Rapid evolution of ritual architecture in central Polynesia indicated by precise ^{230}Th/U coral dating

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In Polynesia, the complex Society Islands chiefdoms constructed elaborate temples (*marae*), some of which reached monumental proportions and were associated with human sacrifice in the ʻOro cult. We investigated the development of temples on Moʻorea Island by ^{230}Th/U dating of corals used as architectural elements (facing veneers, cut-and-dressed blocks, and offerings). The three largest coastal *marae* (associated with the highest-ranked chiefly lineages) and 19 *marae* in the inland ʻOpunohu Valley containing coral architectural elements were dated. Fifteen corals from the coastal temples meet geochemical criteria for accurate ^{230}Th/U dating, yield reproducible ages for each *marae*, and have a mean uncertainty of 9 y (2σ). Of 41 corals from wetter inland sites, 12 show some diagenesis and may yield unreliable ages; however, the majority (32) of inland dates are considered accurate. We also obtained six ^{14}C dates on charcoal from four *marae*. The dates indicate that temple architecture on Moʻorea Island developed rapidly over a period of approximately 140 y (*ca.* AD 1620–1760), with the largest coastal temples constructed immediately before initial European contact (AD 1767). The result of a seriation of architectural features corresponds closely with this chronology. *Acropora* coral veneers were superceded by cut-and-dressed *Porites* coral blocks on altar platforms, followed by development of multitier stepped altar platforms and use of pecked basalt stones associated with the late ʻOro cult. This example demonstrates that elaboration of ritual architecture in complex societies may be surprisingly rapid.

Society Islands | temples | radiocarbon dating | seriation | social stratification

The coevolution of ritual and sociopolitical organization is a topic of theoretical significance in anthropology. The first emergence of formal ritual architecture (shrines and temples) is usually associated with the rise of complex chiefdoms and early states (1). In the Oaxaca Valley of Mesoamerica, a developmental sequence of ritual architecture has been traced archaeologically over 1,300 y (2). Here we present a contrastive case from central Polynesia, demonstrating very rapid elaboration of temple architecture in a highly stratified chiefdom society.

First contacted by Europeans in AD 1767, the complex chiefdoms of the Society Islands (Maʻohi) were among the most stratified and hierarchical in Polynesia (3, 4), incorporating populations estimated by early explorers to exceed 200,000 persons (5). Chiefs controlled intensive production systems based on irrigation and arboriculture (6). As in other complex chiefdoms and incipient states (1), Maʻohi economic, social, and political life was structured around an elaborate ritual calendar controlled by full-time priests. Ethnohistoric accounts describe ritual activities conducted on formal temples called *marae* (6–8). *Marae* consisted of a formal court, upright slabs or stones (frequently of prismatic basalt) representing deities, and in all but the simplest structures, an elevated altar platform (*ahu*) at one end of the court (9). *Marae* size and complexity correlated with the rank and power of the associated chiefs. *Marae* associated with the paramount chiefly lines were monumental, with stepped pyramid-shaped *ahu*. Ceremonies conducted at major temples required human sacrificial offerings to the war god ʻOro (7, 8).

Tracing the development of ritual architecture can provide key data on the evolution of Maʻohi sociopolitical formations, because *marae* offer an empirical index of complexity that can be directly traced in the archaeological record. More than 440 *marae* sites have been recorded throughout the archipelago (9–11). Direct dating of *marae*, however, has been limited to ^{14}C dating of charcoal or of sacrificial offerings (pig and human bone) from *marae* floor deposits or construction fill (12–14). Such radiocarbon chronologies are fraught with problems, including (*i*) the large error ranges on ^{14}C dates, (*ii*) multiple calibration intercepts affecting ^{14}C ages in the last 500 y, (*iii*) problems of "in-built" age derived from dating old wood, (*iv*) the incorporation of older charcoal into construction fill, and (*v*) reservoir effects on dated materials grown in marine environments. Calibrated radiocarbon dates from *marae* have associated uncertainties ranging from 40 to >250 y, limiting their usefulness for developing a fine-grained chronology.

