Revised age for Mojokerto 1, an early *Homo* erectus cranium from East Java, Indonesia

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Abstract

Dates of around 1.8 Ma have been claimed for a hominin cranial vault excavated near Mojokerto City in East Java, Indonesia. Such an early date for presumed *Homo erectus* in East Asia would require a major revision of the general model for timing of initial hominin dispersal 'Out of Africa'. Instead, our field study and redating of two pumice horizons at the site indicate that the age of the Mojokerto cranial vault is less than 1.49 Ma. Furthermore, we argue that a basic understanding of site and regional depositional processes is fundamental for assessing the significance of any radiometric date.

Introduction

In 1936, a hominin cranial vault was excavated near Mojokerto City, East Java (Duyfjes 1936; Fig. 1). The find, termed Mojokerto 1, was of a child too young to be taxonomically classified with certainty, but it is generally regarded as *Homo erectus* (Jacob 1976; Widianto 2001:35). Subsequently, pumice just below the findsite was dated by K/Ar and $^{40}Ar/^{39}Ar$ to 1.9 ± 0.5 Ma (=million years ago) and 1.81 ± 0.04 Ma respectively (Jacob and Curtis 1971; Swisher et al. 1994). These results have been widely quoted, if somewhat cautiously, in both the scientific and popular literature (Sartono et al. 1981; Bellwood 1997). If they are correct, then the cranial vault is about the same age as the earliest *Homo erectus* in Africa (1.89 Ma), and would require a major revision of the general model for timing of initial hominin dispersal 'Out of Africa'. Our work indicates that the previously reported radiometric results do not provide an accurate age estimate for the cranium: they may date nearby pumice, but they are significantly older than Mojokerto 1.

The study area

Mojokerto 1 was found in the Kedungwaru Anticline, the axis of which lies east-west and the crest of which has been truncated by erosion. The strata are horizontal at the axis and dip 20° at the northern edge of the anticline 1.35 km to the north. We constructed a stratigraphic columnar section by measuring the extent, dip and strike of strata from the axis of the Kedungwaru Anticline to its northern edge. For this we used geological exposures along the road between the towns of Perning and Sumbertengah as a convenient transect. Furthermore, the sequences of strata at the Mojokerto 1 findsite and adjacent areas with the same sandy gravel layer were recorded in detail. This sandy gravel is not represented as an outcrop along the road, but its dip and strike were used to extrapolate its position on the road traverse.

The exposed Kedungwaru strata are some 200 m thick and provide a depositional record of a delta complex presumably formed in response to sea level changes or tectonic movement. The complex comprises three sequences - S1, S2 and S3 in ascending order (Fig. 2). Each sequence constitutes three distinct facies associations, interpreted as a prodelta succeeded by a delta front and overlain by delta plain deposits. Each represents the progradation of a fluvial dominated delta into a shallow water sea/lagoon. All the delta plain facies contain vertebrate fossils. Mojokerto 1 was deposited in the earliest of these (S1).

The cranial vault was found at a depth of one metre in gravelly sand/sandy gravel on a point nine metres above a tributary of the Klagen River. At the findsite and in the 3 m scarp below it, the yellow sandstones comprise reworked materials; a range of rock types, including pumice, is evident in the gravels, which occur in localised, size-sorted lenses.

The marine and fluviatile sediments seem overwhelmingly to comprise materials derived and transported by erosion of older geological units, most probably from the Kalibeng Formation of the Kendeng Hills to the north, which is of Miocene to Pliocene age. Analysis of nanofossils from four strata of the Kedungwaru Anticline showed that these are also of Miocene-Pliocene age, indicating that they had been reworked from older sediments (Limbong 1999). However, there are two circumstances in the study area in which the age of specific components may approximate the time of strata deposition – Mollusk Horizons and Pumice Horizons.

Mollusk Horizons

There are two layers of marine sediment containing shellfish: Mollusk Horizon II in the lagoon deposits at the anticline axis, and Mollusk Horizon III in the S2 sequence in both wings of the anticline. The condition of the shells and the fact that bivalves usually remain paired indicates that they were deposited soon after the death of the animal. However, we are uncertain as to which dating technique might realise this dating potential.

Pumice Horizons

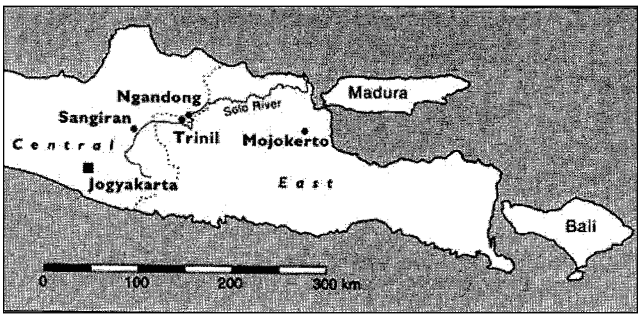

Figure 1 General location of the Mojokerto 1 findsite in East Java, Indonesia.

