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Title Page

Title:

Combined geochemical and geochronological analyses of stone artefacts provide unambiguous evidence of intra- and inter-island interactions in Polynesia.

Short title:

Combining geochemical and geochronological data for provenance studies of stone artefacts from Polynesia.

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Abstract

Stone tool geochemistry provides hard evidence for post-settlement voyaging and inter-island contacts in East Polynesia. This offers promising information on inter-community exchange networks that are not documented by ethnographic accounts. Drawing on "geochemical fingerprints", provenance studies have slowly integrated geological data in order to better constrain the origin of archaeological material. However, the occurrence of overlapping geochemical signatures within Polynesian islands can cause difficulties when attempting to differentiate sources. Identifying clear geochemical characteristics for each island is therefore critical for a comprehensive understanding of the interaction patterns in East Polynesian societies. In this paper, we combine major and trace element data with isotopes as well as ^{40}Ar - ^{39}Ar ages to constrain the local procurement networks that were occurring on the island of Tupua'i (Austral-Cook chain). We also demonstrate that some Tupua'i archaeological material originated from Eiao Island (Marquesas chain) circa 2,000 km north. This represents the first hard evidence for inter-island connections between the Austral and the Marquesas Archipelagos.

Highlights

- New geochronological technique used to establish the provenance of stone artefacts
- Combining geochemistry and geochronology improves sourcing of basaltic artefacts
- A geological setting for Central Eastern Polynesia is defined
- Procurement networks for adze production in Tupua'i (Austral Islands) are described
- Long-distance exchange is evidenced between the Marquesas and the Austral Islands

1 1. Introduction

2
3 The long-distance transfer of prestige goods was
4 an important aspect of the mobility between Pacific islands
5 societies before European contact (Green and Kirch, 1997;
6 Weisler, 1997). Based on geochemical sourcing, it has
7 been possible to identify exotic commodities in
8 archaeological sites and therefore to document wide-scale
9 inter-community interactions during and after the
10 colonization period, in both the western Pacific and eastern
11 Polynesia (see Hermann, 2015 for a review).

12 Geochemical analysis of stone artefacts has been
13 increasingly used in the last 20 years in order to document
14 inter-island and inter-archipelago transfers of stone tools in
15 Central Eastern Polynesia (CEP), where long-distance
16 interactions during the first few centuries after East
17 Polynesian colonization have been widely documented
18 (e.g. McAlister et al., 2014; Weisler and Kirch, 1996;
19 Weisler, 1997, 1998, 2002; Weisler et al., 2016a).
20 Ethnographic accounts do not provide information on long-
21 distance exchange in East Polynesia because these
22 interactions date from a remote period of history.
23 Therefore, only a comprehensive and high-precision
24 examination of stone artefacts involving all required
25 geochemical and geochronological analysis can allow for a
26 proper reconstruction of ancient interaction patterns in
27 CEP.

28 Focusing on stone artefacts from several
29 archaeological sites on Tupua'i Island (Austral-Cook
30 chain), we present a detailed provenance analysis based on
31 two specific aims: (1) documenting intra-island movement
32 of raw material as a part of local procurement strategies
33 and adze production processes, and (2) providing evidence
34 for inter-island transfers of artefacts.

36 2. Geological setting and source discrimination in 37 Polynesia

38
39 In CEP, provenance analyses of stone tools were
40 first based on petrographic features (Weisler, 1993), then
41 on major and trace element compositions (Mills et al.,
42 2010; Kirch et al., 2012; Kahn et al., 2013; McAlister et
43 al., 2014; Rolett et al., 2015; Walter and Sheppard, 1996;
44 Weisler and Kirch, 1996; Weisler, 1998, 2002), and more
45 recently on Sr, Nd and Pb isotopic ratios (Collerson and
46 Weisler, 2007; Weisler et al., 2016a; Weisler and
47 Woodhead, 1995; Woodhead and Weisler, 1997). **Except**
48 **for the above isotopic analyses, most** sourcing studies
49 have focused on quarry sites in order to trace the origin of
50 archaeological artefacts. However, we argue here that
51 provenance studies of stone artefacts must rely on the
52 acquisition of wide and reliable geological data related to
53 this specific geological setting, as most prehistoric quarries
54 in Polynesian islands have yet to be identified. Further

55 complicating matters, several Polynesian islands show
56 similar geochemical characteristics, while others exhibit
57 different but partly overlapping geochemical signatures
58 (Chauvel et al., 1992; Chauvel et al., 2012; White and
59 Duncan, 1996; Zindler and Hart, 1986). One must
60 therefore examine the temporal and geochemical evolution
61 of each island chain in order to constrain the origin of
62 specific basaltic material.

63 The islands of CEP are distributed across four
64 linear chains (Austral-Cook, Pitcairn-Gambier, Society and
65 the Marquesas) spreading over a large part of the South
66 Pacific Ocean due to the Pacific Plate motion towards the
67 NW (Fig. 1). Corresponding hotspots are located
68 underneath young volcanoes at the south-eastern tip of
69 each archipelago. Over the last 20 years, a systematic
70 program of detailed geological mapping, associating
71 geochemical and age data, was conducted in French
72 Polynesia by the National institute for geological survey
73 (Bureau de Recherches Géologiques et Minières). This led
74 to considerably better characterizations of intra- and inter-
75 island petrologic, geochemical, and age variations in the
76 Austral (Chauvel et al. 1997; Maury et al., 2013; Maury et
77 al., 2014a), Gambier (Delavault et al., 2015), Society
78 (Cordier et al., 2016; Guillou et al., 2005) and Marquesas
79 Islands (Chauvel et al., 2012; Guillou et al., 2014; Maury
80 et al., 2014b).

81 Major element compositions are variable both
82 within a given island and between different islands. The
83 total alkali/silica diagram (**SiO₂ versus K₂O+Na₂O**)
84 provides a useful classification of igneous rocks, from
85 mafic to felsic and from tholeiitic to silica-undersaturated,
86 and these petrographic groups are often specific to volcanic
87 edifices or periods of magma emplacement. TAS
88 classification can be combined with TiO₂ versus MgO
89 plots in order to identify geochemical variations within
90 volcanic edifices, and therefore discriminate a number of
91 localities as potential sources of rock supply.

92 Trace element variations can also be used to
93 differentiate different geological units that share the same
94 petrographic characteristics. As summarized by Dupuy et
95 al. (1989), Polynesian lavas display selective enrichments
96 in incompatible elements: alkali and alkali earth elements
97 (K, Rb, Ba, Sr) as well as high field strength elements (Nb,
98 Zr, Ti, Hf) and light rare earth elements (La, Ce, Nd).
99 Consequently, trace element data combined with major
100 element data can be used to assign artefacts to a geological
101 source at a restricted geographical scale, typically within
102 an island or a specific volcanic edifice.

103 Plume-related basalts have been documented as
104 chemically and isotopically heterogeneous because of the
105 dynamic evolution of the mantle over time (White and
106 Duncan, 1996; Chauvel et al., 1992; Chauvel et al., 2012;
107 Delavault et al., 2015). Four main geochemical mantle

08 end-members, characterized by specific isotopic
09 compositions, have been identified in CEP islands. The
10 HIMU (High $^{238}\text{U}/^{204}\text{Pb}$) signature, characterized by low
11 $^{87}\text{Sr}/^{86}\text{Sr}$ and very high $^{206}\text{Pb}/^{204}\text{Pb}$, is found in lavas from
12 Ra'ivavae, Tupua'i, Rurutu and Mangaia. The EM
13 (Enriched Mantle) signatures, defined by higher $^{87}\text{Sr}/^{86}\text{Sr}$
14 ratios and lower $^{143}\text{Nd}/^{144}\text{Nd}$, Nb/Th and Ta/La ratios
15 (White and Duncan, 1996; Chauvel et al., 1992), are
16 present in the source of Rarotonga and Pitcairn volcanics
17 as EM1 (Enriched Mantle type I), while EM2 (Enriched
18 Mantle type II) dominates that of most Society and
19 Marquesas islands (Zindler and Hart, 1986; White and
20 Duncan, 1996; Chauvel et al., 1992). Compared to EM2,
21 EM1 shows even lower $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios
22 together with rather low $^{206}\text{Pb}/^{204}\text{Pb}$. The identification of
23 such isotopic signatures provides obvious information for
24 provenance analysis.

25 Moreover, most Polynesian archipelagos show
26 correlations between island ages and corresponding
27 distances to the presumed hotspot area located at the SE
28 end of the volcanic chain (Delavault et al., 2015; Maury et
29 al., 2013; Maury et al., 2014; Guillou et al., 2005; Guillou
30 et al., 2014; Turner and Jarrard, 1982; Guillou et al., 1994).
31 As a result, the general age progression along volcanic
32 chains provides another variable that can be used for
33 source discrimination. Hence our use of geochronological
34 analyses to further constraint exotic sources and identify

135 the provenance of stone artefacts from archaeological
136 contexts.

137
138 **3. The study site: Tupua'i (Tubuai) Island, Austral-**
139 **Cook chain**

140
141 Tupua'i (23°23'00"S, 149°27'00"W), together with
142 Mangaia (Southern Cook chain), is well known for the
143 unusual 'HIMU' isotopic signature of its lavas, which
144 display very high $^{206}\text{Pb}/^{204}\text{Pb}$ ratios (Maury et al., 2013;
145 Vidal et al., 1984). The island was mapped between 1989
146 and 1995 by the BRGM team (Maury et al., 1994; Maury
147 et al., 2000; Maury et al., 2013). Three types of basalt
148 rocks (alkali basalts, basanites and nephelinites) and three
149 types of intermediate lavas (basanitic tephrites, tephrites
150 and peralkaline phonolites) were emplaced between 10.04
151 and 8.77 Ma. Such a relatively high-resolution geological
152 study allows us to postulate that local sources are well
153 constrained on the island. Additionally, several quarry
154 sites, including the Tanataetea site, have been identified as
155 possible sources of fine-grained basalt procurement
156 (Hermann et al., 2012; Hermann, 2013, 2016).

