnessed the culmination of the greatest maritime migration in human history. Perennial debates have critiqued whether Oceanic settlement was purposeful or accidental, the timing and pathways of colonization, and the nature and extent of postcolonization voyaging—essential for small founding groups securing a lifeline between parent and daughter communities. Centering on the well-dated Tangatatau rockshelter, Mangaia, Southern Cook Islands, we charted the temporal duration and geographic spread of exotic stone adze materials—essential woodworking tools found throughout Polynesia— imported for more than 300 y beginning in the early AD 1300s. Using a technique requiring only 200 mg of sample for the geochemical analysis of trace elements and isotopes of fine-grained basalt adzes, we assigned all artifacts to an island or archipelago of origin. Adze material was identified from the chiefly complex on the Austral Islands, from the major adze quarry complex on Tutuila (Samoa), and from the Marquesas Islands more than 2,400 km distant. This interaction is the only dated example of down-the-line exchange in central East Polynesia where intermediate groups transferred commodities attesting to the interconnectedness and complexity of social relations fostered during postsettlement voyaging. For the Cook Islands, this exchange may have lasted into the 1600s, at least a century later than other East Polynesian archipelagos, suggesting that interarchipelago interaction contributed to the later development of social hierarchies.

Polynesian archaeology | geochemical sourcing | adzes | voyaging | exchange

The Cook Islands are considered the "gateway" for human colonization of East Polynesia, the last major region on Earth to have been discovered and permanently settled. Prehistorians have long debated whether the Polynesian colonization of the eastern Pacific was purposeful or accidental (1–3). The possible pathways of colonization have been defined by computer simulations of seasonal winds and currents using different starting points and directions and durations of travel (4–6) whereas critiques of canoe performance (7, 8) have informed the debate. Postcolonization voyaging between islands was essential for securing a lifeline between parent and daughter communities (e.g., ref. 9), to obtain prestigious commodities from distant islands for elites (10), and for integrating far-flung communities under a centralized authority, such as the Tongan maritime state (11). Some, however, have opined that postcolonization voyaging and artifact transfer in East Polynesia were minimal (7, 12).

The spatial and temporal dimensions of exotic artifacts in well-secured archaeological contexts provide a powerful means for documenting the geographic span, frequency, and temporal duration of voyaging, contributing to understanding the process of island colonization and also the development of social structures—both fundamental tenants of anthropological inquiry. In this regard, the woodworking stone adze was essential in Polynesian societies because it was indispensable for shaping canoe hulls, bowls and other artifacts, felling trees for forest clearance permitting agricultural expansion, and fashioning planks and posts for house construction. Indeed, stone adzes or the by-products of their manufacture, use, and reworking are ubiquitous in most archaeological sites throughout the region. The major sources of fine-grained basalt, the singular raw material used for adze manufacture across tropical Polynesia, are restricted to a few known localities. Previous studies have shown that these essential tools were sometimes transported more than 1,000 km within interaction spheres involving exchanges of goods and services (11, 13–15).

Two themes have emerged that encompass all studies of the spatial and temporal distribution of exotic adze material throughout Polynesia: (*i*) the development of social complexity and expansion of social networks or interaction spheres (that is, the distribution of fine-grained basalt adzes were, in some cases, controlled by elites) (e.g., ref. 10); and (*ii*) the geographic extent and frequency of voyaging (15, 16). These themes, however, have been constrained by a lack of well-dated archaeological contexts of adze material because most previously analyzed artifacts have been surface finds

Significance

Oceania, the last region settled on Earth, witnessed the greatest maritime migration in human history. Scholars have debated how and when islands were colonized and the role of postsettlement voyaging in maintaining founding colonies and in subsequent diversification of island societies. We geochemically "fingerprinted" exotic stone artifacts from a well-dated archaeological site in the Cook Islands, matching artifacts to their geological sources and demonstrating that the geographical voyaging network extended beyond the Cook Islands to include the Austral, Samoa, and Marquesas archipelagos—up to 2,400 km distant. We further demonstrate that Polynesian interarchipelago voyaging lasted from about AD 1300 to the 1600s, suggesting that long-distance interaction continued to influence the development of social structures in East Polynesia well after initial colonization.

Author contributions: M.I.W. and P.V.K. designed research; M.I.W., R.B., J.M., E.S.P., P.S., R.K.W., Y.F., J.-x.Z., and P.V.K. performed research; M.I.W. and R.B. analyzed data; and M.I.W., R.B., and P.V.K. wrote the paper.

Reviewers: G.R.C., Australian National University; and B.R., University of Hawaii.

The authors declare no conflict of interest.

[1]To whom correspondence may be addressed. Email: kirch@berkeley.edu or m.weisler@uq.edu.au.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1608130113/-/DCSupplemental.

or museum specimens lacking clearly associated age (13, 17–19). Previous studies have also been constrained by an inability to assign all artifacts to geological localities because many adze sources and quarries await discovery (20). The intrasource geochemical variability of known quarries is not well-understood, making many source assignments tentative, at best, and some geochemical techniques do not analyze the comprehensive range of chemistry required for robust artifact source assignments. In this article, we resolve these issues by using the most comprehensively dated stratigraphic sequence of adze material now known for tropical Polynesia—from the Tangatatau rockshelter (site MAN-44) situated on Mangaia Island in the Southern Cook Islands, considered the gateway archipelago for prehistoric colonization and settlement of East Polynesia (16, 21). Keying on the Tangatatau rockshelter assemblage provides a rare opportunity to examine the "uptake" of exotic goods at a well-dated habitation locale likely occupied by nonelites, in contrast to several recent studies that examine adze production and consumption at chiefly complexes and stately centers ruled by paramounts in Tonga (10), Hawaii (11), and the Austral Islands (18). Significantly, we used trace element and isotope geochemistry to assign 36 artifacts from site MAN-44 to an island or archipelago of origin and, when sufficient data are available, to specific quarries or sources, thereby resolving the difficulty of separating intraisland sources in the Cook Islands (ref. 22, p. 396). We also used inductively coupled plasma mass spectrometry (ICP-MS) for geochemical analysis and applied a method of sampling artifacts (23), using only 200 mg of powder—a major advance for studying museum collections and small artifacts.