Following U-series methods first applied to temple dating in Hawaiʻi (15), we applied ^{230}Th dating to *marae* on Moʻorea Island (Fig. S1), with the aim of developing a high-precision chronology of temple construction. *Marae* on Moʻorea incorporated various kinds of corals as architectural elements (1). In large *marae* near the coast, the *ahu* fill consists of heaped or stacked coral heads in the genera *Porites* and *Acropora* (Fig. 1). The lack of abrasion on the delicate *verrucae* of the *Acropora* branches indicates that the corals were collected while living, from the nearby lagoons and fringing reef (2). In both coastal and inland *marae*, *Porites* coral blocks were cut and dressed and incorporated into the front facings of *ahu* along with prismatic basalt dikestones. The inner faces of the coral blocks (in contact with the *ahu* fill) were left unworked, and their nonabraded surfaces again indicate that the corals were collected while alive. These *Porites* coral blocks range in size from smaller rectangular slabs *ca.* 20–30 cm wide, as at Marae Nuʻupure (Fig. 2), up to blocks exceeding 1 m in length, as in Marae Nuʻurua, the largest temple on Moʻorea Island (Fig. S2) (3). Fan coral heads of *Acropora* spp. were set on end to form part of the front facings of low, simple *ahu* platforms on a number of smaller *marae* in the interior valleys (Fig. S3). In addition, trimmed pieces of *Acropora* were placed on *ahu* of some *marae* in the interior valleys, apparently as offerings (Fig. S4). It is probable that the use of *living* corals was an ideological component of Maʻohi temple ritual. Given that coral heads were collected while living and rapidly used either as *ahu* fill or shaped into facing blocks, the *date of final growth* of the coral specimen should closely approximate the *date of construction* of the *marae* architecture into which the coral was incorporated, so long as (*i*) coral surfaces of near-zero age at the time of collection by the Maʻohi are preserved, and (*ii*) the ^{230}Th-^{234}U-^{238}U system in the coral has remained closed.

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Fig. 1. *Acropora* and *Porites* coral heads used as fill in the *ahu* of Marae Nu'upure. Arrow points to branch tips sampled for U-series dating.

Fig. 2. In situ cut-and-dressed *Porites* coral blocks forming a base course in the *ahu* façade of Marae Nu'upure, topped with a remnant row of pecked basalt cobbles. Note fill of whole coral heads behind the façade.

Results

Coral Dating. We obtained samples of coral architectural elements or offerings from three large coastal temples referred to as "royal *marae*" by Emory (9), and from 19 structures in the 'Opunohu Valley (Table S1). The 'Opunohu Valley was first comprehensively surveyed by Green (12, 16, 17) and is the subject of continuing archaeological studies (18–21). Fifty-six archaeological corals from 22 *marae* were dated via TIMS (thermal ionization mass spectrometry) U-series techniques similar to those used in our earlier study (15). U-Th methods are presented in *Materials and Methods*, and analytical data are available in Dataset S1. Table 1 provides a summary of the analyzed corals including preferred dates for *ahu*. Fig. 3 is a ranked plot of our preferred ages from each *marae*.

Multiple corals were dated from each of three large coastal *marae* (Nu'urua, Nu'upure, and Umarea) to assess the reproducibility of dates at each site. The dated samples were collected from either (*i*) intact heads of *Porites* or *Acropora* corals that were stacked to form the respective *ahu* (e.g., Fig. 1), or (*ii*) in one case, a cut-and-dressed *Porites* block from the *ahu* façade at Nu'upure (Fig. 2). In the coastal *marae*, only corals that preserved identifiable growth surfaces were sampled.

Dated corals from the coastal *marae* ($n = 12$) are visibly pristine on interior surfaces, and representative samples ($n = 4$) analyzed by XRD (x-ray diffraction) show no significant replacement of primary coral aragonite with secondary calcite (Table 1). These samples meet widely applied geochemical criteria for corals that are suitable for accurate U-series dating. That is, the corals from the coastal *ahu* have U ($\approx$2.4–3.4 ppm), common Th (^{232}Th, generally $\approx$100–500 ppt), and initial ^{234}U/^{238}U (activity ratios, 1.147 ± 0.007) that are similar to those of living or young, well-preserved shallow-water corals elsewhere in the Pacific (compare Table 1 and refs. 22, 23). Replicate analyses of these corals agree, in two out of three cases, within analytical errors (e.g., samples 91-A-1a and -1b, 92-Ba and -Bb, and 92-C-1a and -1b in Table 1). Sample 92-C-1b is discordant with respect to four other dates for Marae Umarea that are in mutual agreement; we infer that it may have been contaminated by older carbonate.

