

Supplement I: Geology and Discovery Record of the Trinil *Pithecanthropus erectus* Site, Java

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SUPPLEMENT I (SI I)

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REFERENCES

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Pithecanthropus erectus



SI I-1. *Pithecanthropus erectus* Skullcap (Trinil 1, left) and proximal portion of Femur I (Trinil 3, right);. The Skullcap photograph was taken at the Naturalis Biodiversity Center, Leiden, by the authors (Huffman et al. 2015). The image of the femur is colorized from a Dubois (1926: Figure 1, SI II-242; also, SI II-241).

When Dubois notified government sponsors of the Skullcap discovery in October 1891, he transmitted two specimen photographs (now lost) and reported, “*the upper part of the occipital portion is covered by a stony mass so hard and strongly adhering to the bone that it cannot be removed for the time being without causing damage to this precious fossil*” (SI II-173). This external mass was “*mainly consisting of the same lime concretion found at many places in the lowlands of central Java on bones extracted from the black clay*” (SI II-173). Dubois (1894a) cleaned off the hardened exterior agglutinate before he departed Java in 1895. He clarified the geological distribution of carbonate concretions, writing “*many bones from Trinil, which in sandstone-like tuffs at the surface [exposures of the LB are] partially covered with lime [CaCO₃] concretions, that adhere tightly to its surface. This is especially so with some [Axis lydekkeri] deer antlers ... and a large buffalo skull [Bubalus palaeokerabau]*” (SI II-208). He further noted, “*limestone concretions [occur] near Trinil at various levels (even up to 10 meters below the surface [in the incised embankment]) between thin beds of 1-, 2- to 3-cm thickness*” (SI II-209). Pebble conglomerate filled the Skullcap endocranial cavity, further making *in situ* discovery clear (Figure 2b, main text). Dubois did not remove the cranial fill until after September 1895. The endocranial surface which emerged is finely preserved, but full preparation of the exterior revealed it to be pitted much beyond the area affected by the stony mass (Dubois 1924b: Plate II: Fig. 1-3).

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Left Bank Outcrops

a LEFT BANK OUTCROPS AROUND THE 1891-1908 EXCAVATIONS



b CROSS-BEDDED CONGLOMERATIC SANDSTONE IN BAULKS

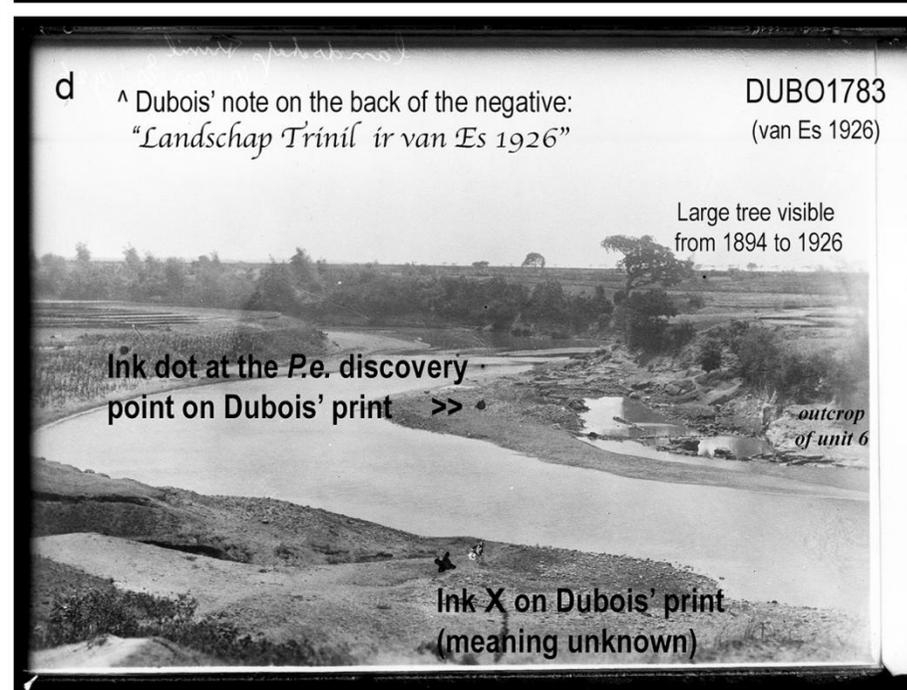
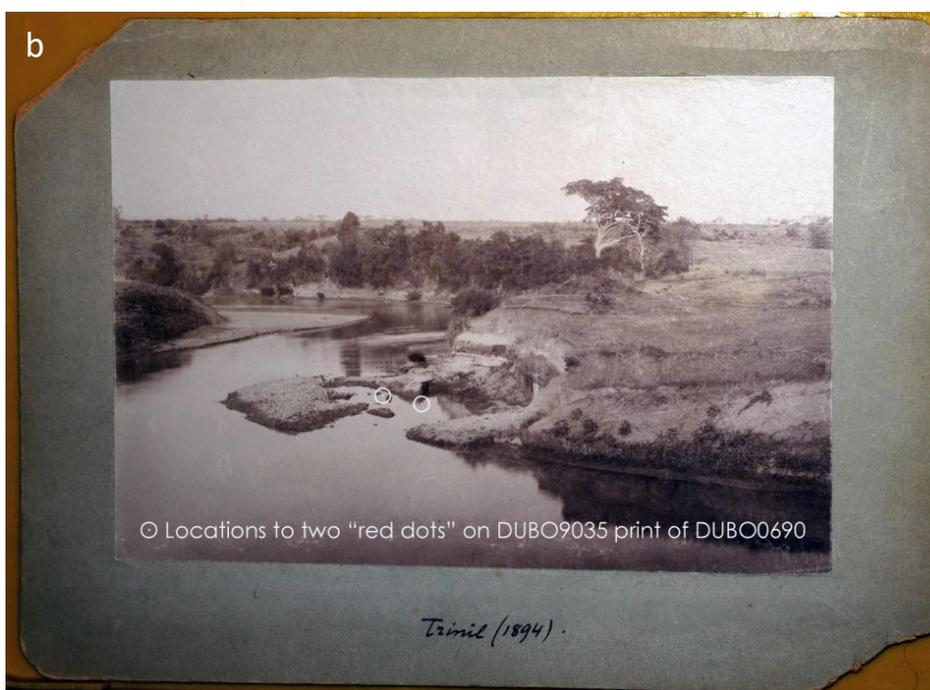
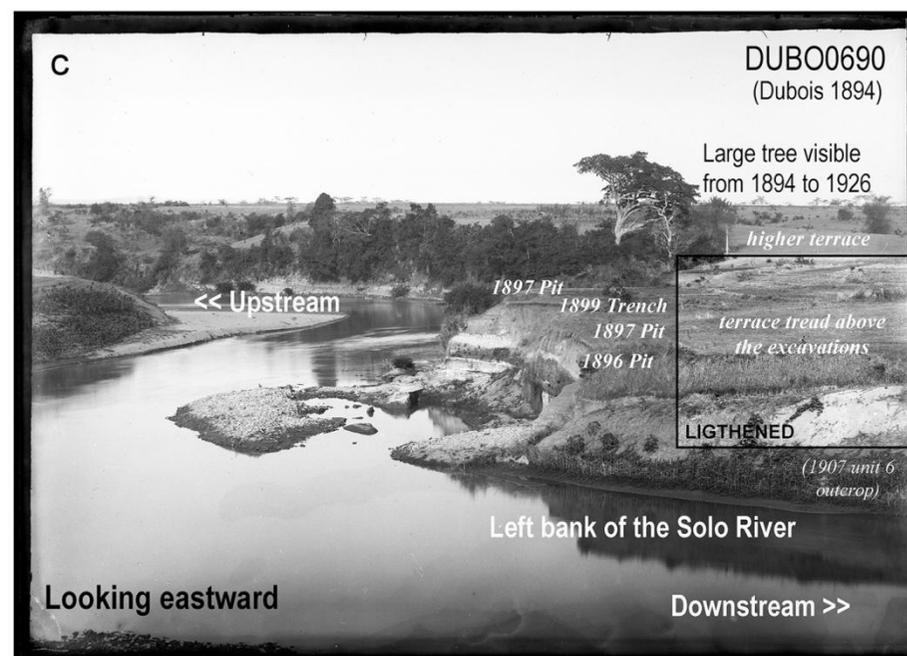
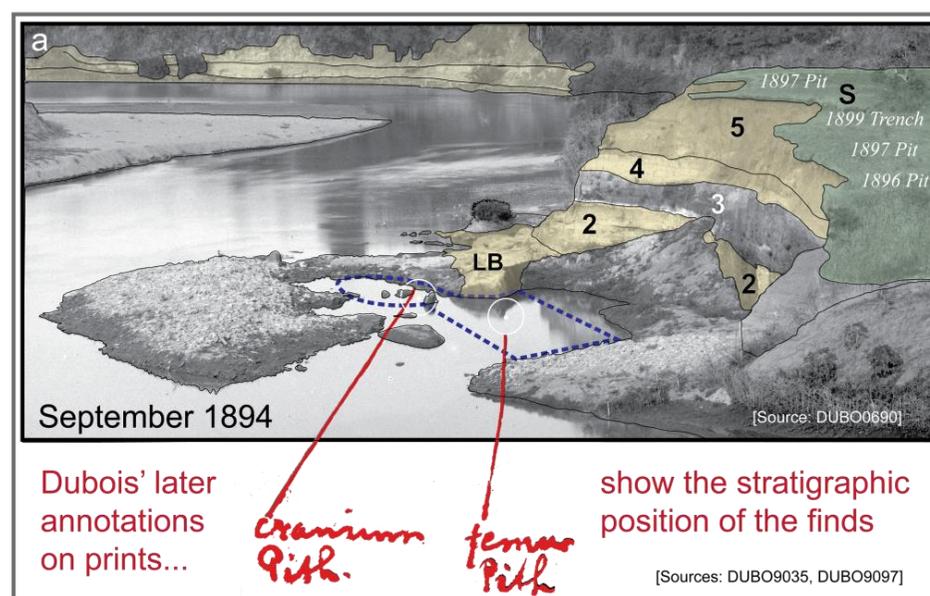


SI I-2. (a) Excavation-scars and -baulks are exposed along the left bank of the Solo during dry season periods of low-water level (also, Huffman et al. 2018). This 2008 view looks westward across former trenches and excavated platform (foreground) towards a mid-river gravel bar which partially covers the former 1891-1892 *Pithecanthropus erectus* (*P.e.*) discovery area. One author (OFH) analyzed the stratigraphic sequence exposed in the platform, finding that Soeradi et al 1985 (SI I-18) represented key stratal relationships reasonably well (Huffman 2016). Another current author (PCHA) investigated the outcrops near the *P.e.* discovery spot in 2018. (b) An enlarged portion of ‘-2a’ highlights cross-bedded conglomeratic sandstone exposed. From Dubois’ Java years onwards, geological studies have treated the *P.e.* bonebed and superjacent strata as bedrock (e.g., van Es 1931, Duyfjes 1936, Soeradi et al. 1985, and I.J.J.S.T. 1992; SI II-16 to -19). Scores of site photographs and first-hand accounts from the period of excavation substantiate the lithified condition and flat-lying attitude of the eight-to-nine meters of volcanoclastic strata that were excavated between the main bonebed and soil of the terraced upland surface to the south (de Vos and Aziz 1989; Huffman et al. 2015, 2018). The highest-elevation terraced surfaces in the valley lie ~20 above the river (e.g., SI I-7a). Source for this image is the YouTube video “Trinil 3” by Chris Turney (posted April 28, 2008; downloaded 01/20/2014).

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Historic Left Bank Outcrops

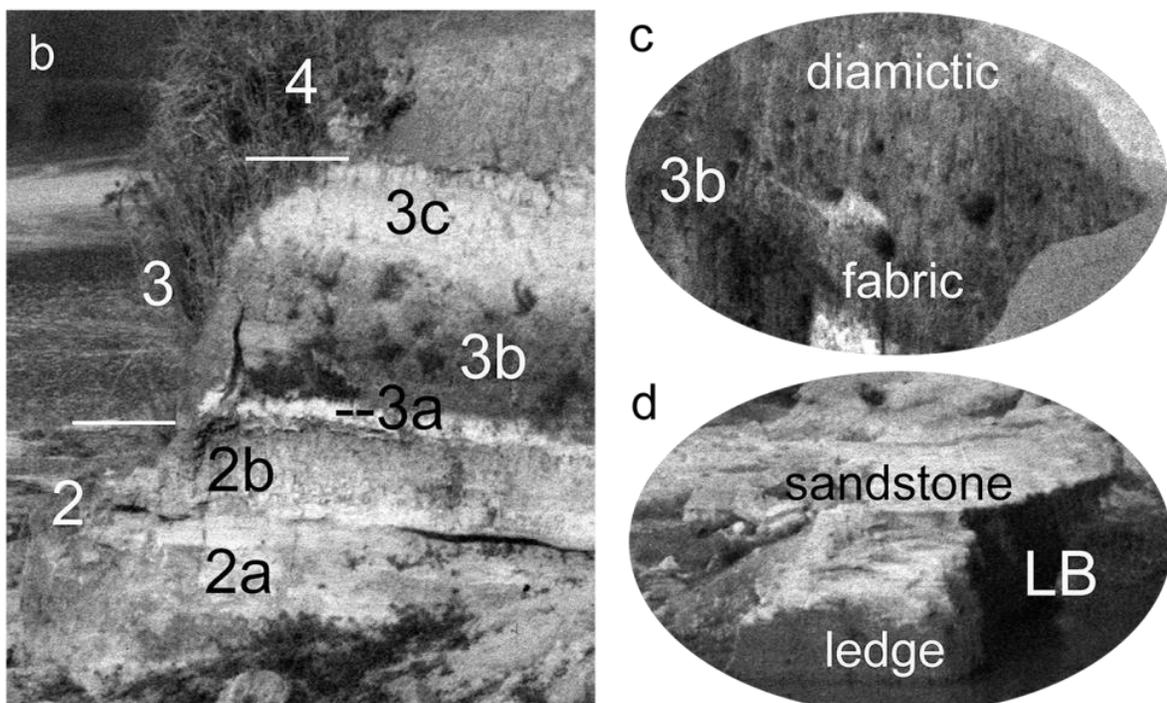


SI-3. Dubois' annotations on unpublished prints of the 1894 photograph situate the *Pithecanthropus erectus* discovery relative to nearby geography and geology (Huffman et al. 2015, 2018). (a) Dubois' annotations (Figures 3c and 4a, main text) and our interpretations of them tie the discovery site to the stratigraphic units that we recognize in the nearby embankment and later Dubois excavations, as detailed in SI I-4. The unit 2 outcrop in 1894 was partially obscured by material that had collapsed from near soil level in the 1893 40-m Trench. (b) One of Dubois' annotated prints of the 1894 photograph has his handwritten inscription "Trinil (1894)" and two dots at the discovery points. Another print has markings that highlight the discovery pits and trenches, and shows the placement of the "Cranium Pith." and "Femur Pith." (as used in Figure 3c, main text). The back side of a third print has the Dubois note, "Find spot of *P. erectus* viewed from near the pillar Trinil September 5 1894," the pillar being the Dubois monument at the present-day Trinil Museum dedicated to the *Pithecanthropus erectus* discovery (code for the annotated print is DUBO3286). Annotated scans of the complete 1894 image (c) and a 1926 photograph (d), both of which look eastward from about the same camera station located on the right bank near the Dubois' 1893 pillar, allow the images to be superimposed and the extent of 1895-1908 excavations to be visualized (Figure 9, main text, and SI II-42). The ink dot is absent in van Stein Callenfels' (1929) published version of the 1926 photograph.

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High-resolution scan of Dubois' 1894 photograph

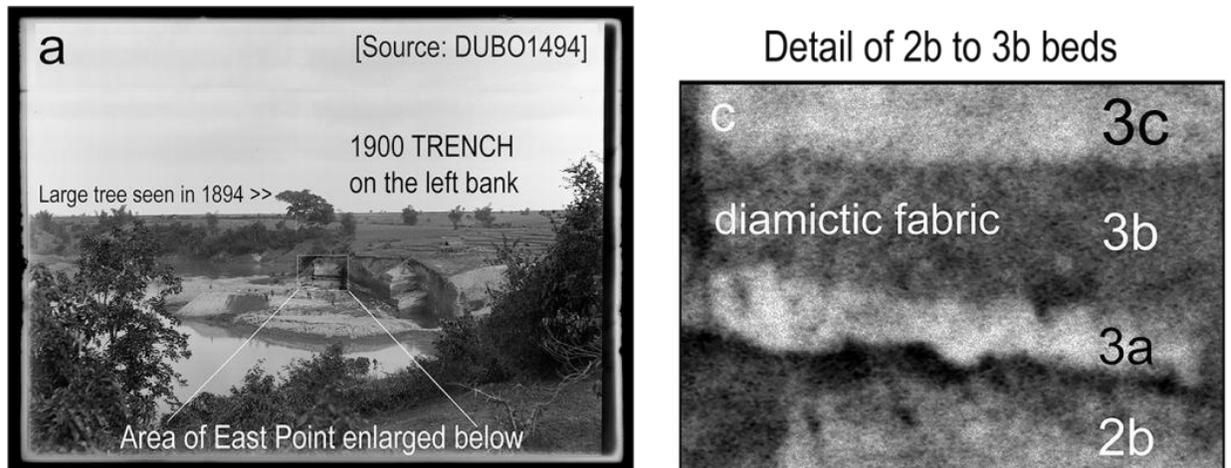


SI I-4. High-resolution scanning of Dubois' 1894 photograph allows the beds in the former backwall of the 40-m Trench to be divided into useful stratigraphic units, **LB** (1) and **2-4**, as presented in Figures 3c and 4a, main text (also, Huffman et al. 2015, 2018). (a) The inundated excavation around the discovery points (SI I-3a) has a shape fitting the combination of the Skullcap Pit, 25-m Trench and 40-m Trench (Figure 3a, main text). (b and c) Unit **2** includes light-colored subunits. The upper one is notable for a prominent depositional base. The middle of unit **3** consists of a dark-colored subunit exhibiting an apparent diamictic sedimentary fabric, which would probably represents lahar deposition. The lighter-colored subunits above and below this diamictic subunit might contain unusually high volcanic ash content. Volcanic diamictons are often termed “breccia,” “tuff breccia,” “conglomeratic tuff” or “boulder tuff” by geologists working on the Neogene in Java. These diamictons are characterized by extreme ranges in clast sizes, and often have boulders in a sand-mud matrix. (d) The rock ledge beside the Pit and trenches appears to consist of indurated sandstone that would have formed at the top of Dubois' Bed of Lapilli (our Lapilli bed, **LB**; Figure 2a, main text).

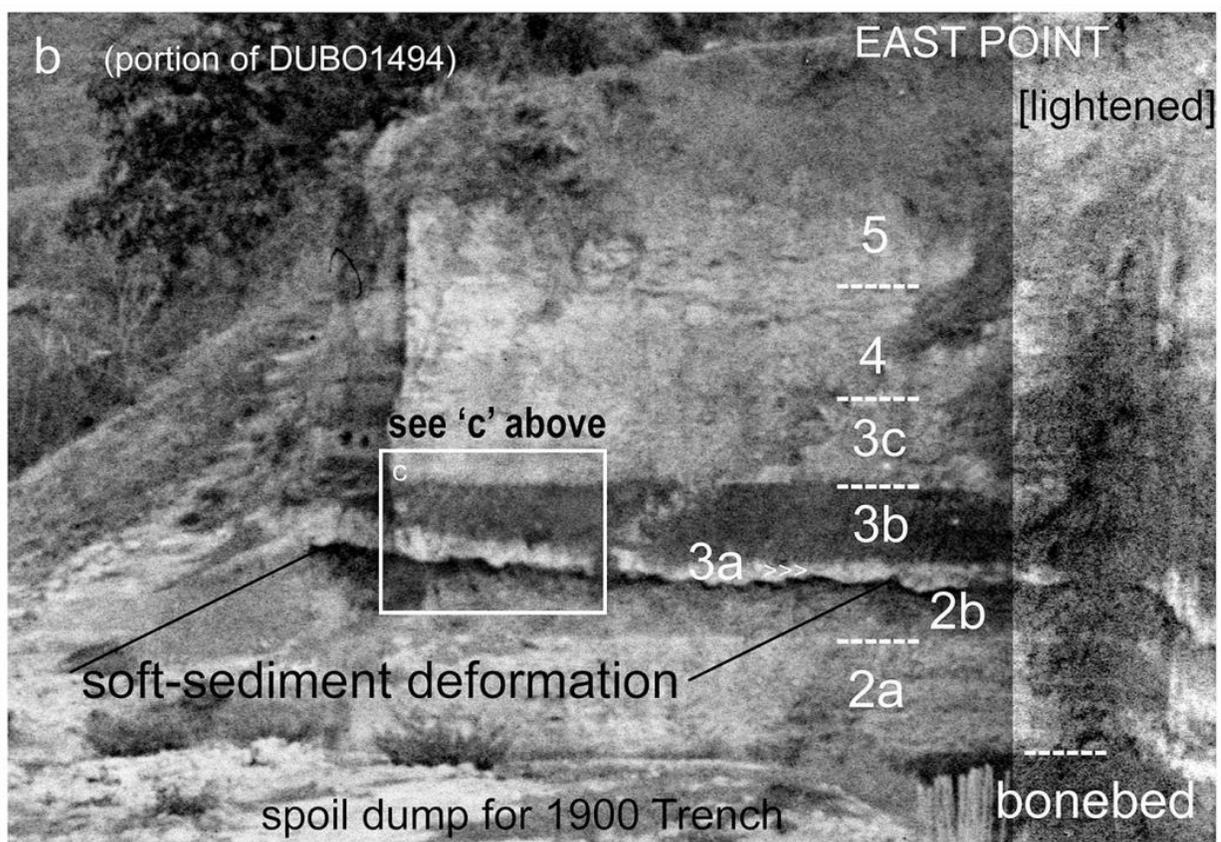
Supplementary Information [part] I

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High-resolution scan of Dubois' 1900 photograph DUBO1494



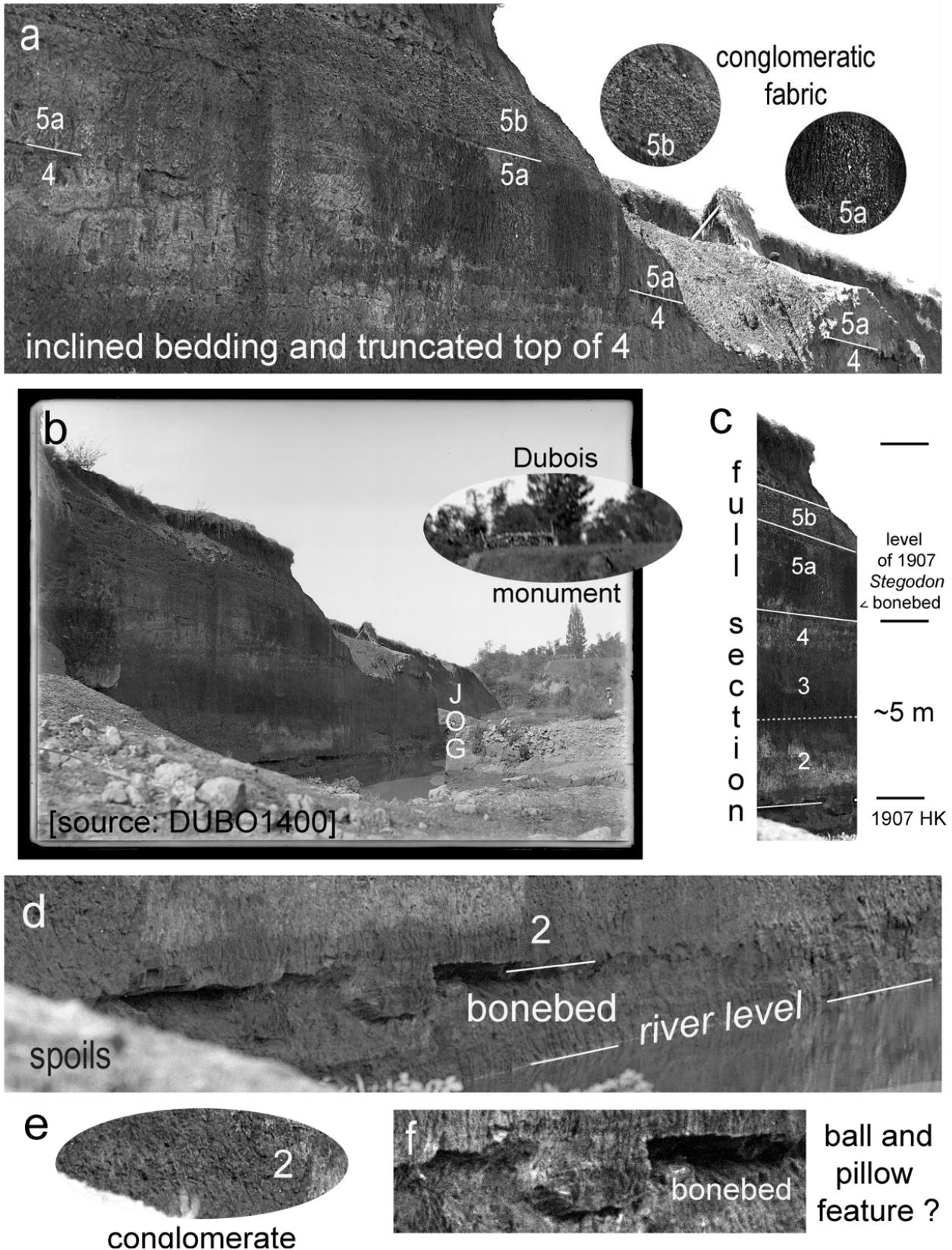
Stratigraphic detail of Dubois' 1900 Trench near East Point



SI I-5. This key November 1900 photograph, which was taken from Camera station II (SI I-7a), shows that the stratigraphic units recognizable in the 1894 embankment extended into the 1900 Trench. Its backwalls around East Point reveal stratigraphic and sedimentological details that are particularly useful for stratigraphic correlation with the 1894 image. The units lie at about the same elevation (relative to seasonal low-water levels) in 1900 as they did in 1894, demonstrating that the units in the 1892-1900 excavations were essentially flat lying. The stratigraphic continuity between the excavated sequences is clearest for unit 3, largely due to the distinctive diamictic fabric of its middle subunit and the light-colored basal subunit. The soft-sediment deformation features, such as those that 3 appear to exhibit, reflect sedimentary accumulation atop a substrate that was unconsolidated at the time of deposition. When this photograph was taken in November, the excavators were unearthing the main bonebed (LB-HK) in the western part of the 1900 Trench (Figure 4a, main text). The Camera station II was a top of the right bank north of the Dubois monument (II in SI I-7). Negatives of Dubois' three 1900 photographs were scanned for our use courtesy of the Naturalis Biodiversity Center at 4800 dots-per-inch resolution.

