

covering approximately 150 years. It was shown that even under the extreme assumption that the Sun was responsible for all the global warming prior to 1970, at the most 30% of the strong warming since then can be of solar origin.

There are 31 periods during which the 10-year averaged sunspot number consistently exceeds a level of 50. The average length of such episodes is about 30 years, the longest being 90 years (around 9000 BC). The distribution of the durations of such episodes is given in Fig. 4a. The number of high-activity periods decreases exponentially with increasing duration. The current level of high solar activity has now already lasted close to 65 years and is marked by the arrow on the figure. This implies that not only is the current state of solar activity unusually high, but also this high level of activity has lasted unusually long. Assuming the previous episodes of high activity to be typical, we can estimate the probability with which the solar activity level will remain above a sunspot number of 50 over the next decades. The result is given in Fig. 4b, which shows that there is only a probability of  $8\%_{-4\%}^{+3\%}$  that the current high-activity episode will last another 50 years (and thus reach a total duration of 115 years), while the probability that it will continue until the end of the twenty-first century is below 1%. □

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**Correspondence** and requests for materials should be addressed to S.K.S. (solanki@mps.mpg.de).

## Archaeology and age of a new hominin from Flores in eastern Indonesia

M. J. Morwood<sup>1</sup>, R. P. Soejono<sup>2</sup>, R. G. Roberts<sup>3</sup>, T. Sutikna<sup>2</sup>, C. S. M. Turney<sup>3</sup>, K. E. Westaway<sup>3</sup>, W. J. Rink<sup>4</sup>, J.-x. Zhao<sup>5</sup>, G. D. van den Bergh<sup>6</sup>, Rokus Awe Due<sup>2</sup>, D. R. Hobbs<sup>1</sup>, M. W. Moore<sup>1</sup>, M. I. Bird<sup>7</sup> & L. K. Fifield<sup>8</sup>

<sup>1</sup>Archaeology and Palaeoanthropology, School of Human and Environmental Studies, University of New England, Armidale, New South Wales 2351, Australia

<sup>2</sup>Indonesian Centre for Archaeology, Jl. Raya Condet Pejaten No. 4, Jakarta 12001, Indonesia

<sup>3</sup>GeoQUEST Research Centre, School of Earth and Environmental Sciences, University of Wollongong, Wollongong, New South Wales 2522, Australia

<sup>4</sup>School of Geography and Geology, McMaster University, Hamilton, Ontario L8S 4K1, Canada

<sup>5</sup>Advanced Centre for Queensland University Isotope Research Excellence (ACQUIRE), University of Queensland, Brisbane, Queensland 4072, Australia

<sup>6</sup>Royal Netherlands Institute for Sea Research, 1790 AB Den Burg, Texel, The Netherlands

<sup>7</sup>School of Geography and Geosciences, University of St Andrews, St Andrews, Fife KY16 9AL, UK

<sup>8</sup>Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

Excavations at Liang Bua, a large limestone cave on the island of Flores in eastern Indonesia, have yielded evidence for a population of tiny hominins, sufficiently distinct anatomically to be assigned to a new species, *Homo floresiensis*<sup>1</sup>. The finds comprise the cranial and some post-cranial remains of one individual, as well as a premolar from another individual in older deposits. Here we describe their context, implications and the remaining archaeological uncertainties. Dating by radiocarbon ( $^{14}\text{C}$ ), luminescence, uranium-series and electron spin resonance (ESR) methods indicates that *H. floresiensis* existed from before 38,000 years ago (kyr) until at least 18 kyr. Associated deposits contain stone artefacts and animal remains, including Komodo dragon and an endemic, dwarfed species of *Stegodon*. *H. floresiensis* originated from an early dispersal of *Homo erectus* (including specimens referred to as *Homo ergaster* and *Homo georgicus*)<sup>1</sup> that reached Flores, and then survived on this island refuge until relatively recently. It overlapped significantly in time with *Homo sapiens* in the region<sup>2,3</sup>, but we do not know if or how the two species interacted.

