impermeable sediment blanket in Middle Valley above very young oceanic crust that is the primary control on the style of hydrothermal circulation in this area, resulting in the formation of a seafloor mineral deposit similar in size and grade to ore deposits mined on land. □

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# Megaliths and Neolithic astronomy in southern Egypt

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**The Sahara west of the Nile in southern Egypt was hyperarid and unoccupied during most of the Late Pleistocene epoch. About 11,000 years ago[1] the summer monsoons of central Africa moved into Egypt, and temporary lakes or playas were formed. The Nabta Playa depression, which is one of the largest in southern Egypt, is a kidney-shaped basin of roughly 10 km by 7 km in area[2–4]. We report the discovery of megalithic alignments and stone circles next to locations of Middle and Late Neolithic communities at Nabta, which suggest the early development of a complex society. The southward shift of the monsoons in the Late Neolithic age rendered the area once again hyperarid and uninhabitable some 4,800 radiocarbon years before the present (years BP). This well-determined date establishes that the ceremonial complex of Nabta, which has alignments to cardinal and solstitial directions, was a very early megalithic expression of ideology and astronomy. Five megalithic alignments within the playa deposits radiate outwards from megalithic structures, which may have been funerary structures. The organization of the megaliths suggests a symbolic geometry that integrated death, water, and the Sun. An exodus from the Nubian Desert at ~4,800 years BP may have stimulated social differentiation and cultural complexity in predynastic Upper Egypt.**

Pastoralists seem to have entered the Nabta region (Fig. 1 inset) during the summer rainy season beginning ~10,000 years BP. Most of the early sites at Nabta consist of small concentrations of artefacts with one or more hearths, evidence of repeated summer occupation by small family groups. In addition to bones of gazelles, hares, jackals, and small mammals, most of the sites also contain bones of cattle, which may have been used for milk, blood, and transport[5,6].

There were three major moist periods in the Holocene epoch in the Eastern Sahara, each of which is documented by massive silt deposits in the seasonal playas, for which we have over 100 radiocarbon dates[7]. These three playa episodes of the Early, Middle, and Late Neolithic ages were separated from each other by periods of hyperaridity, at 7,300–7,100 years BP and 6,700–6,500 years BP, when the water table was lowered to the same or lower levels than those of today. The preceding playa silts were extensively eroded and in some instances sand dunes filled the hollows. The alignments, megalithic structures and sandstone circles were placed in sediments that probably accumulated between 7,000 and 6,700 years BP, at the end of the Middle Neolithic.

These Neolithic settlements reveal repeated occupation over several millennia during the summer rainy season, when there was enough water in the playas for large groups and their animals. At 8,100–8,000 years BP in the Early Neolithic, dates that are well established by a cluster of radiocarbon dates from charcoal and ostrich eggshells, larger communities appeared. One village (E-75-6) contained more than 18 houses, arranged in two (possibly three) straight lines, and deep walk-in wells, which required significant labour investment and control[3,8]. One well that we excavated was 4 m in width and 3 m deep; the existence of this well may have made it possible for some people to live in the desert throughout the year. The construction of the wells may be the first indication of emerging social control that later made the design and execution of the megalithic complex of the Late Neolithic possible.

Although primarily attracted to the playa for its water and forage, these nomadic groups must have engaged in a variety of activities during summer occupation, such as social bonding, marriage, trade, and ritual. The abundance of cattle remains in the Middle and Late Neolithic settlements is consistent with the ritual traditions of modern pastoralists, who may slaughter cattle to mark socially important events. We excavated two types of cattle tumuli at Nabta. The most common type consists of unshaped blocks of sandstone containing disarticulated bones of one or more cattle. One such tumulus (E-96-1) has yielded a date of 5,500 years BP ± 160 years, from charcoal in a hearth. The second type of cattle tumulus (E-94-1), which may have marked a place and an event of considerable ideological significance for the group, consisted of an articulated skeleton of a young cow buried in a roofed, clay-lined chamber, which was covered with unshaped sandstone blocks. Wood from the roof of the chamber yielded a radiocarbon date of 6,470 ± 270 years BP.

