Centre for Archaeological Science

Key Research Project

Size matters: Elephantoid dispersal, evolution, paleoecology and extinction in Asia

This 4-year ARC Future Fellowship project to Gert van den Bergh aims at investigating the evolutionary history, dispersal and paleo-ecology of Elephantoids. The research focuses on Asia and seeks to enhance our understanding of the relation between changing environments, faunal evolution, adaptation, inter-specific competition, extinction, and human interaction, by addressing specific themes around fossil elephants and their relatives in Asia.

For Africa, a wealth of information from paleontological, paleoclimatic, paleoenvironmental and paleoecological studies, in relation to the evolution of early hominins and their living environments, has become available over the past decades. At the same time, evidence for the exit of hominins from Africa into Asia has been pushed back in time with the findings of 1.7 Ma old hominins at Dmanisi, Georgia, and sites with stone tools dated to 2 Ma in Pakistan and to 1.7 Ma in China. The early appearance of hominins in Asia at Dmanisi around the same time as H. erectus appeared in Africa has opened the possibility that Homo erectus was not the first hominin to have left Africa, contrary to the generally held model “Out of Africa I”. Archaeological and paleoanthropological research in Asia is now rapidly catching up with work that has been done in Africa over the last century, but detailed information on the paleoenvironmental and paleoecological setting that determined Asian hominin evolution, and the associated fossil faunas, still lags far behind. Gert's project aims at increasing our knowledge of megafaunal evolution during the period of hominin expansion in Asia.

Late Middle or Late Pleistocene fossil *Elephas* skull from the Menden alluvial terrace along the Solo River in Central Java. (photo: Gert van den Bergh).

Stegodon fossils excavated in 2010 at the 800,000 years old site Mata Menge on Flores. On right is a maxilla fragment with molar, and at the bottom is a pelvis fragment (photo: Gert van den Bergh).
Elephant fossils and paleo-environmental reconstructions

The enamel of mammalian teeth contains stable isotope signatures that are now widely used to reconstruct dietary and habitat preferences, enabling paleoenvironmental reconstructions. Fossil elephant remains are relatively common in the fossil record, and they were widely dispersed over a wide range of habitats and climatic zones, including remote tropical islands. As the successive molar teeth of elephants develop over extended periods, spanning several years, their molar enamel contains high-resolution, multi-annual proxy records of environmental parameters. By analysing δ¹³C values of biogenic carbonate incorporated inside the enamel, seasonal variations in food resources (consumption of C₄ versus C₃ plants) can be reconstructed. The δ¹⁸O values of both carbonate and phosphate in tooth enamel depend largely on the δ¹⁸O of drinking water, which in turn has an isotopic composition that is a function of local climatic conditions. The analysis of stable isotope records of molars from multiple elephantoid species from fossil sites can, thus, reveal patterns of intra-specific competition for food resources, as well as climatic and vegetation conditions. When analysing multiple samples from single molars taken along a track across incremental growth lines, seasonal fluctuations in such parameters can also be detected.

Excavation near the village of Sunggu (Central Java, Indonesia) of the *Elephas* skeleton, of which the skull is shown above (photo: E. Setiabudi).
Adaptation and insular dwarfing

The molar proxy records from single elephantoid lineages may also reveal temporal shifts in food resources. *Stegodon*, a widespread predominantly Asian genus, reached various remote islands such as Timor and Sumba, where environmental conditions were much drier than on the Southeast Asian mainland. This may have forced insular *Stegodon* populations to consume larger proportions of low-quality grasses as compared to their mainland ancestors, and this should be reflected in the enamel isotopic composition. Food limitations on islands are often mentioned as the driving force of dwarfing of large ungulates on islands. A decrease in insular elephant body-size must have been an adaptive response to island environments under strong selective pressures, as it has occurred over and over again independently. In fact, the phenomenon is part of a predictable pattern, known as the “Island Rule”, according to which large ungulates, (such as elephants) tend to become smaller, while small mammals (such as murine rodents) tend to become bigger on islands.