Liang Bua is a cave formed in Miocene limestone on Flores, an island in eastern Indonesia located midway between the Asian and Australian continents (Fig. 1). The cave is situated 14 km north of Ruteng and 25 km from the north coast, overlooking the Wae Racang river valley at an altitude of 500 m above sea level (08° 31' 50.4" S, 120° 26' 36.9" E). It is 30 m wide and 25 m high at the entrance, and up to 40 m deep (Fig. 2). Formed as an underground cavern by karst dissolution, the northern end was then exposed by invasion of the Wae Racang. This river now lies 200 m distant from and 30 m below Liang Bua, but five river terraces at different elevations in the valley indicate a complex process of incision over a substantial period.

Our research at Liang Bua aims to recover evidence for the history of hominin evolution, dispersal and cultural and environmental change on Flores—an island with evidence of Early Pleistocene hominin occupation by 840 kyr<sup>4,5</sup>. Work involved removing backfill from four previously excavated Sectors (I, III, IV and VII) and then continuing the excavations. We have reached a maximum depth of 11 m without encountering bedrock.

Thus far, the most significant find at Liang Bua is a hominin skeleton in Sector VII, close to the east wall. Remains include a skull, mandible, pelvis and leg bones, some of which were still articulated when discovered (Fig. 3), with sufficient distinctive features to be designated a new hominin species, *Homo floresiensis*<sup>1</sup>.

Sector VII, 2 m by 2 m in area, was excavated to red clay containing water-rolled boulders at 7.2 m depth (Fig. 4). The skeleton, together with animal remains and stone artefacts, was deposited on a gently sloping surface in dark-brown silty clay at 5.9 m depth, then covered by slope wash sediments. There was no stratigraphic or artefactual evidence for deliberate burial. The overlying layers of clay, silt and rockfall show that this slope was maintained until light-brown and grey ('white') tuffaceous silts settled in the lower, northern part of Sector VII. These tuffaceous silts were derived from volcanic eruptions and occur elsewhere in the cave, providing a useful stratigraphic marker horizon that is bracketed by ages of 13 and 11 calibrated kyr (Supplementary Table 1a) from associated charcoal, using acid-base wet oxidation, stepped-combustion (ABOX-SC) <sup>14</sup>C (refs 6, 7 and Supplementary Information). From 4 m depth to the surface, deposits are horizontally laid and the same stratigraphic sequence extends across the cave floor, indicating a consistent pattern of sediment accumulation.

Radiocarbon and luminescence dating methods were used to infer the age of the hominin remains (Supplementary Table 1a, b), which, given their completeness and degree of articulation, must have been covered by fine sediments soon after death, when still partially fleshed. Three charcoal samples from the lowermost

excavated deposits in Sector VII were pretreated and graphitized using the ABOX-SC method, and the <sup>14</sup>C content of the most reliable component was measured by accelerator mass spectrometry. The two samples associated with the skeleton (ANUA-27116 and ANUA-27117) yielded statistically indistinguishable calibrated ages centred on 18 kyr (68% confidence intervals: 18.7–17.9 and 18.2–17.4 cal kyr, respectively).

Luminescence dating of sediments was used to confirm the validity of these <sup>14</sup>C ages; in particular that 'infinitely old' charcoal had not been contaminated by radiocarbon of Holocene age, resulting in the unexpectedly young ages for a hominin skeleton with so many primitive traits. Optical dating<sup>8,9</sup> of potassium-rich feldspar grains, using the infrared stimulated luminescence (IRSL) emissions, yielded ages of 14 ± 2 (LBS7-40a) and 6.8 ± 0.8 (LBS7-42a) kyr for samples collected above and alongside the skeleton, respectively. Both samples exhibited significant anomalous fading (see Supplementary Information), which will cause the measured ages to be too young, but we could not reliably extend the measured fading rates to geological timescales using available fading-correction models<sup>10</sup>. Both IRSL ages, therefore, should be viewed as minimum estimates of the time since the sediments were last exposed to sunlight.

