ARCHAEOLOGY

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New precise dates for the ancient and sacred coral pyramidal tombs of *Leluh* (Kosrae, Micronesia)

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Monumental tombs within ancient civilizations worldwide hold precious clues for deciphering the architectural skill, acumen, and industry of prehistoric cultures. Most tombs were constructed from abiotic materials—stone, soil, and/or clay, predominately—and were built to permanently inter royalty or high-status individuals. On the island of Kosrae in the central Pacific, monumental tombs were constructed with scleractinian coral and were confined to the prehistoric island capital of *Leluh*, where they served as temporary mortuary processing points. Like other prehistoric tombs, the *Leluh* tombs were dated by association—from the remnants of the temporarily interred. We present new dates for three sacred tombs using high-precision U-Th dates from 24 corals collected directly from the structural materials. The results suggest that the tombs were built about 700 years ago during the 14th century, about three centuries earlier than previously reported. The new dates redefine the peak occupation of *Leluh* and place its ruling paramountcy at the leading edge of the developing trans-oceanic political hierarchies, as well as the social and economic systems that dominated the civilizations in this part of the world.

INTRODUCTION

Monumental tomb structures dating back to 3500 BC provide an archive of the architectural styles and cultural practices of ancient civilizations (*1–3*). Most ancient tombs were built to permanently inter royalty and were constructed of locally and/or regionally available abiotic resources, such as limestone, granite, and clay (*2*), and are dated by association (*4*, *5*). On the central Pacific island of Kosrae (5°18′N, 162° 58′E), however, there is a singular exception (Fig. 1). The ruins of the prehistoric capital city of *Leluh* (~AD 1250–1850) (*6–9*) contain several royal tombs, called *saru*, that are uniquely characterized by the use of biotic material (scleractinian coral) in their construction.

Kosrae is the easternmost island in Micronesia (Fig. 1B) and has been a key landmark for Pacific mariners over the centuries (*10*). Recognized as one of the ancient twin capitals of eastern Micronesia, *Leluh* supported a complex hierarchical society that developed over the six centuries preceding European contact in the mid-18th century. At its peak, *Leluh* covered an area of about 270,000 m^2 and was home to ~1500 people, including kings (*Tokosras*), chiefs, and commoners (*8*) (fig. S1). Today *Leluh* is listed on the National Register of Historic Places, USA, along with the ruins of *Nan Madol* (*11*), its twin on the neighboring island of Pohnpei. The shared history of these sister ancient capital cities is most apparent in their distinctive architecture—both are sprawling cities of man-made islets, canals, and walled compounds built of prismatic basalt in a header and stretcher style (*7*) (fig. S2). However, the use of coral in the structures on *Leluh* is a fundamental difference between these two ancient capitals.

Unlike other more well-known pyramidal mortuary chamber structures that culminate in an apex and are permanently sealed (*1*, *2*), the pyramidal structures of *Leluh* were truncated, that is, a pyramidal frustum with a rectangular base, with a central crypt only accessible from above (Fig. 2). *Leluh* contains two royal burial complexes, *Insrūun* and *Insaru* (*8*) (Fig. 1C). *Insrūun* was destroyed by a typhoon early in the last century; however, the *Insaru* complex and three of its tombs or *saru* (*Lūrūn*, *Bat*, and *Inol*-1) remain intact (*8*) (Fig. 2). Historical accounts suggest that the corpse of a Kosraean king, anointed with coconut oil and bound in mats and colored cordage, would have been interred in the *saru* for up to 3 months. A house was erected over the *saru*, and all the chiefs mourned and presented offerings to the deceased (*12*). After this time, the royal bones were exhumed, cleaned, re-bound, and secondarily buried in a deep hole on the nearby reef (*8*). *Leluh*'s truncated pyramidal tombs were, thus, temporary processing points that served a key function after the death of a high-status individual (*13*, *14*).