Supplementary Information [part] I
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High-resolution scan of Dubois' 1900 photograph DUBO1400

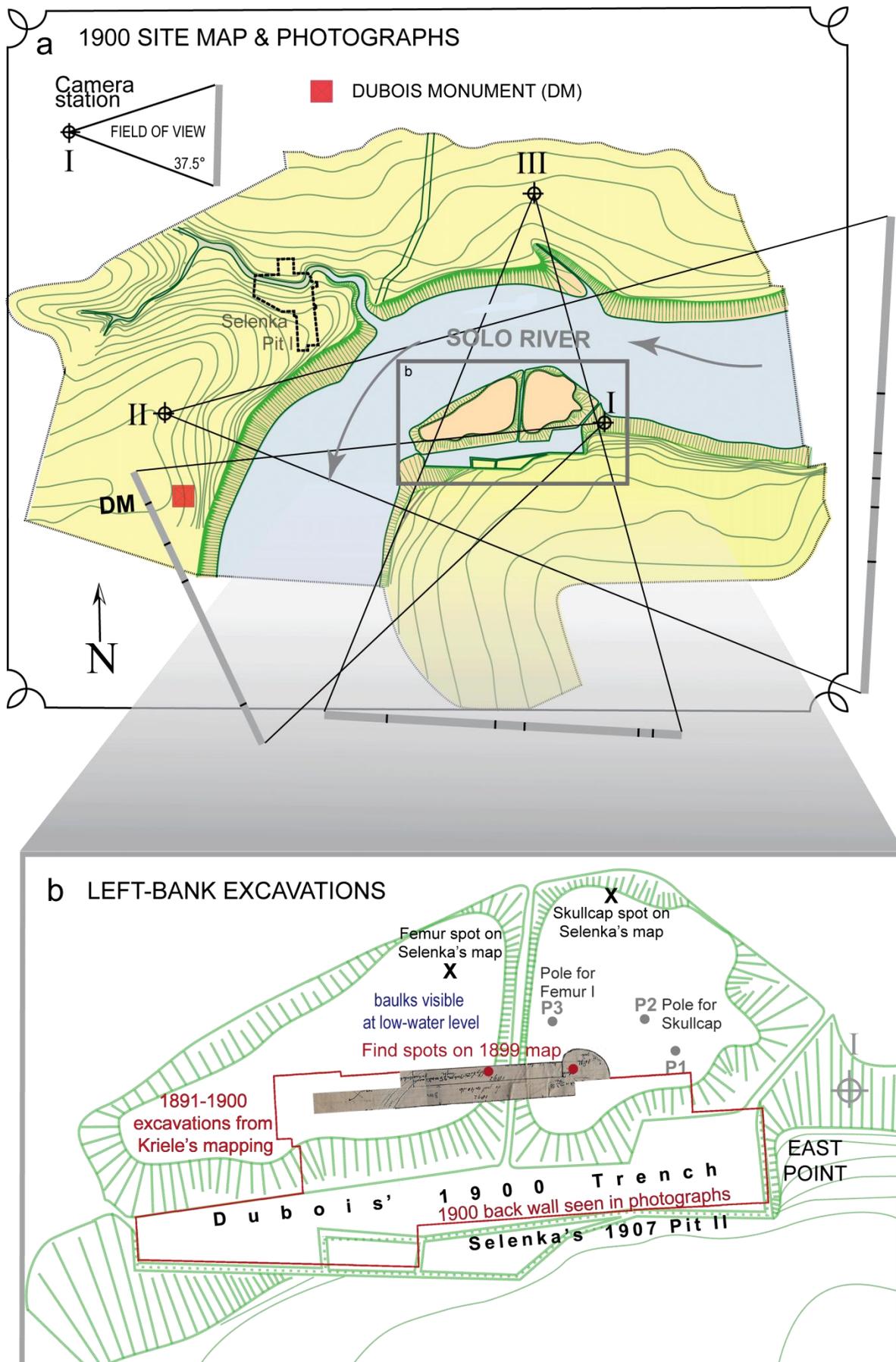


SI I-6. A third Dubois 1900 photograph, which was taken from Camera station I (SI I-7a), shows the main bonebed (**LB-HK**) when freshly excavated and the common occurrence of conglomeratic fabrics in the overlying beds. A portion of unit 5 near the JOG in the backwall (Figure 5a, main text) has been cut back near the top of the embankment, apparently due to soil instability. The Dubois monument is seen on top of the right-bank in the distance with trees that Dubois had planted (SI II-69).

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Topographic features of the Trinil area in the 1900 Site Map

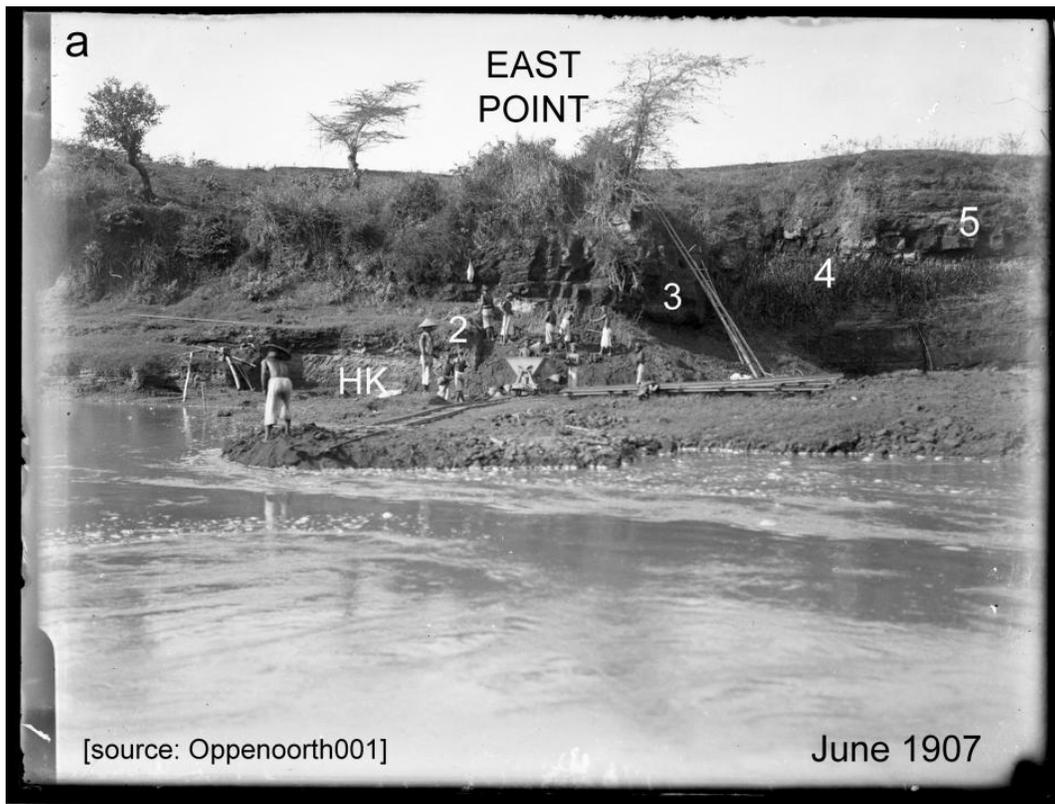


SI I-7. The topographic features of the Trinil area in the 1900 Site Map, a document that Dubois possessed but did not publish (Figure 6a, main text). (a) The locations of the three 1900 Camera stations (I-III) are given, and we determined the photographic fields of view from landscape points visible in multiple photographs. We used the intersections of rays from the camera stations through the poles P1-P3, points on trench backwall, and many other landscape features to verify their relative locations (the tick marks on the gray bars denote examples of the rays used). The terrace upland on the right bank around Dubois monument sits at a significantly higher elevation than the terrace south of the 1900 Trench on the left bank. (b) Attempts to position the Skullcap and Femur I discovery points relative to the modern landscape have proved problematic. Locations in Kriele's 1899 map (red dots, here; also, Figure 3, main text), the three poles on the spoil pile visible in several 1900 photographs (Figure 4, main text) and Selenka relocation points (Figure 6b, main text) are inconsistent with other records. Moreover, the exact spatial relationship between Dubois' 1900 Trench and the Selenka Expedition 1907 Pit II is not fully established (also, Alink et al. 2016). This version of Dubois' 1900 Site Map was made from Naturalis Biodiversity Center scan M...059-220 (SI II-222; also, SI II-224/-225); the image of the 1891-1893 pits and trenches is from Figure 3a, main text, and the outline of 1891-1900 excavations is from SI II-135 and -155.

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Selenka Expedition Photographs June 1907

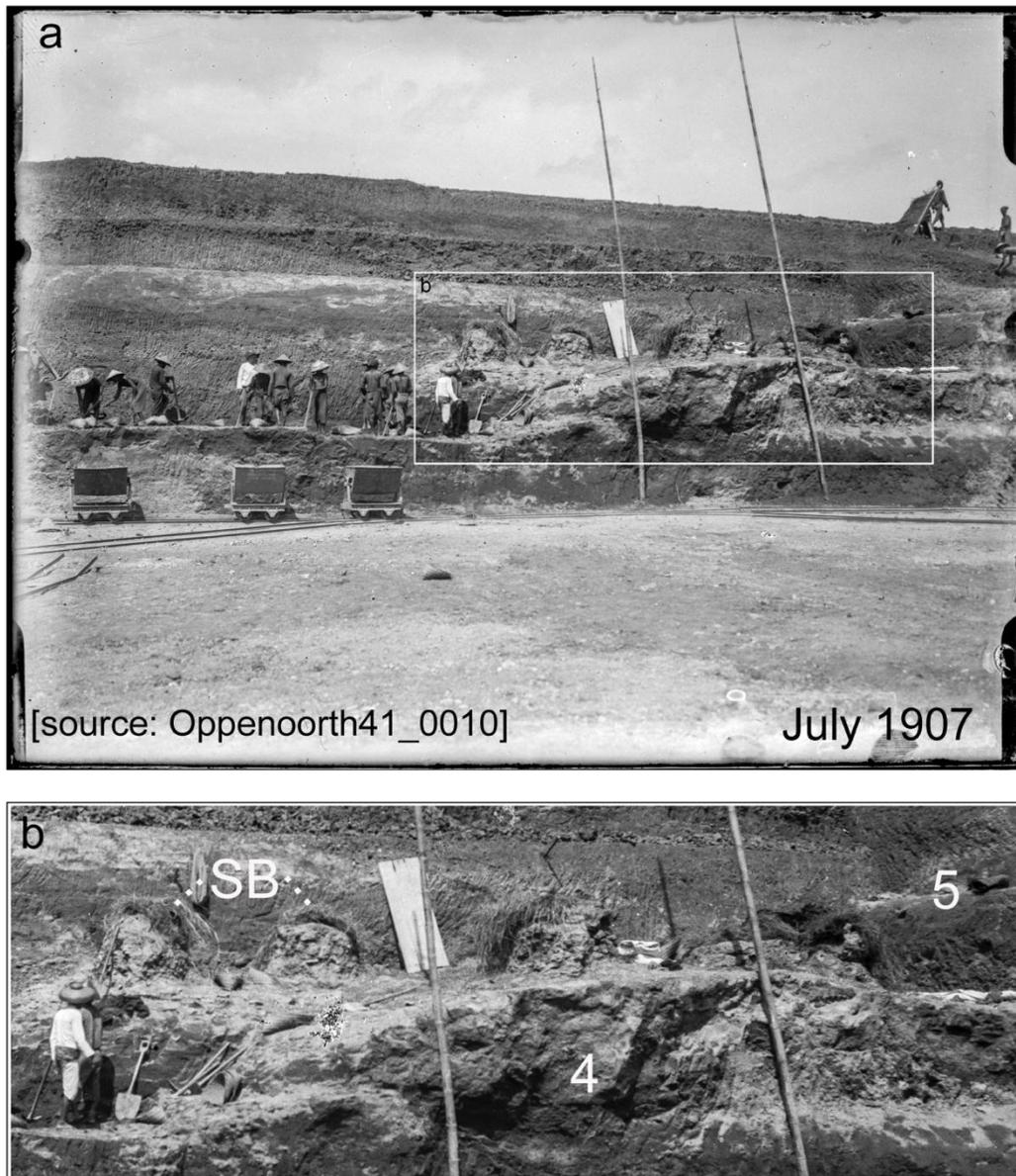


SI I-8. Selenka Expedition personnel readily identified the *Pithecanthropus erectus* bonebed on the left bank in 1907, as illustrated in these photographs taken by supervising geologist W.F.F. Oppenoorth. (a) He had begun excavating near East Point by June 1907. About this time, the bonebed “*was visible from the Solo when it was exposed above water and immediately produced ... bones and teeth;*” a buffalo skull had already been found at the site (Oppenoorth 1911: Fig. 20, xxxiv, Berkhout and Huffman 2021: 37). The bonebed was termed the Hauptknochenschicht (**HK**) later in 1907 (SI II-250; also, Berkhout and Huffman 2021). Units **2** and **3** are recognizable in the former walls of Dubois’ 1900 Trench to the right and left of the ladder, where grass and detritus still covered the walls in June 1907. (b) A greater area of the **HK** was unearthed as the river level fell during mid 1907. J.M. Oppenoorth made these images available to us from her family archives; negatives were scanned at high resolution courtesy of Naturalis Biodiversity Center.

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Selenka Expedition Photograph July 1907 (Oppenoorth41_0010)

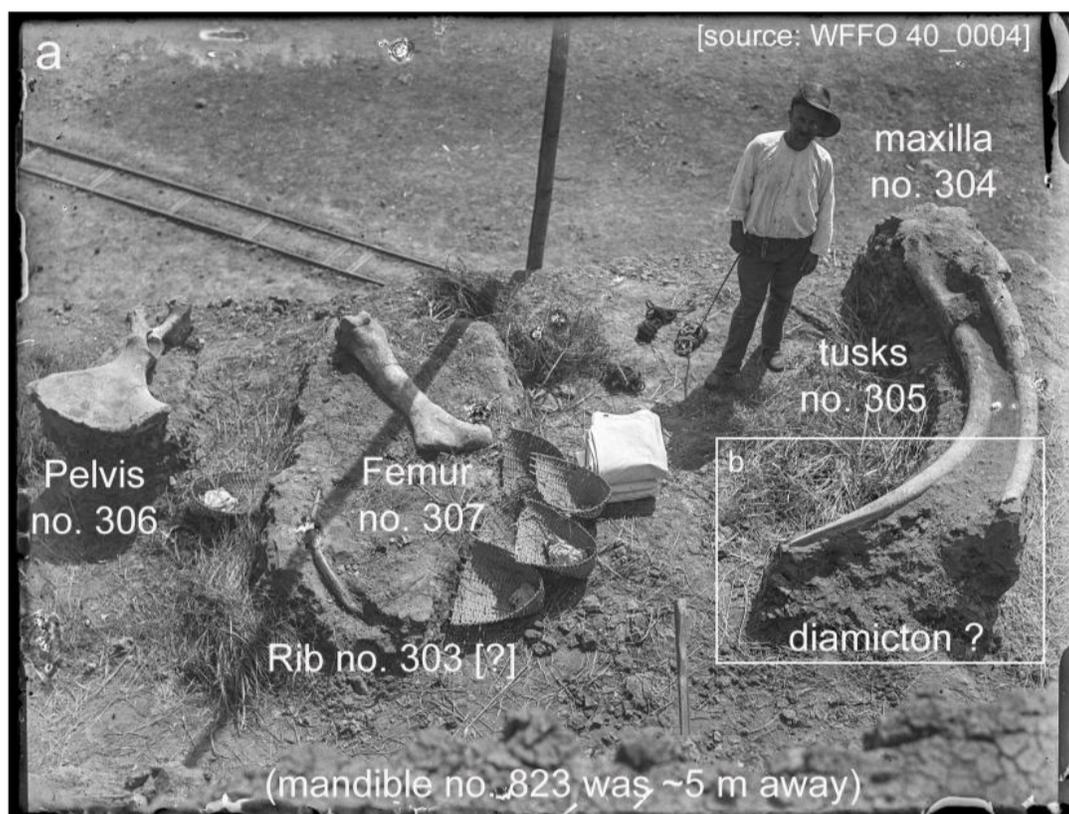


SI I-9. Selenka's excavators encountered hard-to-dig strata as they deepened the 1907 Pit II downward from the terrace upland, which was being cut into stair-steps over a broader area (shown in Figure 6b, main text). (a) *"In the beginning of July the steep riverbank ... , landward of Dubois' excavations, was removed the highest wall reached 8 to 9 meters"* (Oppenoorth 1911: xxxiv, Berkhout and Huffman 2021: 37). As Pit II was expanded westward from East Point (Figure 7b, main text), a shallow fossil concentration, the *Stegodon* bed (SB), was encountered (SI I-10). (b, a closeup from 'a') The SB fossils are seen covered with straw while awaiting removal. The strata below the SB (our unit 4) formed blocky excavation faces of well-lithified sedimentary rock, most likely sandstone (contradicting proposals of terrace deposits occurred above main bonebed level in the excavations, SI I-35). J.M. Oppenoorth made the negative of this image available to us from her family archives. The negative was scanned in 2015 at 4800 dpi resolution courtesy of the Naturalis Biodiversity Center (we provided the source code convention used).

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Selenka Expedition
Photograph July 1907 (Oppenoorth40_0004)



SI I-10. (a) The proboscidean remains in the *Stegodon* bed (SB), Selenka Pit II, were predominantly the disarticulated and dispersed elements of a large *Stegodon trigonocephalus* individual. The remains occurred at the top of bed with a clayey conglomeratic sedimentary fabric (also, SI I-9) which appears to be indicative of laharic deposition (also, Oppenoorth 1911: Fig. 24, Berkhout and Huffman 2021: 42). Farther west near the ‘JOG’ in the backwall of the 1900 Trench (Figure 5a and 7a, main text), this stratigraphic level was poorly resistant to erosion, apparently due to its muddy lithology (Figures 4, 7 and 8, main text). (b) Oppenoorth (1911: xxxvi) characterized the SB as “light grayish clay” and described the proboscidean remains as “a skull with upper jaw and tusks (2.10 meters long...), a thigh bone (over 1 m long), the pelvis and ribs, ... associated lower jaw... vertebrae, two ribs and a femoral head (see [his] Fig. 23 [xxxvii]) [and] *hippopotamus molars*” (Berkhout and Huffman 2021: 40 and 41). Mandible 823 is anatomically larger than multiple *Stegodon* mandibles that are reasonably attributable to the main bonebed (van den Bergh 1996 in Table 4, footnote 4, main text; also, Janensch 1911, Pohlich 1911, and Selenka and Blanckenhorn 1911, Tafel XXIV, Berkhout and Huffman 2021: 155). J.M. Oppenoorth made a photographic negative of this image available to us from her family archives, and in 2019, the negative was scanned at 4800 dpi resolution (courtesy of the Naturalis Biodiversity Center) to illustrate the taphonomy of the *Stegodon* remains.

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Selenka Expedition

Plate I, fig. 2 and plate VII, fig. 2 from Selenka and Blanckenhorn, 1911

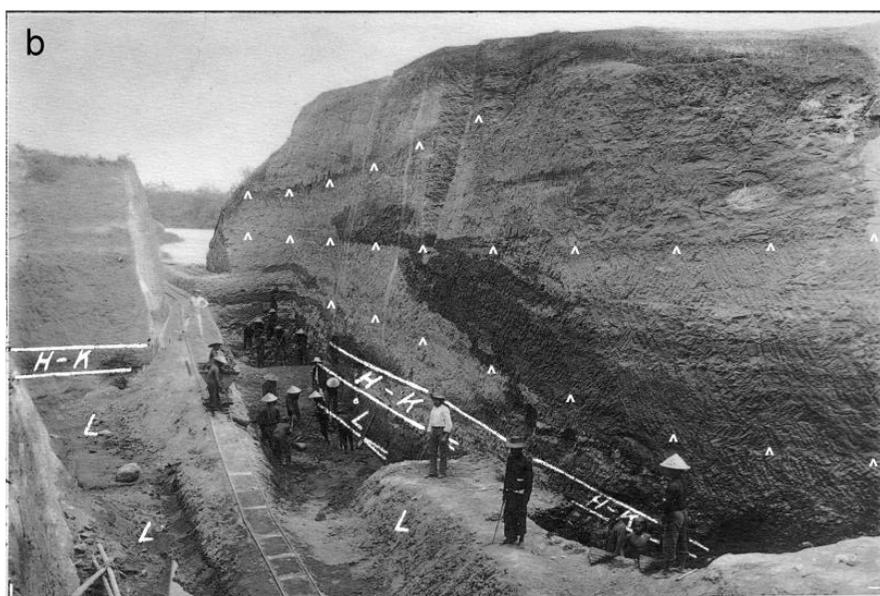


Fig. 2. Grube I am rechten Ufer des Soloflusses Anfang August 1907. (Phot. von Carthaus)

H-K = Haupt-knochenschicht
Main Bonebed

L = Lahar-konglomerat
Lahar conglomerate

PIT I FOSSIL-ENTRY FREQUENCY IN THE 1907 LISTING FOR HAUPTKNOCHENSCHICHT (SUBUNITS) LAYERS 15, 16 AND 17

U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A	layer
-8																					15
-7																					16
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36																					16
37																					17

LEGEND

Letter of column > **C B A**

15	10	2	3	15
16	1			16
17	0(1)	2	3	17

Number of row ^ Number of entries for each layer within the meter square. Numbers in the parantheses with Layer 17 are finds below the HK. Numbers in the parantheses with Layer 15 are finds above the HK.

In each square of the 1907 Pit I, the number of 1907 Listing entries (which have both layer number and location square information) is posted graphically here:
Layer 15 (top number),
Layer 16 (middle number) and
Layer 17 (bottom number).

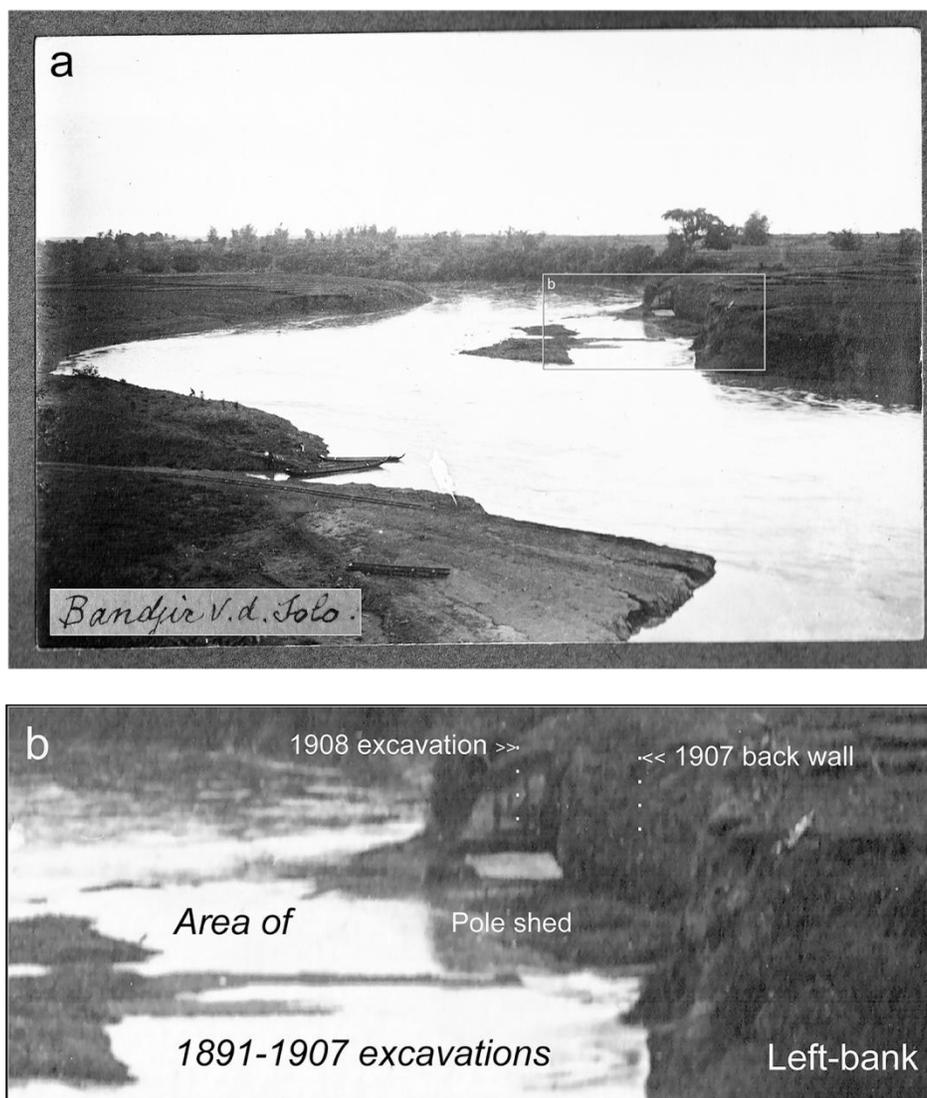
Table 2 (main text) lists:
545 entries from Layer 15,
86 entries from Layer 16,
and 429 entries from Layer 17.

