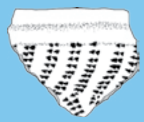

Caution Bay Studies in Archaeology 1

Archaeological Research at Caution Bay, Papua New Guinea

Cultural, Linguistic and Environmental Setting

Edited by

Thomas Richards, Bruno David, Ken Aplin and Ian J. McNiven

Chapter 9.
The Caution Bay Project Field and Laboratory Methods

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Introduction

This chapter reports on the personnel, research structure and analytical methods employed in the Caution Bay project, constituting the sum of the various phases of field and laboratory research at Caution Bay. We stress that from the onset our approach has been to investigate through excavation the character of the archaeological record at a landscape scale, rather than more detailed investigations of a handful of sites that would have provided limited spatial understandings across the whole of the study area. That is, limited excavations at numerous sites were favoured over large-scale horizontal excavations of a few sites. This choice of strategy has arguably been vindicated by the discovery of rich cultural deposits that would have been entirely missed had we focused on the 'best' surface sites, none of which possess the treasured and then-unexpected Lapita horizons subsequently found at depth following excavation at sites with minor post-Lapita surface cultural deposits. Be that as it may, we present here baseline details into the analytical methods used for all of our excavations and laboratory research, critical background information that details how 122 Caution Bay sites have been excavated and analysed, towards publication in a sequence of forthcoming monographs.

Project Personnel and Research Structure

The Caution Bay Project is co-directed by Bruno David, Thomas Richards and Ian McNiven from Monash University, and Ken Aplin, Research Associate with the Smithsonian Institution's National Museum of Natural History. As Project Manager, Thomas Richards is responsible for the overall running of the project, which has included coordinating the field research, laboratory processing, and analysis of finds, as well as appointing and managing personnel, and now increasingly focused on the assembling of monographs. Bruno David, Project Director, originally conceived the project, supervised the surveys in 2008-2009 and emergency salvage excavations at six sites in early 2009, and continues to guide all aspects of the research. Field Director Ian McNiven supervised the major archaeological salvage excavations of late 2009-early 2010, with overall responsibility for the major fieldwork program including the scheduling of excavations, implementation of fine-grained excavation protocols, quality control, standardization of methods, and compilation and checking of excavation data and notes.

Monash University employed 91 field staff to supervise and carry out the salvage excavations (Appendix D). In addition, many local community representatives, primarily from Boera, Papa, Lea Lea and Porebada villages, were employed directly by the developer, and it was common for 30 to 50 community representatives to assist in the archaeological excavations and field laboratory work on a daily basis.

Matthew Leavesley, then of the University of Papua New Guinea (UPNG), was the UPNG Student Coordinator, responsible for recruiting, training and supervising the many UPNG Student Archaeology Trainees who worked on the salvage excavations and in the field laboratory (Appendix D).

Each excavation square was under the immediate supervision of an Excavation Director, who supervised a team usually consisting of an Assistant Archaeologist and others, including UPNG Student Archaeology Trainees and local community representatives. Each Excavation Director was responsible for ensuring that the Caution Bay excavation protocols were followed throughout the excavations, including photography, record-keeping, labelling and packaging of in situ finds and excavated sediment for transport to the field laboratory. The Excavation Directors received instructions on field methods from the Field Director (Ian McNiven) who regularly held meetings to ensure the maintenance of standard methods.

The Field Laboratory Supervisor, Cassandra Rowe, was responsible for managing the flow of excavated material for processing into the field laboratory and on to Monash University and the UPNG for subsequent university-based laboratory processing and analysis. Other supervisory staff in the field laboratory included the Sieving Supervisor, and expanded operations to cover for the processing of backlog from late March to early June 2010 required the appointment of a Deputy Laboratory Supervisor, Assistant Laboratory Supervisor and an Assistant Sieving Supervisor (Appendix D).

The Caution Bay field and laboratory investigations have been conducted in accordance with standardized protocols; these are presented below rather than repeated in the many excavation reports to be published in this monograph series. All aspects of the field salvage operations are considered first, beginning with the excavation strategy, followed by the excavation and field laboratory methods, before moving on to the post-fieldwork laboratory processing and specialist analytical methods.

Field Methods

The entire study area was surveyed before excavation plans were devised; i.e., we already knew how many (surface) sites existed across the core study area before excavations began (see Chapter 8). All excavated sites are located within the core study area, but not all of the 591 sites recorded there were available for excavation during the major salvage operations. Fifty sites, 15 located in the northwest and 35 in the southwest of the core study area, were excluded because development project redesign left them outside the main construction impact area. Of the remaining sites, 150 showed evidence of being stratified (i.e., surface clues indicated the presence of buried deposits) and thus suitable for excavation (e.g., Figure 9.1), although one of these was found to contain unexploded ordnance from World War II, rendering it unexcavatable, leaving 149 stratified archaeological sites to potentially excavate with the time and resources available. A desire to obtain an excavation sample from each of a range of small (up to 25m^2 in size), medium (26-1000m^2) and large (>1000m^2) sites across the study area landscape guided selection of the sites for excavation. Where numerous sites of the same size were available in a portion of the study area, and not all of these could be excavated due to time restrictions, those with the highest surface artefact density and diversity were chosen for excavation.

One hundred and twenty-two sites were excavated in the core study area at Caution Bay, with 211 excavation squares, each usually measuring 1m × 1m in size, and together totalling 207.5m^2 (Figure 9.2; Figure 1.2). Six of the sites (ABEN, ABEO, ABEP, ABEQ, ABES and ABIP) were initially excavated in early 2009, and the other 116 during the major salvage operations which occurred from late September 2009 to late March 2010, although four of the early 2009 sites also had additional squares excavated during the major operations. Generally, 1m^2 was excavated on small sites, 1m^2 to 2m^2 on medium-size sites, and 3m^2 to 5m^2 on large sites (Figure 9.3).

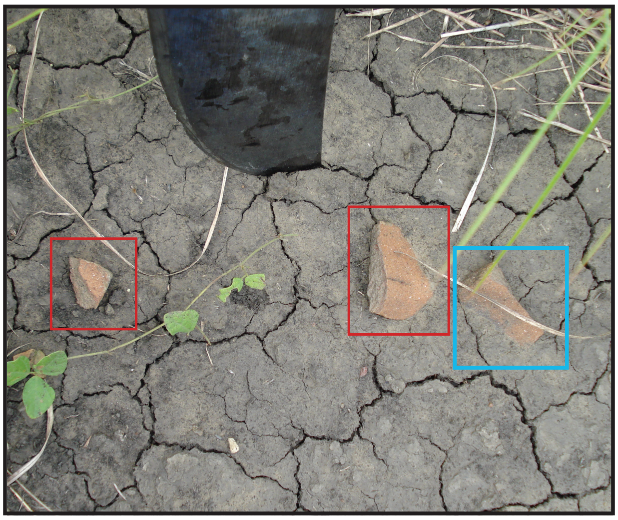

Figure 9.1. Pot sherds on the surface (red rectangles) and embedded in the ground (blue rectangle), site AAJB, west-central core study area, 12 February 2009 (Photo: Jeremy Ash).

Excavations at Caution Bay were conducted in accordance with the following standard procedures (except 'stepping out' squares)(Figure 9.4):

1. A few days before a site was scheduled for excavation, a team re-located each site and confirmed its extent by re-checking the limits of the spatial distribution of surface cultural materials. The location(s) of pits to be excavated was determined and, if necessary, the grass was cut around the planned excavation area prior to the commencement of excavations.
2. A site datum (wooden or metal peg) was established and used for site mapping and excavation (elevation) recording purposes.
3. A site description was written by the Excavation Director, noting the topography, vegetation cover, other natural features, relative position of excavation squares and datum, extent and nature of cultural material on the surface, and the nature and location of any disturbance on or adjacent to the site. These new details complemented records from the original surveys.
4. An excavation pit, usually a 1m × 1m square, was strung onto offset metal survey arrows with coloured string line (Figure 9.4b). Each excavation square was aligned in a N-S/E-W orientation. A differently coloured string was used along the southern side of each square to facilitate orientation during excavation and on photographs.
5. Digital photographs were taken of the site surrounds, the site surface and the excavation square prior to excavation. Photographs were

FIGURE 9.2. SITES EXCAVATED IN THE CAUTION BAY STUDY AREA, WITH NUMBERS OF EXCAVATION SQUARES AND STEPPING OUT SQUARES. (PNG NMAG = PAPUA NEW GUINEA NATIONAL MUSEUM AND ART GALLERY).

Site Identification			Excavation Squares				Stepping Out Squares			
PNG NMAG Site Code	Monash University Field Code	Site Name	Number of Squares	Pit Length (m)	Pit Width (m)	Area Excavated (m²)	Number of Squares	Pit Length (m)	Pit Width (m)	Area Stepped Out (m²)
AAHM	JDA2		1	1.00	1.00	1.00				
AAHN	JDA3		1	1.00	1.00	1.00				
AAHO	JDA5		2	1.00	1.00	2.00				
AAHP	JDA6		1	1.00	1.00	1.00				
AAHR	JDA8		1	1.00	1.00	1.00				
AAHS	JDA9		1	1.00	1.00	1.00				
AAHV	JDA12		1	0.50	0.50	0.25				
AAHX	JDA14		1	1.00	1.00	1.00				
AAIB	JDA18		1	1.00	1.00	1.00				
AAIC	JDA19		1	0.50	0.50	0.25				
AAIG	MLA1		1	1.00	1.00	1.00				
AAIJ	MLA4		1	1.00	1.00	1.00				
AAIT	MLA14		2	1.00	1.00	2.00				
AAIU	MLA15		1	1.00	1.00	1.00				
AAIZ	AK2		1	1.00	1.00	1.00				
AAJB	AK4		1	1.00	1.00	1.00				
AAJH	AK10		1	1.00	1.00	1.00				
AAJI	AK11		1	1.00	1.00	1.00				
AAJJ	AK12		1	1.00	1.00	1.00				
AAJK	AK13, MLA12		1	1.00	1.00	1.00				
AAJM	AK15		2	1.00	1.00	2.00				
AAJN	AK16		1	1.00	1.00	1.00				
AAJQ	AK19		1	1.00	1.00	1.00				
AAJU	AK23	Kurukuru 1	1	1.00	1.00	1.00				
AAJV	AK24		1	1.00	1.00	1.00				
AAJX	AK26		1	1.00	1.00	1.00				
AAKD	AK32		2	1.00	1.00	2.00				
AAKL	AK37		1	1.00	1.00	1.00				
AAKM	AK38		2	1.00	1.00	2.00				
AAKQ	AK42		1	1.00	1.00	1.00				
AAKX	AK49		1	1.00	1.00	1.00				
AAKZ	AK51		1	1.00	1.00	1.00				
AALG	AK58		1	1.00	1.00	1.00				
AALR	AK69		1	1.00	1.00	1.00				
AALU	AK72		1	1.00	1.00	1.00				
AALW	AK74, MLA7		2	1.00	1.00	2.00				
AAMC	AK80		1	0.50	0.50	0.25				
AAMG	AK84		1	1.00	1.00	1.00				
AANB	AK105		1	1.00	1.00	1.00				
AANM	AK116		1	1.00	1.00	1.00				
AANO	AK118		1	1.00	1.00	1.00				
AANR	AK121		1	1.00	1.00	1.00				
AANV	AK125		1	1.00	1.00	1.00				
AANX	AK127		1	1.00	1.00	1.00				

Site Identification			Excavation Squares				Stepping Out Squares			
PNG NMAG Site Code	Monash University Field Code	Site Name	Number of Squares	Pit Length (m)	Pit Width (m)	Area Excavated (m^2)	Number of Squares	Pit Length (m)	Pit Width (m)	Area Stepped Out (m^2)
AAOI	AK138		1	1.00	1.00	1.00				
AAPH	AK163		1	1.00	1.00	1.00				
AAPN	AK169		1	1.00	1.00	1.00				
AAQC	AK184		2	1.00	1.00	2.00				
AASA	JA53		1	1.00	1.00	1.00				
AASE	JA75		1	1.00	1.00	1.00				
AASF	JA74		1	1.00	1.00	1.00				
AASG	JA73		1	1.00	1.00	1.00				
AASI	JA71		2	1.00	1.00	2.00				
AASL	JA68		1	1.00	1.00	1.00				
AASN	JA66		1	1.00	1.00	1.00				
AASP	JA64		1	1.00	1.00	1.00				
AASQ	JA63		1	1.00	1.00	1.00				
AATA	JA93		1	1.00	1.00	1.00				
AATB	JA92		1	1.00	1.00	1.00				
AATF	JA88		1	1.00	1.00	1.00				
AATP	JA78		1	1.00	1.00	1.00				
AATV	JA35		1	1.00	1.00	1.00				
AAUG	JA24		5	1.00	1.00	5.00				
AAUJ	JA21		2	1.00	1.00	2.00				
AAUQ	RS11		1	1.00	1.00	1.00				
AAUY	JA15		1	1.00	1.00	1.00				
AAVA	JA13		1	1.00	1.00	1.00				
AAVC	JA11		1	1.00	1.00	1.00				
AAVD	JA10		1	1.00	1.00	1.00				
AAVM	JA1	Ataga 1	1	1.00	1.00	1.00				
AAVX	RS60		5	1.00	1.00	5.00				
AAVY	RS61, RS58		5	1.00	1.00	5.00				
AAVZ	RS62		2	1.00	1.00	2.00				
AAWA	RS63	Nese 1	5	1.00	1.00	5.00				
AAXK	RS53		1	0.50	0.50	0.25				
AAXL	RS54		2	1.00	1.00	2.00				
AAYB	RS30		1	1.00	1.00	1.00				
AAYD	RS32		1	1.00	1.00	1.00				
AAYJ	RS84		1	1.00	1.00	1.00				
AAYL	RS86	Moiapu 2	5	1.00	1.00	5.00				
AAYM	RS87	Moiapu 1	7	1.00	1.00	7.00	8	1.00	1.00	8.00
AAZD	RS101	Moiapu 3	1	1.00	1.00	1.00				
ABAM	AH13	Edubu 3	1	1.00	1.00	1.00				
ABAN	AH14	Edubu 2	3	1.00	1.00	3.00				
ABAO	AH15	Edubu 1	3	1.00	1.00	3.00				
ABAU	AH21		1	1.00	1.00	1.00				
ABBK	AH37		3	1.00	1.00	3.00				
ABBQ	NA/AK1		1	1.00	1.00	1.00				
ABBS	NA/AK3		1	1.00	1.00	1.00				
ABCE	AKRoad3		8	1.00	1.00	8.00				
			1	1.00	0.50	0.50				
ABCK	NA/AK8.2		1	1.00	1.00	1.00				
ABCL	NA/AK8.3		1	1.00	1.00	1.00				
ABCM	NA/AK8.4		1	1.00	1.00	1.00				

