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RESEARCH ARTICLE

Imported obsidian at Caution Bay, south coast of Papua New Guinea: cessation of long distance procurement c. 1,900 cal BP

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ABSTRACT
Until now, the evidence for imported obsidian along the south coast of Papua New Guinea has been limited to eleven excavated sites all dating after c. 2,000 cal. BP. Here we present new archaeological evidence for the sourcing and importation of 4,689 obsidian artefacts from 30 excavated sites at Caution Bay. pXRF analysis of a sample of the artefacts revealed that all but one came from a source on West Fergusson Island some 670 km away. During Lapita (here beginning c. 2,950 cal. BP) and post-Lapita times, the proportion of sites with obsidian artefacts was high, and remained so for a thousand years before suddenly ceasing c. 1,900 cal. BP. Technological analyses of obsidian artefacts from Bogi 1 and ABKL—the richest obsidian sites at Caution Bay—indicate intense unipolar and bipolar reduction and the occasional recycling of unipolar flakes into bipolar cores during both Lapita and post-Lapita times. We suggest that this is a result of the importation of obsidian to Caution Bay through down-the-line exchange.

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Introduction

Along the south coast of Papua New Guinea (PNG), obsidian is the only archaeological stone artefact raw material that has been tracked to a specific source. West of Mailu/Amazon Bay, nine sites have been shown to contain obsidian artefacts, all of which originated from Fergusson Island some 40 km north of the eastern tip of mainland PNG (Figure 1). The geographical distribution of obsidian through time is of special significance to archaeology, as it allows for long-distance interactions to be modelled between a limited number of potential source locations occurring north and east of mainland New Guinea and widespread recipient sites and regions (Golitko et al. 2012; Leavesley and Read 2011; Sheppard et al. 2010; Summerhayes 2004, 2009; Torrence et al 1996; White et al. 2006).

Recent archaeological excavations at Caution Bay ~20 km northwest of Port Moresby, in the Central Province of PNG, have revealed extensive evidence of human occupation during the mid- and late Holocene (David et al. 2011; McNiven et al. 2011, 2012a,b; Richards et al. in press) (Figure 1). These findings extend evidence for coastal occupation back to at least 5,000 cal. BP, followed by the arrival of Lapita settlers beginning c. 2,950–2,900 cal. BP, leading to a continuation of ceramic using (and probably ceramic manufacturing) settlements into the period following the demise of recognisably Lapita ceramics after 2,600–2,500 cal. BP. Until now, the database for archaeologically dated, sourced imported goods from the south coast of PNG has been limited to obsidian artefacts from twelve excavated sites. The Caution Bay excavations provide an opportunity to shed further light on obsidian distributions and long-distance interactions along the south coast for a period nearly 400 years prior to that previously known, and for a region from which many sites have been sampled.

Previous studies

Obsidian-bearing sites along the south coast of Papua New Guinea

West Fergusson Island, located 670 km east of Caution Bay by sea, is currently the only known source of obsidian for sites from Amazon Bay to the Vailala River, spanning the reach of obsidian artefacts along the south coast of the island of New Guinea. Approximately 350 km southwest of Fergusson Island, more than 2,000 obsidian artefacts were recovered from excavations on Mailu (sites Oraido 1 and Mailu 3) and on the nearby mainland at Selai in Amazon Bay and dating to the last c. 2,000 years

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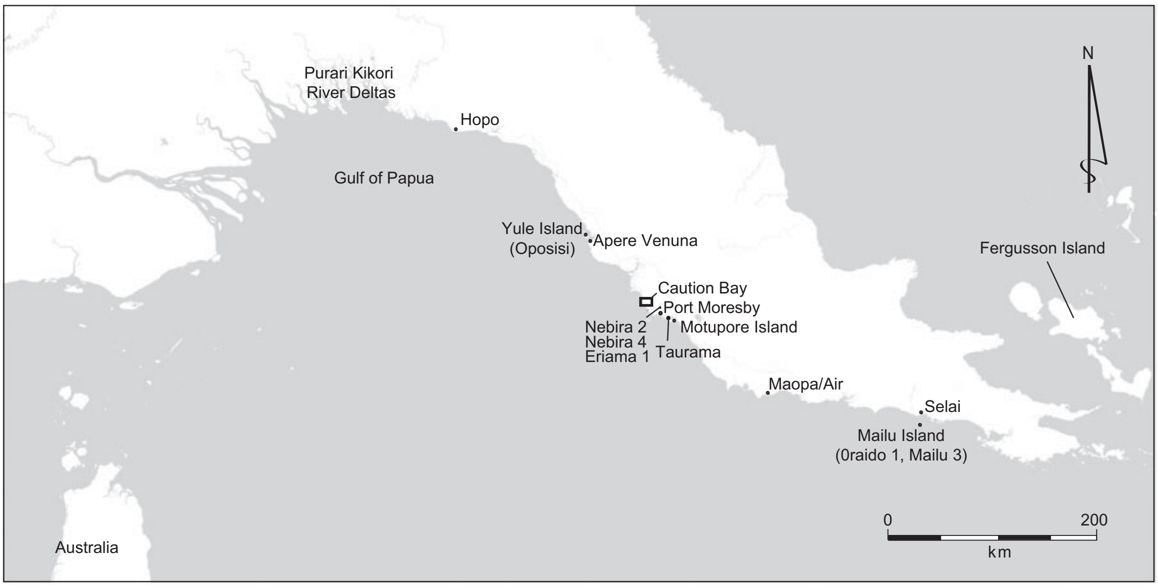

Figure 1. Map of Papua New Guinea showing locations referred to in text.

(Irwin 1985, 1991). A further 150 km west of Mailu, and thus more distant from Fergusson Island, seven obsidian artefacts were found at the Maopa/Air site on the Aroma coast dating to 300–400 years ago (Bird et al. 1981:70; Irwin 1991).

Some 200 km northwest of Maopa/Air, 32 obsidian artefacts were found around Port Moresby at Nebira 4 (Bird et al. 1981:70). Here the obsidian is found in layers likewise dating to 'about 2000 years ago' (Allen 1972:123). Fourteen tiny flakes were found at Nebira 2 on another part of the same hill-site as Nebira 4, dating to the '11–14th century AD' (Bulmer 1975:55, 1979:19), and two flakes from Eriama 1 located approximately 5 km east of Nebira, in levels dating to the '13–15th century AD' (Bulmer 1979:19). Also in the Port Moresby region, on the shores of Bootless Bay, 17 obsidian flakes were recovered from excavations at Taurama in levels dating from '50 B.C. to A.D. 1100' (Bulmer 1975:53–54, 1979:19; but see Allen 1977:411 for a discussion on the reliability of these ages). However, Eriama 1, Taurama and the Nebira sites each had major dating problems or limitations. Offshore from Taurama, a single obsidian flake was identified from excavations on Motupore, an island located in the middle of Bootless Bay, 15 km southeast of Port Moresby. Here occupation of the site began about 800 years ago (Allen 1977).

