Stone tools and foraging in northern Madagascar challenge Holocene extinction models

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Edited by Conrad Phillip Kottak, University of Michigan, Ann Arbor, MI, and approved May 31, 2013 (received for review March 30, 2013)

Past research on Madagascar indicates that village communities were established about AD 500 by people of both Indonesian and East African heritage. Evidence of earlier visits is scattered and contentious. Recent archaeological excavations in northern Madagascar provide evidence of occupational sites with microlithic stone technologies related to foraging for forest and coastal resources. A forager occupation of one site dates to earlier than 2000 B.C., doubling the length of Madagascar's known occupational history, and thus the time during which people exploited Madagascar's environments. We detail stratigraphy, chronology, and artifacts from two rock shelters. Ambohiposa near Iharana (Vohémar) on the northeast coast, yielded a stratified assemblage with small flakes, microblades, and retouched crescentic and trapezoidal tools, probably projectile elements, made on cherts and obsidian, some brought more that 200 km. ^{14}C dates are contemporary with the earliest villages. No food remains are preserved. Lakaton'i Anja near Antsiranana in the north yielded several stratified assemblages. The latest assemblage is well dated to A.D. 1050–1350, by ^{14}C and optically stimulated luminescence dating and pottery imported from the Near East and China. Below is a series of stratified assemblages similar to Ambohiposa. ^{14}C and optically stimulated luminescence dates indicate occupation from at least 2000 B.C. Faunal remains indicate a foraging pattern. Our evidence shows that foragers with a microlithic technology were active in Madagascar long before the arrival of farmers and herders and before many Late Holocene faunal extinctions. The differing effects of historically distinct economies must be identified and understood to reconstruct Holocene histories of human environmental impact.

hunter-gatherer | microliths | settlement

The known prehistory of Madagascar is unusually short: the earliest known villages date no earlier than A.D. 700. Occupation, including substantial towns, occurred along most of Madagascar's coasts by A.D. 1100 (1, 2). These early sites yield distinctive earthenware ceramics, and often direct evidence of connection to the Indian Ocean trade network. Evidence for the use of stone tools, except for weights, sharpening stones, and vessels, has been absent, most of these early villages (3) probably having relied on iron tools. In all these respects, the early record in Madagascar matches that of the nearby Comoro Islands (4, 5). Linguistic evidence tightly links the Malagasy language to languages of southeastern Borneo, but also shows borrowings from other Indonesian languages as well as a major influence from an East African Bantu language (6–9). This evidence suggests that contacts and migration from Indonesia began *ca*. A.D. 700, and may have lasted 500 y or more (6, 8, 10). Genetic evidence from modern Malagasy people links their biological ancestry to both Indonesia and East Africa (11–13) and genetic models suggest Indonesian settlement *ca*. A.D. 500–700 (14, 15). Contacts between Madagascar, East Africa, and the Comoros have continued into historical times, and are especially marked from A.D. 800–1200 (4), but genetic and linguistic evidence does not establish when these contacts began.

Published evidence is sparse for human occupation or visits to Madagascar before coastal villages were established. Bones with reported cut-marks are described from paleontological sites: a *Paleopropithecus ingens* radius from Taolambiby in the southwest is radiocarbon dated to 402–204 cal B.C. (16), and *Hippopotamus lemerlei* bones from Anjohibe cave in the northwest are associated with a date of 2288–2035 cal B.C. (17); in neither case are there associated artifacts. Changes in pollen and charcoal deposition in sediment columns in the southwest interpreted as anthropogenic date roughly to A.D. 0 (18, 19). The oldest radiocarbon (^{14}C) date from an archaeological site is at Lakaton'i Anja, in the extreme north: cal A.D. 256–573 (20, 21).

The nature and chronology of human settlement in Madagascar is of particular interest because 40–50 species of vertebrates, including all endemic terrestrial species greater than 10 kg in body mass, became extinct during the Holocene (22–25). Radiocarbon dating and historical evidence suggest that most of these species survived in at least some areas until A.D. 1000, but few after A.D. 1500 (26). Attempts to explain the extinctions are varied and remain controversial (19, 26–30); it is likely that humans played a role, but how and when remains unclear.

Here we report evidence that stone tool-using foragers occupied Madagascar before the iron-using agriculturalists who were the earliest previously known settlers; and that these foragers were active in northern Madagascar at least as early as 2000 B.C. Taken together, the evidence doubles the length of Malagasy prehistory, and forces a reconsideration of the nature and chronology of human environmental impact on the island.