Maximum ages for sediment deposition were obtained using the light-sensitive red thermoluminescence (TL) emissions from grains of quartz<sup>11,12</sup>. The TL signal is less easily bleached than the IRSL

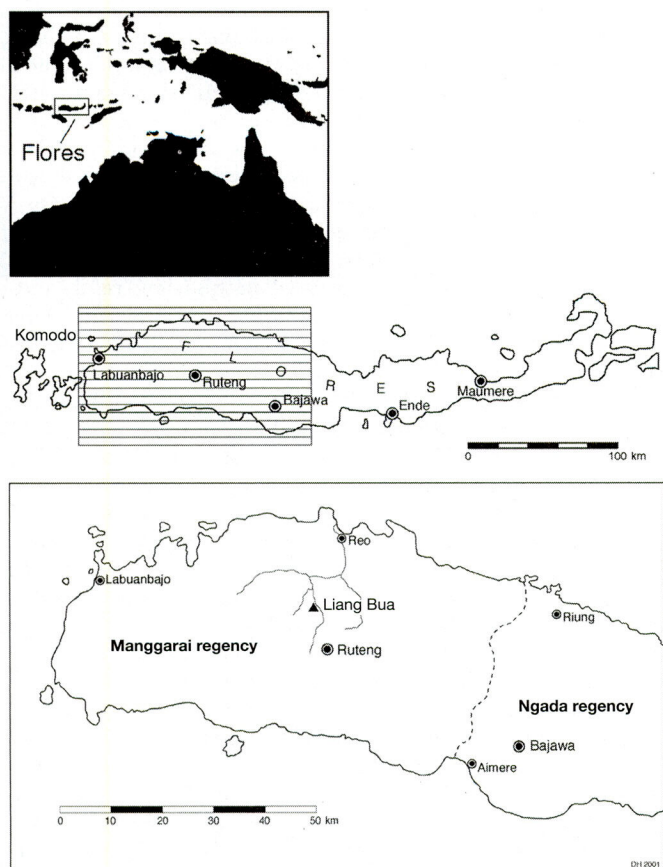


Figure 1 General location of Flores in eastern Indonesia, and Liang Bua in western Flores.

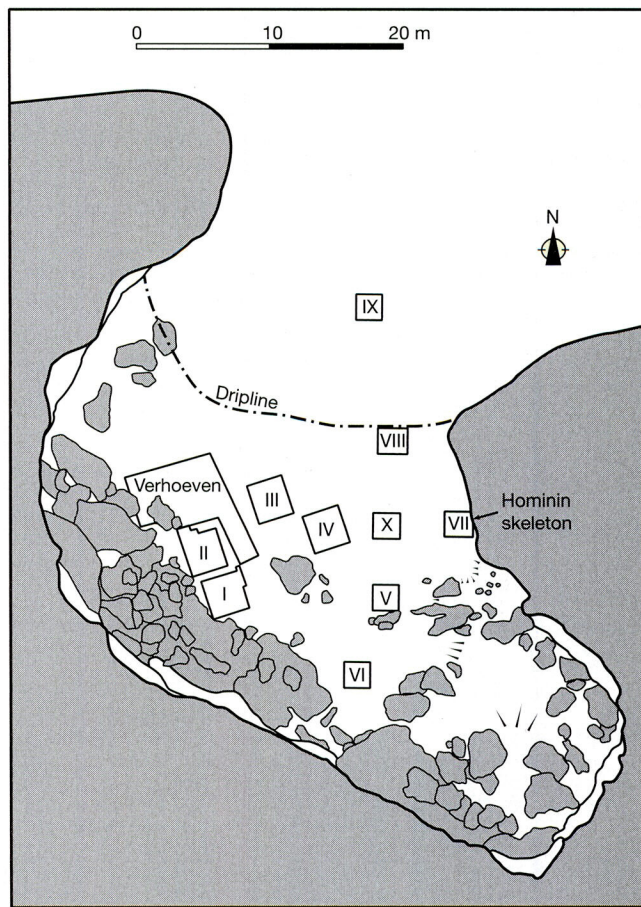


Figure 2 Plan of Liang Bua showing the locations of the excavated areas (Sectors) and the hominin skeleton (in Sector VII). Father Theodor Verhoeven carried out the first large-scale work at the site in 1965, and R. P. Soejono excavated ten Sectors between 1978 and 1989. Beginning in 2001, we extended the excavations in Sectors I, III, IV and VII.

signal, but does not suffer from anomalous fading. The TL ages for the two samples— $38 \pm 8$  (LBS7-40b) and  $35 \pm 4$  (LBS7-42b) kyr—are statistically indistinguishable, supporting our contention that the body was rapidly buried soon after death. The TL and IRSL ages bracket the time of deposition of the hominin-bearing sediments to between  $35 \pm 4$  and  $14 \pm 2$  kyr, which is consistent with the  $^{14}\text{C}$  ages centred on 18 kyr.

