Spatial Organization and Socio-Economic Differentiation at the Dhar Tichitt Center of Dakhlet el Atrouss I (Southeastern Mauritania)

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Abstract The emergence of socio-political differentiation is a core theme in world prehistory, and the West African archaeological record offers unique insights into the range of pathways towards increasing complexity and the origins of socio-economic inequalities. During the second half of the second millennium BC, the Tichitt-Oualata escarpments of southeastern Mauritania witnessed the development of societies with monumental funerary architecture and substantial drystone settlements that relied on an agropastoral economy based primarily on pearl millet (Pennisetum sp.) cultivation and livestock-raising. Previous spatial analyses of site size have shown that the Dhar Tichitt landscape exhibited a multi-tiered settlement hierarchy, with Dakhlet el Atrouss I (80 ha) as the main regional center, with almost 600 compounds forming an intricate layout and hundreds of funerary tumuli in the vicinity of the site. The limited presence of imported prestige goods, however, has sparked considerable controversy regarding the socio-political complexity of the community inhabiting the site. The aim of this article is to understand whether remote sensing and spatial analyses can inform us about the extent of socio-economic differentiation at Dakhlet el Atrouss I, the largest site ascribed to the Tichitt Tradition. On the basis of relevant ethnographies exploring the dynamics of household wealth in agropastoral economies, I explore the degree of compound size variation at the site and neighborhood levels using well-established econometric methods that increasingly feature in archaeological studies of inequality and socio-political complexity. This paper represents the first application of Lorenz Curves and Gini Coefficients in African prehistory and illustrates a considerable degree of spatial and socio-economic differentiation at Dakhlet el Atrouss I.

Résumé L’émergence de la différenciation socio-politique est un thème central de la préhistoire mondiale, et les séquences archéologiques ouest-africaines offrent un aperçu unique de l’éventail des voies vers une complexité croissante et des origines des inégalités socio-économiques. Au cours de la seconde moitié du deuxième millénaire av. J.-C., les escarpements de Tichitt-Oualata du sud-est de la Mauritanie témoignent du développement de sociétés à l’architecture funéraire monumentale et aux importants établissements à l’architecture en pierre sèche reposant sur une économie agropastorale basée principalement sur la culture du mil perlé (Pennisetum sp.) et l’élevage. Des analyses spatiales antérieures ont montré que le paysage de Dhar Tichitt présentait une hiérarchie de peuplement à plusieurs niveaux. Dakhlet el Atrouss I (80 ha) est le principal
centre régional, avec près de 600 enceintes formant une
plan de site complexe et des centaines de tumuli
funéraires à proximité du site. La présence limitée
de produits de prestige importés a toutefois suscité
une controverse considérable quant à la complexité
sociopolitique de la communauté habitant le site.
L’objectif de cet article est de comprendre dans quelle
mesure la télédétection et les analyses spatiales peu-
vent nous renseigner sur l’étendue de la différencia-
tion socio-économique à Dakhlet el Atrouss I, le plus
grand site attribué à la tradition Tichitt. Sur une base
ethnographique qui observe la dynamique de la rich-
esse des ménages dans les économies agropastorales,
j’explore le degré de variation de la taille des enceintes
au niveau du site et du quartier, en utilisant des méth-
odes économétriques bien établies qui figurent de
plus en plus dans les études archéologiques sur les
inégalités et la complexité sociopolitique. Cet article
représente la première application des courbes de Lor-
enz et des coefficients de Gini dans la préhistoire afric-
aïne et illustre un degré considérable de différenciation
spatiale et socio-économique à Dakhlet el Atrouss I.

Introduction

The origins and development of inequalities associ-
ated with socio-economic differentiation are questions
that archaeologists have a core ethical responsibility
to consider and explore (Flannery & Marcus, 2012;
Kintigh et al., 2014; Trigger, 2003). These questions,
however, remain relatively underexplored in the con-
text of southern Saharan prehistory (although see Mac-
Donald, 2020). In southeastern Mauritania, the second
millennium BC witnessed the emergence of complex
agropastoral societies in Tichitt-Oualata escarpments
(MacDonald, 2013; Munson, 1971). These commu-
nities relied primarily on pearl millet cultivation and
livestock-raising. Dakhlet el Atrouss I (80 ha), located
at the core of one of the main Tichitt Tradition monu-
mental funerary landscapes, was the main regional
center of a multi-tiered settlement hierarchy (Holl,
1993; MacDonald, 2015). However, the extent to
which the Tichitt Tradition represented the endogenous
development of social complexity in the highlands of
southern Mauritania has been challenged by McIntosh
and McIntosh (1988) based on the limited number of
imported prestige goods. Well-established economet-
ric methods, particularly the Gini Coefficient, offer
an avenue for assessing socio-economic differentia-
tion in archaeological contexts through a different set
of evidence, namely household wealth differentiation
(e.g., Ames & Grier, 2020; Basri & Lawrence, 2020;
Bogaard et al., 2019; Kohler & Higgins, 2016), primar-
ily as reflected in asymmetries in living space area but
it can also be computed by including the size and num-
ber of storage facilities. Nonetheless, these methods
have not been previously applied to the African record.
This study represents the first attempt at harnessing
their quantitative potential by assessing their relevance
and suitability for understanding the unique pathways
towards social complexity found in the prehistory of
the West African Sahel.