Oval clusters of large recumbent slabs constitute the megalithic structures (Fig. 1), which we initially thought might mark high-status burials. However, no firm evidence of human burials was found in any of these features. Although churning clay vertisol would probably have destroyed all buried material except large rocks, the structures may have served primarily as proxy tombs for high-ranking individuals who died on the trail. Excavation and

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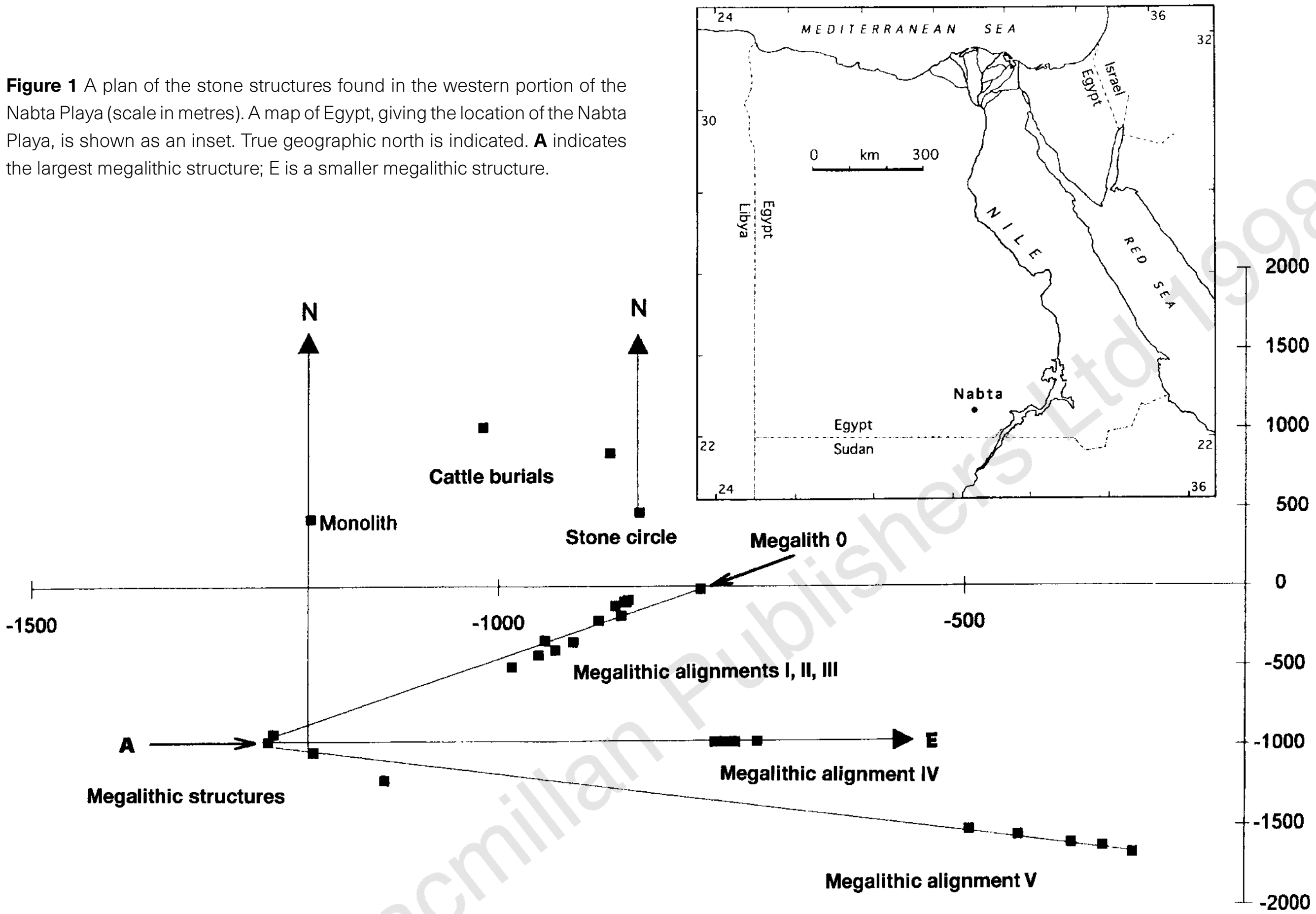


**Figure 1** A plan of the stone structures found in the western portion of the Nabta Playa (scale in metres). A map of Egypt, giving the location of the Nabta Playa, is shown as an inset. True geographic north is indicated. **A** indicates the largest megalithic structure; E is a smaller megalithic structure.

drilling of five of the structures showed that each one was built over a modified table rock, which perhaps functioned symbolically as a cenotaph. We obtained a radiocarbon date of 4,800 years BP ± 80 from one of the smaller structures (E-96-1; structure E).