Diagnostic evidence for *H. floresiensis* is also found at Liang Bua in deposits of greater age, showing that we are not dealing with an abnormal individual but a long-standing population. At 4.3 m depth in Sector IV, deposits beneath a stratigraphic unconformity yielded a mandibular left premolar with the same distinctive morphology as premolars in the complete hominin mandible from Sector VII. Flowstone stratigraphically overlying the unconformity returned a thermal ionization mass spectrometry (TIMS) uranium-series age of  $37.7 \pm 0.2$  kyr (sample LB-JR-6A/13-23, Supplementary Table 1c), which provides a minimum extension of the time range for *H. floresiensis*.

In addition, a juvenile *Stegodon* molar from 4.5 m depth, just below the isolated hominin premolar, yielded a coupled ESR/uranium-series age of  $74^{+14}_{-12}$  kyr (sample LB-JR-8a, Supplementary Table 1e). Hominin remains excavated from between this dated level and 7.5 m depth, for which a maximum age of  $95 \pm 13$  kyr for sediment deposition was obtained by TL dating (sample LBS4-32a, Supplementary Table 1b), are not yet species-diagnostic. They include, however, from a depth of 5.8 m, the radius of an adult with an estimated height of about 1 m (ref. 1) that we provisionally assign to *H. floresiensis* because of its size; the holotype lacks arms for direct comparison. If confirmed, this identification would extend the minimum antiquity of *H. floresiensis* to about 74 kyr.

Concerning the behavioural context of *H. floresiensis*, associated small faunal remains include those of fish, frog, snake, tortoise, varanids, birds, rodents and bats. Many are likely to have accumulated through natural processes, but some bones are charred, which is unlikely to have occurred naturally on a bare cave floor.

The only large animals in the Pleistocene deposits are Komodo dragon and another, even larger varanid, as well as an endemic, dwarfed species of *Stegodon*. At least 17 individuals of *Stegodon* are represented in Sector IV, and at least 9 in Sector VII. The extent of

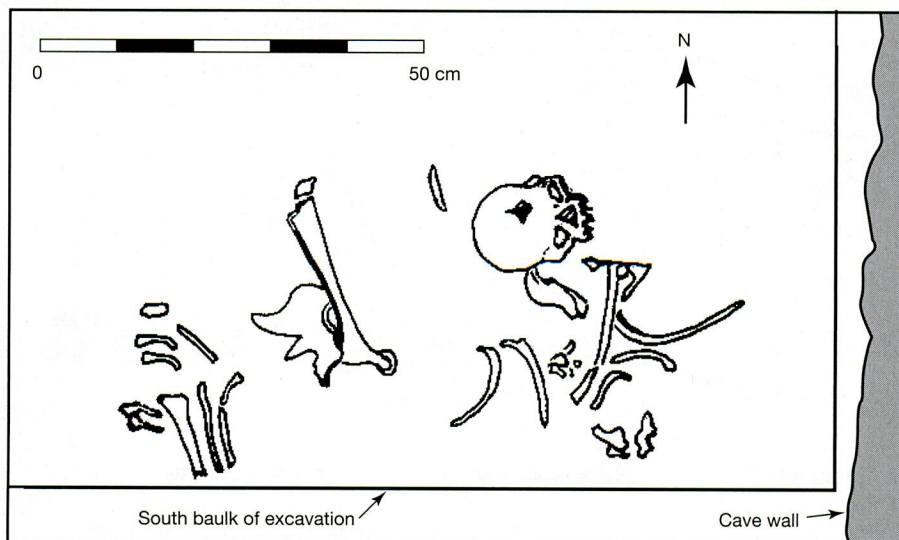
dental wear on *Stegodon* molars also indicates that most individuals were juveniles (Age Group 1 of ref. 13), with 30% (five individuals) in Sector IV being neonates. Adults are only represented by two poorly preserved post-cranial elements and a single molar-ridge fragment. Other large mammals, such as macaque monkey, deer, pig and porcupine, first appear in the overlying Holocene deposits, which lack evidence for *H. floresiensis*. These animals were almost certainly translocated to Flores by *H. sapiens*.