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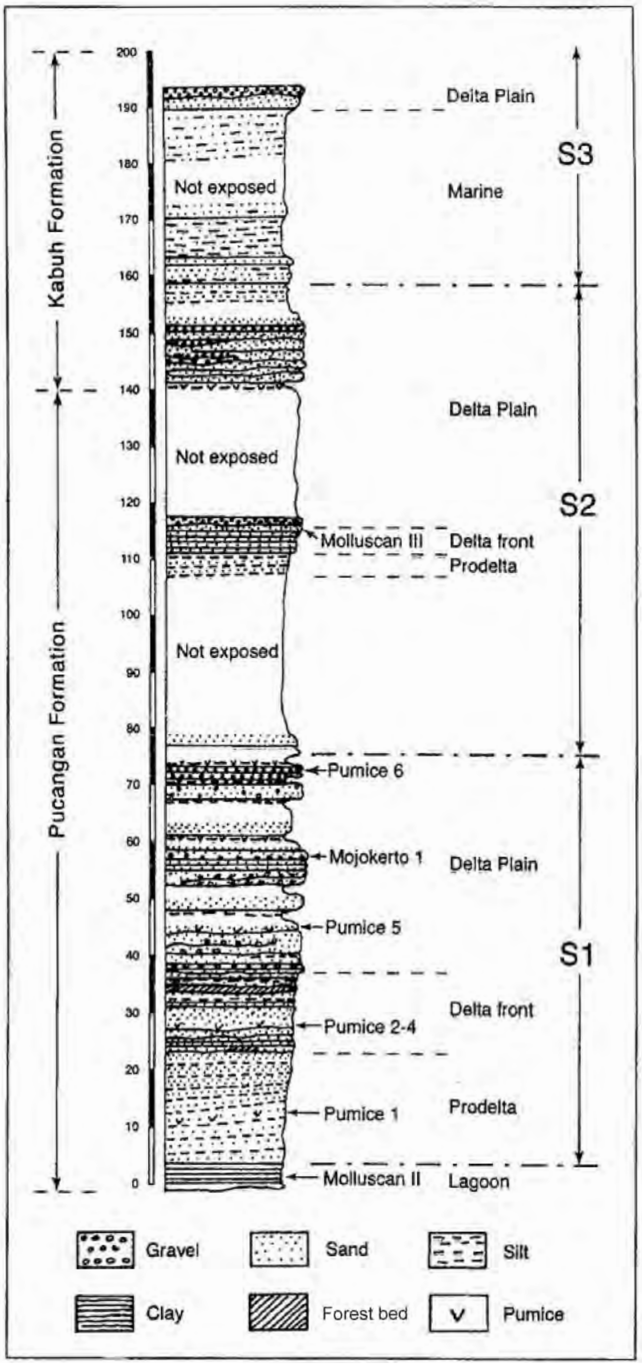

Figure 2 Geological column section of the Kedungwaru Anticline showing the position of Pumice Horizons and the Mojokerto findsite.

There are six pumice horizons in the Mojokerto stratigraphic sequence (Fig. 2). Most are gravelly admixtures of size-sorted pumice and other rock types, indicating that their components may be of different sources and ages. They are also of limited extent. Pumice Horizon 6, located 15 m stratigraphically above the findsite, could potentially provide a minimum age for the cranium. However, this horizon is exposed in a low scarp only 15 m long, is size sorted and is mixed with other gravel. It is, therefore, uncertain whether the age of the pumice within Pumice Horizon 6 approximates its time of deposition. In contrast, the depositional features of Pumice Horizon 5, located 13 m stratigraphically below the Mojokerto 1 findsite, mean that its pumice and time of deposition are of the same age.

Pumice Horizon 5 is exposed in the wall of a quarry 320 m north of the anticline axis on the west side of the road between Perning and Sumbertengah, and 300 m west of the Mojokerto findsite. It is a 15 cm thick layer of pumice cobbles, pebbles and granules with virtually no other rock types, and extends at least several hundred metres. The pumice is water-rolled, indicating that it has been transported into the region from some distance, but it has not been size-sorted. This evidence indicates that Pumice Horizon 5 represents a 'flush' of new material entering the system, presumably because of volcanic eruptions. Pumice from this horizon has not been extensively reworked and is therefore particularly suitable for dating (Fig. 2). In order to test previously reported dates for the locality, pumice samples from Pumice Horizons 5 and 6 were collected for zircon fission track dating.

