8. Conclusions: geology, palaeontology and archaeology of the Soa Basin, central Flores, Indonesia

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To summarise our major research findings for the Soa Basin –

a) The basement volcanic breccias of the Soa Basin, comprising the Ola Kile Formation, were formed during the Pliocene, with an uppermost age of ~1.86 Ma. Layers of tuffaceous silt are sometimes interspersed with the breccias, but there are no associated terrestrial fossils or stone artefacts.

b) Major deposition of fluviatile and lacustrine sediments in the basin began about 1 million years ago and ceased ~650,000 BP.

c) The 16 terrestrial fossil fauna sites now known in the Soa Basin sediments are between 900,000 and 700,000 years old. Species evident 900,000 years ago included pygmy *Stegodon sondaari*, giant tortoise (*Colossochelys* sp) and Komodo dragon (*Varanus komodoensis*), while from 880,000 to 700,000 years ago only large-bodied *Stegodon* (*S. florensis*), Komodo dragon, crocodile, rat and bird are represented in the fossil record. The inferred faunal turnover coincided with a major volcanic eruption that blanketed the entire basin, and is closely followed by the first proxy evidence in the stratigraphic sequence for hominins - stone artefacts.

d) On present evidence, the distribution of stone artefacts in the sequence suggests that hominins were not present in the Soa Basin 900,000 years ago, but were present by 880,000 BP.

In summary, our work has significantly increased the range of stratigraphic, geochronological, palaeontological and archaeological evidence for the arrival of hominins on Flores. The date for hominin presence in the Soa Basin has also been pushed back and now approaches the timing for extinction of the pygmy *S. sondaari* and giant tortoise. Whether hominins played a role in this extinction is not yet clear. The large bodied *S. florensis*, which recolonised the island by 880,000 BP, appears to have been directly ancestral to the sub-species, *S. florensis insularis*, found 780,000 years later at the site of Liang Bua some 40 km to the west. This subspecies was about 30% smaller than its Soa Basin ancestor and was associated with the tiny endemic hominin species, *Homo floresiensis* (van den Bergh *et al*., 2008).

The Flores faunal island community thus seems to have maintained an inherent, undisturbed stability and phylogenetic continuity throughout the Pleistocene. There are no new successful colonizations or extinctions evident in the fossil record between the Soa Basin faunal turnover

around 900,000 years ago, contemporaneous with a major volcanic eruption and followed closely by the first evidence for hominins; and another faunal turnover at Liang Bua around 17,000 years ago, contemporaneous with a major volcanic eruption and followed closely by the first evidence for modern humans (Morwood *et al.*, 2004, 2008; van den Bergh *et al.,* 2008). The biological evidence indicates that Flores was always difficult to reach, and was beyond the dispersal abilities of most land animals. How early hominins managed the feat is not known, but it probably involved an extremely rare combination of natural events, such as a tsunami carrying a group of hominins out to sea on a tree or vegetation mat (Smith, 2001).

Islands can also preserve faunal lineages long after they had disappeared from source mainland areas. Komodo dragons, for instance, previously occurred in India, Java, Timor and Australia, (Molnar, 2004), but are now only found on Flores and a few adjacent islands (Fig. 8.1). Similarly, Liang Bua now provides the most recent credible date for *Stegodon* in the world: in contrast, this genus was extinct in Java by 120 ka ago (Westaway *et al.,* 2007; van den Bergh *et al.,* 2008). Sulawesi to the north has also preserved a number of early faunal lineages including very primitive pig, bovid and primate species (Figs. 8.2a, 2b).

It seems likely, given these circumstances that the Soa Basin knappers were directly ancestral to the tiny endemic species *Homo floresiensis*, and this species, with a range of very primitive morphological traits (e.g. Morwood *et al.,* 2005; Tocheri *et al.,* 2007), was a late descendant of an early, small bodied hominin population long-replaced on the Asian mainland. Of particular note here is that *H. floresiensis* is the only known non-African hominin species with primitive, Australopithecine-like body proportions – i.e. exceedingly short legs (Morwood *et al.,* 2005;

Figure 8.1: Giant varanids previously occurred in India, Java, Timor and Australia, but a relict population of Komodo dragons is now only found on Flores and a few adjacent islands (Photo: Mike Morwood).