Peistocene deposits in Sector VII contain relatively few stone artefacts; only 32 were found in the same level as the hominin skeleton. In Sector IV, however, dense concentrations of stone artefacts occur in the same level as *H. floresiensis*—up to 5,500 artefacts per cubic metre. Simple flakes predominate, struck bifacially from small radial cores and mainly on volcanics and chert, but there is also a more formal component found only with evidence of *Stegodon*, including points, perforators, blades and microblades that were probably hafted as barbs (Fig. 5). In all excavated Sectors, this ‘big game’ stone artefact technology continues from the oldest cultural deposits, dated from about 95 to 74 kyr, until the disappearance of *Stegodon* about 12 kyr, immediately below the ‘white’ tuffaceous silts derived from volcanic eruptions that coincide with the extinction of this species. The juxtaposition of these distinctive stone tools with *Stegodon* remains suggests that hominins at the site in the Late Pleistocene were selectively hunting juvenile *Stegodon*.

The chronologies for Sectors IV and VII show that *H. floresiensis* was at the site from before 38 kyr until at least 18 kyr—long after the 55 to 35 kyr time of arrival of *H. sapiens* in the region<sup>2,3,7,14-18</sup>. None of the hominin remains found in the Pleistocene deposits, however, could be attributed to *H. sapiens*. In the absence of such evidence, we conclude that *H. floresiensis* made the associated stone artefacts.

Stone artefacts produced by much heavier percussion also occur in older deposits at Liang Bua. At the rear of the cave, for example, river-laid conglomerates contain stone artefacts, including a massive chopper. TIMS uranium-series dating of overlying flowstones indicates that these artefacts are older than  $102.4 \pm 0.6$  kyr (sample LB-JR-10B/3-8, Supplementary Table 1c), but we do not know which hominin species manufactured them.

Further afield, the Soa Basin, which lies 50 km to the east of Liang



**Figure 3** Plan of the hominin skeleton as found during excavation of Sector VII at Liang Bua. The relationships between skeletal elements and their proximity to the east and south baulks are shown. The right tibia and fibula were flexed beneath the corresponding femur

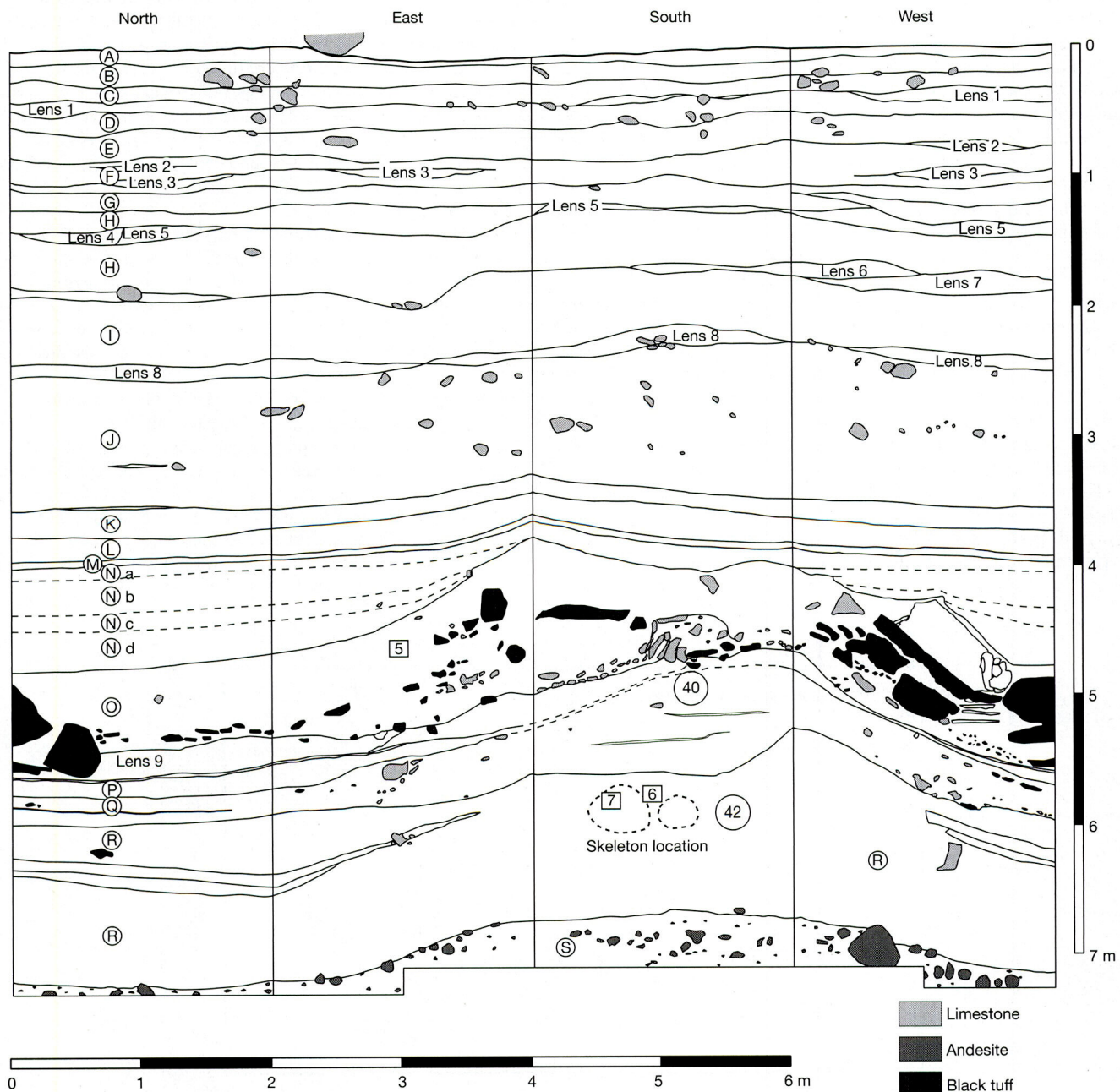
and patella. Additional skeletal remains, such as the arms, may lie in unexcavated deposits immediately to the south.