Dating

Sample preparation

The Mojokerto pumice samples were prepared and the fission tracks counted by O'Sullivan at the University of Melbourne. They were crushed and apatites and zircons in the 60-250 µm size range were separated using a Gemini table and standard magnetic and heavy liquid techniques. Zircon grains were mounted in FEP teflon, and after optical-quality polishing, were etched in an eutectic KOH-NaOH melt at 225°C for ~125 hours. Neutron irradiations were carried out in a well-thermalized flux in the HIFAR reactor, Lucas Heights, Australia.

Fission track ages were measured using the external detector method, which was particularly important in this study since it allowed dating of individual grains within a sample rather than relying on a bulk sample age, which can contain contaminants. The muscovite detectors were etched for 20 minutes in 48%HF at room temperature to reveal the induced tracks. Thermal neutron fluences were monitored by measuring the track density recorded in muscovite attached to pieces of the U3 standard glass. Fission tracks were counted in transmitted light using a dry 100x objective at a total magnification of 1600x. Only grains with sharp polishing scratches were counted. A total of 51 individual grains was dated.

Ages were calculated with the standard fission track age equation using the zeta calibration method (Hurford and Green 1982) and errors were calculated using published methods (Green 1981). Data originally showed evidence of asymmetric spreads of single-grain ages. Therefore, the 'central age' (Galbraith and Laslett 1993), which is essentially a weighted-mean age, was reported. Data from grains deemed to be obvious contamination, based on their significantly older ages, were removed before a final age calculation was made. A personal zeta calibration factor of 87.8 ± 3 (for PO'S) was determined empirically using zircon age standards with independently known ages.

Results

Analytical results and distributions of the primary zircon grain ages for Pumice Horizons 5 and 6 are shown in Fig. 3. The sample from Pumice Horizon 5 yielded a zircon fission track date of 1.49 ± 0.13 Ma. Because of the depositional characteristics of the horizon, we are very confident that this provides a maximum age for Mojokerto 1.

In contrast, a zircon fission track age of 1.43 ± 0.15 Ma for Pumice Horizon 6, located 15 m stratigraphically above

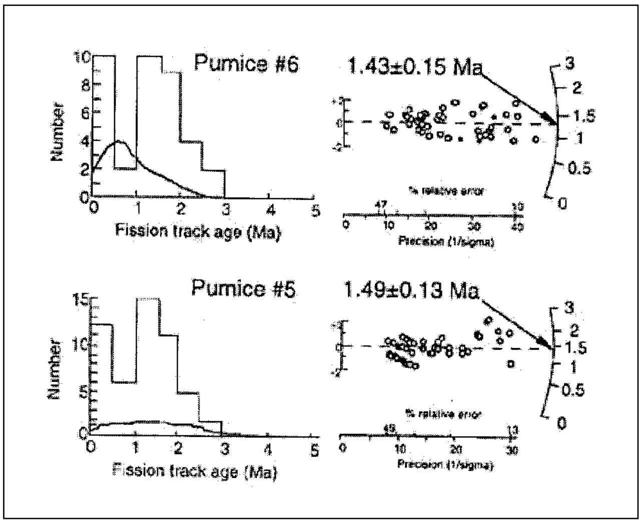

Figure 3 Single grain age results from Pumice Horizons 5 and 6 in the form of simple histograms and radial plots. On radial plots, each age has unit standard error (±2) on the y-axis, its actual precision is indicated on the x-axis, and its age is read by extrapolating a line from the 0-point through the plotted point to the logarithmic age scale on the right perimeter.

the Mojokerto 1 findsite, may provide a minimum age for the cranium, or may date older reworked material.

Discussion

The fission track date of ~1.49 Ma for Pumice Horizon 5 fits well with a very specific palaeo-magnetic fluctuation in the Mojokerto sequence, the Sangiran Excursion, characterised by a large westerly swing of declination and estimated to date between 1.57 and 1.48 Ma. The Sangiran Excursion at Mojokerto occurs just below the change in sedimentation facies from marine to fluviatile (Hyodo et al. 1993; Hyodo 2001). At the well-known Sangiran early hominin site 190 km to the west, this excursion also occurs just beneath a change in sedimentary facies, from marine to lacustrine, indicating a widespread change in relative sea level that encompassed both sites. Pumice Horizon 5 and the upper boundary of the Sangiran Excursion at Mojokerto closely match in position and age. They provide, therefore, independent crosschecks for the maximum age for the cranium: it must post-date 1.49 Ma.