SI I-11. (a) The base of the channelized unit 6 is seen to reach river level west of 1907 Pit II (from Selenka and Blanckenhorn 1911: Plate I, Fig 2, Berkhout and Huffman 2021: 5). (b) The strata above the **HK** in the right-bank Pit I, north of the present-day Trinil Museum (Figure 6a, main text), also contained channel-form features (Selenka and Blanckenhorn, 1911: Plate VII, Fig. 2, Berkhout and Huffman 2021: 50). The ^s have been added to highlight selected sedimentological relationships. Despite lithofacies in Pit I and II, the Selenka Expedition geologists do not appear to have established a reliable stratigraphic correlation between deposits in the two excavations (SI I-7a shows their locations). The uncertainty continued when Duyfjes (1936) attributed some of the post-**HK** sequence on the right bank to terrace deposits, while recognizing all the post-**HK** sequence on the left bank to be his bedrock Kabuh Formation (SI I-16). (c) The 1907 Listing of Selenka fossil finds (PM_S_II_Selenka_FB_1-78, Museum für Naturkunde, Berlin) allows their irregular vertical and horizontal distribution fossils within the Hauptknochenschicht (**HK**) to be mapped (north is up). The **HK** finds were reported for the three stratigraphic layers in Pit I (Table 2, main text) and the distribution for each subunit is shown for each one-meter square.

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Selenka Expedition October 1908 Photograph



SI I-12. The high backwalls of the 1907 Pit II were still standing vertically in 1908. (a) This photograph, which looks upriver from a high point on the right bank, shows that most of Pit II was inundated by flooding in October 1908. (b) A portion of the 1907 backwall near East Point was freshly excavated (the face behind the pole shed with a light-colored roof). The photograph was taken (without known scientific purpose) by W.J. ('Wim') Oppenoorth, a friend of Selenka Expedition geologist C.M. Dozy and the brother of W.F.F. Oppenoorth; the photograph is in an Oppenoorth family album and labeled "*Banjir of the Solo,*" referring to a flood stage of the river (inset within '-12a'; J.M. Oppenoorth, pers. comm., 2019). W.J.O.'s granddaughter has the album, and J.M. Oppenoorth, his grandniece, provided us with a scan of the photograph and its provenience history.

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Selenka Expedition
June 1907 photograph(Oppenoorth41_0005)

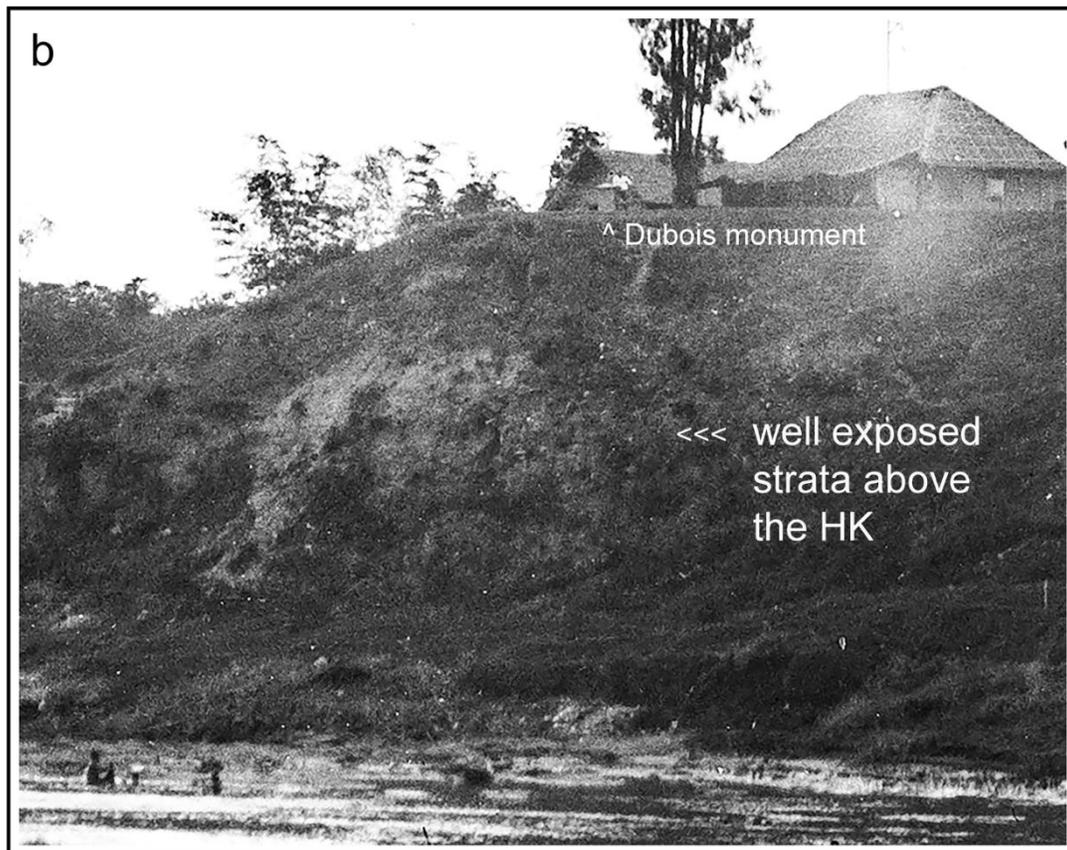
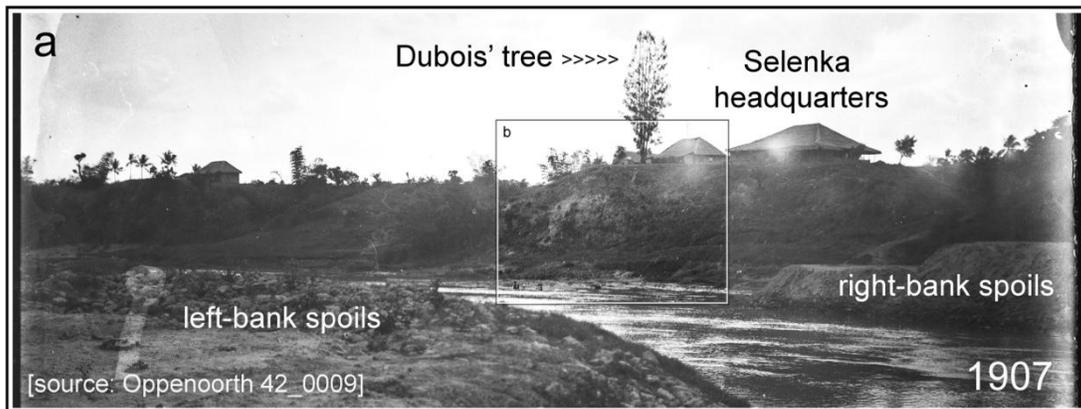


SI I-13. The Selenka Expedition Pit I encountered flat-lying, well-indurated volcaniclastic and muddy strata, which were amply described and pictured in the Expedition's published and unpublished materials. (a) The sedimentary consolidation of the stratal sequence is evident in this high-quality unpublished version of an image taken in June 1907 by W.F.F. Oppenoorth (see Selenka and Blanckenhorn 1911: Plate III, Fig. 3, Berkhout and Huffman 2021: 36; J.M. Oppenoorth provided a negative which Naturalis Biodiversity Center scanned at our request). (b) Near the bottom of the excavation, as this enlarged portion shows, a group of workers were using pickaxes to unearth the **HK** and several meters of superjacent beds. The **HK** had already been removed from the nearby inundated area, and the horizontal structural attitude of the **HK** is clear from its interface with the water.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Selenka Expedition Photograph July 1907 (Oppenoorth42_0009)



SI I-14. From Dubois' day forward, strata above the main bonebed were visible (and could have been examined geologically) on the right bank, as shown in this photograph of the embankment below the Selenka field headquarters (now the location of the Trinil Museum). The strata in the embankment appear to be flat lying. An unpublished cross section authored by W.F.F. Oppenoorth shows a "dark *Melania* [mollusca-bearing] claystone," which was encountered near the bottom of Selenka Expedition Pit I, continues horizontally south beneath this embankment (document PM_B_IX_146, Museum für Naturkunde, Berlin). J.M. Oppenoorth made a negative of this image, among many others, available to the authors from her family archives; the Naturalis Biodiversity Center courteously provided us a high-resolution scan.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Geological Survey excavation in Trinil 1932

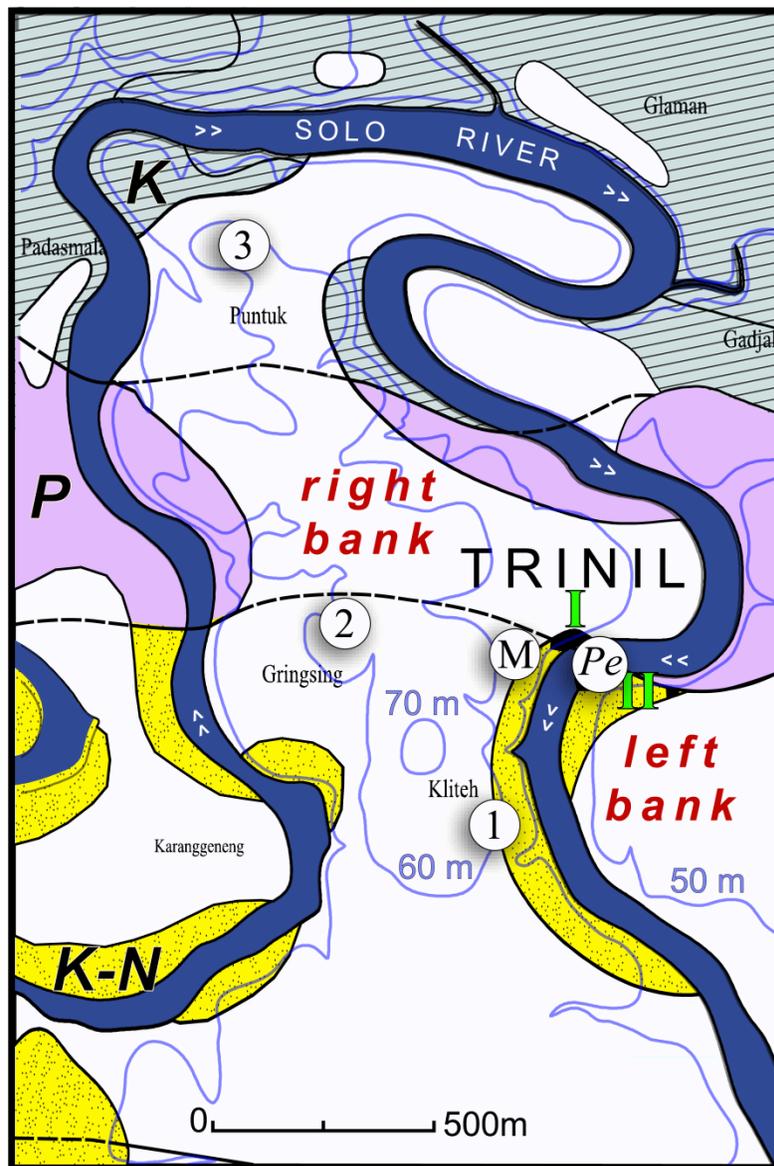


SI I-15. W.F.F. Oppenoorth made lantern slides of a Geological Survey of the Netherland Indies excavation conducted at Trinil in 1932 under his supervision. No maps or cross sections of this work have been located, but his slides are labeled “*Trinil Excav. 1932*” reveal a large right-bank excavation that was cut into (and perhaps through) the **HK** in the vicinity of Selenka Pit I. Trenching of the left bank evidently had ended in 1908. The 1931-1932 Survey work produced 1306 vertebrate fossils and numerous molluscan shells, most if not all apparently from the **HK** (von Koenigswald 1934, 1934/1935; Duyfjes 1936; van Benthem Jutting 1937; Joordens et al. 2009). The 1932 Trinil dig was part of a program of geological mapping and excavation that was conducted along the Solo River valley, and the work led to the discovery of 14 *Homo erectus* specimens and ~25,000 other fossils at Ngandong (Huffman et al. 2010, Oppenoorth 1932, Rizal et al. 2020, as described in SI I-40, below). The Trinil and Ngandong excavators followed field procedures like those of the Selenka Expedition. They used similar forms of provenience description by location and individual stratigraphic units. For example, an annotation about one 1932 Trinil find reads “*Sheet 93B* [referring to the pre-World War II Dutch topographic quadrangle] *Ingr.*[aving; excavation] *I, block C, Layer* [bed] *II. 23. VII. 1932,*” meaning Excavation I, block C, from source stratum II, the **HK** of Selenka, and recorded in the fossil registry on July 23, 1932 (van Benthem Jutting 1937). J.M. Oppenoorth made these slides available to us from her family archives, and we asked the Naturalis Biodiversity Center to scan them at high resolution.

Supplementary Information [part] I

Citations in the text of the paper to this information has the form of 'SI I-#.' (Or in case of Suppl. Inf. part II: 'SI II-#.') The inferred taxonomic identifications of the finds are in brackets.

Duyfjes' Geological map (1936)



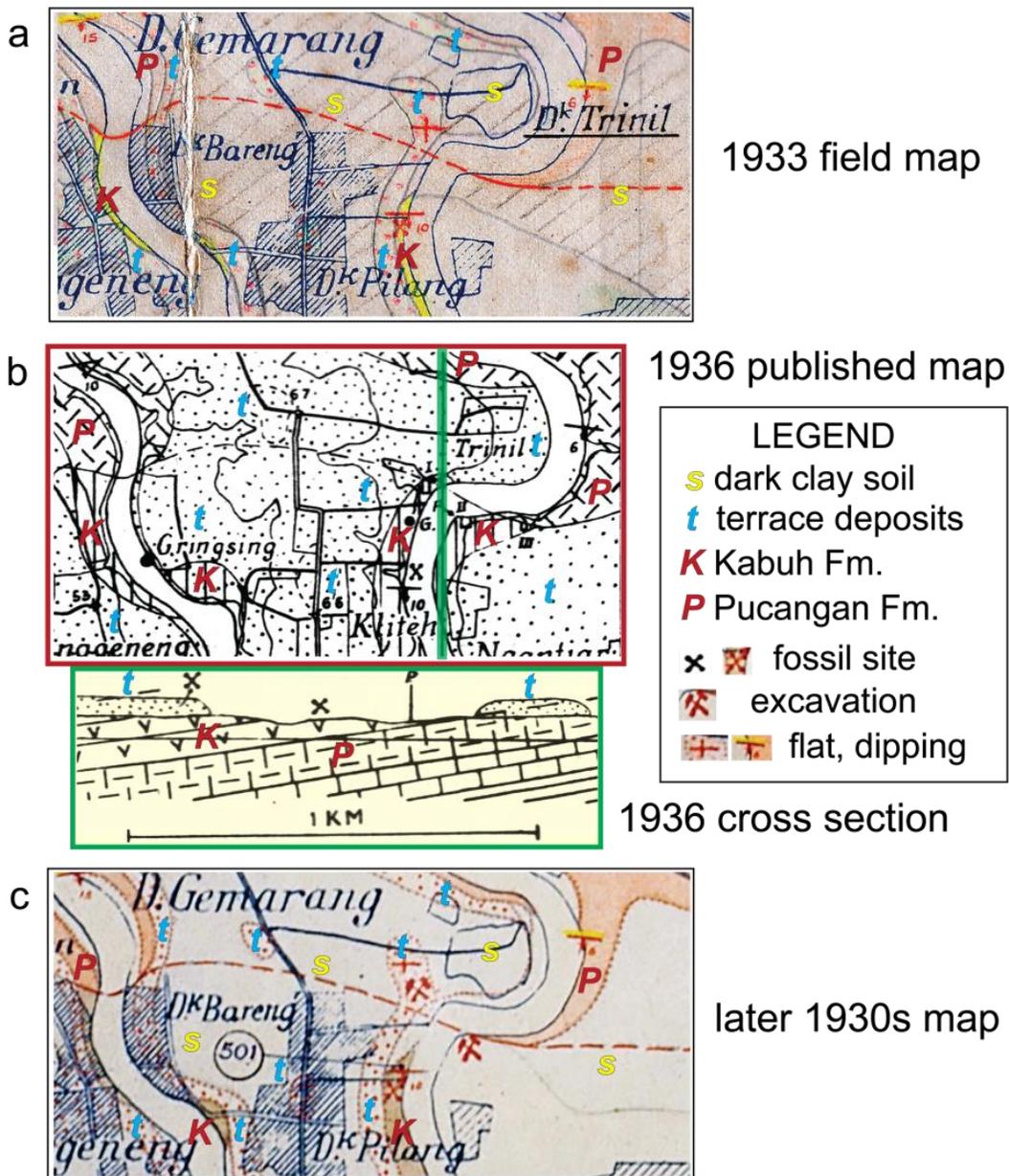
SI I-16. Duyfjes' (1936) geological map of the Trinil area (redrafted from B.W. Seubert in Huffman 2020) shows the presence of widespread terrace deposits (white) overlying gently south-dipping Kalibeng (**K**), Pucangan (**P**) and Kabuh-Notopuro (**K-N**) Formations. The **Pe.** marks the approximate location of Dubois' *Pithecanthropus erectus* site (see SI I-17 for detail). The Selenka Expedition 1907-1908 Pit II (**II**) and Pit I (**I**) were on opposite sides of the river with Pit **I** located northeast of the present-day Trinil Museum (**M**; SI I 7). Duyfjes' (1933) field map of this area had terrace deposits surrounding Pit I (SI I-17a), but for publication in 1936, he raised the elevation of the contact between the terrace deposits and the Kabuh Formation so as to place both formations in the immediate vicinity of Pit I (SI I-17b). **1** and **3** denote locations where we observed four- to ten-meters of horizontal strata that conform to Duyfjes' recognition of a thick widespread flat-lying unit atop the right bank (Huffman 2016). Duyfjes' mapping has served as a basis for stratigraphic understanding of the Trinil area since the 1930s, although uncertainty continues about the extent of terrace deposits versus the Kabuh Formation there (e.g., SI I-19).

Supplementary Information [part] I

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Duyfjes' mapping around Trinil

DUYFJES' MAPPING AROUND TRINIL

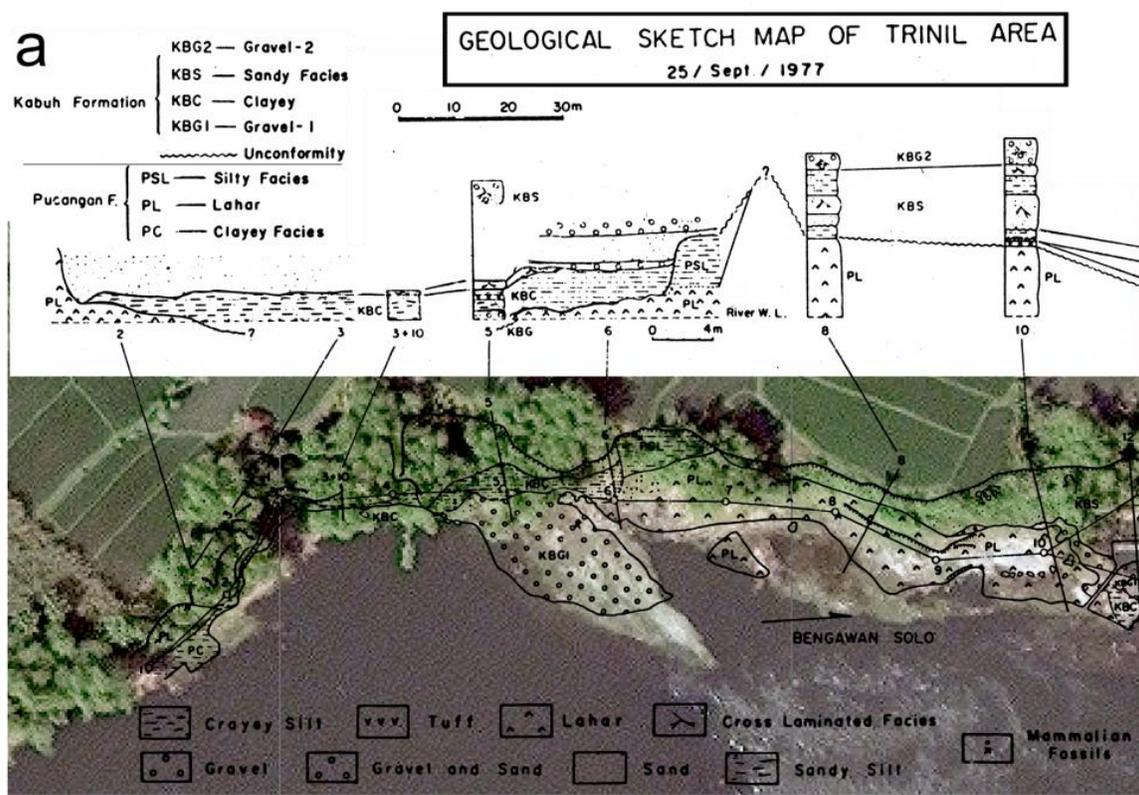


SI I-17. Three versions Duyfjes' geological mapping of the discovery area (cropped and annotated): (a) The map from his unpublished report on the 1933 fieldwork (courtesy of the Geological Library at the Geological Research and Development Centre, Bandung; background in Huffman et al. 2005); (b) Duyfjes' (1936) published map with a north-south cross section (a portion is highlighted in green); and (c) a later unpublished map (retained by Naturalis Biodiversity Center, Leiden, and provided to us by F.P. Wesselingh). Four key relations are portrayed (Huffman 2016). First, flat-lying terrace deposits surround the Survey's 1932 and Selenka's 1907-1908 right-bank excavations (most easily seen in 'a' and 'c') with >9m of post-**HK** section exposed (per Selenka and Blanckenhorn 1911 and SI I-15). Second, the contact between the Kabuh Formation and terrace deposits is stratigraphically higher in the published map than in unpublished ones. Third, in all versions, Duyfjes mapped the Kabuh Formation beneath terrace soil on the left embankment south of the former *Pithecanthropus erectus* discovery site, although he saw a full development of terrace deposits farther south on that bank (shown in his cross section). Finally, Duyfjes measured south dip in both the Kabuh and Pucangan formations but placed substantial thicknesses of horizontal terrace deposits on top of these and older formations on the right bank. The **HK** is situated near the base of the Kabuh Formation in Duyfjes' cross section, which greatly exaggerates the thickness of the terrace deposits. Duyfjes' work is the only known geologic mapping of the right- and left-banks recorded at a scale as fine as 1:25,000 (Huffman 2020 and Berkhout and Huffman 2020 have translations of Duyfjes' publication and report on the Trinil area). Berghuis et al. 2021 redescribed and renamed Duyfjes' units locally.