Jungers *et al.,* in press). One general implication is that the first hominins to exit Africa and reach East Asia did so before the appearance of *H. erectus*. When skeletal evidence for the Soa Basin knappers is finally found, it will not just be of local or regional interest!

The Soa Basin findings have many other implications for the history of faunal evolution and dispersal at the local, regional and more general levels. In fact, much of their significance lies in their wider context. For instance, given its geographic position, Flores cannot have been the only island in the region settled by early hominins. In fact, the first hominins that reached the island most likely came from Sulawesi - not west along the Sunda Island chain, as is generally supposed (e.g. Morwood and Oosterzee, 2007 c.f. O'Connor, 2007). The required sea crossing is now ~300 km, but at times of low sea level 'Greater Sulawesi', including Selayar Island, would have approached to within 80 km of Flores, and the fossil record indicates that animals did make this crossing: *Stegodon florensis* on Flores is more closely related to a *Stegodon* species from Sulawesi than to *S. trigonocephalus* from Java (van den Bergh, 1999).

In addition, whether they swim or raft on flotsam, land animals are at the mercy of ocean currents when making sea crossings, and the predominant pattern of ocean currents in island Southeast Asia is from north to south, the Indonesian Throughflow (Fig. 8.3; Kuhnt *et al.*, 2004). This would have facilitated accidental drift crossings from the north but provided a formidable obstacle to west-east movement between islands – as is clear when the fossil records from a north to south transect of islands in the region, from the Philippines to Timor, are compared. The earliest, large-bodied land animals known from the Philippines, on the island of Luzon, comprise giant tortoise, a pygmy

Figures 8.2a, 2b: Babirusa, the most primitive living pig species, is only found on Sulawesi and a few adjacent islands. It has no close, extant relatives in mainland Asia. Similarly, tarsiers are amongst the most primitive living primate species, and were once found throughout Eurasia and North Africa. They now only occur on a few refuge islands in Southeast Asia, including Sulawesi (Photos: W. K. Fletcher and D. M. Baylis).

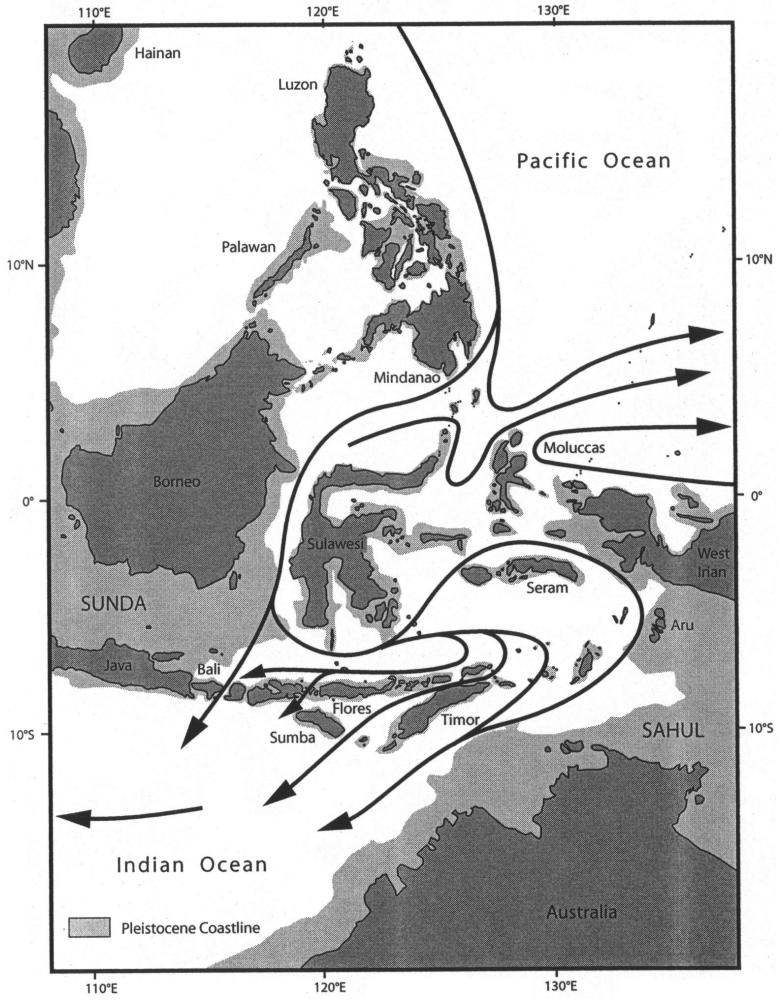

Figure 8.3: The predominant ocean currents in Southeast Asia flow from north to south – the Indonesian Throughflow. Currents would have been a prime determinant of animal dispersals, as confirmed by the fossil record (after Kuhnt et al 2004).