The Study Site: Tangatatau Rockshelter, Mangaia Island

Tangatatau (site MAN-44), situated in the Veitatei District of Mangaia Island [Universal Transverse Mercator (UTM) coordinates, zone 4, 609100E and 573100N] is a spacious rockshelter formed by an overhanging block of limestone along the 25-m high inland escarpment of upraised coral reef known as the "makatea." The main occupation floor is about 45 m long and ranges from 5 to 8 m wide, with a total area of 225 m^2 under the dripline. The site was first discovered during a reconnaissance survey in 1989, when a 5-m long test trench and one additional test unit were excavated, revealing well-stratified cultural deposits (24). Major excavation was undertaken in 1991, when an additional 23 m^2 were excavated, primarily in the rockshelter's central area (21). The main excavation block, which incorporated the 1989 test trench, consists of 24 contiguous 1-m units; stratigraphy within this block was recorded and correlated using a Harris matrix system. Details of the excavation, stratigraphy, and radiocarbon dating are reported in detail elsewhere (25).

The stratigraphy within site MAN-44 consists of a complex sequence of occupation deposits ranging from relatively thick layers to thin beds and ashy lenses, interspersed with 59 discrete features, most of which were combustion features, such as earth ovens and hearths, but also included pits and postmolds. Using a Harris matrix (figure 5 of ref. 21), this complex stratigraphy was synthesized into 19 stratigraphic zones. Zone 1 consists of preoccupation deposits, with an upper component (zone 1B) incorporating evidence of early human presence, such as Polynesian-introduced *Rattus exulans* bones. Zones 2 and 3 are occupation deposits rich in artifacts and faunal material, including abundant basalt preforms, flakes, and debitage indicating extensive adze production. These early occupation deposits were truncated by zone 4, a series of large, intercutting pits, which are in turn capped by zone 5, a thin midden bed that forms a distinctive stratigraphic marker. Zones 6 and 7 consist of ashy midden deposits with considerable quantities of shellfish. Zone 8 is another major occupation deposit with many hearth features and a rich artifact content. Zone 9 is contemporaneous with zone 8 in the eastern part of the excavation. Zones 10 through 14 are thin midden beds of shellfish and ash that represent discrete, probably short-term depositional events. These beds are capped by zone 15, an ashy midden rich in charcoal, which is in turn capped by zone 16, a deposit of white ash that represents an intensive burning event across the shelter floor. Zone 17 is the uppermost deposit and contains a small quantity of post-European contact artifacts. Zones 18 and 19 consist of strata separated from the main excavation area by a large rockfall boulder that prevented them from being precisely correlated with the rest of the sequence; zone 18 is roughly contemporary with zones 2–5 whereas zone 19 corresponds to the sequence from zones 6 through 16.

The stratigraphic sequence at site MAN-44 has been dated with 60 ^{14}C dates, one of the largest sets of radiocarbon dates from any similar site in East Polynesia. These dates include an initial set of 30 dates on unidentified wood charcoal (21), 16 accelerator mass spectrometry (AMS) dates on extirpated or extinct avifauna and *R. exulans* bones from zone 1, and 14 high-precision AMS dates on botanically identified, short-lived taxa selected from the main occupation deposits. Full details on all dates are provided elsewhere (25). A Bayesian calibration of the full suite of radiocarbon dates provided the following estimated time spans for the main occupation sequence: Deposition of zone 1B, cal AD 1024–1344; onset of occupation at MAN-44, cal AD 1265–1290; deposition of zone 2, cal AD 1303–1364; deposition of zones 3–4B, cal AD 1355–1375; deposition of zones 5–7, cal AD 1378–1502; deposition of zones 8 and 9, cal AD 1445–1587; and deposition of zones 10 to 17, cal AD 1537–1672.

The MAN-44 excavations yielded a rich suite of 638 classified portable artifacts, not including several thousand basalt flakes and debitage (especially from zones 2 and 3). The artifact assemblage exhibits considerable temporal change, especially in the fishhooks and adzes. Fishhooks in the lower stratigraphic zones (zones 2–4) are predominantly of pearlshell (*Pinctada margaritifera*), a mollusk that does not occur naturally on Mangaia and that had to be imported from other islands with suitable lagoon habitats. Above zone 5, hooks were made mostly of locally available *Turbo setosus* shell, and pearlshell hooks are completely absent above zone 8. These changes are indicative of a reduction in long-distance exchange interaction and therefore are of relevance to the present study (26).

Thirty whole or partial adzes and 54 adze preforms, along with a large quantity of lithic production material (flakes and debitage), were recovered from the main excavation block. The greatest amount of material was found in zones 2 and 3, but lithic production and the use of adzes continued throughout the sequence. There is significant change in adze form through time, with the earlier assemblage (zones 2 through 4) being dominated by quadrangular sectioned, largely untanged adzes and the later assemblage by triangular sectioned adzes with pronounced tangs.