Many aspects of precontact *Leluh* remain uncertain, including the chronology of tomb construction. It is speculated that the twin tombs of *Lūrūn* and *Bat* are roughly 400 to 600 years old and *Inol-1* is about 200 years old (*6–8*). The unique coral pyramidal tombs of *Leluh* present the opportunity to provide new dates for the age of construction on the basis of the biotic structural material. Hence, by using precise U-Th dating techniques, we determine the age of corals used in tomb construction to redefine the chronology of not only tomb construction but also the peak occupation of *Leluh*, and thus make inferences about the role that *Leluh* played in trans-oceanic political domination.

RESULTS

To estimate the construction ages, 47 coral samples were collected from three *saru*—*Lūrūn*, *Bat*, and *Inol-1* (Fig. 3, fig. S2, and table S1). In addition, living corals were collected as control samples. High-precision U-Th dating techniques (*15–17*) were used on the 24 corals that passed the screening tests for secondary calcite. The determined ages of coral deaths varied from 702.4 ± 6.5 to 1094.8 ± 5.4 years for *Inol*-1, from 691.1 ± 4.8 to 5717 ± 23 years for twin tomb 1—*Lūrūn*, and 625.6 ± 6.5 to 1036.8 ± 6.6 years for twin tomb 2—*Bat* (table S2). The wide age intervals of hundreds to thousands of years indicate that a mixture of live and fossil coral was used to line the crypts (Fig. 4), infill walls, and

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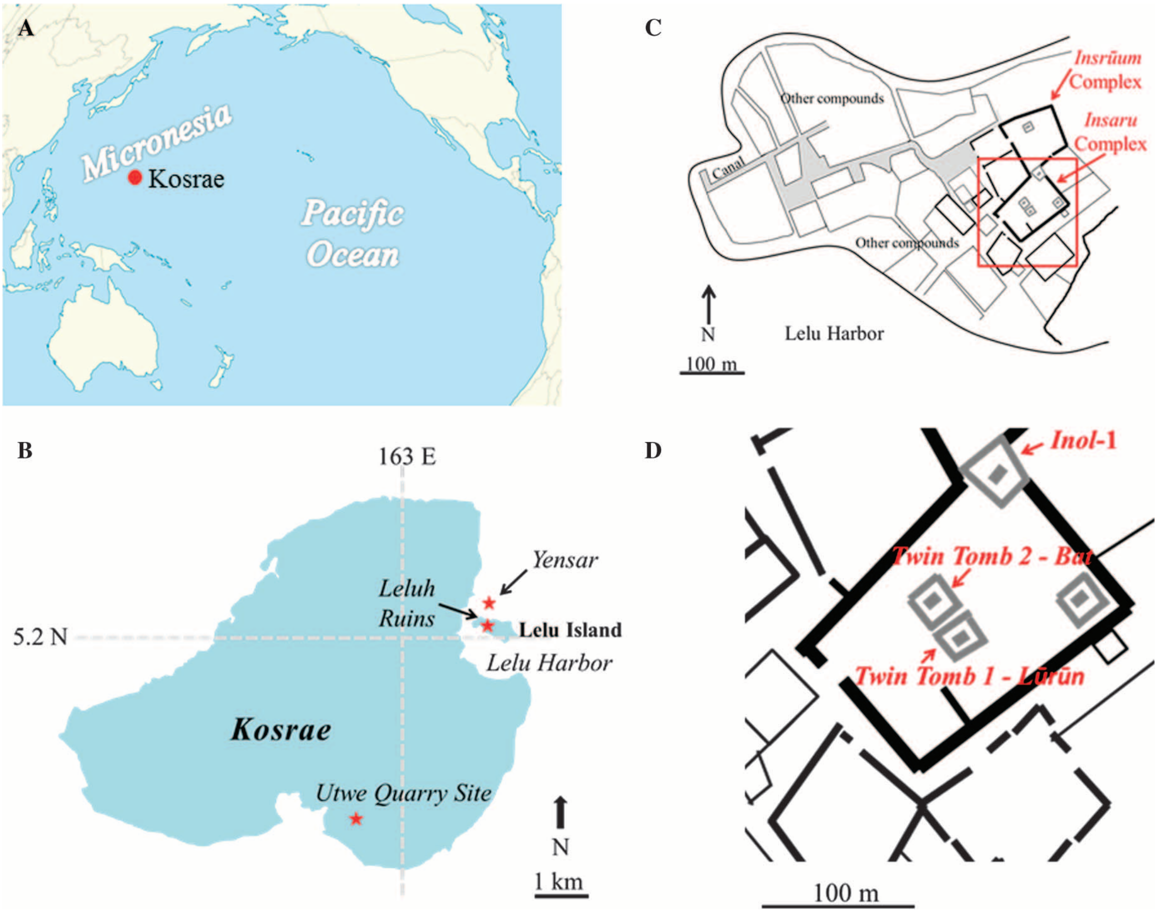

