



Research Article

Genetic relatedness, social status and cemetery organisation: the Xiongnu Tamir necropolis, Mongolia

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Archaeologists are increasingly integrating the analysis of ancient DNA into cemetery studies; however, while such efforts highlight relatedness and descent, biological kinship forms only one aspect of social organisation in human societies. Here, the authors demonstrate this using the Tamir necropolis in Mongolia (100 BC–AD 100) as a case study. Employing a pipeline that combines linear discriminant analysis, machine-learning classifiers and cultural phylogenetics, they interrogate the cultural and social dynamics that structured the cemetery, disentangling the influence of genetic relatedness, social status and cultural tradition and offering a powerful framework for the investigation of social organisation in ancient populations.

Keywords: Mongolia, palaeogenetics, machine learning, phylogeny, funerary assemblages, cultural transmission

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Introduction

With exponential growth in archaeogenetic research, close biological relationships are being revealed in an increasing number of burial sites, in some cases extending across multiple generations (e.g. Margaryan *et al.* 2020; Villalba-Mouco *et al.* 2022; Rivollat *et al.* 2023; Gneccchi-Ruscone *et al.* 2024; Penske *et al.* 2024). Such studies offer the opportunity to examine the genomic structure of past communities alongside kinship systems and social practices that include patrilineal and matrilineal organisation, multiple reproductive partnerships and levirate unions. Yet it remains crucial to acknowledge that genetic ties do not, on their own, define kinship, which may equally be reflected through social practices such as adoption or marriage alliances (Harden & Koellinger 2020; Brück 2021). For this reason, genomic evidence must be integrated with the spatial and structural layout of funerary ensembles to understand how each community conceptualised proximity between burials.

Identification of biological relatedness between individuals within a cemetery often leads to the assumption that the site is ‘familial’. But were biological ties the main organising factor, or did other aspects—such as the cemetery serving as a burial place for local leaders, some of whom were related—play a greater role in determining who was buried where? This article addresses that question through the case study of the Xiongnu cemetery of Tamir, Mongolia. Although genetic links between individuals were identified in earlier analyses (Keyser *et al.* 2020), we seek to determine whether the cemetery’s organisation was primarily structured by biological relatedness or by socioeconomic factors that themselves involved kinship ties. In undertaking this endeavour, a methodological pipeline is proposed that combines: 1) decision-based statistical approaches to evaluate whether kinship or socioeconomic status shaped mortuary practices; 2) cultural phylogenetics analysis to assess the transmission of funerary behaviours, whether or not linked to kinship; and 3) unsupervised machine-learning algorithms to detect underlying patterns in the data that may otherwise not be visible.

Furthermore, when kinship ties allow for the reconstruction of one or more lineages across several generations, the detailed study of each grave and its associated artefacts enables us to explore how funerary practices and associated material culture were transmitted: were these practices consistent from one generation to the next or did they evolve? Are the associated artefacts similar? Do we observe a pattern of vertical transmission—of rites and artefacts—within families or, conversely, a horizontal transmission? Do the changes reflect broader societal or economic developments (Cavalli-Sforza 1986; Jeong *et al.* 2018; Gneccchi-Ruscone *et al.* 2024)? Can we disentangle the influence of familial continuity from that of broader structural transformations?

To address these questions—first, whether familial considerations were the primary structuring principle of the cemetery and second, whether the transmission of funerary rites and associated artefacts followed vertical or horizontal modes—we combine linear discriminant analysis (LDA), recent advances in machine learning (Labba *et al.* 2023) and cultural phylogenetics (Ludes *et al.* 2024). We test this methodological framework on the Xiongnu-period cemetery of Tamir (100 BC–AD 100), located on the Mongolian steppe (Figures 1 & 2), where marked variability in material culture reflects



Figure 1. Map of present-day Mongolia, showing the locations of four archaeological sites—Tamir, Egyin Gol, Noin Ula and Gol Mod—and the capital city Ulaanbaatar (figure by authors).

the influence of the Xiongnu elite, the presence of Chinese imports and diverse funerary traditions (Turbat & Crubézy 2021).

Within this burial ground, published palaeogenetic analyses have identified two family lineages (A & B), comprising 20 individuals up to six generations—all descending from a common ancestor (Keyser *et al.* 2020)—alongside 28 individuals unrelated to either lineage (Figures 3 & S1). In both lineages, spousal pairs are consistently interred side by side. All members of Lineage A cluster within a single sector of the cemetery, while members of Lineage B alternate between northern and southern zones across generations, sometimes separated by distances exceeding 250m. By integrating genetic evidence, spatial organisation and artefactual data, our aim is to clarify the principles governing the cemetery's layout and the choices that shaped its funerary landscape.

Material

Although numerous necropolises in Mongolia have been partially excavated (Brosseder 2007), complete excavation is rare. To date, only the Egyin Gol cemetery in northern Mongolia has been excavated in its entirety (Giscard *et al.* 2014), and only at Egyin Gol and Tamir has a full sector containing high-ranking individuals of the local elite been explored extensively (Turbat & Crubezy 2021). The Tamir necropolis is situated west of the Tamir–Orkhon river confluence, on a promontory overlooking the floodplain, at the threshold of the steppes that extend south toward the Gobi Desert.