Dates for multiple corals cluster at each of the coastal *marae*. For example, five *Porites* heads from the *ahu* at Nu'urua yield a mean date of AD 1743 ± 4 y (Table 1; all errors 2σ), with no scatter beyond that expected from analytical uncertainties (i.e., mean square weighted deviation 1.5). At Nu'upure, three *Acropora* heads from the *ahu* fill and a cut-and-dressed *Porites* block from the *ahu* façade yield overlapping dates with a mean of AD 1761 ± 10 y. At Umarea, three heads of *Porites* and *Pocillopora* coral from the *ahu* fill yield a similar mean of AD 1761 ± 10 y (omitting a single discordant result).

The good agreement among coral dates at each *marae* supports the underlying assumptions of U-series dating of archaeological corals, namely that (*i*) the Ma'ohi harvested living corals to construct the dated *ahu*, (*ii*) coral carbonate of near-zero age (at the time of collection) has been preserved on nonworked coral surfaces, and (*iii*) the dated corals preserve closed ^{230}Th-^{234}U-^{238}U systems. In contrast, in the case of failure of one or more of these assumptions, the coral dates would be expected to scatter. It follows that the date of final coral growth (measured via U-series analysis of the outermost carbonate of the fossil corals) closely approximates the *construction ages* of the *marae* architectural elements into which the corals were incorporated.

In contrast to the corals dated at the coastal *marae*, mineralogical and geochemical properties of some (12 of 44) corals from the considerably wetter 'Opunohu Valley indicate that they may not be suitable for accurate U-series dating. Five *Porites* corals from the 'Opunohu were found to contain calcite in amounts ranging from $\approx$2–5%, indicating that primary aragonite has been partially replaced or in-filled by secondary calcite of younger age. Seven corals (mostly *Acropora*) were found to have anomalously low U concentrations relative to the range defined by other samples that we have analyzed from the same genus, suggesting that such corals may have lost U in either the marine or terrestrial environments. Finally, three corals have anomalous back-calculated initial ^{234}U/^{238}U ratios (defined as those outside of analytical uncertainty from the range of 1.147 ± 0.007, which is similar to that ratio in modern seawater; e.g., ref. 22). In all, 12 corals failed to meet one or more of the above geochemical criteria for reliability; accordingly, we consider their dates to be of uncertain reliability. The remaining 32 dated corals from the 'Opunohu Valley meet our geochemical criteria for reliable dates.

At *marae* in the 'Opunohu Valley, where we have dated multiple geochemically suitable corals, we generally observe good agreement among dates for cut-and-dressed blocks of *Porites* corals, although not for *Acropora* offerings (if present). At *marae* 125B, dates for three *Porites* blocks (sampled on their nonworked surfaces) are in excellent agreement, with a mean date of AD 1710 ± 4.2 y. In contrast, dates for three *Acropora* coral offerings collected from the same *ahu* yield older, scattered dates of AD 1605 ± 14, 1629 ± 7.3, and 1666 ± 5.9 y. We interpret the mean date of the *Porites* blocks as the date of *ahu* construction and note that some of

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Table 1. Summary of dated corals from Mo'orea *marae*

