Late Holocene Cultural Dynamics and Trans-Saharan Connections in Southeastern Mauritania:

A Remote Sensing Approach



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Many events have unfolded between October 2019 and January 2023. I started my doctoral journey in 2019, with a project that aimed to study early dog domestication in Eurasia. That initial topic soon proved impossible to undertake, given the closure of international borders due to the ravaging impact of the COVID-19 pandemic as well as the Russian invasion of Ukraine; both leave behind an upsettingly high death toll. Changing topics to study the archaeological record of southeastern Mauritania provided both the reassurance that I again had a viable doctoral project to complete and a stimulating challenge. I had to familiarise myself more deeply with novel analytical techniques as well as an extensive body of literature on the prehistory and socio-political context of African societies.

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Abstract

This doctoral thesis investigates the prehistoric and medieval archaeological record of southeastern Mauritania (*c.* 2,000 BC to AD 1,100). The highlands of southeastern Mauritania present an extraordinary archaeological record for documenting the emergence, consolidation, and reorganisation of cultural dynamics. A remote sensing approach represents the most viable research methodology, politically and logistically, for this study. My work integrates quantitative methods and transdisciplinary theoretical developments to characterize and assess diachronic cultural trends in terms of regional settlement dynamics, the nature of funerary landscapes, and supra-regional connectivity. The results include the identification and spatial distribution mapping of >9,000 funerary tumuli and 1,140 settlements belonging to the Tichitt Tradition, many of which were previously unpublished or undocumented.

The Tichitt Tradition represents the growth and consolidation of a thriving agropastoral economy based on cattle-keeping and pearl millet (*Pennisetum glaucum*) cultivation throughout during the second millennium BC, structured around extensive, drystone settlements. I interpret these Late Holocene cultural dynamics through the lens of Complex Adaptive Systems, unfolding within the cultural milieu of pre-colonial African polities. The expansion of Tichitt Tradition communities was characterized a conservative but decentralized reproduction of material and ideological forms leading to high systemic coherence, conforming to Kopytoff's Internal African Model. From the first millennium BC, Tichitt Tradition communities witnessed a drastic release and reorganisation of settlement patterns amidst severe aridification trends and the arrival of Lybico-Berber groups. This scenario led to migration outflows and the formation of interstitial communities with greater adaptive creativity, reflected in a greater diversity of settlement styles and the syncretism of pottery traditions described by Kevin MacDonald. The interplay between concepts of spatial and socio-political centrality and liminality—illustrated by the shifting trends of funerary monument clustering in relation to settlement centers—highlights issues of translocal resilience and landscape memorialisation among agropastoral communities in dryland ecosystems.

Introduction

This thesis approaches the study of the prehistoric and Islamic archaeological record of southeastern Mauritania from a remote sensing perspective, integrating quantitative methods and transdisciplinary theoretical developments from African archaeology, complexity theory, economics, and political anthropology. Remote sensing represents the most viable archaeological research approach for the study of Saharo-Sahelian borderlands due to regional accessibility restrictions due to political insecurity, the growing availability of very high resolution (VHR) satellite imagery for free, which substantially reduces survey costs, as well as the high detection rates of drystone architectural components in arid upland ecosystems.

The Introduction of this thesis provides contextual information in relation to the geography, geology, and environmental setting of southeastern Mauritania. It also describes the history of research in the region, outlining the main themes emerging from this research, namely the origins of food production and the development of social complexity. It concludes by dissecting the structural breakdown and rationale of this article-based doctoral thesis, which aims to bring to the forefront issues of adaptive resilience, inequality, migration, and landscape memorialization through a discussion of the Late Holocene settlement dynamics of southeastern Mauritania.

1. Geography and geology of southeastern Mauritania

The Islamic Republic of Mauritania is a sovereign country located in Northwest Africa, with a population of *c.*4.6 million by 2021 estimates. The capital, Nouakchott, is found on the westernmost part of the country, by the Atlantic coast. The country is divided into 15 regions (*wilayas*). Since independence from France in 1960, elites belonging to the Beidane or White Maure ethnic group (which comprises *c.* 30% of the population) have dominated the nation-

state's political, economic, and military hierarchies, with human right organizations highlighting the historical continuities of relationships of strong vertical dependence between the Beidane and the Haratin, who make up 40% of the population (Fleischman 1994). The predominant religion is Sunni Islam, and Mauritania is socio-politically more closely aligned with the Maliki school of Islamic jurisprudence (Freire 2021). The 2019 presidential elections represented the first peaceful transition of power since independence, with the victory of Mohamed Ould Ghazouani. The economic basis of the country is concentrated on the primary sector (agriculture, livestock, fishing), with iron ore and petroleum as important resources.

Most of the country is characterized by vast, arid, low-altitude flatlands, including clayey plains (*regs*) and shifting sand dunes (*ergs*). A series of sandstone ridges and plateaux, where most spring-fed oases are found, bisect these plains. The highest mean elevation (340 metres a.s.l.) is found within the Adrar Plateau, in central Mauritania.

The extensive study area of this remote sensing thesis comprises a series of uplands and escarpments, encompassing the highlands of south-central (Tagant Plateau) and southeastern Mauritania (Dhar Tagant, Dhar Tichitt, Dhar Oualata, Dhar Néma). The Tagant Plateau is geographically bounded by the Khatt lowlands to the north, which separate it from the Adrar, and by the Diewk pass to the south, dividing the Tagant and the Assaba highlands (Chiron 1974). The westernmost part of the Tagant Plateau is located 380km east from Nouakchott, while the town of Oualata/Walatah near the boundary between Dhar Oualata and Dhar Néma, is found 950km east of Nouakchott. The vast sandy expanse of the Majabat al-Koubra (encompassing the *ergs* of Mrayyé, Ijafene, and Ouarane) extends northeast of Dhar Tagant and Dhar Tichitt (Carité 1989; Dars 1991).



Figure 1. Topographic map of southern Mauritania, with study regions in bold.

These escarpments (*dhar* in Hassaniya Arabic) are geological elevations of the Cambro-Ordovician sub-horizontal series of the Taoudenni basin (Renaud 1961; Trompette, 1973). The Taoudenni sedimentary basin is a syneclise (Carité 1989: 47), a large and shallow continental depression formed by slow subsidence (Schlüter 2008). The infilling comprises 2-3 kilometers of sedimentary clastic rocks, forming a series of horizontal sandstone and siltstone beds, with presence of quartzites and basaltic and jasper deposits at their base in some areas (Munson 1971; Deynoux 1980; Amblard-Pison 2006), amidst dolomites and limestones containing stromatolites (Sequence 1), as well as brachiopods and graptolites (Sequences 2-3; Carité, 1989: 47). The escarpments are sloping planes of varying steepness between the flat upland areas on the edge of the plateau and the interdunal lowlands at their base, with a variable height of around 100 in several sections of Dhar Oualata, 200m in parts of Dhar Tichitt and up to nearly 350m west of Ganeb in Dhar Tagant. In this way, the escarpments generate an

environmental and topographic ecotone which offer human groups the possibility to interact with different resources on a daily or seasonal basis.

The *dhars* are intersected by numerous steep and narrow canyons (*dakhla*, pl. *dakhlat*) that channel torrential streams during the short rainy season (mid-July to September). These streams generate alluvial fans upon leaving the *dakhlat*, transitioning into shallow and gently meandering gullies (*oued* or *wadi*) that drain at interdunal alluvial lowlands (*baten*) located at the base of the escarpment (Figure 2). Salt-flats (*sebkha*) are found on the deeper parts of the elongated endorheic basins of the *baten*, which are known to have hosted freshwater lakes during considerable parts of the Holocene and often host diatomite beds (Munson 1971; Hugot 1977). Short-lived seasonal lakes can still form occasionally in these areas of the landscape due to temporary aquifer overflow and surface streams formed from rainwater runoff (Giraud 1991). Veins of volcanic rocks ("agators") are also commonly found in parts of Dhar Tagant and Dhar Oualata (Ould-Khattar 1995; Amblard-Pison 2006). Dhar Tagant and parts of Dhar Oualata also present high concentrations of ironstone caps and ferruginous horizons (Ould-Khattar 1995), which would have offered opportunities for raw material extraction to prehistoric ironworking communities in the region. Beyond the *baten*, the Aouker, a sea of semi-stable dunes, stretches for many kilometres (200km from Dhar Tichitt to the Affolé mountains). Dune encroachment towards the escarpments represents one of the main natural threats to heritage preservation in the region, with sites in the easternmost part of Dhar Tichitt and northern Dhar Oualata being most affected.

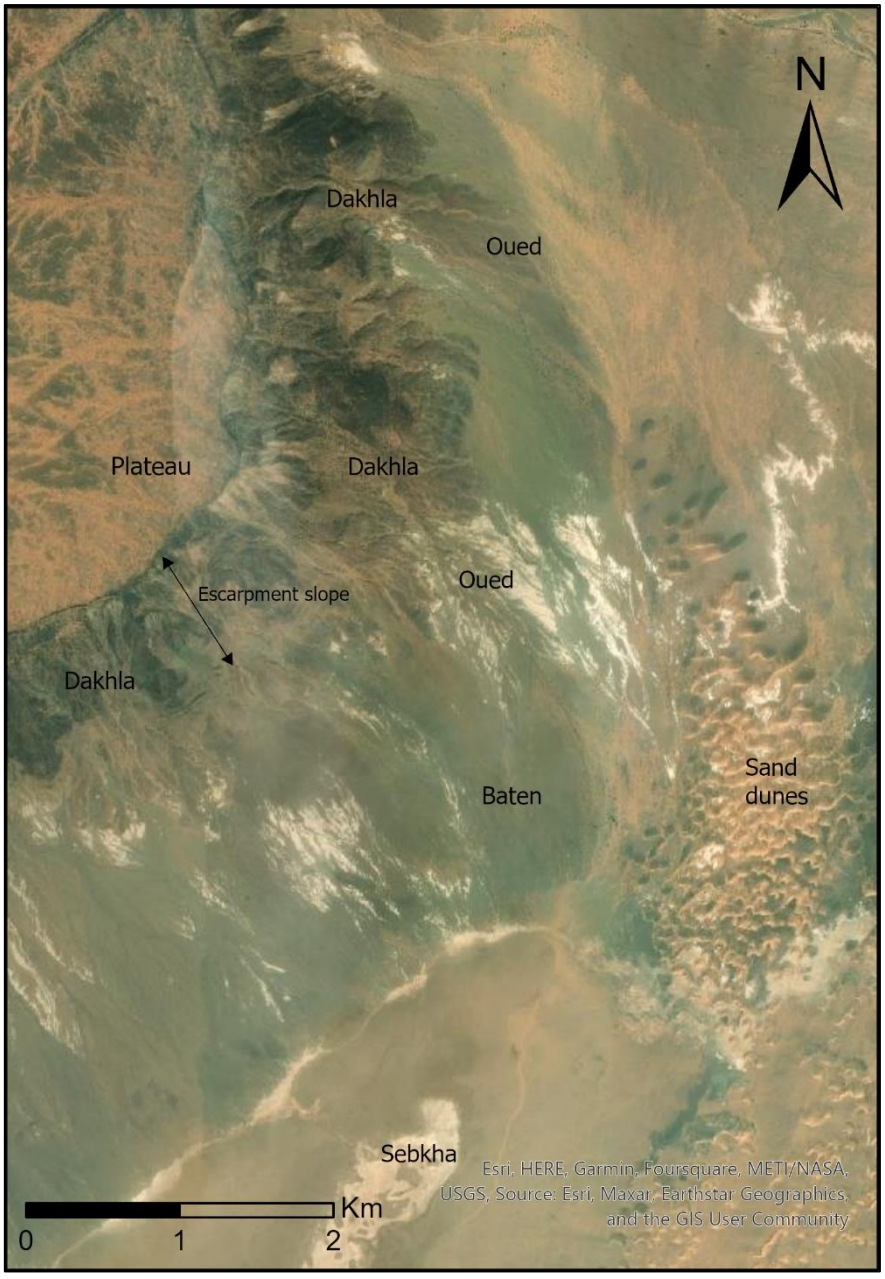


Figure 2. Geomorphological structure of the Mauritanian dhars (Dhar Tagant region).

1.1 Regional environmental setting

The Hodh basin, which encompasses the Aouker depression and the surrounding sandstone escarpments, is a very arid region and logistically very difficult to access and traverse, except by air or by camel, according to Munson (1971). Rainfall patterns in southern Mauritania are structured in broadly horizontal bands (Figure 3): Dhar Tichitt and the northern half of Dhar Oualata are found between the 50-100mm isohyets (delineating the southern edge of the

Sahara), Dhar Tagant and the southern half of Dhar Oualata are found between the 100-200mm isohyets, and most of Dhar Néma is found between the 200-300mm isohyets.

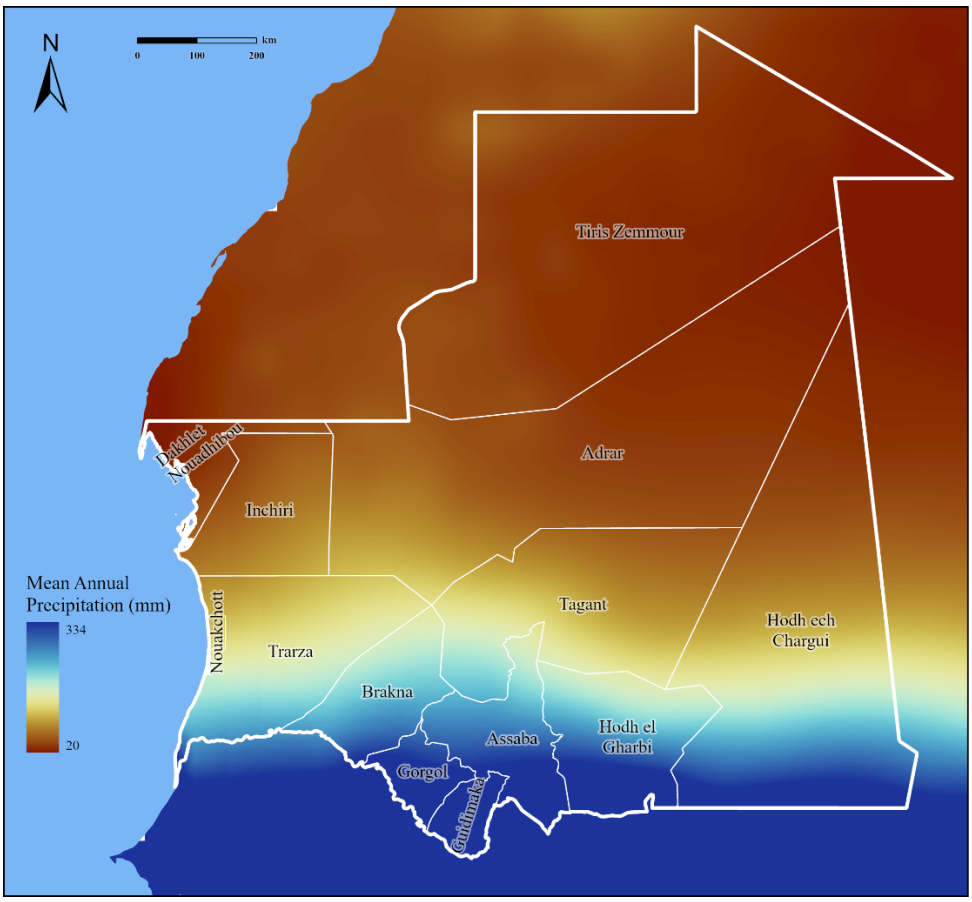


Figure 3. Map of rainfall patterns in Mauritania, using average data from the period between 1991-2020. Data source: https://climateknowledgeportal.worldbank.org/

The mean average temperature is 25ºC, with the highest regional temperatures (48-50ºC) having been recorded in mid-April and early May. The region is also exposed to a lot of sunlight, with Global Horizontal Irradiation values of ~6 kWh/m^2. The wind blows almost daily and constantly, often loaded with sand particles (Amblard-Pison 2006). The Harmattan, an easterly wind coming from the Sahara, blows most frequently during July and August.

The vegetation of the region, encompassing the vegetation types A.12 and A.15 from Rattray (I960), illustrates the transitional nature of the region between the Sahara and the Sahel. In these ecosystems we find perennial grasses such as *Stipagrostis* spp. (formerly genus *Aristida*),

including the Saharan *S. pungens* (*sbot* in Hassaniya), a tall and extremely drought resistant plant with deep roots and long leaves, and a source of edible wild grains (Burkill 1985; Arhab *et al.* 2006); *Panicum turgidum* (*morkba*, palatable for livestock); *Latipes senegalensis*, *Pennisetum divisum*, *Cymbogon schoenanthus* (*idkir*; a fragrant plant often made into herbal tea); and the distinctively Sahelian annual grass *Cenchrus biflorum* (*initi* or cram-cram, considered a relevant famine food and valuable fodder [National Research Council, 1996]). The low shrub *Euphorbia balsamifera*, which is also native to the Canary Islands, *Maerua crassifolia* (*atil*, a small evergreen tree, the leaves of which, boiled or in infusions, are edible and can treat human digestive disorders), and the large canopied tree *Vachellia tortilis* (formerly *Acacia tortilis*) are also found in the region. Orchards with palm trees (*Phoenix dactylifera*) yielding dates have long been a famous feature of local oasis towns.

The transitional nature of this region is also illustrated among the wild fauna (Munson 1971; Amblard-Pison 2006). There are several Saharan species which often display nocturnal behaviours to minimise heat exposure, such as the addax (*Addax nasomaculatus*), the brown-necked raven (*Corvus ruficollis*), the fennec (*Fennecus zerda*), and the jerboa (*Jaculus jaculus*). Saharo-Sahelian species include the grey bustard (*Ardeotis arabs stieberi*, increasingly rare in the region due to overhunting), the golden jackal (*Canis aureus*), gazelles (*Gazella dorcas* and *G. dama*), gerbils (*Gerbillus* spp.), the Egyptian hare (*Lepus aegyptius*), and the rock hyrax (*Procavia capensis*). Typically Sahelian species include the porcupine (*Hystrix cristata*) and the sand fox (*Vulpes pallida*), with small birds (e.g., Ralliformes) often congregating on the *baten*. Several species of lizards and snakes (including the Saharan horned viper [*Cerastes cerastes*] and cobras [*Naja* spp.]) have also been documented in the region.

1.2 Modern human presence in the region

The region has a very low population density, of which over 70% is comprised of nomad camel pastoralists. The Islamic entrepôts of Tichitt and Oualata were founded during the twelfth and thirteenth centuries AD and flourished during the apogee of the trans-Saharan caravan trade. Over 3,000 people inhabited Tichitt by the end of the eighteenth century, and the town was surrounded by over 20,000 palm trees and extensive pearl millet fields, as the UNESCO World Heritage report (1996) reads. Today, neither Tichitt nor Oualata have more than 1,500 inhabitants each, with a decline starting with the exhaustion of West African gold deposits and growing competition from other sources of salt, and the abolition of slave trade (Munson 1971). This downwards trend was intensified from the second half of the nineteenth century by the impact of internal conflict, famine, epidemics, and locust plagues (Amblard-Pison 2006). During the French colonial occupation, the reorganization of trading routes and political administration favored Néma and Tidjikja over the former trading towns, particularly Tichitt, which is becoming increasingly isolated politically and economically (Amblard-Pison 2006). The ongoing process of desertification compounded the impact of these factors, fostering gradual settlement abandonment. The town of Akreijit was founded in 1850 after a group splintered from Tichitt (Munson 1971), in a process that conforms to the expectations of the Internal African Frontier model proposed by Kopytoff (1987).

In the Tagant, one of the most relevant socio-demographic processes is its increasing aridity, which has led to a very considerable decrease in the number of large bovids in favor of sheep and camels while simultaneously fueling rural exodus towards the towns (Ould-Khattar 1995). These processes are drastically reshaping regional landscapes.

The cultural demography of the region encompasses three main groups:

1. *Hassaniya*-speaking Berbers, subdivided into *Bidan*/*Beidane* and *Haratin*. The Beidane are nomadic pastoralists who engage in camel herding and control the caravan trade, and are also owners of most date palm orchards, who are nonetheless tended by the *haratin* (Amblard-Pison 2006). In Mauritania, the *haratin* historically belonged to the lower strata of a closed, hierarchical socio-economic system, dispossessed of the right to own any land (or weapons), which forced them to survive through master-serf relationships. Even though slavery has been officially abolished in Mauritania, the *haratin* are still generally treated as socially inferior (McDougall 2015; Wiley 2016);

2. Massena, who are ethnically Black Africans and speak Aser (a Soninke dialect, part of the Mande language subfamily). They are permanent residents in the towns of Tichitt and Akreijit, and work in traditional agriculture growing cereals, vegetables, as well as selling dates and engaging in craftwork (Amblard-Pison 2006). They also practice non-nomadic sheep-goat pastoralism and process salt from the dry lakebed *sebkhas* (Munson 1971); and

3. Nemadi ("master of dogs" in Soninke), a small tribe (n = *c.*200) in eastern Mauritania who speak Hassaniya, potentially mixed with other local dialects, and with special morphemes for dogs, hunting, and houses (Arnaud 1906; Brosset 1932; Gabus 1951/52; Taine-Cheikh 2013). They have traditionally subsisted as nomadic, dog-aided hunters, targeting primarily addax (Munson 1971).

2. History of Research

The first mention of the archaeological potential of southeastern Mauritania comes from an Arabic travel literature source (*rihla*) dating to 1830 by Ahmad Ibn Twayr al Janna (1788–1849), a Mauritanian scholar born in Ouadane/Wadan (Adrar Plateau, Mauritania), who went across the region as part of a five-year pilgrimage route to Mecca (Norris, 1977; Stewart 2012).

This scholar highlighted the abundance of pottery shards as proof of an important regional population density in ancient times (Amblard-Pison 2006). In the first half of the twentieth century, Amblard-Pison (2006) distinguishes two key research phases: the "meharist" period and the "research pioneers". The term "meharist" makes reference to colonial army patrols which mimicked Arab practices and mounted camels, with the term "meharist" itself making reference to a breed of dromedaries from Mahra, an ancient sultanate in the region of present-day eastern Yemen. Soldiers attached to the Tichitt or the Oualata regiment, such as Coronel Roulet or Pierre Laforgue, traversed the region and noted the presence of archaeological remains. Laforgue even excavated some tumuli in the Ganeb region (easternmost Dhar Tagant), finding numerous stone objects (Hubert, Laforgue, Vanelsche 1921), but apparently losing an important proportion of them during a camp relocation ("*dans un de ces déménagements impromptus si frequents dans la vie d' un méhariste*"; Verneau 1920), with the rest being shipped to the *Muséum national d'Histoire naturelle* in Paris, although they had not arrived at their destination yet by the time of Verneau's paper.

The oldest publication describing the archaeology of southeastern Mauritania was a discussion on the rock art from Keddamou, including the first regional mention of a wheeled chariot, by Yves de Boisboissel (1914). René Verneau (1920) discussed archaeological remains, primarily chipped and polished stone arrowheads and hachettes, retrieved from El Glatt (northern Dhar Oualata; Figure 4) by the baron Doujat d'Empeaux, former territorial cavalry quartermaster, and donated to the *Musée d'Ethnographie* in Paris. The evidence led Doujat d'Empeaux to suggest the existence of a dense, sedentary population at the site, sustained by water sources, such as wadis, that were no longer active in the region. Doujat d'Empeaux was also the first to note the presence of archaeological settlements in the Tagant Plateau itself, near Tidjikja (Verneau 1920). In September 1934, Theodore Monod undertook a large-scale rock art survey mission in the western part of the Sahara that also led him to explore parts of southeastern

Mauritania (Monod 1937a, 1937b, 1938). Travel accounts by O. du Puigaudeau and M. Senones, who visited the Tagant (1936-1938), noted the presence of rock art and archaeological sites in the region, although very little spatial precision was provided, which has led to issues of re-identification in subsequent fieldwork (cf. Ould-Khattar 1995).

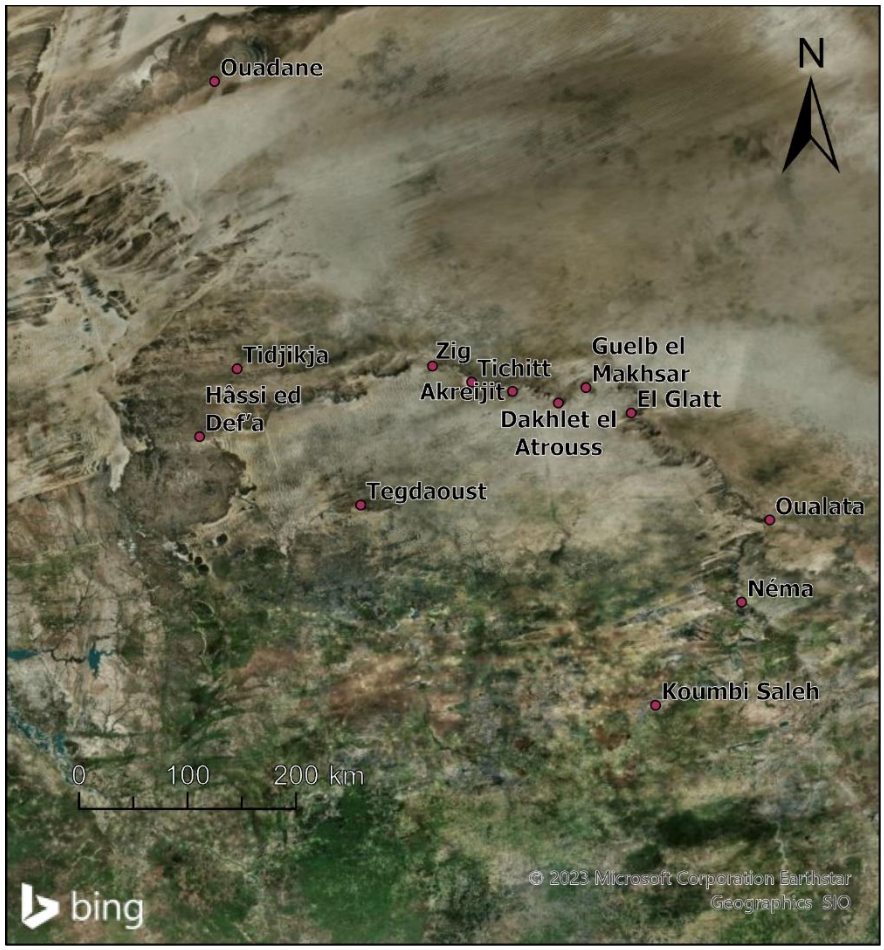


Figure 4. Map with the distribution of localities in Mauritania mentioned in this Introduction.

Raymond Mauny was one of the first occasionally to record the distribution patterns of artefacts and structures (Mauny and Laforge 1939), providing a site plan for Guelb el Makhsar (v.147), in eastern Dhar Tichitt (Mauny 1951). Mauny (1951) strongly emphasized the relevance of the archaeological record of the highlands of southeastern Mauritania as an avenue for understanding the impact of aridification in the life of sedentary communities in West Africa, given how Neolithic communities used to live in a region which nowadays could no longer

have sustained their agropastoral lifestyles. Amblard-Pison (2006) indicates that most remains and correspondence from this period are thought to have been deposited at IFAN (*Institut Fondamental d'Afrique Noire*) in Dakar (Senegal) and at the *Musée de l'Homme* in Paris, although it is relevant to note that the vast majority of the collections formerly held at the *Musée de l'Homme* were later transferred to the *Musée du Quay Branly – Jacques Chirac*, which opened in 2006.

This period also witnessed growing interest in the Islamic archaeology of southeastern Mauritania. The medieval entrepôt of Koumbi Saleh (southern Mauritania) was discovered by the French explorer Albert Bonnel de Mézières in 1914, with ensuing fieldwork projects documenting a 10m tell rising above the surrounding plain, with settlement activity beginning before the eighth century AD, perhaps as early as the fifth century AD (Van Doosselaere 2014); between the eleventh and fourteenth centuries, the settlement witnessed the development of a dense urban layout based on stone architecture (Berthier 1997; Robert-Chaleix *et al.* 2004–2005; Van Doosselaere 2014), including the Columns Tomb, an elaborate funerary complex without parallels in the region (Bonnel de Mézières 1923; Thomassey and Mauny 1951; Saison *et al.* 2004–2005; Capel *et al.* 2015). This apogee was followed by a period of relative decline until its abandonment in the seventeenth century (Berthier 1997; Robert-Chaleix *et al.* 2004–2005; Van Doosselaere 2014). The combined presence of a Grand Mosque, Arabic epigraphy, imported goods from northern Africa, and east-oriented funerary enclosures evidences the Islamic nature of the site, which was initially considered the Muslim city that al-Bakri mentioned as part of the capital of the medieval West African state of Ghana/Wagadu (Thomassey and Mauny 1951; Triaud 1999; Levtzion and Hopkins 2000; Capel *et al.* 2015). Ghana was a large and durable kingdom with a hereditary male ruler, most likely of Soninke ethnicity, controlling a number of smaller polities, and with a political economy centred around cattle and gold, deeply involved in trans-Saharan trade networks that connected Sahelian West

Africa and the Mediterranean Basin. The rise of Ghana is associated with a period of increasing urbanism and the consolidation of interregional interaction in the Middle Niger (Gestrich 2019). By the 14th century, the ruler of Ghana was under the authority of the Empire of Mali.

However, the main phases of urban occupation and growth at the center of the Koumbi Saleh tell site date to the 11th and 14th centuries, so if it ever was a capital of Ghana, it must have been so after al-Bakri's description of the late 11th century capital as a very large twin town with royal quarters, which not fit the nature and urban morphology of Koumbi Saleh (cf. Berthier 1997; McIntosh 1998; MacDonald 2013; Gestrich 2019). It must also postdate the kingdom's gradual conversion to Islam. This conversion was associated with a considerable level of commercial and political interactions and even cooperation between Ghana and the Almoravid Empire, but it seems unlikely that it was coercively imposed through direct Almoravid conquest (Conrad and Fisher 1982).

The site of Tegdaoust (Tamchakett, southern Mauritania), believed to be the trading entrepôt of Audaghost also mentioned by al-Bakri and other early Islamic authors (Devisse 1983; Levtzion and Hopkins 2000), has similarly received considerable archaeological interest. The site, located within the Rkiz sandstone massif, was first identified by Lieutenant Boery in 1923 (Boery 1927). The large main artificial mound (12ha) was excavated by a French team between 1960–1976, which documented that the site was occupied almost continuously from the eighth to the fourteenth centuries, with stone architecture developing during the eleventh century (Devisse 1983; Polet 1985; Robert-Chaleix 1989). The site also has a large Islamic necropolis nearby, along a path used until recently by salt caravans (Robert 1970: 474).

Returning to the prehistoric record, an important watershed moment was in 1967 when Patrick Munson began a series of prospections and excavation in Dhar Tichitt. Munson (1971) was the first to develop a chrono-cultural framework for the Tichitt Tradition sequence in the region,

on the basis of a small set of valid radiocarbon dates from archaeological sites (n=15). Munson (1971) argues that the occupation of the Mauritanian *dhars* represents a dynamic evolutionary sequence, which experienced a systemic change in subsistence from hunter-fishing-herding to a combination of herding and increasingly intensive cereal cultivation, with percentages of *Pennisetum* as ceramic temper and seed impressions increasing from 3% to 61% within the Classic Tichitt phase, reaching 80-90% in the Late Tichitt period. This sequence has proven reliable in terms of the technological and stylistic nature of the ceramic assemblages (MacDonald 2013; Table 1).

Munson's Phases	**Phase**	**Chronology**	**Features**
Akreijit	Pre-Tichitt	2600–1900 BC	Mobile herders and hunter-gatherers living in small temporary campsites.
Khimiya/Goungou	Early Tichitt	1900–1600 BC	Initial cultivation of domesticated pearl millet. Considerable degree of mobility.
Nkahl/Naghez/Chebka	Classic Tichitt	1600–1000 BC	Development of vast settlements comprising conjoined clusters of stone-walled compounds.
Arriane/Akjinjeir	Late Tichitt	1000-400 BC	Period of intense aridification and associated demographic decline in the Tichitt-Oualata region. Expansion into Mali.
N/A	Terminal Tichitt / Early Iron Age	400 BC – AD 200	Development of complex stonewalled settlements in the Tagant region with evidence of iron metallurgy.

Table 1: Brief summary of the calibrated archaeological sequence of the Tichitt Tradition, southeastern Mauritania, after Munson (1971), Ould-Khattar (1995), and MacDonald (2013, 2020).

While this framework remains the most accepted chronological sequence in the literature, based on data from both radiometric dates and pottery seriation, some authors are reluctant to adopt it on the basis of limitations in the extent of dated intra-site stratified deposits and prefer to treat Tichitt Tradition sites more synchronously in their analyses (e.g., Amblard 1984; Amblard-Pison 2006; Holl 2009). Some additional inconsistences in chronology that these authors mention derive from the consideration of radiocarbon dates that are not actually associated to archaeological sites, such as mollusks from distant natural deposits or from non-AMS bone collagen samples with suspected contamination (Munson, 1989).

Soon afterwards, around 1970, a long-term project "Mission archéologique de Tichitt" directed by Henri Hugot (who had taken over the directorship of the IFAN from R. Mauny in 1963) began, involving surveys, excavations, and restoration, primarily around the site of Akreijit (v.72, formerly named Monodville by Hugot [1981]), which represents the most thorough attempt at investigating an individual Tichitt Tradition site archaeologically. From 1975, Hugot's fieldwork was conducted within the framework of bilateral agreements between the IMRS (*Institut Mauritanien de Recherche Scientifique*) and the *Ministère Français de la Coopération* (Amblard-Pison 2006).

In line with Munson's (1971) dynamic model, Amblard (1984) proposed, on the basis of the nature and spatial distribution of lithic assemblages within sites, a diachronic trend involving the movement over time from a lowland lake shore occupation in the *baten* to the development of village communities in the upland escarpments as surface water levels receded. The region acted as a refugium within the southern Sahara into the first millennium BC, when external groups arrived and aridification trends intensified (Amblard-Pison 2006). These dynamic models contrast with the more socio-economically static framework proposed by Holl (1986), who claimed that the occupations in the lowlands and uplands were essentially contemporary and represented two sides of a seasonal adaptive cycle. He argued that large, central

architectural sites surrounded by smaller satellite villages were occupied during the wet season and based on livestock herding and bulrush millet cultivation, and dry season sites in interdunal depressions or near other permanent water sources, where the same communities engaged in wild plant gathering and fishing. However, Munson (1989) notes how the sites that Holl considers contemporaneous in his analysis do not have similar ceramic decorations, despite their nearby location, which would require the seasonal manufacture of completely different pottery assemblages. I agree with the notion that seasonality ought to be considered a fundamental dimension of social life in the Sahel and that it likely played an important role in structuring land use patterns in certain regional contexts of southeastern Mauritania, such as Dhar Néma during the second millennium BC (Person *et al.* 2012). However, it is increasingly clear that the Tichitt Tradition experienced considerable spatial and cultural changes over time in terms of settlement patterns and pottery assemblages (Munson, 1971; Amblard-Pison 2006; MacDonald 2015).

The 1980s saw archaeological research efforts expand into Dhar Oualata and Dhar Tagant, involving a collaboration between the IMRS, the Faculté des Lettres et Sciences Humaines of the University of Nouakchott, and the French CNRS. The focus between 1982 and 1987 was the identification and description of sites in Dhar Oualata, and sites in Dhar Tagant and the Guilemsi ridge were first visited in 1987 (Ould-Khattar 1995; Amblard-Pison 2006), thus considerably expanding the spatial range of the Tichitt Tradition. Survey work in the western Aoukar basin by Robert and Ould-Khattar in 1989 led to the identification of many sites, particularly in the vicinity of the Taskast wadi, generally in the form of surface scatters. The sites in the northern half of the Taskast wadi sites are mostly prehistoric, whereas those in the southern half are generally medieval in date, with ceramic parallels with the assemblages from Tegdaoust 1 level IV (Ould-Khattar, 1995). This renewed emphasis on fieldwork was likely inspired by observations made by Munson (1971: 93), who mentioned how high-altitude aerial

photographs showed a high density of settlements persisting to the eastern end of Dhar Tichitt and along at least the northern half of Dhar Oualata, where a continuous series of lake beds could also be discerned. At the same time, he also noted how "to the west of Tichitt there is no evidence of lake deposits at the base of the escarpment, and a low altitude aerial reconnaissance along the dhar from Zig (a town in the westernmost end of Dhar Tichitt) to Tichitt (a distance of about 35 km.) revealed no architectural sites of this phase" (Munson 1971: 92). This pattern was further reinforced by the blank space observed in site distribution maps (cf. Vernet 1993) west of the town of Zig. The only prior publication including material from Dhar Tagant was one by Hubert *et al.* (1921), the merit of which for the study of the region was minimal, according to Ould-Khattar (1995: 37-38): "*dont le seul mérite est d'exister et de présenter de manière approximative des sites archéologiques*".

A desire to investigate these unchartered spaces led to a survey by a Franco-Mauritanian team, led by Mohammed Ould-Khattar (1995), who engaged in an 18-year survey of the Tagant plateau and the escarpments, collecting information on over 200 sites. Nonetheless, due to concerns regarding the future integrity of the sites due to looting or tourists visiting, he did not report intra-site maps (with a few notable exceptions authored by Robert Vernet) or site distribution maps in his dissertation or in any subsequent publication. As such, this difficult but ultimately understandable decision has decisively hampered our understanding of the Dhar Tagant archaeological record up to this day, with little to no evidence that knowledge of the distribution of archaeological sites in the Dhar Tichitt-Oualata-Nema region has led to any meaningful looting or disturbance (Prof. Kevin MacDonald, pers. comm.). A list in paper, presumably with the coordinates and names of the sites, is said to have been handed in to the Mauritanian authorities (*L'Institut Mauritanien de Recherche Scientifique*) and to the archives of the G 0848 of the *Centre National des Recherches Scientifiques* (CNRS) almost 30 years ago (Ould-Khattar 1995: 68). It may be inferred that the report in the IMRS has currently a

rather low accessibility (whose deposition by Ould-Khattar was confirmed in a telephone interview with him on 26/05/2020), and while the report in the French archives might be more easily available, its existence could not be confirmed orally. After his doctoral thesis, Ould-Khattar went on to undertake a successful career as UNESCO representative and did not engage in any further archaeological research in the region.

Some preliminary fieldwork and dating took place at the site of Hâssi ed Def'a in the Tagant (Rolando and Riser, 1992). Furthermore, two French fieldwork projects between 1994 and 1996 further contributed to data-gathering on Tichitt Tradition settlements, leading to the first comprehensive documentation of archaeological sites from Dhar Tichitt and Dhar Oualata, including site plans, assemblage characterization and intra-site distribution of material culture, and twenty-four additional radiocarbon dates associated with settlements (Amblard-Pison 2006). However, excavation of funerary contexts has so far been very limited, restricted to five burials and a handful of funerary monuments, out of the many thousands present in the region (paper 4).

The latest fieldwork efforts in the highlands of southeastern Mauritania aimed to expand our understanding of Dhar Néma, the southeasternmost escarpment, which remained unsurveyed throughout the twentieth century. The first survey and test excavation mission, guided by extensive use of available historical imagery, was undertaken in February 2000 by a team led by Kevin MacDonald and Robert Vernet. The main contributions include a contextualization of this peripheral region in the political ecology of the Tichitt Tradition, emphasizing the relevance of cultivated pearl millet in subsistence strategies (Fuller *et al.* 2007), as well as evidence of iron-smelting in the first millennium BC (MacDonald *et al.* 2009). They also nuanced the demographic impact of the arrival of Lybico-Berber groups in the region, advocating for some degree of cultural syncretism rather than replacement, on the basis of influences in pottery making and decoration (MacDonald *et al.* 2009; MacDonald 2011). A

separate research mission led by Alain Person, whose scope overlaps with the study areas explored by the MacDonald and Vernet team, has undertaken eight annual missions to the region, beginning in February 2001 (Person *et al.* 2006; Person *et al.* 2012). They focused on understanding prehistoric land use in the different geomorphological ecotones of the regional landscape (Person *et al.* 2012), within but also beyond the escarpment, incorporating the proximal interdunal and colluvial areas as well as the zones of the *baten* closer to large wadis or shallow lakes (*mares*). They also made important contributions towards characterizing the regional rock art corpus, which display clear stylistic and iconographic parallels with that of the Tichitt-Oualata region (Amblard-Pison *et al.* 2010). They distinguished two chrono-stylistic phases in engravings, the first and main one having anthropomorphic figures, cattle, oryx, and even giraffes, a species which appears to have persisted in Dhar Néma longer than in Dhar Tichitt; and a later one, defined by the presence of horses and ostriches (Amblard-Pison *et al.* 2010).

3. Contemporary Research Context

The region of southeastern Mauritania has not seen any archaeological fieldwork on the ground since these two missions, in no small part due to growing concerns regarding regional insecurity in the Sahel, with the British Foreign and Commonwealth Office (FCO) advising against all travel to the areas of Dhar Néma, Dhar Oualata, and most of Dhar Tichitt (https://www.gov.uk/foreign-travel-advice/mauritania). Archaeology is a political endeavor, profoundly affected by local and regional instability. A geopolitically strategic region due to the impact of climate change on food security and the presence of oil, the Sahel has witnessed the rise of cross-border security threats, such as terrorism, militant insurgencies, organized crime, and unregulated immigration networks (Boukhars 2012), particularly since the dawn of

the twenty-first century, following global US counterterrorism interventions after 9/11 (Keenan 2008). Terrorism may be understood as the premeditated use of violence or threatening intimidation to attain political or ideological aims (Ganor 1998). Terrorist incidents in the western Saharo-Sahel region include the kidnapping of foreign tourists by the Salafist Group for Preaching and Combat (GSPC) in the Tassili region of Algeria in 2003, a GSPC attack on a military base in Mauritania in 2005 with a toll of 15 soldier casualties, and the killing of an American school director in Nouakchott in 2009 (Boulassel 2020). Insecurity in southeastern Mauritania and the wider Sahel has increased further following the 2012 military uprising in neighboring Mali and the limited success of G5 Sahel states (Burkina Faso, Chad, Mali, Mauritania, Niger) in counter-terrorism operations, particularly against Nusrat al-Islam (JNIM), a Salafi Jihadist organization affiliated with al-Qaeda, formed in 2017, shortly after the announcement of a G5 Sahel Joint Force, through the merging and reorganization of several militant groups in the Maghreb and West Africa (Pellerin 2019). Moreover, the distance of the region to the capital, the limited development of road systems, and the desertic nature of the landscape constrains the range of action of law enforcement, making the monopoly over the means of violence more difficult to implement (cf. Risse 2015).

In addition to political insecurity, the onset and impact of the Covid-19 public health emergency brought most travel, and by extension, fieldwork projects, to a sudden halt. The social and economic impact legacies have still not unraveled fully even as travel restrictions have been lifted. Amidst this complex scenario, there has been a widespread awareness about the need to reconceptualize research approaches in a predominantly field-based discipline such as archaeology (Ogundiran 2020; Scerri *et al.* 2020). Contingency planning will remain at the core of ongoing and future research design. For graduate students and faculty alike, the importance of well-structured modular dissertations—with clearly identifiable, independent while interrelated tasks—as part of contingency planning strategies cannot be understated

(Lelieveldt 2004; Krause *et al.* 2021). In this context, desk-based methods offer promising complementary alternatives, even though it remains difficult and often impossible to replicate the personal and academic value of collecting data and experiencing a landscape in person (Krause *et al.* 2021). The cyberspace, digital ethnographies, and remote sensing have become increasingly prominent as avenues of enquiry across many fields, from archaeology and anthropology to political science, geography, and sociology (Krause and Szekely 2020). This need came at a time when we were witnessing an exponential technological development which is expanding the number of communication and remote sensing platforms. Corporations such as Google and Microsoft have been progressively increasing the resolution of their freely available imagery services, especially Google Earth and Bing Maps. A considerable reduction in survey costs, the synoptic view afforded, and the non-invasive nature of this modern satellite technology provide an attractive, comprehensive and suitable method to approach the study of extensive cultural landscapes, across the globe (Wiseman and El-Baz 2007; Parcak 2009; Lasaponara and Masini 2012; MacDonald *et al.* 2018). These affordances can decisively contribute to continue enhancing our archaeological knowledge of under-explored and logistically challenging regions, as shown for example by Vernet (2017) who made use of Google Earth satellite imagery to provide a more comprehensive account of the distribution of archaeological heritage across the Adrar region of central Mauritania, with a focus on linear stone-built features and enclosures.

4. Interpreting the socio-political organization of Tichitt Tradition communities

The political organization and internal complexity of the Tichitt Tradition has long been highlighted, Munson (1971) proposed that the origins of agriculture and complexity in Tichitt were associated with human responses to climate change: aridification led to the spatial

concentration of surface water and wild grain patches and thus humans domesticated pearl millet, which was cultivated by increasingly territorial farming communities given the high degree of circumscription of agricultural lands, restricted to seasonal flood-recession practices on silt deposits on former lake beds (Munson 1980). Following Carneiro (1970), Munson (1980) argues that the autonomous agricultural villages would have experienced fission and expansion with demographic growth, eventually competing for the available land, first through agricultural intensification, and subsequently through direct conflict and internal warfare – as reflected in the establishment of large walled settlements and the presence of a higher number of *Pennisetum* seed impressions on pottery during the Classic Tichitt Tradition period. The population of losing villages would have experienced subordination, with political units growing larger, more complex, and increasingly centralized under a paramount chief, which enforced socio-political stability and the decrease in internecine conflict until the impact of aridification trends and the arrival of Lybico-Berber groups (Munson 1980), processes which led to the collapse of the previous socio-political system and outward migration flows towards the Tagant and present-day Mali. The notion of complex socio-political organization in Dhar Tichitt is supported by evidence for the development of a strong settlement hierarchy (Holl 1993).

A parallel theory for the emergence of socio-economic complexity and political centralization in the highlands of southeastern Mauritania was developed by MacDonald (1998) through the concept of Mobile Elites, which emphasizes the pastoral origins of the Tichitt Tradition, articulating power relationships not through the conflict over agricultural land but through the control of mechanisms to negotiate ownership over cattle, a catalyst of a whole range of social relationships in pastoral communities. This theory is based on three main tenets that characterize the Saharan archaeological record from 4000 BC, namely the accumulation of cattle, the possession and exchange of valued polished objects made of stones from distant raw

material sources (hachettes, stone rings, beads), and the construction of funerary monuments (MacDonald 1998). Cattle are long-lived and mobile, which means that they can be accumulated as well as traded for bridewealth, agricultural goods, or durable valued objects, thus representing a medium for stockpiling wealth from one year to another. However, cattle herds can be decimated by natural disasters, such as droughts, raids, or plagues, and material and social insurance ought to be secured and negotiated to mitigate risk and avoid starvation, with valuable currencies offering a medium to invoke mutual support agreements or traded for livestock to replenish herds (MacDonald 1998). The role of these items in exchange networks is attested by their shared presence across communities with different ceramic and lithic traditions, often in mortuary contexts, and therefore cannot be simply attributed to population dispersals (MacDonald 1994). Fortunate lineages may have experienced transitory wealth accumulations that would tend to dissipate fairly quickly through centrifugal forces, such as exogamous marriage. Nonetheless, MacDonald (1998) argues that social structures may have shifted towards hereditary, ascribed ranking under certain circumstances, such as prolonged or particularly intense droughts that prevented the replenishment of most livestock herds alongside higher territoriality upon relocation in productive agricultural ecosystems amidst increasingly unpredictable climatic conditions. Elite authority was consolidated through the redistribution of cattle and long-distance exchange goods made of semi-precious stones, and ritual displays of coercive force, conspicuous consumption, or the construction of funerary monuments. These patterns would have led to the independent formation and maintenance of complex, semi-sedentary agropastoral societies in areas with environmental stimuli, such as Kerma in the Nile Valley or the Tichitt Tradition in the highlands of southeastern Mauritania. The presence of large, empty enclosures that appear to be the base of cattle kraals at large "classic Tichitt" sites such as Akreijit and Dakhlet el Atrouss I does suggest the existence of

competitive stress for cattle wealth and territory within this complex polity (MacDonald 2015; MacDonald 2020).

Beyond southeastern Mauritania, Tichitt tradition pottery assemblages and imported phthanite siltstone have been found at small sites in the Ndondi Kossokel area of the Méma region of Mali, near the modern political boundary with Mauritania (MacDonald 1994); atop an inselberg, the 6ha site of Saberi Fïta also features stone walls and grinding equipment (MacDonald 2015). More extensive sites with the local Faïta facies of the Tichitt tradition are Kolima Sud-Est (11ha, 900-400 BC; Takezawa and Cisse 2004) in the Méma region, as well as at Dia Shoma Horizon I (19ha, 800-400 BC; Bedaux et al. 2001; MacDonald 2011), in the western side of the Middle Niger floodplain. In a similar pattern to Tichitt tradition sites further north, the earthen architecture at the Malian sites – perhaps initially adopted in substitution of the sandstone of the Mauritanian escarpments that was no longer available – was predominantly manifested through curvilinear forms until the mid-first millennium AD, when rectangular features become more common (MacDonald 2020). These sites have also yielded evidence of livestock rearing, rice (*Oryza glaberrima*) cultivation, earthen architecture, metallurgy, and iron smelting, indicating the successful socio-economic adaptation of Tichitt tradition communities to new landscapes and leading to the growth of large sedentary communities (MacDonald 2013). Thus, this archaeological evidence potentially lends further credibility to the linguistic suggestion that the early urban communities of the Middle Niger basin, associated with the Soninke founders of the Ghana/Wagadu state, were ultimately descendants of black Tichitt communities that migrated southwards.

5. Thematic Rationale and Structure of the present Doctoral Thesis

The aforementioned contextual insights resonate with my own doctoral journey. Before the pandemic, I was initially planning to explore the interactions between early humans and social carnivores in Pleistocene Eurasia through bone taphonomy. However, in the context of fieldwork restrictions, I embraced the affordances of remote sensing to explore how aspects of subsistence, social inequality, climate change, and cultural interactions shaped settlement patterns and funerary practices in the southern Sahara, with a focus on southeastern Mauritania.

The prehistory of the southern Sahara holds an important record for documenting and analyzing the processes, temporalities, and mechanisms through which agro-pastoral communities navigated aridification trends, which tested human resilience networks and decisively impacted survival prospects through the challenges that a reduction in rainfall patterns poses to food security and water accessibility in dryland ecosystems. The region of southeastern Mauritania is of great scientific interest for two important reasons. First, the transitional nature of the Mauritanian *dhars* favored the emergence of mosaic ecotonal ecosystems that offered a refuge to mobile hunter-herder populations migrating southwards from the drying Central Sahara: presently dry lakebeds indicate the existence of substantial freshwater lakes at the base of a series of sandstone escarpments, with these water reservoirs receding over time (Munson 1971; Person *et al.* 1996; Person and Jousse 2005; MacDonald 2013; Holl 2009). Secondly, there is growing archaeological evidence that local human populations developed a series of transformative, even contextually radical, innovations in terms of lifestyle, technology, and the organization of the built environment.

A question of particular interest involves the emergence of food production systems in West Africa. The region of southeastern Mauritania is less than 200km northeast of the present-day edge of the northern distribution range of several wild grasses belonging to the same genera as

important African domestic agricultural staples, such as *Digitaria*, *Pennisetum*, *Echinochloa* millets and *Sorghum* (Munson 1971). Well-dated instances of domesticated pearl millet (*Pennisetum glaucum*) have been documented in southeastern Mauritania in the first half of the second millennium BC, in a process that may have had a very strong endogenous component (Munson 1971; Amblard-Pison 2006; MacDonald *et al.* 2009).

The emergence of village life and urbanism is also a question of utmost importance in the region, a topic grounded in the existence of large, elaborate, drystone masonry settlements, structured through walls and household enclosures, which as mentioned above, has captured the attention of scholars for over a century. These adaptations enabled them to set and reformulate in their own social and cultural terms the conditions of their survival for over two millennia, in the face of relentless climate change.

A last focal point of my research entails understanding the processes through which communities negotiated the underlying political tensions associated with emergent possibilities for socio-economic differentiation, both throughout the social biography of the Tichitt Tradition and later on, given suggestive diasporic links between the inhabitants of southeastern Mauritania and later pathways towards socio-political complexity in the West African Sahel (MacDonald 2020), such as the formation of the later first-millennium AD Soninke Ghana/Wagadu empire or the heterarchical organization of metal-using agropastoral urban societies around the Inland Niger Delta (in present day Mali; McIntosh 1998, 2005).