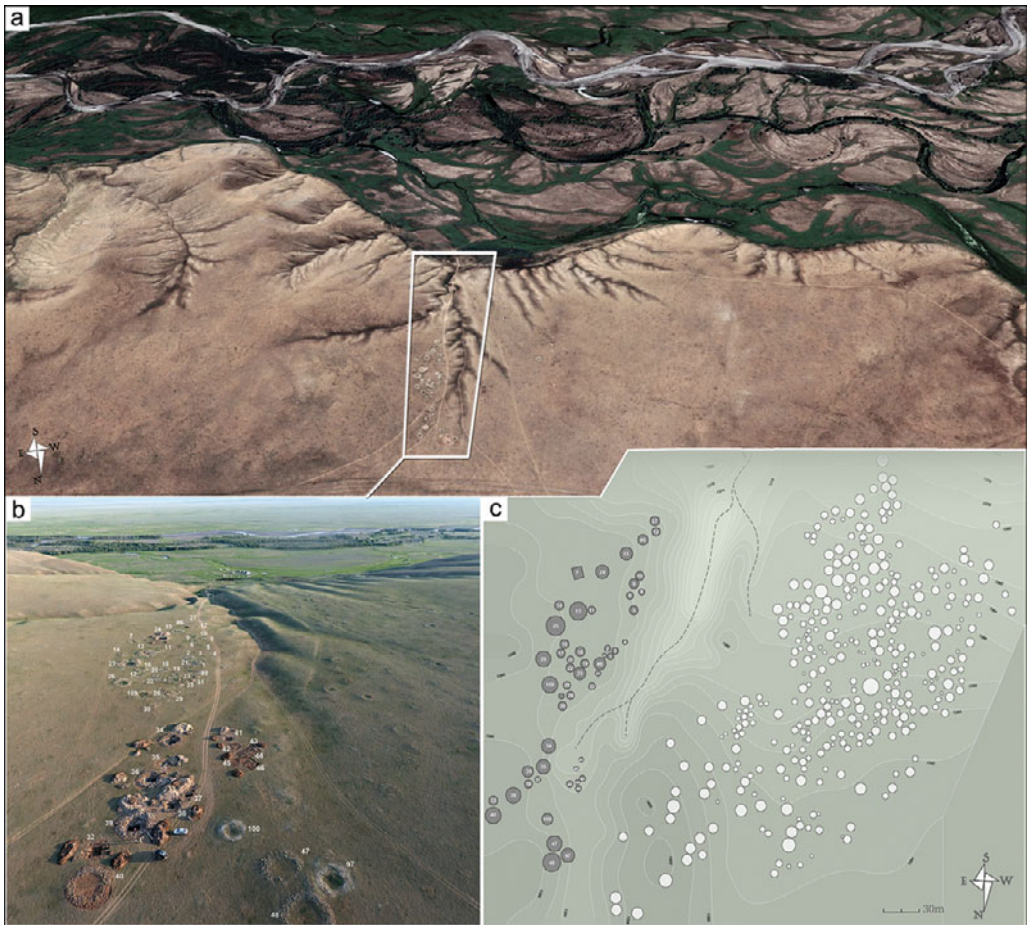


Figure 2. Satellite and aerial views of the eastern and western sections of the Tamir necropolis: a) satellite image (Google Earth, CNES–Airbus); b) aerial photo showing graves under excavation, the Tamir River is located at the top of the image; c) topographic detail of Tamir (grey: excavated area) (photograph (b) by B. Noost; figure by authors).

The necropolis is divided into two sectors, western (344 tombs) and eastern (54 tombs), separated by a ravine. The present study is concerned only with the eastern sector, where large (elite) tombs date from the first century BC to the end of the first century AD. Some tombs feature stone circles over 20m wide and quadrangular pits more than 6m deep (Figure 4, Table S1). Many tombs have been looted, sometimes repeatedly. While precious metals are under-represented—identifiable only through overlooked elements including gold earrings and metal belt plates (Figure S2)—ordinary iron furniture, Chinese lacquerware, pottery and faunal remains are present or fragmented. These are represented in analyses as present/absent (binary coding) or in numerical terms (quantitative coding) (Table S2).

The necropolis was created around 100 BC at a time when the Xiongnu confederation, defeated by the Han, had to retreat to the north of the Gobi Desert