Site Identification			Excavation Squares				Stepping Out Squares			
PNG NMAG Site Code	**Monash University Field Code**	**Site Name**	**Number of Squares**	**Pit Length (m)**	**Pit Width (m)**	**Area Excavated (m^2)**	**Number of Squares**	**Pit Length (m)**	**Pit Width (m)**	**Area Stepped Out (m^2)**
ABCN	NA/AK8.5		1	1.00	1.00	1.00				
ABCO	NA/AK8.6		1	1.00	1.00	1.00				
ABEN	Bogi1	Bogi 1	8	1.00	1.00	8.00	61	1.00	1.00	61.00
ABEO	ML19, Bogi2		2	1.00	1.00	2.00				
ABEP	Nadi1		2	1.00	1.00	2.00	8	1.00	1.00	8.00
ABEQ	Nadi2		2	1.00	1.00	2.00				
ABER	Kon1, JD5	Konekaru 1	3	1.00	1.00	3.00				
ABES	Line 11 Mound		1	1.00	1.00	1.00				
ABHA	JD6	Tanamu 1	2	1.00	1.00	2.00	28	1.00	1.00	28.00
ABHC	JD15	Tanamu 2	2	1.00	1.00	2.00				
ABHD	JD16	Tanamu 3	5	1.00	1.00	5.00				
ABHF	JD8	Harakiare 1	2	1.00	1.00	2.00				
ABIS	JD11		2	1.00	1.00	2.00	16	1.00	1.00	16.00
ABIT	JD12		2	1.00	1.00	2.00				
ABIU	JD13		3	1.00	1.00	3.00				
ABIV	JD14		5	1.00	1.00	5.00	20	1.00	1.00	20.00
ABIW	JD17		1	1.00	1.00	1.00	8	1.00	1.00	8.00
ABJX	ML4		1	1.00	1.00	1.00				
ABJY	ML5		1	1.00	1.00	1.00				
ABKA	ML7		2	1.00	1.00	2.00				
ABKC	ML9		1	1.00	1.00	1.00				
ABKF	ML12		3	1.00	1.00	3.00				
ABKH	ML14		1	1.00	1.00	1.00				
ABKI	ML15		2	1.00	1.00	2.00				
ABKK	ML17		1	1.00	1.00	1.00				
ABKL	ML18		2	1.00	1.00	2.00	4	1.00	0.50	2.00
							4	0.50	0.50	1.00
ABKN	ML20		2	1.00	1.00	2.00				
ABKO	ML21	Ruisasi 1	2	1.00	1.00	2.00				
ARM	JD9, JD10		5	1.00	1.00	5.00				
Totals			**211**			**207.50**	**157**			**152.00**

taken at the base of each XU of each excavated square, and of significant finds or features during excavation.

6. Each square was excavated in <3cm thick Excavation Units (XUs) following the sub-surface site stratigraphy.
7. Excavation was by small hand trowel and brush (Figure 9.4c,d); in the case of human burials, pointing trowels, small plastic spatulas, fine paint brushes and wooden toothpicks were also used.
8. Elevation readings were taken at five locations (four corners and centre of square) at the base of each XU, to the nearest millimetre using an automatic level (Figure 9.4e).
9. The most significant finds, such as charcoal for radiocarbon dating, decorated ceramics, worked shell items, ground stone artefacts, obsidian items and any unusual finds were recorded in situ in three dimensions, given a consecutive identification number within its corresponding XU and individually bagged.
10. Small, sealed bags of unsieved sediment samples were taken from each XU for laboratory-based sediment and pollen analyses.
11. All other excavated sediment from each XU was double-bagged in the field and, along with any separately bagged in situ finds, was sent to the field laboratory for processing, including weighing, wet sieving, and sorting (Figure 9.4f).
12. At the completion of excavation, stratigraphic sections were drawn to scale on graph paper of two to four faces of each excavation square;

Figure 9.3. Excavations in progress at Caution Bay: (a) View from site ABIW east to excavations at site Tanamu 3 (ABHD) (left and centre) and AAJM (far right, in mid-distance), in the west of the study area, with the Dirora Gotera Range in the background, 7 December 2009 (Photo: Nic Dolby); (b) View of excavations at site Nese 1 (AAWA) on the northern slope of Moiapu Hill, in the east of the study area, 10 November 2009 (Photo: Ceri Shipton).

photographs were also taken of the four walls of the completed pits.

13. Details of the excavation of each XU were recorded on a standard Excavation Form that included the following information:
    - Observations on sediments excavated and cultural material content.
    - The total volume (to closest 0.5 l) of excavated sediments (calculated using graduated buckets).
    - The elevation readings for the centre and corners at the base of each XU.
    - A plan drawing showing the position of sub-XUs, stratigraphic units, sub-strata, disturbances, features, rocks, and in situ finds.
    - A table listing the three-dimensional coordinates of each in situ find, with brief description and consecutive find number.

Figure 9.4. Excavation at site Edubu 1 (ABAO), 26 September 2009 (Photos: Thomas Richards): a. Excavation in progress at (left to right) Squares A, B and C; b. Square B, strung out with offset metal survey arrows, prior to commencement of excavation; c. Start of excavation in Square B; d. Excavation of Square C; e. Elevation reading being taken with automatic level; f. Excavated soil being transferred to plastic bag for transport to field laboratory for wet sieving.

In addition to the 211 pits thus excavated, a further 157 'stepping out' pits, each usually 1.0m × 1.0m in size and together totalling 152m^2, were excavated from eight of the sites (Figure 9.2). Our original plan was to shore the sides of the deeper squares, but when the time came to put this into practice, the study area was considered to be a construction site and new occupational health and safety requirements gave us no alternative but to 'step out' (and thereby expand the size of excavations on all sides) once any given square exceeded 1.20m depth (Figure 9.5). Furthermore, as the excavated squares increased in depth, so did the stepping out squares, and with increasing depth, new rows of stepping out pits were added. In sandy sites, the outer stepping out pit faces were shored with plywood and star pickets where deeper excavations were required, and safety fences were additionally erected beyond these (Figure 9.5a). The stepping out squares were variously excavated in 10cm or 50cm XUs, primarily with trowels (Figure 9.5b), but also sometimes shovels, and also partly with mattocks at one inland clay site. At another site with very deep cultural deposits a backhoe was employed to excavate parts of some of the stepping out squares, scraping in 10cm vertical increments. Sediment from stepping out operations was not sieved, but stockpiled in the vicinity of the excavation ready for backfilling operations at the completion of excavations. The archaeologists recorded the provenance and collected significant artefacts during stepping out operations – typically decorated pottery, ground stone artefacts, obsidian, other flaked stone, and worked shell items were collected and bagged. Three substantially complete Lapita pots were partially exposed during stepping out operations at sites Tanamu 1 and Bogi 1, and here excavation was refined while the pottery was carefully hand-excavated and collected (David *et al.* 2013: fig. 10). The practice of stepping out reached its climax with the Bogi 1 excavation, where the excavation of adjoining 1m × 1m Squares C and D extended to a depth of 3.5m within an approximately 8m × 8m stepping out area (McNiven *et al.* 2011: fig. 2; David *et al.* 2013: fig. 8). Significant lower portions of several other squares at Bogi 1, two containing a human burial, were also carefully excavated following removal of more than a metre of overlying sediment by stepping out operations. These operations will be further reported in the Bogi 1 monograph.

Professional surveyors working with the archaeologists undertook detailed mapping of each archaeological site. The site datum, excavation squares, vegetation cover, roads and tracks, and hydrological features were recorded and later reproduced in the form of digital topographic maps with 10cm contour intervals for all sites except a few along the eastern edge of the study area, for which 50cm contour intervals were employed. The final site maps to be presented in the forthcoming Caution Bay monographs are drafted from these surveyor maps.

Figure 9.5. Stepping out operations at Caution Bay: a. Phase 1 of stepping out completed at site Bogi 1 (ABEN) with excavation Squares C and D protected by a wooden cover in the centre of the stepping out area, 5 January 2010 (Photo: Ian McNiven). Note the star picket and plywood shoring around the periphery of the stepping out pit, as well as other protective and safety measures being installed prior to the next stage of excavation; b. Hand excavation of stepping out squares in progress around excavation Squares D and E (with plywood on bottom in centre of photo) at site (ABIV), 9 March 2010 (Photo: Ben Shaw).

A well-equipped, custom-built, secure field laboratory that included wet sieving, drying, sorting and storage areas was established within the field base camp located on the southern edge of the study area (Figures 9.6-9.8). The purpose of the field laboratory was to complete the basic processing of the excavated sediment, including sieving and preliminary sorting and to package materials for transportation to Monash University or, in a few cases, to the University of Papua New Guinea for detailed sorting and analysis.

Each day, the excavated material (XU bags, sediment sample bags and bags of individual in situ finds) from sites undergoing excavation was transported to the field laboratory, logged-in upon arrival and temporarily stored while awaiting processing. The process undertaken was

FIGURE 9.6. WET SIEVING AND SORTING OPERATIONS IN THE CAUTION BAY FIELD LABORATORY, SEPTEMBER 2009 – MAY 2010 (PHOTOS: CASSANDRA ROWE): A. WET SIEVING TEAM AT WORK; B. CLOSE-UP OF WET SIEVING THROUGH 2.1MM MESH SIEVE; C. WET SIEVE RESIDUE ON TRAYS DRYING ON SHELVES PRIOR TO SORTING; D. SORTED SIEVE RESIDUE ON TRAYS; E. SORTING TEAM AT WORK ON SIEVE RESIDUE.

as follows, with all actions tracked and measurements recorded:

1. Each bag of sediment was weighed prior to wet sieving through 2.1mm-mesh sieves.
2. Materials retained in the sieves were placed on labelled trays to air-dry for several days.
3. The dried retained materials from the sieves were weighed and subject to an initial sorting to remove larger non-cultural items (e.g., rootlets, rocks, carbonate concretions, fossil coral, etc.), the nature and weight of which were also recorded on discard, and the residue rebagged.
4. Approximately one-fifth of the total excavated XUs were further sorted to separate cultural shell, bone, pottery, stone artefacts, charcoal, etc., from non-cultural material, the latter being recorded and then discarded.
5. For each XU, the unsieved sediment samples, special finds and in situ charcoal samples,

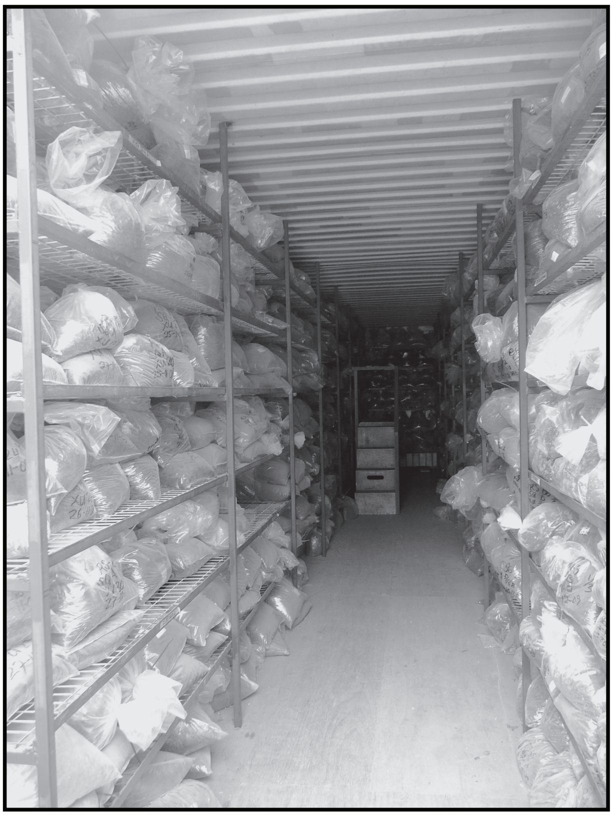

Figure 9.7. Excavated sediment temporarily stored inside container prior to wet sieving, Caution Bay field laboratory, 19 March 2010 (Photo: Cassandra Rowe).

plus the preliminary or fully-sorted material, were packaged for either air freighting to the Monash University archaeology laboratories or, in the case of squares from five sites (AAYM, ABBQ, ABCK, ABCM, ABCN, ABCO), for ground transportation to the UPNG archaeology laboratory in Port Moresby, for final sorting, cataloguing and analysis.

The field laboratory was in operation from late September 2009 to early June 2010.

Analytical Methods

An enormous amount of unsorted and partly sorted excavated material was transported to Monash University from the Caution Bay field laboratory. Care was taken that this material would be safely stored until separation of the excavated material into flaked stone, shell, bone, ceramic, charcoal and other categories could occur. To this end, laboratory procedures at Monash University were established by Bruno David to ensure the efficient processing of this material, with minimal opportunity for mixing or data loss to occur. In particular, all in situ finds other than charcoal were immediately lightly washed, air-dried, and individually bagged and labelled into new self-seal plastic bags. Charcoal samples were re-air-dried and re-bagged. All laboratory work was undertaken under the direct supervision of a Laboratory Supervisor, always an experienced archaeologist, who ensured that all laboratory assistants followed stipulated procedures.

Sites were generally selected for final sorting in the order that they were to be analysed and written up. Each laboratory assistant was generally responsible for sorting the contents of one XU through to completion, including individually bagged in situ finds. Bags were opened and placed in clean, labelled trays for sorting, or in a small number of cases, air drying prior to sorting. All materials – consisting of all items >2.1mm wide, as this was the mesh size used for wet sieving in the field – from those bags were then sorted into different categories of finds such as shell, bone, charcoal and flaked stone, leaving a residue of non-cultural rocks, fine gravel, fossil coral fragments, carbonate nodules, rootlets and insect parts. The total amount of sorted materials totalled many tons of sieved material, and all of it was individually sorted, with all cultural materials including the massive amounts of comminuted shell kept for quantitative and qualitative analysis. At this stage the Laboratory Supervisor checked the accuracy of the sorting, making corrections where necessary, then weighed and recorded the non-cultural discard, and finally oversaw the packaging of the cultural material classes into separate, labelled bags in preparation for long term curation and specialist analyses. In situ charcoal was handled minimally, repackaged, weighed, and in many cases submitted for radiocarbon dating (see below).

Following final sorting of each site into cultural material categories, the most important cultural objects, including decorated pottery sherds, adze- and axe-heads, shell arm bands and perforated ceramic discs, were professionally photographed at the Monash University Scientific Photography studios by Steve Morton, and drawn by technical archaeology artist Cathy Carigiet in preparation for the site report chapters of the forthcoming monographs. In addition, while the laboratory sorting was in progress, the drafting of field section drawings into digital format began and continues to the present. All digital drafting is being undertaken at Monash University by technical artists Toby Wood (formerly) and Kara Rasmanis (presently).