Several fundamental research questions emerge from these themes:

1. How can remote sensing contribute to the archaeological study of Saharo-Sahelian prehistory?
2. What was the extent of lineage power asymmetries and household inequality within the agropastoral societies that inhabited extensive Tichitt Tradition settlements?

3. What spatial dynamics structure the distribution of funerary tumuli? Are the greatest concentrations found near large settlements or rather separate from them? In contexts of liminality, what socio-political, economic, and ecological factors may explain their presence at a distance from habitation sites?
4. How can we explain the far-reaching distribution of Tichitt material culture (ceramics, architectural forms) across vast distances, from south-central Mauritania to western Mali and the Middle Niger? What role did mobility play in the structuring the expansion of semi-sedentary agropastoral settlements?
5. Were Medieval Islamic trading towns, such as Tegdaoust, placed *ex novo* in the landscape of the southern Mauritanian highlands, or was their location influenced by pre-existing regional exchange networks and prehistoric land use patterns within culturally significant places?

A modular approach based on a series of five articles offers an opportunity to develop a logical series of independent, yet deeply interconnected "modules" through which to explore these topics at both macro and micro scales across time and space using remote sensing methods. Three of these articles are case-studies of varying scope, while the remaining two aim to provide a big-picture overview and understanding.

1. *Monumental funerary landscapes of Dhar Tagant (south-eastern Mauritania): towards ethical satellite remote sensing in the West African Sahel*

In the first paper of the thesis, I first explore the ethics of conducting remote sensing research in Africa, as well as the opportunities and challenges for collaborative engagement with local communities in the context of fieldwork restrictions. This paper also outlines the results of a regional remote sensing survey in order to characterize the distribution of funerary monuments in the Dhar Tagant area, providing relevant insights about landscape use, mobility, and

memory, particularly among societies with a strong pastoral component. A remarkable concentration of monuments where the Taskast wadi intersects the Tagant plateau can be explained by the importance of this passageway in the seasonal mobility schedules of these communities in search for water and pasture. I employ morphometric approaches to quantitatively define two different types of ring tumuli, confirming a hypothesis derived from visual examination of the satellite imagery. My co-author Jonathan Lim provided technical support with map-making and ArcGIS implementation of methodological solutions, which proved invaluable in my transition to remote sensing research. The paper has been published in the journal *Archaeological Prospection* (Linares Matás and Lim 2021).

2. *Spatial organization and socio-economic differentiation at the Dhar Tichitt center of Dakhlet el Atrouss I (southeastern Mauritania)*

The origins and development of material inequalities form a fundamental question in world prehistory that archaeologists have a core ethical responsibility to consider and explore. In this regard, the West African archaeological record offers unique insights into the range of pathways towards increasing complexity and the origins of socio-economic differentiation.

This paper aims to determine the degree of compound size heterogeneity, globally and by neighborhoods, at Dakhlet el Atrouss I (*c.* 1600-1000 BC), the largest Tichitt Tradition site. 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 (Holl 1993; MacDonald 2015). The limited presence of imported prestige goods, however, has sparked considerable controversy regarding the socio-political complexity of the community inhabiting the site. My morphometric approach aims to explore socio-

economic differentiation at the household level in ways that complement studies of settlement patterns and circumvent the limited evidence for imported goods.

Households are socio-economic units characterized by shared residence and/or the collective pooling and consumption of resources. The conceptualization of households as autonomous and relatively self-sufficient units that fostered the intensification of production processes for the purposes of private accumulation has considerably influenced the archaeology of early food-producing societies. 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. Among the Banama, the Dogon, and other rural Sahelian communities, for example, 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). Furthermore, among the patrilineal and virilocal Dogon, the distribution and morphometrics of compounds represents a tangible mechanism for the legitimization og authority narratives (Lane 2006).

Building upon these relevant ethnographies, which illustrate how the size of rural households in labor-limited agricultural systems is strongly correlated with their potential labor output, productive income, wealth, and prestige, I explore the degree of compound size variability at Dakhlet el Atrouss I.

A relevant issue when studying settlement layouts is the fact that these settlements are often palimpsests with protracted material biographies. This fact is culturally embedded among the Dogon of Mali, who recognize that portions of villages become abandoned or occupied at different times (Douny 2014). Identifying typologically different compounds may help

mitigate this issue, but only detailed intra-site time series mapping using radiocarbon dates would provide sufficient certainty in this regard.

This paper represents the first application of Lorenz Curves and Gini Coefficients in African archaeology and one of the first attempts at modelling the significance of compound size asymmetries at the neighborhood level. The results obtained illustrate a considerable degree of spatial and socio-economic differentiation at Dakhlet el Atrouss I, contributing to a larger trend of academic scholarship supporting the idea that the development of social complexity in the West African Sahel preceded the local adoption of iron metallurgy in the first millennium BC and had a predominantly endogenous origin. The paper has been published in the journal *African Archaeological Review* (Linares-Matás 2022).

3. *Memory, agency, and labor mobilization asymmetries in the funerary landscapes of southeastern Mauritania, West Africa*

The archaeological study of funerary rites offers invaluable insights into cultural attitudes towards the dead and the socio-economic dynamics of the living. The materiality of remembrance is a political statement, rooted on the ability of different social agents to mobilize labor pools and networks of obligations within a given cultural framework. This paper explores how the materiality of memory and labor mobilization within prehistoric societies at the southern edge of the Sahara offers insights into cultural attitudes towards the dead and the socio-economic dynamics of the living. The paper provides a big-picture overview of the distribution of stone funerary monuments in southeastern Mauritania. It also presents a size-based classification system for pre-Islamic conical tumulus cairns in the highlands of southeastern Mauritania that has much wider applicability within prehistoric Saharan archaeology. Understanding the spatial distribution and size variability in burial monuments within funerary landscapes provides insights into the social energetics of ancestor

memorialization Through the first application of Gini coefficients to the study of funerary landscapes, the paper then analyses several large, spatially bounded clusters ("tumulus fields") in the Dhar Tichitt region which are subsequently used to contextualize the socio-economic dynamics of labor mobilization at three previously undocumented tumulus fields in the western margin of the nearby Tagant Plateau, spanning over two hundred tumuli each. The measurement of tumuli sizes complements studies of settlement patterns and circumvents the absence of other relevant mortuary data, such as the presence and frequency of imported goods within graves. The spatial distribution of these persistent nodal points offers potential avenues for understanding the articulation of status and authority through the mobilization of social obligations and access rights across potentially contested territorial thresholds, in the wake of increasing aridity and greater seasonal mobility in the southern Sahara from the first millennium BC onwards. This paper was accepted in January 2023 by the *Journal of Anthropological Archaeology*.

4. *Shifting sands: climate change, non-linear settlement dynamics, and social resilience at a Saharan frontier*

The highlands of southeastern Mauritania present an extraordinary archaeological record for documenting the emergence, consolidation, and reorganization of cultural dynamics, which illustrate the applicability of complex adaptive system cycles in the diachronic study of human societies. These trends include several alternative pathways towards increasing social complexity at the interface between the Sahara Desert and the Sahelian grasslands to their south, pathways that command great interest in terms of validating the creativity, resilience, and ingenuity of indigenous African communities as well as in the global comparative study of past human experiences from an archaeological perspective.

This paper aims to characterize over three millennia of human landscape use by societies of

the Tichitt Tradition in the highlands of southeastern Mauritania, West Africa. It represents a thematic review and thorough contextualization of a large-scale remote sensing archaeological survey (n = 1,140 settlements). This endeavor is rooted in the integration of archaeological datasets with a theoretical framework inspired by insights from Africanist anthropology (particularly Kopytoff's Internal African Model), archaeology (including McIntosh's 2005 discussions of heterarchy and Canós Donnay's 2016 notion of "shifting sedentism"), and complexity theory through the lens of Complex Adaptive Systems and resilience cycles (cf. Holling and Gunderson 2002).

The Tichitt Tradition represents a durable manifestation of pre-existing trends towards socio-economic differentiation among mobile Saharan communities, who were able to reorganize, grow and consolidate during the second millennium BC in an ecological niche that enabled the development of a thriving agropastoral economy based on cattle-keeping and pearl millet cultivation. Pearl millet (*Pennisetum glaucum*) cultivation likely started as a seasonal component of a generalized broad-spectrum pastoral economy that included the exploitation of wild terrestrial and aquatic resources, soon becoming a paramount agricultural staple that sustained a semi-sedentary lifestyle structured around extensive stone-walled settlements. The growth and consolidation of Tichitt Tradition communities during the second millennium BC was characterized by a protracted process of conservative but decentralized reproduction of material and ideological forms leading to high systemic coherence, mirroring expectations derived from the Internal African Model developed by Kopytoff (1987). On the other hand, the first millennium BC witnessed a drastic release and reorganization of settlement patterns amidst severe aridification trends and the arrival of Lybico-Berber communities, which led to the formation of interstitial communities with much greater adaptive diversity and creativity. Migration outflows from the Tichitt-Oualata region played a fundamental coping mechanism role in the face of intense aridification trends, highlighting the relevance of plastic and multi-

scalar approaches in the characterization of social resilience. These relocation dynamics contributed to the emergence of several alternative pathways towards socio-political complexity elsewhere in West Africa.

The archaeological record of southeastern Mauritania illustrates how mobility and connectivity constitute a recurrent survival strategy for agropastoral communities across the shifting and unstable frontier between the Saharan desert and the semi-arid grasslands of the Sahel. Evidence for cultural and demographic interactions between Tichitt Tradition societies from southeastern Mauritania and those from the Middle Niger region of Mali may offer interesting insights into the formation processes of urban polities and empires in the West African Sahel. Furthermore, the dynamic frontier conditions of southeastern Mauritania appear to have significantly contributed to the formation of the initial cultural background for widely shared traits of pan-African political culture, in line with Kopytoff's (1987: 15) own intuition of the relevance of Saharo-Sahelian Neolithic communities in this process. Future inclusion of thousands of archaeological sites identified in the highlands of southeastern Mauritania into the Endangered Archaeology of the Middle East and North Africa (EAMENA) project database, to be made available to researchers as well as relevant national and regional authorities, will facilitate and further promote the monitoring, investigation, and safeguarding of cultural heritage in the region. This paper is currently under consideration at the *Journal of World Prehistory*.

5. *Connectivity and socio-economic interactions across time and space in the southern Sahara: medieval Tegdaoust (Mauritania) and its hinterland*

Urbanism and complex Medieval West African states, such as Mali and Songhai, are thought to have emerged, at least partially, through the control of prestige goods (gold, ivory, salt) and enslaved people transported for large distances across trans-Saharan routes. However, most Islamic urban centers in the Sahara developed from earlier forms of semi-permanent

occupation within their regions. Understanding processes of connectivity at the intersection between the southern Sahara and the West African Sahel requires a multi-scalar approach to explore local details in a transregional context. This paper uses a combination of spatial analyses, analytical phenomenology, palaeoecological records, and historical data to identify processes of cultural and socio-economic change at the oasis town of Tegdaoust (Hodh El Gharbi, southeastern Mauritania), a key node of early Islamic trans-Saharan caravan routes.

The distribution of funerary monuments can provide relevant insights about landscape use, mobility, and memory, including among societies with a strong pastoral component that move between highland and lowland areas in search of fresh water and greener pastures. Very high-resolution multispectral satellite imagery also proved effective for calculating vegetation indices. The results suggest a relationship between seasonal vegetation patterns and past human settlement. Furthermore, the coexistence of at least six clusters of prehistoric tumuli, a large medieval cemetery, and post-medieval tombs in the landscape around Tedgaoust illustrates the sustained cultural significance of the Rkiz highlands in the socio-economic networks of human communities in southeastern Mauritania. The presence of large clusters of funerary tumuli—a mortuary practice that was largely abandoned throughout North Africa following Islamic conversion—evidences the endogenous roots and cultural relevance of human occupations in the wider landscape of this oasis town prior the development of extensive trans-Saharan connections during the medieval period. The passageways that channel these movements tend to act as liminal places, contested spatial thresholds between different territories and topographies, making them prime locations for the placement of visible monuments. The natural passageway of the Taskast wadi promoted considerable connectivity between the communities of the Tagant plateau and those areas further south for over a millennium. Least-cost pathways drawn to and from the entrepôt of Tegdaoust also suggest that the Taskast wadi represented a main route within trans-Saharan trade networks, connecting the western Sahel to

the Islamic communities of northwest Africa in medieval times. This paper, co-authored with Jonathan Lim (University of Oxford), was presented at the Graduate Archaeology at Oxford ’21 Conference, and is accepted for publication as a chapter in the *British Archaeological Reports* volume collecting that conference’s proceedings.

The last part of the thesis is the “Conclusions” section, which summarizes and links the methodological approaches employed in the different papers, and discusses the results and theoretical developments in relation to cultural dynamics presented in this thesis, with a focus on key aspects of monumental funerary landscapes and settlement patterns in southeastern Mauritania. The section emphasizes the value of integrating desk-based approaches with collaborative, community-centered fieldwork as soon as logistically feasible. It ends with a series of proposed future lines of research aiming to enable a better understanding of prehistoric social dynamics in the region, highlighting in particular the role of relevant ethnoarchaeological insights and novel quantitative approaches to generate more comprehensive datasets and more holistic interpretive frameworks.

6. Methodological approaches

The spatial analyses in this thesis make use of orthorectified VHR satellite imagery and were conducted on the ArcGIS Pro software package, using Bing Maps as a basemap. A publicly available 30-m Digital Elevation Model (DEM) of Mauritania was used in calculations that required inputting landscape topography.

- Clustering analysis was undertaken to determining site groupings for settlements in Dhar Tagant (Paper 1) and for funerary monuments in two places: at the entrance of the Taskast wadi (Paper 1) and in across the Rkiz Massif area (Paper 5). The first and last

instances employed an automatic, density-based, 'self-adjusting' (HDBSCAN) algorithm based on spatial stability, while in the second instance, a 'defined-distance' (DBSCAN) algorithm was employed to account for spatial proximity between clusters.

- Viewshed analysis was employed to infer visual relationships. Cumulative reflective viewsheds provided information about the visibility of funerary monument clusters from the area around the entrance of the Taskast wadi on the side of the Dhar Tagant escarpment (Paper 1), while projective binary viewsheds were simulated at regular 100m intervals along a least cost pathway (using Tobler's Hiking Function) to recreate what an individual would see when travelling between Tedgaoust and its associated Islamic cemetery (Paper 5).
- Multivariate morphometrics (robust pairwise permutation MANOVAs) were applied to PCA values reflecting the size, circular symmetry, and circular alignment of funerary monuments (ring tumuli) in Dhar Tagant to quantitatively define two main tumuli classes with outer rings (Paper 1).

An additional avenue of enquiry in this thesis involves the use of well-established econometric methods to generate standardized indices through which it becomes possible to undertake quantitative cross-cultural comparative studies. In this regard, the Gini coefficient measures distribution unevenness within a sample, with higher values corresponding to a greater degree of unevenness, representing socio-economic differentiation, while the Lorenz Asymmetry Coefficient (LAC) informs us about which size classes are contributing most to the population's total distribution unevenness. My use of these two coefficients to characterize the extent of household wealth differentiation at the Tichitt Tradition sites of Akreijit and Dakhlet el Atrouss I (Dhar Tichitt), including within neighborhoods (Paper 2), represents the first time that they have been employed in African prehistory. Additionally, I have explored the relevance of Gini coefficient values to characterize the extent to which variability in tumulus area values

could inform us about labor mobilization asymmetries within and between societies in the construction of funerary monuments (Paper 3).

Lastly, another relevant methodological approach developed within the thesis is the application of the Jenks Natural Breaks algorithm for structuring quantitative data. This mathematical approach forms the main basis for a size-based classification system for simple tumulus cairns, generated through the application of using morphometric data from thousands of funerary monuments from five tumulus fields obtained through a remote sensing survey of the southeastern Mauritanian highlands (Paper 3). This framework has wide applicability for the characterization of the Saharan monumental funerary record. The Jenks Natural Breaks algorithm was also an important quantitative component in the quantitative distribution of neighborhood class divisions on the basis of Lorenz Asymmetry and Gini Coefficient values (Paper 2), the establishment of five settlement ranks/classes (Paper 4), and in the classification of Normalized Difference Vegetation Index (NDVI) values derived from Landsat-08 multispectral data of the Tegdaoust (Paper 5).

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RESEARCH ARTICLE

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Monumental funerary landscapes of Dhar Tagant (south-eastern Mauritania): Towards ethical satellite remote sensing in the West African Sahel

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Abstract

The remembrance of the dead is a ubiquitous dimension of most human societies, and the spatial dimension of mortuary practices actively constitutes an essential element of the cultural significance of certain places in the landscape. The visual prominence of stone-built funerary monuments in dry upland areas is particularly conducive to their multiscalar study through above-ground remote sensing methods. In this paper, we characterize the nature and distribution of Late Holocene drystone funerary monuments in the Dhar Tagant region of south-eastern Mauritania using freely available, very high-resolution (VHR) satellite imagery. We contextualize them in relation to the monumental mortuary records of Senegal and Mali within the West African Sahel, exploring their similarities and differences with other monumental funerary landscapes in semi-arid environments. Ethical considerations and a self-reflective attitude must be at the forefront of archaeological research, and we discuss the ethics of remote sensing research in the study of funerary practices in Africa, as well as the opportunities and challenges for remote collaborative engagement with local communities in the context of fieldwork restrictions.

KEYWORDS
Bing Maps, funerary tumuli, GIS, multivariate statistics, Tichitt Tradition, viewshed analysis

1 | INTRODUCTION

The Covid-19 public health emergency is accelerating current efforts to rethink how research in a predominantly field-based discipline such as archaeology is conducted (Ogundiran, 2020; Scerri et al., 2020). A considerable reduction in survey costs, the synoptic view afforded and the non-invasive nature of remote sensing provide an attractive, comprehensive and suitable method to approach the study of cultural landscapes, proving particularly successful in the survey of vast, underexplored and/or politically unstable territories across the globe, from tropical jungles to deserts (Harrower & Comer, 2013; Lasaponara & Masini, 2012; Parcak, 2009; Schaber & Gumerman, 1969; Schmidt, 1940; Wiseman & El-Baz, 2007).

Very high-resolution (VHR) digital satellite imagery achieves sub-1 metre ground sampling distance (GSD) under good conditions, which allows investigators to locate and characterize a wide range of archaeological features (Bewley et al., 2016; Rayne et al., 2017). In the central Sahara, the combination of WorldView 2 (with a resolution of 0.46-m panchromatic and 1.84-m multispectral at nadir) and airborne imagery using kites usefully documented the development of Garamantian early urban trading communities during the late first millennium BC and early first millennium AD around oases and their productive hinterlands, which supported intensive agricultural zones

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(Mattingly & Sterry, 2013). However, spaceborne remote sensing relying on VHR commercial imagery has long been associated with high acquisition costs and the technical proficiency required for the application of advanced computational methods to high-resolution commercial satellite imagery (Davis & Douglass, 2020; Klehm & Gokee, 2020).

The exponential technological development witnessed during the 21st century has expanded the number of remote sensing platforms, with major technological corporations, such as Google and Microsoft, have been progressively increasing the resolution of their freely available imagery services, especially Google Earth and Bing Maps. The Endangered Archaeology of the Middle East and North Africa (EAMENA) project (https://eamena.org/) has developed a comprehensive image interpretation and recording based on the visual inspection of these open-access imagery portals. However, this imagery may not be suitable for the visual identification of archaeological features in specific geographical areas, due to the uneven coverage or visibility issues. Therefore, remote sensing methods ought to be adjusted to the environmental conditions of the selected study area and the specific research questions to be addressed. The widespread distribution and often clustered presence of still-standing drystone structural features in semi-arid upland environments has proven particularly conducive to remote sensing research, because they can be readily detected from VHR satellite imagery (e.g., Biagetti et al., 2017; Mattingly & Sterry, 2013; Rayne et al., 2017; Sadr & Rodier, 2012).

In the highlands of the Sahara and the northern Sahel, stone features were an important part of the architectural repertoire of Late Holocene communities (Amblard-Pison, 2006; di Lernia, 2013; MacDonald, 2015). They provide enduring evidence of human presence across this vast region, and their spatial distribution, predominantly on the edge of upland areas and along watercourses, offer insights into the seasonal mobility of pastoral communities in search of water and pastures (di Lernia, 2006). In semi-arid environments, these physical references would have offered visual landmarks in their mobility across the landscape and/or rooted sources of territorial identity. The presence of human skeletons within a range of excavated tumuli types from the central and southern Sahara confirms their role in mortuary rituals (Gauthier, 2015; Paris, 1996). In this paper, we document and analyse the monumental funerary landscapes along Dhar Tagant (a sandstone escarpment in south-eastern Mauritania), by analysing the morphometric properties and spatial distribution of ring tumuli, first reported in surveys by Ould-Khattar (1995).

Current legislation does not place constraints on remote sensing archaeological research making use of open-access imagery. For example, UN Resolution 41/65 (Principle XII) states that sensing other countries without their consent is legitimate as long as such states have been given access to data 'on a non-discriminatory basis and on reasonable cost terms' (Oduntan, 2019). Active space investments and/or domestic space regulations, such as the Kyl–Bingaman Amendment (Zerbini & Fradley, 2018), can constrain the collection and dissemination activities of particular third parties. However, this international legal framework renders African states which may lack such regulations more vulnerable to both the benevolent and clandestine surveillance of their heritage and natural resources, with clear privacy and national security implications (Oduntan, 2003, 2019). It is worth remembering that some of the earliest attempts at exploring Africa's past arose in a colonial context of land dispossession and genocide (Pwiti & Ndoro, 1999; Robertshaw, 1990), and early colonial scholars were often complicit by attempting to strip native ownership away from heritage sites, with Great Zimbabwe being a notoriously infamous example (e.g., Caton-Thompson, 1931; Chirikure, 2015, 2020; Hall, 1990). Parker (1923) was also challenged for grossly misattributed the authorship of Senegambian megalithic burials to non-local groups, such as Carthaginian artisans of Garamantian ethnicity (Migeod, 1924; Ozanne, 1965; Palmer, 1939; Thilmans et al., 1980; Thomas, 1924). Therefore, it is crucial to engage more broadly about the ways in which knowledge about the African past is collected, classified, represented and curated (Giblin, 2013; Tuhiwai Smith, 2012), particularly when addressing Indigenous or local heritages from an outsider perspective, to prevent remote sensing from becoming the arena for an unethical and neocolonial scramble for data.

To achieve the goals of an ethically informed and professionalized postcolonial archaeology, archaeologists generally ought to go beyond merely complying with the requirements of legislation (Lane, 2014); we ought to identify, disassemble and unlearn the legacies of pervasive colonial influences in relation to our intersecting identities and institutional context to avoid a never-ending perpetuation of ties of subordination (Appiah, 2005; Gosden, 2004, p. 162; Haber, 2014; Hingley, 2014; Mama, 2007; Said, 1993, p. 47). Researchers should engage in a consensual dialogue and negotiation with relevant local authorities, whereby research is taking place through mutual agreement, and involving the reinvestment of remotely acquired knowledge in ways that allow African students and scholars to articulate their research priorities in ways relevant to their own decolonial agendas, perhaps through follow-up collaborative research in the field (Chirikure, 2015; Layton, 1989; Ogundiran, 2020; Pawlowicz et al., 2020; Smith, 2014). These collaborative discussions are even more relevant when we consider funerary landscapes, because processes of memory making are derive not only from the physical acts of monument construction as it structures ontological order (Barrett & Ko, 2009) but also from subsequent and protracted iterations, as shown by Clack and Brittain (2011) in their study and characterization of the Mursi megaliths in the Lower Omo Valley (south-western Ethiopia).

2 | REMOTE SENSING AND FUNERARY ARCHAEOLOGY IN THE WEST AFRICAN SAHEL

All human societies remember their dead, in some form or another, and the relationship between ways of living and mortuary practices is an important aspect of funerary archaeology everywhere in the world (Sherratt, 1990). The spatial dimension of mortuary practices actively constitutes an essential element of the cultural significance of

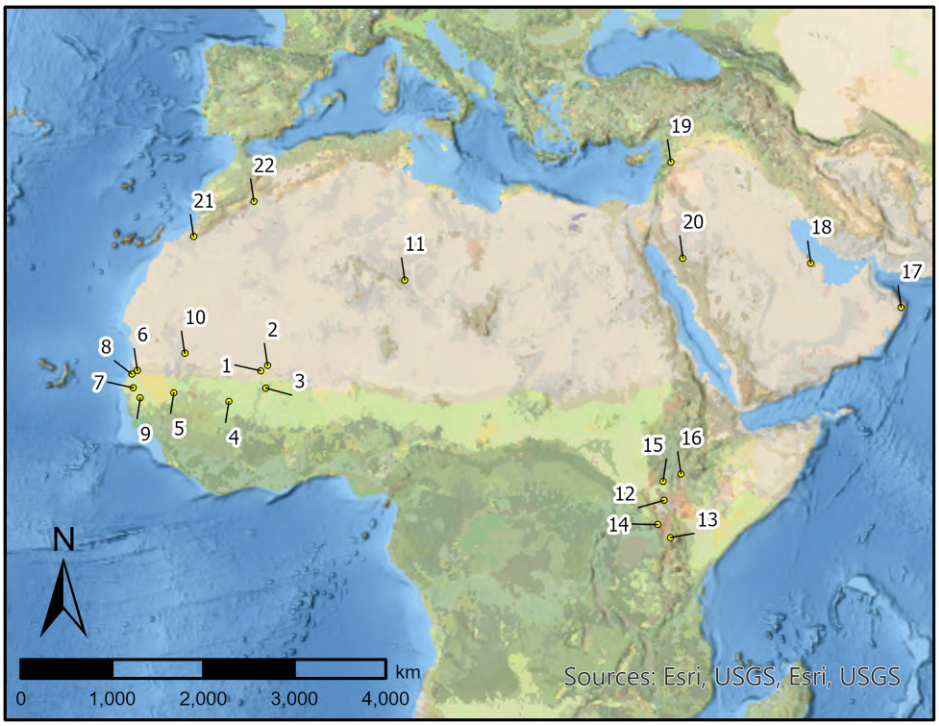
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landscapes, particularly when we envision funerary monuments as places in which memory and meaning are created, ascribed and reimagined (Hirsch, 1995; Johannesson, 2012; Metcalf & Huntingdon, 1991; Van Dyke & Alcock, 2003). Funerary landscapes are also locales of life where social norms and identities are renegotiated and resources are obtained and exploited (Parker Pearson, 1993; Giraud & Cleuziou, 2009, p. 164).

The study of funerary landscapes and remote sensing are inextricably linked in the history of archaeology, starting with Crawford's surveys and aerial photo identification of Britain's Stonehenge Avenue and wider ritual landscape during the 1920s (Barber, 2016). The high degree of surface visibility in the semi-arid West African Sahel, characterized by high temperatures throughout the year and irregular annual rainfall of between 100 and 600 mm, is well suited for undertaking remote sensing surveys through an analysis of historical aerial photographs and satellite imagery. Correspondingly, aerial photography has been a staple of archaeological research in the region for the past 60 years. The study of Senegambian funerary landscapes saw the earliest use of aerial photography in African archaeology when Clos-Arceduc (1962) visualized the mounds at the Thiekène Mbacké monument complex, a large earthen tumuli field in the Djourbel region of Senegal (McIntosh & McIntosh, 1993; Pradines, 1996). Fieldwork on a tumulus at Thiekène Mbacké identified a pronounced geophysical anomaly that corresponded with seven inhumations and a bundle of iron artefacts inside the Kael 1 ring-ditch burial mound (Magnavita, 2017). Research in central and western Senegal had undoubtedly been encouraged by the discovery of a gold pectoral by Joire (1943) in Mound P at Nguiguélah, near the town of Rao, and the reports from Gard and Mauny (1961, p. 163) of other extant tumuli in the Lac de Guiers and Djourbel regions (Figure 1). At Santhiou Kohel, a tumulus inhumation was accompanied by a decapitated dog and a possible double human sacrifice, but, in contrast to Mound P, it seemed to lack grave goods (Gallay et al., 1982). The dense distribution of thousands of these earthen mounds across a large area of western Senegal (32,000 km^2) suggests a highly ritualized, organized and labour-intensive process (McIntosh & McIntosh, 1993).

Remote sensing has also proven a suitable method in assisting archaeological fieldwork in Mali. The *Centre International pour le Dévéloppement de l'Elevage en Afrique* (CIPEA) identified 700 potential archaeological sites on aerial photographs, most of them in the Méma region of western Mali (Togola, 2008, p. 9). The aerial imagery was deposited in the *Institut Géographique National* in Bamako, and the relationship between putative sites, landforms and villages formed the structural basis for subsequent fieldwalking surveys in the flat landscapes of the region (Togola, 2008). Stereoscopic pairs of aerial photographs are useful for identifying mounds raising above the visually homogeneous floodplains of western Mali (MacDonald, 2017). Black-and-white historical aerial photographs can also provide glimpses into areas that were subsequently developed, although they can be unreliable for planning field surveys if land use has changed considerably (MacDonald, 2017).

Nowadays, the assessment of satellite imagery also comprises an integral part of current desk-based assessments aiming to identify suitable areas for conducting fieldwork in the West African Sahel.



Site ID	Name
1	Lake Fati (Mali)
2	Timbuktu (Mali)
3	Bandiagara Escarpment (Mali)
4	Tamani (Senegal)
5	Falemne Valley (Senegal)
6	Lac de Guiers (Senegal)
7	Djourbel (Senegal)
8	Nguiguelah (Senegal)
9	Sine-Ngayene (Senegal)
10	Taskast wadi (Mauritania)
11	Tadrart Acacus (Libya)
12	Lake Turkana
13	Laikipia (Kenya)
14	Cheranagi Hills (Kenya)
15	Lower Omo Valley (Ethiopia)
16	Boreda (Ethiopia)
17	Jalan (Oman)
18	Aali (Bahrain)
19	Homs (Syria)
20	al-Ula (Saudi Arabia)
21	Draa Wadi (Morocco)
22	Jabal Bouïa (Morocco)

FIGURE 1 Map showing the archaeological sites and geological features mentioned in the paper [Colour figure can be viewed at wileyonlinelibrary.com]

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Two related surveys targeting the Azawad (Tombouze Project, around Timbuktu; Park, 2010, 2012) and the Lakes (Gorbi Valley, near Lake Fati; Coutros, 2017) regions of Mali made a similar use of ASTER and Landsat-8 medium-resolution satellite imagery to determine the coordinates of potential sites to be verified during their subsequent ground-testing fieldwork. The true colour of satellite imagery can make it easier to detect dark red brown patches that could represent laterite-tempered mud architectural features, such as the recently documented tumuli fields of the Pays Dô region of Mali (MacDonald et al., 2018). Dô and Kiri were two small Mande confederations (*kafu*), and their union was the ideological and political foundation for the development of the empire of Mali, a hierarchical and coercive state that was established during the thirteenth century (MacDonald et al., 2018). Conversations and observations with members of local communities, who prized large storage vessels within the mounds, led to the identification of numerous funerary tumuli built of clay covered by lateritic cobbles and gravel (MacDonald et al., 2018, p. 80).

Archaeological research in Mauritania has also made use of airborne remote sensing methods. Thomassey and Mauny (1951) deployed aerial imagery to complement their excavations at Koumbi Saleh (southern Mauritania) to document and interpret this site, which was part of the Medieval Ghana empire and was involved in trans-Saharan trade networks. Due to a paucity of archaeological excavations, Vernet (2017) recently made use of Google Earth satellite imagery to provide a more comprehensive account of the archaeological heritage of the Adrar region of central Mauritania, with a focus on linear stone-built features and enclosures. In the highlands of south-eastern Mauritania, the escarpments around Dhar Tichitt were sporadically visited by several French colonial researchers during the first half of the 20th century, who highlighted in their brief surveys the existence of large and well-preserved stone-masonry villages and funerary monuments (Laforgue, 1924, 1932; Laforgue & Mauny, 1939; Mauny, 1950, 1951; Verneau, 1920). The initial aerial survey and fieldwork results reported by Patrick Munson (1971) encouraged further research in the area, with subsequent researchers, such as Hugot at Akreijit (Holl, 1986), Amblard (1984, 1996) and Amblard-Pison (2006) at both Dhar Tichitt and Oualata, and two teams have conducted fieldwork in Dhar Néma (e.g., MacDonald et al., 2009; Person et al., 2006). At least one of these teams (MacDonald, personal communication) made extensive use of available historical imagery to inform fieldwork through the identification and characterization of sites belonging to the Tichitt Tradition (ca. 1900–400 BC), an early agropastoral economy based on intensive domestic pearl millet cultivation and livestock rearing (Amblard-Pison, 2006; Fuller et al., 2007; Holl, 1985; Munson, 1971). The Dhar Tichitt landscape exhibits a hierarchical settlement pattern (Holl, 1993), and the main settlements were surrounded by high (approximately 2 m) and robust (approximately 1–1.5 m thick) stone walls with structured access gateways capped with lintel stones (MacDonald, 2020; Munson, 1971; Vernet, 1993).

The research by Park (2010) and Coutros (2017) in Mali also highlighted the centrality of south-eastern Mauritania for understanding settlement patterns and population movements in the Western Sahel during the first millennium BC and the first millennium AD: the pottery parallels (*Faïta* facies) and the presence of stone enclosures on the highlands around Lake Fati illustrate a certain degree of relationship with the practices associated with the late Tichitt Tradition and the Bandiagara Escarpment (Coutros, 2017). In contrast, the earliest ceramics around Tombouze (Phase 1) highlight a greater affinity with the twine-impressed and sand-tempered assemblages of central Saharan proto-Berber groups (Park, 2010). The contact phase between these two main cultural groups in both south-eastern Mauritania and central Mali during the second half of the first millennium BC is correlated with the expansion of ironworking technology in the wider Western Sahel region. Within Mauritania, these patterns have been documented archaeologically through excavations conducted in the Dhar Néma region (MacDonald et al., 2009) and by fieldwork surveys in Dhar Tagant conducted by Ould-Khattar (1995). However, the publicly available level of documentation for the archaeological heritage of Dhar Tagant remains insufficiently detailed for assessing the spatial extent and architectural nature of sociocultural interactions during the second half of the first millennium BC and the first half of the first millennium AD. Therefore, we present here a preliminary characterization of the landscape distribution and morphometry of late prehistoric funerary tumuli in the Dhar Tagant region based on a comprehensive visual survey of freely available satellite imagery, which to our knowledge represents the first remote sensing publication aiming to analyse in depth the archaeological record of south-eastern Mauritania.

3 | AN ETHICAL ARCHAEOLOGICAL REMOTE SENSING FRAMEWORK FOR MAURITANIA

In Mauritania, the participation of externally funded researchers is often welcomed and actively encouraged by national authorities (MacDonald personal communication), although these local research needs cannot be easily addressed in the field due to security concerns: the UK's Foreign, Commonwealth & Development Office, for example, has advised against all travel to a number of provinces in eastern Mauritania, including Tagant, for a number of years (https://www.gov.uk/foreign-travel-advice/mauritania). Undertaking remote sensing research into the prehistoric past of Mauritania is therefore a relevant way to address local research needs. Dr. Robert Bewley (EAMENA Director) and his advisor Pieter Tesch have acted as a liaison on behalf of the authors with Dr. Sidi Ould Salem, head of the Mauritanian Ministry of Culture, and his advisor (Dr. Camara) to request permission and inform about the research to be conducted in the region. These initial contacts and verbal research approvals followed preliminary remote sensing surveys aiming to probe the suitability of the imagery for archaeological research and heritage management and preceded the more detailed spatial analyses carried here.

The work conducted so far in the context of our research mainly relates to the Stage 1 of our framework (Figure 2), and a formalization of future collaboration between the University of Oxford and the

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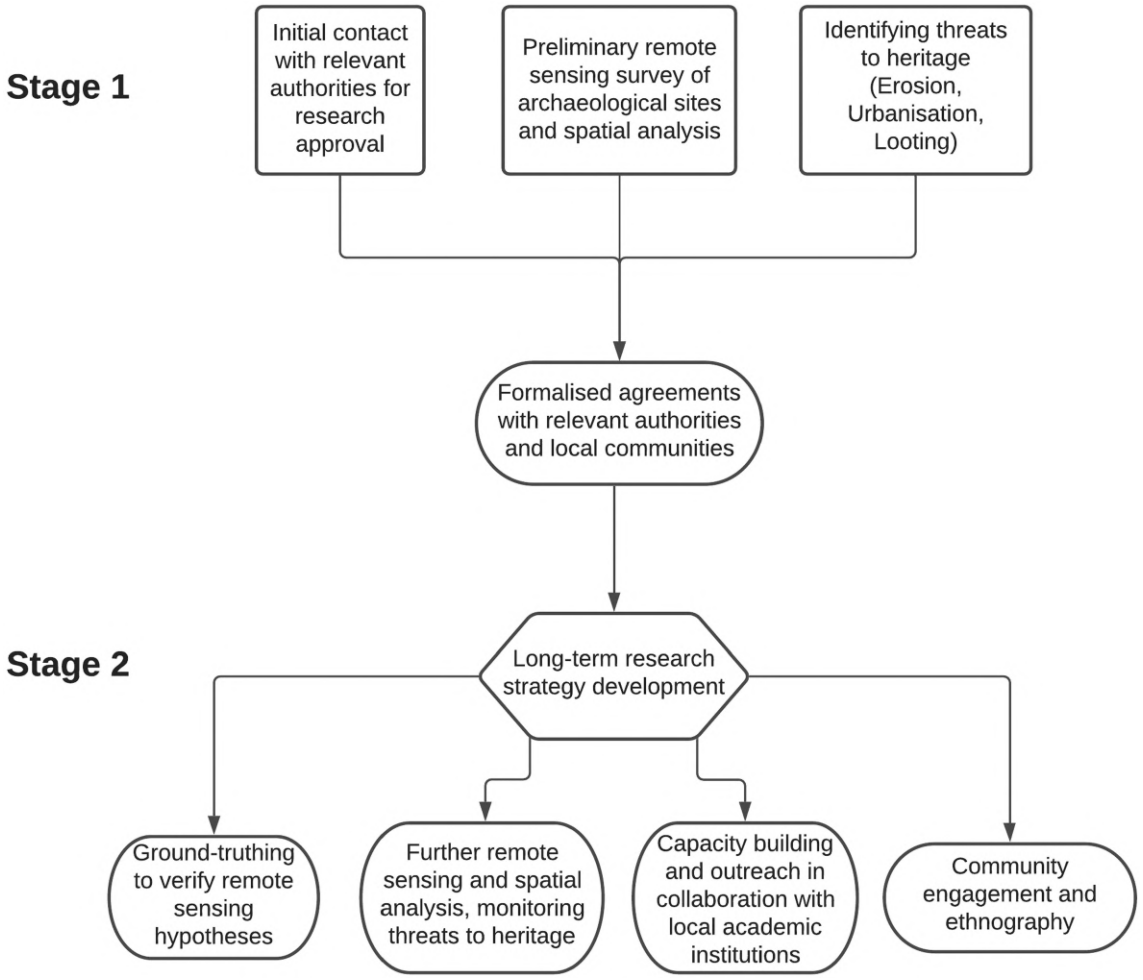


FIGURE 2 Our proposed multi-stage ethical framework to inform and structure archaeological remote sensing in Mauritania

Mauritanian authorities is taking place. There are strong research incentives for an ethically informed remote sensing project to progress into Stage 2, involving a greater degree of personal and community engagement beyond ground truthing.

Endangered heritage monitoring: The multi-institutional EAMENA team has demonstrated the usefulness of integrating image interpretation, land-use mapping and traditional field survey to record, assess and analyse the preservation status of funerary landscapes in the Homs region of western Syria (Rayne et al., 2017, p. 20). The consensual and collaborative documentation of landscape modification through photogrammetry and satellite imagery archives of archaeological sites at risk of destruction by climate change or anthropogenic processes can lead to more active and effective institutional and external monitoring (Brooks et al., 2020; Campana, 2017; Khalaf & Insoll, 2019; Parcak et al., 2016; Rayne et al., 2020). These phenomena are likely to intensify in the face of increasing regional aridification, which also severely threatens the food security of agropastoral communities throughout the Sahel and beyond. High-resolution remote sensing datasets generated through remote sensing research in southern Mauritania will ideally form part of structured and integrated heritage inventories that can usefully inform subsequent archaeological fieldwork in the region and conservation policies to enhance the monitoring and safeguarding of sites, with knowledge transfers facilitated through outreach and local training workshops.

Institutional collaboration and capacity building: Certain aspects of collaborative research may be challenging when some countries lack specialized scholars, as could hinder local processes of knowledge generation and reception. The structural challenges and constraints that African social sciences researchers face are numerous, ranging from global structural frameworks that privileges certain forms of Africanist scholarship over local African voices (Hountondji, 2002; Mkandawire, 1993), a retrogressive and gerontocratic institutional hierarchy (Ake, 1994; Zeleza, 2003) and a systemic lack of funding opportunities, which leads to a lack of fair and accessible means for the generation and presentation of novel ideas by local scholars (Mama, 2007; Tettey & Puplampu, 2000). Ideology and religion may also explicitly dictate or implicitly shape national research priorities: for example, there is a lack of national scholars specializing in the pre-Islamic history and archaeology of Mauritania (Ould-Khattar, personal communication). Therefore, any externally led project ought to consider how its methods and research outputs will contribute to improving the

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situation or otherwise. In Mauritania, outreach lectures and training workshops at the University of Nouakchott could prove inspirational for young scholars (Ould-Khattar, personal communication).

Ethical remote sensing and local community engagement: The use of geospatial technologies should not be conceptualized as inherently incompatible with 'on-the-ground' collaboration with participant local communities (Klehm & Gokee, 2020, p. 4); ethical research ought to avoid alienating local communities from the heritage in the landscapes that they inhabit should they wish to engage and participate in the process. East Africa has witnessed several particularly successful examples on how remote sensing and the archaeology of living communities in Africa can go hand in hand. Arthur et al. (2020) collaboratively mapped recent settlement histories in southern Ethiopia with Boreda elders, jointly charting architectural features, physical settings and the oral histories associated with sacred groves and other features in the landscape. Abandoned fortifications in particular hint at conflict and resistance versus neighbouring slave raiders and the (northern) Ethiopian state (Arthur et al., 2020). This approach highlights and documents the multifaceted nature of human landscape use. As shown by Lunn-Rockliffe (2018) working alongside the Sengwer community of the Embobut Forest (Cheranagi Hills, Kenya), collaborative research has considerable implications for empowering local communities amidst attempts to uproot and displace them, through the documentation of the deep histories of community presence within the land.

These processes of community engagement are not always straightforward, however; the experiences of widespread population genetic sampling suggest that some of the complexities of research may hinder the communities' comprehension of the disclosed information and the actual purpose of the investigation, which in turn may compromise the degree to which consent was sufficiently informed (MacEachern, 2013; Nyika, 2009). It is the ethical responsibility of researchers to communicate in a clear and easy to understand way to prevent such issues from arising, perhaps by inviting a locally trusted translator to mediate in the conversation and keeping records of interview transcripts—and ideally a summary of research outputs—in relevant local languages for future consultation (cf. Rearden & Fienup-Riordan, 2013). Furthermore, geopolitical and public health issues may prevent on-the-ground collaboration with local communities. Fostering grassroots collaboration schemes with local communities through web applications can help towards the coidentification, mapping and characterization of archaeological features visible in the satellite imagery (cf. Harris, 2012). At the same time, the applicability of community engagement approaches and crowd-source mapping mechanisms in these contexts remains relatively untested, particularly in the absence of on-the-ground data quality validation mechanisms due to fieldwork restrictions.

Moreover, communities who may claim an ancestral connection with a particular heritage have occasionally been territorially displaced and/or experience sociopolitical marginalization, and 'recently' arrived local communities may have very little emotional or cultural connections with the prehistoric heritage that coexist in the landscape. For example, Kennedy (2011) described how the Bedouin communities of the Eastern Desert of Jordan and Saudi Arabia refer to the seasonal hunting camps and funerary sites that he had surveyed in the desert using satellite imagery as 'the works of old men'. Similarly, Ould-Khattar (1995) relates how nomadic Berber pastoralists in the Tagant (Mauritania) did not identify with the original builders of archaeological sites in the region, despite camping near the sites and occasionally making use of some of the stone structures.

Water points and paths are relevant components of agropastoral communities in arid landscapes (Biagetti et al., 2012), and Ould-Khattar (1995, p. 56) mentions the familiarity of local nomads that visit Dhar Tagant with local freshwater sources, such as perennial springs and seasonal watercourses. At the same time, the depth of landscape and cultural knowledge of local communities may fluctuate from one generation to the next, as stressed by Biagetti et al. (2012) for the Kel Tadrart Tuareg living in the Acacus mountains, whose ability to read Tifinagh inscriptions is quickly fading, and steep and narrow passageways are losing their historical primacy since the advent of four-wheeled vehicles in the region (Biagetti et al., 2012). Thus, even in the absence of cultural continuity, mapping subsistence routes and landmarks in detail would undoubtedly help us illustrate potential relevant hotspots for prehistoric settlement and mobility, as well as help record the seasonal lifeways and landscape interactions of contemporary nomadic groups.

4 | METHODOLOGY

4.1 | Best practices in remote sensing recording

The ever-growing body of data collected through spaceborne and airborne remote sensing requires researchers to ensure that they follow best practices in the systematic examination, processing, description, analysis and interpretation of available information. When undertaking a visual remote sensing survey using freely available satellite imagery, the extent of the survey ought to be accurately mapped, ideally alongside landmarks such as topography, hydrography and settlements, followed by a comprehensive report documenting the location and description of identified sites. A minimal site documentation should include a coordinate reading at its approximate centre, size in hectares, a picture depicting the site visually and a brief site description of visible surface features and its surroundings (MacDonald, 2017; Wilson, 1982, p. 195). The process of feature recording from spaceborne imagery is not always straightforward, given how atmospheric conditions at the time of data capture might affect the clarity and visibility of the imagery. The combination of multiple imagery sources that account for annual or seasonal variation can help overcome this potential limitation, while also providing an initial validation stage that is particularly relevant when ground survey data are not yet available, as suggested by Rayne et al. (2017). Unfortunately, the GSD of Google Maps and Google Earth satellite imagery for our Dhar Tagant survey area was rather coarse, which prevented cross-platform identification of individual features readily visible on the Bing Maps imagery.

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During the early stages of remote sensing research in an under-explored region, several authors have highlighted the importance of developing a general and standardized morphological classification, arranged on hierarchical principles and anchored in quantitative ranges (Kennedy & Bewley, 2004, 2009; Kennedy & Bishop, 2011; Wilson, 1982). For these reasons, we undertook a comprehensive morphometric characterization of funerary tumuli in the Dhar Tagant region, complementing preliminary qualitative typological assessments outlined by Ould-Khattar (1995). When researchers commission or directly acquire satellite imagery, pattern recognition algorithms (e.g., Davis, 2019) can semi-automatically digitize archaeological deposits with suitable spatial and morphological accuracy. To apply such automated procedures on the freely accessible imagery hosted on web-mapping portals used here (i.e., Bing) requires special licensing. As such, for our analyses here, we computed detailed and metrically accurate transcription of feature data on GIS after manually recording and digitizing the sites.

4.2 | Analytical methods employed

ArcGIS Pro 2.7, a geographical information system (GIS) software package, was employed to manipulate satellite imagery and carry out spatial analyses using in-built geoprocessing tools. Bing Maps was loaded into the GIS as a basemap after obtaining a license key from Microsoft. Metadata for Bing Maps imagery is not readily available; however, most of our study area seems to have orthorectified VHR imagery of 30–50 cm (i.e., already corrected for distortions derived from terrain morphology and viewing angle), making it ideal for visual inspection and analysis.

Based on this freely available satellite imagery service, we undertook a preliminary survey of Dhar Tagant (south-eastern Mauritania). Dhar Tagant is an escarpment complex located south of the town of Tidjikjia and west of Dhar Tichitt (Figure 3). These *dhars* represent a topographical transition encompassing flat upland areas on the edge of the Tagant Plateau, slopes of varying steepness intersected by shallow wadis and narrow canyons (*dakhlat*) and interdunal alluvial lowlands (*baten*) that mark the start of the Aoukar Depression (Holl, 2009; Munson, 1971).

Dhar Tagant was surveyed archaeologically by a Franco-Mauritanian team in the late 1980s, collecting information on over 200 sites (Ould-Khattar, 1995). Nonetheless, intrasite maps (with a few notable exceptions authored by Robert Vernet) or site distribution maps have not been publicly reported, due to concerns regarding their future integrity due to tourist and local nomadic groups visiting and potentially looting them. Indeed, Challis et al. (2005, p. 460)

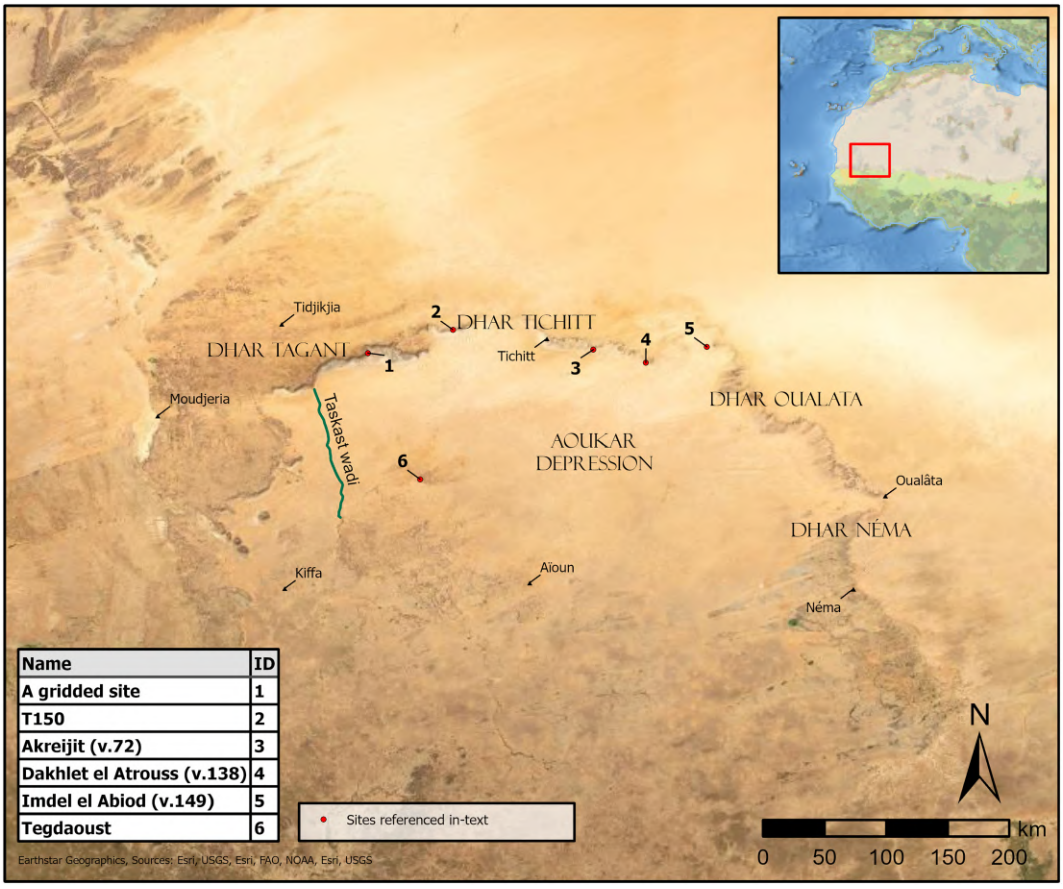


FIGURE 3 Map of south-eastern Mauritania with the archaeological sites and geological features mentioned in the text [Colour figure can be viewed at wileyonlinelibrary.com]

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mention, for example, that it was not unusual for locals to take grindstones and pottery away from sites in the Guilemsi Ridge (north of Tidjikja, Tagant Plateau). This situation has hampered any subsequent attempt at understanding the Dhar Tagant archaeological record up to this day, and the material heritage of the region remains insufficiently documented, in contrast with Dhar Tichitt and other areas of the West African Sahel, despite similar underlying issues.

