Megalicth tombs in western and northern Neolithic Europe were linked to a kindred society

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Paleogenomic and archaeological studies show that Neolithic lifeways spread from the Fertile Crescent into Europe around 9000 BCE, reaching northwestern Europe by 4000 BCE. Starting around 4500 BCE, a new phenomenon of constructing megalithic monuments, particularly for funerary practices, emerged along the Atlantic façade. While it has been suggested that the emergence of megaliths was associated with the territories of farming communities, the origin and social structure of the groups that erected them has remained largely unknown. We generated genome sequence data from human remains, corresponding to 24 individuals from five megalithic burial sites, encompassing the widespread tradition of megalithic construction in northern and western Europe, and analyzed our results in relation to the existing European paleogenomic data. The various individuals buried in megaliths show genetic affinities with local farming groups within their different chronological contexts. Individuals buried in megaliths display past admixture with local hunter-gatherers, similar to that seen in other Neolithic individuals in Europe. In relation to the tomb populations, we find significantly more males than females buried in the megaliths of the British Isles. The genetic data show close kin relationships among the individuals buried within the megaliths, and for the Irish megaliths, we found a kin relation between individuals buried in different megaliths. We also see paternal continuity through time, including the same Y-chromosome haplotypes reoccurring. These observations suggest that the investigated funerary monuments were associated with patrilineal kindred groups. Our genome investigation provides insight into the groups associated with this long-standing megalithic funerary tradition, including their social dynamics.

Significance

A new phenomenon of constructing distinctive funerary monuments, collectively known as megalithic tombs, emerged around 4500 BCE along the Atlantic façade. The megalithic phenomenon has attracted interest and speculation since medieval times. In particular, the origin, dispersal dynamics, and the role of these constructions within the societies that built them have been debated. We generate genome sequence data from 24 individuals buried in five megaliths and investigate the population history and social dynamics of the groups that buried their dead in megalithic monuments across northwestern Europe in the fourth millennium BCE. Our results show kin relations among the buried individuals and an overrepresentation of males, suggesting that at least some of these funerary monuments were used by patrilineal societies.


The authors declare no conflict of interest.

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Data deposition: Raw sequencing reads produced for this study have been deposited in the European Nucleotide Archive (accession no. PRJEB1045).

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that many megaliths were used for collective burials (27, 29, 31), it has been difficult to evaluate which members of the communities were buried in the tombs. Some assemblages include males, females, juveniles, and children, implying familial burials. Many tombs have poorly preserved human remains and also show secondary usage in later times, complicating assessments. The use of megaliths as burial grounds for the community as a whole would imply some level of shared ideology over vast geographical areas (31, 32). However, it has also been argued that the monumental burials and associated rich material culture reflect the emergence of social differentiation or stratification (33–36; see ref. 37 on segmentally structured societies), with the monuments perhaps symbolizing status and territorial markers (37–40).

Some scholars hypothesize that the people buried in the megalithic structures were kin related (41–43). Analyses of mitochondrial data (mtDNA) from megalithic burials at Falbygden and Gotland in modern-day Sweden have revealed a large lineage variation, and thus the groups did not seem to have been organized matrilineally (44, 45; however, contra ref. 43). Genomic data are necessary to provide deeper information on kin relations and the social dynamics and general social structure of the societies or groups. However, as genomic data have been available from only a few individuals from megalithic burials, the origin and dispersal dynamics of the funerary practices, as well as the population history of the people that used the burial constructions, have also remained uncertain.

In the present study, we investigated the genetic structure and demographic affinities of people buried within megaliths to shed light on this burial phenomenon, the social dynamics of the people buried in the monuments, and their demographic history. We generated and examined genome sequence data from 24 individuals from five megalith burial sites located in Ireland, the Orkney Islands, and the Island of Gotland in the Baltic Sea dated between ca. 3800 and 2600 cal BCE encompassing wide-ranging examples from the megalithic tradition in northern Europe. The study also incorporated three individuals from nonmegalith contexts from mainland Scotland (3370–3100 cal BCE) and the Czech Republic (4825–4555 cal BCE) (Table 1).

