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

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9

10 **Abstract**

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

25

26

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 cut
6 through sometimes arbitrary archaeological classifications and provides direct evidence for
7 maritime interaction if materials are sourced from off-island locations. The new evidence
8 presented of terminal Pleistocene maritime transportation of raw materials adds to the global
9 discourse about the beginnings of maritime interaction networks. Island Southeast Asia (ISEA)
10 features very strongly in this debate, as well as new data from the Izu Islands, Japan (Kuzmin,
11 2016), the Northern Channel Islands, USA (Erlandson, et al., 2011), and the Aegean, Eastern
12 Mediterranean (Carter, 2016), now challenging old paradigms about Pleistocene maritime
13 capabilities of hunter gatherer societies and initial raw material transportation being
14 associated only with the spread of Neolithic cultures. Unfortunately, in ISEA, the data for
15 correctly identifying off-island resource use is significantly under-researched as seen in a
16 recent review paper suggesting that there are up to 10 additional, so far unknown, obsidian
17 sources being utilised in ISEA (Reepmeyer, et al., 2011b, Spriggs, et al., 2011).

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

28 In this paper we present new data on two new obsidian sources represented at the Tron Bon
29 Lei rockshelters on Alor Island (Samper Carro, et al., 2015). In addition, we will show that a
30 further third obsidian source matches obsidian raw material utilised in Timor Leste
31 (Reepmeyer, et al., 2011a). The new data provides additional evidence for maritime raw

1 material transportation during the terminal Pleistocene / early Holocene transition, and it will
2 be discussed whether sea-level rise during this time might be an important factor stimulating
3 increased social interaction between island communities in the region.

4 **Site Context**

5 Today Alor has a land area of about 2100 km². As one of the Wallacean islands, Alor has never
6 been connected by a land bridge to Sunda (the enlarged southernmost extension of Eurasia)
7 or Sahul (Australia, New Guinea and the Aru Islands) or to the larger islands of Timor or Flores
8 (Kealy, et al., 2015). During the last lower sea stand, when sea levels were about 130 m below
9 present, it was merged with neighbouring Pantar, Pura, Kambing, Rusa, Ternate and Treweng
10 islands; forming an island of about 3800 km² (accounting for uplift of ~0.5m/ka) (Figure 1). It
11 was at about this time that the Tron Bon Lei sites were first occupied (Samper Carro, et al.,
12 2015).

13

14 [Figure 1]

15 Figure 1. Above: Location of the Tron Bon Lei rockshelter on Alor Island. Landmass extension
16 during occupation history. Below: Location of research area, the darker shaded area shows
17 the extension of the Wallacea region.

18

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

1

2 [Figure 2]

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

5

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

20

21 [Figure 3]

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

23

24 The upper excavation units (EUs) contained a small number of earthenware sherds. Aside
25 from obsidian, stone artefacts were manufactured primarily from basalt (43.6% of the
26 assemblage) with small numbers of chert artefacts (2.8%) also recovered. The faunal
27 assemblage is dominated by fish (Samper Carro, et al., in press, Samper Carro, et al., 2015).
28 The non-fish component comprises small quantities of marine turtle (Chelonioidea), small

1 mammals, reptiles and birds. A detailed study of the fish bones from Tron Bon Lei has shown
2 that as in neighbouring Timor Leste carnivorous species dominate in the Pleistocene and early
3 Holocene levels and that an increase in smaller herbivorous/omnivorous reef fish occurs
4 during the Holocene as sea level rose and coral reefs were established (O'Connor, et al., 2011,
5 Samper Carro, et al., 2015).

6 **Methods and Results**

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

21

22 [Figure 4]

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

25

26 [Table 1]