157 The archaeological material examined in this paper
158 consists of 48 samples, including 23 surface-collected
159 artefacts from quarries and domestic or ceremonial sites,
160 and 25 artefacts from the Atiahara site, located at the north
161 coast of Tupua'i (Table 1, Fig. 2). This well-stratified site

62 consists of a succession of 4 cultural layers and 3 sterile
63 sand deposits of aeolian and marine origin. The cultural
64 sequence corresponds to a succession of four domestic
65 occupations that were dated between AD 1215 and 1390
66 based on radiocarbon dates on wood charcoal (Hermann et
67 al., 2015). In total, the Atiahara assemblage includes 43
68 polished adzes, 75 preformed and recycled adzes, and more
69 than 2,600 flake wastes and flake tools distributed over a
70 total excavated area of 216 m² (Hermann, 2013, 2016).
71 Based on macroscopic observation of artefacts, we
72 consider that the 25 samples submitted for geochemical
73 analyses represent the diversity of exploited raw material
74 on the site.

76 4. Material and methods

78 Major and trace elements were measured by
79 Inductively Coupled Plasma-Atomic Emission
80 Spectrometry (ICP-AES) for 48 samples at PSO/IUEM
81 (Plouzané, France): 25 from the Atiahara site, 16 from
82 surface sites, and 7 from quarry sites and outcrops. The list
83 and locations of the archaeological and geological samples
84 are shown in Table 1. Eight samples were then selected for
85 Sr and Pb isotopic analyses: 3 artefacts from deep layers of
86 the Atiahara site (At3-229-064, At3-317-065 and At3-395-
87 066), 2 geological samples from Tupua'i quarries (Tan1-
88 006 and Pahatu8-059), and 3 geological samples from

189 Mangaia (Cook Is.) collected by P.V. Kirch in the valleys
190 of Mata'are, Veitatei and Keia (Table 1). Sr isotopes were
191 analysed by Thermo Scientific Triton Mass Spectrometer
192 (TIMS) at PSO/IUEM (Plouzané, France) and Pb isotopes
193 were determined using a Nu Plasma Multicollector -
194 Inductively Coupled Plasma Mass Spectrometer (MC-
195 ICPMS) at the ENS Lyon (France). Finally, one Mata'are
196 quarry sample from Mangaia and two adzes from Atiahara
197 (At3-229-064 and At3-317-065) were dated by the
198 ⁴⁰Ar/³⁹Ar method at LSCE. Further details on analytical
199 procedures are described in Supplementary Data -
200 Appendix A.

202 5. Results

204 5.1. Major and trace element analysis

206 Major and trace element data from artefacts,
207 quarries, and geological outcrops in Tupua'i, with
208 additional data from other islands of the Austral-Cook
209 chain (Mangaia, Ra'ivavae, Rapa Iti) and the Marquesas
210 (Eiao) are shown in Tables 2 and 3. In Tupua'i, three types
211 of basalt rocks (alkali basalts, basanites and nephelinites)
212 and related intermediate lavas (tephrites) share the same
213 silica-undersaturated and incompatible element-enriched
214 signature typical of many Polynesian ocean island basalts
215 (Dupuy et al., 1989). Their genesis is ascribed to low

16 partial melting degrees of enriched mantle that decrease
17 from alkali basalts to nephelinites (Caroff et al., 1997).
18 Lavas from Tupua'i and the Mata'are quarry in Mangaia
19 (Cook archipelago) display depletions in Rb, Ba, Th and K
20 relative to Nb, La and Ce (Fig. 4c). This is considered
21 characteristic of an HIMU affinity (Chauvel et al., 1992;
22 Chauvel et al., 1997).

23 Almost all archaeological artefacts share the
24 petrographic and geochemical features of Tupua'i lavas.
25 The samples were clustered in 6 groups and associated
26 with different possible sources based on petrographic
27 groups and TiO₂-MgO plots (Fig. 3).

28 - Clusters 1 and 2 match the fine-grained basanites found at
29 the Tanataetea quarry and analysed as samples Tan3-005
30 and Tan1-006 (Table 2 and 3; Fig. 4a and 4b).

31 - Cluster 3 corresponds to a peculiar group of basanites that
32 are petrographically characterized by the presence of
33 recrystallized olivines and a dark green colour on polished
34 surfaces. The source of this rock remains uncertain at this
35 stage, as several lava flows in the Austral-Cook chain
36 display the same trace element patterns, including RV-11,
37 RV-27 and RV-35 on mount Rairua in Ra'ivavae (Maury et
38 al., 2013), at Mata'are quarry in Mangaia, and TB-3 on
39 Rereti'i ridge in Tupua'i (Table 2 and 3; Fig. 4c). A rock
40 sample from adze At3-229-064 was therefore selected for
41 further isotopic analyses in order to constrain the
42 geological origin of these artefacts.

243 - Clusters 4 and 5 are tephritic rocks similar to those found
244 in several locations on Herani volcano in Tupua'i,
245 including geological samples TB-137 and TB-243 (Table 2
246 and 3; Fig. 4d and 4e).

247 - Cluster 6 corresponds to sample At3-317-065, which has
248 been identified as an alkali basalt adze fragment (Table 2).
249 This aphyric rock is very different from highly porphyritic
250 alkali basalts from the oldest Tupua'i volcanic edifice and
251 does not show the typical features of HIMU-derived
252 Tupua'i lavas. Its major and trace element compositions are
253 very similar to those of Eiao Island (Marquesas) artefacts
254 and uppermost alkali basalts that derive from a dominantly
255 EM2 mantle source and display relatively smooth
256 enrichments in the most incompatible elements (Table 3;
257 Fig. 4f; Caroff et al., 1995; Charleux et al., 2014).

258

259 *5.2. Sr and Pb isotope analysis*

260

261 The Sr and Pb isotopic compositions of the
262 geological samples collected in Tupua'i quarry sites and of
263 most artefacts except sample At3-317-065 show obvious
264 similarities with previous data published for the island
265 (Fig. 5, Chauvel et al. 1992; Maury et al., 2013; Schiano et
266 al., 2001). Two of the adzes collected in the Atiahara site
267 (At3-229-064 and At3-395-066, Table 4) show lead and
268 strontium isotopic compositions consistent with Tupua'i
269 lavas: an average of $^{87}\text{Sr}/^{86}\text{Sr} = 0.702804 \pm 0.000008$ (2σ)

70 and $^{208}\text{Pb}/^{204}\text{Pb} = 40.1638 \pm 0.0020$ (2σ) for sample At3-
71 229-064, and an average of $^{87}\text{Sr}/^{86}\text{Sr} = 0.702797 \pm$
72 0.000008 (2σ) and $^{208}\text{Pb}/^{204}\text{Pb} = 40.261498 \pm 0.0023$ (2σ)
73 for sample At3-395-066. These values are very close to the
74 average compositions of Tupua'i island: $^{87}\text{Sr}/^{86}\text{Sr} =$
75 0.702840 ± 0.000225 (2σ) and $^{208}\text{Pb}/^{204}\text{Pb} = 40.2249 \pm$
76 0.5828 (2σ) (Fig. 5). In contrast, adze At3-317-065 shows
77 a lesser radiogenic Pb composition, with an average of
78 $^{208}\text{Pb}/^{204}\text{Pb} = 38.9991 \pm 0.0020$ (2σ) and is more radiogenic
79 in Sr with an average of $^{87}\text{Sr}/^{86}\text{Sr} = 0.703922 \pm 0.000008$
80 (2σ) (Table 4, Fig. 5). Interestingly, this sample shares
81 isotopic similarities with both Rapa Iti in the Australs and
82 Eiao in the Marquesas (Table 4, Fig. 6). Therefore this
83 sample was dated by the ^{40}Ar - ^{39}Ar method to better
84 constrain its origin.

86 5.3. Geochronology

88 ^{40}Ar - ^{39}Ar plateau ages, isochron ages, and total
89 fusion ages are given in Table 5 and Appendix C. The
90 isochron ages are considered more reliable than the plateau
91 ages because the isochron approach makes no assumption
92 regarding the trapped component, and it combines
93 estimates of analytical precision and internal disturbance of
94 the sample (scatter around the isochron).

95 The plateau age of the mildly altered Mata'are
96 sample (Mangaia, Cook Is.), calculated from 7 steps out of

297 10 with 78.8% of the gas released, is 20.17 ± 0.63 Ma.
298 This coincides with the isochron age of 20.03 ± 0.66 Ma
299 that we retained to take into consideration the non-
300 atmospheric value of the $^{40}\text{Ar}/^{36}\text{Ar}$ intercept, which may
301 indicate subtle excess $^{40}\text{Ar}^*$ (Table 5). This data fits a
302 previously measured K-Ar age for Mangaia, the oldest
303 high island in the CEP (19.3 ± 0.6 Ma; Turner and Jarrard,
304 1982; Fig. 7).

305 The age spectra of adze At3-229-064 demonstrate
306 an exponential decrease from high ages at low temperature
307 steps to the age plateau, which correlates with an increase
308 of the K/Ca ratio. The plateau age, calculated from 6 out of
309 10 steps (i.e. 60% of the gas released), is 10.32 ± 0.32 Ma;
310 equivalent to the total fusion age (10.41 ± 0.30 Ma) and the
311 isochron age of 10.30 ± 0.32 Ma. This age fits the
312 previously known range of activity of Tupua'i (10.04-8.77
313 Ma by the unspiked K-Ar method; Maury et al., 2000; Fig.
314 7), further demonstrating the local origin of this artefact.

315 The plateau age of adze At3-317-065 is calculated
316 from 10 out of 11 steps corresponding to the 81% of the
317 gas released. This plateau age (5.61 ± 0.21 Ma) is
318 equivalent to the isochron age (5.68 ± 0.24 Ma) and to the
319 total fusion age (5.59 ± 0.21 Ma). Available K-Ar ages for
320 Eiao Island (5.52 - 4.98 Ma; Guillou et al., 2014) fit that of
321 Atiahara adze sample At3-317-065 (Fig. 7), while those of
322 Rapa Iti lavas are younger (4.8 - 4.1 Ma; Maury et al.,
323 2013). Furthermore, other contemporaneous volcanoes in

24 the Gambier (6.26-5.66 Ma; Delavault et al., 2015; Guillou
25 et al., 1994) and in Ra'ivavae of the Australs (10.6-5.4 Ma;
26 Lassiter et al., 2003; Maury et al., 2013) have clearly
27 different isotopic characteristics (Figs. 5 and 6). Therefore,
28 this age result corroborates the geochemical evidence for
29 an exotic origin of adze At3-317-065 from Eiao
30 (Marquesas), circa 2,000 km north of Tupua'i.

32 6. Discussion

34 6.1. Assessing geological provenances without ambiguity

36 Archaeometric studies of stone tool assemblages
37 provide major insights for tracing patterns of mobility
38 within and between Pacific islands. Previous work has
39 shown that Sr, Nd and Pb isotopic data used together with
40 major and trace element data permits assignment of
41 artefacts to sources, because they provide additional
42 constraints on their geochemical signatures (Collerson and
43 Weisler, 2007; Hermann, 2013, 2016; Weisler et al.,
44 2016a).

