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Land bridge formation and proboscidean immigration into the Japanese Islands during the Quaternary

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Abstract

Two land bridge stages are inferred between the mainland of Japan and the adjacent continent during the past one million years, on the basis of the detailed stratigraphy of the Quaternary sequence in the mainland, its accurate correlation with the marine isotope stages (MIS) and with the ODP cores in Japan Sea, and the proboscidean biostratigraphy in the sequence. The two land bridge stages are placed at MIS 16 and MIS 12, which are indicated by the immigration of the proboscidean species from the continent, *Stegodon orientalis* and *Palaeoloxodon naumanni* respectively. An additional land bridge stage at MIS 36 is also suggested by the immigration of *Mammuthus trogontherii*.

Key-words : Land bridge, Immigration, *Stegodon orientalis, Palaeoloxodon naumanni*, Quaternary, Japanese Islands

Introduction

The Japanese Islands are composed mainly of four major islands (Hokkaido, Honshu, Shikoku, Kyushu) and the Ryukyu Islands which are separated from each other by narrow straits with varying depths (Fig. 1). In the Japanese Islands, three biogeographic regions have been recognized since the latter part of the nineteenth century. They are Hokkaido, the Honshu-Shikoku-Kyushu complex and the Ryukyu Islands. The boundary between the first and second regions runs through the Tsugaru Strait with the maximum depth of ca. 130m (Blakiston's line). The Tokara Strait, with the maximum depth of more than 500m, represents the boundary between the second and third regions (Watase's line). Furthermore, the boundary between the second region and the adjacent continent is drawn through the Tsushima Strait with the maximum depth of ca. 130m (Korean Strait line).

Since the dawn of the Japanese biogeography and paleomammalogy, the questions as to when, where from and how mammals migrated into the main part of Japan (the Honshu-Shikoku-Kyushu complex in biogeographic sense) have been of crucial interest. Recent advances in stratigraphy and chronology, paleomammalogy and paleo-oceanography throw a new light on these long-standing questions.

Land bridge stages and proboscidean immigrations

In the Honshu-Shikoku-Kyushu complex, fluvio-lacustrine and marine sequences covering all the periods of the Quaternary are accurately dated by tephrostratigraphic and magnetostratigraphic methods as well as other chronological techniques. The sequences are best investigated in the Osaka Plain (Itihara *et al.*, 1997; Fig. 1). Recent studies have revealed that the sequence can be closely correlated with the marine isotope stages (MIS), and thus each horizon of the sequence can be dated precisely (Fig. 2a, b). The marine clay beds numbered