Results

Ambohiposa. In the course of survey in 2007 we discovered a small rock shelter, known locally as Ambohiposa, overlooking the Bay of Iharana near Vohémar (S13° 22′/ E49° 59′) (Fig. 1). A small test in its floor deposit revealed stratified layers with tiny fragments of flaked chert. Ambohiposa is situated in the east-facing slope of a massif of Mesozoic igneous and sedimentary rocks, including layers of basalt, rhyolite, marl, siltstone, and sandstone, reaching an altitude of 80 m. The shelter has a good view northeast over the Bay of Iharana and the low plain to its east and southeast, which is composed of sand ridges separated by marshy areas. The sheltered area of Ambohiposa is small, only 4 m

Author contributions: R.E.D., C.R., and H.T.W. designed research; R.E.D., C.R., and H.T.W. performed research; R.E.D., C.R., H.T.W., Z.J., G.O.K., and F.B. analyzed data; and R.E.D., C.R., H.T.W., Z.J., G.O.K., and F.B. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1306100110/-/DCSupplemental.

ANTHROPOLOGY

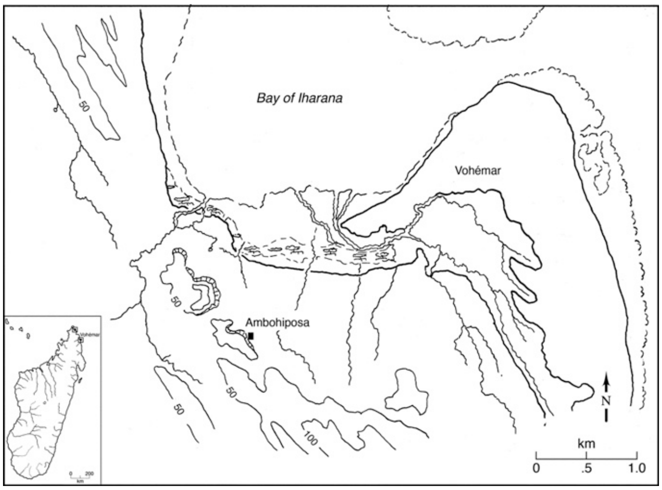

Fig. 1. The location of Ambohiposa.

long, with an overhang that protects only about 1.2 m (Fig. S1). The deposits were excavated in six natural stratigraphic layers (*SI Text S1*).

We suggest the following depositional history. A period of weathering and the deposition of strongly oxidized sediment ends with the deposition of layer 6. Organic layer 5 formed above this and is the surface on which there were one or more brief occupations by people using stone tools. A probably brief period of spalling of the back wall or roof leads to the deposition of layer 4, a deposit of stone debris. This is succeeded by additional deposition of organic material with evidence of further occupations by people creating layer 3. These organic sediments are sealed under layer 2, a thin layer of oxidized reddish sediment, washed from above relatively recently. Layer 1 is recent leaf liter. Kaolinite is a major component of the silty material found in all levels; it forms on the hilltop above and could have been washed down. A minor inclusion is quartz, which could have been a component of the bedrock or introduced by wind or water.

Flaked stone items recovered primarily from washing and sorting are very small, a majority from a range of crypto-crystalline silicates, which we term "chert," and a minority of a volcanic glass which we term "obsidian" (Table S1). The chert items can be opaque and gray, tan or brown, or translucent and brown. The few unmodified pieces are < 2 cm in length. Included are rare flakes of a translucent agate, white or gray in color. Some of the fragments and flakes have pot-lid scars attributable to either deliberate heating, which improves flaking, or accidental burning. Survey in the area of Ambohiposa identified small blocky fragments of opaque brown chert in a gully 80 m north of the shelter, and small rounded pebbles of translucent gray and white agate on the slope of the hill of Ambatomalana 180 m northwest of the shelter. The obsidian is usually opaque and black. No sources are known in the far north or northeast of Madagascar.

Chert waste recovered by fine-screen washing includes 2002 pieces of blocky shattered chert weighing 189 g in total. Some of the shatter fragments could be products of natural fracture. We recovered 292 chert flakes (including blade fragments)—thinner pieces with an exterior face with the scars left by earlier flake removals and an inner face resulting from their removal from a core—weighing a total of 14 g. Most of these flakes are unweathered and exhibit bulbs from directed percussion or pressure; they are certainly a result of human action. Some result from a simple and widely known procedure termed "bipolar reduction" (31–33) used throughout the world wherever available raw material pieces are small. In our samples, there is a bipolar core remnant of chert (Fig. 2*A*) with scars on both faces originating from both ends and a few small fragments of such cores. Some of the larger chert flakes are products of these cores, and one in particular (Fig. 2*B*) has clear scars on both faces originating from both ends. Others are probably fragments of such flakes.