Some of the samples of sediment collected from individual XUs were subject to standard pH and/or particle size analysis for selected sites. Pollen and micro-charcoal were extracted from sediment samples from a small sample of excavated archaeological sites for environmental analyses, which are ongoing (e.g., Rowe *et al.* 2013: 1139). Palynological analysis of three sediment cores collected off-site from the Caution Bay study area in early 2010 has resulted in modelling of

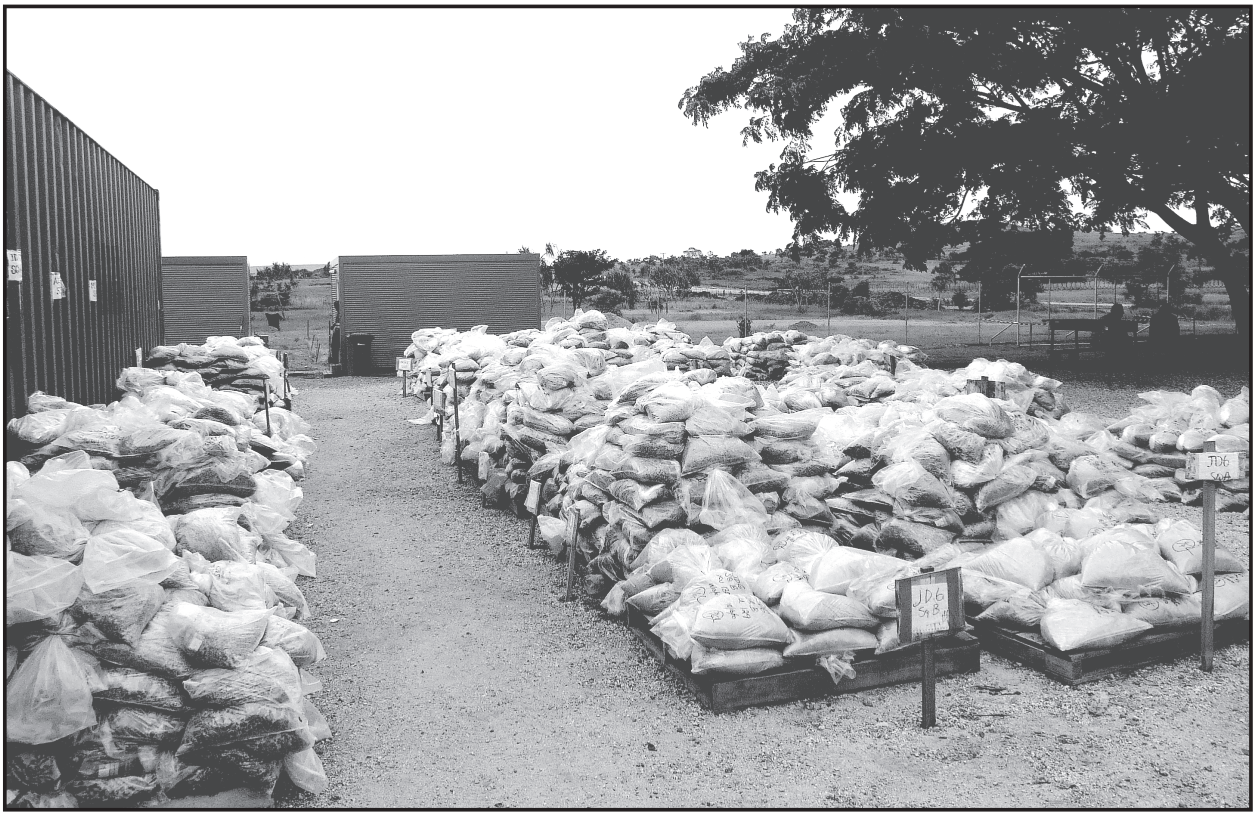

Figure 9.8. Excavated sediment temporarily stored outside container prior to wet sieving, Caution Bay field laboratory, 19 March 2010 (Photo: Cassandra Rowe).

the timing and formation of the mangrove-dominated shoreline, as well as characterisation of nearby inland vegetation changes over the past *c.* 2000 years (Rowe *et al.* 2013).

Also in preparation for write-up, many sites have been radiocarbon-dated, with XUs to be dated selected by the archaeologist principally responsible for writing up the site, with actual sample identification and selection in the case of molluscan remains usually undertaken by specialist archaeomalacologists. About a third of the sites have so far been subjected to very detailed radiocarbon dating often involving many dozens of AMS radiocarbon determinations on individual items. Many other sites have already had preliminary dating completed and are awaiting more intensive radiocarbon dating to occur in conjunction with detailed analyses.

Following sorting, analysis of the different classes of materials has and continues to be undertaken by experts who are an integral part of the Caution Bay research team. Pottery analysis is being undertaken by Bruno David, with Holly Jones-Amin (Monash University) undertaking ceramic conservation and reconstruction. Jerome Mialanes (Monash University) is undertaking the stone artefact analyses. Ken Aplin is studying the non-molluscan faunal remains. Molluscan remains are undergoing analysis by the team of Helene Peck (James Cook University), Brit Asmussen (Queensland Museum and University of Queensland), Patrick Faulkner (University of Sydney) and Sean Ulm (James Cook University). Katherine Szabó and Claire Perrette (University of Wollongong) are studying the worked shell artefacts. Fiona Petchey is overseeing the Caution Bay Accelerator Mass Spectrometry (AMS) dating at the Waikato Radiocarbon Dating Laboratory in Hamilton, New Zealand and has undertaken, with Sean Ulm and others, a detailed study of ΔR values for molluscan species commonly occurring in the Caution Bay excavated assemblages. Bayesian chronological model-building employing the AMS dates is also undertaken by Fiona Petchey in conjunction with the lead archaeologist working on each site.

Each site to be included in the forthcoming monographs on the Caution Bay investigations is under the overall responsibility of one archaeologist, who prepares a site report chapter that discusses the environmental setting of the site, investigations, stratigraphy, finds, and in conjunction with Fiona Petchey, chronological modelling of site occupation. The specialists analyse the finds and write them up in light of the chronostratigraphy worked out by the lead archaeologist. The specialists either prepare stand-alone chapters on the results of their analysed materials (e.g., ceramics, shell, etc.), or where there is not much material, sections to go in the site report chapter.

As is commonplace in archaeological analyses, data were analysed and visualized at a number of scales:

- Excavation Unit (XU): For each square in each site, the XU forms the minimum unit for presentation of the raw data. However temporal and spatial comparisons, and taphonomic issues, cannot be clearly and confidently explained at this scale.
- Stratigraphic Unit (SU): All materials attributed to the same stratum may be quantified and analysed as one unit that represents stratigraphically associated remains. However, this can only happen after the sum of XUs from a given SU has been empirically demonstrated to represent a discrete temporal unit.
- Analytical Unit (AU): For the purposes of analysis some assemblages are divided into separate analytical units that encompass materials from the same time frame or chronostratigraphic unit. These analytical units incorporate stratigraphic units that essentially represent chronologically modelled temporal phases or human occupation horizons at the site.
- Square: The results of quantified materials are reported for each square from a site. This enables past activities in discrete spatial areas at a site to be considered independently of other squares. Also, it is at this level that taphonomic issues affecting the condition of cultural materials and their vertical distribution were identified and discussed.
- Site: Discussion of each material occurred at a site scale, and involved all excavated squares in a consideration of chronological trends and spatial patterns in all variables of interest, including taxonomic, technological, raw material and decorative.

The analytical methods employed by the specialist experts are detailed below.

Pottery Analysis

The variables we have chosen to record on pottery sherds are particularly aimed at retrieving information about vessel decoration and vessel form, and broadly correspond to those utilized by archaeology projects previously undertaken for the south coast of New Guinea, in particular those investigating the history of the ancestral *hiri* trade (e.g., Frankel *et al.* 1994; Irwin 1985). Vessel parts are illustrated in Figure 9.9.

At the start of analysis of each site, the total number and total weight of sherds are calculated for each XU. The sherds are then separated into two size categories: <3.0cm and ≥3.0cm maximum length. For the <3.0cm sherds, the decorated body and rim sherds are analysed for their decoration, and the number of total rim sherds quantified. All other sherds <3.0cm long – the plain body sherds – are only counted and weighed by XU without further analyses. For the ≥3.0cm sherds, the following characteristics are recorded:

1. Instances of conjoining sherds.
2. Weight (in grams, to nearest 0.01 g).
3. Maximum length (in millimetres, to nearest 0.01mm).
4. Presence of complete or partial pre-firing perforations.
5. Presence of finger or tool (e.g., rock) dimple impressions on internal sherd surfaces (indicating manufacture by paddle and anvil technique).
6. Presence of paddle decoration or paddle grooves on external sherd surfaces (indicating manufacture by paddle and anvil technique).
7. Presence of paddle edge marks on external neck surfaces (indicating manufacture by paddle and anvil technique).
8. Techniques of body decoration (e.g., impression, incision, drilling, painting, slipping, infilling, modelling). Each instance of body decoration was identified and characterized sherd-by-sherd, rather than fitting observed instances into pre-established typologies of decorative techniques and forms.
9. Colours of painting, slipping and infilling.
10. Tools employed in body decoration (e.g., shell, comb).
11. Techniques, colours and tools used in lip decoration.
12. Location of decoration. The ‘Decorative Fields’ of Frankel *et al.* (1994) are followed here.
13. Maximum lip thickness (in millimetres, to within 2 decimal points).
14. Maximum rim thickness (in millimetres, to within 2 decimal points).
15. Maximum neck thickness (in millimetres, to within 2 decimal points).
16. Maximum carination thickness (in millimetres, to within 2 decimal points).
17. Maximum body thickness (in millimetres, to within 2 decimal points).
18. Maximum rim or body thickness (for non-lip sherds where rim and body cannot be differentiated; in millimetres, to within 2 decimal points).
19. Orientation angle.
20. Inclination angle.
21. Rim length, measured along external sherd surface (in millimetres, to within 2 decimal points).

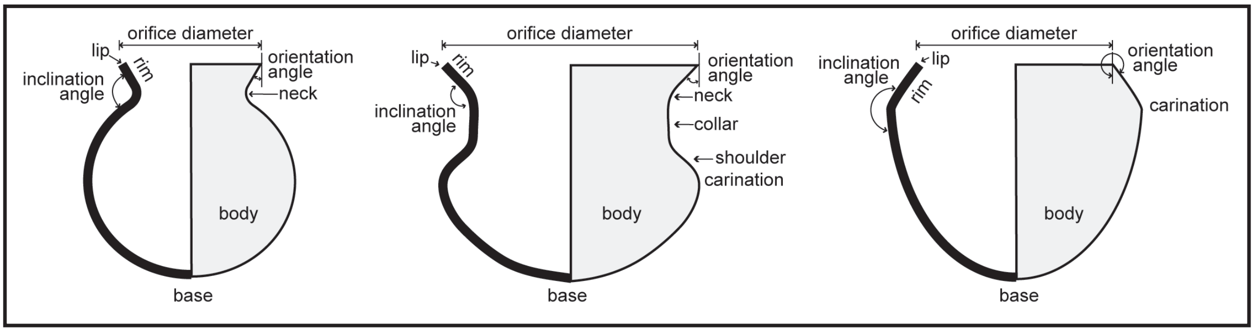

Figure 9.9. Key terms used for ceramics.

22. Rim course (after Frankel *et al.* 1994).
23. Rim profile (after Frankel *et al.* 1994).
24. Lip profile. Each instance of lip profile was identified and characterized sherd-by-sherd, rather than from a pre-established typology of lip profiles.
25. Orifice diameter, measured from the external edge of the lip (i.e., incorporating sherd wall thickness) (to nearest centimetre).
26. Percentage of diameter present (at 5% intervals).
27. Pot shape. A dish is defined as a vessel whose width is larger than its depth; a bowl a globular vessel of similar width and depth; a jar a vessel deeper than its width; and a pot a vessel of indeterminate relative width and depth.

Once the physical analysis of an assemblage was completed, taphonomy (sherd fragmentation, post-depositional movement) was addressed, before the chrono-stratigraphic distributions of sherd characteristics were analysed by individual square, or finer units where multiple periods of occupation are present, to reveal details of body decoration, lip decoration, and vessel shape characterizing the assemblage. These standardized pottery analytical methods have been fully applied to a score of Caution Bay assemblages, with dozens more having a basic level of analysis currently completed.

Pottery Conservation

There are hundreds of thousands of sherds from the excavated sites at Caution Bay, in highly varying states of preservation, and with differing conservation requirements. Due to the sheer number of sherds, not all items that would benefit from treatment will receive it; priority is being given to conjoinable decorated items and any sherds used to reconstruct substantial portions of pots, as these cases provide the best return of information for effort and resources.

An integrated and staged cultural materials approach is employed for conserving Caution Bay ceramics, the primary aims being to:

1. Understand the degradation mechanisms of low-fired Caution Bay pottery.
2. Develop and apply appropriate treatment methods according to ceramic material structure and state of degradation.
3. Strengthen the conjoined sherds and pots sufficiently to allow archaeological documentation (drawing and photography) and study of the objects in Australia and their return to PNG for display at the National Museum and Art Gallery, where there is some but variable permanent environmental control.
4. Improve dialogue, specialist knowledge and technology transfer and engagement with archaeologists and museum personnel in PNG.

Pottery assemblages from Caution Bay present complex deterioration challenges and significant conservation issues. Preliminary investigations indicate that the deterioration of Caution Bay ceramics is associated with handmade paddle and anvil construction and low firing temperatures. Low-fired earthenware vessels are difficult to conserve and lift in the field, and across the world such ceramics often do not make it to the laboratory (Vandiver 2001: 380). Problems associated with the conservation of low-fired pottery have been largely overlooked by conservators and archaeologists; the treatment applied to such pottery from Caution Bay is discussed below.

Treatment

Conservation of the Caution Bay pottery includes the following actions and treatments: locating conjoinable sherds, identifying the presence of soluble salts, removal of salts (desalination), cleaning, consolidation of friable sherds, adhering and filling areas of loss. All stages of treatment are documented in notes and photographs. Conservation treatments employed here are first tested, and if promising, initially applied to control samples before being applied more widely.

The method we have employed for finding joins in an assemblage involves laying out all sherds from a given square in labelled trays on a large table to examine them for macroscopic similarities (co-occurrences of individual attributes). Initially, each tray has sherds from the same XU. As the sherds are sorted into different fabric types based on fabric colour, texture and inclusions, the sherds are sub-divided into separate trays, each containing sherds that visually appear to be of the same fabric. Conjoins are first searched for among the sherds from a given XU, and then conjoins are sought from neighbouring XUs. Eventually, all sherds from a square are examined and cross-compared many times.

