– ARTICLE –

The Cult of the Birdman: religious change at ʻOrongo, Rapa Nui

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ABSTRACT

On the island of Rapa Nui the Cult of the Birdman reflected a very visible expression of political competition and co-operation at the island-wide level. This paper synthesizes recent archaeological and chronological information for the cult's central site – ʻOrongo, in order to document the temporal shift in ideology from an emphasis on lineage autonomy to a more integrated leadership. While Rapa Nui was experiencing internal pressures from the loss of arable land and territory reconfiguration, brought on by soil nutrient depletion and limited rainfall, we hypothesize it was only the events associated with repeated European contact that were sufficiently disruptive to initiate rapid social change at the collective level. One social response was a realignment of ideological values represented by the formation of the Cult of the Birdman. The first activities at ʻOrongo, occurred during the early AD 1600s. Activities intensified near AD 1800 possibly due to the negative impacts of European contact and it is hypothesized that stone house construction occurred at this time.

Keywords: Rapa Nui, cult, Birdman, radiocarbon dating, religion, ʻOrongo

INTRODUCTION

The short prehistory of Rapa Nui began with Polynesian colonization of an ecological context untouched by humans. This event occurred around AD 1100–1300 (Hunt and Lipo 2006, 2011; Mulrooney *et al.* 2011; Wilmshurst *et al.* 2011) and prehistoric use of the landscape persisted until the combined effects of European slave raiding and disease almost completely eliminated the indigenous population by AD 1864 (Metraux 1940; Routledge 1919). Between these two temporal end points, the small founding population is estimated to have grown rapidly in the first few centuries (Stevenson 1984). Slash-and-burn techniques cleared the coastal palm forest by AD 1450 (Mieth & Bork 2003) and groves in the higher elevations by the early 17th century (Horrocks *et al.* 2015). Within these cleared areas, agricultural field systems were established in both near-coastal and the more remote upland locations on Maunga Terevaka (Mulrooney *et al.* 2013; Stevenson 1997) (Figure 1). This agricultural system based principally upon sweet potato, taro, and yam, grown within rock gardens (Wozniak 1999; Stevenson *et al.* 2006; Horrocks and Wozniak 2008; Horrocks *et al.* 2015), supported the development of eleven regional chiefdoms (Stevenson 2002) represented by centrally located ritual centers positioned at coastal locations. Costly megalithic architecture in the form of large platform complexes, statues, and elite dwellings characterized these central places which expanded in size and elaboration soon after settlement.

Previous research has argued that 17th century prehistoric Rapa Nui experienced significant ecological problems such as landscape erosion created by rapid deforestation (Meith & Bork 2003) that may have reduced agricultural productivity and led to violent internal conflict amongst the regional chiefdoms (Flenley & Bahn 2002; Van Tilburg 1994; Vargas *et al.* 2006). A more recent consideration of the problem indicates that soil degradation was restricted to the steeper slopes at locations on Poike, Rano Kau, and Maunga Terevaka (Mieth & Bork 2012) and may not have had the devastating impacts to farming once proposed. However, recent geomorphological investigations also show that in the middle 17th century a change in land-use occurred as people relocated out of drier areas on the western slopes of the island and abandoned the higher elevation field systems of the interior (Mulrooney 2013; Stevenson & Haoa 2008; Stevenson *et al.* 2015). New paleoecological evidence has also emerged that argues for a generalized drought lasting from *ca.* AD 1570–1720 that may have favored the Rano Kau water source (Cañellas-Boltà *et al*. 2013; Rull 2016).

These newly identified regional shifts in settlement have been identified as a response to variation in rainfall and biogeochemical landscape constraints coupled to nutrient depletion from rainfall leaching and farming, which eliminated the elevated island interior from production.

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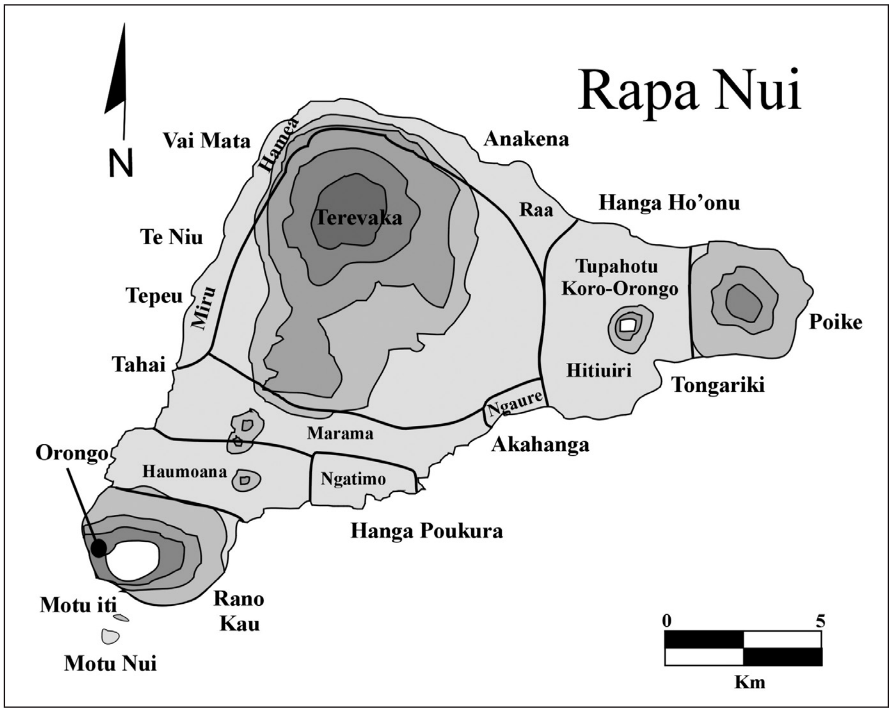

Figure 1. Map of Rapa Nui with places mentioned in the text and the limits of ethnohistoric territories redrawn from Routledge (1919).

This reduction in arable land may have had significant consequences for many of the regional chiefdoms and could have reduced their ability to feed lineage members, to invest in ritual and feasting, and to fund public architectural construction and expansion. These circumstances also had the potential to push the Rapanui to reassess their political institution and the religious system that supported it, yet the interpretation of the archaeological record and early contact literature now favors a political and social continuity during prehistory (Rainbird 2002; Mieth & Bork 2012; Hunt & Lipo 2011; Boersema 2015) instead of a devastating societal collapse (Diamond 2005; Flenley & Bahn 2002).

On the heels of this developing context, Dutch navigators made brief contact with Rapa Nui in AD 1722. Over the next 140 years Rapa Nui was often visited as a re-supply point for water and fresh produce by whaling vessels and explorers that resulted in a modest exchange of European trade goods (Richards 2008). The impacts of this early contact activity on the Rapanui world view and health are difficult to gauge but representations of European sailing ships are found in petroglyphs, as stone burial tombs (*ahu poepoe*) (Shaw 2000), and as earthwork replicas (Métraux 1940; Stevenson & Haoa 2008). Decisive and documented demographic reductions do not occur until the early AD 1860s when slave raiding and disease decimate the population (Boersema 2015).

It is possible that a number of social and technological responses may have emerged within this context of extended internal agricultural adjustments and unforeseen external stresses from European contact. These responses may have included a reconfiguration of lineage territories (Shepardson 2005), new farming strategies that reflected the landscape biogeochemical structure (Vitousek *et al.* 2014), a redistribution of population (Stevenson *et al.* 2015), and the emergence of a greater emphasis on competitive leadership ideology based upon ritually driven competition. This last social dynamic is characterized by the emergence of the Birdman Cult.