4.2.1 | Clustering analysis

In our preliminary survey, every apparent settlement was digitized with a point feature in the approximate centre of the site, assigned into clusters with the Density-based Clustering tool. The 'self-adjusting' (HDBSCAN) algorithm (Campello et al., 2013) was used to automatically group sites into clusters based on cluster probability or stability.

4.2.2 | Multivariate morphometric analysis

The funerary monuments in Dhar Tagant were analysed according to their size, shape and distribution. Apparent tumuli were visually identified and then digitized as point features placed in the centre of the monument. Three metrics were measured:

Size: The outline of the tumuli and, where present, their enclosing outer ring were digitized manually as two separate polygon layers. In order to automatically obtain an approximation of the diameter of these circular tumuli, the Minimum Bounding Geometry tool was carried out on both polygon layers to generate a circle of best-fit around each feature—the tool was also able to report the diameter of the circles. The two layers were then merged with the Spatial Join tool and then exported as a table for further statistical analysis.

Circular symmetry ('roundness'): The actual outlines of the tumuli (and their outer rings, where present) were compared with their perfectly circular, 'idealized' versions generated above, as a measure of roundness. The area of the features was divided by that of their circular versions to obtain an index measuring symmetry with values ranging from 0 to 1, where higher values indicate that a feature is more circular.

Deviation of tumuli alignment from geometric centre of monument: For tumuli possessing an outer ring, the extent of tumuli deviation from the geometric centre of the ring monument was measured. The 'Feature to Point' tool was used to generate a point at the geometric centre of both the tumuli and the outer ring. A geoprocessing model was then created to automatically iterate the generation of polylines between these two points using the Points to Line tool. The length of this line was noted and used in the statistical analysis.

A table of ring tumuli and the morphometric values generated above were subjected to multivariate statistical analyses in R (version 3.5.1; R Core Team, 2018), a free software environment for statistical computing and graphics. To select the most suitable variables and prevent the simultaneous use of highly correlated ones, we performed the Kaiser–Meyer–Olkin (KMO) factor adequacy test (0.6 cut-off value) and assessed with the Bartlett test whether the resulting correlation matrix was an identity matrix (i.e., one where all residual correlations are zero), both using the psych library (Revelle, 2018). To reduce the dimensionality of the dataset while retaining the original distances between the morphometric data from monument clusters, we undertook a principal component analysis (PCA) using the FactoMineR library (Le et al., 2008). The PCA graph was generated using the library ggfortify (Horikoshi & Tang, 2018) with the 'Dark2' Brewer palette. To test the significance of the PCA variables, we employed the Mardia multivariate normality test using the MVN library (Korkmaz et al., 2014) followed by a robust pairwise permutation MANOVA (999 permutations) using the library RVAideMemoire (Hervé, 2019). A similar methodological workflow is used in geometric morphometric analyses to test for multivariate statistical significance in non-parametric distributions (e.g., Linares-Matás et al., 2019; López-Cisneros et al., 2019; Yravedra et al., 2019).

Workflow: An automated geoprocessing workflow is available as an ArcPy script, and the R code for the multivariate morphometric analysis is also accessible from the link in the Data Availability Statement.

4.2.3 | Viewshed analysis

Cumulative reflective viewshed analysis was used to infer visual relationships between a sizable group of 137 funerary monuments and their immediate landscape, where the Taskast wadi meets the Dhar Tagant escarpment. Using a publicly available 30-m Digital Elevation Model (DEM) of Mauritania (Lee, 2013) as a surface, we calculated which parts of the landscape the monuments were visible from, assuming the height of individual observers in the landscape was 1.75 m tall (a standard human [male] height, cf. Gillings & Wheatley, 2001), and the monuments no taller than 2 m (after Ould-Khattar, 1995). The Density-based Clustering tool was once again used to assign each monument to a cluster, based on their proximity. This time, a 'defined-distance' (DBSCAN) algorithm was used (Ester et al., 1996), with a minimum of two features per cluster and a search distance of 300 m—six clusters were identified in this manner. The reflective cumulative viewshed was carried out on all 137 monuments as a group. Reflective viewsheds were also generated for each individual monument cluster.

5 | RESULTS

5.1 | Settlement patterns in the Dhar Tagant region of south-eastern Mauritania

Our preliminary survey of the Dhar Tagant using freely available satellite imagery noted that prehistoric sites can be found throughout the escarpment, albeit in clusters of variable extent and density (Figure 4). Our survey confirmed the general pattern documented for Tichitt

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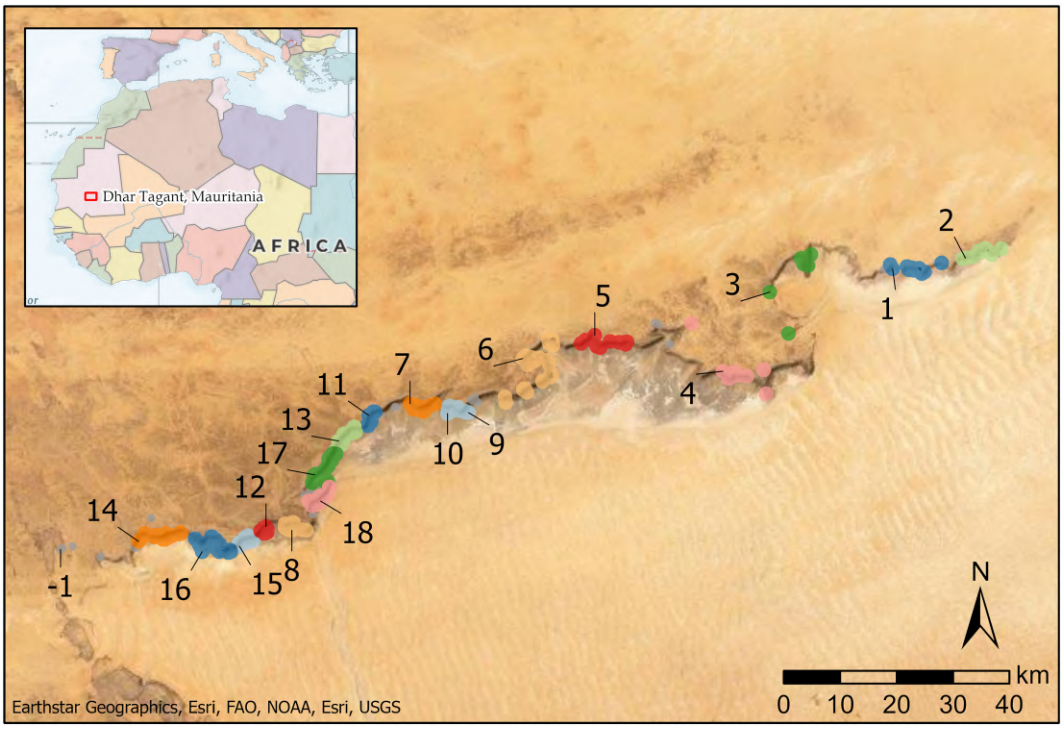


FIGURE 4 Distribution of settlement clusters along Dhar Tagant [Colour figure can be viewed at wileyonlinelibrary.com]

Tradition drystone sites, which predominantly comprise a series of enclosed household compounds forming larger aggregated spatial units on the flat plateau and escarpment slopes (MacDonald, 2015).

On the basis of size and complexity, we have tentatively identified the following settlement types:

Type 1: Simple enclosures

These are small, isolated enclosures. They could potentially represent cattle kraals and are found throughout the study area. Some of these structures may have been reused or constructed anew in the recent past by local nomadic pastoralists.

Type 2: Sites with multiple enclosures

These are small, isolated and asymmetrical collections of around 3–15 enclosures, occasionally joined together. They are mostly found on slopes, without enclosing walls. In some instances, however, they are located in relatively inaccessible and include defensible areas with partial fortifications.

Type 3: Large complexes

These are large conglomerations of enclosures in an organic, disorganized pattern. There are two main variants: those found on the slopes of the escarpment and those built on the flat plateau that overlooks them, such as the early ironworking community of T150 (dated ca. 150 BC–AD 50; MacDonald, 2020; Ould-Khattar, 1995; Figure 5). Sites on slopes are often less nucleated and do not exhibit outer fortifications, whereas those atop the escarpments normally feature boundary walls. The largest walled settlement encompasses approximately 35 ha. Within the established Tichitt-Oualata sequence, the Late Tichitt phase (ca. 1000–400 BC) witnessed the increasing development of defensible settlements at the top of the escarpment, notionally due to conflict between Tichitt Tradition populations and incoming Berber groups (MacDonald, 2020). The dates provided by Ould-Khattar (1995) suggest that the bulk of occupation in the Tagant was during or after this Late Tichitt period, with 12 of a total of 15 ^{14}C calibrated determinations falling between 800 cal. BC and cal. AD 500, which is consistent with the presence of ironworking at most of the stonewalled settlements on the plateau edge (Ould-Khattar, 1995, p. 175).

Type 4: Grid complex

Finally, we have documented a unique site complex in the region, with potential streets as part of a well-structured layout style (Figure 6). A series of regular circular features are evenly distributed within rectangular enclosures. Their functionality and significance are still unknown, but, given their morphological divergence from Tichitt Tradition domestic enclosures, we do not rule out a potential role in funerary practices. Two wadis that converge on the base of the slope separate the different components of this agglomeration. The presence within a 2-km radius of several agricultural terrace complexes on the escarpment slope may hint at some degree of agricultural intensification.

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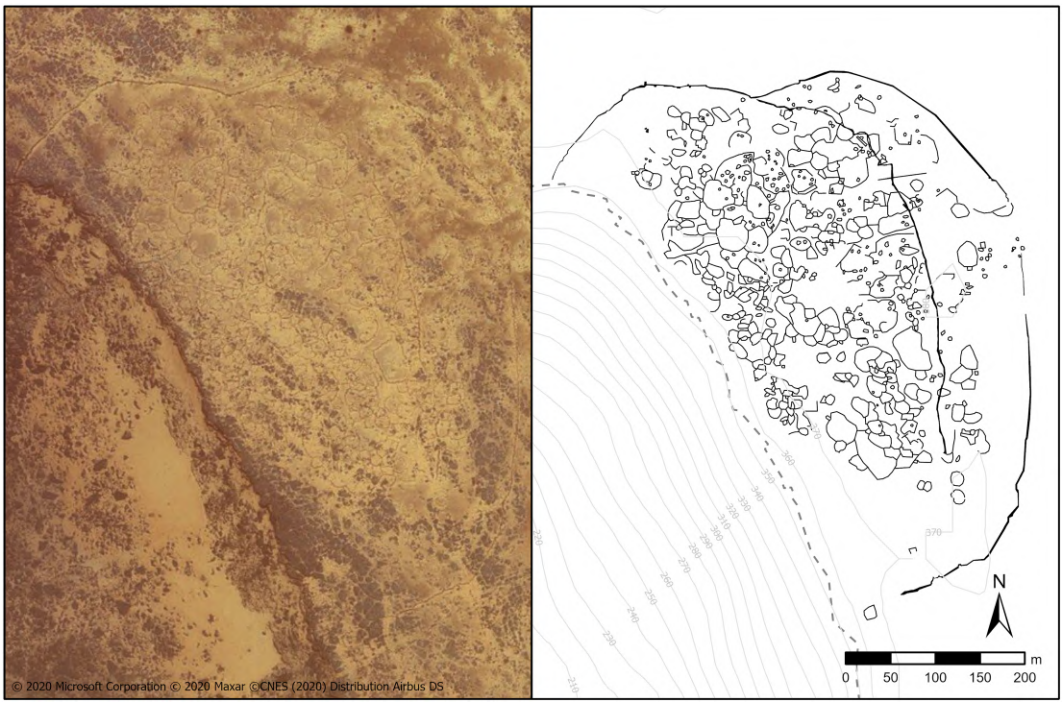


FIGURE 5 T150, a double-walled settlement on the flat plateau edge of the Dhar Tagant escarpment [Colour figure can be viewed at wileyonlinelibrary.com]

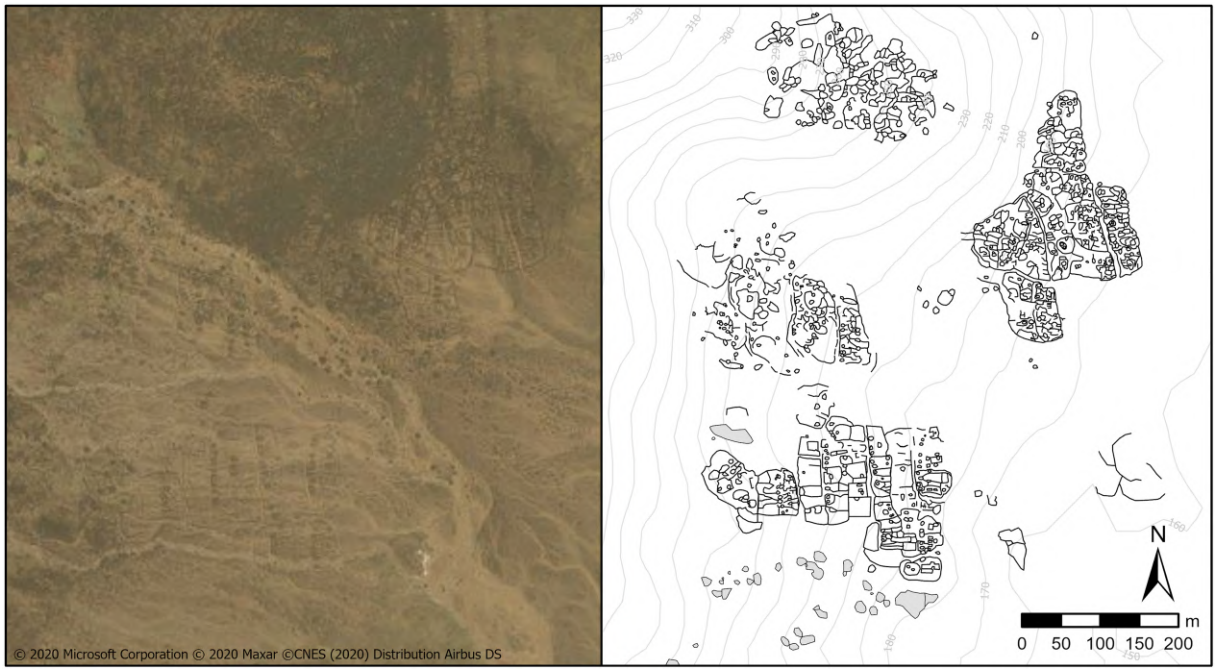


FIGURE 6 Gridded site complex in Dhar Tagant [Colour figure can be viewed at wileyonlinelibrary.com]

5.2 | Funerary monuments of Dhar Tagant

Tichitt Tradition funerary cairns have been identified along the central Dhar Tichitt escarpment, particularly in the vicinity of Dakhlet el Atrouss (Amblard-Pison, 2006). Cairns are stone monuments visible on satellite imagery as small circular or oval features, sometimes associated with ring enclosures of varying size, although ring tumuli are not particularly common in Dhar Tichitt. Beyond the Dhar Tichitt clusters, funerary monuments do not seem particularly common along other south-eastern Mauritanian escarpments, such as

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Dhar Oualata and Dhar Néma (MacDonald, 2015; MacDonald et al., 2009).

To improve our understanding regarding the nature of the monumental funerary landscapes of south-eastern Mauritania, we conducted a preliminary remote sensing survey along the Dhar Tagant escarpment (approximately 235 km). The existence of at least two categories of funerary monuments in Dhar Tagant, with some degree of internal morphological variability, is suggested in survey accounts of the region (Ould-Khattar, 1995, pp. 432–437; Figure 6). Descriptions of conical funerary monuments in the region commonly highlight the existence of a stone ring (Ould-Khattar, 1995, p. 69). Using the ring tumuli described by Ould-Khattar (1995) as an initial diagnostic feature (Figure 7), we have identified a total of 183 ring tumuli so far, which increases to 276 potential stone funerary monuments when we include tumuli-like stone features lacking an outer ring.

These features differ in size and shape from suggested funerary monuments in the western Adrar region of Mauritania, which tend to comprise low-level heaps of stones and a rectangular plan (Gauthier, 2015), as well as potential rectangular funerary features found in association with rock art at the Guilemsi Ridge in the Tagant, approximately 50 km north of Tidjikja (Challis et al., 2005).

The spatial distribution of funerary monuments in the region was unreported in distribution maps, although Ould-Khattar (1995) mentioned the existence of at least one major cluster around site T172 (the precise location of which remains undetermined): *C'est dans la zone située au Nord de ce monument et les hauteurs voisines que se situe la majorité des monuments funéraires, nous en avons décompté une cinquantaine sans avoir été exhaustif*. (Ould-Khattar, 1995, p. 124 [Translation by the author: Most funerary monuments were found in the area located to the North of this monument and the neighbouring uplands, numbering around fifty without this being comprehensive.]).

Indeed, the local densities and degree of clustering of the Dhar Tagant monuments are noteworthy (Figures 8–10).

To ascertain quantitatively the typological nature of ring mound funerary monuments, we undertook multivariate statistical analyses. Based on the KMO factor adequacy test values (overall value = 0.74), we selected the following variables: inner tumulus diameter (0.69), ring diameter (0.68), ring circular symmetry (0.82) and deviation of central feature alignment (0.83). Bartlett's correlation matrix test yielded a statistically significant result (p value = 1.216404e-44), demonstrating that the resulting dataset was conducive for our research purposes.

The Mardia multivariate normality test confirmed that the PCA values had a non-normal distribution, and therefore, we tested significance through a robust pairwise permutation MANOVA (Table 1). This test confirmed that the composition of Clusters 9 and 14 were significantly different from all other spatial clusters.

The differences between these funerary monument clusters are visually represented through a PCA (Figure 11). The results can be interpreted through a combination of the PCA factor map and visual examination of satellite imagery.

The funerary monuments of Cluster 9 are generally more elongated and asymmetrical and are located on a slope above a relatively large drystone settlement (Figure 12), whereas the funerary monuments of Cluster 14, at the entrance of the Taskast wadi, are smaller and more symmetrical. In our view, the funerary monuments of Cluster 9 do not readily fit either type described by Ould-Khattar (1995), whereas those from Cluster 14 do perhaps fit well with Ould-Khattar's monument type on the right side of Figure 7, although a definite attribution would require ground verification. Given the lack of regional parallels for comparative contextualization, without ground verification and systematic dating, it is difficult to interpret whether the unusual morphometric nature of Cluster 9

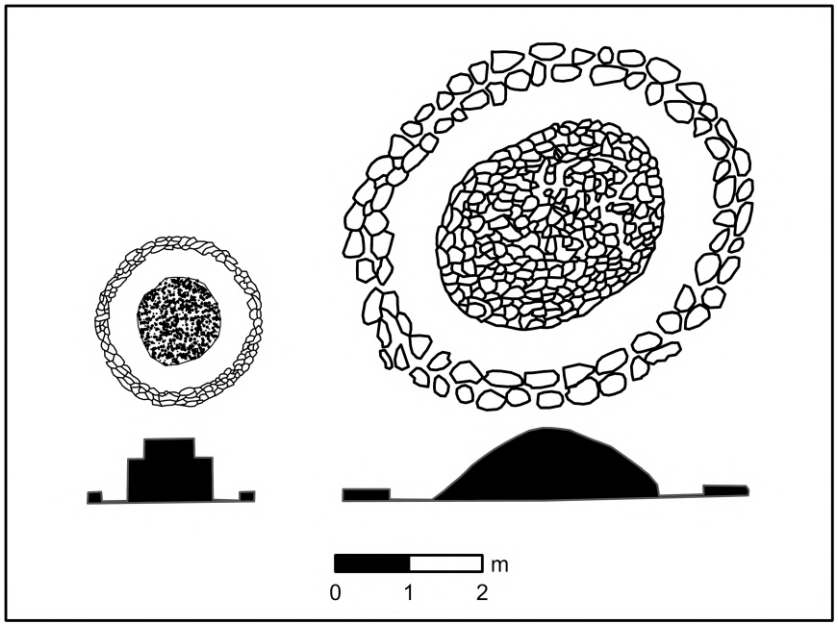


FIGURE 7 Two types of prehistoric funerary monuments in the Dhar Tagant region of south-eastern Mauritania (vectorized after Ould-Khattar, 1995, fig. 35)

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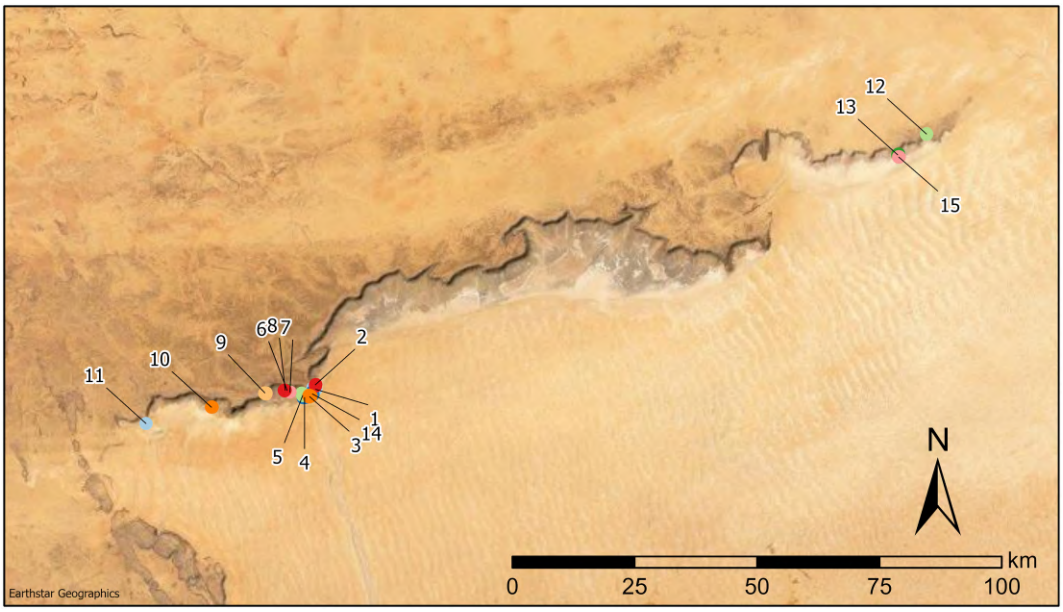


FIGURE 8 Distribution of funerary monument clusters along the Dhar Tagant region [Colour figure can be viewed at wileyonlinelibrary.com]

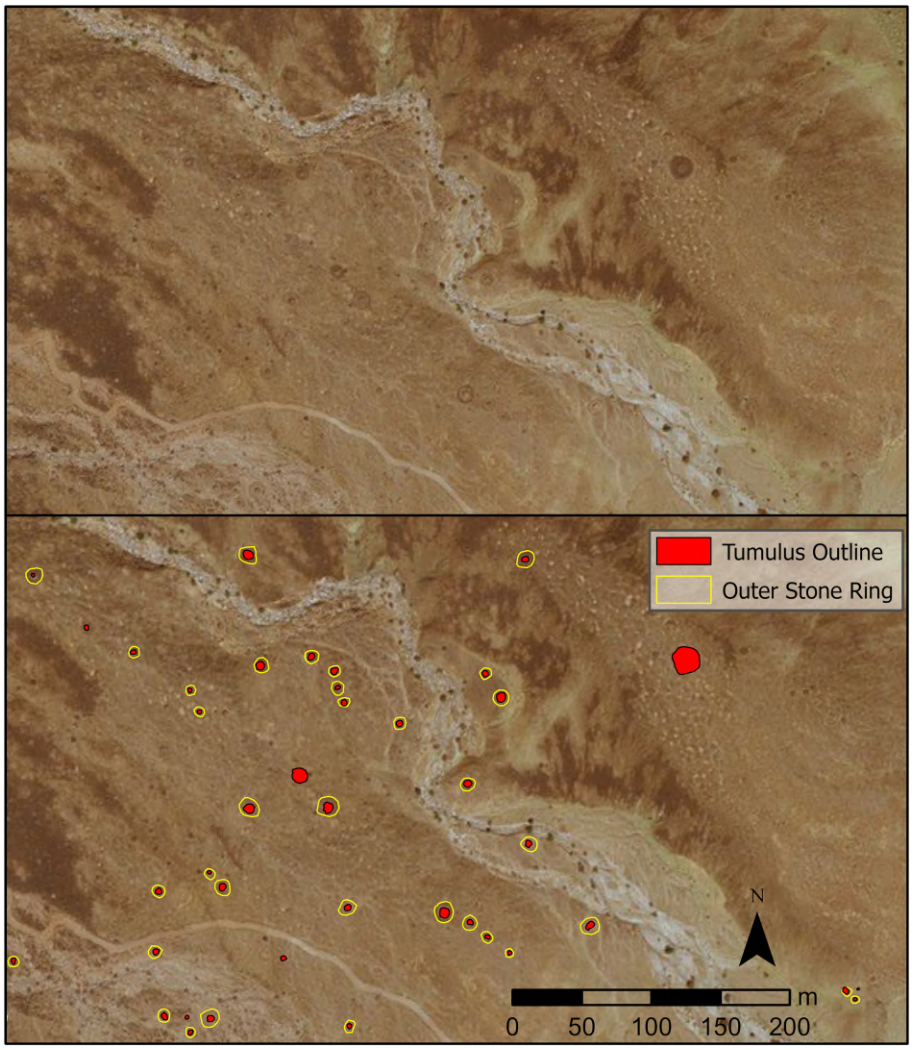


FIGURE 9 Satellite view of several ring tumuli from Cluster 1, at the entrance of the Taskast wadi (Dhar Tagant) [Colour figure can be viewed at wileyonlinelibrary.com]

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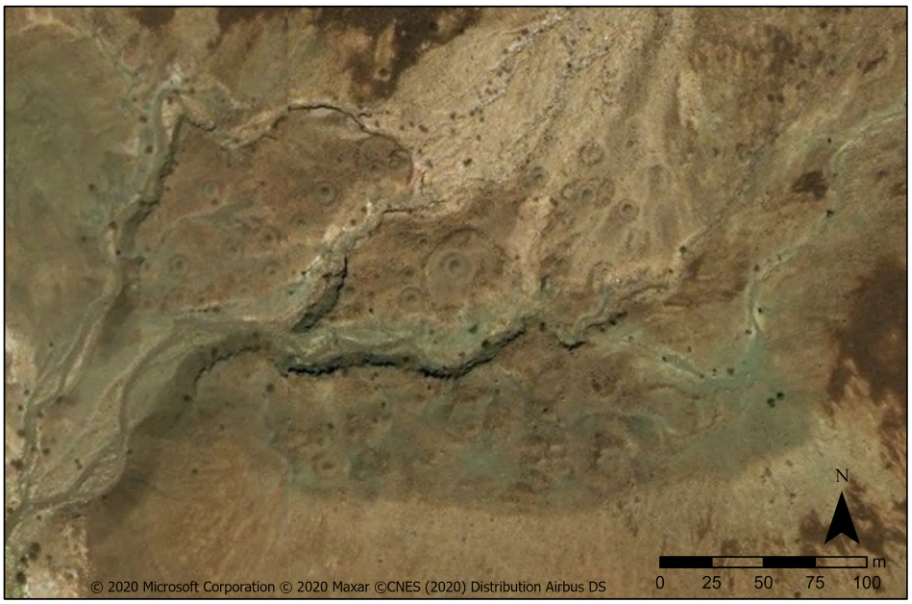


FIGURE 10 Satellite view of Tumuli Cluster 8 from Dhar Tagant. Note the presence of additional enclosures around some of the central ring monuments [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Pairwise comparisons of principal component analysis (PCA) coordinate data by funerary monument cluster using permutation MANOVAs (test: Wilks, 999 permutations)

Pairwise comparisons using permutation MANOVAs						
Cluster ID	**1**	**4**	**5**	**8**	**9**	**13**
4	0.966					
5	0.091	0.215				
8	**0.035**	0.316	**0.032**			
9	**0.001**	**0.001**	**0.001**	**0.001**		
13	**0.007**	0.305	0.378	0.388	**0.001**	
14	**0.005**	**0.002**	**0.002**	**0.001**	**0.001**	**0.023**

Note: Statistically significant *p* values (<0.05) are in bold.

monuments is a result of their chronology, specific cultural considerations or their topographic location.

The highest concentration of funerary monuments (49.6%, n = 135) can be found within 15 km^2 near the origin of the Taskast wadi. The Taskast wadi (Oued Taskast) defines an important part of the boundary between the regions of Assaba and Hodh el Garbi, and it still is the main axis of mobility across the Hodh basin (see Figure 3). We have selected this place as our focus area for undertaking detailed visibility analysis (Figure 13), based on its historical significance for human mobility across the landscape and the degree of monument clustering documented. Our cluster-based and cumulative reflective viewsheds (Figures 14 and 15) indicates that people approaching the entrance of the wadi along the base of the escarpment slopes would have seen these funerary monuments, and the central clusters (2–5)

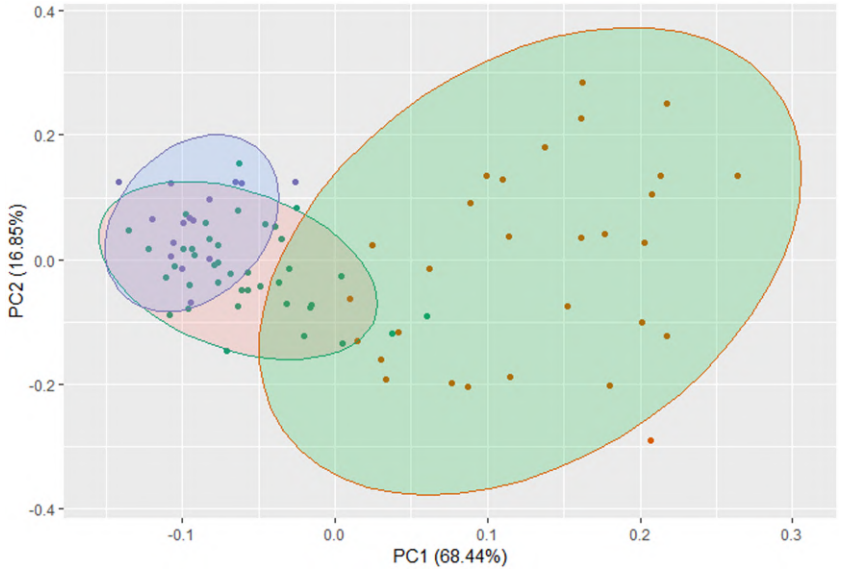


FIGURE 11 Principal component analysis for funerary monument clusters in Dhar Tagant. PC1 and PC2 (shown here) explain 82.88% of the variance in the dataset. The legend numbers represent our Cluster ID assignation. Cluster 1 stands as representative of all those which were not statistically different from it, as a way to simplify the graph [Colour figure can be viewed at wileyonlinelibrary.com]

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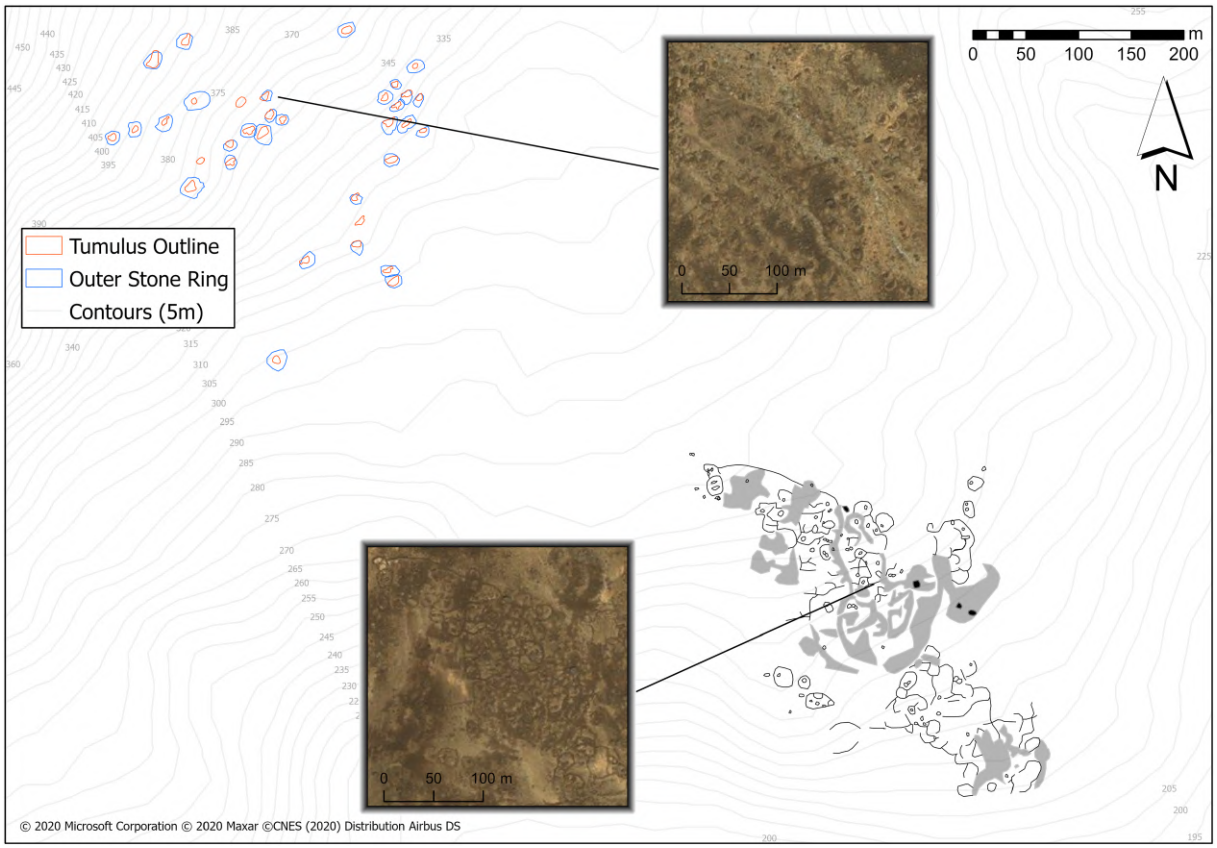


FIGURE 12 Cluster 9 funerary monuments in their landscape context. Note their position on the slope above a sizeable settlement (7.7 ha) that morphologically resembles those of the Tichitt Tradition [Colour figure can be viewed at wileyonlinelibrary.com]

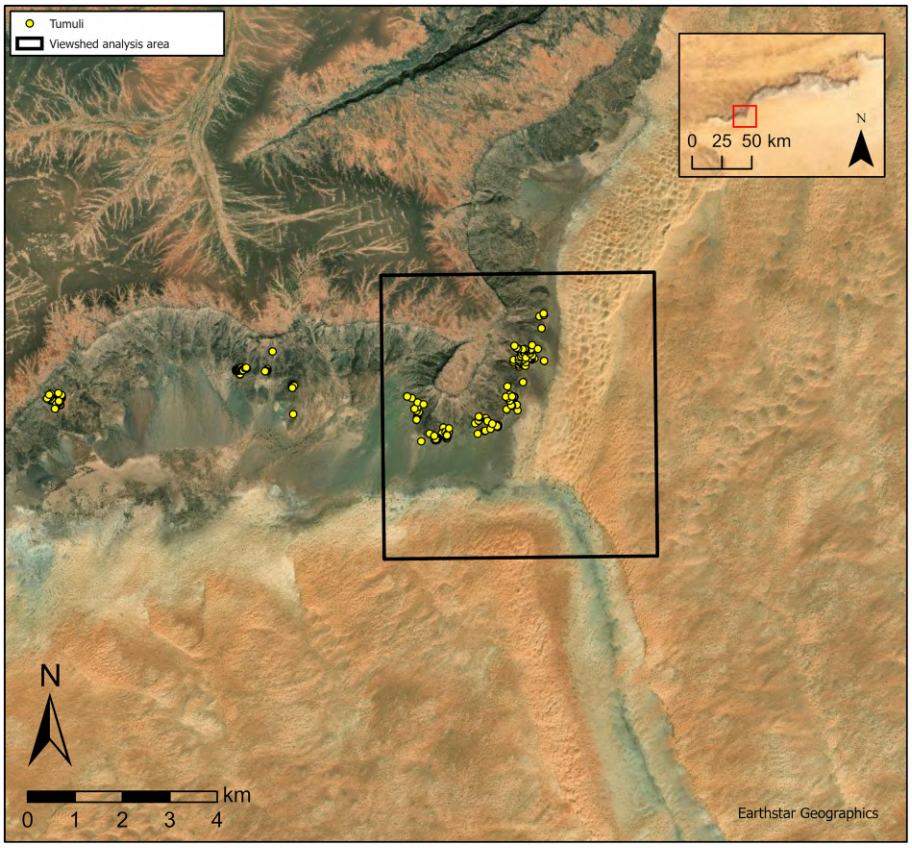


FIGURE 13 Satellite imagery showing our viewshed analysis area in the Upper Taskast wadi (Dhar Tagant) [Colour figure can be viewed at wileyonlinelibrary.com]

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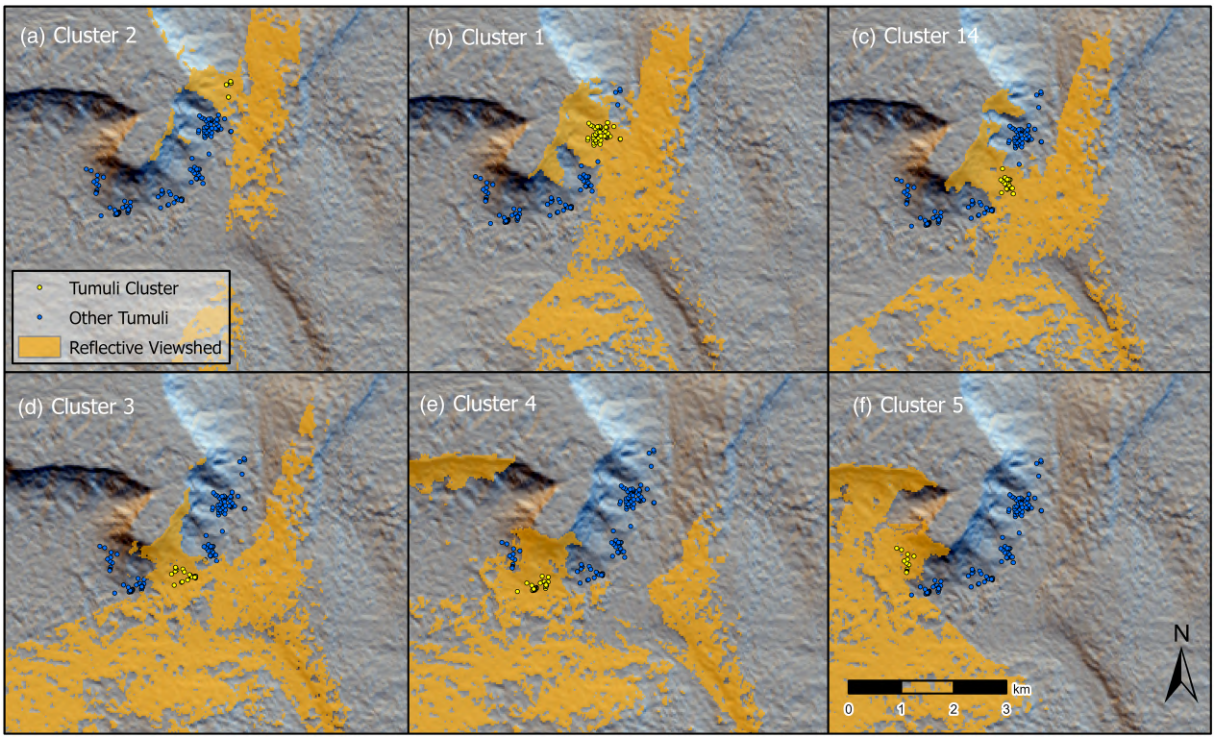


FIGURE 14 Mosaic of reflective viewshed analyses for the different funerary monument clusters at the entrance of the Taskast wadi [Colour figure can be viewed at wileyonlinelibrary.com]

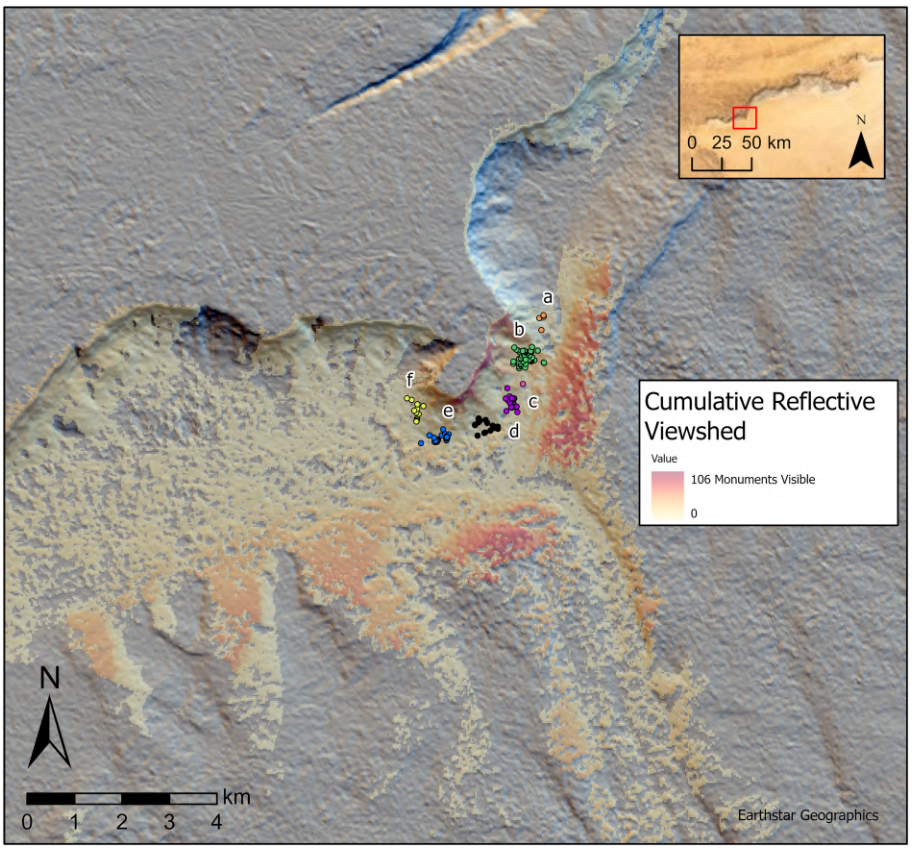


FIGURE 15 Cumulative reflective viewshed of the totality of funerary monuments at the entrance of the Taskast wadi. On the left: local satellite imagery for visual reference; on the right: cumulative reflective viewshed on a hillshade DEM visualization. For an association between ID keys (a–f) and cluster number, see Figure 14 [Colour figure can be viewed at wileyonlinelibrary.com]

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would have been visible also as people approached the escarpments from the wadi itself. The relevance of visibility and topography in the constitution and significance of funerary monuments in the wider MENA region is most prominently illustrated by the hundreds of Nabatean rock-cut tombs found in the hinterland of Petra, Jordan (Wadeson, 2012). At the same time, it is also worth noting that no single spot in the Taskast landscape was able to visualize all 135 funerary monuments. Interestingly, due to the rugged topography of the slope created by intersecting wadis, none of the funerary clusters exhibit any degree of intervisibility, which means that they are not visible from one another. Although the relevance of the monuments themselves seems clear, it is however unknown whether any of these individual monument clusters, determined through spatial statistics, held any particular sociocultural significance. In settlement contexts, exclusionary nonmutual viewsheds have previously been used to suggest political autonomy or territoriality (Lambert, 2002; Lock & Harris, 1996), and we aim to explore this sociopolitical dimension further in subsequent studies of Late Holocene settlement patterns and funerary landscapes in southern Mauritania.

6 | DISCUSSION: REMOTE SENSING, MONUMENTAL FUNERARY LANDSCAPES AND SOCIAL ORGANIZATION IN SEMI-ARID ENVIRONMENTS

The interdependent relationship between the physical configuration and asymmetries in the social constitution of places is a central dimension in contemporary African archaeology (Klehm & Gokee, 2020; Wynne-Jones & Fleisher, 2015), and remote sensing can decisively contribute to this discussion through the large-scale study of settlement patterns and monumental funerary landscapes. The use of remote sensing for the study of monumental funerary landscapes in semi-arid landscapes is indeed growing in popularity, because technological advances are enabling detailed spatial analyses at unprecedented rates and scales: a recent paper details the application of computational machine learning methods automatic delineation of Khirgisuur stone burial monuments in Mongolia (Monna et al., 2020), whereas an ongoing project combining light aircraft remote sensing and fieldwork aims to document the Bronze Age and Nabatean funerary landscapes around the Al Ula wadi of northern Saudi Arabia (Smith, 2019).

Large clusters of funerary monuments developing over considerable time periods represent permanent and deeply rooted ancestral claims to the land. At the same time, funerary landscapes are particularly active spatial and conceptual locales of social interaction in the negotiation and establishment of cultural identities, along a multiscalar axis of centrality and liminality (Ashmore & Knapp, 1999; Di Paola, 2018; Holm et al., 2009). In south-eastern Mauritania, the nucleation of funerary monuments around Dakhlet el Atrouss has been invoked to stress the sociopolitical and ideological centrality of this site within wider regional settlement hierarchies during the second millennium BC (Holl, 1993; MacDonald, 2015). Most funerary features around this Tichitt Tradition megasite are cairns, a conspicuous element of Levantine and North African prehistory (Bradbury, 2011; Gatto et al., 2019; Gauthier, 2015), with the two largest features being located within two large enclosures that form part of the settlement layout, whereas most are found on the flat plateau to the north of the site and the surrounding escarpment slopes. The largest prehistoric settlement identified in Dhar Tagant (approximately 30 ha) also features a single ring tumulus feature within the walled area (Ould-Khattar, 1995), and another one in the immediate vicinity. In Morocco, south of the Atlas Range, the pre-Islamic site of Jabal Bouïa is also considered a central place, with the settlement overlooking a large necropolis and the surrounding plain (Bokbot, 2019; Margat & Camus, 1959). In a similar fashion, albeit at a considerably larger scale, the monumental funerary landscapes of Bahrain during the Early Dilmun I-II period (ca. 2200–1800 BC), studied through extensive aerial surveys and large-scale excavations, show increasing nucleation around the royal cemetery of A'ali, mirroring processes of sedentarization, vertical hierarchization and centralization taking place in settlements for the living (Højlund, 2007; Højlund et al., 2008; Kveiborg, 2007; Laursen & Johansen, 2007; Laursen, 2008; Magee, 2014, p. 164).

Nonetheless, the monument clusters around the Taskast wadi examined through satellite imagery do not exhibit a close spatial association with medium or large settlements (>3 ha). A lack of association between spaces of the living and funerary landscapes has also been documented for the tumuli fields in Pays Dô, interpreted as persistent focal points in the sacred landscape of the 12 Dô villages, integrated ideologically through ritual practices associated with an interconnected network of shrines (MacDonald et al., 2018). Similarly, the Senegambian tumuli fields along the River Gambia (Sine Ngayène, Wanar, Wassu and Kerbatch), encompassing over 1500 years of human funerary practices and statecraft practices, lack associated settlements despite comprehensive ground surveys (Bocoum, 2000; Gallay et al., 1982; Laporte et al., 2012). The investment of wealth and labour involved in the construction of large earthen mounds and megalithic monuments is considerable, as these sites contain over a thousand funerary monuments, combining earthen mounds and almost a hundred stone circles made of carefully worked laterite pillars (Gallay, 2006; Holl et al., 2007; Laporte et al., 2012; Ozanne, 1965; Thilmans et al., 1980). This pattern indicates a degree of social stratification in the wider Senegambia region, whose geographical positioning may have allowed these agricultural communities to control the flows of valuable mineral resources, such as iron and gold (Posnansky, 1973, 1982). These extensive monumental funerary landscapes appear to have acted as catalysts of identity and belonging by virtue of their cosmological centrality in their respective socioeconomic systems.

At the same time, societies with a strong pastoral component experience seasonal patterns of mobility in search of fresh water and greener pastures, often moving between highland and lowland areas. The earliest occupations of the basalt flow landscapes of the Orontes basin of western Syria by seasonal herding communities are tentatively associated with the arrival of domesticated donkeys to the region during the Chalcolithic and the early Bronze Age (Philip &

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Bradbury, 2010, p. 160). The study of satellite remote sensing data spanning over 50 years (Corona KH4-B and KH7, as well as panchromatic and multispectral Ikonos imagery) and historic aerial photographs led to the identification of hundreds of thousands of potential cairns on the uplands (Bradbury, 2011; Bradbury & Philip, 2011). The passageways that channel these movements tend to act as liminal places, spatial and sometimes contested thresholds between different territories and topographies (Van Gennep, 1909). A particularly dramatic example is Foum Larjam, an extensive protohistoric tumuli field on the Jabal Ben Selmane mountains, extending along the Draa Wadi in central Morocco (Bokbot, 2019; Mattingly et al., 2017).

The Late Pastoral communities (3900–1700 cal. BC) of the Tadrart Acacus region of the central Sahara erected large conical tumuli visible from considerable distances, near passageways, hilltops or steep slopes—rather than on adjacent lowland areas and often away from settlements (di Lernia, 2013). These visual cues marked the existence of 'places to be remembered' (di Lernia, 2006, 2013; di Lernia & Tafuri, 2013), and they may have assisted small livestock transhumance between ephemeral summer camps in the lowlands and specialized winter settlements in upland areas, which offered seasonal refugia under increasingly arid conditions (Cremaschi & di Lernia, 1999; di Lernia, 2006, 2013; Holl, 1998). The largest funerary feature in the Tadrart Acacus landscape is an undated 'keyhole monument' (35 m in diameter) involving a central tumulus and a complex arrangement of enclosing oval rings (di Lernia, 2013, p. 184). Located on a high terrace, it marks the starting point of an important wadi (di Lernia, 2013, p. 184). The spatial context of this monument resembles that of the dense monument clusters documented around the start of the Taskast wadi in Dhar Tagant, which are also visible from adjacent lowland areas, as shown above.

The Taskast wadi represents a reliable route of interaction between the highlands of the Tagant Plateau and the southern Mauritania lowlands that nomadic camel pastoralists still follow to this day (Ould-Khattar, 1995). The bulk of the prehistoric occupation of Dhar Tagant has been linked with processes of aridification during the first millennium BC in the Tichitt-Oualata region (MacDonald, 2015, 2020; Ould-Khattar, 1995), and it is plausible that Late and Terminal Tichitt communities in the Tagant mirrored Late Pastoral groups in their reliance on small livestock over cattle, with greater mobility demands but lower water requirements; nonetheless, further fieldwork involving zooarchaeological research is still needed to confirm the subsistence base of late prehistoric communities in Dhar Tagant. The centrality of the Taskast valley in regional mobility patterns is further evidenced by long-distance connections between the western Sahel and the Islamic communities of northwest Africa through the medieval entrepôt of Tegdaoust, located deep in the Hodh basin (Levtzion, 1985; Mauny, 1961; McDougall, 1985; Robert, 1970). Preliminary visual survey of satellite imagery in the highland areas around Tegdaoust has also revealed the presence of several ring tumuli and standalone conical cairns resembling those at the Dhar Tagant entrance of the Taskast wadi, which further strengthen the degree of socio-economic connectivity and cultural significance of this geographical features to prehistoric and Medieval communities.

The presence of a stone ring around the main body of the cairn, an additional layer of elaboration that enhances the visual appearance of the monument, is a common feature of Dhar Tagant funerary monuments. Similarly, it seems to be a recurrent pattern among Lybico-Berber communities in the central and western Sahara (Gauthier, 2011) and in East Africa, where the relationship between the construction of drystone architectural features and the emergence and spread of pastoralism is particularly strong (Davies, 2013; Hildebrand & Grillo, 2012; Mack & Robertshaw, 1982; Marshall et al., 1984; Wendorf, 1998). At Lokori (south-western Turkana), 167 funerary structures consisting of a central cairn with a ring of standing stones have been documented; the excavated examples show that they cover a burial pit hosting a single individual of varying age and sex but in all cases without associated grave goods (Davies, 2013; Lynch & Robbins, 1978, 1979; Soper & Lynch, 1977). The Laikipia cairns (central Kenya) also seem to have experienced a certain degree of spatial regularity in their distribution, which perhaps indicates some degree of trail marking in addition to their relevance for place making and remembrance of the dead (Lane et al., 2007). The spatio-temporal patterning of pastoral sites and stone-built features appears to indicate novel forms of material engagement with the landscape, as notions such as mobility, memory and territoriality were redefined. With regard to the Dhar Tagant landscape, it appears that the Late and Terminal Tichitt phases involved some degree of political decentralization in comparison with the socio-economic hierarchies documented for the Classic Tichitt in Dhar Tichitt-Oualata (Holl, 1993; MacDonald, 2020; Munson, 1971). The considerable clustering of funerary monuments at the entrance of the Taskast wadi, a liminal location in relation to the main walled settlements in Dhar Tagant, appears to hint at higher seasonal mobility requirements by the communities of the late first millennium BC and the early first millennium AD in the region.