Two modified items are made from crescent-shaped pieces of opaque tan chert, triangular in cross-section, also resulting from bipolar reduction (Fig. 2 *C* and *D*). Both items are from the older reddish sediment of layer 6 in the north unit and perhaps older than the other items discussed here. Both items have slight overall light polish of geological origin, which makes it difficult to interpret the sequence and direction of flake removals, as well as small black accretions, probably natural manganese. Neither of these items are typologically "crescents," a type well known from Later Stone Age sites in East Africa and elsewhere, because they are made from bipolar flakes rather than blade segments and they are not backed. Some flakes do not show clear evidence of having been struck from two ends, and may have been detached from cores by a direct blow of the hammer stone without an underlying anvil. One nearly complete brown chert triangular

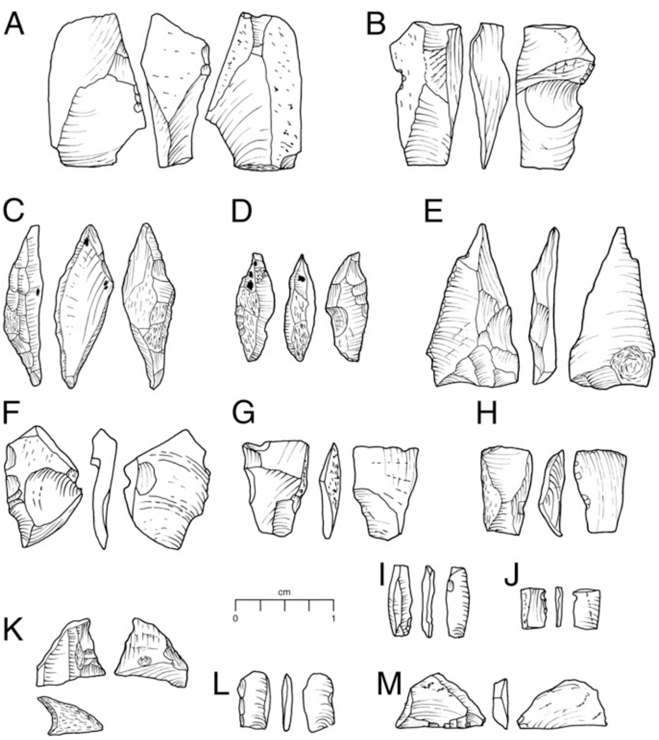

Fig. 2. The chipped stone items from Ambohiposa. For core fragments, flakes and blades, length (Ln) is measured along the last-used striking axis, width (Wd) is perpendicular to that, and thickness (Thk) is perpendicular to width. For finished crescentic and trapezoidal pieces, length is the longest dimension, and so forth. A "+" indicates that the item is definitely broken and the dimension was greater. (*A*) Bipolar core remnant, chert (central unit, layer 2) Ln: 1.62, Wd: 0.97, Thk: 0.72. (*B*) Bipolar flake, chert (central unit, layer 3) Ln 1.41, Wd: 0.72, Thk: 0.43. (*C*) Bipolar crescentic flake with retouch, light brown chert (north unit, layer 6) Ln: 1.74, Wd: 0.60, Thk: 0.37. (*D*) Possible bipolar crescentic flake with retouch, light brown chert (north unit, layer 6), Ln: 1.18, Wd: 0.41, Th: 0.31. (*E*) Triangular flake, chert (South Unit, layer 5) Ln: 1.67, Wd: 0.91, Thk: 0.36. (*F*) Retouched flake, chert (central unit, layer 4) Ln 1.25, Wd: 0.86, Thk: 0.31. (*G*) Trapezoidal flake fragment, chert (central unit, layer 4) Ln 0.96, Wd: 0.71, Th 0.23. (*H*) Trapezoidal flake fragment, chert (south unit layer 5) Ln: 0.91, Wd: 0.50, Thk: 0.23. (*I*) Microblade, chert (central unit, layer 5) Ln 0.74, Wd: 0.18, Thk:0.12. (*J*) Segment of possible microblade core preparation flake, chert (central unit, layer 5) Ln 0.41+, Wd: 0.26, Thk: 0.09. (*K*) Fragment of microblade core, obsidian (north unit, layer 5) Ln: 1.36+, Wd: 1.40+, Thk: 0.81+. (*L*) Microblade segment, obsidian (central unit, layer 3) Ln 0.60, Wd: 0.35, Thk: 0.11. (*M*) Small flake, obsidian (central unit, layer 5) Ln 0.53, Wd: 0.89, Thk: 0.16.

flake is a product of conventional flake removal from such a core (Fig. 2*E*). Nibbling on the edges may result from binding to a haft, and polish on the tip suggests use in cutting or perforating. Fragments of larger flakes without clear evidence of flakes struck from two directions may have been detached from either bipolar cores or larger amorphous cores. A brown chert flake (Fig. 2*F*) has small flakes removed from its left edge, perhaps from utilization or perhaps from retouch to create a reinforced edge useful in scraping. Two chert flake fragments are notable for their trapezoidal shape. One (Fig. 2*G*) is the proximal end of a larger flake whose left side was retouched to emphasize the trapezoidal shape. The other (Fig. 2*H*) is from the distal end of a flake. No additional retouch was needed to create a trapezoidal form. This item is made from rare fine translucent brown chert. We emphasize that none of these are typologically "trapezes," a type well known from Later Stone Age assemblages elsewhere, because they are not made from blade segments by retouching the distal and proximal sides. Finally, there are a few small, narrow, parallel-sided chert microblades (Fig. 2 *I* and *J*).