The Birdman Cult has been viewed as a pre-European contact development based upon archaeological investigations that place its emergence in the middle 16th century (Ferdon 1961; Flenley & Bahn 2002) and scholars have speculated that it may have been a component of ancestor worship that focused on the megalithic statues (*moai*) (Van Tilburg 1994; Boersema 2015) while others have raised the possibility of the cult being a post-contact innovation (Pollard *et al.* 2010). In this paper, we evaluate chronometric data from the investigations conducted by Ferdon (1961) Cristino (1995), and Orliac & Orliac (1996) and conclude, based on the current evidence, that activities at 'Orongo originated before European contact in AD 1722 but intensified in the last part of the 18th century. Identifying the beginning of the Birdman Cult in the archaeological record serves as a proxy indicator of the period when Rapa Nui was experiencing a social reformation and was looking for a new ideological pathway and leadership alternatives that crystalized after contact with European navigators.

PREHISTORIC SOCIOPOLITICAL CONTEXT

The prehistoric political system of Rapa Nui is inferred to have been a hierarchical chiefdom with its roots in Ancestral Polynesian Society (Kirch 2000). Settlement pattern analyses of megalithic platforms (*ahu*) and residential dwellings (McCoy 1976; Stevenson 1986; Stevenson & Haoa 2008) have revealed spatially demarcated central places and inequalities in house architecture that reflect social ranking (see Morrison 2012 for an alternate interpretation). These platforms, and their associated statues, were first built soon after island settlement (Wallin *et al.* 2010) where they grew in size and architectural complexity at central locations. The largest *ahu* are few in number and were often positioned at the location of shallow bays that provided easier access to the ocean. It is hypothesized that these structures were commissioned and produced by corporate groups, or allied descent lines, that marked ritual precincts (Stevenson 1986). Chiefs and priests lived directly inland of them (Wallin *et al.* 2010). Lesser ranked individuals lived near their fields in loosely assembled hamlets stretching inland from the *ahu* (McCoy 1976; Vargas *et al.* 2006; Stevenson & Haoa 2008). Between the larger monuments many smaller versions of *ahu* proliferated and are interpreted to be constructions of individual lineages or sodalities (Stevenson 1986).

All of the statue-bearing monuments are presumed to have been dedicated to the ancestors; thus suggesting an established political system that had major connections to a religious system that defined a chief's descent from an ancestral line. Archaeological survey of *ahu* at the regional or island-wide level (Englert 1948; McCoy 1976; Stevenson 1986; Martinsson-Wallin 1994) documents uniformity in the form of architectural components (e.g., platforms, plazas, crematoria) and similar building materials (e.g., tuff, scoria) that reflect cooperation in economic exchange, but expressions of an integrated governance, or paramountcy, at the regional level has not been discovered archaeologically or reported in the ethnohistoric oral history. The largest *ahu* on Rapa Nui located at Tongariki is a potential candidate for the residence of a paramount chief but there are no recognized material expressions of an elevated leadership role at present.

A partial understanding of post-European contact Rapa Nui sociopolitical structure also comes from the documentation of oral traditions of 20th century descendants interviewed by Routledge (1919) and Métraux (1940). These informants state the population of Rapa Nui was divided into ten tribes along lines of paternal descent. According to Métraux, each of these tribes had a common ancestor who was descended from Hotu-matua, the first 'king' of the island (Métraux 1940: 121). The tribes initially occupied specific geographic areas on the island and relied on descent and kinship affiliation. There was a loose dichotomy of lineages grouped together: those in the northwest and west of the island were called the Tu'u, or *mata nui*, and the eastern lineages were the people of Hotu-iti, or *mata iti* (ibid: 124). This dual division separated groups based on rank where the Tu'u were high-ranking groups and the Hotu-iti low-ranking. Lee (1992) argues that the dual division was fueled by intertribal alliances and warfare, and Métraux takes the stance that the two groups were "two antagonistic confederations of tribes fighting for the hegemony of the entire island" (Lee 1992: 14; Métraux 1940: 125). While evidence of warfare is inferential and difficult to place (often people cite *mata'a* obsidian tools as weapons [Flenley & Bahn 2002]; when they are fairly ambiguous as such [Hunt & Lipo 2011; Lipo *et al.* 2016], this dual division was likely a late development in the wider sociopolitical trajectory of the island.

PERIPHERAL CULTS AND IDEOLOGICAL CHANGE

On Rapa Nui, the Cult of the Birdman is thought to represent a significant change in the form of leadership. The prehistoric political structure on the island recognized the legitimacy of chiefly authority based both on their descent from the founding ancestors of the island as well as from the gods themselves (Métraux 1940: 130). The *ariki-mau*, or chief, was seen to possess *mana,* a type of supernatural power that separated him from the commoners and legitimized his leadership role. Coupled to this were other key concepts found throughout Polynesia such as honor (personal integrity, virtue), *tapu*, and *aloha* (Fienberg 2002). The first two concepts further reinforce the status of the leader while *aloha* is a reciprocal form of deference where the chief recognizes the needs and of the people in his lineage during decision making and the lesser ranked persons recognize his authority through gift giving. The maintenance of genealogical title and effective leadership requires the integration of all three aspects.

The achievement and maintenance of authority is however constantly under evaluation by those with similar aspirations. Contrary to the rigid models of ranked societies (Sahlins 1958) the achievement of leadership in hierarchical society can be flexible. Fienberg's (2002) discussion of the Anutan chieftanship (Solomon Islands) indicates that the personal attributes of expertise, wisdom, perception, physical strength, and generosity can be the foundation for an aspiring leader when exhibited in the context of weakness, or inaction, of a current chief.

Assuming that Métraux is correct, the Cult of the Birdman took advantage of the idea that people, not directly descended from the gods, could also increase their own level of personal *mana*. Every year, the selected Birdman was considered to possess an elevated level of *mana* not because of his genealogical position, but because the god *Makemake* chose that particular man as a physical manifestation of himself for the year (Metraux 1940: 336) based upon his success in the competition to acquire the first egg of the sooty tern.

Participants in peripheral cults are often not those of lower social rank, but rather 'a class of socially mobile people whose ambitions are at odds with their traditional obligations' (Lewis 1975: 131). Routledge (1998: 260) described the cult participants as 'men of importance'. Métraux (1940: 333) interpreted this as the category of *matatoa,* the warrior, of which only dominant, victorious tribes took part in the quest for the egg and the attendant ceremonies, for 'the privileges at stake were too important to be vested in an inferior or defeated group'. The *matatoa* were socially mobile; although they already held the political responsibility for leading the lineages in day-to-day activities, they could never be higher than the chief. The cult's emphasis on the annual finding of the first egg highlighted a basis in achievement as ordained by the god *Makemake*. Through such a ceremony, the *matatoa* found a way to compete with each other, as well as to live with a level of supernatural *mana* comparable to the chief, if only for a year.

Lewis (1975: 130) proposes that religious movements that involve direct spirit possession arise as peripheral cults to central religions. Such central religions are usually characterized as rigid and dogmatic, removing religious experience from people and placing it in the control of expert priests. Peripheral cults arise as a mechanism for individuals in society to practice agency and to react to changing circumstances when the central religion has become too rigid in its dogma to react appropriately to an unstable situation. Such cults often become means to social and political change and are a perceived avenue to liberation, and represent a wholly new ideology that may be directly opposed to the central religion and which have their origins in 'intrusive external pressures' (Lewis 1975: 157).