Future collaborative engagement with local communities in southern Mauritania may offer ways to better understand and complement interpretations of the ecogeographical significance of the distribution patterns of settlements, rock art locales and/or visually prominent funerary monuments, even in the absence of cultural continuity. For example, the Joint Hadd Project in eastern Jalan (Oman) has highlighted the depth of the vernacular geographical knowledge of local Bedouin collaborators and how the representation of space delineated through the distribution of Early Bronze Age collective burials in the region resembles the distribution visual cues that nomadic Bedouins use to orientate themselves as they move through this arid region (Giraud & Cleuziou, 2009). Indeed, integrating remote sensing approaches with local landscape knowledge networks is proving a very successful approach across a wide range of environments (e.g., Davis et al., 2020; Lim et al., in press) and is well on its way to become a standard ethical practice in archaeology.

7 | CONCLUSIONS

Monumental funerary landscapes are palimpsests of memory. In the West African Sahel and beyond, they represent a commemoration of

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belonging, identity and authority through reference to ancestors, while simultaneously comprising a range of conspicuous visual cues that guide the lives and movements of the living. In semi-arid environments, these material manifestations of mortuary practices contributed to the creation of place, shaping the roots of identity among sedentary agricultural societies and providing visual cues to assist and channel the movements of seminomadic pastoralist groups through the landscape. In Dhar Tagant (south-eastern Mauritania), funerary monuments are usually located on visually prominent areas, often along communication routes, but unlike the isolated monuments in the Tadrart Acacus, they also exhibit a high degree of clustering—particularly near the entrance of the Taskast wadi. Their liminal position, at the entrance of this interregional pathway but separated from the main walled settlements in the area, is in stark contrast with the pattern documented around Dakhlet el Atrouss. These differences may be potentially suggesting more decentralized and more actively negotiated socio-economic and political landscapes during the Late Tichitt phase in the Dhar Tagant. Forthcoming research into the nature and distribution of settlement sites in the region will elucidate further the significance of the patterns of land use and memorialization reflected by the funerary monuments in the region.

Our research is part of consolidated and emerging projects aiming to monitor endangered heritage at a pan-regional scale, particularly in areas of limited accessibility on the ground, with an explicit focus on regional training to facilitate the research initiatives of local archaeologists and international collaborations (Fisher et al., 2021; Rayne et al., 2017). Postcolonial archaeological research should be proactive and decentralizing, starting by exploring the implications and purposes of what we do, and the way we do it, taking into account whose heritage is being interpreted. Ethical remote sensing research ought to promote the collaborative use of accessible datasets that maximize cross-platform portability and knowledge sharing, as it will provide invaluable assistance towards informing heritage protection and planning policies. Remote sensing research could therefore be seen as an opportunity to contribute responsibly to the development of more nuanced versions of the African past, in ways that highlight the innovativeness and resilience of local resource management strategies in the context of climate change, challenging entrenched and overtly negative stereotypes about the African past, present and future (Giblin et al., 2014; Smith, 2014).

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The ArcPy and R Scripts for Processing Tumuli Geometric Data in Mauritania, which we applied to Dhar Tagant funerary monuments in the present paper is openly accessible from the Oxford Research Archive (ORA): https://doi.org/10.5287/bodleian:eXk1YngGB.

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ORIGINAL ARTICLE

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 qui reposaient 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

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centre régional, avec près de 600 enceints formant une un 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 peuvent nous renseigner sur l'étendue de la différenciation 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 richesse 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 méthodes 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 Lorenz et des coefficients de Gini dans la préhistoire africaine et illustre un degré considérable de différenciation spatiale et socio-économique à Dakhlet el Atrouss I.

Introduction

The origins and development of inequalities associated 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 context of southern Saharan prehistory (although see MacDonald, 2020). In southeastern Mauritania, the second millennium BC witnessed the emergence of complex agropastoral societies in Tichitt-Oualata escarpments (MacDonald, 2013; Munson, 1971). These communities 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 monumental 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 econometric methods, particularly the Gini Coefficient, offer an avenue for assessing socio-economic differentiation 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), primarily as reflected in asymmetries in living space area but it can also be computed by including the size and number 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 participation of multiple members in the decision-making process. This kinship-based institution is fluid and flexible, 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 village of Be on the Mayo Kébbi river (northern Cameroon), 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 habitation 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 unit 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

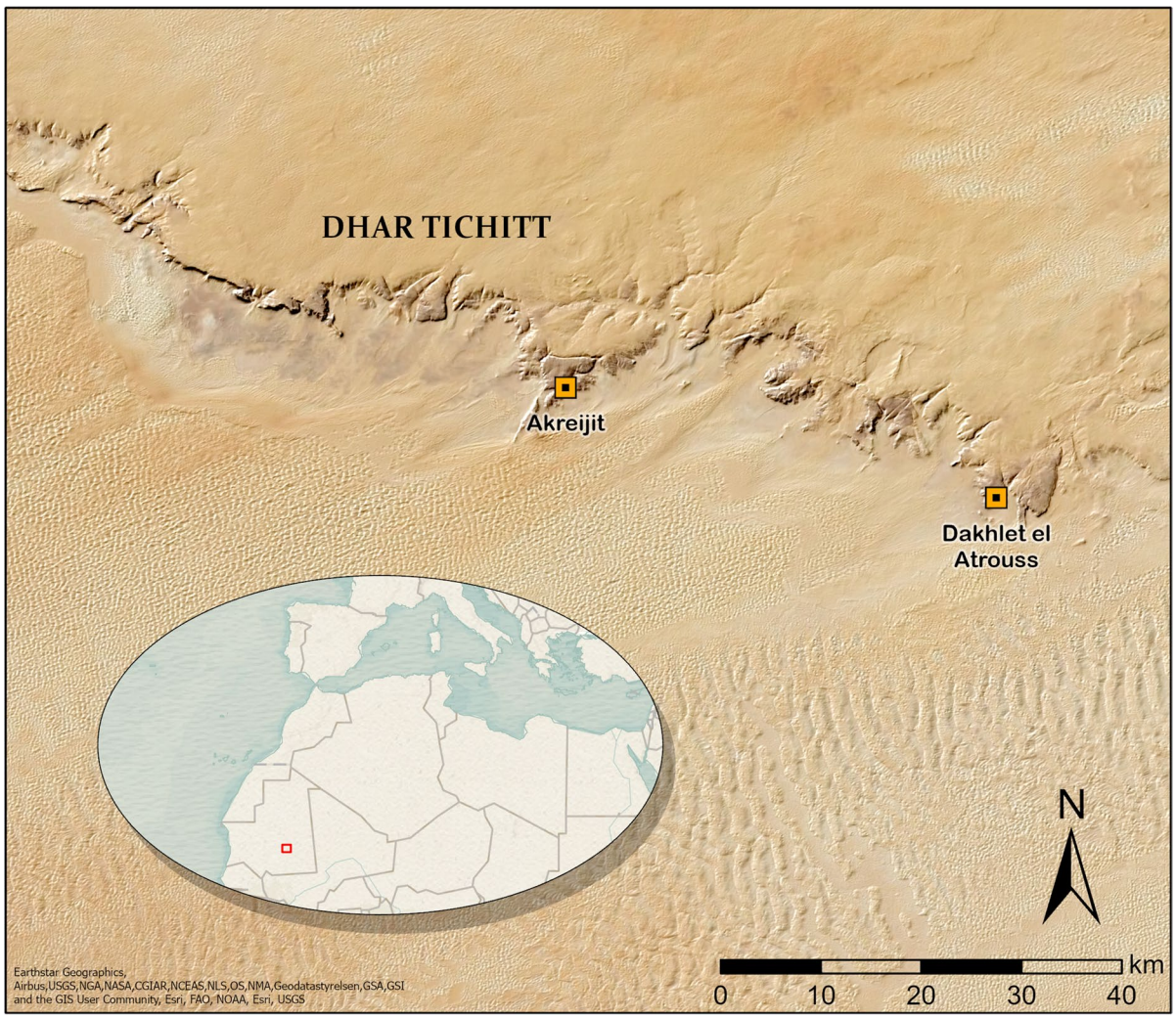


Fig. 1 Dhar Tichitt (southeastern Mauritania) with the location of Dakhlet el Atrouss and Akreijit, the two main archaeological sites discussed in the text

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 *décrue* farming (Amblard-Pison, 2006). *Décrue* 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

Table 1 Brief summary of the archaeological sequence of the Tichitt Tradition, southeastern Mauritania, after MacDonald (2015, 2020) [In brackets, the original terminology devised by Munson (1971)]

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/Akjinjeir 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 stonewalled settlements in the Tagant region with evidence of iron metallurgy

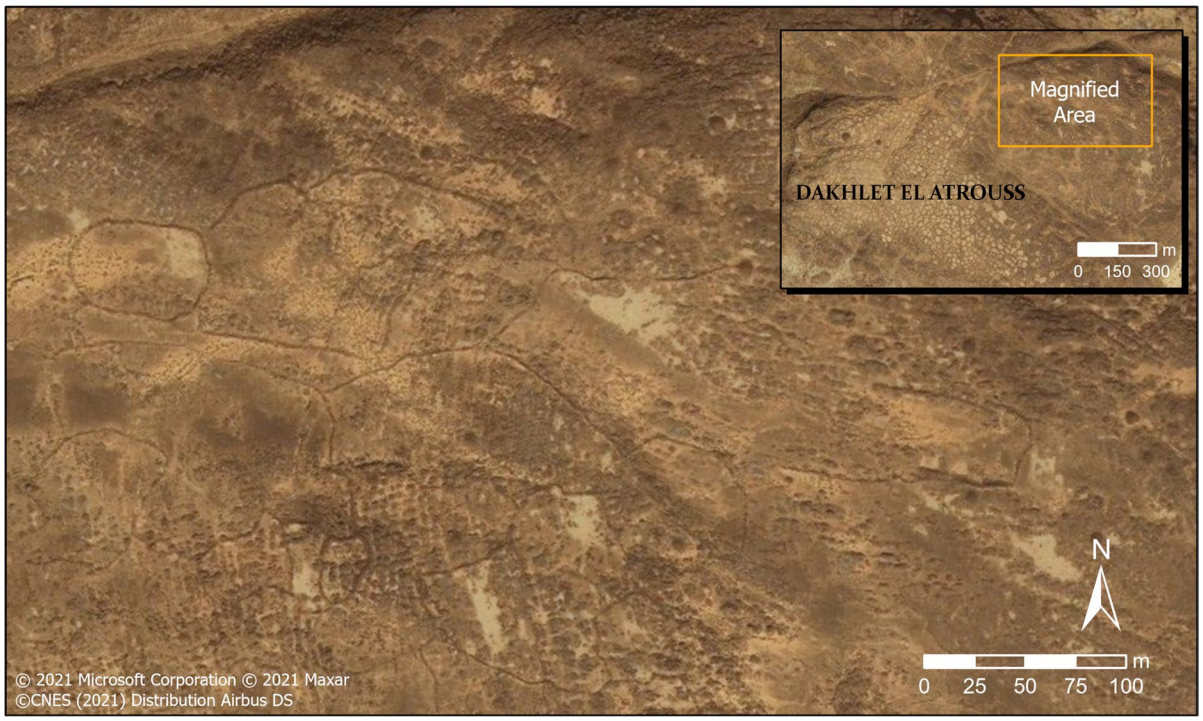


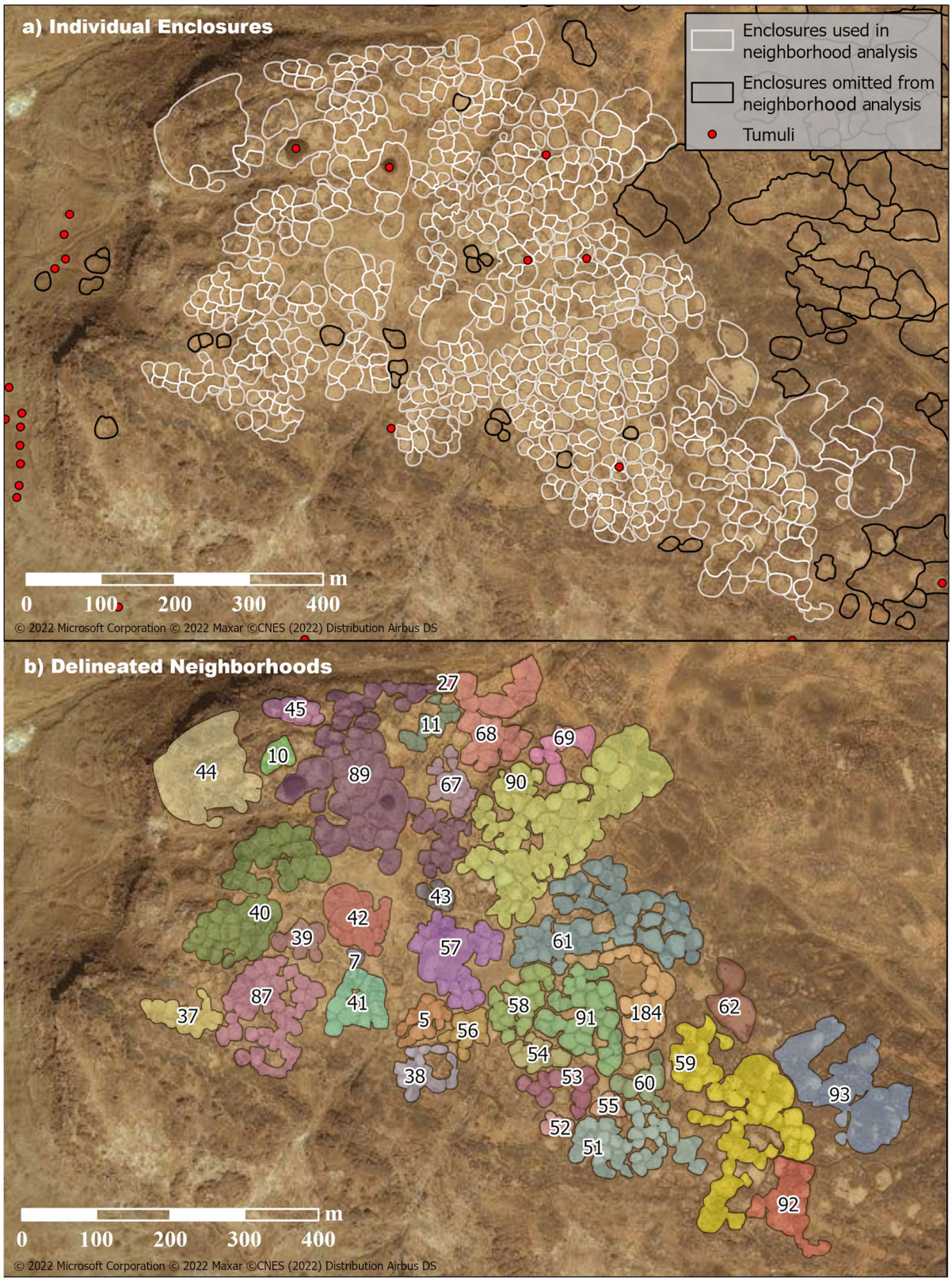
Fig. 2 Large enclosures on the periphery of Dakhlet el Atrouss (Note the scattered presence of some funerary tumuli north of the enclosures. These monuments further highlight the cultural relevance of the Dakhlet el Atrouss landscape)

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


a) Individual Enclosures
Enclosures used in neighborhood analysis
Enclosures omitted from neighborhood analysis
Tumuli
m
0 100 200 300 400
© 2022 Microsoft Corporation © 2022 Maxar ©CNES (2022) Distribution Airbus DS
b) Delineated Neighborhoods
27
45
11
68
69
10
44
89
67
90
43
40
42
39
57
61
7
87
41
37
5
58
91
184
62
56
54
59
38
53
60
93
55
52
51
92
m
0 100 200 300 400
© 2022 Microsoft Corporation © 2022 Maxar ©CNES (2022) Distribution Airbus DS

◂**Fig. 3** Visual representation of the analytical tool employed to generate compound neighborhood clusters

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 orthorectified 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 m^2) is considerably larger than that of the second-largest enclosure (3881.137m^2), 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

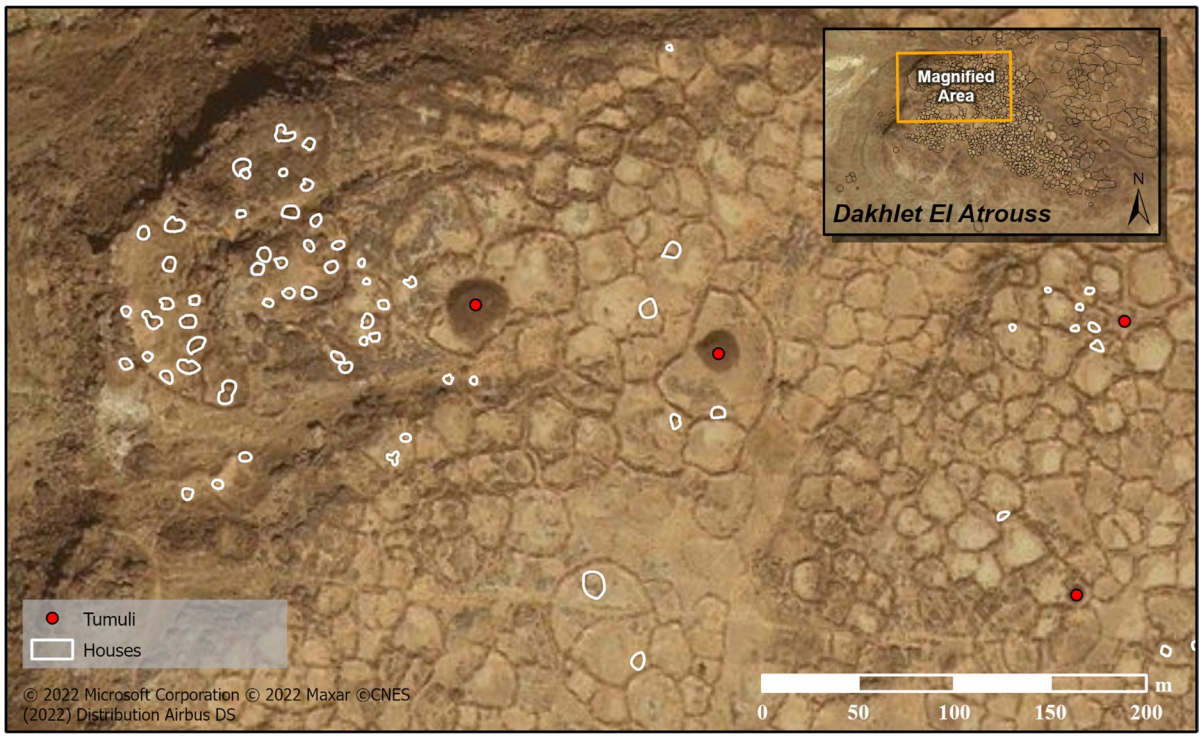


Fig. 4 Western peripheral enclosure with individual stone houses (Note the presence of two very large funerary tumuli, the largest in the region. They have been suggested to represent collective burials, which could suggest the existence of lineage-based sources of status or authority)

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

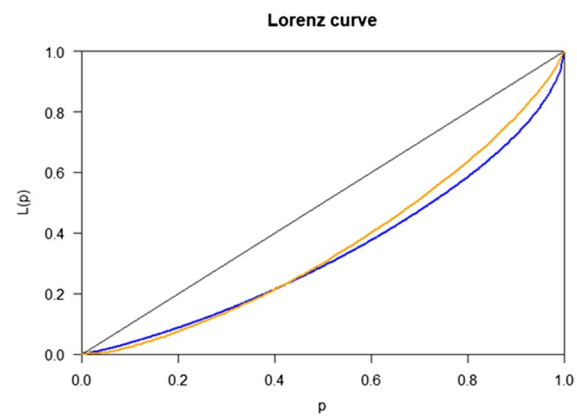


Fig. 5 Lorenz Curve illustrating the distribution unevenness values of Dakhlet el Atrouss I (in blue) and Akreijit (in orange). The greater divergence of the blue curve from the theoretical line of equality indicates a larger degree of unevenness, and, by extension, a larger Gini coefficient value, for 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 northernmost 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

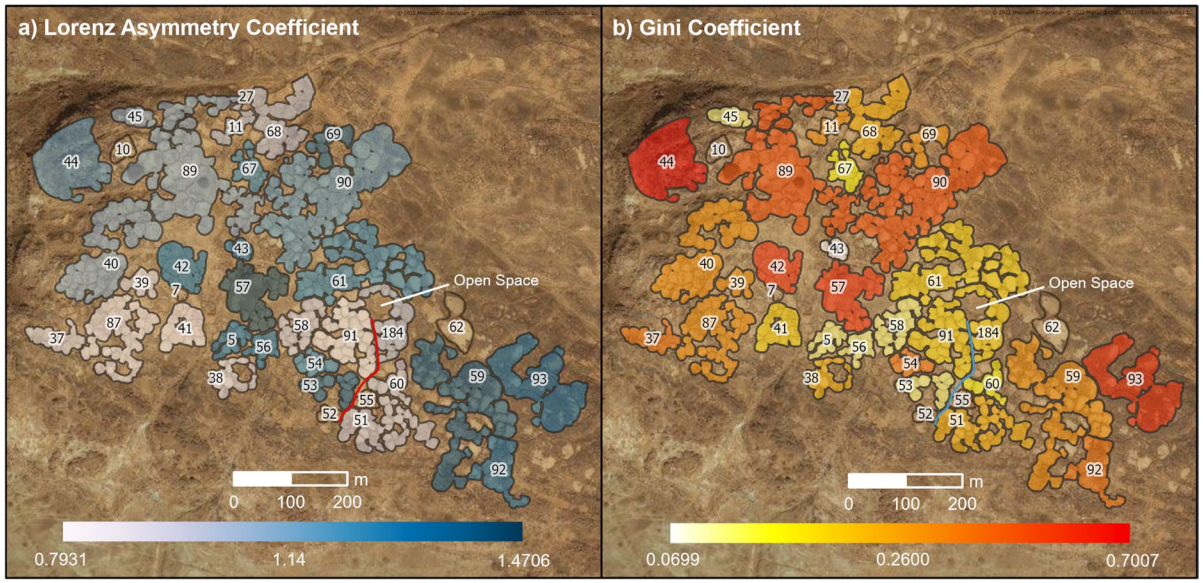


Fig. 7 Spatial representation of Lorenz Asymmetry Coefficient and Gini Coefficient values at the neighborhood level for the large Dhar Tichitt site of Dakhlet el Atrouss I, southeastern Mauritania

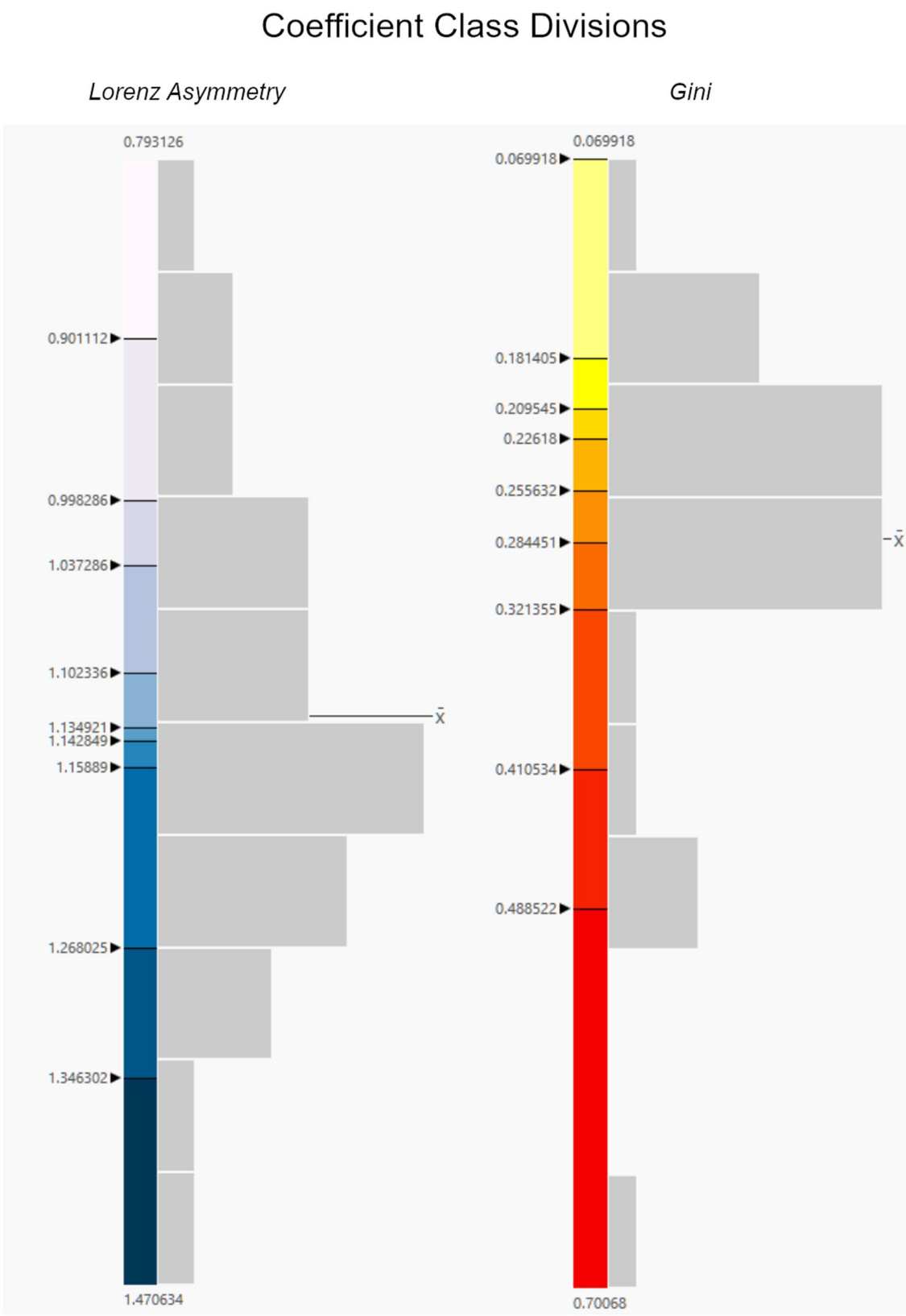
Akreijit (Holl, 1986; Vernet, 1993), some degree of value inflation due to time averaging may appear in archaeological applications of Gini coefficient values (Kohler & Higgins, 2016).

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 differentiation (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 Méma 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 socio-economic 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
0.793126
0.901112
0.998286
1.037286
1.102336
1.134921
1.142849
1.15889
1.268025
1.346302
1.470634
x̄
Gini
0.069918
0.069918
0.181405
0.209545
0.22618
0.255632
0.284451
0.321355
0.410534
0.488522
0.70068
x̄

◂**Fig. 8** Histogram outlining the quantitative distribution of neighborhood class divisions on the basis of Lorenz Asymmetry and Gini Coefficients, alongside a visual representation of the subdivisions generated by the Jenks natural breaks optimization algorithm

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 Atrouss 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).

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	0.2806087	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	0.2232436	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	0.2844506	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	1.222208	10	596.2	476.5	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

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

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

Table 4 Contextual information of Gini Coefficient values for a range of settlements from around the world (Data obtained from Kohler et al. (2017), Supplementary Table 2)

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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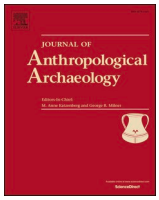
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Memory, agency, and labor mobilization in the monumental funerary landscapes of southeastern Mauritania, West Africa

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ABSTRACT

The archaeological record of southeastern Mauritania has considerable potential to contribute to longstanding anthropological debates in world prehistory, such as early cereal domestication or the emergence and organization of complex societies, although research remains limited. The archaeological study of funerary rites offers invaluable insights into cultural attitudes towards the dead and the socio-economic dynamics of the living. The materiality of remembrance is a political statement, rooted on the ability of different social agents to mobilize labor pools and networks of obligations within a given cultural framework. As such, understanding the spatial distribution and size variability in burial monuments within funerary landscapes provides insights into the social energetics of ancestor memorialization. To that end, this paper first presents a size-based classification system for pre-Islamic conical tumulus cairns in the highlands of southeastern Mauritania, West Africa, that has much wider applicability within prehistoric Saharan archaeology. Through the first application of Gini coefficients to the study of funerary landscapes, the paper then analyses the spatial distribution and degree of monument size variability within large, spatially bounded clusters ("tumulus fields") in Dhar Tichitt in order to contextualize the socio-economic dynamics of labor mobilization at three previously undocumented tumulus fields in the western Tagant Plateau.

1. Memory, agency, and labor in prehistoric funerary landscapes

The relationship between the living and the dead is central in the constitution of the social universe for many human societies, including in Africa, a continent with a sheer diversity of cultural practices and funerary behaviors (Gluckman, 1937; Evans-Pritchard, 1949; Goody, 1962; Fortes, 1965; Bloch, 1971; Thomas, 1982; Metcalf and Huntingdon, 1991; Lee and Vaughan, 2008; Insoll, 2011).

Places of burial act as loci of meaning and memory, as well as locales of dynamic social interactions and renegotiations of status and identities (Parker Pearson, 1993; Chouin, 2002; Van Dyke and Alcock, 2003; Kankpeyeng et al., 2013; Dueppen, 2022). These processes recognize the agency and power of ancestors (Helms, 1998), while granting a considerable degree of political capital to those among the living who claim descent from them and, in consequence, associated rights to land or other resources (Saxe, 1970; Goldstein, 1976; Renfrew, 1976; Tainter, 1976; Chapman, 1981; McAnany, 1995; Hill and Hageman, 2016).

In this context, the construction of large funerary tumuli entails a considerable degree of social energy investment, with the scale of labor networks reflecting to a large extent the aggregate of relationships between people recognizing a responsibility towards the deceased or their corporate lineage (Binford, 1971; Tainter, 1976; Hildebrand et al., 2011; Scarre and Laporte, 2015; Zena, 2021). These elaborate burial customs constitute fundamental mechanisms both for coping with mourning among the living (Malinowski, 1925) and for bestowing ancestor status on the deceased through the social acknowledgement of their authority before and after death (Fortes, 1965; Da Costa, 2014; Insoll, 2016; Dueppen, 2022).

The materiality of monumental funerary practices provides us with an opportunity to explore the distribution, spatial configuration, and size of burials using remote sensing methods. These non-invasive approaches are becoming an increasingly popular avenue of undertaking large-scale archaeological surveys (Parcak, 2009; Lasaponara and Masini, 2012; Davis and Douglass, 2020), especially in the context of fieldwork restrictions due to security concerns or recent pandemic-related travel bans. Exponential advances in the quality of freely available satellite imagery platforms, such as Bing Maps or Google Earth, which now provide comprehensive coverage of most regions in the world, have further reduced associated survey costs (Rayne et al., 2017; Linares-Matás and Lim, 2021). The hypervisibility of stone tumuli in aerial images from arid ecosystems, such as the Saharo-Sahelian ecotone, offers an ideal avenue for documenting and analyzing funerary landscapes using remote sensing methods (Gauthier, 2015;

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Biagetti et al., 2017; Rayne et al., 2017; MacDonald et al., 2018; Costanzo et al., 2021; Linares-Matás and Lim, 2021; Linares-Matás, 2022).

The use of stone tumuli to demarcate human graves in the landscape became a typical dimension of Saharan mortuary architecture from the fifth millennium BC, rapidly spreading southwards and westwards from the Eastern Sahara, until the mid-first millennium AD and the expansion of Islam (Gatto, 2012; Davies, 2013; Sawchuk et al., 2018; Mattingly et al., 2019). In this paper, I analyze a series of spatially bounded monument clusters (henceforth referred to as "tumulus fields") in Dhar Tichitt (southeastern Mauritania) as the basis for a comparative assessment of the newly discovered funerary landscapes of Tabarit, a series of three tumulus fields in the westernmost part of the Tagant Plateau (Figs. 1 and 2). Morphometric data from these large datasets allow the generation of a size-based classification system for simple cairns and funerary tumuli in the southeastern Mauritanian highlands as a whole. This classification system could have a much wider supra-regional applicability in terms of the quantitative characterization of prehistoric funerary landscapes in the Sahara, where these monuments are ubiquitous.

Additionally, the relative placement of tumulus fields in the landscape in relation to settlements and the degree of internal monument size variability may provide insights into the specific nature and socio-political organization of the communities involved in their construction (Posnansky, 1982; Laporte et al., 2012; di Lernia, 2013; Gatto et al., 2019). As such, the study of intra-site spatial distributions and an assessment of Gini coefficient values for each tumulus field enables a preliminary characterization of socio-economic dynamics of memory, agency, and labor within prehistoric funerary landscapes. The spatial and quantitative assessment of labor mobilization networks embedded in the mortuary monuments of southeastern Mauritania may offer invaluable insights into the formation of complex polities, including the origins of the first empires in the West African Sahel.

2. The funerary landscapes of southeastern Mauritania

The escarpments of southeastern Mauritania boast an extensive funerary record. These *dhars*, as they are known in Hassaniya Arabic, encompass the topographical transition between flat uplands, steep slopes intersected by shallow wadis and narrow canyons (*dakhlat*) and interdunal alluvial lowlands (*baten*). During the first half of the twentieth century, this area was occasionally visited by colonial administrators and researchers, who noticed the presence of drystone settlements and tumuli (e.g., Verneau, 1920; Laforgue & Mauny, 1939). The first detailed archaeological fieldwork was conducted by Patrick

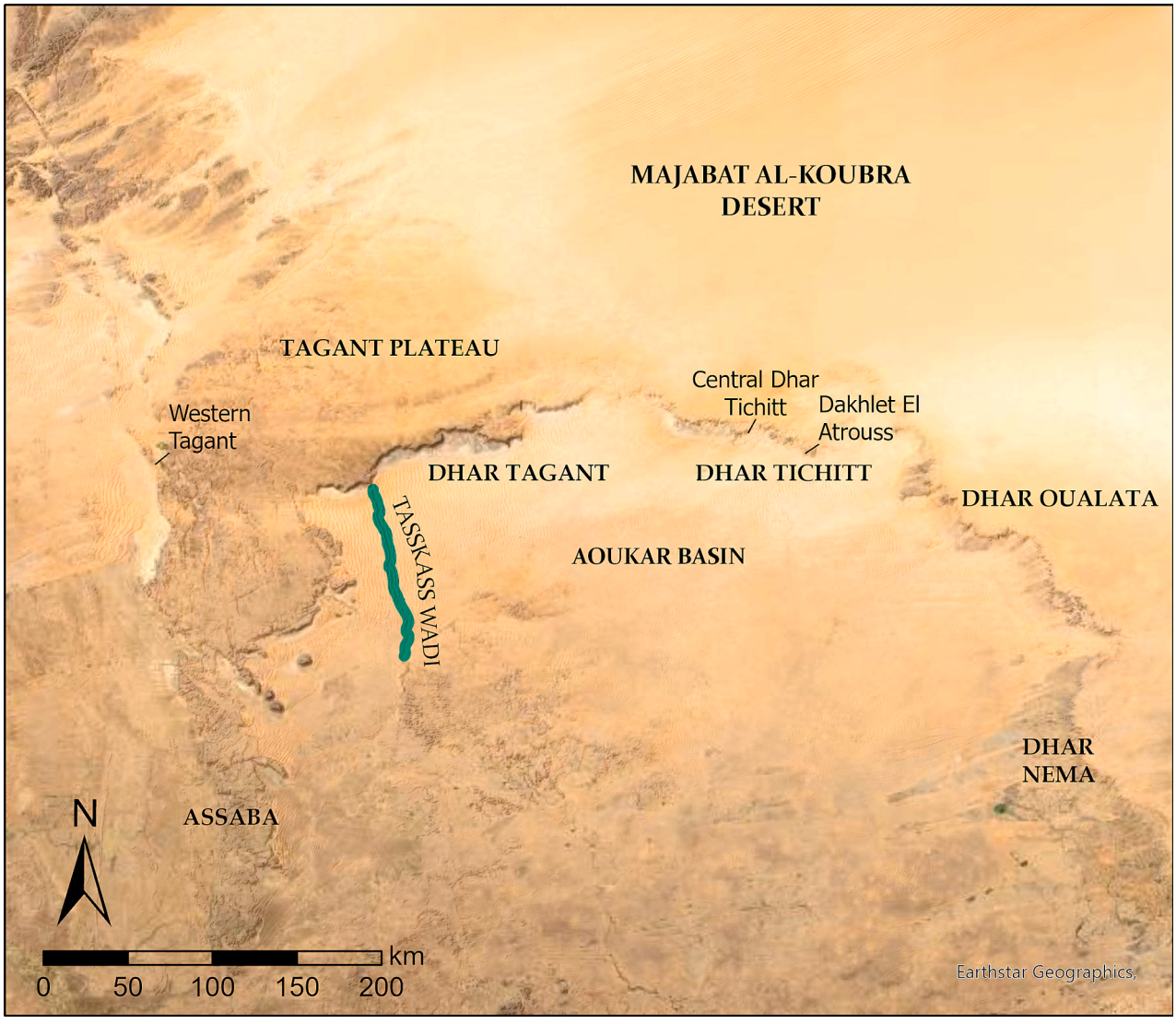


Fig. 1. Map showing the highlands of southeastern Mauritania, including the distribution of the main study areas (Western Tagant, Central Dhar Tichitt, and Dakhlet el Atrouss) chosen for an in-depth comparative analysis of funerary tumulus fields.

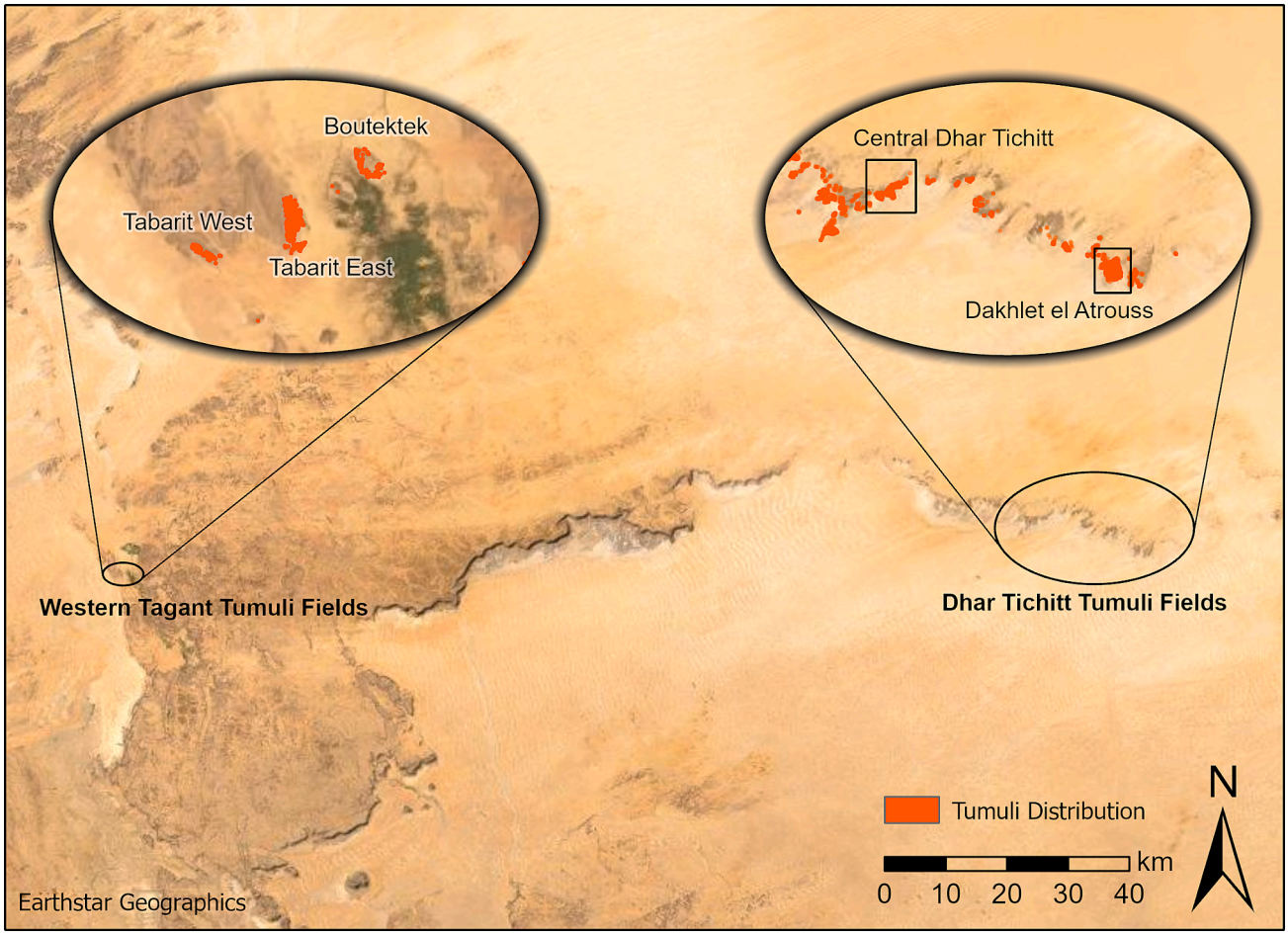


Fig. 2. Distribution of the 5 funerary tumulus fields within the highlands of southeastern Mauritania chosen as case-studies in the present paper.

Munson (1971), who documented the multi-stage settlement sequence of the Tichitt Tradition from the late third millennium BC to the end of the first millennium BC (Table 1), a pattern confirmed by subsequent investigations at Dhar Tichitt and Dhar Oualata (Vernet, 1993; Amblard-Pison, 2006; MacDonald, 2013). Munson (1971) also produced the first archaeological sequence of sub-Saharan crop domestication anywhere in Africa. While the origins of cereal domestication in the southern Sahara have even deeper origins into the third or early fourth millennium BC (Manning et al., 2011; Fuller et al., 2021), southeastern Mauritania remains crucial to understanding the agricultural development of pearl millet (*Pennisetum glaucum*), a cereal of pan-African importance even today.

Table 1
Brief summary of the calibrated archaeological sequence of the Tichitt Tradition, southeastern Mauritania, after Munson (1971) and MacDonald (2015, 2020). While this framework remains the most accepted chronological sequence in the literature, based on data from both radiometric dates and pottery seriation, some authors are reluctant to adopt it on the basis of limitations in the extent of dated intra-site stratified deposits and prefer to treat Tichitt Tradition sites more synchronously in their analyses (e.g., Amblard, 1984; Holl, 2009).

Phase	Chronology	Features
Pre-Tichitt	2600–1900 BCE	Mobile herders and hunter-gatherers living in small temporary campsites.
Early Tichitt	1900–1600 BCE	Initial cultivation of domesticated pearl millet. Considerable degree of mobility.
Classic Tichitt	1600–1000 BCE	Development of vast settlements comprising conjoined clusters of stone-walled compounds.
Late Tichitt	1000–400 BCE	Period of intense aridification and associated demographic decline in the Tichitt-Oualata region.
Terminal Tichitt/ Early Iron Age	400 BCE – AD 200	Development of complex stonewalled settlements in the Tagant region with evidence of iron metallurgy. Greater emphasis on pastoral mobility in some areas.

The existence of spatio-temporal settlement dynamics during the Late Holocene in the southern Sahara is intrinsically linked to climatic fluctuations, with episodes of greater humidity creating novel ecological niches for agro-pastoral communities relying on livestock and pearl millet cultivation, while aridification trends appear to have disrupted local viabilities of certain subsistence strategies (Munson, 1971; Holl, 1985; Vernet, 1993; MacDonald, 2015; Linares-Matás, 2022). 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 that included the exploitation of wild terrestrial and aquatic resources (Holl, 2009; MacDonald, 2015). During the second half of the second millennium BC, the region witnessed an increasing reliance on cultivated crops within a semi-sedentary lifestyle, characterized by chaff-tempered pottery vessels, grinding stones, granaries, lithic arrowheads, and extensive stone-walled settlements articulated around household compounds (Munson, 1971; Amblard-Pison, 2006; Holl, 2009; MacDonald, 2013). Increasing investment in agricultural production may have been an innovative solution to accommodate a growing population in the well-watered landscapes of the Sahelian savanna during the second millennium BC (Linares-Matás, 2022). Increasing aridification across the Sahel and the suggested arrival of Berber communities in the region on the basis of stylistic affinities in pottery assemblages during the Late Tichitt period (c. 1000–400 BCE)

seem to correlate with a considerable decline of permanent human settlement in the Tichitt-Oualata region (Munson, 1971; Holl, 1985; MacDonald, 2011) and the funneling of population west into Dhar Tagant and southeast into Dhar Néma (Ould-Khattar, 1995; Person et al., 2006; MacDonald et al., 2009; MacDonald, 2020). It is tempting to see this demographic process—reflected in the archaeological record through ceramics with cord-wrapped roulette decoration, imported phthanite siltstone, cattle remains, and cattle figurines—as a relevant catalyst in the consolidation of more permanent settlements in the Middle Niger and the Macina regions of Mali, such as Kolima Sud-Est, Dia Shoma, and Akumbu, from which the Sahelian empires of Ghana and Mali would arise (MacDonald, 2015; MacDonald and MacDonald, 2000). Towards the end of the Late Tichitt period and into the first millennium AD ("Terminal Tichitt" or "Early Iron Age"), large iron-working communities living in walled settlements comprising semi-permanent stone houses and compounds were also consolidated in Dhar Tagant (Ould-Khattar, 1995; MacDonald, 2020; Linares-Matás and Lim, 2021).

The first Tichitt Tradition burial in this region was identified in 1949 by Raymond Mauny (1961), within the consolidated sands of site v233, in Dhar Oualata. This and the other handful of burials so far identified within Dhar Oualata were found without an associated visible superstructure, and indeed the first necropolis constituted by burials without a stone superstructure lay southeast of v304, with field research identifying the remains of at least five individuals (Amblard-Pison, 2006: 243). The identification of these burials and others like them was facilitated by the exposure of human remains—generally in a medium to poor state of preservation—as a consequence of erosion associated with aeolian processes and intense seasonal rains. Tichitt Tradition tumuli are often circular or oval stone monuments of varying size, ranging from 0.6 to 2 m in height and generally being 3–6 m, though sometimes surpassing 13 m in diameter (Amblard-Pison, 2006).

The tumuli found within the geographical sphere of the Tichitt Tradition are, as far as we know, primarily composed of stone. They also exhibit a relatively low degree of typological diversity, in contrast with the pattern documented in Central Saharan regions, such as Algeria's Tassili n'Ajjer or northern Chad's Tibesti massif (cf., Gauthier, 2015). Amblard-Pison (2006) describes four types of cairns in the Dhar Tichitt region: simple tumuli, enclosed tumuli ("*tumulus ceinturés par un ensemble de dalles*"), closed crater tumuli ("*tumulus à cratère fermé*"), and ring tumuli ("*tumulus à couloir*"). Additionally, some rectangular monuments have been found in the Guilemsi Ridge, located within the Tagant Plateau (Challis et al., 2005), although they bear little resemblance to the tumuli discussed in the present paper.

While all these tumuli are for the most part visible on high-resolution satellite imagery, it appears that the first three types (simple, enclosed, closed crater tumuli) cannot at present be diagnostically identified visually using available remote sensing images (Amblard-Pison, 2006: 250). Even though enclosed tumuli and closed crater tumuli are rare within the Dhar Tichitt region (Amblard-Pison, 2006), their precise identification could nevertheless prove useful for ascertaining spatio-temporal trends in the funerary landscapes of other regions of south-eastern Mauritania, particularly Dhar Tagant. Future integrated field-work and remote sensing research using machine learning algorithms could attempt to distinguish these subcategories of monuments in order to test that possibility. In the meantime, circular non-ring tumuli are considered together here for the purposes of the analysis presented in this paper. In contrast, ring tumuli can be readily distinguished from other types of funerary monuments in satellite imagery (Gauthier, 2015; Linares-Matás and Lim, 2021). They are also relatively unusual in Dhar Tichitt, as they are only found on the periphery of some settlements, including Dakhlet el Atrouss I, in numbers far below those of simple tumuli. Since they are very common in Dhar Tagant (Ould-Khattar, 1995), particularly around the entrance to the Taskast wadi (also known as Oued Tasskass, see Fig. 1 above; Linares-Matás and Lim, 2021), it is plausible that they could also provide information regarding the temporality of landscape occupation, but no dating framework is currently available in that regard.

Despite the paucity of excavated burials (*c.*15; Amblard-Pison, 2006: 241), some general spatial trends have previously been observed in the field for Dhar Tichitt funerary landscapes. These patterns can now be assessed via remote sensing surveys. Tumuli rarely appear in isolation and are more frequently found in dense concentrations on the slopes of or atop of escarpments where they constitute large necropolises, generally on the periphery of settlements (predominantly on the escarpments between settlements v26 and v138). On rare occasions, burials are found within the settlement, even within compounds, as documented at Akreijit (v72), a site in Dhar Tichitt which is not associated with large tumuli concentrations in its immediate periphery. Two ring tumuli were also found within the walls of the largest Dhar Tagant settlement (Linares-Matás and Lim, 2021).

Excavation of one undated funerary tumulus (6.60 m in diameter, 1.30 m in height) from Dhar Oualata, which was partially covered by a sand dune and surrounded by large oblique stone blocks, yielded a single inhumation, with the body very flexed in lateral decubitus position and interred without grave goods (Amblard-Pison, 2006: 249). A similar pattern of individual burials in large necropolises with a general absence of grave goods has been documented for other excavated Tichitt Tradition funerary tumuli contexts. If this trend holds more broadly, a premise of this paper, it would offer interesting analytical possibilities for a remote sensing analysis of socio-economic organization. This is the case because it would entail that status, however transient and distributed, appears to have been primarily expressed and negotiated through the mobilization of the social networks of labor involved in the construction of these funerary monuments, rather than by disposing of wealth through grave goods. A future research priority would therefore involve testing and refining this premise.

3. Methodology

Following the protocol outlined in Linares-Matás and Lim (2021) and after obtaining the relevant license key from Microsoft, very high resolution orthorectified satellite imagery from Bing Maps was loaded into ArcGIS Pro 2.7. as a base-map in which to undertake geospatial analyses and document archaeological sites. Individual funerary tumuli were identified through visual inspection and manually delineated.

The size-based classification system for simple funerary monuments in the highlands of southern Mauritania was carried out by applying the Jenks Natural Breaks algorithm, which establishes class breaks that group similar values together and maximize between-class differences based on data-specific patterns (de Smith et al., 2018).

To generate density values within a tumulus field, the number of funerary monuments was divided by the "minimum bounding area", understood as a minimum bounding rectangle in the form of a "convex hull" representing the smallest convex polygon that can enclose all the digitized funerary monuments within a single tumulus field.

The volume of a monument is generally used as a reliable proxy for inferring the scale of energetic expenditure and labor mobilization involved in its construction (Abrams, 1994; Bernardini, 2004; Abrams and Le Rouge, 2008; Zena, 2021). In the absence of monument height values that would enable us to calculate volume, area (two dimensions) seems to be a better estimator of labor mobilization asymmetries than diameter (one dimension), as several researchers have noted a general correlation in prehistoric mounds and earthworks between the area and volume of material involved in the construction (Abrams and Bolland, 1999; Magnani and Schroder, 2015; Miller, 2021). Well-established econometric methods, particularly the Gini Coefficient, offer an avenue for assessing socio-economic differentiation in archaeological contexts through the nature of value distributions in quantitative datasets (Kohler and Higgins, 2016; Bogaard et al., 2019; Ames and Grier, 2020; Basri and Lawrence, 2020; Fochesato et al., 2021; Linares-Matás, 2022). Traditionally, they have been employed to calculate household

wealth through living space area, sometimes in combination with other variables, such as the size and number of storage facilities (e.g., Bogaard et al., 2019; Ames and Grier, 2020; Fochesato et al., 2021). However, there may be scope for tentatively exploring social differentiation through the lens of tumulus size variability expressed using Gini coefficient equations (cf., Müller et al., 2021). Regardless of outcome, further research in the field combining monument size measurements as well as targeted excavations to assess the presence or absence of grave goods as well as patterns of demographic representation will be necessary for an accurate characterization of socio-economic differentiation among these prehistoric communities. The Gini coefficient values of the tumuli clusters were calculated using the 'ineq' package in R version 4.0.4 (Zeileis, 2014; R Core Team, 2022).