Obsidian waste recovered by fine-screen washing includes one obsidian microblade core fragment weighing 0.17 g, and 18 tiny obsidian flakes and microblade fragments weighing 0.52 g. Illustrated are the microblade core fragment with the scars of three microblade removals (Fig. 2*K*), a microblade medial segment with possible retouch on the left edge (Fig. 2*L*), and a flake with utilization on its pointed right side (Fig. 2*M*).

Even though a small sample of tiny items, they are clearly a stone tool assemblage created and used by people: most raw materials have not been found near the shelter and must have been carried in, directed blows were used to detach a series of flakes from cores, and there is evidence of retouch or use on some pieces.

A high proportion of shatter is typical of samples from stone tool making by the bipolar technique. The stratigraphic distribution of items indicates that there may have been visits at the time of layers 6–3, but that the strongest evidence for human use of the site was during the time of layer 5.

From layers 3–5 of the north unit, we recovered two small fragments of pottery, both oxidized to a red color, and with coarse angular quartz inclusions. The color and inclusions indicate manufacture during the earliest-known phase of village occupation near Vohémar, defined from excavations at Ampasimahavelona, 3 km east of Ambohiposa. In the north unit the upper organic layers are thin and compressed, and these could be intrusive sherds deposited later than the occupation that left the stone artifacts.

Two small fragments of wood charcoal from layer 5 of the south excavation unit were submitted for accelerator mass spectrometry (AMS) ^{14}C dating: Beta 251455: 1110 ± 40 B.P., cal A.D. 870–1010, and Beta 251454: 760 ± 40 B.P., cal A.D. 1210–1290. These two pieces of charcoal are unlikely to be of the same age, but they both date to the time of the earliest village sites in the area, during the Ampasimahavelona and Razanakoto Phases (*SI Text S1*).

The evidence from Ambohiposa demonstrates that people using stone tools lived in the far north of Madagascar. However, in the absence of preserved bone, shell, or diagnostic plant remains, we have little knowledge of their way of life. The limited absolute dating evidence suggests the stone toolmakers of Ambohiposa were contemporary with the earliest iron-using villagers of Vohémar. We spent much of our seasons of 2009, 2010, and 2011 searching for sites with better dating evidence.

Lakaton'i Anja. The cave of Lakaton'i Anja is situated in the Montagne des Français in the Gorge of Andavakoera (S 12° 20′ E 49° 21′) (Fig. 3). The cave was first excavated in 1986–1988 (18, 19). The gorge has vertical cliffs of coralline limestone on either side delimiting a relatively flat floor with large fallen blocks and breakdown that have at times dammed the small stream meandering from west to east, creating marshy areas. Lakaton'i Anja looks northeast over a meadow, deforested since 1990.

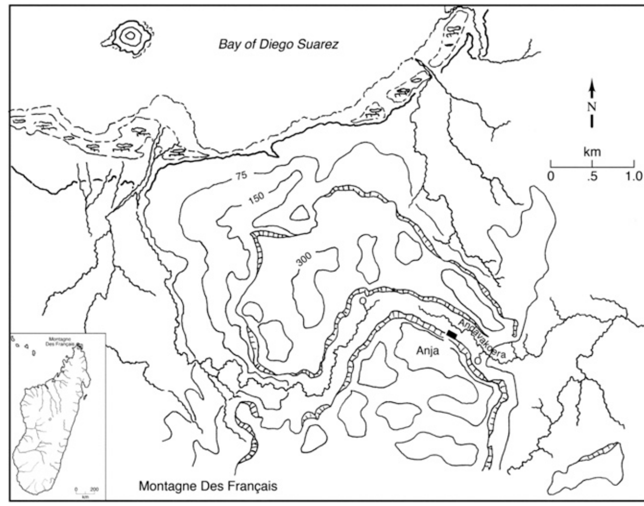

Fig. 3. The location of Lakaton'i Anja.