Results

Trace element and isotopic values for artifacts and sources are presented in Tables S1–S5. On the basis of normalized multitrace element patterns, 19 of 36 artifacts (52.7%) in this study can be assigned to fine-grained basalt sources on the island of Mangaia. In Fig. 1*A*, seven artifacts are compositionally almost identical and match the pattern for source rock sample KC-05-3, from the Mata'are source, Mangaia (27). Thirteen artifacts (seven adze flakes, four bevel fragments, one adze fragment, and one blank/preform) can be assigned to Veitatei, a location on the same island, based on the match with basaltic source rock 2009-332 (Fig. 1*B*). This finding is validated by Nd and Sr isotope data (Fig. 2): All artifacts matched with Mangaia overlap with the compositional field defined by isotope data from the same island although overlap exists with isotope data for volcanic rocks from Tubuai (Austral Islands). In these cases, normalized multitrace element patterns point to Cook Islands sources. No isotope data for artifact sample 2009-406 was available. Some mismatch can be observed for the most incompatible and mobile elements (Cs, Rb, Ba, but also Pb) and the most compatible elements (Co and Ni). Most incompatible elements are prone to secondary alteration or remobilization during rock–seawater interaction or from weathering during exposure, and thus are less reliable, including

ANTHROPOLOGY

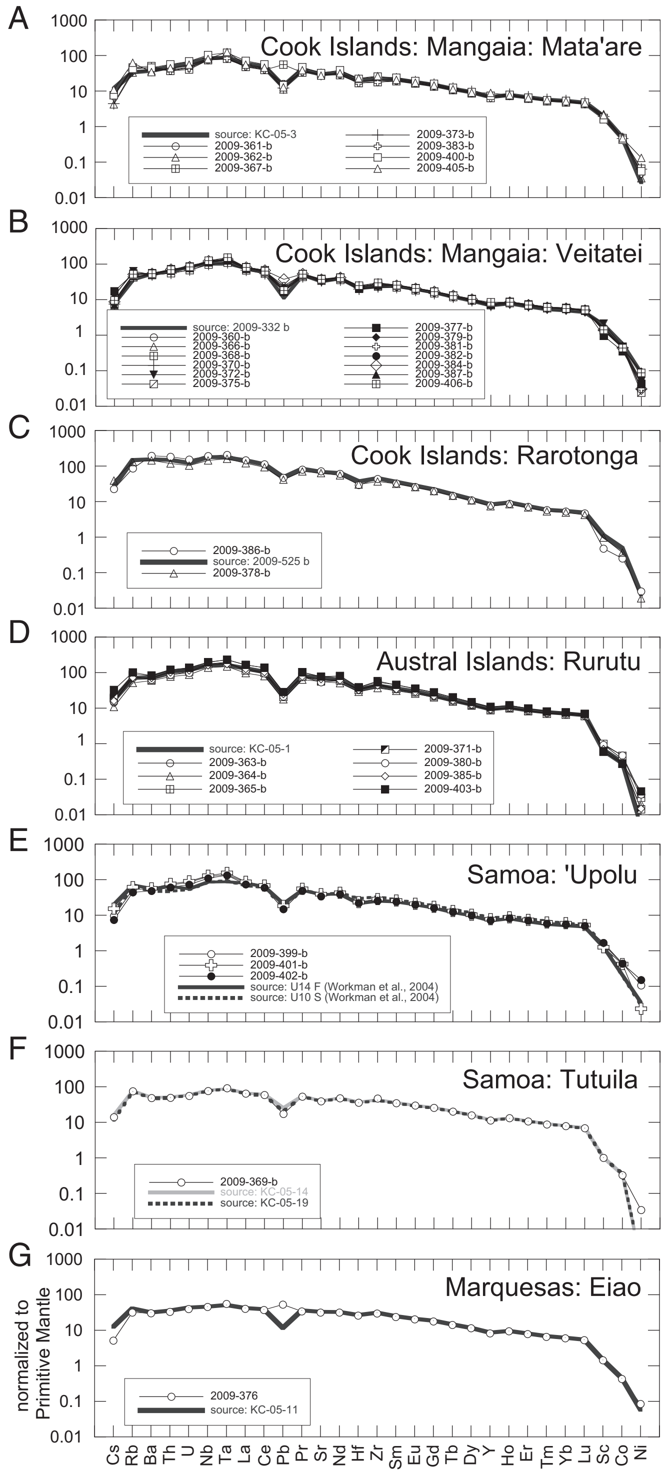

Fig. 1. Primitive mantle normalized trace element diagrams showing selected adze compositions in comparison with likely source rock compositions. The close similarity for Mangaia and Austral Islands compositions testifies to very similar petrogenetic processes and mantle sources. Note that similarities in some cases break down for Pb, Cs, and Ni, likely reflecting contamination during sample handling, mobility during weathering, and breakdown of instable olivine (primitive mantle composition value according to ref. 43). Artifacts have been assigned to sources on (*A*) Mata'are, Mangaia, Cook Islands; (*B*) Veitatei, Mangaia, Cook Islands; (*C*) Rarotonga, Cook Islands; (*D*) Rurutu, Austral Islands; (*E*) 'Upolu, Samoa; (*F*) Tutuila, Samoa; and (*G*) Eiao, Marquesas.

Pb. Lead can be introduced when sampling by drilling or abrading with metallic bits as we have done here with the artifacts. The discrepancy for Co and Ni is explained by the very low concentrations encountered; for instance, in all basaltic samples studied here, Ni is present at 0.08–0.01 times primitive mantle, and Co at slightly higher concentrations of 0.5 times primitive mantle. Therefore, the perceived "mismatch" is in the order of 0.05 times primitive mantle, which is exceedingly small and possibly within the analytical error, but accentuated by the nature of the logarithmic presentation. One stone adze fragment (2009-386) is compositionally and isotopically similar to volcanics found on the island of Rarotonga, Southern Cook Islands (Fig. 1*C*). The match to the source rock (2009-525) is not as close as for other Cook Islands artifacts, possibly due to weathering-related elemental remobilization. Artifact 2009-378 cannot be assigned to any known source on the basis of trace element data. However, this artifact can be discriminated isotopically from the Austral, Samoa, and Marquesas island groups because it plots within the field defined by Rarotonga, in close proximity to artifact 2009-386 (Fig. 2).

