Provenience Reassessment of the 1931–1933 Ngandong *Homo erectus* (Java), Confirmation of the Bone-Bed Origin Reported by the Discoverers

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ABSTRACT

The Geological Survey of the Netherlands Indies unearthed 14 *Homo erectus* fossils in 1931–1933 from a single excavation site on Java (Excavation I Ngandong). Survey geologists attributed the hominin discoveries (along with thousands of other vertebrate remains) to a thin, gravelly volcaniclastic stratum situated near the base of a fluvial-terrace remnant ~20m above the Solo River. The geologists were present 24 days during the 27-month-long operation, witnessing and documenting only a few human fossils *in situ*. Moreover, they published limited amounts of detail about the discoveries. Their provenience account is nonetheless substantially corroborated by surviving records. Key materials are presented here for the first time, including the geologists' photographs of two human fossils *in situ* and a 1:250 site map from 1934 showing individual *Homo erectus* discovery points.

Calvarial specimens Ngandong I, II, V, VI, and VIII are the five best-documented finds. Each is securely attributable to the basal volcaniclastic fossil bed. In March 1932, geologist W.F.F. Oppenoorth photographed Ngandong V while it was still embedded in the fine volcaniclastic gravel <0.5m from the basal terrace contact. He previously had examined the contexts of Ngandong I and II when only <150m^2 of the excavation were open and all vertebrate fossils reportedly were being found in the gravely sandstone comprising the bottom ~0.7m of the sequence. In June 1932, geologists C. ter Haar and G.H.R. von Koenigswald photographed the Ngandong VI in a ~2m x 2m horizontal exposure of the basal volcaniclastic sandstone/fine conglomerate in which marl cobbles and 17 disarticulated non-hominin fossils also occurred. In August 1933, von Koenigswald removed part of Ngandong VIII from the basal bed near where six antler fragments and a *Stegodon* tusk were found. For the remaining nine discoveries, nothing is revealed in the available material to contradict the basal-bone-bed origin attributed to them by the discoverers. With some of the finds, such as Tibia B, there is virtually no substantiating documentation, while with others, such as Tibia A, it is unclear how the geologists knew about the stratigraphic context.

The provenience detail that we present greatly improves the prospects for identifying the *Homo erectus* stratum at the site and collecting rock and fossil samples useful for radioisotopically dating the hominin, among other purposes. The documentation also substantially strengthens the inference that the hominin assemblage represents individuals who died at approximately the same time and whose remains were deposited at Ngandong within a few months of death. Support for this is provided by the limited amount of pre-burial weathering in evidence on the *Homo erectus* fossils, the highly delicate bony structures present in some calvarial specimens, and a combination of plastic deformation and sandstone-filled fractures occurring in several vaults—features which evidently represent warpage followed by breakage as the bone dried during burial.

INTRODUCTION

Paleoanthropologists have good reason to be keenly interested in the human fossils excavated at Ngandong, Java, during 1931–1933 by the Geological Survey of the Netherlands Indies. The human assemblage consists of 12 cranial specimens, including substantially complete calvariae, and two right tibiae, one of which is essentially whole (Tables 1 and 2). The Ngandong material routinely

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TABLE 1. 1931–1933 NGANDONG *Homo erectus* SPECIMENS, ORDERED BY DATE OF DISCOVERY AND SURVEY REGISTER NUMBER, WITH NAME CHANGES OVER TIME.

DISCOVERY	NAME CHANGES						
Date (*dig day*)[1]	**Register[2]**	**1930s[3]**	**1951[4]**	**1975[5]**	**1980[6]**	**2004[7]**	**This paper**
September 15, '31 *(3)*	29	Ngandong I	Solo Skull I	Ngandong 1	Solo 1	Ng 1	Ngandong I (Ng 1)
September30, '31 *(18)*	195	Ngandong II	Solo Skull II	Ngandong 2	Solo 2	Ng 2	Ngandong II (Ng 2)
October 13, '31 *(31)*	272a	Ngandong III	Solo Skull III	Ngandong 3	Solo 3	Ng 3	Ngandong III (Ng 3)
October 13, '31 *(31)*	272a	Ngandong III	Solo Skull III	Ngandong 4	Solo 3A	Ng 4	Ngandong III (Ng 4)
January 25, '32 *(135)*	3493	Ngandong IV	Solo Skull IV	Ngandong 5	Solo 4	Ng 5	Ngandong IV (Ng 5)
March 17, '32 *(187)*	7594	Ngandong V	Solo Skull V	Ngandong 6	Solo 5	Ng 6	Ngandong V (Ng 6)
May 24, '32 *(255)*	9775	Ngandong VII	Solo Skull VII	Ngandong 8	Solo 7	Ng 8	Ngandong VII (Ng 8)
June 13, '32 *(275)*	9975	Ngandong VI	Solo Skull VI	Ngandong 7	Solo 6	Ng 7	Ngandong VI (Ng 7)
January 17, '33 *(489)*	14518	Tibia B	Solo Tibia B	Ngandong 14	…	Ng 10	Tibia B (Ng 10)
Feb.-Mar. '33 *(~535)*	?	Tibia A	Solo Tibia A	Ngandong 13	…	Ng 9	Tibia A (Ng 9)
Aug. 22/30, '33 *(710/718)*	19109, -587	Ngandong VIII	Solo Skull VIII	Ngandong 9	Solo 8	Ng 11	Ngandong VIII (Ng 11)
September 27, '33 *(746)*	21331	Ngandong IX	Solo Skull IX	Ngandong 10	Solo 9	Ng 12	Ngandong IX (Ng 12)
September 27, '33 *(746)*	21332	Ngandong X	Solo Skull X	Ngandong 11	Solo 10	Ng 13	Ngandong X (Ng 13)
November 8, '33 *(788)*	22205	Ngandong XI	Solo Skull XI	Ngandong 12	Solo 11	Ng 14	Ngandong XI (Ng 14)

[1]For discussions of the phylogenetic placement of the material, see Antón (2001, 2002, 2003); Antón et al. (2007); Baab (2008); Balzeau (2006); Balzeau and Grimaud-Hervé (2006); Westaway (2008); Wolpoff et al. (1994). Date of discovery is from ter Haar (1934b) with the days from the start of the excavation in parentheses. Ter Haar did not give a date for Tibia A, but it is shown on the Site Map in excavation units dating from February or March 1933 (see Figure 6C).

[2]Specimen number in the Ngandong Fossil Register of the Geological Survey of Netherlands Indies; Tibia A did not have a label (ter Haar 1934b).

[3]Specimen names used by the Geological Survey of the Netherlands Indies in the 1930s, from ter Haar (1934a, b; see also Oppenoorth [1932d, f] and von Koenigswald [1933b, 1939]).

[4]Specimen names in von Koenigswald (1951: 217; see also 1955, 1956, 1958) and Weidenreich (1951). See also Jacob (1967).

[5]Specimen names in Jacob (1975a: 107), the *"Catalogue of Fossil Hominids"*(see also Jacob 1972, 1975b, 1977, 1978, and Rightmire [1990]).

[6]Specimen names in Santa Luca (1980: 16), who does not name the tibiae (see also Santa Luca 1977, 1978).

[7]Specimen names in Indriati (2004: Table 2), who also lists three discoveries made in the 1970s from unspecified locations at Ngandong—Ng 15 (1976), frontal, sphenoid, occipital, left temporal, and parietal bones; Ng 16 (1976), a left parietal fragment (4cm x 8.5cm); Ng 17 (1978), a left acetabulum of a pubic fragment (4cm x 6cm). Kaifu et al. (2008) recently used a "Ng _" naming formulation in which the designations from "Ng 9" to "Ng 14" do not match the specimens with the same names in Indriati (2004). Other naming conventions have been adopted (e.g., Balzeau et al. 2003; Wolpoff 1999).

TABLE 2. 1931–1933 NGANDONG SPECIMENS—ORDERED FROM THE MOST-COMPLETE TO THE LEAST-COMPLETE ANATOMICALLY (CRANIAL, THEN POST-CRANIAL REMAINS)—WITH NOTES ON THE RECOGNITION OF DISCOVERIES' SIGNIFICANCE IN THE FIELD.

Specimen Name[1]	Degree of Preservation[2]	Notes of Field Recognition of Significance
Ngandong VI (Ng 7)	Essentially a whole calvaria*	Panudju recognized Ng 7 as hominin, giving ter Haar and von Koenigswald the chance to witness it *in situ*
Ngandong XI (Ng 14)	Calvaria w/o anterior base*	Panudju recognized Ng 14 as hominin, giving von Koenigswald the opportunity to witness it *in situ*
Ngandong X (Ng 13)	Calotte and basal margins *	Field crew collected shattered pieces of the specimen, apparently after having recognized it as significant
Ngandong V (Ng 6)	Calotte and basal margins *	Panudju recognized Ng 6 as hominin, allowing Oppenoorth to photograph the specimen *in situ* (see Figure 12)
Ngandong IX (Ng 12)	Calotte and basal margins *	Field crew collected shattered pieces of the specimen, apparently after having recognized it as significant
Ngandong I (Ng 1)	Calotte and basal margins *	Samsi recognized Ng 1 as a significant find (identifying it as a "tiger skull fragment")
Ngandong III (Ng 3)	Calotte w/o anterior	Oppenoorth recognized Ng 3 as hominin, after the specimen had been taken to storage at Ngandong
Ngandong IV (Ng 5)	Calotte w/o posterior & inferior	Field crew did not recognize Ng 5 as significant, and shipped it with other fossils to Bandung
Ngandong VIII (Ng 11)	Paired, whole parietals	Field crew recognized one part of Ng 11 as significant, allowing von Koenigswald to witness it *in situ*
Ngandong II (Ng 2)	Nearly a whole frontal	Samsi recognized Ng 2 as a significant find (identifying it as a "ape skull fragment")
Ngandong VII (Ng 8)	Right parietal fragment	No one recognized Ng 8 as hominin until after ter Haar and von Koenigswald returned from unearthing Ng 7
Ngandong III (Ng 4)	Fragment of a calvaria	Ng 4 was recognized as separate from Ng 3 in 1947
Tibia B (Ng 10)	Right tibia, nearly complete	Details of discovery, other than date, are lacking
Tibia A (Ng 9)	Majority of a right tibial shaft	The provenience label on Tibia A was lost before the specimen was recognized as hominin

[1]As defined in Table 1.

[2]The characterizations of anatomical preservation are based mostly on descriptions and photographs in Weidenreich (1951), Santa Luca (1977, 1980), Jacob (1967, 1975a, b), Rightmire (1990), Balzeau (2007), Balzeau et al. (2003), Balzeau and Grimaud-Hervé (2006), and Indriati (2006); see also Westaway 2002, 2004.

*Weidenreich's (1951: 239, 240) "six best preserved skulls…on the whole, surprisingly alike," wherein Ngandong XI (Ng 14) "comes closest to…a standard form." The specimens generally were found intact within masses of carbonate-cemented sandstone and conglomerate, rather than as separated fragments that were reassembled, to judge from the photographs of Ngandong V and VI (Ng 6 and 7) *in situ* and Ngandong I (Ng 1) after initial cleaning (Oppenoorth 1932b; see Provenience account of Ngandong VIII [Ng 11] for special case). However, the specimens have been reconstructed to varying degrees; for example, Antón (1999: 227–228) observed that Ngandong II (Ng 2) is "composed of several pieces reconstructed with a brown-colored adhesive," and Ngandong IV (Ng 5) was "reconstructed from multiple fragments;" Balzeau et al. (2003) report that even the most complete of specimens, Ngandong VI (Ng 7), has multiple fractures in the fossilized bone; Kaifu et al. (2008: 553, Table 1) indicates that in Ngandong VIII (Ng 11) "the two parietals are joined with plaster," compromising the reliability of the reconstruction, and Ngandong XI (Ng 14) "is put together from many fragments, and various large gaps are filled with plaster."

is included in investigations on the evolution of *Homo,* being especially notable for excellent preservation of multiple specimens from one site.

Most paleoanthropologists consider the assemblage to be late representatives of the long-standing paleontological species *Homo erectus*, although the first three finds originally were named *Homo (Javanthropus) soloensis* (Oppenoorth 1932b), and even today, some anatomical features which have been used to distinguish the Ngandong fossils from robust, anatomically modern *Homo sapiens* are still under

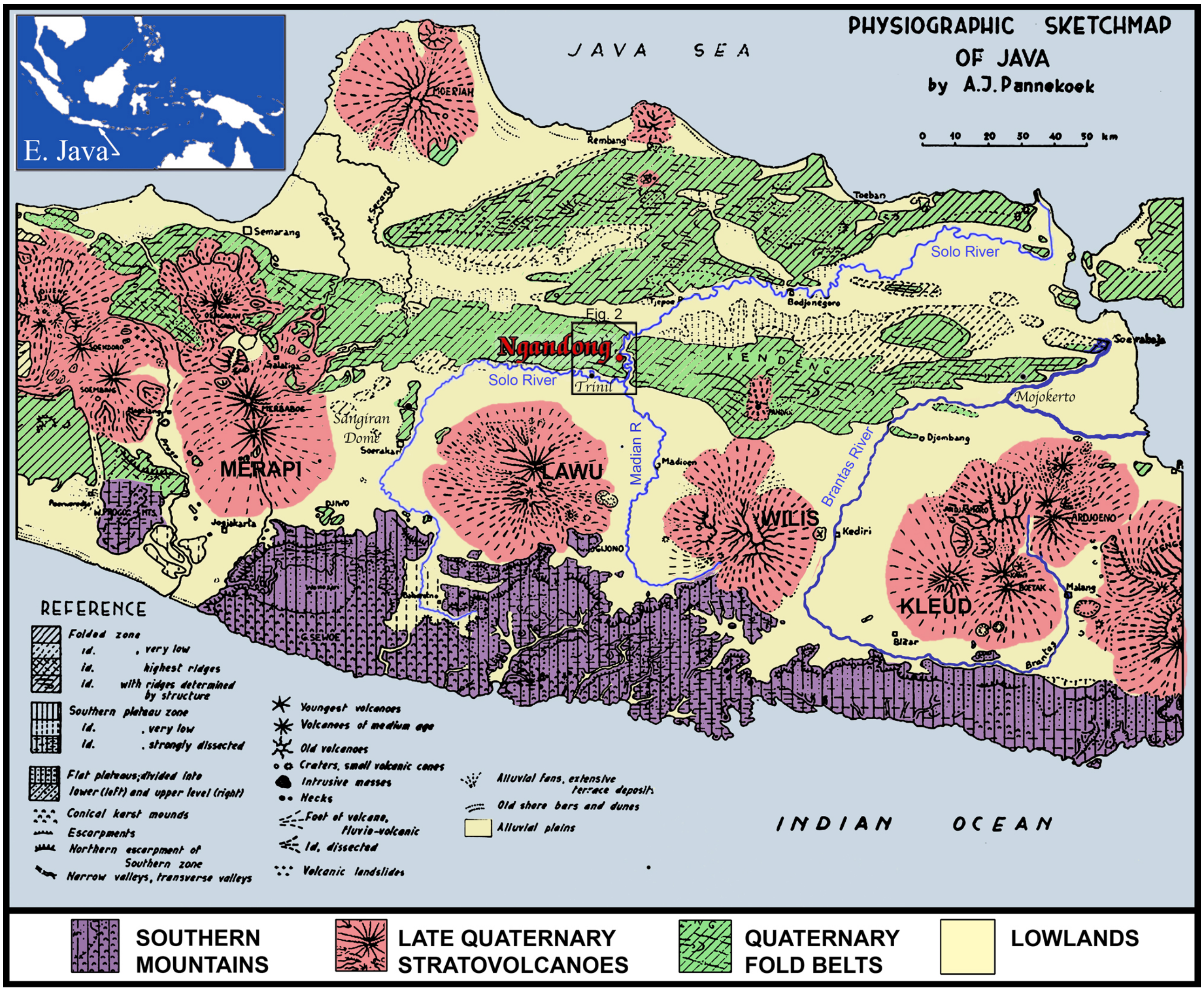


Figure 1. Eastern Java physiographic map (after Pannekoek 1949) with inset map of Southeast Asia. Ngandong is situated along the Solo River where it passes through the Kendeng Hills, a tectonically active belt of late Tertiary bedrock. We refer to the section of the river passing through the hills as the Solo River Gap. Upstream, the drainage includes several stratovolcanoes, such as the 3,265m Mount Lawu, and headwaters in the Southern Mountains near the Indian Ocean.

consideration (e.g. Antón 2002, 2003; Antón et al. 2007; Balzeau and Grimaud- Hervé 2006; Durband 2009; Hawks et al. 2000; Westaway and Groves 2009; Wolpoff et al. 1994, 2001).

The Ngandong finds were unearthed with thousands of non-hominin vertebrate fossils. Only one other site on Java rivals Ngandong in the great volume of co-occurring non-hominin remains—the seminal discovery at Trinil—but the high number of hominin fossils found at Ngandong is unique for the island, and rare for paleoanthropological occurrences in any fluvial context globally. It is particularly regrettable therefore that fundamental parameters about Ngandong have remained uncertain for many decades. The exact discovery circumstances, depositional history, taphonomy, and geological age of the *Homo erectus* specimens all have continued to be questioned. Until confidence is gained in knowing where, when, and how the 14 human specimens accumulated, paleoanthropological interpretation of them will be severely constrained. In this paper, we reduce the uncertainties and improve the foundation for understanding the assemblage by clarifying its provenience, depositional context, and geological age.

The three Survey geologists responsible for the Ngandong operations, W.F.F. Oppenoorth, C. ter Haar, and G.H.R. von Koenigswald, asserted that all 14 of the *Homo erectus* specimens came from one thin bone bed in a terrace remnant situated well above the Solo River in eastern Java (Figures 1–5; see Table 3 below; Oppenoorth 1936; ter Haar 1934a; von Koenigswald 1933b, 1956). We confirm their account for at least five of the discoveries by making use of previously unpublished Survey reports and the discoverers' personal documents and photographs. While our analysis uncovered nothing to dispute the reported provenience for the remainder of the assemblage, the records are too limited in the case of some finds to offer specific support for the bone-bed provenience.

Oppenoorth, ter Haar, and von Koenigswald had first-hand knowledge of the discoveries and were expert in the

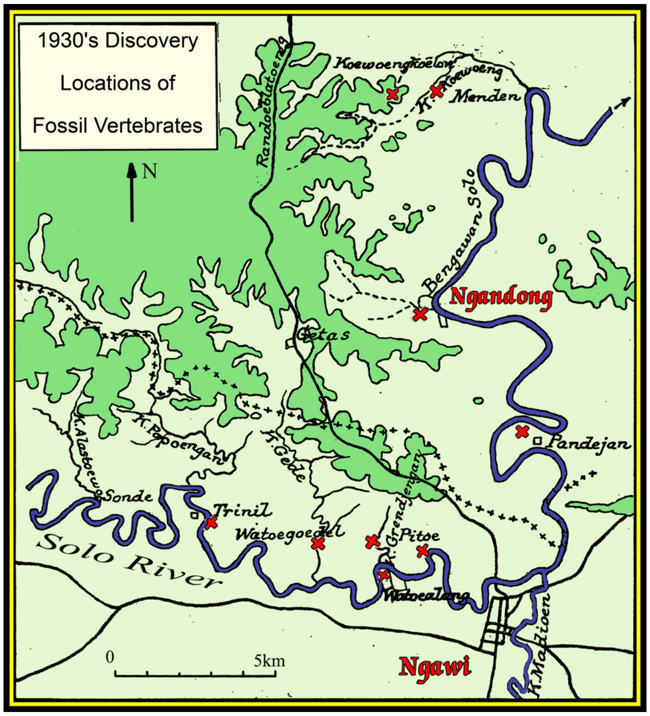


Figure 2. Oppenoorth's map of Geological Survey early 1930's vertebrate-discovery localities along the Solo River (after Oppenorth 1932a). With ~25,000 fossils, Ngandong was the most prolific of the excavation sites and the only one to yield Homo erectus *fossils.*

geology and paleontology of Java. This would be reason enough, one might argue, to accept their accounts of the stratigraphy and fossil occurrence at the site. On the other hand, as we document here for the first time, the three geologists worked only 24 days total at the excavation over the 27 months it was active (see Table 4 below). The day-to-day responsibility had been given over to their geological assistants, while Oppenoorth, ter Haar, and von Koenigswald devoted their time to matters more central to the Survey's overall mission. The records of the assistants are missing. Moreover, the Survey did not publish a final report on the excavation. Even the Survey's site map showing the discovery points of individual hominin fossils was not published and has remained unknown to the paleoanthropological community for more than 75 years. Furthermore, while the three geologists each published on Ngandong, they never jointly produced a paper or wrote an internal Survey report bringing together all of their experiences at the site.

To improve understanding of the discovery history and geological context, we have combined the surviving records into a description that is far more detailed than what has been published previously (e.g., Oppenoorth 1932–1937; ter Haar 1934a; von Koenigswald 1951, 1955, 1956). The unpublished records we used include the Site Map (see Figure 6 below), a site cross section by ter Haar (see Figure 7 below), the history of excavation as documented by the Site Map (see Figures 8–9 below), and photographs that Oppenoorth and von Koenigswald saved in their personal files (see Figures 10–14 below; see Research Methods). Other unpublished materials containing information essential to our analysis include a series of internal Survey reports written by ter Haar (1931, 1932, 1934b) and von Koenigswald (1933c, 1934a, b, n.d.—1934/1935).

The occurrence of multiple *Homo erectus* specimens in one bone bed would be especially valuable paleoanthropologically if one could accept the discoverers' conclusion that most or all of the human individuals lived concurrent-

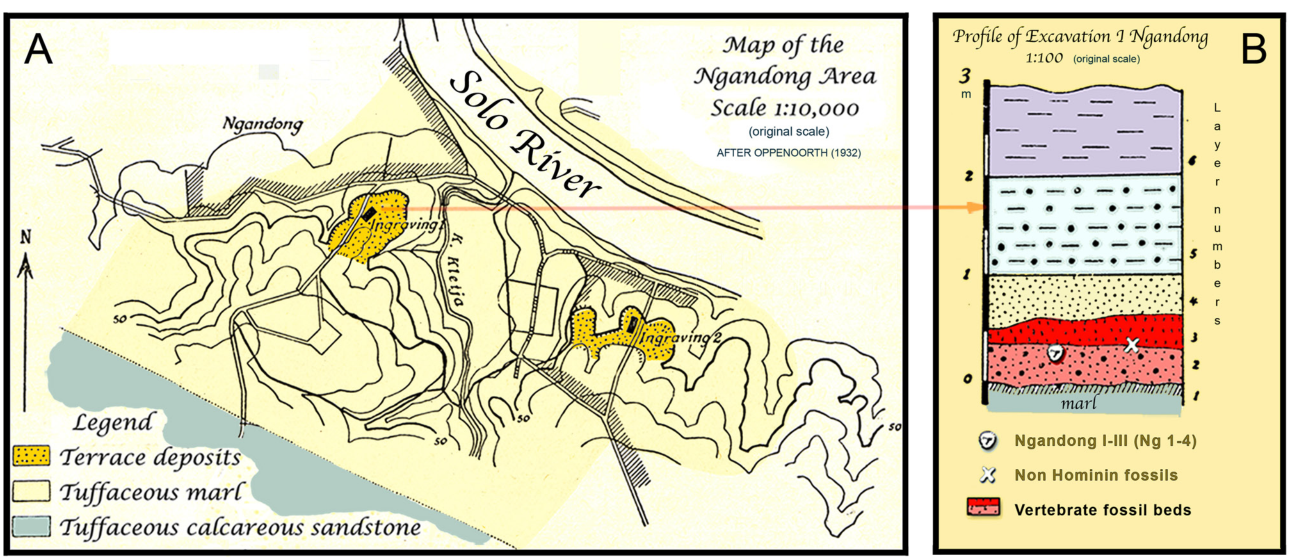


Figure 3. A—Oppenoorth's 1931 topographical and geological map of Excavation I Ngandong (Ingraving 1 on the map; after Oppenoorth 1932b). In the first three months following discovery, the Survey had mapped the geomorphic context of the fossiliferous terrace-deposits at Ngandong. B—Oppenoorth's stratigraphic column for the Homo erectus*-bearing sequence (after Oppenoorth 1932b), based on his October 27, 1931, fieldwork, when he evaluated the discovery circumstances of Ngandong I–III (Ng 1–4). See Table 3 for his corresponding lithological description. We refer to Layers 2–6 as the Ngandong Formation, following Marks (1957), as explained in Table 3. No details were published on Ingraving 2.*

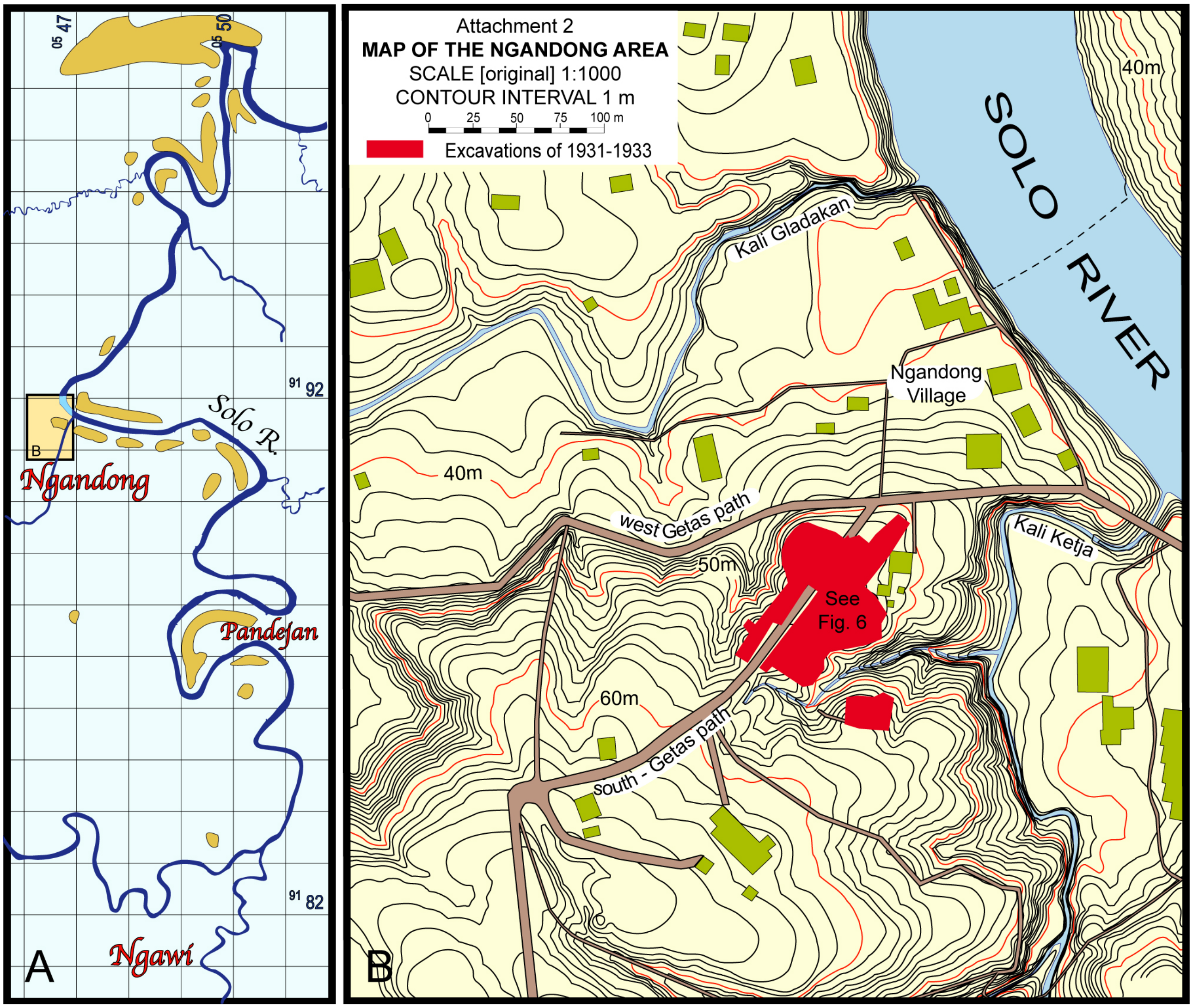
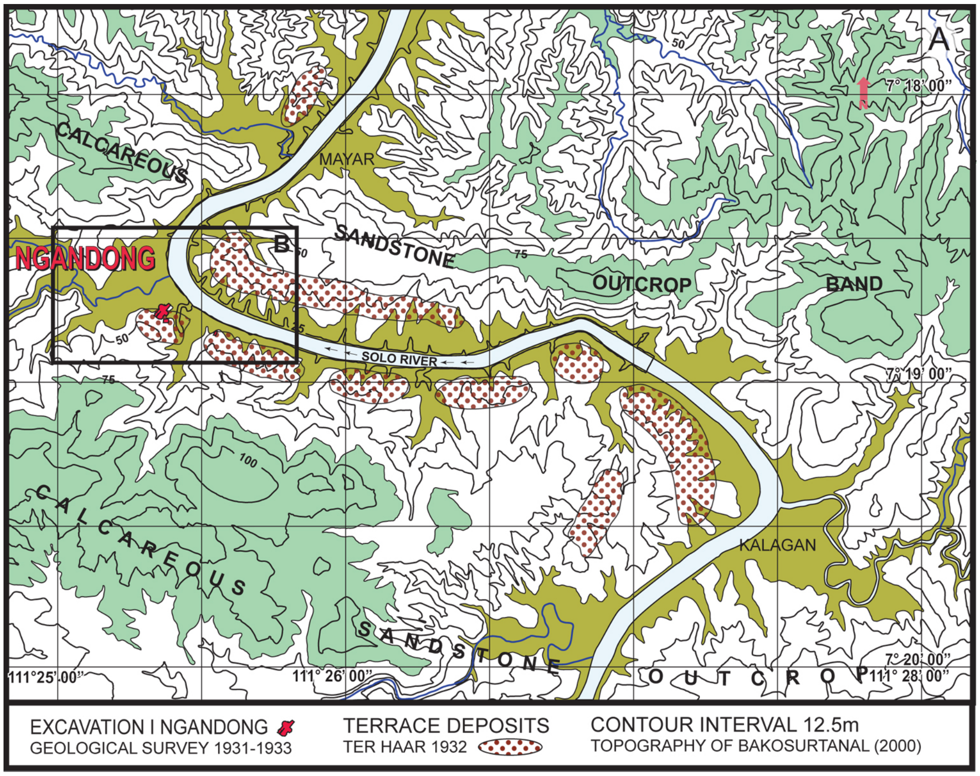


Figure 4. A—Schematic representation of ter Haar's June 1932 mapping of the terrace deposits (gold) in the Solo River Gap (ter Haar 1932; see also, Sidiarto and Morwood 2004; Suminto et al. 2004). B—Survey's 1934 1:1000 topographic map of the Ngandong area (redrafted from an Attachment in ter Haar 1934b; see Research Methods for further explanation; the roads and paths generally are located in the same position today as in the 1930s, but most buildings have been replaced).

ly (e.g., ter Haar 1934a; von Koenigswald 1956). This would be particularly intriguing in light of the low population densities normally assumed for early hominin groups and the tendency for fluvial sedimentary processes to disperse, rather than concentrate, skeletal materials.

The Ngandong *Homo erectus* fossils are even more significant if one accepts the Late Pleistocene age proposed for them on the basis of radioisotopic dating (Bartstra 1987; Bartstra et al. 1988; Rizal 1998a, b; Swisher et al. 1996, 1997, 2000; van der Plicht et al. 1989; Yokoyama et al. 2008). In the best known study, antelope and bovid teeth from the Ngandong bone bed were dated at ~27–46ka with electron-spin-resonance and uranium-series methodologies; the dates are *"surprisingly young and, if proven correct, imply that H. erectus persisted much longer in Southeast Asia than elsewhere"* (Swisher et al. 1996: 1873, 1997, 2000; but see Grün and Thorne 1997). Even if the actual age for the Ngandong *Homo erectus* is twice the ~27–46ka, it *"would still make Ngandong several hundred thousand years younger than any classic Homo erectus"* (Antón 2001: 40, see also, Antón 2002, 2003, and Antón et al. 2007). Direct radioisotopic (gamma-ray spectrometric) dating of two Ngandong cranial fossils—Ngandong I and VI (Ng 1 and 7)—leads to age estimates between ~40ka and ~60–70ka, supporting the proposition that late *Homo erectus* of Java was contemporaneous with *Homo sapiens* in Australasia, Southeast Asia, and portions of the Old World farther west (Yokoyama et al. 2008).