Beneath the surface slabs of the largest megalithic structure (E-96-1; structure A) we found a sculptured rock, which has some resemblance to a cow. It was standing upright with its base 2 m below the surface, and its long axis was oriented a few degrees west of north. The rock had been blocked into place by two smaller slabs. Further beneath it, at a depth of 4 m, the shaped table rock had a similar northward orientation.

Excavations of the megaliths contained in the alignments reveal that they are not bedrock material. These slabs, typically measuring 2 m by 3 m, were brought from exposed sandstone, over distances of 0.5 km or more, and then embedded during the Late Neolithic in playa deposits. Megalith 0, with an exposed length of 1.05 m, is shown in Fig. 2 and is the northernmost stone of alignment II. Numerous deflated hearths and Late Neolithic pottery[9], all of which appear to be contemporaneous with the megalithic alignments, surround the megaliths and cattle tumuli.

The longest series of standing megaliths (megalithic alignments I, II and III; Fig. 1) was originally interpreted[2] as a single line of megaliths orientated approximately 10° east of north. Our re-evaluation of the alignment indicates that the slabs are organized into three separate lines, which radiate outwards from the largest of the megalithic structures, E-96-1 structure A, with azimuths of 24.3°, 25°, and 28°. During the 1997 season, we combined theodolite and differential global positioning system measurements to map the megaliths, and established the centre of structure A at 22° 30′ 29.7″ N, 30° 43′ 31.2″ W. We discovered two additional megalithic alignments, which also radiate out from the vicinity of structure A, with azimuths of 90.02° and 126°. We have not

**Figure 2** Megalith 0, the northernmost stone of alignment II (Fig. 1).

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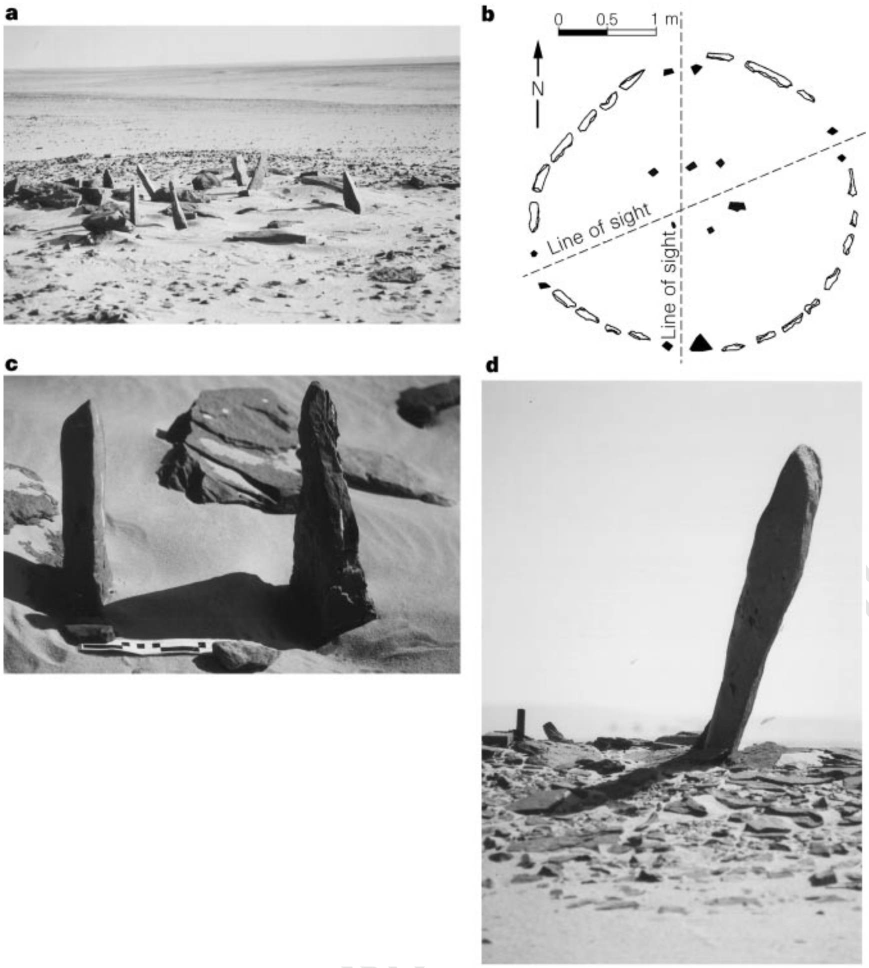


**Figure 3** Stone circle and monolith. **a**, **b**, Stone circle, E-92-9. **b**, The outer eight standing stones that establish sighting slots, in addition to the mix interior standing stones, are shown in black. Recumbent stones are shown in white. **c**, Southwest window of circle in **a**, **b**. **d**, Standing monolith (height 1 m).

excavated the bases of these megaliths, but they appear to be similarly embedded in playa deposits.