The second largest assignment to one island is seven artifacts that are similar to basaltic source rock KC-05-1 and the broader chemistry of the Classic Period ceremonial and quarry complex at Vitaria, Rurutu, Austral Islands (18, 28) (Fig. 1*D* and Fig. S1). In Fig. 2, Rurutu Nd and Sr isotope data delineate two clusters, one of which overlaps with data for Mangaia. Fortunately, artifacts from this study overlap with the compositional field of Rurutu, which is distinct from the Mangaia data, halfway between Mangaia and Marquesas. Three complete adzes (2009-399, -401, and -402) originated from 'Upolu island, Samoa, suggested by the match in trace element data to published compositions for two basaltic volcanics (ref. 29, samples U14 and U10). For reasons outlined above, the match deteriorates somewhat for the most and least incompatible elements. The assignment of these three artifacts is confirmed by matching Nd and Sr isotopic data shown in Fig. 2. Two source flakes from the major quarry complex at Tatangamatau, Tutuila Island, Samoa (KC-05-14 and -19) can be matched to artifact 2009-369 (Fig. 1*F*). Additional support is provided by the agreement with regards to Nd and Sr isotope data (Fig. 2). Sample 2009-376 is exceptional and significant because it is the only artifact that can be linked to the Marquesas archipelago; the closest similarity with trace elements is from source rock KC-05-11 (Eiao

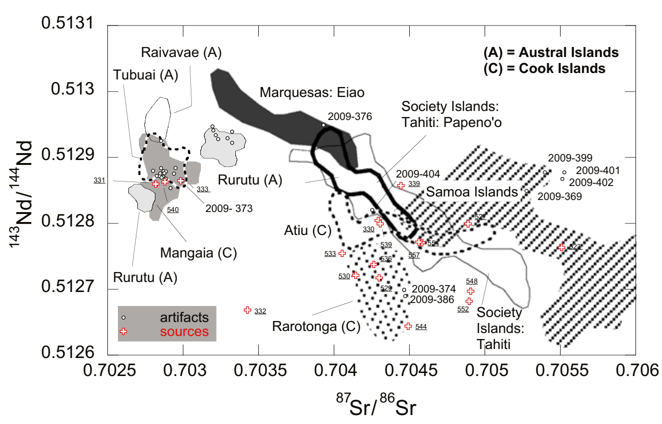

Fig. 2. Diagram of $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ isotope ratios showing compositional fields for oceanic islands in the Pacific Ocean based on literature data (Austral Islands, Cook Islands, Marquesas, Society Islands, and Samoa). Also displayed are compositions of stone adzes (white circles) and source rocks (crosses). The majority of artifacts plot in two tight clusters within the fields defined by volcanic rocks belonging to Rurutu (Austral Islands) and Mangaia (Cook Islands), with a third group of four artifacts plotting close to the compositional field for Samoa. Several artifacts show strong isotopic similarity with Eiao, Marquesas (artifact 2009-376), Atiu, Cook Islands (artifact 2009-404), and Rarotonga, Cook Islands (artifacts 2009-374 and -386).

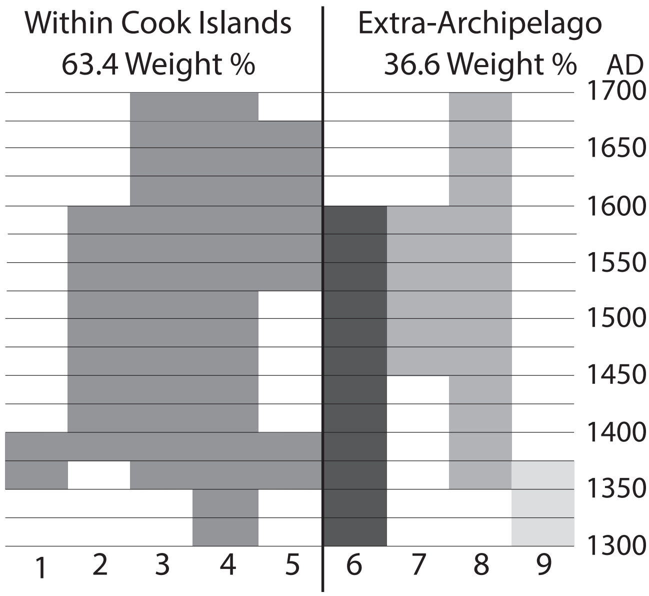

Fig. 3. Distribution of sources through time. Within Cook Islands: 1, Cook Islands only (24.2% weight); 2, Mangaia, Mata'are (26.7%); 3, Mangaia, Veitatei (3.8%); 4, Mangaia Island (5.9%); and 5, Rarotonga (2.8%). Extra-archipelago: 6, Austral Islands, Rurutu, Vitaria (9.9%); 7, Samoa, Tutuila, Tatangamatau (1.7%); 8, Samoa, 'Upolu Island (22.9%); and 9, Marquesas, Eiao Island (2.1%).

island) (30) (Table S4). In the rare earth element plot, this match is good for all elements, except for Cs and Pb, the two most mobile elements (Fig. 1*G*). Isotopically, this interpretation is strengthened by the match with data for this island although, based on Nd and Sr data without considering trace elements, a source from the Tahiti, Society Islands is also possible. The latter artifact highlights the capability of assigning artifacts to sources unequivocally when multielement and isotope data are combined because ambiguities arising from one set of data can be minimized or eliminated when the other dataset is used for validation.

In sum, 52.7% of all sampled basalt artifacts from site MAN-44 can be assigned to three distinct locations within the Cook Islands: two sources on Mangaia Island at Veitatei ($n = 13$) and Mata'are ($n = 7$), and three artifacts from Rarotonga. Seven artifacts (19.4%) can be linked to the Vitaria quarry complex on Rurutu, Austral Islands. Four artifacts originated from the Samoa group, specifically the islands of 'Upolu and Tutuila at the large quarry complex at Tatangamatau. Finally, one artifact can be traced to the island of Eiao, Marquesas and its island-wide quarry complex. The results are summarized in Dataset S1.