45 However, even the entire set of information
46 available through rock chemistry (element and isotope
47 analysis) can be insufficient to properly discriminate
48 islands of origin. This is due to similar rock types arising
49 across CEP islands, but also to trace element patterns and
50 isotopic compositions both overlapping between different

351 islands, as we show for Eiao and Rapa iti, as well as for
352 Mangaia and Tupua'i (Figs. 4, 5 and 6). In such cases, we
353 argue that cross-referencing isotopic and geochronological
354 data can provide enough proxies to unambiguously assign
355 a source to a given artefact (Fig. 7). For instance, a strong
356 HIMU geochemical signature and an age circa 20 Ma
357 would readily identify any artefact or raw basalt as
358 originating from Mangaia Island, because these two
359 characteristics combined have no known equivalent in
360 Polynesia. Associating ^{40}Ar - ^{39}Ar (which can be performed
361 on a 120 mg sample, see Supplementary Data - Appendix
362 A) with major, trace elements and Sr, Nd, Pb isotopic
363 analysis therefore proves to be the most accurate way to
364 constrain stone artefact provenance in intraplate volcanic
365 islands of the Pacific. **Due to the time consuming
irradiation of the samples by specific nuclear reactors
(as described in Appendix A), Ar-Ar dating cannot be
used routinely in provenance studies, but can be used to
solve particular issues of source-assignment. For
example, Ar-Ar dating would help separate possible
Tupua'i-sourced artefacts from Mangaian ones in the
Tangatatau site recently discussed by Weisler and
colleagues (2016a).**

375 6.2. Local procurement strategies and adze production 376 process

377

78 Major and trace element data show a clear
79 clustering of the geological samples collected in Tupua'i,
80 **which corresponds to the geochemical variability**
81 **previously identified for the island (Maury et al., 1994;**
82 **Maury et al., 2000; Maury et al., 2013). We identify**
83 **several local procurement sources of basanite, tephrite**
84 **and phonolite, including the previously undocumented**
85 **Pahatu and Tanataetea quarries. Most of the artefacts**
86 **collected in domestic contexts were made-up of**
87 **basanites from the Tanataetea quarry and the Panee**
88 **area, as well as of tephrites from the Herani volcano.**

89 The distribution of flaked basalt boulders or dykes,
90 adze preforms, and knapping wastes (flakes and discarded
91 blanks) within the island suggests an organized form of
92 adze production, in quarries and procurement areas on one
93 hand, and in coastal settlements on the other. It has been
94 shown that stone knapping activities involved both
95 specialized craftsmen working in permanent workshops in
96 the vicinity of fine-grained basalt quarries of Tanataetea
97 and Pahatu (Fig. 2) and non-specialists within domestic
98 contexts like the Atiahara site (Hermann, 2013, 2016, in
99 press). Additionally, the Atiahara site assemblage shows
00 uneven distribution of fine-grained basalt and difficult
01 access to good-quality raw material, which can be
02 interpreted as an aspect of the control by pre-European
03 social elites over local valued resources.

405 6.3. Inter-archipelago transfers of artefacts: a Marquesas- 406 Austral connection

407
408 Our identification of an Eiao adze (At3-317-065)
409 within the Atiahara site in Tupua'i is the first hard evidence
410 of a link between the Marquesas and the Austral Islands
411 soon after the settlement of CEP by Polynesian
412 communities. This provides new insights into the potential
413 scale of ancient long-distance interaction in the region.

414 This artefact was associated with the layer 3,
415 which has been dated to the second half of the 14th century
416 (1345-1395 cal. AD; Hermann et al., 2015). Nonetheless,
417 this adze show obvious maintenance before it has been
418 discarded and recycled as a wedging stone in the filling of
419 a posthole. Thus, it is possible that this valuable object was
420 acquired by Tupua'i people prior to this date and was then
421 later transferred to the Atiahara residential area. In either
422 case, the chronological context associated with the adze
423 fits our current understanding that long-distance
424 interactions were active in CEP at least until the 15th
425 century AD.

427 7. Conclusion

428
429 Long-distance transfers of stone adzes in Central
430 Polynesia were first interpreted in the terms of independent
431 "interaction spheres" in CEP (Rolett, 2002; Weisler, 1998,

32 2002). To the contrary, our data and a number of more
33 recent studies (Clark et al., 2014; Collerson and Weisler,
34 2007; McAlister et al., 2014; Weisler et al., 2016a) indicate
35 that early inter-archipelago interactions extended beyond
36 the limits of restricted regions.

37 Furthermore, we provide a clear chronological
38 context for an adze imported from Eiao to Tupua'i. This
39 directly corresponds to Weisler et al.'s (2016a) recent call
40 for more stratigraphic sequences with imported material as
41 necessary for better understanding the nature and the
42 evolution of early inter-community interactions in CEP.

43 Additionally, our methods described here
44 demonstrate that an integrated use of geological data in
45 provenance studies help to unambiguously assign a source
46 to a given artefact, and thus to refine current understanding
47 of the spatial extent of adze production processes and inter-
48 community exchange systems among Eastern Polynesian
49 chiefdoms.

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52
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471
472
473 **References**

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Figure Legends

Fig. 1: Bathymetric map of Central Eastern Polynesia showing its linear island chains and the - 4,000 m isobath. The names of the islands discussed in this paper (**Tupua'i**, **Mangaia**, **Eiao**, **Rapa Iti**) are in bold characters and their age spans in italics. Hotspot locations are shown as red empty circles.

Fig. 2: **Geological map of Tupua'i (modified from Maury et al., 2000)** showing numbered archaeological samples (red crosses) collected by Hermann between 2010 and 2012, and geological samples (blue crosses) collected by BRGM between 1989 and 1995.

Fig. 3: Plots of TiO_2 versus MgO for the different clusters of Tupua'i stone artefacts and possible sources of procurement. Red crosses correspond to geological samples (TB=Tupua'i, RV=Raivavae, MAN=Mangaia, RI=Rapa Iti) and red squares to quarry sites samples. Circles correspond to archaeological artefacts (grey for the Atiahara site and white for surface finds in Tupua'i). Eiao sD samples are from Duncan et al. (1986), Eiao FC-05-11 is from Collerson and Weisler (2007). Rapa Iti sample is from Palacz and Saunders (1986). Ra'ivavae samples are from Maury et al. (2013). **Error bars are indicated unless smaller than data points.**

Fig. 4: Incompatible element patterns of selected artefacts from Atiahara site and of some of their potential sources. Eiao data are from Weisler and colleagues (2016). Patterns are normalized to the Primitive Mantle (Sun and McDonough, 1989).

Fig. 5: Plots of Pb and Sr isotopic compositions for CEP islands. Stars and squares surrounded by red contours represent archaeological samples analyzed in this paper. Error bars (2σ) are smaller than data points. For each diagrams G stands for granulate and P for powder. Geological data is from the GEOROC database (<http://georoc.mpchmainz.gwdg.de/georoc/>).

Fig. 6: Magnified plot of Pb and Sr isotopic compositions for CEP islands. Red star represents sample At3-317-065, red and black crosses represent Eiao data. Sample KC-05-11 is a flake originally collected by archaeologist R. Suggs on Eiao (Weisler, pers. com.), and sample D-465 is an Eiao adze found in Makatea: both analyses were published by Collerson and Weisler (2007). Samples 2012-563 and 2012-573 were collected by M. Charleux and published by Weisler and colleagues (2016). Error bars (2σ) are smaller than data points. Geological data is from the GEOROC database (<http://georoc.mpchmainz.gwdg.de/georoc/>).

Fig. 7: Island ages and isochron dating of artefacts. Geochronological data are from Dalrymple et al. (1975), Turner & Jarrard (1982), Diraison (1991), Maury et al. (2000), Caroff et al. (1999).

Figure 1 :



Figure 2 :

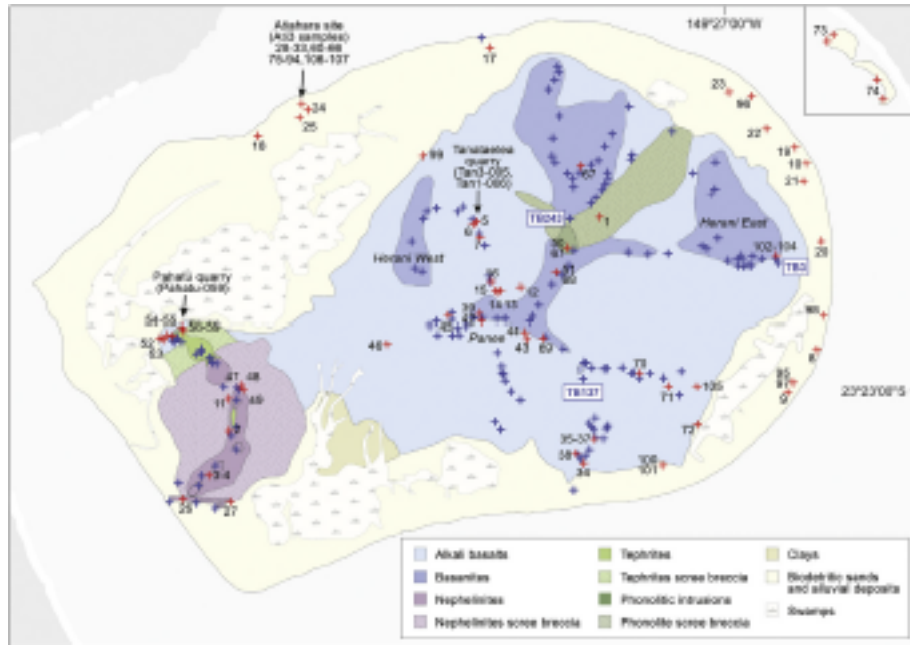


Figure 3 :