Results

We present genome data from 27 individuals excavated from European Neolithic contexts, of whom 24 were buried in megaliths; Primrose Grange (n = 11) and Carrowmore (n = 1) in Ireland; Lairo (n = 1) and Midhowe (n = 2) in the Orkney Islands, Scotland; and Ansarve (n = 9) in the island of Gotland, Sweden (16, 45, 46) (Table 1 and SI Appendix, section S2). Individuals from the Scottish “short cist” burial Balintore (n = 1) and the Czech Republic Kolin Rondel site (n = 2) (46), associated with the Stroked Pottery culture, were also investigated. These individuals were all radiocarbon-dated to between 4825 and 25 cal BCE (Table 1) and compared with previously generated data from 36 individuals from 16 megalithic sites (Fig. 1 and Dataset S1.3), as well as with farmer groups of nonmegalithic contexts (Dataset S1.3), to investigate the population history of people buried in megaliths.

The individuals buried in these megaliths from the British Isles and Scandinavia show an ancestry similar to other contemporaneous farmer groups (Fig. 2A), with a majority of their ancestry related to early Neolithic farmers and a partial admixture component related to European Mesolithic HGs (Fig. 2B) (1, 2, 5–7, 10, 16, 46). To further explore the demographic history of the individuals buried in the megaliths, we investigated the genetic affinities among sets of individuals and groups, using an f2 outgroup test for groups of individuals buried in megalithic or nonmegalithic contexts, as well as between individuals from Atlantic coastal and inland Neolithic sites (SI Appendix, section S11.3 and Fig. S19). These analyses showed genetic associations between individuals from the same/similar geographic region and time period (Fig. 2A and SI Appendix, Figs. S16 and S17). However, some tests (SI Appendix, Fig. S19) indicated similar trends as shown in our principal component analysis (PCA) and previous studies (5, 11, 15, 47, 48) and suggested a demic connection among western European Neolithic groups to the exclusion of central European Neolithic groups, as well as a connection between the British Isles and Iberian groups (SI Appendix, section S11.4 and Figs. S20–S22). These results were not driven by greater levels of HG ancestry among the populations at the fringes of the Neolithic expansion (11, 12, 15, 16) (SI Appendix, section S11.4).

Interestingly, we also found a significant farmer-specific genetic affinity between the British Isles Neolithic populations and the Scandinavian populations (Ansarve and Gökhem; Fig. 1) to the exclusion of central European farmers (SI Appendix, Figs. S21 and S22). This observation is compatible with a further migration of farming groups along the European Atlantic coast, as has been suggested by the archaeological record (21, 49). We found that significantly more males than females were buried in the British Isles megaliths (31 of 42 randomly sampled individuals: P = 0.0014, binomial test) and at the Primrose megalith alone (9 of 11; P = 0.032) (SI Appendix, section S8). However, other megalithic tombs with at least four individuals investigated, including Ansarve (6 of 9; P = 0.25), Gökhem (1 of 4; P = 0.93), La Mina (2 of 4; P = 0.68), Holm of Papa Westray (2 of 4; P = 0.68), and Isbister (Tomb of the Eagles) (8 of 10; P = 0.054), did not show the same striking pattern, nor did nonmegalithic burials from the British Isles (15) (nonmegalithic burials: 6 of 10: P = 0.27, cave burials: 10 of 15: P = 0.27, both nonmegalithic and cave burials: 16 of 25; P = 0.11). Overall, genetic data from all individuals from megalithic contexts suggest a higher male-to-female ratio in these burial chambers (41 of 60; P = 0.0031) (SI Appendix, Table S3), although the tendency is similar (but not significant) for nonmegalithic burials (SI Appendix, section S8).