The circle (E-92-9) of small upright and recumbent slabs, with a diameter slightly less than 4 m (Fig. 3a–c), contains four sets of upright slabs, which may have been used for sighting along the horizon. The circle is too small to have functioned as a precise sighting device. The centre lines of the two windows have azimuths of 358° and 62°. Taking into account refraction, we estimate the azimuth of the first gleam of the summer solstice Sun 6,000 years before the present to have been 63.2°, which would have been visible through the slots of the circle. The location on the horizon of the rising Sun close to the summer solstice may have acquired additional significance because of Nabta's proximity to the Tropic of Cancer. At this latitude, the Sun crosses the zenith on two days, approximately three weeks before and after the summer solstice. Vertical structures cast no shadows under the zenith Sun, and within the tropics the day of the zenith Sun is often regarded as a significant event[10].

In addition to the north–south sight-line in the calendar circle, other suggestions of the importance of cardinality are provided by the east–west megalith alignment that extends from structure A and the isolated monolith (Fig. 3d), which lies 1.8° east of north from megalithic structure A. The exposed and buried slabs of structure A, as well as many of the exposed slabs in the other megalithic structures, were also aligned with their long sides approximately north–south.

Although no star was visible at the north celestial pole during most of the occupation of Nabta, north directionality would have been important for nomadic groups navigating across the Sahara. The standing megaliths would have been apt devices to acknowledge the zenith Sun near the onset of the rainy season. Placed in playa deposits, the megaliths would have been partly submerged in the rising waters of the summer monsoon, and they may have been considered to be ritual markers of the onset of the rainy season. The megalithic complex may have been an expression of interconnections between the Sun, water, death, and the fertile Earth. The unusual standing monolith, either chosen for its shape or intentionally sculptured, is a suggestive symbol of male fertility.

The symbolic richness and spatial awareness seen in the Nabta complex of the Late Neolithic age may have developed from adaptation by nomadic peoples to the stress of survival in the desert. The ceremonial complex could not be more recent than the onset of hyperaridity in the region around 4,800 years BP, suggesting that the astronomy and ceremonialism of Nabta occurred before most of the megalithic features of Europe, Great Britain, and Brittany were established. Within some 500 years after the exodus from Nabta, the step pyramid at Saqqara was constructed, indicating that there was a pre-existing cultural base, which may have originated in the desert of Upper Egypt. An exodus from the Nubian desert at ~5,000 years BP could have precipitated the development of social differentiation in predynastic cultures through the arrival in the Nile valley of nomadic groups who were better organized and possessed a more complex cosmology. □

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# Inbreeding and extinction in a butterfly metapopulation

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**It has been proposed that inbreeding contributes to the decline and eventual extinction of small and isolated populations[1,2]. There is ample evidence of fitness reduction due to inbreeding (inbreeding depression) in captivity[3–7] and from a few experimental[8,9] and observational field studies[10,11], but no field studies on natural populations have been conducted to test the proposed effect on extinction. It has been argued that in natural populations the impact of inbreeding depression on population survival will be insignificant in comparison to that of demographic and environmental stochasticity[12,13]. We have now studied the effect of inbreeding on local extinction in a large metapopulation[14] of the Glanville fritillary butterfly (*Melitaea cinxia*)[15]. We found that extinction risk increased significantly with decreasing heterozygosity, an indication of inbreeding[6], even after accounting for the effects of the relevant ecological factors. Larval survival, adult longevity and egg-hatching rate were found to be adversely affected by inbreeding and appear to be the fitness components underlying the relationship between inbreeding and extinction. To our knowledge, this is the first demonstration of an effect of inbreeding on the extinction of natural populations. Our results are particularly relevant to the increasing number of species with small local populations due to habitat loss and fragmentation[16].**