Fig. 1. Maps of Kosrae and Lelu Island. The ancient city of *Leluh* was built up as a man-made extension on the lagoon island of *Lelu* on the eastern side of Kosrae, Micronesia. (**A**) Location of Kosrae in the northwest Pacific Ocean. (**B**) Map of Kosrae with the *Leluh* ruins, located in *Lelu* Island. (**C**) General schematic of the ancient city of *Leluh* on *Lelu* Island. (**D**) An enlarged map of the selected area in *Leluh* [red square in (C)] with the three tombs examined in this study: *Inol-1*, twin tomb 1—*Bat*, and twin tomb 2—*Lūrūn*.

as facades. The determined minimum coral dates represent the possible oldest ages of *saru* construction as follows: *Inol-1* AD 1310.7 ± 6.5, twin tomb 1—*Lūrūn* AD 1322.0 ± 4.8, and twin tomb 2—*Bat* AD 1387.5 ± 6.5 (table S3).

The surveys along the facades of the three *saru* indicate that eight types (genera) of coral were used as tomb fascia (*Acropora*, *Favia*, *Favites*, *Goniopora*, *Hydnophora*, *Platygyra*, *Pocillopora*, and *Porites*; table S3). Observations within the crypts of the pyramidal tombs show that only two types of coral (*Porites* and *Platygyra*) were used to line the crypts. The largest number of coral colonies (but lowest diversity of coral types) was documented on the façade transects of twin tomb 2—*Bat*, which according to our coral dates was the last of the three *saru* examined to be built. Whereas a larger diversity of coral types was used as fascia on the older *saru*, that is, on *Inol-1* and twin tomb 1—*Lūrūn*, where a smaller quantity of colonies were counted (table S3).

To determine if the corals used in *saru* construction are a random subset of those corals available on the reef, we compared the diversity of corals used in construction with the proportional composition of the surrounding shallow reef community. On the contemporary reef, a total of 10,887 colonies were identified on 66 belt transects pertaining to 154 species of hard coral from 49 genera. Overall, the taxonomic composition of corals used in the tomb construction was not a proportional subset of the shallow (3 to 5 m) water live coral community on the surrounding reef (x^2 = 2487, df = 38, P < 0.0001). Even when the analysis was restricted to the 17 most common coral genera (each comprising more than 1% of the shallow water live coral community), the composition of corals documented in *saru* fascia did not reflect the surrounding live coral community (x^2 = 2674, df = 16, P < 0.0001). The contemporary coral reef community was dominated by the genus *Porites*, followed (in decreasing order) by *Acropora*, *Galaxea*, *Heliopora*, *Platygyra*, and *Leptoria* (fig. S3). These corals were used to construct the *saru* of *Leluh* (fig. S3); however, there were 37 genera present on the reef that were not recorded in the *saru* (fig. S4). These include *Diploastrea*, *Plerogyra*, *Pocillopora*, *Seriatopora*, *Turbinaria*, *Montipora*, *Pavona*, *Gardinoserus*, *Fungia*, and *Astreopora*.

DISCUSSION

The chronology of *saru* construction is still subject to speculation (*6*–*8*). All three *saru* examined here were excavated in 1910 (*18*). At that time, the tombs of *Lūrūn* and *Bat* were empty. These tombs were believed to be used as temporary processing sites. However, skeletal remains of a 50-year-old man and a dog and shell artifacts were found in *Inol-1*.