We found greater macrohaplogroup mtDNA diversity than Y-chromosomal (YDNA) diversity. Whereas the haplogroups present from megalithic burials harbor haplogroups K, H, HV, V, U5b, T, and J (among others), males from megalith burials belong almost exclusively to YDNA haplogroup I, more specifically to the I2a sublineage, which has a time to most recent common ancestor of ~15000 BCE (51). This pattern of uniparental marker diversity is

Fig. 1. Map of Europe with megalithic burial sites (red squares) and nonmegalithic sites (red circles) from this study, and comparative published data from megalithic sites (black squares) sequenced to date in Europe (Dataset S1.3). The date range represents the 95% CI of available samples from these sites, except for La Mina in Spain. Blue shading represents the estimated distribution of early megalithic burials. Bold italic type indicates dates (95% CI) estimated for the start of dolmens and passage grave monuments, based on samples from these contexts. Regular text indicates time interval associated with the earliest cultural material in the megaliths (27, 45).
found not only among individuals buried in megaliths, but also in other farmer groups from the fourth millennium BCE, which display similar patterns of uniparental marker diversity (SI Appendix, Figs. S6 and S23) (10, 15, 48, 52). Some mtDNA lineages appear to be overrepresented at megalithic sites, with information from more than six individuals, including Primrose (n = 11; K1a+195 and K1a4a1 at 36% and 18% frequency, respectively), Ansarve (n = 9; J1c5 and K2b1a1 at ~20% frequency), and Isbister (n = 10; K1a+195 at 20% frequency). Males from the present study belonged to YDNA haplogroup I, and those who could be resolved beyond this level were characterized as belonging to the I2a2a or I2a1b branch. Four of the 10 Primrose/Carrowmore males (Primrose 9, 12, 13, and 16) could be further resolved to the former sublineage, while the two Scottish males and the four Ansarve males could be further placed in the latter branch (Table 1 and SI Appendix, section S11.5).

Using READ (Relationship Estimation from Ancient DNA) software (55), we inferred six kin relationships among the megalithal individuals of this study: five relations among the Irish megaliths (two first-degree and three second-degree connections) and a second-degree relation in the Ansarve tomb (Fig. 3 and SI Appendix, section S11.6), suggesting a scenario of more recent admixture with HGs in northern Europe. First-degree relationships are characterized by either parent-offspring or a full sibling relationship, second-degree kin connections are represented by half-siblings, grandparent-grandchild, aunt/uncle-niece/nephew, and double cousins. Combining the READ predictions, uniparental lineages, radiocarbon dating, and age at death if available for those individuals who could be assessed, we inferred the potential familial structures (SI Appendix, Fig. S10). The first is composed of sex-biased admixture between HGs and the individuals of the megalithic contexts, we assessed the affinity of all individuals buried in megaliths with sufficient genetic data, to an Early Neolithic farmer or a HG ancestry on the autosomes and the X chromosome using f4-statistics (SI Appendix, section S11.5).

Higher levels of HG admixture on the autosomes than on the X chromosome implies a greater genetic contribution of male HGs than female HGs to these individuals, suggesting an HG male sex bias admixture. We find that in general, megalith groups do not harbor higher levels of HG ancestry on the autosomes compared with on the X chromosome (SI Appendix, Table S7 and Dataset S1.6), but the Scottish MN farmers of this study showed a tendency toward an HG male-sex biased admixture in the recent past. The Scandinavian (Ansarve and Gökhem) individuals displayed an HG admixture for both the autosomes and the X chromosome (SI Appendix, Table S7), suggesting a scenario of more recent admixture with HGs in northern Europe.
of three individuals from Primrose Grange (Tomb 1; individuals Primrose 2, 17, and 18), which overlap broadly in time (Fig. 3). Primrose 2 and 17 were predicted to be related in the first degree, representing a father-daughter relationship. Primrose 17 and 18 were predicted to be second-degree relatives (harboring the same mtDNA lineage but with possibly different YDNA haplogroups) and thus could have been half-siblings or double cousins. However, the YDNA prediction is hindered by low coverage and few informative markers, and thus a grandfather-grandson or uncle-nephew relationship cannot be fully excluded.

