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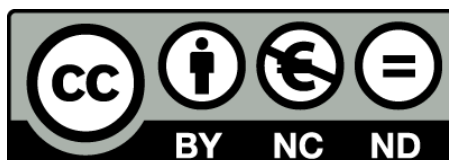
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1 **Title: Late Pleistocene/early Holocene maritime interaction in Southeastern Indonesia –**
2 **Timor Leste**

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4

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9

10 **Abstract**

11 This study analysed over 1000 obsidian stone artefacts excavated from two adjoining
12 shelters on Alor Island Indonesia using portable XRF. The study showed an unambiguous
13 separation of three different source locations (Groups 1, 2 and 3). Two sources (Group 2 and
14 3a, b, c) dominate the assemblage numerically. Group 1 and 2 indicate use of a single
15 volcanic formation with a strong match between Group 1 artefacts and artefacts from sites
16 in Timor Leste. Obsidian occurs in the earliest occupation layer in the Alor sites but do not
17 include Group 1 artefacts which occur only after approx. 12,000 cal BP. Currently the
18 geographical location of the Group 1 outcrop is unknown, however based on the late
19 appearance of the Group 1 artefacts in the Alor sequence it is likely that the location is not
20 on Alor, but rather on another island of the Sunda chain. The dating of Group 1 artefacts in
21 widely spaced sites on the never geographically connected islands of Timor and Alor
22 indicates that maritime interaction between islands began by at least the terminal
23 Pleistocene. The distribution of the obsidian in Tron Bon Lei shelter Pit B shows that there
24 were periods of more intense interaction punctuated by periods when interaction declined
25 or ceased.

26

27

1 **Introduction**

2 Identifying social interaction in prehistory is notoriously difficult, being based largely on
3 typological or stylistic comparison of different material expressions of assumed cultural
4 identity (for example red-slipped pottery or flake-blade techno-complexes, Bellwood, 1997).
5 Geochemically tracking the movement of raw materials provides the unique capability to
6 cut through sometimes arbitrary archaeological classifications and provides direct evidence
7 for maritime interaction if materials are sourced from off-island locations. Unfortunately, in
8 Island Southeast Asia (ISEA), the data for correctly identifying off-island resource use is
9 significantly under-researched as seen in a recent review paper suggesting that there are up
10 to 10 additional, so far unknown, obsidian sources being utilised in Island Southeast Asia
11 (Reepmeyer, et al., 2011b, Spriggs, et al., 2011).

12 Off-island resource use has important implications for the understanding of maritime
13 capacity of hunter-gatherer societies. Until recently it has been assumed that seafaring
14 technology during the Pleistocene and Early Holocene was simple and maritime interaction
15 networks limited. In ISEA the assessment of maritime capability has changed in the last
16 decade with evidence showing Upper Pleistocene hunter-gatherers ability for pelagic fishing
17 (O'Connor, et al., 2011), increased social interaction between distant communities, including
18 maritime transportation of raw materials being traced back to the terminal Pleistocene –
19 early Holocene transition (Bulbeck, 2008, Neri, et al., 2015, Pawlik, et al., 2015, Torrence
20 and Swadling, 2008), and indications that a ‘community of practice’ existed in pre-Neolithic
21 societies connecting islands in shared ‘identities’ (O'Connor, et al., forthcoming).

22 In this paper we present new data on two new obsidian sources in the Tron Bon Lei
23 rockshelters on Alor Island (Samper Carro, et al., 2015). In addition, we will show that a
24 further third obsidian source matches obsidian raw material utilised in Timor Leste
25 (Reepmeyer, et al., 2011a). The new data provides additional evidence for maritime raw
26 material transportation during the terminal Pleistocene / early Holocene transition, and it
27 will be discussed whether sea-level rise during this time might be an important factor
28 stimulating increased social interaction between island communities in the region.

29 **Site Context**

1 Today Alor has a land area of about 2100 km². As one of the Wallacean islands, Alor has
2 never been connected by a land bridge to Sunda (the enlarged southernmost extension of
3 Eurasia) or Sahul (Australia, New Guinea and the Aru Islands) or to the larger islands of
4 Timor or Flores (Kealy, et al., 2015). During the last lower sea stand, when sea levels were
5 about 130 m below present, it was merged with neighbouring Pantar, Pura, Kambing, Rusa,
6 Ternate and Treweng islands; forming an island of about 3800 km² (accounting for uplift of
7 ~0.5m/ka) (Figure 1). It was at about this time that the Tron Bon Lei sites were first occupied
8 (Samper Carro, et al., 2015).

9

10 [Figure 1]

11 Figure 1. Above: Location of the Tron Bon Lei rockshelter on Alor Island. Landmass extension
12 during occupation history. Below: Location of research area.

13

14 Alor is largely volcanic in origin with a mountainous interior dropping steeply to a narrow
15 coastal margin. The Tron Bon Lei shelters discussed here are formed in a ridgeline above the
16 coastal village of Lerabain approximately 33 m above sea level and 160 m inland from
17 today's seashore (Figure 2). The shelters are formed in fine-grained, dark to light grey,
18 basaltic to andesitic volcanic deposits known as the Alor Formation which are of a presumed
19 Late Miocene-Early Pliocene age (Noya, et al., 1997). The Alor Formation intersects with the
20 calcareous Laka Formation and also contains volcanic breccias (Noya, et al., 1997),
21 presenting as intercalated sub-angular to rounded clasts measuring up to ~50 cm in
22 diameter. Inside the shelter the floor consists of unconsolidated sediment with some large,
23 fine-grained volcanic boulders on the surface that are of the same composition as those that
24 can be seen in the shelter walls.

25

26 [Figure 2]

27 Figure 2: Plan view and section of the Tron Bon Lei rockshelter. Location of Pit A and B
28 marked at the site.

1

2 In 2014, three 1 m² test pits were excavated in two adjoining shelters (Figure 2). Pit A was
3 excavated to 70 cm when bedrock was encountered. Pit B was extended to 3.2 m before
4 reaching bedrock. Pit A presented challenges for dating as little organic material was
5 preserved and only modern dates for the upper part of the sequence were obtained.
6 Obsidian artefacts were scarce in the Pit A assemblage where only one piece of in total 59
7 samples was allocated to Group 1. Here we focus on Pit B which contains the majority of
8 artefacts of Group 1 and has a clearly defined chrono-stratigraphic sequence. Thirteen
9 stratigraphic layers were identified in Pit B, which included discrete well-defined
10 stratigraphic features such as hearths and layers of flowstone (Figure 3, see also Samper
11 Carro, et al., in press). Radiocarbon dating results for Pit B suggest three main phases of
12 activity at the site: 1) late Holocene (*ca.* 3500 cal BP); 2) terminal Pleistocene-early Holocene
13 (around 12,000 to 7500 cal BP); 3) late Pleistocene-Last Glacial Maximum (*ca.* 21,000 -
14 18,000 cal BP). The stratigraphy has been described in detail elsewhere (Samper Carro, et
15 al., 2015). Here we focus on the changing distribution of obsidian sources within the
16 sequence.

17

18 [Figure 3]

19 Figure 3: Section drawing of Pit B, Tron Bon Lei, with location of radiocarbon dates.

20

21 The upper excavation units (EUs) contained a small number of earthenware sherds. Aside
22 from obsidian, stone artefacts were manufactured primarily from basalt (43.6% of the
23 assemblage) with small numbers of chert artefacts (2.8%) also recovered. The faunal
24 assemblage is dominated by fish (Samper Carro, et al., in press, Samper Carro, et al., 2015).
25 The non-fish component comprises small quantities of marine turtle (Chelonioidea), small
26 mammals, reptiles and birds. A detailed study of the fish bones from Tron Bon Lei has
27 shown that as in neighbouring Timor Leste carnivorous species dominate in the Pleistocene
28 and early Holocene levels and that an increase in smaller herbivorous/omnivorous reef fish

1 occurs during the Holocene as sea level rose and coral reefs were established (O'Connor, et
2 al., 2011, Samper Carro, et al., 2015).