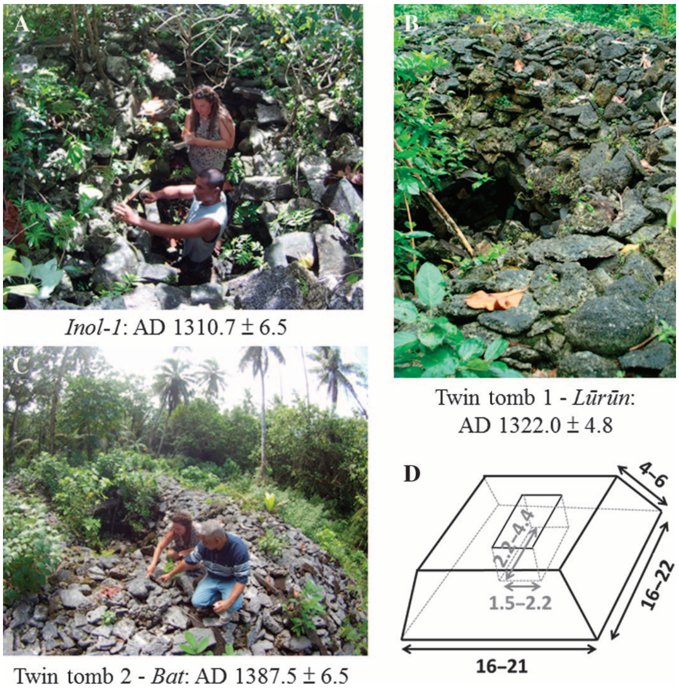

Fig. 2. Truncated coral pyramid tombs. (**A**) *Inol-1*. (**B**) Twin tomb 1—*Lūrūn*. (**C**) Twin tomb 2—*Bat*. (**D**) General shape and dimensions (in meters) of the *Insaru* tombs and crypts. U-Th-dated, coral-inferred minimum construction ages are given by tomb. Photographs by Jean-Paul Hobbs.

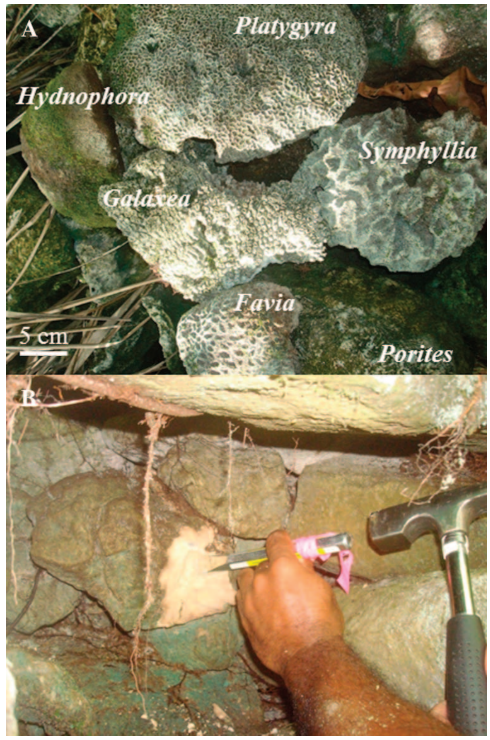

Fig. 3. Corals of the *Leluh* tombs. (**A**) Six genera of scleractinian corals in situ on the outer wall of tomb *Inol-1*. (**B**) Collecting a sample of *Porites* from inside the crypt of twin tomb 1—*Lūrūn*. Photographs by Zoe Richards.

Radiocarbon dating of the bones indicated that *Inol-1* was in use in more recent times, from AD 1824 to 1850 (*6*). Although no direct determined dates were obtained for the twin tombs—*Lūrūn* and *Bat*, an associated construction date sometime around AD 1600–1650 has been proposed on the basis of their centralized location and construction style (*8*). The determined coral U-Th dates we present indicate that all three tomb structures are far older, constructed during the 14th century. *Lūrūn* was built around AD 1322.0 (±4.8), followed about 65 years later in AD 1387.5 (±6.5) by *Bat*. *Inol-1* is the oldest of the three, dated to AD 1310.7 (±6.5) (table S3).