We propose that contact with Europeans beginning in the early 18th century resulted in pressures in both the psychological and biological domains that over several generations led to a post-contact distress that was addressed through a change in ritual practice. Boersema (2015) provides a concise summary of the contact events which start with the killing of 12 Rapa Nui on the shore of the island by the crew of Captain Roggeveen in 1722. Subsequent visits by the Spanish in AD 1770 (Gonzalez), the English in 1774 (Cook), the French in 1786 (La Pérouse), and two English whaling vessels are without major incident, except for the wounding of a person with a musket by one of Cook's crew (Thomas & Berghof 2000).

After AD 1806 the frequency of contact events was increasing and the Rapa Nui were now hostile to European visitors (Boersema 2015: 131). This was reinforced as a result of forced kidnapping of islanders by the American schooner *Nancy* under the command of J. Crocker. In 1821 the sexual abuse of women and a shooting injury of several persons by the crew of the vessel *Pindus* aggravated the situation. The Rapa Nui were increasingly wary of each new encounter and while barter continued over the next 40 years the vast majority of it occurred in small boats offshore (Boersema 2015).

It appears from the navigator accounts that interactions were welcomed until approximately AD 1806 when an abrupt change in Rapa Nui attitude arose and Europeans were met at the shoreline with a shower of stones. We hypothesize that this reversal of attitude reflects the period when biological pathogens began to seriously impact the health of the population who inferred (correctly) that the illness must have come from the outsiders. While syphilis has been identified in an individual from near this time period (Owsley *et al.* 1994), we are of the opinion that a broad scale epidemic of another easily transmitted disease such as pneumonia, smallpox, or tuberculosis was likely behind this new hostility. Hunt and Lipo (2011) suggest the first major disease outbreak was brought by the Spanish in AD 1770 and the aftermath was witnessed by Captain Cook four years later. There is no other information at present to support the Spanish role in disease transmission, but nevertheless, the known world was now falling apart and we propose a solution was sought through isolationism and the restructuring of leadership. The Rapa Nui site of 'Orongo may represent a material manifestation of this process and we look at the archaeological record to determine if the activities used in the Birdman ceremony fit into the post-contact historical time line.

ARCHAEOLOGICAL CONTEXT AT 'ORONGO

The archaeology of 'Orongo has primarily focused on the extraordinary proliferation of petroglyphs found at this site high upon the slope of Rano Kau, the volcano at the southwestern edge of Rapa Nui (Figure 1). Nowhere else on the island has such a high frequency of Birdman depictions – 'Orongo has 86% (~413) of the 481 iterations of the birdman motif found on the island (Lee 1992: 66). Clearly, 'Orongo had a special role in the prehistory of Rapa Nui. An analysis of the site with respect to the wider prehistory of the island will illustrate how 'Orongo's role changed over time in response to the changing conditions of the island's society.

Edwin N. Ferdon (Ferdon 1961) was the first to systematically excavate and formally record the archaeology of 'Orongo, although some initial record-taking was done by Palmer (1870), Pinart (1878), Geiseler (1883), Thompson (1889), Agassiz (1889) and by Katherine Routledge (1920) during her ethnographic research on the island in 1914–15. Mulloy (1975) followed up with additional detailed descriptions of the house complex and the methods of construction prior to their restoration and Horley and Lee (2009) have described the painted images within the house interiors.

Ferdon (1961) divided 'Orongo into three main sections: Complex A, 'Orongo Village (Complex B), and Mata Ngarau (Complex C) (Figure 2). Due to its lack of a local name, Complex A had fallen out of knowledge until it was uncovered at the time of the Ferdon's excavation in the mid-1950s (Lee 1992: 131; Ferdon 1961: 251). These sites

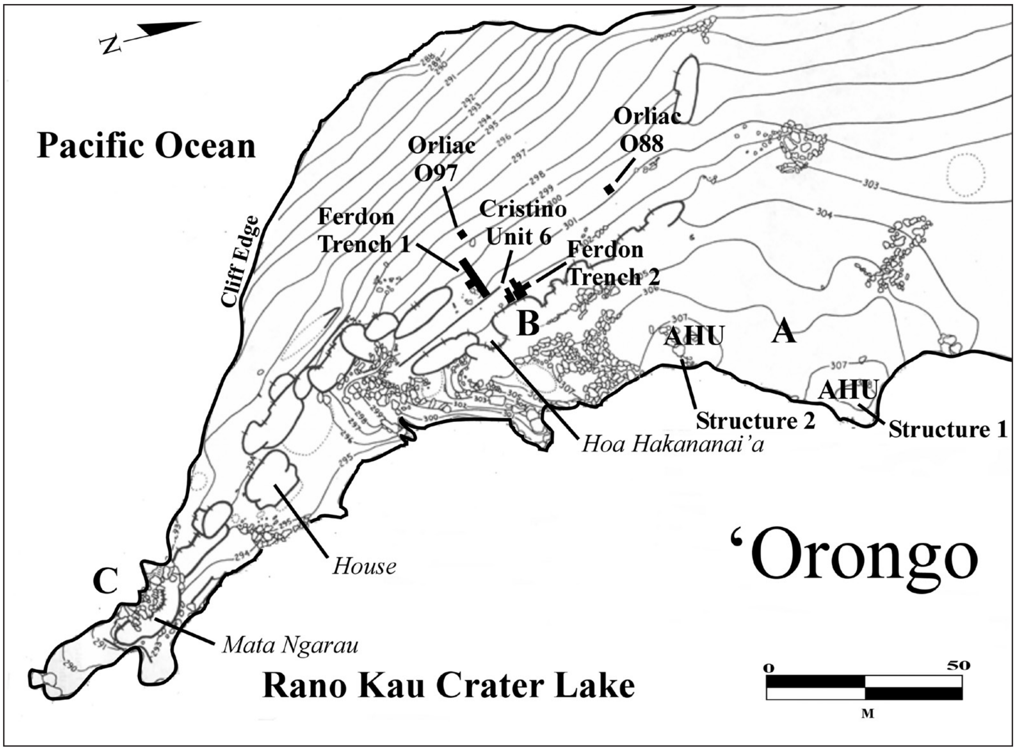

Figure 2. The ʻOrongo ceremonial center with stone house locations and complexes A, B, and C noted (adapted from Mulloy 1975).

combined together form the whole ceremonial complex of ʻOrongo – but individually they tell a story of religious change.

Complex A

Ferdon's excavations at Complex A revealed a large plaza, two structural foundations, and a number of petroglyphs depicting the god *Makemake*. He argues that this section of ʻOrongo was occupied first and is associated with the deity of *Makemake* and pre-Birdman ceremonies. In relation to the other complexes of the ʻOrongo village, Ferdon states that Complex A was abandoned around AD 1420 based on radiocarbon date (540±70 BP, T-193, Table 1) taken from a sample of charcoal in a fire pit in front of Structure I (Ferdon 1961: 248). Recalibration of this date (Stuiver and Reimer 1986–2011) derived from bulk charcoal with a potential in-built age is not so specific and defines a 2-sigma age range of AD 1300-AD 1617.

The two structures of Complex A are foundations of *ahu* platforms. Structure I has a boulder pavement leading up to the platform, and behind it is a pit within which the remains of a child were found (Lee 1992: 132). Structure II is a slightly raised platform on the margin of a plaza that has some highly weathered images of *Makemake* and birdmen. In addition to the two structures, a supposed solstice marker was positioned in front and west of Structure I. The stones of the solstice marker are adorned with crude petroglyphs depicting faces. The faces are associated with *Makemake*. On one boulder leading up to Structure I, however, Ferdon (1961: 231) noted a *Makemake* face with a much more sophisticated petroglyph of a Birdman superimposed upon it.