We show here that two of the dated specimens which gave the Late Pleistocene results, Ngandong I and VI (Ng 1 and 7), are among the five from the site that are reliably attributable to a basal volcaniclastic stratum of the Ngandong terrace remnant (see Figure 3B; see Figures 7 and 13 below; see Table 5 below; Huffman et al. 2008a, b). We also provide data supporting the hypothesis that these *Homo erectus* had died a short time (geologically) before burial in the bone bed. The ~60–70ka estimate therefore might be



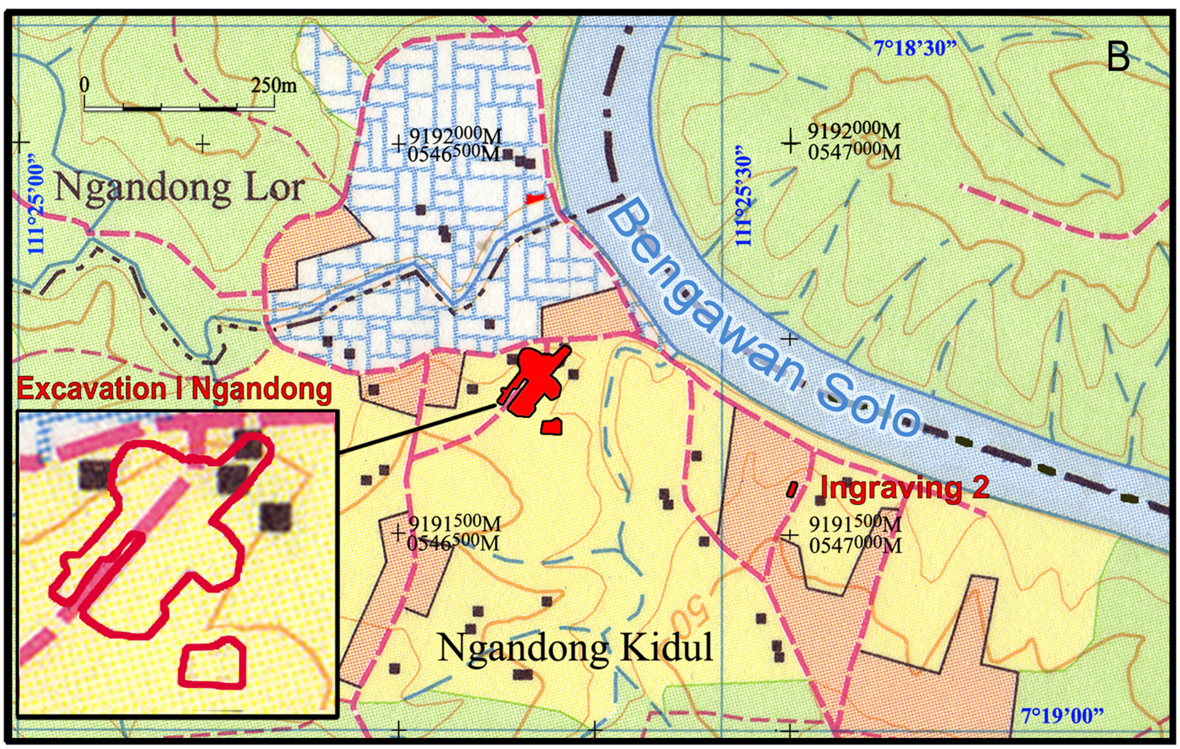


Figure 5. A—Modern topography of the Solo River Gap near Ngandong (after Bakosuturnal 2000) with ter Haar's (1932) mapping of terrace deposits superimposed (see also Figure 4A). The bedrock along the River upstream of Ngandong is largely Pliocene marl, while the major ridges are underlain by calcareous sandstone. The variations in bedrock lithology played an obvious role in establishing the meander pattern in the Solo River Gap (Lehmann 1936). B—Topography near Ngandong (from Bakosuturnal 2000) with our relocations of the Excavation I Ngandong (inset) and Ingraving 2, based on a comparison of B to various Survey maps (see Figures 3A, 4, and 6).

viewed a maximum age for the entire Ngandong fossil deposit.

The young reported geological age for Ngandong *Homo erectus* prompts a comparison of the population's material culture, which is notable for the paucity of associated artifacts, to *Homo sapiens* ~30ka in Southeast Asia and Sahul (Australia, New Guinea, and nearby islands) which has a rich archaeological record. The Sahul *Homo sapiens* culture includes evidence of freshwater shellfish exploitation, long-distance sea-faring trade, ground-stone and wasted-hatchet tools, beads, ochre and art, and burial of the dead (Habgood and Franklin 2008). Closer to Java in the Niah Cave of northern Borneo, there is evidence of *"habitat-tailored hunting technologies…processing of toxic plants…and, perhaps, the use of fire"* (Barker et al. 2007: 244). For Ngandong, only one object specified as having originated in the basal-bone bed has been provided adequate documentation as an artifact, and that object is a small spheroid of andesite (Oppenoorth 1936; von Koenigswald 1951) which potentially was reworked for a significant time before deposition at Ngandong.

Further variety in Late Pleistocene *Homo* is indicated by *Homo floresiensis,* a taxon with a previously unknown set of anatomical features discovered on Flores, an island 1100 km east of Ngandong in the Nusa Tenggara archipelago (Brown et al. 2004; Morwood et al. 2004; Morwood and van Oosterzee 2007). The cave site where the fossils were discovered has an early Late Pleistocene record of human occupation, which has also been attributed to *Homo floresiensis* (van den Bergh et al. 2009; Westaway et al. 2007a, b; Westaway and Groves 2009). Elsewhere on this remote island, the archaeological record appears to extend to the late Early Pleistocene (Morwood et al. 1998; O'Sullivan et al. 2001). The youngest *Homo floresiensis* post-dates evidence of a behaviorally modern human occupation on Timor, east of Flores, as well as on Australia (O'Connor 2007). It therefore is possible that four anatomically and culturally distinct variants of *Homo* inhabited the Old World during part of the last 100,000 years—three in the Southeast Asia and one in Java, the Ngandong *Homo erectus*.

A Late Pleistocene date (~10–100ka) for Ngandong is relevant furthermore to several long-held concepts in Asian paleoanthropology, and we should mention the most contentious issues. Ngandong has figured prominently in the Mutli-Regional theory of modern human origins since the 1940s. The young date from Ngandong has been advanced as a challenge to the theory (Swisher et al. 1996), and conversely, is seen consistent with it (the Ngandong population, or an ancestor to it, having contributed genetically to *Homo sapiens* in the region; Hawks et al. 2000; Webb 2006; Wolpoff et al. 2001). However, the presence and significance of reputed anatomical similarities between Ngandong and some fossil *Homo sapiens* of Australia, part of the latest evidence presented in support of the Multi-Regional theory, is vigorously disputed (e.g., Durban 2009; Westaway and Groves 2009).

The Late Pleistocene age from Ngandong also appears to be in conflict with the sequential order of mammalian faunas recognized in Java. The Punung Fauna, which is best documented from caves near the southern coast of Java, contains extant species—including rain-forest components, such as orangutan and siamang—unknown in the other fossil assemblages on the island; moreover, a case has been made that the Punung Fauna includes *Homo sapiens* (Aziz 2000; de Vos 1983; Storm 2001; Storm et al. 2005; van den Bergh 1999; van den Bergh et al. 1996, 2001). The Ngandong Fauna, by contrast, has a number of extinct species, lacks rain-forest components, and apparently includes only *Homo erectus*. This leads to an interest in temporally ordering the Punung Fauna (with an introduction of extant rain-forest species and *Homo sapiens*) in the Late Pleistocene and the Ngandong assemblage (with a mixture of extant and extinct species including *Homo erectus*) in the Middle Pleistocene, far older than the radioisotopic results from Ngandong would indicate.

The paleoanthropological implications of a Late Pleistocene date naturally have raised interest in the accounts of the geological context for the Ngandong finds, published so many decades ago. If the provenience is not credible, the discoverers' contention that the hominin fossils represent a paleodeme, contemporaneous with the rest of the fauna, is unsupported, and the Late Pleistocene dates for the Ngandong hominin fossils are readily disputed. In this event, scientists would have far greater latitude in situating Ngandong in a paleoanthropological framework. It is important to bear in mind, however, that if only one *Homo erectus* fossil has reliable provenience and then is securely dated to Late Pleistocene, the species range is extended into this young period.

Given the scientific stakes involved, many investigators have expressed an understandable frustration with the limited information published on the Ngandong geological context (Bellwood 1997; Dennell 2004; Grün and Thorne 1997; Santa Luca 1977, 1978, 1980; van den Bergh 1999; Roberts et al. 2005; Westaway 2002). Inadequate documentation has allowed critics to argue that the non-hominin teeth used in obtaining the youngest radioisotopic ages do not date the *Homo erectus* specimens themselves, which still could be reworked and significantly older. If reworked, moreover, the multiple human specimens from the site would not necessarily represent a paleodeme or even be of the same geological age.

Grün and Thorne (1997: 1575) offered the sharpest criticism of the reliability of the reported geological history for the specimens: *"We consider the Solo high terrace to represent a mélange of materials reworked from different levels, sites and ages."* They gave no particulars in support of this contention. Dennell (2004: 87) did relate comments of von Koenigswald (1951) that might be construed to support the view of Grün and Thorne: *"All we know is that the hominids 'were found neither in one particular spot nor in a special Layer but were irregularly distributed throughout the whole site."* Grün and Thorne and Dennell are not alone in their skepticism. Others indirectly divorce the *Homo erectus* specimens from their depositional setting by characterizing the context as "alluvial" (Indriati 2006; Yokoyama et al. 2008), terminology suggesting that more latitude might exist in the range of potential ages for the fossils than indicated by the actual stratigraphic setting within a fluvial terrace remnant well above the Solo River.

We should stress that the discoverers' statements in the 1930s were not ambiguous when it comes to essential points of context. The following is what von Koenigswald (1933a: 33, translated) stated while the excavations were underway, for example:

> *Till now, remains of five human skulls have been found in Ngandong.…Other parts of the skeleton such as teeth, lower jaws, vertebrae or extremities have not been identified among the huge number of bones from this discovery site (till the end of May 1932, the catalogue had grown to 9,100 specimens). The skulls, referred to as Ngandong I–V here, are all together from the Excavation Ngandong I, and were found in a pebble Layer which forms the boundary between Layers 2 and 3 (*[see Figure 3B]*).*

Oppenoorth (1932f) and Weidenreich (1951) published photographs of Ngandong *Homo erectus* in their discovery beds. Bartstra (1982, 1987, 1994; Bartstra et al. 1988) was among those in more recent decades who attempted to keep attention on the discoverers' reports, but he was unable to locate more specific documentation, such as Survey maps and photographs, which might prove the point (see also Swisher et al. 1996, 1997, 2000).

Having discovered these very kinds of archival materials, we are able to address the co-occurrence question in detail. The available unpublished documents, although only a small part of the records kept by the Survey in the 1930s, are sufficient to confirm the basal-bone bed context for at least five of the Ngandong *Homo erectus* and make more credible the discoverers' claims that the other finds also came from the same stratum (see Table 5 below).

But Grün and Thorne (1997), Dennell (2004) and others (e.g. Roberts et al. 2005; Santa Luca 1980; van den Bergh 1999; Westaway 2002) have had other concerns about Ngandong. They question whether the terrace deposit and embedded non-hominin fossils are substantially younger than the *Homo erectus* specimens themselves; that is, whether the human material might have been reworked from an older geological formation (Bartstra et al. 1988). Geochronological studies of the Ngandong material use radioisotopic techniques that estimate the geological age of the hominin by measuring the time since burial. For these estimates to be valid, there cannot have been a geologically significant gap in time between death and deposition at Ngandong. A span of tens-of-thousands or hundreds-of-thousands of years would be important to the evolutionary placement of the hominin population; a few millennia would be much less of an issue. The greater the difference, the more likely is the possibility that the *Homo erectus* remains were fossilized and mixed with fresher non-hominin skeletal material at the site.

The fossilization of bone is thought to occur over a few thousand years to a few tens-of-thousands of years, and generally to result from protein degradation (largely the loss of collagen), secondary mineralization (the introduction of calcite, for example), trace element uptake, and alteration and recrystallization (Kohn 2008; Koen and Law 2006). In modern eastern Java, vertebrate fossils commonly occur on the surface in various areas of Quaternary outcrop, indicating that a portion of the embedded assemblage is fossilized well enough to survive exposure and become new sedimentary constituents. While some Java hominin fossils probably were buried shortly after the individual died (Huffman et al. 2006), reworking should not be ignored in considering the geological age of individual Javan *Homo erectus* specimens.

Fossilization prior to deposition at Ngandong is what Santa Luca (1977, 1980), who originated the reworking hypothesis, and Grün and Thorne (1997) had in mind (see also Dennell 2004). In the case of the Ngandong assemblage, however, there is no difference in the degree of fossilization of the human and non-hominin remains, according to the discoverers' accounts. The non-hominin material at Ngandong was *"thoroughly fossilized…so strongly calcified that a high pitched sound is generated when the specimen is hit with an instrument….the high lime content almost certainly originates in the underlying…marl beds"* (von Koenigswald, 1933a: 87, translated). The human specimens also were *"highly mineralized"* (Balzeau et al. 2003; Weidenreich 1951: 228), although there also were portions of the terrace where "leaching" resulted in fossils being more weathered than normal (Oppenoorth 1932c: 109, translated). Once excavated, the fossils were subject to rapid degradation (ter Haar 1934b). But overall, the *Homo erectus "preservation…*[is] *exactly the same as in the numerous animal bones"* (von Koenigswald 1951: 218; see also Bartstra et al. 1988). Proposing an admixture of recently dead and fossilized remains, as Santa Luca and Grün and Thorne have done, is therefore in conflict with the description of von Koenigswald, the geologist who examined more of the Ngandong material than anyone else. Grün and Thorne do not document their opinion that the preservation of the human and non-hominin material differed fundamentally. Moreover, Santa Luca (1980: 9), who never saw the non-hominin material, apparently misunderstood the situation when he asserted that the non-hominin remains had been *"buried after minimum exposure"* while the human fossils *"show many signs…of transported elements."*

While we cannot resolve the primary-versus-reworked question using the archival approach taken in this paper, we can report that there is nothing in the available record that is at odds with the discoverers' conclusion that thousands of animals and all the human individuals died a short time (geologically) before deposition in the Ngandong bone bed.

We attribute the spectrum of opinions expressed in the past about the geological context to four historical circumstances, rather than to actual stratigraphic uncertainty. First, while Oppenoorth (1932b) provides a location map that allows others to locate the site (see Figure 3A), the Survey did not publish either its detailed map of Excavation I Ngandong (Site Map; see Figure 6 below) or the final report on the excavation (ter Haar 1934b). Second, few of the researchers who have visited Ngandong since the 1930s have used the unpublished documents available at the old Survey offices in Java (e.g., see Figure 4; see Figures 6 and 7 below), nor have they assembled all of the fragmentary bits of published information about the site. Third, in part because of the first two circumstances, there has not been a thorough, modern geoarchaeological study of the site. Fourth, for many years paleoanthropologists were cautious in recognizing a Late Pleistocene age for the youngest *Homo erectus* because of the complex implications that arise out of a contemporaneity of this extinct species with *Homo sapiens*.

By presenting a detailed site map, among the other key historical documents, we provide a firmer basis for reassessing the geoarchaeology of Ngandong and the understanding of the paleoanthropological implications of the specimens (Ciochon et al. 2009; Huffman et al. 2008a, b). This approach has proved valuable with other *Homo erectus* found in Java before World War II (e.g., de Vos and Aziz 1989; and, Huffman et al. 2005, 2006). The opportunities for new understandings are possibly greater at Ngandong than for any other Javan site (e.g., Huffman et al. in press).

Our reassessment begins with reconsidering the discovery history of the 1931–1933 fossils. After describing our archival sources and providing background necessary to fully utilize the information they contain, we address the provenience of each of the 14 *Homo erectus* Ngandong finds, and rank the records to highlight those with the strongest documentation (see Table 5 below). In the Discussion, we use the provenience results to assess the geological age of the Ngandong *Homo erectus*, and then propose a taphonomic model for the fossils.

RESEARCH METHODS

This paper makes broad use of unpublished materials. These include internal Survey reports of ter Haar (1931, 1932, 1934b) and von Koenigswald (1933c, 1934b, n.d.—1934/1935) written during the Ngandong discovery operations or within a year after its end in December 1933. We refer to the discovery operation as Excavation I Ngandong, following the usage of the 1934 Survey (“Ingraving I Ngandong”). In addition to the internal reports, we scrutinize accounts published at the time (e.g., Oppenoorth 1932c, e, g) which are not referred to in the literature of the last 40 years, and others that have been utilized sparingly (e.g., von Koenigswald,1933a; and, ter Haar 1934a). To promote understanding of the little-used and unpublished reports, we quote key statements in them (highlighted in blue and italicized), translating the original Dutch and German where necessary.

Central to the documentation of Excavation I Ngandong is a Site Map produced in 1934 at a scale of 1:250 (Figure 6). The Map displays the outcrop limits of the Ngandong terrace deposits, the surveyed outlines of the excavations (including monthly and annual blocks), the pre-excavation topography at the site, and the discovery points for all but one of the 14 *Homo erectus* finds. The Map was an attachment in a Survey final report on the excavation done by ter Haar (1934b; see van den Bergh 1999 for the first mention of the Map in the literature). Ter Haar’s report also contained a topographic map of a broader area around Ngandong (see Figure 4B) and a geological cross section of the site (Figure 7).

The original of ter Haar’s 1934 report that we copied at the library of the Geological Research and Development Centre (Bandung), GRDC, in 2001 did not have map and cross section attachments. Full-sized black-and-white photocopies of the attachments were available in the files of Naturalis (Leiden), a result of archival research that had been undertaken in Bandung years before. The scans and photographs of the copies at Naturalis (e.g., see Figure 6B) formed the basis for the drafted editions of the maps and cross section presented in Figures 4B, 6 and 7, and provide us with a nearly complete copy of ter Haar’s report. The Site Map does not show the location of ter Haar’s cross section, which we have positioned based on topography and the position of fossil discovery points (see Figure 6A). Ter Haar’s cross section has a (vertical) bar scale (see Figure 7), but the Site Map lacks a scale bar, having only a stated scale, as was the normal practice at Survey. In creating scale bars for our illustrations of the maps (see Figures 4B and 6), we have graphically matched the cross section, the maps, Oppenoorth’s published map (see Figure 3A) and modern topographic maps (see Figure 5).

Also highly valuable to understanding the provenience of the Ngandong discoveries are Oppenoorth’s unpublished photographic prints and lantern slides of excavation operations and *Homo erectus* specimens *in situ*. His granddaughter, J.M. Oppenoorth, generously has made the photographic material available to us from her family’s possessions (see Figures 10–12, and 14 below). Other photographs kept by von Koenigswald for decades are available from his archive in Germany (see Figure 13 below).

The files of the GRDC Library contain hundreds of unpublished geological reports like those of ter Haar and von Koenigswald that we use. Some background is in order on the nature of such reports. The documents evidently were intended solely for internal Bureau use. Many of them were written by the geologists of the Java Mapping Program, discussed below, following individual field sessions lasting from several days to about three weeks (see examples in Huffman et al. 2005). This is the case with ter Haar’s 1931 and 1932 reports concerning Ngandong. Documents of this kind typically include the “when and where” of the geologists’ field travels, summaries of the stratigraphic and structural geologic relations they observed, and their draft geological maps of the areas investigated (generally at 1:25,000 to 1:50,000).

The primary publications of the Java Mapping Program geologists were 1:100,000 quadrangle maps accompanied by lengthy, formal geological explanations of the mapping (Oppenoorth 1928; Huffman et al., 2005). The unpublished reports are written in a style and format similar to the published texts, but there are important differences in content. Firstly, the reports are generally intermediate in detail between the Survey’s published products and what presumably was recorded in the geologists’ field notes. Stan-

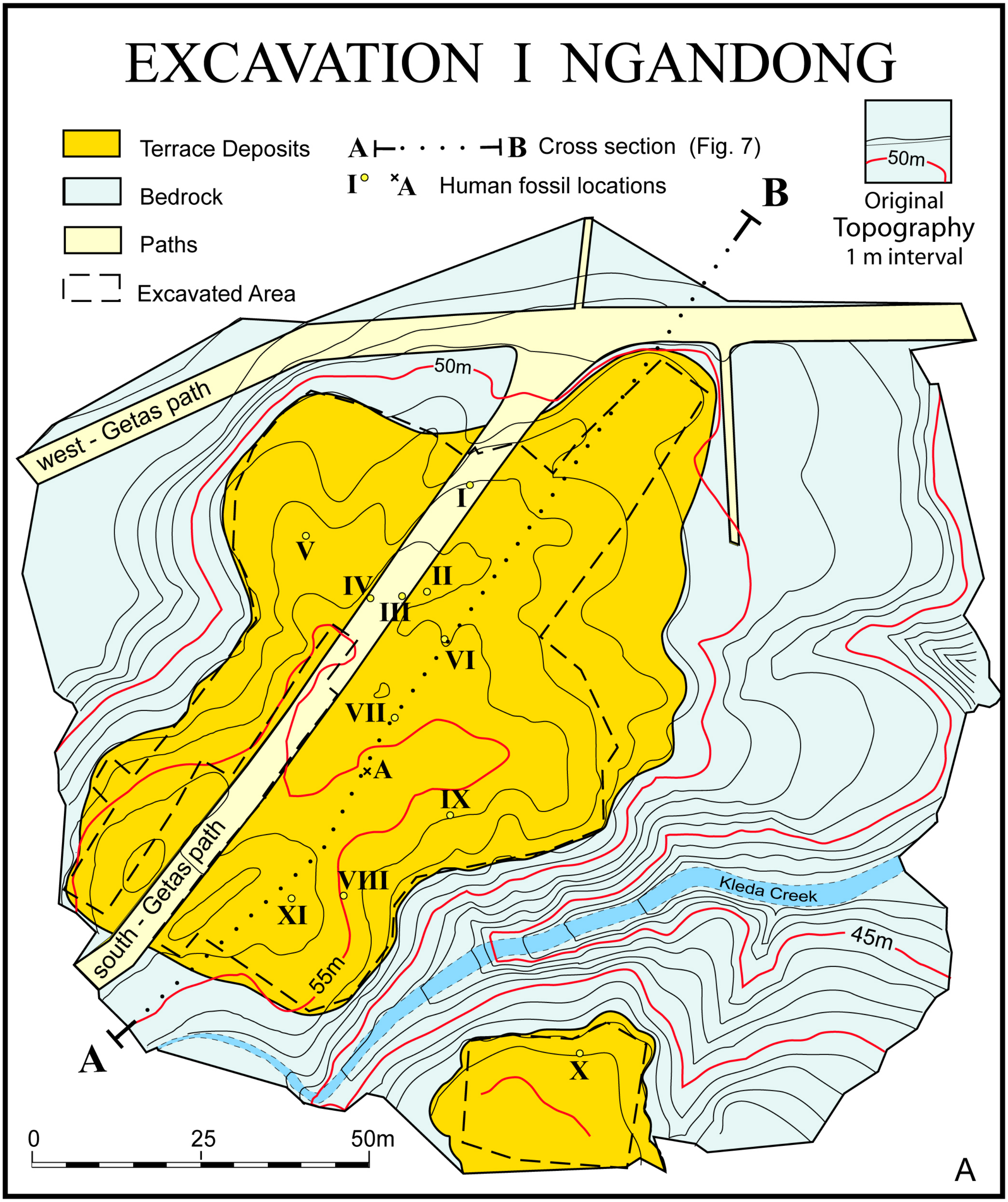


Figure 6A. 1934 Survey Site Map of Excavation I Ngandong (see also 6C, next page) with discovery points of 13 of the 14 Homo erectus *specimens found in 1931–1933 (Tibia B is not shown). We refer to the Terrace Deposits shown on this map as the Ngandong Formation, as explained in Table 3.*

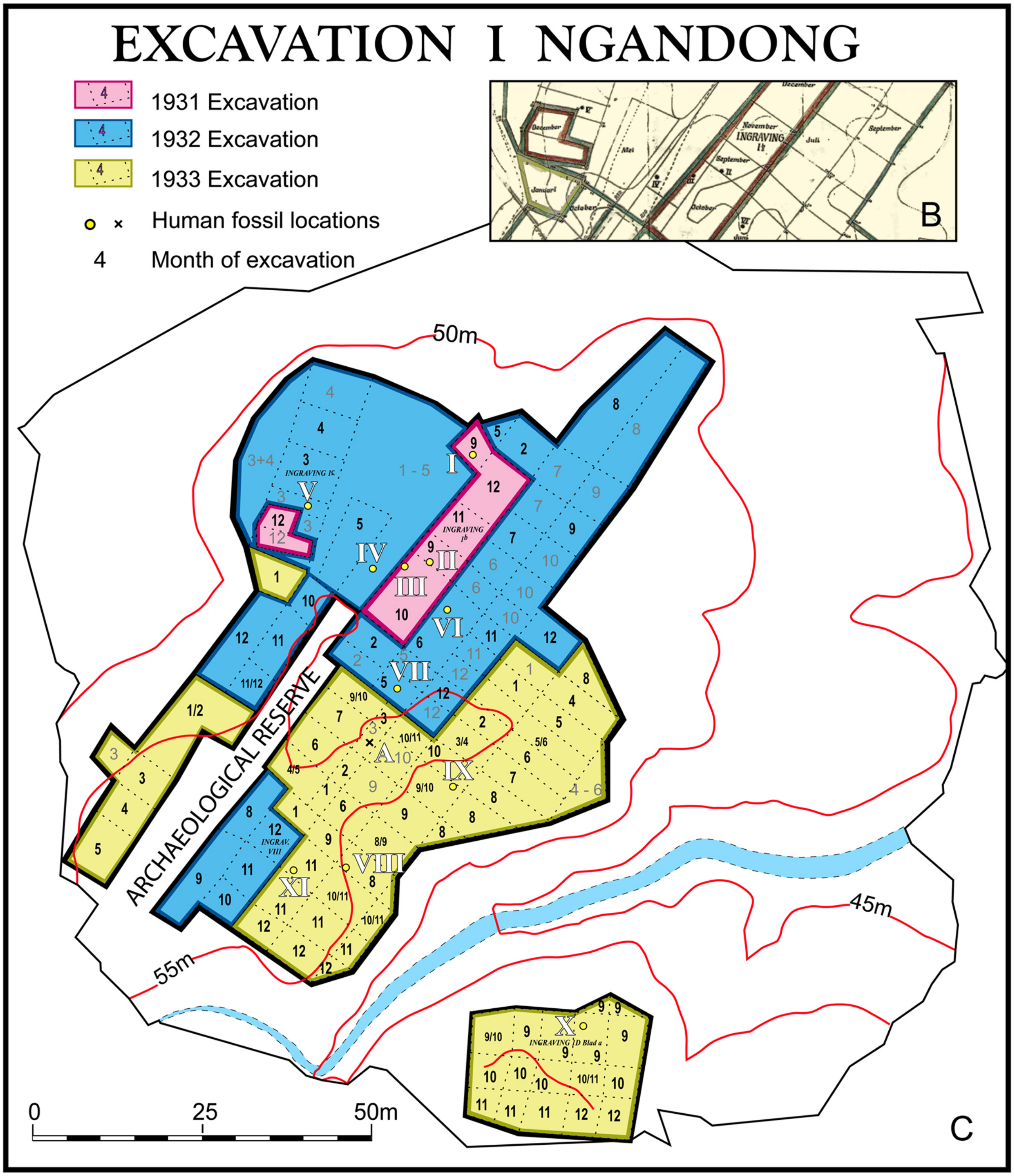


Figure 6B and 6C. 1934 Survey Site Map of Excavation I Ngandong (see also 6A on previous page) with discovery points of 13 of the 14 Homo erectus *specimens found in 1931–1933 (Tibia B is not shown). The inset (B) is a portion of the source document (from an Attachment in ter Haar 1934b; see Research Methods about construction of the bar scale). The months in which various blocks were excavated is shown in C by the 1, 2…12 (representing January, February…December); inferred months are in gray.*

dardized field note books were employed by the Survey geologists, and so valued as a permanent record that they were kept in the Survey Library until well after Indonesian Independence in 1948 (M. M. Purbo-Hadiwidjoyo, pers. comm. to O.F.H., 2001). Ter Haar undoubtedly referred to his field notes as he wrote his internal reports and publications on Ngandong. Regrettably, the note books themselves are no longer in the GRDC Library, and were not located

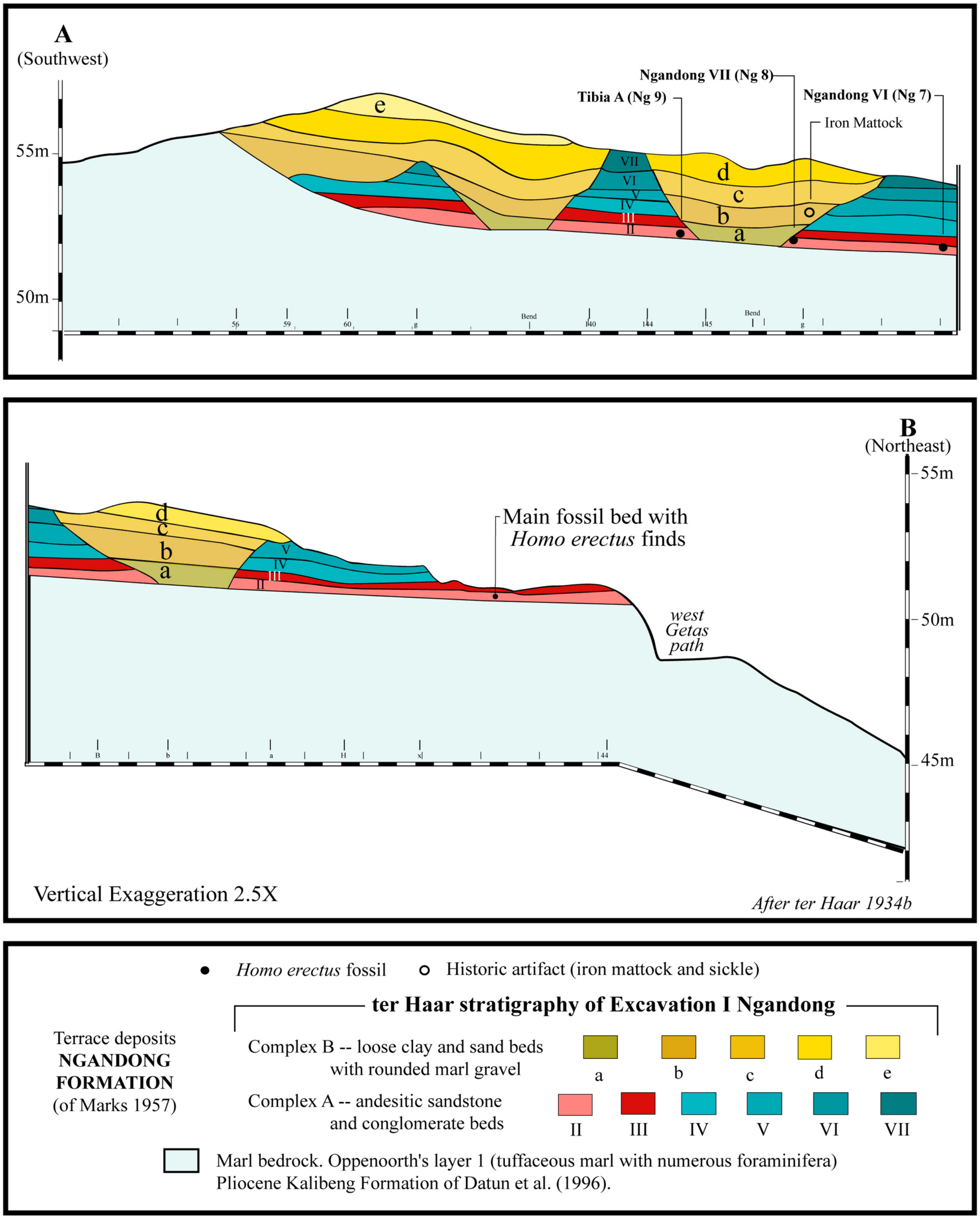


Figure 7. Ter Haar's (1934b: Attachment) cross section of Excavation I Ngandong (Figure 6A shows the line of the cross section). The details ter Haar portrayed for the internal stratigraphy of the terrace sequence are suspect, based on the fieldwork of Ciochon et al. (2009), but ter Haar's interpretation reflects an actual presence of lenticular bedding and infra-formational erosion seen in site photographs (see Figures 10B, 11 and 14). Sartono (1976) published a copy of the cross section.

during our archival research.

Secondly, the unpublished Survey reports are often less carefully composed than the publications of the same geologists on the same topics. Most of the reports were written as working papers intended to inform superiors of work progress as the basis for publications written years later. The reports were generally not peer-reviewed, even within the Survey, and their conclusions were often revised in later reports and publications by the same geologist. Therefore, the content of the reports is most reliably employed when confirmed by other sources.