Before sorting, sherds must be labelled to prevent the loss of provenance information and find numbers. This is done temporarily by applying 3M™ Micropore™ Surgical Tape (a fibrous white, latex-free, hypoallergenic paper tape), which is soft and pliable, taking care to test that the tape will not remove the ceramic surface or slip. XU and square detail is transcribed onto the tape with a 3B pencil prior to application to the sherd (Figure 9.10a).

Once identified, conjoined sherds are examined prior to adhering, and a standardized form is employed to record details such as: Munsell® colour code for exterior, interior, core colours and core layers, oxidized and reduced surfaces, inclusions and voids, and finishing techniques such as incisions, slips and burnishing. The sherds are weighed before and after cleaning and prior to adhering.

Analytical methods include visual inspection, water solubility testing, long-wave ultraviolet (UV) light (365 nm), infrared light, optical microscopy, polarized light microscopy (PLM) and Dino-Lite digital microscopy at 50× magnification.

The presence of soluble salts in archaeological objects is one of the most serious conservation problems (Bradley *et al.* 1999: 771). Chlorides, nitrates and sulphates are readily soluble in water and are absorbed by pottery. The Caution Bay pottery is tested for salts to ascertain if desalination is required. Soluble salts found in ceramic bodies could deliquesce when the pottery is returned to PNG's humid environment, where subsequent recrystallization could lead to disintegration of conjoined sherds and pots.

Chemical spot-testing to identify salts is undertaken following the methods described by Odegaard *et al.* (2005), chloride using silver nitrate, nitrates using iron (II) sulphate and sulphates using barium chloride. A sample is removed from the sherd onto a watch glass which is then swept into a test-tube and tested with the reagent.

When salt crystals are visible during microscopic inspection but are not identified during spot-testing, a sherd is soaked in deionized water for 24 hours. The test

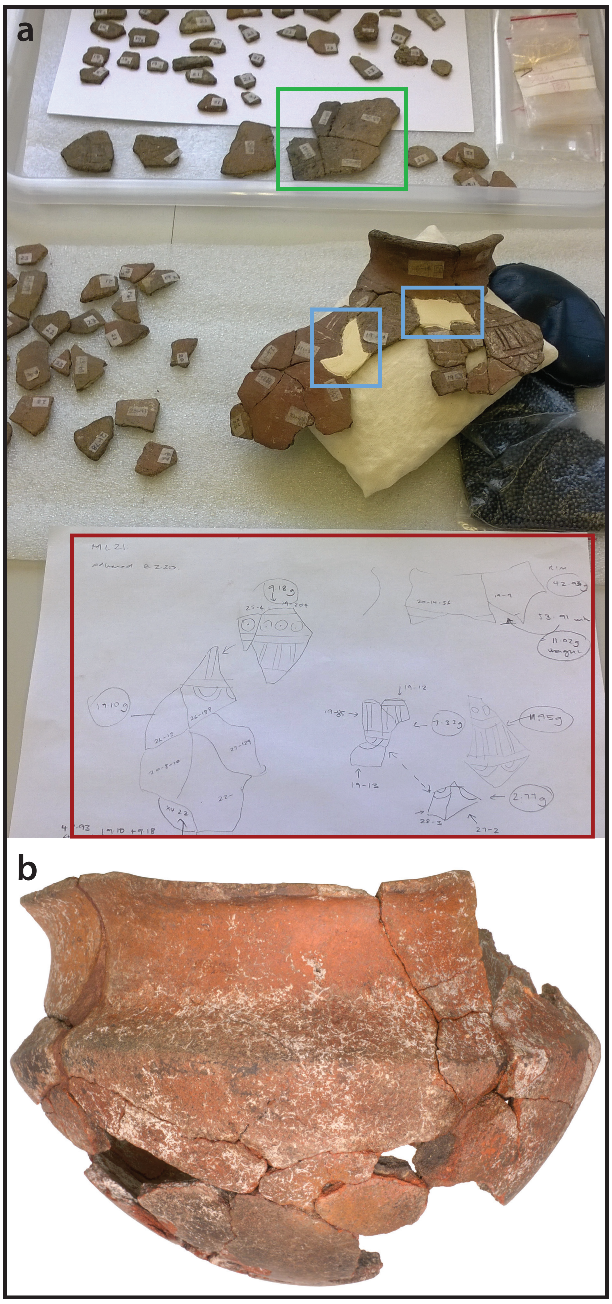

Figure 9.10. Excavated pottery conservation: (a) Site Ruisasi 1 (ABKO) pottery conjoining in progress showing 3M Micropore™ tape labels on sherds, conjoined sherds (green rectangle), a conjoin map (red rectangle) and structural fills on a partially reconstructed pot (blue rectangles) (Photo: Holly Jones-Amin); (b) Shoulder-carinated Lapita pot with a collar and globular base from site Bogi 1 (ABEN), Square F, XU14, reconstructed from 23 conjoining sherds, which has undergone mechanical reduction of carbonates, desalination and infilling using Paraloid (Photo: Steven Morton).

solution is then measured for salts with a conductivity meter. A chloride meter (Jenway model PCLM3) is used to confirm or rule out the presence of chloride salts. Two vessels have had further tests to confirm that soluble salts were not present using Environmental Scanning Electron Microscopy Backscattered Electron (ESEM-BSE) images and Environmental Scanning Electron Microscopy Energy Dispersive Spectroscopy (ESEM-EDS) observations utilizing secondary electron (SE) and backscattered imaging (BSE). X-ray powder diffraction (XRPD) require ~1g of ceramic sample, which is crushed by hand in a mortar and pestle to sub-10 µm particle size, and scanned using a Bruker D8 Advance diffractometer. These tests also identify minerals present.

Highly friable sherds are tested for water solubility to ascertain methods and materials for cleaning, desalination and consolidation. Non-conjoining test sherds are immersed in a bath, or swabbed with, deionized water. Sherds exhibiting solubility soften and crumble during this process. Disintegration indicates the vulnerability of the ceramic bodies to water and the solubility of some constituents. Consolidation is required before desalination treatment of friable Caution Bay pottery (see consolidation section below).

Prolonged immersion of porous ceramics can leach out trace elements from manufacture and from pottery use, therefore desalination is only undertaken when salts have been identified via spot tests, and when necessary, by employing ESEM-EDS and XRPD.

Pottery with identified salt problems are placed in plastic tubs and introduced to deionized water via capillary action. Once the sherds are wet, water is added to the bath and a line is drawn on the container to indicate the level of water for subsequent changes of water that is measured in millilitres. Sherds are monitored for any changes to their hardness and surface decoration. Water is tested with a conductivity meter to see if salt ions are present. Water is changed weekly until the conductivity is close to the deionized water. Samples of desalinated water are kept and tested for the presence of chlorides using a Jenway Model PCLM3 Chloride meter at another institution. During desalination, sherds are cleaned by brushing gently with a boar or a synthetic bristle brush. Care is taken with slipped surfaces that can be damaged when the sherds are wet.

Although sherds were subject to wet sieving on site, and some also to very brief and gentle hand cleaning in water during lab sorting activities prior to conservation, conservation cleaning allows for more accurate visual information about the manufacture or decoration of the pottery, and can assist in the identification of slips and allow access to the sherd surface should any surficial or geochemical analysis be required (Tschegg 2009: 2156). Conservation cleaning of soil and rootlets is undertaken prior to consolidation and adhesion. Pottery that cannot be washed due to solubility is cleaned by brushing with soft artist brushes. Rootlets are removed using tweezers in a 'picking action'. More stubborn sediment is gently loosened with a bamboo skewer and swabbed with a barely-dampened cotton wool swab. Swabs are frequently changed to prevent micro-scratching from dirty swabs. Vacuuming is undertaken through tulle net to prevent small sherd fragments from being vacuumed up. Micro-cleaning is undertaken for concretions with the aid of a microscope, using micro-swabs dampened with deionized water, bamboo skewers and a scalpel. Swabs are examined for pottery slip transfer under the microscope, if slip transfer is found alternative solvents are tested for cleaning.

No chemical treatments have been used to reduce carbonates; instead carbonates have so far only been removed manually using a scalpel. Carbonates are visible as a film of calcareous accretion on sherds belonging to a vessel from site Bogi 1, Square F, XU14 that is now reconstructed (Figure 9.10b). The presence of carbonates was confirmed using a hydrochloric acid and barium hydroxide spot-test (Odegaard *et al.* 2005: 102-103) and interpretation of elemental data obtained from ESEM-EDS. In addition, XRPD identified the presence of carbonates in the sherds from this vessel. Carbonates may be an indication that a calcareous beach sand temper (containing shell matter) was used (Leach *et al.* 2008: 436, 446). Alternatively, the carbonates may be from the depositional environment, as shell grit is abundant within the Bogi 1 sediment, so the carbonate may have been redeposited in the pores of the ceramic during burial (Freestone 2001: 621).

Consolidation is a standard practice for weakened archaeological ceramics, both for lifting fragmenting objects out of the ground and also post-excavation to hold weakened structures together (Pye 2001: 138; Strahan and Unruh 2002). Consolidation can be seen as a preventative treatment, as it safeguards the object against future disintegration, and as a remedial measure as it counters the damage that has already taken place (Pye 2001: 138). Consolidation is a major treatment intervention and is only undertaken with considerable forethought. Reversible consolidants added to friable objects cannot be removed successfully, as breaking down the secondary forces between the consolidant and its substrate can severely damage or destroy a weak object. Consolidants may not penetrate completely and, consequently, they may exacerbate weaknesses, or they can interfere with analytical testing, making re-treatment difficult and can change the visual appearance of the ceramic by changing the patina of the surfaces, changing its colour and/or imparting sheen.

Two consolidants are currently used for the Caution Bay project: Paraloid B-72® in acetone (Coote and Sand 1999:

337; Koob 2009: 113; Loo 2007: 3), and tetraethoxysilane (TEOS) Wacker Silres BS OH 100 (Franzoni *et al.* 2013). Paraloid B-72® is a Class A material with excellent ageing characteristics (Horie 2010: 159) that forms mechanical reinforcement throughout a consolidated substrate without reacting to it.

The glass transition temperature (Tg) of Paraloid B-72® is 40°C (Buys and Oakley 1993: 191) and is suitable for an object to be displayed and stored at the PNG National Museum and Art Gallery in Port Moresby where the temperature range is usually 25-28°C (Hoare 2005) and relative humidity levels range from ~70% to 90% (Sunshine State Stories 2011). Paraloid B-72® was prepared for consolidation in an acetone/ethanol solution (5% w/v solution, 90:10 acetone/ethanol v/v) based on results and recommendations from previous applications (e.g., Coote and Sand 1999: 337; Koob 2009: 113; Loo 2007: 3). Consolidation using Paraloid B-72® produces a shiny film that is reduced by brushing the consolidated ceramic surface with acetone and blotting the brush.

The Wacker Silres BS OH 100 consolidant is a partially hydrophobic polymerized ethyl silicate base with ethanol. It is a commercial stone strengthener that has been previously applied to ceramics (e.g., Constancio *et al.* 2010). Wacker Silres BS OH 100 cross-links in situ to form a 3-D network. The resultant polymer bonds chemically to the ceramic structure, building strengthening supportive networks (Wacker Chemie AG 2006: 12). The silane is applied by dripping the solution from a pipette until the ceramic fabric is completely wetted. On drying, it changes the patina minimally, remaining matt and only slightly darker; and soil and accretions are easily removed from the surface after application of this consolidant.

Application methods for both consolidants are informed by the existing literature, and we have trialled methods on low-fired ceramic sherds donated for testing purposes. Caution Bay sherds consolidated with Paraloid B-72® have had consolidant both applied using a pipette onto the dry sherd and by pre-wetting with ethanol before application; the latter procedure ensures good penetration and distribution of the consolidant into the ceramic matrix. This method results in a sherd with less sheen requiring little reduction of excess consolidant prior to adhesion.

Once conjoins have been identified, the order of bonding is planned and a dry run (using adhesive tape only) is undertaken, to identify the correct sequence for adhering sherds to prevent misassembly. Preparation for complex reconstructions includes hand-drawing a map of conjoining sherds (Figure 9.10a).

Paraloid B-72® is used for adhering pottery. A 40% Paraloid B-72® (w/w) solution in acetone is prepared using Koob's (2009: 117) method and poured into 40mL collapsible aluminium tubes. To reduce sherd edge crumbling, the sherd edges are consolidated with 5% Paraloid B-72® (w/v solution, 90:10 acetone/ethanol v/v) prior to adhering sherds together. Once adhesive has been applied to sherds for conjoining, non-friable surfaces are taped together with 3M Micropore tape precut to differing lengths and widths to suit the conjoin and weight of sherds, to hold them in place while the adhesive sets. For sherds with friable surfaces, clamps and bamboo skewers standing in a tray containing glass beads are used to help support joins as the adhesive dries (Loo 2007: 3). After setting, if alignment is not satisfactory, realignment is achieved by the application of heat from a heat gun until the thermoplastic adhesive becomes flexible (Koob 2009: 117).

Conjoins which have small areas of adjoining edges due to sherd edge erosion are sometimes reinforced with fill. Structural fills are undertaken only for larger vessel reconstructions where critical sherds are missing and without which the reconstruction would be unstable (Figure 9.10a). Fill consists of 40% Paraloid B-72® (w/w) in acetone, bulked with microballoons and tinted with Kremer pigment. Infills are smoothed with acetone, scalpel and files. Aesthetic fills are not carried out.

Final Comments on Pottery Conservation

Pottery conservation is still in progress on the Caution Bay ceramics and variations on the above described methods or new methods may be applied if warranted. As with the above methods, the most suitable potential methods will be tested prior to application and systematically reported. A further consideration is that all of the pottery will be repatriated to PNG in the near future, so preparations for transportation and display are in progress. Conjoined pottery is currently stored in clear polypropylene containers padded with low-density polyethylene foam sheeting (Cell-Aire®) for support and protection during forthcoming transportation. Custom-made marine grade stainless steel supports have been prepared for several large reconstructed pots soon to be taken to Port Moresby and displayed at the PNG National Museum and Art Gallery. Pottery conservation results will also be seen in forthcoming Caution Bay volumes, usually where conjoined sherds are illustrated in the pottery analysis chapters for specific sites, but more extensively for sites where large-scale vessel reconstructions occur (e.g., David *et al.* 2013).

Stone Artefact Analysis

Almost all of the excavated sites at Caution Bay have stone artefacts, and frequently in considerable quantity, especially due to the recovery of numerous small flakes in the 2.1mm mesh sieves following wet sieving operations at the field laboratory. It was apparent from the start that the stone artefact assemblages were generally comprised of a large amount of knapping debris and low numbers of retouched artefacts and formal implement types, so an emphasis on typology would have been inappropriate as the vast majority of stone artefacts would have been ignored. As such, a technological analysis of all the recovered stone artefact assemblages from Caution Bay is being undertaken.