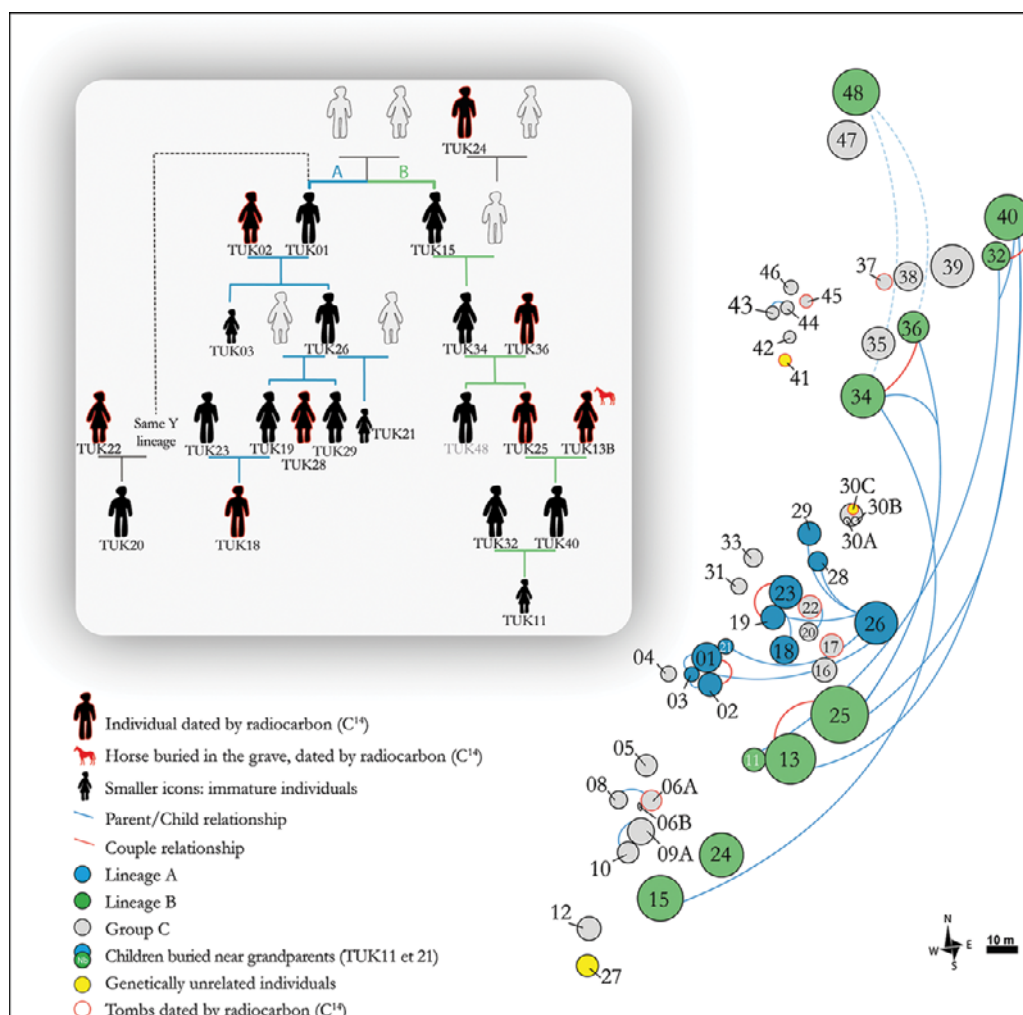


Figure 3. Genealogy (inset) and spatial distribution of individuals from the necropolis. The genealogy covers five to six generations; tombs 22 and 20, not part of a lineage but Y-line related, are shown due to their location. The spatial map shows lineages, couples and parent–child links; red-outlined circles or icons indicate dated individuals (figure by A. Alcouffe).

(Loewe 1974). Those buried at the necropolis were likely members of the Northern Xiongnu, a confederation that emerged as internal divisions weakened the Xiongnu Empire and facilitated the growing Chinese influence in the steppe world (Giscard *et al.* 2014). The funerary assemblages reflect this shift, with an increasing number of objects from China and more distant western regions indicating the integration of Xiongnu elites into long-distance exchange networks. One of the earliest dated tombs in the necropolis (Tomb 02) contains a Chinese-origin seal; while not linked to the imperial court, the seal may represent a local aristocratic alliance with Chinese agents, either political or economic in nature. The Northern Xiongnu were ultimately defeated by the



Figure 4. Excavation photographs: a) stone circle during excavation (foreground: tomb 47, background: tomb 48; photograph by P. Gérard); b) zenith view of a filled stone circle (tomb 24; photograph by B. Noost); c) excavation of one of the deepest tombs (tomb 40; photograph by D. Nikolaeva); d) stratigraphy showing modern soil, Xiongnu layer and substrate (figure by authors).

Han in AD 89, prompting their leaders to flee westward (De Crespigny 1984). The eastern section of the Tamir necropolis appears to have been abandoned around AD 100, coinciding with these events, and the last tombs (Tombs 18, 32, 11) are notably poorer. While these chronological markers provide a preliminary framework, Bayesian modelling and radiocarbon calibration of individual burials allow us to refine the mortuary sequence and better understand the temporal dynamics of the site.

Ten graves were excluded from the analysis: six from earlier excavations (Purcell & Spurr 2006); two with incomplete information due to later disturbance (Tombs 47 and 48); and two (Tombs 14 and 07) dating to a period after the Xiongnu, belonging instead to the Turkic horizon (seventh–eighth centuries). A total of 44 graves were therefore included in the study, representing 47 individuals—19 of whom are genetically related—buried in 42 single graves, one double grave (Tomb 06) and one triple grave (Tomb 30).

The sample is composed of 24 males and 23 females, only seven of whom were under 20 years of age at the time of death (only two under five years of age; Crubézy 2017). Genetic analysis identifies two lineages (A: 10 individuals, B: 9 individuals), spanning five to six generations (Keyser *et al.* 2020). Spouses are buried together, while young children lie near grandparents. Lineage A is clustered centrally, with two collateral members (Tombs 22, 20). Lineage B individuals are dispersed. The 28 unrelated individuals form group C. Y-chromosome and mtDNA markers trace male and female lines of descent (Figure S3), while short tandem repeat (STR) data help confirm familial ties; no close relatives were identified for three individuals (Keyser *et al.* 2020), two of whom are peripheral (see online supplementary material (OSM) for details). The remaining 25 group C individuals showed partial STR matches, indicating possible distant relationships (Zvénigorosky *et al.* 2020).