Discussion

In East Polynesia, long-distance interaction between island societies was a fundamental colonization strategy linking parent with multiple daughter communities to support the establishment of socially and economically viable groups. Postcolonization voyaging and interaction supported socially mediated imperatives such as the acquisition of high status goods, the fostering and maintenance of strategic alliances, and establishing individual and group prowess or "mana" (14).

The Tangatatau rockshelter adze assemblage is remarkable in its high proportion of artifacts from extraarchipelago sources; 33.3% by count and 36.6% by weight of analyzed artifacts were imported to Mangaia (Dataset S2). Geochemically "fingerprinting" fine-grained basalt adze material from the Tangatatau rockshelter allowed us to define the voyaging sphere (network) size, directionality, and time span of postcolonization interaction (31). The closest extraarchipelago source of imported adzes was from Rurutu Island, 663 km (358 nautical miles) in the northern Austral Islands. Some 1,706 km (921 nautical miles) distant are 'Upolu and Tutuila islands, Samoa whereas the greatest distance of imported material, and thus maximum extent of the network, comes from the northern Marquesas, Eiao Island at 2,415 km (1,303 nautical miles). The "directionality" of interaction all points to the Cook Islands because, at present, there is no physical evidence of material exported from the archipelago. This finding is further supported by the evidence from MAN-44 for the regular importation of pearl shell for fishhook manufacture. A large corpus of radiocarbon age determinations and associated imported adze material from Tangatatau documents the time span of interarchipelago voyaging from the early AD 1300s to at least the 1600s (artifacts 2009-402 and -399). If we remove these two artifacts from consideration, then there is marked falloff in imports after the late AD 1500s (Fig. S2), which is about a century later than many East Polynesian voyaging spheres (32, 33).

It is noteworthy that an adze fragment (2009-363) and two polished adze flakes (2009-371 and -385) closely match an unmodified flake from Marae Tararoa (KC-05-1) (13) (Table S2) situated within the major chiefly complex at Vitaria, Rurutu and that four other artifacts match the general chemistry for the Vitaria quarry complex (Fig. S1). This ceremonial complex is thought to have developed during the late prehistoric or Classic Period of Rurutu (18), with tanged triangular cross-section adze forms. Significantly, a reverse triangular adze (2009-403) originated from Rurutu dates to AD 1303–1364 in the MAN-44 site whereas four artifacts (2009-363, -364, -365, and -385) of Vitaria origin are also from the 14th century, specifically, AD 1303–1375 (Dataset S2). One artifact dates to AD 1378–1502 (2009-371) and another to AD 1445–1587 (2009-380). Together, these results demonstrate that the Vitaria quarry was used for at least a century before the beginning of the Classic Period and development of the ceremonial complex, and perhaps into the late 16th century (18, 34). This collection is the largest of adze materials from excavated and securely dated contexts that document use of the Vitaria quarry for about three centuries (that is, AD 1303–1587).

Four artifacts are of Samoan origin, including three adzes from undocumented sources or quarries on 'Upolu Island. One is a reverse triangular tanged adze from a test unit separate from the Tangatatau main block excavations, which cannot be directly correlated to the main MAN-44 stratigraphic sequence. However, this adze form is the most common in the last few centuries of the prehistoric period in the Cook Islands (ref. 35, p. 98), and radiocarbon age determinations from this unit bracket deposition to between AD 1400 and 1700. Two additional adze fragments (a reverse triangular adze, 2009-402, and a reverse trapezoidal adze, 2009-401) date from AD 1355–1375 and AD 1537–1672, respectively. Unlike previously analyzed surface finds lacking stratigraphic context (ref. 11, p. 10493), these finds are the most securely dated adzes known to have been exported from 'Upolu. One reworked adze (2009-369) derives from the major adze quarry complex at Tatangamatau, Tutuila Island (36) and is associated with a date of AD 1537–1672. This finding, again, is significant because most artifacts recovered outside Samoa have been surface finds with unclear dating (refs. 12 and 37 and ref. 38, p. 104). This artifact demonstrates that Tutuila was exporting adzes as late as the 1600s, up to two centuries later than previously reported (ref. 16, p. 126 and ref. 38, p. 104). This evidence for continued voyaging contact between the Cook Islands and Samoa is furthermore of considerable import because it has often been tacitly assumed that there was little or no contact between the island groups of East Polynesia and the West Polynesian homeland region, after the initial settlement of East Polynesia.

Imports from the Marquesas, Samoa, and the Australs were all present during the period from AD 1303–1375 (zones 2 and 3 in the MAN-44 sequence)—the earliest time to which we can assign

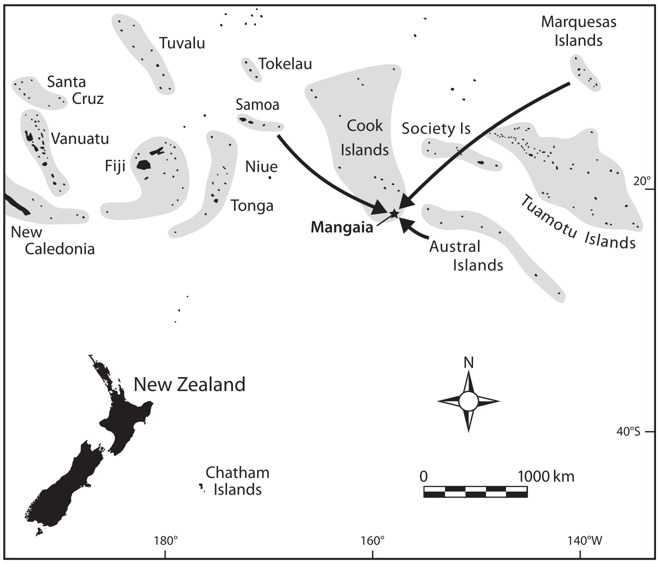

Fig. 4. Map of the central Pacific showing the sources of adze material imported to the Tangatatau rockshelter, Mangaia Island, Southern Cook Islands.

artifacts to any source. The farthest source was the Marquesas and, unsurprisingly, this source was the first to drop out of the interaction network. Communities on Samoa and Rurutu (Austral Islands) continued to interact (directly or indirectly) with Mangaia as late as AD 1445–1587 (zone 8) whereas contact with ʻUpolu continued until as late as AD 1537–1672 (zone 10) (Figs. 3 and 4 and Fig. S2).