3 **Methods and Results**

4 This sourcing study includes over 1000 obsidian stone artefacts excavated from two test pits
5 in adjacent shelters in Tron Bon Lei Pit A (n = 59) and Pit B (n = 1005). Artefacts were
6 selected by size and all artefacts larger than the threshold of covering the complete X-Ray
7 beam (~6 mm diameter) were analysed, 2998 artefacts were rejected based on size. The
8 thickness of the artefact was disregarded, taking into account increased variability in the
9 calculated elemental concentrations. The artefacts were geochemically analysed by portable
10 X-Ray Fluorescence analysis (pXRF) with a Bruker Tracer III-SD. Manufacturer recommended
11 settings of 40 keV and 42 μ A were employed using a 0.1524 mm Cu, 0.0254 mm Ti and
12 0.3048 mm Al filter in the X-Ray path and a 60 second live-time count at 145 FWHM setting.
13 The raw counts of the pXRF were calibrated using 40 international standards provided by
14 MURR (Glascock and Ferguson, 2012). Each artefact was analysed at two spots and the
15 averages are presented here (Supplementary Table 1). Element concentration of manganese
16 (Mn), iron (Fe), thorium (Th), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr) and
17 niobium (Nb) were calculated.

18

19 [Figure 4]

20 Figure 4: Principal component analysis of the Tron Bon Lei assemblage, + represent Group 1,
21 \square represent Group 2, \bullet represent Group 3a, \bullet represent Group 3b, \bullet represent Group 3c.

22

23 [Table 1]

24 Table 1: Summary statistics of pXRF analysis, averages represent absolute ppm counts
25 (ANU9000 is an in-house reference standard, West New Britain – Kutau/Bao source).

26

27 The sourcing of the artefacts using Principal Component Analysis in the Past 3 freeware
28 program (Hammer, et al., 2001) shows an unambiguous separation of three different source

1 locations¹ (Figure 4). There is a linear spread of samples which indicates that the size of the
2 artefacts increases variability in pXRF analyses (Ferguson, 2013, Lundblad, et al., 2008).
3 Taking into account machine-induced geochemical variation, two source locations (Group 1
4 and Group 2) show a low-level of intra-source variability suggesting that artefacts
5 provenanced to both source locations originate from single volcanic formations (Table 1).
6 Group 3 obsidian artefacts present a slightly higher intra-source variability and it is possible
7 that multiple outcrops of the same volcanic event were utilised (Figure 4: 3a, 3b, 3c,
8 however there is a high potential that we only see the utilisation of one outcrop with higher
9 variability in the geochemical signature). Group 3 artefacts can primarily be separated by
10 discrepancies in Zr values (Group 3a: 220 ppm, SD 21.7; Group 3b: 185 ppm, SD 10.2; Group
11 3c: 134 ppm, SD 20.3), Group 3c with additional low Rb (78 ppm, SD 18.6) and Nb (8 ppm,
12 SD 1.6) values. Group 2 has particular low Fe values (8370 ppm, SD 1238.6) and the
13 geochemical signature of Group 1 shows an, for the region, unusual high Rb/Sr ratio (Rb 191
14 ppm SD 16.9, Sr 186 ppm SD 15.3; Average ratio 1.03).

15

16 [Figure 5]

17 Figure 5. Discriminant Function Analysis of Tron Bon Lei assemblage in relation to Island
18 Southeast Asian and Western Pacific obsidian sources (data taken from pXRF analysis of
19 ANU obsidian reference collection and SEM-EDXA and LA-ICP-MS data from Reepmeyer, et
20 al., 2011b).

21

22 Artefacts from Alor were compared with the large reference database of Western Pacific
23 and Island Southeast Asian obsidian sources (Reepmeyer, et al., 2011b, Summerhayes, 2009,
24 Tykot and Chia, 1997). None of the identified groupings could be matched to any of the
25 known sources in the region (Figure 5). The obsidian sources of the Western Pacific are
26 relatively well understood (Reepmeyer, et al., 2016, Summerhayes, 2009), unfortunately,
27 this is not the case for obsidian sources in Island Southeast Asia, where a recent study of
28 ~100 artefacts was able to successfully source only 40% of the assemblages (Reepmeyer, et

¹ This indicates that the sources are geochemically sufficiently different from each other to be separated, taking into account that the samples don't meet minimum requirements for infinite thickness.

1 al., 2011b). Widening the geochemical comparison database to include un-sourced artefacts
2 from Island Southeast Asia and using Discriminant Function Analysis in PAST3, there is a
3 strong match between Group 1 artefacts and artefacts from sites on Timor Leste (Ambrose,
4 et al., 2009, Reepmeyer, et al., 2011a). Timor obsidian from several rock shelter sites (Buri
5 Ceri Uato and Buri Ceri Uato Mane, Hatu Sour, Jerimalai, Laili, Matja Kuru 1 and 2) show the
6 exploitation of one particular obsidian source recurrently (Figure 6). Our results suggest that
7 it is highly likely that we are seeing the utilisation of this same obsidian source in the Tron
8 Bon Lei site.

9

10 [Figure 6]

11 Figure 6. Discriminant Function Analysis of pXRF data comparing Tron Bon Lei artefacts with
12 obsidian artefacts from the wider area. Ellipses represent 95% confidence intervals from
13 PCA groupings, red ellipse shows artefacts distribution of Timor Leste rockshelters.

14

15 In the larger Pit B assemblage Group 1 artefacts are relatively abundant. In total, 167 pieces
16 in Pit B (16.4% of the obsidian assemblage analysed) were allocated to Group 1. The earliest
17 occurrence of Group 1 artefacts in the stratigraphy is in Layer 11, EU 39-32, which has been
18 dated to approx. 11,500 cal BP (10,140±45 bp (SANU 40125), an additional date of
19 10,230±30 bp (SANU 41825) on an *in situ* fish hook confirms this age)². A terminal
20 Pleistocene-Holocene transition age for the initial use of Group 1 obsidian transportation
21 into the site is confirmed by this.

22

23 [Figure 7]

24 Figure 7. Artefact and faunal assemblage distribution at Tron Bon Lei rockshelter.

25

26 Group 1 artefacts are not distributed equally throughout the stratigraphy (Figure 6).
27 Separated by layer/EUs we can see a bimodal distribution with Group 1 artefacts being most

² For calibrated age-ranges, see Supplementary table 2

1 abundant in Layer 10 (63 artefacts, 20% of the assemblage) and a second peak in Layer 7 (25
2 artefacts, 43% of the assemblage). Layer 10 is bracketed by radiocarbon dates of 9340 ± 35
3 bp (ANU40128) and 8745 ± 35 bp (ANU39538). There appears to be a general lack of obsidian
4 utilisation in Layer 9 (7355 ± 35 bp (ANU39539) and 7250 ± 25 bp (ANU40039)), Layer 8 shows
5 only minimal use of Group 1 artefacts (15 artefacts, 7% of the assemblage). Layer 7, which
6 has the second peak in Group 1 obsidian utilisation, is bracketed by dates of 7060 ± 30 bp
7 (ANU40121) in Layer 8 and 6620 ± 30 bp (ANU40123) in Layer 6. If we compare the
8 distribution of Group 1 artefacts to the general utilisation pattern of obsidian sources at the
9 Tron Bon Lei site, we see that only in Layer 10 do Group 1 utilisation peaks match use of all
10 obsidian sources at the site. During the second peak of intense obsidian utilisation, in Layer
11 8, Group 1 artefacts were not abundant. Only slightly later, in Layer 7 after general
12 utilisation of obsidian has peaked, we can see an increased use of Group 1 obsidian. Group 1
13 obsidian was then utilised in all later Layers 6 to 2 in small numbers. The distribution of
14 Group 1 artefacts at TBL relates closely to the dates for the first inception of its use in rock
15 shelter sites in Timor Leste. Although a single obsidian artefact from this source was located
16 in the lower levels of Jerimalai dated to ca. 42,000 cal BP (Reepmeyer, et al., 2011a), the
17 majority of the Timor Leste artefacts derive from levels dated after 14,000 cal BP, even in
18 the case of sites such as Matju Kuru 2 (Langley and O'Connor, 2015) and Laili (O'Connor, et
19 al., 2016) where initial occupation dates back to ca. 35,000 cal BP and 42,000 cal BP
20 respectively.

21 Group 2 artefacts first appear in Layer 11 and from Layer 10 onwards Group 2 is the most
22 abundant obsidian raw material throughout the stratigraphy, particularly during the two
23 peak utilisation periods in Layer 10 and 8. Group 3 (all three sub-sources combined)
24 artefacts occur in all layers of the site. They first appear in Layer 13 where they are the only
25 obsidian source utilised and are most abundant in Layer 10 ($n = 128$, 40% of the assemblage)
26 and 11 ($n = 114$, 65% of the assemblage). In tendency this source has been utilised more
27 intensely in the earlier layers (Layer 13 = 100%, Layer 12 = 88%, Layer 11 = 65%) and its
28 abundance significantly decreases proportionally in later layers (Layer 6 = 29%, Layer 3 =
29 31%, Layer 2 = 28%).