Household Organization and Wealth Asymmetries in
Rural Sahelian West Africa

Households are socio-economic units characterized
by shared residence and/or the collective pooling and
consumption of resources (Allison, 1999; Wilk & Rathje,
1982). Blanton (1994) also emphasizes the
existence of shared responsibilities and the participa-
tion of multiple members in the decision-making pro-
cess. This kinship-based institution is fluid and flex-
ible, while simultaneously representing a structural
locus for a multiplicity of activities in the realms of
the biological and socio-economic reproduction of
its component members (Linares, 1984, p. 407; also
see Holl, 1993, 2006). In Sahelian West Africa, the
compound, an enclosed space that corresponds to the
material representation of the household, is a very
relevant dimension of structured social space in rural
settlements. A paradigmatic example is the Fulani vil-
lage of Be on the Mayo Kébbi river (northern Cam-
eroon), which articulated around fifty-six compounds,
each including one or more houses (David, 1971).
The factors affecting the number of houses within a
compound at any given time are diverse, including
the wealth and status of the kin group, the number
of cohabiting adult women in the household, and the
economic strategies of the compound head and their
affines (David, 1971, p. 115). The impermanence of
the building materials, as well as the availability of
labor and land, allowed for a fluid adaptation of the
internal boundaries within the compound to changes
in the number of people within the household due
to deaths, marriages, or lineage fission processes
(David, 1971, p. 120).
At the same time, the spatio-temporal structuring of settlements becomes a conducive medium through which to depict and embody the socio-political ideals that communities envisage for their past, present, and future. Among the Dogon of Mali, a patrilineal and virilocal sedentary agricultural community from east-central Mali, the distribution and morphometrics of compounds represent a tangible mechanism for the legitimization of specific narratives of authority (Lane, 1994). The Dogon live in compounds within nucleated villages on the plateau and along the foot of the Bandiagara escarpment, a steep sandstone cliff, 180-270 m a.s.l. overlooking the alluvial Gondo plain (Lane, 2006). This geological and ecological setting closely resembles the landscapes of southeastern Mauritanian dhars, the principal focus of this article. Their society is structured along agnatic lineage lines that form extended households (ginna), which act as independent units of production within the villages. These households possess usufruct rights to work agricultural fields on the neighboring valley (Lane, 1994, p. 200). Dogon compounds contain one to four houses around an open, multi-purpose activity area, with the space enclosed using drystone masonry (Lane, 1994; Lauber, 1998). The ginu na (the lineage head compound) is most often the longest-standing compound and tends to be occupied by the eldest member of the lineage (Lane, 1994). Within this permanent and predictable arena, daily routine and generational time coalesce, as it is considered the legitimate and appropriate space for conviviality, the storage of collective agricultural output, ancestor worship, and the birth of new lineage members, which explains its different internal composition and architecture (Lane, 1994, p. 209).

The conceptualization of households as autonomous and relatively self-sufficient units that fostered the intensification of production processes for private accumulation has played a considerable role in archaeological approaches that have sought to understand the organization of early food-producing societies (e.g., Flannery, 1972, p. 48; also see Byrd, 1994; Flannery, 2002). In semi-arid subtropical regions, where rural farming systems do not rely on irrigation, the direct relationship between labor input and agricultural production does indeed play a paramount role in the ability of the household to generate and accumulate wealth. Being the head of a large, extended household leads to greater social prestige and wealth, as documented by Bohannan and Bohannan (1968) among the Tiv of Nigeria. Similarly, in extant Bamana villages of central Mali, Zeh (2000, p. 264) noted how the sizes of their compounds were a function of the number of male members that the habitational unit had, since the number of brothers and sons strongly influenced the productive capability of the household under a labor-limited agropastoral system (Zeh, 2000, p. 264; cf. Bogaard et al., 2019). Among the Bamana, the Dogon, and other rural Sahelian communities, the size of lineage-based production units traditionally dictated the amount of land that could be cultivated and, to a lesser extent, the size of the livestock herd that could be managed (Zeh, 2000, p. 264). Since parents obtain greater benefits from the unpaid labor of family members, including offspring (Hill, 1982, p. 91–92), they are disincentivized from assisting their children in setting up independent, viable households of their own. Instead, they usually opted to preserve the structural integrity of the lineage, even if such arrangements are inherently unstable and a source of inter-generational tensions. Therefore, the relationship between compound size and lineage wealth is a key dimension of intra-site differentiation in rural West African communities. More broadly, compound size can be seen as a reflection of the household’s capacity to procure space and mobilize resources (Basri & Lawrence, 2020).

Based on the nature of the assets involved, household members may possess three main types of heritable wealth: embodied attributes; relational positionality within social networks; and material, encompassing tangible possessions such as house facilities, land/livestock ownership, and portable prestige goods (Bowles et al., 2010; Prentiss et al., 2018). Recent large-scale comparative archaeological studies have identified the house-floor area as a quantitative variable that seems to provide a relatively standardized, cross-cultural proxy for material household wealth (cf. Basri & Lawrence, 2020; Bogaard et al., 2019; Fochesato et al., 2019; Kohler & Smith, 2018; Kohler et al., 2017). Exploring the spatial dimensions of asymmetries in the control and management of endogenous and concurrent sources of wealth, power, and status differences is thus a promising and relevant research avenue for African archaeology. This approach may help illustrate aspects of the socio-economic and political organization of pre-colonial polities, as we show here in relation to the communities of the Tichitt Tradition that emerged in
the highlands of southeastern Mauritania in the second millennium BC.

Archaeological Approaches to Socio-economic Differentiation in Southeastern Mauritania

The southeastern Mauritania sandstone escarpments (dhar in Hassaniya Arabic) are a topographic transition between the Tagant Plateau and the Hodh Depression (Fig. 1). These highlands encompass the flat upland areas on the edge of the plateau; slopes of varying steepness intersected by shallow wadis and narrow canyons (dakhlat) that carry flash torrents during the short summer rainy season (mid-July and late September); and interdunal alluvial lowlands that formerly constituted elongated endorheic basins (baten), with seasonal or year-round freshwater lakes fed by a higher water table and streams formed from rainwater runoff (Holl, 2009; Munson, 1971; Vernet, 1993). Several French colonial researchers, who sporadically visited the escarpments around Dhar Tichitt and Dhar Oualata during the first half of the twentieth century, mentioned the existence of large and well-preserved drystone-masonry villages and funerary monuments (Laforgue, 1924; Laforgue & Mauny, 1939; Mauny, 1950, 1951; Verneau, 1920). The first

Fig. 1 Dhar Tichitt (southeastern Mauritania) with the location of Dakhlet el Atrouss and Akreijit, the two main archaeological sites discussed in the text
detailed archaeological fieldwork in the Dhar Tichitt landscape was carried out during the late 1960s by Patrick Munson (1971), who documented a multi-stage sequence of settlement development in the region and suggested that the main occupation phase at most large settlements dated to the second half of the second millennium BC, coeval with the last major humid phase of the Holocene in the region (Vernet, 1993). Subsequent projects have expanded the documentation and excavation process of sites with stone features along Dhar Tichitt (Amblard, 1984; Amblard-Pison, 2006; Holl, 1986), Dhar Oualata (Amblard-Pison, 2006), and Dhar Néma (MacDonald et al., 2009; Person et al., 2006). Further west, the Dhar Tagant area was first comprehensively surveyed in the 1980s by a Franco-Mauritanian team, led by Ould-Khattar (1995), and this region has recently been the focus of remote sensing research aiming to understand in more detail the nature and distribution of prehistoric settlements and funerary monuments (Linares-Matás & Lim, 2021a).