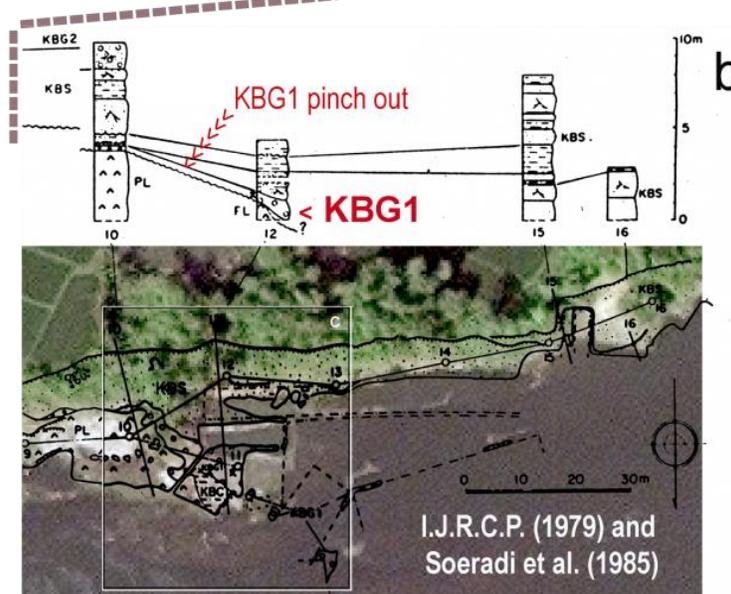
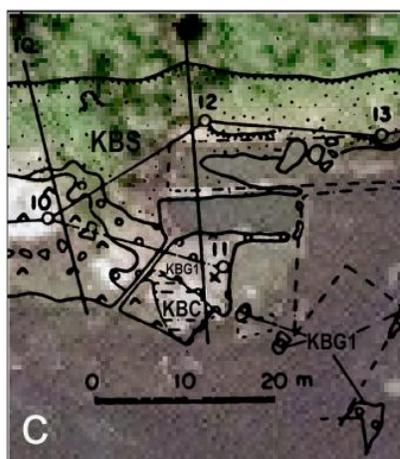
Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Geological mapping of the Indonesian-Japanese team in 1979



KBG1 (= Hauptknochenschicht) pinches out against the Pucangan breccia, east of the Dubois-Selenka excavations

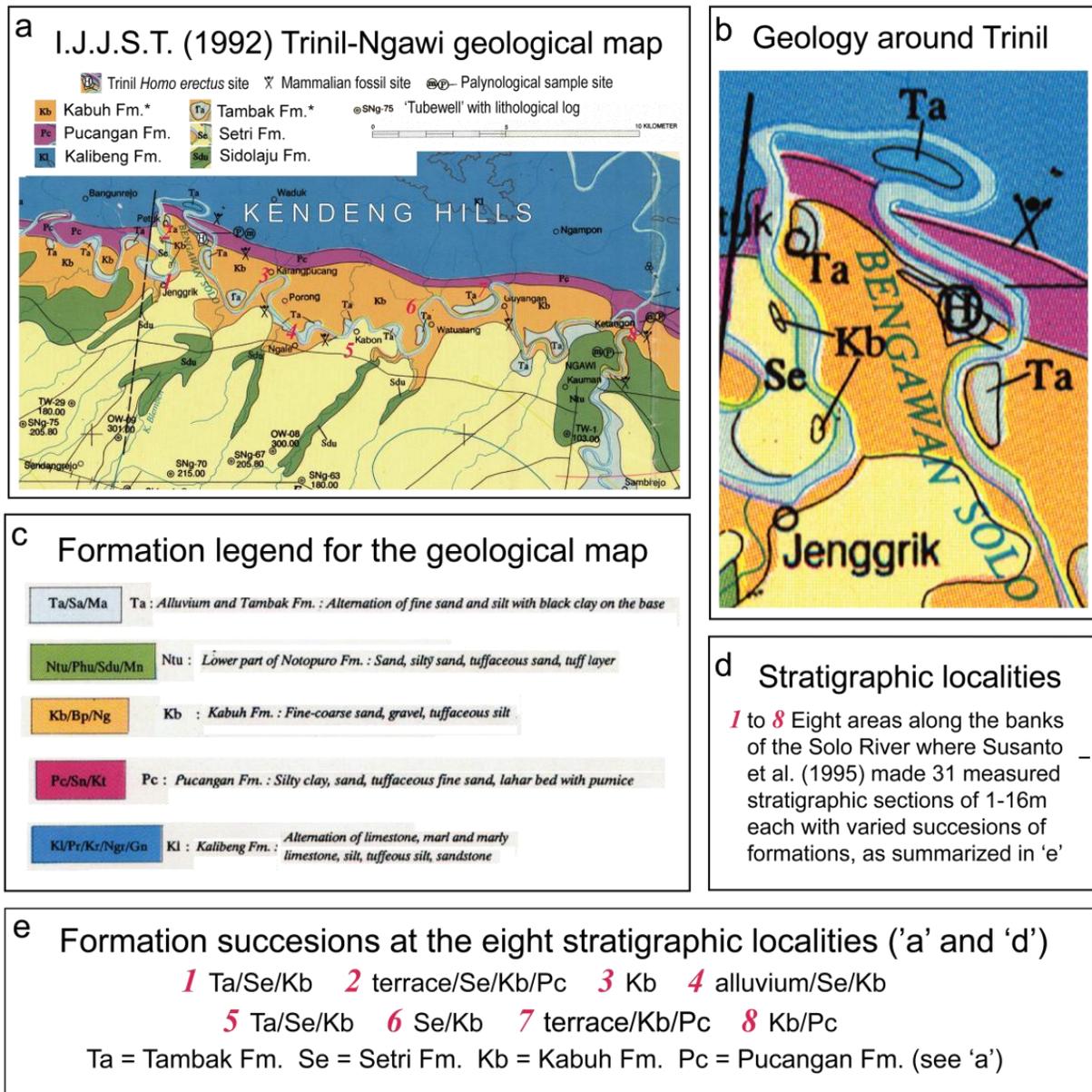


SI I-18. A geological map and several measured sections of the left bank were published at the fine scale of 1:250 (Soeradi et al. 1985; previously published by I.J.R.C.P. 1979). (a) The mapping is registered here onto satellite imagery (as it is in Figure 6d, main text; after Huffman 2016). North is up (as it is Figure 3a, main text, but opposite to the orientation shown in Figure 6d, main text, which maintains the historical presentations of the maps). (b) Soeradi et al. found that the lithology and paleontology of their KBG 1 map unit matched the features of main bonebed of Dubois and Selenka (**LB** and **HK**; also, Aimi and Aziz 1985). (c) The KBG 1 overlies a muddier KBC unit and both of them pinched out to the east. Soeradi et al. agreed with Duyfjes' (1936) assignment of the bonebed and overlying strata to his self-defined and regionally mapped Kabuh Formation (also, SI I-19). Soeradi et al. did not see the $\sim 9^\circ$ south dip that Duyfjes attributed to the strata (SI I-17b) but the onlap and pinch out of the KBG 1 and KBC eastward onto a diamicton-bearing unit (PL, lahar) confirms a relationship first described by Dozy (1911a: xli, Berkhout and Huffman 2021: 47) and observed by the authors (Huffman 2016). SI I-2 shows a river-level view of the platform and excavations scars seen in '-18c'. Soeradi et al. did not tie superjacent eight meters (section 15 in 'b') of sandy, gravely and clayey bed exposed in the riverbank to the stratigraphy visible in the photographs of Selenka and Blanckenhorn (1911). Berghuis et al. (2021) consider much of the strata in the left bank to be terrace deposits and redescribe and locally rename Duyfjes' Kabuh and Pucangan Formations (SI I-35).

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Geological map of the Indonesian-Japan Joint Study Team 1992



SI I-19. (a to c) Multiple geological field teams have identified prominent outcrop bands of the Kabuh and Pucangan Formations in Solo River valley but advanced various interpretations of the overlying terrace deposits (e.g., Berghuis et al. 2021, Berkhout and Huffman 2020, Datun et al. 1996, de Genevraye and Samuel 1972, de Terra 1943, I.J.J.S.T. 1992, Sartono 1976, Soeradi et al. 1985, Susanto et al. 1995, van Bemmelen 1949, Widiasmoro and Boedhisampurno 2001; see van Gorsel 2022b regarding van Bemmelen). This map was prepared by Indonesian-Japan Joint Study Team (I.J.J.S.T. 1992) who had mapped the Kabuh and Pucangan from Sangiran Dome to Kedungbrubus (Figure 1b has the locations; the elements of I.J.J.S.T. mapping are rearranged and annotated here). At Trinil, I.J.J.S.T. mapped alluvium and Recent deposits (combined as “Ta...”) on the terrace upland south of the *Pithecanthropus erectus* discovery area (“Ta...”) is not otherwise described). A few patches of “Ta...”) were recognized above the Kabuh Formation on the right bank (also, Datun et al. 1996). The light-yellow unit mapped on the south side of the Solo River valley represents a thin sedimentary cover of materials derived from Lawu volcano. (d and e) The simplicity of the I.J.J.S.T. geological interpretation around Trinil stands in marked contrast to complex of stratigraphic interpretation proposed by other field teams who worked along the banks Solo River, a situation which we represent here with stratigraphic synopses at eight localities taken from the work of one field team (Susanto et al. 1995; also, I.J.R.C.P. 1979). Comments on are terraces of the Trinil area in SI I-35.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Trinil fossils in the Dubois Collection.

***Axis lydekkeri* (Dubois collection number: 1440)**

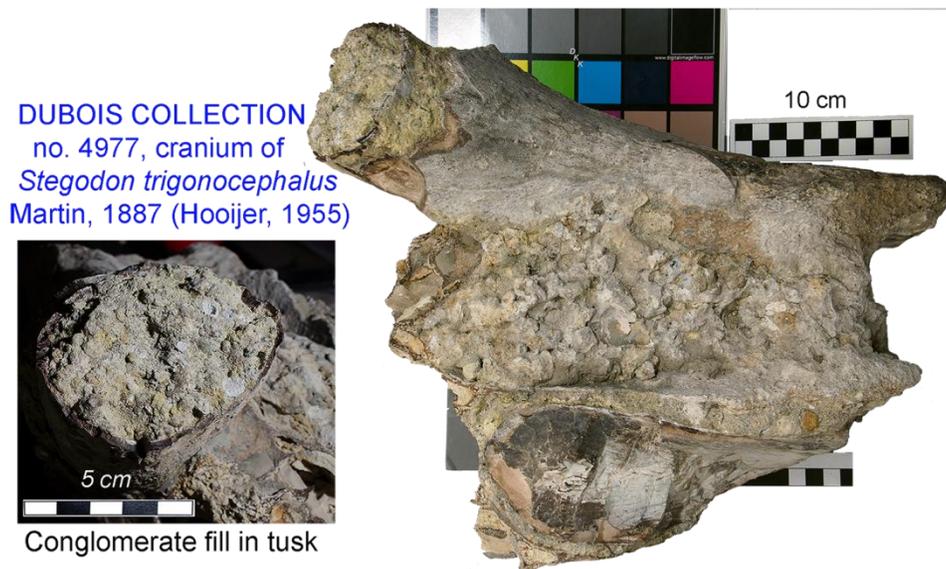


SI I-20. (top) Antler and cranial fragment of *Axis lydekkeri* with label written by G. Kriele that has provenience information. The specimen is coated in andesitic sandstone which is often seen on Trinil fossils of the Dubois Collection, DC. (bottom) Coarse volcanoclastic sandstone fills part of the *Bupalus* horn core, also a common matrix feature on the large specimens in the DC. The photographs for SI I-20 to -24 were taken by OFH in 2010 and 2013. The DC vertebrate specimens have strikingly uniform fossilization and exhibit a higher level of preservation than we have seen from at other sites in the *Homo erectus*-bearing formations of eastern Java. See SI II-243 for some of Dubois' photographs of additional Trinil fossils in the DC.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Trinil fossils in the Dubois Collection. Dubois collection numbers 4977 (*Stegodon*) and 4361 (*Bibos*)



SI I-21. (Top photographs) Conglomerate adhering to a partial cranium of *Stegodon trigonocephalus* and filling the cavity of its tusk. (Bottom photographs) A half mandible of *Bibos palaeondaicus* is marked “Trinil,” which is a spelling of Trinil that Dubois’ field team used only in 1891 (SI II-12). The specimen, which exhibits typical Trinil fossilization, has a dense, dark-purplish brown, porcellaneous interior, which is visible where the specimen is chipped in the upper right (Ingicco et al. 2015 have images and an account of a Hylobatidae femur from Trinil with similar fossilization; also, Hill et al. 2015, Huffman et al. 2018, Pop et al. 2020, Ruff et al. 2015). See also pages SI I-20 and -22–24.

Supplementary Information [part] I

Citations in the text of the paper to this information has the form of 'SI I-#.' (Or in case of Suppl. Inf. part II: 'SI II-#.') The inferred taxonomic identifications of the finds are in brackets.

Trinil fossils in the Dubois Collection.

Batagur sp., Dubois collection number 2751

DUBOIS COLLECTION no. 2751, *Batagur* sp., Trinil



"Attempt to use these carapace fragments in making the larger parts more complete. Follow that with numbering the remaining portion"

E. Dubois



SI I-22. A *Batagur* carapace, reconstructed according to Dubois' written instructions, and fragments of sandstone matrix removed from the fossil (note also Selenka and Blanckenhorn 1911: xxxv, Figure 21, showing jacketed "turtle" specimens from their Pits I and II at Trinil; Berkhout and Huffman 2021: 39). See also pages SI I-20/21 and -23/24.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Trinil fossils in the Dubois Collection.

Conglomerate infilling of bovid scapula, Dubois collection number 6594

Conglomerate in large bovid scapula



SI I-23. Conglomerate infilling a portion of a large bovid scapula with enlargement showing fresh crystals and lithic clasts. See also pages SI I-20 to -22 and -24.

Supplementary Information [part] I

Citations in the text of the paper to this information has the form of 'SI I-#.' (Or in case of Suppl. Inf. part II: 'SI II-#.') The inferred taxonomic identifications of the finds are in brackets.

Trinil fossils in the Dubois Collection.

Wood from Trinil, Dubois collection number 10176



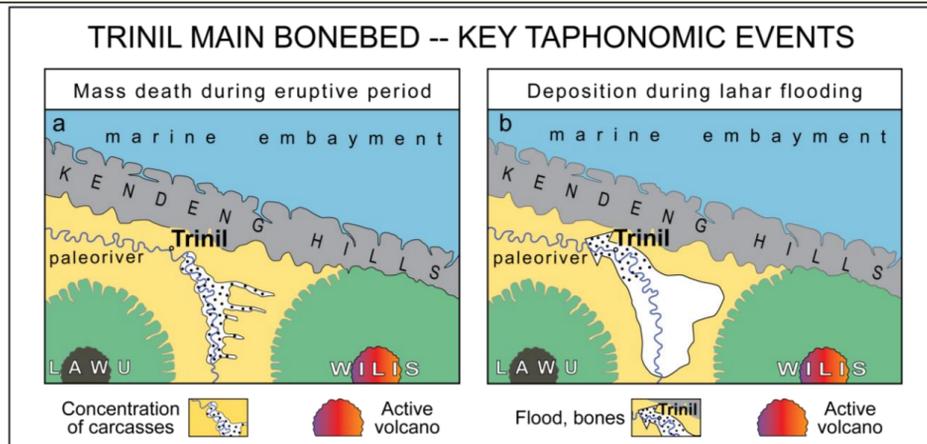
DUBOIS COLLECTION no. 10176, Trinil wood

SI I-24. The **LB** contained large fragments of wood, according to Dubois, as did the **HK** in the reporting of the Selenka Expedition personnel (e.g., Carthaus 1911b: 14; Berkhout and Huffman 2021: 72). The five pieces comprising this specimen in the Dubois Collection fit the firsthand accounts of the wood (e.g., SI II-75) but no documentation on the stratigraphic source of these particular specimens has been found in the Naturalis records. See also pages SI I-20 to 23.

Supplementary Materials I Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Key Taphonomic Events



SI I-25. Comments and proposals regarding the origin of the main bonebed (Figure 12, main text). This paleogeographic reconstruction presented above has the Trinil paleo-river flowing westward and eruptions occurring at paleo-Wilis, a large stratovolcano during deposition of the Pucangan Formation, which existed near modern-day Wilis (Figure 13, main text; Huffman 2001a, b, 2020). Had Lawu been the primary source for clastic materials in the main bonebed, the flooded part of the drainage system might have had a different configuration and the trunk river might have flowed eastward (e.g., Sartono 1976, Berghuis et al. 2021) but the sequence of events in the formation of the main bonebed would have been largely the same. Similar taphonomic benchmarks (e.g., mass death of ungulates) and sedimentary development (e.g., lahar-flood accumulation) led to the deposition of the Ngandong *Homo erectus* bonebed (Ngandong site, Table 5, main text, and SI I-40; Huffman et al. 2010a, b, Rizal et al. 2020).

A central issue in assessing the origin of the main bonebed is to explain how thousands of large, disarticulated, little-abraded vertebrate bioclasts and numerous other biotic remains became concentrated (with certain internal irregularities) within a thin, localized, poorly sorted gravelly volcanoclastic sand along a lowland section of a large perennial river. The analysis in FORMATION OF THE MAIN BONEBED leads to plausible hypotheses about the events and contingencies involved, as summarized in the FORMATIONAL EVENTS subsection, main text. To guide further investigation, a more complete version of the proposals follows.

Several characteristics of the biofacies are particularly significant. When bonebeds are considered worldwide, they are seen to “form through complex combination of biotic and abiotic mechanisms” and “multitaxic bonebeds are frequently a source of paleocommunity data” (Brinkman et al. 2007: 221, 223), as is the case at Trinil. Leverage is enhanced further when: (i) evidence of “hypothetical standing population” comes from the “catastrophic mortality of a gregarious group” (Eberth et al. 2007b: 283, 290), as evidently is true for the main bonebed assemblage (Table 4, main text); (ii) three- or more-taxa dominate in near-equal shares of the mass-death population, such as Trinil’s *Bibos*, *Bubalus* and *Axis*; (iii) “paraphyletic” aquatic- and terrestrial-components in close association contribute to interpreting causality (Eberth et al. 2007a: 104), as it is with the aquatic- and forest animals in the main bonebed; and (iv) key taxa are “isotaphonomic” and have “similar general taphonomic histories” (Blob and Badgley 2007: 341), as is evident in taphonomic analysis for ungulate species attributable to the main bonebed.

On the other hand, the Trinil main bonebed departs significantly from global norms for fluvial bonebeds. First, the Trinil bonebed is an unusual lowland-river deposit in having so many disarticulated and often near-whole vertebrate elements exhibiting fine surface preservation. Exposure of carcasses tends to weather and fragment bones substantially, and rivers generally damage bioclasts and disperse them along their courses, rather than preserve and concentrate them locally (Behrensmeyer 1991, 2007; J. Rogers, pers. comm. 2018), as evidently happened in formation of the main bonebed. Second, there is no known indication that a substantial portion of the main bonebed vertebrate fossils were reworked from older sedimentary formations, which distinguishes Trinil from the great majority of bony bioclast concentrations having multi-individual and multi-dominant species characteristics.

Third, the bioclasts of terrestrial species in the main bonebed at Trinil do not exhibit typical size- or shape-sorting, nor have strong evidence of fluvial abrasion, normal for fluvial bonebeds deposited in a paleo-drainage lowland. Fourth, even though the main bonebed was deposited in the lower reaches of its paleo-drainage, the Trinil case should not be classified with many others as either a normal “channel-fill” or “channel-lag” concentration (Rogers and Kidwell 2007: 6-7) because the bioclasts in these concentrations have variable abrasion levels and are shape- and size-sorted by their selective movement in river currents (Behrensmeyer 1991, 2007, Blob and Badgley 2007, Eberth et al. 2007a,b, Lyman 1994). Fifth, lahar-flood transport, as Dubois and Selenka’s geologists thought occurred in the formation of the Trinil bonebed, is rare globally in several statistical senses. Bonebeds caused by flooding and drowning were only 18% of 185 bonebed sites studied in one worldwide sample (all outside Indonesia) and the closest volcanic categories, “debris flows” and “ash falls,” are just 5% of the sites (and lahar flood cases are not mentioned; Behrensmeyer 2007: 84).

Finally, we note that Rogers and Kidwell (2007: 24), while not specifically considering the Trinil main bonebed in their global review of bonebeds, “find it conceptually difficult to accept ... that disarticulated bones and teeth of numerous animals delivered from widely separated point sources at different times would travel downstream ... and collectively accumulate.” Our proposals for the origin of the main bonebed avoid these conceptual difficulties by marshalling evidence favoring simultaneous death of hundreds of ungulates in one section of the Trinil paleo-river drainage (specifically, the flood zone where living animals had concentrated) and *en masse* transport of the skeletonized, little-weathered remains by lahar flooding, which resulted in little bioclast-damage and -sorting.

Ungulate populations in the Trinil hinterland doubtless inhabited wide areas across the flanks and lowlands of the stratovolcanoes (for example, see Butak bonebed, SI I-42). The paleo-drainage was occasionally affected by large eruptions, as is typical for stratovolcanic terranes. Large portions of the landscape surrounding an active volcano in the Trinil paleo-watershed might be rendered uninhabitable during periods of intense eruption or drought, and severe resource limitation might force hundreds of ungulates towards areas with plentiful water and forage.

Evidently during the taphonomic events preceding the deposition of the main bonebed, a refuge for *Axis*, cattle, water buffalo, *Stegodon*, *Duboisia*, *Sus* and *Rhinoceros* (Table 1 and 2, main text) existed in the floodplain of the trunk Trinil paleo-river or lowland tributary (Figure 12a, main text). Tigers and a few dogs also presumably inhabited the refuge, as perhaps did hominin groups. Grass and forbs were sufficiently widespread there to sustain the deer herd. Reed grounds or the woody forest undergrowth presumably would offer safe harbor. The Trinil deer were in the riverine refuge long enough for many males to shed antlers. The forest in the refuge seemingly had fewer ground-living and arboreal animals than did tree-covered areas elsewhere in the watershed. Denser forests were likely to have been widespread around the hilly areas of the stratovolcanoes and in the Kendeng Hills and Southern Mountains (Figure 1b, main text). The water courses passing through the refuge had the same diverse suite of riverine reptiles, fishes and molluscs as existed in other perennial tributaries and standing water bodies of the watershed.

Catastrophic mortality decimated the ungulates in the refuge along the Trinil paleo-river flood plain. The ungulate individuals were largely in the prime of life. Their deaths most plausibly resulted from particularly devastating volcanic events (ash falls, pyroclastic-surge eruptions, or lahars) or intense drought. The kill-off might have come from a worsening of the conditions that caused the ungulates to flee into the refuge, or an independent calamitous event. Hundreds of ungulate individuals could have perished over hours to weeks (particularly in the case of volcanism) or weeks to months (if drought led to the deaths). Perhaps, the animal aggregation and mass mortality might have been far upriver and the cadavers transported part way downstream by flooding to a location where the bodies deteriorated before further transport took the bones to Trinil.

Almost all of the carcasses decayed to the point of skeletonization, creating a scatter of the tens-of-thousands of bony elements across the flood plain. Exposure was too short for the bones to weather to ruin. Bioerosion did not prominently affect them. The bony elements were broken, plausibly by the trampling of the large ungulates that survived. Avian scavengers and other consumers of carcasses left no record of substantial contribution to the skeletonization. Tiger, dog and hominin populations played little-if-any role in the death of the ungulates. Ash falls possibly inhibited scavenging and preserved bone surfaces. The hominin population in Trinil paleo-lowland used lithic tools so sparingly that no flakes or artifacts came to be embedded with the voluminous amounts of granules and pebbles excavated from the bonebed.

A lahar flood inundated the paleo-river floodplain, sweeping up thousands of decomposed skeletal remains. When the waters surged through the channel, the flood had sufficient hydrodynamic competence to suspend and carry nearly whole *Stegodon* and large-bovid crania. The bone field might have been situated one to several kilometers upstream of Trinil or several tens of kilometers upriver, but the lahar flood water largely originated in the volcanic uplands, as flooding in the region normally does today. Most of the sand and gravel in the lahar flood had entered the flood before it reached the skeletal scatter. The lithic materials gave the flood waters a density sufficient to move the largest skeletal elements and lithic boulders downriver.

Stratovolcanic landscapes in Java offer multiple opportunities for the development of lahar flooding (SI I-37). In the main bonebed case, a crater lake at the center of an active volcano might have emptied catastrophically; a sector of the volcano might have collapsed into a debris-flow which evolved into a lahar flood after dilution by discharge from other tributaries of the watershed; or a part of the highlands might have been struck so heavily by rainfall during a wet-season storm that the lahar flood arose when rivers bulked up with sand and fine gravel. Multiple parts of the watershed might have contributed water to the flood, but they did not furnish substantial numbers of vertebrate bioclasts that had had taphonomic histories which were notably different than those in the principal area of bone scatter.

The flooding incorporated logs, reeds and leaves, and river-living reptiles, fish and molluscs from the paleo-river floodplain or other points along the drainage. As the bone-rich flood proceeded downstream, the bones were not shape- and size-sorted because the surge moved in hyperconcentrated flow regimes with little interruption. The lahar flooding presumably completed the disarticulation of bony sections of certain remains which had not been fully disjoined during exposure. A few skeleton elements stayed together and retained vestiges of soft tissues. Crocodiles left impressions on some bones, perhaps indicating access to what remained of fleshy tissues.

The river bottom at Trinil had been lined with dark-colored mud and gastropod banks before the lahar flooding arrived. Even earlier, the river had carved older consolidated diamicton into bedrock edges of the channel. The flood waters during the main bone bed event might have backed up behind bedrock constrictions, producing the bonebed accumulation in a matter of hours. Bed-load traction movement deposited pebbly sand with large-scale crossbedding as it passed the present-day left bank. Over the course of hours or days, internal streams and pulses segregated bioclasts and lithic materials sufficiently to create internal lithic and bioclastic facies within the main bonebed *in toto*. A pulse carrying the *Pithecanthropus erectus* (*P.e.*) materials and many other large mammal bioclasts followed an initial surge which carried fewer bioclasts and more cobbly gravel. The Skullcap and Femur I arrived at Trinil together with hundreds of Trinil fauna bones. The hominin femora from the 1900 excavation might have been embedded within minutes, hours or several days earlier or later than the original *P.e.* remains.

The main-bonebed flood also might have deposited bioclast concentrations down stream of Trinil, but more likely, as the flooding continued, the high-rate flow dispersed skeletal fragments along the trunk river and deposited them in low densities along various sections of its floodplain, estuary, delta or immediate offshore. If heavy rain or landscape disturbance continued in the watershed, high-rate flows potentially passed Trinil for days or several months after the main bioclast-rich flood had surged down valley. Several meters of sandy volcanoclastic deposits containing vertebrate- and molluscan-bioclasts which represent the same perimortem events as those expressed in the main bonebed might have accumulated on top of it. Although differing in geological age from the main bonebed, the Ngandong *Homo erectus* bonebed is a sandy fossil concentration in the lower portion of the ~3m thick lahar flood deposit that included a prominent later muddy diamicton (Tables 5, main text, SI I-40).

At Trinil fluvial deposition continued for millennia after the main bonebed formed, leading to the accumulation of the overlying Kabuh Formation. The remains of a few large mammal individuals were embedded, notably ~5m above the main bonebed in the *Stegodon* bed. Few bony materials were otherwise embedded because large mammal remains almost always decomposed substantially before they entered the river systems, and the surviving bones were reworked repeatedly during periods of exposure and burial.

Uplift of the Kendeng Hills tilted the Kabuh and Pucangan Formation gently southward, but in the immediate vicinity of Trinil, a structural anomaly within the regional monoclinical movement preserved the horizontal structural attitude. Long afterwards, the Solo River formed its present main valley and became Java’s largest river (Figures 1b, main text). The Solo River ultimately flowed in a strongly meandering course and then incised. At the left-bank *Pithecanthropus erectus* site, the incision penetrated eight-to-nine meters of the Kabuh Formation, exposing the LB.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Additional notes on selected vertebrate species and plant remains from the main bonebed.

Axis lydekkeri

SI I-26. *Axis lydekkeri* (Lydekker's deer): The main bonebed had largest assemblage of *Axis lydekkeri* skeletal remains known from a single deposit. Stable carbon isotope data from six isolated *A. lydekkeri* teeth from the current museum collection fall tightly within a $\delta^{13}\text{C}$ range generally attributable to a "pure C4 diet" and reportedly showed minimal seasonal variability (Janssen 2017, Janssen et al. 2016: 150). *A. lydekkeri* appeared first in Java before the earliest-known *Homo erectus* fossils and then continued as descendent subspecies through the time that the Ngandong *Homo erectus* lived (Table 5, main text), when the deer had somewhat different antler morphology and a larger body size (de Vos 1996a, Gruwier et al. 2015, Leinders et al. 1985, Sondaar 1984, van den Bergh et al. 1999, 2001). *Axis* is also the most numerous identified taxa of the Pening *Homo erectus* discovery bed (Tables 4, main text, and SI I-43), so that Lydekker's deer inhabited the Mojokerto paleo-delta when dry grasslands with few dryland trees dominated, delta plain and associated river valley (Morley et al. 2020). The deer was the most common ungulate fossil in swamp deposits that formed under wet climatic conditions at Sangiran Dome (Bukuran bonebed, SI I-44).