30 Unfortunately, none of the raw material sources identified in the assemblage could be
31 matched to a known obsidian source in the region, albeit some inferences can be made by

1 the occurrence of Group 3 obsidians as the dominant source in the lower Layers and the
2 later addition of Group 1 and 2 obsidians. We assume that Group 3 artefacts derive from a
3 local source on Alor island, with Group 2 artefacts most likely also local. Supporting the
4 assignation of Group 3 obsidian to a local source is the occurrence of small unworked
5 nodules (in the form of small river-rounded pebbles, on average 10-20 mm in diameter)
6 whose cortex matches cortex on some of the Group 3 artefacts. No unworked nodules were
7 found which matched Group 1 or 2 artefacts.

8 **Discussion**

9 Recent research has shown that social interaction between distant communities, including
10 maritime transportation of raw materials in ISEA, can be traced back to the terminal
11 Pleistocene – early Holocene and it has been proposed that these changes might be
12 associated with sea-level rise in post-LGM times (Bulbeck, 2008, Neri, et al., 2015, Pawlik, et
13 al., 2015, Torrence and Swadling, 2008). Sea-levels during the Pleistocene/Holocene
14 boundary at 11,000 – 12,000 cal BP rose on average 12 m kyr⁻¹ (Grant, et al., 2012) and it
15 has been argued that the loss of landmass from rising seas would have put established
16 populations under pressure to adapt a more coastal and maritime focused economy (Barker
17 and Richards, 2013, Soares, et al., 2008).

18 However, at Tron Bon Lei we are not able to see a change in maritime subsistence between
19 the lower occupation layers dating to 18,000 – 20,000 cal BP and the presumed initial
20 maritime transportation of Group 1 obsidian (Samper Carro, et al., 2015). These findings
21 echo recent results from sites in the Central Philippines (Neri, et al., 2015, Pawlik, et al.,
22 2015), where the authors found no evidence for changing maritime exploitation patterns
23 during this time period. On the other hand, Woodroffe et al. (1988, 2000) and Chappell
24 (1993) have argued that rising sea levels would have indeed stimulated maritime migration
25 and subsistence pursuits as sea-level rise creates more productive marine environments for
26 human exploitation, such as reefs, localised back beach lagoons and estuaries, than the
27 precipitous steep coastlines accompanying sea-level lows. This might seem to be particularly
28 apposite in regions such as Timor and Alor where offshore profiles are steep.

29 Stable maritime exploitation patterns at the Tron Bon Lei rockshelter might be not
30 surprising as the precipitous coastline during the time of sea-level rise did not change

1 dramatically. The rockshelter today is 160 m distance to the shore in 33 m elevation, at the
2 low point during the LGM it was not further than 2 km distance to the shore in ~157 m
3 elevation. Due to the steep offshore profile on the south coast of Alor and north coast of
4 Timor the distance between Timor and Alor would have increased less than 0.5 km as sea
5 levels rose to the mid Holocene high stand and thus there would have been little loss of land
6 on these islands.

7

8 [Table 2]

9 Table 2: Abundances of obsidian artefacts in Tron Bon Lei and comparison sites in Timor
10 Leste.

11

12 The pattern of first appearance of raw material transportation of obsidian from Group 1
13 during the time period of 12,000 to 10,000 cal BP is replicated in a number of rockshelter
14 sites throughout the region. We compared raw material access of Group 1 obsidian at eight
15 rockshelter sites in Timor Leste (Table 2, new data added for Laili and Hatu Sour added in
16 Supplementary table 1) with the Tron Bon Lei site. In Jerimalai (Reepmeyer, et al., 2011a)
17 shelter at the eastern end of Timor, a single obsidian artefact was recovered from the
18 earliest level dated to around 42,000 cal BP. However most obsidian occurs in excavation
19 units dating within the age-bracket 15,000 – 4000 cal BP, and an even later beginning of raw
20 material usage at around 11,000 cal BP is likely (Supplementary Table 2, see also O'Connor,
21 et al., 2011, Reepmeyer, et al., 2011a).

22 Matja Kuru 1 (MK1, Sq A and AA) and 2 (MK2, Sq D), are located to the west of Jerimalai,
23 about 5 km from the coast and face south to the large freshwater lake, Ira Laloro. MK2
24 returned an age estimate of 35,500 cal BP for one of the lowest units, additional dates in
25 associated excavation units confirmed this antiquity (Langley and O'Connor, 2015,
26 O'Connor, et al., 2014). At MK2, 30 obsidian flakes were recovered occurring mostly in the
27 Holocene, the earliest deposition of three flakes in EU 33 are bracketed by dates of 9205±55
28 bp (NZA17001 in EU 32) and 9260±60 bp (OZG898 in EU35). MK2 appears to have little
29 evidence of occupation before these dates and there appears to be a hiatus of occupation

1 during the LGM. The oldest date for MK1 was 13,690±130 bp (ANU11616 from Square AA,
2 EU 21), but an inversion is evident in the age estimate of 9940±60 bp (OZF-784 from EU25)
3 15-20 cm lower in the profile, and indicates some vertical disturbance. The second square,
4 MK1 Sq A, only returned mid-Holocene dates, starting at 6000 cal BP (Langley and O'Connor,
5 2015, O'Connor, et al., 2014). Obsidian was found throughout the sequence in both
6 excavation squares starting from the lowest units in MK1, Sq AA, with a single artefact in EU
7 25, but most artefacts are associated with mid-Holocene layers.

8 Hatu Sour is a small cave on the central northern coast of Timor Leste near the modern
9 village of Laleia. It has a Holocene sequence (Brockwell, et al., in press) with earliest
10 occupation layers dated to 9650±45 bp (ANU26609, in EU 35), EU 12 has a mid-Holocene
11 date of 6165±25 (ANU27105) and the uppermost layers returned a date of 315±25 bp
12 (ANU26606). Obsidian artefacts appear sometime prior to the mid-Holocene in EU 17 and
13 continue through the sequence into the late Holocene.

14 At Laili, which dates to approx. 44,000 cal BP, Holocene deposits are not preserved
15 (O'Connor, et al., 2016), but two obsidian flakes were found in EU 4 which dates to 11,000 –
16 15,000 cal BP (brackets are 12,789±47 bp (D-AMS 001649) in EU 5 and 10,295±43 bp (D-
17 AMS 007342) in EU 2). Bui Ceri Uato (BCU) and nearby Buri Ceri Uato Mane (BCUM) are on
18 the Baucau Plateau. The Baucau sites are exceptional as they show the utilisation of multiple
19 obsidian and local pitchstone sources in Timor Leste (Ambrose, et al., 2009, Glover, 1986).
20 At BCU, local pitchstone use occurs from the lowest units (EU 30) associated with the initial
21 occupation of the site at 11,000 – 12,000 cal BP and cluster recurrently with another
22 concentration in EU 21-20 (Glover, 1986). Group 1 obsidian was found in the second
23 concentration in EU 20 and again in EU 7A. At BCUM, Group 1 obsidian occurs only from EU
24 44 onwards (brackets are 7566±70 bp (Wk19306) in EU 48 and 6240±60 bp (OZJ531) in EU
25 43) and EU 18 (2989±43 bp, OZJ527) (Olivera, 2008). No obsidian was found in uppermost
26 layers dating to the late Holocene and there is an inversion with a mid-Holocene date in EU
27 16A (5357±54 bp, OZJ526), the excavators suggest that obsidian only occur in mid-Holocene
28 layers dating between 7500 cal BP and 5500 cal BP (Ambrose, et al., 2009).

29 Clearly most of the evidence for obsidian use in the Timor Leste sites dates from about
30 14,000 cal BP or 12,000 cal BP onwards, even when sites have a much longer occupation
31 record. The exception to this is Jerimalai where a single artefact is associated with units

1 dated to 42,000 cal BP (Reepmeyer, et al., 2011a). The stratigraphic contexts of the single
2 obsidian flake in Jerimalai indicates that that there is a possibility of vertical displacement of
3 the obsidian from higher in the profile. At Jerimalai an excavation unit less than 10 cm
4 above the artefact was dated to post 14,000 cal BP (O'Connor, et al., 2011). With these
5 exceptions Group 1 obsidian first appears just prior to the terminal Pleistocene after sea-
6 level had already risen about 60 m. Later usage of Group 1 obsidian during the second peak
7 at Tron Bon Lei in mid-Holocene layers coincides with the mid-Holocene distribution of
8 obsidian in sites such as BCU, BCUM and MK1 Sq A and AA. This might show a re-
9 intensification of interaction after a relatively short hiatus, when new sites are added to the
10 network.