The other Irish putative pedigree structure was integrated by two individuals from Tomb 1 (Primrose 6 and 7) and one individual from Carrowmore 4 (from the Listhogil Tomb at the Carrowmore site in close vicinity), who harbored different mtDNA lineages. While the 95% CI dating range of Primrose 6 and Carrowmore 4 overlap, Primrose 7 might be slightly younger than the other two individuals. The Carrowmore 4 and Primrose 7 males were inferred to be at least second-degree related (3.14 SE below the expected value for two unrelated individuals), and the best prediction was a first-degree relation (1.79 SE below the value for a second-degree relation, although not statistically significant at the 95% level; SI Appendix, section S10). If a first-degree relation is assumed, then the sole possible kin connection is a father-son relationship, because the individuals are not maternally linked. In the case of a second-degree relationship, any paternally related second-degree familial connection is possible. The other two READ-predicted second-degree kin relationships in the Irish burials (Primrose 6-Pimrose 7 and Primrose 6-Carrowmore 4; 1.04 SE and 0.50 SE below the threshold for an unrelated pair, respectively) involved a familial connection of the male individuals to Primrose 6 (female).

Within the Ansarve megalith, we identify a second-degree relationship between the contemporaneous males Ansarve 14 and Ansarve 17 (Fig. 3 and SI Appendix, section S10). Both males have the same YDNA haplotype but different mtDNA lineages, suggesting that they could be related through any second-degree paternal kin relationship. Morphologically, Ansarve 14 was predicted to be an adult, and Ansarve 17 was predicted to be a juvenile (SI Appendix, section S2). Such observations might favor a grandfather-grandson or uncle-nephew relatedness over half-siblings or double cousins; however, the latter alternatives are still compatible with the data (SI Appendix, Fig. S12). READ analyses from other megalith burials
where genetic data from at least four individuals were available per site (Gökhem, La Minu, Ibister, and Holm of Papa Westray; Fig. 1) did not reveal any evidence of genetic kinship relations. However, such observations may be hindered by the limited number of individuals investigated or by low genome coverage, which decreases the power to infer kinship (SI Appendix, section S10).

**Discussion**

The genetic variation and characteristics of individuals buried in megalithic tombs, and also from individuals buried according to other traditions, suggest that the megalithic tradition was linked to socially stratified Neolithic farmer societies, with the genetic data suggesting close connections between Neolithic populations in Atlantic Europe (5, 15, 48) (Fig. 2 and SI Appendix, Figs. S19–S22). Finds of probable early cremation graves from the Primrose Grange, the Kolin Rondel site (the Czech Republic), and the Primrose Grange indicate that postmortem practices were similar in other areas, which suggests close connections between the Scandinavian, British, and Irish Neolithic populations. This signal is weaker than the signal observed between the Iberian Peninsula and the British Isles, however (5, 11, 15, 47, 48) (Dataset S1.3), suggesting that migration between the British Isles and Scandinavia along the Atlantic coast was less frequent than that between Iberia and the British Isles (SI Appendix, section S11.5).

The Y2 YDNA lineages that are very common among European Mesolithic HGs (2, 3, 15, 56, 57) are distinctly different from the YDNA lineages of the European Early Neolithic farmer groups (8–10), but frequent in the farmer groups of the fourth millennium BCE (2, 3, 8–10, 15, 56, 57), suggesting a male HG adixture over time. The megalithic individuals do not show higher levels of HG ancestry on the autosomes than on the X chromosome, but the Scottish MN group shows a tendency toward a male-biased HG admixture in farmer groups, similar to previous observations (58). For the Scandinavian farmer groups, in contrast to the other megalithic groups, we found an HG admixture for both the autosomes and the X chromosome. When these findings are considered together, it appears as if the geographic regions—a social dymanics between HGs and Neolithic farmer groups, and thus the genetic admixture with HGs, differed somewhat in different geographic regions—an observation consistent with a combination of previous genetic sex bias admixture events occurring on the continent and more recent regional encounters with HG groups with a less pronounced sex-biased admixture.