Location	Sample no.*	Genera	Form[†]	"Zero-age" surface present	Calcite (wt%)	Low [U]	Anom.[‡] ^{234}U/^{238}U	^{232}Th pg/g	Date (AD)	Error (y, 2σ)	Preferred date (AD)	Error (y, 2σ)
Coast, Nu'urua (Emory site 82)												
	82-A	*Porites*	1	Yes				147	1733	9.9	1743	4.0
	82-B	*Porites*	1	Yes				156	1747	11.0		
	82-C	*Porites*	1	Yes				117	1747	14.0		
	82-D	*Porites*	1	Yes				339	1743	5.7		
	82-E	*Porites*	1	Yes				236	1749	10.7		
Coast, Nu'upure (Emory site 91)												
	91-A-1a	*Acropora*	1	Yes	0.1			301	1767	6.1	1761	10
	91-A-1b							426	1763	6.3		
	91-A-2	*Acropora*	1	Yes	0.0			1,425	1753	11.9		
	91-B	*Acropora*	1	Yes	0.0			346	1746	8.4		
	91-C-2	*Porites*	2	Yes	0.0			497	1763	8.2		
Coast, Umarea (Emory site 92)												
	92-Ba	*Porites*	1	Yes				438	1766	6.0	1761	10
	92-Bb							217	1763	12.5		
	92-C-1a	*Porites*	1	Yes				178	1759	5.5		
	92-C-1b							165	1697	13.2		
	92-C-2	*Pocillopora*	1	Yes				329	1750	8.6		
'Opunohu Valley (ScMo-#)												
	105-1	*Porites*	2	Yes	0.0			280	1686	9.2	1686	9.2
	105-3	*Porites*	2	Yes	5.2			897	1736	18.9		
	106A-2	*Porites*	*2*	Yes	0.0			3,450	1726	18	1726	18
	106A-3a	*Porites*	*2*	Yes	0.0			404	1699	11		
	106A-3b							1,005	1659	15.1		
	106A-3c							2,152	1681	18.0		
	106J-3	*Porites*	2	Yes	0.0			4,237	1614	25.8	1633	25
	106J-4	*Porites*	2	Yes	0.0			3,411	1652	20.4		
	123B	*Acropora*	3	No	0.0	X		253	1617	9.4	1617[§]	9.4
	124D-1	*Porites*	2	Yes	1.9	X		223	1690	11.9	1690[§]	12
	124D-3a	*Porites*	2	No	0.0			879	1585	10.3		
	124D-3b							1,464	1574	11.5		
	124D-3c							2,928	1579	21.8		
	124 H-CS1	*Acropora*	4	No	0.0		X	116	1691	4.3	1691[§]	3.1
	124 H-CS2	*Acropora*	4	No			X	106	1690	4.8		
	124I-1	*Porites*	2	Yes	0.0			668	1687	14.3	1690	11
	124I-3	*Porites*	2	Yes	0.3			1,995	1694	16.3		
	124J-2a	*Porites*	2	Yes	0.2			866	1733	12.4	1723	16
	124J-2b							1,950	1726	21.4		
	124J-3	*Porites*	2	Yes	0.0			538	1713	7.7		
	124Q-2	*Porites*	2	Yes	0.0			420	1686	5.7	1686	5.7
	124S-1	*Porites*	2	Yes	4.7			764	1684	9.7	1694	27
	124S-2	*Porites*	2	Yes	0.0			4,258	1694	26.6		
	125A-2	*Acropora*	3	Yes		X		48	1637	19.2	1637[§]	19
	125B-1	*Acropora*	4	Yes	0.0			141	1666	5.9	1708	4.2
	125B-2	*Acropora*	4	No	0.0			256	1629	7.3		
	125B-3	*Acropora*	4	No	0.0			246	1605	13.5		
	125B-4	*Porites*	2	Yes	0.0			312	1710	9.2		
	125B-5	*Porites*	2	Yes	0.2			153	1706	7.5		
	125B-6a	*Porites*	2	Yes	0.0			84	1712	8.9		
	125B-6b							290	1707	9.0		
	125E-3	*Acropora*	3	No	0.0	X		71	1708	10.1	1708[§]	10
	125F-1	*Porites*	2	Yes	0.0			4,850	1706	30.0	1706	30
	125F-2	*Porites*	2	Yes	2.3			465	1711	12.0		
	125F-3	*Acropora*	4	No	0.0			44	1453	12.8		
	128–1	*Acropora*	3	Yes	0.0	X		138	1684	8.6	1684[§]	8.6
	144-I-1	*Acropora*	4	Yes	0.0	X	X	548	1637	17.5	1637[§]	17
	144J-1	*Acropora*	4	No	0.0	X		579	1634	17.4	1634[§]	18
	144L-2	*Porites*	2	Yes	0.0			1057	1737	16.4	1730	11
	144L-3	*Porites*	2	Yes	0.0			628	1724	15.4		
	144M-1	*Porites*	2	Yes	4.6			1,952	1662	8.9	1662[§]	8.9

*Sample numbers at coastal *marae* correspond to site numbering of Emory (9); sample numbers at 'Opunohu Valley sites correspond to numbering of Green and Descantes (17). Suffixes -a, -b, or -c denote replicate analyses of single coral.