Technological approaches to flaked stone artefacts in Melanesia, and along the south coast of mainland PNG in particular, remain largely untried. Such approaches can reveal previously unknown information on techniques of manufacture, a particularly useful avenue of enquiry when considering the distinctiveness and connections between local pre-ceramic, Lapita and post-Lapita cultural practices (e.g., Clarkson and Schmidt 2011; Hanslip 2001; McCoy 1982; Pavlides and Kennedy 2007; Reepmeyer *et al.* 2011; Sheppard 1993; Symons 2003; Torrence 2011). A technological attribute-based analysis was thus conducted for all Caution Bay sites with these aims in mind.

The following sections detail the information recorded during the analysis of flaked stone artefact assemblages, how measurements were made and variables recorded, and how the results are presented and discussed.

Raw Materials

Raw material type was recorded for each stone artefact, with chert proving to be the most common type at the excavated Caution Bay sites. Chert can be found together with deep-water limestone in the Eocene Port Moresby beds located 'along the south coast of the mainland at Port Moresby' where they 'form coastal foot hills' (Davies and Smith 1971). Chert is distributed across the study area landscape in the form of nodules of varying sizes (Glaessner 1952). Chalcedony has a similar distribution, but is less common than chert, and it is also less commonly represented in the excavated assemblages. Quartz is another material used for flaking at Caution Bay, albeit in small quantities. Quartz was most likely procured from local creek-beds and riverbeds. Igneous materials (basalt, gabbro, dolerite) must have been imported from elsewhere as there are no local sources, with the closest known potential sources located in areas to the north of Port Moresby within the Sadowa intrusive complex (Davies and Smith 1971), east of Port Moresby on the Sogeri Plateau (Davies and Jaques 1984; Mabbutt 1965), or to the southwest in Torres Strait (Rhoads and Mackenzie 1991).

Another stone material identified among the sites investigated is obsidian, a high-quality volcanic glass. The closest source of obsidian to the study region is on Fergusson Island (Summerhayes 2009), part of the D'Entrecasteaux group east of the island of New Guinea and approximately 380km from Caution Bay as the crow flies (~600km following the coastline by sea). However, a number of obsidian sources known to have been widely used by Lapita peoples elsewhere are found in the Talasea region of New Britain, a straight-line distance 540km away to the northeast (~1450km by sea). Determining the source(s) of the obsidian artefacts from the study area is important to our research (see Other Analyses below), as it should inform on the degree to which local human populations maintained contacts – directly or indirectly – with their ultimate homelands during the Lapita-period, or continued Lapita-era trading patterns into the post-Lapita period, or renewed or initiated entirely new contacts in post-Lapita times.

Technological Variables

Attributes recorded on stone artefacts were selected in order to answer questions regarding the different types of reduction strategies used (unipolar and/or bipolar percussion, core rotation as evidenced by the number of core platforms, flake scars on cores, dorsal flake scar numbers and orientations, and remnant platforms on the dorsal surfaces of flakes), the type of reduction stage performed in situ (flake size, cortex presence, termination type), and whether these strategies varied in intensity over time and across space (core size, flake size, platform type, size, and preparation, retouching). Figure 9.11 defines the measurement methods used and attributes recorded for each piece of analysed artefactual flaked stone from the Caution Bay sites. The attribute values and how these characterize each stone assemblage are presented in detail in each site report. Analytical results are also tabulated by number and percentage of items belonging to the different fracture types, providing a summary of the size and composition of each assemblage. Additional tables provided in the individual stone artefact reports record metric attributes of cores, unretouched flakes, and retouched flakes. A summary table of technological indicators, primarily consisting of secondary variables (including Minimum Number of Flakes, Minimum Number of Flakes to core ratios, etc.), is also provided for each site, with results from different excavation squares listed in adjacent columns to assist comparisons.

Minimum Number of Flakes (MNF) was calculated for each assemblage as it helps to estimate knapping intensity. A modified version of Hiscock's (2002) MNF was employed using the following formula:

$$MNF = C + T + CL$$

Where C stands for the number of complete flakes, T for the highest sample of transversally broken flakes (either proximal or distal) and CL for the highest sample of complete longitudinally broken flakes. The MNF was calculated for each XU and then summed for the entire

Figure 9.11. Stone artefact analysis variables.

Variable	Definition and Recording Procedure
Fracture type	A stone artefact is defined by its fracture type: • *Unipolar core*, being a piece of stone containing one or more platforms from which flakes were removed using freehand percussion, leaving flake scars. • *Bipolar core* is characterized as a piece of stone resting on an anvil for stabilization. During the removal process, the point of contact with the anvil is often crushed and displays small flake scars originating from the point of contact. • *Flake*, defined by the presence of a ventral surface. Flakes are either complete or broken. Broken flakes are further divided into proximal (where a bulb of force is present), distal (where the termination is present), medial (where both proximal and distal ends are absent), lateral split cone (where a flake has broken along its longitudinal axis) and broken other (where it is not possible to place the flake in any of the above categories). • *Bipolar flake* defined by McNiven (1992:3) as “formed by resting either a core or retouched flake against an anvil so that the force of the percussor along the percussion axis also impacts the anvil.” They “tend to exhibit the same features as unipolar flakes, with the addition of a secondary set of impact features (e.g. crushing and small flake scars) on the distal margin of the flake” (McNiven 1992:3). Since the core is positioned against the anvil, the flake platform is often crushed by the percussor. When broken, only fragments showing the distal end (bipolar distal flake) or part of the distal end (bipolar axial flake) can be defined as bipolar as they retain the characteristic features of bipolar percussion. • *Flaked piece*, being a stone exhibiting definite evidence of human modification in the form of flake scars only. • *Manuport*, being a stone imported from somewhere else (as evidenced by raw materials foreign to the site) and exhibiting no traces of human modification. • *Potlid*, as defined by Hiscock (1988:326) is “a concave-convex or plano-convex fragment of stone. Potlids never have a ring-crack or any other feature relating to the input of external force. They often have a central protuberance, indicating an internal initiation to the fracture. Potlids are the result of differential expansion of heated rock.”
Cortex	The presence of cortical surface on the surface of an artefact. On flakes, the amount of cortex was recorded in 25% increments of the total dorsal flake surface; cortex location was also recorded.
Dorsal flake scars	The number and orientation of flake scars present on a flake’s dorsal surface were recorded.
Flake termination	Five types of terminations were recorded: feather, hinge, step, outrepassé and crushed.
Length	Axial length (distance from fracture initiation to fracture termination) was measured for complete flakes only. Maximum length was measured for broken flakes and all other artefacts. All measurements were made to the nearest 0.1mm with digital calipers.
Weight	Weight of the artefact to the nearest 0.1 g.
Overhang removal	The presence of small flake scars left on a flake’s dorsal surface by the removal of platform overhang during core platform preparation.
Old platform remnant	Old platform removal was recorded for flakes that reveal the remnant of an old platform on their dorsal surface. The number of old remnant platforms were recorded.
Platform surface	Six platform surfaces were recorded: cortical, flat, multiple-flaked, facetted, crushed or unidentified.
Platform thickness	Distance across the platform surface from the dorsal to the ventral surface. Recorded to the nearest 0.1 mm with digital calipers.

Variable	Definition and Recording Procedure
Platform width	Distance across the platform surface from one lateral margin to the other. Recorded to the nearest 0.1 mm with digital calipers.
Raw material	Type of rock used to manufacture the artefact.
Termination type	Four types of terminations were recorded: feather, step, hinge and outrepassé (See Cotterell and Kamminga 1987 for definitions).
Thermal alteration	Crazing and the presence of potlid scars caused by a rapid increase in temperature were recorded on artefacts. On flakes, the surfaces on which potlid scars occur were recorded.
Thickness	The axial thickness (distance between the flake dorsal and ventral surfaces, measured at the intersection of the axial length and axial width) was measured for complete flakes only. Maximum thickness was measured for broken flakes and all other artefacts. All measurements were recorded to the nearest 0.1mm with digital calipers.
Width	The axial width (distance between the flake lateral margins, measured half way along the length) was measured for complete flakes only. Maximum width was measured for broken flakes and all other artefacts. All measurements were recorded to the nearest 0.1mm with digital calipers.
Retouching	Retouching was recorded when an edge exhibited a minimum of 5mm of continuous retouch flake scars. Its location, direction (dorsal and/or ventral) and type (fine, abrupt, invasive) were also noted.

square. While this method could overestimate the MNF calculated for a square as a whole, calculating the MNF using overall complete and broken flake numbers for the entire square as a single combined analytical unit would lead to a significant underestimation of the MNF. However, since the MNF calculation method does not include all types of flake fragments, in particular the category 'broken flake, other' which makes up most of the lithic assemblage at each site, the MNF is still likely to remain a slight under– rather than over–estimate of the actual number of flakes present.

Colours and Heat Alteration

In the early stages of analysis it was observed that the colours of chert artefacts vary significantly, although the source material seemed to be of similar quality and apparent origin, suggesting the possibility of colour alteration of the chert through high-temperature heating. We were interested in determining the presence or absence of deliberate heat-treatment of lithic raw materials, applied for the purpose of improving the flaking characteristics before tool production, but also any other origin of extreme heating of the chert that could have taphonomic implications for the assemblages, especially in relation to increased brittleness and therefore the post-depositional fracturing of flakes.

The colour of stone artefacts was recorded using the Munsell® Geological Rock-Color Chart (Munsell Color 2011). Figure 9.12 lists the different colour values identified on chert and other materials studied thus far in assemblages from across the Caution Bay study area. Colour values #5 and #6 appear to be natural chert colours as indicated on naturally occurring chert samples found in the study area. These two colour values were sometimes observed together on the same sample. Colour values #17 to #19 are likely to be caused by the oxidization of iron elements present within the stone during heat application (Purdy and Brooks 1971). However, the presence of these two colour values is not sufficient to tell whether heat application was intentional or accidental. It was necessary to record additional indicators of thermal alteration to circumvent this problem (see Hiscock 1985, 1990 for the importance of measuring thermal alteration on stone artefact assemblages). Recording the location of potlid scars on flakes was required, since potlid scars on a flake's ventral surface (especially on small flakes) confirm that heat application was unintentional as it took place after rather than before manufacture (Mercieca 2000).

Non-Molluscan Faunal Remains

The non-molluscan faunal assemblages from the Caution Bay sites include three main categories of remains:

FIGURE 9.12. COLOURS (MUNSELL COLOR 2011) RECORDED ON FLAKED STONE ARTEFACTS FROM CAUTION BAY.

Colour		Munsell Colour Code	Munsell Colour Name	Rock Type
1		5YR 3/4	Moderate Brown	Chert
2		5YR 5/2	Pale Brown	Chert
3		10YR 4/6	Moderate Reddish Brown	Chert
4		10R 6/6	Moderate Reddish Orange	Chert
5		10YR 8/2	Very Pale Orange	Chert
6		10YR 6/6	Dark Yellowish Orange	Chert
7		10YR 6/2	Pale Yellowish Brown	Chert
8		10Y 4/2	Grayish Olive	Chert
9		5R 6/6	Light Red	Chert
10		5YR 4/1	Brownish Gray	Chert
11		5YR 2/2	Dusky Brown	Chert
12		5R 2/2	Blackish Red	Chert
13		10YR 4/2	Dark Yellowish Brown	Chert
14		5R 8/2	Grayish Pink	Chert, Chalcedony
15		10R 2/2	Very Dusky Red	Chert
16		N3	Dark Grey	Chert, Obsidian
17		5R 4/2	Grayish Red	Chert
18		5R 5/4	Moderate Red	Chert
19		10R 5/4	Pale Reddish Brown	Chert
21		5Y 8/1	Yellowish Gray	Chert
22		N1	Black	Chert, Obsidian
25		10G 6/2	Pale Green	Chert

1. Bone from vertebrate animals.
2. Eggshell from bird and reptile eggs.
3. Cytoskeleton of invertebrates including exoskeleton of crustaceans and urchins, and endoskeleton of cuttlefish.

Each of these categories of remains is readily distinguished in the excavated assemblages from Caution Bay. Different procedures were used to characterize each category.

Bone from Vertebrate Animals

Five major groups of vertebrates can be represented in any excavated assemblage – fish, frogs, reptiles, birds and mammals. Each of these vertebrate groups has a distinctive skeletal anatomy and, with undamaged bones, virtually any bone can be allocated to one of the five groups. Fish bone is the most readily distinguished of the five groups, partly on account of textural properties that are not seen in other groups of vertebrates. Uniquely, fish bone often has a 'ropey', finely granular, or flaky, plate-like surface texture.

Fragmentation of bone results in a loss of diagnostic morphological features. For fish bone, this is countered to some degree by the textural differences noted above, allowing even very small bone fragments to be allocated to this group. By contrast, for other groups of vertebrate fauna, the ability to identify fragmented remains depends on how much morphology is preserved. Fragments that retain some part of an articular surface are potentially identifiable, whereas fragments derived from long bone shafts are rarely identifiable even to major group. Fragments of turtle carapace and plastron also show a distinctive surface texture coupled with a spongy internal structure that allow discrimination down to quite small fragments.

The first step in sorting an excavated bone assemblage was to separate bone fragments derived from each of the major vertebrate groups – fish, frogs, reptiles (excluding turtles), turtles, birds, and mammals. Bone that could not be confidently allocated to any group was left in an 'unidentified' category.

Within each major group, a second step involved attempts to identify individual fragments to lower taxonomic levels. Identification used the following resources:

- For fish, Barnett's (1978) manual and the underlying collection of the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, the Australian National University (ANU prefix when referring to particular reference specimens); and the osteological collection of the Northern Territory Museum and Art Gallery (NTMF prefix).
- For other groups, the osteological collections of the Australian National Wildlife Collection, CSIRO (CM prefix), and the Australian Museum, Sydney (AM prefix), combined with primary taxonomic literature for mammals.

The level of taxonomic discrimination varies across groups. For fish and reptiles, identifications were generally possible to genus or family level only. The great majority of the fish bone derives from members of the Class Osteichthyes (the bony fish). The other major group of fish – the Class Chondricthyes (sharks and rays) – has highly mineralized teeth but otherwise possess a cartilaginous skeleton that rarely survives in archaeological contexts. For mammals, the degree of taxonomic resolution depended on the particular skeletal elements and their degree of completeness. For mammalian teeth, identification to species level is generally possible. In contrast, post-cranial elements are often determined only to family level, though for some groups this can be further refined if assumptions are made concerning geographic ranges of potential species. Distributional information for Melanesian mammals is summarized by Flannery (1995a, 1995b) and Bonaccorso (1998).