From this meadow, one climbs up a rugged slope of large angular blocks about 6 m to the shelter. The overhang was created by the erosion of a cave, which was parallel to the valley, such that the back wall of the shelter was the south side of the cave. The sheltered sandy floor of Lakaton'i Anja is spacious, 18 m long from east to west, and 4.5 m wide within the drip line (Fig. S2).

In the 1980s excavations, two occupations were identified: higher layers associated with local earthenware and imported ceramics dating to the 11^{th} to 14^{th} centuries, and lower layers with few artifacts, but continuing to yield bone and charcoal. This lower unit was dated earlier than any other archaeological site known for Madagascar. After the identification of tiny stone tools at Ambohiposa, we resumed excavations at Lakaton'i Anja in case recovery procedures used in the earlier excavations missed small stone tools.

The excavations in the 1980s comprised nine 1-m squares, designated with the letters A to I. The excavation units of the 1980s work penetrated only up to 0.4 m, the upper portion of the sandy deposit now termed layer 4. In 2011, we excavated two units, termed J and K (Fig. S2). Deposits from the modern surface to 0.70 m below surface were excavated in natural stratigraphic layers, most layers being removed in up to four arbitrary spits or sublayers (*SI Text S2*).

All excavated layers had concentrations of fine white material, probably phytoliths, and mollusk shell fragments, largely terrestrial gastropods below layer 3. Given the angle of the rear wall of the cave, we estimate that there are more than 5 m of stratified deposit below. Although layers 1–3 are well defined, as a result of ashes and organic material introduced by the later occupants, layers 4 and 5 are less well-defined, either because of a more episodic human occupation or because of greater age and more weathering. These layers are penetrated by large later termite burrows, which we tried to clean out separately from the surrounding sediment. However, results from single-grain optically stimulated luminescence (OSL) dating (*SI Text S3* and Fig. S3) suggest that some sediment may have moved from the upper layers into lower layers.

As at Ambohiposa, the procedure of washing the screened debris and sorting it under magnification yielded not only more bones, but small stone artifacts (Fig. 4 and Table S2). Flaked stone items are primarily from a range of tan to reddish silicates, or chert. These are roughly sorted into fine-grained and coarse-grained varieties, both obtainable several kilometers away. All pieces are less than 2 cm in length. The agate and obsidian found in Ambohiposa are not attested, but nonlocal crystal quartz items occur.