Sources of tool quality basalt on Mangaia were located early after colonization of the island and were used continuously throughout the sequence (Fig. 3); these sources included sources at Mataʻare and Veitatei near the center of the island. Despite a small source of adze rock near Moturakau islet, Aitutaki Island 389 km (210 nautical miles) northwest of Mangaia, none of this material was identified at Tangatatau. However, four artifacts, the only ones from within the Cook Islands, but not from Mangaia, showed links with Rarotonga (197 km, 107 nautical miles north northwest) dating between AD 1355–1375 and AD 1537–1672.

Conclusions

Prior geochemical studies documented the transfer of fine-grained basalt adze material after the colonization of most East Polynesian archipelagos; however, the dates for the end of such regional voyaging and interaction are not well known (31, 32, 39). It is likely that the cessation of long-distance voyaging occurred at different times for each archipelago, reflecting the variability in types and sizes of islands, dates of colonization, productivity of the terrestrial landscape over time, human population trajectories, evolving social conditions, island accessibility (such as the position and direction of currents and seasonal winds), and distance to other islands. These issues are of no small importance because the scale and frequency of postcolonization voyaging underpins fundamental theoretical arguments of how East Polynesian island societies developed under varying degrees of isolation during fewer than 1,000 y of occupation—a relatively short time span in world prehistory. The well-stratified and dated context of the Tangatatau adze assemblage has allowed us to outline the geographic scale and frequency of imported adze material over time in the Southern Cook Islands, demonstrating that external contact continued for at least 300 y after colonization and possibly longer. At least three archipelagos were engaged in this interaction network—one of which, Eiao (Marquesas), was nearly 2,500 km distant. Eiao material has also been recovered from the Tuamotus (13), Mangareva (15), the Society Islands (15), the Line Islands (40), and the Australs (41), attesting to the widespread importance of this source. In addition to the great distance involved, voyaging canoes traveling from the Marquesas would have encountered the 1,500-km-long screen of the Tuamotus Archipelago—the navigational crossroads of central East Polynesia (13)—then likely traveling northeast through the Society Islands before reaching the Southern Cook Islands. This instance is the first dated occurrence (AD 1303–1364) of down-the-line exchange in central East Polynesia where intermediate groups most likely played a role in the transfer of commodities such as adze material (ref. 19, p. 439). This finding attests to the interconnectedness and complexity of social relations during the first few centuries after East Polynesian colonization. Although this longest of contacts with Mangaia was short-lived based on the presence of adze material at Tangatatau, extraarchipelago contacts persisted with the Austral Islands until the AD 1500s and a century later with Samoa. The late contacts with Samoa also reveal some continued porosity in the boundary between East and West Polynesia.

The decline of East Polynesian voyaging begs the obvious question as to why it stopped. The reasons are undoubtedly complex, multifaceted, and unique to an island or archipelago, and it is insightful to key on the well-dated Tangatatau habitation site with imported adze material over much of the sequence. Internal social conditions during later prehistory, such as the increased importance of maintaining productive agricultural lands or escalation of intertribal conflicts (whether on Mangaia or the archipelagos it was in contact with), outweighed the need for obtaining prestige items acquired from long-distance voyaging (31, 32). Our results from the Tangatatau rockshelter have enhanced our understanding of the extent and duration of long-distance voyaging in East Polynesia. Nonetheless, more well-dated stratigraphic sequences from other East Polynesian archipelagos, coupled with high-precision and comprehensive geochemistry for imported adze materials, will be required before we will be able to fully comprehend how, why, and when postcolonization voyaging declined across this vast region.

Materials and Methods

Artifact Sampling. Specimens (n = 36) were selected to cover the range of stratigraphic zones in the Tangatatau rockshelter sequence. All adzes and flakes were first examined without magnification, and then those that were particularly fine-grained were selected for geochemical analysis. This selection included seven (23%) of all whole or partial adzes, one blank/preform, and 28 (19.7%) of the combined adze flakes (n = 17), bevel fragments (n = 6), and nondescript polished adze fragments (n = 5). The whole and partial adzes represented the sequence of typological change known for the Cook Islands with untanged forms in the lower zones of the rockshelter and late prehistoric tanged adzes in the upper layers; the nondescript polished adze fragments could not be assigned a specific type but, along with the highly polished adze bevel fragments, represent the reworking of finished adzes. The adze flakes were defined by one to three polished surfaces. Dataset S3 lists the catalog numbers, provenience, measurements, and other descriptive attributes for all analyzed artifacts.

Source Material. The major impediment to assigning artifacts to geologic localities or quarries is the lack of source material, which is especially true for Central East Polynesia (18, 20). Only two small sources are known for the Cook Islands: one near Moturakau on Aitutaki, the other at Mataʻare, Mangaia Island (27). Samples for this study were obtained there as well as from all other islands that had exposures of seemingly tool-grade basalt (Fig. S3; 38). The trace element and isotope geochemistry of these samples is presented in Tables S1–S5. The geochemistry of potential sources and known quarries was also obtained from the archaeological literature for the Austral Islands (18), Samoa (42), and the Marquesas (30), and from nine archipelagos throughout Polynesia (13). Provenancing using isotopes was facilitated by the large database from the literature, comprising hundreds to thousands of individual analyses for Polynesian oceanic island basalts (OIBs). Useful online databases are PetDB (www.earthchem.org/petdb) and GeoReM (georem.mpch-mainz.gwdg.de/sample_query_pref.asp).