An important dimension in the characterization of the socio-economic organization of West African societies was the timing of the adoption of pearl millet (Pennisetum glaucum) cultivation and the increasing reliance on this crop. Based on contemporary botanical distributions and ethnographic data, Murdock (1959) proposed that several seed crops and other plants were independently brought under domestication near the headwaters of the Niger River by 4500 B.C. Harlan (1971) has suggested that indigenous West African crops likely had a spatially diffuse domestication pattern. Archaeological research indicates that this socio-economic transformation probably occurred further north in the West African Sahel (Manning, 2010). The evidence comes from both the physical grains themselves as well as from AMS-dated impressions on pottery sherds tempered with the chaff of domesticated pearl millet (Pennisetum sp.) at Karkarichinkat, in the Tilemsi Valley (Mali), dating to 2500 BC (Manning et al., 2011). On the basis of the gradual evolution of non-shattering rachises (Fuller 2007), the origins of cereal domestication in the Sahara may have even deeper origins, potentially around the early fourth millennium BC (Fuller et al., 2021; MacDonald, 2015; Manning, 2010). By the first half of the second millennium BC, pearl millet was also cultivated at Ounjougou (Bandiagara escarpment, Mali) and in the Gourma region of Mali, northern Ghana, and the Mauritanian dhars (Amblard, 1984; D’Andrea et al., 2001; Fuller et al., 2007; Munson, 1971).

Attempts to understand the degree of socio-economic differentiation at Dhar Tichitt communities represent a longstanding dimension of archaeological research in this region. The limited number of imported elements (such as carnelian and amazonite beads) at mid-second-millennium BC Dhar Tichitt sites (southeastern Mauritania) reported by Amblard (1984, p. 273) sparked opposite responses in the literature. Holl (1985a, p. 94) claimed that they indicated the existence of consolidated long-distance trade networks controlled by elites. In contrast, McIntosh and McIntosh (1988, p. 101) considerably downplayed their significance for contributing to our knowledge of the socio-economic organization of Tichitt communities and potential inequalities within these agropastoral communities. Nevertheless, imported elements are not the only—nor necessarily the most relevant—source of evidence for understanding the endogenous articulation of socio-political power and internal competition within communities in the southern Sahara and the West African Sahel (MacDonald, 1998, 2013). For example, in the absence of elite burials with lavish grave goods at Jenné-jeno Phase III (AD 400–900), a period when the settlement reached 33 ha in area and was increasingly involved in expansive trade networks, McIntosh (1999) suggested that power asymmetries were likely articulated through polycentric heterarchical structures of local governance, with political influence and authority distributed between clans and specialist groups.

In southeastern Mauritania, several factors other than imported materials seem to indicate some degree of socio-economic differentiation among households. These include the demarcation of social space through stone compounds (Munson, 1971), the existence of multi-tiered settlement hierarchies (Holl, 1993), the clustering of funerary tumuli at certain Dhar Tichitt centers such as Dakhlet el Atrouss I (80 ha)—including the integration of very large monuments within the spatial layout of the site (Amblard-Pison, 2006; MacDonald, 2015)—and the considerable diversification of form and decoration of pottery during the Classic Tichitt phase (Table 1), potentially related to increasing specialization of use (MacDonald, 2011).

Holl (1993, p. 105) argued that the spatial coherence of the compound represents a suitable
archaeological avenue for understanding household organization in Tichitt Tradition communities. In the absence of a suitable chronological resolution to conduct a temporal analysis of shifts in the spatial organization of compound clusters and household units (cf. Holl, 2006, p. 26), the assessment of spatial asymmetries in compound size represents the main avenue for studying spatial manifestations of time-averaged household wealth variability. At the same time, communities are more than individual, modular, and self-sufficient economic units. Households are an intrinsic part of a wider social and spatial fabric, through communal labor and rituals that weaved together and mobilized a polycentric network of agents, and on the basis of intra-settlement clustering through neighborhoods. This intra-site settlement pattern is a paradigmatic feature of the central Anatolian Neolithic, documented at sites such as Aşıklı Höyük and Çatalhöyük (Düring, 2006). At these sites, individual buildings are directly adjacent to others in groups of 30 to 40, with each cluster separated from the rest by streets and open midden areas (Düring & Marciniak, 2005). At Çatalhöyük, the lower levels are characterized by the pre-eminence of neighborhood clusters and the differential distribution of burials, which subsequently gave way to the rise of more autonomous households, with buildings directly accessible from open spaces, as the prime dimension of social and spatial association within the settlement (Düring & Marciniak, 2005; Hodder, 2005). Therefore, the existence of intra-settlement compound clusters documented at large classic Tichitt sites, particularly at Dakhlet el Atrouss I (Holl, 1993), merits the consideration of compound neighborhoods as potential units of analysis alongside individual compounds in the multi-scalar study of socio-economic differentiation and intra-site spatial structure at the site.

Methodology

In this article, I explore the usefulness of assessing intra-site socio-economic differentiation on the basis of compound and clustered neighborhood size asymmetry using spatial data from Dakhlet el Atrouss I (18° 22′ N; 8° 46′ W), located in the Dhar Tichitt escarpment of southeastern Mauritania (Vernet, 1993). Situated towards the edge of an elevated plateau over the Aouker basin, Dakhlet el Atrouss I is the largest site of the Tichitt Tradition (three times larger than the second biggest site in Dhar Tichitt). It comprises nearly 600 compounds, two very large funerary monuments within the layout of the site, and hundreds of unexcavated funerary tumuli in its immediate hinterland (MacDonald, 2013; Vernet, 1993; Vernet and Ould Mohamed Naffé, 2003). Along with an intricate organization of space, these features confirm its status as a large regional center (Vernet, 1993, p. 273). Dakhlet el Atrouss I also exhibits a series of large peripheral enclosures without internal features, which are unlikely to represent inhabited compounds (Fig. 2), and have been interpreted as the base of cattle kraals (MacDonald, 2015) or as agricultural fields for décurs farming (Amblard-Pison, 2006). Décurs farming involves planting crops in high-moisture areas associated with the recession of seasonal floods, a common and sustainable agricultural practice among subsistence farming communities in arid and semi-arid environments (di Lernia et al., 2020). Therefore, these features are best left out