Axis lydekkeri is probably phylogenetically related to extant hyelaphid deer (Gruwier et al. 2015; also, Gruwier 2019). The hyelaphid *A. porcinus* (Hog Deer) lived historically in Pakistan, India, Sri Lanka, Indochina and southwestern Yunnan, China (e.g., Duckworth et al. 2015, Lekagul and McNeely 1988). "Hog Deer has long been known in Myanmar ... and occurred throughout the country wherever there were grassy plains In the southwestern coastal lowlands of Cambodia, where apparently the species was once common ..., the species appears to use an open habitat mosaic including brackish ... sedge marshes and 'upland' tall ... grasslands, and areas of scrubby open secondary woodland interspersed with 'dry' short stature grasslands Hog Deer is a primarily a grazer of young grasses...; it also takes herbs, flowers, fruits and browse" (Timmins et al. 2015: 8, 10, 11).

The largest and most-thoroughly investigated native populations of *Axis porcinus* live along foot of the Himalaya, notably in the Kaziranga National Park (KNP), 430km² located in northeastern India along the Brahmaputra River, its plains and nearby hills. The prime area of deer occupation is dominated by tall- and short-grasslands, wetlands and mixed-deciduous forests (e.g., Bradley-Martin and Vigne 1989, Choudhury 2010, Rahmani et al. 2016, Bajariu 2016). KNP averages ~ 2200mm of precipitation per year, but has a severe dry season marked by months of <100mm in rainfall. In recent decades, KNP has been known to support 5045 *A. porcinis* (1999 census; and perhaps triple this number) and 1666 *Bubalus arnee* (in 2002; Wild Asian Water Buffalo), 1206 *Elephas maximus* (in 2005), 468 *Cervus duvaucelli* (in 2002; Swamp Deer), 431 *Sus scrofa* (in 1999), 100 *Muntjacs muntjac* (in 1972) and 86 *Panthera tigris* (in 2000), together with many other large- and small-terrestrial animals, birds and aquatic species, including Gharial. Floods periodically inundate 70-80% of KNP, drowning as many as a thousand Hog Deer in each event.

Axis kulhii is the living hyelaphid species that occurs nearest geographically to Java's former Lydekker's deer population, and potentially is a descendant of *A. lydekkeri*. *A. kulhii* inhabits the still-forested Bawean Island (~192km², 0-646 m elevation) in the middle of the Java Sea ~150km north of eastern Java (Blouch and Atmosoedirdjo 1978, 1987, Hoogerwerf 1966, 1967; also, Rademaker et al. 2016). *A. kulhii*, which is primarily a nocturnal feeder, "grazes on herbs and grasses, but also browses young leaves and twigs" (Blouch and Atmosoedirdjo 1978, Semiadi et al. 2015: 4). The second related extant island species, *A. calamianensis*, lived historically in parts of the Palawan archipelago, southeastern Philippines (Widmann and Lastica 2015). *Axis* population evidently passed through Borneo at some points in the geological past. No *Axis* populations are known elsewhere in Sundaland or farther eastward into the Philippine archipelago, Sulawesi or Nusa Tenggara, all of which are all separated from Sundaland by deep oceans. Modern hyelaphid appear to generally prefer mosaic landscapes with water, grass and other palatable plants, as well as safety in forests, scrub or tall grasslands.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

**Additional notes on selected vertebrate species and plant remains from the main bonebed.
Bibos palaesondaicus and *Bubalus palaeokerabau***

SI I-27. Large-body bovids, *Bibos palaesondaicus* and *Bubalus palaeokerabau*: A grass-prone diet is seen in the $\delta^{13}\text{C}$ results from several dozen isolated large-bovid teeth from Trinil (reported as *Bubalus palaeokerabau* and species undetermined; Janssen 2017, Janssen et al. 2016; modern Southeast Asian bovids evidently were not sampled). However, when Weinand (2005: v and 81; also, 2007) analyzed the astragali metrics for various Southeast Asian bovids, including 81 large-body specimens from Trinil, he concluded that the bovids were anatomically adapted more for “heavy cover” of “densely vegetated river valleys and upland forests, broken by open grasslands.” The large-sized bovid species from the main bonebed are anatomically like (and often inferred as having been the ancestors of) extant *Bibos javanicus* (Banteng cattle) and *Bubalus arnee* (Wild Asian Water Buffalo), respectively (Dubois 1908, Hooijer 1958a). Amano et al. (2016b: 158; also, 2016a) observed mesowear- and microwear-patterns on *Bibos javanicus* molars that reflect both grazing (“feed on grass”) and browsing (“feed on dicotyledonous plants”).

Modern and historic natural populations of Banteng inhabited open- and mixed-forests, from coasts to mountain highlands, and in some cases, rely upon the browsing on herbs and bark. The same is quite plausibly inferred for *Bibos palaesondaicus*. In Java, human settlement drove Bantengs into remote areas, forced them into suboptimal habitats, gave rise to domestication (Bali Cattle), and led to Banteng introductions into non-native habitats, far and wide (in part from S. Hedges, pers. comm., 2018). In the historic past, Banteng lived “very frequently [from] ... mountain forests [to] ... flat-lying jungles along the coasts, especially near marshy lakes, gently streaming rivers or ... widening of mountain valleys” (Encyclopaedie van Nederlandsch-Indie 1895-1905). *Bos javanicus* inhabited Java’s ever-wet westernmost tip to its easternmost seasonally dry end of the island, being well known from Ujung Kulon National Park with ~3000-mm rainfall per year and Baluran National Park with ~1600-mm annually, on opposite end point of Java (Whitten et al. 1996). The essentials for Banteng were forests, grazing land, fresh water and sources of salt. No native *B. javanicus* population is known to have dispersed eastward across narrow seaways leading from Bali towards the drier islands of Nusa Tenggara archipelago or the wetter landscapes of Sulawesi and the Philippines.

Banteng herds native to historic Java, Borneo and Indochina are sometimes assigned to separate geographic subspecies, such as *Bos javanicus birmanicus* in Cambodia (Matsubayashi et al. 2014). Banteng were common historically in south and east Borneo, grazing and browsing in forested landscapes (for example, Banteng occur in 5 of 15 orangutan protected areas; Gardner et al. 2014, 2016, 2021, Matsubayashi et al. 2014, McKinnon et al. 1996). At Niah Cave, Sarwak, northern Borneo, Pleistocene cave deposits yielded *Bos* remains along with those *Pongo* and other forest-dwelling genera (also, Table 5, footnote 6, concerning *Bos* in cave assemblages from the Sumatran highland).

Banteng were formerly widespread in wet central Thailand, including its forested western and northern mountains (Corbet and Hill 1992, Humphrey and Bain 1990, Lekagul and McNeely 1988). Moreover, around 250 of these cattle still reside in the forests of one mountain sanctuary in Thailand, where the animals browse as needed on shrubs, herbs and tree bark in the dry season, and co-exist with Gaur (a bovid), Asian Wild Buffalo, Sambar (*Rusa deer*), Sumatran Serow, muntjacs, Clouded Leopard, Sun Bear, and Tiger, among other forest species (Prayurasiddhi 1997). Banteng is one of two large-bodied prey species of the robust tiger population there (Pakpien et al. 2017). Thousands of wild *Bos javanicus* also thrive primarily on grasses in the dry-deciduous forests in eastern Cambodia (Duckworth et al. 1999, Gray and Phan 2011, Gray et al. 2012, 2016, Nguyen 2009, Steinmetz 2004).

An inadvertent experiment in Banteng-foraging adaptability was conducted in NW Australia. Over 6000 free-ranging pure-strain Banteng inhabit open eucalypt-forest on the Cobourg Peninsula (11.3°S, 132.2°E), an area with ~1300mm average

annual rainfall. Set free there 170 years ago in the absence of large terrestrial predators, the small introduced population expanded numerically to overspread ~70km⁻³ (1988) by shifting their diet to primarily sedges, trees and shrubs, with peak grass consumption now being ~40% in the late wet season (Bowman et al. 2010, Calaby 1975, Choquenot 1993, Corbett 1995, De Konnick 2014).

Bubalus palaeokerabau, like *Bibos palaesondaicus* are Bovidae-Bovini, probably of the subtribe Bubalina (e.g., Castelló 2016, Grubb 2005, Hassanin 2014). *Bubalus arnee* and the domesticate *Bubalus bubalis* (Asian Water Buffalo) have habitat tolerances exceeding what one might envision, although some evidence of this is far afield from Java. The largest present-day Wild Asian Water Buffalo population occurs in Assam, India, (Choudhury 2010, 2017), particularly in Kaziranga National Park (KNP) along the Brahmaputra River, described above (Mahanta et al. 2016, Bajari 2016). Some 1963 buffalo were counted at KNP in 2008, when the Buffalo primarily frequented dense grasslands and open-seasonal forests that are subject to high-levels of wet-season rainfall and annual floods, as well as severe dry months. With densities of 6.45km⁻² the Buffalo are closely tied to ample grass forage and freshwater bodies, which the buffalo use frequently for wallowing (sources cited under *Axis*, above). Present-day herds there are only a small remnant of broad South Asian populations that existed in the region thousands of years ago.

During the Holocene, Wild Asian Water Buffalo (*Bubalus arnee*) were not restricted to grassy lowlands but inhabited both major river valleys and the adjacent mountains in Indochina (e.g., Bacon et al. 2018, Hedges et al. 2008; also, Kaul et al. 2019). A montane remnant numbering >40 individuals is still to be found along the grassy riverbanks and in adjacent deciduous forests in ~70km² of the same Thai sanctuary with the Banteng mentioned above (Chaiyarat 2002, Chaiyarat et al. 2004). Feral Asian Water Buffaloes share the Baluran National Park, Java, with Banteng, and appear to be less tolerant of browsing there than are the wild cattle (S. Hedges, pers. comm., 2018). Feral buffalo also inhabit savanna lands of very dry Komodo islands (~800 mm per year rainfall), near Flores in the Nusa Tenggara archipelago.

However, the most remarkable feral *Bubalus bubalis* occurrence is in NW Australia (as arguably is the case for Banteng), where Asian Water Buffaloes introduced in the mid-19th Century now number hundreds of thousands. In the absence of large terrestrial predators such as tigers, and by grazing and subsidiary browsing the Asian Water Buffaloes have spread over hundreds of thousands of square kilometers, inhabiting a far broader range than the Banteng, and exhibiting astounding ecological flexibility in that dry climate (Bowman et al. 2010, Corbett 1995, Freeland and Choquenot 1990, Petty et al. 2007, Saalfeld 2014).

Broad Pleistocene dispersal and adaptation by speciation in *Bubalus* is evident in forest *Bubalus* spp. known from islands east of Sundaland. *Bubalus palaeokerabau* is full-size when compared to modern *B. arnee* but dwarf buffaloes occur on islands beyond the limits of Sundaland (Burton et al. 2005, 2016, Rozzi 2017). *Bubalus mindorensis* (tamaraw) was formerly widespread on the 9,735 km² Philippine island of Mindoro, where the species ranged from “sea level to the high peaks (to over 1,800 m), inhabiting open grassland or forest glades, thick bamboo-jungle, marshy river valleys, and low to mid-elevation forests” (Boyles et al. 2016: 4, Cebrian et al. 2014, Custodio et al. 1996.; also, Croft et al. 2006, Huffman, B., 2016).

Smaller miniaturized forest buffalo occur on Sulawesi (181,000km²) as *Bubalus depressicornis* (the Lowland Anoa) and *B. quarlesi* (the Mountain Anoa, which is the smaller, more antelope-like than the Lowland species; Burton et al. 2005, 2016, Rozzi 2017). These dwarf species indicate that Pleistocene *Bubalus* populations were present in eastern Sundaland, and unlike Banteng, succeeded in crossing ocean barriers that separated Sulawesi and the Philippines from Borneo while evolving into miniaturized species. The dispersal to islands peripheral to Sundaland, together with the ecological range of modern *Bubalus arnee*, support the notion that *Bubalus* spp. were widely distributed between mainland Indochina and Java during the Pleistocene. This might indicate that *Bubalus palaeokerabau* potentially was more adaptable to varied paleoenvironmental conditions than was *Bibos palaesondaicus*.

Supplementary Information [part] I

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Additional notes on selected vertebrate species and plant remains from the main bonebed.

Duboisia santeng

SI I-28. *Duboisia santeng* (Dubois, 1891): Dubois' Antelope is a boselaphin notable for its small size, unique horn-core anatomy, and concentration in the *S.-H.e.*, especially in the main bonebed (e.g., van den Bergh 1988). In reviewing various evidence concerning the *D. santeng* from Trinil, Rozzi et al. (2013; also, 2014) related the mesowear properties of the teeth to those of “a forest dweller living in close canopy settings.” Janssen et al. (2016), on the other hand, obtained a C4 signal from three Trinil samples of *Duboisia* enamel which was similar to the results obtained from more numerous specimens of other ungulate species from Trinil. One fossil calotte with intact horn cores and cranial dimensions like the Java specimens has been described as *Duboisia* aff. *D. santeng* from a fluvial site in the Khorat Plateau, Thailand (Nishioka and Vidthayanono 2018). *D. santeng* was only slightly more massive than the diminutive deer *Axis lydekkeri* (Hooijer 1958, van den Bergh 1988). The estimated body mass of ~54kg for *D. santeng* is an ~70% size reduction from *Boselaphus namadicus*, an extinct boselaphin from the Middle Pleistocene Siwalik Group (Pakistan; Rozzi and Palombo 2014, Rozzi et al. 2013). *Duboisia* is sometimes linked phylogenetically to the Indian Nilgai (Blue Cow), *Boselaphus tragocamelus*, one of the two extant South Asian boselaphins. *B. tragocamelus* males weigh ~250 kg; the species are mixed feeders in small groups across South Asian ecological zones but are known nowhere closer to Java (Sankar and Goyal 2004). Imported Nilgai have thrived on grass in the dry cattle rangeland of south Texas since the 1930s.

Supplementary Information [part] I

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Additional notes on selected vertebrate species and plant remains from the main bonebed.

Stegodon trigonocephalus

SI I-29. *Stegodon trigonocephalus*: The main bonebed has the greatest concentration of *Stegodon trigonocephalus* known (where it joins *Axis lydekkeri* is this distinction) except possibly for the Ngandong *Homo erectus* bonebed (Tables 5, main text). Dental specimens that are reasonable attributable to the main bonebed indicate a MNI of 32 (van den Bergh 1999). *S. trigonocephalus* is member of the extinct family of generally large-bodied proboscideans that were widely distributed in Southeast Asia, East Asia and South Asia during the Pleistocene, so that *Stegodon* spp. might have occurred widely in Sundaland during this time period (e.g., Zeitoun et al. 2016). The *Stegodon* spp. that are known from islands east of Sundaland are dwarfed in stature (e.g., Powley et al. 2021, van den Bergh 1999, 2001, 2019, van den Bergh et al. 2001, 2008, van der Geer et al. 2010, 2016). Presumably, like modern elephants, *S. trigonocephalus* lived in herds of related individuals. Evidence favoring a diet of C4 plants for East Java *Stegodon* comes from the stable-carbon-isotope signals in the enamel of three teeth, all isolated surface finds, that were collected from near the discovery site of the Mojokerto child skull in an area of the upper Pucangan Formation outcrop, 2.5km east of long-known discoveries of large-sized *S. trigonocephalus* specimens at Gondang (Cosijn 1931, 1932, Dubois Collection; see Huffman and Zaim 2003). The three specimens had measured $\delta^{13}\text{C}$ values of -0.73 (hominin site) and -0.07 to -0.88 (Gondang), all within the range associated with C4 vegetation (with corresponding $\delta^{18}\text{O}$ of -6.83 and -6.68 and -7.41; T. Cerling and J. Kappelman in Huffman and Zaim 2003).

Supplementary Information [part] I

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Additional notes on selected vertebrate species and plant remains from the main bonebed. Rhinoceros, Trinil pig and Trinil tiger

SI I-30. Rhinoceros, Trinil pig and Trinil tiger: Three prominent forest-prone large vertebrates occur in the main bonebed. Javan rhinoceros had wide forest distribution in the prehistoric past, going back approximately as long as any species of *Homo* inhabited Java. The Javan rhinoceros (*Rhinoceros sondaicus*) occurs in the Trinil H.K., Kedung Brubus and Ngandong faunas, which comprise the majority of the *Stegodon-Homo erectus* fauna association (Tables 5, main text). The teeth of *R. sondaicus* also commonly occur in the Holocene and Late Pleistocene rain-forest cave assemblages of Java, Sumatra, and northern Borneo (Niah Cave; Cranbrook and Piper 2007, Dammerman 1934, Aimi and Aziz 1985, Simanjuntak 2001, Storm and de Vos 2006, Storm et al. 2005, 2013, Westaway et al., 2007, 2017). *R. sondaicus* existed as subspecies in Java, Sumatra, Borneo (at least its northern portion), the western Malay Peninsula, Indochina (western mountains of Thailand, Cambodia, the Laos uplands, and Vietnam), and eastern South Asia, notably Assam and the Sundarbans delta. The teeth of the species are abundant (NISP = 238) in the Vietnam Coc Muoi cave, along with the teeth of tapir, cattle, *Sus* and serow, among other species, in a late Middle Pleistocene rainforest paleoenvironment (MIS6-5 transition; Bacon et al. 2008b; also, Bacon et al. 2004-2008a). Older fossil occurrences are known from southern China, Myanmar and Pakistan. *R. philippinensis*, a related fossil species from Luzon dating to 709ka, demonstrates the capacity of the rhinoceros to migrate east of Sundaland (Ingicco et al. 2018).

The ecology of *Rhinoceros sondaicus* is best known from Java, where the species lived historically in the rain-soaked, perhumid forests of West and Central provinces (Groves and Leslie 2011, Hoogerwerf 1970, van Strien et al. 2008). While principally a lowland-forest dweller, these Javan rhinoceros groups inhabited coastal forests and montane forests on the upper volcanic slopes. The species “is a generalist browser and consumes little to no grass and few herbaceous species, preferring leaves, shoots, and twigs of woody species” and is well-suited anatomically for reaching vegetation over its head, (Groves and Leslie 2011: 199). *R. sondaicus* is less specialized anatomically than the one-horned *R. indicus* (Indian Rhinoceros) of South Asia, Indochina, southern China (as *R. sinensis*). *R. indicus* (~ *R. kendengindicus*) also occurs in the *S.-H.e.* of Java (Table 5, main text). Modern *R. indicus* consumes more grass than does the Javan rhinoceros.

The extinct Trinil Pig (*Sus brachygnathus*) has a MNI of 9 in the Dubois Collection (Table 4, main text). The $\delta^{13}\text{C}$ results for Trinil *S. brachygnathus* enamel are consistent with individuals living from of C3 vegetation and having the omnivorous behaviors normal to *Sus* (Janssen et al. 2016). *Sus* spp. probably originated in Southeast Asia, where they are widely distributed, and mostly inhabited forests (e.g., Melletti and Meijaard 2017). Judging from anatomical and genetic studies, *S. brachygnathus* is most closely related phylogenetically to the present-day Javan Warty Pig of Java and Sumatra, and the Bawean Warty Pig of the forested Bawean Island in the Java Sea (e.g., Badoux 1959, Hardjasamita 1987, Rademaker et al. 2016, Semiadi et al. 2015).

Janssen et al. (2016) found that the enamel of a Trinil tiger specimen has carbon- and oxygen-isotopic values “reflecting a food chain with a mixed C₃/C₄ base.” The Trinil taxon is one of numerous subspecies of *Panthera tigris*. Of the South Asian tiger, Bhattarai (2011: 1) summarized, “the basic habitat requirements ... include the thick cover of forest, proximity to water and ... an abundance of large and medium-sized prey” (also, Chanchani et al. 2014). Tigers still inhabit Sumatra, where they prefer thick understory, and prey by surprise and stealth on medium- to large-ungulates and ground-dwelling primates, such pigs, muntjacs, deer and macaques (e.g., Goodrich et al. 2015, Linkie et al. 2008, Wibisono et al. 2011). A robust tiger population in a Thai mountain reservation preys on Banteng and another large-bodied bovid species (Pakpien et al. 2017). The Trinil dog *Xenocyon trinilensis* Stremme, 1911 is the only other large carnivore known from Trinil. Stremme (1911: 83-86; Tafel XVI, Fig. 1 and 2) had named a partial left mandible with P3, M1 and M2 (Museum für Naturkunde, Berlin, specimen MB.Ma.28893) as the new canid species.

Supplementary Information [part] I

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**Additional notes on selected vertebrate species and plant remains from the main bonebed.
Muntjac, macaque, porcupine, leopard cat, langur and gibbon**

SI I-31. Low- but seemingly significant-frequency of other forest-prone species (muntjac, macaque, porcupine, leopard cat, langur and gibbon; Table 3, main text) indicate a modest extent of forest in the area of ungulate death associated with the formation of the main bonebed. Although the fossils of rat, python and monitor lizard are components of the Trinil assemblage, hundreds of small- to medium-sized arboreal and ground-dwelling species, which have not identified among Trinil fossils, presumably also inhabited the watershed. Paleobotanical remains support this supposition.

Supplementary Information [part] I

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Additional notes on selected vertebrate species and plant remains from the main bonebed. Riverine species

SI I-32. Riverine vertebrate species are common in the main bonebed. Aquatic reptile- and fish-specimens (NISP of 330 in the DC) are equal in numbers to *Duboisia*, *Rhinoceros* and *Sus* combined (NISP of 353), and fall between those of *Duboisia* and *Stegodon* (NISP of 499 and 231, respectively). Turtle shells and crocodylian skulls, some largely complete (SI I-22), are prominent in the aquatic assemblage, as they are in field accounts (SI II-44, -47, -148, -170, -171). *Crocodylus siamensis* (Siamese Crocodile) was historically widespread from Java, Borneo (Mahakam River) and Indochina (e.g., Bezuijen et al. 2012, Cox 2004, Das 2015, Griggs and Kirshner 2015, Han et al. 2015, Platt et al. 2006). The species concentrates in “freshwater lakes, swamps and slow-moving rivers, from near sea level to an elevation of 600 meters” in Cambodia, where reptilian populations still exist locally; the reptiles prefer water bodies with gentle banks in both open- and shaded-areas surrounded by forest (Han et al. 2015: 154; also, Daltry et al. 2003, Sitha et al. 2005). *Gavialis bengawanicus* Dubois 1908 is closely similar in morphology to *G. gangeticus*, the Gharial, of present-day South Asia and westernmost Indochina, and resembles a fossil of a narrow-nosed crocodylian (cf. *Gavialis*) from Sulawesi and *Gavialis* cf. *bengawanicus* from northeastern Thailand (Delfino and de Vos 2010; also, Das 2015). *G. gangeticus* inhabits deep dry-season pools and wet-season inundated areas of large rivers (Saikia 2012; also, Choudhury et al. 2007; also, Lang et al. 2019).

Supplementary Information [part] I

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**Additional notes on selected vertebrate species and plant remains from the main bonebed.
Rodents *Hystrix* and *Rattus* and other taxa**

SI I-33. A specimen of *Hystrix lagrelli* (Dubois Collection no. 1487) and the holotype of *Rattus trinilensis* (no. 1478) bear labels indicating they were found in 1899, presumably from the LB-HK, and are identified in the museum catalog (de Vos and Sondaar 1892; de Vos 1989; Muser 1982; SI II-129). Several ape or monkey teeth were found in the 1899 Trench, most likely from the LB-HK. One of the two non-hominin Catarrhines finds attributable to the LB in firsthand accounts (SI II-133) might be the isolated silvery langur *Trachypithecus cristatus robustus* molar which is only specimen of this species from Trinil (no. 3738, Hooijer 1962). One specimen of *Prionailurus bengalensis*, present in the Dubois Collection (no. 1484), was found in the trench of 1900, based on a note with the specimen (de Vos and Sondaar 1892; de Vos 1989).

Supplementary Information [part] I

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Additional notes on selected vertebrate species and plant remains from the main bonebed. Plant remains

SI I-34. Dubois’ August 1891 memorandum noted (SI II-168, -170 and -171) “... fossilized wood [and] imprints of leaves [occurred in the **LB** of the Skullcap Pit, where] the tree trunks and leaves are always found horizontally [and the remains were] similar to wood from a European bog.” Kriele’s August 27, 1893, letter (SI I-44) reported that “much wood” was present the **PFZ** in the 40-m Trench, as it was in the **LB** of 1896 Left-bank Pit (SI I -93). Carthaus (1911a: 14, Berkhout and Huffman 2021: 72-73) observed that the “woody remains ... in the main bonebed [included] tree trunks and branches up to 1- or 3-meters long.” Dozy (1909: 609) noted that “wood, fossilized in various manners, and carbonized wood occur ... in both Pits” presumably including the HK of Pit II. Schuster (1911a: 243, 244, 246) reported that “the fossilized reed grass of *Cyperus* ... [was] abundant in the Hauptknochenschicht” (HK, which also had some remains of a Sterculiacean tree and an evergreen wood-apple tree, as well as (1911b) silicified wood of another evergreen tree and a tree-like evergreen shrub. Regarding herbaceous remains, Schuster (1911a: 244) further reported that “the fossilized reed grass of *Cyperus* is not only abundant in the Hauptknochenschicht and the main leaf bed but is also present in the intervening clay and ash layer” (Berkhout and Huffman 2021: 205) suggesting that the Cyperaceae (sedge-) grounds might have occupied fully open vegetation or forest understories.