[†] Form and architectural occurrence of dated coral: 1, head of *Porites* or *Acropora* stacked to form *ahu;* 2, cut-and-dressed *Porites* block (with nonworked inner faces) forming *ahu* façade; 3, "fan coral" head of *Acropora* set on end to form facade of *ahu;* 4, nonarchitectural offering of *Acropora* placed on *ahu.*

[‡] Anomalous initial ^{234}U/^{238}U activity ratio (i.e., ^{234}U/^{238}U ratio, back-calculated from ^{230}Th/U age, is not equal to 1.147 ± 0.007).

[§] Date is of low reliability, on the basis of geochemical properties of dated coral (i.e., calcite content, [U], and initial ^{234}U/^{238}U ratio).

the *Acropora* offerings do not preserve outer surfaces that would have had zero age at the time of collection by the Polynesians (Table 1). Thus, the *Acropora* offerings at *marae* 125B likely have some "in-built" age relative to the time of *ahu* construction.

Similar relations are observed at *marae* 125F. There, a *Porites* block yields a date of AD 1708 ± 10 y (concordant with the *Porites* dates from *marae* 125B), whereas an *Acropora* offering yields a much older date of AD 1453 ± 13 y. Such an age difference suggests that the *Acropora* offering was reused, having been moved to the *ahu* as elaboration of the *marae* progressed. Indeed, the analogous practice of taking "founder stones" from older temple sites when constructing a new temple is well documented in the ethnohistoric record (6, 8, 24). The hereditary titles of the chiefs who constructed the older *marae* were then bestowed on the new temple (8). We infer that similar practices were sometimes associated with the movement of coral offerings from earlier *marae* to later ones. At some *marae*, the only corals available for dating were *Acropora* offerings. In light of our results for such corals at *marae* 125B and 125F, we interpret their dates as providing only a maximum constraint on the age of construction of the associated *ahu*.

At other *marae* of the ʻOpunohu Valley where we have dated multiple *Porites* blocks that meet our geochemical suitability criteria (sites 106A, 106J, 124D, 124I, 124J, and 144L), the dates are in good agreement, consistent with our interpretation of such dates as the times of *ahu* construction. *Marae* 106A, 106J, and 124J, however, yield discordant dates for their *Porites* blocks and thus require further consideration. At *marae* 106A, three older dates ranging from AD 1659 to 1699 scatter; by elimination, the remaining date of AD 1726 ± 18 y is considered the best available date for *marae* 106A. At *marae* 106J, two *Porites* blocks yield relatively imprecise ages of AD 1614 ± 26 y and 1652 ± 20 y that scatter more than expected from analytical uncertainty; we adopt their mean age and an uncertainty that encompasses both dates, 1633 ± 25 y, as the preferred date for the *ahu* at *marae* 106J. At *marae* 124J, the mean date from two analyses of one *Porites* block, AD 1731 ± 11 y, is discordant with the date of a second block, AD 1713 ± 7.7 y; we adopt the weighted mean date and expand the error to account for excess scatter, yielding a preferred date of AD 1723 ± 16 y.

Radiocarbon Dating. We applied radiocarbon dating to four of the same *marae* dated by U-series, dating six charcoal samples obtained through test excavations in the *marae* courts or *ahu* fill (Table S2). Because the charcoal samples are derived from construction fill, there is a reasonable probability that the charcoal derives from human burning events on the landscape that predated the construction of the *marae* enclosures or *ahu*. Thus the ^{14}C dates should be taken as *terminus ante quem* dates for the structures. For site 124S, the ^{14}C dates suggest enclosure construction between calibrated (cal) AD 1396 and 1489. The 124S *ahu*, a later construction event based on stratigraphy, has a highest probability age of cal AD 1800–1940, which we reject due to the absence of postcontact artifacts. The second highest probability age of cal AD 1678–1765 is a reasonable estimate for *ahu* construction that accords well with our U-series age of AD 1694 ± 27 y. The single ^{14}C age of cal AD 1482–1666 for site 124H is from enclosure construction fill and again must be regarded as a *terminus ante quem*. The U-series age for the *ahu* at 124H is AD 1691 ± 3.1 y. Site 124J has a single ^{14}C age of cal AD 1455–1637 from enclosure construction fill. Our U-series age of AD 1723 ± 16 y from the *ahu* is as much as *ca.* 280 y younger, indicating that either the enclosure was an earlier construction event or the charcoal date reflects pre*marae* activities. Finally, we dated two samples from site 124T, a *marae* that lacks coral but that we included because it is an instance of an important architectural feature, the use of pecked basalt cobbles. The two ^{14}C ages from 124T are essentially identical (i.e., cal AD 1720–1826 from the *marae* enclosure fill and cal AD 1719–1826 from the underlying terrace). Both ages suggest that the use of pecked cobbles is a late phenomenon, in agreement with results from other *marae* using pecked basalt (24).