ʻOrongo Village – Complex B

ʻOrongo Village is characterized by two rows of about 55 houses, all facing southwest, and constructed with large tabular slabs of basalt (Figure 2). One house, called R-13 by Ferdon, was once the site of the statue called *Hoa Hakananai'a* (Figure 3), a statue removed in AD 1868 by the H.M.S. *Topaze* (Van Tilburg 1992, 2006) and now on display in the British Museum (Routledge 1919). The house was built around the statue, which faced away from the ocean toward the rim of Rano Kau crater (Ferdon 1961: 234). Ferdon argues that rooms R-13, R-12, and R-14 were originally one large house, presumably to hold *Hoa Hakananai'a* (Figure 2).

Lee (1992) notes that petroglyphs are scattered around the houses on small boulders with a few in the houses themselves. All the Birdmen petroglyphs in the village were created in bas-relief, a later development from the initial practice of simply pecking the outline of the Birdman. *Komari* (female genetalia) symbols are more frequent at this locality and *Makemake* faces are also present (Lee 1992: 135). Ferdon (1961) argues that ʻOrongo Village was occupied after AD 1540 (see our evaluation below) as a place to live during religious ceremonies.

Table 1. *Summary of all known radiocarbon dates from 'Orongo, Rapa Nui. Shortlived samples consist of small twigs.*

Location	Lab No.	Sample	Year	B.P.	Cal 2 S.D.	Sample Type	Reference
Ahu 1 , Complex A	T-193	Charcoal	1960	540±70	1300–1617	No Data	Ferdon 1961
Complex B, Trench 1, L.1	K-506	Charcoal	1956	220±100	1426–1950	No Data	Ferdon 1961
Complex B, Trench 1, L.2	K-514	Charcoal	1956	380±100	1390–1820	No Data	Ferdon 1961
Complex B, Trench 1, L.4	K-520	Charcoal	1956	540±100	1270–1640	No Data	Ferdon 1961
Complex B, Trench 1, L.1	M-708	Charcoal	1957	100+200/−100	——	No Data	Ferdon 1961
Complex B, Trench 2, Facing B-C	T-194	Charcoal	1956	470±70	1320–1690	No Data	Ferdon 1961
O88, F	Beta-099347	Charcoal	1995	210±50	1640–1950	Shortlived	Orliac and Orliac 1996
O88, JA	Beta-099356	Charcoal	1995	200±50	1650–1950	Shortlived	Orliac and Orliac 1996
O88, 25/34 cm, D	Beta-099348	Charcoal	1995	30±80	1673–1954	Shortlived	Orliac and Orliac 1996
O97, 10 cm, L.1	Beta-099340	Charcoal	1995	130±60	1655–1950	Shortlived	Orliac and Orliac 1996
O97, 18 cm , L.2	Beta-099339	Charcoal	1995	250±50	1510–1880	Shortlived	Orliac and Orliac 1996
O97, 27/34 cm, A	Beta-099338	Charcoal	1995	100±70	1660–1950	Shortlived	Orliac and Orliac 1996
O97 30 cm, L.2	Beta-099337	Charcoal	1995	——	Modern	Shortlived	Orliac and Orliac 1996
O97, 41/58 cm, C	Beta-099335	Charcoal	1995	30±70	1680–1940	Shortlived	Orliac and Orliac 1996
O97, 45 cm, G	Beta-099336	Charcoal	1995	320±70	1440–1950	Shortlived	Orliac and Orliac 1996
OR.MNG.11	Beta-099341	Charcoal	1995	100±50	1670–1945	Shortlived	Orliac and Orliac 1996
OR.MNG.13	Beta-099342	Charcoal	1995	240±60	1510–1950	Shortlived	Orliac and Orliac 1996

Figure 3. The statue of *Hoa Hakananai'a*. (Drawings by C. Arévalo Pakariti, Easter Island; Copyright EISP, Jo Anne Van Tilburg), (Van Tilburg 1992, 2006).

Mata Ngarau – Complex C

Mata Ngarau is another section of 'Orongo with houses, somewhat spatially continuous with the 'Orongo village that were constructed in a semi-circle that faces the offshore islets associated with the Birdman ceremonies (Figure 2). Ferdon (1961) argues that Mata Ngarau, in addition to 'Orongo village, was occupied in AD 1540 after Complex A was abandoned around AD 1420. However, Lee (1992) writes that Mata Ngarau's petroglyphs are often obscured and covered by the masonry of houses, suggesting that the houses may have been an even later development.

The petroglyphs at Mata Ngarau are of high-quality, showing different steps of development for the Birdman motif from simple pecked forms that allowed for considerable graphic variation to a firmly established later canon of bas-relief depictions (Lee 1992: 140). Several Birdmen are shown frontally, with splayed legs and arms, yet the prevailing design is a profiled human crouching figure surmounted with a bird head. In one case, the classical profile Birdman is superimposed with a *Makemake* face carved in bas relief. The carvings of the Birdmen cover all available surfaces on the basaltic rocks of Mata Ngarau, featuring a remarkable degree of superimposition with *komari* designs (Lee 1992: 143). The *komari* is thus a later addition to the Birdman depictions.

ARCHAEOLOGICAL CHRONOLOGY OF 'ORONGO

The crater edge location, visibility, architectural distinctiveness, and ubiquitous petroglyphs at 'Orongo, made it a destination for 19th century European visitors but the site complex was not observed by the earliest explorers. Of the early navigators, only the physician of the La Pérouse expedition in 1786 climbs Rano Kau, and although geographically closer than any previous European visitor, the La Pérouse expedition does not verify the presence of ʻOrongo in the 18th century. It is not until nearly three-quarters of a century later that ʻOrongo is described by Palmer (1869), Pinart (1878), Geissler (1883), and Thompson (1891); and finally mapped by Routledge (1920). Modern scientific excavations are relatively few at ʻOrongo and we rely upon the investigations of Ferdon (1961), Orliac & Orliac (1996), and Cristino (1995) for primary radiocarbon and obsidian hydration chronological data. We link these few data to the test unit excavation profiles to assess the duration and intensity of site activities at ʻOrongo.

The Norwegian Archaeological Expedition Excavations

Edwin Ferdon excavated two test trenches in front of the houses in Complex B as part of the Norwegian Archaeological Expedition (Heyerdahl & Ferdon 1961) (Figure 2). Trench 1 was located about 6 m downslope of Room 14 (Ferdon 1961: Figure 67: 241 and Figure 2 here). Four recognizable levels were documented (Figure 4). Starting from the surface, Level 1 was a thick (20–30 cm) charcoal rich level with a lower stratigraphic non-conformity (Level 2) interpreted to represent a brief period of discontinued deposition. This rested on a hard grey-brown soil (10–20 cm thick) with yellow-brown subsoil inclusions interpreted to be an artificial fill layer (Level 3). This capped an earlier charcoal and soil midden (Level 4, 10–40 cm thick) which had accumulated on a yellow-brown, non-cultural horizon (Level 5).

The stratigraphy in Trench 2, located in front of the entrance to Room 12 (Ferdon 1961, Fig 68: 242) shared some similarities with Trench 1 and provided a context for the interpretation of the latter. Beneath a surface layer of post-occupational rubble (0–55 cm below ground surface) the excavators again revealed the same hard grey-brown artificial fill layer (15–25 cm thick) noted in Trench 1. The foundation of Room 12 rested upon this deposit and it was inferred that the fill layer was created to stabilize the surface immediately prior to room construction. Thus, the hard grey-brown soil in Trench 1 (Level 3) may have been an apron in front of the house or spoil from creation of the foundation. Beneath the fill layer in Trench 2, a dark grey soil (15–40 cm thick) with charcoal flecks covered a discontinuous loose brown soil that contained conical pits penetrating the subsoil. Ferdon interpreted the fill of these pits as originating from fine wind-blown sediments with charcoal from downslope locations. We now know that pits of this shape, and the fine sediments and charcoal particles within them, are characteristic of ancient gardening for the cultivation of tubers (Stevenson *et al.* 1999).