Grave goods define the ‘wealthy’ individuals, who were buried with traditional Xiongnu prestige items, Chinese imports such as lacquerware, precious stones such as jade and jasper, and metals including gold, silver and bronze (see OSM; Duchesne *et al.* 2026; Table S3). ‘Wealthy’ individuals are buried at around 4m deep, often with two coffins and at least two prestige items. ‘Poor’ individuals lack grave goods or have poor-quality items, buried approximately 2.5m deep, often without a coffin. ‘Intermediate’ status shows burial at around 3.5m with one prestige item. Horse bones appear exclusively in wealthy graves, while goat offerings are found only in graves belonging to group C (Table S4, Figures S4 & S5).

Methods

Familial affiliations were determined from genetic data and wealth status is based on associated artefacts. To examine whether the cemetery’s structure was shaped by familial or other factors, and whether funerary traits were transmitted vertically or horizontally, we combine linear discriminant analysis, machine learning and cultural phylogenetics. Statistical modelling and supervised learning were first applied to the data to predict familial affiliation and wealth status for each individual. Then, K-means clustering assessed cultural similarities among individuals to distinguish kin from non-kin. This analysis has two possible outcomes: 1) all related individuals cluster together, indicating strong familial determinism; or 2) the opposite pattern emerges, requiring an investigation of the criteria underlying funerary selection, trait assignment and funerary organisation. Finally, cultural phylogenetics was used to explore generational changes in funerary traditions.

Linear discriminant analyses

We employed an LDA (Fisher 1936), using R 4.4.3 (R Core Team 2023), to classify individuals into predefined groups and predict group membership. We compared variables related to kinship and wealth (Table S6), excluding those that showed perfect collinearity. The resulting classification matrix includes prediction errors. A Wilks’ Lambda test was applied to assess the model’s discriminatory power.

Supervised machine-learning algorithms

We applied various machine-learning algorithms commonly used for classification tasks, including Random Forest Classifier (RFC), Support Vector Machine (SVM) and Gradient Boosting Classifier (XGBoost) (Ray 2019; Bentéjac *et al.* 2020; Bickler 2021). We also tested different validation strategies, such as Leave-One-Out cross-validation, which tests the model on a single observation at a time, and a standard 80/20 split between training and testing datasets. Based on performance metrics (Labba *et al.* 2023) we identified the algorithms best suited to our dataset. These models were then employed to predict kinship relationships and infer patterns of wealth distribution.

While class imbalance—especially between lineages A and B—remains a concern, we chose not to apply oversampling techniques such as SMOTE, as these produce artificial data, which we considered inappropriate for an archaeological dataset. Instead, lineages A and B were combined into a single ‘family’ group and compared to unrelated individuals (group C), resulting in a more balanced comparison (19 versus 28 individuals).

Unsupervised machine-learning algorithms

We conducted exploratory clustering using the K-means algorithm (Hartigan & Wong 1979), combined with Random Forest (Sinaga & Yang 2020; Yu *et al.* 2021). Unlike supervised learning, this approach does not rely on predefined labels. It aims to minimise intra-cluster variance and maximise inter-cluster separation. To refine the model, we applied an optimal silhouette score to determine the most appropriate number of clusters (maximum of 10).

All supervised and unsupervised calculations were conducted in Python (3.9.0 version) via the IArch application available at: <https://github.com/Chahrazed-Labba/IArch>

SHAP library for explainability

To interpret classifications and cluster structures, we used the SHAP (SHapley Additive exPlanations) library. SHAP plots rank variables by their contribution to the model output. Each observation is assigned a Shapley value, with higher values (towards the right of the x-axis) indicating greater influence on classification or clustering.

Cultural phylogeny tree construction

To explore the transmission of family traditions, we applied a cultural phylogenetic approach to distinguish horizontal from vertical trait transmission (Cavalli-Sforza & Feldman 1981; Nunn *et al.* 2010). Analyses were conducted using PAUP* v.4 (phylogenetic analysis using parsimony; Swofford 2003) on 47 individuals and 14 traits coded as 0, 1 or 2 (Table S7). The reference (0) was based on Tomb 24—the earliest burial—and used to root the tree.

Given the sample size (>20 taxa), a heuristic parsimony method was applied. After adjustment, 250 000 trees were retained per iteration. A total of 51 most-parsimonious

trees (score: 84) were recovered after exploring over 420 million possibilities. A 50 per cent majority-rule consensus tree was computed.

Tree statistics

Concordance between data and consensus tree was assessed using the Retention Index (RI), which is unaffected by sample size, and the Homoplasy Index (HI), which reflects external influence (social pressure, society, etc.). For each trait, RI and HI values were calculated to infer transmission mode: vertical if RI is greater than 0.59; horizontal otherwise (Collard *et al.* 2006; Nunn *et al.* 2010; Duchesne 2020). Both indices range from 0 to 1.

Bayesian MCMC: which structuring factors are best supported?