A case in point is the cross section that accompanied ter Haar's 1934 unpublished report (see Figure 7). Van den Bergh (1999) noted that the cross section showed two sets of strata separated by an unconformity, and expressed concern about the implication that this had for the provenience of the human fossils. However, in separating the terrace deposits into two series of strata, ter Haar (1934a: 57, translated) emphasized that *"all* [hominin] *skulls were recovered from the lowest layers"* of the older series. In his estimation, therefore, infra-formational erosion at the unconformity did not affect the occurrence of any of the *Homo erectus* fossils in the basal-bone bed (as discussed further with respect to the provenience of Ngandong VIII, Ng 11, below). Furthermore, caution is advisable in taking ter Haar's representation of stratigraphic relationship on the cross section literally. The diagram must have been prepared largely on the basis of the fieldwork done by Oppenoorth, von Koenigswald, and Panudju, not ter Haar alone. His last visit to the site while the excavations were underway was in June 1932, when somewhat less than half of the excavation had been completed (see Figure 8E–F below). The first author of this paper worked at Ngandong in August 2008 using the cross section and other material published here (see Ciochon et al. 2009), and did not see evidence to support the two-series interpretation of ter Haar. Ter Haar (1932) did recount having observed lenticular beds and intraformational erosion within the terrace sequence, which are evident in site photographs (see Figure 14 below; see also Figures 10B and 11 below).

BACKGROUND

At points in our evaluation of the Ngandong provenience record, we rely on a broader understanding of the historical circumstances at the Survey in the 1930s. Before addressing the discovery and geological context of the 14 *Homo erectus*, we give background on the Survey organization, discovery of Ngandong, history of excavation, field personnel on the project, and the geologists responsible for it back at Survey headquarters.

SURVEY

The *Homo erectus* discoveries at Ngandong were a product of the Java Mapping Program (Javakaarteering). This was an organizational unit of the Bureau of Mining (Mijnwezen) in the colonial government of the Netherlands Indies. The Program was sometimes indicated to be the geological component of the Exploration Service (Opsporingsdienst), and often is referred to as an element of the Geological Survey of the Netherlands Indies. For this reason, we say that the Survey conducted Excavation I Ngandong and discovered the hominin fossils.

As the Survey employees most responsible for the Ngandong operations, Oppenoorth, ter Haar, and von Koenigswald generally are acknowledged to be the discoverers of the *Homo erectus*. The two geological field assistants who had daily on-site responsibility for the field operations, Samsi and Panudju, also should be considered discoverers. Samsi recognized Ngandong I and II (Ng 1 and 2) as significant finds, drawing Oppenoorth's attention to the specimens that became the first human-fossil discoveries in Java since the *Pithecanthropus erectus* was found at Trinil 35 years before. Having been instructed to be vigilant in watching out for additional human remains, Panudju identified six *Homo erectus*—Ngandong V, VI, VIII, IX, X, and XI (Ng 6, 7, 11, 12, 13, and 14)—as probable hominin fossils (see Table 2).

The great paleoanthropological success that the Survey had at Ngandong was quite unexpected. Searching for hominin fossils was beyond the everyday scope of the Bureau mission. The organization had practical objectives of mine management, mineral exploration, engineering geology, and assessing the impact of volcanic eruptions. The Bureau at one time employed ~70 Europeans and Indo-Europeans as managers, scientists, and support staff, and ~90 Indonesian assistants, and was one of the largest geological surveys in the world (Huffman et al. 2005). The Survey operated from spacious headquarters with a geological library, a paleontological museum, and analytical laboratories in Bandung.

Few more competent organizations than the Geological Survey of the Netherlands Indies existed outside Europe and North America in 1931. However, at least two conditions were strongly deleterious to both the conduct of the excavation and the analysis of its discoveries. First, Excavation I Ngandong was operated under the constraints of a rigid government bureaucracy with competing- and often higher-priority objectives. Second, the excavation was conducted during the global Great Depression which had severe impacts in the Indies.

One consequence of these circumstances was that Oppenoorth, ter Haar, and von Koenigswald were only at Ngandong a total of 24-man days during the 828-day operation (Table 4; Figures 8 and 9). Three-quarters of their field time was in 1932. The level of supervision diminished in 1933 when Oppenoorth retired from the Survey. Von Koenigswald paid short but important visits to Ngandong on September 8–9 and in November 1933. Ter Haar and von Koenigswald returned for part of a day in July 1934 after the completion of the excavation, just before ter Haar finished his summary report with the Site Map (see Figure 6) and cross section (see Figure 7).

The experiences of Oppenoorth, ter Haar, and von Koenigswald put each of them in a position to publish authoritatively on the Ngandong *Homo erectus*. However, their accounts and interpretations were limited by their infrequent

TABLE 3. OPPENOORTH'S LITHOSTRATIGRAPHY OF EXCAVATION I NGANDONG IN 1931.

Unit Name[1,3]	Lithologic description[2]
Layer 6	Layer 6 closely resembles Layer 5, but principally consists of rounded pieces of *Globigerina* marl mixed with tuffaceous components. This Layer grades upwards into the top soil. ~1.0m thick.
Layer 5	Layer 5 is polymictic pebble conglomerate, mostly the product of erosion of Tertiary tuffaceous marl (which contains plagioclase, hornblende, and augite, but lacks hypersthene, and contains marine fossils, such as *Globigerina)*, mixed with younger volcaniclastic material (identical to that of Layer 4), including small pebbles of hypersthene andesite in a matrix of loose quartz, plagioclase, augite, hypersthene and hornblende crystals. ~1.0m thick.
Layer 4	Layer 4 is gravelly sand, similar to Layer 2, with loose crystals of quartz, plagioclase, hypersthene, augite, green- and brown-hornblende—all slightly rounded, except for the quartz crystals; additionally, there are small pebbles of hornblende-augite-hypersthene andesite, but no dacite, which is a rock type that the quartz crystals indicate was present in the source area. ~0.30–0.50m thick.
Layer 3	Layer 3 is marly, tuffaceous sandstone, consisting of loose crystals of plagioclase, augite, hypersthene, and green- and brown-hornblende with small pebbles of hypersthene-augite andesite.[4] ~0.16–0.30m thick.
Layer 2 **(HOMININ BED)**	**Layer 2, the bone-bearing Layer, is gravelly sand, containing all the ingredients of hypersthene andesite in the form of loose crystals and small pebbles.** [4] **~0.46m thick.** Oppenoorth (1932b: 52, translated) later reported: *"The fossil vertebrate remains are exclusively found in Layers 2 and 3, and then primarily in the upper part of Layer 2, where the skulls also were found. A fairly hard crust, which has formed around the fossils, is made up of tuffaceous sand and fine gravel, cemented by lime."*
Layer 1 (local bedrock)	Layer 1 is late-Tertiary tuffaceous marl bedrock with numerous small foraminifera, such as *Globigerina*, *Orbulina universa*, and *Pulvilulina menardii*; most likely of late Pliocene age [Kalibeng Formation of Datun et al. 1996].

[1] The Survey also used Roman Numerals for the same Layers (1 = I, 2 = II, etc.).

[2]From Oppenoorth (1932b: 52, translated and edited) with thickness values added from von Koenigswald (1933b), based on Oppenoorth's October 27, 1931, fieldwork (see Table 4), when ~150m^2 of the excavation was open (see Figures 6–8).

[3]We refer informally to Layers 2–3 as the basal or basal-bone bed or stratum, and units 2–6 as the Ngandong Formation—the latter terminology follows Marks (1957: 102) in the *"Stratigraphic Lexicon of Indonesia"* where he applied the name *"Ngandong Layers (Formation)…Pleistocene"* to the *"Terrace-deposits of Solo-River…near Ngandong."* He doubtless was referring to Oppenoorth's (1932b) description and profile (see Figure 3B) of Layers 2–6 lying ~20m above the Solo River at Excavation I Ngandong, as well as similar strata at "Ingraving 2" (see Figure 3A). He might also have been aware of ter Haar's (1932) mapping of ~20m terrace deposits elsewhere in the vicinity of Ngandong (see Figure 5A). The new lexicon for Indonesia (Haratrap et al. 2003) does not mention the Ngandong Formation, or give another name to *Homo erectus* strata at Ngandong. The Systematic Geological Map of Indonesia 1:100,000 quadrangle (Datun et al. 1996) does not show the *Homo erectus*-bearing terrace deposits of Ngandong at all. Oppenoorth's Layers 2–6, along with various other fluvial terrace remnants in the region, were referred to as "terrace deposits" in the 1930s (e.g., see Figures 3A, 5A, 6, and 7) and more recently (e.g., Bartstra et al. 1988; Itihara et al. 1985; Swisher et al. 1996). A mixture lithostratigraphic and geomorphic terminology also has been employed (e.g., Bartstra 1977; de Terra 1943; Sartono 1976). We use the term Ngandong Formation because it more properly identifies the discovery beds as a specific mapped rock unit (see Figures 3A, 4A, and 6).

[4]Ter Haar (1934a: Figure 4) reports that the heavy mineral separates from Layers 2 and 3 sand contained ~50% augite, ~25% hypersthene, ~20% hornblende, and ~5% aegirine augite, providing additional evidence of the fresh volcaniclastic nature of the basal beds.

field visits, strong dependence on field personnel and procedures, little in the way of field and laboratory collaboration, and the fact that no two, let alone all three, wrote a joint paper or report that combined their individual observations and sorted out any differences in interpretation. Furthermore, their publications focused on paleoanthropological issues, more than the excavation operations and geology. The lack of detail about the operations in particular has been a source of suspicion concerning the provenience reported for the finds.

TABLE 4. SCHEDULE OF SURVEY PERSONNEL WORK AT THE NGANDONG *Homo erectus* SITE DURING 1931–1938.

Activity	Schedule of Survey Personnel
Site discovery[1]	Carel ter Haar, on the afternoon of August 27, 1931[1]
Daily excavation supervision[2]	Samsi (geological assistant)—September 12 to October 31, 1931 (49 days) Panudju (geological assistant)—November 1, 1931, to December 18, 1933 (779 days)
Headquarters personnel working at Excavation I Ngandong	GEOLOGISTS (24 days during the 828-day formal excavation; see also von Koenigswald 1951) W.F.F. Oppenoorth (Java Mapping Program leader)—7 days (four trips1931 and 1932)[3] C. Ter Haar (Geologist)—6 days (one trip in 1932; also the site discovery trip and one post-dig trip in 1934)[4] G.H.R. von Koenigswald (Paleontologist)—11 days (four trips in 1931–33; also one trip in 1934)[5] GEOLOGICAL ASSISTANTS (149 days during the 828-day dig) Headmantri Dramoh—24 days[6] Sajadi (geological assistant; surveyor)—27 days[7] Andojo (geological assistant in training)—49 days[8] Markum (geological assistant in training)—49 days[9]
Post-dig visits by geologists in 1930s	July 1934—J. Zwierzycki (Java Mapping Program leader, after Oppenoorth's retirement in 1933) and J. Duyfjes (geologist) with ter Haar and von Koenigswald—part of a day[10] April 9, 1938—P. Teilhard de Chardin (paleontologist; Geological Survey of China), H. de Terra (geologist; Carnegie Institution, Washington, D.C.), and H. Movius (archaeologist; Peabody Museum, Harvard University) with von Koenigswald—part of a day[11]

[1]Ter Haar (1931) and other sources referred to in the text.

[2]Ter Haar (1934b).

[3]Ter Haar (1934b) lists Oppenoorth's visits as Oct. 27 (1 day during the trip of Oct. 21–30, 1931), Mar. 21–22 (2 days during the trip of Mar. 20–24, 1932), Aug. 14 (1 day during the trip of Aug. 12–23, 1932), and Oct. 27–29 (3 days during the trip of Oct. 24–31, 1932). Oppenoorth photographed and removed Ngandong V (Ng 6) on March 21–22, 1932 (ter Haar 1934b).

[4]Ter Haar (1934b) lists his one site visit as June 19–24 (6 days during trip of June 18–25, 1932). Ter Haar (1932) removed Ngandong VI (Ng 7) on June 19, 1932, with von Koenigswald, and did reconnaissance mapping of terrace deposits elsewhere in the Solo River Gap (see Figure 4A). Ter Haar (1931) discovered the site and put in a test excavation on August 27–28, 1932 (2 days of work before the formal excavation began). He visited the completed excavation in July 1934 with von Koenigswald and others (von Koenigswald n.d.-1934/1935).

[5]Ter Haar (1934b) lists von Koenigswald's visits as June 19–24 (6 days during trip of June 18–25, 1932), Nov. 12–13 (2 days during trip of Nov. 6–17, 1932), and Sept. 8–9 (2 days during the trip of Sept. 3–11, 1933). Von Koenigswald (1955, 1956; ter Haar 1932) photographed Ngandong VI (Ng 7) in place on June 19, 1932. He removed Ngandong VIII (Ng 11) on Sept. 8–9, 1932 (von Koenigswald 1933c; ter Haar 1934b). Ngandong XI (Ng 14) was also removed under his supervision during (1 day in) November 1933 (Mijnwezen, 1933; von Koenigswald 1934b, 1956; Zwierzycki 1933–1935; however, ter Haar [1934b] did not list this visit to Ngandong, or reported that von Koenigswald was present at the removal).

[6]Dramoh was at Ngandong when Samsi set up the dig (Sept. 13), and again in the company of Oppenoorth on Oct. 27, 1931, as Panudju was about assume supervision. Dramoh visited 11 times—four times in the company of Oppenoorth—on Sept. 13, 1931, Oct. 27, 1931 [with Oppenoorth], Nov. 26–28, 1931, Dec. 29–31, 1931, Feb. 2–4, 1932, March 21–2, 1932 [with Oppenoorth], May 4–5, 1932, July 27–28, 1932, Aug. 14, 1932 [with Oppenoorth], Sep. 28–Oct. 1, 1932, Oct. 28–29, 1932 [with Oppenoorth] (ter Haar 1934b).

[7]May 12–18, 1932, July 27–August 2, 1932, and Oct. 16–28, 1932 (ter Haar 1934b).

[8]March 21–May 8, 1932 (ter Haar 1934b).

[9]Feb. 15–March 24, 1933; June 13–25, 1933 (ter Haar 1934b).

[10]von Koenigswald (n.d.-1934/1935). Lehmann (1936) conducted a geomorphological study of the Solo River gap in 1933, but he did not specifically indicate having visited Excavation I Ngandong.

[11]Movius (1938a, b, 1944); de Terra (1943); de Terra et al. (1938).

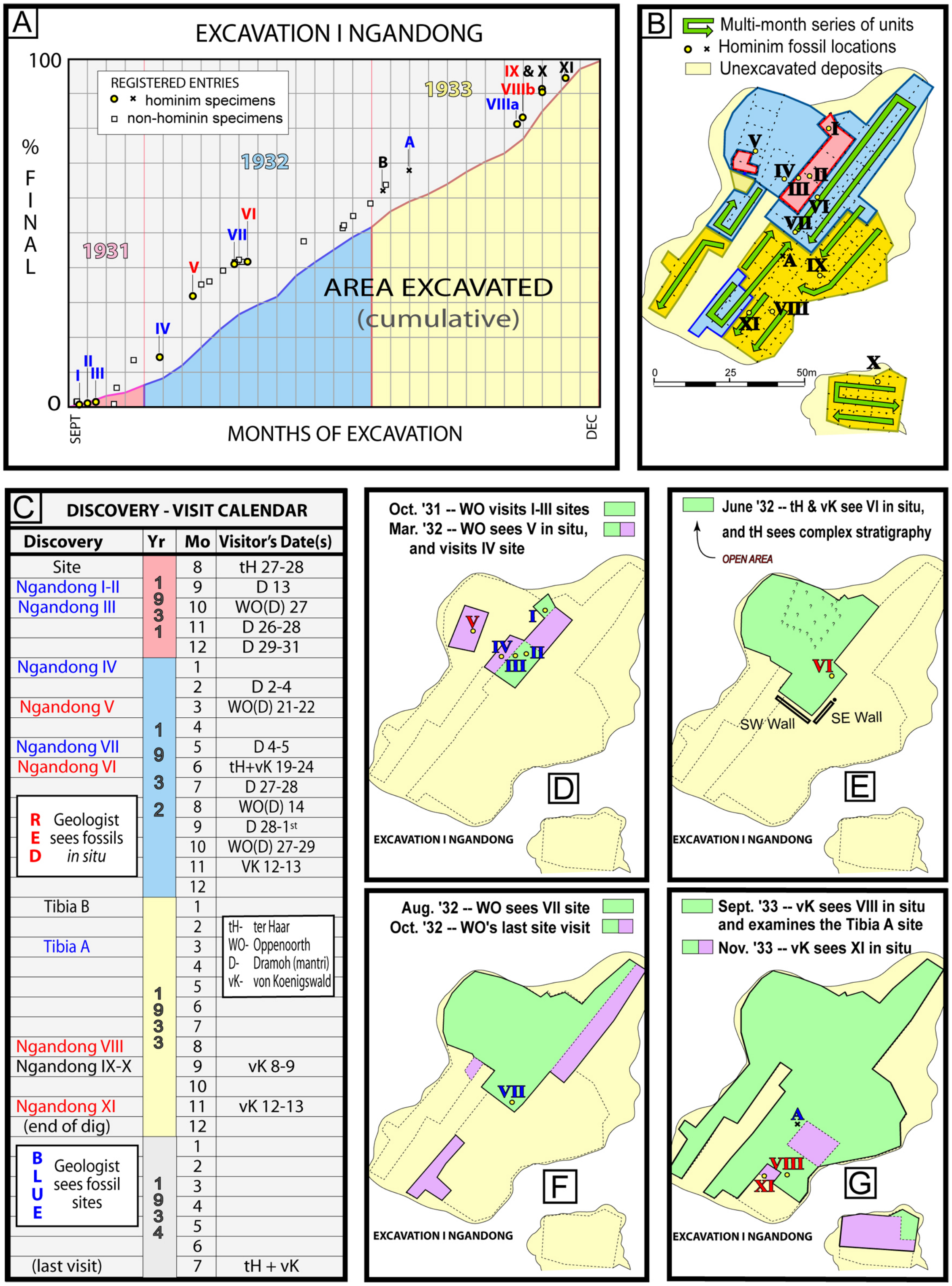


Figure 8. Graphs and maps showing the history of Excavation I Ngandong and Homo erectus *fossil discoveries. A—Cumulative area excavated over time (from Figure 6C, as a percent of the total area) plotted with the fossil discovery pattern over time (Register Numbers as a percent of total entries). B—Progress of the excavation during late 1932 and 1933 (arrows) which presumably resulted in long exposures of the terrace sequence in the excavation walls. C—Schedule showing the visits of geologists Oppenoorth, ter Haar, and von Koenigswald, as well as the Survey's lead geological assistant Dramoh, to Excavation I Ngandong, and a listing of the* Homo erectus *fossils and discovery points they examined (see also Table 4). D to G—Status of the excavations at key points during the discovery events (see Figure 6C for details).*

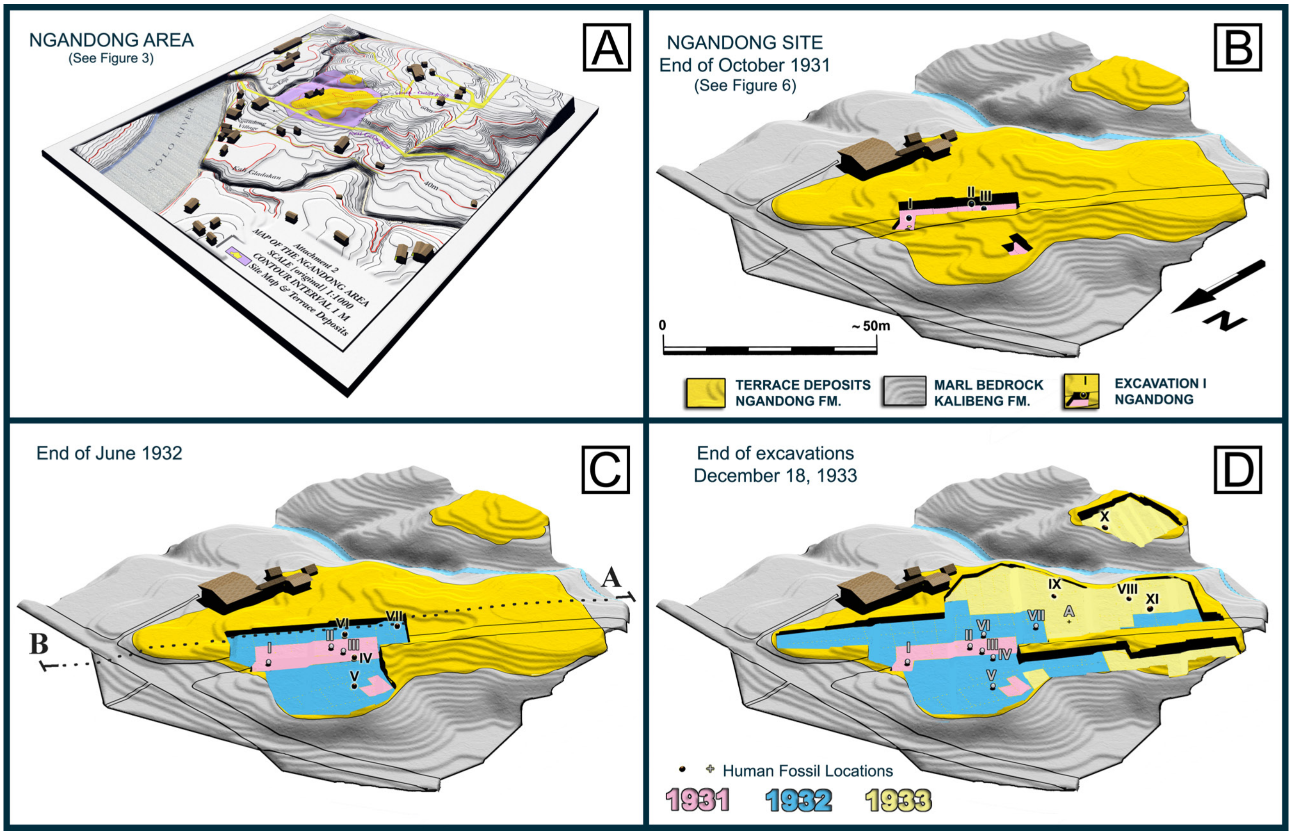


Figure 9. Block diagrams showing the setting and progress of Excavation I Ngandong over time.

SITE DISCOVERY

Ter Haar (1931) found vertebrate fossils at Ngandong on the afternoon of August 27, 1931. He had been mapping the geology of the area as one of several such assignments he had within the Java Mapping Program. When he had local men excavate at the spot the next day, they recovered the fossils of a variety of animals. Ter Haar (A.I.D. Preangerbode 1932b, translated) is quoted in an April 1932 newspaper article as saying:

> *As it turns out, on the first afternoon of our* [ter Haar and his field assistants] *stay at Ngandong, after I had visited the 'bathing facility' at the Solo river, I encountered a gravel layer along a narrow foot path, from which a piece of bone was exposed: a gravel layer overlying the marine Layer at a level of about 20 meters above the river level….The next afternoon I directed the workers to excavate the soil at this location and soon we found a piece of skull with horns of a buffalo, the largest that has so far been found with a width between the tips of the horns of 2 meters! We also found various other remains of fossilized animals especially those of bantengs, deer, etc.*

Besides the banteng (Javan cattle) and deer fossils, ter Haar had recovered the now well-known buffalo-cranial specimen (*Buffelus palaeokerabau*) with intact horn cores two meters across (see also Oppenoorth 1936; Swisher et al. 2000; von Koenigswald 1956).

The Ngandong site is ~150m southwest of the current bank of the River (see Figure 4B). The fossiliferous deposits represent an abandoned bed of the Solo River ~20m above the modern river, the height of which the Survey measured at ~33m above sea level in 1931–1933 (de Terra 1943; Lehmann 1936; Oppenoorth 1932c, 1936; ter Haar 1932, 1934a). A fluvial depositional context seemed likely to ter Haar (1931) when he found the site in August. This setting was confirmed soon after the excavations got underway. River-living species were found among the terrestrial taxa of the kind ter Haar had unearthed, and terrace deposits were mapped at about the same elevation at a number of points in the Solo River Gap (see Figures 3A, 4A and 5A; Oppenoorth 1932b; ter Haar 1932). Modern topographic mapping shows that the Ngandong site lies just above 40m above sea level (see Figure 5).

EXCAVATION HISTORY

Formal excavation began on September 13, 1931, just 18 days after ter Haar first found vertebrate fossils (ter Haar 1934b). Oppenoorth was able to act so quickly, because, as head of the Java Mapping Program in 1930, he (1932b) had initiated excavations at 17 sites in terrace deposits and bedrock formations along the Solo River (see Figure 2; the Survey ultimately collected ~37,000 fossils from these excavations; von Koenigswald n.d.—1934/1935). The explicit objective of the excavation project was to recover vertebrate remains with well-determined stratigraphic contexts (Oppenoorth 1932b). The new fossil collections were expected to help date the Pliocene and Quaternary sequence of eastern Java (see Huffman et al. 2005 for further background). Excavation I Ngandong would prove to be the most abundantly fossiliferous dig of 1930–1934, rivaling the productivity of the excavations undertaken in the older Kabuh Formation at Trinil from 1890 to 1908 (see Selenka and Blanckenhorn 1911, for example).

Ter Haar (1934a) states that the terrace covered 7,500m² at the Excavation I Ngandong site. Our measurement, based upon the Site Map, is ~6,300m², divided into two remnants. The larger remnant extended ~110m in a southwest-northeast direction by ~75m transversely. The smaller one, located to the southeast of the first and separated from it by ~20m, measured ~20m x 30m. The southern geological contact of this remnant is not marked on the Site Map (see Figure 6A). The excavated area of ~4,610m² was ~73% of the mapped outcrop of the terrace deposits.

The large remnant is undoubtedly the outcrop from which ter Haar unearthed the buffalo skull and other fossils on August 28. Specifically the discovery point must have been at the north end of the terrace remnant in the pathway just north of what became the Ngandong I (Ng 1) discovery block (see Figure 6A). Excavations in the large remnant accounted for ~90% of the total area excavated. The northern half of the main remnant contained all of the 1931 excavation blocks and most of those dug in 1932 (see Figure 6C). The southern half included all the 1933 units and the late 1932 dig that flanked the archaeological reserve (see Figure 8). More information is available on the provenience of the *Homo erectus* specimens discovered in the northern half of the larger remnant than elsewhere in Excavation I Ngandong, presumably because greater attention was paid to the excavation by the Survey geologists during 1931–1932 as compared to 1933 (see Figure 6C).

The Excavation I Ngandong expanded at a broadly constant rate of ~165m² per month over the 27-months of operation (see Figure 8A). This amounts to ~5.4m² per day. Where the deposits were 2m thick, the average rate of excavation equates to ~11m³ per day. About 6% of the total excavation was done in the last 3½ months of 1931. The remaining 94% is split evenly between 1932 and 1933. The monthly rate of excavation changed significantly over the course of the dig, being considerably slower during the first 5 months, about half the 27-month average, and increasing substantially in August-December 1933, nearly double the average, as the field crew apparently pushed to finish the field operation by year end.

Excavation continued through the rainy months from November to April each year, as well as the dry seasons from July to September (see Figure 8A). Digging did not stop even during the first quarter of 1933, when other Solo River excavations and nearly all other Java Mapping Program fieldwork was shut down due to heavy rains. The wet-monsoon conditions—muddy cart trails, for example—would account for the fact that none of the geologists visited Ngandong during December, January, and February (see Table 4).

In summarizing the numbers of fossils collected from various Solo River sites excavated in 1930–1934, von Koenigswald (n.d.—1934/1935: 3, translated) gave the Ngandong total as *"more than 25,000 specimens."* Years later, he (1951: 214, 1956) reasserted the number, *"over 25,000 mammalian remains were excavated."* Given that there were 23,553 entries in the Ngandong Fossil Register maintained by the field supervisors (see further description below), he must have been taking into account the multiple-specimen entries made in the Register. Thirty fossils were recovered on an average day. Had all the 23,553 Register entries come from the Excavation I Ngandong, there would have been ~5.4 entries made per square meter. Over a quarter of the terrace remnants were not excavated in the 1930s (see Figure 6), and researchers are still today collecting specimens from the site (e.g. Ciochon et al. 2009; Sartono 1976). The total number of vertebrate fossils originally deposited at Ngandong therefore was undoubtedly far larger than 25,000.

A significant ambiguity endures, however, concerning how many of the Register entries came from Excavation I Ngandong versus those originating from other excavations that the Survey included in the Ngandong project. In 1931, Oppenoorth showed an *"Ingraving 2"* as a second dig 0.36km to the east of the *Homo erectus* site (see Figure 3A). Presumably some fossils listed in the Register were from this second site. On the other hand, Oppenoorth, ter Haar, and von Koenigswald's statements taken *in toto* appear to us to imply that the overwhelming majority of the ~25,000 fossils came from the *Homo erectus* dig of Excavation I Ngandong.

FIELD METHODS

Much about the field protocols employed at Ngandong can be inferred from the Site Map (see Figure 6), site photographs (Figures 10–11; see Figures 12–14 below) and descriptions of the field methods. To summarize: The excavation plan produced a series of consistently aligned monthly blocks with long vertical faces clearly showing the stratigraphic relations in the terrace deposits. The shallower beds were stripped away to reveal the bone-rich interval at the base of the terrace deposits, exposing these beds across sizeable excavation blocks. Prominent fossils were left on pedestals, protected, tagged, and recorded for provenience. The assistants surveyed block outlines and transmitted summary field provenience records to Bandung headquarters along with periodic shipments of fossils. Headquarters staff monitored operations from the correspondence, especially in 1931 after *Homo erectus* was found and during 1933.