Seriation of Architectural Features. Temporal changes in *marae* architecture were independently assessed by applying occurrence seriation, an archaeological method for the relative chronological ordering of material phenomena (25–27). Originally applied to pottery, seriation has recently been used for architecture, including temple and house structures in Hawaiʻi and *marae* temples in the Society Islands (28, 29). In developing our *marae* seriation, we evaluated different morphological and architectural features of *marae* for their chronological sensitivity. Some features, such as the presence of an enclosing court, persist throughout the temporal sequence and are therefore not useful for seriation. The following features of *marae* are temporally sensitive: (*i*) the form of the *ahu*, a platform, or stepped (pyramidal form); (*ii*) the different architectural uses of corals, including *Acropora* veneers, shaped *Porites* blocks, or simple use of corals as offerings; and (*iii*) the use of pecked basalt cobbles in *ahu* facades or in enclosing walls. The latter architectural form was first described by Emory (9) and is associated with the rise of the ʻOro cult in late precontact times (8, 30).

Table 2 shows a best-fit seriation for Moʻorea *marae*, which maximizes the temporal continuity of the features described above and minimizes gaps. The seriation corresponds well with the progression of U-series dates, giving us considerable confidence in its validity. Indeed, only one site is out of order with respect to the U-series dates—site 128, whose date has been identified previously as of uncertain reliability.

Discussion

Emory (9) first proposed an inferred sequence of *marae* architectural development. His sequence began with simple structures lacking an enclosing wall, progressed to walled enclosures with raised *ahu*, and ended with a phase of elaboration of *ahu* with multiple steps. Green's more intensive survey (12, 16, 17) in the ʻOpunohu Valley compelled him to develop a new classification to accommodate the range of *marae* variation. Green (12) argued that most *marae* in the valley were "associated with the last major occupation of the locality and dated to the eighteenth century". In addition, Green proposed that the variation in *marae* types was a reflection of social change in late Maʻohi society: "[A]s Tahitian society differentiated and became increasingly stratified, *marae* types also proliferated to fulfill these new functions".

Wallin (10) synthesized data on *marae* across the archipelago, proposing a new typology of five major types, organized into a hypothetical developmental model. Type 5, with worked stones in the

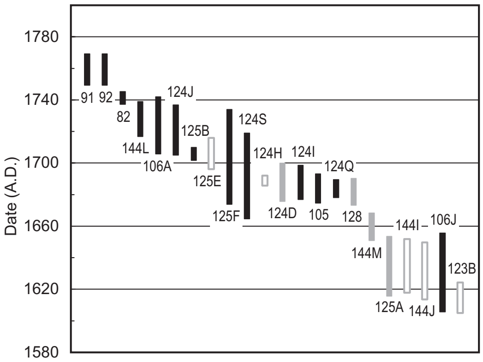

Fig. 3. Ranked plot of dates at each *marae* based on U-series ages of constituent corals; box heights are 2σ errors. Black boxes indicate dates for *ahu* construction of highest reliability; gray boxes indicate dates of uncertain reliability based on geochemical criteria; open boxes indicate dates for *Acropora* corals with possible in-built age at the time of *ahu* construction.