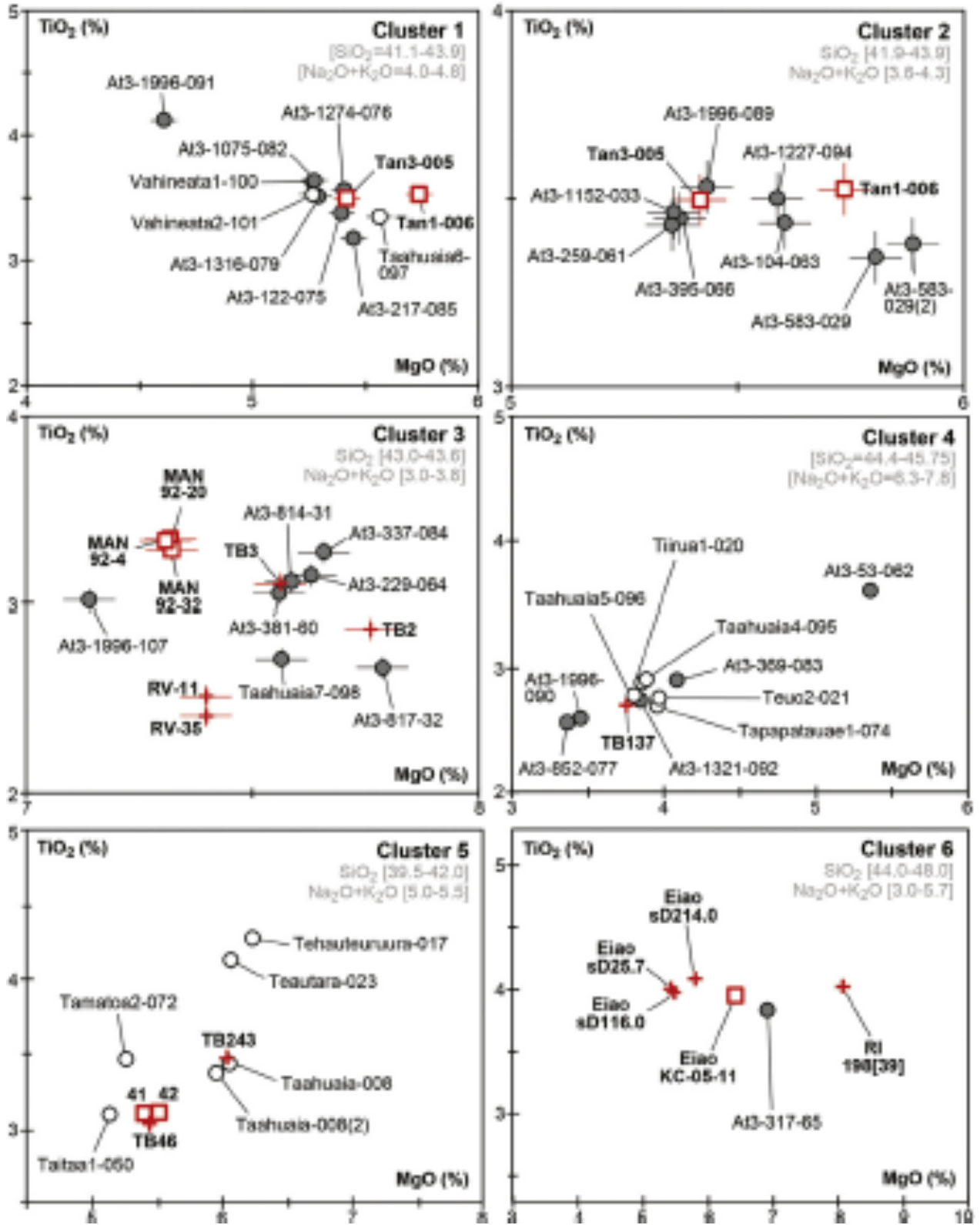


Figure 4 :

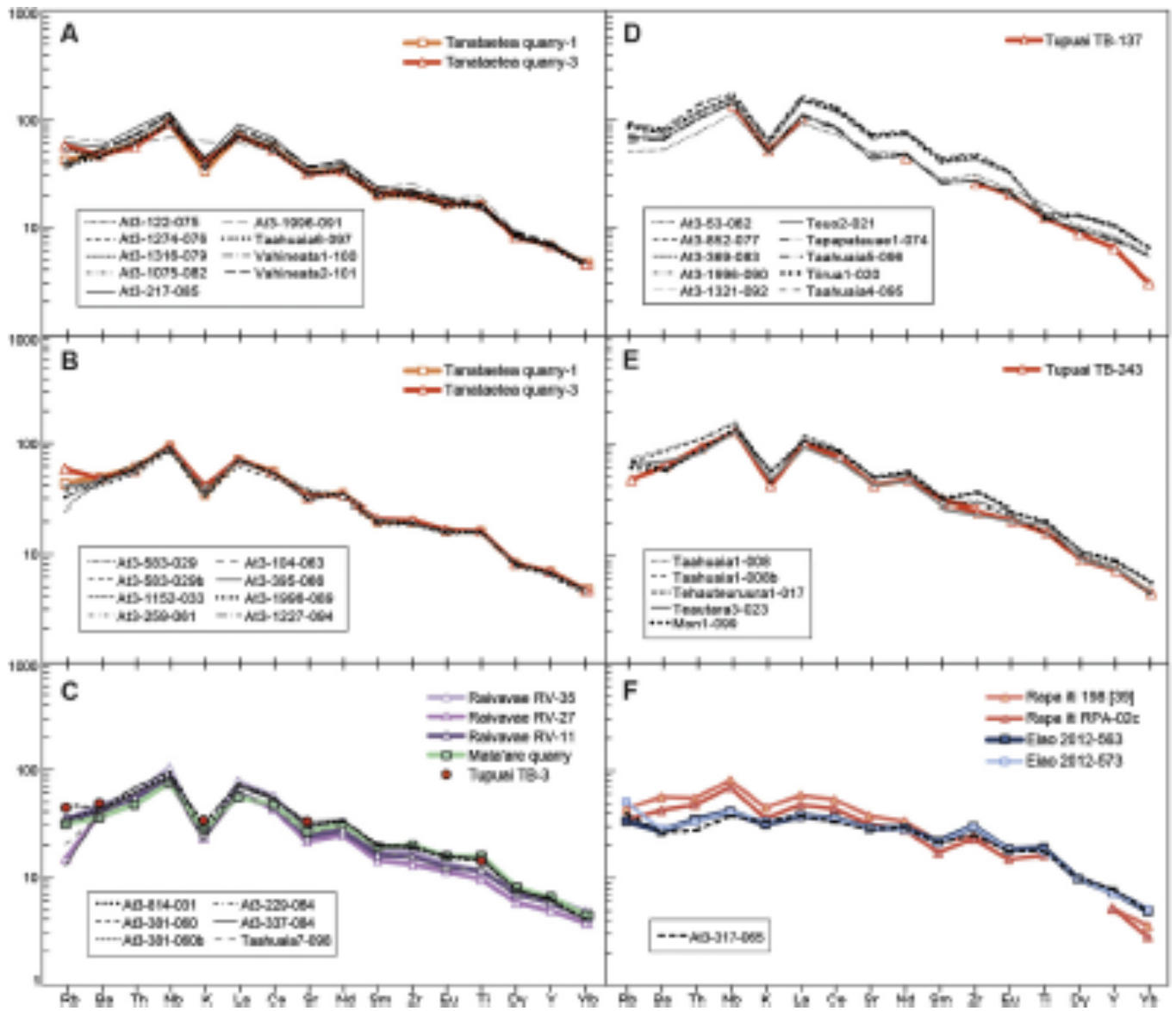


Figure 5 :

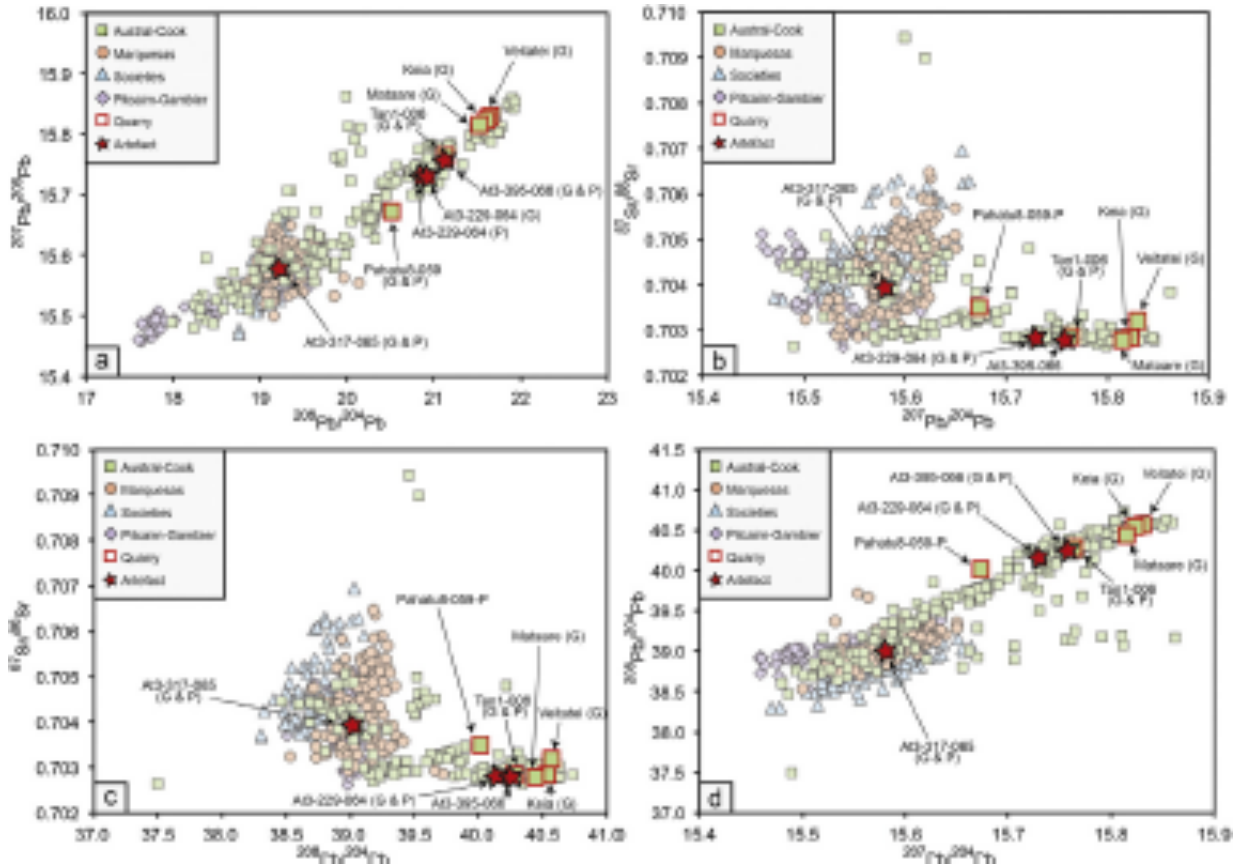


Figure 6 :