In the following paragraphs we document and further characterize the field methodologies largely using the accounts of the discoverers. Ter Haar's (1934b: 3, translated) summary report states:

> *At the excavation, blocks of approximately similar size were excavated one after the other. The position of these blocks are indicated on the attached map (see Attachment 3* [see Figure 6]*), each block shown with the month and year excavated. Since the upper Layers were usually either completely barren or contained poorly preserved material, they were in general completely excavated away so that both lowest Layers II and III* [the same as Layers 2 and 3, respectively]*…remained* [see Table 3; see Figures 3B and 7]*: these Layers II and III are the main fossil carriers in the complex, and the excavation had to be done with utmost care in order to prevent damage of*

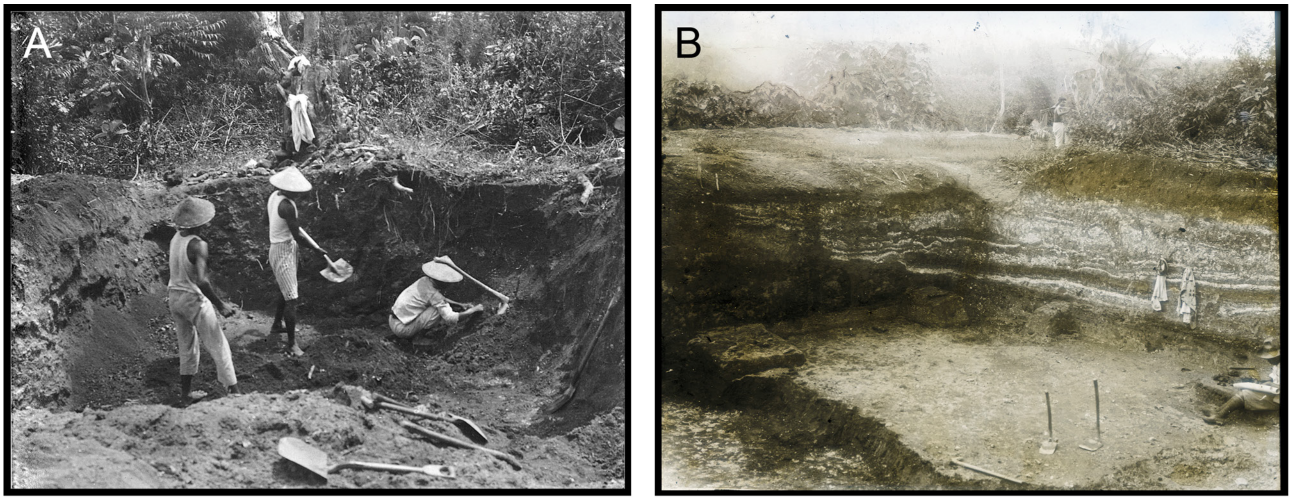


Figure 10. Excavation I Ngandong excavation techniques. A—Laborers digging at Ngandong (scanned from a print in Oppenoorth's personal photograph album). Oppenoorth (1932c–g) published this image widely in 1932, leaving an impression that the Homo erectus *were unearthed in ill-defined units dug with shovels and mattocks. A caption accompanying one of the five published copies (Oppenoorth 1932f) refers to the locality as the discovery place of Ngandong I (Ng 1). An annotation in another Oppenoorth (1932c, translated) publication noted, "photo plate willingly provided by 'Actueel Wereldnieuws'," a news agency in Java that may have owned the image. B—A better illustration of the Survey excavation techniques, this photograph shows fossils on pedestals (lower left, center and right) and a geological assistant (center at the right edge) taking notes on, or possibly referring to, a rolled map or diagram. Oppenoorth's Layer 2/II containing fossils in its upper part evidently was exposed across the excavation floor. The stratum was dug away completely to expose the underlying marl on the lower left. In the excavation walls, a white-layered unit exhibited lenticular- and channel-form bedding (e.g., at the shirt on wall), and a dark-colored wedge of strata (thinning toward right) was situated between the white-layered unit and bone-bearing stratum. The wedging unit might have been the andesitic conglomerate and sandstone of Layer 3/III. The contact between the wedge and white-Layered unit might have been the unconformity between ter Haar's upper complex of beds and Layers 3 and 4 (see Figure 7). This photograph undoubtedly shows Excavation I Ngandong, although Oppenoorth's lantern slide of this image is labeled "Ngandong Exc. 7" (Ngandong Ingr 7), a designation is not specifically identified on the Site Map (see Figure 6C). Our explanation for his use of the "Exc. 7" terminology lies in the idiosyncratic way that the Survey had of identifying excavation blocks. For example, the Site Map identifies one area of Excavation I Ngandong as "Exc. VIII," and the specimen labels from the site have a variety of unit provenience descriptors, such as "Exc. IC, Bl. IX," "Exc. I B bl 4 Ngandong," "Exc. IVb," and "Exc. IV, block 4" (translated).*

the expected bones. Where the terrace was excavated this was always done till the Tertiary was reached (here, a grey-green Globigerina marl). The status of the excavation was reported [to Survey headquarters] *weekly by the lead mantri* [geological assistant Samsi and Panudju] *with attached sketches of the excavation. These reports and sketches are bundled together for each year (1931-1933) and will be referred to in the future as 'Bundel verslagen Ngandong 1931' etc. Part of the first reports and correspondence about Ngandong can also be found in the 'Bundel Watualang-Pitu 1930-1931.'*

The collected bones were labeled and registered in an Original Ngandong Fossil Register" [Originaal-register fossielen Ngandong], then packed and shipped to Bandung in crates; *"each bone was wrapped in Chinese paper to which glue was added, resulting in a strong elastic wrap…*[and] *broken bones…were glued together with Arabic glue.…It was very important to prevent long exposure to sun light: rapid and total desiccation could* [cause] *defoliation and occasionally total weathering of the bones. The bones exposed during the excavation were therefore immediately covered with leaves. During the preliminary preparation they were laid out to dry in the sun only after having been treated with glue and wrapped in Chinese paper. For each shipment to Bandung, a packing list was prepared, which was a copy of the Original Ngandong Fossil Register.…These lists were copied in Bandung and entered into a register, titled: the Duplicate Ngandong Fossil Register* [Duplicaat-register fossielen Ngandong]. *Both registers contain 23553 fossil numbers: Ngandong tops all other fossil locations in the area, as far as the quantity of fossil material is concerned."*

Von Koenigswald (1933c: 1, translated) also commented on the excavation protocols at Sidorejo and Ngandong, confirming what ter Haar described, *"instructions were given to remove the overburden only, in order to uncover a larger area of the bone bed, and then to dig this out as a single unit, as has been done at, for instance, Ngandong."* This approach is seen in the site photographs (see Figures 10B, 11A, B; see Figure 13 below) wherein the excavations reached into marl.

Von Koenigswald (1951) noted that Ngandong VI (Ng 7) was one of the fossils covered by leaves for protection. Oppenoorth (1936: 401) added that the fossils were *"wrapped in old newspapers and packed…with …padi* [rice field] *straw."* Fragments of newspaper (interestingly, written in English) still adhered to some specimens when von Koenigswald photographed them in 1931 (e.g., Oppenoorth 1932b: Plaat III).

Except possibly for areas dug in early 1932 (where no monthly outlines are shown on the Site Map; see Figure 6B),

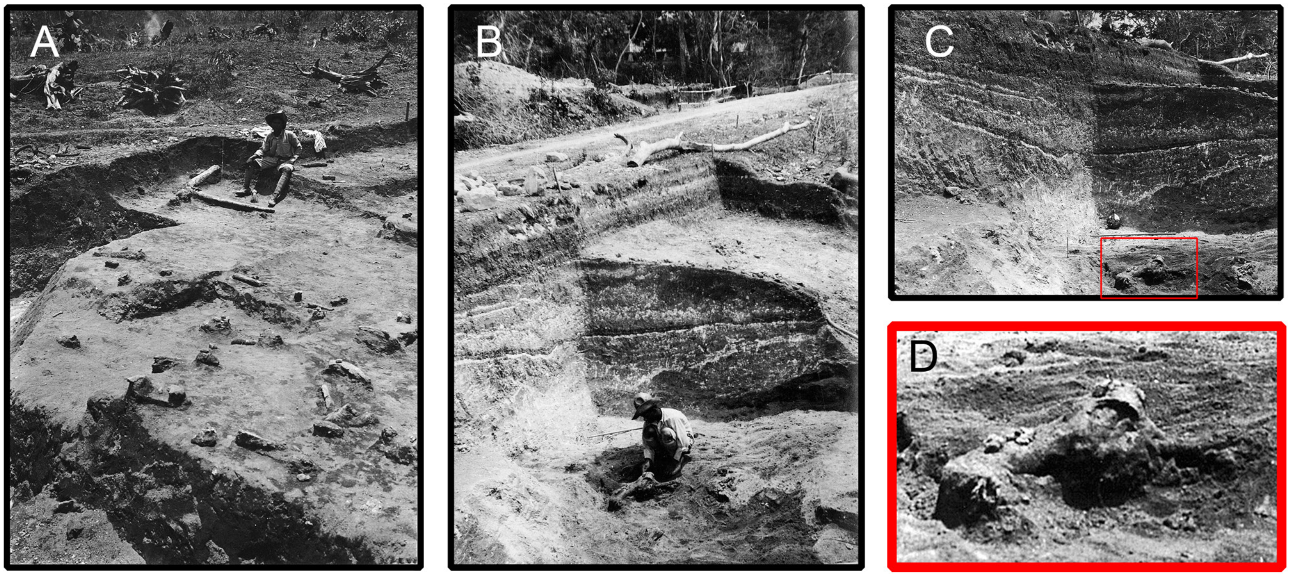


Figure 11. Oppenoorth's October 1932 photographs of the bone bed at Excavation I Ngandong. A—Fossils on excavation pedestals where the bone-bearing stratum, resting on marl (middle left edge), was at a shallow depth and had been excavated away in thin horizontal levels. Note the broken elephantid tusk about 2m long at the feet of the geological assistant, and the disarticulated, generally broken condition of the fossils. Small pieces of paper, which are seen at several places on the fossils, evidently were part of the Survey record-keeping system (see also Figure 13). Scanned from a print in the Oppenoorth's personal photograph album; the print is labeled "October 1932" in Oppenoorth's hand (J. Oppenoorth, pers. comm., 2007). An Oppenoorth lantern slide of this image is labeled "Excavation Ngandong I. bone bed. Ng VII bone bed" (Ingr. Ngandong I. beenderlaag. Ng VII beenderlaag). The scene must have been from the eastern part of Excavation I Ngandong where the October 1932 units encountered the bone-rich interval at a shallow depth (see Figure 7, for example). The "Ng VII" probably referred to "Ngandong excavation VII" (Ingraving VII Ngandong), a portion of Excavation I Ngandong (see caption of Figure 10B). B and C—Nearly a full exposure of the terrace sequence in the heart of Excavation I Ngandong, as shown in scans of two prints from Oppenoorth's photograph album. D is an enlargement of the area of the red box in C. The geological assistant is seen in B cleaning sand- and fine-gravel away from a large fossil, perhaps bones that were articulated. The fossil bed is below a white-Layered unit with lenticular bedding (see also Figure 10B). The prints are annotated "October 1932" and "Ngandong Ic oct 32;" an Oppenoorth lantern slide of the full scene is labeled "Ngandong Ic, block 9, 1.4., October 1932" (Ngandong Ic bl.9 l.4. oct.32.).

the outlines of excavation units were surveyed with a transit by the field personnel. The surveying must have begun at the start of operations in 1931, because the topographic mapping of the original terrace surface includes areas excavated away in that year. The surveying results presumably were passed on periodically to headquarters. Judging by ter Haar's statement, Samsi and Panudju also prepared sketches of the excavations that were sent to Bandung as part of the weekly correspondence. From these documents and surveying data, the headquarters personnel should have been able to track the progress of field operations and to know the provenience of fossils being sent in to Bandung from Ngandong.

The dig began with excavation blocks oriented parallel to the long axis of the main terrace remnant and along the south Getas path, where ter Haar had discovered the site in August 1931. By May 1932, several concurrent sets of units were being dug, and a sequence of blocks, which were aligned in long rows, had been started (see Figure 6C). For example, a total of 38 blocks were dug in an organized- and apparently-pre-determined pattern over 14 months on the east side of the excavations (see Figure 8B). About 60% of the monthly blocks of Excavation I Ngandong covered 20–50m^2.

These field protocols produced long excavation walls along which the details of the terrace stratigraphy should have been traceable. For example, when Oppenoorth paid a visit to Ngandong in August 1932, there was a ~70-m-long wall for him to examine in the middle of the northern half of the main remnant (assuming the field crew had not systematically backfilled along the long wall; see Figures 6C and 8B). In both August and October 1932, he apparently also saw a transverse wall extending from the middle of the deposit to its western edge. Ter Haar (1932) presumably examined much of the same wall in June 1932. Von Koenigswald probably would have had other long-wall exposures when he arrived in November 1932. By mid-1933, a geological section of the full ~110m length of the main terrace remnant apparently had been exposed (see Table 4; see Figure 8C). However, none of the geologists visited the site at this time.

The concentration of fossils in the basal beds and the modest rate at which fossils were unearthed would have allowed considerable care to be given to recording the location of each prominent fossil. Site photographs appear to capture this procedure in action. Figures 10B and 11A show fossils cleaned and positioned on pedestals. Paper tags are seen at fossils in the photographs (see Figures 11A and Figure 13 below). We acknowledge that photographed scenes may not be fully representative of excavation conditions. All of the photographs we have appear to have been taken when headquarters personnel were visiting. None are known to have been made by the field supervisors who apparently had not been issued cameras.

Oppenoorth (1936: 400, translated) specified that *"a register of the finds was maintained with* [sequential discovery] *number, date and number of the Layer"* for each entry. Handwritten labels are seen affixed to specimens that von Koenigswald (1933b) photographed for publication in 1933. Old labels are found on the fossils still in the GRDC collection. The labels have a standard format–sequential number, date of discovery, location within the excavation, and discovery stratum. The stratum designations apparently employed the Oppenoorth Layer (*"laag"*) scheme (see Table 3; see Figure 3B). The same information was recorded in the Register, and may have been written on the paper tags placed on fossils exposed on excavation floors (see Figures 10 and 11; see Figure 13 below). The Ngandong Fossil Register was likely to have been similar to the listing that the Survey produced for the vertebrate fossils found during early 1936 in the Mojokerto district (Huffman et al. 2005; see especially their figure 8).

Based on foregoing evidence, we conclude that each Ngandong vertebrate discovery (or in some cases, co-occurring groups of specimens) were recorded with the following data: (1) sequential, date-ordered number, (2) date of discovery, (3) excavation block of the find, (4) discovery bed, and (5) anatomical element and/or taxonomic identity in the case of important fossils. No notations of surveying readings, taken from block corners or other reference points, were included in this data set. Nonetheless, if the Survey method was carried out precisely and systematically, it would have provided reliable general geographical and geological provenience information.

Procedures such as these had been practiced in Java since the Trinil excavation of Dubois in the 1890s and Selenka in 1907–1908 (Selenka and Blanckenhorn 1911; see also de Vos and Aziz, 1989, and Oppenoorth 1907, 1911). Oppenoorth (1911: XXXV, translated) recounted the removal- and recording-practices followed when he was the excavation supervisor at Trinil:

> *When a worker hit a bone, he immediately stopped digging and called one of the preparation people who in turn called the European supervisor who was present. The latter then gave the worker a* [paper] *ticket on which was noted the sequential number, the Pit, the Layer, the quadrant, the date, and in the case of elongated pieces the orientation. This ticket was later laid in the basket together with the fossil after it was wrapped in Chinese paper to keep the pieces together, and this was transported to my residence for further preparation.*
>
> *The same number in the basket was also marked on the chart with the Pit's ground grid, which was handed to the supervisor each morning, so that I could correctly enter the information in the diary notebook, such as where and in which Layer a particular fossil had been found. Both pits were subdivided into a square grid. This was numbered in the longitudinal direction and lettered in the perpendicular direction. The supervisor was not allowed to throw a single find away, even when it appeared that it had absolutely no value.*

If one substitutes Samsi and Panudju for the *"European supervisor"* and Register for *"diary notebook,"* this account appears to be closely parallel to the procedure that Oppenoorth set up at Ngandong.

FIELD PERSONNEL

We have no biographical information on Samsi and Panudju. Men in their positions (known at the time as mantris) were trained in surveying, geology, and paleontology to perform various supporting roles in the laboratory and field, and normally served full careers with the Survey (Huffman et al. 2005). Samsi and Panudju would have had several years of previous Survey experience in junior positions before being given the Ngandong supervisory assignment. Oppenoorth (1936: 400, translated) referred to the men as *"young natives, who had been in training to become mantris."* Four other Survey geological assistants worked at Ngandong for a total of 149 days (see Table 4). The great majority of the labor needed for conducting the operations evidently was provided by men hired specifically for the effort with the geological assistants serving as site managers.

Although we cannot have a satisfactory understanding of how well Samsi and Panudju reported on the stratigraphy exposed in Excavation I Ngandong without their field records, which have not been located, we can point to several aspects of the site stratigraphy that should have allowed them to accurately report on the field relationships, even if their overall understanding of geology was rudimentary. First, only one stratum in the terrace deposit was densely fossiliferous—Layer 2/II, the thin unit at the base of the formation, and the reputed *Homo erectus* bed (see Table 3; see Figure 3B). Second, the fossils from the bone-rich interval typically were encased in a carbonate-cemented volcaniclastic sandstone and fine conglomerate which was less prevalent higher in the stratigraphic succession (Oppenoorth 1932b, c, e, f; von Koenigswald 1933b). As a result, the basal-bone-bed fossils should have been readily distinguishable in both the field and laboratory from those originating in younger strata lacking the carbonate cementation. Third and most importantly, there was a marked lithological contrast between the sub-horizontal terrace deposits, which were 2–3 meters thick in the middle of the terrace remnant, and the underlying bedrock, which is well lithified and structurally dipping marl (see Table 3; see Figures 3B and 7). For this reason and because the unconformity dips only 1-2°, it furnished an easily traceable base beneath the fossiliferous bed. The unconformity had a slight northward tilt (ter Haar 1934b), lowest in elevation at the northeastern tip of the main remnant, 1–3 m higher along the eroded sides, and several meters higher yet near the southwestern edge (see Figure 6A).

GEOLOGISTS

Because we depend so substantially on the accounts written by Oppenoorth, ter Haar, and von Koenigswald, it is important to understand their technical backgrounds and personal histories in 1930–1936.

Ir. Willem Frederik Florus Oppenoorth (1881–1965) was born in The Netherlands, and graduated from Delft Technical University (Technische Hoogeschool Delft)—as did most Survey geologists. Publications spanning 30 years and his long record at the Survey demonstrate wide-ranging technical abilities and interests (Oppenoorth 1907–1937; Oppenoorth and Zwierzycki 1917). Oppenoorth published seven articles on Ngandong in 1932, an impressive accomplishment for the manager of the still ambitious Java Mapping Program. This was a time when E.C. Ch van Hulst-Oppenoorth, Oppenoorth's daughter, who was 18 years old at the time, remembers that her father brought home *"a lump of mud"* containing one of the *Homo erectus* fossils, and cleaned it on an unused table in the family home before completing the task at the Museum (Joke Oppenoorth, pers. comm., 2007).

After Oppenoorth (1932a–f) had disseminated the news of the Ngandong discoveries around the world, he retired from the Survey and left Java at a point when the Ngandong project was still ongoing. As a consequence, he had much less information on the 1933 results than on those of 1931–1932. Oppenoorth's official retirement date was July 31, 1933 (De Mijningenieur 1933), although it is not clear exactly when he left Java (Joke Oppenoorth, pers. comm., 2007). Dr. Jozef Zwierzycki assumed responsibility of the Java Mapping Program (Zwierzycki 1933–1935), perhaps leaving a gap in the management of Ngandong excavation during the first half of 1933 when no Survey geologists visited the site. General conditions at the Survey did not improve in late 1933. There continued to be reshufflings of the job assignments of Survey geologists, as well as changes higher up in the bureaucracy to cover priority assignments with a reduced work force (Zwierzycki 1933–1935; see also Huffman et al. 2005).

The Indies government may have been motivated to retire Oppenoorth by a need to eliminate higher-paid civil servants from its payroll. Salaries of personnel and program budgets already had been reduced. *"Steps to combat the Crisis"* had hit Indies professionals as early as July 1931 with a 10% salary reduction, 3½% crisis charge, 3½% loss of location bonus, and reduction in field bonuses (A.I.D. Preangerbode 1932a, translated). Oppenoorth also had compelling personal reasons for wanting to return home. His 22-year old son had already left for school in Holland, his 20-year-old daughter and 17-year old son wanted to study there, and most importantly, his wife was so ill that her life was at risk by staying in the tropics (Joke Oppenoorth, pers. comm., 2007).

Oppenoorth's interest in Ngandong did not end with his retirement. He hoped to continue research on Ngandong after retiring. He made a formal request to export the human fossils to The Netherlands for study, but after some controversy, the materials were placed in the hands of Professor W.A. Mijsberg, Department of Anatomy, Medical Faculty, Batavia (Zwierzycki 1933–1935). He kept the specimens from 1935 to 1942, when they were returned to Bandung during the Japanese occupation (Jacob 1967; Shipman 2001). Mijsberg never published an anthropological analysis of the collection, despite high expectations for his *"expert judgment"* (Adam 1936: 113, translated) and confidence that he would *"publish them when he has time"* (Movius 1938a: 23).

With the originals of the human fossils out of reach, Oppenoorth focused on studying the Solo River valley artifacts. In 1935 or 1936 he submitted an article on *"The Tools of Homo soloensis of Ngandong"* to *L'Anthropologie*, but the paper was rejected (Oppenoorth n.d.—1935/1936: 1, translated). Oppenoorth (1936, translated) then published a paper entitled *"A Prehistoric Cultural Center along the Solo River"* in the *Journal of the Royal Netherlands Geographic Society*. After he submitted a contribution to the 1937 International Symposium on Early Man in Philadelphia, Oppenoorth (1937) felt that his retirement had put him too far out of the mainstream to pursue the research on Ngandong or even attend the conference in the United States (Joke Oppenoorth, pers. comm., 2007). Oppenoorth never returned to Java, but thankfully preserved a photographic album, a collection of lantern slides, and other documents relating to his experience there.

Oppenoorth was well qualified to determine the stratigraphic context of the *Homo erectus* discoveries. A graduate of the premier technical university in The Netherlands, he had gained much Indies experience in the field after working for the Selenka expedition at Trinil in 1907. He surely visited his own Solo Valley excavations before the October 1931 field trip, acquiring understanding of the range of lithological and stratigraphic conditions present. He had risen to a high-level managerial position in the Survey, where field geology was the most highly valued technical skill, and he was in charge of the Survey's most important field-mapping program. In taking personal charge of Excavation I Ngandong in 1931–1932, Oppenoorth did the field assessment of Ngandong I–III (Ng 1–4), and evaluated the context of Ngandong V (Ng 6) while the fossil was still *in situ*.

Ir. Carel ter Haar (1894–1936), the site discoverer, is the least known of the three geologists involved in Ngandong. Born in South Africa and raised in The Netherlands, he graduated from Delft Technical University as an Ingenieur (Harting 1936). He served fifteen-years as a geologist with the Survey, five in remote mining-exploration assignments and the remainder at Survey headquarters in Bandung. Before discovering the Ngandong site, ter Haar had mapped and described vertebrate-bearing deposits in Central Java, producing a still-important quadrangle map and report of the area (ter Haar 1929, 1935). He had a particular interest in sedimentary petrography (ter Haar 1934a), but his Survey work in the 1930s was mostly geological mapping. Simply put, Survey geologists with ter Haar's tenure in the Indies were competent field men, however sophisticated their academic knowledge might have been.

Although he discovered the Ngandong site, ter Haar visited the excavation only once while it was underway—in June 1932 (see Table 4; see Figure 8B). His knowledge of the operations and geological details otherwise must have come from his colleagues' reports and personal communications. In August of 1932, ter Haar gave a presentation on *"The Homo Soloensis — A new primitive human from Java"* (Bataviaasch Nieuwsblad 1932, translated). In January 1934, with Ngandong operations just finished and Oppenoorth retired, ter Haar gave a second public lecture on Ngandong. This presentation became his one publication on the site (ter Haar 1934a). Ter Haar (1932, 1934b, translated) also wrote critically valuable Survey reports on the discovery of Ngandong VI (Ng 7) and the excavation summary, *"The Ngandong Terrace, Report on the Discovery, Excavation and Geological situation evident there."* At the same time, he (1934c) wrote about the archaeological reserve (Dutch: Natuurmonument) at Ngandong but we have not located the document.

Oppenoorth was in Holland and unavailable to ter Haar when he prepared the excavation summary. Ter Haar was living in the Netherlands when Oppenoorth wrote his 1936 and 1937 Ngandong papers. Oppenoorth (1936, 1937) does not mention collaboration, nor even cite ter Haar's (1934a) publication, so that the two former colleagues apparently were not in communication while both living in The Netherlands. Ter Haar (1934a) had ideas on the terrace stratigraphy of the Solo River area in general that Oppenoorth would have found hard to accept (Zwierzycki 1933–1935). However, there had been a year's overlap in the time between ter Haar's June 1932 fieldwork and Oppenoorth's departure from the Indies, so that the two geologists would have had ample time to discuss provenience of the discoveries of Excavation I Ngandong. Illness prevented ter Haar from publishing more on Ngandong. In the same year he gave his public lecture, produced his only publication on Ngandong, and wrote the key unpublished reports about the site, he was forced by tuberculosis to return to Holland where he died in 1936 at the age of 42 (Harting 1936).

Dr. G.H. Ralph von Koenigswald (1902–1982) began work at the Survey on January 23, 1931. He had received a doctorate at the University of Munich three years earlier (see Huffman et al. 2005, and Tobias 1976, 1984, 2005 for biographical accounts). His arrival in Java was just seven months before ter Haar found the Ngandong site. Von Koenigswald was hired to bolster paleontological dating of the non-marine formations being mapped by the Java Mapping Program, an objective he largely fulfilled over the course of his first four years in Java (von Koenigswald, 1933a, 1934a–c).

Von Koenigswald's position at the Survey initially did not involve him in field studies. This difference represented a prominent contrast between his work and that of the rank-and-file Survey geologists such as ter Haar (see Huffman et al. 2005, regarding of the work of another Survey field geologist). There were other factors of contrast—for example, von Koenigswald's advanced level of education, his German citizenship, and a specialized role at the Survey. The situation permitted von Koenigswald to publish on wide ranging topics, some quite esoteric (von Koenigswald 1931a, b, 1932a, b, 1933a, b, d, 1934c, d), while his colleagues were focusing their efforts on writing internal reports directed toward proximal, often practical Survey objectives. Von Koenigswald appears to have placed academic aspirations over bureaucratic ones, while most other geologists aimed at 25-year Survey careers marked by promotions up the Bureau's multi-tiered and competitive organizational chain toward a pensioned retirement. Oppenoorth and Zwierzycki had followed this career trajectory with a high degree of success. Finally, while most of his European co-workers were married with children, von Koenigswald was single in the early 1930s.

Von Koenigswald analyzed the non-hominin fossils collected from Ngandong in the fall of 1931 as a contribution to Oppenoorth's (1932b) paper on *Javanthropus* and photographed the hominin specimens for his supervisor (von Koenigswald 1956). Oppenoorth sent von Koenigswald with ter Haar to the site on June 19–24, 1932, for the recovery of Ngandong VI (Ng 7; ter Haar 1932). Von Koenigswald did not return to the site for 16 months, but this was a period when the only hominin fossils recovered were the two human tibiae (see Table 1; see Figure 8C). In January 1933, von Koenigswald (1933b, translated) published an academic book in Java, entitled *"Contribution to the Knowledge of Fossil Vertebrate Animals of Java."* While not focusing on Ngandong *per se*, this work included much significant information on the provenience of non-human fossils from Ngandong, as well as photographs of many specimens. On July 19, 1933, von Koenigswald submitted a paper for publication in Germany on the physical anthropology of Ngandong I–V (Ng 1–6), including discovery dates and Register numbers for the *Homo erectus* fossils.

Relations between von Koenigswald and Oppenoorth might not have been smooth during the years when they worked on Ngandong. Von Koenigswald (1956: 69) seems to have taken exception to Oppenoorth's strong proprietary attitude toward Ngandong, recalling 30 years later that *"we hardly saw anything of the finds"* while Oppenoorth was working on them. Antipathy directed towards Oppenoorth partially could explain the criticisms that von Koenigswald (1934b: 1–2, translated) leveled at his former boss' management of the Solo Valley excavations:

> *"The activities of this author, under the supervision of the leader of the Java Mapping Program at that time, Ir. Oppenoorth, were almost exclusively restricted to determination* [of the faunal composition] *and he was not permitted to personally visit the discovery sites, resulting in added difficulties in his work, because of the inaccurate information on the circumstances under which the discoveries were made. This made it almost impossible to obtain a precise evaluation of the stratigraphic problems, but under the leadership of the new chief of the Java mapping program, Dr. Zwierzycki, collaboration with the geologists was allowed to take place as best as possible. And so, this author was able to personally view the profiles and visit the discovery sites. A visit was made in September 1933 to the excavations near Ngawi and again in November, at which time also a visit was made to Mojokerto"*

However, other evidence indicates that von Koenigswald was not especially concerned about the exact provenience of fossils (Huffman et al. 2005). The quoted statement nonetheless highlights the short-comings in Survey management of Excavation I Ngandong which both limited the Survey geologists' first-hand knowledge of the discovery contexts and circumscribes what we can possibly determine about the contexts today.

Von Koenigswald apparently communicated his complaints about Oppenoorth's management of Excavation I Ngandong to close associate Dr. P.V. van Stein Callenfels (1940: 96–97; see also, Adam 1937, von Heine-Geldern 1945, and Jacob 1967), who then stated inaccurately, *"the excavations at Ngandong and other places in 1931/1933 were carried out in a very unscientific way, their supervision being left to native surveyors* [geological assistants] *who were quite ignorant of prehistory, palaeoanthropology and prehistoric research methods."* Von Koenigswald also appears to have passed on his animus towards Oppenoorth to American archaeologist Hallam Movius, a visitor in 1938 (see below), who noted that Oppenoorth had been *"jealous of everyone"* and was *"kicked out* [of the Indies] *by authorities,"* based on conversations with von Koenigswald and others.

None of the Survey geologists, not even Headmantri Dramoh, went to Ngandong in early-middle 1933. One geological assistant spent 49 days there in February, March, and June 1933 (see Table 4), but this apparently was a training exercise and brought no special expertise to the operation. The inattention of headquarters may have stemmed from the transition in management of the Java Mapping Program from Oppenoorth to Zwierzycki, as well as the worsening financial conditions in the Indies during the Great Depression.

Dr. Jozef Zwierzycki (1888–1961) did bring his own academic strengths and long-Bureau experience to the Ngandong project, but there is little evidence that he took a personal interest in Ngandong. He did not visit the site until July 1934, months after the excavations had ended (Zwierzycki 1933–1935). Born in western Poland (at Krobia), Zwierzycki was trained at the Berlin Mining Academy (which later became the Technische Universität), and received a doctorate from the University of Berlin in 1913, completing a thesis on *"The Cephalopod beds in German East Africa"* (ARSIF—Zwierzycki n.d.; Piatkowski 1962; Westerfeld 1961: 664, translated). Zwierzycki's limited employment prospects made his joining the Mijnwezen attractive. He proved a hardy trekker and skilled geologist in the tropical forests of Sumatra and New Guinea before becoming the Leader of the Sumatra Mapping Program in 1928–1933 and then assuming the equivalent position over the Java Mapping Program.

The situation in Java during 1933 put Survey leaders like Zwierzycki under increasing pressure to produce economically relevant results. High-science projects such as the Solo River excavation program were at risk. Indeed, Zwierzycki had to defend the Java Mapping Program for its very existence, after having watched his own Sumatra research program terminated (Huffman et al. 2005; Zwierzycki 1933–1935). To garner support for Java mapping, he stressed application of the Program work to the petroleum industry, something that he could not claim for the Solo River excavations. Ngandong was closed down at the end of 1933. From August to December, the pace of digging at the site increased, apparently in anticipation of the upcoming termination of operations (see Figure 8A), so that Zwierzycki may have made the decision to end Excavation I Ngandong immediately upon assuming leadership of the Java Mapping Program in July 1933.

Late 1933 was a busy and productive time for von Koenigswald, but one that also brought distressing news about his Survey career. He was deeply engaged in preparing internal Survey reports and a series of publications on the mammalian faunas of Java, the main reason he had been hired by the Bureau (von Koenigswald 1934a–d, 1935a–e; see Huffman et al. 2005 for review of his 1936 publications). The biostratigraphy he erected included the Ngandong Fauna. It was based on fossils found in the terrace deposits of the Solo River valley generally, not just those excavated at Ngandong. At the end of December 1933–just days after the end of Excavation I Ngandong—von Koenigswald received a letter informing him that, despite many accomplishments, his Survey position would be terminated in May 1934. The reason given was that the *"last remaining Germans are all leaving;"* his dismissal ultimately took place at the end of 1934 (ARSIF-von Koenigswald n.d.; Zwierzycki 1933–1935, December 1933, translated).

Von Koenigswald's departure was only one of the changes at the Bureau. The higher-ups jockeyed to save their positions in the face of department consolidations, and lower level personnel were not spared; 65 mantris, fossil preparators, and laboratory staff once had been employed by the Sumatra and Java Mapping Programs, but a mere 16 remained by the end of 1934 (Zwierzycki 1933–1935, letter dated January 8, 1935).

The Survey was no longer capable of conducting an excavation such as Ngandong or analyzing a great number of vertebrate fossils. Within a year after the end of the Ngandong operations, Oppenoorth and ter Haar were in The Netherlands, and von Koenigswald had been dismissed. The Ngandong *Homo erectus* specimens were not in the hands of either Oppenoorth or von Koenigswald, but rather had been transferred to an uninterested Mijsberg. The fate of the remaining ~25,000 specimens is unclear. Those not saved for special reasons by von Koenigswald are missing, apparently discarded decades ago.

Von Koenigswald continued to work in Java after his dismissal. He had a contract for part-time work at the Survey in 1936 to analyze the paleontological collection and hominin discovery from Mojokerto (Huffman et al. 2005). He regained his Survey post in July 1937, thanks in large measure to four years of persistent advocacy within the Bureau hierarchy by Zwierzycki (ARSIF-von Koenigswald n.d.). Von Koenigswald's rehiring came after he had made a highly beneficial tour of Europe, the United States, and China, during which he attended the International Symposium on Early Man at the Academy of Natural Sciences

Philadelphia in March and obtained the financial support from the Carnegie Institution (Huffman et al. 2005; von Koenigswald 1937b). However, when he arrived in Java in mid-1937 to take up his new Survey position (as a geologist rather than paleontologist), his paleoanthropologic research was sent into a new direction with the discovery of *Homo erectus* fossils at Sangiran Dome. Before his return to Java, von Koenigswald had intended to include a search for stone tools in the terraces along the Solo as part of the research sponsored by the Carnegie Institution, Washington, D.C. His (1937a: 4) proposal had stated:

> *From the upper-pleistocene river terraces along the Solo river, where in Ngandong the remains of Solo man had been found, only a few implements are known. Research for new sites and more implements is necessary.*

By 1938, however, with *Pithecanthropus* cranial fossils coming out of Sangiran Dome, von Koenigswald was focused entirely on the new finds, not those made at Ngandong four to six years earlier. In April, he accompanied Helmut de Terra, Pierre Teilhard de Chardin and Hallam Movius to Sangiran, Ngandong, and other eastern Java sites (see Table 4). His guests accepted his conclusion that the *Homo erectus* discoveries at Ngandong originated in the basal beds of the terrace deposits, although no details of what the visitors saw at the site have survived (de Terra 1943; de Terra et al. 1938; Movius 1938a, 1944, 1948).