Cultural phylogeny explores structuring patterns using cultural data only. To test the relative likelihood of competing evolutionary models, we implemented a Bayesian inference using Markov Chain Monte Carlo (MCMC) simulations (Ludes *et al.* 2024). We tested multiple scenarios: 1) with no prior hypothesis, assuming either 2) familial or 3) economic structuring; and 4) based on cladistic results. Analyses were conducted using MrBayes (3.2.7 version) (Huelsenbeck & Ronquist 2001), with two independent runs over one million generations, using default parameters.

Results

Cultural patterns

Lineages A and B show clear cultural profiles distinct from group C (LDA accuracy: 95 per cent, Wilks' Lambda: 0.0013). Only two misclassifications occurred: Tomb 22 (group C) resembles lineage B, and Tomb 32 (lineage B) matches group C. A higher error rate would have suggested either weak group distinctions or poor variable selection. Lineage members are marked by lamps, faunal remains (notably horse bones), richer grave goods and single grave (Figure 5a). XGBoost (70% accuracy) and SHAP analysis reveal similar patterns (Figure 5b). Although based on a less precise model than LDA, three individuals from group C exhibit cultural traits strongly reminiscent of lineage members. These traits include large and deep tombs, dual coffins and prestige items—features that contribute most to modelled lineage differentiation.

Wealth patterns

LDA predicted wealth with 100 per cent accuracy (Figure S6). Of five identified couples, two were wealthy, one intermediate, one poor and one mismatched (a wealthy male (Tomb 40) and a poor female (Tomb 32), likely reflecting late economic collapse). Indeed, using precise historical timelines, radiocarbon dates (Table S8) and genealogical data, we refined the temporal correlation between individual burials and the broader socioeconomic context—namely, the collapse of the empire. Bayesian calibration in OxCal (v.4.4.4; Bronk Ramsey 2021) places the end of the Xiongnu Empire

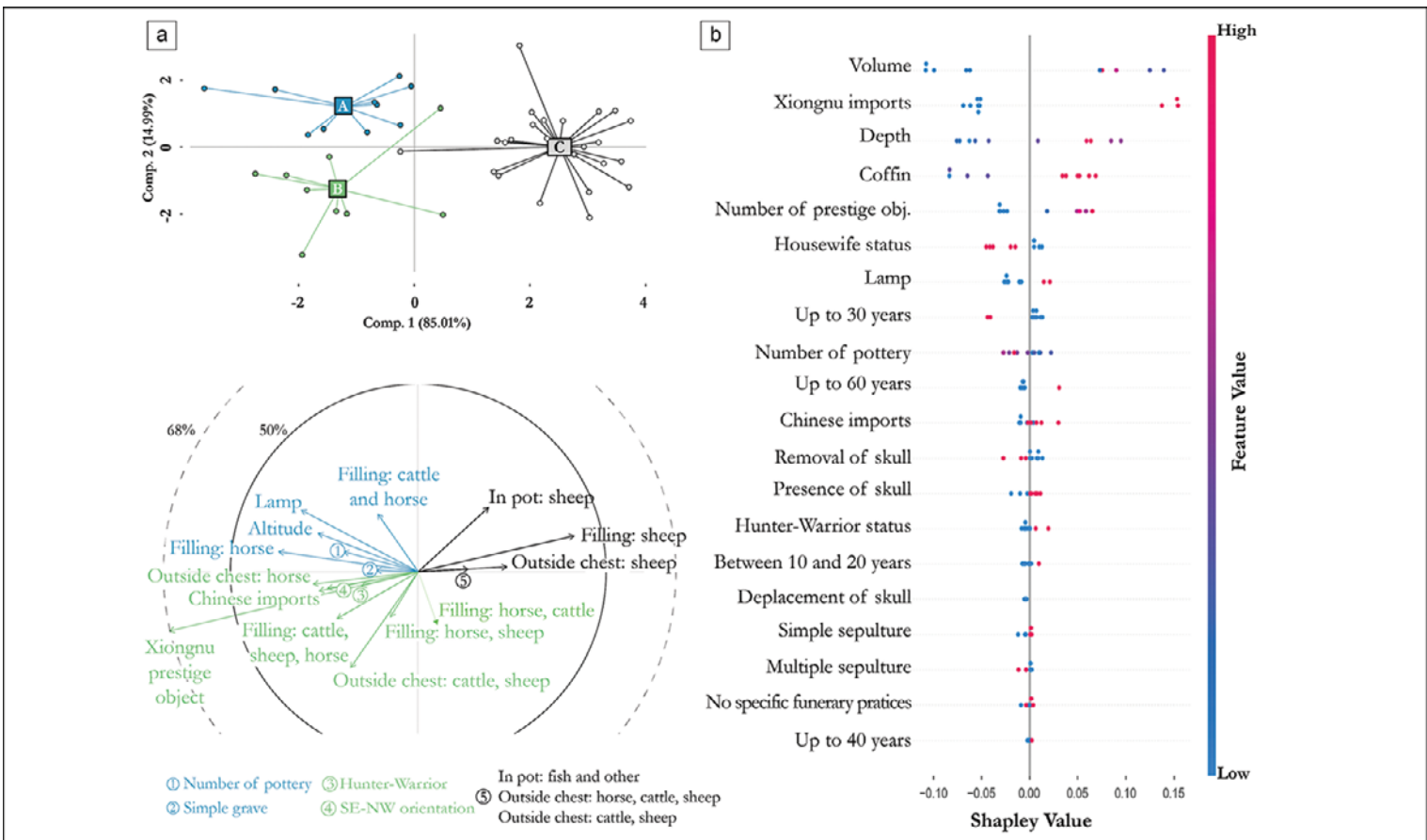


Figure 5. Results for 'family' prediction: top image a) LDA plot showing the proximity of the two lineages and their cultural distances relative to group C. Two individuals are predicted to belong to the wrong group: one individual from lineage B (green) is assigned to group C (grey), and one individual from group C is assigned to lineage B. Lower image a) the variable plot shows their contributions to the classification according to lineage (blue: lineage A, green: lineage B, black: group C); b) XGBoost: SHAP output from lArch highlighting key traits for lineages A and B combined (high values in red) (figure by A. Alcouffe).