Stegodon, a pygmy elephant, a primitive pig and rhino. Around 2.5 million years ago, a similar but reduced suite of terrestrial animals occurred in the Walanae Fauna of Southwest Sulawesi - giant tortoise, a pygmy *Stegodon*, a type of pygmy 'elephant' with four tusks and *Loxodonta*-like molar cusps, and a primitive pig with four tusks (Figs. 8.4a, 4b).

Further south, in Flores, the range of animals present in the Early Pleistocene 900,000 years ago, is a diminished subset of those in Sulawesi, but also includes the pygmy *Stegodon sondaari*, giant tortoise and Komodo dragon, with the latter being derived from a dispersal of varanids across Australasia by the Miocene (Molnar, 2004; Morwood *et al.*, 1998). The same limited range of animals - *Stegodon*, giant tortoise and a giant varanid - occurs in the Pleistocene fossil deposits of the Atambua Basin in West Timor (Hooijer, 1971, 1972a, 1972b; Verhoeven, 1968).

Figure 8.4a, 4b: About 2.5 million years ago, animals on Sulawesi included giant tortoise; a primitive, pygmy 'elephant' with four tusks; and a primitive pig with four tusks (Drawings courtesy of Hans Brinkerink).

On this basis, we argue that the source of animals, including early hominins, reaching Flores was Sulawesi, and beyond that the eastern edge of continental Asia, in the vicinity of the present-day island of Borneo – probably via the Philippines, with the island of Palawan being the most obvious transit route for animals migrating from the mainland to island Southeast Asia. The colonisation mechanism was most probably accidental drift dispersal; meaning that hominin colonisation for Sulawesi may have been significantly earlier than 880,000 years ago. In turn, Flores was probably the source area for animals reaching Timor, where we anticipate that initial hominin colonisation occurred significantly less than 880,000 years ago.

If the Flores evidence provides any guideline, the arrival of early hominins, as well as modern humans, on islands would have had major faunal impacts, including extinctions. In this context, similar faunal turnovers elsewhere in island Southeast Asia are very suggestive. Pygmy *Stegodon* and giant tortoise are found in the earliest known land faunas of Sulawesi immediately to the north and Timor immediately to the southeast. With their shell armour, giant tortoises are effectively immune to predation – except by humans – and in all documented cases, their extinction has coincided with the arrival of humans. In fact, giant tortoises, which were common in island faunas worldwide, may be more symptomatic of hominin-free rather than specifically island environments. In Sulawesi, the later extinctions of *Elephas* and *Stegodon* have also been attributed to the arrival of hominins – in this case modern humans (Glover, 1981): a reasonable supposition given evolutionary trends and human impacts on islands generally. Knowing when animals became extinct, and the context, will help explain why they became extinct, and whether climate change,

natural catastrophes or hominins were involved; as the better dated faunal sequences on Flores indicates.

On a final note, our research has yielded results with implications for the history of faunal dispersal, evolution and replacement on Flores, and more generally in Southeast Asia. Hopefully, it will also provide evidence fundamental to the planning of future conservation strategies – on the present and past distribution of animal species; the environments they formerly occupied; how different species responded to environmental changes, natural catastrophes and human activities; and even when they became locally or regionally extinct (c.f. Morwood *et al.*, 2007). At present, Southeast Asia is experiencing rapid population growth, development and extensive land clearance, with serious impacts on its unique fauna and ecosystems, and potentially threatening areas of great natural and cultural heritage value, such as the Soa Basin. Evidence from palaeontology and archaeology on the long-term evolutionary, biogeographic and cultural history of the region is, therefore, very relevant and timely.

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Artistic reconstruction of the Soa Basin during the Middle Pleistocene as envisaged by students from the Ledalero Seminary, Maumere, Sikka District, Flores.