Zwierzycki returned to Poland in 1938 as a Bureau retiree. *"During the destruction of Warsawa* [in World War II]*, Zwierzycki lost his house and all documents that he had kept about his Indies period, as well as his library;"* these losses were only part of very difficult wartime experiences for him because he spent a year in Auschwitz before being reassigned as a prisoner to do geological work in Berlin, and then escaped in 1944 while being moved back to Poland (Westerveld 1961: 229, translated). After the war, he resumed his academic career, in 1948 becoming a Professor of Geology at the University of Wroclaw, near his home province.

When the Japanese occupied Java in World War II, von Koenigswald was imprisoned also. After the War, he escaped the continuing chaos of Java, where the fight for Indonesian independence from The Netherlands had broken out. He went to New York City, and then back to Europe. He played a pivotal role in the history of physical anthropology by borrowing the Ngandong, Sangiran Dome, and Mojokerto *Homo erectus* specimens from the Bureau and carrying them to New York City for joint studies with the eminent human anatomist and steadfast von Koenigswald friend, Dr. Franz Weidenreich. Weidenreich (1951) died while writing a monograph on the Ngandong hominin fossils. Von Koenigswald returned to Indonesia only once during the rest of his life (Tobias 2005).

Von Koenigswald (1956) wrote a 14-page account on Ngandong in *"Meeting Prehistoric Man"* that reveals several significant results which were not published elsewhere. In the 1960's and 1970's he again facilitated anatomical studies of the Ngandong fossils. First, while the specimens were still at the Geological Institute, Utrecht, he directed the doctoral research of Teiku Jacob (1967) of Gadjah Mada University. Then after von Koenigswald had moved in retirement to the Forschungsinstitut Senckenberg, Frankfurt, he made the Ngandong material available to the American doctoral candidate, Albert P. Santa Luca (1977, 1978, 1980). By this time, von Koenigswald had lost his strong personal interest in the Ngandong hominin discoveries, and related little of his first-hand knowledge on the Ngandong history and geological context to Santa Luca (A.P. Santa Luca, pers. comm. 2007). With Santa Luca's project finished, von Koenigswald returned the Ngandong hominin remains to Indonesia in 1978, where they still reside at the Laboratory of Bioanthropology and Paleoanthropology, Gadja Mada University Faculty of Medicine, Yogyakarta (Java; Balzeau et al. 2003).

In summary, Oppenoorth, ter Haar, and von Koenigswald did not spend enough time at Ngandong to witness the discovery of most of the *Homo erectus* fossils, and saw only a small fraction of the non-hominin remains *in situ* (see Table 4; see Figure 8C). To prepare their reports and publications on the finds, the geologists relied on their brief examinations of the site, a set of field systematic procedures, the records kept by Samsi and Panudju, and whatever oral communications these and other geological assistants provided. In view of this history, we adopt a cautious attitude towards accepting generalizations reported about the hominin discoveries, while also recognizing that we have no greater authority on the finds than the three geologists who oversaw Excavation I Ngandong. Our analysis therefore tests the reasonableness of the reported provenience of each *Homo erectus* specimen against various other records available to us. We focus on the issue of the basal-bone bed context attributed to the fossils.

PROVENIENCE

NGANDONG I–III

The first *Homo erectus* was unearthed on September 15, 1931, only three days into the formal excavation. Two more discoveries were made during the first month of operations, one human specimen for every 100 vertebrate fossils excavated. Samsi, who was the on-site supervisor during this period of time, had not recognized any of the three discoveries as human, but did record Ngandong I and II (Ng 1–2) on the Register as a tiger-skull fragment (*"potongan kepala harimau"* in Malay) and an ape-skull fragment (*"potongan kepala kera"*), respectively (ter Haar 1934b: 5, translated). Samsi probably paid very special attention to the provenience of the two discoveries, as well as their taxonomic identification, because both taxa are rare as fossils in Java, and he could have assumed reasonably that Oppenoorth and von Koenigswald would be highly interested in the geological circumstances of the finds.

Oppenoorth had been forewarned that a significant fossil would be part of the October 14 shipment he received in Bandung. Dramoh, the lead geological assistant for the Survey, had seen the Ngandong collection in a field storage facility at Watualang and wrote Oppenoorth a letter, dated

September 28, stating that *"1 rounded skull fragment seems like a tiger skull, but is broken at the front of the animal skull"* (ter Haar 1934b: 5, translated; the letter was sent two days before Ngandong II, Ng 2, was found). When Oppenoorth realized on October 19 that the *"tiger"* and *"ape"* were actually human, Excavation I Ngandong became more than a source of paleontological information, and now represented the first human fossil site to be discovered in Java in over 35 years. Oppenoorth had dreamed of such an event for decades (Shipman 2001).

Oppenoorth left Bandung for the Solo Valley sites on October 21, just two days after identifying Ngandong I and II as hominin. He found the third human specimen in the Survey's field-collection shed at Ngandong on October 23 or 27, the specific date being different in two sources (ter Haar 1934b; Oppenoorth, 1936). Ter Haar (1934b: 5, translated) recounted the events this way:

> *October 19, 1931: Arrival in Bandung of the cases with Ngandong I and II. Unpacked and recognized as human remains by Ir. W.F.F. Oppenoorth. October 21-30, '31: Trip to the Solo valley by Ir. W.F.F. Oppenoorth; Ngandong III was found on the shelf in the shed at Ngandong on October 27 and not in situ, since according to Oppenoorth's own notations, this fossil had been found two weeks earlier (i.e. October 13, 1931). Ngandong III was apparently packed separately, hand carried to Bandung and there registered under No. 272a in the Duplicate Ngandong Fossil Register by the Chief of the Java Mapping Program (i.e., Oppenoorth).*

Oppenoorth (1936: 401, translated) had found a *"rounded lump"* of *"cemented lime and gravel,"* and two *"saucer-shaped"* pieces in the shed.

Pieces of the calotte are missing from Ngandong III, which strongly suggests that some hominin material went unrecognized and was discarded in the field. Excavation loss in Ngandong III (Ng 3) probably includes the missing interval between the mastoid and superior temporal bone, and the triangular, blunt-edged missing piece in the occipital (see Weidenreich 1951: Plates 20A and 20C). The breakage of the occipital includes cracks which extend far into the preserved bone. The loss of fragments during excavation may obscure the presence of peri-mortem injury to the individual (for example see the fracture pattern in Figure 2 of Boylston 2000).

Ngandong III was determined to include the probable remains of a fourth human fossil fragment when further laboratory preparation was done at the American Museum of Natural History in 1947 (von Koenigswald 1951; Weidenreich 1951). Evidently the presence of the fragment had been obscured during the Survey's preparation by carbonate-cemented sandstone and fine-grained conglomerate matrix. Ngandong I–III thereby came to include Ng 4, and the 13 specimens recovered in the 1930s thereafter were often thought of as the remains of as many as 14 individuals (see Table 1). Ng 4 was identified as the sphenoid angle of a right parietal by Weidenreich (1951), a *"piece of the sphenoid angle of the parietal"* by Jacob (1967: 9), a *"r*[ight] *parietal fr*[agment]" by Indriati (2004), and the *"posterior part of a left squamous temporal"* by Santa Luca (1980: 18). Von Koenigswald (1951: 215) noted that Ng 4 *"certainly belongs to a different individual."* Weidenreich (1951: 231) reported that *"a small piece of bone…was attached to the right side* [of the main piece, and he]*….decided not to attach it* [to the other calvarial specimen]*."* Jacob (1967) concurred with recognition of the second individual. Others have been more circumspect, while also not refuting the contention that two individuals are represented (*"probably…another individual,"* Santa Luca [1980: 6]; *"treated as separate,"* [Rightmire 1990: 41]). Given the history of the Ngandong III discovery, it is quite plausible to speculate that additional material from the Ng 4 individual was missed during excavation.

Oppenoorth investigated the stratigraphic context of Ngandong I–III (Ng 1–4) on October 27, using the outcrops bordering the ~150m^2 excavation that was then open (see Figures 6C, 8D, and 9B; Huffman et al. 2008a, b). To better manage the excavations he replaced Samsi with geological assistant Panudju, effective November 1, and arranged to set up a permanent camp at Ngandong (ter Haar 1934b). Oppenoorth (1932b) finished his manuscript naming a new hominin species, *Homo (Javanthropus) soloensis,* by the end of 1931, only two months after returning from the field (but before the January discovery of Ngandong IV, Ng 5). Ngandong I (Ng 1) was his holotype. Ngandong I–III (Ng 1–4) was the hypodigm. He (1932b: 62, translated) attributed all three human finds—as he did all of the first ~3,000 non-hominin fossils from his *"systematic excavation"*—to a bone-rich interval lying within ~0.7m of the base of the terrace deposits (see Table 3; see Figure 3B).

The validity of this stratigraphic framework, which is still the standard for the site, is the central provenience issue for Ngandong I–III (Ng 1–4). On the basis of the evidence we present below, Oppenoorth had a solid basis for his determination of the discovery context, despite not having seen any of the three human specimens *in situ*. In brief, he had set up the systematic excavation and documentation procedures; the stratigraphic situation at the site was generally straightforward; and, the bone-bed matrix on the fossils had a distinctive lithology. Each of these three evidentiary points is addressed below.

Samsi and the field crew evidently followed normal Survey practices from the beginning of Excavation I Ngandong. Digging was done in rectilinear pits oriented parallel to the long axis of the main terrace remnant (see Figure 6). Fossils were entered into the Register. Each specimen or related group of fossils found in September 1931 received a sequential, date-ordered number. Recording provenience data was presumably already a continuous process in which specimens of substantial size were documented separately. Samsi was mapping the unit boundaries and original surface topography with a transit as the field crew moved from one excavation block to the next. This is clear because the unit boundaries and surface topography from September and October 1931 are shown on the Site Map in areas that were later excavated away. Samsi also evidently was reporting (as Oppenoorth, 1932b, published) that all of the fossils were being found in a basal-bone bed.

Oppenoorth presumably had the field records available to him when he arrived at Ngandong on October 27 to examine the discovery points of Ngandong I–III (Ng 1–4). Dramoh had joined him on the field trip, providing better communications with the native men on the crew. We cannot tell whether the workmen had excavated away all of the basal-bone-bear bed from the area opened up by October 27. This would have left Oppenoorth with nothing of the discovery strata except what he could see in the sidewalls of the pit.

Even if the peripheral outcrops were all that remained, however, the stratigraphic context appears to have been closely constrained by the remaining exposures. The discovery points for Ngandong I–III (Ng 1–4) were within 2.5m of then-existing walls, judging from the Site Map (see Figure 6C). The Ngandong I (Ng 1) point was just 1.5m from a wall of its ~25m^2 discovery unit. Three excavated walls evidently were within 2.5-4.0m of the Ngandong II (Ng 2) discovery point, which was in a ~30m^2 unit ~17m south of the Ngandong I (Ng 1) location. Less than ~53m^2 of excavation had been open when Panudju recognized Ngandong II (Ng 2) as an ape-skull fragment, and only 100m^2 more had been excavated by the time that Oppenoorth arrived. Ngandong III (Ng 3–4) reportedly was found adjacent to the west wall of the ~90m^2 October pit (see Figure 6C). The area beyond this wall produced Ngandong VI (Ng 5) in January 1932, and a fresh excavation face probably was present very near the Ngandong III (Ng 3–4) discovery point when Oppenoorth arrived. Ngandong II (Ng 2) had been found only ~4m away from Ngandong III (Ng 3–4) discovery point, which in turn was only ~5m from the place where Ngandong IV (Ng 5) would later be discovered.

Even assuming that Samsi failed to pay attention to provenience details in September and October, we would be more concerned about the provenience record of Ngandong III (Ng 3–4), which he had not noticed was especially valuable material, than that of Ngandong I and II (Ng 1 and 2), which he identified as the *"tiger"* and *"ape"* skulls (see Table 2). Oppenoorth and Dramoh could have verified Samsi's work by examining the site and referring to Samsi's own notes and the Register.

In sum, therefore, Oppenoorth was presented with a straightforward geological exercise in evaluating the general stratigraphic context of Ngandong I–III (Ng 1–4). He had to check the reported provenience of the human fossils against the stratigraphy evident in the small excavation and observe the context of the fossils then being unearthed.

When Oppenoorth arrived, he also closely observed the clastic composition and cementation of the strata, details he included in his lithological descriptions (see Table 3) and published statements. He doubtless had heard in advance about the nature of the deposits from ter Haar and Dramoh, who had seen early exposures of the excavations. Oppenoorth also surely had noticed (and may have examined closely) the matrix on the fossils that ter Haar had brought to Bandung from the site in August. The lithologic variation in the terrace sequence would have allowed him to compare the matrix on Ngandong I–III (Ng 1–4) to the beds he recognized, increasing his confidence in the assignment of the finds to the lithologically distinct basal stratum present in the excavation (see Table 3).

Whatever the exact basis for his determination, Oppenoorth was specific and clear in his characterization of the geological context of the human and vertebrate finds when he wrote about Ngandong I–III (Ng 3–4) in December of 1931. He found a series of *"Layers"* totaling ~3.0m (see Table 3 and Figure 3B). We characterize his terrace-deposit sequence in the following way (from <u>bottom</u> to <u>top</u>): ~0.5m of gravelly andesitic sandstone (his Layer 2; the marl was Layer 1); then, ~0.2m of muddier volcaniclastic sandstone (Layer 3); succeeded by a second ~0.4m of gravelly andesitic sandstone (Layer 4)—bringing the total for the basal volcaniclastic strata to approximately a meter (~0.9 to ~1.2m); and finally ~2.0m of marl-clast conglomerate with volcaniclastic sand in the matrix (Layers 5 and 6). Judging from Oppenoorth's descriptions, site photographs (see Figures 7, 10, and 11), and other accounts, the lower third of the sequence was overwhelmingly made up of relatively fresh volcanic detritus. The fresh condition is indicated by the prominence of the highly labile heavy minerals mentioned in Table 3. The upper two-thirds of the sequence was a mixture of marly and volcanic sediment (see also the quotation given below under Ngandong VIII, Ng 11, from ter Haar 1934b).

As for the distribution of vertebrate fossils and the provenience of Ngandong I–III (Ng 1–4), Oppenoorth (1932b: 52, translated; our underlining) stated unambiguously: *"the fossil vertebrate remains are exclusively found in Layers 2 and 3, and primarily in the upper part of <u>Layer 2</u>, <u>where the skulls</u>* [Ngandong I–III (Ng 1–4)] *<u>also were found</u>."*

Oppenoorth's stratigraphic sequence and provenience description were reviewed in the field repeatedly during 1932–1933 by the Survey geologists. Oppenoorth (1932a–g, 1936, 1937) made his own assessment of Ngandong V (Ng 6) in March 1932. Ter Haar evaluated Ngandong VI (Ng 7) in June of that year, as discussed below (see also von Koenigswald 1933a, 1951, 1956). Although ter Haar (1932, 1934a, b) found that the basal fossiliferous bed (Layers 2 and 3) was missing in some parts of the excavation, where the strata had been cut out by erosion before the upper marl-conglomerate was deposited (see Figure 7; see Figure 14 below), Oppenoorth did not report signs of this circumstance in the area exposed on October 27, 1931. Neither did ter Haar or he ever express doubt that the human fossils came from the basal volcaniclastic context that Oppenoorth recognized during his first field visit.

Nor did Oppenoorth report evidence of historic human disturbance of the stratigraphy in the excavation exposures. The Ngandong I and III locations were situated in what had been the pathway leading south from Ngandong to Getas village (see Figure 6A). Ter Haar later reported the presence of deeply buried historic artifacts at one point within Excavation I Ngandong site east of the Ngandong I–III discovery locations (see Figures 7 and 14). Because stratification in the upper part of the Ngandong Formation was generally clear (see Figures 10B and 11B, C), there is good reason to conclude that Oppenoorth was in a position to detect any disturbance in the terrace beds, and found no indications of intrusion.

The provenience records of Ngandong I and II (Ng 1 and 2) therefore are specific, internally consistent, and unambiguous as to the geographic location of the finds (see Figure 6) and their stratigraphic position in the volcaniclastic basal-bone bed of the Ngandong Formation (see Figure 3B). In short, if Oppenoorth (or the field crew) made a basic mistake in establishing the provenience of these two discoveries, our scrutiny of the records has revealed no indication of it. As for Ngandong III (Ng 3 and 4), the quality of the provenience record is diminished by the fact that the field crew treated the find as they would have any other coming out of the excavation. This might be viewed as increasing the chances that mislabeling or poor record keeping occurred before Oppenoorth recognized the special importance of the fossil in the storage shed. Problems of this kind did affect the provenience record of the two tibiae from Ngandong, as described below.

When Oppenoorth left Ngandong in October 1931, he instructed Panudju to leave any newly found human fossils in place and cable headquarters with the news of the discovery (ter Haar 1934b). Panudju missed the next discovery opportunity, removing Ngandong IV (Ng 5) in January 1932 and shipping the specimen together with other recent finds to Bandung. Oppenoorth's luck improved about two months later when he received a telegram announcing that another human fossil, the calvaria Ngandong V (Ng 6), had been discovered.

NGANDONG IV AND V

Ngandong V (Ng 6) is among the best documented of the *Homo erectus* finds (Huffman et al. 2008a, b), following only Ngandong VI (Ng 7) in the quality of available provenience records. This is largely because Panudju recognized the specimen as human and cabled word of the new discovery to Bandung while the fossil was still in place, as Oppenoorth had requested of him (von Koenigswald 1951). And then, Oppenoorth and Dramoh personally removed the specimen from its context.

When Oppenoorth came to Ngandong for this purpose, he evidently also examined the discovery circumstances of Ngandong IV (Ng 5), the find which Panudju had not recognized as hominin before removing. We begin by describing the provenience of the second-found and better-documented of the two discoveries, because the provenience case for Ngandong IV (Ng 5) is better made having explained the documentation for Ngandong V (Ng 6).

Ngandong V (Ng 6) came to light on March 17, 1932, after six months of excavation, and was registered as specimen 7894 (ter Haar 1934b). Oppenoorth and Dramoh arrived at Ngandong on March 21, only four days after Ngandong V (Ng 6) first was exposed. The date of discovery was changed on the Register to March 21, to match the date of removal, rather than the day when Panudju recognized the find (Oppenoorth 1932e). Panudju, as well as Oppenoorth, should be acknowledged as a discoverer of Ngandong V (Ng 6).

There had been 3,401 paleontological entries added to the Register in the 52 days since the discovery of Ngandong IV (Ng 5), some 65 specimens per day, about twice the rate averaged during the total project. Digging had not yet achieved the higher pace it reached in later 1932 and 1933 (as judged by the area excavated over time; see Figures 6C and 8A). Therefore, the first quarter of 1932 was a time when either highly fossiliferous strata were being exposed, possibly around the Ngandong V (Ng 6) location, or sites other than Excavation I Ngandong were contributing greatly to the fossil count.

The find was made on the western side of the Ngandong Formation outcrop in an unlabeled excavation block, which comprised ~20m² (see Figure 6C) and sat between a block dug in December 1931 and another excavated in March 1932 (this is an area indicated on the 1934 Site Map [see Figure 6C] to be part of "Excavation I[c]"). The discovery point is ~1.1m and 1.3m, respectively, from the north and south walls of the ~2.5m x 8m discovery block. Although this leaves us uncertain as to exactly where within the unit the Ngandong V (Ng 6) wall was located when Oppenoorth and Dramoh saw the fossil (Figure 12), the geographic position of the find is closely constrained by the small size of the discovery block. This area was ~15m west of the pit that Oppenoorth had examined in late October 1931 and used as a basis for his stratigraphic standard of the site (see Table 3; see Figure 3B).

In June 1932, soon after Oppenoorth (1932c: 109, translated; see also 1932f) witnessed Ngandong V (Ng 6) in place, he reported the discovery in a local technical journal, giving the following details about the context:

> *Ngandong V….was discovered in the portion of the terrace that is adjacent to a ravine, so that the layers have been leached severely, yielding a lesser state of preservation (the bone is more weathered and much coarser than in the other skulls* [Ngandong I-IV, Ng 1-5]*)….It was possible to make a photo in situ (*[see Figure 12]*), before it was excavated by this author personally. The top of the skull was resting inversely on a gravel layer, while in the braincase a rounded marly limestone clast had been deposited, a possible cause for the broken condition.*

The published captions for the Ngandong V (Ng 6) site photographs state only that the calotte was *"mostly covered with sand"* and *"encrusted with lime-cemented sand"* (Oppenoorth 1932c: 107, 1932f: 274, translated).

High-quality prints of Oppenoorth's photographs, which we obtained from his personal photograph album, confirm the skull's inverted original orientation, the fossil's stratigraphic position <0.5m from the basal unconformity, and the volcaniclastic lithology of the discovery bed (see Figure 12). We place very high value on the corroborative implications of the photographs that Oppenoorth (1932c, 1932f) published at the time and then kept among his personal possessions for decades (see Figure 12).

The apparent lithological make up of the matrix substantiates Oppenoorth's description of the *Homo erectus*

Figure 12. Oppenoorth's March 21–22, 1932, photograph of Ngandong V (Ng 6) in situ. The full image is A, while B and C are enlarged portions of it. Scanned from one of two prints of the outcrop in Oppenoorth's photograph album. One print is labeled "Maart 32," while Oppenoorth's colorized lantern slide of this image is labeled "Profile of Skull V" (Profiel schedel V). The full image is similar in content to a photograph that Oppenoorth published (1932f: Abb 7, translated) with the caption: "The Ngandong V skull in its original position. The head is still mostly covered by sand; a matchbox is shown beside it. D = Bone bearing Pleistocene (Diluvial) terrace deposit. P = Underlying Pliocene marl" (the D and P, which are shown on the published illustration, are omitted here; see also van Heekeren 1972: Plate 20a). Elsewhere, Oppenoorth (1932c: 109, translated) noted that "the top of the skull was inverted." He (1932c, e, translated) published a less revealing photograph of the find with the caption: "The native employee is pointing at the recently discovered skull. It is encrusted in lime-cemented sand and can hardly be recognized as a skull" (see also von Koenigswald 1951).

stratum as a richly volcaniclastic deposit (see Table 3). The material surrounding the calotte consists of granule conglomerate with scattered marl cobbles and a sandy-muddy matrix; that is, the discovery bed was quite poorly sorted. No other fossils are visible around Ngandong V (Ng 6). Nor is there a concentration of cobbles seen in the photograph at the stratigraphic level of the *Homo erectus* specimen.

After Excavation I Ngandong was completed, Oppenoorth (1936: 404, translated) explained how cobbles were concentrated some places in the bone-rich interval and were missing elsewhere:

> *The fossil bones of Ngandong were…encountered in Layers 2 and 3…*[But] the separation of these two layers can *only be observed cleary when, as is often the case, a thin layer of calcareous-marl pebbles* [pebbles and cobbles] *is present, which usually occurs between these two Layers was clearly present; the lower layer is the more gravelly of the two, while the upper one is sandier. The* [human] *skulls themselves were in the upper portion of Layer 2, directly below or sometimes partly within the pebbly Layer with the concave side turned down. Both Layers contain fossil bones in large quantities, sometimes arranged in such a manner that it was difficult to say whether they belonged to Layer 2 or Layer 3.*

Only two specimens, Ngandong V and VI (Ng 6 and 7), are known from the discoverers' accounts and site photographs (e.g., see Figures 12 and 13) to have been found in an inverted anatomical position, so that Oppenoorth's 1936 statement implies that he was specifically attributing these two finds to the upper portion of Layer 2/II, despite the fact that no horizon with a concentration of marl gravel occurred in the excavation wall from which Ngandong V (Ng 6) came.

There also is no sign in the Ngandong V (Ng 6) site photograph (see Figure 12) of a break in sedimentation at the level of the calotte. We have no further description from Oppenoorth as to how clear the "pebbly layer" was elsewhere in the unit from which Ngandong V (Ng 6) was discovered. Von Koenigswald (1933c: 33, translated) wrote briefly about the provenience of Ngandong I–V (Ng 1–6), restating that all five finds had been *"found in a pebble layer which forms the boundary between Layers 2 and 3* [of Oppenoorth, 1932b]*…distributed over a surface area of about 600 m^2."*

The density of fossils from one place to the next in the basal beds was, like the distribution of the cobbles, also highly variable. Several previously unpublished photographs show that some portions of bone-rich bed contained clusters of bones whereas nearby portions had none (see Figures 11A and 13). The variability in the concentration of fossils would explain the difference between the general characteristics of the basal-bone bed (as described in Table 3, for example), and what is seen in the outcrop photograph of the Ngandong V (Ng 6) wall.

In sum, the location of Ngandong V (Ng 6), which is posted on the Site Map (see Figure 6C), and Oppenoorth's specimen photographs (see Figure 12) and previous descriptions of Excavation I Ngandong (see Table 3; see Figure 3B), substantially confirm the Survey's attribution of Ngandong V (Ng 6) to the lower, volcaniclastic beds of the Ngandong Formation, the same strata that produced Ngandong I–III (Ng 1–4).

The provenience record of Ngandong IV (Ng 5) is another matter. What confidence we have in it comes largely in knowing that the specimen was found between the discovery points of Ngandong II–III (Ng 2–4) and Ngandong V (Ng 6), excavations that Oppenoorth investigated closely (see Figure 6). Ngandong IV (Ng 5) came to light on January 25, 1932 (Oppenoorth 1932c) in the midst of the rainy season. At that time, a total of ~3,500 fossils had been collected from Ngandong with 3,221 Register entries having been made since Ngandong III (Ng 3–4) was unearthed 104 days before (see Table 1). The average rate of Register entry had been 31 per day, about average for the dig overall. However, the November to January fossil-discovery rate was higher than it had been during September and October 1931, while the excavation rate continued at its earlier slow pace (see Figure 8A). The field crew must have been encountering richer fossil beds, collecting more of the fossils encountered, or registering substantial amounts of material from beyond the limits of Excavation I Ngandong.

Ngandong IV (Ng 5) was *"sent to Bandung together with other fossils"* (ter Haar, 1934b: 5, translated) with Panudju having attached no particular significance to the discovery. No details are reported on who recognized the fossil as hominin or when exactly in early 1932 this occurred. Oppenoorth's paper (1932b) on *Homo (Javanthropus) soloensis* was completed in December 1931 before Ngandong IV (Ng 5) was found.

Oppenoorth presumably examined the site of the January find in mid-March 1932, finding that the Ngandong IV (Ng 5) discovery point was only ~5m west of the Ngandong III (Ng 3–4) location he had examined the previous October. Additionally, the Ngandong IV (Ng 5) find spot was just 2m east of an unexcavated portion of the terrace deposits (a part dug in May 1932), judging from the Site Map (see Figures 6C and 8D). This should have afforded Oppenoorth a reliable way to place the find in its proper stratigraphic position, even as late as March.

The Ngandong IV (Ng 5) discovery point was at the western edge of the south-Getas path, in a portion of a 1932 excavation area that is not labeled as to the month. The site is also within the boundaries of an older path slightly west of the south-Getas path (not shown in Figure 6C). A full thickness of terrace deposits existed at this point by inference from the Site Map, which shows little or no topographic expression of either path. The discovery context is not shown on ter Haar's cross section (see Figure 7), which is located farther to the east (see Figure 6A).

In summary, we have uncovered no specific reason to doubt the discoverers' conclusions that Ngandong IV (Ng 5) came from the basal volcaniclastic layers of the Ngandong Formation, but the find has less reliable provenience documentation than Ngandong I–III (Ng 1–4), let alone the clear records available for Ngandong V (Ng 6).

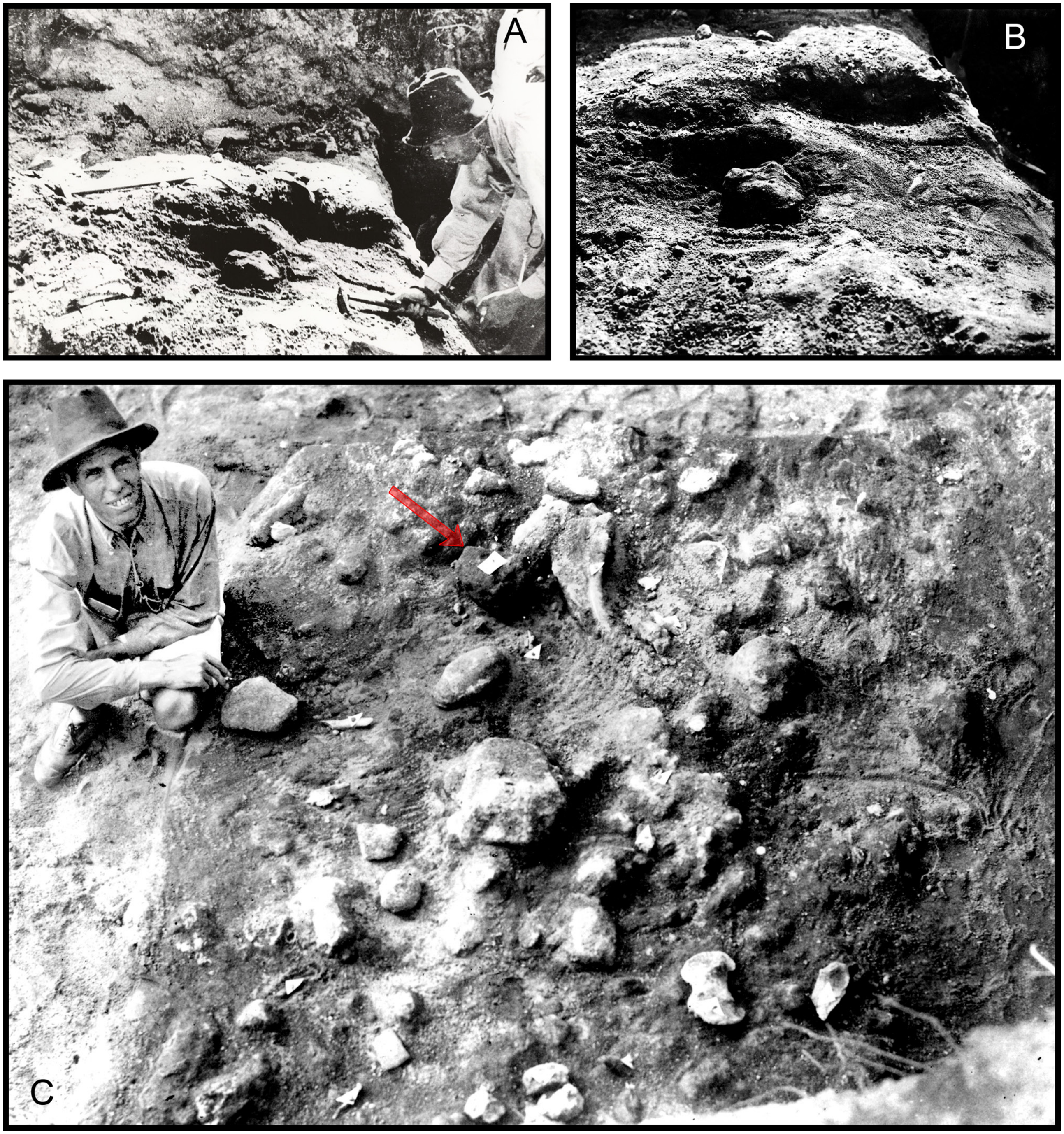


Figure 13A, B, C. Von Koenigswald's June 1932 photographs of ter Haar unearthing Ngandong VI (Ng 7), an event that both ter Haar (1932) and von Koenigswald (1951, 1955, 1956) described (see quotations in the text). A—ter Haar scrapes sand away from the calvaria; the image was published by Weidenreich (1951: 289, Plate 16a; see also van Heekeren 1972, Plate 19) with the caption: "Excavation of Ngandong Skull VI. The skull, with a heavy encrustation, is resting on its vault. To the right is the late C. ter Haar, the discoverer of the site" (scanned image from the Von Koenigswald Archive, Research Institute Senckenberg, Frankfurt, #16-1-15; published with permission). B—the Homo erectus *fossil (center) while still covered with sand; scanned from a print in ter Haar (1932: Foto 1, translated) having the caption: "Original emplacement of the Ngandong VI skull. The convex side is turned downwards; the frontal…towards the viewer." C—ter Haar squats beside the ~2m x 2m pedestal with Ngandong VI (Ng 6), at red arrow (scan from the Von Koenigswald Archive, image #16-1-15, published with permission). Ter Haar (1932: 2, translated) captioned a similar photograph: "After the Layer containing the skull was excavated over a ~2 x 2 m area and the fine[r]-grained material was removed, a good overview of the remaining coarser material was obtained: rounded pieces of white marl and calcareous marl, with irregularly deposited bones in between." The vertebrate fossils were marked by small pieces of paper (a rectangle for the Homo erectus specimen and triangles for 17 non-hominin fossils).*

