A review on paleoenvironment suitability for hominid fossils and other early vertebrate faunas: a case from Pucangan and Kabuh Formations, Central and East Java, Indonesia

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ABSTRACT

The northern part of the East Java Basin has become a focus of research by earth scientists, among others, because of the existence of hominid fossils and remains of other vertebrate taxa within the Quaternary sedimentary sequence. Fossil-bearing layers are found in the Kendeng Zone, mostly within the well-known Pucangan and Kabuh Formations, which are distributed from Central to East Java. However, not all formations contain vertebrate fossils as well as hominid elements. It is important to consider what factors may have influenced the concentration of vertebrate fossils in those formations. In this study, we describe sedimentary facies at three key field locations: Sangiran, Ngawi, and Mojokerto. Our study indicates that vertebrate remains and hominid fossils mainly accumulated in continental sediments associated with lacustrine and fluvial systems. In this regard, Sangiran and Ngawi B offer the greatest prospect for yielding hominid remains, owing to their unique paleoenvironmental and paleogeographical settings as a highland during the Early-Middle Pleistocene period. Certain parts of the Kabuh Formation in the Mojokerto region also hold high potential, especially those displaying evidence of continental deposition.

INTRODUCTION

The northern part of the East Java Basin (the area between 110°30' to 113° E and 6°22' and 7°41' S) has become a focus of considerable interest to earth scientists due to the existence of oil and gas resources, and a continuous sequence of sediment-

ary layers from Mid-Miocene to Pleistocene in age, some of which have yielded fossils of early hominids as well as a wide range of other vertebrate fossils which occur in certain Quaternary sediments.

Based on physiographical expression, the northern part of the East Java Basin can be divided into four zones. From north to south, these are the North Java Sea Platform, Rembang, Randublatung Depression, and Kendeng. The Kendeng Zone is the most famous zone for paleontologists, since a number of hominid and other vertebrate fossil assemblages occur within this zone in the Pucangan and Kabuh Formations [1]. Furthermore, the Kendeng Zone can be divided into three sub-zones: West Kendeng (between Mt. Ungaran and Purwodadi), Middle Kendeng (between Purwodadi and Mt. Pandan), and East Kendeng (between Mt. Pandan and Mojokerto) (Figure 1).

The Pleistocene lithological unit exposed at Pucangan hill 20 km north of Jombang (East Java) was named as "Pucangan" and Kabuh is the name of a village located about 7 km north of Ploso, in the Jombang region of East Java [3].

In the Sangiran area, hominid and other vertebrate fossils have mostly been correlated with the Pucangan and Kabuh Formations. In terms of their relative stratigraphical positions, the preceding formation is older than the later formation [4]. Along with Sangiran, Trinil is also well known as the site of hominid fossils and large vertebrate faunal assemblages. At Trinil, which is located about 8.5 km west of Ngawi (East Java), Dubois found the first pieces of the hominid fossil he named *Pithecanthropus erectus*, which is now known as *Homo erectus* [5].

Figure 1. Kendeng Zone and sub-zones: West, Middle, and East Kendengs [2].

The Pucangan and Kabuh Formations extend through the Kendeng Zone, raising the question of why hominid and other vertebrate fossils found within these formations are mostly concentrated within the Sangiran area only. In this article, we will address this problem by examining sedimentary facies at two key sites in East Java: Ngawi and Mojokerto.

MATERIALS AND METHODS

We conducted field mapping survey in three prospective areas: Sangiran, Ngawi, and Mojoroto. As many as three measured stratigraphic sections (MSS) on each area were completed in order to systematically record the geological and paleoenvironmental setting. Fifteen samples were taken from each MSS and prepared for fossil analysis. Analyses were conducted using optical and polarizing microscopes.

RESULTS AND DISCUSSION

Sangiran area

Located on the eastern end of West Kendeng, Sangiran is one of the world's most longstanding and celebrated sources of

Figure 2. Key sites discussed in the text. The main localities under study are in Central and East Java, namely Sangiran, Ngawi, and Mojokerto.

Homo erectus fossils and other vertebrate fauna. The fossils mostly come from layers positioned stratigraphically between the Sangiran and the Bapang Formations [6]. Those names of formations introduced by Itihara et al. [7] for the Pleistocene sediment exposed in the Sangiran area are synonymous with the Pucangan and Kabuh Formations, respectively.

In the Sangiran area, the Pucangan Formation consists of the following three lithological components (from lower to upper): lower volcanic breccia, diatomaceous clay member, and black clay member (see Figure 3). The Pucangan Formation comprises Lower Pleistocene sediment and unconformably overlies the Upper Pliocene Kalibeng Formation.

The lower volcanic breccia contains tuffaceous sand with andesitic fragments and in some places displays *Corbicula*-bearing clay and mollusc shells [8]. According to Sartono [9], the presence of the lower volcanic breccia is related to the eruption of Mount Lawu during the Lower Pleistocene.