immediately before the final two generations buried at Tamir (preceding individuals TUK40 and TUK32), estimating the collapse around AD 85—virtually identical to the historically reported date (De Crespigny 1984) (Figure S7). These dates lend substantial support to the hypothesis of a progressive economic decline in the final generations.

Both LDA and machine-learning approaches reveal marked economic and cultural distinctions between lineages, with patterns of wealth appearing more sharply delineated than those of kinship. These findings tentatively suggest that the organisation of the necropolis may have been structured more by social stratification than by familial affiliation—a hypothesis warranting further investigation (see below).

Similarity patterns among individuals

Clustering analysis (optimal $k = 5$; Table S9) assigns over half of lineages A and B to two wealthy clusters—cluster 1 (male) and cluster 2 (female). This pattern suggests that kinship may play a role in cluster formation, though not exclusively, as several individuals are not grouped with their genealogical relatives. The remaining clusters correspond to individuals subject to cranial removal practices (cluster 3), economically disadvantaged individuals (cluster 4) and older males also exhibiting cranial removal (cluster 5). Notably, certain lineage members (e.g. Tombs 03, 11, 19, 21, 32, 34, 36, 40) are positioned outside their expected familial clusters. Overall, clustering supports the view that socioeconomic status, more than genetic relatedness, structured the layout of the necropolis.

Cultural and economic specificities and their change over time

Data suggest that practices involving tomb architecture (e.g. volume, depth, number of coffins) and the inclusion of grave goods such as Xiongnu artefacts, prestige items and indicators of wealth were predominantly transmitted vertically—passed down from generation to generation—along familial lines (Table S10). In contrast, tomb orientation, the abundance of pottery, lamps and swords, as well as practices such as cranial removal, appear to reflect horizontal transmission through broader social mechanisms. Some traits, such as inferred social roles (e.g. hunter-warrior versus domestic activity; see OSM) and the presence of Chinese imports, display vertical transmission influenced by strong social mediation, as indicated by high HI values.

The consensus phylogenetic tree (Figure 6) highlights the cultural complexity of Tamir. Clade 1, comprising nine out of 11 related individuals, is the closest to ancestor TUK24. Clade 2 includes mostly unrelated individuals with divergent cultural traits. A third, intermediate clade features both related and unrelated individuals, suggesting the existence of three cultural pools: elite familial, general familial and unrelated.

All evolutionary model comparisons support a scenario based on the cladistically derived tree (Table S11), with economic variables providing the best explanatory power. The familial model—hypothesising that related individuals would exhibit similar funerary and cultural features—was consistently outperformed by economic, cladistic and even random models.