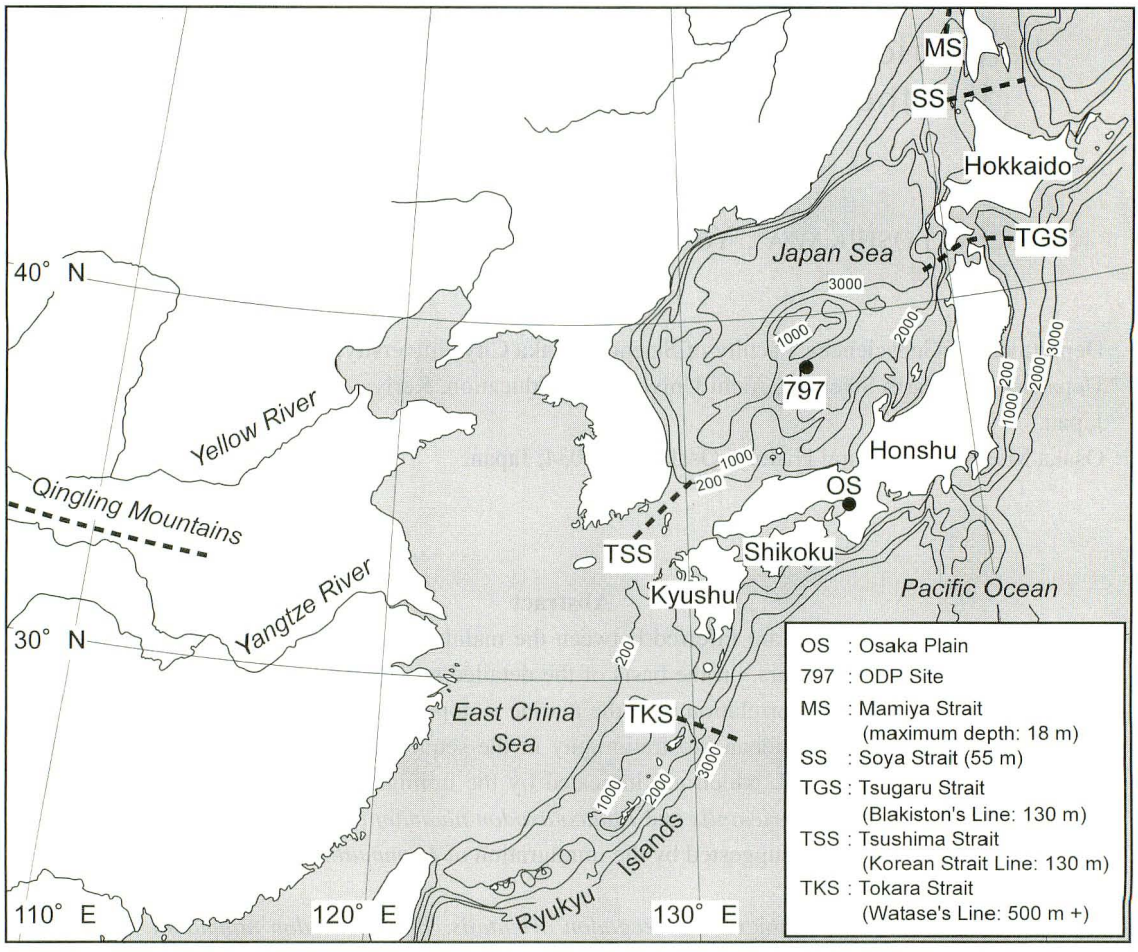

Fig. 1 Map of east Asia showing the locations of the places related to this paper. Bathymetric contours are in meters.

Ma1 to Ma13 (Fig. 2b) yielding warmth-loving floras are coincident with high stands of sea level, and therefore denoted by odd-numbed MIS. The fluvio-lacustrine mud, sand and gravel interposed between the marine clay beds, yielding cold-loving floras are correlated with low stands of sea level, and therefore denoted by even-numbered MIS (Itihara *et al.*, 1997; Yoshikawa and Mitamura, 1999).

On the other hand, proboscidean fossils are obtained successively in the sequence, and the stratigraphic range of each proboscidean form has been determined (Kamei *et al.*, 1988; Kawamura, 1998; Taruno, 1999) (Fig. 2b). Furthermore, systematic studies of the fossil proboscideans have revealed whether each form was an immigrant from the continent or arose locally in the region. The first appearances in the Honshu-Shikoku-Kyushu complex of the species conspecific or closely related to continental species are indicative of their immigration from the continent, and probably suggest the land bridge formation which allowed their immigration (Kawamura, 1998; Konishi and Yoshikawa, 1999).

Stegodon aurorae, a small specialized endemic stegodontid, first appeared around 2.6 Ma (million years ago) and persisted until 0.7 Ma in and around the Osaka Plain. This species probably arose in this region from *S. miensis* or *S. shinshuensis*, an early Pliocene large stegodontid in Japan closely related to the Chinese species, *S. zdanskyi*. Subsequently, the primitive mammoth *Mammuthus trogontherii* appeared around 1.2 Ma (MIS 35). The remains of this species from Japan were called *Parelephas protomammonteus, P. proximus, Archidiskodon paramammonteus, M. shigensis* and so on, by previous authors (see Kawamura *et al.*, 2007; Taruno and Kawamura, 2007). This species is also recorded in northern China between 1.66 Ma and 1.1 Ma (Wei *et al.*, 2006). Its appearance in the Osaka Plain suggests its immigration through a land bridge that formed between China and this region. The timing of the land bridge formation is inferred to be the even-numbered MIS just prior to MIS 35, possibly MIS 36, but the paleontological and stratigraphic data are relatively insufficient around this horizon.