ACKNOWLEDGMENTS. We thank Les O'Neill and Matthew Harris for preparing the illustrations. The excavation and radiocarbon dating of Tangatatau rockshelter was funded by US National Science Foundation Grant BNS-9020750. The Australian Research Council (Discovery Grants DP0986542, DP0773081, and DP1115547) supported the geochemical analyses, and the University of Queensland (Archaeology Strategic Plan) funded a postdoctoral fellowship (to E.S.P.).

1. Irwin GI (1992) *The Prehistoric Exploration and Colonisation of the Pacific* (Cambridge Univ Press, Cambridge, UK).
2. Lewis D (1972) *We, the Navigators* (Australian National Univ Press, Canberra, Australia).
3. Sharp A (1956) *Ancient Voyagers in the Pacific, Memoir 32* (The Polynesian Society, Wellington, New Zealand).
4. Di Piazza A, Di Piazza P, Pearthree E (2007) Sailing virtual canoes across Oceania: Revisiting island accessibility. *J Archaeol Sci* 34(8):1219–1225.
5. Levison MG, Ward G, Webb JW (1973) *The Settlement of Polynesia: A Computer Simulation* (Univ of Minnesota Press, Minneapolis).
6. Montenegro A, Callaghan RT, Fitzpatrick SM (2014) From west to east: Environmental influences on the rate and pathways of Polynesian colonization. *Holocene* 24(2): 242–256.
7. Anderson A (2014) Seafaring in Remote Oceania: Traditionalism and beyond maritime technology and migration. *The Oxford Handbook of Prehistoric Oceania*, eds Cochrane E, Hunt T (Oxford Univ Press, Oxford).
8. Irwin GI, Flay RGJ (2015) Pacific colonisation and canoe performance: Experiments in the science of sailing. *J Polyn Soc* 124(4):419–443.
9. Weisler MI (1995) Henderson island prehistory: Colonisation and extinction on a remote Polynesian island. *Biol J Linn Soc Lond* 56:377–404.
10. Kirch PV, Mills PR, Lundblad SP, Sinton J, Kahn JG (2012) Interpolity exchange of basalt tools facilitated via elite control in Hawaiian archaic states. *Proc Natl Acad Sci USA* 109(4):1056–1061.
11. Clark GR, et al. (2014) Stone tools from the ancient Tongan state reveal prehistoric interaction centers in the Central Pacific. *Proc Natl Acad Sci USA* 111(29):10491–10496.
12. Cochrane EE, Rieth TM (2016) Samoan artefact provenance reveals limited artefact transfer within and beyond the archipelago. *Archaeol Ocean*, 10.1002/arco.5090.
13. Collerson KD, Weisler MI (2007) Stone adze compositions and the extent of ancient Polynesian voyaging and trade. *Science* 317(5846):1907–1911.
14. Kaeppler AL (1978) Exchange patterns in goods and spouses: Fiji, Tonga and Samoa. *Mankind* 11(3):246–252.
15. Weisler MI (1998) Hard evidence for prehistoric interaction in Polynesia. *Curr Anthropol* 39(4):521–532.
16. Allen MS, Johnson KTM (1997) Tracking ancient patterns of interaction: Recent geochemical studies in the southern Cook Islands. Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach, ed Weisler MI (New Zealand Archaeological Association, Otago, New Zealand), Monograph 21, pp 111–133.
17. McAlister A, Sheppard PJ, Allen MS (2013) The identification of a Marquesan adze in the Cook Islands. *J Polyn Soc* 122(3):257–273.
18. Rolett BV, West EW, Sinton JM, Iovita R (2015) Ancient East Polynesian voyaging spheres: New evidence from the Vitaria adze quarry (Rurutu, Austral Islands). *J Archaeol Sci* 53(1):459–471.
19. Weisler MI, Green RC (2001) Holistic approaches to interaction studies: A Polynesian example. *Australasian Connections and New Directions: Proceedings of the 7th Australian Archaeometry Conference*, eds Jones M, Sheppard P (University of Auckland, Aukland), Research in Anthropology and Linguistics 5, pp. 417–457.
20. Weisler MI, Sinton JM (1997) Towards identifying prehistoric interaction in Polynesia. Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach, ed Weisler MI (New Zealand Archaeological Association, Otago, New Zealand), Monograph 21, pp 173–193.
21. Kirch P, Steadman D, Butler V, Hather J, Weisler MI (1995) Prehistory and human ecology in the Cook Islands: Archaeological excavations at the Tangatatau rockshelter, Mangaia. *Archaeol Ocean* 30(2):47–65.
22. Walter R, Sheppard P (2001) Cook Island basalt sourcing: Current issues and directions. *Australasian Connections and New Directions: Proceedings of the 7th Australian Archaeometry Conference*, eds Jones M, Sheppard P (University of Auckland, Auckland), Research in Anthropology and Linguistics 5, pp 383–399.
23. Ma J, Bolhar R, Weisler MI, Feng Y, Zhao J (2011) Reproducibility of elemental analyses of basaltic stone artefacts by quadruple ICP-MS using different sample sizes and digestion methods, with implications for archaeological research. *Archaeometry* 53(5):890–899.
24. Kirch PV, Flenley JR, Steadman DW, Lamont F, Dawson S (1992) Ancient environmental degradation: Prehistoric human impacts on an island ecosystem. *National Geographic Research and Exploration* 8:166–179.
25. Kirch PV, ed, *Tangatatau Rockshelter (Mangaia, Cook Islands): The Evolution of an Eastern Polynesian Socio-Ecosystem*, Monumenta Archaeologica (Cotsen Institute of Archaeology Press, Los Angeles), in press.