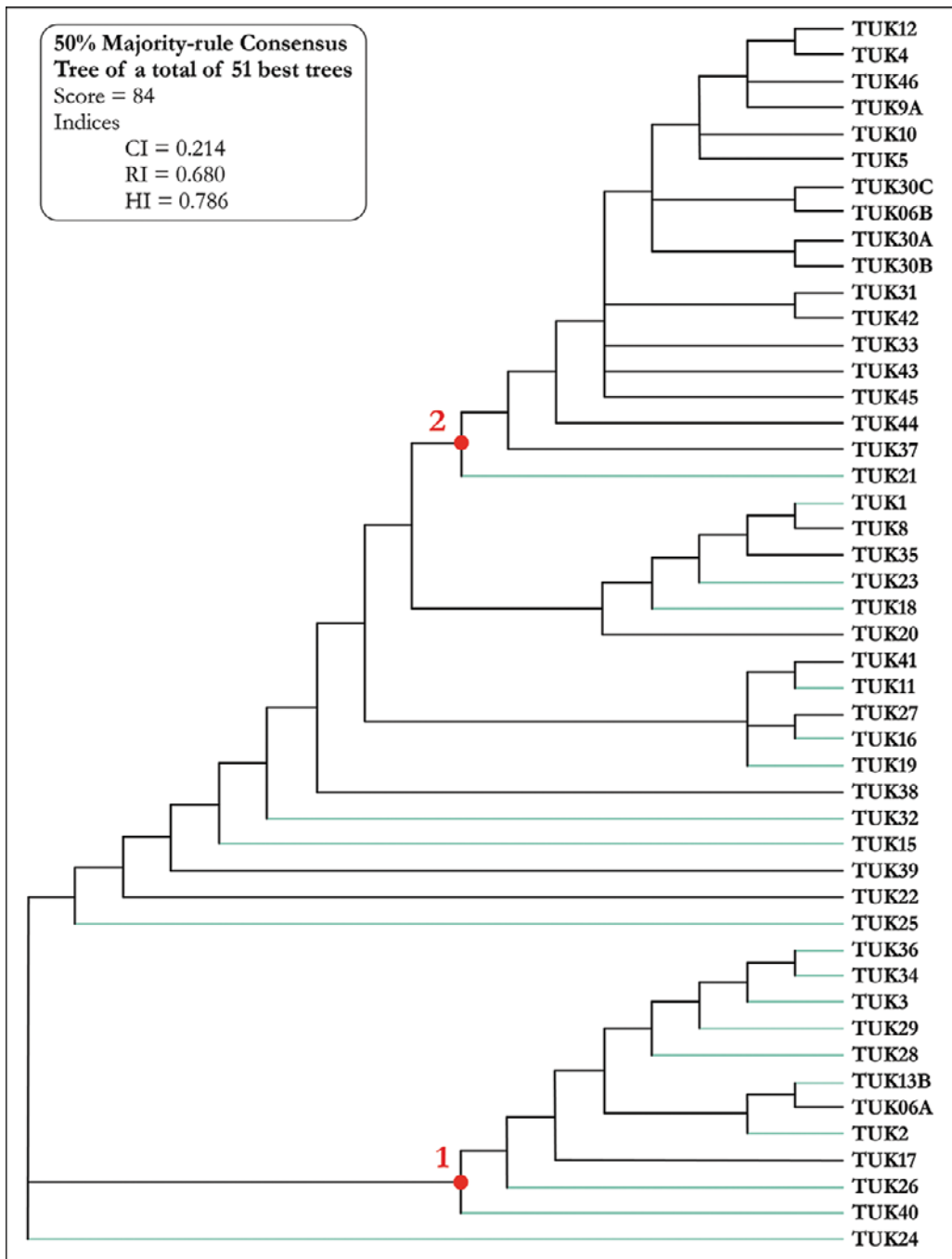


Figure 6. Consensus phylogenetic tree (heuristic search). Green branches indicate related individuals (lineage A and B). Clade 1 includes mostly related individuals; Clade 2 consists mainly of unrelated individuals, except for one case (figure by A. Alcouffe).

Taken together, the phylogenetic and Bayesian analyses indicate that economic factors, rather than biological kinship, structured the cultural organisation of the Tamir necropolis.

Discussion

The Xiongnu Empire was the first recorded polity of the Central Asian steppes, established between the late third and second centuries BC. Throughout their history, the Xiongnu maintained complex relations with the Chinese Han dynasty, navigating and negotiating a fluid frontier zone (Miller 2015). The Xiongnu Empire was neither genetically homogeneous (Jeong *et al.* 2018) nor culturally uniform (Di Cosmo 2002). It unified diverse regions under a clan-based aristocracy led by the Shanyu, who governed internal hierarchy and external diplomacy (Brosseder & Miller 2011).

Location, chronology and historical context

Some Xiongnu burial sites are subdivided into distinct sectors, as seen at Egyin Gol (Crubézy *et al.* 1996) and at Tamir, where our study focused on the eastern sector. The location of the site follows a well-attested Chinese tradition favouring visibility of a river, forest and mountain (Johannesson 2011; Giscard *et al.* 2014; Ensor 2021). At Tamir, the burial site is situated on a promontory that likely functioned as a ‘sacred’ landscape. This research presented here, which aimed to understand how this particular sector of the burial site—containing a diverse array of tombs—was spatially and socially organised, enhances our understanding of Xiongnu funerary practices.

The combined use of STR markers and mitochondrial and Y-chromosomal haplotypes enabled the identification of two extended lineages—designated A and B—spanning up to six generations, as well as several unrelated individuals (Keyser *et al.* 2020). These lineages may represent local elites, given the modest presence of Chinese imports compared to sites like Noin Ula (Brosseder 2007; Turbat & Crubézy 2021).

Genealogical analysis, combined with radiocarbon dating and Bayesian chronological modelling, suggests that this burial sector was in use for approximately two centuries, from the early first century BC to the end of the first century AD. The earliest phase corresponds to the aftermath of military defeats (129–119 BC) inflicted upon the Xiongnu by Han generals, leading to a retreat northward beyond the Gobi Desert—into the very region where Tamir is located. The final burials align with the Han defeat of the Northern Xiongnu (AD 89), after which Xiongnu identity fades from Chinese sources between AD 100 and 150 (Di Cosmo 2002). These events appear to be reflected in the changing burial practices at Tamir, suggesting significant sociopolitical shifts within Xiongnu society.

During the period in which the Tamir necropolis was in use, contact with China initially intensified before undergoing economic decline—a development echoed in the variable wealth of the tombs. This reflects shifting frontier power dynamics.

Who was buried, and on what grounds?

Members of group C do not share close genetic ties among themselves (Keyser *et al.* 2020) but they appear to have been granted the privilege of burial near their distant relatives, who also held positions of leadership. Few parent-child or spousal ties appear in group C, suggesting selective burial based not solely on familial ties and at least partially on social or symbolic capital.