11 The pattern of separate systems regulating subsistence patterns and obsidian
12 transportation is repeated in later layers where we can see a short-lived disappearance of
13 Group 1 obsidian usage (Figure 6, Layer 9). This pattern cannot be explained through
14 changing environment, we do not see a parallel drop in maritime resource exploitation
15 (Figure 6), but it is reflected in a general drop of lithic artefact production/use at the site.
16 Interestingly, we can see a proportional sharp increase in use of the Group 2 source in Layer
17 9, however, this distribution is defined by very small artefact numbers.

18 Ambrose et al. (2009: 615) already noted the later date of initial raw material transportation
19 in ISEA than in the Bismarck Archipelago where Mopir obsidian from West New Britain was
20 transported to New Ireland by 20,000 – 18,000 cal BP (Summerhayes and Allen, 1993). This
21 remains the oldest evidence for inter-island transportation of obsidian raw material in the
22 Indo-Pacific region. Initial obsidian exploitation of a local source for tool manufacture at
23 Tron Bon Lei is dated to the LGM, which again is significantly later than in West New Britain,
24 where obsidian flaked tools are associated with the earliest occupation layers at around
25 44,000 cal BP at Kupo Na Dari (Torrence, et al., 2004). This might indicate that Alor was not
26 occupied prior to the LGM, which appears unlikely considering the Upper Pleistocene dates
27 on Timor Leste. Similarly, it is unlikely that increased raw material transportation between
28 Alor and Timor Leste sites, as well as between West New Britain and New Ireland
29 (Summerhayes and Allen, 1993) and in the Central Philippines (Neri, et al., 2015), can be
30 identified as indicative of the advent of advanced sailing technology. Distances involved in

1 maritime transportation between these islands are fairly short (~30 km, up to 60 km) and
2 there is island-intervisibility across all sea gaps (Kealy, et al., 2015).

3 Alignment of coastal communities to maritime exploitation and sea crossing might be
4 related to sea level rise as increased productivity in marine environments may have led to
5 larger and more shell beds, the growth of reefs and estuaries in river deltas (Woodroffe, et
6 al., 2000). These newly established environments might have been productive enough to
7 allow population growth and stimulate intensified maritime subsistence pursuits. At the
8 same time it is possible that increased precipitation and warming at the beginning of the
9 Holocene made inland travel more difficult as rainforest increased (Burrows, et al., 2016,
10 Reeves, et al., 2013) and areas which were previously more open vegetation became denser
11 and likely more inhospitable to traverse. We see increased burning regimes of the direct
12 post-LGM period (Haberle and Ledru, 2001) giving way to more humid environments which
13 might necessitate increased human intervention to manage productivity. We can see
14 intensified forest management strategies during this period in sites such as Niah cave on
15 Sarawak (Barker, et al., 2011). Unfortunately, palaeo-vegetation data is scarce in our
16 research area, so that we are unable to replicate this evidence, but there is no reason to
17 assume that increased forest management was not also an adaptive necessity for hunter-
18 gatherer communities in the South Wallacean islands. In this context, increased maritime
19 connectivity might be an alternative or additional strategy to cope with changed
20 environmental circumstances.

21 Imagery of boats is pervasive in the cultures of the Wallacean Islands (Ballard, et al., 2004).
22 Houses and even entire villages are built to reference boats, and boats are a recurring motif
23 in the rock art and later in the woven cloth made throughout the region. Even today on
24 many of the smaller islands of the Lesser Sunda group movement between villages is heavily
25 dependent on water transport as roads are few or non-existent and inland regions often
26 mountainous and impassable. In this respect it is interesting to note that Group 1 obsidian,
27 on the Alor coast and with widespread occurrence along the Timor Leste coast, does not
28 occur at all in the inland sites of Uai Bobo 1 and 2 despite large lithic assemblage sizes
29 (Glover, 1986). This could be viewed as a material reflection of social or familial networks
30 maintained between coastal groups on adjacent islands communities and the lack of such
31 networks between the coastal and inland communities in the same island. Although we do

1 not yet know the source for the Group 1 obsidian, its presence in sites in both Timor Leste
2 and Alor, from at least the terminal Pleistocene demonstrates the antiquity of maritime
3 interaction in this region.

4 **Conclusion**

5 The application of pXRF to obsidian artefacts provides the opportunity to analyse large lithic
6 assemblages in a relative short amount of time. Here we present the results of more than
7 1000 obsidian analyses from the Tron Bon Lei rock shelter on Alor Island. The data shows
8 that three obsidian sources have been exploited, with all sources being separated
9 unambiguously by pXRF geochemical finger-printing. There is the option of one source being
10 sub-divided into three separate outcrops, but more data is necessary to confirm these
11 results. None of the obsidian artefacts could successfully be sourced to any of the known
12 sources in Island Southeast Asia or the Western Pacific.

13 The distribution of obsidian throughout the stratigraphy shows that initially most likely local
14 sources were exploited in low numbers. The two other obsidian sources were added later,
15 most likely not starting before the terminal Pleistocene. Two peak utilisations phases were
16 identified with a short hiatus which is not equally reflected in the faunal assemblage. It is
17 currently unclear why less lithic artefact deposition occurred in Layer 9 at the site.

18 The geochemical analysis showed that one obsidian source could be matched with obsidian
19 artefacts in terminal Pleistocene sites on Timor Leste. However, it is probable that neither
20 Timor Leste nor Alor were the locality for this source which is expected to be somewhere in
21 the Sunda Arc. The appearance of the same source obsidian on both islands which were
22 never connected via a land bridge, provides indisputable evidence for the maritime
23 transportation of obsidian to these islands starting in the terminal Pleistocene. It has been
24 suggested that sea-level rise may have provided the impetus for increased maritime
25 interaction in the transition from the terminal Pleistocene to the early Holocene, however,
26 the earliest transportation of obsidian raw material at the sites is not associated with
27 evident changes in maritime resource use. An increased maritime subsistence focus may
28 have led to social or familial links between islands, and resulted, over time, in the
29 emergence of maritime interaction networks.

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4

1 **References**

- 2 Ambrose, W.R., Allen, C., O'Connor, S., Spriggs, M., Oliveira, N.V., Reepmeyer, C., 2009. Possible
3 obsidian sources for artefacts from Timor: narrowing the options using chemical data, *Journal of*
4 *Archaeological Science* 36, 607-615.
- 5 Ballard, C., Bradley, R., Nordenborg Myhre, L., Wilson, M., 2004. The ship as symbol in the prehistory
6 of Scandinavia and Southeast Asia, *World Archaeology* 35, 385-403,
7 10.1080/0043824042000185784.
- 8 Barker, G., Lloyd-Smith, L., Barton, H., Cole, F., Hunt, C., Piper, P., Rabett, R.J., Paz, V., Szabó, K.,
9 2011. Foraging-farming transitions at the Niah Cave, Sarawak, Borneo, *Antiquity* 85, 492-509.
- 10 Barker, G., Richards, M.B., 2013. Foraging-Farming Transitions in Island Southeast Asia, *Journal of*
11 *Archaeological Method and Theory* 20, 256-280.
- 12 Bellwood, P., 1997. *Prehistory of the Indo-Malaysian Archipelago*, University of Hawai'i Press,
13 Honolulu, HI.
- 14 Brockwell, C., O'Connor, S., Litster, M., Willan, R., in press. New insights into Holocene economies
15 and environments of central East Timor: Analysis of the molluscan assemblage at the rockshelter site
16 of Hatu Sour, NT *Naturalist*.
- 17 Bulbeck, D., 2008. An integrated perspective on the Austronesian diaspora: The switch from cereal
18 agriculture to maritime foraging in the colonisation of Island Southeast Asia, *Australian Archaeology*
19 67, 31-51.
- 20 Burrows, M.A., Heijnis, H., Gadd, P., Haberle, S.G., 2016. A new late Quaternary palaeohydrological
21 record from the humid tropics of northeastern Australia, *Palaeography, Palaeoclimatology,*
22 *Palaeoecology* 451, 164-182.
- 23 Chappell, J., 1993. Late Pleistocene Coasts and Human Migrations in the Austral Region, in: Spriggs,
24 M., Yen, D.E., Ambrose, W.R., Jones, R., Thorne, A., Andrews, A. (Eds.), *A community of culture: The*
25 *People and Prehistory of the Pacific*, Research School of Pacific Studies, The Australian National
26 University, Canberra, pp. 43-48.
- 27 Ferguson, J.R., 2013. X-Ray fluorescence of obsidian: approaches to calibration and the analysis of
28 small samples, in: Shugar, A.N., Mass, J.L. (Eds.), *Handheld XRF for Art and Archaeology*, Leuven
29 University Press, Leuven, pp. 113-134.
- 30 Glascock, M.D., Ferguson, J.R., 2012. Report on the Analysis of Obsidian Source Samples by Multiple
31 Analytical Methods, University of Missouri Research Reactor, Columbia.
- 32 Glover, I., 1986. *Archaeology in East Timor, 1966-67*, Department of Prehistory, Research School of
33 Pacific Studies, Australian National University, Canberra.
- 34 Grant, K.M., Rohling, E.J., Bar-Matthews, M., Ayalon, A., Medina-Elizalde, M., Bronk Ramsey, C.,
35 Satow, C., Roberts, A.P., 2012. Rapid coupling between ice volume and polar temperature over the
36 past 150,000 years, *Nature* 491, 744-747.
- 37 Haberle, S.G., Ledru, M.-P., 2001. Correlations among Charcoal Records of Fires from the Past 16,000
38 years in Indonesia, Papua New Guinea, and Central and South America, *Quaternary Research* 55, 97-
39 104.