The abundance of charcoal from Trench 1 and Trench 2 provided sufficient material for the radiocarbon dating of bulk samples characteristic of the period (Table 1). Ferdon was able to bracket the time period for the emplacement of the compact house construction fill layer with a date from above the deposit in Trench 1 (380±100 BP, K-514) and a date from a charcoal deposit in a pit beneath the layer in Trench 2 of AD 470±70 BP, T-194). Based upon his interpretation of rapid site formation processes, he favored an AD 1540–1576 date for the emplacement of the fill deposit and the beginning of room construction in this area. However, the bulk samples of charcoal submitted for age assessment are not described in detail and are thus unreliable.

The Orliac Excavation

In 1995, Catherine and Michel Orliac made two small test excavations on the western sloping apron of the site located in front of the openings to the stone house entranc-

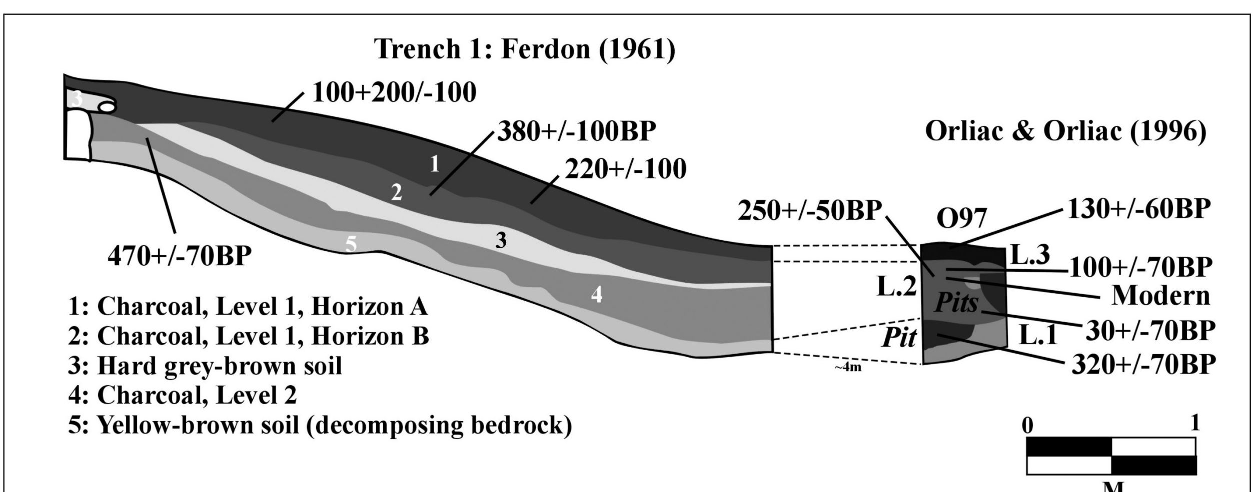

Figure 4. Trench 1 soil profile (Ferdon 1961) combined with the O97 east soil profile (Orliac and Orliac 1996). Location of Ferdon's radiocarbon dates are approximate.

es (Orliac & Orliac 1996). Test Unit O88 was positioned about 15 m WSW from the structure containing Rooms 3, 4 and 5 (Figure 2). The second test unit, O97, was located on the apron about 20 m WSW of Room 14 and about 4 meters west of the southwestern limit of Trench 1 excavated by Ferdon (1961). Test Unit O97 contained a recognizable stratigraphy consisting of midden deposits and Test Unit O88 contained midden and a fill layer associated with house construction activities as initially identified by Ferdon (1961). The midden deposits contained thousands of charcoal fragments and substantial amounts of marine, faunal, and artefactual specimens. Within Test Unit O88 were 7 mollusk shell fragments, 26 bird bones, 2 fish bones, and 29 pieces of obsidian, intermixed with 6257 charcoal fragments. Similarly, Test Unit O97 yielded 1147 mollusk fragments, 134 bird bones, 65 fish bones, and 153 obsidian flakes/fragments within a matrix containing 3959 pieces of charcoal. Also present in the test units were carbonized fragments of sweet potato (*Ipomoea battas*) along with two tentatively identified pieces of carbonized yam (*Dioscorea sp.).* The presence of food remains and obsidian flakes within a dense charcoal midden is indicative of activities that could have involved food processing and cooking.

Radiocarbon dates from the new excavations (Table 1) were on small twigs as noted by the excavators (Orliac and Orliac 1998: 4):

> Enfin les brindilles ont été préférées aux charbons de grande dimension afin de limiter "l'effet de réservoir" ; celui-ci peut être considéré comme nul dans les structures contenant un grand nombre de rhizomes de graminées/cypéracées, car ces derniers, ayant une durée de vie limitée à quelques années, ont été préférés pour les mesures.

The dating of the charcoal conducted by Beta Analytic was conducted prior to the botanical taxanomic study of this project, thus no species identifications are available.

Test Unit O88

TU O88 was a 50 × 50 cm square, 55 cm deep, and contained six recognizable stratigraphic levels (Figure 5). From bottom to top, the first stratum (L.1) was a yellow-ochre to chocolate brown silty loam of decomposing bedrock. This was covered by a charcoal rich 3–5 cm thick layer (L.2) with stone fragments of 1–5 cm in diameter. Above this was an argillaceous yellow-brown loam (L.3) interpreted by the excavators to have been deposited by either a strong erosive event or earthmoving associated with the construction of the stone houses. Resting upon this stratum was a thick deposit of charcoal rich loam with recognizable subdivisions (L. 4, 5, 7) based upon soil color and texture. At the surface was another brown-black to black 15 cm thick soil deposit (L.9) also rich in charcoal.

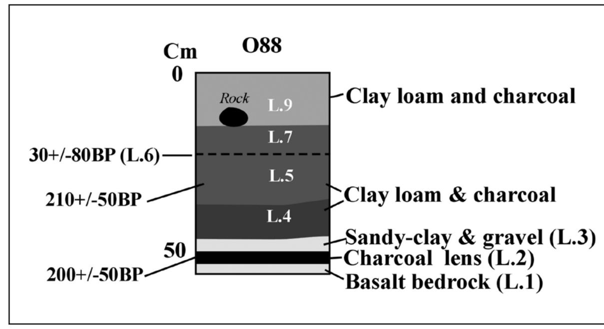

Figure 5. Test Unit O88 west soil profile (Orliac and Orliac 1996). Sandy-clay and gravel layer (L.3) represent evidence for the 'Orongo stone house construction.

Charcoal samples from three of the contexts were dated. A fragment from L.2 labeled O88-JA (Beta-099356) returned an age of 200±50 BP. Higher up in the profile from the thick deposit containing L. 4, 5, 7, a sample labeled O88-F returned an age of 210±50 BP (Beta-099347). The third date was from O88-D, a fragment from 35–34 cm below the surface in L.6; a strata present in the eastern profile sandwiched between the continuous L. 3 and L. 7 deposits. This sample was dated to 30±80 BP (Beta-099348). If the sandy-clay and gravel layer (L.3) has been correctly interpreted as the fill deposit associated with house construction, then the radiocarbon date of 200±50 BP from the sealed context below this layer suggests that the stone houses were constructed after this date (AD 1649–AD 1894).