The previously reported K/Ar and $^{40}Ar/^{39}Ar$ dates of ~1.9 and 1.8 Ma are, therefore, no more than gross maximum ages for Mojokerto 1. They may date pumice in reworked deposits and/or the hornblende in the deposits may present problems for these dating techniques (Jacob and Curtis 1971), but they do not provide an actual age for the cranial vault.

However, there are still too many uncertainties to more precisely date the cranium. If the date of 1.43 ± 0.15 Ma for material from Pumice Horizon 6 also approximates the time of deposition of this layer, then the cranium is around 1.46 Ma in age (i.e. midway between Fission Track dates of ca 1.49 and 1.43 Ma). Given the depositional features of Pumice Horizon 6, comparative geochemical analysis and multiple dating of samples of pumice from the horizon is now required to establish the real significance of this Fission Track result.

Concerning palaeo-magnetic evidence for the site, the top of the depositional sequence had normal geomagnetic polarity, whereas the hominin cranium findsite and the base of the sequence had normal and intermediate, and reverse and intermediate geomagnetic polarities, respectively (Hyodo et al. 1993). On the basis of similarities between the palaeo-magnetic sequences at Mojokerto and at the better dated Sangiran fossil hominin site, these palaeo-magnetic fluctuations were interpreted as the Bruhnes Chron (beginning 0.78 Ma), the Jaramillo Subchron (1.07 to 0.99 Ma) and the Olduvai Subchron (1.95 to 1.77 Ma), respectively – giving a probable age of ~1.0 Ma for Mojokerto 1. However, dates for, and the stratigraphic position of, Pumice Horizon 5 and the Sangiran Excursion make correlation of the normal polarity magnetozone at the findsite with the Jaramillo Subchron extremely unlikely *unless* there have been massive changes in rates of sediment accumulation over time. This would have resulted in the 13 m of sediment from Pumice Horizon 5 to the findsite taking about 0.5 Ma to accumulate, while the 100-125 m of sediments of reversed polarity between the findsite and the Bruhnes Chron took 0.21 Ma (Fig. 2). Further work is required to refine the palaeo-magnetic sequence.

Problems with interpretation of Mojokerto palaeo-magnetic data include the possibility that some of the normal geomagnetic polarities may be the result of more recent overprinting; the absence of suitable outcrops means that are significant gaps in the record, and there is ambiguity in identifying and therefore dating specific changes. For instance, Swisher et al. (1994) interpreted the normal geomagnetic polarities of the cranium findsite as the Olduvai Subchron, which ended ~1.77 Ma, in support of the early K/Ar and $^{40}Ar/^{39}Ar$ dates for the cranium. Our better provenanced results now show that this cannot be the case (cf. Huffman 2001).

Paradoxically, pumice from Pumice Horizon 5, a geological stratum 13 m below the Mojokerto 1 findsite, provides a better age-estimate than samples from the immediate vicinity of the fossil, or even samples adhering to the fossil itself. The fission-track date is still a maximum age, but at least it approximates the actual time of deposition for a layer near the base of the delta-plain in which the hominin cranial vault was deposited. There was debate about the specific findsite (Swisher et al. 1994), but never any doubt that all possibilities lay within the sandy gravel near the base of this depositional facies. More recently, archival research has demonstrated that the findsite was ‘within a few metres or perhaps a few tens of metres’ of the Mojokerto monument erected to commemorate the discovery (Curtis et al. 2002:110).

From a regional perspective, the same facies also presents the earliest opportunity in the Kedungwaru Anticline geological sequence for fluviatile deposition and preservation of terrestrial faunal remains. If hominins arrived in East Java before 1.49 Ma, then the evidence for this will not be found in sediments of the Kedungwaru Anticline.

In conclusion, this study emphasizes the importance of ‘chronological hygiene,’ especially a grasp on the depositional history of the materials being dated, and thereby has shown that previously claimed radiometric results for the Mojokerto cranium cannot be correct. Other controversial dates for ‘early’ hominin sites, such as Sangiran (compare Swisher et al. 1994 with Larick et al. 2001:4871; Larick et al. 2001: Fig. 2 with Semah et al. 2001: Fig. 2) and Ngandong in Java (compare Swisher et al. 1996 with Westaway 2002) need to be assessed with this in mind.

More specifically, current dating evidence for the Mojokerto sequence is clearly inadequate and further work is required to date this important site. The cranium, however, is definitely not 1.8 Ma old, as previously claimed. In the context of available dating evidence and the overall stratigraphic sequence for the site, it may be older than any other hominin remains yet found in Java, but still compatible with the earliest well-dated hominin finds in Central and East Asia (Gabunia and Vekua 1995; Zhu et al. 2001).

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