The Glanville fritillary metapopulation on the Åland islands in southwest Finland is well suited to the study of factors affecting population extinction[15,17,18]. This metapopulation consists of numerous small, more-or-less isolated, local populations breeding on dry meadows with one or both of the larval host plants, *Plantago lanceolata* and *Veronica spicata*. The Glanville fritillary has a yearly life cycle in northern Europe. Adult butterflies mate and females lay eggs in June; caterpillars feed in conspicuous family groups of 50–250 larvae, which facilitates large-scale censusing; caterpillars diapause from August until March, continue feeding in the spring and pupate in May. We have located about 1,600 suitable meadows, ranging from 6 $m^2$ to 3 ha in size, within an area of 3,500 $km^2$. Autumnal surveys have revealed that larvae were present in 524, 401, 384 and 320 meadows in late summer of 1993, 1994, 1995 and 1996, respectively. Local populations can be very small, often consisting of just one sib-group of larvae, the offspring of one pair of butterflies. Consequently, population turnover rate is high, with an average of 200 extinctions and 114 colonizations observed per year. The number of local populations has declined during the study period, probably because of a sequence of unfavourable summers.

Populations were characterized between 1993 and 1995 in terms of size (number of larval groups) and isolation (distances to and the sizes of neighbouring populations[19]). Female butterflies were caught in June 1996 from 42 local populations across Åland (Fig. 1), chosen to include relatively large ($\geq$5 larval groups), non-isolated populations (from which 5–10 females were sampled per population), as well as small (<5 larval groups) and isolated populations (from which two females were usually sampled per population).

Individual heterozygosity was determined at seven polymorphic enzyme loci and one polymorphic microsatellite locus (see Methods). The number of heterozygous loci per female was normally distributed, ranging from zero to seven. Heterozygosity differed significantly among the populations ($P = 0.02$). A significant fraction (19%) of variance in heterozygosity among populations was explained by population size in 1993 and by longitude. Heterozygosity was low in populations that had been small in 1993 and in those in eastern Åland. The latter effect apparently reflects large-scale regional changes in abundance in the past[18,20].

Accuracy of heterozygosity as a relative measure of inbreeding is largely dependent on the number and degree of polymorphism of markers used to estimate heterozygosity as well as the magnitude of the differences in inbreeding being measured. The variance in inbreeding among populations is expected to be high in this metapopulation, because there is substantial gene flow in many dense regional networks of local populations[21], but also close inbreeding in many local populations that are extremely small and quite isolated. Thus, differences in average heterozygosity of local populations, even if based on a limited number of polymorphic loci, should reflect real differences in the degree of inbreeding.

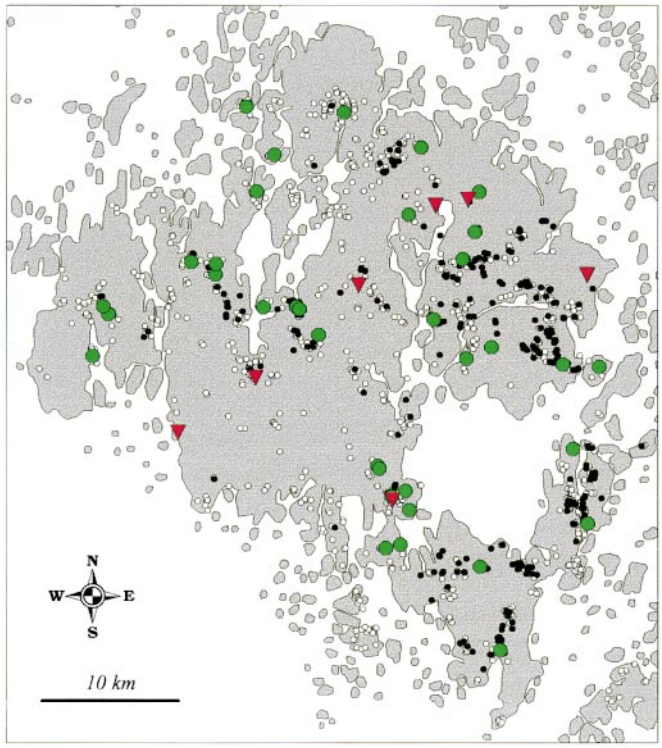


**Figure 1** Map of Åland in southwestern Finland showing the locations of the 42 local populations from which adult female butterflies were sampled in summer 1996 (large symbols). All known suitable meadows are shown as small circles, with meadows in which Glanville fritillary larvae were present in autumn 1995 indicated by black circles (and large symbols), and unoccupied meadows by white circles. Of the 42 local populations sampled, the 35 that survived to autumn 1996 (green circles) are distinguished from the seven that went extinct (red triangles).


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