An additional 100 km to the northwest of Port Moresby are the sites of Apere Venuna on the mainland coast south of Yule Island, and Oposisi on Yule Island itself (Vanderwal 1973). At Apere Venuna, two obsidian flakes were found and provenanced to the West Fergusson Island source (Vanderwal 1973:127, 214). Vanderwal (1973:127) also recovered two obsidian flakes from Oposisi. An additional 17 obsidian artefacts were found when the site was re-excavated in 2007; 11 of these, from levels dating to c. 2,000–1,000 cal. BP, were also sourced to West Fergusson Island (Allen et al. 2011). Northwest of Oposisi, 11 obsidian artefacts, all sourced to West Fergusson Island, were excavated from the site of Hopo inland and east of the Vailala River in levels dating from c. 2,600 cal. BP (when they are associated with dentate-stamped ceramics) to c. 1,870–1,631 cal. BP. No obsidian artefacts were found at Hopo nor at any other excavated site nearby after that time (Skelly et al. 2016:135–136). Nor have any obsidian artefacts been found in any of the five excavated sites at the mouth of the Purari-Kikori River deltas further to the west (Barker et al. 2012, 2015; Frankel et al. 1994; Frankel and Vanderwal 1982), or from any of the 20 lowland archaeological sites excavated slightly further inland along the Kikori River in dense rainforest settings (David 2008; David et al. 2010, 2015; McNiven et al. 2010; Rhoads 1983).

Island Melanesia contains three other obsidian source groups (Admiralty Islands, New Britain and Banks Islands in Vanuatu) (Figure 2), and artefacts from these three other sources have been found in archaeological sites in the north, east and west of PNG but never along the south coast of the mainland. The timing and changing access to obsidian from these various sources have been key to informing changing social connections between people at individual sites, islands and island archipelagos through time, but do not apply to the south coast (Summerhayes 2009; Summerhayes and Allen 2007).

Obsidian distribution networks

The current obsidian distribution model for the south coast of PNG is based on the work of Irwin

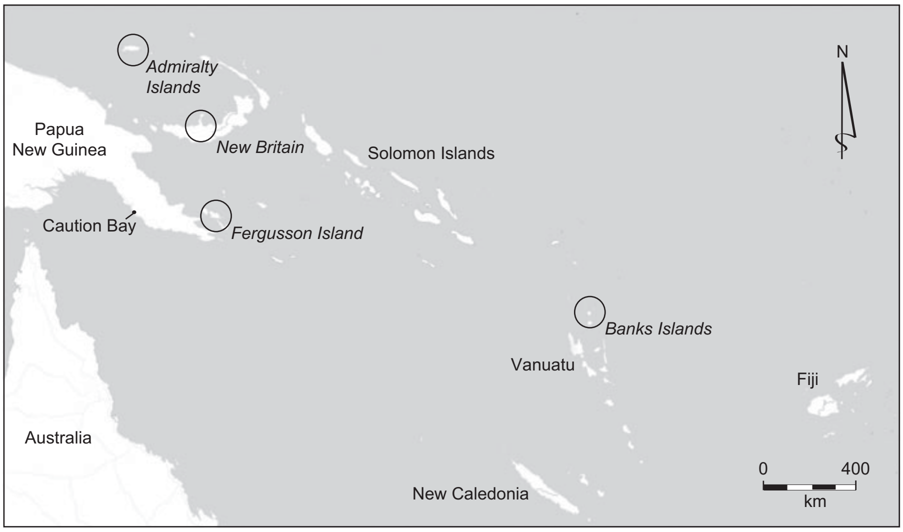

Figure 2. Location of the four obsidian source groups in Melanesia.

(1991) and Irwin and Holdaway (1996) at Mailu. They hypothesised that fluctuations in obsidian quantities and mean weights correspond to changes in settlement patterns. They suggest that more obsidian was brought to Mailu via direct procurement during the initial settlement period (c. 2,000 BP)—*the coloniser mode*—as evidenced by a greater quantity of (foreign) obsidian from the east, larger complete flakes and higher number of flake scars on core surfaces, than in later periods of occupation. The decrease in obsidian quantities and overall mean weights and increasing reduction intensities between c. 1,750 and 1,000 BP is attributed to a change in settlement patterns and a shift from direct procurement to down-the-line exchange that focussed on pottery production and trading—*the trader mode*. This coloniser/trader model is not unique to the south coast of PNG and has also been used by Sheppard (1993) to explain changes in obsidian procurement in the Reef/Santa Cruz Islands of the Solomon Islands. In each case, it is assumed that reduction intensities correlate with raw material availability; that is, that technological strategies geared towards raw material conservation are implemented when obsidian accessibility becomes limited. Specht (2002) compared the mean weight of Bismarck sourced obsidian artefacts at pre-Lapita, Lapita and/or post-Lapita sites located from tens to thousands of kilometres away from the Bismarck Archipelago. His analysis showed a decrease in mean obsidian weights during the post-Lapita period, indicating increased levels of reduction and decreasing replenishment of new, larger obsidian pieces from the source, thus adding support for Irwin's model. This colonising versus trading model distinction can be re-examined with the new Caution Bay evidence that is based on a significantly increased database for the south coast.

The New Caution Bay evidence

Archaeological excavations conducted at Caution Bay in 2009–10 revealed many rich and stratified shell, animal bone, ceramic and lithic assemblages. Out of 55 excavated sites for which the lithic assemblages have been analysed, 30 sites contain obsidian artefacts (Figures 3 and 4). A total of 4,689 obsidian artefacts weighing 544.8 g were recovered from excavated sediments wet sieved through 2.1 mm-diameter mesh (Table 1). The number of obsidian artefacts varied widely between sites, from one to over 2,000 artefacts.

The results presented here only concern those sites and cultural horizons for which radiocarbon dates have been obtained. A total of 721 AMS radiocarbon dates on individual fragments of shell or charcoal have been acquired from these 30 sites, enabling most of the assemblages to be dated with confidence (Table 1). With a large obsidian dataset, the Caution Bay assemblage provides the opportunity to explore changing rates of incoming foreign raw materials through time, and with this to reassess current understandings of the movement of goods and people through time along the south coast of PNG.

Methods

Lithic analysis

An initial assessment of the Caution Bay obsidian showed that obsidian artefacts were extremely small and lacked retouching, thereby limiting the benefits offered by a typological study. A technological analysis was thus performed on the artefacts to identify in what form the obsidian reached Caution Bay (e.g. nodules, prepared cores or large flakes), to describe the nature of the obsidian reduction process, and to quantify the