In Island Southeast Asia, climatic conditions grade from tropical rainforests in Borneo, Sumatra, Sulawesi and West Java, to increasingly drier conditions and more pronounced seasonality eastward along the Lesser Sunda island chain, a pattern that seems to have been even stronger during glacial periods.

Pleistocene dwarfed elephant remains have been found on the islands of Java, Sulawesi, Flores, Timor, Sangihe, Sumba, Luzon and Mindanao. On Java, which was intermittently connected to the Asian continent, occurrences of large-bodied, “continental”-sized, elephants are also well-documented. The wealth of elephant fossils from these islands offers a unique opportunity to test the hypothesis that food limitation was the dominant factor leading to insular dwarfing of elephants. If true, then dwarfing of elephants should be more pronounced and more rapid on smaller islands, and with increasingly drier habitats dominated by low quality food resources, such as grasses. The enamel of fossil *Stegodon* teeth from Timor, and to a lesser degree from Flores, shows frequently signs of marked linear enamel hypoplasia, a condition that is commonly related to severe nutritional stress, suggesting that food resources were, indeed, limited. As part of this project, modelling of food resource availability for each island will be made using a mathematical model. Body-masses of insular fossil elephants will be estimated based on fossil molars and postcranial elements. Body-size ratio for each insular elephant population will be calculated relative to the body size of the ancestral mainland species, and correlated against food resource availability.

![Growth curve of the mandibles plotted against dental wear age class for various Indonesian Stegodon species and subspecies. Plotted are the maximum widths of the horizontal ramus of the mandible as a function of dental wear age class.](image-url)
**Elephantoid and hominin interactions**

Another aspect that will be investigated by Gert is the interaction between humans and elephants. Through time, there has seemingly been increased interaction and competition, which has led to the demise of elephants in many regions, including large parts of Asia. To date, Flores is the only oceanic island where *Stegodon* is known to have co-occurred with pre-modern hominins. Over a period of 800,000 years, *Stegodon florensis* decreased 30% in linear size measurements. For the Early to early Middle Pleistocene, hundreds of fossils of the intermediate-sized *Stegodon florensis* have been excavated at various sites in the Soa Basin, spanning a time period of c. 180,000 years. The *Stegodon* fossils are commonly associated with stone artefacts.

Quaternary faunal succession on Flores. *Stegodon florensis* survived for 800,000 years, sharing the island with hominins. During that period, *S. florensis* decreased 30% in linear proportions. The Komodo dragon, an opportunistic hunter/scavenger, is the only animal that survived this entire period. The Archaic hominins seem to have survived a major volcanic catastrophe 0.9 Ma ago, but together with *Stegodon* became extinct towards the terminal Pleistocene. Their demise corresponds with another volcanic event, but the arrival of modern humans may also have played a role in their demise.
More fossil and archaeological evidence will emerge over the next 5 years with Mike Morwood's ARC-funded project “In search of the first Asian hominins: excavations at Mata Menge, Flores, Indonesia” which is expected to yield a wealth of new fossil remains and improved dating of the various sites on Flores. So far, no evidence has been found that the stone tool makers from the Soa Basin actively hunted Stegodon during the Middle Pleistocene, but the overwhelming evidence from the site of Liang Bua indicates that, by the Late Pleistocene, juvenile dwarfed Stegodon was an important food resource targeted by Homo floresiensis. The combined circumstances of a comparatively “simple” insular ecosystem, an abundance of archaeological and paleontological sites, and geological sequences representing long periods make Flores an ideal case study for human-elephantoid interactions.

**Main Collaborators**

- Indonesian Geological Survey Centre, Bandung, Indonesia
- Indonesian National Research and Development Centre for Archaeology, Jakarta, Indonesia
- Netherlands Centre for Biodiversity NATURALIS, Leiden, The Netherlands
- National Museum of Natural History (Smithsonian Institution), Washington DC, USA
- ELETTRA Synchrotron facilities in Trieste, Italy