These observations imply that the groups that erected and used the megalithic burial structures were stable and stratified, but probably not isolated farmer societies (37, 41). The genetic connection of the individuals from the Primrose Grange and Carrowmore burials, spatially distanced by only 2 km and in contemporaneous use, suggests that transgenerational patrilineal kin groups were not excluded. The observation of maternal continuity across time at the Gotlandic Ancestral burial sites was also consistent with the theory that people buried in the megalithic tombs belonged to patrilineal segments of the groups/societies rather than representing a random sample from a larger Neolithic farmer community living in close vicinity. The sex ratio in the Irish megaliths is also in line with this finding. If one of the main functions of the tombs was to contain the remains of the deceased of a patrilineal segment, this would explain the inclusion of more males than females in the tombs. However, the finding that three of the five kinship relationships in these megaliths involved females indicates that female kindred members were not excluded. The observation of paternal continuity across time at the Gotlandic Ancestral megaliths and at the Irish megaliths is a strong indication that specific family groups used these stone constructions for burial and other funerary practices. Of course, the patterns that we observe could be unique to the Primrose, Carrowmore, and Ansearve burials, and future studies of other megaliths are needed to provide additional data that can inform us further about social organization in the Neolithic.

**Materials and Methods**

Archaeological Samples (SI Appendix, sections S1 and S2). Bones and teeth from human remains representing 27 individuals (Table 1) from seven sites were sampled for ancient DNA analyses; Primrose Grange (Tomb 1) and the Listhogd court cairn at Carrowmore (Ireland), the Laird and Midhowe chambered tombs in Orkney and the Balintore short cist burial (Scotland), the Ansearve dolmen on the Island of Gotland (Sweden), and the Kolon Rondel site (the Czech Republic). Twelve samples were radiocarbon dated using accelerator mass spectrometry, and datings were available for the other samples.

**Sequencing** (SI Appendix, section S3). DNA was extracted from bones and teeth (60, 61), and DNA sequences in the extracts were converted to blunt-ended Illumina libraries. For some individuals, uracil-DNA-glycosylase (UDG)-treated, whole-genome capture-enriched, and/or single-strand libraries were also generated. All samples were prepared in dedicated ancient DNA facilities. The libraries were sequenced on Illumina HiSeq platform 2500 or XTen.

**NGS Data Processing and Authentication** (SI Appendix, section S4). Overlapping paired-end reads were trimmed and merged (62), and the fragments were mapped to the human reference genome (63). Fragments with identical start and end positions were considered PCR duplicates and collapsed into consensus sequences. Contamination was estimated based on phylogenetically informative sites on the mitochondrial genome using Contamix (64), on the X chromosome using ANGSVD v.0.902 (65), and on the autosomal data using VerifyBamID v.1.1.2 (66). All libraries except the UDG-treated libraries showed signs characteristic of aDNA damage (67).

**Uniparental Haplogroups** (SI Appendix, sections S6 and S7). We inferred the most likely haplogroups from mitochondrial consensus sequence from each individual (68, 69). Y chromosomal haplogroups were further assigned by investigating informative single base substitutions obtained from the International Society of Genetic Genealogy (version 11.110 from April 21, 2016, https://isogg.org/). Geographical and temporal distribution of Y chromosomal haplogroups are outlined in SI Appendix, section S11.6.

**Population Genetic Analysis** (SI Appendix, section S11). The data from the investigated individuals were merged with various published datasets depending on the nature of the analyses. At each SNP position, a single read (minimum mapping and base quality of 30) was drawn at random to represent a haploid copy from the ancestral individual. Transition sites were treated as missing data to exclude potential postmortem damage. For each ancient individual, a PCA was conducted together with 203 modern Europeans (70, 71), and ancient individuals were plotted using Procrustes transformation (72). Ancestry components were inferred (73) based on 1,718 modern-day individuals from 179 populations and all ancient individuals (SI Appendix, Table S5). Common modes among the different runs were identified, and clusters were aligned across different values of K using pang (74). F2 and F4 statistics were computed (71) to estimate shared drift between populations.

**Kinship Relationship Inferences** (SI Appendix, section S10). Familial relationships were inferred (55) for individuals. Data generated with different library building strategies were handled separately to avoid potential biases.

**Data Availability.** Raw sequencing reads produced for this study have been deposited in the European Nucleotide Archive (accession no. PRJEB31045).

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