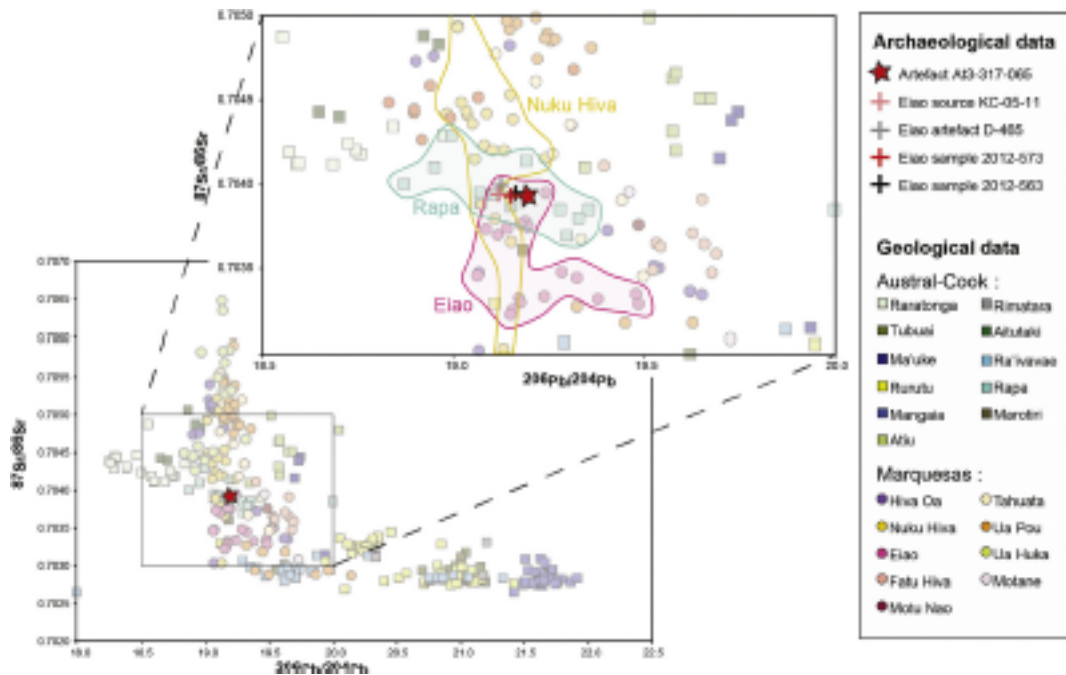


Figure 7 :



Tables Legends

Table 1: List, GPS location and description of archaeological samples collected in Tupua'i.

Table 2: Major element oxide values (wt%) and trace element values (ppm) of Tupua'i artefacts.

Table 3: Major element oxide values (wt%) and trace element values (ppm) of related sources.

Table 4: Sr and Pb isotopic ratios of artefacts and related sources.

Table 5: Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ data from incremental heating experiments.

Table 1 - List, GPS location and description of archaeological samples collected in Tupua'i.

Sample no.	Sample type	Site, Provenience	Coordinates (UTM)	Alt.	Description
Tan3-005	Artefact	Tanataetea workshop	6 K 246605 7414013	49 m	Adze preform type 3A
Tan1-006	Artefact	Tanataetea quarry	6 K 246591 7413998	53 m	Natural prism
Taahuaia1-008	Artefact	Field Taahuaia	6 K 250777 7412610	5 m	Adze fragment distal
Tehauteuruura1-017	Artefact	Field Mataura	6 K 246806 7415934	4 m	Adze type 1A (12 cm)
Tiirua1-020	Artefact	Field Taahuaia	6 K 250840 7413757	4 m	Adze fragment distal (6 cm)
Teuo2-021	Artefact	Field Taahuaia	6 K 250641 7414663	5 m	Adze fragment type 1A distal (8 cm)
Teautara3-023	Artefact	Field Taahuaia	6 K 249593 7415533	4 m	Adze type 2C (5 cm)
At3-583-029	Artefact	Atiahara, Layer 3 (K5)	6 K 244479 7415453	-	Massive flake fragment
At3-814-031	Artefact	Atiahara, Layer 4 (Q5)	6 K 244479 7415453	-	Adze
At3-817-032	Artefact	Atiahara, Layer 4 (Q5)	6 K 244479 7415453	-	Prism
At3-1152-033	Artefact	Atiahara, Layer 4 (W3)	6 K 244479 7415453	-	Adze preform (fragment)
PaneeSouth-041	Geological	Dyke Panee south 1	6 K 246721 7412828	338 m	Dyke
PaneeSouth-042	Geological	Dyke Panee south 2	6 K 246735 7412845	344 m	Dyke
Taitaa1-050	Artefact	Taitaa summit 1	6 K 247725 7413705	418 m	Flakes
Taitaa2-051	Artefact	Taitaa summit 2	6 K 247643 7413485	416 m	Flakes
Pahatu2-053	Artefact	Petit Pahatu workshop 1	6 K 242813 7412629	35 m	Adze fragment (preform)
Pahatu8-059	Artefact	Petit Pahatu workshop 3	6 K 243032 7412771	13 m	Adze preforms, flakes
At3-381-060	Artefact	Atiahara, Layer 3 (H4)	6 K 244479 7415453	-	Adze preform
At3-259-061	Artefact	Atiahara, Layer 1/surf	6 K 244479 7415453	-	Adze preform
At3-53-062	Artefact	Atiahara, Layer 5 (N12)	6 K 244479 7415453	-	Adze preform
At3-104-063	Artefact	Atiahara, Layer 6 (N13)	6 K 244479 7415453	-	Flakes
At3-229-064	Artefact	Atiahara, Layer 7 (L14)	6 K 244479 7415453	-	Polished adze fragment
At3-317-065	Artefact	Atiahara, Layer 3 (B3)	6 K 244479 7415453	-	Adze fragment
At3-395-066	Artefact	Atiahara, Layer 4/5 (H2)	6 K 244479 7415453	-	Adze fragment
Tamatoa2-072	Artefact	Surface, Field Tamatoa 2	6 K 249306 7411711	10 m	Flakes
Tapapatauae1-074	Artefact	Motu Tapapatauae, shore	6 K 253781 7415930	-1 m	Flakes
At3-122-075	Artefact	Atiahara, Layer 5 (M13)	6 K 242774 7412337	-	Adze roughout
At3-1274-076	Artefact	Atiahara, Layer 4/5 (X2)	6 K 244479 7415453	-	Polished adze fragment
At3-852-077	Artefact	Atiahara, Layer 3 (F1)	6 K 244479 7415453	-	Adze preform
At3-1316-079	Artefact	Atiahara, Layer 4 (V1)	6 K 244479 7415453	-	Flake
At3-1075-082	Artefact	Atiahara, Layer 4/5 (Q3)	6 K 244479 7415453	-	Polished adze fragment

At3-369-083	Artefact	Atiahara, Layer 3 (J4)	6 K 244479 7415453	-	Adze preform (fragment)
At3-337-084	Artefact	Atiahara, Layer 3 (L10)	6 K 244479 7415453	-	Polished adze fragment
At3-217-085	Artefact	Atiahara, Layer 6 (L12)	6 K 244479 7415453	-	Adze roughout
At3-1996-089	Artefact	Atiahara, Layer 3 (K11)	6 K 244479 7415453	-	Adze preform (fragment)
At3-1996-090	Artefact	Atiahara4, surface	6 K 244479 7415453	-	Adze preform (fragment)
At3-1996-091	Artefact	Atiahara, Layer 3 (K13)	6 K 244479 7415453	-	Adze preform (fragment)
At3-1321-092	Artefact	Atiahara, Layer 5 (T1)	6 K 244479 7415453	-	Adze preform (fragment)
At3-1227-094	Artefact	Atiahara, Layer 4 (Y2)	6 K 244479 7415453	-	Adze preform (fragment)
Taahuaia4-095	Artefact	Field Taahuaia	6 K 250482 7412134	4 m	Adze preform (fragment)
Taahuaia5-096	Artefact	Dry riverbed Taahuaia	6 K 249991 7415499	3 m	Adze roughout (fragment)
Taahuaia6-097	Artefact	Field Taahuaia	6 K 250443 7412081	5 m	Flake
Taahuaia7-098	Artefact	Field Taahuaia	6 K 250840 7412876	6 m	Adze preform
Mon1-099	Artefact	Surface, chez Monette	6 K 246017 7414889	12 m	Adze preform
Vahineata1-100	Artefact	Vahineata,FieldTamatoa1	6 K 248878 7411067	14 m	Adze
Vahineata2-101	Artefact	Vahineata,FieldTamatoa2	6 K 248878 7411067	14 m	Adze
Reretii-102	Geological	Reretii	6 K 250252 7413593	60 m	Prism
At3-1996-107	Artefact	Atiahara, Layer 5 (O11)	6 K 244479 7415453	-	Dyke

Table 2- Major element oxide values (wt%) and trace element values (ppm) of Tupua'i artefacts