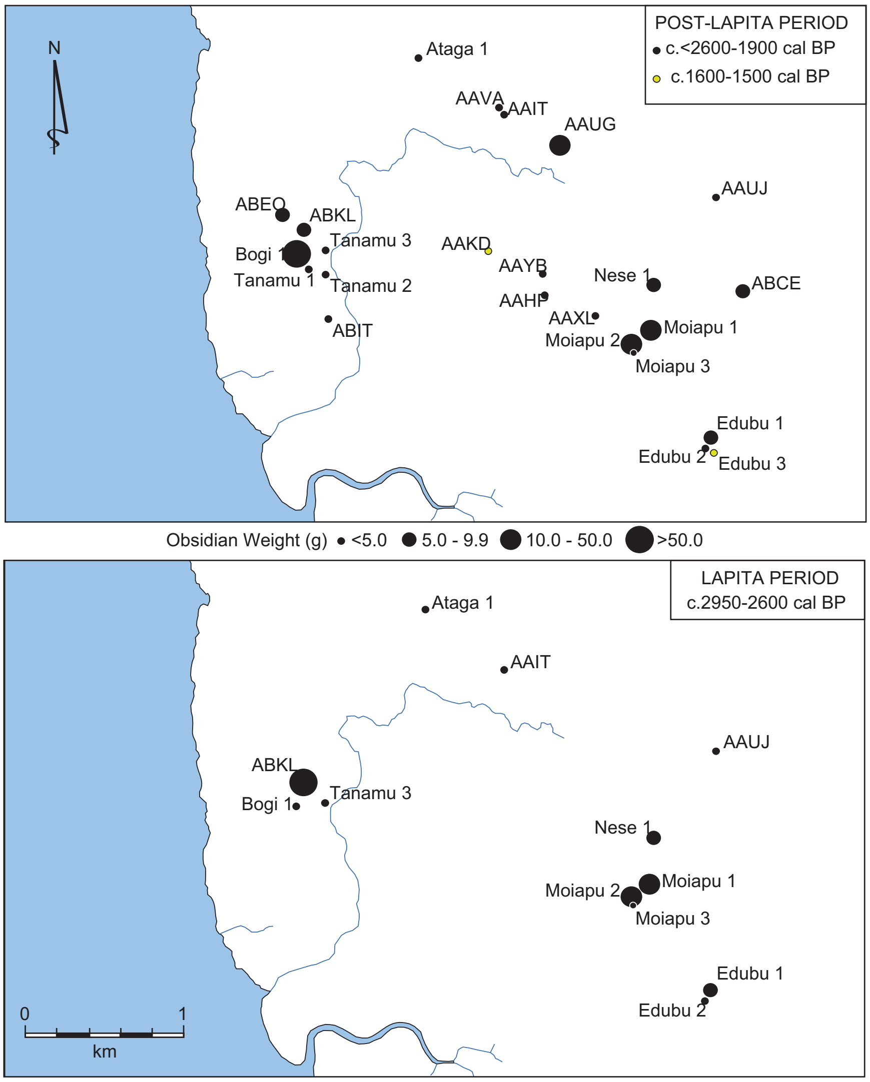

Figure 3. Distribution of sites with obsidian across the Caution Bay landscape, Lapita and post-Lapita periods.

degree to which obsidian was reduced. The technological analysis presented here is based on the obsidian assemblages of the Bogi 1 and ABKL sites, because 85.3 per cent of the Caution Bay obsidian assemblage for which we have associated radiocarbon ages is contained within these two sites. These two coastal sites are in close proximity and are marked by intensive episodes of stone artefact manufacture. Most (90.7 per cent) of the Caution Bay obsidian bipolar artefacts came from these two sites. Each of the two sites also has two distinct periods of occupation covering the period since the arrival of Lapita peoples:

- A Lapita phase of occupation covering the period between c. 2,900–2,500 cal. BP, which combines the assemblages of Bogi 1 (Squares C, PP, SS and TT) and ABKL (Squares A and B). At ABKL, the chronological resolution is not fine enough to determine exactly when Lapita ended sometime between 2,600 and 2,500 cal. BP.
- a post-Lapita phase covering the period between c. 2,300–2,000 cal. BP combining the assemblages of Bogi 1 (Squares A, B and C) and ABKL (Square A).

pXRF analysis

Portable X-Ray Fluorescence (pXRF) is becoming relatively common for obsidian sourcing as it provides an excellent distinction between sources using the mid-Z elements: Rb, Sr, Y, Zr and Nb. For the current research, a Bruker Tracer III-SD pXRF was employed, using optimal settings for the mid-Z elements (40 kV, 30 μA) with a filter (12 mil Al + 1 mil Ti + 6 mil Cu), for a 300-second run time.

A pelletized international standard (BHVO-2) was analysed to understand the accuracy of the instrument before each run and after 15 samples during a run. The results of this analysis are presented in Table 2. Calibration to parts per million (ppm) for the obsidian artefacts was a two-part process: first, the raw data were processed using Bruker's obsidian (OB40) calibration in S1CalProcess (Speakman 2012). These results were then improved by applying a linear regression based

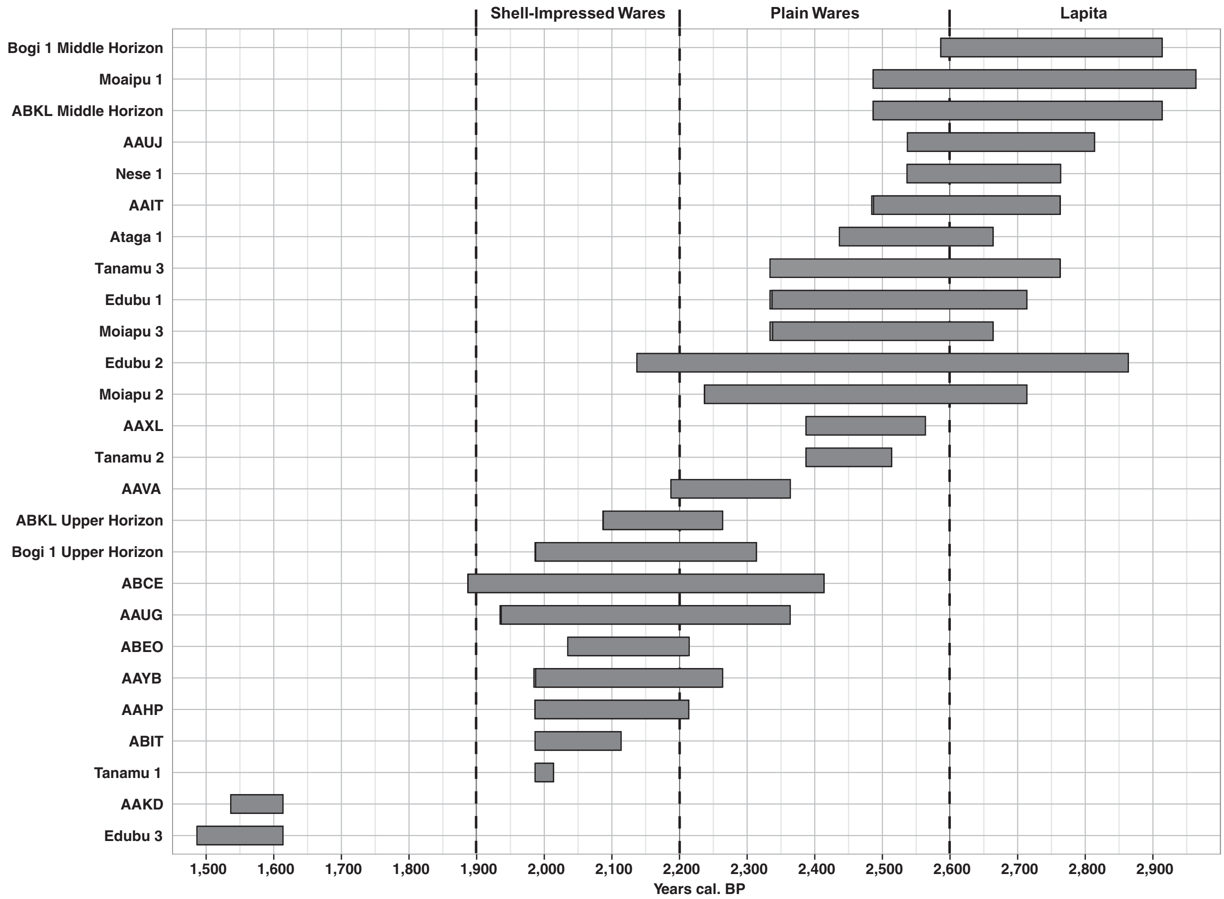

Figure 4. Calibrated radiocarbon ages for occupation sites containing obsidian artefacts, Caution Bay. Occupation begins earlier than 2950 cal. BP (start of Lapita) at some sites, but the diagram does not show these earlier times as no pre-Lapita obsidian has been found at any site. Age ranges within individual sites are calibrated to 68.2 per cent probability and rounded to the nearest 50 years.

Table 1. Obsidian-bearing sites, Caution Bay (the calibrated ages represent the total spread of the 68.2% probability range rounded to nearest 50 years, calibrations undertaken using Oxcal 4.2 with Intcal 09 dataset) (Bronk Ramsey 2009, 2013; Reimer et al. 2009).