Place names for newly documented archaeological localities (Tabarit, Boutektek, Guelb ed Dâmi) were retrieved from Mapcarta Geonames (https://mapcarta.com/Map).

4. Results

This large-scale remote sensing survey has so far identified 9,028 funerary tumuli in the highlands of southeastern Mauritania, across an area of over 130,000 km^2 (Fig. 3).

After generating bounding polygons for each of the tumuli within these five study-areas (sample size = 2,833), the Jenks Natural Breaks algorithm was applied to generate a size-based classification system useful for characterizing simple tumuli in Saharan contexts (Table 2). Three main categories (small, medium, and large) were identified and then subdivided for further analytical resolution in contexts where such distinctions may be warranted. A fourth category ("very large") is so far restricted to the two massive tronco-conical tumuli of up to 5 m in height documented within Dakhlet el Atrouss, the largest Tichitt Tradition site and so far the largest prehistoric site found in southern Mauritania (Holl, 1993; Amblard-Pison, 2006; MacDonald, 2013; Linares-Matás, 2022).

Table 2
Size-based classification system useful for the characterization of simple tumuli generated using the Jenks Natural Breaks algorithm (n = 2,833). Note how the statistically generated classes based on diameter values roughly approach *a priori* intuitive geometric categories (i.e., <5 m, 5–10 m, 10–15 m, >20 m).

Tumuli Size Category	Tumuli Size Class	Diameter Range (m)	Area Range (m^2)
Small	1a	0.91–4.1	0.68–13.18
	1b	4.11–5.7	13.19–25.81
Medium	2a	5.71–7.2	25.82–40.26
	2b	7.21–8.6	40.27–58.20
Large	3a	8.61–10.5	58.21–87.20
	3b	10.51–13.7	87.21–152.38
Very Large	4	21.36–29.4	152.39–679.97

A core-finding of this study was the identification of large tumulus fields in the Western Tagant, an area that has hitherto received little archaeological research. To the best of my knowledge, these sites remain unpublished and undocumented by archaeologists, although it is not implausible that they were visited by Odette du Puigaudeau in 1937 or by a Franco-Mauritanian team that undertook extensive survey work in the Tagant in the 1980s; however, the focus of documented research has been along the Dhar Tagant Escarpment (Ould-Khattar, 1995), an area that has also been emphasized in recent remote sensing work (Linares-Matás and Lim, 2021). Two tumulus clusters in Dhar Tichitt (Fig. 4),

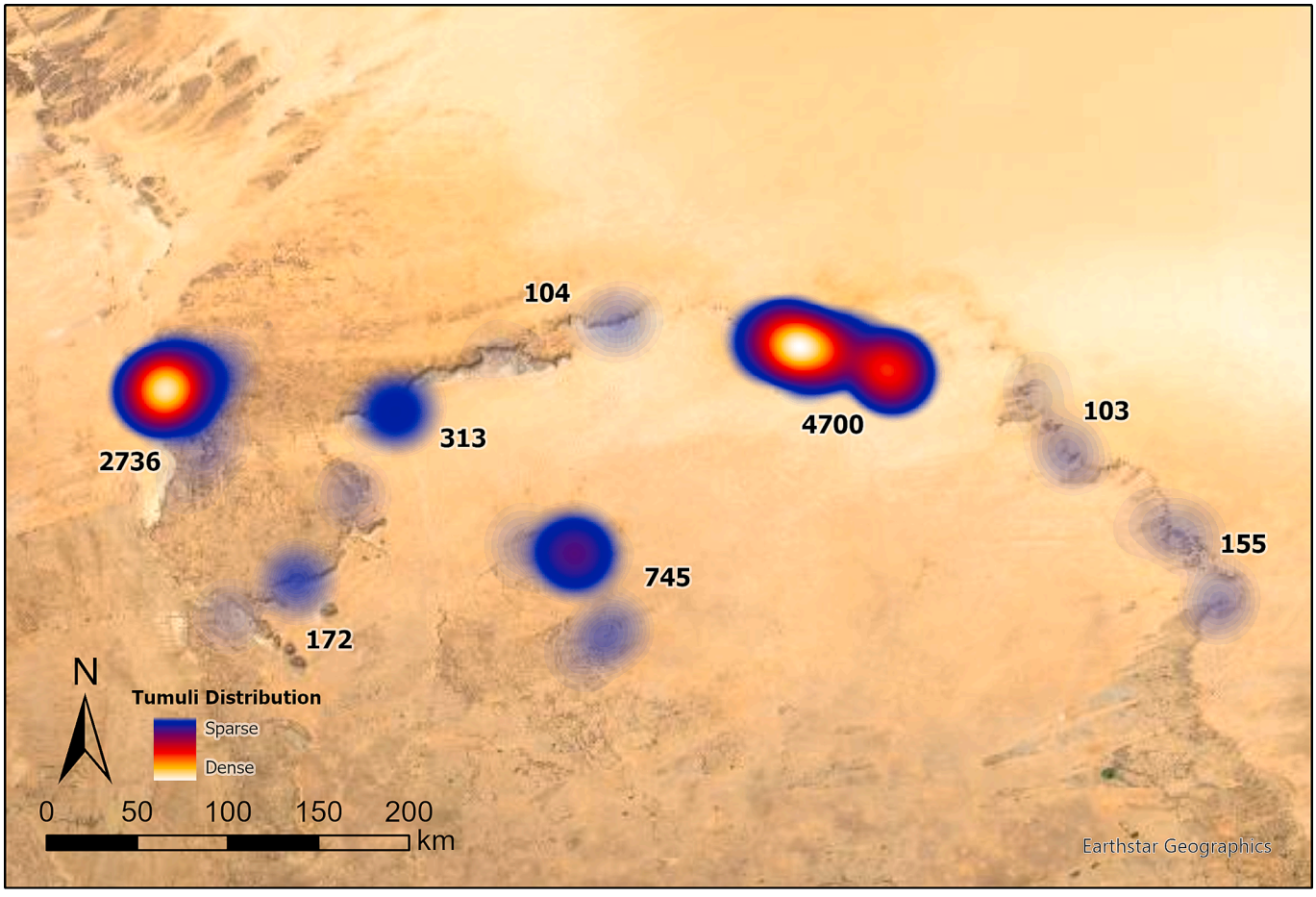


Fig. 3. Heatmap distribution of simple stone funerary tumuli within the highlands of southeastern Mauritania (n = 9,028). The two densest hotspots are located in Dhar Tichitt and the western Tagant, respectively (see Fig. 2 above). The numbers correspond to regional quantities of recorded tumuli.

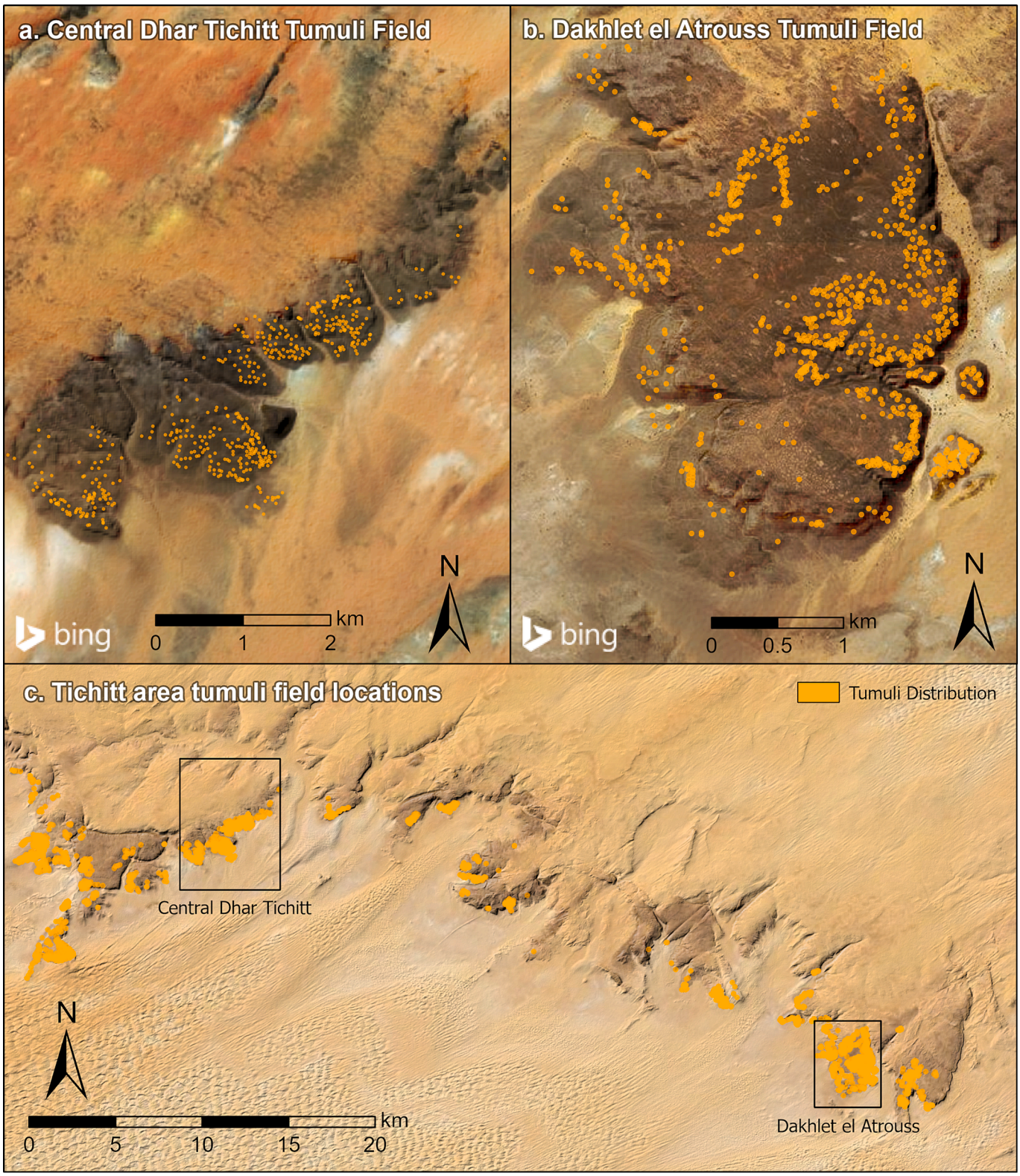


Fig. 4. Distribution of funerary tumuli in the eastern side of the Dhar Tichitt escarpment, with insets showing the intra-site distribution patterns at the two tumulus fields chosen as control samples in the present study.

where funerary monuments have previously been recorded (Amblard-Pison, 2006), were examined through visual inspection and spatial analysis to validate and contextualize the Western Tagant sites (Figs. 5–7).

The two very large monuments at Dakhlet el Atrouss are exceptional within the Saharan funerary record as a whole and suggest a large-scale mobilization of labor beyond the usual scale of Saharan pastoral communities, further illustrating the complex organization and socio-economic differentiation that are suggested by analyses of compound size variability and asymmetry at Dakhlet el Atrouss I (Holl, 1993;

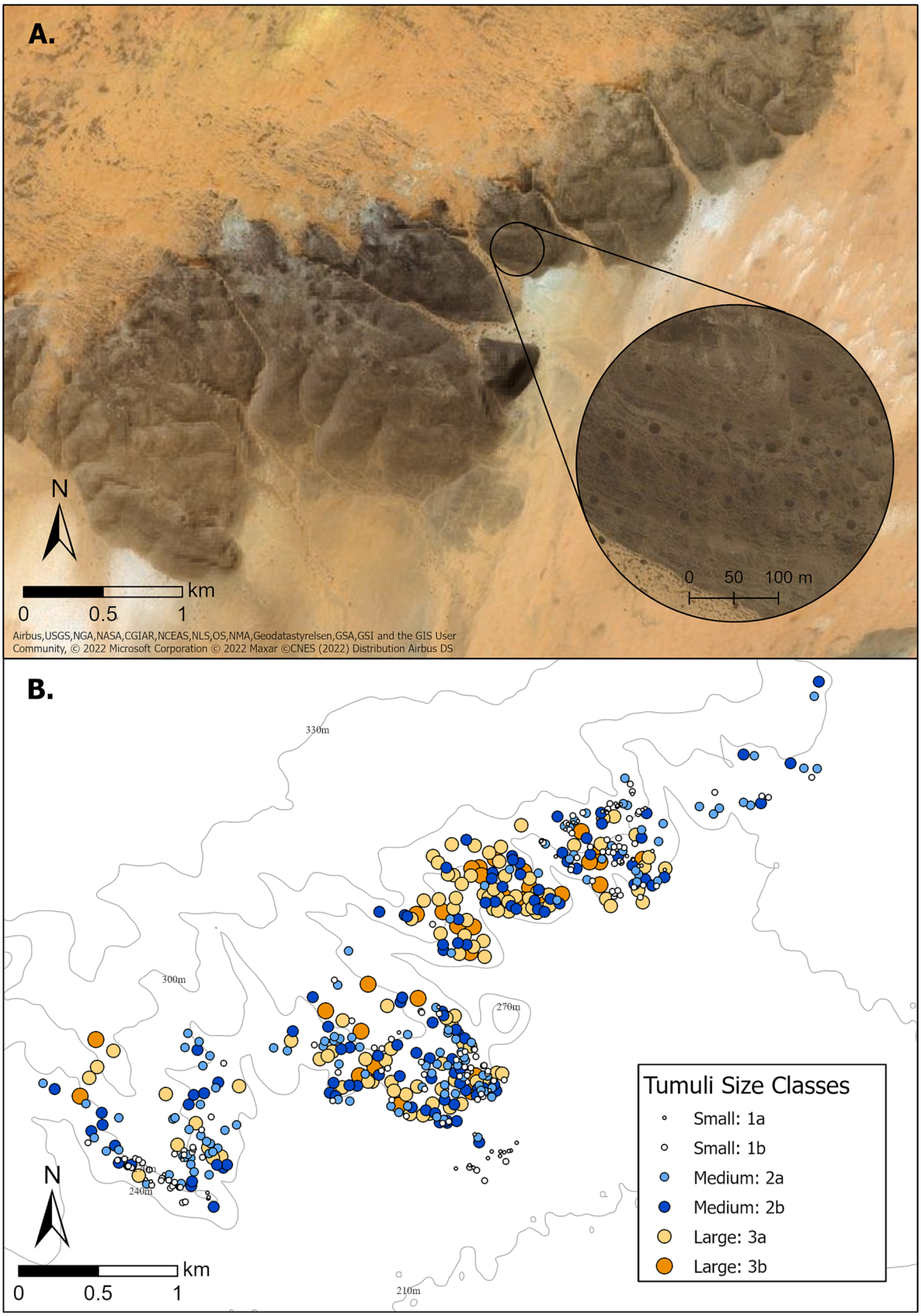


Fig. 5. Size-based distribution map of funerary tumulus clusters in the central section of the Dhar Tichitt Escarpment, with zoomed-in high-resolution satellite imagery inset above. A) Satellite imagery basemap with zoomed-in inset. B) Vectorized representation of tumuli distribution, arranged by size class (symbol size for indicative purposes only, not to scale). Note the preponderance of large-sized tumuli in the central part of this tumulus field.

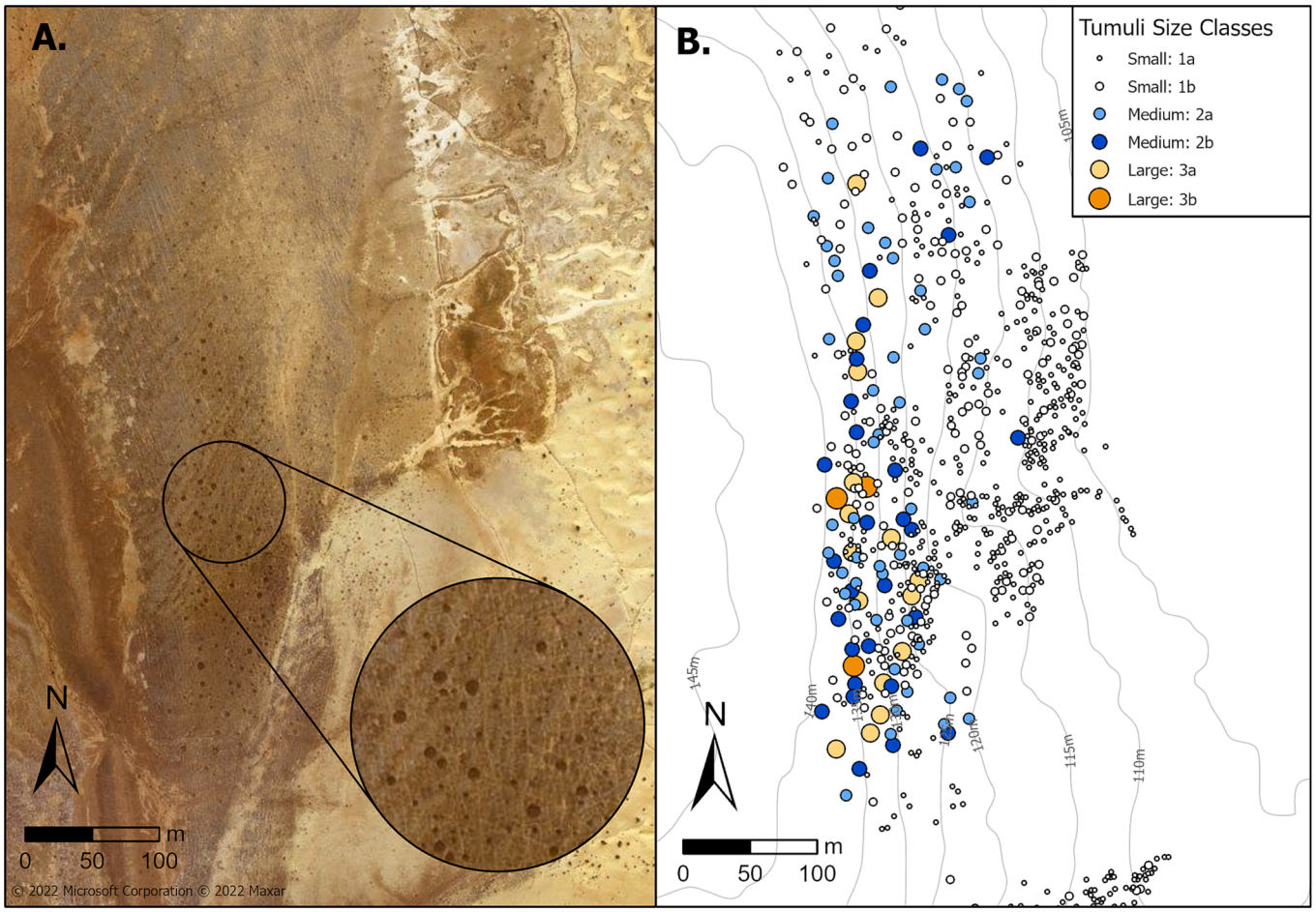


Fig. 6. Map of the Tabarit East tumulus field in the Western Tagant, one of the largest and densest concentrations of funerary tumuli in southern Mauritania (see Table 3 below). This tumulus field is located on a hill with a maximum elevation of 145–140 m sloping eastwards. Most of the large tumuli are placed on a north–south axis on the higher ground.

Linares-Matás, 2022).

One of the main aims of this study is to understand the variability in monument sizes within tumulus fields, and the relationship that such variability may have had with socio-economic differentiation related to asymmetries in labor mobilization potential (Table 3).

Understanding variability in tumulus size is important, since size appears to be directly correlated with overall levels of energy expenditure, including the costs associated with daily activity disruption and the degree of social involvement in the mortuary act (Tainter, 1976). Since the sample analyzed here follows a non-parametric distribution (Shapiro-Wilk normality test: $W = 0.94837$, p-value $< 2.2e{-}16$), I applied a Kruskal-Wallis rank sum test, which identified significant differences between groups (chi-squared $= 1108.5$, df $= 4$, p-value $< 2.2e{-}16$). Subsequently, a pairwise Wilcoxon rank sum test with continuity correction was undertaken to identify which groups showed statistically significant differences. Interestingly, all pairwise combinations with the exception of Tabarit East and Boutektek showed significant differences (Table 4). The fact that Tabarit East and Boutektek are found in close geographical proximity, share similar Gini coefficient values (indicating a broadly equivalent value dispersion), and do not differ significantly in terms of the actual nature of their size composition by both diameter and area may indicate that a similar socio-cultural population segment was involved in their construction.

The lack of significant correlation between Gini coefficient values and the number of tumuli shows that the former are not unduly affected by sample size (Spearman's rank correlation rho $= -0.4$, p-value $= 0.5167$). This can be more intuitively understood visually by the fact that the two localities with the greatest number of tumuli (Tabarit-East and Dakhlet el Atrouss I) are found at opposite ends of the Gini coefficient value distribution within the sample (Fig. 8).

Lastly, the breakdown of the number of funerary monuments per tumulus size class gives a more comprehensive quantitative description of these tumulus fields (Table 5). Consistent with the lower size averages noted in Table 3, a much greater proportion of small funerary monuments was documented at the Western Tagant tumulus fields, whereas the tumulus clusters within the central segment of the Dhar Tichitt Escarpment had the greater proportion of large tumuli.

5. Discussion

Comprising over 9,000 stone cairns and tumuli, the outstanding funerary record of the southeastern Mauritanian highlands has a considerable and hitherto almost untapped archaeological potential. This potential is also shared by several other regions in the Sahara-Sahel borderlands. The emphasis on stone tumuli, with bodies on a raised sandy bed or directly resting over the rocky substrate (Amblard-Pison, 2006), represents a creative adaptation to the constraints associated with the excavation of a burial on the hard bedrock of sandstone massifs, while simultaneously creating a series of phenomenological affordances in terms of visual cues and embedded memories in the landscape (di Lernia, 2006; di Lernia, 2013).

These monuments are external expressions of continuities hosted in the layered narratives of individual and communal memories, an imposition from earlier generations of beings and things upon the

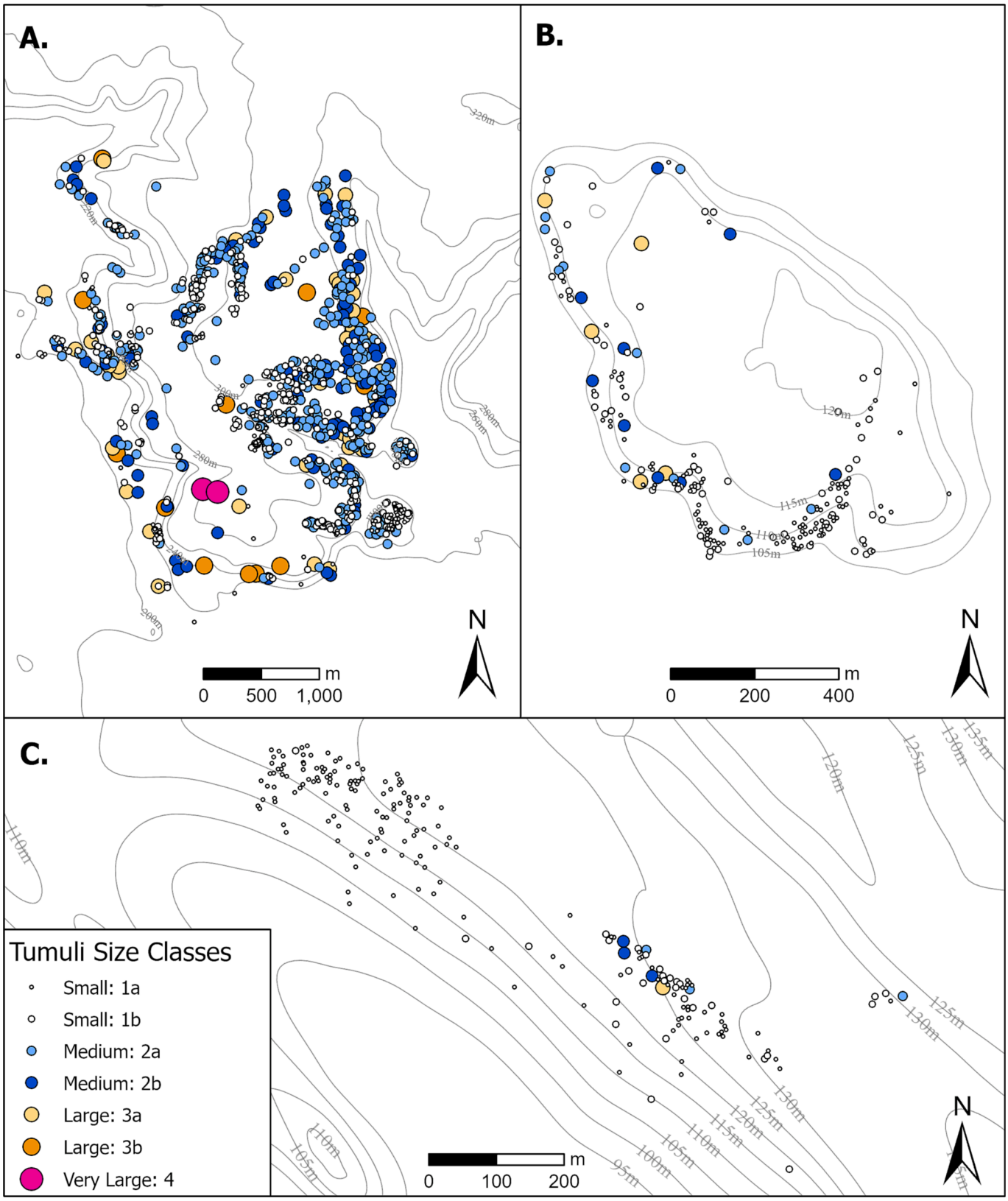


Fig. 7. Size-based distribution of funerary tumuli in A) the hinterland of Dakhlet el Atrouss (Dhar Tichitt; see Fig. 4 for further reference), B) Tajal Boutektek (western Tagant); C) Tabarit West (western Tagant). Note the presence of two very large tumuli within the Dakhlet el Atrouss I regional center, as described in the text. These remain by far the largest yet found in southeastern Mauritania. At Boutektek, the tumuli are predominantly facing the better-watered western side of the hill.

Table 3
Quantitative characterization of the five tumulus fields described and discussed in the present paper. Note how the sites with lower Gini coefficient values have lower densities and larger mean tumulus sizes.

Site	Number of Tumuli	Mean Tumulus Diameter (m)	Mean Tumulus Area (m^2)	Minimum Bounding Area (ha)	Overall Density (tumuli/ha)	Gini Coefficient
Tabarit East	841	4.432 ± 1.82	14.195 ± 14.01	91.767	9.164	0.4391
Tabarit West	205	3.661 ± 1.38	9.181 ± 8.59	21.442	9.56	0.4000
Boutektek	200	4.614 ± 1.8	14.841 ± 12.8	52.417	3.815	0.4135
Dakhlet el Atrouss	907	6.0 ± 1.92	31.4 ± 29.8	899.76	1.008	0.3200
Central Tichitt	531	7.791 ± 2.37	42.12 ± 25.99	812.39	0.653	0.3353

Table 4
Results of the pairwise Wilcoxon rank sum test with continuity correction applied to tumulus diameter values, expressed as p-values. Note the lack of statistically significant differences (p-value > 0.05, in bold) between the Tabarit East and the Boutektek tumulus fields, while every other pairwise comparison showed statistically significant differences.

	Boutektek	Dakhlet el Atrouss	Tabarit East	Tabarit West
Dakhlet el Atrouss	<2e−16			
Tabarit East	**0.21**	<2e−16		
Tabarit West	6.0e−09	<2e−16	1.9e−09	
Central Dhar Tichitt	<2e−16	<2e−16	<2e−16	<2e−16

consciousness of the living (cf., Edmonds, 1999; Gosden, 2005). Writing of Madagascar, Bloch (1971) notes that there are two main kinds of social action, one offering permanence of rights and continuity of identity—articulated around descent groups and the huge stone tombs of the ancestors—and another pertaining to marriage relationship and interactions with neighbors, often in heterogeneous areas where ancestors are not entombed. As such, the interconnectedness of normative rules regarding burial practices and the practical facts of everyday life eventually demands that the former be adjusted, renegotiated, or reformulated accordingly. Excavations at Akreijit recovered abundant skeletal remains within one of the compounds, within the sandy substrate (7–25 cm) that constituted the habitation surface, a pattern that prompted Amblard-Pison (2006) to argue against the existence of a rigid frontier between the realm of the living and that of the dead. At the same time, however, the living clearly had strong concerns and well-defined mechanisms through which the dead were frequently disposed and memorialized *outside* settlements, indicating some degree of ontological separation that may have prevented constant permeability. Moreover, the existence of very large necropolises that were *not* associated with settlements of the living further problematizes the applicability of Amblard-Pison's statement to all sites and time periods encompassed within the Tichitt Tradition. It is also certainly possible, of course, that we may be witnessing here hints of diachronic changes entailing a shift in emphasis from a household-centered mortuary tradition to a more corporate, collective locus of identity within the highlands of southeastern Mauritania. These patterns, observed albeit differently manifested in other regions, such as southern Mesopotamia,

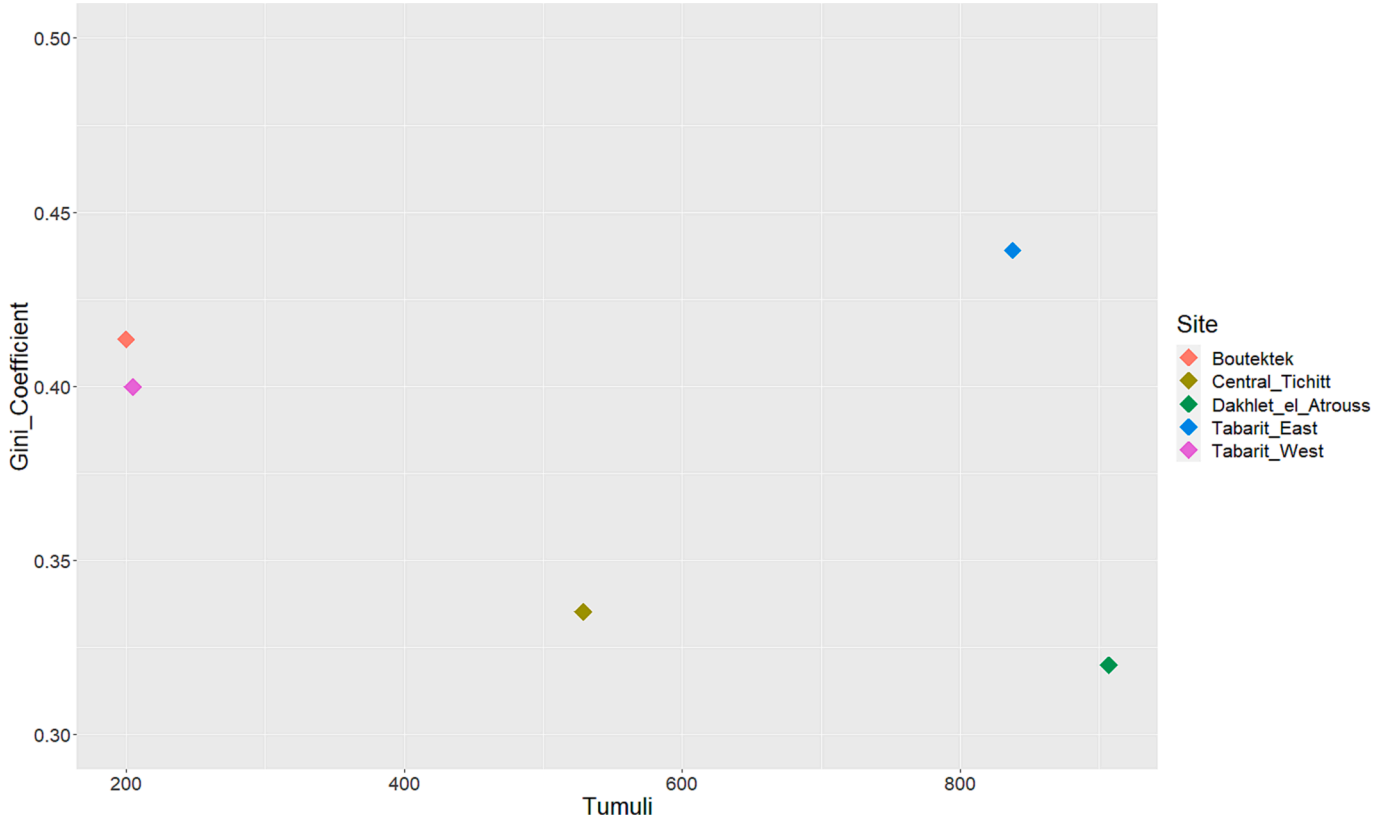


Fig. 8. Graphical representation of the relationship between Gini Coefficient and tumulus field size. Graph created using the ggplot2 library in RStudio (Wickham, 2016; R Core Team, 2022).

Table 5
Size-based distribution of funerary monuments at each of the main tumulus fields discussed in the paper.

Tumulus Size Class	Dakhlet el Atrouss	Central Dhar Tichitt	Tabarit-East	Tabarit-West	Boutektek
1a	111 (12.24 %)	47 (8.85 %)	545 (64.8 %)	169 (82.44 %)	115 (57.5 %)
1b	301 (33.18 %)	123 (23.16 %)	196 (23.3 %)	29 (14.15 %)	59 (29.5 %)
Total Small	412 (45.42 %)	170 (32.02 %)	741 (88.1 %)	198 (96.58 %)	174 (87 %)
2a	311 (34.09 %)	118 (22.22 %)	53 (6.3 %)	3 (1.46 %)	12 (6 %)
2b	128 (14.29 %)	112 (21.09 %)	28 (3.33 %)	3 (1.46 %)	9 (4.5 %)
Total Medium	439 (48.4 %)	230 (43.3 %)	81 (9.63 %)	6 (2.9 %)	21 (10.5 %)
3a	41 (4.52 %)	99 (18.64 %)	16 (1.90 %)	1 (0.488 %)	5 (2.5 %)
3b	13 (1.43 %)	32 (6.026 %)	3 (0.36 %)	0	0
Total Large	54 (5.95 %)	131 (24.67 %)	19 (2.26 %)	1 (0.48 %)	5 (2.5 %)
4	2 (0.22 %)	0	0	0	0
Total	907	531	841	205	200
Total Sample	2,833				

Early Classic Mesoamerica, and West Africa's Inland Niger Delta (McIntosh, 1999; Paul et al., 2013; Brereton, 2016), are generally associated with increasing nucleation and sedentarization; in some instances, however, they may also be attributed to the presence of a strong pastoralist component in socio-economic organization, with the spatial loci of identity expanding beyond settled lands to similarly encompass the landscapes traversed by people-with-livestock on an annual or sub-annual basis (di Lernia, 2013; Honeychurch, 2014; Wright, 2014; Boles, 2017; Jaffe et al., 2021). As such, the funerary record indicates that there may have been one or two periods of considerable change in the socio-economic and cultural organization of prehistoric communities in the southern Sahara and northern Sahel, as represented by the archaeological record of the highlands of southeastern Mauritania. In order to better characterize the nature of these changes, two intrinsic factors are of particular relevance for understanding the socio-economic dimensions of funerary tumuli, especially when the latter are found in large and dense concentrations: monument placement and size.

5.1. *Space, memory, and power: Placing tumulus fields in the landscape*

Where within the overall landscape a community chooses to recurrently place funerary monuments constitutes its social necrogeography (Semple and Brookes, 2020), and the placement of funerary monuments within prehistoric landscapes has been a prolific area of archaeological enquiry (e.g., Tilley, 1994; Soetens et al., 2002; Cummings and Whittle, 2004; Fleming, 2005). The interplay between visibility and topography is an important dimension in structuring the nature, spatial distribution, and cultural significance of funerary monuments in the Sahara, with tumuli often located on elevated parts of the landscape (cf., Gatto et al., 2019; Linares-Matás and Lim, 2021).

The establishment of formalized disposal areas for the dead, such as cemeteries or burial structures, in association with the control of scarce or valuable resources (such as agricultural land or prime pastures) is an important priority among corporate groups, particularly in societies that rely on spatially restricted and cyclically renewable resources, for example certain hunter-gatherer communities and most agropastoralist societies (Saxe, 1970; Goldstein, 1976; Renfrew, 1976; Tainter, 1976; Chapman, 1981; Posnansky, 1982; Pardoe, 1988; Sherratt, 1990; Sereno et al., 2008; Cummings et al., 2015; Shelach-Lavi, 2015; Jaffe et al., 2021; Dueppen, 2022; Schulting et al., 2022). The ability to establish "genealogies of place" through the transmission of property ownership and access rights to the next generation is also mobilized in order to create ties of debt and obligation in descendants and affines that will often be reflected in funerary investment and the maintenance and commemoration of these burial spaces (Saxe, 1970; Goldstein, 1976; Renfrew, 1976; Chapman, 1981; McAnany, 1995; Pollington, 2008; Halsall, 2010; Hein, 2017). This framework may explain why, in southeastern Mauritania, dense tumulus clusters are located at the immediate periphery of some large settlements, as seen at Dakhlet el Atrouss, or – to move further afield - the Moroccan site of Jabal Bouïa (Bokbot, 2019). On the Tagant Plateau, this phenomenon is rare, but it is clearly attested at Guelb ed Dâmi, where a 25 ha walled settlement overlooks a tumulus cluster (n = 84) located on a small promontory *c.*500 m to the northwest and across a valley traversed by a seasonal stream. Bokbot (2019) stresses how Jabal Bouïa also overlooks a fertile agricultural plain, a pattern that appears to be mirrored at Dakhlet el Atrouss I (Holl, 1993; Amblard-Pison, 2006; Linares-Matás, 2022). This pattern most likely reinforced the cosmological and political centrality of these nucleated living spaces (cf., MacDonald, 2013).

The extent to which this framework explains the spatial distribution of the Tabarit tumulus fields in the uplands of the Western Tagant is unclear, however, since visual inspection has so far failed to document any associated substantial settlement. Ground surveys may provide positive evidence of such settlements if their invisibility is due to the use of perishable building materials or the action of burial processes associated with alluvial deposition and sand encroachment. If future fieldwork does identify a substantial nearby settlement(s), then the present-day agricultural exploitation of the surrounding fields using flood-recession techniques would support an interpretation that incorporates the control of resources as a relevant dimension for explaining their spatial distribution and orientation, particularly for Tabarit-East and Tajal Boutektek (Fig. 9), both of which directly overlook farmland areas. The location of the Boutektek tumuli on the western edge of this upland area seems to particularly emphasize a desire to establish visual prominence and control over the lowlands beside it. Were future ground surveys to corroborate the apparent absence of associated settlements, however, a different explanation might be required.

In fact, a pattern of extensive tumulus fields or large tumuli lacking an association with sizeable spaces for the living is far from uncommon. It has, for example, also been documented through remote sensing methods in relation to the Central Sahara (e.g., di Lernia, 2013; Gauthier, 2015; Biagetti et al., 2017) and the Taskast wadi in Dhar Tagant (Ould-Khattar, 1995; Linares-Matás and Lim, 2021), as well as extensively on the ground in the Fezzan region of southwestern Libya (di Lernia, 2006) and at several locations in the West African Sahel, including the Pays Dô (Mali; MacDonald et al., 2018), northern Ghana (Anquandah, 1987; Kankpeyeng et al., 2013) and Senegambia (e.g., Clos-Arceduc, 1962; McIntosh and McIntosh, 1993; Gallay, 2006; Laporte et al., 2012; Magnavita, 2017; Holl, 2022).

Structuring flows of people, livestock, and valuable goods through the creation of monumental funerary landscapes that integrate cosmological centrality and socio-economic viability may have been at the heart of all these tumulus clusters. Such "liminal" funerary spaces could have played a central role in social cohesion and exclusion dynamics, by creating loci of identity and belonging that transcended the scale of the household, the lineage, or the village (MacDonald et al., 2018). Moreover, these shared sources of identity could have potentially consolidated spatially extensive socio-political networks that played an important role in the structuring of exchange systems (cf., Cohen, 1966). For example, Posnansky (1982) suggested that Senegambian tumulus fields assisted local agricultural societies in controlling and articulating the exchange of iron, gold, and other mineral resources. In the Sahara, far-reaching exchange networks involving stone beads, axes, and

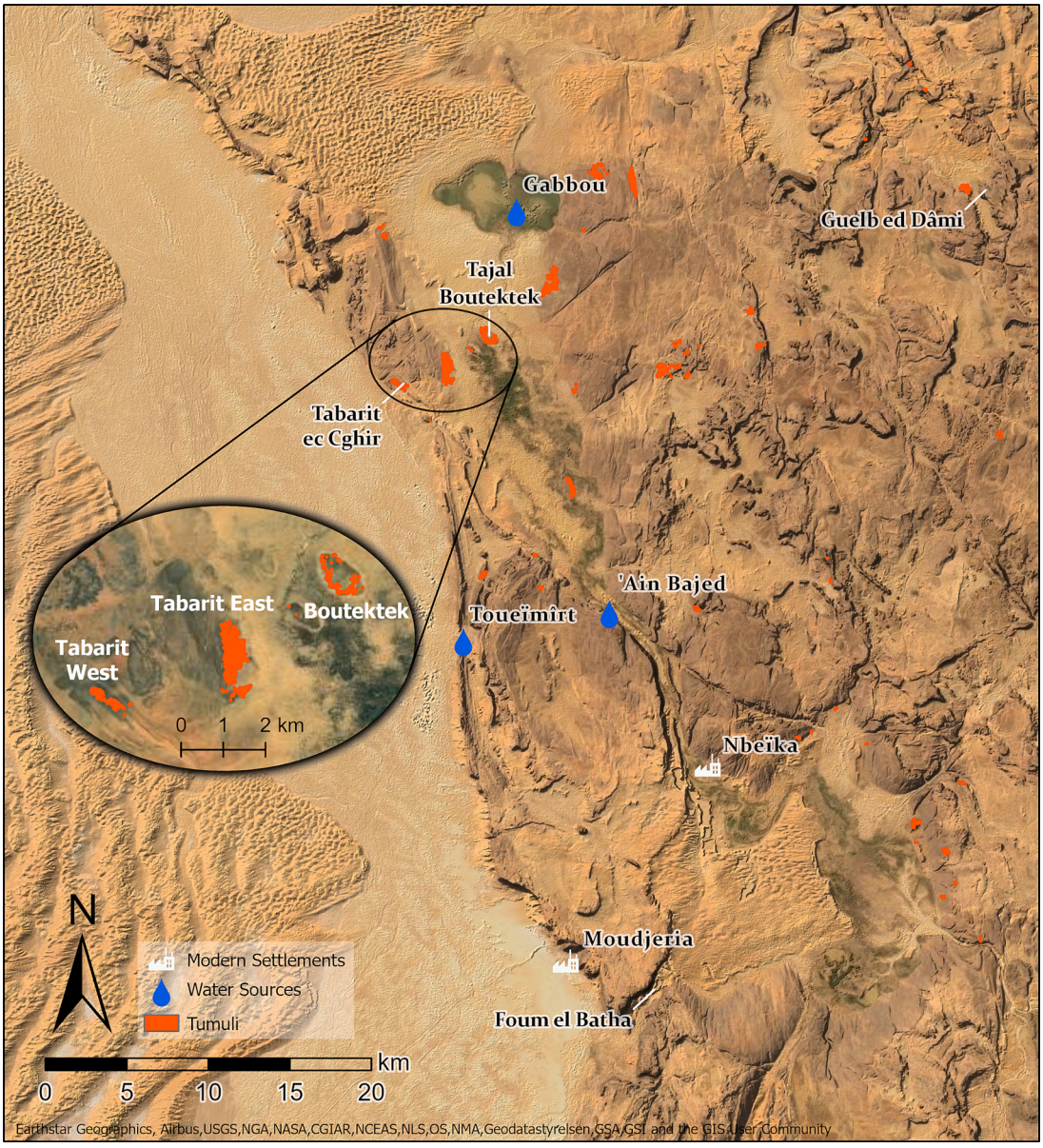


Fig. 9. Map of the Western Tagant showing the distribution of funerary monuments, the main tumulus clusters mentioned in the text, and relevant regional geomorphological features and modern settlements.

bracelets have been documented from the late fifth millennium BC, and a limited number of imported elements (MacDonald, 1998), such as carnelian and amazonite beads, have been found at Tichitt Tradition sites in southeastern Mauritania (Amblard, 1984: 273), although it is unclear to what extent they played a relevant role in structuring socio-political complexity (McIntosh and McIntosh, 1988). Instead, social organization appears to have been predominantly based on endogenous processes, such as agropastoral production and labor mobilization (MacDonald, 2013; Linares-Matás, 2022).

The emergence of tumulus fields in the Western Tagant should perhaps be better understood through processes of spatial translocation and socio-economic transformation. A combination of migratory movements towards less dry areas of the southern Mauritanian highlands (such as Dhar Tagant or Dhar Néma) and a greater emphasis on smaller livestock seems to have enabled Tichitt Tradition communities to mediate the growing unpredictability of pearl millet cultivation in the context of the increasing aridity that the southern Sahara experienced during the first millennium BC and the early first millennium AD. Mobility flows are an ontological cornerstone of many societies with a strong pastoral component, since they need to adapt to seasonal fluctuations in the distribution of green pasture and surface water in order to sustain their livestock herds (e.g., di Lernia, 2006; Hildebrand and Grillo, 2012; di Lernia, 2013). Therefore, a greater emphasis on seasonal mobility would have resulted in uplands offering refugia and/or vantage points overlooking liminal areas of frequent transit, becoming particularly attractive locales of enduring social value, ideal emplacements for establishing new funerary landscapes or reimagining old ones. Such a trend has been documented in the Tadrart Acacus highlands of southwestern Libya through both spatial analyses and isotopic studies (cf. Cremaschi and di Lernia, 1999; Tafuri et al., 2006; di Lernia, 2013; Biagetti et al., 2015). In similar vein, the topographic location of tumulus fields on upland areas flanking seasonal watercourses that acted as both corridors of mobility as well as sources of freshwater may be a useful framework for understanding the location of the Tabarit funerary landscapes. The interplay between the cultural significance that imbued these sacred places and a topography that funnelled transhumant pastoralist groups and/or camel caravans moving through the lowlands northwest of the Tagant Plateau (see Fig. 9 above). This interpretation

would be consistent with other regional patterns of tumulus clusters in the region, such as those located around the intersection between the uplands of Dhar Tagant and the lowlands of the Aoukar Basin at the entrance of the Taskast wadi (Linares-Matás and Lim, 2021). These relationships may have been further reinforced by culturally specific histories, cosmologies, and mythologies, providing a more textured and multi-layered justification of their positioning within the landscape (cf., Morris, 1991).

By virtue of their materiality, visibility, and positionality within the landscape, tumuli create effective and attractive opportunities for extended collective engagement at different spatio-temporal scales with the dead through material signs that mediate and enhance evocation and remembrance (Casey, 1987; Kwint et al., 1999; Sutton, 2008; Robb, 2010; Malafouris, 2013; Malafouris, 2016). These material signs are not merely "stores of information"; rather, they constitute transactional arenas of and for cognition, insofar as they accumulate, evoke, and update individual and collective ways of material engagement with the world (Prezioso and Alessandroni, 2022). In sum, such persistent and sacred nodal points in the landscape would have acted as "places to be remembered" in the western Tagant (cf. Di Lernia, 2013). These regional catalysts combined aspects of ancestor cults with articulations of political authority and socio-economic integration through the mobilization of social obligations and access rights across potentially contested territorial thresholds. These processes of identity and memory therefore transcend the making of the monument, as they are iterated and reformulated through subsequent engagement, with the potential to act as memories of a myriad of social relationships and collective bonding (Becker and Martin, 1982; Connerton, 1989; Williams, 2003; Barrett and Ko, 2009; Clack and Brittain, 2011; Hein, 2017; MacDonald et al., 2018; Dueppen, 2022).

5.2. *Burial size and labor mobilization in the study of prehistoric tumulus fields*

Each society has a specific logic of resource expenditure through which the grammars of ceremonialism and ancestrality are expressed in the landscape. In the context of societies that build stone mortuary architecture, often placing them together to form tumulus fields, variability in monument size indicates that resource allocation in funerary practices was asymmetrical within the community, even in the absence of grave goods. Who gets to be memorialized and monumentalized, and how, is a decision informed by a number of intersectional attributes, including, but not limited to, age, sex, social status, and the timing, place, and manner in which the death occurred (Morris, 1991; Fausto and Heckenberger, 2007; Weiss-Krejci, 2013).

Variability in the size of individual tumuli, in particular, may attest to asymmetries in the scale of labor mobilization networks and other relations of production at the time of monument construction (Sjogren, 1986; Zena, 2021). Among the Serer of western Senegal, for example, Becker and Martin (1982) reported that the size of the tumulus when a person passes away is proportional to the number of socially invested individuals that the family can feed, and for how long. As such, there can be a relationship between tumulus size and household wealth in assets or social capital. At the same time, tumulus size variability was probably not always exclusively associated with the status and power of the deceased or with the differential ability of individuals and lineages to mobilize ritual sanctions or other mechanisms of social control, given how several other contingent variables could have affected cycles of production. Nonetheless, the disruption of everyday activities and schedules to attend and engage in the mortuary ritual is in itself a relevant consideration within discussions of social energy expenditure and labor mobilization networks through duty-status relationships (Binford, 1971; Tainter, 1976). These practices involve extensive engagement with the material world in ways that can reduce, downplay, or exalt socio-economic differentiation.

This ethnographic insight from rural West Africa about how a small-scale society is able to mobilize relatively large pools of labor beyond kin networks for ritualized monument construction through distributed agency illustrates some key principles of collective action theory (Edmonds, 1999; Carballo, 2012; Carballo et al., 2014; DeMarrais and Earle, 2017). Simultaneously, it also highlights the importance of reciprocity, reputation and compensation for understanding certain aspects of cooperative social behaviors (DeMarrais, 2016; Miller, 2021). As such, while tumulus size variability may not reliably inform about the extent of social inequality, particularly given the biases associated with our lack of estimates regarding the contemporaneity of the different burials or the number of individuals not granted a monumental burial, understanding monument size distribution patterns may offer us a preliminary glimpse into the rich socio-economic dynamics within prehistoric Mauritanian society as expressed through its mortuary record.

The Gini coefficient values obtained for the Dhar Tichitt tumuli clusters (<0.35) are not low and show remarkable consistency with those obtained for household compounds at Dakhlet el Atrouss I and Akreijit (Linares-Matás, 2022). Nonetheless, it is clear that the Tabarit tumulus fields (Gini coefficient > 0.4) seem to exhibit a greater degree of burial size differentiation (see Fig. 6 above). In the absence of any dating directly associated with these sites, it is necessarily to rely for now on an observed trend that suggests a later settlement of the Dhar Tagant region in relation to Dhar Tichitt, with the bulk of Dhar Tagant sites seemingly dating to the first millennium BC and first millennium AD (Ould-Khattar, 1995; MacDonald, 2020). These dates are also consistent with the passing remarks made by Odette du Puigaudeau, who noted that many rock paintings in the region depict camels and have *tifinagh* inscriptions[1] (du Puigaudeau, 1993: 111), although other motifs present at several Tagant rock art sites, such as extinct Sahelian fauna and naturalistically rendered pastoralist scenes (du Puigaudeau, 1993: 111), are undoubtedly earlier (cf., Muzzolini, 1986).

Assuming that such a chronological framework (i.e. the late first millennium BC to early-mid first millennium AD) applies to the Tabarit tumulus fields, we can infer that labor mobilization for funerary architecture and mortuary rituals became a particularly conducive arena in the western Tagant for expressing, negotiating, and reinforcing socio-economic status differences. In this regard, even though relatively small kin groups could have mobilized sufficient labor to complete the smaller tumuli (cf., Abrams and Le Rouge, 2008), the larger Tabarit ones (diameter = 13 m) are likely to have required a larger-scale mobilization suggestive of more consolidated social networks. However, information regarding the remains of burial rites, the nature, quantity, and diversity of grave goods, if any, as well as osteological and anthropological data from the skeletal remains themselves, is required before reaching any more definitive conclusions about the socio-economic organization or status of the communities represented in the Tabarit tumulus fields.