| Phase                  | Chronology  | Features                                                                 |
|------------------------|-------------|---------------------------------------------------------------------------|
| Pre-Tichitt (Akreijit phase) | 2600–1900 BC | Mobile herders and hunter-gatherers living in small temporary campsites |
| Early Tichitt (Khimiya/Goungou phases) | 1900–1600 BC | Initial cultivation of domesticated pearl millet. Considerable degree of mobility |
| Classic Tichitt (Nkahl/Naghez/Chebka phases) | 1600–1000 BC | Development of vast settlements comprising conjoined clusters of stone-walled compounds |
| Late Tichitt (Arriane/Akjineir phases) | 1000–400 BC | Period of intense aridification and associated demographic decline in the Tichitt-Oualata region |
| Terminal Tichitt / Early Iron Age | 400 BC–AD 200 | Development of complex stone-walled settlements in the Tagant region with evidence of iron metallurgy |
of quantitative analyses of household wealth based on compound area.

A standardized index is required in order to undertake meaningful and cross-culturally comparable quantitative studies. The Lorenz curves and the Gini coefficient have been used in the recent archaeological literature as an approach for the analysis of household wealth differentiation (Ames & Grier, 2020; Basri & Lawrence, 2020; Bogaard et al., 2019; Fochesato et al., 2019; Kohler & Higgins, 2016). Lorenz curves are cumulative distribution graphs bisected by a 45° line from the origin point, with the divergence between the curve and the line visually representing the degree of socio-economic inequality. The Gini coefficient, standardized between 0 and 1, is used to measure “the fraction of the area below the equality line that falls above the “Lorenz curve” (Smith et al., 2014, p. 312). In other words, the Gini coefficient measures distribution unevenness within a sample, with higher values corresponding to a greater degree of unevenness, representing socio-economic differentiation. In turn, the Lorenz Asymmetry Coefficient (LAC) informs us about which size classes are contributing most to the population’s total inequality, reflected by the Gini coefficient. A LAC value of less than 1 implies that inequality is due to the smaller entries, whereas a LAC value of more than 1 means that inequality is primarily driven by the largest individuals.

Archaeological studies of household wealth inequality rely on two main assumptions: that the size of the housing unit represents the wealth of the occupants and that the number of inhabitants in each unit remains constant over the period covered in the study (Basri & Lawrence, 2020). While these assumptions are often difficult to test due to issues associated with data resolution, this approach has been rather successful in characterizing the nature and explaining the emergence of wealth inequality across a number of different settings, which suggests that it represents a robust quantitative approach (Ames & Grier, 2020; Basri & Lawrence, 2020; Bogaard et al., 2019; Kohler & Higgins, 2016).

ArcGIS Pro 2.7, a geographical information system (GIS) software package, was employed to manipulate satellite imagery and conduct spatial analyses.
using in-built geoprocessing tools. Bing Maps was loaded into the GIS as the base map after obtaining a license key from Microsoft. The study area has ortho-rectified VHR imagery of 30–50 cm (i.e., already corrected for sensor distortions derived from terrain morphology and viewing angle), making it ideal for visual inspection and analysis. Individual enclosures were manually drawn as polygons using Bing Maps. While the imagery resolution was very well-suited to this digitization method, there is some degree of uncertainty inherent to the process of manually digitizing site plans from VHR imagery, e.g., misidentification of features, mischaracterization of external compound walls, or mischaracterization of internal compound subdivision. Future verifications in the field will conclusively confirm the accuracy of the representations presented here. To generate “neighborhoods,” adjoining polygons that shared borders were merged using the Dissolve and Spatial Join tools (Fig. 3). We selected those neighborhoods with five or more compounds for analysis. Once the size of each compound and compound neighborhood were measured, the Gini value was calculated using the “ineq” package in RStudio, R version 4.0.4 (RStudio Team, 2021; Zeileis, 2014), following Basri and Lawrence (2020). For comparative purposes, we also calculated the Gini Coefficient value of Akreijit, another large Tichitt Tradition site, studied more extensively (Holl, 1986; Vernet, 1993). The visual representation of index classes followed the Jenks natural breaks optimization algorithm, a data-specific system that best groups similar values together and maximizes differences between classes when setting boundaries between data values (de Smith et al., 2018; Jenks, 1967).

Results

Several issues need to be considered in order to adequately assess the outcome of the global calculation of compound size asymmetry at Dakhlet el Atrouss I. The most important of these lies with the calculation of the global Gini Coefficient of Dakhlet el Atrouss I, and specifically whether to include the largest enclosure (main component of neighborhood ID 44 in Fig. 3), located in the northwestern periphery of the site, in the analysis (Fig. 4). The area of this enclosure (11,103.68 m²) is considerably larger than that of the second-largest enclosure (3881.137 m²), a particularly sensitive issue in a study of compound size asymmetries: the Gini Coefficient of Dakhlet el Atrouss I with this enclosure is 0.3506, whereas without it this site-level value decreases to 0.3219. Furthermore, there is also an archaeological rationale for excluding this enclosure from the analysis as it incorporates at least 36 potential housing complexes in stone architecture, which runs counter to the expected association between compound and household space. While it is certainly possible that some of the compounds included in the analysis may have hosted two or more individual houses, these are not built of stone, which has implications in terms of perceived structural permanence and social attitudes. A working hypothesis to explain why there is such a mismatch between the number of houses and that of compounds in this western peripheral enclosure involves a chronological difference. On the basis of observations from settlements found in the Dhar Tagant region (Linares-Matás & Lim, 2021a; Ould-Khattar, 1995), it appears that individual stone houses lacking association with closely circumscribing compounds are more likely to date to later phases of the Tichitt Tradition. Individual stone houses are also observed in the enclosed area on the southeastern side of the site. A later chronology for this western peripheral enclosure may be consistent with a model of settlement growth towards the periphery of the plateau from the central parts of the settlement. Given that the structure of household space is different from that seen elsewhere at Dakhlet el Atrouss I, and that not excluding them may unduly amplify the pattern of socio-economic differentiation at the site, it seems more appropriate to exclude this particular enclosure from our global Gini coefficient calculations for the site, at least at this stage of research.