PNG NMAG Site Code	*Site Name (Monash Code)*	*Square*	*Calibrated Age Range BP*	*Number of obsidian artefacts*	*pXRF*	*Obsidian Weight (g)*	*Obsidian Mean weight (g)*	*Total Assemblage Size*	*Per cent Obsidian*
AAHP	(JDA6)	A	2250-2000	15	8	1.03	0.07	139	10.8
AAIT	(MLA14)	A	2750-2500	1	0	0.34	0.34	71	1.4
AAKD	(AK32)	A	1600-1500	1	1	0.09	0.09	15	6.7
AAUG	(JA24)	A	2350-1950	22	11	6.16	0.28	1283	1.7
		B	2350-1950	1	0	0.01	0.01	50	2.0
		C	2350-1950	13	3	2.05	0.16	109	11.9
		D	2350-1950	76	38	32.56	0.43	1662	4.6
		E	2350-1950	2	2	0.46	0.23	71	2.8
AAUJ	(JA21)	A	2800-2550	1	1	0.48	0.48	823	0.1
AAUY	(JA15)	A	No datable material	1	0	0.53	0.53	10	10.0
AAVA	(JA13)	A	2350-2200	12	8	2.33	0.19	641	1.9
AAVM	Ataga 1 (JA1)	A	2650-2450	1	1	0.05	0.05	1002	0.1
AAWA	Nese 1 (RS63)	B	2750-2550	3	3	3.22	1.07	403	0.7
		D	2750-2550	3	3	1.96	0.65	158	1.9
		E	2750-2550	3	2	0.71	0.24	668	0.4
AAXL	(RS54)	A	2550-2400	4	0	1.90	0.48	698	0.6
		B	2550-2400	12	0	1.09	0.09	270	4.4
AAYB	(RS30)	A	2250-2000	6	6	1.59	0.27	225	2.7
AAYJ	(RS84)	A	Dating in progress	1	0	0.02	0.02	64	1.6
AAYL	Moiapu 2 (RS86)	A	2700-2250	12	9	1.49	0.12	301	4.0
		B	2700-2250	25	12	2.21	0.09	970	2.6
		C	2700-2250	5	4	4.95	0.99	515	1.0
		D	2700-2250	24	19	5.32	0.22	700	3.4
		E	2700-2250	14	9	2.40	0.17	560	2.5

(*continued*)

Table 1. Continued

PNG NMAG Site Code	Site Name (Monash Code)	Square	Calibrated Age Range BP	Number of obsidian artefacts	pXRF	Obsidian Weight (g)	Obsidian Mean weight (g)	Total Assemblage Size	Per cent Obsidian
AAYM	Moiapu 1 (RS87)	F	2950-2500	122	65	17.28	0.14	1772	6.9
AAZD	Moiapu 3 (RS101)	A	2650-2350	18	13	2.27	0.13	699	2.6
ABAM	Edubu 3 (AH13)	A	1600-1500	1	0	0.01	0.01	262	0.4
ABAN	Edubu 2 (AH14)	A	2850-2150	1	1	0.04	0.04	307	0.3
		B	2850-2150	3	1	0.16	0.05	820	0.4
ABAO	Edubu 1 (AH15)	A	2700-2350	17	17	3.26	0.19	2593	0.7
		B	2700-2350	6	6	1.91	0.32	3021	0.2
		C	2700-2350	5	5	0.15	0.03	1604	0.3
ABCE	(AKRD3)	A	2400-1900	13	13	1.95	0.15	1472	0.9
		B	2400-1900	3	3	0.47	0.16	1488	0.2
		C	2400-1900	51	29	6.92	0.14	1078	4.7
		D	2400-1900	19	8	2.66	0.14	982	1.9
		E	2400-1900	8	2	0.25	0.03	998	0.8
		H	2400-1900	6	4	0.58	0.10	449	1.3
ABEN	Bogi 1	A	2300-2150	317	0	49.33	0.16	4324	7.3
		B	2300-2050	495	0	58.28	0.12	5613	8.8
		C	2200-2000	542	0	66.25	0.12	4842	11.2
		C	2900-2600	1	0	0.06	0.06	236	0.4
		PP	2900-2600	2	2	0.54	0.27	365	0.5
		SS	2900-2600	1	0	0.13	0.13	344	0.3
		TT	2900-2600	8	4	0.63	0.08	464	1.7
		D	Dating in progress	NA	8	NA	NA	NA	NA
		M	Dating in progress	1	1	6.84	6.84	NA	NA
ABEO	(ML19)	1	Dating in progress	2	0	0.41	0.21	230	0.9
		A	Dating in progress	109	0	14.33	0.13	963	11.3
		B	2200-2050	58	0	14.18	0.24	2758	2.1
ABEP	Nadi 1	1	NA	1	0	0.22	0.22	391	0.3
		2	NA	4	0	0.16	0.04	283	1.4
		B	NA	7	0	0.60	0.09	419	1.7
ABEQ	Nadi 2	B	Dating in progress	2	0	0.09	0.05	165	1.2
ABES	Line 11 Mound	1	Disturbed	4	0	1.24	0.31	384	1.0
ABHA	Tanamu 1 (JD6)	B	c. 2000	1	1	0.03	0.03	1258	0.1
ABHC	Tanamu 2 (JD15)	A	2500-2400	9	9	2.15	0.24	369	2.4
		B	2500-2400	2	2	0.19	0.10	210	1.0
ABHD	Tanamu 3 (JD16)	B	2750-2350	4	3	0.48	0.12	146	2.7
		C	2750-2350	8	7	1.98	0.25	104	7.7
		D	2750-2350	2	2	0.75	0.38	76	2.6
ABIT	(JD12)	B	2100-2000	1	1	0.18	0.18	101	1.0
ABIV	(JD14)	B	Dating in progress	20	0	4.01	0.20	1246	1.6
		C	Dating in progress	5	0	0.25	0.05	405	1.2
		D	Dating in progress	30	0	5.56	0.19	1316	2.3
ABKL	(ML18)	A	2250-2100	31	20	5.48	0.18	414	7.5
		A	2850-2650	58	0	7.10	0.12	566	10.2
		A	Dating in progress	39	0	5.98	0.15	344	11.3
		B	2800-2500	2128	0	156.97	0.07	6783	31.4
		B	Dating in progress	249	0	28.97	0.12	890	28.0
		D	Dating in progress	17	0	0.61	0.04	39	43.6
Total				4689	379	544.84	0.12	65,001	7.2

NA = not available

on twelve pelletized international standards (AGV-2, BCR-2, BIR-1a, BHVO-2, DNC-1a, GSP-2, QLO-1, SDC-1, SDO-1, SRM 278, SRM 688, W-2a), each run three times using the same settings as for the archaeological samples. One of the major issues cited with obtaining accuracy in applying pXRF to archaeological artefacts is their size and morphology (Davis et al. 2011; Golitko et al. 2010; Shackley 2011). As this was a non-destructive analysis, standard protocol to cater for problems with morphology was to ensure that the flattest surface possible was placed on the pXRF's analytical window. In regard to size, the Bruker Tracer III-SD has an analytical window of 4 mm × 3 mm, therefore, artefacts needed to be larger than this to ensure accuracy. At the same time, the mid-Z elements require an infinite thickness of roughly 3 mm, which is the minimum thickness required to absorb all the X-rays emitted from the pXRF (Speakman 2012). All artefacts were measured for their maximum length, width and

Table 2. Error ranges of Bruker Tracer III-SD during analysis.