In contrast, the larger average size of Dhar Tichitt tumuli—with Gini coefficient values consistent with those extrapolated from household compounds (0.3–0.33)—suggests that there was a greater overall energetic expenditure per monument in this region during the second millennium BC. This would be consistent with a polyfocal, heterarchical social organization with multiple competing lineages investing in the

[1] Tifinagh is an abjad (consonant-only) script used to represent Berber languages, representing one of the later stages in the evolution of the Libyco-Berber script (Pichler 2007). It has been used as a marker of the southwestward spread of Lybico-Berber populations across North Africa and the Canary Islands (Biagetti et al. 2015; Farrujia de la Rosa 2015), and it considerably declined in use after the Islamic conquest of the Sahara. These historical processes leads to a temporal ascription to the second half of the first millennium BC and the first millennium AD. Similarly, the earliest securely-dated context for camels in West Africa is currently around the third century AD in Senegal (MacDonald and MacDonald 2000), although presumably their presence may be documented slightly earlier in southern Mauritania, a region closer to the Maghreb.

materiality of ancestor remembrance. Nevertheless, the construction of two very large tumuli (>20 m in diameter) at the regional center of Dakhlet el Atrouss I may indicate the temporary coalescence of social power in the hands of a restricted number of lineages within an otherwise unstable political landscape. Such potential for centripetal dynamics within large agropastoral communities coupled with evidence for cultural and demographic interactions between Tichitt Tradition societies from southeastern Mauritania and those from the Middle Niger region of Mali may offer interesting insights into empire formation processes in the West African Sahel.

5.3. Integrating burial size and spatial distribution data in the interpretation of the tumulus fields of the western Tagant

Combining insights from the size and distribution of funerary tumuli within spatially constrained areas of the southeastern Mauritanian landscape may provide us with a better understanding of the relationships between these variables and social organization across time and space in the western Tagant. The presence of several tumulus size classes within spatial distribution clusters suggests that each of these potential corporate lineage units may have included a variety of status ranks, perhaps related to aspects such as gender, seniority, degree of relatedness, labor occupation, or the nature of the individual's death (Tainter, 1976; Insoll, 2016). Such material and ideological foundations of spatial burial organization that combine placement and size could have assisted in processes of elite consolidation. At the same time, Sawchuk et al. (2018) highlight how social investment may be more closely related to community-building endeavors underpinned by collective action than personal power and prestige. As such, a future assessment of the relationship between tumuli size, grave goods, and bioarchaeological data should, when logistically possible, be incorporated into the preliminary discussions presented here about the nature of socio-political organization of Late Holocene agro-pastoralist communities in the Western Tagant region of southeastern Mauritania.

An important dimension highlighted by Zena (2021) in relation to the construction of megalithic stelae in southern Ethiopia is the fact that the scale of interpersonal, material, and knowledge-based networks relevant for labor and resource mobilization can vary by site, over time, and across the landscape. On one hand, exponential increases in monumental and artefactual investment within a cultural sequence have also been observed in other contexts and are generally associated with the formalization of material forms of expression within an increasingly dynamic and competitive social and ritual landscape (Zhang et al., 2013). Such a trend of greater investment and increasing differences in size and ornamentation was documented for the Afunfun tumuli (Agadez, central Niger) through the addition of stone encircling walls or standing stone alignments (Paris, 1996), which may indicate a greater degree of social differentiation. This pattern is consistent with expectations of the "diminishing returns" of conspicuous consumption in elite mortuary contexts, something that requires a disproportionate increase in investment relative to social gains (Tainter, 1988; Murphy, 2020). In contrast, both Sawchuk et al. (2018) and Zena (2021) document a pattern of decreasing and diminishing expenditure among pastoral societies in East Africa, which may suggest that large-scale mortuary rituals achieved the consolidation of a more cohesive community, although it is clear that monument construction remained relevant for the maintenance and renewal of social relations.

I would argue that this latter trend is more appropriate in the context of the southeastern Mauritanian highlands, given the overall decrease in monument size observed on the basis of average diameter and area between the tumulus fields of Dhar Tichitt and those of the western Tagant (Table 3). The fact that monumental funerary architecture remained a key dimension of socio-cultural practices is shown in the high feature densities, and the considerable dispersion of tumulus size classes seen in the Gini coefficient values. This pattern suggests that a wide range of social agents, with differential potential for labor pool mobilization, were actively involved in burial rituals. One possible explanation for it is a greater "democratization" within western Tagant communities (compared to those of Dhar Tichitt) regarding who was eligible to be buried within a tumulus. Alternatively, it may reflect an overall increase in social differentiation, even if on average the scale of energy investment per tumuli was lower in the western Tagant than in Dhar Tichitt.

This kind of variation in the mobilization of labor pools over time can also occur within a single site, particularly in the context of large tumulus fields that formed over hundreds of years since their protracted material biographies are more likely to reflect shifts in social, economic, or cultural priorities over multiple generations than cemeteries with a more constrained depositional history. At such locales, the gradual coalescence of multiple temporalities of interment is an important issue. Intra-site spatial patterns can become disrupted with the weakening of generational memories about who their ancestors are and where are they buried, offering opportunities for meanings to be reinvented and stories to be reattributed in ways that may result in spatial palimpsests that encompass multiple, often competing, grammars and logics of monumental placement. At both Tabarit-East and Tabarit-West, the distribution of smaller funerary cairns on lower elevations *vis à vis* the larger monuments (see Fig. 4 above) could be a further reflection of socio-economic differentiation. At the same time, however, if we assume that more prominent areas were monumentalized first and that the tumulus field expanded downslope from this central core, following common forms of spatial growth and development (Tainter, 1976) it could also reflect a diachronic trend of decreasing labor investment. A typological aspect that precludes tentative assessments of chronological sequences is the fact that there is no clear sense of disruption in the architectural nature of funerary tumuli from an analytical, remote sensing perspective. Stylistic genealogies and traditions could have continued to shape the way in which specific materials and choreographies of human labor were structured in the celebration and remembrance of the dead (Gosden, 2005), even if every tumulus and each collective experience of construction was uniquely shaped and constituted. Assessment of grave goods' data, if and when available, may provide useful insights in this regard. Further chronological work is required to better understand the temporalities of cultural engagement with the landscape through the study of material depositions associated with funerary tumuli.

Lastly, integrating desk-based approaches with collaborative, community-centered fieldwork and suitable data-sharing solutions as soon as logistically feasible will undoubtedly improve data resolution, social impact, and capacity building potential for archaeological heritage in Mauritania, as shown for other countries in Africa and elsewhere (e.g., Rayne et al., 2017; MacDonald et al., 2018; Davis et al., 2020; Linares-Matás and Lim, 2021; Lim et al., 2022). A more ethically oriented approach of this kind will also mitigate perceptions of remote sensing as an aerial panopticon inherently detached from local needs and realities, and actively contribute to negotiations of local identities, landscape memories, discourses of belonging, and Indigenous rights (Davis et al., 2021; Fisher et al., 2021; Lim et al., 2021; Wadsworth et al., 2021).

6. Conclusions

Funerary monument construction trends and associated ritual practices offer invaluable insights into the politics and energetics of memory and labor mobilization within prehistoric societies, as well as cultural attitudes towards the dead and the socio-economic dynamics of the living. Southeastern Mauritania's tumulus fields formed "places to be remembered" (*sensu* Di Lernia, 2013), acting as persistent nodal points of socio-economic and cultural integration over time. This offered multiple avenues for the articulation of social status and/or political authority through the mobilization of social obligations and access rights across potentially contested territorial thresholds.

The very large size of some Dhar Tichitt tumuli may indicate the temporary coalescence of social power in the hands of a restricted number of lineages at Dakhlet el Atrouss I, within an otherwise distributed and polyfocal socio-political system. On the other hand, the Tabarit tumulus fields are not associated with settlement areas and exhibit greater Gini coefficient values (>0.4) may show differentiation in household labor mobilization for funerary architecture in the late prehistory of the western Tagant. These processes could both be tentatively linked with increases in seasonal pastoral mobility amidst aridification trends in the southern Sahara from the first millennium BC onwards.

The size-based classification system presented in this paper was generated using morphometric data from thousands of simple tumulus cairns within five tumulus fields obtained through a remote sensing survey of the southeastern Mauritanian highlands. This classification system has a much wider applicability potential than this, however, since it can be readily used to characterize other clusters of simple tumuli that are ubiquitous within prehistoric funerary landscapes across the Sahara.

Future remote sensing research should attempt to study the reliability of reconstructed patterns of labor mobilization asymmetries by applying Gini coefficients on tumulus area values and through the generation of bespoke experimental assessments of the architectural energetics for building prehistoric stone tumuli in terms of person/hours estimates. Tumulus volume, in turn, could be derived either from monument height measurement in the field or from the analysis of very high resolution Digital Surface Models (DSM). Acquisition of a DSM with a *c.*1 m resolution would also enable the precise and detailed modelling of viewsheds and pathways within any given tumulus field.

Lastly, future collaborative fieldwork in the Tabarit landscape ought to assess the role of cultural and demographic syncretism between Tichitt Tradition communities and incoming Berber populations during the first millennium BC or the potential influences from first millennium AD urban polities in the Middle Niger, such as the Ghana/Wagadu empire as reflected in the region's funerary record. It should also explore whether the trend of individual burials with little to no grave goods documented for Dhar Tichitt tumuli is replicated in the Western Tagant mortuary landscapes. Additionally, future biomolecular studies may assist in elucidating the dynamics of kinship and social authority that may have been at play in how spatial and morphometric distribution were constituted within tumulus fields (cf. Bouwman et al., 2008). In the meantime, it is expected that the outcomes of this satellite remote sensing research in Mauritania will be integrated into the much larger EAMENA database (https://eamena.org/) for the benefit of researchers and national heritage authorities alike.

CRediT authorship contribution statement

Gonzalo J. Linares Matás: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Shifting sands: Climate change, non-linear settlement dynamics, and social resilience at a Saharan frontier

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Abstract

The archaeological study of settlement dynamics provides invaluable diachronic insights into the interplay between climate change and socio-economic organization in past human communities. This paper presents the results of a large-scale remote sensing survey in the highlands of southeastern Mauritania (n = 1,140 settlements). I integrate theoretical insights from Africanist anthropology, historical archaeology, and complexity theory to characterize over three millennia of non-linear human landscape use trends in this region. The growth and consolidation of Tichitt Tradition communities during the second millennium BC was accompanied by a protracted process of conservative but decentralized reproduction of material and ideological forms leading to "high systemic coherence". On the other hand, the first millennium BC witnessed a drastic release and reorganization of settlement patterns amidst severe aridification trends and the arrival of Lybico-Berber communities, which led to the formation of interstitial communities with greater adaptive diversity. Migration outflows from the Tichitt-Oualata region contributed to the emergence of several alternative pathways towards socio-political complexity elsewhere in West Africa, highlighting the relevance of plastic and multi-scalar approaches in the characterization of social resilience. The archaeological record of southeastern Mauritania also illustrates how mobility and connectivity have constitute a recurrent survival strategy for agropastoral communities across the shifting and unstable frontier between the Saharan desert and the semi-arid grasslands of the Sahel.

Keywords

African archaeology, Tichitt Tradition, Internal African Frontier, Complexity theory.

1. Introduction

1.1 Settlement dynamics, Sahelian prehistory and the genesis of pre-colonial African societies

The process of decolonizing African archaeology involves the intentional undoing of historical narratives and discourses about the African past, and there is an established awareness that these conversations ought to be re-centered around concepts emerging from a close assessment of African societies (McIntosh 1999; Singleton 2001; Ogundiran 2012; Mitchell and Lane 2013; Giblin *et al.* 2014; Chirikure 2021). A better understanding and awareness of the African archaeological record offers immense potential for culturally empowering national and international audiences, while also challenging biased accounts and complementing incomplete narratives about the experiences of human societies across time and space. Several pressing questions emerge in this context, such as addressing how archaeology can best illustrate the formative pathways of the social and political modes of organization of African polities, and how studies of settlement patterns contribute to a more holistic understanding of Africa's prehistoric heritage.

Settlements are a type of place-making locale emerging from social interactions between members of the human group(s) that consistently or intermittently inhabit a series of structured functional spaces (Flannery 1972; Cribb 1991; Lane 1994; Parker Pearson and Richards 1994; Flannery 2002; Swerida 2022). The placement of settlements within the landscape is generally non-random, with each society, and sometimes each segment within society, having a series of culturally specific value systems that assist in determining the relative weight of different socio-ecological factors when choosing where to settle (Ucko *et al.* 1972; Jochim 2022). These often respond to the varying influence of several relevant and often inter-related factors such

as connectivity and distance to other sites, raw material availability for building structures and technological production, or the reliability of the water supply (Smith 1972; Wilson 1982).

Settlement patterns are inherently multi-scalar in nature, comprising an aggregate of analytical units. Each of the levels at which they operate—individual structures, local settlements, as well as regional or zonal patterns of settlement distribution—can offer complementary insights into the socio-economic and political dynamics of human communities (Trigger 1967; Parsons 1972; Bevan and Connolly 2006; Kohler *et al.* 2007; Fennell 2008; Harrower *et al.* 2022). For example, MacDonald (2020) has emphasized the regional and typological diversity of earthen architecture in the prehistory of the West African Sahel, with a shift from curvilinear to rectangular structures observed in the Méma region of Mali around the mid-first millennium AD, linking it with wider processes of demographic and socio-economic change. Analyses of these components can thus be diachronic or synchronic, based on the level of chronological control available for individual sites and landscapes (Wilson 1982).

The analysis of demographic, social, economic and political processes in prehistory becomes of utmost interest in the study of Africa's past, given Kopytoff's (1987: 15) suggestion that "many of the widely shared fundamental traits of pan-African political culture must have initially been laid down in the Saharan-Sahelian Neolithic, often under frontier-like conditions". The highlands of southeastern Mauritania represent one such key ecotone in this cultural, theoretical, and methodological context, a frontier ecosystem between the pastures of the Tagant Plateau and the seasonal lakes of the Hodh Basin, as well as between the Sahara Desert and the Sahelian grasslands throughout the Late Holocene.

French researchers and colonial administrators were already remarking upon the heritage of the region and its archaeological potential, including still-standing drystone settlements and funerary monuments, during the first half of the twentieth century (e.g., Verneau 1920; Mauny

1951). Field surveys based on local knowledge are generally a more time-effective and culturally sensitive method of archaeological exploration of settlement patterns on the ground, particularly in contexts of poor site visibility, lack of prior information, and/or initial local mistrust of archaeologists (Canós Donnay 2016). The first detailed archaeological fieldwork was conducted by Patrick Munson (1971) in the Dhar Tichitt region. Munson outlined a multi-stage cultural sequence (Tichitt Tradition) on the basis of settlement morphology and composition, extending from the late third millennium BC to the end of the first millennium BC. The overall robustness of his chrono-cultural framework was confirmed and refined by subsequent fieldwork at Dhar Tichitt and in the nearby plateau regions of Dhar Oualata and Dhar Néma (Vernet 1993; Person *et al.* 2006; MacDonald *et al.* 2009; MacDonald 2013). An additional phase of occupation, from the end of the Late Tichitt period into the first millennium AD ("Terminal Tichitt" or "Early Iron Age"), was later defined from comprehensive survey work in Dhar Tagant and includes evidence of iron-working and large walled settlements (Ould-Khattar 1995; MacDonald 2020; Linares-Matás and Lim 2021a). Munson (1971) also produced what was, at the time, the earliest archaeological evidence of sub-Saharan crop domestication through the presence of chaff-tempered pottery and pearl millet (*Pennisetum glaucum*) grains themselves. While the domestication pathways of this cereal of pan-African importance have since been shown to have deeper origins elsewhere (Manning *et al.* 2011; Fuller *et al.* 2021), research in southeastern Mauritania remains paramount for understanding the socio-economic processes associated with the emergence of large agro-pastoral economies in the Saharo-Sahelian belt (Holl 1986; Amblard 1996; MacDonald 2015).

Exploring the prehistoric dynamics of landscape use and settlement patterns in the highlands of southeastern Mauritania therefore offers an unparalleled avenue for understanding the formative pathways of African socio-political systems in their own terms. Simultaneously, it serves as a way to start empirically testing Kopytoff's intuition in relation to the spatio-

temporal framework for the genesis of many defining features of historical and contemporary African political systems. Field surveys based on local knowledge are generally the most time-effective and culturally sensitive method of archaeological exploration on the ground, particularly in contexts of poor site visibility, lack of prior information, and/or initial local mistrust of archaeologists (Canós Donnay 2016). Nonetheless, regional security concerns in many parts of Africa, including this region of Mauritania, have limited accessibility in the past and continue to do so today, a situation only exacerbated during the COVID pandemic. In this context, spaceborne surveys offer a complementary and cost-effective avenue for undertaking systematic and independent assessments of settlement patterns (Wiseman and El-Baz 2007; Parcak 2009; Harrower and Comer 2013; Lim *et al.* 2022). The promising visual detection rates of stone-built features in arid highland environments in tandem with the increasingly higher resolution of freely available satellite imagery provides an invaluable avenue for archaeological research (Rayne *et al.* 2017; Vernet 2017; MacDonald *et al.* 2018; Linares-Matás and Lim 2021a; Linares-Matás 2022; Wilson 2022).

In this paper, I present the results of a comprehensive remote sensing settlement survey over an area of more than 40,000 km^2 in the highlands of southeastern Mauritania, encompassing the Tagant Plateau and the chain of escarpments extending from Dhar Tagant in the west to Dhar Néma in the southeast (Figure 1). This overview integrates known site distributions with the results of in-depth remote sensing survey work in order to better characterize the spatio-temporal dynamics of landscape occupation in the highlands of southeastern Mauritania from the second millennium BC to the first millennium AD. Next, I explore aspects of political and demographic resilience and collapse by looking at changes in site distribution patterns and socio-economic adaptations in the face of strong aridification trends and cultural contact associated with the arrival of Berber communities in the region. As part of this settlement pattern analysis, I combine aspects of site size, spatial distributions, and the number and nature

of settlement features to explore what I consider to be three core dimensions of prehistoric settlement dynamics in southeastern Mauritania: 1) the spatial processes associated with the interstitial biographies of socio-cultural expansion into unpopulated areas of the landscape (cf., Kopytoff 1987); 2) the configuration of mobile space in Saharo-Sahelian prehistory through an assessment of "shifting sedentism" processes (cf., Canós Donnay 2016); and 3) the role of self-organizing dynamics and other non-linear processes underscoring supra-regional settlement systems over the *longue durée* (cf., McIntosh 2005).

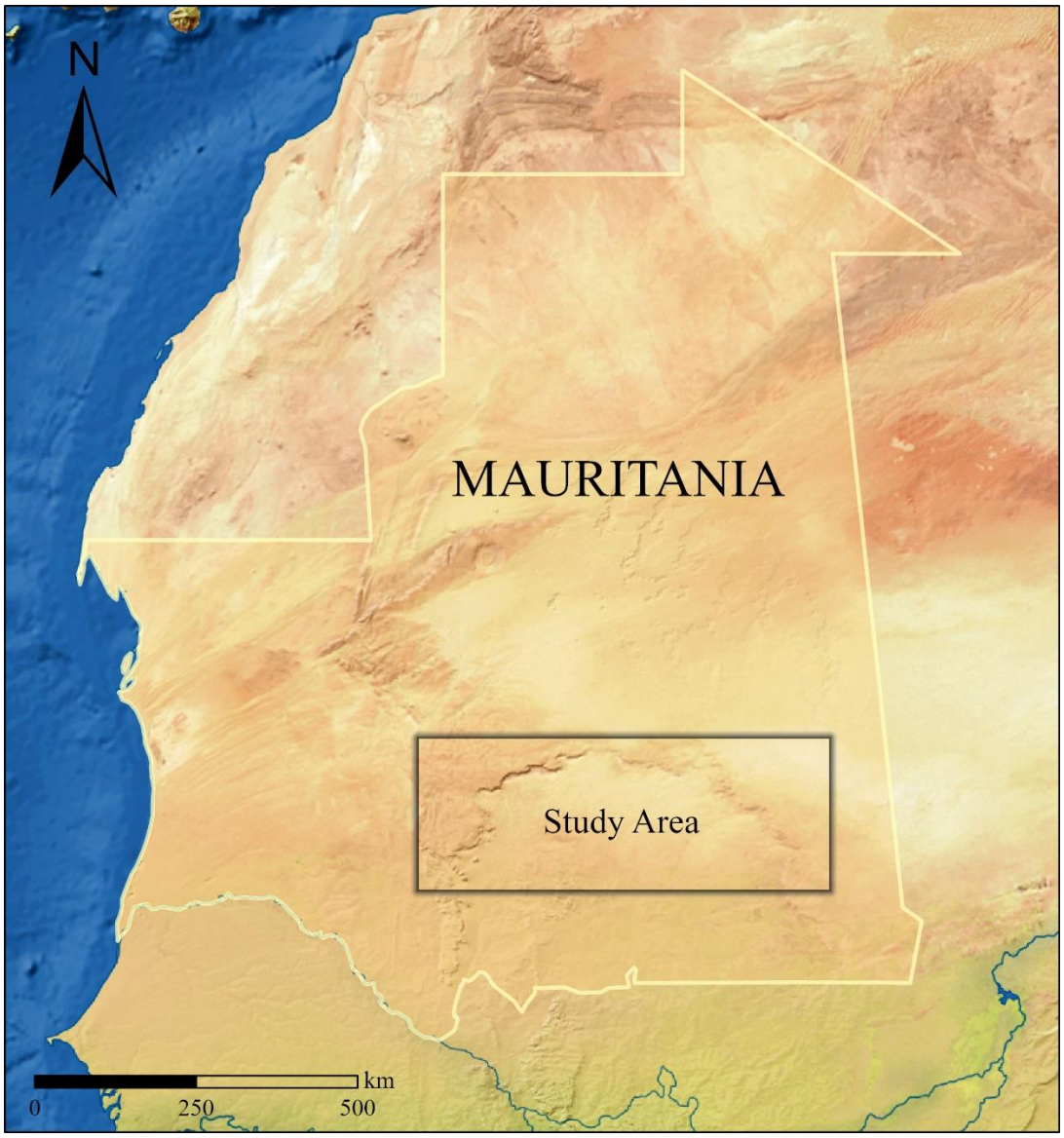


Figure 1. Topographic map of Mauritania, with remote sensing survey area highlighted.

Systematic regional surveys of settlement patterns, like the one presented here, aim to assess the extent of landscape occupation to infer cultural processes from the changing nature of the social and economic practices documented at archaeological sites, as well as from changes in the location of sites themselves within the landscape (Parsons 1972; Covey 2015; Harrower *et al.* 2022). This landscape-wide approach has a long history within archaeological research (e.g., Braidwood 1937; Willey 1953; Sanders 1965; Trigger 1965 for some early paradigmatic examples, as well as, e.g., Munson 1971; McIntosh and McIntosh 1980; MacDonald 1994; Togola 2008 in the context of Sahelian West Africa). In this regard, understanding palaeoenvironmental and climatic trends offers a relevant framework through which to discuss patterns of human adaptation and cultural change over time via the lens of settlement dynamics, particularly in arid areas where rainfall fluctuations can decisively impact the productivity of local ecologies (Chami *et al.* 2003; Kuper and Kröpelin 2006; Drake 2012; Finkelstein and Langgut 2014). To discern and characterize the genesis of African polities more reliably through an archaeological lens without essentialising them, we first need to discuss their features and internal social dynamics.

1.2 The Socio-Political Pathways of African Societies

In their classic foundational study, Evans-Pritchard and Fortes (1940) characterized the typological diversity of African political systems into two main categories: societies with centralized administration (states) and a wide range of polities where the main framework of the political system rested on competing lineage segments of permanent, unilateral descent groups. In segmentary societies, the spheres of ritual, political, and economic authority are not neatly aligned since they are regulated by different corporate units at a territorial scale defined by kinship ties, rather than centrally imposed administrative boundaries (Southall 1956; McIntosh 1999). This is partly possible because no corporation or lineage segment has a

dominant place in the socio-political structure through organized force. Additionally, political office did not intrinsically provide lasting economic privilege, a dimension modulated instead by household productivity (Evans-Pritchard and Fortes 1940; McIntosh 1999). Instead, lineage structures entail a series of rights and duties, distributed across many segmentary levels, which can be used to mobilize collective action in terms of reciprocal protection as well as aid, compensation, and responsibility towards the dead. In this context, segments that would otherwise represent an autonomous unit merge with others to fulfil some of these duties, thus creating a multi-layered interlocking of relationships that contribute to maintaining social cohesion among segmentary corporate groups, especially in the absence of a specialized political authority (Middleton and Tait 2004 [1958]). These constituent units of the segmentary lineage system emerge through processes of splitting and are formally regarded as complementary and politically equal, regardless of whether they share the same level of population or wealth, as power is extended in the lineage structure rather than concentrated within the strongest segment (Middleton and Tait 2004 [1958]).

Internal political authority can be primarily articulated through the lineage system itself, although other social structures, such as age-sets, ritual associations, and secret societies, may also be vested with some degree of political authority, independently of or in conjunction with lineage corporations. The ritual sphere offers an additional avenue for actively maintaining order and community cohesion through the cyclical reproduction of social structures. As noted by Evans-Pritchard and Fortes (1940), a common belief system has the centripetal power to regularly affirm and consolidate an ideology of collective solidarity and interdependence between lineage segments, thereby tempering the centrifugal rise of private sectional interests and segmentary autonomy that might emerge in daily practices. On the basis of the principles of political formation observed in the Grassfields region of Cameroon, Kopytoff (1987 1999) argued that these processes of reproduction generally took place in ways that mirrored the

ideological and material structures of the source community (or communities) from which they had come in terms of regulating spatial organization, ritual practices, and the accepted avenues of socio-political legitimacy and authority (see Vansina 1990 for a description of similar processes among Bantu-speakers' polities).

An important aspect to bear in mind in large-scale diachronic studies of settlement systems is that factors such as the architecture and spatial organization of a site do not necessarily clearly illustrate the socio-political organization of the society. There are historical and ethnographic examples of centralized rule within a system of widely dispersed, shifting villages, such as among the Bemba of Zambia (Evans-Pritchard and Fortes 1940) or in the Upper Casamance region of Senegal (Canós-Donnay 2012); similarly, the Tallensi of Ghana were ascribed to the category of "acephalous" or stateless societies even though their settlements were dense and permanent (Fortes 1940). Indeed, McIntosh (1999) commented on how remarkably robust Fortes and Evans-Pritchard's (1940) proposition that there was no direct relationship between population density and political centralization in Africa has proven since it was first formulated, with the lineage system acting as one of the main mechanism of social integration and political organization.

Nevertheless, the study of settlement dynamics is fundamental for understanding the genesis and socio-political pathways of many African polities. Following Kopytoff (1987), their initial emergence is intrinsically tied to processes of immigration and colonization of territories within an institutional vacuum, which allowed people in the frontier to produce and reproduce new polities. These dynamics result from two relevant socio-ecological dimensions of political experience. The first of these is the existence of social mechanisms for demographic expansion and/or conflict resolution over issues of witchcraft or political succession that entailed processes of fission and segmentation, coupled with the large availability of sparsely populated landscapes where new settlements could be established (Kopytoff 1987). Under these

circumstances of constant flux and circulation, a successful claim to anteriority and territorial precedence, of having arrived first, became a fundamental principle in the negotiation and legitimization of authority in many African polities. In terms of intra-group interactions, Kopytoff (1999) argues that the earliest settlement appears to have held a prominent ritual and political role among certain Aghem polities of the Cameroonian Grassfields, with the head of this first village (Zong∂Ku) becoming by ideological and political consensus the main *primus inter pares*. The ideological and political primacy of chiefs or senior members from firstcomer lineages granted them a considerable power in interactions with newcomers, who had to seek authorization to settle in their territory, a process that entailed the negotiation of usufruct rights as well as land ownership allocation (Kopytoff 1987). The power to grant land—an otherwise costless resource given its ample availability—but also to evict local settlers, played a key role in the establishment and regulation of relationships between firstcomer and newcomer lineages through exercising control over people (Kopytoff 1999; McIntosh 1999; Whitelaw 2015).

An important dimension of authority derived from settler primacy emerges not through claims of land ownership in a colonial, economic sense but fundamentally from the establishment of ritual relationships to the land. In the West African Sahel, the mediation of the land-granting chief with the deities of the bush was a necessary step if the newcomers were to work the land safely (Raynaut 1997; Dueppen 2012b). Additionally, the ritual authority of chiefs is contingent upon the approval or tacit acquiescence from the Earth's forces and the deities of the bush, without which a chief's powers are void (Fortes 1940). The most frequently discussed dimension in this regard is a chief's ability to make, petition, or implore for rainfall (Fortes 1940; Chirikure *et al.* 2017). The institution of rain petitioning is not exclusively the preserve of mystical rulers monopolizing occult ritual knowledge, however, instead being seen in some societies, such as the Shona of Southern Africa, as a collective effort of ecological healing (*mukwerera*) enacted at the beginning of the agricultural cycle by different members of society

at the household, village, and chiefdom levels under the aegis of relevant political and ritual leaders (Chirikure 2021).

The relevance of these social dynamics is illustrated by the fact that the management of people was the main mechanism in the political ecology of wealth and power across many labor-limited agricultural societies in Africa (Goody 1976; Guyer and Belinga 1995; Bogaard *et al.* 2019). This principle of "wealth in people" appears to have counteracted the potential for the concentrated power to allocate property rights among firstcomer lineages to be converted and consolidated into a permanent instrument of social oppression. This social dynamic was buttressed by strong and widespread ideological principles prioritizing the active (re)distribution of land towards those that needed it and could make use of it, a "fairness in flexibility" ideal rooted on a horizontal distribution of socio-political power, rather than disproportionally privileging those lineage members with most wealth or political influence (Shipton 1994: 350). In these models, there is much greater emphasis on material wealth dispersion and maximizing fertility over material accumulation, since principles of generosity are intrinsically linked with political legitimacy (King 2018); moreover, goods are readily transferred in a centrifugal fashion through bridewealth payments and the practice of royal–commoner marriage (Goody 1976). The purchasing of titles and society membership also leads to a cycle of material redistribution as a way of transforming and translating economic wealth into social capital. These active ideological and socio-political processes of centrifugal lineage wealth distribution highlight the importance of enacting power through socially distributed richness over the accumulation of material goods and means of production in private hands or individual lineages. Even if a chief (or more precisely, a chief's corporate lineage) "owns everything", it is still the people who make up the source, the aim, and the substance of chiefly authority (Kopytoff 1999). Fortes (1940) recorded a similar ideological structuring of moral and political authority as distributed among its members, since the office belongs to the

maximal lineage and the community and its incumbency, and thus rank, is temporary, rotating among the different lineage segments. As such, surplus was predominantly invested in the reproduction and consolidation of social networks – where power was embedded – rather than hoarded and/or converted to items of ostentatious display (Goody 1976; Prins 1980).

Mobilizing the labor of different types of people also grants the ability to mobilize different types of knowledge from a cultural, technological, and ecological perspective, and at multiple spatial scales, from local to regional and beyond. Individuals or organizations with coveted knowledge could mobilize and accumulate followers from whom it was possible to extract tribute – the legitimate mechanism for converting "wealth in people" into material goods – and through whom they could establish new polities, although these followers had some degree of freedom to abandon a leader who failed to offer protection or deliver on their promises (Guyer and Belinga 1995). In this context, achieving a comfortable degree of food security was a fundamental enterprise needed to retain followers, making the control, management, distribution, and successful exploitation of land, both for agricultural production as well as in terms of cattle pastures, a paramount responsibility of corporate lineage heads (Chirikure 2021). This principle does not necessarily exclude social participation in large-scale exchange networks of prestige good distribution, however, (cf. Blanton *et al.* 1996), as each of these arenas provide different sources of tensions and opportunities within the system (McIntosh 1999). Nevertheless, prestige good economies tend to be far more conspicuous in the archaeological record, while these processes of internal wealth distribution would generally leave few if any archaeological traces of any existing socio-economic disparities. Therefore, only marginal or contingent differences in terms of cultural distinction and control over non-human means of production tend to arise between elites and commoners under this style of socio-economic organization (McIntosh 1999; Chirikure 2021).

As such, while descent remains a fundamental principle for legitimizing authority, a willingness and ability to distribute land and other material goods through generous displays ensures the continued support of followers and thus enables the thriving development of novel frontier polities (Kopytoff 1987). The provision of shelter, physical and ritual safety, and potential for social interactions is therefore an added dimension of political power for lineages wielding firstcomer primacy to build and consolidate a social following, as argued by Chirikure (2021) in relation to the rise and sustained legitimacy of political elites at Great Zimbabwe. Guyer and Belinga (1995) highlight how this dynamic composition of social and ritual power emerges as a paramount gateway and marker of successful leadership in environmentally uncertain ecosystems, such as those that characterize much of North and West Africa, spanning the Sahara Desert, the Sahelian belt, and savanna-forest ecotones further south.

Understanding where, when, and how the antecedents of these complex socio-economic features may have emerged in the context of African prehistory would provide a legitimizing depth to the experiences and histories of many living communities, while also anchoring discussions around the fundamental contributions that African societies and their pasts can make towards expanding our conceptualization of past and ongoing human experiences across the globe. These two dimensions represent a powerful intellectual and moral impetus towards the archaeological documentation and assessment of Sahelian landscapes, with a focus here on the highlands of southeastern Mauritania.

1.3 Harnessing complexity theory and non-linear models as conceptual frameworks for the study of Sahelian prehistory

Human societies have multiple, dynamic, and interconnected components. Systems thinking has a long history within archaeological thought, starting with Binford and Binford (1968), who were strong proponents of the ability of archaeology to describe and explain dynamic

cultural processes using middle range theory. Kent Flannery was a strong early proponent of cybernetic approaches, emphasizing the role of positive feedback loops in the realization of unpredictable outcomes, both in the context of plant domestication in Mesoamerica (Flannery 1968) and the emergence of the state (Flannery 1972). In the latter, he highlighted the important role played by processes of interconnectivity, integration, promotion, and internal differentiation. Clarke (1968) explored the role of material culture attributes and artefacts in assembling and transmitting horizontal and transgenerational communication by treating patterned regularities across time and space as emergent properties of cultural systems that covaried with variety, namely the diversity and quantity of information that the system could process. Renfrew (1972) argued that while a rigorously mathematical approach remains difficult to implement in archaeology, systems theory can provide a useful framework for describing the feedback mechanisms of interconnected subsystems.

Complexity theory characterizes human societies as Complex Adaptive Systems, comprising dynamic networks involving human and non-human agents able to learn and adaptively respond to interactive feedback (Casti 1979; Mitchell Waldrop 1992; Knappett 2011; Byrne and Callaghan 2014; Youngman and Hadzikadic 2014; Daems 2021). This vision challenges traditional homeostatic visions of stability and equilibrium by highlighting change, adaptiveness, and creativity. From a behavioural and analytical perspective, these Complex Adaptive Systems are:

1) **Adaptive**. The ability of interactive, semi-autonomous agents to modify their strategies as knowledge and experience accumulates. Adaptiveness thus requires agents to possess a degree of contextual awareness and the internal capability to change. The resulting dynamic entanglements continuously create or reimagine interdependent participatory niches for the agents involved in the system (Holling 2001).

2) **Open**. An important dimension is the fact that complex adaptive systems are not closed or homeostatic, a typical assumption in early cybernetic theories, where changes in one subsystem lead to expected and predictable changes elsewhere (Luhmann 1995). Instead, the permeability and interactive capacity of Complex Adaptive Systems in terms of receiving and processing external input flows can lead to unpredictable parameter reorganization. Adaptive agents can draw upon these exchanges of energy, matter, or information to endogenously promote changes in the system in ways that may not have been possible to predict or enact under prior parameter configurations (Wood and Matson 1973). In open systems, human communities can readily extract and process information from different dimensions of their environment, which enables them to adapt and evolve in the face of changing climatic conditions.

3) **Nested**. A property consisting in the fact that the adaptive cycle of an agent simultaneously interlocks and operates with the adaptive cycles of other agents at multiple scales. Nestedness often emerge independently of interaction type and can be hierarchically structured either in a consistent or a competing way—where order within each scale is arranged in a different sequence (Cantor *et al.* 2017). Nested systems with bi-directional, cross-scale feedback mechanisms are described as a "panarchy" (Gunderson and Holling 2002; Allen *et al.* 2014; Sundstrom and Allen 2019).

4) **Emergent**. Emergence refers to instances where an operating entity exhibits properties that each of its interconnected constituent parts lack. Since the aggregate is not attained by linear summation, the system is considered to be non-linear (Holling 2001). Self-organization or "spontaneous order" constitutes an emergent property that unfolds within open complex systems in the context of decentralized, feedback-driven patterning within particular behavioural milieus. In the context of Sahelian archaeology, McIntosh (2005) employs these insights to explain the process of

population nucleation in the Middle Niger region of Mali by the middle of the first millennium AD without having to rely on the presence of vertical political hierarchies. He argues that the formation of a multi-satellite, multi-corporate urban complex with multiple town settlements, including the well-known site of Jenné-jeno, was the result of a prolonged co-evolutionary process of reciprocal adaptive selection involving a series of specialized communities (farmers, herders, fishers, hunters, potters, blacksmiths, etc.) interacting in mutualistic symbiosis, emmeshed in long-distance trade networks but lacking a ruling elite (McIntosh and McIntosh 1993; McIntosh 1999). As such, and from a global perspective, urban coalescence represents a fluid and emergent process of gravitational nucleation in the absence of a predetermined layout, articulated through landscape knowledge networks that could not have been readily anticipated from the states and prior conditions of their "rural" constitutive elements (Jantsch 1982; Johnson 2001; McIntosh 2005; Batty 2007; Sengupta 2017).

5) **Chaotic**. In systems with highly integrated adaptive feedback mechanisms, small changes in initial conditions can lead to very different, disproportionate, and often unintended outcomes. In this regard, rare events often have the potential to occur at a greater frequency within these nested systems than would be expected under a bell-curve distribution (Redman and Kinzig 2003). This volatile, "far-from-equilibrium" state is typical of Complex Adaptive Systems, which are often referred to as approaching "the edge of chaos". In other words, complex systems are transformed by the collective action of their constituent agents, who think and act locally on the basis of input flows of information from their neighbors and environmental surroundings, but the impact of their actions transcends their local context in a probabilistically uncertain, non-linear fashion rather than directionally following a fixed and linearly progressive sequence (Howard 1971; Ross 1985; Waldrop 1992; McIntosh 2005). Therefore,

> control *over* places *through* people, as well as control *over* people *through* places, may emerge as fundamental dimensions of political power in the West African Sahel and elsewhere precisely because individual or collective actions at the scale of daily activities and decision-making can have such a strong ripple effect on the structure and nature of the adaptive cycle of human societies.

Interestingly, amidst their perpetual novelty, Complex Adaptive Systems exhibit recurrent patterns of configuration through a continuous recombination of "top-down" and "bottom-up" effects that enable non-linear probabilistic changes within the system (Sundstrom and Allen 2019). These long-term adaptive cycles emerge through the interplay of three fundamental dimensions within the multi-scalar dynamics of self-organized complex systems: potential, connectedness, and resilience (Holling 1973; Marcus 1998; Holling and Gunderson 2002; Sundstrom and Allen 2019). Potential represents the range of options for agents and networks to accumulate energy; connectedness is a function of the nature, quantity, and influence of relationships between elements and processes, which can be either internal or external to the system, while resilience refers to tolerated levels of disturbance that a system can sustain without transitioning to a different state.

Holling and Gunderson (2002) describe the adaptive cycles of human societies as comprising four main states, namely growth (r), conservation (K), release (Ω), and reorganization (α), which represent different possibilities of becoming within a system and not progressive stages of development. The first two states represent the fore loop, with long and convoluted periods of high potential accumulation and transformation of resources through greater connectedness, while the second two states are generally shorter periods where energy is released that create opportunities for creative innovation and greater adaptive fitness as the system unravels and reconfigures (Holling 2001; Burkhard *et al.* 2011). The transition from growth (r) to conservation (K) states is linked with the consolidation of population sizes and socio-economic

reliance on certain resources, as landscape knowledge networks and material entanglements consolidate. There is no guarantee, however, that the system will ever reach the "activation energy" necessary for it to be defined as being in the K stage, a phenomenon known as the "poverty trap" and characterized by self-reinforcing mechanisms that prevent this kind of socio-political change (Fath *et al.* 2015; Hodder 2016).

A transition towards a state of conservation (K) involves the system becoming more strictly defined, coherent, and specialized. In Clarke's (1968) view, high levels of subsystem redundancy and coherence can provide continuity or equilibrium, a perspective consistent with overall systemic stability in this state (Sundstrom and Allen 2019). Nevertheless, it is very interesting to note that highly integrated ("hypercoherent", *sensu* Rappaport 1977) complex systems are far from perfect. While every added unit of input during the growth or productive phase tends to lead to productive gains, this trend eventually starts to experience decreased output yields per unit of added input (Tainter 1988). These "diminishing marginal returns" effects combine in the conservation state (K) with reductions in resilience, as the system experiences a greater risk of becoming more vulnerable to cascade effects—when localized disruptions caused by internal and/or external stressors compromise it in its entirety (Gunderson and Holling 2002; Marston 2015). This is due to the fact that the ability of systems to re-adjust and self-organize actually follows an inverse trend to their specialized coherence (the "rigidity trap"), where communities continue to engage in practices that no longer represent the best response to the available information from their social and ecological environments, and may even be in conflict with the awareness of individual agents.

This scenario can potentially lead to a subsequent reordering of varying magnitude, once the resilience of the system becomes irreversibly compromised by a disturbance (cf., Diamond 2005; Ward-Perkins 2006; McAnany and Yoffee 2010; Webster 2012). This results from the existence of critical transition thresholds for collective behavior ("tipping points") that can act

either as catalysts or inhibitors for social phenomena (Granovetter 1978; Tainter 1988; Gladwell 2000; Scheffer 2009; Bramson 2019). Furthermore, the impact of stressors can be highly asymmetrical, with some portions of the system that had previously been inhibited experiencing the opposite trend and enjoying a degree of resurgence instead (Hall *et al.* 2016; Smith 2021). These non-linear reconfiguration cascades are particularly critical in those contexts where the crossing of a resilience threshold results from the redefinition of the multi-level components in which the system is embedded ("*new normal*") due to large-scale socio-political transformation (e.g., colonialism, internal conflict) or climate change (e.g., a sustained alteration of rainfall patterns). In these contexts, certain behavioural strategies within the socio-economic backbone of a community, such as cattle-keeping, could be rendered unviable. Thus, while climate may not have major implications on the general shaping of cycles (Shennan 2013), in marginal landscapes, such as the Saharo-Sahelian borderland, climate change can nevertheless decisively affect human adaptive thresholds. This dimension emphasizes the fact that social and ecological resilience is neither constant nor linear, given how moments of instability can lead to novel, unprecedented configurations (Prigogine and Allen 1982).

The process of system reordering encompasses the release (Ω), and reorganization (α) states, during which the system undergoes a period of reconfiguration where different opportunities for creative innovation emerge in order to enable greater adaptive fitness (Scheffer 2009; Bradtmoller *et al.* 2017). In the absence of collective memory protocols that could trigger "remember loops", however, the dynamics of re-organization and adaptation can become inconsistent or possess insufficient fitness (the "vagabond trap"), preventing a transition from reorganization to growth and potentially leading to further release (Fath *et al.* 2015).

Lastly, it is worth highlighting that while known Complex Adaptive Systems experience these cycles, the need for a large number of decisions/accidents to co-occur for a specific historical trajectory to develop makes teleological arguments about the evolution of human societies

unsuitable (Gell-Mann 1994). The nature and outcomes of processes within the adaptive cycles of human societies are neither certain nor linear since society itself is always in the making.

These perspectives on non-linear systems are proving instrumental for disrupting teleological narratives of socio-cultural change in archaeology (Bradtmoller *et al.* 2017; Peters and Zimmerman 2017). Furthermore, approaching socio-ecological dynamics in Sahelian prehistory through the theoretical lens of Complex Adaptive Systems can usefully complement frameworks articulated around the notion of the Internal African Frontier when assessing the genesis and socio-political pathways of African polities. Lastly, ecological fluctuations in rainfall patterns in dryland environments constrain the viability of coping mechanisms due to the existence of non-linear thresholds of viability, thus making them excellent ecosystems for exploring the adaptive resilience cycles and behavioural creativity of human communities (Mitchell 2017; Kinahan, 2018).

2. Methodology

In the context of southeastern Mauritania's Tichitt Tradition, settlements are defined as a series of nucleated or isolated drystone enclosures and/or houses, sometimes delimited by a stone wall, where people lived. Houses existed both within and outside the enclosures. Amblard-Pison (2006) distinguished between site definitions *sensu stricto*, encompassing only well-defined nucleations of enclosures, and *sensu lato*, incorporating satellite features. Ould-Khattar (1995) adopted a more holistic definition, considering a site to be a set of enclosures that exhibit spatial and typological coherence and could not be attributed to any other neighboring site. While this second approach still remains a qualitative assessment, I have favored it as a more integrative approach, adopting an arbitrary *c.*100m spatial cut-off for those instances in which a "typological coherence" criterion did not readily enable a separation between sets of enclosures. In the context of Dhar Tagant, Ould-Khattar (1995) describes as "secondary structures" those that are sometimes found within enclosures, forming subdivisions. Usually up to 20m in diameter and circular, subcircular or rectangular in shape, they can stand-alone or be split into two parts that are either clustered or isolated within the enclosure. They may or may not possess an entrance.

The GIS software package ArcGIS Pro 2.9.1 was used to visualize satellite imagery and carry out spatial analyses using in-built geoprocessing tools. Bing Maps was loaded into the GIS as a basemap with a Microsoft license key. While Bing Maps imagery metadata are not readily available, visual inspection confirms that most of the study area displays very high-resolution (VHR) satellite imagery that has been orthorectified to address distortions derived from terrain morphology and viewing angle, thus making it ideal for visual inspection and analysis. Nonetheless, it is worth bearing in mind that there are several issues associated with spaceborne surveys of settlement patterns, such as the one presented here, particularly in areas where

constructions are made using local materials, since naturally disaggregated rocks could, for example, sometimes be misidentified as collapsed walls and some sites that are within rock-shelters or that are concealed in another way (e.g. because of sand dune encroachment) may be undetectable in aerial and satellite imagery (Amblard-Pison 2006). Additionally, sites lacking visible architecture, such as those primarily comprising pottery or lithic scatters, are only identifiable through careful field surveys.

3. Results

The steep sandstone escarpments (*dhars*) of southeastern Mauritania present a very dense archaeological pattern of past human occupation along the escarpments that frame the Aoukar Basin. Today, the main water sources are restricted to springs, water basins (*gueltas*), seasonal wadis (*batha*), temporary ponds on wadi courses (*daya*), and wells, which can either be shallow holes (*ogla*) or deep wells (*bir*, pl. *biran*), following the terminology employed by Himpan and Himpan-Sabatier (2019). Nonetheless, sedimentological remnants of lake beds indicate that the base of the *dhars* hosted large endorheic lacustrine systems during the late third and early second millennia BC (Munson 1971) which subsequently experienced a gradual but ultimately drastic recession in the context of increasing aridity. The availability of water, arable farmland, and grazing pastures sustained over three millennia of human occupation in the region (Munson 1971; Vernet 1993; Ould-Khattar 1995; Amblard-Pison 2006; Holl 2009; MacDonald 2013; Linares-Matás and Lim 2021).

Early assessments have tended to underestimate the number of sites in the Tichitt-Oualata region. Using aerial photographs at 1/50,000 scale and the notes of previous travelers, Mauny (1951) estimated there to be 127 sites, but this number was substantially revised upwards by Amblard-Pison (2006), who counted 411 settlements. Similarly, Holl's (1986) estimation of 46 sites in Dhar Tichitt was updated to 110 (Amblard-Pison 2006). The numbers of sites reported

through remote sensing surveys based on visual inspection of satellite imagery are very close to the values provided by Amblard-Pison, which were based both on extensive field survey and the examination of aerial imagery (Table 1).

Region	**Reported number of sites**	**Source**	**Remote Sensing Survey Results**	**Coverage Success**
Dhar Tichitt	110	Amblard-Pison (2006)	110	100%
Dhar Oualata	301	Amblard-Pison (2006)	290	96.35%
Total Tichitt-Oualata	411	Amblard-Pison (2006)	400	97.32%
Dhar Néma	40	MacDonald *et al.* (2009)	44	110%
Dhar Tagant	273	Ould-Khattar (1995)	330	120.88%
North Tagant	N/A	N/A	366	N/A
Total settlements from remote sensing survey			1,140	

Table 1: Summary of remote sensing results by region and correspondence with previous site counts derived from field surveys and aerial photographs.

Overall, the coverage success rates of the remote sensing survey are very satisfactory, and it is clear that it has made a very substantial contribution to our understanding of settlement patterns in the Tagant. In relation to the 100% success rate reported for Dhar Tichitt, it is worth noting that, while a very substantial overlap is indeed expected, it is not possible at this stage to discern with absolute certainty whether the 110 sites reported for Dhar Tichitt are in every case identical to the 110 sites detected in the remote sensing survey. The fact that more sites were documented at Dhar Tagant than has been reported previously is not entirely surprising, since Ould-Khattar (1995: 157) rightly pointed out that while he had documented the vast majority of settlements his estimate did not constitute the totality of those present. Lastly, no previous publication has provided a reliable estimate of the number of sites in the northern half of the Tagant Plateau. Most of these sites are thus believed to be documented here for the first time.

According to the Jenks natural breaks algorithm, a standard classification method, the optimal presentation of this settlement dataset involves five subdivisions. Thus, a five-tiered settlement division is proposed for the highlands of southeastern Mauritania (Figure 2; Table 2), on the basis of the following criteria:

- **Rank 1** sites are larger than 75 ha or possess more than 250 compound enclosures. They thus represent very substantial agglomerations in the context of prehistoric Saharo-Sahelian communities (Table 2). Vernet (1993) correctly observed that the largest Tichitt Tradition sites are generally located in exceptional settings, near vast floodable depressions or at the crossroads of valleys and other avenues of mobility.
- **Rank 2** sites are those between 25 and 75 ha or that possess more than 100 compound enclosures. They are large settlements, often with partial or complete walls.
- **Rank 3** sites are medium-sized villages, ranging in size from 5 to 25 ha. There are two main variants, depending on location (they can be placed on the slope or atop the

escarpment, with the former generally being less nucleated and the latter often featuring boundary walls; Linares-Matás and Lim 2021a);

- **Rank 4** sites comprise those between 1 and 5 ha. Generally equated to hamlets or small villages (Holl 1993), they are mostly found on slopes but also occur scattered atop the escarpments, most frequently without enclosing walls. In some instances, however, they are located in relatively inaccessible and defensible areas with partial fortifications;
- **Rank 5** sites - those whose surface is smaller than 1 ha. These sites tend to be isolated or small groups of enclosures. Some of these structures may have been reused or constructed anew in the recent past by local nomadic pastoralists.

The incorporation of the number of compound enclosures in the definition of settlement ranking is pertinent because previous assessments of site size rank in southern Mauritania have used this variable exclusively (e.g., Holl 1986; Ould-Khattar 1995). Furthermore, the number of compounds may assist in accounting for variability in site occupation density, since the number and size of enclosures could be tentatively argued to represent a rough proxy for population size. Settlement distribution patterns for each region are depicted in Figures 3-7.