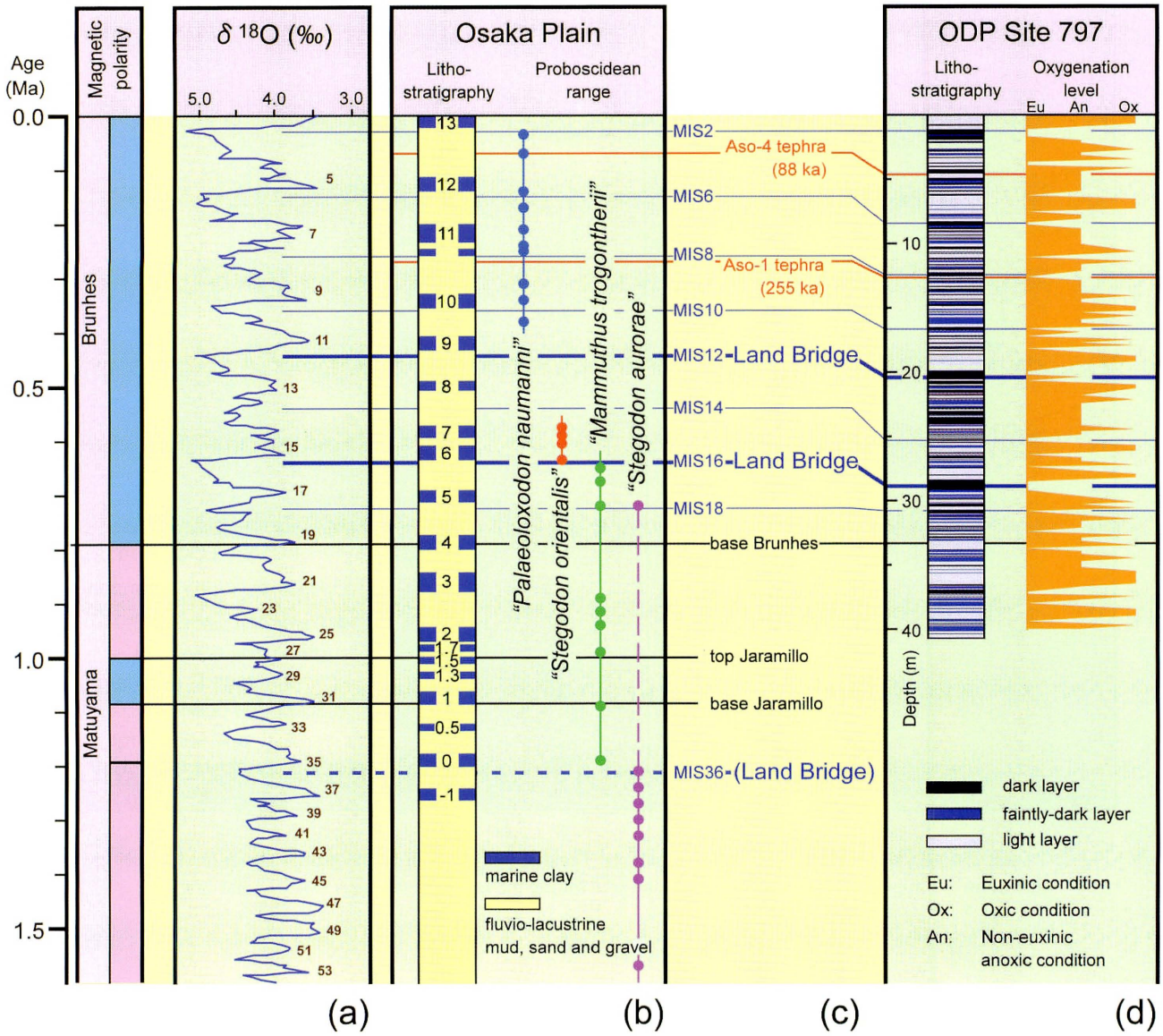

Fig. 2 Stratigraphic data sets. (a) δ ^{18}O record (Imbrie *et al.*, 1984) for the SPECMAP stack for the interval 0-0.62 Ma(Schackleton *et al.*, 1990) and ODP Site 677 for the interval 0.62-2.0 Ma (Schackleton, 1995). Numbers show odd-numbered MIS. (b) Quaternary stratigraphy of the Osaka Plain (Itihara *et al.*, 1997; Yoshikawa and Mitamura, 1999). Correlations with the oxygen isotope record are based on a combination of litho-, bio-, magneto- and tephro-stratigraphy (Itihara *et al.*, 1997; Yoshikawa and Mitamura, 1999; Biswas *et al.*, 1999). Twenty marine clay beds (numbers in the column represent principal marine clay beds), which are characterized by warm-temperate and high sea-level conditions, were deposited during interglacial periods from MIS 37 to MIS 1. In the range chart, black circles indicate proboscidean fossil occurrences. (c) Important marker horizons of oxygen isotope-, magneto- and tephro-stratigraphy. Aso-1 and Aso-4 tephras are well-dated widespread tephras in the Japanese Pleistocene (Machida, 1999). (d) Lithostratigraphy and the bottom water oxygenation level of Quaternary sediments in Japan Sea (Tada *et al.*, 1992). Bottom water oxygenation conditions are estimated from the sedimentary structures and the ratios of organic carbon content to total sulfur content. Thick dark layers representing euxinic condition were deposited during glacial low stand periods (Oba *et al.*, 1991; Tada *et al.*, 1992).