BHVO-2	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb
USGS recommended, ppm	1,290	86,300	103	9.8	389	26	172	18
University of Otago pXRF average (*n* = 24), ppm	1,255	85,585	112	12.5	364	25	159	17
Standard deviation, ppm	48.6	524.4	8.24	0.85	3.5	0.69	1.78	0.59
RSD (per cent)	3.87	0.61	7.34	6.78	0.96	2.76	1.12	3.54

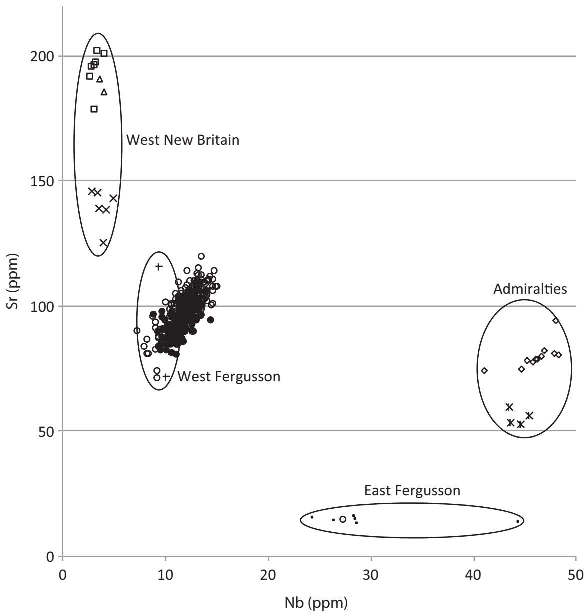

Figure 5. Results of pXRF analysis of obsidian artefacts from Caution Bay. Small circles indicate artefacts: dark circles are above appropriate size of 4 mm × 3 mm × 3 mm, clear circles are below these dimensions. All other symbols are source samples.

thickness in order to identify potential issues caused by 'undersized' artefacts. Figure 5 outlines which artefacts are above or equal to appropriate size, as well as those that are undersized. Based on this analysis, it can be seen that while of concern, size does not sufficiently result in the alteration of chemical data to cause misidentification of a source, which is the principal focus of this analysis.

Results

Sourcing the Caution Bay obsidian

A total of 379 obsidian artefacts drawn from 20 sites across both the Lapita and post-Lapita phases were analysed using pXRF at the Department of Anthropology and Archaeology, University of Otago. In terms of sampling, attempts were made to analyse all artefacts from a site as it became available for analysis, hence not all sites are represented. Of those sites that were analysed, only very small obsidian pieces were excluded (with the exception of ML18 where only a random sample was examined). The results show that all but one artefact within the Caution Bay obsidian assemblage can be conclusively attributed to the West Fergusson source. These results are in agreement with Cunliffe's (2011) pilot pXRF study of 82 obsidian artefacts from Bogi 1 Square C. One artefact, from Edubu 2 Square B XU7 (dated sometime between 2,850–2,150 cal. BP), falls within a different source, in this case, East Fergusson Island (Figure 5). Additional testing is required to confirm this result.

Chronology

At Caution Bay the majority of sites with obsidian continuously cover the Lapita period (c. 2,950–2,550 cal. BP) and continue into a subsequent phase with exclusively plain body, but often decorated lip, pottery (c. 2,550–2,200 cal. BP), followed by a phase of ceramics with standardised shell-impressed indentations (c. 2,200–2,000 cal. BP). Obsidian makes its initial appearance at Caution Bay with the first arrival of Lapita settlers at Bogi 1 c. 2,950 cal. BP (Figure 6). From that initial arrival until c. 2,000 cal. BP, c. 70 per cent of excavated sites possess obsidian artefacts, with obsidian almost entirely ceasing after 1,900 cal. BP (these ages are cited at the full 68.2 per cent probability calibrations of the individual radiocarbon dates – rather than the median ages – and thus the cited total age range of 2,950–1,900 cal. BP may broaden by 50 to 100 years the real age range of obsidian deposition).

The cessation of obsidian-bearing sites after c. 1,900 cal. BP is not merely a function of a decrease in the overall number of excavated sites. Nineteen sites with post-1,900 cal. BP occupation were excavated and have been analysed from Caution Bay (AAJU, AAJV, AANR, AANV, AAPH, AAPN, AAVD, AAVC, AASI, AATP, Tanamu 1, ABHF, ABIU, AAHO, ABJX, ABJY, ABKA, ABKC, ABKF, ABKH, ABKK, ABKN, ABKO, AAIJ, AAIU, ABCL and AAUQ). With the exception of two sites (AAKD Square A and Edubu 3 Square A), obsidian is absent across all the analysed Caution Bay sites after 1,900 cal. BP (Figure 6). Only two obsidian artefacts were recovered from AAKD and Edubu 3, both in horizons dating between 1,600 and 1,500 cal. BP. It is not known whether these two isolated artefacts represent contemporaneous importation of obsidian from West Fergusson Island, recycled raw materials (from earlier periods of importation), or redeposition (disturbance) of deposits. No evidence exists to indicate whether they should be treated as intrusive, although we note that at AAKD, Square B (located about 12 m from Square A) contains radiocarbon dates akin to

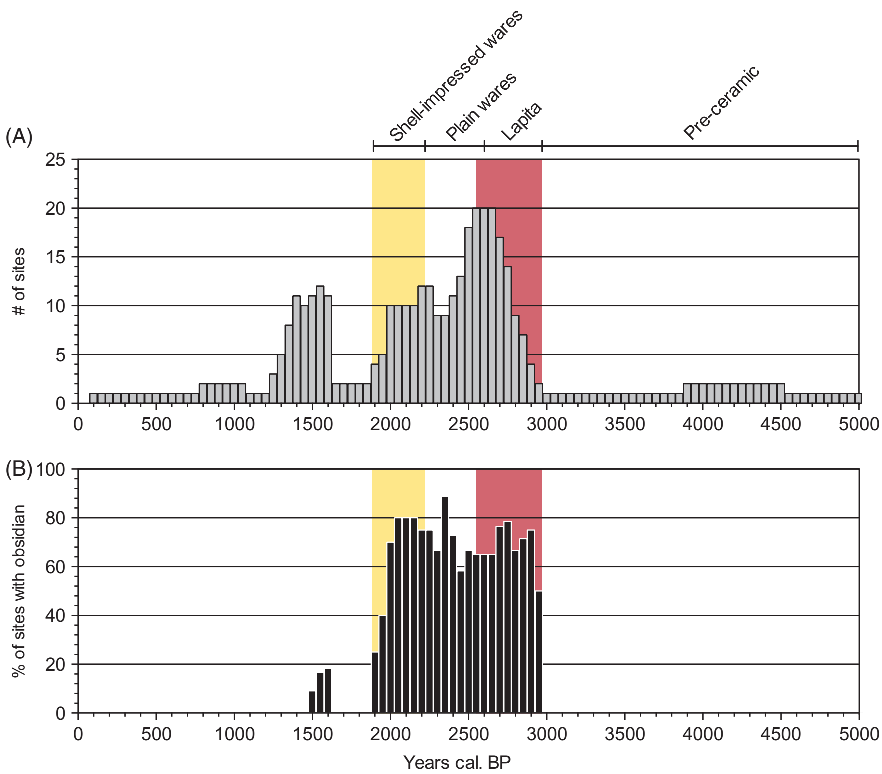

Figure 6. Number of sites (A) and percentage of obsidian-bearing sites (B), in 50 year intervals, Caution Bay (age distributions incorporate full range of 68.2 per cent probability calibrations of each radiocarbon date; hence, for example, the two sites with obsidian dated 1600–1500 cal. BP register here in three rather than two 50-year intervals).

those associated with the obsidian in the upper levels of Square A, plus two pre-1,900 cal. BP dates from XU14 and XU18 deeper down (2,160–2,270 cal. BP and 2,550–2,680 cal. BP, respectively). This indicates the presence of older cultural deposits that could have contained earlier obsidian artefacts recycled into the upper levels of Square A. Either way, obsidian largely or entirely ceases to arrive into Caution Bay after c. 1,900 cal. BP.