- 1 Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for
2 education and data analysis, *Palaeontologia Electronica* 4, 9-15.
- 3 Kealy, S., Louys, J., O'Connor, S., 2015. Islands Under the Sea: A Review of Early Modern Human
4 Dispersal Routes and Migration Hypotheses Through Wallacea, *The Journal of Island and Coastal*
5 *Archaeology*, 1-21, 10.1080/15564894.2015.1119218.
- 6 Langley, M., O'Connor, S., 2015. 6500-Year-old Nassarius shell appliqués in Timor-Leste:
7 technological and use wear analyses, *Journal of Archaeological Science* xx, 1-18,
8 <http://dx.doi.org/10.1016/j.jas.2015.06.012>.
- 9 Lundblad, S., Mills, P.R., Hon, K., 2008. Analysing archaeological basalt using non-destructive energy-
10 dispersive X-Ray Fluorescence (EDXRF): Effects of post-depositional chemical weathering and sample
11 size on analytical precision, *Archaeometry* 50, 1-11.
- 12 Neri, L.A.M., Pawlik, A.F., Reepmeyer, C., Mijares, A.S.B., Paz, V.J., 2015. Mobility of early islanders in
13 the Philippines during the Terminal Pleistocene/Early Holocene boundary: pXRF-analysis of obsidian
14 artefacts, *Journal of Archaeological Science* 61, 149-157.
- 15 Noya, Y., Burhan, G., Koesoemadinata, S., Mangga, S.A., 1997. Peta geologi lembar Alor dan Wetar
16 Barat, Nusa Tenggara - Geological map of the Alor and West Wetar Quadrangle, Skala 1 : 250.000,
17 Pusat Penelitian dan Pengembangan Geologi, Bandung.
- 18 O'Connor, S., Barham, A., Aplin, K., Maloney, T., 2016. Cave stratigraphies and cave breccias:
19 Implications for sediment accumulation and removal models and interpreting the record of human
20 occupation, *Journal of Archaeological Science*, xx, doi:10.1016/j.jas.2016.05.002.
- 21 O'Connor, S., Ono, R., Clarkson, C., 2011. Pelagic Fishing at 42,000 Years Before the Present and the
22 Maritime Skills of Modern Humans, *Science* 334, 1117-1121.
- 23 O'Connor, S., Reepmeyer, C., Langley, M., Piotto, E., Mahirta, M., forthcoming. Communities of
24 practice in a maritime world: shared shell technology and obsidian exchange in the Lesser Sunda
25 islands group, in: Bellina, B., Blench, R., Galipaud, J.-C. (Eds.), *Sea nomads of South-East Asia past and*
26 *present*, NUS Press, Singapore.
- 27 O'Connor, S., Robertson, G., Aplin, K.P., 2014. Are osseous artefacts a window to perishable material
28 culture? Implications of an unusually complex bone tool from the Late Pleistocene of East Timor,
29 *Journal of Human Evolution* 67, 108-119.
- 30 Olivera, N., 2008. Subsistence Archaeobotany: Food Production and the Agricultural Transition in
31 East Timor, *Archaeology and Natural History*, The Australian National University, Canberra.
- 32 Pawlik, A.F., Piper, P., Wood, R.E., Lim, K.K.A., Faylona, M.G.P.G., Mijares, A.S.B., Porr, M., 2015. Shell
33 tool technology in Island Southeast Asia: an early Middle Holocene *Tridacna* adze from Ilin Island,
34 Mindoro, Philippines, *Antiquity* 89, 292-308.
- 35 Reepmeyer, C., Ambrose, W.R., Clark, G.R., 2016. Obsidian sourcing in the Pacific: New results using
36 LA-ICPMS, in: Gratuze, B., Golitko, M., Dussubieux, L. (Eds.), *Recent Advances in Laser Ablation ICP-*
37 *MS for Archaeology*, Springer, New York.
- 38 Reepmeyer, C., O'Connor, S., Brockwell, C., 2011a. Long-term obsidian use at the Jerimalai rock
39 shelter in East Timor, *Archaeology in Oceania* 45, 85-90.

- 1 Reepmeyer, C., Spriggs, M., Anggraeni, Lape, P.V., Neri, L., Ronquillo, W.P., Simanjuntak, T.,
2 Summerhayes, G.R., Tanudirjo, D.A., Tiauzon, A., 2011b. Obsidian sources and distribution systems in
3 Island Southeast Asia: New results and implications from geochemical research using LA-ICPMS,
4 *Journal of Archaeological Science* 38, 2995-3005.
- 5 Reeves, J.M., Bostock, H.C., Ayliffe, L.K., Barrows, T.T., De Deckker, P., Devriendt, L.S., Dunbar, G.B.,
6 Drysdale, R.N., Fitzsimmons, K.E., Gagan, M.K., Griffiths, M.L., Haberle, S.G., Jansen, J.D., Krause, C.,
7 Lewis, S., McGregor, H.V., Mooney, S.D., Moss, P., Nanson, G.C., Purcell, A., van der Kaars, S., 2013.
8 Palaeoenvironmental change in tropical Australasia over the last 30,000 years: a synthesis by the
9 OZ-INTIMATE group, *Quaternary Science Reviews* 74, 97-114.
- 10 Samper Carro, S.C., Louys, J., O'Connor, S., in press. Methodological considerations in the analysis of
11 fish remains from archaeological assemblages: A case study from Tron Bon Lei shelter (Alor,
12 Indonesia), in: Gabriel, S., E., R. (Eds.), *Fishing through time: Archaeoichthyology, Biodiversity,
13 Ecology, and Human Impact on Aquatic Environments*.
- 14 Samper Carro, S.C., O'Connor, S., Louys, J., Hawkins, S., Mahirta, M., 2015. Human maritime
15 subsistence strategies in the Lesser Sunda Islands during the terminal Pleistocene/early Holocene:
16 New evidence from Alor, Indonesia, *Quaternary International*, 1-16.
- 17 Soares, P., Trejaut, J.A., Loo, J.-H., Hill, C., Mormina, M., Lee, C.-L., Chen, Y.-M., Hudjashov, G.,
18 Forster, P., Macaulay, V., Bulbeck, D., Oppenheimer, S.J., Lin, M., Richards, M.B., 2008. Climate
19 Change and Postglacial Human Dispersals in Southeast Asia, *Molecular Biology and Evolution* 25,
20 1209-1218.
- 21 Spriggs, M., Reepmeyer, C., Anggraeni, Lape, P.V., Neri, L., Ronquillo, W.P., Simanjuntak, T.,
22 Summerhayes, G.R., Tanudirjo, D.A., Tiauzon, A., 2011. Obsidian sources and distribution systems in
23 Island Southeast Asia: A review of previous research, *Journal of Archaeological Science* 38, 2873-
24 2881.
- 25 Summerhayes, G.R., 2009. Obsidian network patterns in Melanesia - Sources, Characterisation and
26 Distribution, *Indo-Pacific Prehistory Association Bulletin* 29, 109-124.
- 27 Summerhayes, G.R., Allen, J., 1993. The transport of Mopir obsidian to late Pleistocene New Ireland,
28 *Archaeology in Oceania* 28, 144-148.
- 29 Torrence, R., Neall, V., Doelman, T., Rhodes, E., McKee, C., Davies, H., Bonetti, R., Guglielmetti, A.,
30 Manzoni, A., Oddone, M., Parr, J., Wallace, C., 2004. Pleistocene colonisation of the Bismarck
31 Archipelago: new evidence from West New Britain, *Archaeology in Oceania* 39, 101-130.
- 32 Torrence, R., Swadling, P., 2008. Social networks and the spread of Lapita, *Antiquity* 82, 600-616.
- 33 Tykot, R.H., Chia, S., 1997. Long-distance obsidian trade in Indonesia, *Materials Research Society
34 Symposium Proceedings* 462, 175-180.
- 35 Woodroffe, C.D., Chappell, J., Thom, B.G., 1988. Shell Middens in the Context of Estuarine
36 Development, South Alligator River, Northern Territory, *Archaeology in Oceania* 23, 95-103.
- 37 Woodroffe, C.D., Kennedy, D.M., Hopley, D., Rasmussen, C.E., Smithers, S.G., 2000. Holocene reef
38 growth in Torres Strait, *Marine Geology* 170, 331-346.
- 39