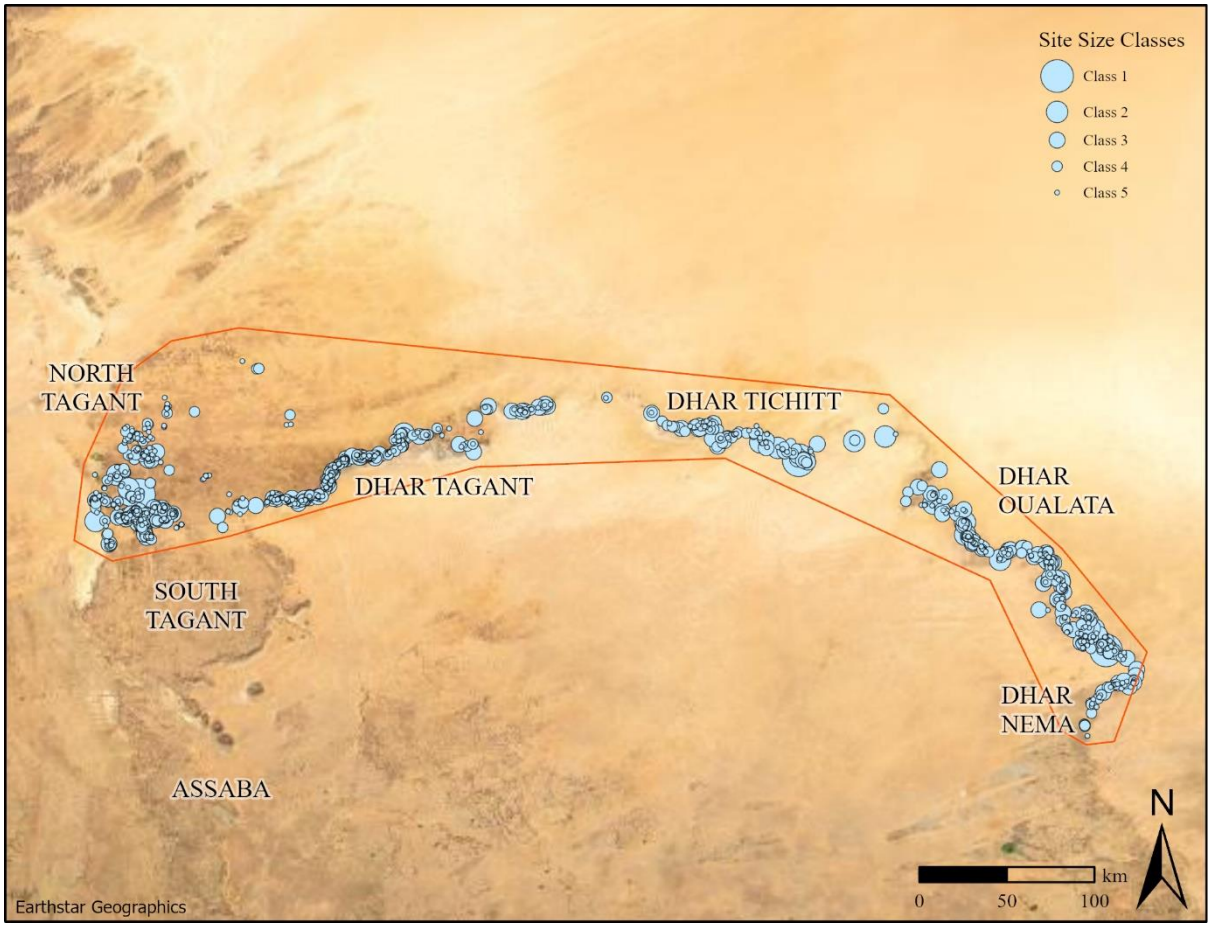


Figure 2. Settlement patterns in the highlands of southeastern Mauritania on the basis of site size class. The red bounding polygon denotes the extent of the settlement survey area. The South Tagant and Assaba regions are the focus of ongoing remote sensing survey work.

Region	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Total
Dhar Tichitt	1 (0.9%)	4 (3.6%)	18 (16.4%)	40 (36.4%)	47 (42.7%)	110
Dhar Oualata	3 (1%)	4 (1.4%)	54 (18.6%)	77 (26.5%)	152 (52.4%)	290
Dhar Néma	0 (0%)	0 (0%)	7 (15.9%)	15 (34.1%)	22 (50%)	44
Dhar Tagant	0 (0%)	4 (1.2%)	27 (8.2%)	91 (27.6%)	208 (63%)	330
North Tagant	1 (0.3%)	7 (1.9%)	25 (6.8%)	112 (30.6%)	221 (60.4%)	366
Total	5 (0.4%)	19 (1.7%)	127 (11.3%)	334 (29.6%)	643 (57%)	1,140

Table 2. Regional distribution of settlements on the basis of site size rank. Percentages are given in relation to the total number of sites in that region.

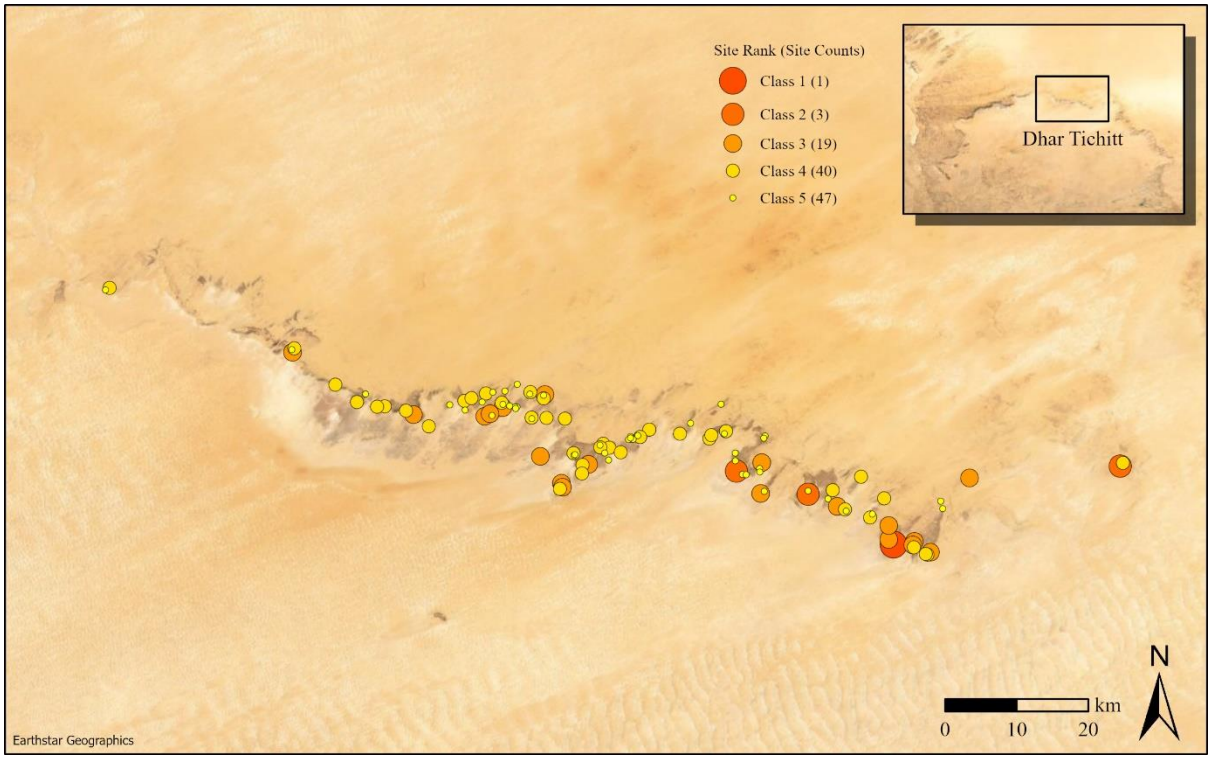


Figure 3. Settlement distribution patterns in the Dhar Tichitt region of southeastern Mauritania.

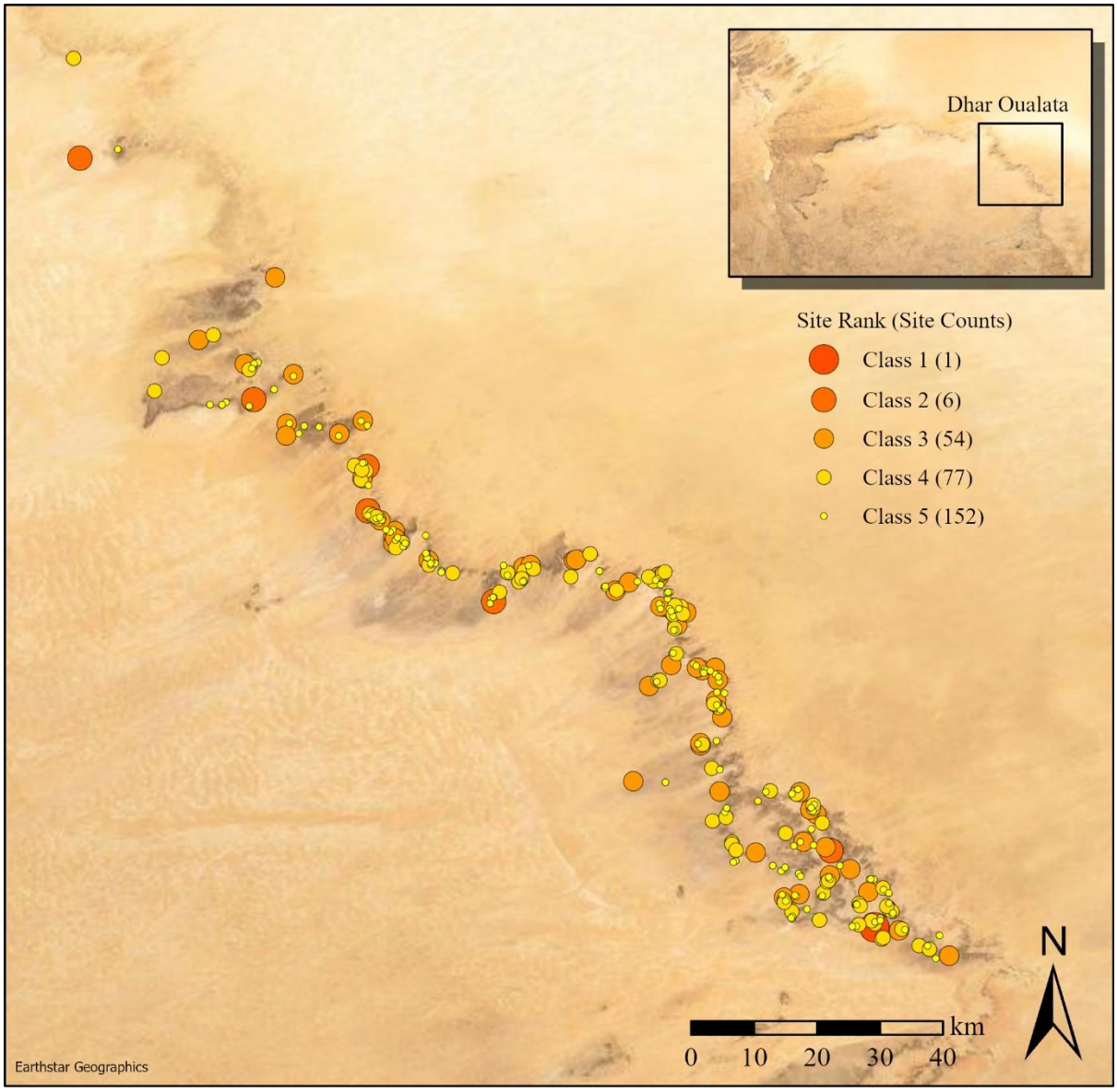


Figure 4. Settlement distribution patterns in the Dhar Oualata region of southeastern Mauritania.

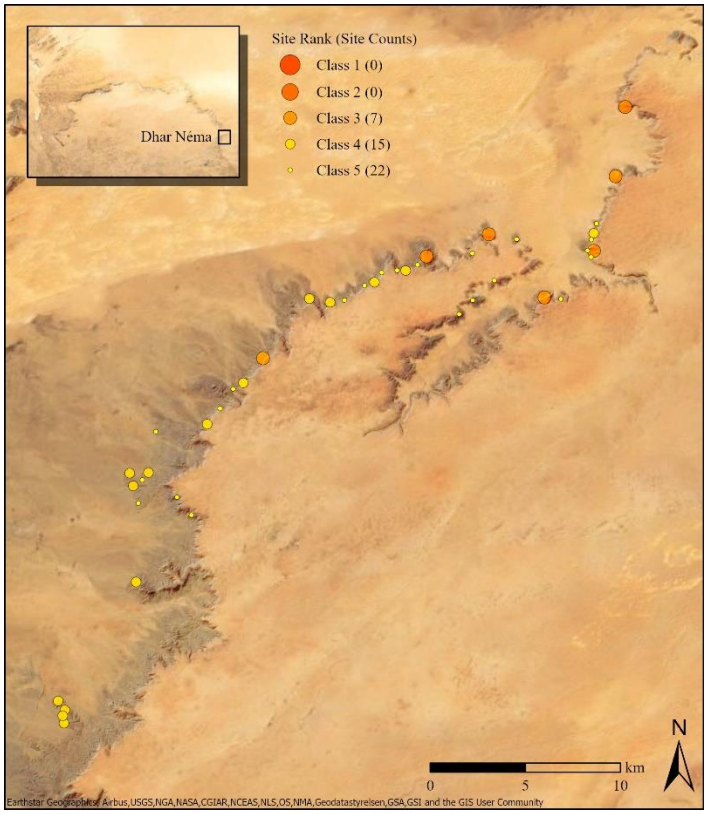


Figure 5. Settlement distribution patterns in the Dhar Néma region of southeastern Mauritania.

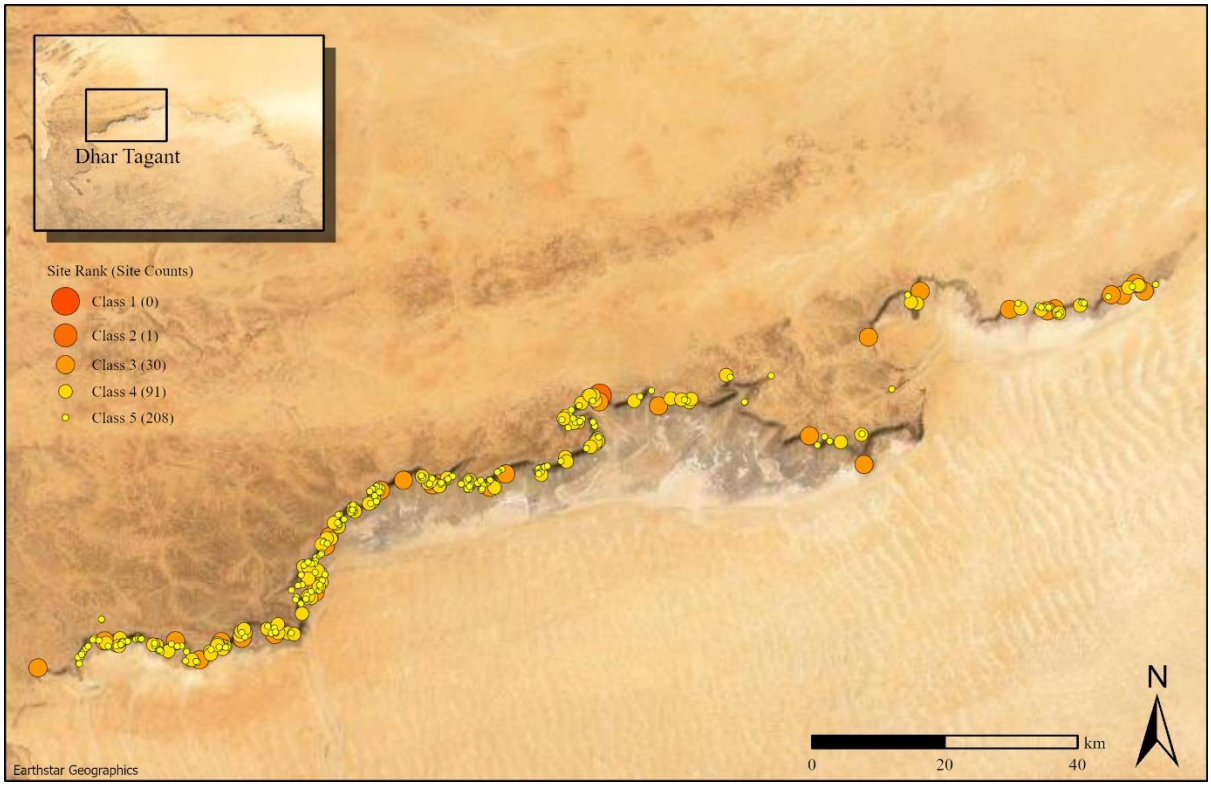


Figure 6. Settlement distribution patterns in the Dhar Tagant region of southeastern Mauritania.

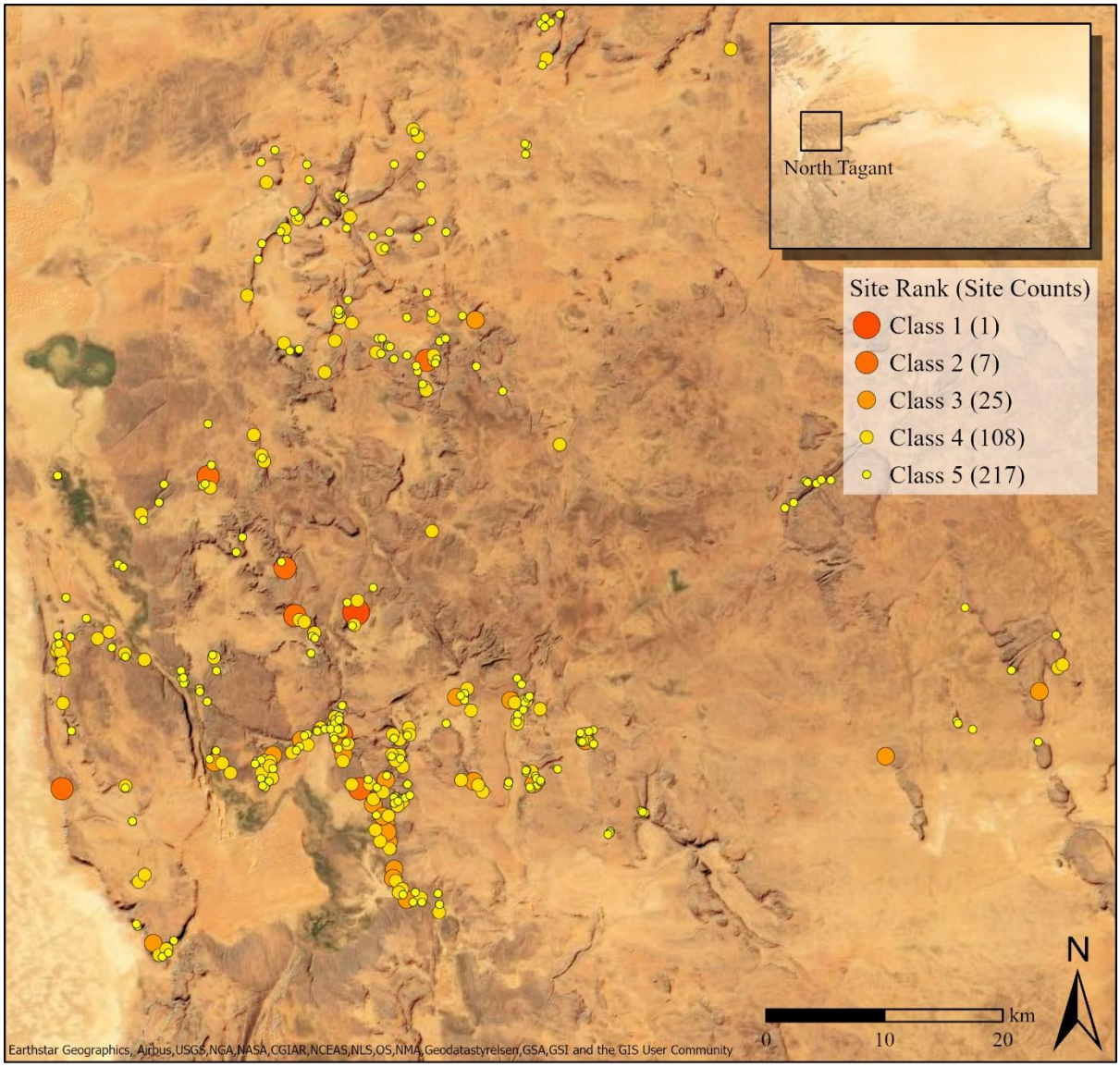


Figure 7. Settlement distribution patterns in the northern Tagant Plateau region of southeastern Mauritania.

Table 3 provides a breakdown of site numbers per typological morphology and region, while Table 4 gives a size rank distribution for those sites considered to belong to the Tichitt Tradition *sensu stricto* exclusively on the basis of attributes visible in satellite imagery (i.e., settlements centred around multiple, thick-walled enclosures; a more holistic definition would also integrate data from ceramic assemblages). Worth noting here is the greater heterogeneity of settlement types in the Dhar Tagant and especially the North Tagant regions.

Type	Néma	Oualata	Tichitt	Dhar Tagant	North Tagant
Tichitt Tradition *sensu stricto*	28	215	89	110	13
House-oriented settlements	0	44	9	25	90
Terminal Tichitt	0	0	0	119	0
Rectangular Houses	0	0	0	8	30
"Sahelian" enclosures	0	0	0	4	2
Tagant compounds	0	0	0	3	197
Single Enclosures	9	22	9	46	24
Islamic	0	0	0	1	2
Others	0	9	3	14	8
Total	44	290	110	330	366

Table 3. Regional settlement distribution on the basis of morpho-typological classification.

Region	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Total
Dhar Néma	0	0	7	15	13	35
Dhar Oualata	3	4	48	59	100	215
Dhar Tichitt	1	4	15	34	35	89
Dhar Tagant	0	2	13	35	60	110
North Tagant	0	0	1	1	11	13
Total	4	10	84	144	219	454

Table 4. Rank size distribution of Tichitt Tradition settlements *sensu stricto* per region.

4. Discussion: Climate change, non-linear settlement dynamics, and social resilience in southeastern Mauritania

The archaeological study of settlement dynamics provides invaluable diachronic insights into the interplay between climate change and socio-economic organization of past human communities. Assessments of settlement size across regional landscapes has been proposed as a powerful descriptor of socio-political organization, with multi-tiered settlement hierarchies with three or more levels being at the core of urbanization processes, administrative complexity, and state formation (Wright 1969; Flannery 1972; Paynter 1982; Huffman 1986; Holl 1993; Marcus 1998; Drennan and Peterson 2004; Harrower *et al.* 2022). Nevertheless, while understanding the modalities of settlement size and settlement distributions remains a relevant concern in studies aiming to characterize the spatial arrangements of human dwelling (cf., Harrower *et al.* 2022), a growing body of empirical data examined through increasingly sophisticated theoretical frameworks is decisively assisting us to discard pervasive models that were developed under the assumption that linear, additive trajectories sufficiently explain patterns of demographic growth and socio-political and cultural evolution (Gronenborn *et al.* 2017). Additionally, site size frameworks tend to be static snapshots criticized for offering little in terms of understanding the internal adaptive cycles of settlement systems (Smith 2021). As such, it is instead useful to explore theoretical frameworks that emphasize processes of change and transformation in settlement dynamics.

The archaeological record from the highlands of southeastern Mauritania enables us to assess the emergence, consolidation, and reorganization of agropastoral societies through the lens of complex adaptive system cycles (Table 5). Determining the relationship between spatio-temporal settlement patterns and climatic fluctuations is paramount for exploring the nature of social resilience and cultural adaptations, as well as the role of migration among human

communities at the Saharo-Sahelian interface in the face of fluctuations in resource availability and predictability. Lastly, the dynamic conditions in Mauritania's prehistoric sequence also have the potential to decisively contribute towards understanding alternative pathways towards increasing social complexity and the formative process of African political systems.

Phase	**Chronology**	**CAS Adaptive Cycle**	**Features**
Pre-Tichitt	2600–1900 BC	Reorganization	Mobile hunter-gatherer-herders living in small temporary campsites.
Early Tichitt	1900–1600 BC	Growth	Pastoral communities with high levels of mobility. Initial cultivation of domesticated pearl millet.
Classic Tichitt	1600–1000 BC	Consolidation	Development of vast settlements comprising conjoined clusters of stone-walled compounds.
Late Tichitt	1000-400 BC	Release	Period of intense aridification and associated demographic decline in the Tichitt-Oualata region.
Terminal Tichitt / Early Iron Age	400 BC – AD 200	Reorganization to Consolidation	Development of complex stonewalled settlements in the Tagant region with evidence of iron metallurgy. Greater emphasis on pastoral mobility in some areas.

Table 5: Brief summary of the calibrated archaeological sequence of the Tichitt Tradition, southeastern Mauritania, after Munson (1971) and MacDonald (2015 2020), with thematic characterization using the CAS adaptive model framework. While this chronological sequence remains the most accepted chronological sequence in the literature, based on data from both radiometric dates and ceramic and architectural seriation, some authors are reluctant to adopt it on the basis of limitations in the extent of dated intra-site stratified deposits and prefer to treat Tichitt Tradition sites synchronously in their analyses (e.g., Amblard 1984; Holl 2009).

4.1 Palaeoenvironmental background to the Sahelian frontier in prehistory

Rainfall patterns in northern Africa are structured in a series of latitudinal bands, which shift northwards or southwards as the Inter-Tropical Convergence Zone (ITCZ) monsoonal front advances or retreats (Kröpelin *et al.* 2006; Armitage *et al.* 2015; Molnar and Rajagopalan 2020). The convective systems underpinning Saharo-Sahelian seasonal rainfall patterns are susceptible to both the impact of temperature on regional shallow circulation patterns as well as to forcings from global-scale tropical atmospheric circulation dynamics, particularly the Hadley Cell, driven by factors such as net energy input at the equator and hemispherical temperature differences (Vallis 2006; Lézine *et al.* 2011; Biasutti 2019; Molnar and Rajagopalan 2020).

The oscillating nature of Saharo-Sahelian climate has long shaped large-scale population and ecosystem dynamics in the region, with human mobility and behavioural flexibility intertwined with wider environmental trends (McIntosh and McIntosh 1988; Hassan 1997; Kröpelin *et al.* 2006; Linseele 2007; Manning 2010; Manning and Timpson 2014; Ozainne *et al.* 2014; Maley and Vernet 2015). Highland areas in the Saharo-Sahelian belt experience localized moist, high-pressure systems that provide more rainfall than in surrounding areas even under hyper-arid conditions (Rognon 1976; Flohn and Nicholson 1980; Nicholson 1994; Kröpelin *et al.* 2006). These topographic clusters of greater water and biomass availability made them very attractive landscapes for human occupation throughout most of the Holocene (Barich *et al.* 1984; Gautier 2007), with fluctuations in resource potential influencing intensity of occupation over time.

While the Early Holocene in the Sahara was characterized by relatively stable wet conditions, the environment turned increasingly seasonal and arid during the Middle Holocene, with marked transgressive clinal changes documented through the fifth millennium cal. BP (Street and Gasse 1981; Gasse and Van Campo 1994; Hassan 1997; deMenocal *et al.* 2000; Kröpelin

et al. 2008; Lézine *et al.* 2011; Armitage *et al.* 2015; Dupont and Schefuβ 2018; Ndiaye *et al.* 2022). Throughout most of the Middle Holocene, the palaeoenvironmental niche for cattle-keeping grew considerably and pastoral communities expanded across the open savanna grasslands of the central and eastern Sahara (Kuper and Kröpelin 2006; Phelps *et al.* 2019). The management of livestock herds represents a relevant social arena among pastoral communities for the negotiation of skill and status, with survival and prosperity of cattle herds acting as a decisive mechanism to establish rank in life, a process that may be reflected in the appearance of monumental tumuli with individual human burials in the southern Sahara (MacDonald 2013). If Middle Holocene societies exhibited a similar pattern of community livestock redistribution through bridewealth and after death to that documented ethnographically, these mechanisms would have tempered social dynamics (Marx 2005; Smith 2005). Social and economic resilience would have been extended through the exchange of marriage partners and the replenishment of any locally depleted herds enabled by the maintenance of long-distance interaction with other communities, a process documented by the extensive trade of polished stone objects (axes, beads, bracelets) throughout the Sahara during the Middle Holocene (Holl 1998; MacDonald 1998). Towards the late Middle Holocene to Late Holocene transition, the archaeological record of Mali shows some of the earliest instances of pearl millet cultivation in Africa, carried out by hunter-herder communities on the southern fringes of an expanding Sahara (Manning *et al.* 2011; Fuller *et al.* 2021).

The onset of the Late Holocene in the mid-fifth millennium cal. BP was characterized by a southward migration of the ITCZ (Lespez *et al.* 2011; Lézine *et al.* 2011; Armitage *et al.* 2015; Ndiaye *et al.* 2022). These palaeoclimatic trends also pushed southwards the "tsetse belt", named after the fly vector of trypanosomiasis (*Glossina* spp.), which has often acted as a biogeographical frontier for livestock rearing (Smith 1979; Gifford-Gonzalez 2000; Mitchell 2018). Together, they fostered the expansion of pastoral communities away from the drying

Central Sahara and into the open landscapes of the southern Sahara and the Sahel. The receding Lake Chad floodplains, the Agadez Basin of Niger, the Tilemsi Valley of Mali and the Tichitt region of Mauritania would have comprised well-watered environments, conducive to agropastoral lifestyles (Smith 1979; McIntosh and McIntosh 1988). Further expansion along the main river basins of Sahelian West Africa may have been driven primarily by local habitat modification and the successful development of dwarf trypano-tolerant cattle and goat breeds from around 2000 BC (MacDonald and MacDonald 2000; Linseele 2007; Wright 2011; Lane 2015). A trend towards breed size reduction has indeed been documented at Sahelian sites such as Chin Tafidet (Niger; Paris 1992), Karkarichinkat (Mali; Smith 1975), Khatt Lemaiteg (Mauritania; Vernet 1992), Dhar Tichitt (Mauritania; Munson 1971), Windé Koroji Ouest south of the Niger bend (Mali; MacDonald 1996) and Gajiganna (Nigeria; Breunig *et al.* 1996).

In general, Late Holocene West African communities demonstrate a considerable behavioural flexibility in their subsistence strategies as they adapted to a diversity of socio-ecological settings. In addition to the strong pastoral orientation discussed above, some societies exhibited a greater fishing component, such as the shell middens of coastal Mauritania and Senegal (Petit-Maire 1979; Vernet 1993), while others, such as Foum el Alba (Mali), predominantly feature pottery and grain-processing elements such as grindstones (Petit-Maire *et al.* 1983). Changing palaeoenvironmental conditions therefore enabled the reorganization of Late Holocene communities south of the Sahara, whose practices and pathways were mediated by mobility structured around the seasonal and longer-term transformation of hydrological landscapes (McIntosh and McIntosh 1988: 99; Marshall and Hildebrand 2002; Ozainne 2013).

4.2 First Reorganization State: The arrival of Pre-Tichitt communities

In the context of the highlands of southeastern Mauritania, even though Late Stone Age (LSA) hunter-gatherers had been present during the late Pleistocene, there seems to be an occupational hiatus until the onset of the Late Holocene, with the arrival of mobile hunter-fisher-herder communities ("Pre-Tichitt") in the region and the gradual regression of permanent lakes in the Hodh depression (MacDonald 2013). While hunter-gatherers tend to schedule their mobility around consumption, exploiting a diverse set of ecological niches and resources to mitigate seasonal risk, the logistics of cattle pastoralists rely predominantly on the relatively narrow consumption patterns of their livestock herds (Binford 1980; Ingold 1987). As such, archaeologists have long conceptualized pastoralist mobility and migration in the Saharo-Sahelian belt as episodic and non-linear, interspersed by relatively long-term residence in favorable environments, i.e. in oases or along wadis and escarpments, interrupted by drought or resource overexploitation (Gabriel 1987; Sadr 1998; Hassan 2000).

The documented sites are generally small, superficial localities resulting from temporary campsite settlements (MacDonald 2013). Some, such as Bou Bteiah, in southern Dhar Néma, are located on rocky outcrops and promontories with a commanding view of extensive lowland areas, making them very suitable emplacements for the monitoring of wild game and livestock herds alike (MacDonald 2015). Faunal remains at southern Dhar Néma sites such as Bou Khzama II and Djiganyai show evidence of a generalized pastoral economy with cattle, sheep, and goats without evidence of dwarfism, freshwater fish (catfish [*Clarias* sp.] and tilapia [*Cichlidae*]), as well as hunted animals, such as *Gazella* sp., *Hippotragus,* and *Kobus* (MacDonald *et al.* 2009). On the technological front, well-sorted sand tempered clay comprises the fabric of ceramics—which generally have simple rims—while the lithic assemblages, with

attributes resembling those of the central Sahara, show a gradual decline of geometric microliths in favor of projectile points (Munson 1971; MacDonald *et al.* 2009).

4.3 Growth State: The emergence of the Tichitt Tradition

The gradual transformation of mobile pastoral communities in the highlands of southeastern Mauritania took place during the Early Tichitt phase (1900–1600 BC). Cribb (1991) mentions how pastoral campsites tend to be in the transitional area between flat steppe or plateaux and topographic features providing shelter, such as mountain slopes, escarpments, or rock outcrops, preferentially near reliable sources of water and firewood. The sandstone escarpments of southeastern Mauritania would have offered a considerable number of locales fitting this description. Mobility defines the socio-economic and cultural system of dryland nomadic societies. This results from the fact that the extensive territoriality of this constrained socio-economic niche is considerably more ecologically unstable than the diversified ecologies of hunter-gatherers, as the spatial availability of suitable pastures shifts in the face of seasonal variations (Cribb 1991: 373). These spatial requirements make securing recurring access rights to suitable but dispersed pastures and watering places in the landscape a priority, which are often articulated through reciprocal social relations (Swidler 1972; Salzman 1980; Perevolotsky 1987; Marx 2005; Karplus and Meir 2013). Informal and fuzzy definitions of access rights de-emphasize exclusivity, for example through collective herding arrangements, favoring the social co-ordination of landscape knowledge regarding changes in the state and location of suitable pastures across territorial boundaries (Tapper 1979; Goodhue and McCarthy 2009) and increasing the resilience of pastoral socio-economic system in the face of climate changes. We currently lack sufficient information to discuss the specific socio-economic dynamics of Early Tichitt pastoral communities, however, since detailed regional osteometric studies are scarce. However, Munson (1971) highlights the importance of

pastoralism as part of a food-production economy since remains of domesticated cattle and goats at Early Tichitt sites outnumber those of wild game by a factor of ten.

Shallow, permanent freshwater lakes have been documented in the Tichitt region during the Early Tichitt phase. The proximity of sites to lakeshore floodplains, the presence of net-sinkers, and the presence of large quantities of fish bones and some instances of crocodiles, hippopotami, and turtles (Munson 1971: 85), highlight the exploitation of aquatic resources, at least seasonally.

The extent and nature of cereal cultivation practices during the early phases of the Tichitt Tradition had long been a source of debate. While 98% of provisionally identified seed impressions in Early Tichitt ceramics from Dhar Tichitt were reported to correspond to *Cenchrus biflorus*, an edible wild grain (Munson 1971; Mauny 1979), direct dating on morphologically domestic pearl millet from v72 (Akreijit) yielded results of 1940–1680 cal. BC (Amblard 1996; Amblard-Pison 2006), squarely within the Early Tichitt phase. Furthermore, the plant tissue impressions at Djiganyai (southern Dhar Néma) almost exclusively belong to pearl millet, with paired spikelets and torn involucre stalks suggestive of domestication (Fuller *et al.* 2007; MacDonald *et al.* 2009). AMS dating has given a range of 1750–1530 cal. BC, confirming the use of by-products of pearl millet cultivation as ceramic temper (Fuller *et al.* 2007). Therefore, it is now widely accepted that the Early Tichitt period witnessed the advent of pearl millet (*Pennisetum glaucum*) processing and farming in the highlands of southeastern Mauritania.

Cultivation is a relational process entangling people, things, and other living beings (Hodder 2011; Bogaard *et al.* 2022). Pearl millet agriculture emerged endogenously among Saharo-Sahelian pastoral communities expanding south during the second half of the fifth millennium BP as a seasonal subsistence strategy to enhance resource predictability further (Neumann *et*

al. 1996; D'Andrea *et al.* 2001; Marshall and Hildebrand 2002; Manning 2010; Ozainne *et al.* 2014; Neumann 2018). Through the lens of the non-linear dynamics of complex adaptive systems, the consolidation of cultivation represents an example of *emergence*. Emergent properties arise when the collective organizational properties of a macro-level behavior transcends the additive (linear) sum of the actions of the preceding constituent parts (Goldstein 1999; Kauffman 1995; Johnson 2001; Carmichael and Hadžikadić 2019). As such, while no set of individual actions may have been oriented towards creating a system of economic subsistence reliant on cultivated plant resources, each household had their own granaries and thus controlled the decision-making process. In this context, the aggregated panarchy of small-scale innovative household experimentations in cropping would have led to one such system coalescing after a protracted process involving positive social and ecological feedback networks (cf., Bogaard *et al.* 2017). This endogenous emergence of cultivation was one regional instance of a wider global pattern of late Middle Holocene domestication processes seemingly carried out by hunter-herder communities and highlights the agricultural agency of mobile communities (Fuller *et al.* 2014).

The existence of extended water availability in Sahelian landscape favored the rapid expansion of agricultural cultivation in the northern Sahel during the first half of the fourth millennium BP, such as in the southwestern Gourma and the Dogon Country of Mali, northern Burkina Faso, the highlands of southeastern Mauritania, and northern Ghana (Ozainne *et al.* 2014). These high rates of dispersal resulted from the interplay of ecological and socio-demographic factors. The inter-annual variability in yield productivity of traditional labor-limited pearl millet farming (450kg/ha), occasionally fluctuating below average effective carrying capacity, would have created pressures for recurrent sequential migration events, particularly in the context of long-term population growth (Rindos 1980; Fuller *et al.* 2019). Inter-annual fluctuations and longer-term trends in rainfall patterns would have modulated rates of

agropastoral community expansion in pursuit of new farmland and grazing pastures (Bohannan and Bohannan 1968; Hassan 2002).

A relevant pattern for understanding the developing settlement patterns of early Tichitt communities may come from mid- to late twentieth century ethnographic assessments of sedentarizing pastoral communities in dryland ecosystems. These "transitional" phases blur the distinctions between mobile and sedentary communities, as agro-pastoral groups with strong pastoral inclinations may opt to set up tents within their compounds during the spring and summer, tents and houses can co-exist in the same settlement (as documented at Tell Toqaan in northern Syria; Sweet 1974: 115), and abandoned households can be occupied by nomad tents (Cribb 1991: 386). While sedentarizing nomads would tend to reproduce the open plan and dwelling alignments that characterize pastoral campsites, gradual population infilling may lead to a dense built environment within the composite village, eventually expanding beyond enclosing features, as documented at Tell-i-Nun (Fars province, southwestern Iran; Jacobs 1979). This pattern maximizes the availability of suitable farmland around the site – even though culturally they confer greater prestige to pastoral activities than to farming practices (Johnson 1969) – while also enhancing security against external threats. Settlements with a strong pastoral vocation are generally occupied by a more fluid population composition, with tent sites changing ownership and not every household being occupied every season. Cribb (1991: 384) argues that this pattern would have considerable archaeological implications, since intra-site deposition will follow irregular spatio-temporal patterns and the overall number of tent sites present is unlikely to "reflect the average size of the communities that had occupied the site in the past". Interestingly, even some of the largest Dhar Tichitt settlements, such as Dakhlet el Atrouss I, which show a very considerable investment of labor in the construction of compound enclosures and evidence of habitation debris, still had internal features like houses and granaries, made of wattle and daub and other perishable materials (Amblard-Pison

2006; MacDonald 2013; Linares-Matás 2022). This pattern may be hinting at some degree of seasonal or inter-annual impermanence of households, potentially even during the Classic Tichitt phase. These potential caveats ought to be taken into consideration when analyzing Tichitt settlements, particularly those encompassing several occupation phases. This is, for example, clearly reflected in the multiple structural aggregations documented at Bou Khzama, with Pre-Tichitt ceramics and microliths in the western section of the site, schist pillar structures, granary bases, eroding inhumations, and grinding stones typical of the Tichitt Tradition immediately to their east; slag mounds, tuyères, and furnaces in the center of the site dating to the first millennium BC and thus likely from the Late Tichitt phase; and a livestock pen or field boundary of unknown date towards the south of the site (MacDonald *et al.* 2009). Protracted biographies of site occupation can also be reflected in internal architectural features, such as evidence of blocked entrances, enclosure extensions, additional walling layers, path reshaping, levelled or reused walls, and large-scale layout changes, as documented at the Dhar Tichitt sites of Akreijit and Dakhlet el Atrouss I (Vernet 1993; Amblard-Pison 2006; Linares-Matás 2022).

Another important dimension to consider in the context of settlement dynamics of agropastoral communities is how unstable early permanent population concentrations tend to be (Bogucki 1988; Bandy 2004). In the context of African societies, social frictions associated with generational segmentation in age sets amidst population increases would represent a typical source of community stress that was predominantly resolved through groups splintering from the "metropole" or source community (Kopytoff 1987). At a supra-regional scale, these processes of dispersal among agricultural pioneer fronts would have initially favored highly suitable areas, such as those described above, with separate highland areas interlocked by extensive lowlands creating conditions for patterns of landscape expansion likely resembling the "leapfrog colonization" model suggested for parts of early Neolithic Europe (cf. Richards

2003; Rockman and Steele 2003; Gronenborn 2004). In the regional context of southeastern Mauritania, demographic growth and agropastoral migratory expansion initially took place in the context of low-density occupation patterns, which facilitated the process of settlement occupation along the extensive escarpments of the region. As intra-site population densities increased but regional landscape occupation remained low, groups would have continued the process of territorial expansion by beginning to reside in emplacements considered second-tier in ecological and/or cultural terms to minimize competition in prime settlements (Codding *et al.* 2022; Weitzel *et al.* 2022).

4.4 Consolidation state: the Classic Tichitt Tradition

The territorial consolidation of agropastoral communities in the escarpments of southeastern Mauritania led to the formation of permanent agglomerations with numerous thick-walled drystone architectural features (Table 4). In the Tichitt-Oualata region, most of these settlements date within a 600-year timespan (1600–1000 BC; MacDonald 2013), while the largest settlements in Dhar Tagant date to the transition between the first millennium BC and the first millennium AD (Ould-Khattar 1995). Several of these population clusters developed into very large settlements (>50ha), exceeding in size any prior settlement documented in the Sahara or West Africa, as well as many later urban sites in Mali's Middle Niger region (MacDonald 2015).

The existence of a clear settlement hierarchy in both Dhar Tichitt and Dhar Oualata (Holl 1993; Amblard-Pison 2006; MacDonald 2015; Tables 2 and 4) is further reinforced by the existence of imposing defensive features at many of the larger sites, including excellently preserved masonry walls up to two meters in height, well-defined access points lined with "archer's redoubts" that lead into a maze complex at the entrance, and gateways capped by massive lintelstones (>100kg) (Munson 1971). This pattern evidences a high degree of architectural

investment and an ideological concern with the material expression of power as much as the achievement of defensive prowess. Settlement walls are technologies of control and exclusion, but also proxies for social cohesion, articulated through mechanisms of containment (Connah 2000; MacDonald 2012). At Dakhlet el Atrouss I, the largest Dhar Tichitt site (> 80ha), the existence of clustered compound neighborhoods also denotes a clear demarcation of settlement space, perhaps relating to lineage quarters (MacDonald 2015; Linares-Matás 2022). The topography of these escarpments led to the formation of a settlement network that resembled a littoral occupation, according to Amblard-Pison (2006). Under these circumstances, inter-site connectivity may have been heavily one-dimensional in a linear fashion, with central nodes playing an important role in intra-regional dynamics, and geographically peripheral sites perhaps acting as linkages in interactions transcending the escarpment system. Interestingly, in their seasonal migratory dynamics, Tichitt Tradition communities began reaching beyond the southeastern Mauritanian highlands for the first time, moving westwards to Dhar Tagant (Ould-Khattar 1995; Linares-Matás and Lim 2021a) and southwards through Dhar Néma into the Méma region of Mali, where they eventually established some permanent settlements (MacDonald 2011).

In terms of subsistence, the very limited presence of fish remains and the absence of net-sinkers, both noted by Munson (1971), suggest that fishing was no longer a particularly relevant economic activity during the Classic Tichitt phase. This is further reflected in the fact that sites were located on the escarpment edge, above the basin and often several kilometers away from the quickly receding lake shorelines. Lake regression would have created very productive ecosystems for plant growth, with thick silt layers and water availability due to seasonal basin filling from wadi outflows and escarpment run-off as well as a higher water table (Munson 1971: 94). These seasonal affordances created agronomically diverse "landscapes of abundance", which could have enabled the sustained cultivation of *Pennisetum*, a crop that

normally requires a minimum annual rainfall of 275mm (Mauny 1979), in a drying ecosystem. The relevance of agricultural production is reflected in the fact that small milling stones were replaced during the Classic Tichitt Tradition by numerous bedrock mortars as well as by a range of large and heavy milling stones, commonly exceeding 10kg and sometimes even in excess of 25 kg (Munson 1971). Furthermore, the increasing intensity of pearl millet production and, to a lesser extent, wild grain collecting, is documented in pottery impressions, over 82% of which now belonging to domesticated *Pennisetum* (Munson 1971; Amblard 1996). Following a period of experimentation with several indigenous crops, pearl millet eventually became the main agricultural staple food of Tichitt Tradition communities amidst anthropogenic selective pressures. This pattern would lend support to the characterization of the escarpments of southern Mauritania as a secondary locus of crop domestication within the diffuse, polyfocal West African agricultural cradle (Harlan 1971).

Favourable environmental affordances in the drying but seasonally well-watered Sahelian savanna are thus able to explain the consolidation of millet cultivation during the second half of the second millennium BC (Manning 2010; Linares-Matás 2022) and its ability to sustain a thriving and densely populated landscape without the need to narrowly envisioning it as a stress-induced response to environmental aridification. An additional dimension that may have further fostered the reliable viability of indigenous West African farming systems in these "landscapes of abundance" entails low labor input cultivation regimes that require field rotation to let soils replenish would have benefitted from the combination of cereal farming with pulse cultivation, thanks to their nitrogen-fixing properties. Domesticated cowpeas (*Vigna unguiculata*) may have been regionally available from at least 1500 cal. BC (D'Andrea *et al.* 2007). Watermelon (*Citrullus vulgaris*) may have also been cultivated in southeastern Mauritania around this time (Munson 1971).

While pearl millet agriculture was undoubtedly a fundamental economic activity, ideologically cattle continued to have a prominent place in the rock art associated with the settlements (Mauny 1949; Munson 1971). Livestock is also well-represented in faunal assemblages, greatly outnumbering those of wild animals (Munson 1971), and large enclosures without internal subdivisions, interpreted as cattle kraals, have been found just north of the settlement area at both Dakhlet el Atrouss I and Akreijit (MacDonald 2015; Linares-Matás 2022). While we lack comprehensive zooarchaeological data for Tichitt Tradition settlements, the pattern from Middle Senegal Valley sites during the Late Holocene is suggestive of practices aiming to maximize herd size with little culling of younger animals (MacDonald and MacDonald 2000: 132). This herd management strategy enhances socio-economic resilience by maximizing and prioritizing the preservation of wealth 'on the hoof' even during harsh climatic conditions (Dahl and Hjort 1976; Western and Finch 1986). Keeping large herds thus represents a powerful mechanism of capital accumulation, of a private nature if owned by individual families or households, which may have underpinned the degree of socio-economic differentiation documented in terms of compound size asymmetries at Dakhlet el Atrouss I (Linares-Matás 2022).

A remarkable dimension of Classic Tichitt Tradition material culture is the recognizable homogeneity it displays in the domestic sphere, ranging from pottery decoration to granary architecture, to the public realm, for example in the drystone walls that enclose many large settlements. Discerning the origins of this pattern and its implications for understanding the political nature of Tichitt Tradition communities has attracted considerable discussion among researchers working in the region. For the most part, these scholars have relied on neoevolutionary concepts and assumptions, namely the notion that the Tichitt Tradition represents a "nation" (Vernet 1993), a "state-level" polity (Amblard-Pison 2006), or a "paramount chiefdom" (Holl 1993). Some of these labels seem to imply that the high systemic

coherence of the Classic Tichitt Tradition represents the outcome of the expansion dynamics of a centralized polity, where directionality is carefully planned by authority stemming from one or more sources within a more or less hierarchical socio-political organization who aims to impose a particular spatial ideology of community life. Evidence for this level of material culture replication as a sign of political affiliation in the context of military interventions and targeted population movements in West Africa is clearly documented in West Africa, for example at the seventeenth- to early nineteenth-century AD site of Ede-Ile, a frontier settlement within the Oyo empire of western Nigeria (Ogundiran 2009). In contexts where these blatant imperial dynamics were not at play, such an argument was advanced for example by Algaze (2001) in relation to the Uruk expansion during the fourth millennium BC in Mesopotamia. In this case-study from southwestern Asia, the idea of a planned political-economic colonization from southern to northern Mesopotamia (cf., Stein and Özbal 2007) has been challenged in favor of hypotheses discussing the influence of economic and ideological interdependence through the control of trading routes by north Mesopotamian settlements that progressively adopted material culture from southern Mesopotamia, without it meaning that it was an occupied region (Collins 2000; Sundsdal 2011). The notion of material culture homogeneity stemming from state-level expansion dynamics or as trade-born is, however, inapplicable in the context of the Tichitt Tradition on the basis of the available evidence.

Some items of material culture, such as polished axes and bracelets, amazonite beads, and copper implements, as well as the presence of rock art depicting chariots, point to the existence of interaction networks that transcended the escarpments of southeastern Mauritania (Holl 1985; Amblard-Pison 2006; MacDonald 2013). Nevertheless, the frequency and relevance of these interactions for the consolidation of socio-political power over the control and management of endogenous agropastoral production is unclear. While future research into the severely underexplored regional funerary record may provide further evidence of long-distance

trade through the presence of imported grave goods, the limited work conducted on the Tichitt mortuary record to date has so far highlighted the general paucity of grave goods (Amblard-Pison 2006). Instead, socio-economic differentiation may have been primarily reflected in the degree of architectural investment and the social mobilization of labor pool (Linares-Matás, in press). This negative evidence tentatively precludes the applicability of trade-based hypotheses for explaining the growth and consolidation of the "systemic coherence" that the Tichitt Tradition system displays. Furthermore, and despite Munson's (1971) initial suggestions, the absence of competing polities and the existence of an extensive territoriality available for migration into ecologically suitable areas within the highlands of southeastern Mauritania means there was little circumscription that would foster struggles over control of resources (*sensu* Carneiro 1970) as the core process behind the emergence of the Tichitt Tradition (MacDonald *et al.* 2009).

Considerable similarities in material culture across time and space, i.e. convergent evolutionary adaptation, can emerge from the long-term, non-linear dynamics of self-organizing systems on the basis of their intrinsic dynamics or in response to external inputs (Johnson 2001; Linares-Matás and Lim 2021b). This is the first alternative explanation that ought to be considered, before any assumptions of centralized political expansion are made. Nonetheless, the evidence for cultural continuity in the sequence between the pre-Tichitt to Classic Tichitt Tradition, shared pottery-making and rock art iconographic traditions, as well as evidence for agropastoral expansion across the landscape, renders the idea of independent convergence rather unlikely in the context of the Tichitt Tradition.

Insights from non-linear dynamics and the Internal African Frontier model provide an elegant and parsimonious framework for explaining "systemic coherence" through a bottom-up approach that is anchored in the endogenous processes of demographic expansion that

southeastern Mauritania experienced during the second millennium BC and therefore does not need to rely on poorly fitting neoevolutionary concepts. The first dimension to consider regarding the applicability of the Internal African Frontier is whether the cultural traditions of the highlands of southeastern Mauritania meet the conditions outlined by Kopytoff (1987). On the basis of the evidence so far discussed, Early Tichitt agropastoral communities do seem to have fulfilled the four criteria outlined by Roth (2013) favoring the formation of internal frontier zones, *sensu* Kopytoff (1987), namely:

- **A widely shared social tendency towards human mobility**, anchored in the aforementioned seasonal livestock management strategies, social fission, and agricultural migratory expansion;

- **The existence of microregional boundaries within cultural and geographical entities**, as constituted by the topographic transition of the sandstone escarpments of southeastern Mauritania;

- **The absence of comprehensively enforced means of centralized control**, which is lacking in early agropastoral communities where land is abundant; and

- **The existence of considerable structural homologies between communities interacting along and across those frontiers**. The early Tichitt communities shared a similar socio-economic organization among themselves and possessed a comparable assortment of material culture with other southern Saharan and northern Sahelian agropastoral communities (cf., Ozainne *et al.* 2014).