Frequency of obsidian through time and space

Obsidian represents only 7.2 per cent of the Caution Bay stone assemblage and rarely represents more than 5 per cent of the stone assemblage of any excavation square (Table 1). Most artefacts are made on locally available chert. The highest concentration of obsidian is found at ABKL in Square B, where it represents 31.4 per cent of the stone artefacts in levels dated between c. 2,800 and 2,500 cal. BP. Such a large quantity and proportion of obsidian in a single square is not seen again in later phases of occupation at any Caution Bay site. Some 545 g of obsidian was recovered from horizons dating between c. 2,950 and 1,900 cal. BP from the 30 obsidian rich sites (67 excavated squares), plus 0.1 g from two sites (two excavated squares) between c. 1,600 and 1,500 cal. BP. The obsidian artefacts themselves are very small and light with 72.2 per cent ($n = 3,384$) each weighing less than 0.1 g and reaching a maximum length of only 35 mm.

Obsidian frequencies are also differentially distributed across space (Figure 3). For the 30 obsidian-bearing sites, 82.9 per cent ($n = 3,889$; 71.0 per cent by weight) of all Caution Bay obsidian artefacts are concentrated at two sites that are in close proximity, Bogi 1 and ABKL. In reality, these two archaeological sites are almost certainly different parts of the same ancient village; the uncertainty rests with the fact that the excavations were spatially discontinuous. This obsidian concentration along the Bogi 1-ABKL shoreline implies that obsidian deposition was spatially patterned, and largely restricted to specific localities within village sites. The fact that obsidian occurred in large quantities at the same locations during Lapita (c. 2,950–2,600 cal. BP) into post-Lapita times (defined here as the period starting shortly after 2,600 cal. BP when dentate-stamped and carinated ceramics stopped simultaneously) suggests continuity in village positioning and in the spatial patterning of activity areas, or at least in the way they involved the processing, storage and discard of obsidian.

This continuity of spatial arrangement is consistent with the evidence of radiocarbon dates and ceramics, which signal both continuous village occupation from Lapita well into post-Lapita times (although there are some expansions and contractions of villages within and between phases), and the

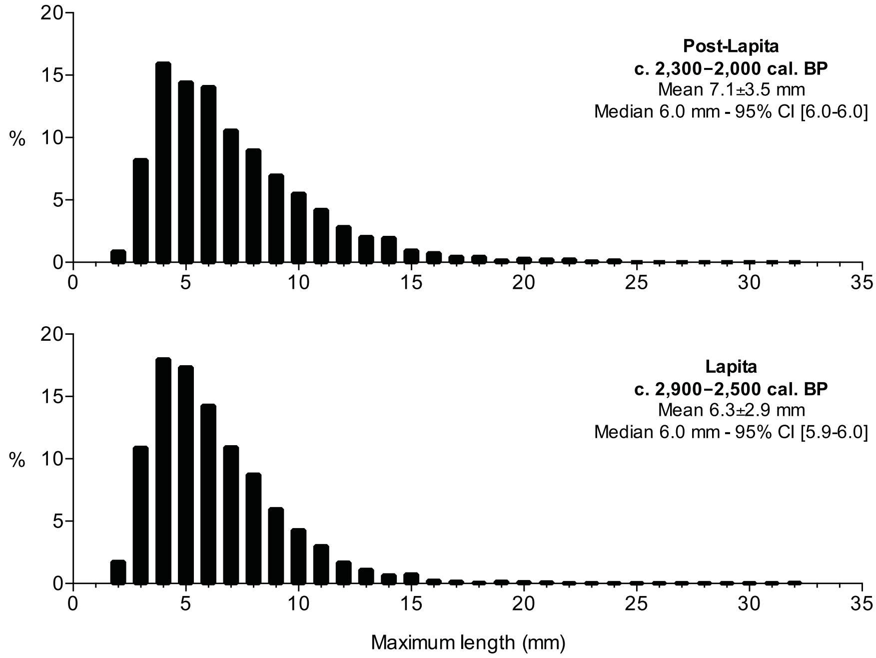

Figure 7. Maximum length of all obsidian artefacts by phase of occupation, Caution Bay.

transformation of ceramic conventions from unambiguously recognisable Lapita forms and designs between c. 2,950 and 2,550 cal. BP (including carinated pots and dentate-stamping, respectively), to a continuation of ceramics but total absence of such Lapita conventions beginning c. 2,550 cal. BP. That is, continuity in village occupation, activity areas, obsidian and ceramic use occur at many sites, even while ceramic conventions radically and rapidly changed from Lapita to something else. At Caution Bay, the rapidity of the ceramic change from Lapita takes place within the lifespan of a single generation, and overlaps temporally with continuities in other cultural practices (David et al. in press).

Obsidian reduction

Caution Bay obsidian artefacts are tiny, averaging 0.12 g in weight and 6.8 mm in length. As can be seen in Figure 7, no apparent change in the maximum lengths of obsidian artefacts can be seen between the two occupation periods at Caution Bay. The small artefact size suggests that considerable effort was made in reducing obsidian. Indeed in both phases of occupation, obsidian artefacts were manufactured through a combination of unipolar and bipolar percussion (Table 3). Further measures of obsidian reduction are explored below.

Cortex

The presence of crenulated cortex indicates that some of the Caution Bay obsidian was collected from secondary deposits (e.g. riverbed) on West Fergusson Island. Proportions of obsidian flakes displaying cortex on their dorsal surface are small (Lapita = 1.4 per cent, $n = 29$; post-Lapita = 0.7 per cent, $n = 9$), as are proportions of small striking platforms (Lapita = 1.5 per cent, $n = 8$; post-Lapita = 3.0 per cent, $n = 11$). The amount of cortex quantified on seven unipolar complete flakes recovered (Lapita $n = 6$; post-Lapita $n = 1$) show that most flakes ($n = 4$) displayed a cortical surface covering less than 25 per cent of their entire dorsal surface. Only one flake was entirely covered with cortex, but it was small, measuring 6.4 mm long by 4.5 mm wide. The rarity of cortex suggests that decortication took place before the obsidian reached Caution Bay, with only minute amounts of cortex remaining on artefact surfaces.

Table 3. Obsidian technological type by occupation, Caution Bay.

Technological type	Lapita	post-Lapita
Bipolar core (non-rotated)	40 (1.8 per cent)	53 (3.8 per cent)
Bipolar core (rotated 90°)	9 (0.4 per cent)	19 (1.4 per cent)
Bipolar flake	97 (4.4 per cent)	36 (2.6 per cent)
Unipolar core	1 (<0.1 per cent)	/
Unipolar flake	1,952 (88.8 per cent)	1,222 (88.2 per cent)
Recycled flake as bipolar core	8 (0.4 per cent)	19 (1.4 per cent)
Retouched flake	20 (0.9 per cent)	23 (1.7 per cent)
Retouching flake	5 (0.2 per cent)	1 (0.1 per cent)
Flaked piece	65 (3.0 per cent)	13 (0.9 per cent)
Total	2,197 (100 per cent)	1,386 (100 per cent)

Unipolar reduction

Unipolar flakes dominate the assemblage of both periods of occupation. The presence of only one Lapita unipolar core and their total absence from post-Lapita deposits, is noteworthy given the number of unipolar flakes recovered (Table 3). Clearly, many unipolar cores were necessary to produce such a large quantity of flakes across numerous sites. It is

Table 4. Median and 95 per cent confidence interval of complete unipolar flakes (excluding flakes <25 mm^2) weight, size, and shape by occupation, Caution Bay.