While the *Inol-1* radiocarbon dates suggest that this *saru* was in use in the mid-1800s (*6*), this does not preclude it having an earlier date of origin. Oral traditions suggest that *saru* were reused (*19*); however, no evidence has been provided in support of this premise. We consider tomb reuse as plausible on the basis of the historical records that (i) the tombs were temporary processing points, and (ii) it is likely that a number of kings or paramount chiefs ruled *Leluh* over the centuries of occupation (*20*). Furthermore, the relatively small amount of space available on the island would have made it impractical for every member of royalty to have been allocated a dedicated *saru*.

Today, the relict pyramidal tombs of *Leluh* stand over 2 m high and over 16 m wide at their respective bases (Fig. 2). It has been estimated that in total, more than 12,000 individual coral colonies would have been used to construct the three *saru* of *Insaru* (*21*). Corals were also used to build other parts of the city, such as the 3-m-high seawall, canals, paths, terraces, and floors of at least 20 other private, feast, and special compounds (*8*). Hence, the local coral resources are likely to have been depleted. Whereas the basalt megaliths used in construction could have been quarried from a site in Utwe (about 15 km from *Leluh*) and transported to *Leluh* via rafts (*7*), there is no evidence that corals were quarried from fossil deposits. Rather, a Kosraen legend tells that coral was taken from the shallow reef around *Leluh* and that the people "formed a long chain across the reef and passed pieces of coral from hand to hand" (*12*). Although it is likely that some fossil coral fragments used in *saru* construction were collected from the high-tide mark, the presence of whole coral colonies with fine-scale structures intact and a lack of surface abrasion (*21*) indicates that some corals were collected alive and were used in construction shortly after they were collected.

The evidence that there is no significant association between the corals used to build the tomb facades and the proportional abundance of corals on the reef suggests that corals were preferentially selected for *saru* construction. The motivation for choice of coral may be due to their size and shape and how this relates to ease of extraction and transport or may serve particular construction purposes (for example, fascia), or it may relate to cultural preferences (*22*). Clearly, the possibilities proposed here should be considered with caution because the composition of reefs today would be different from the composition some 700 years ago.

Nevertheless, to extract and translocate the amount of coral used to build the *saru*, as well as the structures and walls throughout *Leluh*, would have required a highly structured social order that could organize and demand significant labor and logistical support from the population. By the beginning of the 19th century, an already distressed Kosraean population dwindled, as a consequence of a devastating typhoon followed by the arrival of foreign ships, pirates, European whalers and traders, missionaries, and castaways (*10*). The Kosraen populace could no longer keep up with the continuing demands for the construction and maintenance work on *Leluh*, and the ancient city fell into disrepair.

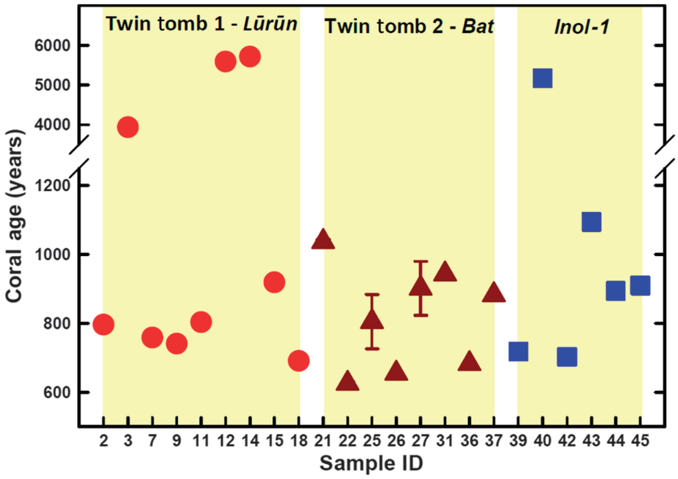

Fig. 4. Determined coral U-Th dates from the three sacred tombs, including twin tomb 1—*Lūrūn* (circles), twin tomb 2—*Bat* (triangles), and *Inol-1* (squares), of *Insaru*.