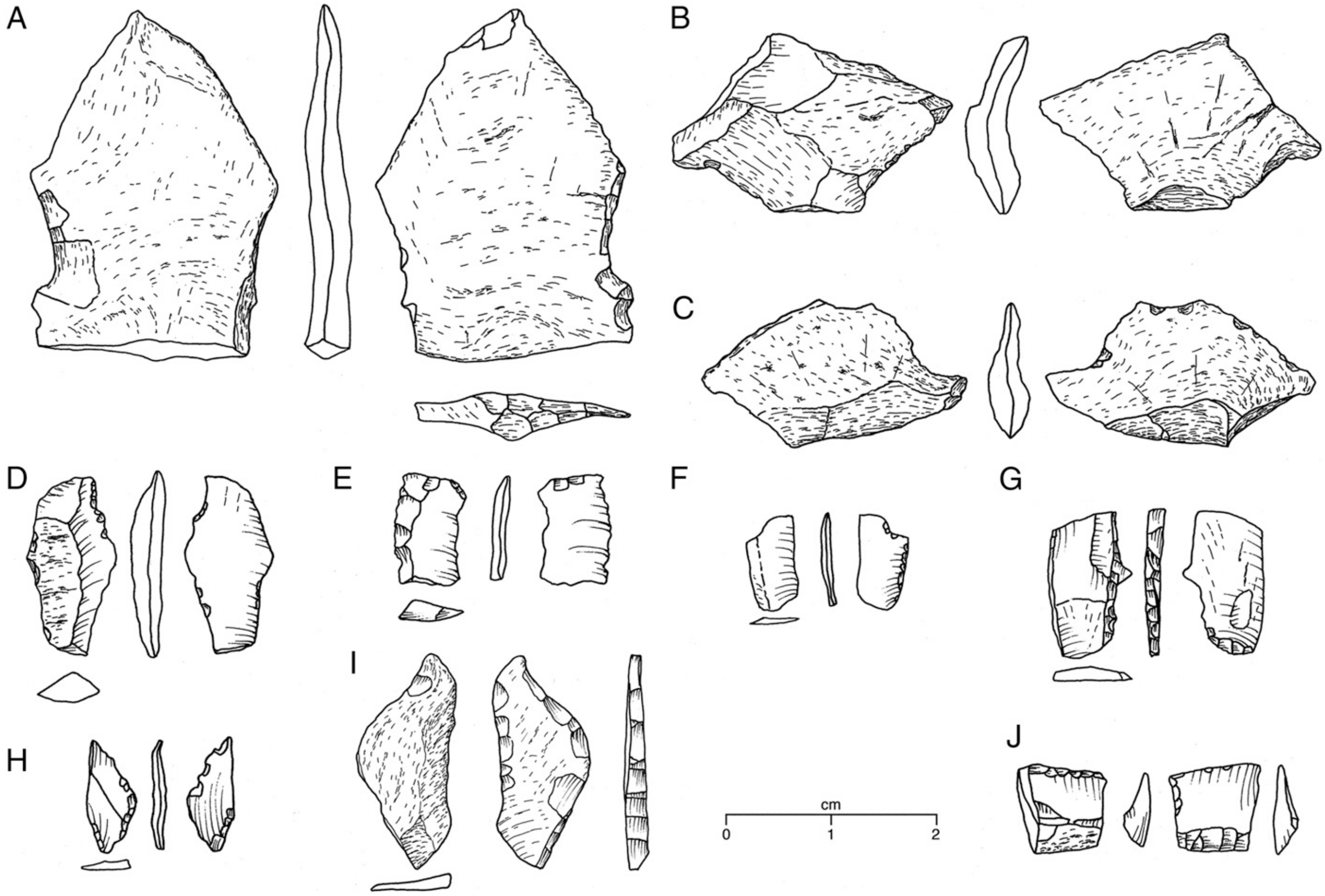

Fig. 4. The chipped stone items from Lakaton'i Anja: (*A*) Distal end, large flake; coarse chert (unit J, layer 5B-C interface) Ln: 3.30, Wd: 2.36, Thk: 0.45, Wt 3.7 g. (*B*) Used flake; coarse chert (unit J, layer 5B) Ln: 1.79, Wd: 2.70, Thk: 0.36., Wt: 1.4 g. (*C*) Used flake; coarse chert (unit J, layer 5C) Ln: 1.39, Wd: 2.43, Thk: 0.46, Wt: 2.0 g. (*D*) Used small blade; coarse chert (unit J, layer 4B) Ln: 1.70, Wd: 0.78, Thk: 0.33. Wt: 0.3 g (*E*) Retouched small blade; fine reddish chert (unit J, layer 5C) Ln: 1.09, Wd: 0.66, Thk: 0.07, Wt: <0.1 g. (*F*) Used small blade; fine reddish chert (unit J, layer 4C) Ln: 0.90, Wd: 0.40, Thk: 0.09. Wt: <0.1 g. (*G*) Retouched small blade; crystal quartz (unit J, layer 4B) Ln: 1.36, Wd: 0.81, Thk: 0.14, Wt: 0.1 g. (*H*) Small crescentic flake; fine reddish chert (unit J, layer 4C) Ln: 1.02, Wd: 0.45, Thk: 0.15, Wt: <0.1 g. (*I*) Large crescent flake; coarse calcareous chert damaged by acid bath (unit J, layer 5A) Ln: 1.92, Wd: 0.82, Thk: 0.23. (*J*) Trapezoidal flake; fine reddish chert (unit J, layer 4C) blade Wd: 0.86, butt Wd: 0.64, bit Width: 0.83, Thk: 0.24, Wt 0.4 g.

The stratigraphic distribution of items in layers 1B to 5C of unit J presented in Table S2 provides evidence of human activities in Lakaton'i Anja. Chunks or shattered fragments of raw material are rare in comparison with Ambohiposa, indicating little bipolar core working. We interpret flakes of coarse brown chert—given the clear bulbs of percussion and platforms—as consequences of the flaking of tabular chert cores to make small flakes for cutting tasks or as blanks for small stone tools (Fig. 4 *A–C*). In 2011, however, no chert cores or core fragments were found and we hesitate to reconstruct the manufacturing sequence. The reddish sediment of layers 3B, 4, and 5 contains varying amounts of chert flakes by weight per unit volume (Table S2, *Right*). There are concentrations of flakes in 5C, 5A, 4C, and 4A. Fine reddish chert flakes and tools are found only in these layers. Among the tools are small blades, some retouched (Fig. 4 *D–F*), crescentic tools (Fig. 4 *H* and *I*), and a trapezoidal tool (Fig. 4*J*) similar to those from Ambohiposa. The more organic brownish sediments of layers 3 and 1 contain significant densities of coarse chert flakes. These layers date to the 11th to 14th centuries A.D., when iron was widely used, and one could infer that the flakes are extrusive from lower layers. If so, retouched tools and items of fine red chert and quartz would be expected in these later levels as well. However, none was found. We infer, rather, that the people who camped in Lakaton'i Anja during the 11th to 14th centuries continued to make and use coarse chert flakes as expedient implements for cutting tasks.