Schuster (1911a: 243; Berkhout and Huffman 2021: 204) saw the fossils in the main leaf bed (which was encountered primarily in the right-bank Pit I) as representing evergreen trees (such as those growing historically in the region), shrubs, deciduous leaf fragments, some epiphytes and Cyperaceae/*Cyperus* sp. From the remains, he concluded that the plants of Trinil belonged to an open tropical forest almost devoid of liana. Flenley (1979: 94) affirmed that “the [leaf] assemblage ... are mainly lowland rain forest species,” probably having drawn this conclusion from Schuster’s illustrations and descriptions (also, Morley et al. 2020: 577, “wet lowland forests”). Regarding the lithofacies of the Main Leaf Bed, Selenka and Blanckenhorn (1911: Tafel X) reported: As digging progressed in 1907 Pit I, there were “thin clay layers ... here and there with leaf imprints and partially carbonized wood [inferred to be in] a fluvial deposit”; the plant-rich interval in 1908 was a “complex [intercalation] of blue-grey ash ... with ... clay[stone] ... and many plant remains” spanning ~3.75m of stratigraphic thickness and lying as low as ~0.35 m above the HK (Berkhout and Huffman 2021: 49). In total, the “main Leaf Bed.... [contained] rapidly thinning beds [lenses] ... of plant material ... most ... in Augite-andesite tuff with mainly green- and brown-hornblende [phenocrysts]” (Schuster 1911a: 4).

Based on her palynological samples, Sémah (1986: 121; also, 1984, and Sémah et al. 2016) inferred an “open [as opposed to a closed canopy forest since] the only quantitatively important taxa are Poaceae [grasses], Cyperaceae [sedges] and ferns.” Polhaupessy (1990, 2002, 2006) analyzed three palynological claystone samples in the Trinil discovery area and one sample was evidently collected just below the HK along the left bank. While herbaceous taxa dominated her recovery and Poaceae (= Gramineae) was the principal component and Cyperaceae was a prominent second, Polhaupessy also identified 22 arboreal taxa, including nine of large-size forest trees and montane elements, such as *Podocarpus* (a prominent component in the “oak-laurel” lower-montane forests of Sundaland and Indochina of Morley 2018: 478). Samples from 3.5-4.5m above the HK (at approximately the level of the *Stegodon* bonebed in Selenka Pit II and the main leaf bed in Pit I) had more dryland arboreal constituents than did in a claystone immediately below the HK. Five claystone samples from the Pucangan Formation recovered Poaceae pollen more frequently than was the case stratigraphically higher. Polhaupessy (2002: 91-92) inferred a “widespread occurrence of grass-dominated swamps within a fluvial setting, and possibly the occurrence of savanna grassland” in “a markedly seasonal climate,” suggesting a shift in paleoclimate from drier conditions during Pucangan deposition towards wetter conditions at the time of the HK.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Terrace deposits at Trinil

SI I-35. Additional comments on the proposed occurrences of Solo River terrace deposits in Dubois' 1891-1893 excavations at the *Pithecanthropus erectus* site (see TERRACE DEPOSITS AT TRINIL, main text).

G.-J. Bartstra asserted that geologically young fluvial fill sat atop the Kabuh in the bluff “*at the spot where the skull-cap and thigh-bones ... were found*” so that “*Dubois not only excavated in the Kabuh Formation, but in terraces of the Solo River,*” by which he meant a substantial thickness of terrace deposits; thus the Trinil “*fossil remains ... come from two stratigraphic units that differ considerably in age,*” making the collections “*a mixture of fossils from the Middle Pleistocene Kabuh beds and the Upper Pleistocene and sub-Holocene Solo Terrace sediments*” (Bartstra 1982: 97, 1983: 330, 335, 336). Despite offers of provenience documentation that dispute this contention, particularly with respect to mixed faunal components comprising the Trinil fossil assemblage (de Vos and Aziz 1989, de Vos et al. 1982, de Vos 1989, Sondaar et al. 1983), Bartstra's comments have had a long-lasting influence on opinions about the Trinil Skullcap and Femur I representing different in geological ages, a hypothesis that largely derives from the *Homo sapiens*-like qualities of the 1892 Trinil long bone (e.g., Bartsiakas and Day 1983, Berghuis et al. 2021, Cartmill and Smith 2008, Day 1984, Dennell 2008, C. Groves in Bellwood 2017, Hooijer and Kurten 1984, Joordens et al. 2015, Kennedy 1983, Klein 1989, 1999, 2009, Lubenow 2004, Pop et al. 2020, Ruff et al. 2013, 2015, van der Geer et al. 2018; also, Day and Molleson 1973).

However, Bartstra had no direct evidence that fossil-bearing terrace deposits had been encountered in the Dubois (or Selenka excavations) on the left bank. Far from it. The strata originally overlaying the LB in the middle of the present-day Solo River had been excavated away a century earlier (e.g., Figures 3c and 4a, main text). Moreover, Bartstra apparently did not see the baulks of the LB which remain in the river near the 1891-1893 pits and trenches. Those remnants are only exposed during periods of extreme low water levels in the dry season, most commonly in October. The LB near the discovery point was inundated in September, when the I.J.R.C.P. (1979) mapped the area, but that field team did map a fossil-rich stratum at river level in the vicinity and interpreted it (their 'KBG 1') as the *Pithecanthropus erectus*-bearing unit (Figure 6d, main text, SI I-18). Bartstra missed this publication and the conclusion of I.J.R.C.P. that the discovery stratum is properly attributed to the Kabuh Formation of Duyfjes (SI I-18).

The only terraces Bartstra mentioned seeing personally near Trinil were located some distance from the 1891-1892 find spots (Bartstra 1983: 333, 334). He (1977, 1982) saw terrace treads with loose gravels lying above the incised river escarpments elsewhere along the Solo River valley, as others had (de Terra 1943, Lehmann 1936, Oppenoorth 1936, Sartono 1976, ter Haar 1931, 1934a,b), and perhaps Bartstra found terrace fills in side banks of the river and its tributaries which later studies observed (I.J.J.S.T. 1992, Rizal 1998a,b, Rizal et al. 2020, Sidarto and Morwood 2004, Saefudin et al. 1995, Suminto et al. 2004, Susanto et al. 1995). Like Duyfjes, who produced a geological map showing Kabuh Formation and terrace deposits around Trinil (SI I-16 and -17), Bartstra stressed the real difficulty in recognizing a clear stratigraphic break between the Kabuh and terraces fills.

Bartstra had not examined the Trinil fossils in the Dubois Collection. His assertion that the Trinil fossils represented mixed geological ages runs counter to the faunal and taphonomic uniformity in the Dubois and Selenka museum collections as we see the fossils. Bony elements in the museums include massive *Stegodon* and bovid specimens, and consistently exhibit little indication of subaerial exposure, fluvial abrasion and mixing of taphonomic- or faunal-components (Hill et al. 2015, Huffman et al. 2018). The matrix adhering to vertebrate specimens, and their consistent stony fossilization, indicate the discoveries had been made in indurated conglomeratic sandstone (e.g., Figure 2c, d, main text, SI I-20 to -24). The lithic materials could well represent a single depositional unit, judging from hand-specimen examination.

Bartstra's miscalculations did not end confusion about terraces on the left bank. Berghuis et al. (2021) conclude that the Pucangan and Kabuh Formations, together with older dipping formations around Trinil, are overlain unconformably by horizontal strath terraces at higher elevations and three Late Pleistocene valley fills at lower elevations (Berghuis et al. 2021 also redescribe and rename locally the formations of Duyfjes 1936 that underlie the terrace surfaces and deposits). The seven terrace units of Berghuis et al. span 27m in elevation (T2 is 13m above the Solo riverbed; T3 is 17m above; T4 is 18m; T5 is 23 m; T6 is 25m; and T7 is 27m above), but a full spectrum of these elevations is not present along the left bank near the former area of Dubois and Selenka excavations. The highest-elevation surface immediately south of the 1900-1907 excavations is half the height of the top terrace surface (T6-T7) across the Solo River, as Dubois and Selenka surely knew (e.g., SI I-14).

Berghuis et al. largely follows the terrace interpretations of Lehmann (1936) and several later publications (summarized in Berkhout and Huffman 2020; also, SI I-19). But Berghuis et al. introduce the idea that lower-elevation terrace fills followed three regional incision events which cut a Solo River valley nearly as deeply as it flows today. One of their fills (T2) is postulated to hold up the left bank lying south of the strata excavated by Dubois and Selenka (strata attributed to the Kabuh Formation by Duyfjes 1936 and I.J.R.C.P. 1979). Berghuis et al. correlate this inferred fill (and apparently the HK below it) to the early Late Pleistocene strath terrace containing the *Homo erectus* bonebed at Ngandong, ~10km away in the Solo River gap (Berghuis et al. Figures 5 and 10 illustrate this correlation but do not show the HK as being inside T2 on the left-bank, obscuring their intended stratigraphic placement of the main bonebed).

The conclusions of Berghuis et al. face considerable geological and paleontological obstacles. First, the extent of lithification in our units 2-6, which is clear from site photographs and reports of “hard” digging in the 1892-1907 excavations, is not in keeping with a Late Pleistocene valley fill. Generally, thin sedimentary

deposits of Late Pleistocene age do not indurate to the observed degree without substantial depositional overburden, and there would have been no overburden according to the Berghuis et al. interpretation.

The Ngandong strath deposit to which Berghuis et al. correlate the proposed Trinil left-bank terrace and the structurally deformed Perring bonebed (SI I-40, -43) are distinctly less lithified than were the beds overlying the main bonebed of the left bank at Trinil, judging from site photographs and firsthand accounts showing the need to use pick axes to remove the strata. By contrast, in digging the Ngandong *Homo erectus* site, traditional short-handled, flat-bladed agricultural mattocks, called ‘patjols’ in Java, readily cut through the ~3m of strath-terrace sands (which had no superjacent deposits); patjols and flat-tipped pits were able to dig vertical faces in the lithified Perring fossil sandstone, which is part of the anticlinally folded Pucangan Formation at the relocated discovery site of the fossil Mojokerto *Homo erectus* child skull (OFH pers. observation).

Taphonomic and faunal evidence also favors a bedrock in the 1891-1908 left-bank excavations. The Trinil fossils are more petrified than those from the Ngandong *Homo erectus* bonebed and the Perring fossil-skull bonebed generally are (OFH pers. observation). The Trinil fauna, which is defined on of known main bonebed finds (Table 2), occurs in ~0.9 Ma Kabuh Formation strata at Sangiran Dome (SI I-45), and is older than the fauna in the Ngandong strath terrace (SI I-40; Table 5, main text). These considerations strongly suggest that Berghuis et al. erred in identifying the beds in the modern embankment along the left shore as geologically young valley fill (and hence Berghuis et al. were wrong to suggest the that 1891-1893 discovery excavation contained fill).

Other unsettled geological issues form barriers to accepting key conclusions Berghuis et al. draw about the geology at Trinil. For example, their illustrations show 5-8° southward dip in the Kabuh Formation and Pucangan Formation on the right bank around Selenka Pit I (see Berghuis et al. Figure 4, 15 and Supplement 2A and 5), despite the horizontal structural attitude that the Selenka Expedition and Duyfjes observed thereabouts. Berghuis et al. also show exposures of dipping Kabuh and Pucangan strata in the right- and left-banks of other parts of the greater Trinil area where meters of horizontal terrace fills are said to cover these bedrock formations.

Conflicting interpretations might be expected to arise from Berghuis et al. approaches to geological mapping. Their geomorphology portrayal comes from digital elevation modelling of satellite data (seen in their Figure 2A with the potential effects of elevation-error unspecified). And Berghuis et al. map of the dipping bedrock formations is largely a revision of Duyfjes' work with his superjacent terrace deposit formation graphically eliminated (compare their Supplement 5 to Duyfjes' maps in SI I-16).

Also troubling is Berghuis et al. reliance on complex poorly documented stratigraphic inferences in the area to the south of the Trinil Museum (SI I-16, '1'). There, they report ~9m of fill (T4) atop inclined strata at 10m above the river, and 11m of fill (T2) on dipping beds at 2.5m above the river. In these relations, Berghuis et al. (2021: Figures 2 and 3) see the multiple incision-infill cycles critical to their interpretation. Each of their fills (T4-T2) is specified to have a horizontal base, scarp-like sides and a flat-lying aggradational top, but no field illustrations of such bases and scarps are provided. T4 and T2 appear to lack diagnostic scarp-like morphologies along their upland edges throughout the area; the bases and thick fills of T4-T2 were rarely observed.

Berghuis et al. leave unexplained relations in their interpretations that seemingly contradictory to Duyfjes' (1936) mapping. His (1936: 19) terrace-deposit unit covered most of the right bank with substantial thicknesses of “*loose sandstone, gravels with fossils*” (SI I-16). No bedrock protrudes through in the right-bank upland, and the terrace-deposit unit locally descends below the river, conditions which are inconsistent with the thin flat-lying terrace fills of Berghuis et al. Our own experience fits Duyfjes mapping better: A quarry ~500m west of the Trinil Museum has >10m of flat-lying sand and gravel underlying a high-elevation terrace surface (a “T5”); a quarry- and other-exposures farther north reveal >4m of horizontal sand and gravel where Berghuis (but less so Duyfjes) map bedrock ('1' and '3' on SI I-16; Huffman 2016). The deposits we observed in these places are less consolidated than those in the 1890s-1900s excavation of the left bank appear to have been.

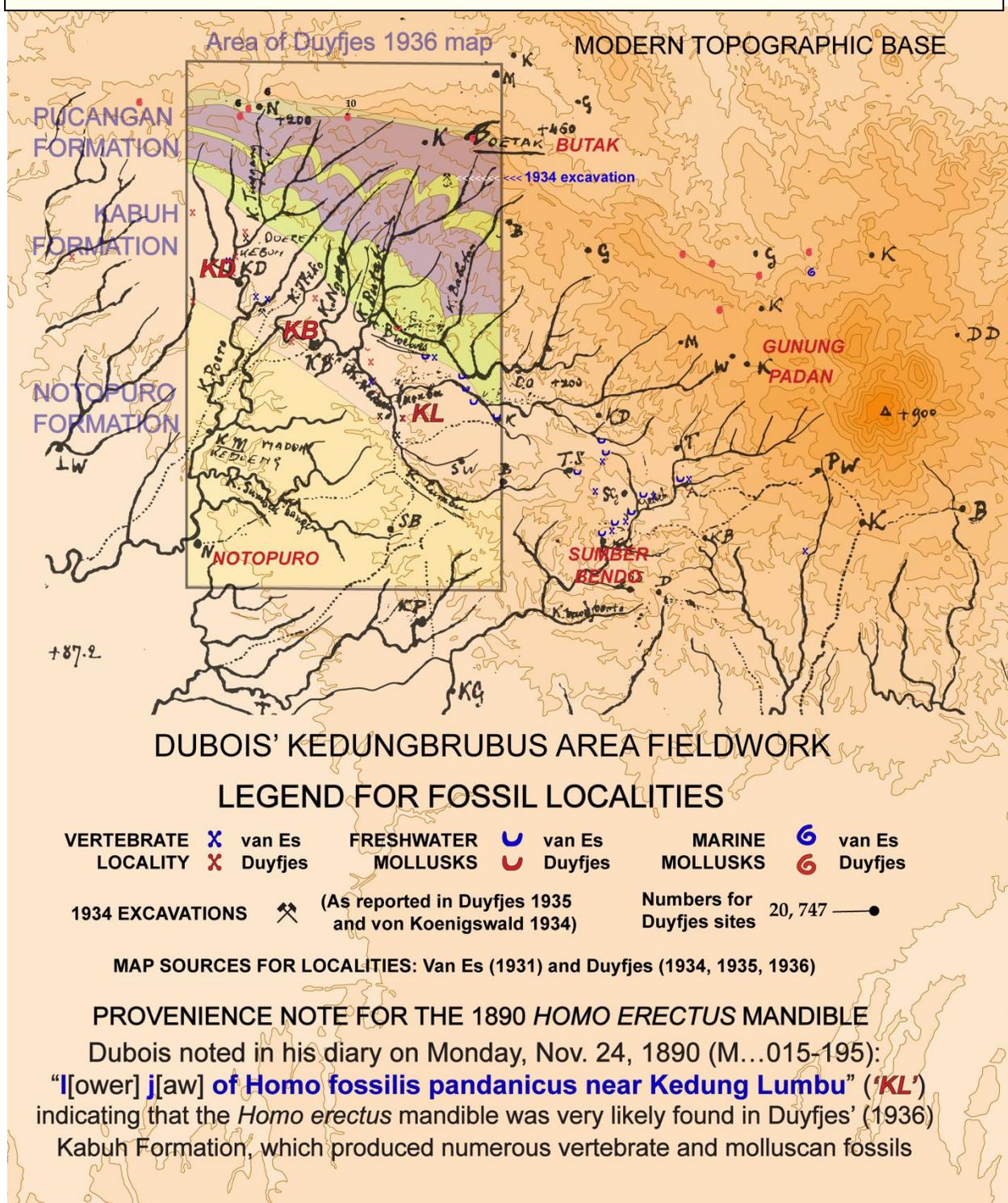
Therefore Berghuis et al. interpretations require much substantiation before acceptance. Verifications should include a single, detailed, geological map of the Trinil area showing both terrace- and pre-terrace units (to replace the mapping techniques described above). Substantiation must include compelling evidence for terrace-fill south of the left-bank Selenka and Dubois excavations, given their firsthand reporting, and an explanation of the thorough lithification of strata dug there in 1891-1908, as shown in numerous historic site photographs. Important also would be full illustration of the bedrock-fill-bedrock-fill sequence that Berghuis et al. envision south of the Trinil Museum, and reconciliation of their interpretation north of the Museum with the results of the Selenka and Survey descriptions there. Several other studies of strata along the Solo River to the west and east of Trinil bear importantly on the terrace history at Trinil (e.g., SI I-19, above) and should be assessed by Berghuis et al.

A plausible reconciliation of geological relations around Trinil, which warrants further field investigations, combines elements from several past interpretations: The LB-HK and younger strata (that is, those removed by excavation and projected to still be present along the left bank) are the Kabuh Formation in flat-lying structural attitude. So are the HK and eight-to-nine meters of superjacent beds around the former Selenka and Survey excavations on the right bank (also, SI I-14). This structural situation could involve flattening of bedrock formations that locally interrupts the normal southward monoclinial dip of bedrock strata along the Solo River and adjacent southern Kendeng Hills (SI I-19, above). The flattened attitudes would help account for the special difficulty separating the Kabuh and terrace deposits near the present-day Trinil Museum on the right bank. Confirmation is needed in particular of the T2-T4 valley fills that Berghuis et al. propose exist there, especially the scarp-like upland edges and flat broad bases their interpretation seems to require. The geological age of the Trinil fauna should continue to be taken as ~0.9 Ma, unless field- and radiometric-age determinations at Trinil firmly establish something younger.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets..

Map of Dubois' Kedungbrubus area fieldwork localities

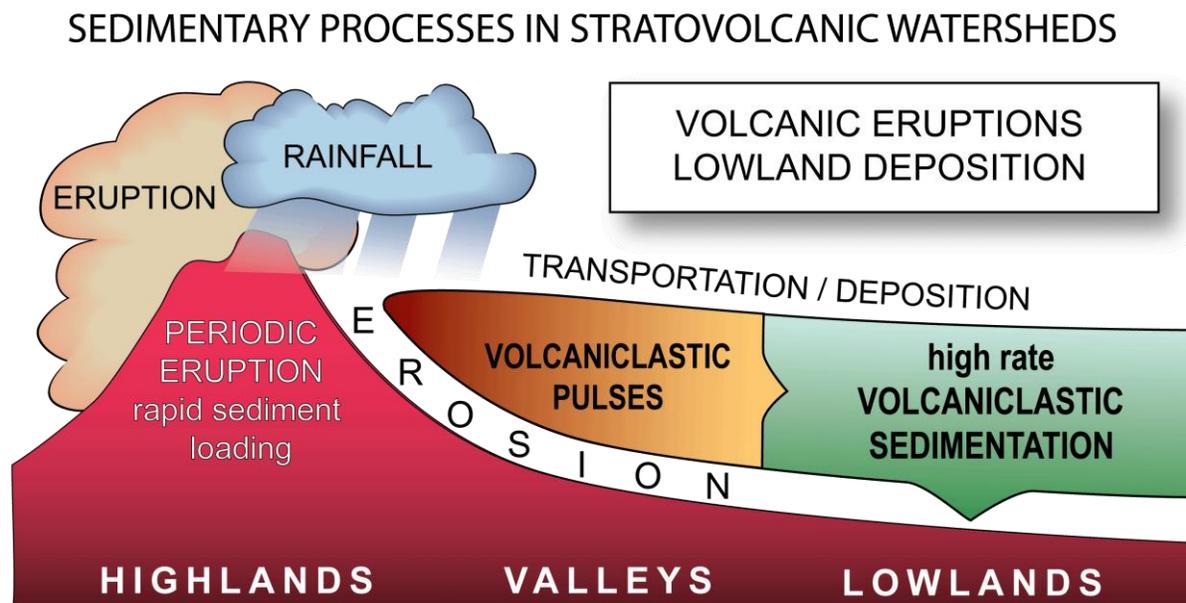


SI I-36. Composite geological illustration of the Kedungbrubus- and Butak-areas (Figures 1b and 13), combining information from: The Pucangan, Kabuh and Notopuro Formations of J. Duyfjes (1936); Dubois' 1890s mapping over a broader area (black); and a modern topographic base (rust-colored). The *Homo erectus* mandibular fragment that Dubois' field team discovered in 1890 probably came from the band of fossiliferous Kabuh Formation outcrop that extends from Kedung Duren (**KD**) to Kedung Brubus (**KB**) and Kedung Lumbu (**KL**). Kedung Lumbu is the former village, “about 2 km southeast of Kedung Brubus” (Dubois 1907: 451, SI II-234), near the discovery spot of the mandible, according to Dubois' diary (SI II-164, -165). Following his perceptive analysis of the local geology in 1890, Dubois returned to the Kedungbrubus collection area in 1894 (SI II-201, -202), when he completed collecting the fossils now curated in the Dubois Collection that form the basis for the Kedung Brubus fauna (Tables 5, main text, and SI I-41). Both Dubois and Duyfjes (1934) excavated fossils from the Butak bonebed (labeled “1934 excavation” on the map; Table 5, main text; SI I-42); the bed is in the lower Pucangan Formation of Duyfjes (Huffman 2020: 20-21, 24-25, 32; also, Suminto et al. 1995a, b). Also, Albers and de Vos 2010, Shipman 2001, Storm 2012, Tobias 1966.

Supplementary Information [part] I

Citations in the text of the paper to this information has the form of 'SI I-#.' (Or in case of Suppl. Inf. part II: 'SI II-#.') The inferred taxonomic identifications of the finds are in brackets.

Sedimentary Processes in Stratovolcanic Watersheds



SI I-37. Sedimentary processes related to eruptions at stratovolcanoes (Figure 1b, main text) dominated the terranes inhabited by those *Homo erectus* populations which are known from in eastern Java fossil remains. This is true for *Pithecanthropus erectus* (Huffman et al. 2012). A century ago, Dubois and the Selenka geologists appear to have envisioned the Trinil main bonebed, and perhaps overlying strata, as a continuation of the laharcic paleogeographic regime which is so prominent in diamictons of the underlying formation (Figure 13, main text). These men were perceptive in focusing on long-run out lahar flows as a mechanism for transportation and accumulation of the main bonebed (Huffman et al. 2012). Subsequent research on lahars amplifies the spectrum of geological conclusions one might draw from the identification of lahar deposits within a sedimentary sequence. In the Pleistocene of eastern Java, the implications of lahar include readily made insights into:

(i) Regional paleogeography (stratovolcanoes existed in the hinterland, and the watersheds were subject to fluvial processes that started as lahars). (ii) Paleo-vulcanology (lahars and coarse-grained sandy deposits of volcanoclastic materials often reflected penecontemporaneous volcanic eruptions, while little- or no-such volcanoclastic accumulation might imply protracted dormancy of the volcanoes in the watershed). (iii) Paleo-sedimentological setting (a high-rate volcanoclastic deposition occurred in the lowlands and adjacent water bodies, as illustrated above). (iv) Depositional mechanisms (modes of fluvial transport related to lahars contributed to sedimentary accumulation down-drainage, particularly when debris flows evolved into floods). (v) Paleoclimate at a basin-wide scale (stratovolcanoes capable of producing lahars are often sufficiently lofty to concentrate rainfall orographically and create rain-shadow effects). (vi) Paleo-hydrology (the rivers delivering lahars to the lowlands are part of an integrated drainage system which originated at volcanic peaks and varied in hydrological features from place to place; e.g., Figure 11, main text). (vii) Montane paleo-vegetation (the highlands of the stratovolcanoes, if not also on their flanks, are forested). (viii) Mass death (both lahar floods and associated volcanism had the capacity to produce high rates of biotic mortality, particularly notable when thousands of large animals concentrate in the path of large volcanic- and fluvial-events).