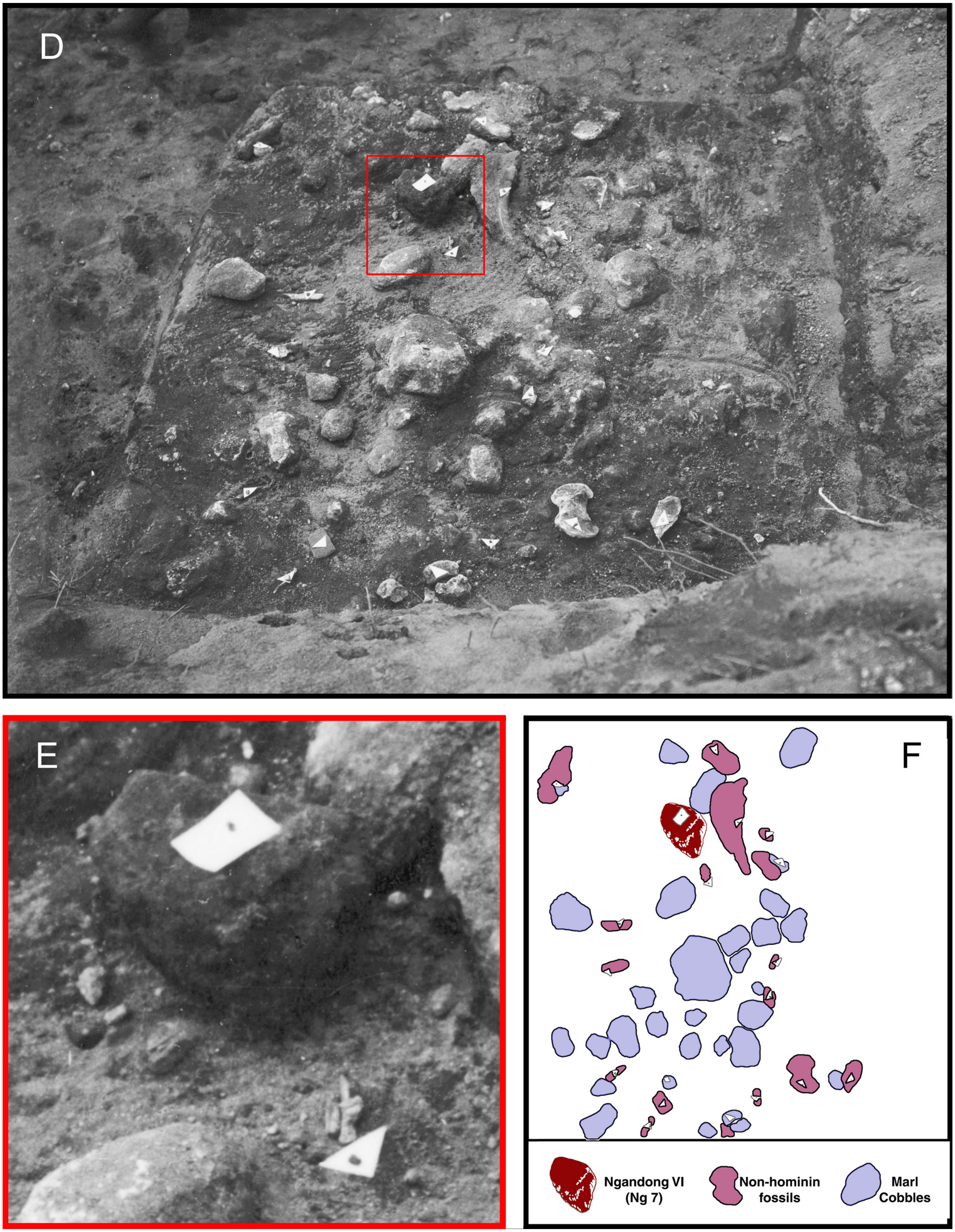


Figure 13 continued. D—a high-quality photograph of the Ngandong VI (Ng 7) block shortly after the time seen in C (scanned from print in Oppenoorth's personal photograph album). E—an enlargement from D showing the Homo erectus *specimen in situ (under the white paper square). F—drawing of the ~2m x 2m surface, highlighting the distribution of fossils and marl cobbles (the shape of the ~2m x 2m square is distorted in D due to the oblique angle at which the photograph, D, was taken, and restored in this drawing).*

NGANDONG VI AND VII

The quality of the provenience records for the Ngandong *Homo erectus* assemblage reaches a zenith with Ngandong VI (Ng 7). Nearly a whole calvaria, the specimen also is the most complete human cranial fossil from the site (see Table 2; Tibia B, discussed below, would be its post-cranial counterpart in the degree of preservation). Ngandong VI (Ng 7) was found after Ngandong VII (Ng 8), but recognized as hominin by the Survey before its numerical successor. Field examination of the Ngandong VII (Ng 8) discovery point by Survey geologists also post-dated the *in situ* inspection of Ngandong VI (Ng 7).

Both ter Haar and von Koenigswald were on hand when Ngandong VI (Ng 7) was unearthed, and the discovery was made near excavation walls that Oppenoorth had previously examined. Little wonder that Ngandong VI (Ng 7) began to serve as an exemplar for the discoverers' conception of the human fossil context at the site. Von Koenigswald's photographs of the site shows Ngandong VI (Ng 7) surrounded by 17 non-hominin specimens (see Figure 13), the only Java *Homo erectus* for which this degree of provenience detail is published.

Ngandong VI (Ng 7) was found on June 13, 1932, the 245th day of excavation. Forty-two percent of the ultimate number of the fossils registered from the site had been collected by this time (see Figure 8A). Only 200 entries had been recorded since the May 24 discovery of Ngandong VII (Ng 8), for an average rate of ~10 per day, about a third of the average for the whole project. The area excavated during late May and early June between the Ngandong VII (Ng 8) and Ngandong VI (Ng 7) discovery points therefore must have had a lower density of vertebrate fossils than average for Excavation I Ngandong, despite the concentration of remains immediately surrounding Ngandong VI (Ng 7; see Figure 13). The evidence implies again that fossils had a patchy distribution in the bone bed.

Once Panudju recognized the Ngandong VI (Ng 7) find as human and cabled word of the discovery to Bandung, Oppenoorth dispatched ter Haar and von Koenigswald to the site (Oppenoorth did not go himself as Swisher et al. [2000] state; von Koenigswald 1951). This was ter Haar's only return to Ngandong since the previous August, and the first opportunity von Koenigswald (1956) had to go to the site (see Table 3; see Figure 8C). Von Koenigswald already had devoted much time to analyzing the Ngandong fauna, and was anxious to see the prolific source of the paleontological and paleoanthropological specimens.

When Panudju showed ter Haar and von Koenigswald the Ngandong VI (Ng 7) discovery point six days after the discovery came to light, the contextual essentials, if not every detail, of what Oppenoorth previously had observed at Excavation I Ngandong were known to the two geologists. The Ngandong VI (Ng 7) find point was only ~2m east of an excavation wall which had been exposed when Oppenoorth established the site stratigraphy in October 1931, a wall which still partially stood in June 1932 (see Figures 6C and 8E). At that time, the field crew was digging from southwest to northeast in a series of monthly units which paralleled those dug during the preceding year (see Figures 8B and 8E; note also that a wall is visible near the discovery point in Figure 13A). The Ngandong II–III (Ng 2–4) sites were <10m to the northwest of the Ngandong VI (Ng 7) discovery point. The original ground surface here was only a few decimeters below that at the Ngandong II and III (Ng 2–4) discovery points (see Figure 6A), so that the section exposed in the excavation walls around the Ngandong VI (Ng 6) was approximately the same thickness as Oppenoorth had measured eight months before (see Table 3; see Figure 3B).

More importantly, the sequence of Layers was similar or the same (see Figure 7). When ter Haar (1932: 1-2, translated) recounted the trip in his field report dated July 12, 1932, he drew the connection to Oppenoorth's 1931 stratigraphic standard:

> *I was accompanied by Dr. R. von Koenigswald, with whom the undersigned, on June 19 was able to excavate the above mentioned skull…'Ngandong VI'…in Layer 3 (see:* [Oppenoorth, 1932b]*). It was found with the convex side downward (see* [see Figure 13C]*). After the Layer which contains the skull was excavated over an area of ~2 x 2m and the fine-grained material was removed, a good overview was obtained of the remaining coarser material: rounded pieces of white marl and calcareous marl, with bones having been deposited irregularly in between (see* [see Figures 13C and 13D]*)."*

Von Koenigswald (1951: 215) remembered:

> *Having discovered the skull, our collectors had carefully covered it with sand and marked the place with leaves.…Like No.* [Ngandong] *V, this skull* [Ng 7] *was resting on its vault. The surface* [of the fossil] *was partly covered by some encrustations.*

Von Koenigswald (1956: 74) also recalled:

> *Ter Haar began to dig carefully with his hands, while I took photographs. Unfortunately, I was so excited that most of the shots were under-exposed.…the cranium itself was still embedded in the gravel.*

Despite the trouble he had operating his camera, von Koenigswald took several shots that made excellent prints (see Figure 13D).

The loose sand and leaves that von Koenigswald mentioned would have kept the bone from degrading in the sunlight, helping to preserve the fine condition of the fossil for the six days between discovery and removal. Since the June 1932 visit was ter Haar's only one to the site during the formal excavation, the description he gave in 1934 about fossil degradation and other field conditions—quoted in Field Methodologies, above—doubtless applied to the circumstances he observed in and around the Ngandong VI (Ng 7) site.

Ter Haar and von Koenigswald did not specifically state how far Ngandong VI (Ng 7) was situated stratigraphically above the basal unconformity of the Ngandong Formation, but the contact was much less than a meter below the fossil horizon judging from site photographs in which ter Haar squats next to the ~2m x 2m unit with his feet on the marl (see Figure 13C; see also Figure 13D). Furthermore, according to his cross section, the find occurred in the uppermost part of Layer 2/II and a normal thickness of this unit existed beneath the specimen (see Figure 7). The calvaria therefore sat within about a half meter of the basal unconformity.

The site cross section also shows the sequence of strata immediately above the unconformity to be similar to or the same as those Oppenoorth had described for the Ngandong I–III sites (see Table 3; see Figure 3B). There is no risk, judging from ter Haar's fieldwork, that this *Homo erectus* fossil originated in his younger stratigraphic complex of the Ngandong Formation. Ngandong VI (Ng 7) thus is securely attributed to the basal-bone-bearing volcaniclastic stratum along with Ngandong I, II and V (Ng 1, 2 and 6).

Ter Haar did later change his mind about his first report that the Ngandong VI (Ng 7) was in Layer 3/III. By the time he (1934b) reviewed the results from the whole of Excavation I Ngandong in middle 1934, he attributed Ngandong VI (Ng 7) to the top of Layer 2/II. The change is not necessarily consequential, however. Judging from the site photographs, as well as ter Haar's account of the discovery, quoted above, the exact stratigraphic discovery level could be described as having been at the contact between Layer 2/II and 3/III; that is, the cobble-sized calvaria rested among marl cobbles and bones in the upper part of Layer 2/II, the bone-rich interval Oppenoorth had seen, with the very-coarse-grained sandstone and fine conglomerate of Layer 3/III covering and surrounding the bone-cobble assemblage, including Ngandong VI (Ng 7; see Figure 13C; see also von Koenigswald 1933c, and the comment by Oppenoorth, quoted above, regarding the lateral change in the marl cobble horizon and the basal-bone interval).

There are 18 fossils in the ~2m x 2m square in which Ngandong VI (Ng 7) rested (see Figure 13D), a density of ~4.5 specimens per square meter. This is about the same as the average frequency of fossils for Excavation I Ngandong on the whole, but more dense than fossils averaged in the May-June portion of the excavations. Von Koenigswald (1951) noted that a few broken cervid antlers were found in nearby excavation exposures, but no other human remains were located.

In summary, Ngandong VI (Ng 7) was found in very poorly sorted volcaniclastic granule-pebble gravel with marl cobbles and disarticulated non-hominin fossils. The find was situated within about a half meter of the basal unconformity of the Ngandong Formation, and beneath about two meters of terrace deposits like those Oppenoorth had found in the vicinity of Ngandong I–III (Ng 1–4; see Table 3; see Figure 3B). The provenience of Ngandong VI (Ng 7) is unambiguously established, given the field photographs of the specimen *in situ* (see Figure 13), a location plotted on the Site Map (see Figure 6), ter Haar's (1932) prompt reporting on the discovery, and his later inclusion of the discovery point on a cross section (see Figure 7).

The documentation for Ngandong VII (Ng 8), by marked contrast, is problematic. Ter Haar (1934b: 6, translated) stated, *"Ngandong VII, discovered on May 24, 1932, was like Ngandong I, II and IV, unpacked in Bandung"* (see also von Koenigswald 1951). Although Panudju was under instructions to notify headquarters of hominin discoveries, he did not do so in this case. Presumably he did not recognize the human specimen for what it was. This oversight is perhaps understandable considering that the fossil is a parietal fragment which would have been more difficult to identify taxonomically than a more complete cranial fossil. Ngandong VII (Ng 8) was registered as specimen 9775, and unearthed on excavation day 255, which was 68 days and 2,181 entries after Ngandong V (Ng 6) was found. There had been a Register-entry rate of 32 per day, close to the average rate for the entire dig (see Table 1; see Figure 8A).

The fragmentary nature of Ngandong VII (Ng 8), or perhaps the timing of shipments from the site to headquarters, might explain the delay that apparently arose in recognizing the human character of the fossil. The discovery number itself—VII—means that the specimen probably remained unidentified as hominin material until after Ngandong VI (Ng 7) was unearthed in June 1932. Confirmation of this comes from the fact that ter Haar (1932) did not mention Ngandong VII (Ng 8) in the report he wrote immediately following the June fieldwork, even when he discussed an excavation wall that was near where this find had been made (see Figure 8E). Thus ter Haar and von Koenigswald did not examine the Ngandong VII (Ng 8) discovery point, or even know of the find, until after returning from the field in June.

Oppenoorth was the next Survey geologist to go to Ngandong. He made his visit on August 14 (see Table 3; see Figures 8C, F). The troubling aspect of this chronology of events is that Panudju's recollection of the discovery particulars for Ngandong VII (Ng 8) three months earlier may have been hazy by August. On the other hand, Oppenoorth appears to have been in a position to determine the stratigraphic context, even at this late date, because the discovery unit was small in size (~25m^2), and an excavation wall existed <2m southeast of the discovery point (see Figures 6C and 8F). The location also was in a portion of the terrace deposit where the basal-bone bed was 2–3m deep, just as it had been at the discovery points of Ngandong II, III, and VI (Ng 2, 3, 4, 7). Furthermore, when Oppenoorth arrived, there apparently were long excavation walls available for his examination (see Figure 8F). This likely afforded him the opportunity to relate the stratigraphic situation near Ngandong VII (Ng 8) to that he knew from elsewhere in the excavation (see Figure 3B) and ter Haar (1932) had related to him in following the June fieldwork.

Uncertainty again arises in the geologic provenience of Ngandong VII (Ng 8), however, because of the troublesome local stratigraphic situation that ter Haar showed on his cross section (see Figure 7). Although the find is placed in the same basal bed as Ngandong II, III and VI (Ng 2, 3, 4 and 7), the younger sedimentary unit of ter Haar's sequence was relatively thick at the Ngandong VII (Ng 8) point, and the younger complex rested directly on the stratum in which Ngandong VII (Ng 8) occurred. Ter Haar had recognized in June that there was a thickened younger sequence in this portion of Excavation I Ngandong. He documented

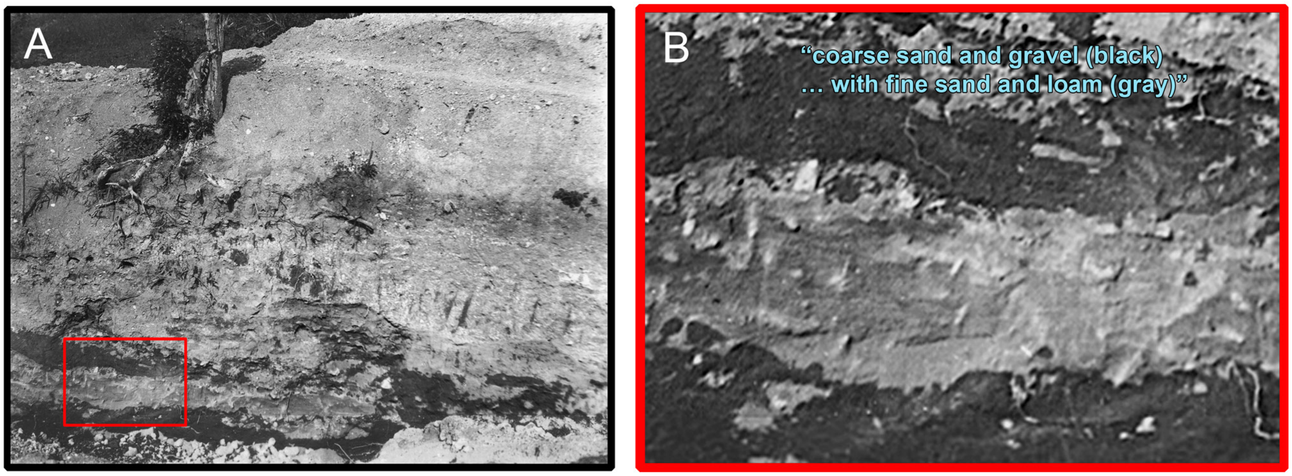


Figure 14. The southeastern wall of Excavation I Ngandong on June 21, 1932 (see also Figures 6C and 8E), illustrating the lithologies and key stratigraphic relations that ter Haar observed in the Ngandong Formation. A shows the whole scene, while B is an enlargement of the cross-laminated sandstone near the base of the Formation. Ter Haar (1932: Foto 3, translated) captioned A: "To the lower left are layers of coarse sand and gravel (black) alternating with fine sand and loam (gray), which gradually thin to the right.…These bone-bearing beds [Layer 2 and 3] disappear towards the south [while] the upper-most layer…becomes much thicker, such that the SW edge of the excavation [see Figure 8E] consists entirely of the approx. 2-m thick deposit of Layer 6 [see Figure 3B]. In the northern part of the excavation a number of Recent objects were found, such as an iron patjol [mattocks], an iron arit [sickle] and a small piece of zinc, at a depth of 0.75, 1.00 and 1.75 m respectively. This spot contains a large tree trunk and the earth is completely reworked (see relations as portrayed in cross section, [see Figure 7])." The lower, dark-colored beds appear to have the same andesitic composition that Oppenoorth found in the Ngandong I–III (Ng 1–4) discovery area (see Table 3), and Ngandong V (Ng 6) excavation wall (see Figure 12). Ter Haar and von Koenigswald also encountered this lithology in the Ngandong VI (Ng 7) excavation square (see Figure 13). The strata above the dark-colored beds in the center right of A appear to contain abundant marl detritus of the kind described by the discoverers (see Table 3). The tree in the upper left of A may be the one near the place where the historic artifacts were unearthed. To produce A, a scan of the bottommost portion of Foto 3 in ter Haar (1932) was combined graphically with a scan of a high-quality print in Oppenoorth's photograph album. The Von Koenigswald Archive has another photograph (#19-01-21) of the stratigraphic relations observed by ter Haar and von Koenigswald in June 1932. That photograph is captioned "cross section through the Ngandong terrace showing sand and gravel." See additional photographs of intra-formational stratigraphic relations in Weidenreich (1951, Plate 17B) and van Heekeren (1972, Plate 20b) .

his observations with a photograph (see Figures 8F and 14). We have no records concerning Oppenoorth's subsequent fieldwork, and thus do not know whether he agreed with ter Haar's interpretation of stratigraphic relations at the Ngandong VII (Ng 8) discovery point. If ter Haar was correct about the stratigraphy here, but Panudju had been imprecise in recording the vertical position of the find or the stratigraphic details at the discovery site, then Oppenoorth and ter Haar might have been led incorrectly into attributing Ngandong VII (Ng 8) to the lower rather than upper complex of strata comprising the Ngandong Formation.

In summary, while we find no information contrary to the discoverers' determination that Ngandong VII (Ng 8) originated from the basal-bone bed (see Figure 7), the strength of the documentary record is diminished by our uncertainty about how exactly the geologists reached their conclusion. The provenience of Ngandong VI (Ng 7), by contrast, is unequivocally established.

TIBIAE

Two right tibiae were the only human post-calvarial fossils recognized at Ngandong in 1931–1933 (see Table 1). While no one has proposed that the long bones are from the same individuals as the cranial fossils, the Survey geologists did place all the *Homo erectus* material in the basal-bone bed and believed all of it came from one living population (e.g., ter Haar 1934a; Oppenoorth 1937; von Koenigswald 1951, 1956). Tibia B (Ng 10) is nearly a complete element, comparable in degree of preservation to the best of the calvarial specimens, while Tibia A (Ng 9) is ~60% of a full element (Tibia A also is anatomically larger than Tibia B—for example, mid-shaft diameter of Tibia A is 126-127% of that in Tibia B, according to Santa Luca [1980]).

The tibiae were found during an eleven-month period in late 1932 and early 1933 when no Survey geologist (nor Dramoh) went to Ngandong (see Table 3; see Figure 8C). The inattention may have been due to the transfer in responsibility for the Java Mapping Program from Oppenoorth to Zwierzycki. Moreover, there are serious problems with the surviving provenience records on both tibiae, neither of which was apparently recognized as hominin in the field, let alone witnessed *in situ* by a geologist.

Tibia B (Ng 10) was found on January 17, 1933 (see Table 1). Its location does not appear on the Site Map (see Figure 6), which we can only assume resulted from uncertainty about the location of the discovery, rather than an inadvertent error in drafting the version of the Map that we have. The only specimen missing from the Map, Tibia B (Ng 10) might have been made in any one of four areas excavated in January 1933 (see Figure 6C). The discovery circumstances for Tibia B are not otherwise described, and we must rely upon the implication of statements by von Koenigswald (1951, 1956) to the effect that the tibia was found in the same excavation and stratigraphic context as the other human fossils.

By contrast, Tibia A (Ng 9) is shown on the Site Map and ter Haar's cross section (see Figures 6 and 7), where the find is attributed to a February-March 1933 portion of the excavation. Although ter Haar did not have a Register entry for Tibia A (Ng 9), as we explain below, he somehow had sufficient provenience detail to post the discovery point in the middle of a ~10-15m^2 block. Although it is not annotated as to month, this block is situated between two small units dating from February and March, part of a 1933 trench with no 1932 excavations nearby (see Figure 6C). Ter Haar (1934b) not only had information on when and where Tibia A was found, but he evidently also had enough geological data to reach a specific conclusion about the geological context of Tibia A. His cross section has the fossil in Layer 2/II where the bed was directly overlain by the upper member, a stratigraphic circumstance similar to the one he portrayed for Ngandong VII (Ng 8; see Figure 7).

How ter Haar (1934b) came to these conclusions about Tibia A is a mystery. The fact that Tibia A (Ng 9) was given the "A" designation, and Tibia B (Ng 10) was discovered on January 17, 1933, suggests that the person at the Survey who named Tibia A (Ng 9) thought it was unearthed before this date. One also might surmise that Tibia A (Ng 9) was recognized between the middle and end of 1932. Von Koenigswald (1951: 215) later arrived at this conclusion, stating: *"the label of* [Tibia A (Ng 9)] *is damaged so that the exact date is unknown, but it was found some time in 1932."* Specimens from Ngandong generally were relabeled once they arrived in Bandung (see Plates in von Koenigswald 1933a), so that damage to the label of Tibia A (Ng 9) must have occurred before the specimen received the new headquarters' label.

These inferences do not settle the issue, however. At least four additional considerations are relevant. First, even with a damaged label on Tibia A (Ng 9), the Survey staff should have been able to determine the date of discovery if Panudju had written a description in the Register that fits a human tibia. Or the staff would have been able to approximate the discovery date, if they recognized the specimen as significant before it was disassociated from the shipment of fossils with which it arrived. Apparently Panudju saw no particular significance in Tibia A (Ng 9), and it was not identified as a human long bone until the specimen had been put into the Bandung collection without a provenience label.

Second, while Tibia B (Ng 10) reportedly was found on January 17, 1933, we know little about when it was recognized as human. The date of recognition could have been in middle or late 1933. Oppenoorth's (1932a–f) 1932 publications, the latest apparently authored in mid-year 1932, make no mention of post-cranial human fossil having been found at Ngandong (he mentions one tibia, Tibia A, in 1937). The first reference to tibiae is in ter Haar's (1934a) publication of April 1934 (Oppenoorth 1936, 1937).

Third, von Koenigswald (1951) made his statement about the date of discovery without having the Site Map and cross section in hand (see Figures 6C and 7). He did have the text of the ter Haar (1934b: 6, translated) report, which stated:

Apart from these skulls also two tibias were found:

Described in the literature as:	*No. in "Original Ngandong Fossil Register"*	*Discovery date*
Tibia A *" B*	*?* *14518*	*?* *January 17 1933*

Finally, although no geologist visited Ngandong between February-March 1933 and von Koenigswald's September 8–9 visit in that year (see Figure 8C), the Site Map indicates that there evidently still was an excavation wall within a meter of the reported Tibia A discovery point (see Figures 6C and 8G), and von Koenigswald had the opportunity to examine the wall in September.

With a von Koenigswald field description, ter Haar would have had a basis for spotting the find on his cross section and the Site Map. However, if von Koenigswald did examine the field location and write a report, he had forgotten about the experience by the late 1940s. This is conceivable considering the extreme difficulty of his war-time experiences. If von Koenigswald did not examine the site in late 1933, ter Haar must have relied on Panudju's notes and recollections. A mistake by Panudju about the depth of the find or nature of the enclosing deposit would put at risk ter Haar's assessment of the discovery geology, as represented on the cross section.

Because it is unclear how ter Haar knew the discovery circumstances and context of Tibia A (Ng 9), we view its provenience record as problematic. Tibia B (Ng 10) is even less well documented because it is not shown on the Site Map (see Figure 6) and no details on its identification as human are known. Available documents therefore do not provide substantiation of the provenience for either tibiae.

NGANDONG VIII

Von Koenigswald had been designated to make site visits (see Figure 8C) by the time the Survey headquarters received word from Panudju in early September 1933 that another human cranial fossil had been found. Referring to the afternoon of September 9, during a five-day inspection visit of a number of sites in the Solo valley area, von Koenigswald (1933c: 2, translated) described witnessing:

an isolated Os Parietale…; a second similar and associated fragment, also found isolated, had already been sent to Watualang. These finds can be combined as Ngandong VIII. In the

> *substantially exposed bone bed, the large tusk (+/- 2.5 m) of a Stegodon, as well as an unusual, not aligned, cluster consisting of 6 Axis deer antler branches, were observed in situ.*

Weidenreich (1951) agreed with von Koenigswald's conclusion that the two parietal bones were from the same individual (see also Jacob, 1967, Santa Luca, 1980, and Antón 1999). Ter Haar (1934b: 6, translated) confirmed von Koenigswald's role in the discovery:

> *Both pieces* [Register numbers 19109 and 19587] *belong together, also according to a note by the* [lead on-site] *mantri Panudju….The fossil was dug out under supervision of Dr. von Koenigswald, who was in Ngandong on September 8-9.* [ter Haar].

Von Koenigswald (1951) later remembered incorrectly that he had removed both pieces on September 8.

The first-found half of the parietal had been discovered on August 22, 1933. This was eight days and 478 Register entries before field recognition of the fossil that von Koenigswald removed. The difference in Register entries and discovery dates equates to 60 fossils or more per day, a frequency significantly higher than average for Ngandong overall and consistent with Ngandong VIII (Ng 11) occurring in a particularly fossiliferous portion of the basal stratum.

The discovery point for Ngandong VIII (Ng 11) was very close to the southeastern wall of the ~35m^2 discovery unit and near a block not dug until October-November 1933 (see Figure 6C). There were ~2.75m of the Ngandong Formation exposed in the excavation walls, because the discovery point was in a portion of the terrace where its surface occurred at 55m, and the Ngandong-Kalibeng formational contact was at ~52.25m, based on bedrock exposures to the east (see Figure 6A).

Although both parietals were removed from the same excavation block and are shown as the same discovery point on the Site Map (see Figure 6), they very likely had been physically separated by some distance *in situ*. This taphonomically important conclusion is supported by the eight-day and 478-entry difference in the record between the finds, the fact that one parietal had been transported to Watualang while the second bone was still in place at Ngandong, and von Koenigswald's statement, quoted above, that each find was "isolated."

The exact original distance between the two parietals is unknown. They could have been separated by as much as 8m, judging from the size and shape of the excavation block, although the fact that only one discovery point is shown on the Site Map might be taken as evidence against a spacing this large (see Figure 6C). Alternately, the two bones could have been separated by just a few centimeters, if the excavators had fortuitously stopped digging on the first day of discovery at a point just between the first and second parietal pieces.

Ter Haar (1934b) specifically attributed the bone-bearing horizon at the Ngandong VIII (Ng 11) site to Oppenoorth's Layer 2/II. His explanation is best read while also referring to his cross section and Oppenoorth's stratigraphic profile (see Figures 3B and 7). Ter Haar (1934b: 7, translated) stated:

> *The terrace deposits themselves can be divided into two different types, representing two stages in the development of the terrace….Complex A—the older Layers, chiefly consisting of andesitic sands and gravels; Complex B—the younger Layers, which are lying discordantly on top of these and consist of a mixture of loose sands containing many rounded pieces of marl. Of the deposits mentioned under A, the two lowest Layers contain the majority of the fossils. Also, all* [of the human] *skulls were found in the bottom Layer of these two (except No. VIII* [Ng 11]*). The deposits mentioned under B also contain much reworked material derived from the Layers mentioned under A, and in places also specifically had bones from them. The numbering of the Layers by the surveyors in charge of the excavation work is not consistent, so that Layers of packet B are often identified as Layers belonging to packet A. For this reason it can be explained that Skull VIII, which according to Panudju's report was found in Layer III, in actual fact was originally found in the lower Layer II (Layer III, in this case, belonging to package B).*

Ter Haar had concluded that: the majority of fossils from Ngandong occurred in Layer 2/II and 3/III (as defined in Table 3 and Figure 3B); all the hominin cranial fossils were discovered in Layer 2/II; and, Panudju had incorrectly assigned Ngandong VIII (Ng 11) to Layer 3/III—the parietals were actually also found in Layer 2/II (where the bed was unconformably overlain by Complex B).

Although we do not have a photograph or a geological illustration of Ngandong VIII (Ng 11) *in situ*, we consider the accounts of von Koenigswald and ter Haar sufficiently detailed and reliable to place the discovery in the basal-bone bed of the Ngandong Formation along with a high-density of large non-hominin fossils. The provenience records also indicate that the parietal bones comprising Ngandong VIII (Ng 11) were physically separated *in situ*.

NGANDONG IX–XI

Ter Haar (1934b: 6, translated) reported that *"Ngandong IX and X were found on the same day, September 27 1933,"* the 746th day of the excavation, and *"were sent to Bandung, separately packed."* This indicates that Panudju recognized both Ngandong IX and X (Ng 12 and 13) as significant finds, and probably knew or suspected that they were hominin remains (see Table 2). The actions taken by the field crew to collect fragments of the smashed skulls support these conclusions. The facts that the two specimens were found on the same day and that both were damaged during collection does not mean that they were found in the same place, however. They actually had quite different provenience, and must be treated separately.

Von Koenigswald had just returned from picking up Ngandong VIII (Ng 11) at the site in late September, and neither he nor ter Haar went to Ngandong immediately to examine the discovery circumstance of Ngandong IX and X (Ng 12 and 13). Von Koenigswald did go to the site shortly after the last human fossil from the site, Ngandong XI (Ng 14), was unearthed on November 8, 1933 (as detailed below). This was 42 days after Ngandong IX and X (Ng 12 and 13) were discovered, and 40 days (and only 348 Register entries) short of the December 18 end of Excavation I Ngandong. If von Koenigswald wrote a report about witnessing Ngandong XI (Ng 14) *in situ*, we have not located it. The reliability of the provenience accounts of all three of the Ngandong IX–XI (Ng 12–14) specimens therefore depends largely on what we can infer about von Koenigswald's observations during the November site visit.

Ngandong IX (Ng 12) was *"shattered when excavated"* so that *"the roof and the lateral walls…were badly smashed and it was possible to unite them only by filling the entire posterior half of the calvarium with plaster"* (Weidenreich 1951: 238). Fragments of the fossil clearly had been lost, such as several slivers of bone at the inferior vault margin. Referring to the reconstruction of the specimen, Rightmire (1990: 49) noted, *"there are several areas where contacts between adjoining bone fragments are slightly misaligned."* The collection damage indicates that Panudju did not locate all the shards of fossil which excavation had broken off of Ngandong IX (Ng 12).