Sample	Location	Petrographic group	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
At3-583-029	Atiahara, layer 3 (K5)	Basanite	42.87	3.345	15.37	14.15	0.200	5.80	11.34	2.91	1.13	0.461	1.67	99.26
At3-583-029b	Atiahara, layer 3 (K5)	Basanite	41.92	3.382	14.74	14.25	0.200	5.89	11.44	2.73	0.95	0.436	3.44	99.38
At3-814-031	Atiahara, layer 4 (Q5)	Basanite	43.09	3.116	13.18	13.86	0.201	7.51	13.22	2.78	0.89	0.481	0.89	99.22
At3-817-032	Atiahara, layer 4 (Q5)	Basanite	44.51	2.670	11.89	12.82	0.201	8.73	13.75	2.00	0.65	0.345	1.47	99.03
At3-1152-033	Atiahara, layer 4 (W3)	Basanite	42.88	3.448	15.78	15.40	0.216	5.37	10.81	3.08	0.98	0.508	0.97	99.44
At3-381-060	Atiahara, layer 3 (H4)	Basanite	43.37	3.060	13.26	13.80	0.202	7.36	12.85	2.77	0.93	0.486	1.07	99.16
At3-381-060b	Atiahara, layer 3 (H4)	Basanite	43.18	3.053	13.11	13.60	0.197	7.31	12.37	2.79	0.93	0.475	1.07	98.10
At3-259-061	Atiahara, layer 1/surf	Basanite	42.86	3.464	15.83	15.45	0.217	5.36	11.01	3.13	1.06	0.506	0.50	99.38
At3-53-062	Atiahara, layer 5 (N12)	Tephrite	45.19	3.609	15.19	15.31	0.217	5.36	7.23	4.72	1.45	0.816	0.46	99.56
At3-104-063	Atiahara, layer 6 (N13)	Basanite	42.67	3.436	15.74	15.27	0.215	5.60	10.62	2.96	1.16	0.502	1.10	99.27
At3-229-064	Atiahara, layer 7 (L14)	Basanite	43.45	3.158	13.05	14.00	0.202	7.78	13.24	2.73	0.79	0.488	0.87	99.75
At3-317-065	Atiahara, layer 3 (B3)	Alkali basalt	47.12	3.85	14.92	13.67	0.168	6.93	9.18	3.27	1.01	0.51	-0.39	100.24
At3-395-066	Atiahara, layer 4/5 (H2)	Basanite	42.34	3.430	15.76	15.36	0.213	5.35	10.80	3.11	1.01	0.493	0.73	98.59
At3-122-075	Atiahara, layer 5 (M13)	Basanite	43.40	3.379	16.12	15.03	0.213	5.39	10.19	3.29	1.36	0.493	1.08	99.94
At3-1274-076	Atiahara, layer 4/5 (X2)	Basanite	43.49	3.564	16.05	15.60	0.218	5.41	10.60	3.64	1.16	0.488	-0.47	99.76
At3-852-077	Atiahara, layer 3 (F1)	Tephrite	45.76	2.574	15.36	14.09	0.243	3.36	7.23	6.44	2.00	1.798	0.22	99.08
At3-1316-079	Atiahara, layer 4 (V1)	Basanite	43.28	3.512	15.88	15.47	0.217	5.29	10.60	3.45	1.34	0.504	0.47	100.02
At3-1075-082	Atiahara, layer 4/5 (Q3)	Basanite	43.81	3.639	15.67	14.65	0.209	5.28	10.48	3.97	1.05	0.558	0.04	99.35
At3-369-083	Atiahara, layer 3 (J4)	Tephrite	45.03	2.900	15.11	14.74	0.240	4.08	7.81	5.38	1.88	1.914	0.89	99.97
At3-337-084	Atiahara, layer 3 (L10)	Basanite	43.35	3.282	12.82	14.08	0.202	7.93	13.61	2.66	0.64	0.448	0.43	99.46

At3-217-085	Atiahara, layer 6 (L12)	Basanite	43.45	3.177	15.89	14.80	0.227	5.45	10.97	3.77	1.30	0.604	0.49	100.13
At3-1996-089	Atiahara, layer 3 (K11)	Basanite	42.79	3.531	15.68	15.60	0.219	5.43	11.00	3.08	0.97	0.470	0.87	99.65
At3-1996-090	Atiahara4, surface	Tephrite	46.35	2.609	15.41	14.19	0.249	3.45	7.37	6.18	2.01	1.803	0.10	99.72
At3-1996-091	Atiahara, layer 3 (K13)	Basanite	43.14	4.122	15.26	14.10	0.197	4.61	10.86	2.69	1.86	0.581	3.13	100.55
At3-1321-092	Atiahara, layer 5 (T1)	Tephrite	45.57	2.746	17.09	13.21	0.243	3.85	9.80	4.85	1.51	0.744	0.99	100.60
At3-1227-094	Atiahara, layer 4 (Y2)	Basanite	42.99	3.501	15.84	15.33	0.217	5.59	10.50	3.30	0.98	0.494	1.11	99.86
At3-1996-107	Atiahara, layer 5 (O11)	Picrite	37.31	3.023	12.32	17.94	0.310	4.86	12.75	1.96	0.33	1.520	6.65	98.96
Taahuaia1-008	Field Taahuaia	Low silica basanite	41.86	3.452	14.03	14.59	0.198	6.04	12.34	4.04	1.33	0.800	2.24	100.92
Taahuaia1-008b	Field Taahuaia	Low silica basanite	40.79	3.384	13.81	14.03	0.189	5.95	11.87	3.98	1.31	0.771	2.24	98.32
Tehauteuruura1-017	Field Mataura	Low silica basanite	41.56	4.281	14.65	16.84	0.230	6.22	7.89	4.68	1.69	1.212	0.28	99.54
Tiirua1-020	Field Taahuaia	Tephrite	45.42	2.894	15.09	14.85	0.238	3.86	7.90	5.99	1.83	1.917	-0.25	99.74
Teuo2-021	Field Taahuaia	Tephrite	45.60	2.768	17.00	13.26	0.235	3.97	9.66	4.88	1.49	0.758	0.48	100.10
Teautara3-023	Field Taahuaia	Low silica basanite	41.47	4.138	15.01	14.91	0.215	6.06	11.05	4.21	1.43	0.651	0.51	99.65
Taitaa1-050	Taitaa-1	Low silica basanite	41.86	3.097	15.04	14.22	0.218	5.13	10.97	4.16	1.36	0.770	2.59	99.40
Taitaa2-051	Taitaa-2	Basanite	43.23	2.356	11.44	13.31	0.200	11.80	12.91	2.19	0.70	0.385	1.47	99.99
Tamatoa2-072	Field Tamatoa	Low silica basanite	42.25	3.469	16.04	14.15	0.233	5.26	10.08	4.36	1.40	0.640	0.77	98.64
Tapapatauae1-074	Motu Tapapatauae	Tephrite	45.23	2.709	17.10	12.99	0.232	3.95	9.25	4.96	1.50	0.754	0.42	99.10
Taahuaia4-095	Field Taahuaia	Tephrite	44.43	2.906	14.89	14.55	0.236	3.87	7.51	5.50	1.77	1.801	1.30	98.77
Taahuaia5-096	Dry riverbed Taahuaia	Tephrite	45.22	2.792	16.71	13.35	0.241	3.80	9.51	4.81	1.48	0.722	1.74	100.37
Taahuaia6-097	Field Taahuaia	Basanite	43.10	3.351	15.21	14.38	0.202	5.57	11.68	2.94	1.15	0.479	1.57	99.63
Taahuaia7-098	Field Taahuaia	Basanite	43.02	2.720	13.85	14.32	0.210	7.40	13.18	2.46	0.66	0.355	1.48	99.66
Mon1-099	Huahine, Monette's	Low silica basanite	41.46	4.358	14.50	16.77	0.234	5.98	7.76	4.93	1.68	1.190	0.40	99.26
Vahineata1-100	Field Tamatoa	Basanite	43.84	3.629	15.50	14.79	0.219	5.27	10.48	3.80	1.04	0.542	0.63	99.73
Vahineata2-101	Field Tamatoa	Basanite	43.67	3.553	15.04	14.79	0.211	5.27	10.98	3.54	1.02	0.550	2.01	100.62

Table 2- cont.

Sample	Rb	Sr	Ba	Sc	V	Cr	Co	Ni	Y	Zr	Nb	La	Ce	Nd	Sm	Eu	Gd	Dy	Er	Yb	Th
At3-583-029	25	795	301	21	334	13	46	55	29	211	62	46	93	45	9.0	2.7	7.9	5.9	2.9	2.1	5.0
At3-583-029b	24	760	278	22	341	20	47	57	29	207	59	41	84	41	8.3	2.6	7.4	5.7	2.9	2.1	4.4
At3-814-031	21	641	296	31	319	153	49	104	29	209	64	49	95	45	8.9	2.6	7.6	5.7	2.8	2.0	5.2
At3-817-032	20	447	181	43	355	366	53	132	25	168	41	31	65	33	6.8	2.1	6.2	4.8	2.7	1.9	2.7
At3-1152-033	16	634	310	19	390	3	48	29	30	217	66	48	95	46	8.8	2.6	7.6	6.0	2.7	2.2	4.8

At3-381-060	31	607	302	32	315	151	50	103	29	218	69	50	98	46	9.1	2.6	7.8	5.6	2.7	2.0	5.7
At3-381-060b	28	622	301	31	317	154	50	103	28	218	67	51	97	46	8.9	2.6	7.6	5.8	2.6	2.1	5.8
At3-259-061	23	646	316	19	390	4	43	30	30	220	67	48	93	46	9.0	2.7	7.6	6.1	3.0	2.3	5.0
At3-53-062	32	1035	368	13	152	3	34	12	38	342	81	64	129	64	12.4	3.8	10.3	7.4	3.7	2.8	6.6
At3-104-063	25	638	307	18	379	3	47	30	29	215	66	48	93	46	9.2	2.7	7.9	6.0	3.2	2.2	4.7
At3-229-064	20	617	279	33	341	160	51	107	29	211	62	48	94	46	8.7	2.7	7.8	5.7	2.8	2.0	5.0
At3-317-065	26	603	187	22	307	71	47	115	36	284	27	26	61	40	9.3	3.0	9.4	7.3	3.7	2.4	2.4
At3-395-066	26	621	302	19	382	4	48	30	30	215	65	47	93	46	9.0	2.6	7.6	6.0	2.8	2.3	4.6
At3-122-075	34	681	335	18	370	3	46	28	31	230	74	51	101	48	9.2	2.8	7.8	6.1	2.8	2.4	5.9
At3-1274-076	24	664	314	19	397	3	49	29	30	218	66	48	97	47	9.2	2.8	7.7	5.9	2.8	2.3	5.2
At3-852-077	58	1564	586	7	71	2	24	3	49	545	125	115	236	106	19.4	5.5	14.6	9.6	4.2	3.3	11.7
At3-1316-079	32	635	314	19	388	3	49	31	31	220	68	49	98	47	8.8	2.7	7.9	6.0	2.9	2.3	5.5
At3-1075-082	25	779	367	19	332	12	46	42	32	235	78	57	113	53	10.6	3.1	8.8	6.5	3.0	2.3	6.3
At3-369-083	58	1470	521	8	104	3	28	6	47	485	112	106	221	102	18.7	5.4	14.3	9.3	4.2	3.1	10.4
At3-337-084	8	690	277	34	354	168	53	113	28	211	59	47	94	46	8.6	2.7	7.6	5.7	2.8	2.0	5.1
At3-217-085	38	772	390	16	325	7	47	46	32	250	85	62	121	56	10.5	3.1	8.5	6.3	3.0	2.4	7.0
At3-1996-089	20	628	298	19	400	21	49	30	30	216	64	47	93	46	8.9	2.7	7.6	6.0	3.1	2.3	4.9
At3-1996-090	59	1542	563	7	74	17	24	5	49	535	127	115	228	106	19.0	5.5	14.9	9.7	4.3	3.2	11.4
At3-1996-091	44	738	442	16	378	23	40	53	33	290	48	42	90	51	10.5	3.1	9.4	6.8	3.2	2.3	5.0
At3-1321-092	39	931	479	8	168	7	30	4	36	301	104	77	145	64	11.3	3.4	9.4	7.0	3.6	2.6	9.2
At3-1227-094	20	730	323	19	383	4	49	30	30	216	67	48	94	47	8.7	2.8	7.6	6.0	2.6	2.3	5.3
At3-1996-107	12	1244	504	9	142	6	51	167	56	561	213	170	320	134	23.4	6.7	17.8	11.7	4.9	3.4	20.6
Taahuaia1-008	47	1029	628	19	307	58	48	78	35	329	117	83	159	70	13.3	3.8	10.3	7.2	3.2	2.1	9.7
Taahuaia1-008b	44	1014	596	19	300	56	46	75	34	319	113	84	160	71	13.2	3.8	10.7	7.3	3.3	2.0	9.5
Tehauteuru1-017	45	1044	407	14	209	9	46	40	39	395	98	75	153	74	13.9	4.2	11.7	7.9	3.8	2.8	7.2