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

29

1 The sourcing of the artefacts using Principal Component Analysis in the Past 3 freeware
2 program (Hammer, et al., 2001) shows an unambiguous separation of three different source
3 locations¹ (Figure 4). There is a linear spread of samples which indicates that the size of the
4 artefacts increases variability in pXRF analyses (Ferguson, 2013, Lundblad, et al., 2008). Taking
5 into account machine-induced geochemical variation, two source locations (Group 1 and
6 Group 2) show a low-level of intra-source variability suggesting that artefacts provenanced to
7 both source locations originate from single volcanic formations (Table 1). Group 3 obsidian
8 artefacts present a slightly higher intra-source variability and it is possible that multiple
9 outcrops of the same volcanic event were utilised (Figure 4: 3a, 3b, 3c, however there is a
10 high potential that we only see the utilisation of one outcrop with higher variability in the
11 geochemical signature). Group 3 artefacts can primarily be separated by discrepancies in Zr
12 values (Group 3a: 220 ppm, SD 21.7; Group 3b: 185 ppm, SD 10.2; Group 3c: 134 ppm, SD
13 20.3), Group 3c with additional low Rb (78 ppm, SD 18.6) and Nb (8 ppm, SD 1.6) values. Group
14 2 has particular low Fe values (8370 ppm, SD 1238.6) and the geochemical signature of Group
15 1 shows an, for the region, unusual high Rb/Sr ratio (Rb 191 ppm SD 16.9, Sr 186 ppm SD 15.3;
16 Average ratio 1.03).

17

18 [Figure 5]

19 Figure 5. Discriminant Function Analysis of Tron Bon Lei assemblage in relation to other Island
20 Southeast Asian and Western Pacific obsidian sources (data taken from pXRF analysis of ANU
21 obsidian reference collection and SEM-EDXA and LA-ICP-MS data from Reepmeyer, et al.,
22 2011b), excluding the Baucau pitchstone source on East Timor based on the substantially
23 different geochemistry (Rb < 12ppm, Zr < 41 ppm, Nb < 2 ppm).

24

25 Artefacts from Alor were compared with the large reference database of Western Pacific and
26 Island Southeast Asian obsidian sources (Reepmeyer, et al., 2011b, Summerhayes, 2009,
27 Tykot and Chia, 1997). None of the identified groupings could be matched to any of the known
28 sources in the region (Figure 5). The obsidian sources of the Western Pacific are relatively well

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 understood (Reepmeyer, et al., 2016, Summerhayes, 2009), unfortunately, this is not the case
2 for obsidian sources in Island Southeast Asia, where a recent study of ~100 artefacts was able
3 to successfully source only 40% of the assemblages (Reepmeyer, et al., 2011b). Widening the
4 geochemical comparison database to include un-sourced artefacts from Island Southeast Asia
5 and using Discriminant Function Analysis in PAST3, there is a strong match between Group 1
6 artefacts and artefacts from sites on Timor Leste (Ambrose, et al., 2009, Reepmeyer, et al.,
7 2011a). Timor obsidian from several rock shelter sites (Buri Ceri Uato and Buri Ceri Uato
8 Mane, Hatu Sour, Jerimalai, Laili, Matja Kuru 1 and 2, radiocarbon ages of these sites are
9 included in the discussion) show the exploitation of one particular obsidian source recurrently
10 (Figure 6). Our results suggest that it is highly likely that we are seeing the utilisation of this
11 same obsidian source in the Tron Bon Lei sites.

12

13 [Figure 6]

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

17

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

24

25 [Figure 7]

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

² For calibrated age-ranges, see Supplementary table 2

1

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

22 Group 2 artefacts first appear in Layer 11 and from Layer 10 onwards Group 2 is the most
23 abundant obsidian raw material throughout the stratigraphy, particularly during the two peak
24 utilisation periods in Layer 10 and 8. Group 3 (all three sub-sources combined) artefacts occur
25 in all layers of the site. They first appear in Layer 13 where they are the only obsidian source
26 utilised and are most abundant in Layer 10 ($n = 128$, 40% of the assemblage) and 11 ($n = 114$,
27 65% of the assemblage). In tendency this source has been utilised more intensely in the earlier
28 layers (Layer 13 = 100%, Layer 12 = 88%, Layer 11 = 65%) and its abundance significantly
29 decreases proportionally in later layers (Layer 6 = 29%, Layer 3 = 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 later
2 addition of Group 1 and 2 obsidians. We assume that Group 3 artefacts derive from a local
3 source on Alor island, with Group 2 artefacts most likely also local. Supporting the assignment
4 of Group 3 obsidian to a local source is the occurrence of small unworked nodules (recovered
5 from XU 41 (Layer 12) onwards, in the form of small river-rounded pebbles, on average 10-20
6 mm in diameter) whose cortex matches cortex on some of the Group 3 artefacts. No
7 unworked nodules were 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 has
15 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 echo
21 recent results from sites in the Central Philippines (Neri, et al., 2015, Pawlik, et al., 2015),
22 where the authors found no evidence for changing maritime exploitation patterns during this
23 time period. On the other hand, Woodroffe et al. (1988, 2000) and Chappell (1993) have
24 argued that rising sea levels would have indeed stimulated maritime migration and
25 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 surprising
30 as the precipitous coastline during the time of sea-level rise did not change dramatically. The