When von Koenigswald returned to Ngandong in November, the edges of the active dig were nowhere near the discovery point of Ngandong IX (Ng 12; see Figures 6C and 8G). The location was in the southeastern portion of the main terrace remnant, very near the northeastern edge of a ~45m^2 unit dug during September/October 1933 (see Figure 6C). The adjacent block had been removed in October 1933, so that the wall which was nearest to the discovery point in September was probably gone when von Koenigswald arrived in November. The surface elevation here was ~1.75m above the basal unconformity of the Ngandong Formation (based on the elevation of the contact cropping out ~10m from the find site). Ngandong IX (Ng 12) has a slight level of weathering, as described by Weidenreich (1951), Santa Luca (1980), and Westaway (2002), and this is consistent with the discovery of the specimen at depth below the level of soil development in the terrace sequence.

What remained of the *Homo erectus* bed at the discovery point was not reported, and how much attention von Koenigswald paid to the contextual circumstances is unknown. For the Survey geologists to conclude that Ngandong IX (Ng 12) came from the same basal beds as the other hominin material, they may have had to rely entirely upon Panudju's records and verbal recollections.

Possession of Ngandong IX (Ng 12) became an issue during World War II but is not a current provenience concern. Jacob (1967: 15) recalled:

> *Individual IX….was brought…to the medical school in Djarkarta [Jakarta] with its fellow skulls* [for care and analysis by Prof. Mijsberg]*. During the Japanese occupation of Indonesia the skulls were brought back to Bandung, and then skull IX was chosen as a birthday present for the Japanese emperor and kept in the Imperial palace of Kyoto. After the war the skull was flown to New York and reunited with the other skulls.*

The diversion raised no question that the existing specimen was the one which had been found in 1933 (von Koenigswald 1951; Weidenreich 1951).

Like the other hominin specimen found on September 27, Ngandong X (Ng13) was broken during removal. *"The calvarium was shattered"* (Weidenreich 1951: 228), arriving at Bandung in the poorest condition of any of the finds. T. Jacob told Westaway (2002) that an excavator's hoe had caused the fragmentation, but the basis for Jacob's conclusion is not reported. Two small quadrangular injuries on the specimen may be attributable to excavators' implements (Weidenreich, 1951). Whether the *"slight depression and thus distortion in the right and left temporal lobes…and in the right occipital region,"* which Holloway (1980: 273) noted, is from ineffective reconstruction or pre-discovery distortion is not clear.

Compared to the other hominin fossil found the same day, Ngandong X (Ng 13) is severely weathered (Weidenreich 1951; Santa Luca 1980; Westaway 2002). Westaway (2002: 191) surmised that, because of the evidence of weathering and some abrasion on the specimen, *"the cranium may have been subject to one or more cycles of reworking with the* [Solo] *fluvial system."* However, Ngandong X (Ng 13) also was the only one of the cranial specimens found in the small terrace remnant (see Figure 6), and some of the damage on the fossil could be due to Recent exposure near the eroded edge of the remnant, leaching of the kind referred to by Oppenoorth and von Koenigswald in the vicinity of the Ngandong V (Ng 6) discovery point. None of the non-hominin specimens with which Ngandong X (Ng 13) occurred were described by von Koenigswald or are known to be in the GRDC collection, so we do not have a ready basis of evaluating the timing of the weathering.

The Ngandong X (Ng 13) location was in a ~40m^2 unit, which is noted on the Site Map as having been excavated in September 1933 (see Figure 6C). The discovery block was one of those excavated rapidly towards the end of the dig (see Figures 8A and 8B). The surface elevation was ~1.5m above the basal unconformity of the Ngandong Formation. The contact was exposed less than 5m to the north, based on the Site Map. No specific information is available on the stratigraphy in the small terrace remnant or the ~1.5m section exposed at the Ngandong X (Ng 13) discovery point. When von Koenigswald arrived, the closest active excavation face was ~6m to the south (see Figure 6C). We can presume with some confidence that the geological relations von Koenigswald observed were consistent with the volcaniclastic basal-bone context that the discoverers reported for all of the human finds. However, because we do not have a report about what von Koenigswald saw at the discovery locations of Ngandong IX (Ng 12) and Ngandong X (13), we have little documentary support for placing them in the volcaniclastic basal-bone bed.

We are more confident in the provenience record of Ngandong XI (Ng 14) than those for the preceding two human discoveries, because von Koenigswald returned to Ngandong in November to remove this last specimen. The geologists' involvement is particularly fortunate because

Ngandong XI (Ng 14) has an extraordinarily fine level of preservation. The calvaria lacks only its anterior base, and is an anatomical exemplar for the Ngandong human cranial fossils, according to Weidenreich (see Table 2).

Concerning the find, ter Haar (1934b: 6, translated) stated, *"Ngandong XI* [Ng 14]*, discovered on November 8, 1933, was also sent to Bandung in a separate package."* This is correct as far as it goes, but misses the role that von Koenigswald played in the discovery. Ter Haar apparently misinterpreted the records of Panudju's special transmittal of the specimen in concluding that von Koenigswald had not been present at the removal. Von Koenigswald's involvement is clear in the archival record.

First, a draft annual Survey report of the Survey's Paleontological Laboratory for 1932–1933 places von Koenigswald at the site: *"Nos. VIII and XI* [Ng 11 and 14] *were dug up under the supervision of Dr. von Koenigswald"* (Mijnwezen 1933: 3, translated). Normal Survey procedures would have had von Koenigswald, as the paleontologist responsible for the vertebrate department, draft this section of the report.

Second, von Koenigswald (1934b) did travel to East Java in November 1933 to collect fossils from sites near Mojokerto, east of Ngandong, with Survey geologist Johan Duyfjes (von Koenigswald 1934b, e; Duyfjes 1936). Duyfjes began working around Mojokerto on November 15 (Duyfjes 1934), making it quite feasible for von Koenigswald to have stopped at Ngandong around this time.

Third, a letter Zwierzycki (1933–1935) wrote to Oppenoorth on November 21, 1933, adds to the record, *"an eleventh skull* [Ngandong XI, Ng 14] *arrived* [in Bandung] *the day before yesterday"*—that is, on November 19—when Zwierzycki noted further that von Koenigswald was still out of the office. Twenty-five years later, von Koenigswald (1956: 75) reaffirmed having played a key role in the Ngandong XI (Ng 14) discovery, but apparently recalled incorrectly carrying it back to Bandung when he stated, *"in November, when I visited the site for the last time, I was able to bring back Skull XI."*

We reconstruct the sequence of discovery events for Ngandong XI (Ng 14) as follows: Panudju identified the specimen as a human cranium upon discovery on November 8, and notified Zwierzycki of the event. Von Koenigswald stopped at Ngandong for a day or so on his way to Mojokerto, and supervised the removal of Ngandong XI (Ng 14) from its sedimentary context. But because he expected to be doing fieldwork around Mojokerto for several days, von Koenigswald had Panudju send Ngandong XI (Ng 14) to Bandung, where it arrived on November 19, ten days after discovery. Von Koenigswald did not write a report about witnessing Ngandong XI (Ng 14) *in situ*, leaving ter Haar in the dark eight months later when he evaluated the history of the discoveries. Consequently ter Haar (1934b) based his discovery account on Panudju's transmittal correspondence, and must have concluded that the specimen came from the basal-bone bed on the basis of information Panudju supplied. What von Koenigswald saw in the field nonetheless was consistent with this conclusion because he agreed that all of the *Homo erectus* specimens originated from this context.

The discovery unit for Ngandong XI (Ng 14) is ~35m^2, and labeled November (see Figure 6C). The nearest wall of this unit was less than a meter away from the discovery point, but because the adjacent block was also dug in November, we cannot be sure where the excavation face was when von Koenigswald arrived. The Ngandong Formation at the discovery point was more than 3m thick, based on the elevations at the surface and contacts of the basal unconformity to the southeast and northwest. Ter Haar's cross section, which passes near the Ngandong XI (Ng 14) site, does not show the *Homo erectus* find (see Figure 7). This supports our contention that in mid-1934 ter Haar did not know about the details von Koenigswald had observed concerning the discovery context.

In summary, the provenience record of Ngandong XI (Ng 14) indicates that von Koenigswald witnessed the specimen *in situ*, although the documentation on contextual details is the poorest for the specimens that Survey geologists witnessed in the field. Because von Koenigswald agreed that all of the hominin finds came from the basal-bone-bed, he presumably observed Ngandong XI (Ng 14) in this stratum also.

RANKING OF RECORDS

Because the documentation for individual Ngandong *Homo erectus* fossils varies widely in quality, we develop eight criteria for comparing and ranking the reliability of the provenience. They are whether (1) the specimen was photographed *in situ*, (2) the specimen was witnessed *in situ* by a geologist, (3) the site of discovery was examined by a geologist, (4) the specimen had been recognized as a significant find by the field supervisor, (5) the discovery circumstances were shown on a geological illustration, (6) the circumstances of discovery are described in a report or publication, (7) the discovery point is posted on the Site Map, and (8) the fossil was entered into the Ngandong Fossil Register. In Table 5, the criteria are further described, and used to rank the reliability of each provenience record. Because the discoverers claimed that all the *Homo erectus* fossils originated in the bone-rich volcaniclastic interval near the base of the Ngandong Formation (see Table 3; see Figures 3B and 7), the ranking identifies those discoveries with the best evidence for this geological context. We separate the finds into three groups based upon our provenience analysis: Most Reliable, Problematic and Least Certain.

The five specimens rated as having the Most Reliable provenience records are Ngandong I, II, V, VI, and VIII (Ng 1, 2, 6, 7, and 11). Each is securely attributable to the basal volcaniclastic strata of the Ngandong Formation at the location shown on the Site Map (see Figure 6). Highest ranked are the two finds that Survey geologists witnessed and photographed *in situ*, Ngandong V and VI (Ng 6 and 7; see Figures 12–13). We further have descriptions by the geologists attributing these finds to the basal portion of the terrace sequence (Oppenoorth's Layer 2/II).

A third discovery among the Most Reliable five, Ngandong VIII (Ng 11), was witnessed in place by von Koenig-

TABLE 5. 1931–1933 NGANDONG SPECIMENS, RANKED BY THE RELIABILITY OF PROVENIENCE RECORDS, WITH SUMMARY OF DISCOVERY HISTORY EVENTS.

	NGANDONG (Ng) *HOMO ERECTUS* SPECIMENS												
Ranking	**VI** 7	**V** 6	**VIII** 11	**II** 2	**I** 1	**VII** 8	**XI** 14	**III** 3-4	**A** 9	**IV** 5	**IX** 12	**X** 13	**B** 10
Criteria													
Photographed [1]	●	●	□	□	□	□	□	□	□	□	□	□	□
Witnessed [2]	●	●	●	□	□	□	●	□	□	□	□	□	□
Examined [3]	●	●	●	●	●	●	●	●	●	●	□	□	□
Recognized [4]	●	●	●	●	●	□	●	□	□	□	●	□	□
Illustrated [5]	●	□	□	●	●	●	□	□	●	□	□	□	□
Described [6]	●	●	●	●	●	□	□	●	□	□	□	□	□
Mapped [7]	●	●	●	●	●	●	●	●	●	●	●	●	□
Registered [8]	●	●	●	●	●	●	●	●	□	●	●	●	●
●●● = *YES* □□□ = *NO* [9]													
Documentation	Best	>>											Worst
RECORDS	***MOST RELIABLE***					***PROBLEMATIC***				***LEAST CERTAIN***			

Because the Survey geologists visited Excavation I Ngandong infrequently (see Table 4), and none of the records on the geological assistants in charge of the day-to-day operations are available, we must depend on the geologists' summary provenience accounts, and provenience records that vary greatly, as summarized briefly in Table 2 and detailed in the text. We rank the strength of the provenience records using eight criteria:

[1]PHOTOGRAPHED—we have photographs of these fossils *in situ* (see Figures 12 and 13).

[2]WITNESSED—Oppenoorth, ter Haar or von Koenigswald witnessed the fossil *in situ* (see Table 4; see Figure 8).

[3]EXAMINED—a geologist visited the site when the stratigraphic sequence was exposed within 2.5m of the discovery point (see Figures 6 and 8).

[4]RECOGNIZED— Field supervisors Samsi and Panudju recognized the specimen as hominin or of special paleontological interest (see Table 2) and presumably documented the provenience with special detail in the operational reports that are missing.

[5]ILLUSTRATED—the discovery context is illustrated either in Oppenoorth's stratigraphic profile (see Figure 3B) or ter Haar's geological cross section (see Figure 7).

[6]DESCRIBED—Oppenoorth, ter Haar or von Koenigswald described the find stratigraphically.

[7]MAPPED—the discovery point is shown on the 1:250 Site Map (see Figure 6).

[8]REGISTERED—The sequential number and discovery date of the specimen were recorded in the Ngandong Fossil Register (see Table 1).

[9]Solid circles of all colors indicate that the criteria is met; open squares of all colors indicate that the criteria is not met. Color differences simply highlight reliability categories.

swald, but we have found no site photograph. In this case, von Koenigswald extracted one of the two parietal bones constituting the specimen from a bone bed with *Stegodon* and deer remains, according to an account he (1933c) included in an unpublished report. Ter Haar (1934b) specified that the discovery horizon was the basal bone bed (the upper part of Layer 2/II).

The remaining two finds ranked as Most Reliable—Ngandong I and II (Ng 1 and 2)—were neither photographed nor witnessed in place, but we conclude that Oppenoorth had a solid basis for attributing the fossils to the basal bone bed (the upper part of Layer 2/II), and provided ample information on his field results (see Table 4; see Figure 3).

Based on the evidence presented above, each one of Most Reliable five *Homo erectus* discoveries is likely (and in some instances, very likely) to have originated in the bone-rich volcaniclastic stratum in the bottom ~0.7m of the Ngandong Formation. That at least one of the fossils came from the basal-bone bed, therefore, is virtually certain, especially considering the compelling photographic evidence we present for Ngandong V and VI (Ng 6 and 7; see Figures 12 and 13). That all five came from this context is considered likely.

Furthermore, we have found nothing with which to dispute the discoverers' attribution of the remaining nine *Homo erectus* fossils to the basal volcaniclastic stratum, although the archival records for Ngandong III, IV, VII, IX, X, XI, Tibia A, and Tibia B (Ng 3, 4, 5, 8, 9, 10, 12, 13, and 14) range from Problematic to Least Certain (see Table 5). The better documented of these cases have conflicting evidence, and the worst case, Tibia B, has no supporting data at all, not even a spot on the Site Map (see Figure 6).

Two additional examples will help illustrate our reasoning in placing certain finds in the Problematic and Least Certain groups. First, we rank Ngandong IX (Ng 12) in the Least Certain group because the Survey geologists may have had only Panudju's reporting available to them when concluding that the fossil originated in the basal volcaniclastic stratum. Second, we rate the provenience record for Ngandong VII (Ng 8) as Problematic after having balanced the strengths and weaknesses of the available information. Specifically, Panudju did not recognize the find as significant, no specific description of the stratigraphy at the location has been found, and a geologist probably did not examine the fossil site until three months after discovery when Oppenoorth had that opportunity. Even at this late date, on the other hand, there probably still was an outcrop in a long excavation wall <2m from the discovery point (see Figures 6C and 8F).

Whether the provenience evidence is considered satisfactory for two, five, eight, or more of the Ngandong *Homo erectus* specimens, the archival records confirm that multiple human fossils occurred in the basal volcaniclastic stratum of the terrace sequence in Excavation I Ngandong.

DISCUSSION

DISCOVERY HISTORY

Survey geologists spent just 24 man-days at Excavation I Ngandong during the 27-month-long project (see Table 3; see Figure 8), and relied on geological assistants Samsi and Panudju to make critical provenience observations about the *Homo erectus* finds, as well as to manage the on-site operations. Oppenoorth visited at Excavation I Ngandong for 7 days from October 1931 to October 1932 (see Table 3), during a period when he devoted much of his time to publishing about the new hominin fossils, and effectively spreading word about them in Asia, Europe, and the United States (Oppenoorth 1932a–g). He retired in mid-1933 while the excavation was still ongoing and before a series of important human fossils came to light (see Table 1; see Figure 8C). Site discoverer ter Haar worked at Excavation I Ngandong only once, in June 1932, apparently because he had other projects of higher priority at the Survey. Von Koenigswald accompanied ter Haar on this occasion and visited three times in late 1932 and 1933, as he became responsible for reviewing discoveries in the field. He witnessed three of the Ngandong hominin fossils *in situ* (Ngandong VI, VIII, and XI; Ng 7, 11, and 14), more than either Oppenoorth (Ngandong V; Ng 6) or ter Haar (Ngandong VI; Ng 7).

Then, because of retirement, illness, dismissal, and other unfortunate circumstances, the geologists were unable to complete the post-excavation research that Ngandong warranted. Field operations were halted in December 1933. Oppenoorth and ter Haar left the Indies in 1933–1934 due to retirement and illness, respectively. Oppenoorth asked to export the hominin specimens to Holland for additional research, but they were stored instead, apparently unstudied, in Jakarta until World War II, when wartime conditions made research impossible. Von Koenigswald, who was the only one of the three to visit Excavation I Ngandong in 1933, when six *Homo erectus* were discovered, lost his Survey job at the end of 1934, after spending most of his time during the preceding three years on biostratigraphic studies. When he returned to Java in 1936 as a Survey employee, following a long overseas trip, his attention was on new *Homo erectus* discoveries his contacts at Sangiran Dome made, not the Survey's past discoveries at Ngandong. By this time, ter Haar had died, and within another year, Oppenoorth felt too far removed from the Ngandong specimens and data to work effectively on the site or its assemblage.

In the end, no two of the three geologists co-authored a report or publication about the site or its discoveries. A full integration of their individual observations and interpretations was left incomplete. Ter Haar's (1934b) relatively short summary of Excavation I Ngandong, as vital as it is to our understanding of the discoveries, was never published, and no comprehensive description of the excavation ever was prepared. Paleontological studies were completed on only a small number of the ~25,000 fossils unearthed (von Koenigswald 1933b), and documentation of potential artifacts from Excavation I Ngandong was inadequate, to say the least (Oppenoorth 1936; van Stein Callenfels 1934, 1936;

further discussed below). The records that the on-site supervisors kept on the Ngandong operations apparently have been lost.

Despite these shortcomings, the information on hand is sufficient to advance substantially our confidence in the methods used at Excavation I Ngandong and the provenience of some individual *Homo erectus* discoveries.

The field crew excavated blocks of consistent alignment (see Figures 6–9), and stripped away the poorly fossiliferous shallow beds to mine a bone-rich interval in the bottom ~0.7m of the terrace deposits. The target stratum was distinctive in its volcaniclastic composition and carbonate-cementing around the fossils (see Table 3). The bed sat on marl across a prominent, nearly horizontal unconformity (see Figure 3B). The field crew dug into the marl at least locally as they removed the fossils from the bone bed (see Figures 10B, 11A, and 11B). The basal contact provided a clear stratigraphic marker for Samsi, Panudju and the Survey geologists to follow, as the crew expanded the excavation—the unconformity forming a datum with respect to which fossils could be readily and reliably related (see Figure 7). The stratigraphic framework within the terrace deposits, as well as the basal unconformity, would have been especially conspicuous in the long excavation faces produced during 1932 and 1933 (see Figure 8).

Prominent specimens were left on pedestals and tagged as the field crew exposed the basal volcaniclastic bed across sizeable excavation blocks (see Figure 11). When Samsi and Panudju listed discoveries in the Ngandong Fossil Register, which progressively grew to 23,553 entries, they noted the discovery bed for each find, following a stratigraphic scheme codified by Oppenoorth in late October 1931 (see Table 3; see Figure 3B). The field personnel surveyed and reported progress weekly to headquarters using sketches to illustrate details. Presumably these included the outlines of excavation units linked to the Register entries. Using the field data, personnel in Bandung therefore should have been able to track the stratigraphic context of the finds as each shipment of fossils was received.

The *Homo erectus* finds were made sporadically during the 27-month excavation (see Table 1; see Figure 8). Two unrelated finds were made on the same day (Ngandong IX and X, Ng 12, and 13). No human discoveries were unearthed during one 214-day-long period (see Table 1), even though the area excavated expanded at a broadly even rate (see Figure 8A).

The Site Map of Excavation I Ngandong, which the Survey prepared in 1934 at 1cm = 2.5m from the transit measurements made during the 27-month-long excavation, gives a geographical provenience for the 13 of the 14 finds (see Figure 6). This map is an authoritative source for the location information because the document was incorporated into the Survey's summary report on Excavation I Ngandong (ter Haar 1934b; see discussion in Research Methods). We have found reason to question the Site Map location for only one of the 13 finds shown, Tibia A. Because the provenience label for this specimen was lost before the fossil was recognized as hominin by the Survey, it is unclear what data ter Haar used to plot the discovery point on the Site Map and his cross section (see Figures 6 and 7). As for the find whose location is not shown on the Site Map—Tibia B (Ng 10)—there is no information about the provenience in any available source from the 1930s, but von Koenigswald's (1951, 1956) statements indicate that he believed the tibia was found with the other hominin fossils.

In contrast to the uniform level of documentation for the geographic provenience provided by the Site Map, the archival record on the geological contexts of the finds is idiosyncratic and widely varying. This has led us to consider the documentation of each discovery, and in Table 5, rank the reliability of the records from Most Reliable (5 specimens) through Problematic (5 specimens) to Least Certain (4 specimens). There are two basic reasons for the variability. First, the quality of the information collected at the time of discovery differed substantially from find to find. For example, the field supervisors did not recognize the special significance of some human specimens before removing them, while in other cases, the Survey geologists were given notice of a hominin discovery, and then photographed the finds *in situ* (see Table 2 and Figures 8, 12 and 13). Second, the amount of the surviving documentation differs greatly from one *Homo erectus* discovery to the next.

The two best-documented of the five Most Reliable finds are Ngandong V and VI (Ng 6 and 7). Survey geologists witnessed them both in place during 1932. Oppenoorth observed the Ngandong V (Ng 6) *in situ* on March 21, four days after it was recognized as hominin by Panudju (see Figure 12). The find was in a low excavation wall ~15m west of the area that Oppenoorth (1932b) had investigated the previous October. He (1932c, e) recorded the geological context of Ngandong V (Ng 6) with high-quality photographs, publishing one view but keeping more informative images among his personal papers (Huffman et al. 2008a, b). The photographs clearly show that the fossil was embedded in fine volcaniclastic conglomerate within 0.5m of the marl (see Figure 12), essentially the same stratigraphic context that he had determined applied to Ngandong I–III (Ng 1–4; see Table 3 and Figure 3B).

Three months later in June 1932, when ter Haar (1932) and von Koenigswald witnessed Ngandong VI (Ng 7) in place, they found that this specimen also originated from the basal-bone-bed context (Huffman et al. 2008a, b). Ngandong VI was removed from a ~2m x 2m horizontal exposure of volcaniclastic sandstone/fine conglomerate in which marl cobbles and 17 disarticulated non-hominin fossils also were found. Von Koenigswald recorded the events photographically (see Figure 13), and ter Haar (1932) promptly wrote a report on their field observations. The provenience records for Ngandong VI (Ng 7) become the most complete published for any *Homo erectus* from Java, thanks to documentation provided by ter Haar and von Koenigswald, and the fact the Oppenoorth saved von Koenigswald's photographs.

Although Ngandong I and II (Ng 1–2) were not witnessed *in situ* by a Survey geologist, the two specimens are included in the Most Reliable group of Table 5, based on

Oppenoorth's (1932b) and ter Haar's (1934b) accounts of the discoveries, as well as the Site Map (see Figure 6). Samsi recognized both specimens as important paleontologically (see Tables 2 and 5), and therefore presumably gave special attention to their provenience. Oppenoorth evaluated the discovery points on October 27, 1931, about 1.5 months into the excavation and at a time when only ~150m^2 of the excavation was open (see Figures 6 and 8D). This was eight days after he had recognized that the field crew was finding human fossils in Excavation I Ngandong.

The stratigraphic information that Oppenoorth published on Ngandong I–III (Ng 3 and 4) includes lithological descriptions of key beds and a summary stratigraphic column, as well as a large-scale but quite accurate geological map (see Table 3; see Figure 3). The discovery horizon for Ngandong I–III (Ng 1–4) was the thin, calcium-carbonate-cemented, bone-bearing interval occurring within a lithologically distinct volcaniclastic unit which comprised the bottom ~0.7m of the Ngandong Formation. The provenience record for Ng III (Ng 3–4) is not included in the Most Reliable group (see Figure 5), because Samsi did not recognize the find as significant before putting it in storage at Ngandong where Oppenoorth identified it as human two weeks after discovery.

Oppenoorth's 1931 stratigraphic work became the Excavation I Ngandong standard, and it evidently was confirmed by the Survey geologists during their subsequent visits to the site (see Figure 8). All three geologists had a chance to examine the stratigraphy of the excavation at about the same stage of exposure in 1932 as a consequence of Oppenoorth's March site visit and ter Haar/von Koenigswald's June fieldwork. Although this was the last time they shared such an experience (see Table 4; see Figure 8), we have very good reason to conclude that the three geologists were completely confident in the habitat of the first ~10,000 vertebrate specimens collected including most or all of the hominin discoveries up to the middle of 1932 (see Tables 1 and 2).

The geologists' visits after mid 1932 were less frequent, as Ngandong VIII–XI and Tibia A and B (Ng 9–14) were discovered (see Tables 1 and 4; see Figure 8). The records during this period are best for Ngandong VIII and XI (Ng 11 and 14). Ngandong VIII (Ng 11) is even in the Most Reliable group (see Table 5). Von Koenigswald removed a portion of this specimen from its discovery context in August 1933. The fossil consists of disarticulated parietal bones which probably were physically separated *in situ*. When von Koenigswald (1934b) removed the second of the two pieces from the bone bed, it contained six deer antlers and a *Stegodon* tusk ~2.5m long. He also witnessed Ngandong XI in place, but because we have no details of what he observed at the discovery point, do not include this specimen in the Most Reliable group.

Ter Haar (1934a, b) attributed all of the human finds to the same volcaniclastic stratum as the finds with the Most Reliable documentation, when he reviewed the written records for the project. Oppenoorth and von Koenigswald agreed with this assessment (e.g., Oppenoorth 1936; von Koenigswald 1951, 1956). Support for including Ngandong III, IV, VII, and IX–XI, and Tibia A and B (Ng 3–4, 8–14) in the bone-bed cohort is progressively less reliable, leading us to rank these specimens in the Problematic and Least Certain groups of Table 5. Neither of the tibiae has Most Reliable provenience records, introducing an unfortunate level of uncertainty in associating the calvarial and postcranial fossils. Nonetheless, we have no archival evidence contradicting the Survey geologists' conclusion that all of the finds came from the basal bone bed.

HUMAN ACTION

Ngandong is generally treated in the recent literature as a hominin-fossil site with associated non-hominin remains, and not as a site which also included evidence of human action. However, at various points of time in the last 75 years, assertions have been made that the Ngandong Formation did produce human-made objects—flaked-stone implements, ground-stone artifacts, bones split for marrow, bone tools, utilized antlers, cut-marked bones—and even that the hominin assemblage included indications of human violence and cannibalism (see Moore and Brumm 2007 for a recent review of lithic material, and the following other accounts and opinions: Bartstra et al. 1988; Choi 2003; Choi and Driwanto 2007; Corvius 2004; de Terra 1943; Jacob 1967; Movius 1938a,b, 1948; Oppenoorth 1932b, d, n.d.-1935/1936, 1936; Soejono 1969, 2001; ter Haar 1934b; van de Hoop 1941; van Heekern 1957, 1972; van Stein Callenfels 1934a, b, 1936a, b, c, 1940; van Heine-Geldern 1945; von Koenigswald 1933b, 1936a, b, 1951, 1956, 1958, 1975; Zwierzycki 1933–1935, February 27, 1936).

Verifiable artifacts from the Ngandong Formation might provide crucial evidence for establishing the presence of humans in the area at the time of deposition of the *Homo erectus*. This result would be highly important to geochronological and taphonomic studies. Unfortunately, despite the many reports of artifacts, Excavation I Ngandong proves to have a poorly substantiated archaeological record. There are at least three severe shortcomings. First, the Survey did not record, preserve, and describe artifacts with the care they afforded the *Homo erectus* fossils. For example, reputed flaked stone tools do not appear to have been given collection numbers at the time of discovery; their discovery locations are not shown on any available site map; illustrations of most of the objects were not published; and, if the objects were saved over the decades, there has been no modern archaeological analysis published.

Second, the archaeology of all Solo River valley terraces was linked to the Ngandong hominins, and surface finds were mixed with those excavated, as conclusions were drawn on the material culture of the *Homo erectus*. This often leaves us unsure whether the artifacts reported in the literature came from Excavation I Ngandong bone bed or some other locality and stratigraphic circumstance. Third, most of the reports on artifacts were written at a time when human action was too readily presumed to account for the features seen on bone and stone objects.

Taking these shortcomings into account, we conclude the following about the evidence reported from Ngandong. A few lithic artifacts were probably present in the basal-bone bed of the Ngandong Formation, and there is one intriguing account of a cut-marked bone from the assemblage (Choi 2003). However, most of the multifold other evidence offered for human action is probably invalid, or at least is suspect. Moreover, because stone tools are generally durable in surface environments and the Ngandong Formation is (at least mostly) a fluvial deposit, the few lithic artifacts found in the basal-bone bed have a good chance of having been manufactured long before deposition. The description of the cut-marked bone, while being quite specific and potentially significant, is in an unpublished dissertation and requires confirmation. Thus the archaeological record, as it currently stands, does not materially promote establishing a human presence near Ngandong during the deposition of the *Homo erectus* beds.

RADIOISOTOPIC DATING

More than two decades of effort has yet to produce a definitive radioisotopic date for the Ngandong *Homo erectus*, although evidence from several studies favors a mid-Late Pleistocene date, and the provenience results reported here support the latest dating study, that of Yokoyama et al. (2008). Three issues are of principal concern with regard to the published geochronological results: (1) the sampling in most cases has not been tied unequivocally to the human-fossil stratum; (2) the uranium-disequilibrium radioisotopic methods which have been employed show evidence of significant uranium loss (leaching), as well as uptake, making it difficult to interpret the data in terms of geological age; and, (3) the analyses published do not specifically evaluate the possibility that the fossils analyzed had experienced multiple cycles of burial and exposure—the reworking issue discussed in the Introduction. In recounting the results of published studies, below, we focus on these three issues.

No radiocarbon dates have been reported for the site, evidently because there is no charcoal in the Ngandong Formation. Mollusks apparently have never been found, so that dating techniques using organic carbonate have not been applied. The bone bed contains fresh volcanic minerals and small rock fragments, which presumably are amenable to Argon-Argon ($^{40}Ar/^{39}Ar$) dating, but it is unclear how the results could be used to establish a date for the living *Homo erectus* (Swisher et al. 2000). The principal methodologies used in published studies are based on uranium radioisotopic decay.

The first radioisotopic dating of the Ngandong Formation was undertaken by Bartstra et al. (1988) over 20 years ago. They sampled a 2.5m sequence in a 1.5m x 1.5m pit at Ngandong, and found 0.5m of vertebrate-bearing strata above marl. Several *"old people who still remembered the old excavation"* helped Bartstra overcome *"difficulty of finding a good stratigraphic sequence"* as he chose a location for a test pit along the archaeological reserve from the 1930s (G.-J. Bartstra, pers. comm., 2009; the sample location in Figure 3 of Bartstra et al. 1988 evidently is incorrect). Radioisotopic studies following the fieldwork used bone fragments, and found evidence of both uranium uptake and leaching in them. The results were considered experimental and gave widely ranging age estimates (van der Plicht et al. 1989).

Swisher et al. (1996, 1997, 2000) used antelope and bovid teeth from Ngandong to obtain electron-spin-resonance (ESR) age estimates of 27±3 to 46±4 ka (date of burial), based on two models for uranium uptake. Uranium-series (U-series) measurements, made on enamel from these samples, gave older apparent dates. Swisher et al. interpret the incongruity as reflecting a history of uranium uptake, followed by leaching. Grün and Thorne (1997: 1575) thought that this *"seems unlikely,"* and characterize the 27–46 ka ESR results as *"likely to be erroneous."*

Even if this is not a problem, the association of the dated teeth to the *Homo erectus* bed might be. Swisher et al. (1996: 1871, 2000) dug a 1m x 1m pit to a level 2.2m below the ground surface, encountering *"volcaniclastic sandstone with cobbles of…marl similar to that described by Oppenoorth as Layer 2,"* and finding two well-preserved antelope teeth and one elephant tooth in this lithofacies. The teeth certainly could be from Layer 2/II, given the lithology of the basal-bone bed (see Table 3; see Figures 3B and 13), but their sampling effort—90 minutes at the site and one small pit—reduces confidence in their ability to have reliably identified the *Homo erectus* stratum. Others have suggested that their pit might have bottomed in backfill from the 1931–1934 excavations, not in the Ngandong Formation (Westaway and Groves 2009). In addition to using the two antelope teeth which they sampled in the field Swisher et al. (1996: 1872) analyzed a bovid tooth they obtained from GRDC (#6679), noting that the specimen had been *"collected from Oppenoorth's Layer 2, 15 February 1932."* The bone-bed provenience of this tooth would be stronger if the information were known to have come from an old label affixed to the fossil.