The second dimension to be considered relates to the fact that Gini Coefficient values are meant to be comparative; i.e., they assess relative differences in inequality. To be meaningful, comparisons should be based on the same data. As such, Gini values derived strictly from house size may not be fully comparable to Gini values resulting from the compound size, even if both approaches aim to associate household living space with socio-economic wealth. To contextualize
the results obtained from Dakhlet el Atrouss I, we compare them with a local point of reference using the same kind of data. For this preliminary assessment, Akreijit, another Dhar Tichitt site that has witnessed extensive fieldwork, was chosen. Future work will increase the analytical resolution at Akreijit, discussing storage space and material culture distribution data, as well as expanding the comparison to a wider range of Tichitt Tradition sites from the different escarpments of southern Mauritania to better capture the spatio-temporal diversity of site types and sizes.

The Lorenz Curve (Fig. 5) shows how the blue curve, representing Dakhlet el Atrouss I, diverges more from the theoretical line of equality, in black, than the orange curve, representing Akreijit. Therefore, we can infer that Dakhlet el Atrouss I has a greater degree of socio-economic differentiation than at Akreijit on the basis of compound size variability. This is quantitatively reflected in their Gini Coefficient values, with Dakhlet el Atrouss I scoring 0.3219 compared to the 0.2874 value obtained sent collective burials, which could suggest the existence of lineage-based sources of status or authority.)

Fig. 4 Western peripheral enclosure with individual stone houses (Note the presence of two very large funerary tumuli, the largest in the region. They have been suggested to represent collective burials, which could suggest the existence of lineage-based sources of status or authority).

Fig. 5 Lorenz Curve illustrating the distribution unevenness values of Dakhlet el Atrouss I (in blue) and Akreijit (in orange). The greater divergence of the blue curve from the theoretical line of equality indicates a larger degree of unevenness, and, by extension, a larger Gini coefficient value, for Dakhlet el Atrouss I. (The graph was generated using the ineq R package).
for Akreijit. It is, however, noteworthy that the average compound size at Akreijit is greater than that at Dakhlet el Atrouss I (Table 2). Akreijit is also more internally complex and subdivided (Fig. 6), likely resulting from changes in compound use. Akreijit also has a peripheral quarter with a considerable number of compounds with stone houses, which may hint at these processes of organic settlement growth and change, as reflected in layout changes over time (Vernet, 1993).

The main methodological innovation developed in this article is the study of well-defined compound clusters in Dakhlet el Atrouss I to assess the intra-site spatial distribution of size unevenness within “neighborhoods.” Such approaches on most archaeological sites would be contingent on detailed and large-scale horizontal excavations. Here, the applicability of this approach is enabled by both the existence of free, very high-resolution satellite imagery for the area and the intrinsic nature of the site, based on a hyper-visible stone architecture with low sedimentation rates that have preserved their outlines exposed. By plotting the Lorenz Asymmetry Coefficient and the Gini Coefficient values by compound cluster over

Table 2 Descriptive statistics of the compound size distributions at two Dhar Tichitt regional centers: Dakhlet el Atrouss I and Akreijit

| Site            | Gini coefficient | Lorenz asymmetry coefficient | Number of compounds | Mean compound area | Median | Standard deviation | Minimum value | Maximum value |
|-----------------|------------------|------------------------------|---------------------|-------------------|--------|--------------------|---------------|---------------|
| Dakhlet el Atrouss I | 0.322            | 1.116                        | 587                 | 395.65            | 318.98 | 324.56             | 61.06         | 3881.14       |
| Akreijit        | 0.287            | 0.895                        | 105                 | 716.10            | 683.27 | 386.21             | 63.17         | 2264.59       |

Fig. 6 Complex compound subdivisions in the central area of Akreijit
a satellite image of the site (Figs. 7 and 8), several results are apparent (Table 3).

First, the central clusters (DeA_C42 and DeA_C57), which also have the most empty space around them, have consistently high values, indicating that they have particularly high internal compound size asymmetry and that the sheer size of the largest compound at each of them is indeed driving the Gini coefficient. The other neighborhoods with high Gini coefficient values are in the western periphery with the huge enclosure (DeA_C44), another on the eastern periphery, and two large ones that begin near the center of the site and expand continuously to the northern edge of the settlement. The large number of enclosures they encompass may include some that were not primarily for occupation, which could be unduly driving up their Gini coefficient values. For example, two of the largest compounds on the left include a monumental funerary tumulus within them, while the northern most enclosures to the right may have fulfilled agropastoral functions since a seasonal watercourse appears to have run through them.

The second main observation, in contrast to the internal cluster asymmetries noted for the prominent central neighborhoods, is the relatively low Gini coefficient values documented for a large set of neighborhoods on the central-eastern part of the site. Of utmost interest here is the fact that some compound neighborhoods of relatively even size (IDs: 91, 184) are distributed around a central, open space representing the end of a long and narrow passageway bisecting this part of the site.

**Discussion**

This paper represents the first application of Gini coefficient approaches in the study of socio-economic differentiation in African prehistory and one of the first attempts at modeling compound size asymmetries at the neighborhood level. The household living area is the most common cross-cultural data type in archaeological studies of inequality since it is a non-portable index of family wealth (Basri & Lawrence, 2020; Bogaard et al., 2019; Fochesato et al., 2019), although potential caveats need to be considered when undertaking an assessment that involves households with relatively long occupancies, since the initial net value of assets owned (heritable wealth) changes over time, even if compound area remained relatively unchanged. Similarly, since larger household use-lives correlate with increased inheritance potential (Bowles et al., 2010), as perhaps documented in the compound dynamics noted at

![Spatial representation of Lorenz Asymmetry Coefficient and Gini Coefficient values at the neighborhood level for the large Dhar Tichitt site of Dakhlet el Atrouss I, southeastern Mauritania](image-url)
Akreijit (Holl, 1986; Vernet, 1993), some degree of value inflation due to time averaging may appear in archaeological applications of Gini coefficient values (Kohler & Higgins, 2016).