Tiirua1-020	54	146 8	540	8	112	3	28	6	46	489	115	105	214	99	18.1	5.3	14.8	9.4	4.2	3.2	10.1
Teuo2-021	43	910	483	9	176	3	31	2	36	305	103	77	146	64	11.7	3.4	9.6	6.9	3.4	2.7	8.7
Teautara3-023	41	883	486	17	373	4	48	51	33	261	94	65	126	61	11.8	3.4	9.9	6.6	3.0	2.2	7.1
Taitaa1-050	49	996	560	14	242	9	45	57	34	329	124	90	163	70	12.5	3.7	10.4	7.1	3.5	2.5	11.4
Taitaa2-051	24	507	245	34	304	666	59	303	24	172	54	41	81	39	7.41	2.3	6.4	4.9	2.6	1.8	4.2
Tamatoa2-072	35	879	457	13	292	3	39	13	33	256	91	66	128	59	11.5	3.3	9.3	6.7	3.1	2.4	7.0
Tapapatauae1-074	45	974	448	8	164	2	29	2	34	301	104	78	150	64	11.7	3.6	9.8	7.0	3.3	2.7	8.8
Taahuaia4-095	47	140 7	527	8	100	13	29	8	47	485	114	102	206	98	17.9	5.2	13.8	9.2	4.1	3.1	10.1
Taahuaia5-096	40	901	468	9	178	14	31	12	36	304	103	75	142	64	11.5	3.4	9.4	6.9	3.4	2.6	8.7
Taahuaia6-097	24	663	309	21	334	18	48	56	30	219	64	46	91	45	8.5	2.7	7.6	6.0	2.9	2.2	5.2
Taahuaia7-098	13	563	262	33	377	45	53	82	27	170	54	41	79	39	7.5	2.2	6.2	5.1	3.0	2.1	4.6
Mon1-099	39	105 7	397	14	212	25	48	45	40	408	100	75	152	76	13.8	4.1	11.1	7.9	3.9	2.7	7.6
Vahineata1-100	23	770	367	19	334	24	46	45	32	236	79	55	108	52	9.7	3.1	8.6	6.4	2.8	2.2	5.9
Vahineata2-101	24	791	372	18	325	24	46	44	32	239	81	56	109	53	10.5	3.2	9.3	6.7	3.0	2.2	6.1

Table 3 - Major element oxide values (wt%) and trace element values (ppm) of related sources.

Sample	Archipelago	Island	Location	Sample type	Petrographic group	Petrographic											LOI	Total
						SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅			
Tan3-005	Austral-Cook	Tupua'i	Tanataete a workshop	Quarry	Basanite	43.71	3.496	15.86	15.75	0.220	5.42	11.18	3.29	1.18	0.505	0.41	101.02	
Tan1-006	Austral-Cook	Tupua'i	Tanataete a quarry	Quarry	Basanite	43.93	3.529	15.86	15.92	0.230	5.74	10.89	3.33	0.99	0.529	0.59	101.55	
Pahatu2-053	Austral-Cook	Tupua'i	Pahatu workshop 1	Quarry	Phonolite	57.37	0.024	18.58	5.38	0.247	0.09	0.85	8.72	4.70	0.051	2.41	98.43	
Pahatu8-059	Austral-Cook	Tupua'i	Pahatu workshop 3	Quarry	Phonolite	59.20	0.040	18.47	5.99	0.302	0.08	1.08	8.63	4.36	0.045	2.33	100.53	

PaneeSouth-041	Austral-Cook	Tupua'i	Panee south slope	Geological	Low silica basanite	41.76	3.123	14.92	14.42	0.215	5.38	11.11	5.09	1.40	0.780	1.17	99.37
PaneeSouth-041b	Austral-Cook	Tupua'i	Panee south slope	Geological	Low silica basanite	41.36	3.071	14.73	14.22	0.212	5.36	10.88	5.05	1.40	0.774	1.17	98.24
PaneeSouth-042	Austral-Cook	Tupua'i	Panee south slope	Geological	Low silica basanite	41.39	3.131	14.89	14.12	0.212	5.49	11.12	4.43	1.53	0.770	1.67	98.76
Reretii-102	Austral-Cook	Tupua'i	Herani cliff	Geological	Tephrite	45.23	2.745	16.93	13.16	0.237	3.83	9.58	4.83	1.49	0.748	1.10	99.89
TB-2	Austral-Cook	Tupua'i	Reretii	Geological	Basanite	44.00	2.880	12.32	13.86	0.200	8.56	12.55	1.66	0.40	0.490	3.13	100.05
TB-3	Austral-Cook	Tupua'i	Reretii	Geological	Basanite	43.40	3.110	13.80	14.45	0.203	7.37	12.00	2.77	1.02	0.510	1.47	100.10
TB-46	Austral-Cook	Tupua'i	Panee	Geological	Low silica basanite	41.65	3.070	14.98	14.78	0.230	5.44	11.13	4.29	1.36	0.850	1.41	99.19
TB-137	Austral-Cook	Tupua'i	Panee south ridge	Geological	Tephrite	45.75	2.700	17.30	13.21	0.250	3.75	9.43	4.85	1.55	n.a	1.18	99.97
TB-243	Austral-Cook	Tupua'i	Taitaa north ridge	Geological	Low silica basanite	41.10	3.480	15.35	14.90	0.230	6.03	11.34	3.95	1.25	0.650	1.36	99.64
Mata'are (a)	Austral-Cook	Mangaia	Mata'are	Geological	Basanite	44.029	3.353	15.11	14.38	0.195	5.583	11.40	3.16	0.83	0.450	1.36	99.85
Keia (a)	Austral-Cook	Mangaia	Keia	Geological	Basanite	45.570	1.807	16.93	11.58	0.202	2.360	7.64	3.28	1.84	0.840	7.18	99.23
Veitatei (a)	Austral-Cook	Mangaia	Veitatei	Geological	Basanite	44.814	3.274	13.39	12.92	0.196	5.370	10.84	2.75	1.06	0.45	4.34	99.41
92-32 (b)	Austral-Cook	Mangaia	Mata'are	Quarry	Basanite	44.87	3.288	14.45	13.16	0.186	5.93	12.21	3.01	0.82	0.437	n.a	98.36
92-20 (b)	Austral-Cook	Mangaia	Mata'are	Quarry	Basanite	45.20	3.349	15.21	13.09	0.197	5.89	11.66	3.44	0.84	0.456	n.a	99.33
92-4 (b)	Austral-Cook	Mangaia	Mata'are	Quarry	Basanite	45.08	3.344	15.04	13.17	0.200	5.87	11.60	3.28	0.82	0.454	n.a	98.86
2009-330-b (c)	Austral-Cook	Mangaia	Mata'are valley	Quarry	-	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
2009-331-b (c)	Austral-Cook	Mangaia	Mata'are valley	Geological	-	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
RV-11 (d)	Austral-Cook	Ra'ivavae	Rairua	Geological	Basanite	44.60	2.520	15.60	12.70	0.180	6.40	12.40	2.63	0.77	0.340	1.54	99.68
RV-27 (d)	Austral-Cook	Ra'ivavae	Rairua	Geological	Basanite	43.86	2.067	13.53	12.45	0.196	10.45	12.01	2.17	0.70	0.314	1.73	99.47
RV-35 (d)	Austral-Cook	Ra'ivavae	Rairua	Geological	Basanite	43.70	2.410	15.50	13.50	0.213	6.40	12.26	2.62	0.70	0.410	1.70	99.41
KC-05-11 (e)	Marquesas	Eiao	Surface	Artefact	Alkali basalt	47.83	3.96	15.44	n.a	0.170	6.41	9.22	3.33	1.05	0.54	n.a	87.95
2012-563	Marquesas	Eiao	Surface	Artefact	Alkali	48.8	4.12	15.48	13.93	0.171	6.54	9.64	3.14	0.961	0.592	n.a	103.38

(f)	as				basalt													
2012-573	Marques	Eiao	Surface	Artefact	Alkali basalt	46.45	3.89	14.71	13.20	0.162	6.34	9.11	3.02	1.01	0.54	n.a	98.44	
(f)	as				basalt													
198-39	Austral-	Rapa iti	Surface	Geologi	Alkali basalt	44.2	4.03	14	12.88	0.150	8.1	10.86	2.6	1.37	0.61	n.a	98.8	
(g)	Cook				basalt													
RPA-02	Austral-	Rapa iti	Surface	Geologi	Alkali basalt	44	3.58	11.69	13.55	0.160	13.1	9.95	2.46	1.07	0.59	0.5	100.65	
(h)	Cook				basalt													

*References : (a) This study (sampled by PV Kirch) ; (b) Weisler et al. (1994) ; (c) Weisler et al. (2016a) ; (d) Maury et al. (2013) ; (e) Collerson & Weisler, (2007) ; (f) Weisler et al. (2016b) ; (g) Palacz & Saunders (1986) ; (h) Liotard (1988).

Table 3 - Cont.