Quantification of Taxonomic Composition

The bone from each of the major vertebrate groups was weighed as a single category, by excavation square and excavation unit, i.e., fish bone, turtle bone, mammal bone, etc. These weights were used to characterize the overall taxonomic composition of each sample. All weights were taken on an electronic balance to a resolution of 0.01 g.

For each of the major vertebrate groups, a list was made of the individual taxa represented, the body part(s) represented, the total number of fragments, and in certain cases, the burning state of the remains. A greater level of detail was recorded for species of particular interest, including pig, dog and rodents (see below).

The assemblages contain too few identifiable specimens to warrant the application of standard methods such as Minimum Number of Individuals (MNI).

Assessment of Taphonomic Condition

The bone from at least one excavated square of each site was subject to detailed examination from a taphonomic perspective, following the general approach of Domínguez-Rodrigo *et al.* (2007). Bone surfaces and fracture edges were examined microscopically for surface modifications including cut and tooth marks, percussion marks, corrosion associated with root contact, abrasion caused by post-depositional movement, and pitting caused by microbial activity. In addition, the burning condition of the bone from each major taxonomic group was quantified by separation (and weighing) of three categories that reflect the intensity and duration of heating (Koon *et al.* 2003; Shipman *et al.* 1984):

1. Unburnt bone – showing no obvious heat alteration.
2. Burnt bone – showing a variable degree of heat alteration but retaining a significant organic component (variably brown, black and blue-green).
3. Calcined bone – showing extreme heat modification and lacking any residual organic component (variably pale grey to white, often fissured and warped).

The burning composition of an assemblage will reflect the intensity of heating of bones that occurs during the cooking process, following discard into a hearth, and following burial if a hearth is subsequently built in that position. However, because the chemical and physical properties of bone are altered by the heating process, which in turn affects its susceptibility to various post-depositional processes including scavenging, microbial breakdown, and chemical solution, the burning composition of an assemblage is also influenced by its post-depositional environment (see Hedges 2002 for review). Under most circumstances, unburnt bone is subject to the most rapid degradation, while calcined bone is the most resistant as it contains the least organic matter and is more densely crystalline in structure (Thompson *et al.* 2011).

Sampling for DNA Analysis and Direct AMS Radiocarbon Dating

Important archaeological issues revolve around the dual questions of the antiquity of various introduced animals in Melanesia, and the genetic affinities of past populations. The greatest interest concerns the history of the three main domesticates – pigs, dogs and chickens. However, there is also considerable interest in two species of commensal rats that have spread with people throughout the western Pacific region – the Pacific Rat (*Rattus exulans*) and the Black Rat (representatives of the *Rattus rattus* complex, including *R. tanezumi*).

Bones of the domesticated and commensal species were assessed for their potential value as a source of ancient DNA and for direct AMS radiocarbon dating. To be useful in either regard, the bone should be unburnt and retain a significant proportion of its original organic component. Bone that has lost most of its organic content typically has a dry, powdery texture.

Eggshell

Bird and reptile eggshell fragments are readily distinguished by a number of characteristics.

Bird eggshell consists of a protein matrix lined with crystals of calcium carbonate. It is rigid and brittle, and usually has a smooth inner surface and a smooth to granular external surface. The combined features of a smooth inner surface and a crystalline fracture surface allows even very small pieces of bird eggshell to be distinguished from other thin-walled rigid materials such as thin-walled bone and invertebrate exoskeleton. Burnt eggshell retains its essential properties, but is often fissured and warped.

Two kinds of bird eggshell are commonly encountered in Melanesian archaeological contexts: cassowary and megapode eggshell. Megapodes (members of the family Megapodidae) are typically mound-building galliform birds found in Australia, Melanesia and Sulawesi. Megapode eggshell is essentially smooth, both inside and out, and are quite thin-walled for their size, usually less than 1mm in thickness. The crystalline texture is visible under low magnification. Cassowary eggshell is typically 1.5-2mm thick and has a coarsely granular outer surface.

Reptile eggshell is thin-walled, typically less than 0.5mm in thickness, and less heavily calcified, with no crystalline structure visible even under low magnification. It has smooth inner and outer surfaces, and is very flexible, with a leathery or parchment-like texture. Eggs of crocodiles and turtles are widely harvested throughout Melanesia but the remains are rarely reported from archaeological contexts, presumably due to their less robust nature.

Only bird eggshell was identified from the excavations. The eggshell fragments are very uniform in thickness and show no significant variation in surface texture. All are likely to derive from megapode eggs.

The bird eggshell was weighed as a single category without reference to burning condition.

Invertebrate Exoskeleton

Three major groups of invertebrates are represented in the assemblages: Echinodermata (urchins), Decapoda (crabs) and Sepiida (cuttlefish).

Urchins are represented by fragments of the test and spines. Test fragments possess a highly distinctive, tuberculate external surface and an internal surface marked by regular alignments of pores. Spines have a radial crystalline structure visible in broken cross-section and a distinctive basal articulation.

Crabs are mostly represented by fragments of claws which are usually more robust than other elements of the exoskeleton. However, all parts of the exoskeleton possess a distinctive gross morphology and a distinctive crystalline internal structure that allows even small fragments to be distinguished from bone.

Further work is required before the bulk of the urchin and crab remains can be identified to lower taxonomic levels. However, prominent among the crab remains are distinctive elements of the mud crab (*Scylla serrata*), while the bulk of the urchin remains appear to be referable to one taxon, the Collector Urchin, *Tripneustes gratilla*.

Crab, urchin and cuttlefish remains were each weighed as single categories.

Reporting

The broad composition of each assemblage is reported by weight, with the bone generally subdivided further and weighed according to separate burning classes. By contrast, for more detailed taxonomic composition of groups such as fish, mammals and crabs the basic unit of comparison is generally a Number of Individual Specimens (NISP) from which proportional abundances are calculated. NISP values are used in preference to a Minimum Number of Individuals (MNI; the smallest number of original animals needed to account for all of the recovered remains) because the small samples available from the majority of the analysed sites dictate that the likelihood of recovering multiple fragments of any one individual is low.

Molluscan Remains

Molluscan remains recovered from each site at Caution Bay were separated by excavation square and excavation unit (XU), with the latter forming the basic unit for quantification and analysis (Bowdler 2014). Laboratory assistants undertook the preliminary sorting of whole or nearly complete specimens to the appropriate taxonomic level (family, genera or species), and fragments into broad possibly identifiable and unidentifiable categories. The senior analysts checked those preliminary classifications and then performed the final identifications, quantification and recording.

Taxonomic Identification of Molluscan Remains

A comparative reference collection of mollusc species from the Indo-Pacific region, with a particular focus on the Port Moresby area, was assembled from the personal collections of the principal archaeomalacologists in combination with the molluscan reference collections of the Archaeology Program, School of Social Sciences, The University of Queensland and the Tropical Archaeology Research Laboratory, James Cook University. In addition, a range of published literature was consulted to support identifications, including Abbot and Dance (1982), Beesley *et al.* (1998), Carpenter and Niem (1998), Cernohorsky (1972, 1978), Coleman (2003), Dance (1977), Habe (1964), Hinton (1972), Kira (1965), Lamprell and Healy (1998), Lamprell and Whitehead (1992), Short and Potter (1987), Springsteen and Leobrera (1986), Wilson (2002), and Wilson and Gillett (1988). Taxonomic identification of the archaeological material was achieved by one-to-one comparison with material from the physical reference collection or, where corresponding taxa were missing from the reference collection, with images and descriptions in the published literature cited above.

All shells and shell fragments irrespective of size (material was recovered in 2.1mm mesh sieves during wet sieving operations in the field laboratory, see above) were identified to the lowest possible taxonomic level based on the presence of diagnostic characteristics, with taxonomic lists created for each excavated square. Care was taken not to 'over-identify' specimens. Where fragmented or heavily degraded material could not be confidently assigned to species level based on preserved diagnostic features, for example, these specimens were identified to genus or family levels only, even where shell morphology resembled the dominant taxa (Szabó 2009: 186). An 'unidentified shell' category was utilized for any specimens that could not be assigned to species, genus or family levels. This procedure minimized any methodological assumptions and avoided subsequent analytical uncertainty, with the unidentified shell being quantified wherever shell assemblage composition is reported. In common with Szabó (2009: 186), during identification and quantification of the molluscan assemblages no assumptions were made concerning whether specific taxa represented subsistence or technologically important species (see Worked Shell Analysis below) within each assemblage. This approach provides for a more comprehensive understanding of assemblage richness and diversity, as well as acknowledging that all specimens (including those subsequently identified as being incidental species or those collected opportunistically) can potentially contribute to an understanding of how past peoples interacted with their environment (see Rowland 1994 for examples).

Modes of Quantification

Several methods are routinely used to calculate the absolute or relative abundance of shell material from archaeological deposits. Further information on quantification methods can be found in Claassen (1998), Grayson (1984) and Reitz and Wing (2008). The four measures used in the Caution Bay analyses are:

- Weight.
- Number of Identified Specimens (NISP).
- Minimum Number of Elements (MNE).
- Minimum Number of Individuals (MNI).

Weights were calculated in grams (to nearest 0.01g) by taxon for each XU, with all specimens identified for a given taxon included in the weight. This method has been used here due to the speed at which quantification can be undertaken following the process of identification, as well as the fact that this method includes all the pieces of shell identifiable to a given taxon as well as the unidentified shell category (as discussed by Bailey 1993; Rowland 1982). One of the major criticisms of this method centres on the loss of shell weight with diagenesis and fragmentation, which has the potential to affect different species (and different-sized individuals within taxonomic groups) at different rates (e.g., Claassen 1998: 60; Zuschin *et al.* 2003: 43). For example, the older the site or more acidic the sediment, there is greater potential for differential loss of calcium carbonate within and between species. The other concern with using weight as a measure of abundance is that heavier-shelled species can be disproportionately represented when compared with lighter-shelled species (see also Mason *et al.* 1998; Szabó 2009: 187). Nevertheless, this is a useful general method for comparing the amount of molluscan versus non-molluscan material within a deposit, as well as determining gross variation in the total mass of shell through an archaeological sequence (e.g., Muckle 1985: 22).

The NISP measure is the number of shell fragments identified to a particular taxon. The major limitation of this method for application to a molluscan assemblage is the level of identifiability of fragmented shell. Although NISP has been criticised for over-representing the abundance of taxa with distinctive sculpture attributes as rates of fragmentation increase (e.g., Grayson 1984: 20-23; Mowat 1995), it is useful for intra- and inter-site comparison of individual taxa and for examining shell fragmentation rates (Claassen 1998: 58; Muckle 1985: 68, 75-78).

MNI counts are based on the identification and quantification of the most diagnostic, non-repetitive element (MNE) of a given taxon. The shell features or diagnostic elements used in MNI calculations in these analyses are taxon-specific, being based on shell morphology and identifiability, both impacted by differential preservation of specimens across the Caution Bay assemblages. For chitons (Class Polyplacophora), the anterior and posterior valves are the most diagnostic non-repetitive elements, with the higher count of these valves used to calculate the MNI (Figure 9.13). For bivalves (Class Bivalvia, being animals with two dorsally hinged, separate and articulating valves), the umbo ('beak') and hinge structure is typically the most diagnostic element (Figure 9.14). Left and right valves are identified using the umbo, with the larger MNE count from one side used to calculate the MNI for a species (or to lowest identification level). For gastropods (Class Gastropoda, being animals with a single shell), the most common non-repetitive diagnostic elements include spires, apertures or umbilici (Claassen 1998: 106) (Figure 9.15). As noted above, however, the large range of species present within the excavated assemblages necessitated genera-specific landmarks to be utilized to calculate MNI; these are shown on Figures 9.14 and 9.15. For example, for *Cypraea* spp. the anterior canal was utilized, as the spire is concealed under the body whorl. Similar approaches have been followed by other archaeomalacologists (e.g., Bowdler 1984; Burns 2000; Mowat 1995). For both bivalves and gastropods, anatomical landmarks forming the diagnostic element for MNI calculation had to be more than 50% complete to avoid double counting of the same individual. The opercula of gastropods (a plug attached to the posterior dorsal surface of the animal body; cf. Bowdler 1984: 141) were identified to species level where possible, and incorporated into the range of MNI relative abundance estimates.

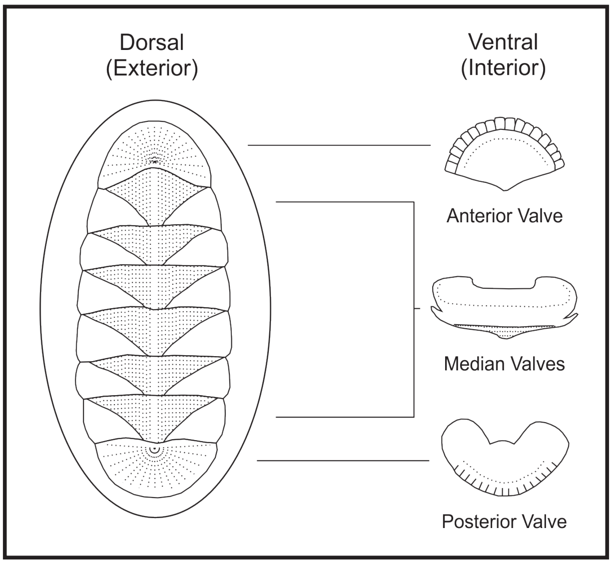

Figure 9.13. Valve determination in chiton (Class Polyplacophora) used for MNE and MNI calculations (after Dell 1951: 9).

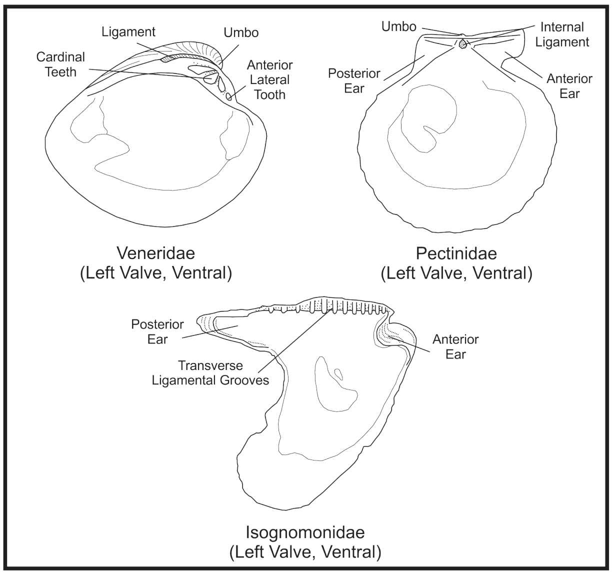

Figure 9.14. Specific landmarks identified for MNE and MNI calculations of bivalves (after Carpenter and Niem 1998: 124, 192, 198).