Variable	Lapita ($n = 167$)	post-Lapita ($n = 132$)	Sig.
Weight (g)	0.09 [0.07–0.11]	0.13 [0.10–0.16]	.006
Length (mm)	7.4 [6.9–8.1]	8.0 [7.0–9.0]	.153
Width (mm)	7.0 [6.7–7.4]	7.9 [7.0–8.1]	.005
Thickness (mm)	1.7 [1.6–1.9]	2.0 [1.8–2.0]	.942
Elongation	1.1 [1.0–1.1]	1.0 [0.9–1.1]	.183

Table 5. Median and 95 per cent confidence interval of bipolar cores weight and maximum length by occupation, Caution Bay.

Variable	Lapita ($n = 49$)	post-Lapita ($n = 72$)	Sig.
Weight (g)	0.27 [0.22–0.31]	0.25 [0.22–0.30]	.690
Maximum length (mm)	9.9 [8.6–10.5]	8.0 [7.0–9.0]	.680

possible that the vast majority of unipolar cores were further reduced into bipolar cores, thus masking their presence. The single Lapita unipolar core is small, weighing 2.56 g with a maximum length of 32.3 mm. It features two platforms and three flake scars, with the longest flake scar measuring 15.0 mm × 4.9 mm. Unretouched and non-cortical complete flakes are small, with many measuring less than 5.0 mm in both length and width.

Flake weights, dimensions and shapes were compared between periods of occupation. Because the data are not normally distributed, a series of Mann–Whitney *U* tests was performed (Table 4) and showed that complete flakes were significantly heavier and wider in the post-Lapita period (the median rather than the mean is more appropriate here as it provides a better measure of the central tendency when outliers are present).

Bipolar reduction

The vast majority of cores recovered were reduced using bipolar percussion (Table 3). Considering the small size of all the obsidian cores, core stabilisation must have been problematic, making the switch to bipolar percussion the only way to successfully pursue core reduction (Hiscock 1996). Obsidian cores were reduced even further, with 28 (23.1 per cent) showing evidence of 90° rotation from their original orientation (Figure 7b and c). Rotated bipolar cores are not a common feature in either of the two occupation phases (Table 3). Bipolar cores (rotated and non-rotated) are slightly more common in post-Lapita deposits (5.2 per cent, $n = 72$) than in Lapita deposits (2.2 per cent, $n = 49$). Results from Mann–Whitney *U* tests indicate that the weight and maximum length of bipolar cores are not significantly different between the two periods of occupation (Table 5).

Complete bipolar flakes constitute a small part of the assemblages from each period of occupation,

Table 6. Median and 95 per cent confidence interval of complete bipolar flakes weight, size, and shape by occupation, Caution Bay.

Variable	Lapita ($n = 77$)	post-Lapita ($n = 25$)	Sig.
Weight (g)	0.14 [0.12–0.20]	0.18 [0.12–0.28]	.275
Length (mm)	8.2 [7.7–9.3]	9.6 [8.0–12.0]	.041
Width (mm)	7.4 [6.6–8.3]	7.0 [6.0–8.0]	.545
Thickness (mm)	2.6 [2.1–3.0]	2.3 [2.0–3.0]	.699
Elongation	1.2 [1.0–1.3]	1.5 [1.1–1.8]	.078

representing 4.4 per cent ($n = 97$) of Lapita and 2.6 per cent ($n = 36$) of post-Lapita assemblages. With a flake:core ratio of 2.0:1 (Lapita) and 0.5:1 (post-Lapita), more bipolar flakes should have been recovered from post-Lapita deposits. It is thus likely that some of the complete unipolar flakes were the product of bipolar percussion. Many bipolar flakes may not have run through the entire length of the core, and therefore, would lack the distinctive diagnostic signs of bipolar percussion (e.g. distal crushing, flake scars originating from the point of contact with the anvil). Mann–Whitney *U* tests reveals that complete bipolar flakes are significantly longer in post-Lapita compared to Lapita deposits (Table 6).

Lateral recycling

Lateral recycling occurs when 'an existing (often worn or discarded) tool serves as a core for the production of usable flakes or is reworked to create a different form' (Amick 2007:223). Several cases of lateral recycling were observed. Twenty-seven unipolar flakes were recycled into bipolar cores by using either one of the flake's lateral margins as a striking platform while the opposite margin rested against an anvil (Figure 8d), or by placing the flake flat against an anvil and using the ventral surface as a striking platform (Figure 8a). Flakes recycled into bipolar cores are rare in both periods of occupation (0.4 per cent, $n = 8$ in Lapita deposits and 1.4 per cent, $n = 19$ in post-Lapita deposits). If we categorise these flakes as parts of the bipolar assemblage, bipolar artefacts (all types) represent 7.1 per cent of Lapita ($n = 155$) and 9.2 per cent of post-Lapita ($n = 127$) assemblages.

Retouching

Due to the exotic nature of obsidian and its stone-working qualities, retouching was expected to be high, implying advanced levels of artefact curation and raw material conservation. However, this was not the case, with retouching only present on 1.2 per cent ($n = 24$) and 2.0 per cent ($n = 24$) of Lapita and post-Lapita unipolar flakes respectively. Only one formal tool type was recovered. A notched tool (Figure 8e) was found in levels dating to c. 2200–2000 cal. BP at Bogi 1 Square C. The recovery of four small complete retouching flakes (Lapita

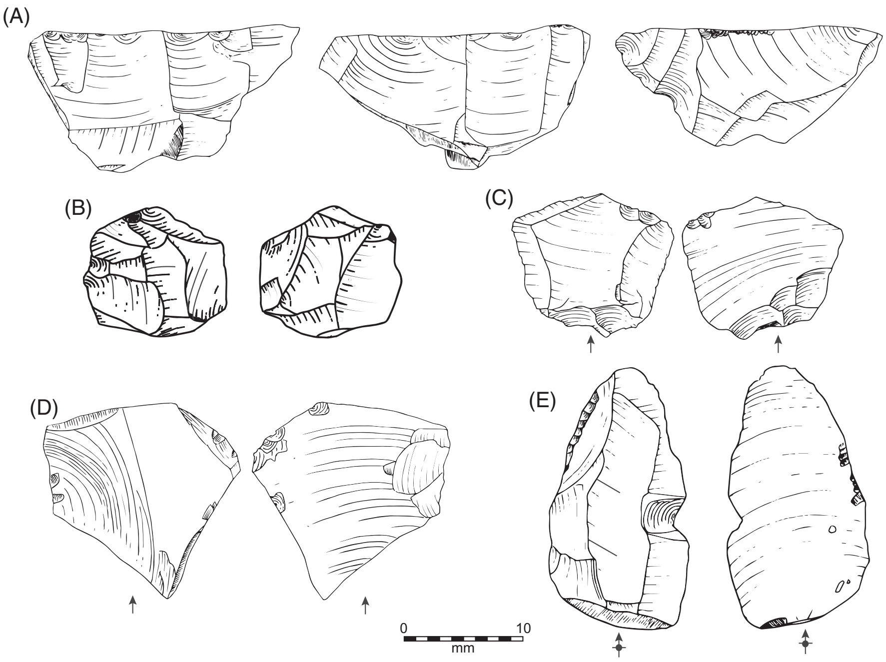

Figure 8. Caution Bay obsidian stone artefacts. (A) Anvil-rested flake-core (ventral surface on top), (B) bipolar core, (C) bipolar flake, (D) unipolar flake recycled as bipolar core, (E) retouched flake (drawing by Jerome Mialanes).