26. Walter R, Campbell M (1996) The Pararoa site: Fishing and fishhooks in 16th century Mitiaro, Southern Cook Islands. *Man and Culture in Oceania* 12:47–60.
27. Weisler MI, Kirch PV, Endicott JM (1994) The Mata'are basalt source: Implications for prehistoric interaction studies in the Cook Islands. *J Polyn Soc* 103(2):203–216.
28. Verin P (1969) *L'Ancienne Civilisation de Rurutu: La Période Classique,* Mémoires Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM, Paris), no. 33.
29. Workman RK, Hauri E, Hart SR, Wang J, Blusztajn J (2006) Volatile and trace elements in basaltic glasses from Samoa: Implications for water distribution in the mantle. *Earth Planet Sci Lett* 241(3):932–951.
30. Weisler M, et al. (2016) Determining geochemical variability of fine-grained basalt sources/quarries for facilitating prehistoric interaction studies in Polynesia. *Archaeol Ocean*, 10.1002/arco.5088.
31. Plog F (1977) Modelling economic exchange systems. *Exchange Systems in Prehistory*, eds Earle TK, Ericson JE (Academic, New York), pp 127–140.
32. Rolett BV (2002) Voyaging and interaction in ancient East Polynesia. *Asian Perspect* 41(2):182–193.
33. Weisler MI (2002) Centrality and the collapse of long-distance voyaging in East Polynesia. *Geochemical Evidence for Trade and Exchange*, ed Glascock MD (Bergin and Garvey, Westport, CT), pp 257–273.
34. Bollt R (2008) *Peva: The Archaeology of an Austral Island Settlement* (Bishop Museum, Honolulu), Bulletin in Anthropology 12.
35. Walter R (1998) *Anai'o: The Archaeology of a Fourteenth Century Polynesian Community in the Cook Islands* (New Zealand Archaeological Association, Otago, New Zealand), Monograph 22.
36. Weisler MI, Kirch PV (1996) Interisland and interarchipelago transfer of stone tools in prehistoric Polynesia. *Proc Natl Acad Sci USA* 93(4):1381–1385.
37. Best SB, Sheppard PJ, Parker RJ, Green RC (1992) Necromancing the stone: Archaeologists and adzes in Samoa. *J Polyn Soc* 101(1):45–84.
38. Sheppard PJ, Walter R, Parker RJ (1997) Basalt sourcing and the development of Cook Islands exchange systems. Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach, ed Weisler MI (New Zealand Archaeological Association, Otago, New Zealand), Monograph 21, pp 85–110.
39. Kirch PV, Kahn JG (2007) Advances in Polynesian prehistory: A review and assessment of the past decade (1993-2004). *J Archaeol Res* 15(3):191–238.
40. Di Piazza A, Pearthree E (2001) Voyaging and basalt exchange in the Phoenix and Line archipelagos: The viewpoint from three mystery islands. *Archaeol Ocean* 36(3): 146–152.
41. Hermann A (2013) Les industries lithiques pre-européennes de Polynésie centrale: Savoir-faire et dynamiques techno-economiques. PhD dissertation (University of French Polynesia, Papeete, French Polynesia).
42. Weisler MI, Woodhead JD (1995) Basalt Pb isotope analysis and the prehistoric settlement of Polynesia. *Proc Natl Acad Sci USA* 92(6):1881–1885.
43. Hofmann AW (1997) Mantle geochemistry: The message from oceanic volcanism. *Nature* 385(6613):219–229.
44. Eggins SM, et al. (1997) A simple method for the precise determination of ≥40 trace elements in geological samples by ICPMS using enriched isotope internal standardisation. *Chem Geol* 134(4):311–326.
45. Miková J, Denková P (2007) Modified chromatographic separation scheme for Sr and Nd isotope analysis in geological silicate samples. *J Geosci (Prague)* 52(4):221–226.
46. Tanaka T, et al. (2000) JNdi-1: A neodymium isotopic reference inconsistency with La Jolla neodymium. *Chem Geol* 168(4):279–281.
47. Shaw DM (2006) *Trace Elements in Magmas: A Theoretical Treatment* (Cambridge Univ Press, Cambridge, UK), pp 243.
48. Weisler MI (1993) Provenance studies of Polynesian basalt adze material: A review and suggestions for improving regional data bases. *Asian Perspect* 32(1):61–83.
49. Mills PR, Lundblad SP (2014) Current perspectives on Hawai'i's stone tool economies. *J Pacific Archaeol* 5(2):30–39.
50. Chauvel C, Hofmann AW, Vidal P (1992) HIMU-EM: The French Polynesian connection. *Earth Planet Sci Lett* 110(1):99–119.
51. Woodhead JD (1996) Extreme HIMU in an oceanic setting: The geochemistry of Mangaia Island (Polynesia), and temporal evolution of the Cook—Austral hotspot. *J Volcanol Geotherm Res* 72(1):1–19.
52. Wood CP, Hay RF (1970) *Geology of the Cook Islands* (New Zealand Geological Survey, Auckland), Bulletin 82.
53. Cheng QC, Macdougall JD, Lugmair GW (1993) Geochemical studies of Tahiti, Teahitia and Mehetia, Society Island chain. *J Volcanol Geotherm Res* 55(1):155–184.
54. Wright E, White WM (1987) The origin of Samoa: New evidence from Sr, Nd, and Pb isotopes. *Earth Planet Sci Lett* 81(2):151–162.
55. Caroff M, et al. (1999) Assimilation of ocean crust by hawaiitic and mugearitic magmas: An example from Eiao (Marquesas). *Lithos* 46(2):235–258.
56. Woodhead JD (1992) Temporal geochemical evolution in oceanic intra-plate volcanics: A case study from the Marquesas (French Polynesia) and comparison with other hotspots. *Contrib Mineral Petrol* 111(4):458–467.