For each site, the MNI of a given taxon has been calculated separately for each excavation square. For any given taxon, the diagnostic element providing the highest MNE count *for the whole square* (i.e., for each diagnostic element, the sum of MNEs from all the XUs added together) is used to calculate the MNI by XU for that square. This procedure was in place irrespective of whether or not that diagnostic element represented the highest MNE count in any individual XU. For example, in the case of bivalve taxa, if right umbos were the most common diagnostic element in the entire assemblage for the square, right umbos formed the basis for MNI calculations in all XUs for that square, regardless of whether left umbos were more common in individual

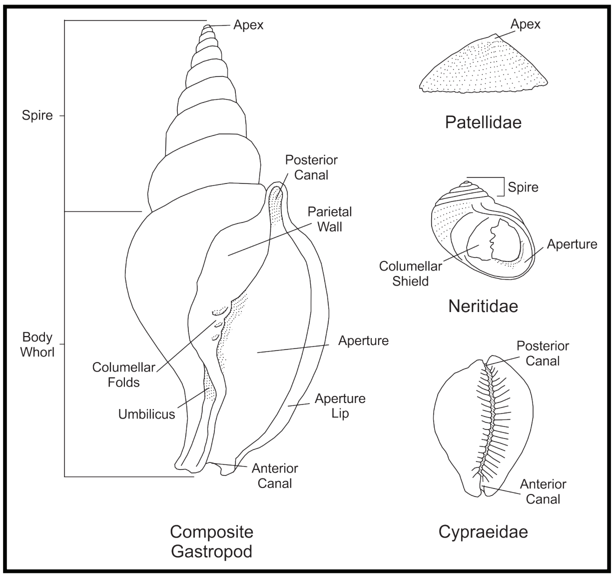

Figure 9.15. Specific landmarks identified for MNE and MNI calculations of gastropods (after Carpenter and Niem 1998: 364, 370, 394, 486 and Harris et al. 2015: 170).

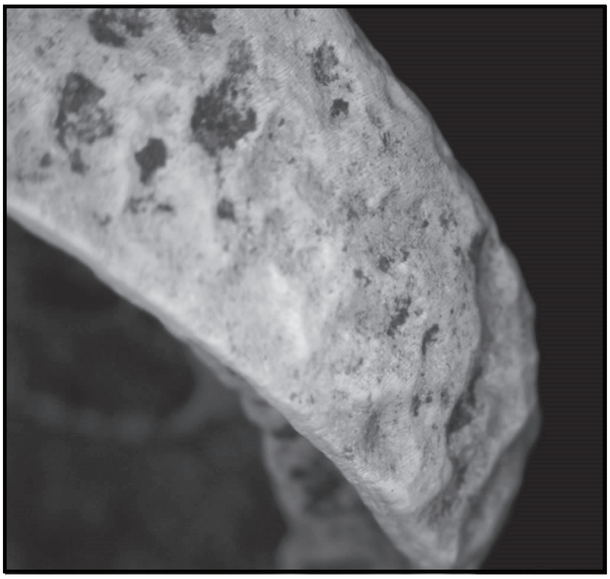

Figure 9.16. Cut *Conus sp.* body with fragment surfaces heavily eroded through acid dissolution (at x30 magnification). From site ABHD, Square C, XU 13b (Photo: Katherine Szabó).

XUs. MNI counts are slightly lower when selecting this approach over others, however the implementation of this more conservative method avoids the effects of aggregation via analysis of arbitrary analytical units and maintains consistency in relative abundance based on MNI regardless of scale, so whether reporting by XU, SU, Analytical Unit, square or site (Grayson 1984: 29).

Worked Shell Analysis

Worked shell is a feature of pre-Lapita, Lapita and post-Lapita archaeological deposits at Caution Bay, with a wide variety of raw materials used and artefacts shaped. While the traditional focus in regional worked shell analysis has been upon the recognition and discussion of defined culture-historical types, such as beads, rings and adzes, assemblages also frequently yield evidence of expedient shell artefact production and use as well as débitage related to artefact production and curation. In order to isolate, analyse and discuss all of these various manifestations of shell working at Caution Bay, a range of methodological procedures were developed; these are outlined here.

Determination of the Worked Shell Sample

A number of artefacts in shell, including beads, ring fragments and other clearly worked items, were identified during the course of the Caution Bay excavations. These were often recorded in situ, bagged separately, and later transported to the University of Wollongong for further analysis. In acknowledgment that on-site recognition was unlikely to capture the full extent of shell working, particularly with regard to unfinished or expedient artefacts and fragments of débitage, protocols were developed for the separation of worked, and potentially worked shell during the course of laboratory sorting. During the analysis of molluscan remains in particular, any obvious or potentially worked shell fragments, where morphology or surface features did not accord with standard patterns seen through the bulk of the midden shell, were separated out (see Molluscan Remains, above). Fragments of shell from taxa that are known to be important raw materials within Pacific sites, such as *Conus* spp., were also set aside. All of the separated shell was sent to the University of Wollongong for further analysis and potential incorporation into the worked shell sample. Detailed analysis of this material has confirmed a number of worked shell and débitage pieces that have greatly increased the sample size, and our understanding of production methods and on-site activities. It is clear that between in situ recording of more-or-less finished shell artefacts in the field, identification of less obvious worked items during general laboratory sorting, and a final rigorous scrutiny for traces of working during the analysis of the midden shell has captured the vast majority of worked shell originally present in the molluscan assemblages.

Protocols for the Identification of Worked Shell

A range of working techniques are typically applied to shell in the generation of formal artefacts, with some forms of modification – such as grinding – being more easily recognizable than others. When the scope of identification and analysis is wide enough, heavily worked pieces with clear evidence of shaping tend to be in the minority in Pacific worked shell assemblages. With most fragments, traces of working are subtle and such traces are often muted or partially obscured by the actions of taphonomic processes (Figure 9.16). These observations are certainly true of the Caution Bay worked shell assemblages. Especially in the upper layers of sites, varying degrees of acid dissolution of shell surfaces from contact with the surrounding semi-humic matrix, probably compounded by accessibility to rainwater, has resulted in degraded chalky surfaces on which no potential traces of working could have been detected. However, on the whole the shell fragments analysed were in relatively good condition, and careful inspection under magnification could usually positively confirm or deny distinct traces of cultural modification.

There seems to be a broad relationship between the structural type of shell being worked and the application of different working techniques (Szabó 2008), which can act as a starting point for initial laboratory analysis. For example, the primary reduction of larger shells with a crossed-lamellar microstructure – where bundles of calcium carbonate crystals are set at a 45° angle from neighbouring bundles – is often direct percussion. Although fractures generated by direct impact in cross-lamellar shell are generally rough with little capacity for fine control, the 45° angle of the crystal bundles means that force generally dissipates without travelling into, and potentially splitting, key parts of the preform. This contrasts with the reduction techniques most often applied to nacreous (mother-of-pearl) shell, which include cutting, sawing, and other abrasive techniques. Although there are structural differences between gastropod (e.g., *Trochus* and *Turbo*), bivalve (e.g., *Pinctada* and *Isognomon*) and cephalopod (e.g., *Nautilus*) nacre, all transform over time to form thin sheets of aragonite separated by organic layers (Figure 9.17). This structure is prone to splitting laterally, with layers shearing apart if impact force is applied, and this is particularly so in empty older shells where the protein 'glue' between aragonite sheets has degraded. Given this, it is unsurprising that the controlled application of force, such as seen in pressure flaking, and various forms of abrasion are predominantly applied to nacreous shell, making reduction by shell-workers much less risky. These are but two of a range of recognized microstructural types that respond differently to force applied in different ways, and are also divergent in the responses to taphonomic processes (Szabó 2008, 2013).

Analytical Procedures

As a starting point all fragments were visually assessed with the naked eye, and if necessary were gently cleaned using a soft-haired calligraphy brush. If fractures were noted to be recent, or taphonomic alteration had removed all surface and edge details, the fragments were not analysed further. The remaining fragments were inspected using a Dino-Lite Premier AM7013MT digital microscope under low (× 15 to × 60) magnification. Any evidence of working as well as examples of taphonomic alterations was photographed with the Dino-Lite. Small artefacts and fragments were photographed entirely with the Dino-Lite, while larger fragments and artefacts were also photographed using an Olympus OM-D EM5 camera and macro lens. Observations on working and taphonomic modifications were entered into spreadsheets during the visual analysis.

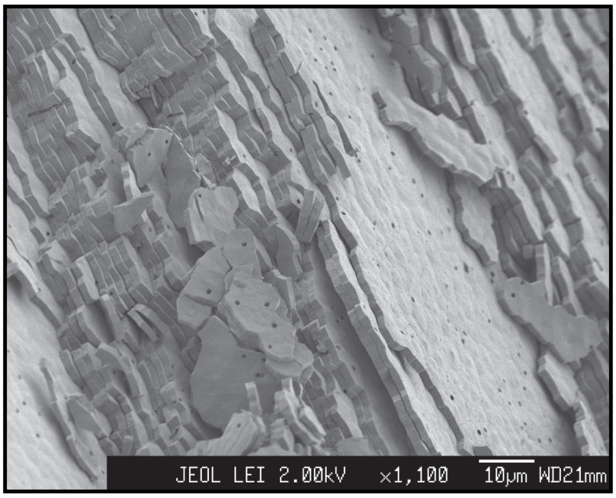

Figure 9.17. Freshwater mussel (*Alathyria jacksoni*) nacre delaminating and crumbling due to organic loss and microbiological taphonomic action which has produced numerous tiny holes. SEM micrograph at x1100 magnification (Micrograph: Erica Weston).

Context of Interpretation

The overarching aim of the identification and analysis of worked shell from Caution Bay was to piece together a holistic picture of shell working through the local pre-Lapita, Lapita and post-Lapita phases. As well as drawing out the distinctive practices and techniques of each chronological point, linkages and divergences between each of these can shed light on cultural transformations and relationships through time. Additionally, potential contrasts between contemporaneous deposits can enhance our understandings of cultural variability, spatial distributions of sites and site types and from that the patterns of human actions within the landscape.

This starting point represents a distinct break from typological approaches, with the basal aim being to identify modes and patterns of shell modification. Thus, in addition to standard types frequently recorded from Pacific archaeological sites, expedient tools exhibiting use-wear with little modification as well as débitage from artefact production attain a status of equal importance in interpretations. This not only increases sample size, but also provides a different perspective on cultural practices, the selection of raw materials, the range of working techniques, and the life history of artefacts from production through use and curation to discard (Bonnardin 2003, 2012; Taborin 1993).

AMS Radiocarbon Dating and Chronological Model-Building

Radiocarbon samples were prepared and analysed at the University of Waikato Radiocarbon Dating Laboratory in New Zealand following standard AMS protocols whereby the shells were washed in dilute HCl to remove surface contamination and charcoal samples were treated with a series of dilute HCl, NaOH and HCl washes prior to CO_2 collection. All shells were tested for recrystallization prior to dating using the Feigl staining technique (Friedman 1959). AMS targets were measured at the Keck Radiocarbon Laboratory, University of California, Irvine, and GNS Science, Wellington.

Before embarking on the chronometric evaluation of the Caution Bay radiocarbon dates it was essential that a number of issues were addressed, including the effects of post-depositional disturbance, wood/charcoal inbuilt age and local marine reservoir (commonly referred to as delta R [ΔR]) offsets in shellfish and other marine samples (e.g., urchins) (Allen and Wallace 2007; Specht 2009; Spriggs and Anderson 1993). All are well-recognized chronometric interpretative issues that have been discussed at length in the literature, but few have been directly addressed except through the exclusion of suspect dates via various 'chronometric hygiene' protocols (e.g., Spriggs 2003; see also Denham *et al.* 2012; Specht 2007) that can reject potentially useful information, and may reduce the chronological evaluation to materials with limited specificity to the event. Typically, the favoured samples for dating archaeological deposits are identified short-lived plant materials. Unfortunately, the reality of research in the Pacific region is that such materials are often rare, difficult to locate and identify, and the association between radiocarbon sample and the target event is often problematic owing to localized disturbance of deposits. Caution Bay is no exception, with only a handful of short-lived charcoal samples identified, and common post-depositional movement of tiny pieces of charcoal through the middens. The remains of shellfish, however, dominate these sites and are generally easy to identify to taxa, while the larger and flatter surfaces of the shell ensures limited vertical and horizontal displacement. Shell, therefore, is the logical sample type on which to develop radiocarbon chronologies once reliable offsets from the global marine reservoir (Reimer *et al.* 2013) can be established. To overcome these issues at Caution Bay, and enable the development of high precision, well-constrained, multi-date sequences, we have undertaken a two-step process to our chronological model-building. First, we developed species-specific marine reservoir [ΔR] corrections for shellfish and urchins specifically for Caution Bay; and second, we used Bayesian techniques to evaluate the radiocarbon data according to observed contextual associations and established understanding of ^{14}C outliers.

Caution Bay Marine Reservoir Corrections

Caution Bay forms part of an open coastline, well-washed by ocean waters, without the upwelling or eddy disturbance typically caused by a fast-flowing current or impingement on this current (Petchey *et al.* 2013). Although the hydrographic diversity of the bay suggests a regime, and therefore regional ΔR value, in keeping with the South Pacific Gyre and water circulation in Torres Strait generally (Petchey *et al.* 2008; Ulm *et al.* 2007), there remains a very real possibility that shellfish reservoir values will vary depending upon habitat and feeding mechanisms of the animals (cf. Hogg *et al.* 1998; Keith *et al.* 1964). The coastline itself is underlain by limestone bedrock and fed by the Lea Lea River as well as a number of small rivers, and although wave scour and tidal currents remove much of this material from the bay, larger particles are laid down on the intertidal flats (Rowe *et al.* 2013) providing a range of enriched and depleted ^{14}C sources to coastal marine animals. To establish species-specific ΔR values for this area, a total of 78 shells belonging to herbivores, suspension feeders and deposit-feeding shellfish and Echinoids – all common throughout the excavated middens – were selected from XU6-XU16a in Square C of Bogi 1, an archaeologically short duration dense shell midden deposit. ΔR results were calculated by comparing the shell ^{14}C results with dates on charcoal with a maximum 1-year lifespan from these same XUs (charred fruit, nut endocarp and culm) (for details see Petchey *et al.* 2012, 2013).