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

6

7 [Table 2]

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

9

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

20 Matja Kuru 1 (MK1, Sq A and AA) and 2 (MK2, Sq D), are located to the west of Jerimalai,
21 about 5 km from the coast and face south to the large freshwater lake, Ira Laloro. MK2
22 returned an age estimate of 35,500 cal BP for one of the lowest units, additional dates in
23 associated excavation units confirmed this antiquity (Langley and O'Connor, 2015, O'Connor,
24 et al., 2014). At MK2, 30 obsidian flakes were recovered occurring mostly in the Holocene,
25 the earliest deposition of three flakes in EU 33 are bracketed by dates of 9205±55 bp
26 (NZA17001 in EU 32) and 9260±60 bp (OZG898 in EU35). MK2 appears to have little evidence
27 of occupation before these dates and there appears to be a hiatus of occupation during the
28 LGM. The oldest date for MK1 was 13,690±130 bp (ANU11616 from Square AA, EU 21), but
29 an inversion is evident in the age estimate of 9940±60 bp (OZF-784 from EU25) 15-20 cm

1 lower in the profile, and indicates some vertical disturbance. The second square, MK1 Sq A,
2 only returned mid-Holocene dates, starting at 6000 cal BP (Langley and O'Connor, 2015,
3 O'Connor, et al., 2014). Obsidian was found throughout the sequence in both excavation
4 squares starting from the lowest units in MK1, Sq AA, with a single artefact in EU 25, but most
5 artefacts are associated with mid-Holocene layers.

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

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

27 Clearly most of the evidence for obsidian use in the Timor Leste sites dates from about 14,000
28 cal BP or 12,000 cal BP onwards, even when sites have a much longer occupation record. The
29 exception to this is Jerimalai where a single artefact is associated with units dated to 42,000
30 cal BP (Reepmeyer, et al., 2011a). The stratigraphic contexts of the single obsidian flake in
31 Jerimalai indicates that that there is a possibility of vertical displacement of the obsidian from

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

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

15 Ambrose et al. (2009: 615) already noted the later date of initial raw material transportation
16 in ISEA than in the Bismarck Archipelago where Mopir obsidian from West New Britain was
17 transported to New Ireland by 20,000 – 18,000 cal BP (Summerhayes and Allen, 1993). This
18 remains the oldest evidence for inter-island transportation of obsidian raw material in the
19 Indo-Pacific region. Initial obsidian exploitation of a local source for tool manufacture at Tron
20 Bon Lei is dated to the LGM, which again is significantly later than in West New Britain, where
21 obsidian flaked tools are associated with the earliest occupation layers at around 44,000 cal
22 BP at Kupo Na Dari (Torrence, et al., 2004). This might indicate that Alor was not occupied
23 prior to the LGM, which appears unlikely considering the Upper Pleistocene dates on Timor
24 Leste. Similarly, it is unlikely that increased raw material transportation between Alor and
25 Timor Leste sites, as well as between West New Britain and New Ireland (Summerhayes and
26 Allen, 1993) and in the Central Philippines (Neri, et al., 2015), can be identified as indicative
27 of the advent of advanced sailing technology. Distances involved in maritime transportation
28 between these islands are fairly short (~30 km, up to 60 km) and there is island-intervisibility
29 across all sea gaps (Kealy, et al., 2015).

30 Alignment of coastal communities to maritime exploitation and sea crossing might be related
31 to sea level rise as increased productivity in marine environments may have led to larger and

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

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

30 **Conclusion**

1 The application of pXRF to obsidian artefacts provides the opportunity to analyse large lithic
2 assemblages in a relative short amount of time. Here we present the results of more than
3 1000 obsidian analyses from the Tron Bon Lei rock shelter on Alor Island. The data shows that
4 three obsidian sources have been exploited, with all sources being separated unambiguously
5 by pXRF geochemical finger-printing. There is the option of one source being sub-divided into
6 three separate outcrops, but more data is necessary to confirm these results. None of the
7 obsidian artefacts could successfully be sourced to any of the known sources in Island
8 Southeast Asia or the Western Pacific.

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

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

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