Bua, has sites of Early and Middle Pleistocene age, where the remains of Komodo dragon and *Stegodon* occur in association with simple, flaked stone artefacts<sup>4,5</sup>. It has been assumed that *H. erectus* made these artefacts<sup>19–21</sup>. The morphological traits of *H. floresiensis* at Liang Bua are consistent with *H. erectus* as an ancestral candidate, but the potential time-depth of hominin occupation of Flores means that, at this stage, we can only speculate as to which species made the Soa Basin artefacts.

Liang Bua provides evidence for distinctive hominins descended from an ancestral *H. erectus* population that survived until at least 18 kyr, overlapping significantly in time with *H. sapiens*. We interpret *H. floresiensis* as a relict lineage that reached, and was

then preserved on, a Wallacean island refuge—in the same way that Flores was a refuge for *Stegodon*, the only other large land mammal on the island during the Pleistocene. In isolation, these populations underwent protracted, endemic change; Flores was home to the smallest known species of the genera *Homo*<sup>1</sup> and *Stegodon*<sup>13</sup>.

On present evidence, the genetic and cultural isolation of Flores was only subsequently breached when *H. sapiens* appeared in eastern Asia with watercraft. How a population of tiny, small-brained hominins then survived for tens of millennia alongside *H. sapiens* remains unclear, as there is currently no evidence for the nature of their interaction; it may have involved little or no



**Figure 4** Stratigraphic section of the Sector VII excavation at Liang Bua, showing the location of the hominin skeleton. Layer key: A, coarse silt; B, silt; C–K, coarse silts; L, tuffaceous silt; M, clay; N (a–d), ‘white’ tuffaceous silts; O, clay and rubble; P, clay; Q, silty clay; R, sandy clay; S, clay with water-rolled volcanic boulders. The circles

enclosing the numbers 40 and 42 indicate the locations of luminescence samples LBS7-40 and LBS7-42, respectively, and the squares enclosing the numbers 5, 6 and 7 denote the locations of <sup>14</sup>C samples ANUA-27115, ANUA-27116 and ANUA-27117, respectively.

direct contact, symbiosis, competition or predation.

The cognitive capabilities of early hominins, however, should not be underestimated, as indicated by the technology of the stone artefacts associated with *H. floresiensis* at Liang Bua. It is also significant that hominins were able to colonize Flores by the Early Pleistocene<sup>4,5</sup>, whereas the required sea crossings were beyond the dispersal abilities of most other land animals, even during glacial periods of lowered sea level.