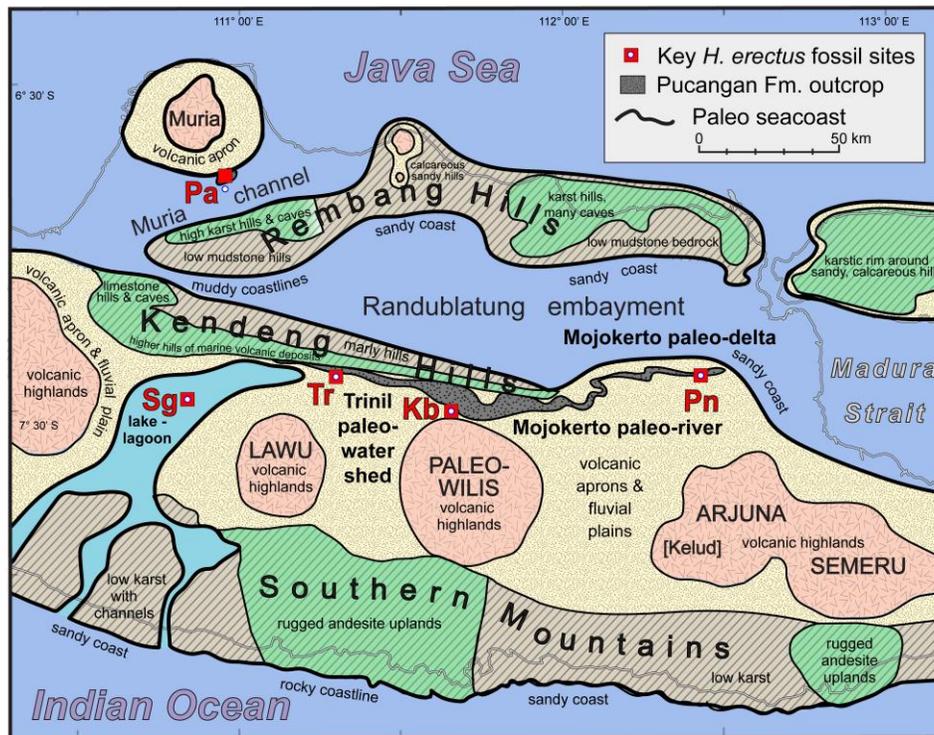
The influence of lahar deposits in the Pleistocene hominin record of Java is well established (e.g., Bettis et al. 2004, 2009, Huffman 2001a, b, Huffman et al. 2006, 2010a, Rizal et al. 2020, Zaim 2010). Dubois had this insight in the 1890s.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Homo erectus paleogeography of eastern Java

HOMO ERECTUS PALEOGEOGRAPHY OF EASTERN JAVA



SI I-38. This paleogeographic map of eastern Java (Figure 13, main text) serves as context for the site summaries in **SI I-39** to **SI I-48** and Table 5, main text. See: **SI I-39** for Trinil, Tr; **SI I-40** for Ngandong, Ng; **SI I-41** for Kedungbrubus, Kb; **SI I-42** for Butak, near Kb; **SI I-43** for Perning, Pn (near Mojokerto); and **SI I-44** to **-46** for Sangiran Dome, Sg; and **SI I-47** for Patiayam, Pa; also, **SI I-48** for Song Terus, not shown). Other paleogeographic representations of the region are in Berghuis et al. (2021), Djubiantono (1992), Djubiantono and Sémah (1993), Lunt (2013), Rizal et al. (2020), Sartono (1976) and Zaim (1989, 2010). Prior to the Pleistocene, eastern Java had a complex geological history of marine and volcanoclastic periods, but few large terrestrial vertebrates are known to have been present (e.g., Lunt 2013). The Java Sea, which occupies part of the Sunda (continental) Shelf, has been stable tectonically compared to Java since the mid Miocene, and the contrast is even more prominent compared to the tectonically active Indian Ocean continental margin south of Java (Figure 14, main text). Bathymetry there descends into an oceanic Sunda trench that reflects subduction of the Indo-Australian tectonic plate beneath the Eurasian plate which underlies Java and the Sunda Shelf (**SI I-50/51**; Kopp 2011, Lemenkova 2021).

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Trinil

SI I-39. TRINIL *PITHECANTHROPUS ERECTUS* MAIN BONEBED (Tr site in Table 5, main text; this summary is intended to be used in conjunction with SI I-40 to -48, below): *Pithecanthropus erectus* (*P.e.*) main bonebed at Trinil (LB, LB-HK and HK) accumulated in a stratovolcanic river drainage that exemplifies the Pleistocene paleo-watersheds in which all *Homo erectus* fossils so far discovered in eastern Java have been found (Figure 14, main text). The Trinil main bonebed formed as a lens spanning ~200m of a paleo-river channel and was generally about a meter thick. Based on firsthand accounts, most of the vertebrate bioclasts were broken, disarticulated, disassociated, well-preserved remains of terrestrial ungulates of the Trinil fauna (Table 3, main text). The remains were mixed with bioclasts of aquatic vertebrates, freshwater molluscs and plants, including sedges and logs, giving the main bonebed a degree biotic diversity exceeding that in any other *H. erectus*-fossil-bearing deposit in eastern Java (Table 5, main text). The assemblage included many craniums of cattle, buffalo, and proboscidean, among thousands of smaller skeletal elements and isolated teeth (SI II). The matrix surrounding the isolated gravel-sized skeletal bioclasts consisted of fluvially transported volcanoclastic materials, and was dominantly well-indurated, very poorly sorted conglomeratic sandstone. This type of material filled the endocranial space of *P.e.* Skullcap (Figure 2c, main text, SI I-2b). As is explained in the FORMATION OF THE MAIN BONEBED, main text, and SI I-25 above, the terrestrial vertebrate fossils in the main bonebed most plausibly originated from the catastrophic mortality of ungulate- and hominin-populations living in the flood zone of the Trinil paleo-river valley (Table 4, Figure 12, main text). The valley lay between the Kendeng Hills and the foot of Lawu volcano and might have had headwaters on Wilis volcano (Figures 11 and 12, main text). After the vertebrate carcasses were skeletonized, the bones were transported by lahar flooding to Trinil along with aquatic fauna (Figure 12, main text). As summarized in PALEOGEOGRAPHIC IMPLICATIONS, main text, the Trinil fauna also occurs in the Grenzbank bonebed (SI I-45 below). It contains reworked bioclasts and lithic materials derived from drainages in the Kendeng Hills and perhaps Southern Mountains, as well as those surrounding stratovolcanoes. The faunal similarity between the main bonebed and Grenzbank suggests that the Trinil fauna is a good representation of the large vertebrate populations present in the region at that time. From the perspective of taphonomic and sedimentary history, the main bonebed is similar to that of the Ngandong *Homo erectus* bonebed (SI I-2 below).

Citation footnotes:

¹ Huffman, O.F. 2017, Huffman et al. 2010a, 2012, 2018, ter Haar 1931, 1934a, b; the Ng fossil concentration is in unit 2/II of Oppenoorth 1932 and unit II of ter Haar 1934b (Huffman et al. 2010a: Table 3 and Figures 3A, and 7, respectively), and Facies C of Rizal et al. 2020: (e.g., Fig. 2, and Supplementary Information: section 2, part 3).

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Ngandong

SI I-40. NGANDONG *HOMO ERECTUS* BONEBED (Ng site in Table 5, main text): Excavation at Ngandong produced 14 *Homo erectus* specimens together with ~25,000 other vertebrate bones.¹ They originated in a ~3m-thick terrace deposit remnant which rests unconformably on deformed marly bedrock ~20m above the Solo River in the Kendeng Hills.¹ The Ngandong *Homo erectus* bonebed is a distinct, thin member of the terrace deposit and consists of fossil-rich, coarse-grained, gravelly, very poorly sorted, partially diamictic volcanoclastic bar sands (locally >5 fossils m⁻³). The bonebed member was recognized by the discoverers¹ and confirmed by field studies in 2008 and 2010.² The bonebed was succeeded by >2m of river-bar sands and a muddy laharic diamicton in a single depositional sequence that reflects the lahar-flood origin of the terrace deposit.² The volcanic materials in the deposit originated from the Wilis and Lawu watersheds (Figure 11, main text). The biotic materials in the bonebed resulted from mass-mortality and lahar-flooding events that were similar to those responsible for the Trinil main bonebed (Figure 12, main text).¹ Since the discovery of the Ngandong *Homo erectus* specimens in 1931-1933, they generally have been considered to be among the geologically youngest representatives of the species (due to their advanced anatomical features and occurrence in a terrace remnant perched above the modern Solo River).¹ Radiometric dates now indicate that the hominin specimens and Ngandong fauna associated with them at the site are early Late Pleistocene age (117 to 108ka in modelled results).² The Ngandong *Homo erectus* bonebed indicates that ancestor populations of *Stegodon-Homo erectus* (*S.-H.e.*) fauna lived through maximum glacio-eustatic paleogeographic changes during the preceding 10-15ka (SI I-49a, below). Combined with radiometric and paleomagnetic studies at Sangiran Dome SI I-45 and -46, below), Ngandong discoveries establish that of *Homo erectus* occupied the stratovolcanic drainages of medial eastern Java for >0.8 Ma. One Ngandong cervid skull reportedly has cut marks³ but the ungulate fossils are otherwise notable for their lack of indications of human action.^{1,2}

Citation footnotes:

¹ Huffman et al. 2008a, b, 2010a, b, 2012; also, Sidarto and Morwood 2004, Suminto et al. 2004. ² Rizal et al. 2020: especially 384, Figure 2, and Supplementary Information 2(3): 4-7, OFH pers. observation. ³ Choi 2003.

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Homo erectus paleogeography of eastern Java Kedung Brubus

SI I-41. KEDUNGBRUBUS *HOMO ERECTUS* FOSSIL COLLECTION AREA (Kedung Brubus in Table 5, main text): The Kedungbrubus area was source for the *Homo erectus* mandibular fragment that Dubois found in November 1890 (SI I-36). The find is one of three key *Homo erectus* discoveries made from the bedrock formations of the Kendeng Hills (Table 5, main text, Tr, Kb and Pn, SI I-38). The hominin specimen is a partial mandibular corpus.¹ Dubois recognized the specimen as *Pithecanthropus erectus* long after his discoveries at Trinil.² The Kedungbrubus hominin find very likely came from the outcrop area of the (later-designated) Kabuh Formation (SI I-36). The Kabuh outcrops commonly produced freshwater molluscan- and vertebrate-fossils (SI I-36). The vertebrate specimens include the Dubois Collection material used to define the Kedung Brubus fauna (Table 5, main text). The Kabuh Formation around Kedungbrubus is “225 meters of ... coarse [-grained], andesitic sandstones,” which are “often cross-bedded,” and contain conglomerate lenses, “occasional ash-tuff layers” and marly beds of reworked marine materials from the older formations in the Kendeng Hills.³ While fluvial accumulation appears to dominate the Kabuh Formation in the Kedungbrubus area, and its situation on the north flank of paleo-Wilis is clear (SI I-38), the paleogeographic details of drainage system during Kabuh deposition remains uncertain.⁴

Citation footnotes:

¹ de Vos and Sondaar 1982, Duyfjes 1936, Storm 2012, van Es 1931. ² de Vos 2014, Dubois 1907, 1924a, Tobias 1966. ³ Duyfjes 1934, 1935, 1936: 143, Hidayat et al. 1995, Huffman 2020: 9; also, van Es 1931, Kimura et al. 1995. ⁴ Sartono 1976. See also, SI I-51.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Butak

SI I-42. BUTAK BONEBED (Kedungbrubus-Butak area in Table 5, main text, SI I-38): The Butak bonebed crops out northeast of the Kedungbrubus area at a local prominence, Butak peak (SI I-36). The Kabuh Formation in the Kedungbrubus-Butak area is underlain by 425m of the Pucangan Formation; 275-m of it consists of gravely diamicton-rich members and the rest has an abundance of andesitic sandstone; the lithofacies represent the onset and continuation of volcanic activity at paleo-Wilis.¹ The thick stratigraphic mass of diamictic- and interbedded-sandy volcanoclastic strata extends laterally in outcrop for >35km east-west.² The exposed relationships make for an open-air cross-section of the cone-shaped northern flank of the immense Pleistocene paleo-Wilis stratovolcano, the full paleogeographic effects of which extended from Trinil to Mojokerto along major river drainages (Figure 11 to 13, main text, SI I-39.-43).⁴ The west-flowing paleo-drainage was part of the Trinil paleo-watershed (Figure 12). The geological formations representing the east-directed drainage clearly crop out in the greater Mojokerto area of the eastern Kendeng Hills, far to the east of Kedungbrubus (SI I-43). The Butak bonebed contained fossils of *Stegodon*, large bovid, *Axis*, *Rusa* deer, *Duboisia*, pig, hippopotamus, anteater, tiger and crocodiles (Table 5, note, main text). The stratigraphically lowest-known vertebrate fossils in the Kedungbrubus-Butak section, the Butak bonebed lies just above a lower boulder-diamicton member that gave a 1.87 Ma K-Ar isochron (whole-rock analysis of an andesite clast).³ The Butak bonebed indicates that lahar-prone slopes of Wilis strato-volcano were inhabited by a diverse large-mammal fauna as early as the Early Pleistocene.

Citation footnotes:

¹ Duyfjes 1936, Huffman 2020: 7, 20-35, Itihara et al. 1985b. ² van Es 1931, Huffman 2020: 23. ³ Bandet et al. 1989, Duyfjes 1934, 1936, Huffman 2020: 25. ⁴ Duyfjes 1934, 1936, 1938a-d (and unpublished mapping from the late 1930s), Huffman 2020: 41; also, Shibasaki 1995, Yamamoto and Suminto 1995. See also, SI I-51.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Perning

SI I-43. PERNING *HOMO ERECTUS* BONEBED, MOJOKERTO AREA (Pn in Table 5, main text, and SI I-38): The Kendeng Hills north of the city of Mojokerto affords good exposures of the Pucangan Formation. Facies changes within members of the Formation, when traced across a hundred kilometers of the eastern Kendeng Hills, indicate the long-standing presence of Mojokerto paleo-delta (as illustrated in the paleogeographic map on page SI I-38).¹ Generally, volcanoclastic non-marine facies on the southwest, which were derived substantially from paleo-Wilis, transition episodically toward the east and north into muddy-marine strata of the former Madura Strait (Randublatung embayment; Figure 13, main text). The Perning *Homo erectus* bonebed, which is the relocated source of the Mojokerto *Homo erectus* child skull fossil, is a thin lithified conglomeratic sandstone lens deposited within a small lobe of the paleo-delta; the lobe is represented in outcrop by ~70-m of deltaic strata in the upper Pucangan Formation.² Pollen spectra and grass-phytoliths from the ~70-m-thick sequence show that the paleo-delta lowlands were characterized by dry grasslands during the time that the Perning *Homo erectus* population lived in the area.³ The palynology also indicates that the paleo-delta and associated river valley had mangroves, swamps, delta- and riparian-forests with montane vegetation in the distance.³ The abundance of grasslands reflect Pleistocene aridity similar to modern climates hundreds of kilometers to the east in one of the driest parts of Indonesia (Nusa Tenggara; e.g., the lowlands of Flores).⁴ The large mammal species in the upper Pucangan Formation at Perning and Jetis-Gondang is Kedung Brubus fauna and many taxonomic elements in it also occur in the Trinil fauna (Tables 3 and 5, main text).⁵ Even forest-prone *Rhinoceros sondaicus* and *Panthera tigris* had habitats in the paleo-delta around the time that the Perning *Homo erectus* bonebed accumulated. The paleogeographic setting of the Mojokerto child skull discovery at Perning indicates that *Homo erectus* and the Kedung Brubus (large-mammal) fauna inhabited the Mojokerto paleo-delta and -river valley(s) under particularly dry climatic conditions.

Citation footnotes:

¹ Duyfjes 1935, 1938a-d, Huffman 2020: 41, sheets 110 and 116. ² Huffman and Zaim 2003, Huffman et al. 2005, 2006; also, Morwood et al. 2003 regarding dating. ³ Morley et al. 2020. ⁴ See Monk et al. 1997. ⁵ Aziz et al. 1995, Cosijn 1931, 1932, Huffman et al. 2006, 2007, von Koenigswald 1934; also, de Vos et al. 2007b.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Bukuran, Sangiran dome

SI I-44. BUKURAN BONEBED, SANGIRAN DOME (Sg with the Ci Saat fauna in Table 5, main text, and SI I-38): The Sangiran Dome is a gently dipping diapiric outcrop of Plio-Pleistocene beds exposed as an ~5- by 8-km uplift within the Solo Basin. The Bukuran bonebed biofacies and lithofacies suggest that early hominin populations encountered complex peri-lacustrine habitats and variable climates in the paleo-Solo Basin (Figure 13, main text, SI I-38, above). Where excavated, the Bukuran bonebed was ~0.4m of sandy silt with seed fossils and skeletal remains. The vertebrate assemblage (NISP = 394) consists of 60% aquatic species (~55% fish, 39% turtle, 6% crocodile and 2% bird fossils); the mammalian specimens are 29% cervid, 9% bovid and 4% hippopotamus, and notably lack the *Stegodon*, *Duboisia* and *Panthera* which occur at other fossils sites at the Dome.¹ The lithofacies and paleontology of the Bukuran bonebed, which is in the upper portion of the Pucangan Formation (see Table 5, note 3; sometimes termed the Sangiran Formation), contains remains of a biota that lived within and surrounding a paleo-lake during a period of heightened tectonic activity. The ~10m of strata that contains the bonebed includes a layer of foraminiferal sand derived from the erosion of distant marine bedrock, thin tuffs representing far-off pyroclastic eruptions, an ~0.75m-thick peaty-shell deposit reflecting an invertebrate-rich lacustrine fauna, and palynological materials indicating a “thick growth of grass ... Cyperaceae [sedges and] ferns” covering a lowland that varied in vegetation over time from swamp to savanna.² The upper Pucangan Formation is thought to contain the earliest *Homo erectus* fossils at Sangiran Dome (Table 5, note 4). The “radius ... of a ... *Bos* sp. [from Bukuran] Revealed two clusters of cut marks ... [indicating] hominids’ intentional defleshing” of a carcass (this taphonomic reporting needs confirmation and discovery circumstances and stratigraphic level of the *Bos* specimens are not specified).³ Paleosols in the upper Pucangan record protracted periods of lowland exposure under “strongly seasonal climate with a dry season oscillating between short[er] and long[er] durations.”⁴

Citation footnotes:

¹ Aimi and Aziz 1985, Kadar et al. 1985. ² Brasseur et al. 2015, Kadar et al. 1985, Tokunaga et al. 1985: 202-203, Yoshikawa and Suminto 1985; also, Sémah et al. 2016. ³ Choi and Driwantoro 2007: 51 and 55.

⁴ Bettis et al. 2009, Brasseur et al. 2015: 97.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Grenzbank, Sangiran dome

SI I-45. GRENZBANK *HOMO ERECTUS* BONEBED, SANGIRAN DOME (Gb with the Trinil fauna in Table 5, main text, Sg in SI I-38): The Grenzbank (“boundary bed”) is the lowest member of the Kabuh Formation and unconformably overlies the Pucangan Formation (see Table 5, note 3).¹ The Grenzbank has a Trinil-like mammalian assemblage that is substantially more diverse taxonomically than vertebrate collections from the Pucangan Formation. Sandstone in the Grenzbank is often cross bedded and streaked with dark-colored heavy mineral laminae representing volcanic provenance. Carbonate-cemented pebbly sandstone lenses in the bonebed indicate that erosion of Kendeng Hills and Southern Mountains contributed sediment to the paleo-drainage in the Sangiran Dome area (SI I-38).² Most vertebrate remains in the bonebed had experienced “multiple reworking events that generally resulted in the ... selective removal of Low-density skeletal elements.”³ For example, individual teeth make up 86% of 215 ungulate-, carnivore- and rodent-specimens that were excavated at in the Brankal-site from the ~2.25-m-thick Grenzbank “granule and pebble gravel [conglomerate] with mammalian and molluscan fossil[s]”; cervids, *Duboisia* and *Sus* were consistently found in six trenches at Brankal, as were *Crocodylus*, Testudinoidea and fish; proboscidean and forest-prone species *Hystrix*, *Rhinoceros*, *Tapirus* and *Tragulus* also were present (but large-bovid remains were rare).⁴ The first hominin fossil discovered at Sangiran Dome was found in 1937. Since then, >80 skeletal hominin fossils have been discovered with ~15% of them originating in the Grenzbank bonebed unit; this discovery density is higher than from any other stratigraphic level at the Dome.⁵ The Grenzbank is ≥ 0.9 Ma, more likely <1.3 than <1.5 Ma.⁶ The *Duboisia*, *Rhinoceros* and *Sus* in the Grenzbank indicates a Trinil-fauna was present during the period of accumulation (Table 5, main text).⁷ Since this formed at an unconformity, the Grenzbank contains a sample of fauna that lived over a longer time span than was the case in the formation of the Trinil main bonebed. Thus, the terrestrial vertebrate assemblage of the Trinil fauna (Table 3, main text) appears to have included all larger-mammal species then present in the intervolcanic watersheds of eastern Java.

Citation footnotes:

¹ Basseur 2009, Itihara et al. 1985c, Sudijono 1985, Zaim et al. 2011. ² Zaim et al. 2011: 366-367; also, Bouteaux 2005, 2008, Bouteaux et al. 2007. ³ Aimi and Aziz 1985 (Trenches III and IV), Sudijono et al. 1985: 75. ⁴ Zaim et al. 2011; also, Basseur et al. 2015, Itihara et al. 1985a, Matsu’ura et al. 2020, Widiyanto et al. 2001 (regarding artefacts). ⁵ Basseur 2020, Matsu’ura et al. 2020. ⁶ Sondaar 1984: 232; also, Bettis et al. 2009, de Vos 1994, Watanabe and Kadar 1985.

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Homo erectus paleogeography of eastern Java Ngebung, Sangiran dome

SI I-46. NGEBUNG HOMININ BED, SANGIRAN DOME (Nb in Table 5, main text): The Ngebung bed, which stratigraphically lies above the Grenzbank bonebed in the lower Kabuh Formation, contained the only *in situ* evidence of tools used to consume large-mammal remains known from the *Homo erectus*-bearing formations of Java. “Whole rock and single grain argon dating of volcanic effluents, ESR dating of volcanic quartz, combined U-series and ESR dating of enamel from herbivorous fossil teeth converge to assign the site an age of 0.8 Ma.”¹ The anthropological materials occur within <2.5m of hydromorphic soil aggregates; they had been reworked locally, contained plant and vertebrate remains and accumulated in a low elevation floodplain with poorly drained soils.² The hominin occupation was situated along the clayey bank “of an ancient river.”³ The non-aquatic vertebrate fossils (NISP = 246) are 81% *Axis*, *Bubalus* and *Stegodon*, representing a well-developed mid-*S.-H.e.* assemblage, reasonably considered a Trinil fauna with Kedung Brubus elements (e.g., *Epileptobos groeneveldtii*).⁴ The bonebed included “an almost undisturbed [hominin] occupation floor” with pebbles that “appear to have been used or worked by man” but not associated with a “workshop.”⁵ A molar with *H. erectus* morphology (NG91-G10 no.1) was recovered.^{4, 6} As further reported by the excavators, but yet to be published upon in detail, the ungulate “skeletons were already dismembered, the skulls opened, and the mandibles broken before deposition;” and “impact and cut marks are visible on long bones from adult bovinds as well as *Stegodon* tusks.”⁷ The Kabuh Formation in the Ngebung portion of Sangiran Dome has three fining-upwards depositional cycles; paleosols (vertisols and protosols) and soil-carbon isotopes from the floodplain facies indicate water-tolerant soils supporting grasses, shrubs and trees (lower cycle) and well-drained soils formed under mixed vegetation and climate with annual dry seasons (middle and upper stratigraphic cycles).⁸ The dating of the Ngebung bonebed (~0.8 Ma) supports the Early Pleistocene geological age assigned to the underlying Grenzbank *Homo erectus* bonebed and Bukuran bonebed in the upper Pucangan Formation. The evidence of hominin activity in the Ngebung bonebed draws attention to the general dearth of *in situ* lithic artefacts in the *H. erectus* formations of Java and therefore represents a break in the common association of stone-tools with archaic hominin activities. Artefacts are common at archaic hominin-fossil areas in Flores, Sulawesi and Luzon.⁹

Citation footnotes:

¹ Falguères et al. 2016; also, Brasseur 2020, Matsu’ura et al. 2020, Saleki et al. 1998. ² Brasseur 2009, Ingicco et al. 2022, Sémah 2001. ³ Simanjuntak et al. 2010: 419; also, Sémah et al. 2003 (figures). ⁴ Bouteaux and Moigne 2010. ⁵ Sémah et al. 1992: 443, also, Moigne et al. 2004a, b. ⁶ Zanolli 2013, Martín-Francés et al. 2018. ⁷ Sémah et al. 1992: 443, also, Moigne et al. 2004a. ⁸ Bettis et al. 2009, Brasseur et al. 2015. ⁹ E.g., Ingicco et al. 2022, Sémah, et al. 2016; Sémah, et al. 1992; Simanjuntak et al. 2010.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Patiayam

SI I-47. PATIAYAM HOMININ-FOSSIL COLLECTION AREA, NORTH CENTRAL JAVA (Pa, not included in Table 5, main text): The Patiayam area lies north of the Kendeng Hills and the mid-island volcanic belt of Java (Figure 1b, main text), and contains a window of strata surrounded by deposits of the historic Muria volcano (which has a 1625m crest and is ~30km across). The *S.-H.e.* fossils at Patiayam come from deposits of a Pleistocene strato-volcano that evidently was a paleo-island separated from the Hills by the Randublatung marine embayment (Figure 13, SI I-38).¹ The volcanoclastic strata were laid down near a lake or swamp and have produced isolated fossils of *Stegodon trigonocephalus*, large bovids, cervid species, *Sus brachygnathus* and *Rhinoceros sondaicus*, together with *Crocodylus* and Testudines.¹ Species that occur are typical of the *S.-H.e.* and include both Trinil fauna and Kedung Brubus fauna elements. Two isolated premolars and six parietal fragments of an archaic hominin species attributed to *Homo erectus* were unearthed from tuffaceous siltstone within the Pleistocene volcanoclastic sequence.² It includes an older eruptive series dated (by K-Ar methods, mid 1980s) to 0.64-1.11 Ma and a younger one dated to 0.41-0.78 Ma.³ Vertebrate fossils were collected at Patiayam as early as 1850 by Franz Junghuhn; the area was a target of Dubois' 1891 field program before de Winter was called to Trinil to supervise initial excavations on the right bank of the Solo River there.¹ The Patiayam collections appear to indicate that *S.-H.e.* species ranged across most or all of the eastern Java and resided along the margin of southern Sunda Shelf (Figure 14, main text). Lasem Pleistocene volcano (806 m) lies ~60 km east of Muria in the Rembang Hills (Figure 13, main text, SI I-38, above). No vertebrate fossils are reported from Lasem but a mudflow tuff there contained a paleo-flora. The Pleistocene Patiayam stratovolcano, westernmost Rembang Hills and Kendeng Hills were separated by structural depressions in which a thick accumulation of marine mudstone which lacks no indication of Pleistocene terrestrial volcanoclastic deposits is evident from drilling results and seismic data obtained in the course of petroleum exploration.^{2, 4} Bawean Island, which lies 160km north-east of Lasem in the Java Sea, evidently also was a Pleistocene volcanic center, but seismic data between Bawean and Java reveals no other centers (e.g., SI I-51a). No archaic-hominin sites or Paleolithic artefacts have been reported from the Rembang-Tuban Hills and Madura Island. In both areas, pre-Pleistocene carbonate formations are widely exposed, including karstic development in the range (Figure 13, main text); the terrain was uplifted and deformed before deposition of the *H. erectus*-bearing formations.⁴ Some caves have young archaeological materials, but none appear to be contemporaneous with the Middle Pleistocene lithic assemblage of Song Terus, Southern Mountains. (SI I-48, below).