The clay-diatomaceous clay member consists mainly of bluish-gray and yellowish clay with diatomite intercalations. This unit is rich in benthonic foraminifera. The 2- to 7.5-m-thick diatomite is characterized by laminated sedimentary structures. The black clay member consists of bluish-gray clay with intercalations of lignite, thin tuffs, and foraminiferal sand. There are at least five layers of foraminiferal sand, and in some places, the sequence contains cross-bedding structures. Some vertebrate-bearing layers, among others between T3 and T4, can also be observed in this unit.

According to Itihara et al. [10], the lower part of the Pucangan Formation, below Shell-1 (S1), was deposited in the brackish to inner bay zone of an estuary, while the upper part is of lacustrine origin (see Figure 3), confirming the results from Suzuki et al. [11], Tipsword et al. [12], and Vos and Aziz [13].

The Kabuh Formation consists mainly of clay, silt, sand, iron sand, and gravel of fresh water origin. However, the lower part of this formation, the so-called Grenzbank bed (or zone), represents the deposit of a coastal environment and gradually changes toward the top of the formation to sediments of distinctly lacustrine and fluvial origin [7]. Three distinct tuff layers are frequently found in the Kabuh Formation: the lower, middle, and upper tuffs.

According to Sudijono [14], the Grenzbank Zone is a pebbly sand bed with one or more lenticular interbeds of hard calcareous sand and pebbles; clay or silt intercalations are often present. The Grenzbank Zone is rich in vertebrate fossils. Some hominid fossils are considered to come from this zone (and/or the top horizon of the Pucangan Formation), such as those specimens known as S1b (Pb), S4 (P.IV), S6 (Ma), S9 (Pc), S15a (Pd), and S22 (Pf) (see Figure 3).

The hominid from Sangiran can be divided into two assemblages: (1) Grenzbank/Sangiran (G/S) and (2) Bapang AG (Above Grenzbank). In terms of its stratigraphy, G/S derives from the layers of the uppermost part of Pucangan Formation and the Grenzbank layer as the lowest part of Kabuh Formation. The Bapang AG is from the lower and middle

Figure 3. Pucangan and Kabuh Formations in the Sangiran area [7, 8, 15, 16].

part of Kabuh Formation [5]. Figure 4 displays some of *Homo erectus* specimens as a member of G/S and Bapang AG assemblages.

Ngawi area

Ngawi is located in East Java about 70 km northeast of Solo. There are two study sites in this area, namely Ngawi A, which is situated north of Ngawi city, and Ngawi B, which is situated about 20 km east of Ngawi A.

In Ngawi A, four formations are exposed, namely (in ascending order) the Kerek, Kalibeng, and Klitik members, and the Pucangan (Figure 5). The Klitik member of the Sonde Formation is characterized by the intercalation of calcareous sandstone and sandy limestone at the base and limestone intercalated by sandy marl at the upper part. It is unconformably overlaid by the Pucangan Formation. Furthermore, Choiriah [17] also studied the benthonic foraminifera content in the Klitik member. Based on the occurrence of benthonic foraminifera, such as *Ammonia beccarii* and *Amphistegina lessonia*, they argued that the Klitik member formed in a marine setting at about 20–100 m

depth (middle nerithic) during the Early–Middle Pleistocene (Figure 5).

According to Choiriah [17], the content of nanoplanktonic fossils in those formations are

- 1 Late Miocene–Early Pliocene or NN12–NN13 (on the basis of last occurrence of *Discoaster quinqueramus*, first occurrence of *Ceratolithus acutus* and *Ceratolithus rugosus*, while *Discoaster asymmetricus* was still absent),
- 2 Late Miocene–Late Pliocene or NN13–NN18 (on the basis of the occurrence of *Ceratolithus rugosus* and last occurrence of *Discoaster brouweri*), and
- 3 Early–Middle Pleistocene or NN19–NN20 (on the basis of last occurrence of *Pseudomiliana lacunose* and first occurrence of *Gephyrocapsa ozeania* and *Gephyrocapsa caribbeanica*). The relative age of Klitik member of Sonde Formation as NN19–NN20 is equal to N22–N23 based on Blow zonation (see Figure 6)[18].

The Pucangan Formation consists of coarse to pebble-boulder sandstone at the base, while the upper part is characterized by the intercalation of sandstone and clay (Figure 6). The relative age of this formation is uncertain due to the lack of diagnostic

Figure 4. The stratigraphical position of *Homo erectus* specimens in Sangiran.

micro-foraminifera fossils. However, according to Pringgoprawiro [3] and Hita and Zaim [19], the Pucangan Formation can be assigned to the Pleistocene. Based on the presence of sedimentary structures, such as the occurrence of cross-bed lamination, the environment of the Pucangan Formation at this site is considered to be terrestrial/continental nature. In Ngawi B, the Kabuh Formation, which overlies the Pucangan Formation, is characterized by sandy conglomerate and sandstone with cross-bedding lamination and fining upward at the lower part and intercalation of sandy clay and tuff at the upper part (Figure 7). Meanwhile, the Pucangan Formation consists of breccia volcanic intercalated with tuffaceous sandstone. Neither the Pucangan nor the Kabuh Formation contains plankton or benthon foraminifera. However, it is considered that the relative age of the Pucangan Formation is Lower Plesitocene, or N22, because the Pucangan Formation unconformably overlies the Upper Pliocene Sonde Formation [20]. In addition, for identification of the relative age of Kabuh Formation, we refer to Koenigswald’s statement in [3] that the identification of the relative age of Kabuh Formation is based on the vertebrate

Figure 5. Pucangan and Kabuh Formations at Ngawi A [17].