Table 2. Occurrence seriation of dated Mo‘orea *marae*

Site no./name	Platform *Ahu*	Stepped *Ahu*	*Porites* blocks	*Acropora* veneer	*Acropora* offering	Pecked basalt	Mean age AD
Umarea		■	?			■	1761 ± 10 y
Nu‘upure		■	■			■	1761 ± 10 y
Nu‘urua		■	■			■	1743 ± 4 y
ScMo-124J		■	■				1723 ± 16 y
ScMo-144L	■		■				1730 ± 11 y
ScMo-106A	■		■		■		1726 ± 18 y
ScMo-125B	■		■		■		1708 ± 4.2 y
ScMo-125E	■				■		1708 ± 10 y
ScMo-125F	■		■		■		1706 ± 30 y
ScMo-124S	■		■				1694 ± 27 y
ScMo-124H	■				■		1691 ± 3.1 y
ScMo-124I	■		■				1690 ± 11 y
ScMo-105	■		■				1686 ± 9.2 y
ScMo-124D	■		■				1690 ± 12 y
ScMo-124Q	■		■				1686 ± 5.7 y
ScMo-144I	?		■		■		1637 ± 17 y
ScMo-106J	■		■				1633 ± 25 y
ScMo-128	■			■			1684 ± 8.6 y
ScMo-125A	■			■			1637 ± 19 y
ScMo-123B	■			■			1617 ± 9.4 y

ahu, was seen as the final stage in this sequence. Recently, Wallin and Solsvik (13, 14) reported a suite of 23 ^{14}C dates from a *marae* complex at Maeva on Huahine Island in the Leeward Society Island. They concluded that *marae* construction at Maeva did not commence until approximately AD 1500. The large “national *marae*” of Mata‘ire‘a Rahi was first constructed no earlier than AD 1500–1550 and rebuilt between AD 1670 and 1820. The other large “national” *marae* of Manunu on Huahine dates to AD 1600–1650.

Our coral U-series and ^{14}C dates from Mo‘orea Island provide a precise, accurate chronology for construction of coastal “royal” *marae* and elaboration of *ahu* in the *marae* of the ‘Opunohu Valley. We draw several conclusions from this series of *marae* dates, combined with the architectural seriation. First, all of the *marae* incorporating coral in their structures fall within a period of just 140 y (*ca.* AD 1620–1760). To be sure, there are *marae* on Mo‘orea older than AD 1620. On the basis of an analysis of nine ^{14}C-dated ‘Opunohu Valley temples, Kahn (31) argues that simple platform *marae* lacking *ahu* were constructed *ca.* AD 1430–1530 and more elaborate *marae* with *ahu* by *ca.* AD 1400–1650. However, the late elaboration of *marae* associated with coral architectural elements occurred within a short time frame. Second, there was a clear progression of architectural development, as evidenced by the strong agreement between the occurrence seriation and the U-series dates. The earliest *marae* have low, simple *ahu* faced with a veneer of *Acropora* fan corals. This form was rapidly replaced with platform *ahu* of up to approximately 1 m high in which cut-and-dressed *Porites* corals were combined with basalt dikestones to form the *ahu* facing. The use of cut-and-dressed *Porites* blocks continued until European contact, with the largest blocks (up to 1 m or more in length) appearing on the large coastal “royal” *marae* of Nu‘urua and Nu‘upure. The most recent architectural forms were *ahu* with multiple steps and the use of pecked basalt cobbles in *ahu* or enclosure wall facings. These two features are confined to sites dating to the 18th century.

Conclusions

Throughout Polynesia, and indeed with complex ranked societies generally, the elaboration of ritual architecture accompanied increased stratification (2, 4, 31, 32). For Mo‘orea Island, we have demonstrated significant changes in temple architecture over a relatively short period of approximately 140 y, immediately before first contact with European explorers in AD 1767. The oldest temples in our dated series are relatively small and used only natural *Acropora* corals as facings in their low *ahu* platforms. In the mid-17th century a significant architectural innovation appeared—the cutting and dressing of *Porites* blocks to face *ahu* platforms, which were elevated up to approximately 1 m in height. There was also a trend for *marae* enclosures to increase in size.