The bones excavated from *Inol-1* (*18*) may in fact represent the last person interred in a royal *saru* on *Leluh*. The fact that the burial cycle was not completed, that is, the bones were not deposited in the hole on the reef, may indicate that widespread changes were already under way in mid-19th century Kosraean culture. Contact with Europeans began in 1824 with the arrival of Duperrey's expedition on board the *La Coquille* (*23*) and intensified from the 1830s to 1860s. The rapid population decline due to the introduction of diseases brought by the western arrivals, coupled with the introduction of Christianity, led to a decline of the ancient feudal system and traditional cultural practices. After 1830, the *saru* were no longer used; the last *Tokosru*, *Awane Lepalik I* and *Awane Oa*, were not buried in *saru*, and the very last *Tokosru* of *Leluh*, *Awane Salik II*, was forced to abdicate in 1874 and was buried in a Christian graveyard (*8*).

The sacred semi-pyramidal tombs of *Leluh* provide a substantive example of the way ancient cultures used local products and altered their immediate environment in the process. The use of coral colonies as construction material distinguishes the sacred monumental tombs of *Leluh* and has helped establish a new chronology indicating an earlier construction date that began in the 14th century, far earlier than previously understood. The U-Th dating techniques applied directly to architectural materials can significantly alter existing archaeological interpretation of these ancient, though remote, civilizations. For the monumental site of *Leluh*, the coral dates have redefined the timing of its peak occupation and elevated the position of its ruling kings in the struggle with *Nan Madol* for control over the trans-oceanic political hierarchies, as well as the social and economic systems that dominated the civilizations in this part of the world.

MATERIALS AND METHODS

Site description

The ancient capital of *Leluh* is located on the small island of Leluh on the eastern side of the volcanic island of Kosrae in Micronesia, NW Pacific Ocean. Kosrae is a relatively young volcanic island (1 to 3 million years) with a land mass of 109.6 km^2 and a maximum elevation of 629 m. It has a high average rainfall (250 to 450 mm per month), particularly from December to June, during which there is an average of 22 days of rainfall per month (www.worldweatheronline.com). The ancient capital of Leluh occurs within a large shallow harbor fed by the Tafeyot River, which empties into the head of the bay. Fringing reefs surround the island of Kosrae and vary in width from <100 m on southern to eastern shores to 1.6 km on western exposures. There is also an extensive mangrove system, and some reefs extend into the mangroves.

Pyramid and reef coral surveys

To determine if corals used in *saru* construction were selected, the diversity of corals used in construction was compared with the proportional composition of the surrounding shallow reef community. Three random belt transects (5 m long, 0.5 m wide) along the facades of each of the three truncated pyramidal tombs were compared to three random belt transects (50 m long, 2 m wide) at 22 sites around the island of Kosrae (Fig. 1). Every coral visible on the surface layer of the truncated pyramid tombs was counted and identified to genus level. Three coral samples were collected from each transect, and additional coral samples were collected from inside the wall of the crypt and a 50-cm-deep hole dug into the corner of each truncated pyramid. Three additional samples were collected alive from the reef. Overall, 48 coral samples of 13 genera were collected (table S1).

The community composition of the modern coral community was quantified on three random belt transects (50 m long, 2 m wide) at 22 sites around the island of Kosrae. Each coral observed within the belt was identified to species and counted. A χ^2 test for association was used to determine if the composition of corals used in the tombs is the same as the proportional composition of corals on the modern fringing reef (figs. S3 and S4).