Test Unit O97

TU O97 was another 50 × 50 cm square, 55 cm deep, excavation on the western site apron downslope from Room 14 and about 2 meters from the WSW end of Ferdon's Trench 1. We have tentatively linked the stratigraphy of TU O97 to that of Ferdon (1961) by comparing the two published soil profile descriptions (Figure 4). The eastern profile of TU O97 revealed three clearly defined strata plus several pit features.

The deepest layer (L.1) of decomposing basalt bedrock was a yellow silty-sand with numerous coarse fragments. Excavated into the bedrock sediment was the base of a pit 8–28 cm deep and filled with a brown silty loam soil. The pit was covered by a thin layer of small and thin rocks. Resting upon this surface was a 35 cm thick stratum of brown silty loam sediment (L.2) with charcoal fragments and aggregates of baked soil. Contained within the stratum were the remnants of small pits that had been excavated into the sediment but their upper extensions were contained entirely within the layer indicating they co-existed with the layer and were not intrusive to the deposit later in time. The upper-most layer (L.3) formed the surface deposit of the profile and was 15 cm thick. It was a compacted charcoal rich sediment with gravel, burned soil, and obsidian flakes.

The soil profile of TU O97 is very similar to that of the adjacent Trench 1 except for the absence of the compact grey-brown soil identified by Ferdon (1961) as originating from ground surface preparation for stone house construction; this layer gradually decreases in thickness and ends within the Trench 1 profile (Figure 5). The charcoal rich Layers 2 and 3 of Trench 1 can be provisionally matched to Level 2 in TU O97.

Numerous dates were processed from the TU O97 excavations. Near the deepest point in the test unit at 45 cm, a sample was dated from the L. 1 pit that penetrated the decomposing basalt bedrock. This sample returned at date of 320±70 BP (Beta-099336). A second sample was processed from Pit C (not shown) at a depth of 41/58 cm which was interpreted by the excavators to be stratigraphically linked to L. 2. This sample returned a modern date of 30±70 BP (Beta-099335). Higher up in the profile at a depth of 30 cm below surface, and within L. 2, a charcoal fragment was also characterized as Modern (Beta-099337). From the same context, the sample at 27–34 cm was dated to 100±70 BP (Beta-099338) and a sample from L.2 at 18 cm below surface was dated to 250±50 BP (Beta-099339). Lastly, a single charcoal fragment was selected from 10 cm below the surface in L. 3. This specimen dated to 130±60 BP (Beta-099340).

The radiocarbon dates by Orliac and Orliac (1996) are not stratigraphically consistent in Test Unit O97 and point to a mixing of the soil deposits, especially Level 2, where in addition to turbation, modern charcoal has also been introduced. It is therefore impossible to establish a time range for the midden within which there is posited evidence for room construction (Ferdon, Trench 1, L.3) in this part (Complex B) of ‘Orongo.

Mata Ngarau

A large pit feature located on the edge of the cliff was initially discovered and partially opened by Claudio Cristino, Universidad de Chile, in a small hand-excavation. A more complete excavation by Orliac and Orliac (1996) revealed the pit to be approximately a meter wide and 60 cm deep. It contained two major strata of charcoal rich soil containing bird and fish bones, fish scales, shell fragments and obsidian. Two radiocarbon dates from this unit returned ages of 100±50 BP (Beta-099341) and 240±60 BP (Beta-099342).

If the radiocarbon dates from Test Unit O88, O97, and Mata Ngarau taken as a group, with the modern dates eliminated, they suggest activity in front of the houses at Complex B and C occurred in the middle AD 1500s (Figure 6) but the majority of the age determinations (9 of 10) indicates that cooking/burning activities start near AD 1650 or later.

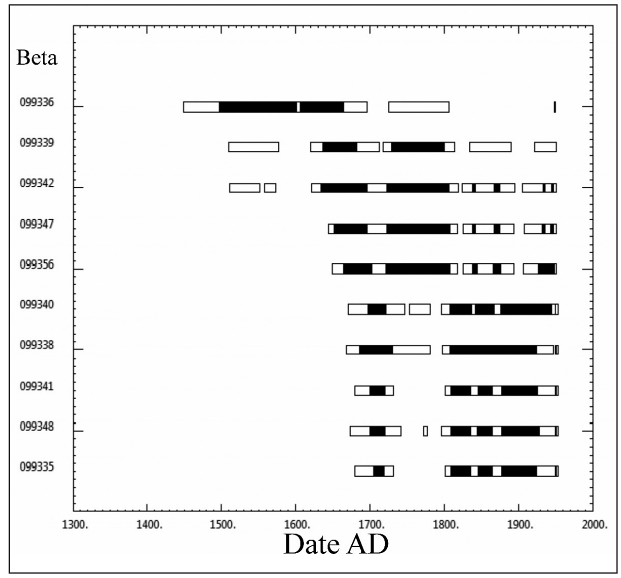

Figure 6. Probability distributions of radiocarbon dates from ‘Orongo (Orliac and Orliac 1996). The black bars represent 1-sigma ranges and the white bars 2-sigma ranges.

The Cristino Investigation

In 1994 a second restoration of the ‘Orongo house complex was undertaken by Claudio Cristino (Cristino 1995). As part of that effort a series of small test units were excavated to better understand the stratigraphy of the area. Obsidian samples from one of these units (Test 6) were made available in 2005 for optical hydration dating and the samples reanalyzed in 2014 to meet current standards for infrared spectroscopic analysis of the hydration layer (Stevenson *et al.* 2013).

Test 6 was a 2 × 2 m block excavation that was placed at the eastern edge of Trench 2 excavated by Ferdon (1961) and in front of the entrance to house R-13. It would have possibly shared the same stratigraphy. Test 6 was subdivided into four 1 m² units and a fifth unit of the same size was added to the southwestern side (Figure 2). The surface rubble layer of collapsed building debris encountered by Ferdon (1961: 242) was no longer present (Cristino 1995: Lamina 3) and excavations started at the modern ground surface. The units were excavated to sterile cultural deposits through the strata recorded by Ferdon (1961: 242, Figure 68). A stratigraphic profile from the excavation report is not available but we infer that the units would have consisted of the hard grey-brown fill soils upon which the house was constructed and an underlying loose dark grey anthropologic horizon with intermixed charcoal that extended to a depth of approximately 55 cm before decomposing bedrock was encountered.

Obsidian samples were selected at different depths for hydration dating (Table 2) and twenty-three samples were prepared for analysis (Appendix I). The obsidian dates from ʻOrongo range in age from AD 1608 to AD 1862 with associated errors of 23–35 years based upon a measurement error of ±0.007 infrared photoacoustic absorbance units. An additional non-quantified uncertainty comes from the borrowing of depth-sensitive soil temperature estimates of 21.2°C–22.1°C from data loggers on Maunga O'koro (250 masl) and their application to the higher elevation of ʻOrongo (300 masl). ʻOrongo could be slightly cooler and the use of a higher temperature will result in a faster hydration rate and age estimates younger than the actual age.

The distribution of dates (Table 2) did not show any clear increase in age with depth and indicated that prehistoric activity had resulted in a mixed deposit. This patterning indicates the simple stratigraphy exposed by Ferdon (1961) is not a reliable guide to the complex depositional history of this location. Therefore, the hydration dates were treated as a set of age determinations unrelated to the stratigraphic structure but reflective of the duration and intensity of activity at this provenience. A summed probability distribution of these values (Figure 7) shows a site occupational range of AD 1600 to the early 20th century and a bimodal distribution with peak usages of obsidian at AD 1653 and AD 1795. The second peak is much larger and suggests an intensification of activities using obsidian at the very end of the 18th century.