Several Dhar Tichitt sites, including Akreijit and Dakhlet el Atrouss I, have preserved granary foundations that could be used in quantitative studies of socio-economic differentiations (MacDonald, 2013; Vernet, 1993). However, they are nearly impossible to discern even in very high-resolution satellite imagery of the kind we have employed here, so their study must be restricted to sites where detailed fieldwork has been conducted, such as Akreijit (research forthcoming). Furthermore, the analysis of storage space tends to overestimate Gini coefficients in relation to measurements using living space. However, it appears that it can provide relevant insights regarding the maintenance of household prestige through estimation of anticipated production surplus income (Bogaard et al., 2018; Fochesato et al., 2019; Kohler & Higgins, 2016). The culturally specific significance of certain portable prestige items is more difficult to correlate cross-culturally. These objects might provide more information about social priorities at the time of burial or the latest stages of occupation and abandonment of living spaces than net household wealth (Ames & Grier, 2020). Besides, Gini coefficients derived from both storage area and portable prestige items are strongly correlated with household living area (Fochesato et al., 2019). Nonetheless, future research will aim to assess the applicability of this correlation at Dhar Tichitt sites and whether any additional insights can be gained by considering the size, number, and distribution of granaries at Akreijit.

The socio-economic and political organization of prehistoric communities in the West African Sahel has been extensively discussed. In the absence of explicit material indicators of individual wealth or power, the social organization of other large sites of the prehistoric West African Sahel, such as Jenné-jeno (40 ha), has been characterized as involving disaggregated hierarchies or instances of heterarchical structures involving polyfocal and competing sources of authority, primarily through reference to Mande ethnography emphasizing the spatial separation of lineages and occupational clusters (McIntosh, 1999). We note the spatial separation of compound clusters at Dakhlet el Atrouss I in ways that highlight internal asymmetries that may reflect lineage power differences. However, we cannot discern at the moment whether the spatial pattern discussed for Dakhlet el Atrouss I represents lineage power asymmetries; the co-existence of two modes of socio-economic and political organization (horizontal vs. vertical); or a diachronic transformation of the socio-political nature of the site over time, with power being initially distributed across a wider set of agents and eventually coalescing into a more restricted number of lineages (or vice versa). What is clear is that the second half of the second millennium BC (the so-called Classic Tichitt period, encompassing Munson’s Nkahl, Naghez, and Chebka phases) represents a period of major socio-economic and political transformation for Dhar Tichitt communities. A vertical hierarchy of settlements developed (Holl, 1993), some of which encompass a much larger number of compounds; and the Tichitt Tradition sites expanded west towards Dhar Tagant and south towards the Mëma region of Mali (MacDonald, 2013).

In agropastoral societies, surplus accumulation and storable wealth—including cattle herds—play an important role in the emergence of socio-economic differences, even if some communities develop mechanisms to downplay them or disrupt their intergenerational transfer (e.g., Wright, 2014). Socially persistent inequalities are more likely to emerge in settlements with stable relationships between households and arable fields, in the context of increasingly limited and controlled access to arable land and intergenerational wealth transmission (Borgerhoff Mulder et al., 2009; Goody, 1976; Gurven et al., 2010; Mattison et al., 2016; Midlarsky, 1999). Indeed, African societies dependent on livestock husbandry tend to be characterized by inequalities in wealth distribution patterns (Konczacki, 1978, p. 49; Sutter, 1987). In rural West Africa, cattle often play a paramount role in socioeconomic dynamics, as the main currency in marriage payments and ritual practices, such as funerary feasts (Zeh, 2000, p. 265).

Cattle had already become a cornerstone of Saharan pastoral societies by the Middle Holocene, likely associated with growing seasonal pressures in relation to the availability of water and plant resources (McIntosh & McIntosh, 1988, p. 99; also, Brass, 2018; Di Lernia, 2013; Marshall & Hildebrand, 2002; Paris, 2000). The consolidation of pastoralism would
Coefficient Class Divisions

Lorenz Asymmetry

Gini

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have entailed a drastic reconfiguration of socio-economic relationships, such as mobility, morality, and property rights (Western & Finch, 1986). Although detailed osteometric studies are still scarce, relevant faunal data on first phalanx epiphyseal fusion and dental eruption and wear patterns from prehistoric sites in the Middle Senegal Valley indicate a consistent cattle herding practice aiming to maximize herd size with little culling of younger animals (MacDonald & MacDonald, 2000, p. 132; cf. Grant, 1982; Grigson, 1982). This approach is relatively inefficient with regard to meat production, but it is the most suitable for preserving wealth "on the hoof", while also prioritizing herd survival even during harsh climatic conditions (Dahl & Hjort, 1976). Keeping large herds involves capital accumulation, generally of a private nature, since herds are often owned by individual households.

The first construction of monumental tumuli with individual human burials around the fifth millennium BC in the western half of the Sahara hints at important transformations within pastoral societies. The site of Emi Lulu (c. 4700–4200 BC) in the Ténéré region of Niger has several excavated tumuli that acted as graves for adult male individuals, although they contained few to no grave goods (Paris, 1996). MacDonald (2013) suggests that the preferential emphasis placed upon the architectural structure could indicate that the individuals achieved status through ensuring the survival and prosperity of herds in the face of adversity, with livestock wealth being subsequently redistributed within the community, mirroring the socio-economic mechanisms that regulate contemporary acephalous pastoral societies. In addition to local cattle transfers, polished stone objects (beads, axes, bracelets) were widely traded across the Sahara by around 4000 BC (MacDonald, 1998). Cattle and small livestock are present from the mid- to the late third millennium in the Sahel (MacDonald, 2015; MacDonald & MacDonald, 2000), from Karkarichinkat, Windé Koroji Ouest in the eastern Inland Niger Delta (Mali), to pioneer sites in the Tichitt-Oualata-Néma region (Mauritania). Their relevance for Tichitt Tradition communities has long been highlighted by MacDonald (2013), who sees the establishment of very large peripheral enclosures to the north of Dakhlet el Atrous I as a clear indicator of the prominent socio-economic role that cattle played.