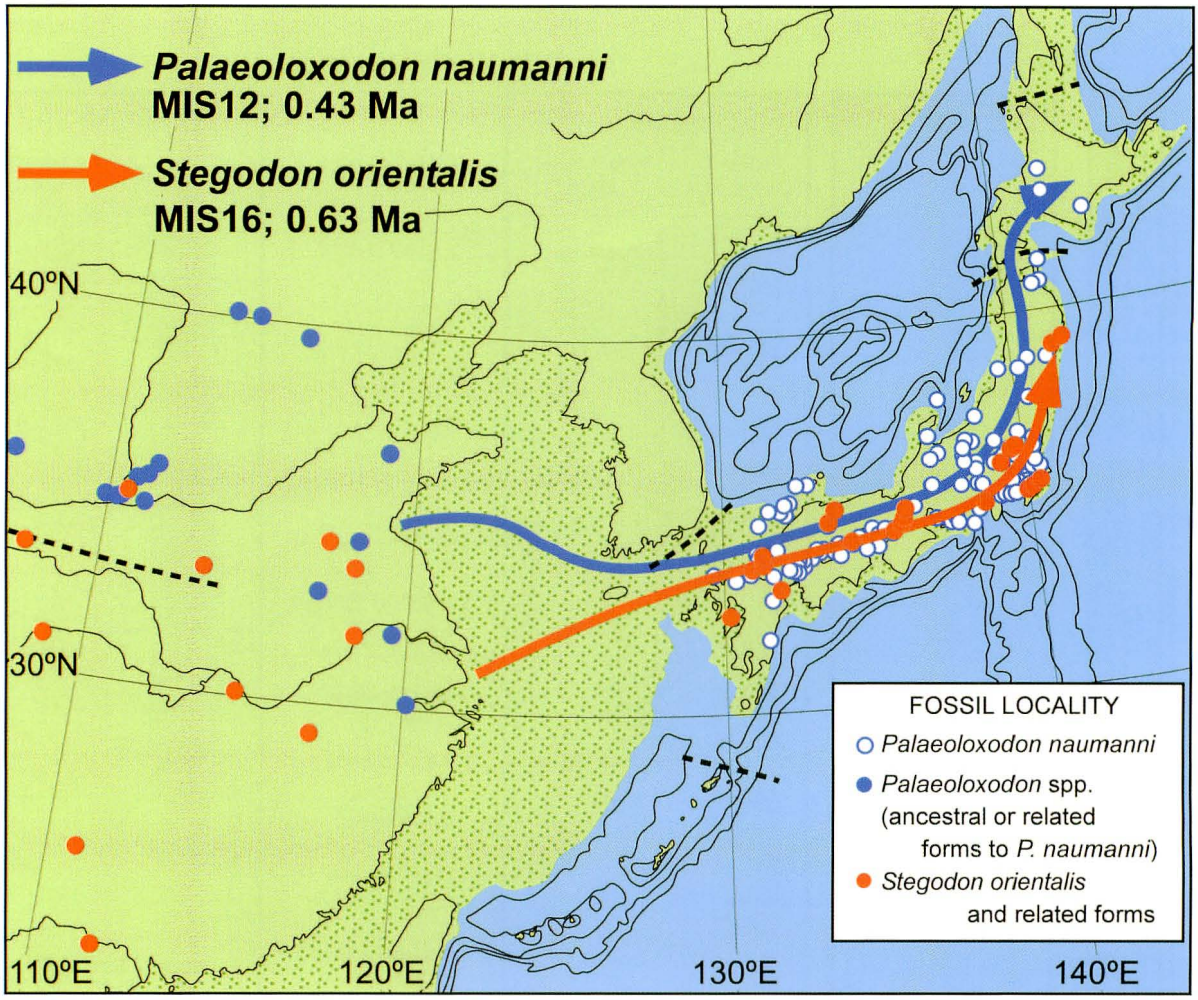

Fig. 3 Routes and ages of the proboscidean immigrations. The distribution of principal proboscidean fossil localities, are also shown. Stipping indicates the inferred land area during the land bridge stages (MIS 16 and 12).

At MIS 15, the mammoth was replaced in the Osaka Plain by *Stegodon orientalis*, a medium-sized stegodontid species well known from the Middle and Late Pleistocene of southern China. Its appearance at this time suggests the land bridge formation between this region and China just prior to MIS 15, namely MIS 16. This species was again replaced by the Naumann's elephant, *Palaeoloxodon naumanni*, which is regarded as an immigrant from northern China. Its appearance in the Osaka Plain at MIS 11 or somewhat later (Fig. 2b), is suggestive of a land bridge existing between the region and China just prior to MIS 11, namely MIS 12. Moreover, the land bridge was possibly present at this time between the region and Hokkaido, which was indicated by the occurrence of this elephant from the Late Pleistocene of Hokkaido, and by its absence from the continental areas adjacent to Hokkaido (Kawamura, 1998; Konishi and Yoshikawa, 1999; Kawamura and Taruno, 2000).