U-Th dating

A chipped subsample, 3 to 10 mm^3, was carefully cut from the outermost 2nd to 4th annual band for the selected 24 corals with aragonitic composition and nondetectable postdepositional calcite (<3%) confirmed by x-ray diffractometry. The subsample was gently crushed into 0.5- to 1-mm^3 segments and physically cleaned with ultrasonic methods (*15*). About 100 to 200 mg were used for U-Th chemistry (*24*). A triple-spike, ^{229}Th-^{233}U-^{236}U, isotope dilution method was used to correct mass bias and determine U-Th isotopic contents (*15*). Isotopic compositions and concentrations were determined on a multicollector inductively coupled plasma mass spectrometer (MC-ICP-MS), Thermo Neptune, with single secondary electron multiplier protocols in the High-Precision Mass Spectrometry and Environment Change Laboratory (HISPEC), Department of Geosciences, National Taiwan University (*17*). U-Th measurement results are summarized in table S2. Criteria of 146 ± 8 for initial δ^{234}U (*25*, *26*) and U contents of 1.9 to 4.0 parts per million (ppm) (*25*–*27*) were applied to evaluate reliable dates of pristine corals. One coral, Insaru-13, with abnormal high U content of 6.57 ppm, did not pass the criteria. We estimated the site-specific nonradiogenic ^{230}Th/^{232}Th ratio and its variability (*16*, *28*) by dating a living coral head, *Pocillopora verruocosa*, collected on 11 February 2012. Using an atomic ratio of 4 ppm, inferred from diverse sites in the Pacific and Indian Oceans with a 100% variability (*16*), we determined the U-Th ages of three replicates as AD 2012.4 ± 1.1, 2012.3 ± 1.2, and 2012.2 ± 1.1 (table S2), matching the collection date. The ratio and uncertainty were used to correct for the contribution of nonradiogenic ^{230}Th to the U-Th age. Coral death dates were calculated by subtracting 3 (±1) years from the corrected U-Th age.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/1/2/e1400060/DC1
Fig. S1. Prismatic basalt walls.
Fig. S2. Selection of samples collected from the coral tombs.
Fig. S3. Proportional composition of the contemporary coral reef community.
Fig. S4. Taxonomic composition of corals used to build the pyramid tomb facades versus the modern reef.
Table S1. Coral samples collected from the *Insaru* compound.
Table S2. Uranium and thorium isotopic compositions and U-Th dates for *Insaru* coral samples by MC-ICPMS, Thermo Electron Neptune.
Table S3. The quantity and type of corals used to construct the *Leluh* pyramids.
References (*29*, *30*)