With regard to cereal agriculture, pearl millet cultivation in the Tichitt-Oualata-Néma region of southeastern Mauritania likely started as a seasonal component of a generalized broad-spectrum pastoral economy, a resilient system in semi-arid regions which also included the exploitation of wild terrestrial and aquatic resources (Holl, 2009; MacDonald, 2015). McIntosh and McIntosh (1988, p. 100) have argued that this adaptive response in the West African Sahel was induced by increasingly difficult conditions during the second millennium BC, mirroring suggestions made by Munson (1971) for southeastern Mauritania in particular. Indeed, occasional seasonal ponds allow small-scale crop cultivation even in hyper-arid environments, as documented in the Tadrart Acacus Mountains of southwest Libya (di Lernia et al., 2020). At the same time, it is relevant to note that lake levels were rising in the Sahara around the mid-second millennium BC, only falling again by the first millennium BC (Nicholson & Flohn, 1980). Therefore, the regional onset and consolidation of pearl millet cultivation in the southern Mauritanian highlands during the second millennium BC (cf. MacDonald, 2015; Manning, 2010) is perhaps better explained by favorable palaeoenvironmental affordances in the well-watered early Late Holocene Sahelian savanna, coupled with increasing knowledge of local landscapes. These relatively more predictable growing conditions would have enhanced productivity and the local carrying capacity of the environment. Increasing reliance on cultivated crops within a semi-sedentary lifestyle may have been an innovative solution to accommodate a growing population. Recent studies are highlighting how a broad range of resources are often employed in scenarios of resource abundance rather than scarcity (Bogaard et al., 2021; Linares-Matás & Lim, 2021b; Steiner et al., 2022; Zeder, 2012). Such a positive feedback loop could have formed the backbone that sustained the “classic Tichitt” stone-walled settlement phase (1600–1000 BC) in the sandstone escarpments of southeastern Mauritania (MacDonald, 2015).
In western Eurasia, the adoption of cattle traction enabled a radical extensification of agricultural production that accelerated inequality in land ownership through the establishment of land-limited farming systems (Bogaard et al., 2019). In West African Sahelian prehistory, the absence of the plow implies that the relationship between cattle pastoralism, crop cultivation, and inequality most likely followed a different trajectory. Recent isotopic work has documented a trend of increasingly intensive manuring in pearl millet farming through the second millennium AD among the agricultural communities of northeastern Burkina Faso, likely enabled by a synergistic seasonal relationship between specialized mobile cattle pastoralists and farming communities near permanent bodies of water (Styring et al., 2019).

Since it is likely that population growth and climate change within a system with a strong agropastoral orientation were at play during the second half of the second millennium BC in southern Mauritania, the potential for socio-economic differentiation to emerge in the region was high. The Gini Coefficient value of 0.32 for Dakhlet el Atrouss I is higher than the one estimated for Akreijit (0.287), which would be consistent with

| Table 3 | Descriptive statistics of the compound size distributions at the neighborhood level in Dakhlet el Atrouss I |
|---------|---------------------------------------------------------------------------------------------------|
| Cluster ID | Gini coefficient | Lorenz asymmetry coefficient | Number of compounds | Mean compound area | Median | Standard deviation | Minimum value | Maximum value |
| DeA_C5 | 0.1814048 | 1.20093 | 10 | 269.5 | 246.3 | 93.97394 | 143 | 434.5 |
| DeA_C11 | 0.2703391 | 1.102336 | 8 | 291.3 | 241.8 | 173.0011 | 131.4 | 682.1 |
| DeA_C37 | 0.3032192 | 0.9455057 | 12 | 283.1 | 239.8 | 185.3482 | 125.1 | 791.5 |
| DeA_C38 | 0.2407065 | 0.9953537 | 12 | 284.5 | 263.1 | 133.8221 | 116.3 | 589.2 |
| DeA_C39 | 0.280687 | 0.9982858 | 7 | 339.5 | 323.8 | 186.9502 | 110.4 | 675.5 |
| DeA_C40 | 0.282134 | 1.134785 | 36 | 434.7 | 352.5 | 243.5196 | 187.8 | 1224.2 |
| DeA_C41 | 0.223436 | 0.8789284 | 13 | 376 | 377.5 | 157.5942 | 127.8 | 688 |
| DeA_C42 | 0.4885222 | 1.268025 | 10 | 562.4 | 288.1 | 690.2392 | 127.4 | 2426.1 |
| DeA_C43 | 0.06991806 | 1.244071 | 5 | 264 | 258.1 | 36.81553 | 221.5 | 316 |
| DeA_C44 | 0.7006797 | 1.142849 | 6 | 2213.6 | 481.3 | 4358.994 | 234 | 11.103.7 |
| DeA_C45 | 0.1597877 | 1.134921 | 7 | 317.1 | 305.4 | 102.1051 | 218.9 | 510.7 |
| DeA_C51 | 0.2481802 | 1.019382 | 29 | 324.2 | 290.3 | 175.75 | 127.4 | 956.6 |
| DeA_C53 | 0.1596995 | 1.346302 | 11 | 308.3 | 286 | 95.60644 | 185.1 | 499.3 |
| DeA_C54 | 0.3213554 | 1.15889 | 10 | 245.99 | 193.3 | 160.9574 | 87.46 | 533.36 |
| DeA_C56 | 0.1584216 | 1.213108 | 8 | 294.4 | 265.7 | 91.39324 | 197.1 | 465.4 |
| DeA_C57 | 0.4691114 | 1.470634 | 16 | 562.7 | 323 | 892.252 | 183 | 3881.1 |
| DeA_C58 | 0.1652864 | 1.037286 | 16 | 303.5 | 285.4 | 90.92494 | 179.6 | 453.7 |
| DeA_C59 | 0.2706208 | 1.312786 | 59 | 504.7 | 440.6 | 322.646 | 148.6 | 1881.8 |
| DeA_C60 | 0.2095448 | 1.023608 | 8 | 332.4 | 324.2 | 132.1545 | 156.8 | 557.5 |
| DeA_C61 | 0.2261796 | 1.148556 | 49 | 363 | 310.4 | 157.9725 | 139.1 | 887.8 |
| DeA_C67 | 0.198546 | 1.1513 | 12 | 262.8 | 250.7 | 101.7356 | 152.8 | 506.3 |
| DeA_C68 | 0.2556324 | 1.093562 | 19 | 485.8 | 417.4 | 248.4724 | 203.2 | 1233.9 |
| DeA_C69 | 0.284506 | 1.325099 | 8 | 393 | 337.1 | 230.7795 | 164.2 | 851 |
| DeA_C87 | 0.2664363 | 0.9011117 | 33 | 346.71 | 309.24 | 171.7742 | 91.03 | 751.69 |
| DeA_C89 | 0.410534 | 1.129998 | 50 | 532.55 | 402.08 | 531.6067 | 94.75 | 2715.66 |
| DeA_C90 | 0.3838747 | 1.140539 | 62 | 469.5 | 341.75 | 400.0072 | 77.44 | 2139.46 |
| DeA_C91 | 0.2172427 | 0.7931259 | 33 | 269.05 | 276.36 | 103.8325 | 61.06 | 459.88 |
| DeA_C92 | 0.3037366 | 1.222028 | 10 | 596.2 | 476.8 | 373.0051 | 230.7 | 1441.3 |
| DeA_C93 | 0.4806417 | 1.231666 | 11 | 1338.9 | 1000.3 | 1377.508 | 215.9 | 4297.5 |
| DeA_C184 | 0.2199222 | 1.076481 | 16 | 348.2 | 320.3 | 148.3282 | 182.2 | 714.8 |
the current consideration of Dakhlet el Atrouss I as the main regional center in Dhar Tichitt at this time. Moreover, 0.32 is higher than the average value reported by Gurven et al. (2010) for horticultural societies (0.27) and more similar to values obtained from assessing the size asymmetry of residential units at the Neolithic site of Tell Sabi Abyad or the late Postclassic Mesoamerican capital of Mayapán (Table 4). These values are consistent with the ranges provided by Kohler et al., (2017, Fig. 2) for regional centers with an economic system based on agricultural production.