Two years after Swisher et al. (1996) was published, Rizal (1998a) reported ESR dates of 19.5–62.3 ka for two bovid teeth excavated in the terrace section from depths of 1.5m (in sandy coarse gravel) and 2.2m (in coarse sand just above marl) at Ngandong. He did not give details on where the sampling took place at the site. The ESR measurements were done by R. Grün. Rizal (1998b) also did experiments in the optical dating of minerals from Ngandong and other terrace sites in the Solo River valley. The techniques used were thermoluminesence (TL) and Infrared Optical Stimulated Luminesence (IROSL). Rizal (1998b) reports TL maximum estimates of ~74 ka and an IROSL range of ~32–106 ka for Ngandong. His results should encourage additional application of luminescence methods.

The photographs, maps and stratigraphic information presented here provide a means by which the sampling of Bartstra et al. (1988), Rizal (1998a, b) and Swisher et al. (1996) can be situated relative to Excavation I Ngandong and the *Homo erectus* discoveries of 1931–1933. A template for recognizing the remnants of this stratum in the field is provided by the photographs of Ngandong V and VI (Ng 6 and 7) *in situ* and Oppenoorth's detailed description of the Ngandong I–III (Ng 1–4) discovery bed (see Table 3; see Figures 12 and 13).

Even if samples are reliably linked to the *Homo erectus* stratum, and geochronological analyses of the samples can be unequivocally interpreted in terms of geological age, there is an additional issue. Using materials that indicate the time since burial will date the living Ngandong population only if there was no significant gap in time between the demise of the human individuals and the deposition of their remains at Ngandong. Most of the published geochronological studies employ methods that might fail to detect multiple episodes of burial and exposure.

The latest study published is important is this regard. Yokoyama et al. (2008)—notably including R. Grün—used gamma-ray spectrometric techniques directly on the original Ngandong I and VI (Ng 1 and 7) specimens. The two fossils are reliably known to have come from the basal-bone bed, based on the data presented here. The uranium-series disequilibrium methodologies of Yokoyama et al. (uranium-thorium and uranium-protactinium methods) led them to estimate that the *Homo erectus* remains were buried between ~40 and 60–70 ka. However, the Ngandong I and VI (Ng 1 and 7) had experienced both uranium uptake, which is expected during burial, and uranium leaching, which complicates estimating the geological age. It is unclear which tests Yokoyama et al. might have conducted to determine whether the specimens were buried in older deposits before being embedded at Ngandong. In using 1931–1932 *Homo erectus* finds directly, Yokoyama et al. had no opportunity to examine the sedimentary rock and fossils that originally surrounded Ngandong I and VI (Ng 1 and 7) in the discovery bed, contextual information that might have allowed further evaluation of the reworking possibility.

Taken as a whole, the available studies fit an age of 40–45 ka, seeming to place the deposition of the human and non-hominin fossils in the mid-Late Pleistocene. We offer further evidence that 40–45 ka is the age of at least some living *Homo erectus*.

TAPHONOMIC CONSIDERATIONS

Taphonomic evidence suggest strongly to us that the specimens Yokoyama et al. (2008) dated were buried at Ngandong a short time (geologically) after the death of the individuals—that is, no geochronologically significant time gap occurred between death and deposition (Huffman et al. 2008b). Descriptions in the physical anthropological literature on Ngandong I and VI (Ng 1 and 7), as well as several other of the human specimens, indicate that the remains probably had not experienced much surface exposure, or even involved fully dried bone when they accumulated at Ngandong. Because the condition of these specimens has been interpreted in the past as indicating that they are reworked fossils (Santa Luca 1978 1980; Westaway 2002; see also Nawrocki et al. 1997), we draw attention to the specific features of the hominin material that lead us to our significantly different conclusions.

The Ngandong VI (Ng 7) calvaria is in such good overall condition that one would not expect it to have been exposed at the surface for a long period of time, an extended duration such as would have occurred if the specimen eroded out of bedrock or was reworked repeatedly during transportation by the Solo River (Huffman et al. 2008b). Most remarkably, despite the fact that Ngandong VI (Ng 7) was embedded with marl cobbles and finer-grained volcaniclastic gravel, which originated far upstream (see Figure 13), the specimen still possesses delicate portions of the basicranium, including the vomer and ethmoid (see illustrations in Balzeau et al. 2003; Weidenreich 1951).

The fine bone in these regions of a calvaria would be subject to rapid destruction when exposed to weathering, eroded out of a river bank, or subjected to bed-load transport with coarse terrigenous materials. Because of its very good condition, therefore, Ngandong VI (Ng 7) would appear to represent the remains of an individual who died shortly before being embedded at Ngandong, remains that were not extensively exposed to weathering, and not reworked in the sense either of having eroded out of a lithified formation or rolled for many kilometers along the stream bed of the Solo River. The mid-Late Pleistocene date of burial estimated by Yokoyama et al. would thus appear to be the geological age of at least one living *Homo erectus*.

A similar case of rapid post-mortem burial can be made for Ngandong V (Ng 6). The specimen, a calotte and basal margins, shows little indication of fluvial abrasion and weathering before burial. Weidenreich (1951: 232) observed that the skull was *"only slightly weathered"* with *"some evidence of erosion"* on the left side of the fossil, *"especially around the base"* (the *"erosion"* is on the side of the specimen opposite to that first exposed by the excavators). Santa Luca (1980: 19) confirmed, *"external surface slightly weathered internal surface smooth with meningeal pattern still clear."*

Although Ngandong V (Ng 6) has less of the base preserved than several other cranial fossils, particularly Ngandong VI and X (Ng 7 and 14), it retains delicate bony portions of the basicranium (see Table 2). Weidenreich (1951: 231) summarized, *"its base is broken out except for the greater part of the nuchal squama of the occipital bone, the lateral part of the left temporal bone, and the anterior part of the orbital areas of the frontal bone."* He (1951: 271) further emphasized that the zygomatic process is preserved on the left side (see also Jacob 1967: 27, 29 with photograph). This portion of the temporal bone was broken off in the other calvarial specimens of the Ngandong suite with the exception of one side each in Ngandong X and XI (Ng 13 and 14). Santa Luca (1980: 18–19) noted of Ngandong V (Ng 6), the *"left temporal complete except for petrous and tip of mastoid process; the upper part of both greater sphenoid wings present."* One of Weidenreich's (1951: Plate 44E) detailed drawings shows the eroded end of the left zygomatic process, as well as the broken tip of the mastoid process on this side of the specimen. Rightmire (1990: 42) noted, *"the glenoid cavity, tympanic bone…are still intact."* Thus, the base of Ngandong V (Ng 6), although mostly missing and eroded locally, still includes delicate regions of bone that generally are lost during surface exposure and fluvial transport.

Equally important, other features on Ngandong V (Ng 6) provide strongly suggestive evidence that the individual died a short time (geologically) before the remains were deposited at Ngandong, and the bone was not even fully dried when embedded. Oppenoorth (1932c: 109, translated) observed that the cranial bone was deformed plastically and also had large sandstone-filled cracks:

> *Ngandong V…is a deformed calvaria….In addition, large gaping cracks run through the skull, which were filled in with cemented volcanic sand.*

The overall effect of the warping is clear on specimen casts and photographs (Santa Luca 1980: 33, Plate 12, bottom; Weidenreich 1951: Plate 22). Kaifu et al. (2008: 553) summarize:

> *In posterior view, the whole vault is slightly deformed to its right in a form of a parallelogram. In basal view, the right temporal bone is anteroposteriorly extended so that the nuchal squama of the occipital faces slightly toward the specimen's left. In addition, the right temporal squama is pushed inward medially.*

There has been no suggestion that the distortion in Ngandong V (Ng 6) or several other Ngandong *Homo erectus* was the result of artificial cranial deformation of the type known in *Homo sapiens* (Antón and Weinstein 1999; Durband 2008). The Ngandong Formation is nearly flat-lying, affected little by tectonic disturbance (see Figures 6, 7, 10B, and 11B). There the basal bone bed evidently was not subjected to folding or faulting that could account for the deformation seen in Ngandong V (Ng 6).

One large crack of the kind Oppenoorth described on Ngandong V (Ng 6) is seen in a photograph of the specimen that he published. The break displaced the entire left posterior wall of the vault, which is >0.5cm thick, judging from the descriptions and illustrations in Weidenreich (1951). The caption for Oppenoorth's (1932c: 110) illustration simply reads, *"view of the left side…after removal of the consolidated part of its surrounding matrix."* Because this side of the vault was fully embedded in the conglomeratic matrix of the discovery bed when Oppenoorth removed the specimen, the damage was very unlikely to have been caused by an excavator fracturing Ngandong V (Ng 6) while exposing it, damage of the type that several other specimens do exhibit (Ngandong III, IX and X; Ng 3, 12, and 13).

The bone of Ngandong V (Ng 6) therefore appears to have been drying while surrounded by compacting sediment, consolidation that warped the bone and then broke it *in situ*. Generally, large cracks in a cranial vault are most likely to form when the bone is substantially dried and reacts to stress in a brittle manner (Krovitz and Shipman 2007), so that the sandstone filled fractures probably record the breakage of dried bone. The sandstone fillings indicate that this dry-bone cracking occurred before the final consolidation of the discovery bed. The infilling clearly took place before carbonate impregnation of the matrix. The burden of the surrounding strata therefore appears to have deformed a still-plastic vault until it dried enough to break rather than bend. Shifting sand and gravel then filled the expanding crack until the process ended with the full consolidation and cementation of the discovery bed.

Decalcification of bone also can render a buried cranial vault susceptible to plastic deformation (Brothwell 1981), but considering the calcium carbonate crust on Ngandong V (Ng 6) and other Ngandong specimens, as well as the proximity of the fossil bed to a source of calcium in the underlying marl, severe calcium depletion during burial seems unlikely. Alternatively, the deformation of Ngandong V (Ng 6) might have taken place under special circumstances when "wet" bone sat on the ground surface before burial at Ngandong, or while "green" remains were being transported to the site. In any probable scenario that accounts for the plastic deformation, the Ngandong V (Ng 6) individual died within a few months or years of being embedded at Ngandong.

It is worthwhile to consider two additional human fossils that appear to have been fresh remains when buried at Ngandong. Ngandong I (Ng 1), the calotte and partial basicranium that has reliable provenience records and that Yokoyama et al. (2008) dated directly, also had sandstone-filled cracks and indications of plastic deformation. Oppenoorth (1932b: 57, translated; also 1933b: Plates II and V, and 1932f) found: *"Ngandong I…shows several cracks, of which the largest ones have considerable separation, having been filled with lime-cemented sand."* Referring to the distortion in Ngandong I (Ng 1), Kaifu et al. (2008: 553) observed that *"the frontoparietal fragment is twisted relative to the major parietooccipital fragment, and the midparietal region is unnaturally flexed in lateral view."* The occurrence of at least two calvarial specimens with plastic deformation—Ngandong I and VI (Ng 1 and 7)—substantially increases the probability that post-burial processes were responsible for the warping (see Kaifu et al. 2008 for indications of deformation in other specimens). We suggest that Ngandong I (Ng 1), like Ngandong V (Ng 6), is from an individual who died so near to the time of burial that the bone had not completely dried, and the warping and sandstone-filled fractures record further drying during the consolidation of the matrix.

Ngandong VIII (Ng 11) presents another instructive case. The parietal bones were found separated by a distance of a few centimeters or a few meters in the volcaniclastic bone bed where the fossil was discovered with a *Stegodon* tusk and six antlers, as described in Provenience (above). Ngandong VIII (Ng 11) is weathered with cracking of the surface seen in photographs (Antón 1999: 228, Figure 4; Santa Luca 1980: 38–39, Plates 17–18; Weidenreich 1951: Plate 25C–F). When the weathering took place is undetermined, however.

Other features of the specimen are even more intriguing taphonomically. Weidenreich (1951: 233; see also, Anton 1999; Jacob 1967; Santa Luca 1980) observed that Ngandong VIII (Ng 11) consisted of:

two parietal bones…found separately, but it was possible to unite them in the sagittal suture without difficulty. The two bones are preserved in their entirety; the coronal, lambdoid, and the right and left squamosal sutures form the borders of the calvarial fragment. None of the sutures bears any evidence of previous fusion….This indicates that the skull fell asunder along the sutures, but no other bones or their fragments were recovered.

Ngandong VIII (Ng 11) probably represents the remains of an individual who had been alive a short time (geologically) before burial, given the nature of the find and the likelihood that the bone bed accumulated as a deposit of the Solo River. Consider the implications of several taphonomic assumptions, for example.

Had the parietals been disarticulated while in the Solo River, they probably traveled only a short distance by the time of deposition (that is, separation came just moments before deposition because longer transport would have dispersed the parietal bones, embedding them farther apart along the stream bed). Had the bone been dried completely while in the Solo, the parietals would have been held together by no more than the interlocking bony digits of the suture, and the flow conditions would not have been rigorous enough to break the interdigitations apart. Had the bones not been dried completely, the parietals would have been held together by collagenous fibers within the sutures and perhaps a covering of skin. With soft tissues still present, the remains would have been those of an individual who had died shortly before the transport. Potentially, fresh remains could have travelled down River for many kilometers. Despite the absence of any reported evidence of tooth marks on Ngandong VIII (Ng 11), one might consider the possibility that a carnivore carried the remains to the point of burial in sandy river deposits along with a *Stegodon* tusk and deer antlers. In most taphonomic scenarios that we see as viable for explaining the context and nature of Ngandong VIII (Ng 11), the time interval between death and deposition is geochronologically insignificant.

As a consequence of the foregoing taphonomic observations, a case can be made that four of the five specimens with Most Reliable provenience—Ngandong I, V, VI, and VIII (Ng 2, 6, 7, and 11)—were deposited soon after death of the individuals (compare to Santa Luca 1980 and Dennell 2004). Whatever the exact post-mortem, pre-burial interval was for these specimens, it probably was short enough to be inconsequential when interpreting radioisotopic results in terms of the geological age of the living individuals.

This conclusion is warranted on the basis of the rate at which fresh-bones generally dry and degrade when exposed to sunlight under warm conditions. Wet- (or green-) bone, which retains much of the chemical composition and elasticity of living bone, transforms over time to dry bone, which has lost collagen- and lipid-proteins and has become more brittle (Krovitz and Shipman 2007; Nielsen-Marsh et al. 2000; Wieberg et al. 2008). Cadavers lying on a soil surface commonly lose the vast majority of their mass through soft tissue decay in just a few days (Carter et al. 2007; see Chin et al. 2007 for one of the few published Southeast Asian examples). Terrestrial carnivores can reduce the time for defleshing to a matter of a few hours. According to experiments conducted by Reeves (2009), avian scavenging, which is generally less well documented than the consumption of carcasses by large terrestrial predators, also leads to rapid loss of soft-tissues.

The end stage of soft-tissue decay of an exposed cadaver is commonly referred to as skeletonization. Full exposure of the skeleton often occurs within a year of death, especially in warm conditions (e.g., Galloway et al. 1989), and is followed over the course of months and a few years by skeletal decomposition. Bones exposed in the tropical grasslands of Africa suffered extensive mineralogical and chemical change, in addition to full drying of the bone and surface weathering, within 15 years (Trueman and Martin 2002; Trueman et al. 2004), placing an outer limit on the normal time frame for the bone-drying process. Elephant bones develop surface cracking more slowly in an African tropical forest (1900mm of rainfall) than on the ground of a savanna (Tappen 1994), leading to the possibility that the drying might be retarded in shaded locales.

Although the post-mortem interval required to dry bone varies considerably, depending on the specific circumstances it experiences, the known rates of surface taphonomic processes indicate that the post-mortem drying and weathering of bone under warm conditions normally takes place in years or tens-of-years. As a consequence, those Ngandong *Homo erectus* specimens showing evidence of limited exposure before burial probably were deposited at the site within a few months or a few years of death. Thus, the methods of Yokoyama et al. (2008) provide a reliable date for the living *Homo erectus* group in proportion to the accuracy of their gamma-ray radioisotopic techniques. Reworking, long a concern in the literature (Santa Luca 1980), would appear to be less important than understanding better the geochemical history of the fossils. Future geochronological research would probably benefit from investigation of dated specimens in conjunction with adjacent sedimentary matrix and associated sets of fossils.

FIELD OPPORTUNITY

The evidence on hand indicates that the opportunity exists at Ngandong to do just the type of field collecting necessary to confirm the geological age of the *Homo erectus* fossils and determine their taphonomic and depositional histories. There had been reports of fieldwork at Ngandong before that of Bartstra et al. (1988), but the geoarchaeological and paleontological work involved remains largely unpublished and therefore does little to illuminate the origin and age of the 1931–1933 discoveries, even in the light of the information presented here. It is valuable to recount the nature of the uncertainties that have arisen over this older fieldwork, before describing the opportunity for new geoarchaeological studies.

Sartono (1976: 15) undertook a brief new search for hominin fossils, apparently having known the layout of the 1931–1933 excavations from the Site Map:

> *A trial excavation* [in the early 1970s]*…very near the north-eastern tip of the monument* [archaeological reserve on Figure 6C]…[In] *about 12 working hours, over one hundred fossil specimens were unearthed….Most…are deer antlers, a few bovid teeth and poorly preserved specimens. Not a single hominid remain was found.*

No notes, maps or specimens from Sartono's work are known to have survived (Y. Zaim, personal comm., 2007).

T. Jacob apparently was more fortunate in discovering human fossils. He attributed three human specimens—two calvariae fragments and a portion of a pelvis—to Ngandong, based on excavations he conducted in 1976–1978, shortly after Sartono's effort (Indriati 2004; Swisher et al. 1996; see also von Koenigswald 1975). Jacob (1977: 476) described the context of the first of his discoveries, Ngandong 15, which were *"fragments of the right orbital portion, the right temporal bone and the right parietal bone;"* the specimen was found during August 1976 in a 2m x 2m square with 160 other fragmentary fossils of deer, water-buffalo, and cattle. A density of 40 specimens per square meter is high relative to that at the Ngandong VI (Ng 7) site or Excavation I Ngandong as a whole. Jacob's (1977) discovery point was 24.5m above the Solo River where the terrace deposits were 0.2m thick. This is extraordinarily thin relative to what was encountered in Excavation I Ngandong. Jacob does not specify where his 2m x 2m square was located, not even verifying it was at Excavation I Ngandong.

Soejono (2001: 147) reported that *"in 1976-1977 a few fragments of a human fossil skull were found together with fossil animal bones at a depth of circa 125-135 cm."* Because of the depth reported, Soejono perhaps was referring to Jacob's second calvarial discovery. Swisher et al. (1996: 1873) cite an unpublished report written by one of Jacob's colleagues (Moelyadi 1982) as indicating that Jacob's excavation was in a *"25 by 14 m area"* adjacent to the old site. But Jacob also dug near Ingraving 2, the 1931 site east of Excavation I Ngandong (see Figure 3A). This leaves uncertain which site produced the pelvic and cranial fossils Jacob assigned to *Homo erectus*. If the pelvic bone could be placed convincingly in the same stratigraphic unit as the 1931–1933 finds, this would add significantly to the inventory of post-cranial elements in the hominin assemblage.

While information is lacking to substantiate that the 1970's finds were hominin fossils that originated from Excavation I Ngandong, Jacob's experiences raise expectations that more *Homo erectus* material could well be present at Ngandong. The sampling and finds reported by Bartstra, Jacob, Rizal, Sartono, and Swisher et al. also make clear a threshold for claiming success in future field efforts—more complete publication of the discovery context.

If exposures with a close lithological and stratigraphic similarity to basal volcaniclastic stratum of 1931–1933 can be identified (e.g., see Table 3; see Figures 3B, 7, 12 and 13), the same sedimentary unit that contained *Homo erectus* specimens probably can be sampled today. Ngandong I, II, V, VI, and VIII (Ng 1, 2, 6, 7, and 11), the fossils in the Most Reliable group, would have the surest link to samples of this kind. The best opportunity for re-identifying the *Homo erectus* stratum is to excavate enough of the current site so that the stratigraphic sequence in new excavation walls can be related to what was revealed in the old ones (see Figures 3B, 7, 10, and 11). Sampling in isolated pits increases the risk of misidentifying the basal volcaniclastic bed and confusing spoil material from the 1931–1933 excavations with strata in place. Sampling precautions would have little geochronological consequence if field and laboratory studies demonstrate that the whole of the Ngandong Formation was deposited in less than a few thousand years (see Bartstra et al. 1988 for an attempt to evaluate this possibility).

The geography of the current landscape in and around the site should be related to the 1934 mapping of the site and surrounding area, so that the discovery points of the 1931–1933 *Homo erectus* can be relocated precisely with respect to remnants of the terrace deposits and the new sampling. Substantial portions of the remaining deposits should be opened up and the stratigraphy documented, so as to determine whether the Survey's basal volcaniclastic bone bed is still present and available for re-sampling. If this facies is identified, new collections of rock and fossils should be made in preparation for taphonomic and geochronological studies. Details should be published, of course.

A geoarchaeological re-examination of Ngandong was begun in 2008 with fieldwork using the archival results presented in this paper (Ciochon et al. 2009). The outlines of the old excavations and the *Homo erectus* discovery points were repositioned relative to the present-day landscape. Undisturbed Ngandong Formation was found in the test pits. In the largest one, conglomeratic, coarse-grained volcaniclastic sandstone had a highly fossiliferous interval ~0.5m above the marl contact, leading to the conclusion that the 2008 field team had successfully relocated the stratum from which the 1931–1933 *Homo erectus* originated (Ciochon et al. 2009). The interval contained carbonate-encrusted, disarticulated fossils and exhibited current laminations (which were similar to those evident in the June 1932 photograph of the basal beds; see Figure 14B). Overall the stratigraphy of the terrace remnants appears to be more complex than Oppenoorth (1932b) described (see Table 3; see Figure 3B). Evidence of the particular interpretation portrayed in ter Haar's cross section was not observed (see Figure 7), however.

SITE FORMATION MODEL

Even if the hominin individuals in the Most Reliable provenience group (see Table 5) are the only ones ever to be confirmed to have been members of a paleodeme, Ngandong raises intriguing questions about the population density and group composition of *Homo erectus* in the region, as well as the events that might have killed so many individuals at one time, and the fluvial processes that concentrated the human and non-hominin remains at Ngandong. Our archival work done before the 2008 field season led us to develop a new site-formation- and paleogeographic-model for the Ngandong Formation (Huffman et al. 2008b, in press). The model proved valuable while working at Excavation I Ngandong in 2008 (Ciochon et al 2009), and should continue to be instructive during future studies on the site and its fossils.

The discoverers only gave brief accounts of the depositional history and taphonomy of the *Homo erectus,* and of course, their ideas are dated after so many decades (e.g., ter Haar 1934a, and von Koenigswald 1956). Recent attempts to reassess the issues met with limited success because they did not adequately consider the implications of the volcaniclastic nature of the bone bed and other geological fundamentals (e.g., Dennell 2004; Nawrocki et al. 1997). Our working hypothesis overcomes some of the difficulties. In closing, we present the principal components of the model to advance discussion of the site formation processes and the paleoanthropological implications of the *Homo erectus* assemblage.

We account for the exceptionally great volume of skeletal material at Ngandong by first postulating that, at the time of death, the animal and human populations had concentrated in the Solo River valley upstream of the site. Eruptions themselves might have led to this faunal concentration if the highlands surrounding the active vent or down-wind areas blanketed with ash had become dangerous or inhabitable. Alternately, as Pat Shipman has suggested to us, a severe drought might have caused the populations to converge in riparian zones of the Solo valley (see Shipman 1975 for a modern case). Under the stress of the catastrophic events, the younger and older members of the *Homo erectus* population might have succumbed earlier than individuals in more robust condition.

A dense scattering of carcasses formed in the valley, as we envision the taphonomic history to be, when deadly ash falls and ash flows were emplaced, or as the herbivores depleted the forage and starved to death. Over a period of months, the *Homo erectus* and non-hominin carcasses decomposed to the point of skeletal disarticulation. The corpses presumably were partially consumed by carnivores, which prominently included tigers and panthers (Hertler and Vomer 2008), and potentially included avian scavengers. The absence of reported carnivore damage on the Ngandong specimens suggests that perhaps the carnivores were so satiated with the abundance of meat that they did not consume much skeletal material.

Then as monsoon rains or new eruptions came, we posit that the bones were swept up by floods originating as mudflows (lahars) on the volcano. The floods presumably also carried off the carcasses of more recent deaths and a few live animals, adding well-preserved remains to those that had undergone skeletonization and weathering. The fluvial transportation generally produced modest bone abrasion and only sorted the skeletal assemblage to a limited degree hydrodynamically because the dense, sediment-charged flood (hyper-concentrated flow) carried the bones mostly in suspension. The human bony remains had varying shapes, including nearly spherical *Homo erectus* calvariae (e.g., Ngandong VI, Ng 7) and flake-like elements (e.g. Ngandong II and VII, Ng 2 and 8; see Table 2).

In addition to the volcaniclastic material from the distant volcano, the sediment-charged waters of the flood picked up marl cobbles that had been shed into the Solo River Gap from the surrounding bedrock of the Kendeng Hills (see Figure 1). The flood waters might have formed a pool upstream of a calcareous-sandstone outcrop belt that crosses the Gap just north of Ngandong (see Figure 5A), causing the rapid accumulation of bone-bearing sands and gravels at the future Ngandong site, as the sediment-charged waters entered the pool.

A sizeable *Homo erectus* population appears to have inhabited the Solo River drainage before the postulated catastrophic events. The same events also possibly resulted in human remains being deposited at other points along the River, such as in the Sambungmacan area, west of Trinil. The principal paleogeographic elements of the region were generally similar to the present-day landforms. Between Ngandong and the Indian Ocean shoreline on the south was the mid-island belt of stratovolcanoes of Java and the Southern Mountains (see Figure 1). The Ngandong site was substantially inland of the Java Sea coast on the north, but the distance upstream from the mouth of the Solo River may have been near or far, depending upon the glacio-eustatic height of sea level and the regional tectonic regime at the time of Ngandong deposition.

If the glacio-eustatic sea level was relatively high at the time, the *Homo erectus* terrain might have been paleogeographically isolated by surrounding seas. The upland core might have been an island, as it is today, or a narrow peninsula jutting eastward regionally from the Malaysian mainland toward the island chain (Nusa Tenggara) where Flores lies, 1100km away. If sea level was low, on the other hand, the area of lowlands north of the Kendeng Hills would have been vastly larger than is the case today. This is because the continental shelf under the Java Sea, which separates Java from Borneo, is broad and shallow (400km x 1200km and generally <50m deep). If low standing glacio-eustatic conditions existed when the Ngandong hominin were alive, thousands of *Homo erectus* might have occupied the huge fluvial and marginal-marine province now below the Java Sea.

Here, the *Homo erectus* might have come into contact with *Homo sapiens* like those known from Niah Cave of northern Borneo, ~1250km from Ngandong. More precise biogeographic alternatives will become clearer as the depostional history, geological age, paleogeography, and paleoenvironment of Ngandong are better established. But the great distances between Niah, Ngandong, and Flores, and the fact that three Late Pleistocene species of *Homo* inhabited the three areas, suggest that the current scientific sample of the prehistoric hominin diversity in Southeast Asia is still significantly incomplete, even after the passage of the 119 years since Eugene Dubois discovered *Pithecanthropus erectus* at Trinil.

CONCLUSIONS

The Ngandong discovery record is stronger than has generally been acknowledged in the paleoanthropological literature over the last four decades, and the record has been considerably strengthened by the addition of the previously unpublished maps, photographs, and discoverers' accounts presented here (see Tables 2, 3, and 4; see also Figures 4, 6, 7, 12, 13, and 14). Based upon these and other archival materials, together with the publications of the Survey geologists, we conclude that at least five *Homo erectus* fossils, and possibly all of the specimens excavated in 1931–1933, originated from one thin, gravelly volcaniclastic bone bed near the base of the terrace sequence—the context claimed for the finds by the Survey geologists.

The five best-documented discoveries are Ngandong I, II, V, VI, and VIII (Ng 1, 2, 6, 7, and 11). These specimens make up the Most Reliable provenience group of Table 5. They include: the best-preserved calvarial fossil (Ngandong VI, Ng 7); the holotype of *Homo (Javanthropus) soloensis* (Ngandong I, Ng 1); another largely complete calvaria (Ngandong XI, Ng 14; see Table 2); both male and female individuals (Ngandong V and VI, Ng 6 and 7, respectively); and one juvenile (Ngandong II, Ng 2; see Table 1). Neither tibiae is in the Most Reliable group, but Tibia A (Ng 9) probably came from the bone bed, as did calvarial specimens Ngandong III, VII, and XI (Ng 3–4, 8, and 14). These fossils comprise the Problematic group of Table 5. For the Least Certain group of the Table—Ngandong IV and IX, and Tibia B (Ng 5, 10, 12, and 13)—substantiation is severely limited or altogether lacking.

The five well-documented discoveries by themselves are sufficient to establish firmly the credibility of the discoverers' contention that multiple *Homo erectus* remains were concentrated in the basal-bone bed of the Ngandong Formation, having been deposited at or near the same time. The provenience data therefore support the proposition that the *Homo erectus* assemblage (or at least the Most Reliable group) represents a paleodeme, and the individuals died together during one catastrophic period. The provenience records also confirm that the *Homo erectus* fossils co-occurred with the variety of terrestrial and aquatic taxa reported by Oppenoorth (1932b). And the *Homo erectus* remains were probably sedimentary constituents which, like the non-hominin fossils and the volcanic- and marl-clasts in the basal-bone bed, were transported by the Solo River before coming to rest at Ngandong.

These results will permit geochronological and taphonomic studies of the Ngandong *Homo erectus* to proceed with greater confidence than previously has been the case. We make one additional advance here.

The provenience detail now in hand greatly improves the prospects of identifying the *Homo erectus* stratum at the site and collecting rock and fossil samples useful for determining the radioisotopic age of the bed. For the dating of any fluvial constituent to succeed in establishing the geological age of the living *Homo erectus*, there cannot have been a geochronologically significant gap in time between the death of the human individuals and the burial of their remains at Ngandong—the *Homo erectus* material certainly cannot be reworked fossils. Likewise, if a non-hominin fossil is dated as a proxy for the age of the *Homo erectus* bed, no significant gap should exist between the death of the animal and the burial of its remains. And if a volcaniclastic constituent is used, no significant gap should occur between eruption and deposition.

We have presented evidence validating the first of these conditions—the penecontemporaniety of living hominins with deposition at Ngandong. Published descriptions of several *Homo erectus* calvarial fossils indicate: (a) delicate bony features (most notably, the ethmoid and vomer remnants on Ngandong VI, Ng 7); (b) limited indications of preburial weathering (e.g., Ngandong V and VI; Ng 6 and 7); and, (c) plastic deformation and sandstone-filled fractures that probably represent the warping and breaking of bone as it dried during burial (Ngandong I and V; Ng 1 and 6). From features such as these, we conclude that at least some *Homo erectus* remains were likely to have been embedded at Ngandong within a few months of death.

Two of the *Homo erectus* specimens analyzed by Yokoyama et al. (2008) when estimating a date for the Ngandong population at ~40 to ~60–70 ky (Ngandong I and Ngandong VI; Ng 1 and 7) are among those showing evidence of rapid burial after death, as well as having secure provenience in the basal-bone bed. The ~40 to ~60–70 ka date therefore is justifiably taken as the date of death of at least some of the Ngandong *Homo erectus* individuals, valid to the extent of the accuracy of the radioisotopic methodology itself. The maximum age of ~60–70 ka calculated by Yokoyama et al. further would apply to the entire Ngandong fossil deposit.

To explain the rapid post-mortem burial of so much skeletal material at one site, we suggest that the human and non-hominin populations were concentrated upstream of Ngandong—aggregated in response to volcanic eruptions or drought—when starvation or new eruptions killed them. And after the skeletonization and disarticulation took place over a matter of months, but generally before severe weathering of the bony remains occurred, the *Homo erectus* and non-hominin skeletal material was carried down the Solo River by lahar flooding to Ngandong. The site therefore appears to have formed as a consequence of a large faunal kill-off and the mass transport of skeletal remains—including *Homo erectus*—by the Solo River.

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