Citation footnotes:

¹ de Vos 2014, Huffman 2001a, Huffman et al. 2000, Saléh 1867, Sartono et al. 1978, Siswanto and Noerwidi 2016, Soeria-Atmadja et al. 1988, van Bemmelen 1949, van Gorsel 2022a, van der Geer et al. 2010, van Es 1931, Zaim 1989, 2010; also, Lunt 2013. ² Zaim 1989, 2010; Y. Zaim, pers. comm. 2011. ³ Bandet et al. 1989, Bellon et al., 1989, Maury et al. 1987, Schuster 1911a, Zaim 1989; also, Lunt 2013, Mulyaningsih et al. 2008. ⁴ Nurani et al. 2008, Lunt 2013, P. Lunt, pers. comm., 2000 to 2005.

Supplementary Information [part] I

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Homo erectus paleogeography of eastern Java Song Terus

SI I-48. SONG TERUS MIDDLE PLEISTOCENE CAVE, SOUTH CENTRAL JAVA (not shown on SI I-38 or Figures 1b and 13, main text): Song Terus cave lies in a karstic upland, Gunung Sewu (Thousand Mountains), lying at ~50-500m in elevation and covering a 10-by-80-km area where the annual rainfall (1500-3000mm) is high for eastern Java. The upland is part of the older Southern Mountains volcanoclastic and limestone terrain, which is traced intermittently from southeastern Sumatra to Bali along portions of the Indian Ocean margin of Sundaland.¹ At Song Terus, “a large number of rolled and fresh artefacts occur In certain layers” within Pleistocene “fluviatile ... [sedimentary] remnants” of the deeper portions of the cave² “Retouched flakes” were unearthed by the hundreds with fragmentary skeletal fossils, including those of the forest-prone species of rhinoceros and tapir which are “c. 300ky, [based on] combined U-series and ESR dating of enamel.”³ The Southern Mountains differed from the stratovolcanic watersheds to the north in topography, soils, climate due to a proximity to the Indian Ocean coast (e.g., the Southern Mountains historically have a wetter November-May monsoon seasons than do parts of eastern Java to the north). The G. Sewu karst formed before ~500 ka,⁴ and the karstic upland was probably present throughout the hominin occupation of Java (Figure 13). The absence of archaic hominin skeletal fossils in the Southern Mountains is most likely due to systematic taphonomic decomposition of remains, rather than a lack of older Pleistocene large-mammal occupation, given the widespread preservation of bony fossils in the *Homo erectus*-bearing formations north of the Mountains (Figure 14).⁵ Other Cave sediments in the Punung area produced the remains of forest species, such as siamang and orangutan. These species characterize the Punung fauna, in which *Homo sapiens* appears and no extinct species occur (Table 4, note 6).⁶ Immigration of *H. sapiens* into Southeast Asia occurred before 63-73 ka, based on widely accepted studies considering genetic and archaeological evidence in Eurasia and Australasia.

Citation footnotes:

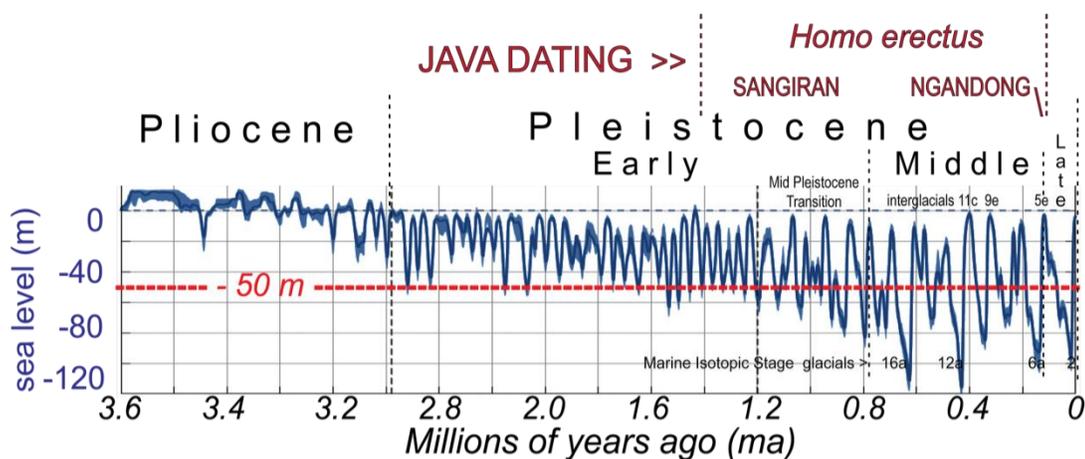
¹ Haryono and Suratman 2010. ² Sémah et al. 2004: 54. ³ Ansyori 2010, Falguères et al, 2016: 9, Hameau et al. 2007, Sémah et al. 2004, Simanjuntak et al. 2010: 419. ⁴ Rizal et al. 2020, Simanjuntak 2002, van Bemmelen 1949, Westaway et al. 2007. ⁵ Huffman et al. 2012. ⁶ Storm and de Vos 2006, Storm et al. 2005, Westaway et al. 2007; also, Kaifu et al. 2022.

Supplementary Information [part] I

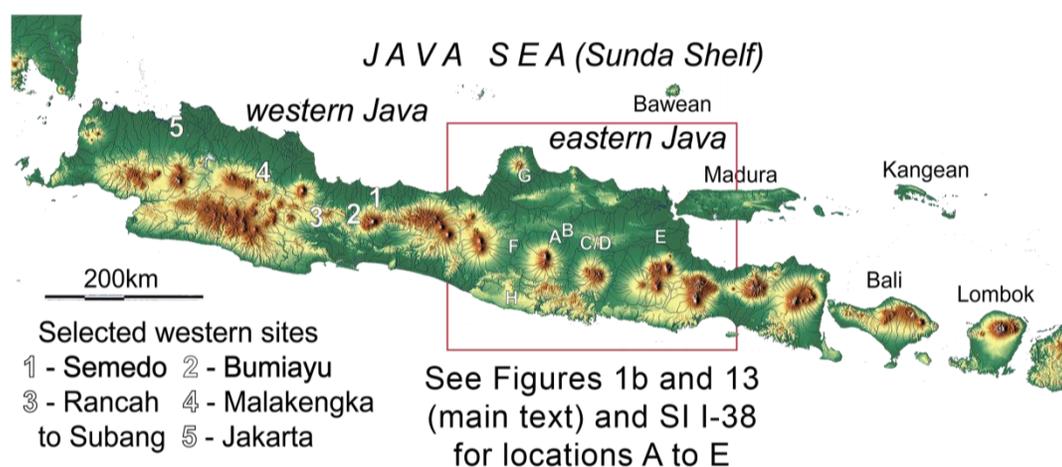
Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#. Inferred taxonomic identifications are in brackets.

Sunda Shelf Paleoclimate Consequences

a SUNDA SHELF EXPOSURE AND PALEOCLIMATE PROXY



b STEGODON-HOMO ERECTUS FAUNA DISTRIBUTION



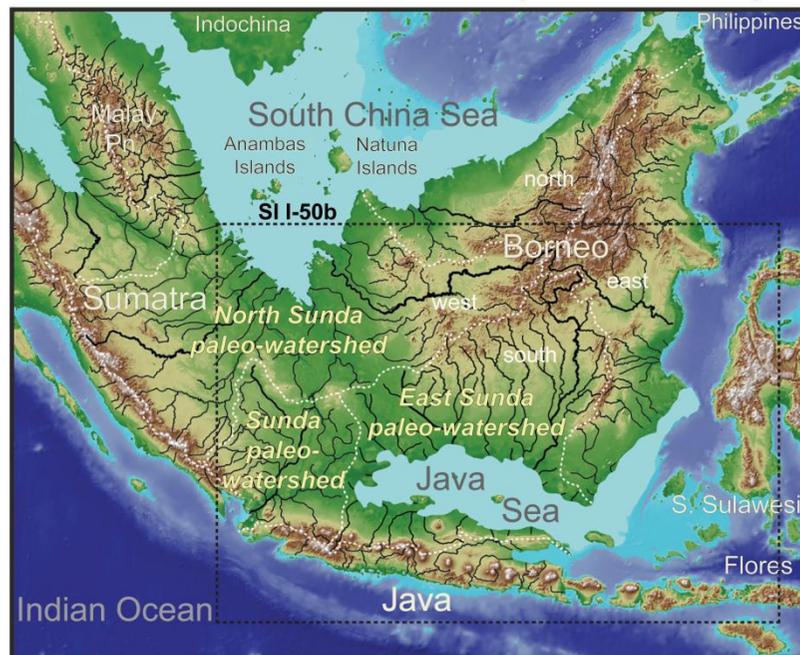
SI I-49. (a) Southern Sundaland experienced profound changes in landscape and climate during the Pleistocene, as illustrated by a proxy curve for global sea level (SL, blue; Berends et al. 2020; also, Past Interglacials Working Group of PAGES 2106). The Sunda Shelf was exposed and inundated to varying degrees over time, and the climate changed repeatedly while *Homo erectus* occupied the region. The 117-108 ka Ngandong *Homo erectus* bonebed (SI I-40) postdates a highstand in last interglacial period (MIS 5e) at ~116-128 ka (described in Rohling et al. 2007, 2017, Rovere et al. 2016; also, Shackleton et al. 2003) and followed the penultimate glacial maximum (MIS 6a) at ~140 ka (described in Cheng et al. 2006, Schneider et al. 2013; also, Railsback et al. 2015). In between these times, the “Java Sea would have [included] a complex ... of lowlands, rivers, lakes, lagoons, shorelines, estuaries, and bays” (Huffman 2001: 242-243; also, Aziz et al. 1995). (b) The *Stegodon-Homo erectus* (*S.-H.e.*) faunas occur in western Java sites similar to those in eastern Java sites (Zaim 2010). Eastern Java locations A to H on the map correspond to site summaries SI I-39 to -47, respectively. In western Java, examples of *S.-H.e.* sites (1-5) are shown in relation to modern coasts, lowlands, rivers, mountains and volcanoes (green/dark tones in the lowlands transition to yellow/light and brown/medium at higher elevations). Archaic hominin fossils have been discovered at Semedo and Rancah (1 and 3) >200km west of Sangiran Dome (e.g., Kramer et al. 2005, Noerwidi and Siswanto 2014, Noerwidi et al. 2016, Siwanto and Noerwidi 2014, Widiyanto and Noerwidi 2020). Vertebrate fossils have been collected since the 1930s from a thick Pleistocene sequence at Bumiayu (2), where the type section for the oldest *S.-H.e.* unit, the Ci Saat fauna, is located (e.g., Sondaar 1984, Suhiryogi et al. 2019, ter Haar 1929, 1935, van der Maarel 1932). A series of *S.-H.e.* sites have been identified from Majalengka to Subang (4) in an outcrop belt along the north flank of the mountains in West Java (Hertler et al. 2007, Insani et al. 2015, Wibowo et al. 2019, Widiyanto and Noerwidi 2020, Zaim 2010, J. Zaim, pers. comm. 2020). Fossils representing the Trinil fauna occurred as far west as Jakarta (5), ~450km west of Patiayam, where a core from a water-resource well contained “a fragment of the left side upper jaw of *Sus brachygnathus*,” a Trinil fauna species; three marine intervals occurred within a predominantly non-marine cored section, and palynological study identified Pleistocene mangroves to mountain forests taxa in the sequence (De Neve 1950, Marks 1956, Yulianto et al. date unknown, Eko Yulianto, pers. comm., 2006).

Supplementary Information [part] I

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Southern Sundaland when sea level was significantly below the present

a PLEISTOCENE SUNDALAND (sea level -50m)



b SOUTHERN SUNDALAND DURING FULL LOWSTAND



Headwaters and divides  LANDSCAPE SPECTRUM  Lowlands and seas

 Schematic lowstand rivers 'a'-'d' Seismic examples in SI I-51

SI I-50. Schematic maps of southern Sundaland, including the Java Sea portion of the Sunda Shelf, when sea level was significantly below the present day (after Huffman et al. 2012, 2013; also, Voris 2000). The presentation is primarily applicable to the last glacial period, since the mapping is primarily based on the modern bathymetry, but it also is reflective of conditions during the penultimate glacial period, if not also prior glacial episodes. (a) Southern Sundaland is divisible into four major watersheds. Three of them are clearly relevant to the *Stegodon-Homo erectus* (*S.-H.e.*) faunas. The East Sunda paleo-watershed drained portions of Central Java and south Borneo and flowed into the paleo-Java Sea. The Sunda paleo-watershed had headwaters in portions of West Java and South Sumatra and led to Sunda Strait. The North Sunda paleo-watershed drained much of Sumatra and west Borneo and emptied into the South China Sea. When Middle and Late Pleistocene sea levels fell below -50m of present day, wide areas of the Sunda Shelf were exposed. The low headwaters and divides in the present-day area of Banka, Belitung and Karimata islands would have facilitated faunal interchange between the Malay Peninsula, Borneo, Sumatra and Java. (b) During glacioeustatic lowstands of ~125m below modern sea level, the Java Sea portion of the Sunda Shelf could be 30 times the area of modern Java (the Java Sea is $\sim 1 \times 10^6$ km² between the Sunda Strait to Karimata- and Makassar-straits, lying west, northwest and northeast of Java, respectively; land area in this portion of the Sunda Shelf would have expanded to roughly 4×10^6 km² during lowstands). The locations of examples of subsea seismic expression of the paleo-watersheds, presented in SI I-51, are identified on the map by the letters 'a' through 'd.'

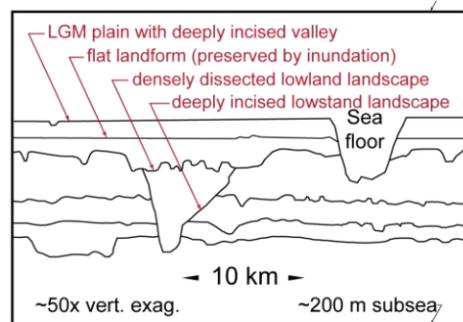
Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SI I-#. Citations to Supplementary Information [part] II are SI II-#.

Pleistocene Seismic Geomorphology of the Java Sea

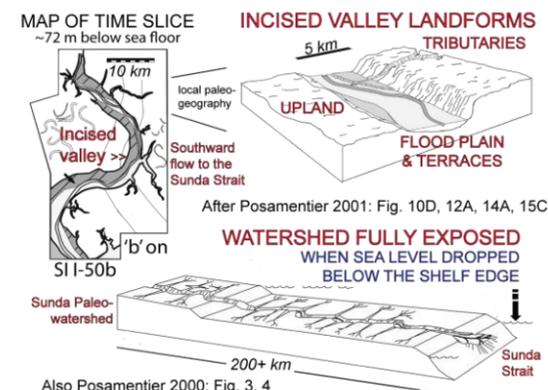
PLEISTOCENE SEISMIC GEOMORPHOLOGY, JAVA SEA

a EROSIONAL LANDSCAPES IN SEISMIC PROFILES ('a' on SI I-50b)



After Huffman et al. 2012, 2013

b LOWSTAND LANDSCAPE IN 3-D DATA

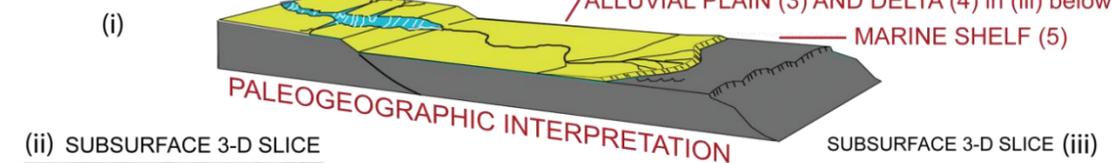


Also Posamentier 2000: Fig. 3, 4

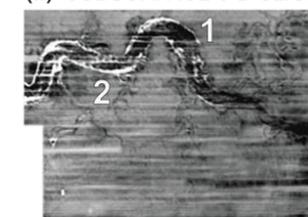
POTENTIAL EASTERN *HOMO ERECTUS* LANDSCAPES

d EAST SUNDA RIVER AND -DELTA DURING PLEISTOCENE LOW SEA LEVEL 3-D SEISMIC DATA, SOUTHEASTERN-MOST SUNDA SHELF ('d' on SI I-50b)

EAST SUNDA RIVER, INCISED-VALLEY (1) AND -TRIBUTARIES (2) in (ii) below, ALLUVIAL PLAIN (3) AND DELTA (4) in (iii) below, MARINE SHELF (5)



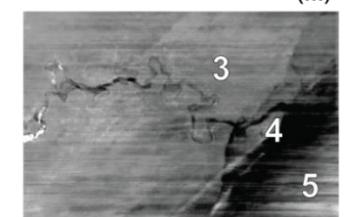
(ii) SUBSURFACE 3-D SLICE



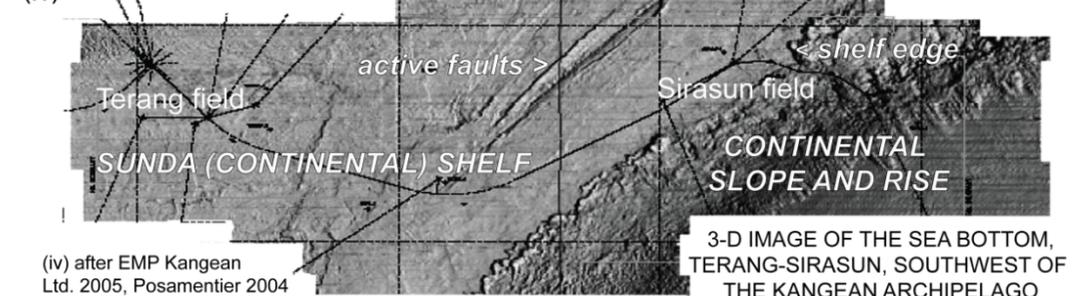
(i) to (iii) after Posamentier 2000, 2001 (in Huffman et al. 2012)

AREA OF PLEISTOCENE PALEO-VALLEY AND -DELTA (www in the subsurface www)

SUBSURFACE 3-D SLICE (iii)



(iv)



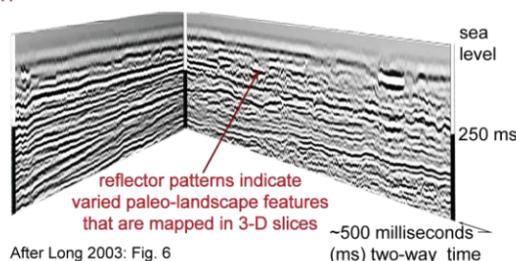
(iv) after EMP Kangean Ltd. 2005, Posamentier 2004

3-D IMAGE OF THE SEA BOTTOM, TERANG-SIRASUN, SOUTHWEST OF THE KANGEAN ARCHIPELAGO

Regarding the Terang-Sirasun fields, see Basden et al. 1999a,b, Cook et al. 2003, Ichimaru Inoue 2015, Noble Henk 1998

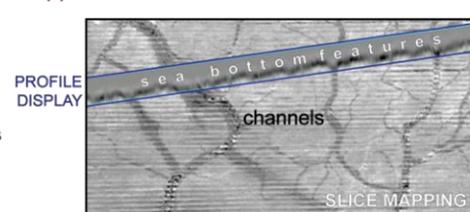
c FLUVIAL PALEO-LANDSCAPES, EASTERN JAVA SEA PGS 3-D DATA ('c' SI I-50b)

(i) PLEISTOCENE IN TOP ~250 MS OF PROFILES



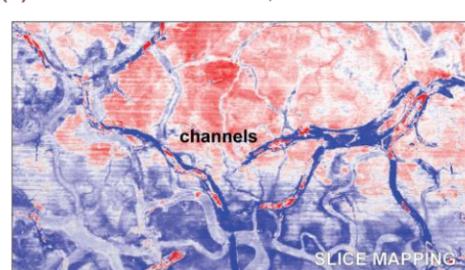
After Long 2003: Fig. 6

(ii) LPG BORNEAN TRIBUTARY CHANNELS



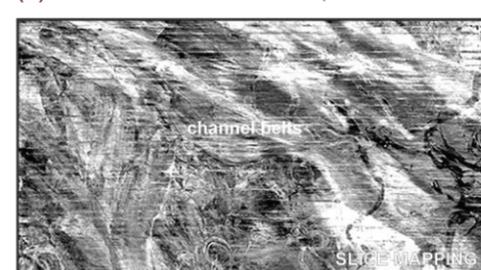
Near sea-bottom slice in the northern part of the data After Huffman et al. 2012

(iii) EAST SUNDA LOWLAND, 150 MS SLICE



Early-Middle Pleistocene fluvial palimpsest (southern area) After Long 2003: Fig. 6 in Huffman et al. 2013

(iv) BORNEAN CHANNEL BELTS, 196 MS SLICE



Early Pleistocene seismic-palimpsest (southwestern area) After Posamentier 2010: Fig. 20 in Huffman et al. 2013

SI I-51. (locations on SI I-50b). Seismic geomorphologic patterns within Pleistocene strata beneath the Java Sea reveal a variety of fluvial paleo-landscapes that large-mammal and hominin-populations might have inhabited. River valleys developed across the whole southern Sunda Shelf during glacio-eustatic lowstands, as illustrated here in example 'b' and 'c(ii)'. Paleo-river systems reached the edges of the continental shelves during the Last Glacial Maximum (~19 ka ago in MIS 2, 14-29 ka), when sea level was nearly -125m below the present (SI I-49a). Subsea seismic evidence from the western Java Sea indicates that during the Last Glacial Maximum and earlier low-sea level episodes braided river belts carried sandy and coarser-grained sediment ('c (iv)') from Borneo southeastward through the distal East Sunda paleo-watershed (also, Posamentier et al. 2004). Seismic data from the southeastern corner of the Java Sea (near the Kangean archipelago in far eastern Java) reveal a low-sea-level incised valley, prograding coastal plain and shore zone with small delta lying adjacent to a shallow marine platform, all west of the modern continental-shelf edge ('d'). Pleistocene physiographic conditions in the valley and plain should have been suitable for large-mammal occupation, including archaic hominin habitation (F.H. Henk, pers. comm. 2000). North of the Kangean archipelago at the southeastern corner of Sundaland ('e' in SI I-50b), seismic profiles reveal Plio-Pleistocene clino-forms representing repeated episodes of low sea-level shelf-slope progradation derived from the East Sunda paleo-river system (Brandsen and Matthews 1992: Fig. 21, Granath et al. 2001: Fig. 9a). Seismic analysis in the western Java Sea (covering 6500km² southeast of 'b' at 'f' in SI I-50b) reveals the drainage pattern of the Sunda paleo-watershed during the Last Glacial Maximum (Gresko and Lowry 1996; also, Posamentier 2001, Susilohadi, 1995, Susilohadi and Soeprapto 2015).

Supplementary Information [part] I

Supplementary Information [part] I is abbreviated as SII-#.
Citations to Supplementary Information [part] II are SI II-#.

Dubois' presence in Trinil

SI I-52. Dubois was present at least 67 days and 46 nights at Trinil during 1890-1894, as deduced from entries in his diaries and tabulated below. He used the diaries to keep track of the expenses he could claim to be refunded. We know from a letter of Kriele and de Winter that Dubois had a house in Trinil (M...059-022). Taking the train easily allowed Dubois to visit Trinil and return to his home at Tulung Agung, East Java (Figure 1b, main text), within one day so that the travels noted in his diaries might only reflect a minimum number of visits, as theoretically day-long trips for which his expensed were not refundable might not have been logged in his diary. Malaria was a recurring problem for Dubois when in the Trinil area (M...33-613) and this limited the time he spent in the Trinil area during 1892 and 1893, including the August 1892 month of Femur I discovery.

Dubois' presence in and around Trinil based on entries in his diaries.

Date	Time spent at Trinil	Remarks	Scanned sources
Nov. 1890	hours?	Survey boat trip along Solo River	M...015-192
7 Sept. 1891	2 days 1 night	Before finding Skullcap and molar	M...015-273
21 Oct. 1891	4 days 3 nights	After finding Skullcap and molar	M...015-283
22 Nov. 1891	4 days 3 nights		M...015-290
25 Dec. 1891	3 days 2 nights		M...015-296/7
14 May 1892	3 days 2 nights		M...015-350
7 June 1892	3 days 2 nights		M...015-355
24 June 1892	5 days 4 nights		M...015-358/9
5 July 1892	7 days 6 nights		M...015-361
12 July 1892	3 days 2 nights		M...015-362
18 July 1892	3 days 2 nights	Before finding Femur 1	M...015-364
24 Sept. 1892	2 days 1 night	After finding Femur 1	M...015-378
22 Oct. 1892	3 days 2 nights		M...015-384
10 Nov. 1892	2 days 1 night		M...015-388
6 June 1893	3 days 2 nights		M...016-049/50
26 June 1893	3 days 2 nights		M...016-054
19 July 1893	3 days 2 nights		M...016-058/9
17 Aug. 1893	3 days 2 nights		M...016-065
14 Sept. 1893	2 days 1 night		M...016-071
19 Oct. 1893	4 days 3 nights		M...016-078/9
12 Nov. 1893	3 days 2 nights		M...016-084
5 Sept. 1894	hours?	Boat trip 1894 photograph	M...016-166

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