While more comparative work is required to contextualize the range of values of residential compounds at Tichitt Tradition sites and the resulting site-level Gini coefficient values, the preliminary results obtained here suggest that socio-economic differentiation at Dakhlet el Atrouss I was considerable, as further reflected in cultural practices such as the construction of numerous funerary monuments, including some considerably large ones. Given that no isotopic evidence from crops is available from Tichitt sites, it is difficult to ascertain the degree of manuring and labor input. However, site sizes and the number of pottery impressions suggest a considerable scale of production. The labor-intensive nature of this agricultural system implies that a key intangible dimension of household inequalities is the differential potential for labor mobilization and access to arable land among households. The ability of households to control and transfer cattle ownership and/or access to land would have created opportunities for material wealth to be accumulated and transmitted from one generation to the next. Nonetheless, the agricultural productivity in the region was, to a considerable extent, intrinsically linked with the opportunities and constraints afforded by Saharan climate cycles. The increasing aridification during the first half of the first millennium BC and the arrival of Berber populations caused the gradual depopulation of the Tichitt-Oualata region (MacDonald, 2015; Munson, 1971).

Conclusions

The second millennium BC witnessed the development of complex agropastoral societies in Tichitt-Oualata escarpments of southeastern Mauritania. These communities relied primarily on pearl millet

| Site                  | Country   | Cultural Attribution | Chronology | GINI value |
|-----------------------|-----------|----------------------|------------|------------|
| Teotihuacan           | Mexico    | Classic Period       | AD 300     | 0.12       |
| Yinjiacheng           | China     | Longshan             | 2300 BC    | 0.13       |
| Vaihingen             | Germany   | LBK Neolithic        | 5200 BC    | 0.15       |
| Nantaizi              | China     | Xinglongwa           | 5400 BC    | 0.15       |
| Hunter-gatherer camp  | Namibia   | !Kung San            | AD 1970    | 0.17       |
| Jerf el Ahmar         | Syria     | PPNA                 | 9200 BC    | 0.2        |
| San Jose Mogote       | Mexico    | San Jose Phase       | 1100 BC    | 0.25       |
| Çatalhöyük            | Turkey    | Neolithic            | 6500 BC    | 0.28       |
| Akreijit              | Mauritania| Tichitt Tradition    | 1000 BC    | 0.287      |
| Mayapan               | Mexico    | Postclassic Maya capital | AD 1330 | 0.32       |
| Tell Sabi Abyad       | Syria     | Neolithic            | 6000 BC    | 0.32       |
| Dakhlet el Atrouss I  | Mauritania| Tichitt Tradition    | 1000 BC    | 0.322      |
| Caracol               | Belize    | Late Classic Maya    | AD 700     | 0.34       |
| Tepe Gawra            | Iraq      | Late Chalcolithic    | 4000 BC    | 0.34       |
| Cahokia               | US        | Lohman Phase         | AD 1075    | 0.35       |
| Jianxin               | China     | Middle to Late Dawenkou | 3050 BC | 0.35       |
| Grewe                 | US        | Early Pioneer Hohokam | AD 600   | 0.36       |
| Jiangzhai             | China     | Early Yangshao       | 4550 BC    | 0.46       |
| Dadiwan               | China     | Late Yangshao        | 3200 BC    | 0.53       |
| Pompeii               | Italy     | Early Imperial Rome  | AD 79      | 0.54       |
| Tikal                 | Guatemala | Classic Maya         | AD 765     | 0.62       |
cultivation and livestock-raising. Dakhlet el Atrouss I (80 ha), located at the core of one of the main Tichitt Tradition monumental funerary landscapes, was the main regional center of a multi-tiered settlement hierarchy. Statistical analyses of compound size asymmetry using econometric methods documented a considerable degree of socio-economic differentiation at the site (time-averaged Gini coefficient value of 0.32), with marked intra-site variation at the compound cluster level. The limited number of imported prestige goods suggests that the main sources of power and wealth were most likely endogenous, such as lineage control of agricultural fields and livestock herds. The two large funerary monuments within the site may have played a key role in shaping socio-economic differentiation at this regional center, particularly if they are proven to represent collective burials, as suggested by Vernet and Ould Mohamed Naffé (2003, p. 89). Their presence further suggests that authority, in its multiple spheres, was distributed and transmitted along complex and polyfocal networks based on kinship ties – potentially mirroring pathways to socio-economic inequality in other parts of Africa and even the Mediterranean (Leppard, 2019; McIntosh, 1999). Future studies will aim to assess the unevenness of funerary monument sizes in the vicinity of Dakhlet el Atrouss I to determine whether similar asymmetries can be documented on this set of data. The lack of resolution at Dakhlet el Atrouss I and other prehistoric megasites due to limited fieldwork precludes an assessment of how much of the site was continuously occupied and whether demographic agglomerations were permanent or predominantly seasonal. Understanding these spatio-temporal dynamics of site use and any phases of compound construction and modification will be a paramount next step to refine the quantitative approach presented here. Despite these inherent limitations, it is evident that remote sensing approaches hold great potential. They provide additional and invaluable insights into the archaeological record of arid landscapes, even in the context of fieldwork restrictions. Based on the contextualization of the results obtained in this paper, it is becoming increasingly clear that the earliest development of social complexity in the West African Sahel preceded the local adoption of iron metallurgy in the mid-first millennium BC (Chirikure, 2015) and had a predominantly endogenous origin.

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