Clearly, the history of hominin occupation, evolution and cultural change on Flores, and by implication other Wallacean islands, is of much greater complexity than hitherto believed. For example, Lombok and Sumbawa are obvious stepping-stone islands for the hominin colonization of Flores from continental Asia and Java. If early hominin populations survived long-term on these islands,

they would have been subject to the same insular speciation pressures evident in *H. floresiensis*. Size reduction is a predictable evolutionary trend, but other trends will reflect island-specific adaptations, demographic changes and the impacts of catastrophic events, such as volcanic eruptions. □

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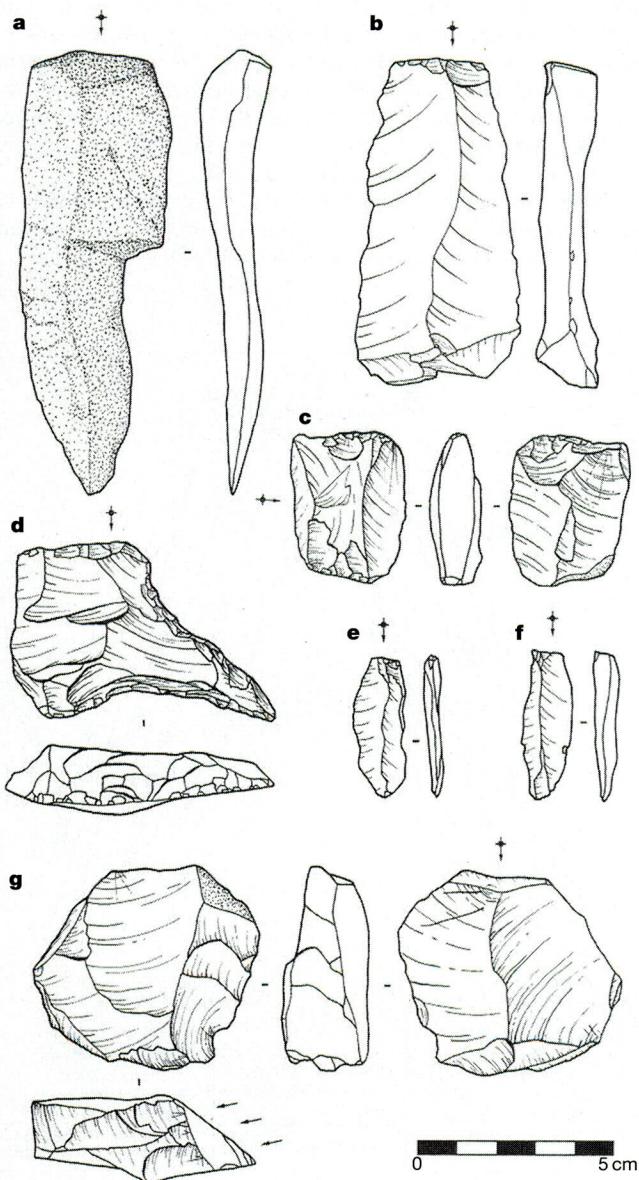
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**Author contributions** M.J.M., R.P.S. and R.G.R. planned and now co-ordinate the research program funded by the ARC Discovery Project grant, which includes the Liang Bua project. T.S. directed aspects of the excavations and analyses. Ages were provided by R.G.R. and K.E.W. (luminescence); C.S.M.T., M.I.B. and L.K.F. (<sup>14</sup>C); W.J.R. (ESR); and J.-x.Z. (uranium-series). R.A.D. and G.D.v.d.B. analysed the faunal remains, and M.W.M. the stone artefacts. D.R.H. supervised the stratigraphic section drawings and other aspects of the project.

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**Correspondence** and requests for materials should be addressed to M.J.M. (mmorwood@pobox.une.edu.au) and R.G.R. (rgrob@uow.edu.au).



**Figure 5** Range of stone artefacts associated with remains of *H. floresiensis* and *Stegodon*. **a, b**, Macroblades. **c**, Bipolar core. **d**, Perforator. **e, f**, Microblades. **g**, Burin core for producing microblades. Arrows indicate position of striking platforms, where knappers detached the flakes from cores by direct percussion using hammerstones.