As at Ambohiposa, this is a small sample of tiny items. However, here too is a stone tool industry created by people: once again, no trace has been found of the raw materials near the site and they must have been carried in; there is evidence of directed blows detaching a series of flakes from cores; the retouched items are unquestionably tools.

Locally manufactured ceramics occur in layers 1–2 in low densities compared with contemporary village sites, but they are familiar and generally datable types known from other sites (*SI Text S4*). All examples have sandy bodies with fine sand inclusions and are from small bowls and jars with various incised and impressed decorations (Fig. S4). Ceramics imported via Indian Ocean trade networks, also well known and absolutely datable, occur in layers 1 and 2. There are four sherds of Persian Gulf *sgraffiato* of the 11th to 13th centuries and a green glazed sherd of either later 13th to 14th century *sgraffiato* or a monochrome of the 14th to 15th centuries. From southern China is the white glazed, white-bodied porcelain fragment of the ring base of a small Song dynasty bowl of the 11th to 13th centuries. In sum, the ceramic evidence from the 2011 excavation, both local and imported, indicates that the uppermost occupational layers at Lakaton'i

Anja date between the 11th and 14th centuries. Occupations were ephemeral and sporadic during this long span of time.

Stone vessels were also used during the later occupations. Carved chlorite schist sherds found in 1986–1987 are complemented by a small chlorite schist fragment from unit J, layer 3B. Glass is represented by a number of small cane beads of opaque red glass, opaque dark glass, and translucent blue-green glass, (*SI Text S5* and Fig. S5), plus a few tiny fragments of small vessels. Most are in the surficial levels, but one dark glass bead is from layer 5.

The animal and plant remains from Lakaton'i Anja are still being studied. Both the 1980 samples (1, 21) and 2011 field identifications of specimens from layers 4 and 5 recorded the bones of small tortoises, birds, tenrecs, and medium-sized lemurs, all of which could be hunted in the gorge. There were also fish bones, anemone spines, fragments of the marine bivalve *Anadara* (cf *Arca*) sp., and estuarine gastropod *Terebralia* sp., all obtainable from nearby coasts 2 km or more away. These observations indicate that the early occupants of Lakaton'i Anja were foragers.

Two dating techniques have been used on samples from the 2011 Lakaton'i Anja excavations: single-grain OSL dating of sediment samples from units J and nearby unit K, and ^{14}C age dating of wood charcoal. OSL dating of layer 5B from both units J and K gave ages of 3,470 ± 370 and 4,380 ± 400 y ago, roughly 1460–2370 B.C. (*SI Text S3*). In both units all OSL ages are in correct stratigraphic order, and are comparable between the two units. An OSL age for a sample collected from the interface of layers 2A and 3 in unit J is in excellent agreement with the dating of the upper layers to the 11th to 14th century based on imported ceramics, providing confidence in the accuracy of the ages for the lower layers. Fig. 5 presents a summary of the distribution of artifacts and the OSL ages in unit J.

At present, AMS ^{14}C ages are available for three small fragments of wood charcoal, none from recognizable features, from the 2011 excavations. Beta 305633: 1,460 ± 40, cal A.D. 565–680 is from layer 4A. This age accords well with previously published dates from sediments provisionally equivalent to layers 3 or 4: cal A.D. 599–937 and cal A.D. 220–540 (1). Two other ages, from layer 5A, resulted in ages of Beta 305634: 1,070 ± 40, cal A.D. 970–1135 and Beta 305635: 930 ± 30, cal A.D. 1045–1220. These two pieces of charcoal are likely to be of the same age, and they both date to the time of the imported and local ceramics found in layer 1. The inconsistent ages and age inversion suggest that these pieces of charcoal were likely introduced into layer 5 by biological activity.

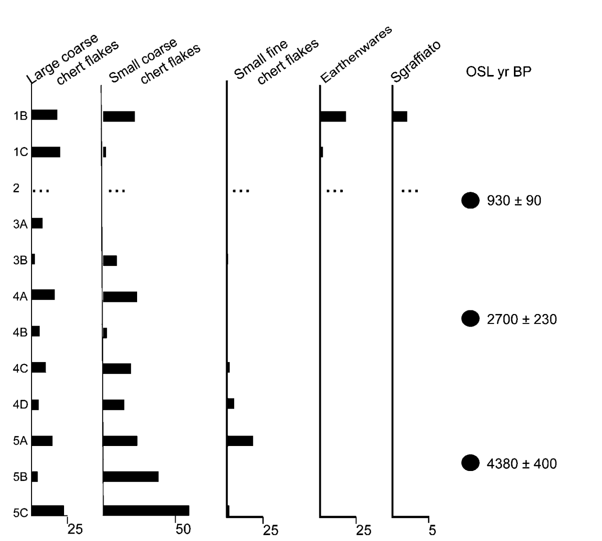

Fig. 5. The vertical distribution of stone flakes, pottery sherds, and OSL dates from unit J, Lakaton'i Anja. The flakes are standardized to #/42 L; the mean layer volume is 42.1 ± 15.3 L.