Table

	n		MnKa1	FeKa1	ZnKa1	GaKa1	ThLa1	RbKa1	SrKa1	YKa1	ZrKa1	NbKa1
Group 1	167	Av.	607	15270	79	25	25	191	186	43	192	20
		SD	90	1846	13	3	3	17	15	3	11	2
Group 2	410	Av.	816	8370	42	22	29	148	168	21	129	12
		SD	123	1239	13	3	4	14	23	2	9	1
Group 3a	385	Av.	1118	48175	101	25	17	137	271	39	220	12
		SD	125	5280	15	3	2	11	25	4	22	1
Group 3b	23	Av.	977	30959	72	25	23	153	233	32	185	13
		SD	100	2961	10	3	2	9	16	3	10	1
Group 3c	20	Av.	1295	59766	108	24	9	78	342	26	134	8
		SD	100	5625	24	2	3	19	30	2	20	2
ANU9000		Av.	475	8649	3	15	3	54	238	21	137	2
MURR-WNB1_05		Pref.	592	8587	30	19	1.5	32	235.7	30	135	2

Figure
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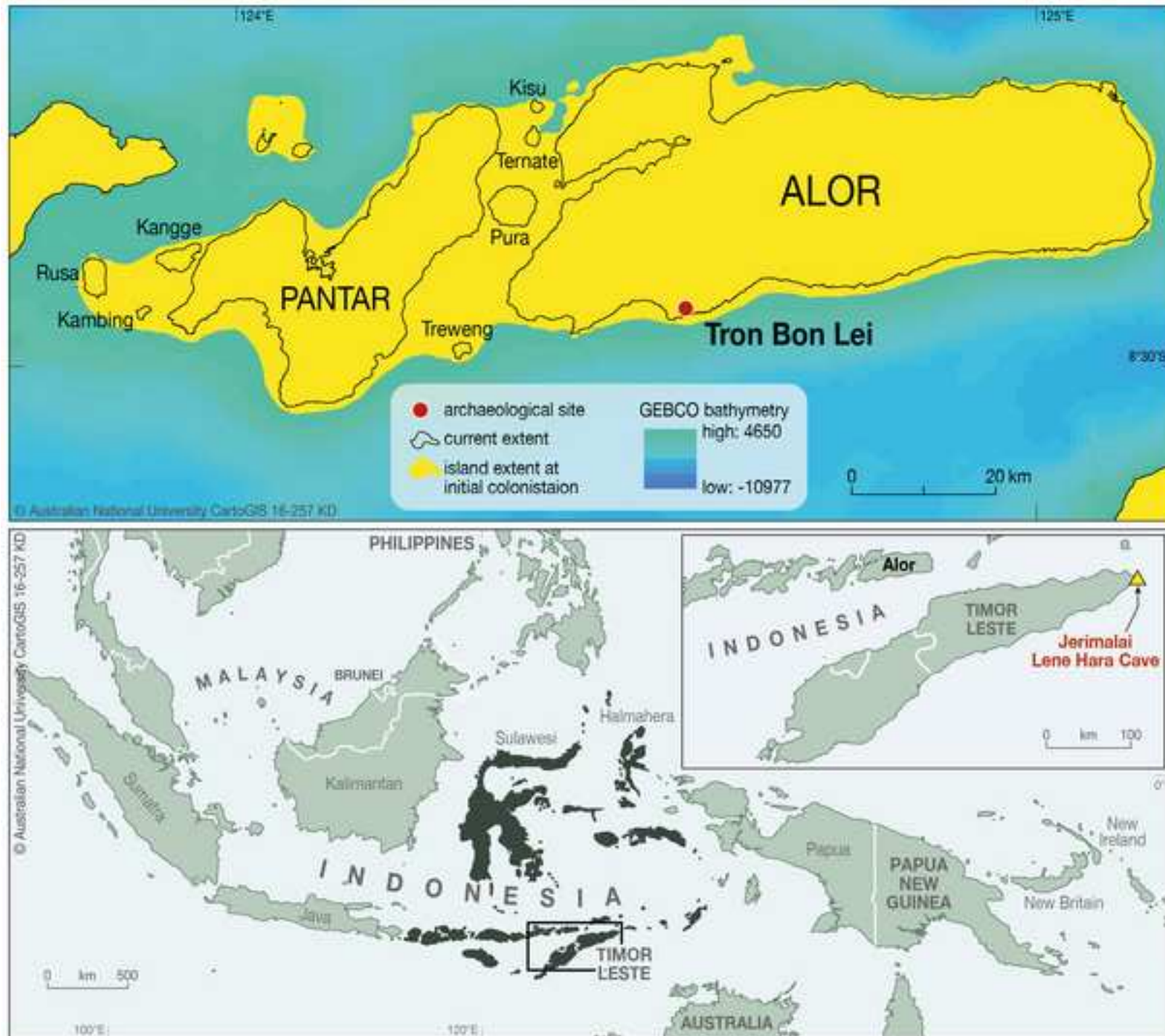
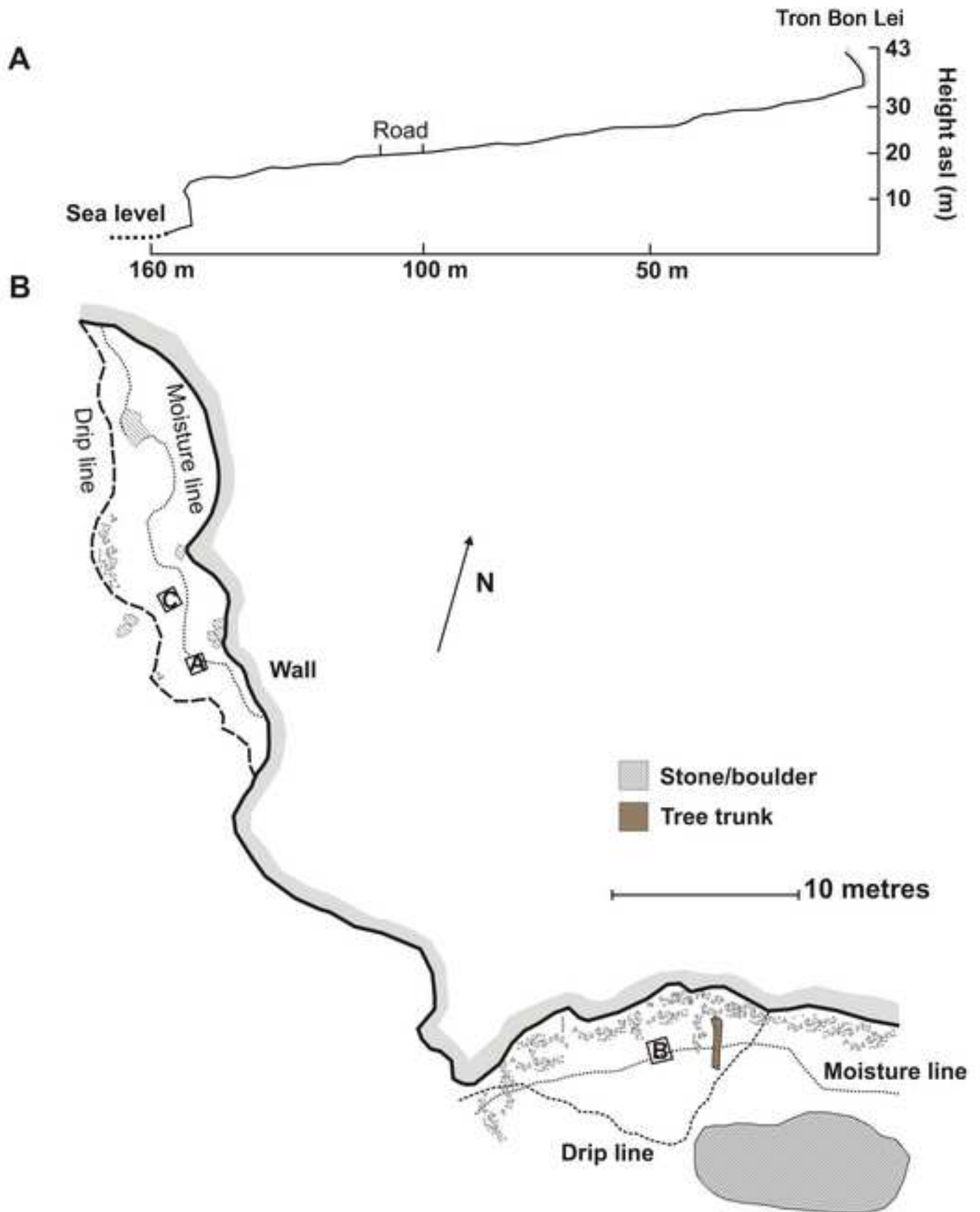
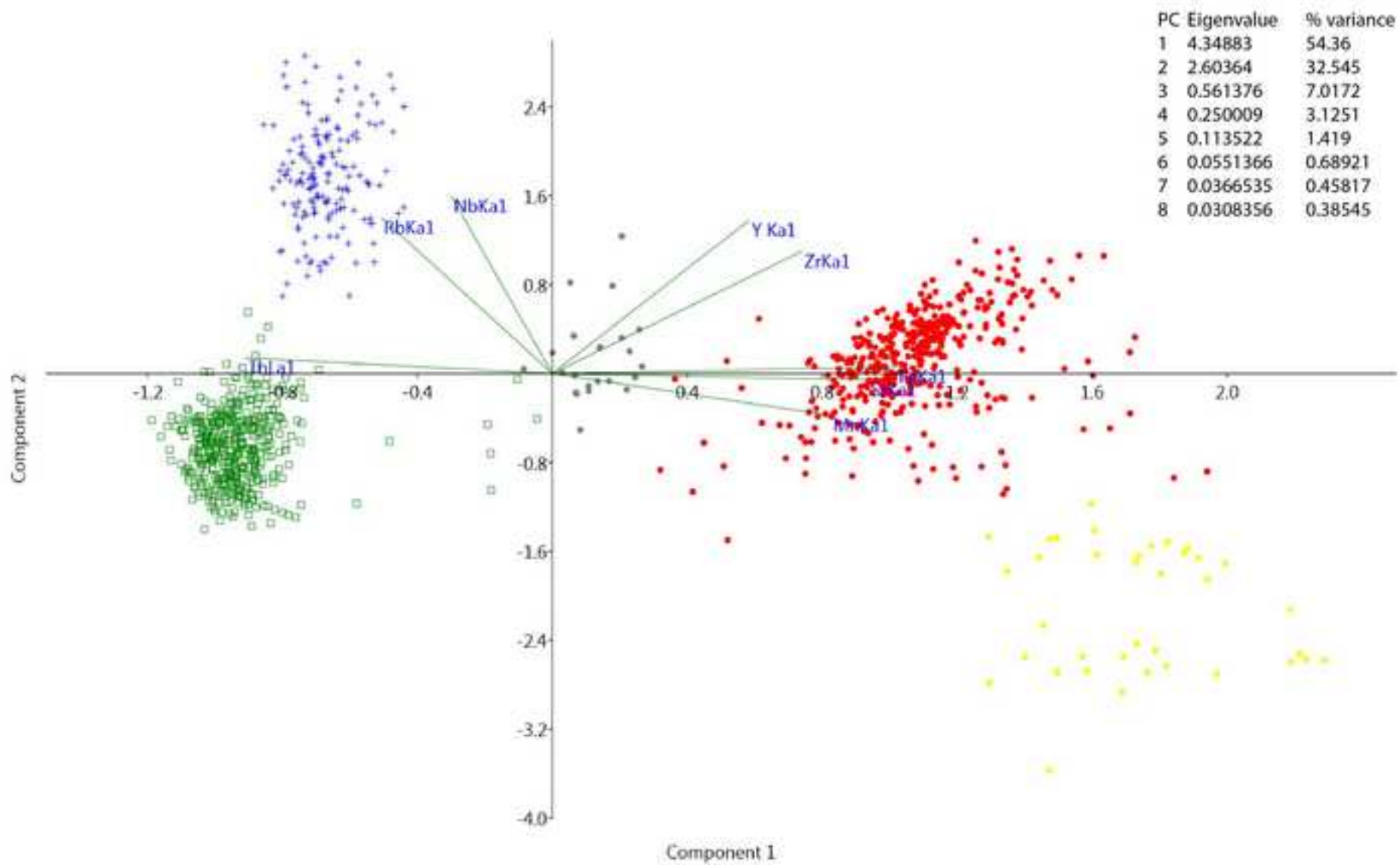