In lineages A and B, only one individual per generation appears to have been buried in this cemetery, typically accompanied by a spouse and young children who died before reaching marriageable age. This restricted pattern strongly suggests that many close relatives—such as siblings—were buried elsewhere. One exception involves two brothers of the same generation. One (Tomb 25) was buried alongside his wife (Tomb 13B) in one of the wealthiest assemblages of the site, near members of lineage A. His brother (Tomb 48), by contrast, was buried over 200m to the north, at the margins of the necropolis. Though this brother had lineage rights, his peripheral burial suggests internal hierarchy even within ‘families’.

Given the small number of closely related individuals per generation, it is legitimate to question whether this funerary sector can be described as ‘familial’ in nature. Our combined analyses—including kinship reconstruction, spatial modelling and cultural phylogenetics—suggest that funerary practices at Tamir were not primarily shaped by biological kinship. Status and symbolic affiliation likely dictated burial location and assemblage.

Tomb 22, for instance, contained a female with no close kinship ties to the individuals interred around them, yet this individual’s son shares the same Y-chromosome lineage as the men of lineage A. This may suggest symbolic or social adoption. Conversely, some individuals from the recognised lineages stand out as culturally distinct. Tomb 19 contained a female from lineage A who may have continued the lineage due to her father’s lack of male heirs. She was buried alongside her husband (Tomb 23), a male with the same Y-chromosome haplogroup as found in lineage B. This case likely reflects a redefinition of descent and conferred a special status upon this female. The individual buried in Tomb 11, the only representative of the sixth generation, was returned to the cemetery in a secondary burial and placed near his grandparents. His inclusion appears to be based more on emotional than symbolic or economic considerations.

Beyond these patterns, other constraints also shaped burial decisions. K-means cluster analysis shows that individuals do not divide neatly into kin-based groups based on cultural similarities. Females, who would not typically be included in a strictly patrilineal funerary complex, were nevertheless buried alongside their husbands in several instances (such as those in Tombs 19 & 34). Other females, including adults in Tombs 36, 34, 40 and 32 and young daughters in Tombs 21, 11 and 03, were buried at the periphery of the necropolis, perhaps reflecting marginality tied to gender, age or symbolic role.

Thus, Tamir does not appear to represent a burial site structured strictly around biological kinship. Instead, it reflects a funerary landscape organised along socioeconomic lines, with kinship playing a secondary or legitimising role.

Organisation of the burial site and marital choices

The burial site at Tamir exhibits a clear spatial and social hierarchy. Individuals from lineage A are buried in the centre of the necropolis, where burial rights appear to have largely followed a patrilineal logic. In lineage B, wealthy males, such as the individual in Tomb 25, were buried with their wives near the lineage A cluster. In contrast, females who married outside their lineage were buried in the northern sector. In the only identified case where a female from lineage A appears to have succeeded her father, her burial is marked by a distinct funerary assemblage, suggesting differential treatment.

Individuals lacking close genetic links to the core lineages—such as the brother in Tomb 48, who did not represent the direct line of descent—were interred at the periphery. Although granted access to the cemetery, these individuals remained symbolically marginal. Access to central funerary space reflected lineage continuity, status and legitimacy.

Lineages A and B display structured patterns of cultural and economic transmission, distinct from those associated with group C. These lineages participated in broader cultural and economic networks that influenced both funerary treatment and marital alliances. While wealth transmission and inherited traits followed ‘familial’ logic, gender roles—such as men as warriors and women as domestic caretakers—were likely group-enforced. These norms also shaped funerary behaviour, including the selection of grave goods and participation in practices such as skull removal, occasionally applied to individuals lacking familial affiliation.

Confronting archaeological and historical data

In the absence of detailed historical records, drawing definitive conclusions remains difficult. However, the dualistic political organisation of the Xiongnu confederation (Barfield 1981)—divided into Right and Left branches—offers an interpretive framework. Each Shanyu appointed two branches, typically led by sons or other close kin, with the Left branch often associated with the heir.

Although lower levels of this structure are poorly documented, the Tamir cemetery may reflect such a division. Lineage A could correspond to the Left branch, and lineage B to the Right—each composed of descendants with political or symbolic authority. This hypothesis aligns with the patrilineal transmission of power in Xiongnu society (Barfield 1981) and the culturally documented prominence of women in Mongolian societies (Broadbridge 2018).

If correct, this interpretation suggests that lineage A followed a strict patrilineal model up to the fourth generation, when a lack of male heirs saw the integration of a socially modest son-in-law. Meanwhile, lineage B appears to have reinforced its patrilineal identity through a wealthy alliance with an individual connected to Chinese elites (Tomb 13B). This may reflect a power shift from the Left to the Right branch and would explain why lineage B continued to bury its male descendants in the necropolis for two further generations, while lineage A, having introduced an outsider, relinquished its central role.

Conclusion

By combining linear discriminant analysis, cultural phylogenetics and machine-learning algorithms, our pipeline reveals the cultural logics and social rules that shaped the Tamir funerary landscape and clarifies the true weight of genetic relatedness in its organisation. Coupled with historical evidence, this framework reveals a system driven not simply by biological kinship, but by the interplay of power, alliance and symbolic affiliation within a nomadic imperial world. This approach demonstrates that multilayered data can overturn long-standing assumptions about social structure, and it offers a powerful, replicable template for reassessing complex burial systems in Mongolia and across Eurasia.

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Online supplementary material (OSM)

To view supplementary material for this article, please visit <https://doi.org/10.15184/aqy.2026.10360> and select the supplementary materials tab.

Author contributions: CRediT categories

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