REFERENCES AND NOTES

1. C. Scarre, *The Human Past* (Thames and Hudson, London, ed. 3, 2013).
2. G. R. H. Wright, *Ancient Building Technology* (Brill Publishing, Leiden-Boston-Koln, 2009), vol. 3.
3. G. R. H. Wright, *Ancient Building Technology* (Brill Publishing, Leiden-Boston-Koln, 2000), vol. 1.
4. J.-F. Saliège, A. Person, F. Paris, Preservation of $^{13}C/^{12}C$ original ratio and ^{14}C dating of the mineral fraction of human bones from Saharan Tombs, Niger. *J. Arch. Sci.* **22**, 301–312 (1995).
5. C. Scarre, Rocks of ages: Tempo and time in megalithic monuments. *Euro. J. Arch.* **13**, 175–193 (2010).
6. J. S. Athens, J. V. Ward, G. M. Murakami, Development of an agroforest on a Micronesian high island: Prehistoric Kosraean agriculture. *Antiquity* **70**, 834–846 (1996).
7. W. N. Morgan, *Prehistoric Architecture in Micronesia* (University of Texas Press, Austin, 1988).
8. R. H. Cordy, The Lelu Stone Ruins (Kosrae, Micronesia). *Asia. Pac. Arch. Ser.* **10**, 1–454 (1993).
9. The orthography of compound names, tombs, titles follow that of Cordy (1993) with the following exceptions. We spell the name of the ancient city *Leluh* (spelt Lelu by Cordy). We spell the sacred compound *Insaru* (spelt *Insru* by Cordy). We have made these changes following advice from Berlin Sigrah of the Kosrae State Historic Preservation Office.
10. F. Hezel, *Foreign Ships in Micronesia: A Compendium of Ship Contacts with the Caroline and Marshall Islands, 1521–1885* (Trust Territory of the Pacific Islands Historic Preservation Office, Saipan, 1979).
11. B. S. Ballinger, *Lost City of Stone: The Story of Nan Madol, the "Atlantis" of the Pacific* (Simon and Schuster, New York, 1978).
12. E. G. Sarfet (1919), in W. N. Morgan, Prehistoric Architecture in Micronesia (Kegan Paul Int., London, 1989).
13. L. H. Gulick (1861), in R. Cordy, *Asia. Pac. Arch. Ser.* **10**, 1–454 (1993).
14. Jones (1861), in R. Cordy, *Asia. Pac. Arch. Ser.* **10**, 1–454 (1993).
15. C.-C. Shen, R. Lawrence Edwards, H. Cheng, J. A. Dorale, R. B Thomas, S. Bradley Moran, S. E. Weinstein, H. N. Edmonds, Uranium and thorium isotopic and concentration measurements by magnetic sector inductively coupled plasma mass spectrometry. *Chem. Geol.* **185**, 165–178 (2002).
16. C.-C. Shen, K.-S. Li, K. Sieh, D. Natawidjaja, H. Cheng, X. Wang, R. Lawrence Edwards, D. Dinh Lam, Y.-T. Hsieh, T.-Y. Fan, A. J. Meltzner, F. W. Taylor, T. M. Quinn, H.-W. Chiang, K. Halimeda Kilbourne, Variation of initial $^{230}Th/^{232}Th$ and limits of high precision U–Th dating of shallow-water corals. *Geochim. Cosmochim. Acta* **72**, 4201–4223 (2008).
17. C.-C. Shen, C.-C. Wu, H. Cheng, R. Lawrence Edwards, Y.-T. Hsieh, S. Gallet, C.-C. Chang, T.-Y. Li, D. Dinh Lam, A. Kano, M. Hori, C. Spötl, High-precision and high-resolution carbonate ^{230}Th dating by MC-ICP-MS with SEM protocols. *Geochim. Cosmochim. Acta* **99**, 71–86 (2012).
18. P. Hambruch, in E. G. Sarfert (Friedrichsen and Co., Hamburg, 1919).
19. Personal communications, Paliknoa Sigrah, Kosrae State Historic Preservation Office, Tofol.
20. *Tokosra* genealogies prior to AD 1800 have not been recorded; however, from 1800 to 1850, ten *Tokosras* reined over *Leluh* for 1 to 10 years each (ref. 8).
21. Z. T. Richards, J. P. A. Hobbs, Prehistoric Pacific Island kings entombed in truncated coral pyramids. *Coral Reefs* **30**, 737 (2011).
22. P. Rainbird, *The Archaeology of Micronesia*. Cambridge World Archaeology Series (Cambridge University Press, Cambridge, UK, 2004).
23. L.-I. Duperrey, *Memoire sur les Operations Geographiques Faites dans la Campagne de la Corvette de S.M. La Coquille, Pendant les Annes 1822–1825* (Annales Maritimes et Coloniales, 1828).
24. C.-C. Shen, H. Cheng, R. L. Edwards, S. B. Moran, H. N. Edmonds, J. A. Hoff, R. B. Thomas, Measurement of attogram quantities of ^{231}Pa in dissolved and particulate fractions of seawater by isotope dilution thermal ionization mass spectroscopy. *Anal. Chem.* **75**, 1075–1079 (2003).
25. K. B. Cutler, R. L. Edwards, F. W. Taylor, H. Cheng, J. Adkins, C. D. Gallup, P. M. Cutler, G. S. Burr, A. L. Bloom, Rapid sea-level fall and deep-ocean temperature change since the last interglacial period. *Earth Planet. Sci. Lett.* **206**, 253–271 (2003).
26. R. L. Edwards, C. D. Gallup, H. Cheng, Uranium-series dating of marine and lacustrine carbonates. In B. Bourdon, G. M. Henderson, C. C. Lundstrom, S. P. Turner, Eds., *Uranium-Series Geochemistry* (Mineralogical Society of America, Washington, DC, 2003), 363–405.
27. G. T. Shen, R. B. Dunbar, Environmental controls on uranium in reef corals. *Geochim. Cosmochim. Acta.* **59**, 2009–2024 (1995).
28. K. M. Cobb, C. D. Charles, H. Cheng, M. Kastner, R. Lawrence Edwards, U/Th-dating living and young fossil corals from the central tropical Pacific. *Earth Planet. Sci. Lett.* **210**, 91–103 (2003).
29. H. Cheng, R. L. Edwards, J. Hoff, C. D. Gallup, D. A. Richards, Y. Asmerom, The half-lives of uranium-234 and thorium-230. *Chem. Geol.* **169**, 17–33 (2000).
30. A. H. Jaffey, K. F. Flynn, L. E. Glendenin, W. C. Bentley, A. M. Essling, Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U. *Phys. Rev. C* **4**, 1889–1906 (1971).

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