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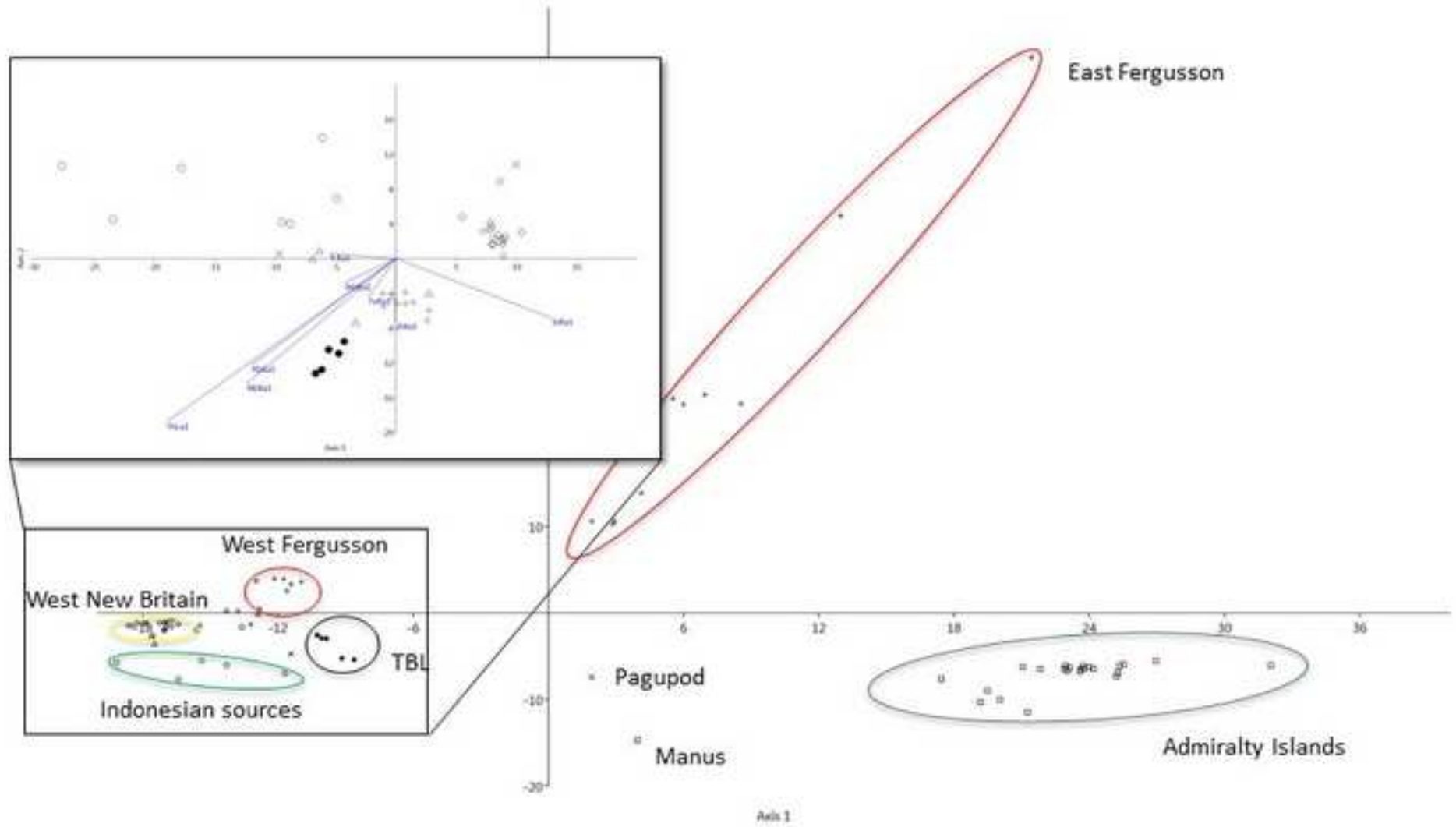
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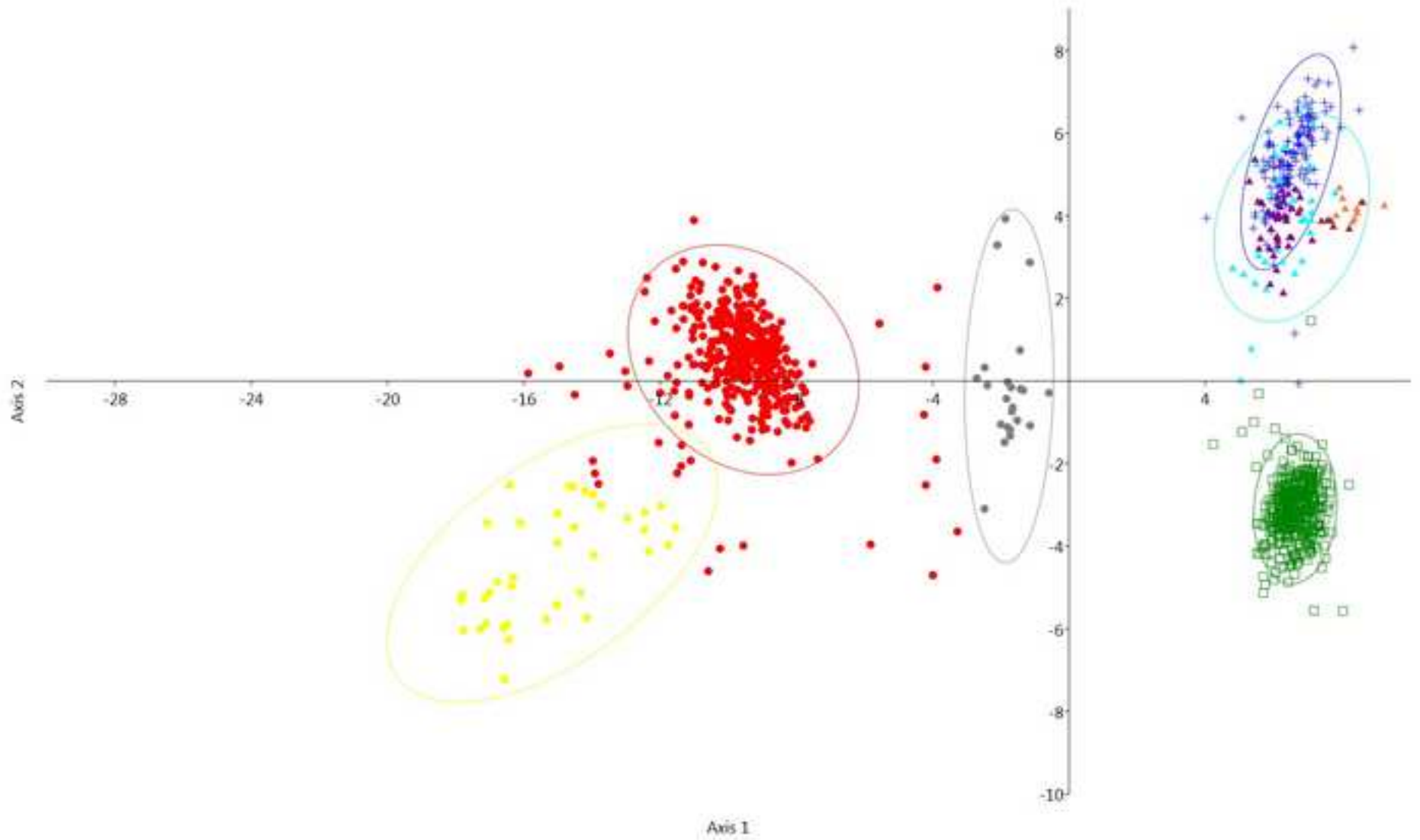
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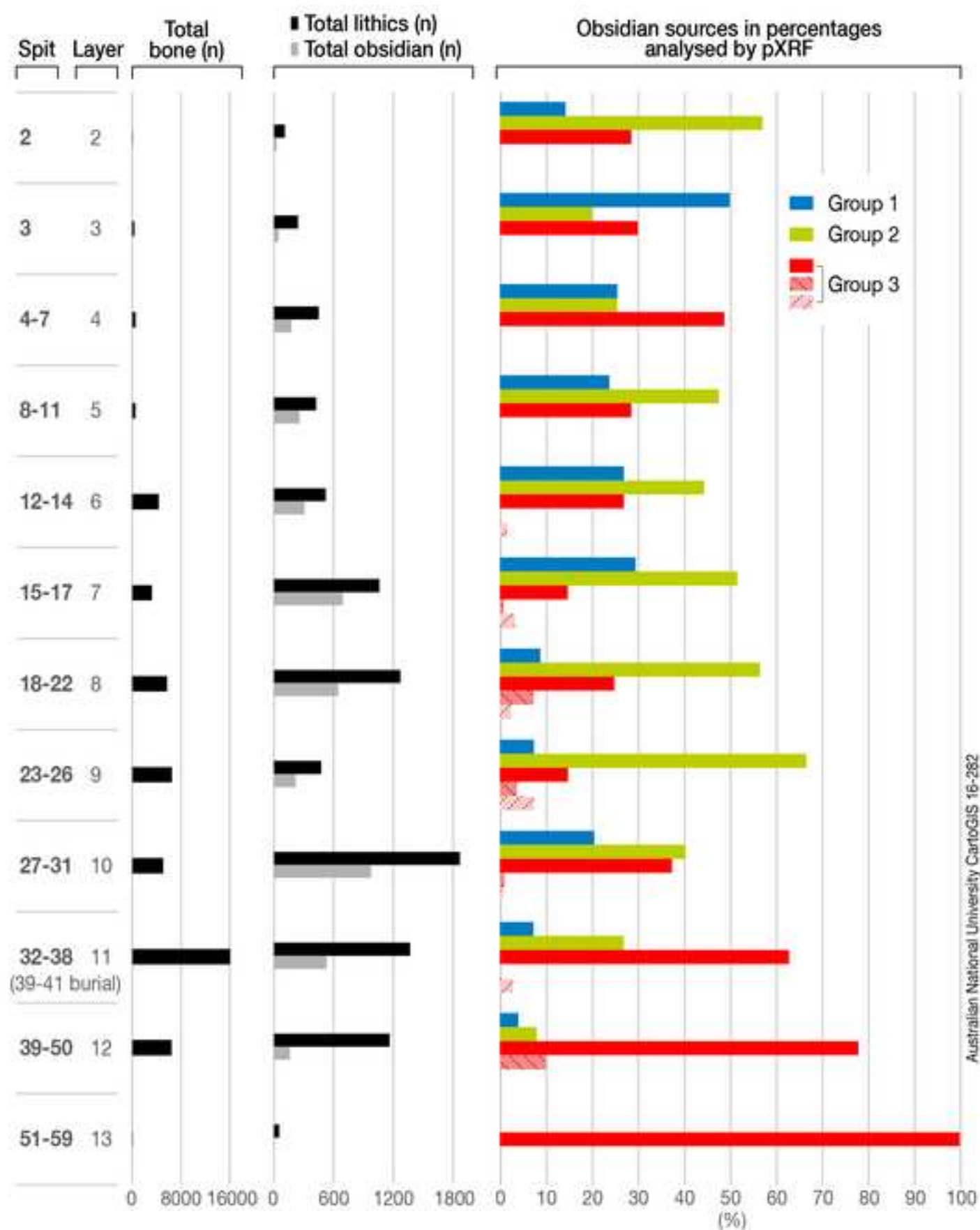
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