Among the land bridge stages inferred above, MIS 16 and 12 are considered to be the colder stages when their continental glaciations were stronger than those during the other even-numbered stages. Hence the sea levels at the stages were significantly lower than those at the other stages (Schackleton, 1987; Rohling *et al.*, 1998). Recent investigations of the ODP cores obtained in Japan Sea (Tada *et al.*, 1992; Tada and Irino, 1999) indicate that the dark layers indicative of euxinic condition of deep sea water are better developed at the horizons correlative with MIS 16 and 12, which resulted from the closed conditions of Japan Sea (Fig. 2d). Such euxinic conditions suggest a land bridge formation between the Honshu-Shikoku-Kyushu complex and the adjacent continent, which

blocked the influx of the Tsushima Current.

Conclusion

This paper deals with the estimation of the immigration ages of such proboscidean species as *Mammuthus trogontherii*, *Stegodon orientalis* and *Palaeoloxodon naumanni* into the mainland of Japan, which are correlative with the ages of the land bridge formation between the mainland and the adjacent continent on the basis of the stratigraphy of the Quaternary sequence in the mainland and Japan Sea, and the proboscidean biostratigraphy of the sequence. We concluded that *S. orientalis* and *P. naumanni* immigrated into the mainland Japan through the land bridges from the continent at MIS 16 (0.63 Ma) and MIS 12 (0.43 Ma), respectively (Fig. 3).

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