Figure 6. Correlation between two time units based on nanno-planktonic and microplanktonic foraminiferas [21].

Figure 7. The stratigraphy of Pucangan and Klitik members of the Sonde Formation at Ngawi A [17].

fossils, especially the presence of the artiodactyla fossils like *Axis lydekkeri* and *Duboisia kroesenii* as the index fossil for the Middle Pleistocene. Based on sedimentary character, the Pucangan and Kabuh Formations in Ngawi B were deposited in a terrestrial/continental environment, and it is likely the Kabuh Formation was deposited in an alluvial environment (i.e., a meandering stream system).

Mojooroto area

Mojooroto is located about 12.2 km northwest of Mojokerto and 81 km east of Ngawi B. The sedimentary formations exposed in this location, from oldest to youngest, are as follows: Sonde, Pucangan, and Kabuh Formations (Figure 8).

The Sonde Formation is characterized by yellowish white to gray marl and clayey marl, contains micro-foraminifera, and is intercalated by tuff in the lower part. According to Pringgoprawiro [3], this formation unconformably overlies the Klitik member of Sonde Formation. The contribution of micro planktonic foraminifera such as *Globorotalia menardii*, *Globorotalia tumida*, *Globorotalia tosaensis*, *Pulleniatina praecursor*, and *Globigerinoides fistulosus* indicates that the relative age of the Sonde Formation is Upper Pliocene (N20–N21). Furthermore, on the basis of benthonic foraminifera, the Sonde Formation was deposited in a marine environment at about 50–200 m depth (middle to outer neritic) (Figure 9).

The Pucangan Formation, which conformably overlies the Sonde Formation, is characterized by blackish sandy claystone, contains abundant mollusca in the upper part, as well as bluish

claystone intercalated by sandstone and claystone in the middle part and blackish marly claystone in the lower part. Based on its micro-foraminifera content, the relative age of the Pucangan Formation is Upper Pliocene (N21). It was deposited in a marine environment at about 5–100 m depth (inner to middle neritic).

The Kabuh Formation conformably overlies the Pucangan Formation and is characterized by sandstone, cross-bedding lamination, marly claystone, and abundant mollusca and micro-foraminifera. Based on its micro-foraminifera content, the

Figure 8. Pucangan and Kabuh Formations at Ngawi B [20].

Figure 9. Pucangan and Kabuh Formations at Mojokerto [22].

relative age of the Kabuh Formation is Upper Pliocene–Middle Pleistocene (N21–N23). The deposit environment of the Kabuh Formation varies between continental/terrestrial and inner neritic (Figure 10).

CONCLUSION

By comparing each stratigraphic section in the East Java Basin study area (see Figure 9), it is possible to discern a pattern in the geological record, which we elucidate as follows:

- 1
- The Pucangan and Kabuh Formations in the Sangiran and Ngawi B areas were deposited during roughly the same interval of time (geological period) and in the same paleoenvironment (i.e., continental/terrestrial setting).

Figure 10. Compilation of the stratigraphy examined.

- 2
- The Pucangan Formation in Ngawi A is younger than the Pucangan Formation at Sangiran and Ngawi B; however, it is also of continental origin. At Ngawi A, the formation coinciding with Pucangan and Kabuh Formations both in Sangiran and Ngawi B is the Klitik member of Sonde Formation, which was deposited in a marine setting. This indicates that the paleogeographical setting at Ngawi A was marine in nature in the Early–Middle Pleistocene. Notably, however, Ngawi B (situated about 20 km east of Ngawi A) was a highland in the Early–Middle Pleistocene.
- 3
- The Pucangan Formation and the lower part of the Kabuh Formation in Mojokerto are older than the same formations from Sangiran and Ngawi B. Those formations from Mojokerto were deposited during the Upper Pliocene. The Pucangan Formation formed in a marine environment, but the paleoenvironment of the Kabuh Formation varies between marine and continental settings. Accordingly, in the Early–Middle Pleistocene, Mojokerto was situated close to the sea where sea-level fluctuation frequently occurs.

With regard to the search for hominid and other vertebrate fossils, Sangiran and Ngawi B are promising areas because of their paleogeographical setting as islands in the Early–Middle Pleistocene. Some parts of the Kabuh Formation at Mojokerto also have potential for yielding such findings, especially the unit that is of continental origin. Therefore, to improve the chances of recovering elusive fossil remains in the Pucangan and Kabuh Formations in the Kendeng Zone, the circumstances of their paleoenvironmental setting should be considered first.

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Competing Interests

The authors declare no competing interests.

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