Sample	Rb	Sr	Ba	Sc	V	Cr	Co	Ni	Y	Zr	Nb	La	Ce	Nd	Sm	Eu	Gd
Tan3-005	36	666	325	19	395	4	52	30	31	225	67	48	93	45	9.2	2.8	7.9
Tan1-006	27	675	337	19	392	3	52	30	31	223	67	48	97	46	8.9	2.7	8.1
Pahatu2-053	321	94	380	0.1	3	2	0	0	66	1588	395	275	470	131	18.1	3.8	12.7
Pahatu8-059	275	182	850	0.1	4	2	0.6	0.7	58	1391	373	268	444	128	18.2	3.8	12.4
Paneesouth-041	49	856	533	14	248	10	45	55	36	330	120	91	169	72	12.6	3.7	10.6
Paneesouth-041b	52	836	522	14	245	10	41	55	35	328	118	90	167	72	13.1	3.7	10.0
Paneesouth-042	62	856	553	15	253	15	47	56	37	331	120	90	168	71	12.7	3.8	10.8
Reretii-102	40	890	461	8	172	7	31	3	36	301	105	76	145	64	11.3	3.4	9.1
TB-2	20	497	335	n.a	288	232	56	127	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
TB-3	28	694	340	n.a	318	162	55	127	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
TB-46	48	910	315	15	265	≤10	50	55	38	326	119	90	n.a	72	n.a	3.4	n.a
TB-137	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	29	283	96	71	n.a	60	n.a	3.4	n.a
TB-243	30	870	445	16	342	9	48	33	33	275	96	70	135	63	13.4	3.5	n.a
Mata'are (a)	20	555	249	25	331	30	47	49	30	218	53	39	83	43	8.5	2.6	7.9
Keia (a)	36	877	534	4	49	3	19	5	37	379	102	82	157	69	12.2	3.5	9.6
Veitatei (a)	23	463	287	31	335	492	74	344	28	218	59	43	90	46	9.6	2.7	8.0
92-32 (b)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
92-20 (b)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
92-4 (b)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
2009-330-b (c)	35	698	337	20	304	29	42	61	28	228	59	47	97	45	8.9	2.7	8.0
2009-331-b (c)	18	560	247	26	325	28	48	44	28	221	55	38	82	41	8.4	2.8	7.8
RV-11 (d)	22	515	280	30	340	95	48	79	27	173	58	41	80	37	7.1	2.1	6.2

RV-27 (d)	10	457	265	33	282	461	55	197	23	146	57	41	76	34	6.3	1.9	5.4
RV-35 (d)	21	582	325	26	329	35	48	60	29	190	73	53	100	44	7.7	2.3	6.7
KC-05-11 (e)	9	421	133	31	324	193	43	77	31	256	24	20	49	33	8.5	2.8	8.5
2012-563 (f)	21	609	194	22	295	74	46	90	34	342	29	26	64	39	9.6	3.1	9.4
2012-573 (f)	32	612	196	22	309	81	45	94	33	342	29	26	63	39	9.5	3.1	9.4
198-39 (g)	28	795	403	n.a	n.a	325	n.a	169	24	278	57	40	96	46	9.8	3.2	n.a
RPA-02 (h)	22	670	296	23	225	391	71	253	24	260	50	33	77	39	7.6	2.5	n.a

Table 4-1: Sr and Pb isotopic ratios of artefacts and related sources (This study)

Archipelago	Island	Sample no.*	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\sigma$	$^{208}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$
Austral	Tubuai	At3-229-064-P	0.702804	0.000008	40.127	0.002
Austral	Tubuai	At3-229-064-G	0.702803	0.000008	40.201	0.002
Austral	Tubuai	At3-317-065-P	0.703912	0.000008	38.996	0.002
Austral	Tubuai	At3-317-065-G	0.703932	0.000008	39.002	0.002
Austral	Tubuai	At3-395-066-P	0.702797	0.000008	40.261	0.002
Austral	Tubuai	Tan1-006-P	0.702803	0.000008	40.268	0.002
Austral	Tubuai	Tan1-006-G	0.702853	0.000008	40.281	0.001
Austral	Tubuai	Pahatu8-059-P	0.703496	0.000008	40.018	0.001
Cook	Mangaia	Mataare-G	0.702791	0.000008	40.443	0.002
Cook	Mangaia	Keia-G	0.702844	0.000006	40.544	0.001
Cook	Mangaia	Keia-G-Dup	0.702838	0.000006	40.539	0.003
Cook	Mangaia	Veitatei-G	0.703186	0.000006	40.571	0.002

* Footnote: P stands for analysis on powder sample, G for analysis on gravels and Dup for complete duplicate analysis.

Table 4-1: Cont.

Archipelago	Island	Sample no.*	$^{207}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$	$^{206}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$
Austral	Tubuai	At3-229-064-P	15.730549	0.0007	20.8499	0.0010
Austral	Tubuai	At3-229-064-G	15.72881	0.000943	20.9587	0.0009
Austral	Tubuai	At3-317-065-P	15.579801	0.000954	19.1880	0.0008
Austral	Tubuai	At3-317-065-G	15.579871	0.000763	19.1925	0.0009
Austral	Tubuai	At3-395-066-P	15.76081	0.000748	21.1367	0.0007
Austral	Tubuai	Tan1-006-P	15.761482	0.000696	21.1413	0.0009
Austral	Tubuai	Tan1-006-G	15.764295	0.000526	21.1408	0.0007
Austral	Tubuai	Pahatu8-059-P	15.673399	0.000433	20.5105	0.0005

Cook	Mangaia	Mataare-G	15.815252	0.000523	21.5235	0.0007
Cook	Mangaia	Keia-G	15.822993	0.000535	21.6029	0.0006
Cook	Mangaia	Keia-G-Dup	15.822861	0.00109	21.6029	0.0013
Cook	Mangaia	Veitatei-G	15.830421	0.000642	21.6500	0.0009

* Footnote: P stands for analysis on powder sample, G for analysis on gravels and Dup for complete duplicate analysis.

Table 4-2: Sr, Pb and Nd isotopic ratios of artefacts and related sources (Published data)

Archipelago	Island	Sample no.*	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2\sigma$	$^{208}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$
Austral	Tubuai	TBA 17 (a)	0.702761		40.229	
Austral	Tubuai	K109 (b)	0.7028		40.29	
Austral	Tubuai	TBA-11 (b)	0.703178		40.323	
Austral	Tubuai	K-109 (b)	0.702864		40.229	
Austral	Tubuai	TU 23 (c)	0.702832		40.306	
Austral	Raivavae	RV-11 (d)	0.702878		40.15634	
Austral	Raivavae	RV-27 (d)	0.702876		40.20646	
Austral	Raivavae	RV-35 (d)	0.702839		40.152211	
Marquesas	Eiao	2012-563 (e)	0.703935	0.000012	38.9699	0.0024
Marquesas	Eiao	2012-573 (e)	0.703922	0.000011	38.9648	0.0067
Marquesas	Eiao	D116.0 (f)	0.70378		38.998	
Marquesas	Eiao	D214.0 (f)	0.703743		38.999	
Marquesas	Eiao	KC-05-11 (g)	0.70394		40.156	
Austral	Rapa iti	198 [39] (f)	0.7038		39.054	
Austral	Rapa iti	RPA-02c (a)	0.703902		39.03	
Austral	Rapa iti	RA-31 (b)	0.704288		39.019	

* References: (a) Schiano et al. (2001) ; (b) Chauvel et al. 1992 (1992) ; (c) Vidal et al. (1984) ; (d) Maury et al. (2013) ; (e) Weisler et al. (2016b) ; (f) Duncan et al. (1986) ; (g) Collerson and Weisler (2007).

Table 4-2: Cont.

Archipelago	Island	Sample no.*	$^{207}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$	$^{206}\text{Pb}/^{204}\text{Pb}$	$\pm 2\sigma$	$^{143}\text{Nd}/^{144}\text{Nd}$	$\pm 2\sigma$
Austral	Tubuai	TBA 17 (a)	15.763		21.052		0.512875	
Austral	Tubuai	K109 (b)	15.76		21.14		0.512886	
Austral	Tubuai	TBA-11 (b)	15.749		21.039			
Austral	Tubuai	K-109 (b)	15.763		21.052			
Austral	Tubuai	TU 23 (c)	15.734		21.115		0.512891	
Austral	Raivavae	RV-11 (d)	15.726763		20.863603			
Austral	Raivavae	RV-27 (d)	15.728588		20.89702			
Austral	Raivavae	RV-35 (d)	15.724814		20.820474			
Marquesas	Eiao	2012-563 (e)	15.5791	0.001	19.1613	0.001	0.512935	0.000005
Marquesas	Eiao	2012-573 (e)	15.5797	0.0021	19.1499	0.0022	0.512942	0.000005
Marquesas	Eiao	D116.0 (f)	15.591		19.188			
Marquesas	Eiao	D214.0 (f)	15.576		19.195			
Marquesas	Eiao	KC-05-11 (g)	15.727		20.864			
Austral	Rapa iti	198 [39] (f)	15.706		19.327			
Austral	Rapa iti	RPA-02c (a)	15.58		19.07			
Austral	Rapa iti	RA-31 (b)	15.594		18.994			

* References: (a) Schiano et al. (2001) ; (b) Chauvel et al. (1992) ; (c) Vidal et al. (1984) ; (d) Maury et al. (2013) ; (e) Weisler et al. (2016b) ; (f) Duncan et al. (1986) ; (g) Collerson and Weisler (2007).

Table 5: Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ data from incremental heating experiments.

Sample no. Experiment no.	wt. (mg)	K/Ca (total)	Age Spectrum*					Isochron Analysis*			
			Total Fusion Age (Ma) ± 2 sigma	Increment s used (oC)	^{39}Ar (%)	Age ± 2 sigma (Ma)	MSWD	N	MSWD	$^{40}\text{Ar}/^{36}\text{Ar}$ ± 2 sigma intercep t	Age (Ma) \pm 2 sigma
Mataare,											
groundmass											
FG-905 to	150	0.3	20.1 \pm	749-	78.84	20.17 \pm	1.65	7 of	1.64	304 \pm	20.03 \pm
FG-915			0.62	1079		0.63		10		8.7	0.66
At3-229-064,											
groundmass											
FG-916 to	150	0.4	10.41 \pm	847-	60	10.32 \pm	1.22	6 of	1.8	300.7 \pm	10.32 \pm
FG-925			0.3	1149		0.3		10		8	0.32
At3-317-065,											
groundmass											
FG-1197 to	150	0.2	5.59 \pm	595-	81	5.61 \pm	1.16	10 of	1.14	293.8 \pm	5.68 \pm
FG-1207			0.21	1097		0.21		11		7.3	0.24

* Footnote: Ages calculated relative to 1.193 Ma Alder Creek Rhyolite sanidine standard