DISCUSSION

ʻOrongo played a role in ancestor worship on Rapa Nui, but it also played an even more centralized role in the pe-

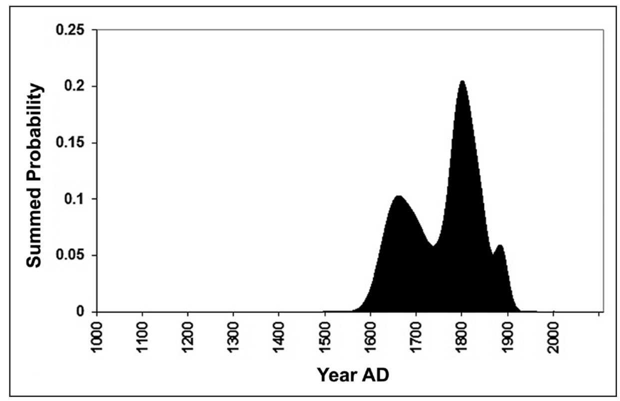

Figure 7. Summed probability distribution of obsidian hydration dates from ʻOrongo.

Table 2. *Obsidian hydration dates from Test 6, ʻOrongo.*

Lab No.	Provenience	Depth (cm)	Hydrated PAS 1630 cm^{-1}	Polished PAS 3570 cm^{-1}	Temp. °C	%OH	Date AD	S.D. Years
1-40/3	Test 6, Unit 1	−26	0.1453	0.1769	21.8	0.09	1702	30
1-P2/8	Test 6, Unit 1	−30	0.1084	0.1561	21.8	0.07	1830	23
1-40/29	Test 6, Unit 1	−53	0.1492	0.1608	21.2	0.08	1645	35
1-40/33	Test 6, Unit 1–2	−10	0.1230	0.1347	22.1	0.06	1771	27
1-40/12	Test 6, Unit 2	−20/−30	0.1222	0.1447	21.8	0.07	1776	27
1-P2/2	Test 6, Unit 2	−40/−50	0.0999	0.1438	21.2	0.07	1837	24
1-53-5b	Test 6, Unit 2	−60	0.1160	0.1609	21.2	0.08	1792	27
1-40/7	Test 6, Unit 3	−13	0.1244	0.1572	22.1	0.08	1774	27
1-53-1b	Test 6, Unit 3	−20	0.0919	0.1159	21.8	0.05	1862	23
1-53-4a	Test 6, Unit 3	−33	0.1139	0.1561	21.8	0.07	1810	25
1-P2/10	Test 6, Unit 3	−33	0.1060	0.1487	21.8	0.07	1831	24
1-40/26	Test 6, Unit 3	−54/−88	0.1525	0.1574	21.2	0.08	1633	35
1-40/28	Test 6, Unit 3	−57	0.1380	0.1416	21.2	0.07	1683	34
1-40/1	Test 6, Unit 3	−60	0.1534	0.1433	21.2	0.07	1608	37
1-40/16	Test 6, Unit 3	−60	0.1476	0.1423	21.2	0.07	1638	36
1-40/8	Test 6, Unit 4	−75	0.1160	0.1476	21.2	0.07	1782	28
1-53-2	Test 6, Unit 4	−75	0.1106	0.1482	21.2	0.07	1801	27
1-40/35	Test 6, Unit 5	−80/−90	0.1319	0.1492	21.2	0.07	1714	32
1-40/18	Test 6, Unit 5	−88/−107	0.1565	0.1537	21.2	0.07	1606	36
1-40/9	Test 6, Unit 5	−90/−123	0.1119	0.1416	21.2	0.07	1795	27
1-40/5	Test 6, Unit 5, F.1	−90/−123	0.1232	0.1487	21.2	0.07	1751	30
1-40/34	Test 6, Unit 5	−107/−126	0.1186	0.1307	21.2	0.06	1756	30
1-40/11	Test 6, Unit 5	−107/−126	0.1134	0.1289	21.2	0.06	1780	29

ripheral cult which later developed around the idea that *Makemake* manifested himself each year in a new Birdman. A determination of the beginning of the cult is central to understanding socio-religious development on Rapa Nui, but the more recent radiocarbon assays by Orliac and Orliac (1996) from the deposits in front of the stone houses leaves a great deal of uncertainty as a result of the broad 2-sigma age ranges. The activity identified *beneath* the cooking midden in the area of Complex B, as represented by Pit B with a radiocarbon date of 320+/-70 BP, gives a calibrated 2-sigma age range of AD 1449–1807 (Figure 6). Similarly, radiocarbon samples from within the thick midden deposits of Test Units O88 and O97 also have broad age ranges that begin in the early 17th century and extend to the early 20th century. The beginning of this age range for midden formation is much earlier than the date of *ca.* AD 1760 estimated by Routledge (1919) as the inception of the ceremony based upon compilation of the names of eighty-six previous birdmen contained within the oral history (Flenley & Bahn 2002).

In reconsideration of the archaeological context, the bulk of the stratigraphic evidence presented by either Ferdon (1961) or Orliac and Orliac (1996) do not demonstrably link the deposits to stone house construction. In Trench 1, Level 3, the inferred house construction fill layer of compacted grey-brown soil (Figure 5) is not stratigraphically connected to the house foundation observed in Trench 2. Similarly, the sandy-clay and gravel layer located low in the profile of Test Unit O88 is well removed from the stone houses and only hypothesized to be associated with house construction based upon the coarse nature of the deposit. In each case the connections are inferential and the deposits could have been created by other earth-moving activities or natural processes.

The obsidian hydration dates from the soil deposits in front of the houses offer a little more certainly about the activities at ʻOrongo because of their lower standard deviations, but they too are not linked to any construction event. The summed probability distributions indicated the beginning of activity at ʻOrongo near AD 1600–1650 and an increase in obsidian discard around AD 1800. This increased frequency of discard is assumed to reflect an intensification of burning/cooking and ritual activity and we hypothesize at this time that the ʻOrongo stone houses were constructed. The late-18th century spike in obsidian dates correlates with the use of ʻOrongo based upon the succession of leaders recounted in the oral history; a structure which reflects a formalization of the collective memory.

If the obsidian dates are representative of the occupational history of Complex B at ʻOrongo, then the creation of midden deposits created by food and charcoal discard begin about the same time as the abandonment of many upland agricultural fields in the middle and late AD 1600s (Stevenson *et al.* 2015) and near the mid-point of the island-wide drought (Cañellas-Boltà *et al.* 2013; Rull 2016). As a result, it is inferred the Rapa Nui may have experienced some compression of arable land and a reconfiguration of land holdings that changed from a radial pattern of coastal-inland lineage territories (Stevenson 2002) to a more coastal focus. The latter is approximated by the 20th century map of clan territories (Figure 1). In the social milieu brought about by these changes, it has been proposed that the Cult of the Birdman began to develop at ʻOrongo in response to internal ecological stresses of the period (McCall 1980; Flenley & Bahn 2002). However, Lewis (1975) notes that peripheral cults normally arise due to ʻacute social disruption' that interrupts the normal workings of a society. A renegotiation of lineage boundaries during this period suggests that Rapa Nui society was likely undergoing a disruption but was it acute enough to result in a peripheral cult? Based upon the currently available and limited radiocarbon and obsidian hydration dates, the archaeological record at ʻOrongo in Complex B and Complex C does argue for some type of collective activity emerging from longer term internal economic problems. But the construction of houses, as reflected by the inferred construction fill layer within the midden of Trench 1, occurred later in time. We propose this period came after the startling interactions associated with European and is reflected by the spike in obsidian hydration dates.