The final stage in architectural elaboration occurred in the early part of the 18th century (*ca.* AD 1723 at *marae* 124J), with the appearance of stepped *ahu* and the first use of uniform-sized pecked basalt cobbles in *marae* walls. According to ethnohistoric sources, these innovations are associated with the rise of the ‘Oro war cult, which originated at ‘Opoa on the island of Raiatea, a ritual center in the Leeward Society Islands (6, 8). This cult was linked to new types of sacred regalia and religious rituals, most notably human sacrifice. Chants and genealogies indicate that ‘Oro was both a fertility god and a god of war who supplanted earlier deities of chiefly lineages to become the primary god of the ruling chiefs (7).

At the time of first contact with Europeans, Mo‘orea and Tahiti were engaged in a series of wars for hegemonic control. The huge *marae* of Maha‘iatea on Tahiti (Fig. S5), with 11 steps in its *ahu*, had been built just before Captain James Cook’s visit in 1769 (33). Our U-series dates from the three “royal” *marae* of Mo‘orea, also incorporating the stepped *ahu* form, indicate that such large temples were first constructed on Mo‘orea at approximately AD 1743 (at Umarea), with the two larger temples of Nu‘urua and Nu‘upure following approximately 20 y later. The construction of these massive temples, with their *ahu* reaching ever higher toward the heavens, was clearly an important part of the strategy of chiefly elite to gain favor with the gods and to assert their power and prestige over their people. The temporal sequence of *marae* development on Mo‘orea Island demonstrates how ritual architecture can be rapidly elaborated in conjunction with political competition and increasing stratification and hierarchy. Rather than a long and slow process of architectural change, as Emory first envisioned for Society Islands *marae*, these structures underwent rapid architectural innovation within a period of just a few generations.

Materials and Methods

Field Sampling of Coral Architectural Elements. We used Green’s survey data from the ‘Opunohu Valley (12, 16, 17) to identify temples with coral architectural elements or coral offerings. He identified 32 structures with coral elements, of which 29 are still extant, but 3 proved to have architectural elements constructed from beach rock rather than coral. Temple sites were located by global positioning system, mapped, and samples were photographed in situ. Samples were cut from coral heads or blocks with a portable Makita rotary saw and placed in sealed plastic bags. Samples were cut from branch tips of *Acropora* corals (where available) or from unworked outer growth surfaces of *Porites* coral blocks.

U-Series Dating of Corals. Internal pieces of coral were isolated by breaking, sawing, and abrading with a tungsten carbide bit. The pieces were cleaned by repeated cycles of ultrasonic treatment and rinsing in deionized water. Approximately 1 g of coral was dissolved in HNO_3 and equilibrated with a mixed spike containing ^{229}Th, ^{233}U, and ^{236}U. U and Th are separated using Fe-hydroxide precipitation, followed by two steps of anion exchange chemistry. Th fractions were reacted with perchloric acid to eliminate any organic compounds from the anion exchange resins. Purified U and Th fractions were loaded as a colloidal graphite sandwich onto single, out-gassed rhenium filaments. Isotopic analyses were done on a Micromass Sector-54 TIMS equipped with a wide-angle, retarding-potential energy filter and Daly-type ion counter. Mass discrimination for U was corrected using the known ^{233}U/^{236}U ratio of the spike, whereas Th ratios were not corrected for mass fractionation. Instrumental performance was monitored by frequent analyses of a secular equilibrium standard. Procedural blanks for ^{238}U, ^{232}Th, and ^{230}Th measured during the course of this study averaged, respectively, 1.3 ± 1.5, 17 ± 11, and 0.0017 ± 0.0008 pg. Coral analyses were corrected for ^{230}Th blanks, which are equivalent to $\approx$1 y of ^{230}Th in growth. Initial Th isotopes were subtracted assuming a ^{230}Th/^{232}Th atom ratio of $4.5 \pm 2.3 \times 10^{-6}$.

Radiocarbon Dating. All radiocarbon dates were run by Beta Analytic using the accelerator mass spectrometer method. Charcoal samples were identified to botanical taxon. Selected specimens include the relatively short-lived tree *Hibiscus tiliaceous*, the endocarp of candlenut seeds (*Aleurites moluccana*), and the endocarp of coconut (*Cocos nucifera*), thereby minimizing any inbuilt age due to old plant material. Conventional ^{14}C ages were calibrated using OxCal 4.1 with the IntCal09 atmospheric curve (34).

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