The results of this research are summarized in Figure 9.18 and indicate that suspension feeding bivalves *Gafrarium* and *Anadara* can be reliably dated following the application of a suitable ΔR. *Gafrarium* spp. tended to have slightly depleted ^{14}C signatures (ΔR = 60 ± 11 ^{14}C years) relative to the South Pacific Gyre average of 6 ± 21 ^{14}C years (Petchey *et al.* 2012), that is indicative of high intertidal estuarine habitats at risk from terrestrial carbon interference – in particular ^{14}C from ancient limestone. More surprising was the enrichment of suspension-feeding *Anadara granosa* shells relative to *A. antiquata*. Isotope values for *A. granosa* (average ΔR = -71 ± 15 ^{14}C years) were influenced by the ingestion of enriched terrestrial carbon sources, in keeping with this species' preference for sandy mud bordering mangrove forest. Conversely, *A. antiquata* had an average ΔR value (-1 ± 16 ^{14}C years) closer to the global marine average,

Figure 9.18. Recommended species-specific ΔR for Caution Bay marine shells (adapted from Petchey et al. 2012, 2013).

Shellfish/Echinoidea	Diet	Average ΔR (^{14}C years) for Species	Average ΔR (^{14}C years) for Genera	Habitat	Isotopic Influence
Batissa violacea	Suspension Feeder	-207 ± 28	-	Associated with rivers.	BRACKISH
Polymesoda erosa	Suspension Feeder	-154 ± 23	-	Landward side of the high intertidal area.	
Cerithidea largillierti	Deposit Feeder	-55 ± 159	-	High intertidal, in mangroves.	ESTUARINE
Gafrarium tumidum	Suspension Feeder	67 ± 16	60 ± 11	High intertidal.	
Gafrarium pectinatum		53 ± 16			
Anadara granosa		-71 ± 15	-39 ± 22	Mid-intertidal to marginally sub-tidal.	
Anadara antiquata		-1 ± 16			MARINE
Echinoidea	Omnivore	11 ± 17		Low intertidal/sub-tidal fringe.	
Conomurex luhuanus	Herbivore	13 ± 31	-	Intertidal and shallow sub-tidal to ~10m depth. On sand, rubble and seagrass bottoms.	MARINE/ESTUARINE
Laevistrombus canarium		156 ± 72	-	Intertidal and sub-tidal to ~55m depth. On muddy sand and algal bottoms.	
Gibberulus gibberulus		31 ± 37	-	Intertidal and shallow sub-tidal to ~20m depth. On sand and seagrass bottoms.	
Canarium labiatum		63 ± 20	-	Intertidal and shallow sub-tidal to ~20m depth. On seagrass and algal bottoms.	
Canarium urceus		55 ± 34	-	Intertidal and shallow sub-tidal to ~40m depth. On seagrass bottoms and sand.	
Euprotomus aurisdianae		70 ± 42	-	Low intertidal and shallow sub-tidal to ~10m depth. On seagrass bottoms and sand.	
Lambis spp.		71 ± 53	-	Shallow sub-tidal to ~5m depth. On sand and mud – various.	

reflecting a preference for sandy-gravels, seagrass beds and shallow-lagoon bottoms (Afiati 2007: 105; Broom 1985: 4-6). Surprisingly, omnivorous echinoids also had an average ΔR (11 ± 17 ^{14}C years) close to the global marine average, but these animals cover a wide range of environments and further work is needed to fully assess the reliability of this genera for ^{14}C chronologies, although results so far show it to be reliable for this part of Caution Bay.

The ΔR values for the herbivorous gastropods were typical of animals living at the boundary between the marine and estuarine environments, though they tended to show more variation than the suspension-feeding bivalves because of the potential to ingest sediment

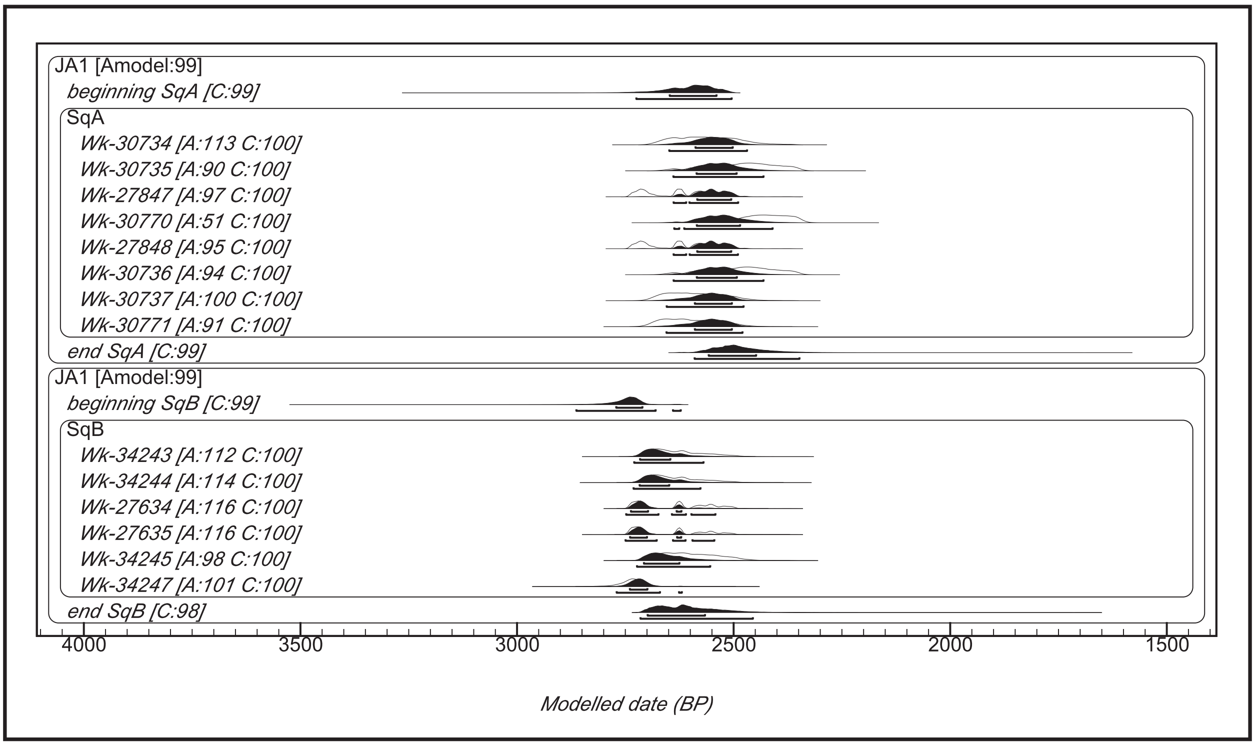

Figure 9.19. Example from site Ataga 1 (AAVM) of an OxCal multi-plot showing the 68.2% and 95.4% probability age ranges as outlined in the text.

while they graze (Figure 9.18). As with the suspension-feeders, specific habitat choice also had an impact on carbon content of the herbivores, with those animals displaying a preference for muddy substrates being most variable. Two outliers were immediately apparent – *Laevistrombus canarium*, which had an elevated average ΔR (156 ± 72 ^{14}C years), and *Conomurex luhuanus* with lower average ΔR values (13 ± 31 ^{14}C years). *L. canarium* has a preference for muddier substrates (Coleman 2003; Carpenter and Niem 1998) whereas *C. luhuanus* prefers sandy environments. We therefore considered *C. luhuanus* to be more reliable for the development of the Caution Bay chronology and utilised this species when necessary. The least reliable shellfish studied were *Polymesoda (Geloina) erosa* (average ΔR = -154 ± 23 ^{14}C years) and *Batissa violacea* (average ΔR = -207 ± 28 ^{14}C years), both of which had a significant terrestrial ^{14}C input related to their tolerance of brackish waters, and *Cerithidea largillierti* which displayed more variation than all other shellfish combined (individual ΔR values range between -287 ± 36 and 223 ± 36 ^{14}C years). We recommend that careful consideration of dietary and environmental conditions are made before *Polymesoda* and *Batissa* spp. shellfish are dated. We do not consider Ceriths suitable for ^{14}C age determination.

For the Caution Bay sites, the most specific ΔR value was applied in calibration procedures – i.e., where a radiocarbon sample was identified to species, the species-specific ΔR offset was applied. Where radiocarbon samples could only be identified to genus, the genus average ΔR offset was applied and so forth.

Chronological Model-Building

To refine the chronological interpretation of the Caution Bay sites we have also utilized Bayesian statistical methods integrated into the program OxCal v4.2.2 (Bronk-Ramsey 2009a, 2013) whereby ^{14}C ages are constrained by prior information such as stratigraphic sequence and archaeological provenance. Radiocarbon dates are grouped within phases (i.e., samples belonging to random scatter of events in no particular order) and each phase is arranged within a sequence separated by a boundary that provides an estimated transition date. The program then calculates how successfully the ^{14}C measurements conform to this prior knowledge and narrows down the calibrated age ranges according to the assumptions that compose the stratigraphic model (cf. Bronk-Ramsey 2009a). The overall model is assessed by the calculation of an agreement index (A_{model}) that measures/evaluates how well the model agrees with the observations. If A falls below 60% (equivalent to the 5% level of a χ^2 test), the model should be re-evaluated (Bronk-Ramsey 1995). This methodology enables us to better define the age of onset, end and duration (span) of a site.

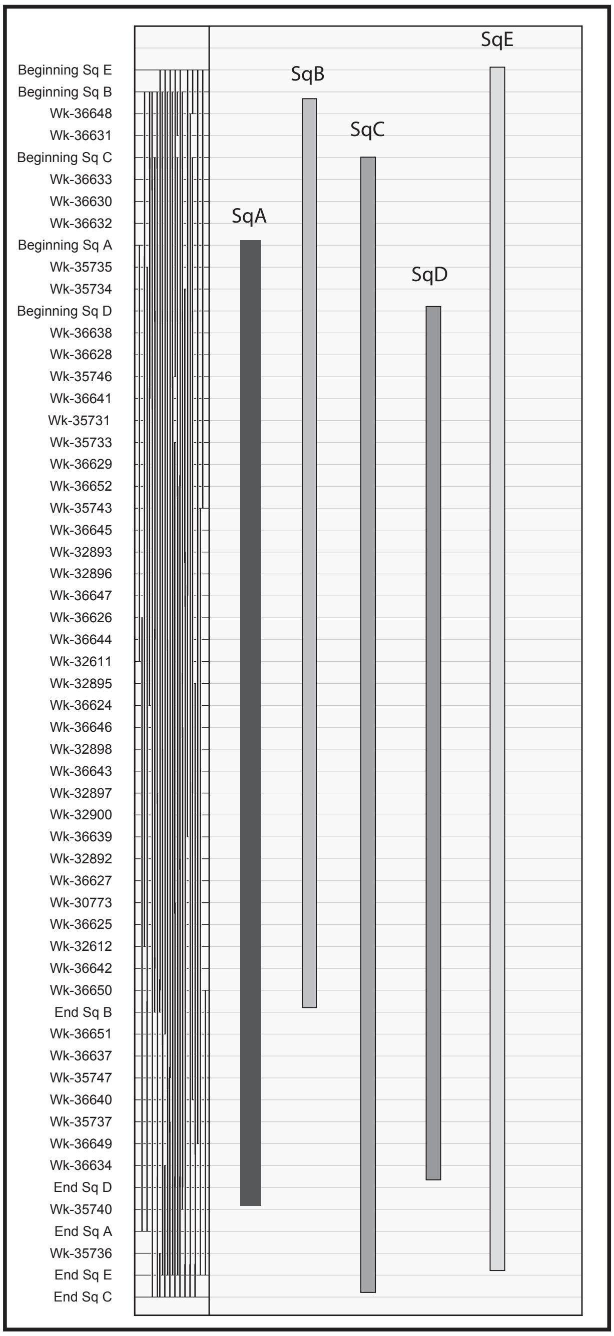

Figure 9.20. OxCal model schematic showing the overlapping phase model for site Nese 1 (AAWA).

For some sites (e.g., Nese 1, Ataga 1, and Tanamu 3) we have relied on the dominance of shell determinations to arrive at a model-averaging approach that does not require the few charcoal samples dated to be identified to short-lived materials. However, at others (e.g., Tanamu 1 and 2), because of the large number of charcoal dates, we have opted to apply an outlier correction as described by Bronk-Ramsey (2009b). The correction factor employed is based on the prior knowledge that the plants used could have come from long-lived taxa such as are found in rainforest settings, and applies the following formula: (Exp(1,-10,0), U(0,3),'t') whereby the exponential distribution runs from -10 to 0 with a time-constant of 1, ensuring modification only to those charcoal determinations that are older. The shifts are then scaled by a common scaling factor that can lie anywhere between 0 and 1000 years.

We have variously presented the results in two ways. Multi-plots of the calibrated data illustrate the 68.2% and 95.4% probability calibrated age ranges, whereby the outline distributions show the calibrated ages for each individual sample and the solid black distributions show the calculated ranges when applying the Bayesian model (Figure 9.19). The model agreement index is shown at the top left of the diagram. Alternatively, we have displayed the dates in the form of the model schematic, which provides a visual representation of the Bayesian model applied and gives an indication of how we have interpreted the archaeological information (Figure 9.20).

Other Analyses

In addition to the analyses described above undertaken for almost every excavated site from Caution Bay, there are also important studies of more limited scope in progress by other collaborating scholars. These include several lines of research at the University of Otago: temper and clay sourcing on ceramics and obsidian sourcing under the supervision of Glenn Summerhayes; technological analysis and raw material sourcing of adze and axe blades by Anne Ford; human skeletal analysis by Hallie Buckley; and aDNA analysis of human, pig, dog, and commensal rat remains led by Lisa Matisoo-Smith.

Finally, a number of student research projects involving Caution Bay material have been completed or are in progress, including BA Honours, MA and PhD theses focusing on certain aspects of stone artefacts, ceramics or molluscan remains at Monash University, the University of Papua New Guinea, the University of Southern Queensland, the University of Otago, and the University of Wollongong. The results of these research projects will be included with the relevant site reports, but some may also be published as stand-alone studies.

Concluding Comments

The above procedures and methods are the standard practices employed for the analyses reported in detail for each of the Caution Bay sites and will not be repeated in the forthcoming monographs, although variations on these methods will be remarked on where relevant.

In all specialist analyses presented in the forthcoming site reports, descriptive results for each square at sites with multiple squares are presented separately, with raw data presented by XU, and many items illustrated with drawings and photographs. This was done to provide a lasting chronicle of these sites and to allow future researchers the opportunity to independently assess and use the data for their own investigations. In each case, however, we conclude with spatial and chronological trends, and other patterns, for each site, or occupation period within a site. Wider trends and conclusions are discussed at the end of each monograph according to its research theme(s).

The results of the Caution Bay project represent a rare opportunity for the Asian-Pacific region, to study in great detail cultural trends that consider large numbers of sites at a regional landscape scale. These results now offer an opportunity to investigate what has taken place in a region when Lapita settlers arrived in an already-populated land-and-seascape, and how those community connections developed through time into the ethnographic period. This, too, represents a unique situation in Pacific archaeology, one that we begin to unfold by telling archaeological stories that revolve around explicit data presentation systematically documented through this monograph series.