ʻOrongo's Complex A has an archaeological record that shows a heavy emphasis on the traditional ancestor worship religion in ancient Rapa Nui society. From petroglyphs depicting the face of *Makemake* to the structural foundation of an *ahu* platform, Complex A seems to be oriented to the worship and recognition of *Makemake*, the main deity of Rapa Nui and from whom the chiefs were said to descend (Métraux 1940: 311). Further, Ferdon argues that ʻOrongo's Complex A was only occupied up until AD 1420 and then abandoned in favor of ʻOrongo village and Mata Ngarau. The abandonment of Complex A and the use of ʻOrongo village and Mata Ngarau as ceremonial centers suggest a movement away from ancestor worship toward the Cult of the Birdman, although the timing of this shift now appears to be much later due to a more recent chronological assessment of activities.

A later emergence of the cult is understandable when placed into the wider sociopolitical context. Peripheral cults are often not completely separated from the larger society from which they originate: ʻthese movements are ultimately contained within wider, and in reality often pluralistic, worlds of which they are a part' (Lewis 1975: 127). It is possible that the statue *Hoa Hakananai'a* was once located at Complex A and later moved to ʻOrongo village. *Hoa Hakananai'a* is actually one of the only statues considered to be directly related to worship on the island; it was used for initiation rites for children as well as the feasts of the Birdman (Métraux 1940: 306, 335). Furthermore, the statue has both birdmen and *komari* motifs carved into its back, showing that it was being used in association with the Birdman Cult. This kind of re-appropriation of monuments usually associated with ancestor worship for Birdman iconography was a likely result of ancestor worship's failure to create an experiential component of religion that could react to the changing social pressures on the island.

When ʻOrongo's Complex A was abandoned, activities shifted to ʻOrongo Village and Mata Ngarau. The early stone architecture of this initial period, if any, is not known but planting pits and fire-related features were present. After activities at the site had been occurring for about 150 years (AD 1650–1800) it is our hypothesis that stone houses were then built, and the concept of the Birdman was formalized and depicted by petroglyphs. ʻOrongo's two lines of houses were said to be split by which tribes the participants came from; 'those from Hotu-iti dwelt in the western group of houses, and those from Tu'u in the houses to the east' (Métraux 1940: 335). Mata Ngarau was reserved for specialized *rongorongo* chanters, priests that chanted sacred lore and held specialized religious knowledge (Lee 1992: 138). The spatial division of ʻOrongo village and its separation from the new class of priests at Mata Ngarau may be evidence that the Cult of the Birdman at the time of house construction had attained a level of prominence in society that had taken over ancestor worship as the central religious form of the island. Add to this scenario an increased frequency of European contact events after AD 1800 (Boersema 2015) and the possible introduction of diseases by the Spanish in AD 1770, and the intensification of cult activities reflects the seriousness of new problems. Supportive evidence for a connection of historical events to changes in the society's material expressions prior to missionization comes in the form of burial tombs approximating the shape of European ships (e.g., *ahu poepoe*) (Shaw 2000) and the construction of earthen replicas of western vessels (e.g., *miro o'one*) (McCoy 1976; Stevenson & Haoa 2008).

CONCLUSION

Our analysis of the chronometric data from ʻOrongo suggests that the original temporal time line is later than previously determined. Radiocarbon and obsidian hydration dating of deposits in front of the stone houses indicates that middens found in association with an extensive petroglyph complex and stone houses did not begin until around AD 1600. The 16th century radiocarbon dates from the work of Ferdon (1961) likely stem from bulk charcoal samples with a large in-built age that made the assessments too early (Mulrooney 2013). Our results point to an intensification of site activities in the very late 18th century that may have included the construction of the stone houses. This sequence of events is in contrast to earlier archaeological reconstructions but is supported by the island oral history.

ʻOrongo's role as the site of a peripheral cult likely began when Complex A was abandoned and ancestor worship moved to ʻOrongo village. Birdmen petroglyphs were gradually added to the boulders at Mata Ngarau by creation/sponsorship/supervision by *matatoa* warriors interested in achieving greater status in the power void forming as people lost faith in their chiefs and religion. Gradually, these depictions became more skillful and more people began partaking in the associated annual competition to find the first sooty tern egg. Houses were built at ʻOrongo village and Mata Ngarau, and a new priestly class began to distinguish themselves from ordinary participants. Ancestor worship may have been gradually forgotten, as the deity of *Makemake* was incorporated more and more into the Birdman ceremonies.

The reasons for the cult emergence are not completely clear. We have hypothesized that the Rapa Nui underwent a territorial restructuring in response to soil nutrient depletion in the interior uplands, and a long dry period experienced by farmers, but we presently have no empirical data to connect this situation to the emergence of the Birdman Cult directly. While long-term economic problems may have been an impetus for early ritual activities at ʻOrongo, the intensive collective ritual behavior occurs well after European contact and may have been a response to the detrimental effects of pathogens possibly introduced by the Spanish in AD 1770 (Hunt and Lipo 2011).

Despite the many investigations and restorations of ʻOrongo we know remarkably little about the construction history of the complex, the types of rituals, the extent of food consumption, and the nature of daily activities that actually took place. This analysis shows that ʻOrongo was a dynamic place that expressed the Rapanui's changing view of the world but the emphasis on restoration and the lack of explicit and broad research questions has led to an undeveloped interpretation of the complex. This analysis has not been able to assign absolute ages to individual stratigraphic deposits, or house construction events, and thus the arguments are open to revision. Detailed stratigraphic excavations coupled to highly detailed recovery methods, additional obsidian dating, and materials analysis are now required to enhance our understanding of how ritual activities and world-view might have changed at ʻOrongo from late prehistory through the post-contact period.

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APPENDIX I: OBSIDIAN HYDRATION DATING METHODS

A dating sample was prepared by cutting each obsidian flake with a water-lubricated circular diamond saw which isolated a 3 mm × 3 mm hydrated surface area. The sides and base of the sample were polished to remove any old surfaces. The hydrated archaeological surface was measured for its diffused water content using a MTEC infrared photoacoustic accessory (IR-PAS). The infrared water band and at 1630 cm^{-1} was recorded on the spectrum output and its absorbance intensity (height) measured using a baseline tangentially placed to the peak minima. The magnitude of the absorbance intensity forms the basis for calculating the age of the artifact.

An obsidian hydration age is estimated using the Arrhenius equation:

$$K = A \exp E/RT \quad (1)$$

where: A is a high temperature diffusion constant or frequency factor ($absorbance^2$/day at 140°C), E is the activation energy in Joules/mol, R is the universal gas constant (8.314 Joules/mol), and T is the archaeological temperature in degrees Kelvin. The parameters A and E are predicted from the structural water content of the obsidian using the rate prediction equation of Stevenson *et al.* (1998). The structural water content (OH) was determined by subtracting the molecular water peak at 1630 cm^{-1} from the total water peak at 3570 cm^{-1} that represents a combination band for H_2O and OH (Table 2).

The ʻOrongo ground temperature was estimated by the monitoring of the soil matrix at 10 cm, 25 cm, and 50 cm below ground surface at Maunga O'koro (250 m), a location with nearly the same elevation as ʻOrongo (300 m) (Stevenson *et al.* 2015). These values are 22.1°C (10 cm), 21.8°C (25 cm) and 21.2°C (50 cm). Soil relative humidity can also reduce the hydration rate by a few percent. At depths of 10 cm and greater the %Rh of the soil is approximately 98% (Stevenson *et al.* 1993).

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