Discussion

The stone tools from Ambohiposa and Lakaton'i Anja are unlike anything reported from Madagascar. The small assemblages were discovered in sites and contexts indicative of intermittent occupation by small groups engaged in foraging. Some of the tools have morphologies that suggest use in composite projectiles, reinforcing the interpretation of these sites as foraging camps. The occupations at Ambohiposa may be coeval in age with the earliest iron-using villages in its region, but foragers were visiting Lakaton'i Anja cave a millennium or more before the widespread manufacture and use of iron. Although the stone tools are so few that we cannot make precise comparisons, they resemble those known from southern and eastern Africa, southern Arabia, and south Asia, and are unlike those from Southeast Asia. Blench (34) has recently argued, on diverse evidence, for a migration to Madagascar from East Africa long before the use of iron, and limited genetic evidence may support this proposal (13). Our findings do not contradict this proposal.

Many have viewed the Holocene extinctions as catastrophic and quick following human settlement of Madagascar, by analogy with well-known cases in Pacific islands. However, many now-extinct species in Madagascar have been dated after A.D. 1 (26), and extinctions continued until at least A.D. 1500. Our unique evidence shows that extinctions occurred long after human arrival on the island. Although human activities were involved, including hunting, the specific causes and patterns remain to be determined. More generally, the view that Madagascar's history can be sharply divided by the arrival of humans between an undisturbed Eden and anthropogenic chaos is no longer tenable. The activities of foraging populations have environmental consequences that differ in both degree and nature from those of Iron Age farmers and pastoralists, and changes in paleoenvironmental proxies interpreted as signaling "human arrival" may in fact be signals of a change in human economy. Fire is used differently as a tool by foragers, farmers, and pastoralists. Interpreting Holocene histories of fire regimes requires distinguishing not only between "natural" and "anthropogenic," but also among different, historically distinct, patterns of fire use by people.

We have demonstrated an earlier epoch of stone tool-making foragers, but the data from Lakaton'i Anja and Ambohiposa do not establish when foragers first arrived in Madagascar. Research is urgently needed across the island to locate and excavate more forager sites, and especially residential bases, to understand the chronology, origins, geographic spread, and environmental impacts of the human occupation of Madagascar.

Materials and Methods

Excavation. At Ambohiposa, each context was excavated and sieved in 3-mm screen. Larger rock fragments were examined for evidence of use and then discarded. Everything else was saved, and washed through 1-mm screen, dried, and sorted under magnification to recover stone, bone, and charcoal fragments. We excavated ~25% of the area of layers 3–5. Soil samples removed from the section were studied by Fourier transform infrared spectroscopy to establish that soil-forming processes were similar (*SI Text S6* and Fig. S6). At Lakaton'i Anja each context was excavated and sieved using the same methods. In addition, samples from the general excavation of layers 4 and 5 were cleaned in a bath of 10% (vol/vol) HCl for 1 h or more to diminish calcite encrustation. Everything remaining was dried and sorted under magnification. The flotation heavy fractions are being cleaned in a 5% (vol/vol) solution of formic acid buffered with calcium phosphate to protect the bone (35). For more detailed information on sample locations, grains measured, dose-rate data, and other basic data and values, see Tables S3–S7.

Dating. All radiocarbon dates are corrected for ^{13}C fractionation, calibrated with OxCal 4.1.7 (36) using the southern hemisphere calibration curve (37) and presented at 2σ (SE). Details of the single grain optically stimulated luminescence dating are found in *SI Text S3*.

ACKNOWLEDGMENTS. We thank Stephen A. Brandt, Alison Carter, Paul Goldberg, Stephen M. Goodman, J. Mark Kenoyer, Amanda Logan, Anthony E. Marks, Vincenzo Morra, Alison F. Richard, Victor Razanatovo, Arlene M. Rosen, Steven A. Rosen, and Marilee Wood for their assistance, as well as the technicians and students who served as field crews. We thank the Government of Madagascar for permission to conduct the research, and gratefully acknowledge the assistance of the responsible authorities of the Regions of Sava and Diana, the cities of Iharana and Antsiranana, the Commune Rurale of Ramena, and the Antsingy Conservation Association and its President, Augustin Irzon. Research was funded by the British Institute in Eastern Africa, the McDonald Institute for Archaeological Research, University of Cambridge, and the University of Michigan. Field support was provided by the Musée d'Art et d'Archéologie, Université d'Antananarivo.

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