$n = 3$; post-Lapita $n = 1$) measuring 4.4 ± 1.7 mm in maximum length indicates that some tool maintenance occurred at this site.

Discussion

Several inferences can be drawn from these results to assess obsidian distributions through time and, by extension, broader patterns of social interaction.

Nature and intensity of the reduction process

The small size of obsidian artefacts and the rarity of cortex indicate that obsidian is likely to have passed through many hands before reaching Caution Bay. There are two possible implications, either or both of which may be the case.

1. The obsidian was progressively reduced during its down-the-line travel between the source (Fergusson Island) and final place of deposition (Caution Bay) a distance of some 670 km. More sites of the Lapita period ('Lapita sites') should then be present between Caution Bay and Fergusson Island.
2. From the onset, obsidian was prepared at the source in anticipation of long-distance transport (direct procurement).

We cannot yet determine with the evidence at hand under what form, e.g. decortified nodules or pebbles, obsidian originally reached Caution Bay. The reduction process was so intensive that the vast majority of unipolar cores virtually disappeared from the assemblages as they were further reduced via bipolar percussion. As noted previously, only one unipolar core measuring 32.6 mm in length was recovered, suggesting that cores or flake-cores were initially reduced at Caution Bay through direct unipolar reduction. However, the vast majority of cores were reduced using bipolar percussion and were at their time of discard much smaller than the single unipolar core recovered. This line of evidence indicates that once cores became too small to be effectively worked via unipolar percussion, reduction continued through bipolar percussion. This implies limited access to larger obsidian pieces, and thus a rare resource.

No major temporal changes in the nature of reduction were observed between the Lapita and post-Lapita periods of occupation. Reduction intensity was high, with the use of bipolar percussion and lateral recycling indicating the extreme reduction measures to which the obsidian was subjected. Bogi 1 and ABKL are the two sites where bipolar percussion was found in high proportions, with approximately 91 per cent ($n = 282$) of all Caution Bay bipolar artefacts ($n = 311$) found at these two sites. Bipolar percussion certainly contributed to the increased number of artefacts at Bogi 1 and ABKL, but is bipolar percussion a typical feature of Caution Bay sites? Instances of bipolar percussion occur at another nine sites, but in much smaller quantities and proportions suggesting that its practice was rather limited. Using flake size as a proxy for reduction intensity, the slightly larger size of unipolar and bipolar complete flakes between c. 2,300 and 2,000 cal. BP than previously suggests that more obsidian reached Caution Bay then than during the earlier occupation period dated between c. 2,900 and 2,500 cal. BP. The heaviest piece of obsidian recovered from all sites, a flake-core weighing 16.6 g was found at AAUG Square D in levels dating to c. 2,350–1,950 cal. BP. While the presence of such a large artefact does not make a trend (the second-heaviest piece, weighing 5.7 g, was also found at AAUG Square D; it is within the range of material found at Bogi 1 and ABKL), the presence of larger obsidian artefacts may indicate an increase in the quantity of obsidian reaching Caution Bay.

Caution Bay is located in an area where high-quality chert is readily available in large quantities from the coastline to the foothills (Davies and Smith 1971). Understanding the importation of obsidian thus needs to be set in a context of the ready availability of this other type of local, good-quality flakeable raw material. Given this context, the obsidian was not likely to have been imported simply to provide domestic cutting edges; its value, we argue, must have taken into account something more, such as the meaningfulness of both the source (West Fergusson Island) and of the social mechanism by which it arrived (exchange relations between source and destination). The use of imported obsidian in the manufacture of functional tools thus lies not merely in the everyday domestic realm of food processing, artefact manufacture and the like, but in special activities that give significance to a raw material already imbued with enhanced social value. Barton (1918:64) mentioned that on the Kumusi River, obsidian was obtained by barter from Goodenough Island, located approximately 230 km to the southeast (most likely originating from West Fergusson Island since there are no known sources of obsidian on Goodenough Island), for body scarification. Sheppard's (1993:135) view of obsidian as a "concrete symbol of exchange" highlighting social relations likewise helps reconcile the presence of obsidian in an area already rich in high-quality stone material.

Obsidian distribution through time and space along the South Coast of PNG

The presence of obsidian at Caution Bay as early as c. 2,950 cal. BP is nearly 400 years earlier than any obsidian previously found along the south coast of PNG. Obsidian first arrived at Caution Bay with the earliest known Lapita migration to this region. The settlement of the Lapita migrants among local non-Lapita populations inhabiting Caution Bay must have been a negotiated process, whether by more or less free choice, impost or necessity (McNiven et al. 2012a:150–151; Skelly and David in press; see also Summerhayes and Allen 2007:116–117). The movement of obsidian over a 670 km journey by sea is a noteworthy feat in itself, as it highlights the existence of social networks spanning West Fergusson Island to Caution Bay. That such long-distance movements ceased at Caution Bay by c. 1,900 cal. BP suggests a major change in those inter-regional, social connections.

In other localities along the south coast, obsidian exchange appears to have been established at approximately the time that it ceases at Caution Bay. For example, at Oposisi (Vanderwal 1973:48) to the northwest of Caution Bay, obsidian dates from its earliest occupation c. 2,000 cal. BP through to c. 1,000 cal. BP (Allen et al. 2011). Similarly, the settlement of the island of Mailu far to the southeast of Caution Bay (i.e. much closer to the West Fergusson Island obsidian sources) also dates to c. 2,000 years ago and is characterised by large quantities of obsidian during the initial settlement period (Irwin 1991; Irwin and Holdaway 1996). Obsidian continued to reach Mailu until '3–400 years ago', then temporarily ceased before recommencing again (Irwin 1991:506). We suggest that relations between Caution Bay coastal dwellers and incoming seafarers from the east—probably traders coming either directly from West Fergusson Island, or intermediary traders from more proximal locations—broke down after c. 2,000–1,900 cal. BP, severing long-standing exchange partnerships that may have stood for some 1,000 years. Alternatively, this major change in social connections could be related to worsening social relations within Caution Bay causing passing traders to avoid the area, noting that the arrival of obsidian perdures at the defended hilltop settlements of Oposisi (Allen et al. 2011; Vanderwal 1973) and Nebira 4 (Allen 1972) for hundreds of years after it ceases to arrive at Caution Bay.

Conclusions

Our new results from Caution Bay indicate that all the obsidian (except for a single artefact) came from West Fergusson Island located 670 km away, initially arriving with the first Lapita settlers c. 2,950 cal. BP. During Lapita into post-Lapita times, the proportion of sites where obsidian was deposited was high, remaining so for nearly 1,000 years before suddenly ceasing c. 1,900 cal. BP. Long-distance social ties with eastward regions that had been established during the Lapita period appear to have been maintained over this entire period, as obsidian continued to arrive uninterruptedly for another c. 600 years after the end of the Lapita period. Results from the technological analyses at Bogi 1 and ABKL indicate that obsidian arrived at Caution Bay as small unipolar cores/flake-cores almost entirely devoid of cortex, requiring the intensive use of a combination of unipolar and bipolar reduction. Here similarly high levels of reduction intensity were found in Lapita and post-Lapita deposits, despite a statistically significant increase in stone artefact dimensions during the post-Lapita period of occupation. Nonetheless, the difference in obsidian size was not sufficient to consider a change in obsidian procurement, and the high level of reduction through the entire sequence suggests that the quantity of obsidian reaching Caution Bay during the Lapita and post-Lapita period was limited, probably as a result of down-the-line exchange. The cessation of incoming obsidian took place not during, nor at the end of, the Lapita period, but rather some 600 years later, c. 1,900 cal BP, well after the 'demise' of (read 'transformation out' of) Lapita in this part of the south coast of PNG.

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