The coexistence of these dynamics led to the formation of interstitial frontier landscapes in the highlands of southeastern Mauritania that contributed to the expansion and consolidation of agropastoral settlements. In establishing their new community, these individuals would have

relied on previous conceptualizations of what constitutes a "good society" in its ideological dimension (Kopytoff 1987). Given the relationship between ideology, socio-economic organization, and settlement nature, I propose that these processes would have also been reflected in the material dimensions of life as communities expanded, from economic basis to architectural forms, evoking the material agency of the stylistic universes in which humans are emmeshed (Gosden 2005). This would also be consistent with Kopytoff's suggestion that the Neolithic of the Sahara-Sahel likely provided a conducive ecological and cultural context for the genesis of widely spread African socio-political systems.

In Central Europe, a comparable prehistoric context of gradual but fast-paced decentralized farming expansion underpinned by demographic expansion and population movement is reflected in the degree of material cultural coalescence visible within Neolithic Linearbandkeramik (LBK) settlements in terms of settlement plans, house construction techniques to stone artefact typologies and pottery decoration patterns, despite some variability and heterogeneity (Gronenborn 1999). This resembles the considerable degree of internal homogeneity documented among Early Tichitt Tradition communities (Munson 1971; Amblard-Pison 2006; MacDonald 2105), although more in-depth intra- and inter-assemblage analyses are needed to better understand the extent of typological and technological variability in Tichitt Tradition material culture.

Furthermore, while perpetual novelty is a common dimension of self-organized complex adaptive systems due to the exceedingly large number of possible recombinations, they also tend to exhibit a series of recurrent patterns (Kauffman 1993; Holland 1995). This variable degree of predictability favours the formation and consolidation of landscape knowledge networks pertaining to the nature, distribution, agency, and circulation of capital *sensu lato*, encompassing people, objects, other living organisms, geological resources, etc. (Abel *et al.*

2006). These adaptive information flows ("remember feedback loops" in Bradtmoller *et al.* 2017) contribute to maintaining integrity by influencing forms of self-organization. Here, such self-reinforcing selective pressures favored the conservation of ecologically suitable Tichitt Tradition architectural solutions and agropastoral lifestyles over several centuries. On the basis of the properties and predictions of Complex Adaptive Systems theory, it is therefore possible to envision how a network of complex collective behaviors and environmental information processing may emerge in human societies under relatively simple rules of operation, even in the absence of centralized socio-political control mechanisms (Mitchell Waldrop 2009: 13). It would be illustrative to learn the extent to which local shortfalls in agricultural production within Tichitt Tradition settlements may have been covered by decentralized grain-supplying exchange systems, given the conspicuous absence of centralized storage facilities, since this would offer an additional indication of distributed socio-economic complexity.

Meeting the preconditions for the formation of frontier landscapes can assist in explaining the "systemic coherence" of a decentralized community undergoing a process of demographic and territorial expansion in sparsely populated ecosystems. Furthermore, the principle of anteriority, an important concept within the Internal African Frontier model, provides insights into a social and cultural mechanism that may have fostered the consolidation of complex socio-economic differentiation and the territorial structuration of political and exchange networks. The African ethnographic literature discussed above (section 1.2) consistently highlights the role of anteriority in the consolidation of complex socio-political and religious relationships within and between settled communities. The timing of a lineage's arrival to a settlement determines belonging to two broadly divided categories: firstcomer and newcomer lineages. Firstcomer lineages experience important privileges, since their settlement priority enables the establishment of a special spiritual connection with the landscape and underpins

the legitimate redistribution of farmland, two important mechanisms through which to mediate and exercise control over people (Kopytoff 1999; Whitelaw 2015).

Lineage seniority therefore acts as a fundamental structuring principle for articulating power among lineages constituting the social fabric within individual settlements and well as in the context of the wider cultural landscape (Holl 1986; Kopytoff 1987; McIntosh 1999; Eldredge 2015; King 2018). Within these cultural systems, asymmetric land tenure regulations that legitimized inheritance and patronage through reference to customary rights derived from ancestral migration and settlement were a fundamental dimension of political power in many precolonial African societies (Stahl 2004; Gokee and Thiaw 2020). These privileged political strategies granted preferential resource mobilization pathways to elites but were insufficient on their own to sustain the permanent development of large-scale transgenerational inequality under a labor-limited agropastoral system, given how low regional population densities in the Sahel afforded a relative abundance of arable land and that it was people who added value to land resources through their labor and knowledge (McIntosh 1999; Bogaard *et al.* 2019). These landscape affordances would have encouraged any discontented groups to express their resistance through lineage fission and migration into unpopulated or less contested landscapes, spatially and economically disentangling themselves from any emergent coercive elite forces (Kopytoff 1987; McIntosh 1999). Additionally, ethnographic examples from West Africa and elsewhere indicate that collective action can remove potential elites from power before, and even after, their authority becomes institutionalized (Bohannan 1958; Fowles 2002; Dueppen 2012a). Therefore, to legitimize their authority, leaders would have likely had to rely on popular measures to achieve effective control over people, with collective organization favoring diffuse rulership methods based on social reciprocity, cosmological mediation, and local governance networks (Fleisher and Wynne-Jones 2010; Monroe 2013). These perspectives may better encapsulate the political ecology of Tichitt Tradition communities,

particularly supra-regional processes of socio-political prominence during the Consolidation state, than categories of social organization, such as nation, state, or paramount chiefdom, uncritically extrapolated from other regional pathways.

Tichitt Tradition communities may have first arrived near the confluence between Dhar Tichitt and Dhar Oualata (Amblard-Pison 2006). Survey on this area is difficult because it is one of the areas in the region that has experienced the most sand encroachment, partially covering even very large settlements (Linares-Matás and Lim 2021a). Settlement seems to have initially focused on Dhar Tichitt, soon expanding southwards into Dhar Oualata (Amblard-Pison 2006) and Dhar Néma, albeit exhibiting a far less dense settlement pattern in the latter despite its higher rainfall (MacDonald *et al.* 2009). Interestingly, both the results of field surveys and remote sensing desk-based assessments have documented a disproportionate clustering in the distribution of funerary monuments of the Tichitt Tradition, which are primarily found in the Dhar Tichitt region rather than in Dhar Oualata or Dhar Néma (Amblard-Pison 2006; MacDonald *et al.* 2009). The difference is an order of magnitude higher, with *c.* 4700 funerary monuments documented in Dhar Tichitt versus the 258 tumuli found in the other two regions combined (Linares-Matás, in press). I am inclined to agree with MacDonald *et al.* (2009) that this difference may be rooted in a conceptualization of Dhar Tichitt as an ideological centre of gravity. The dynamics of expansion and consolidation within the Internal African Model would explain why Dhar Tichitt may have been considered an ancestral locality and a source of socio-political authority at the supra-regional landscape level, with lineage seniority underpinned by firstcomer primacy at its core. Dhar Tichitt could have also remained a desirable burial and even pilgrimage place for lineages that splintered during the phase of expansion, since while they may have become firstcomers in their local and regional landscapes, they may have remained subordinate or peripheral within broader Tichitt Tradition lineage dynamics.

4.5 Release with or without struggle? The Late Tichitt phase

If there is a topic in the study of complex societies that has attracted more attention than their emergence, it is undoubtedly the question of their decline, collapse, or reorganization (Diamond 2005; McAnany and Yoffee 2010). Resilience represents a particularly relevant emergent property of complex adaptive systems. Resilience is a continuous and elastic process, generally defined as the capacity of a system to absorb disturbance, recover, and reorganize while still remaining recognizable, functionally equivalent, and structurally homologous (Gunderson and Holling 2002; Redman and Kinzig 2003; Gronenbron *et al.* 2017). Resilience encompasses an interlinked network of people, things, other beings, and environmental processes within the ecosystem (Holling 2001).

The presence of settlement enclosing walls, asymmetries in compound sizes, markedly clustered monumental funerary landscapes, and an agropastoral economic base were features that underpinned the growth and consolidation of Tichitt Tradition communities. At the same time, these internal dynamics also betray potential sources of tension involving political and territorial disputes over lineage seniority, competition for cattle wealth and pastures, skeletal and social stress due to increasing agropastoral workloads, or diminishing agricultural yields due to soil exhaustion and decreases in water input due to lower rainfall and run-off amidst increased aridity. While freshwater gastropods occurring in stagnant and slow flowing permanent watercourses are present at Dhar Néma sites in the second millennium BC, they are absent from contexts post-dating 900 cal. BC, where only smaller catfish and tilapia persists, a pattern that illustrates how watercourses were becoming only seasonal in this area (MacDonald *et al.* 2009). Since Dhar Néma receives more rainfall than the Tichitt-Oualata region, the situation in the core of the Tichitt Tradition would have been even more drastic. During the early first millennium cal. BC, the site of Ounjougou on the Bandiagara plateau (Mali) also

witnessed very arid climatic conditions, with the seasonal drying of freshwater pounds and the final phases of Neolithic occupation in the region (Ozainne 2013). The subsistence trends of earlier but comparable processes of desertification in the Central Sahara towards the end of the Middle Holocene indicate that cattle herding gave way to either more mobile pastoral economies involving small livestock or communities settled or migrated to areas of the wider landscape that preserved viable access to springs, wells or oases for longer, establishing more sedentary agropastoral lifestyles (Cremaschi and di Lernia 2001; di Lernia *et al.* 2002). For example, MacDonald *et al.* (2009) outlines how a more extensive occupation with typical Tichitt Tradition pillar structures and some evidence of iron metallurgy began at Djiganyai (Dhar Néma) from the early first millennium BC while a reduction in settlement intensity and greater mobility were becoming apparent in the Tichitt-Oualata escarpments. Recent surveys on the main agricultural adaptation strategies of contemporary rural Sahelian households to noticeably decreasing rainfall patterns highlight the role of crop diversification towards drought-tolerant and early maturing varieties, changing planting times, income diversification, water conservation practices, and a greater reliance on agroforestry resources in enhancing food security (Tambo and Abdoulaye 2012; Zakari *et al.* 2022). Archaeological perspectives note how livestock ownership can further enhance community resilience (Manning and Timpson 2014). Moreover, migration also emerges as a relevant household-level response to social and ecological stress amidst unfavorable climatic conditions in African dryland environments (Wiederkehr *et al.* 2018).

The emergence of internal tensions that eventually led to social destabilization has long been reported for agricultural communities, such as Early Neolithic LBK societies in southern Central Europe (Gronenborn 1999), generally linked to a combination of factors such as population increase, resource competition, and climatic instability. Proximity to conspecifics initially leads to overall increases of positive fitness as group sizes grow, a dynamic known as

Allee effect (Codding *et al.* 2019). A dependence on dense, predictable, and cyclically renewable resources that can be readily transformed into social payoffs, such as crops, livestock herds, or fishing areas, would have fostered pressures for collective action in relation to subsistence, architectural investment, and defensive within-group cooperation (Dyson-Hudson and Smith 1978; Codding *et al.* 2019; McCool *et al.* 2022b). Nonetheless, these social dynamics are non-linear, with tipping points leading to very different outcomes once optimal group size and population density thresholds are surpassed. This pattern corresponds to the "negative density dependence" prediction of Ideal Free Distribution (IFD) models, whereby *per capita* habitat suitability declines due to resource competition (cf., Fretwell and Lucas 1969). In contexts of sustained demographic growth, periods of climatic instability or relative resource scarcity are often correlated with higher levels of social stress and/or interpersonal violence (McCool *et al.* 2022a; Schulting *et al.* 2022), since high within-group cooperation can promote the rise of between-group competition (Lambert and Welker 2017; Larsen *et al.* 2019; Weitzel *et al.* 2022). This trend may help explain the defensive placement and architectural investment documented among large Classic Tichitt Tradition settlements.

Nonetheless, while scarce, patchily distributed resources, such as livestock herds or stored cereals, may sometimes foster an initial incentive for violence, continued engagement seems to depend on the existence of social frameworks enabling the conversion into lineage or individual status and wealth (Mercer 1999; Glowacki and Wrangham 2013; Wiessner 2019). Alternatively, conflict can also spiral out of control among societies with strong revenge duties and social substitution ideologies, where retribution can be exerted not just directly against the offender, but against any member of their community (Kelly 2000).

The decreasing proportion of wild game in the Early and Classic Tichitt Tradition phases in relation to domestic livestock are in stark contrast with observed arrowhead numbers (Munson

1971; MacDonald 2015), a trend also observed in the British Neolithic (Mercer 1999). This pattern may signal the social relevance of bow and arrow weaponry, which has proven quite effective in both ambush raids and open confrontations (Schulting 2013). No iconographic or funerary evidence attributed to the Classic Tichitt Tradition suggests that violence had become an endemic heroic reality performed by warrior elites during this period. Nevertheless, even in the absence of formalized iconography or specialized weaponry, skeletal data may provide considerable evidence for interpersonal violence, as documented in the European Neolithic (Mercer 2007; Schulting 2013). In these contexts, potentially all the adult males of the community may engage in violent confrontations, albeit only situationally (Schulting 2013). Only future osteoarchaeological research targeting Tichitt Tradition funerary assemblages will be able to elucidate the prevalence of iconographically invisible interpersonal violence.

The emergence of warrior elite ideology may have been curtailed by the existence of communal narratives of power structured around principles of lineage seniority as well as symbolic and material exclusion through walls (cf., Sastre 2008). At the same time, it is not infrequent for emergent complex societies to experience processes of heightened demographic and resource stress that can trigger a release phase with the outbreak of intercommunal violence and subsequent social reorganization (Walker 2001; Milner *et al.* 2013; McCool *et al.* 2022a).

A relevant socio-political dynamic towards the end of the Classic Tichitt Tradition and into the Late Tichitt phase was the intensification of aridification trends in the southern Sahara and northern West African Sahel during the first millennium BC (cf., Breunig and Neumann 2002; Vernet 2002; Magnavita *et al.* 2009; Ngomanda *et al.* 2009), as well as evidence for the arrival of Lybico-Berber populations to southeastern Mauritania. The latter is illustrated by Tifinagh inscriptions and the appearance of male warrior elite iconographies involving horses, chariots, spears and specialized weaponry, such as swords, within the rock art corpus (Munson 1971;

Mauny 1979; Vernet 1993; Challis *et al.* 2005). Certain items of material culture at Late Tichitt sites have also been attributed to the arrival of these groups, such as *couscousières* (Munson 1971), bronze arrowheads, and superimposed habitation structures (Vernet 1993). Munson (1971) made these Lybico-Berber groups directly responsible for a considerable decrease in population numbers, site sizes, and the placement of settlements in hidden and defensible positions within the escarpments.

Rock art illustrates that intercommunity violence unquestionably happened. For example, there is a particularly vivid conflict scene in the Guilemsi Ridge of the Tagant region involving mounted warriors and armed human figures on foot facing unmounted individuals lying on the floor and surrounded by spears (Fig. 8). Within the Guilemsi rock art corpus, there are two main horse depiction styles: one "bi-triangular" that resembles those found in distant places in Lybia and even Chad, while others are quite different and have "unusually short muzzles" within an otherwise naturalistic style, which may betray anatomical unfamiliarity; the dynamic conflict scene was painted in the latter (Challis *et al.* 2005). Therefore, we may be witnessing both perspectives of violent frontier encounters: some paintings appear to have been made by Lybico-Berber individuals who may have perpetrated raids, while others were more likely painted by local community members who witnessed or experienced an incursion of armed horsemen (Challis *et al.* 2005).



Figure 8. Rock art panel from the Guilemsi Ridge, in the Tagant Plateau (Mauritania). The painted composition depicts a series of armed horse-riders, two armed human figures on foot, and several human figures laying horizontally surrounded by spears, presumably thrown by the mounted warriors. British Museum 2013,20134.12424 © TARA/David Coulson https://africanrockart.britishmuseum.org/country/mauritania/guilemsi/

At the same time, the appearance, elaboration, and frequency of specialized weaponry and mounted warrior iconography or fortified hillforts, are not necessarily directly linked with an increase in the frequencies of sharp force skeletal trauma. Instead, these features are often associated instead with a reduction of interpersonal violence, a pattern amply documented in Europe during the Neolithic to Bronze Age transition (Oosterbeek 1997; Robb 1997; Vander Linden 2006; Harding 2007; Aranda-Jiménez *et al.* 2009; Schulting 2013). This may be related to a shift in conflict demographics, from the situational mobilization of many individuals to an arena where participation was culturally and ritually limited to a restricted few (Schulting

2013). This trend nonetheless relied on such a warrior elite ideology to become hegemonic, enforcing normative cultural behaviors, and there is no evidence at present that such a shift occurred among the leaders of Tichitt Tradition communities, although this may still be a function of the very incomplete knowledge of funerary assemblages in the region. In fact, some degree of syncretism may account for the nature of Late Tichitt pottery assemblages and polished stone industries in southeastern Mauritania and the Méma region of Mali (MacDonald *et al.* 2009; MacDonald 2011). I propose that a more powerful explanatory framework ought to combine the arrival of mounted groups that at least occasionally engaged in violent raids, as described above, with the aridification trends of the first millennium BC, in order to argue for a multi-causal increase in unpredictability and uncertainty. In this context, research into Sahelian household resilience shows that both diversification or specialization of household activities can assist in coping with deteriorating circumstances (Harts-Broekhuis 1997). In terms of subsistence, this may have manifested itself in a reversal in the proportion of domesticates to wild animal species during the Akjinjeir/Late Tichitt phase, with addax (*Addax nasomaculatus*) and *Gazella sp*. remains considerably outnumbered those of livestock, a trend suggesting a greater reliance on hunting (Munson 1971). This pattern likely emerged due to the combined impact of a drying climate and the southward migration of Saharan fauna with the political unrest and uncertainty that may have arisen in association with mounted warrior raids (Vernet 1993). Crop failures, livestock theft, raids from mounted warriors that threatened the remaining crops and animals, decreases in rainfall would have contributed to the delegitimization of the ritual authority of lineage chiefs contingent on the control of natural forces (cf., Fortes 1940). The weakening of those integrative ideologies that had contributed to social cohesion and the maintenance of order within large agropastoral communities would have led to increases in internal dissension and scalar stress. A continuation of practices no

longer well-suited to these social and ecological changes would have become increasingly unfeasible (i.e. the "rigidity trap").

Since wealth in people was a fundamental dimension of political power in the West African Sahel, an inability to weather these circumstances, perhaps because of a lack of community support, would transcend the limits of systemic resilience and trigger in complex adaptive systems a transition into an energy release state (Holling and Gunderson 2002; Scheffer 2009; Bradtmoller *et al.* 2017), manifested here through a rise in lineage fissioning and settlement abandonment due to centrifugal forces encouraging population dispersal (Bandy 2004; Diamond 2005; McAnany and Yoffee 2010). This volatile unravelling would have enhanced opportunities for creative innovation and self-organization, leading to greater adaptive fitness under the new set of circumstances (Holling 2001; McIntosh 2005; Burkhard *et al.* 2011; Retaillé and Walther 2011). An expansion into other habitats would have considerably alleviated social stress, limited the viability of targeted raids, and likely led to a reduction in intergroup violence. Such a pattern of declining interpersonal violence has been observed, for example, across interior eastern North America during the Woodland period (3000-1000 cal. BP; Miller 1999; Miller *et al.* 2013), where a negative density-dependent settlement pattern fitting these circumstances has been documented (Weitzel *et al.* 2022). These dissipation factors promoted the eventual reorganization of human communities during the Terminal Tichitt or Early Iron Age in the highlands of southeastern Mauritania. During this period, human communities exhibited a greater emphasis on mobility at the expense of sedentism (Amblard-Pison 2006; Linares-Matás and Lim 2021a), as well as large-scale migrations, primarily westwards towards the Tagant (Ould-Khattar 1995; MacDonald 2020; Linares-Matás and Lim 2021a), and southeastward beyond Dhar Néma and into the wider Niger Bend (Vernet 1993; MacDonald *et al.* 2009; MacDonald 2020), and southwards towards the Rkiz massif (Vernet 1993; Linares-Matás and Lim, in press). In these Sahelian landscapes of mobility,

cultures and places do not outright disappear, since many social practices may continue, as suggested by the dynamics of the Internal African Frontier (Kopytoff 1987), but they become spatially redefined and relocated within socio-economic networks that migration entails. Some of these migrations may have begun as part of seasonal transhumance movements that favoured the acquisition of knowledge regarding the suitability and population density of these landscape for a subsequent dispersal of a more permanent nature, which fits the pattern described by MacDonald *et al.* (2009) in relation to the Tichitt expansion into the Méma region of Mali. It is noteworthy that pearl millet becomes documented in the Niger Inland Delta and the Middle Senegal Valley from 1000–800 cal. BC (Ozainne *et al.* 2014), perhaps fueled or facilitated by a Tichitt diaspora (MacDonald *et al.* 2009).

4.6 The Reorganization pathways of Tichitt Tradition Communities

A key dimension for the study of Tichitt Tradition settlement dynamics consists in charting their diachronic trajectory, i.e. understanding how and why the system changed over time. Increasing aridification across the Sahel and the suggested arrival of Berber communities in the region on the basis of stylistic affinities in rock art and pottery assemblages during the Late Tichitt period (*c.* 1000–400 cal. BC) correlated with a considerable decline of permanent human settlement in the Tichitt-Oualata region (Munson 1971; Holl 1985; MacDonald 2011). This process also involved the funneling of population west into Dhar Tagant and southeast into Dhar Néma and the Méma region of Mali (Ould-Khattar 1995; Person *et al.* 2006; MacDonald *et al.* 2009; MacDonald 2020). In terms of the southeastern dispersal, this demographic process—reflected in the archaeological record through ceramics with cord-wrapped roulette decoration, imported phthanite siltstone, cattle remains, and cattle figurines—emerges as a relevant catalyst in the consolidation of more permanent settlements in the Middle

Niger and the Macina regions of Mali, such as Kolima Sud-Est, Dia Shoma, and Akumbu, from which the Sahelian empires of Ghana and Mali later arose (MacDonald 2015).

Westward, the presence of Tichitt Tradition communities in Dhar Tagant was documented by Ould-Khattar (1995), who conducted extensive field surveys and generated a preliminary chronological framework for the region. A relevant observation is the fact that the oldest settlement so far documented in Dhar Tagant (1430–1312 cal. BC) is around 500 years more recent than the starting date for the Early Tichitt Tradition in Dhar Tichitt. The dating for the earliest Dhar Tagant is consistent with the material culture assemblages, since stone implements are considerably less common than at earlier Tichitt Tradition sites, while grindstones and ceramics are abundantly present (Ould-Khattar 1995: 287) This chronology helps to corroborate two aspects: that Dhar Tichitt lineages, the closest escarpment section to the Tagant Plateau, would have likely experienced a relationship of seniority rooted on anteriority of settlement over those in Dhar Tagant; and that the process of agropastoral spread and lineage expansion that characterized the Early Tichitt Tradition phase continued into the Classic Tichitt Tradition period. This pattern is also a testament to the carrying capacity limits of local environments relying on pearl millet cultivation in the face of continued demographic growth, which promoted the rapid advance of agricultural frontiers (Fuller *et al.* 2019).

A very considerable number of Dhar Tagant settlements are small, dispersed, and fortified slope sites, which resembles the description provided by Munson (1971) for Late Tichitt communities, and likely corresponds to both the local impact of climate change and Lybico-Berber incursions (cf., Challis *et al.* 2005), as well as the material expression of the expansion or relocation of Late Tichitt communities from Dhar Tichitt. Towards the end of the Late Tichitt period and into the first millennium AD ("Terminal Tichitt" or "Early Iron Age"), however, Dhar Tagant witnessed the formation of large iron-working communities, such as T150 (91 cal. BC – cal. AD 9) that were living in large walled settlements comprising semi-permanent stone

houses and compound enclosures (Ould-Khattar 1995; MacDonald 2020; Linares-Matás and Lim 2021a). These sites commanded catchment areas with arable soils for cereal cultivation, iron ore sources to sustain metallurgy, grazing pasturelands for their livestock, and the sandstone escarpment acted as a source of stone raw material and channeled seasonal watercourses downslope through canyons and wadis.

As such, after a substantial population relocation from the Tichitt-Oualata escarpments during the Late Tichitt phase, the archaeological record indicates that the wider Tagant region experienced a steady reorganization and transition from growth (r) to a series of conservation (K) pathways during the late first millennium BC. These processes were linked with the consolidation of population sizes and socio-economic reliance on certain resources and techniques, particularly ironworking, as landscape knowledge networks and material entanglements consolidated. On the basis of these transformations, I argue that the different settlement dynamics of Dhar Tagant and the northern Tagant Plateau were anchored in divergent manifestations of a fundamental dimension of social resilience in the Sahel, namely the translocal management and connectivity of people *through* spaces of mobility and the movement of places *alongside* people.

A reliance on a rigid sedentary/mobile dichotomy is generally not very useful for understanding the landscape occupation dynamics of agropastoral communities (cf. Cribb 1991), but it proves particularly unhelpful for examining the lived experiences of human communities in the Sahelian borderlands. Pastoralism in dryland ecosystems relies on access to seasonal patchily distributed resources, with regional ecological variations in cyclical resource stability and predictability, as well as climatic trends, necessarily structuring patterns of pastoral community mobility in the Sahara and the Sahel since the early Holocene (di Lernia *et al.* 2002; Marshall and Hildebrand 2002; Brooks 2006). As such, rather than emerging temporarily as a behavioural response to mitigate ecological stress (Binford 1990), mobility was a constant

feature within the agropastoral cycles of Sahelian communities (Retaillé and Walther 2011). This dynamic can be explored in the archaeological record through the notion of "shifting sedentism" (Canós Donnay 2016). This concept derives from settlement dynamics in the Upper Casamance region of southern Senegal, where village communities recurrently experience organic movement in the form of small-scale shifts (<1km) and a diversity of processes entailing larger scale relocations (>1km), with segments or entire communities abandoning an existing village to establish themselves in an existing or newly-founded settlement and with little evidence of reoccupation of previously abandoned areas (Canós Donnay 2016). Relocations involving dispersal into previously unoccupied landscapes are generally associated with the use of movement as a problem-solving mechanism in the face of uncertainty derived from social or ecological stressors (Retaillé and Walther 2011; Canós Donnay 2016). As places move, the circulation flows of people, things, and other beings play a paramount role in the constitution and reconstruction of landscape spaces in the Sahel. The archaeological record documents the existence of extensive interaction networks in the Sahara involving polished stone axes, beads, and bracelets since the Middle Holocene and extends into the Tichitt Tradition period (Holl 1998; MacDonald 1998). When accompanied by exchanges of marriage partners, the sharing of information regarding resource distribution, and/or livestock transfers, these relationships would have greatly enhanced social resilience throughout the network (cf., Sterly *et al.* 2016).

Shifting the traditional analytical emphasis from the vulnerability and risk-management individual units at the household or community level (Redman 2005) towards encompassing circulation throughout the interconnected network enables the development of a multi-scalar and more plastic approach to social resilience (Sterly *et al.* 2016). This vision is particularly conducive to integration with the 4E frameworks recently developed in the context of cognitive science and Material Engagement Theory (e.g., Malafouris 2013; Newen *et al.* 2018). As such,

I propose that social resilience ought to be seen as 1) **embedded** and emergent within the social, political, ecological components of multi-level complex systems; 2) **extended** through translocal flows that mobilize and connect places, beings, and things, as well as 3) **embodied** and constituted by each of these participating agents; and 4) **enacted** both daily and in the face of exceptional circumstances through interactive processes and social practices.

This translocal resilience framework creates opportunities for exploring expressions of power *through* places, rather than merely *over* them (cf. Allen 2003). Since the bidirectional movements and circulation of people and things are enabled and constrained by topography, the interplay between social organization and landscape agency frames the conceptualization of place and mobility, both within the spatial range of cultural horizons and at the frontiers. This is important because it contributes to reconciling ideas of interstitial communities in African landscapes as loci of both conservatism and creativity depending on the available spectrum of cultural possibilities and the degree of systemic coherence: while the more homogeneous replication of ideological and material life inherent to the Internal African Frontier is most applicable for understanding states of growth and consolidation, emerging diversity and novelty are quintessential features of social dynamics during reorganization phases, characterized by permeable frontier-frontier connectivity and mobility rather than unidirectional metropole-frontier migration, as illustrated by Ogundiran (2014) in relation to the Yoruba settlement of Early Osogbo (southwestern Nigeria).

Within climatic trends towards aridification and the subsequent greater reliance on migration, as well as the hunting and small livestock over cattle or large-scale crop cultivation during the first millennium BC, the mobility requirements of communities in southeastern Mauritania would have been amplified, and the remembrance and control of communication routes became fundamental social dynamics during the Late to Terminal Tichitt Tradition phases. A relevant example is documented through the clustering of funerary monuments in certain areas of Dhar

Tagant, particularly around the entrance of the Taskast wadi (n = 135), one of the main axes of mobility across the Hodh basin (Linares-Matás and Lim 2021a).

A fundamental dynamic of the Late Tichitt Tradition that subsequently becomes a cornerstone of Terminal Tichitt Tradition or Early Iron Age communities in the Tagant involves the transformation of households. This process entailed changes in both the social institution of the household, as well as in the relationships between households within settlements. These are evidenced first by a solidification of household architecture, with nuclear houses now being built on stone, often independent from extended household compounds. This trend was already becoming apparent in the differential morphology of peripheral neighborhoods at Dakhlet el Atrouss I (Dhar Tichitt), which are expected to belong to a later date than the core of the settlement, on the basis of expected settlement growth patterns (Linares-Matás 2022). The second dimension is the reduction of settlement densities, with more spatial separation between households and between household clusters, which hints at a weaker degree of socio-political integration and low expected incidence of external threats, which would have also reduced internal competition and household travel distances to arable farmlands. This pattern has been documented at several sites of the Northern Tagant Plateau. Terminal Tichitt or Early Iron Age households in this region tend to have better-defined internal subdivisions, often following the formula of one main compound, a circular subdivision, two or more circular houses, and a rectangular feature. Additionally, preliminary visual inspection suggests a lower degree of household differentiation than for example at large Classic Tichitt Tradition sites, although future research should aim to quantify these observations (cf., Linares-Matás 2022). Nonetheless, there are also some large walled settlements in higher-altitude, more defensible positions within the landscape that have associated funerary monument clusters, such as Guelb ed Dâmi (Linares-Matás, in press), which may be indicative of a considerable degree of variability regarding the cohesion of North Tagant communities over time. While the absence

of dates for individual sites and of a chronological framework for the region restricts the nature and certainty of the inferences that can be made at this stage of research, some tentative suggestions can be advanced with the explicit aim of offering hypotheses to guide future fieldwork research questions.

Socio-economic transformations tend to have considerable impact in the spatial organization of community life. In southeastern Mauritania, the introduction of ironworking and the arrival of Berber groups towards the end of the Late Tichitt may have involved the creation of novel identities and the reconfiguration of political relationships. The emergence of ritually charged activities associated with the creation of new professions (blacksmiths; cf. McNaughton 1988), may have been accompanied by greater agricultural production and demographic growth (de Barros 1988). Both factors could have offered more opportunities for small-scale exchange between households, which may have acted as a risk-buffer network and reduced the need for simultaneous labor requirements in the yearly cycle that demanded the pooling of resources among lineages and extended households (Wilk and Netting 1984). These processes could have favoured the emergence and consolidation of smaller but autonomous nuclear households as the primary socio-economic unit. For example, the introduction of cash-crop farming in and the development of petty trade in rural Mali altered the traditional social and economic cohesion of lineages, traditionally expressed as nuclear families clustered together in compounds inhabited by extended households. The Bamana village of Denyekoro experienced a dispersal of households as they began to work and live in individual houses interspersed with associated small plots of land and became responsible for their own private production and welfare, independently from their lineage (Zah 2000: 78).

Ethnographic evidence from agropastoral communities in the Sahel also highlights that the growth of several spatially extensive but weakly integrated, household-oriented settlements can

be the result of internal kinship dynamics, so explanatory frameworks do not necessarily have to rely on socio-economic transformations. Among Gouin communities in western Burkina Faso, for example, generational change leads to the fission of the agnatic household as a unit of production, with the matriline acting as the main unit of multigenerational material accumulation (Dacher 1997). This instability in terms of house membership and communities of residence leads to weakly integrated settlements, comprising a series of dispersed compounds or compound clusters and possessing limited centralized authority or civic activities (Capron 1973; Dacher 1997; Dueppen 2012b). These communities also lacked endogenous specialist households, with pottery and ironworking production taking place at the household level (Dacher 1997). Dueppen (2012b) describes how many sites in western and central Burkina Faso were precisely formed through the long-term residential occupation of spatially segregated households in the landscape, in processes that may also be reminiscent of "shifting sedentism" dynamics (cf., Canós Donnay 2016).

This paradoxical principle of cultural landscape stability through social and settlement fluidity, with permanent yet shifting towns together with the ebb and flow of more ephemeral villages, is an expected property of the panarchy, i.e. those nested non-linear systems possessing a multi-level arrangement (Gunderson and Holling 2002). I argue that this framework is particularly useful for understanding the nature of some of the largest sites found in the North Tagant. The most extensive site is a polyfocal settlement comprising households with variable degrees of spatial integration but without any evidence of civic architecture or public spaces, encompassing an area over 180ha. In the absence for the moment of any kind of chronological control, it is unclear how many of these enclosures were occupied simultaneously. However, given the limited layout structure, I would argue that this settlement pattern entailed expansive and spontaneous organic growth, shaped by the topographic materiality of the Tagant Plateau, representing an example of "shifting sedentism" (cf., Canós Donnay 2016). This pattern is also

reminiscent of Anglo-Saxon "wandering settlements", such as Mucking in eastern Britain, where the distribution of finds and pottery, as well as over 200 sunken huts, documented a relatively dense group of buildings dating to the fifth century AD at the southern end of the site, while the site's "center of gravity" gradually moved northwards during the sixth and seventh centuries, ultimately resulting in a large number of widely dispersed farmsteads (Hamerow 1993). Comparable settlement biographies may help contextualize the spatially extensive but weakly integrated sites in the Tagant region, but only future targeted fieldwork will elucidate the specific nature and temporality of the processes at play in this region.

At the same time, pre-existing dynamics of first-comer seniority could generate centripetal forces towards settlement nucleation and socio-political centralization through the harnessing of the new ritual affordances associated with ironworking, which may also partially explain the rise of large walled settlements during the Terminal Tichitt phase, such as T150 in Dhar Tagant (Ould-Khattar 1995; MacDonald 2020). For example, a shift from household-level pottery and iron making production to a pattern of specialized smelting and smithing centred around the ancestral settlement household (Mound 4) was observed at Kirikongo by the end of the Yellow II phase, Dueppen (2012b). The centralization of iron metallurgy was accompanied by the rise of richly furnished children burials (containing cowrie shells, cattle bones, and polished stones), probably associated with the harnessing of spiritual power associated with the deep digging involved in iron ore extraction by firstcomer lineages (Dueppen 2012a). These pathways towards centralization and inequality were not irreversible, however, as collective action was able to prompt a relatively rapid decoupling of household ancestrality from the spiritual power of ironworking, with the displacement of smelting and smithing practices to a peripheral household (Mound 11), which may nonetheless suggest the maintenance of craft specialization as an endogenous household activity (Dueppen 2012a). This process of reorganization was accompanied by an increase in inter-household interactions, illustrated by

the relocation of food preparation activities to outside areas (Dueppen 2012b). The appearance of several large, fortified settlements in Dhar Tagant and the northern Tagant Plateau may be hinting at processes of increased inter-community competition and conflict. Nevertheless, far more archaeological research towards establishing a reliable regional chronological framework and into the organization of everyday life in Tagant communities is still necessary to ascertain the nature of community cohesion and integration in different settlement types, its relationship with between- and within-household dynamics, and the patterns of belonging and interactions between different settlements.

An increase in self-organizing, decentralized peer-to-peer interactions during a reorganization phase can also contribute to explain dynamics of population nucleation. McIntosh (2005) argues that a co-evolutionary process of reciprocal adaptive selection involving a symbiosis network of specialized communities (farmers, herders, fishers, hunters, potters, blacksmiths, etc.) led to the formation of formation of a multi-satellite, multi-corporate settlements in the Middle Niger. As such, while newly found nuclear household-level self-sufficiency can weaken lineage dependence and the primacy of extended households, leading to the centrifugal dispersion of households in spatial and social terms, trends towards specialization reinforces interdependencies and interconnectivity at levels above the household through resource exchange networks. At the same time, however, the dynamics of re-organization and adaptation can become inconsistent or possess insufficient fitness protocols (the "vagabond trap"), thus preventing a transition from reorganization to growth and potentially leading to further release (Fath *et al.* 2015).

Therefore, emerging differences in social and political complexity can be explained through reference to the non-linear dynamics of Complex Adaptive Systems as they unfold within the cultural milieu of pre-colonial African polities. Increases in social complexity and household

interconnectivity can become structured in either a centralized or a polyfocal and heterarchical manner, depending on the relative weight of narratives of firstcomer primacy and the existence of alternative sources and holders of political and ritual power decoupled from lineage-based, ancestral seniority (cf., Crumley 1995; McIntosh 1999). A diachronic perspective indicates that the socio-political, economic, and migratory dynamics of Tichitt Tradition agropastoral communities of southeastern Mauritania can be seen as a relevant precursor of two fundamental indigenous pathways to complexity in West African prehistory: the emergence of centralized Sahelian empires, such as Ghana/Wagadu on one hand, and the rise of decentralized, heterarchical urban forms, such as Jenné-Jeno, on the other (Munson 1980; Holl 1985; MacDonald 2011). Simultaneously, the translocal social resilience mechanisms of migration westwards also enable us to infer that Tichitt Tradition communities were directly ancestral to the Gangara communities, most likely Soninke/Sarakolé groups who inhabited the Tagant Plateau at the time of the Islamic arrival during the early second millennium AD (Mauny 1961; Munson 1980; Holl 1985; Ould-Khattar 1995).

5. Conclusions

The highlands of southeastern Mauritania present an extraordinary archaeological record for documenting the emergence, consolidation, and reorganization of cultural dynamics, which illustrate the applicability of complex adaptive system cycles in the diachronic study of human societies. These trends include several alternative pathways towards the increasing social complexity at the Saharo-Sahelian interface, which command great interest in terms of validating the creativity and ingenuity of indigenous African communities and in the global comparative study of past human experiences from an archaeological perspective. The Tichitt Tradition represents a durable manifestation of pre-existing trends towards socio-economic differentiation among mobile Saharan communities that were able to reorganize, grow and consolidate during the second millennium BC in an ecological niche that enabled the development of a thriving agropastoral economy based on cattle-keeping and pearl millet cultivation. Pearl millet cultivation likely started as a seasonal component of a generalized broad-spectrum pastoral economy that included the exploitation of wild terrestrial and aquatic resources, soon becoming a paramount agricultural staple that sustained a semi-sedentary lifestyle structured around extensive stone-walled settlements.

Mobility, migration, and translocal interactions represent essential components of social resilience in drylands, particularly in contexts of resource unpredictability and climate change. This pattern is apparent in Tichitt Tradition settlement dynamics, most evidently during its growth phase in the early second millennium BC and in the aftermath of its release phase during the late first millennium BC and the first millennium AD. In the first instance, the origins of the Tichitt Tradition can be traced back to emergent “disequilibria” within Neolithic pastoral communities in the Central Sahara, which migrated southwestwards towards southeastern Mauritania at the onset of the Late Holocene, amidst strong desiccation trends. Migration also

played a fundamental role as a coping mechanism for Tichitt Tradition communities in the face of intense aridification trends. These processes of relocation set the scene for the development of a diversity of multi-dimensional and still poorly analyzed processes of reorganization that unfolded within the Tagant region, while further south the descendants of the Tichitt diaspora became a relevant part of the backbone of both early Sahelian empires, such as Ghana/Wagadu, and heterarchical urban communities in West Africa. Supra-regional mobility and interconnectivity represents a critical dimension for the security, resilience, and survival of agropastoral communities facing disruptive climate change in the Saharo-Sahelian borderlands.

The Tichitt Tradition trajectories also illustrate two important dimensions of frontier dynamics: a) the conservative but decentralized reproduction of material and ideological forms in processes of population expansion leading to "high systemic coherence" that Kopytoff (1987) characterized in his Internal African Frontier model seen in the Tichitt Tradition expansion during its growth and consolidation states; b) a greater adaptive diversity, creativity, and spontaneity of interstitial communities as settlement patterns and socio-economic strategies reconfigure and systemic coherence rapidly decreases during release and reorganization phases (cf., Ogundiran 2014). The dynamic frontier conditions in the prehistoric sequence of the highlands of southeastern Mauritania therefore appear to have significantly contributed to the formation of the initial cultural background for widely shared traits of pan-African political culture, in line with Kopytoff's (1987: 15) intuition of the relevance of Saharo-Sahelian Neolithic communities in this process.

This work represents an important contribution towards renewing long-term endeavors that aim to describe, recognize, and highlight emergent patterns of complexity in the archaeological record of southeastern Mauritania, through interrelated dynamic dimensions of material culture, socio-political organization, and settlement patterns. It provides a coherent research

agenda that emphasizes the importance of integrating multiple lines of enquiry in future multidisciplinary and collaborative research both remotely and on the ground. From a methodological perspective, the visibility of drystone architectural components in satellite imagery from arid highland ecosystems leads to high degrees of identification success rates for these settlement categories and facilitates the delineation of site sizes, which provides a reliable empirical dataset. At the same time, the low-resolution chronological and archaeological datasets currently available for southeastern Mauritania do not yet allow for a definitive corroboration of these theoretical developments. These interpretations of settlement pattern dynamics ought to be seen as preliminary since it is difficult to determine the relationships between multiple sites which may or may not be contemporaneous until they are assessed in the field. The inclusion of thousands of archaeological sites identified through remote sensing in the highlands of southeastern Mauritania into the Endangered Archaeology of the Middle East and North Africa (EAMENA) project database (https://eamena.org/database; Rayne et al. 2017), which will be made available to researchers as well as relevant national and regional authorities, will facilitate and promote the monitoring, investigation, and safeguarding of cultural heritage in the region.

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Connectivity and socio-economic interactions across time and space in the southern Sahara: Medieval Tegdaoust (Mauritania) and its hinterland

Gonzalo J. Linares Matás and Jonathan Lim

Abstract

The integration of spatial analysis techniques and remote sensing offers a promising avenue for archaeological research into the arid landscapes of the West African Sahel. Amidst the dunes of the Aoukar Basin, the oasis town of Tegdaoust (Hodh El Gharbi, southeastern Mauritania) emerged as a key node of early Islamic trans-Saharan caravan routes. The trading locality was located on the sandy Nouadache Cirque, in the Rkiz highlands, an area to the east of the southern end of the Taskast wadi. The natural passageway of the wadi promoted considerable connectivity between the communities of the Tagant plateau and those areas further south for over a millennium, as illustrated by the existence of morphological parallels in mortuary architecture and pre-Islamic ceramic assemblages. In this privileged geographical position, the caravansary prospered for centuries during the medieval period, although the Almoravid conquest near the end of the 11th century AD and processes of aridification had a noticeable impact. In this paper, we use a combination of spatial analyses to identify multiscalar processes of cultural and socio-economic interaction, exploring Tegdaoust and its immediate hinterland as well as the relationships between communities at both ends of the Taskast wadi, in the context of wide-ranging trans-Saharan connections. Very high-resolution multispectral satellite imagery is effective for identifying archaeological features, and for calculating vegetation indices to suggest a relationship between seasonal vegetation patterns and past human settlement. Spatial statistics were used to infer distinct clusters of pre-Islamic funerary monuments around Tegdaoust. A large Islamic cemetery (Tegdaoust Nord) was located 2km to the north. The generation of viewshed analysis strongly suggests that the placement of the Tegdaoust Nord cemetery atop the plateau overlooking the settlement enhanced its sense of solitude, while least-cost pathways corroborate the relevant role of the Taskast wadi in structuring regional patterns of mobility.

Keywords: African Archaeology, Analytical Phenomenology, Remote Sensing, Funerary Landscapes, Burial Practices, Islamic Conversion.

1. Introduction: Socio-political complexity and trans-Saharan networks

The Sahara (*sahra* in Arabic, meaning "desert") is a hyper arid landscape, with stony highlands and vast, low-lying areas of sand dunes. It also encompasses grasslands and oases, well-watered microenvironments conducive to vegetation growth and human habitation. Understanding processes of connectivity in the Sahara requires a multi-scalar and diachronic approach that explores local details in a transregional scope. The relationship between interconnectivity, complexity, and stability is a relevant dimension to consider in the study of socio-political systems (Kohler and van der Leeuw 2007; Miller and Page 2007; White 2015). The constraints and opportunities on mobility and settlement characteristic of semi-arid and desert environments, with a necessary emphasis on water availability, offer an exciting avenue into a better understanding of spatial patterns associated with human connectivity (Mitchell 2005; Mattingly *et al*. 2019). The development of socio-political complexity in the southern Sahara and the Sahel ("shore" in Arabic) was sometimes attributed to the southward expansion of Berber and Arab-led trade networks (Bowill 1958; Austen 2010). In this context, urbanism and complex Medieval states, such as Mali and Songhai, are thought to have emerged, at least partially, through the control of prestige goods (gold, ivory, salt) and slaves transported for large distances across trans-Saharan routes (Levtzion 1985: 183; Devisse 1988; Insoll 2003). However, it is important to note how most Islamic urban centres in the Sahara developed from earlier forms of semi-permanent occupation within their regions (Mattingly 2003; Nixon 2020). Although local belief systems were common until the 19th century and likely continue to persist in places, Islamization of the Sahara was particularly intense during the 11th century, when the Almoravids, a community of orthodox Sanhaja Berbers, temporarily unified through conquest a region extending from southern Mauritania to the Iberian Peninsula (Levtzion and Hopkins 2000; Insoll 2003; Nixon 2020).

1.1. Medieval trade networks in the Sahara: the site of Tedgaoust

The existence of medieval Islamic trade networks in the Sahara is amply demonstrated in the archaeological record (Figure 1): in the Niger Bend, glass beads and pottery fragments have been found in the hundreds at the site of Gao-Sané (Insoll 1998) and at the entrepôt of Essouk-Tadmekka, from AD 750 onwards (Nixon 2009). In the Northern Sahel, the site of Tegdaoust (Tamchakett, southern Mauritania) is believed to be the trading entrepôt of Audaghost mentioned by al-Bakri and other early Islamic authors (Devisse 1983).



Figure 1: Map of main archaeological sites and cultural regions mentioned in the text. Map by authors, Basemap ©ESRI.

The site of Tedgaoust, enclosed by two branches of a temporary wadi in the sandy Nouadache Cirque (Figure 2), was first identified by Lieutenant Boery in 1923 when exploring the Rkiz sandstone massif (Boery 1927). The large main artificial mound (12ha) was excavated by a French team between 1960–1976, which documented that the site was occupied almost continuously from the 8th century to the 14th century (Devisse 1983; Polet 1985; Robert-Chaleix 1989). Early occupation layers, from as early as the 7th century AD, were followed by mud-brick structures from the late 9th to early 10th centuries (Robert 1970; Devisse 1983). It is probably one of the only Saharan Islamic sites where excavations have revealed entire areas of the town's earliest phases (Devisse 1983; Polet 1985; Nixon 2020). While stone buildings were

built in the 11th century, the town experienced a considerable decline from the end to the 12th century, being completely abandoned by the 15th century (Robert 1970; Devisse 1983). Most of the visible structures, standing 0.5–0.8m tall, correspond to a partial and truncated resettlement that took place a couple of centuries later, at a time when tobacco had already been introduced to the region (Rosenberger 1985). The urban stratigraphy shows the superimposition of three settlements, with the first two sharing a similar layout, with old walls and paths forming the foundations of newer buildings and roads, while the third layer entailed a considerable reconfiguration of previous patterns (Robert 1970; Devisse 1983).

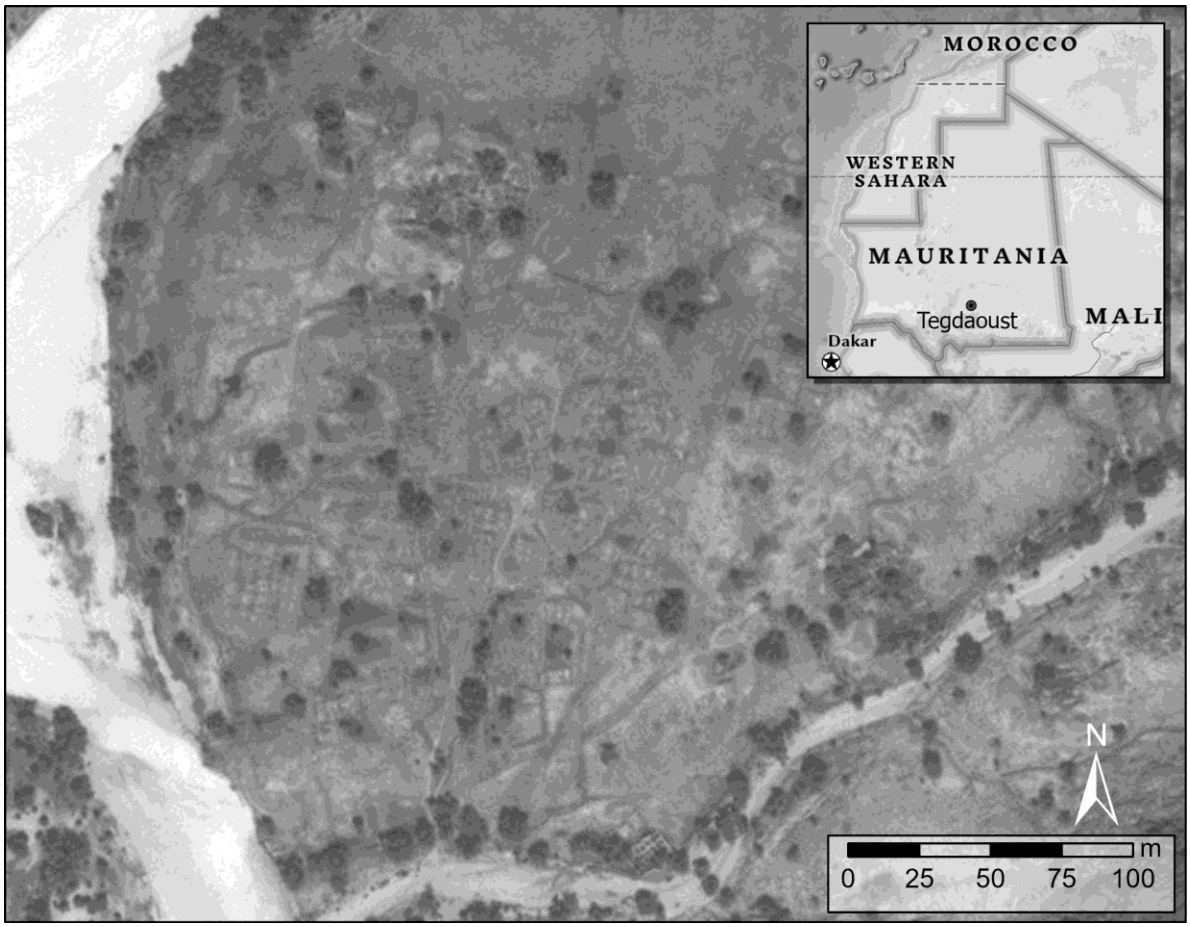


Figure 2: Satellite view of Tegdaoust, an important trans-Saharan trading settlement in southern Mauritania. Map by authors, Basemap ©ESRI and ©Bing.

Residential quarters are particularly dense in the vicinity of the central cluster. Some houses are "Mediterranean" in style: three rooms, an ante-room, and a large courtyard with a well and the kitchen (Robert 1970). Such houses with rooms arranged around a central courtyard are also common at the entrepôt of Essouk-Tadmekka (Nixon 2017). Objects of local manufacture and imported items, such as glazed ceramics, glass beads and vessels, gold ingots, and Fatimid

coin-weighs were common, evidencing strong links with North Africa (Robert 1970; Launois and Devisse 1983; Devisse 1988). Indeed, the town is described in contemporary sources to have had a considerable number of North African traders and markets (Devisse 1983: 5–29). To the northeast of the main settlement area we find a *musallā* (Figure 3), an open praying enclosure that was intended to congregate all the members of the Muslim community for festivities—particularly those involving feasts, next to a building with a prominent mihrab (Robert 1970). The peripheral location of the *musalla*, mirroring the pattern documented at Essouk-Tadmekka, likely reflects the dynamic nature of these trading towns, catering to the spatial needs of camel caravan flows (Nixon 2020).

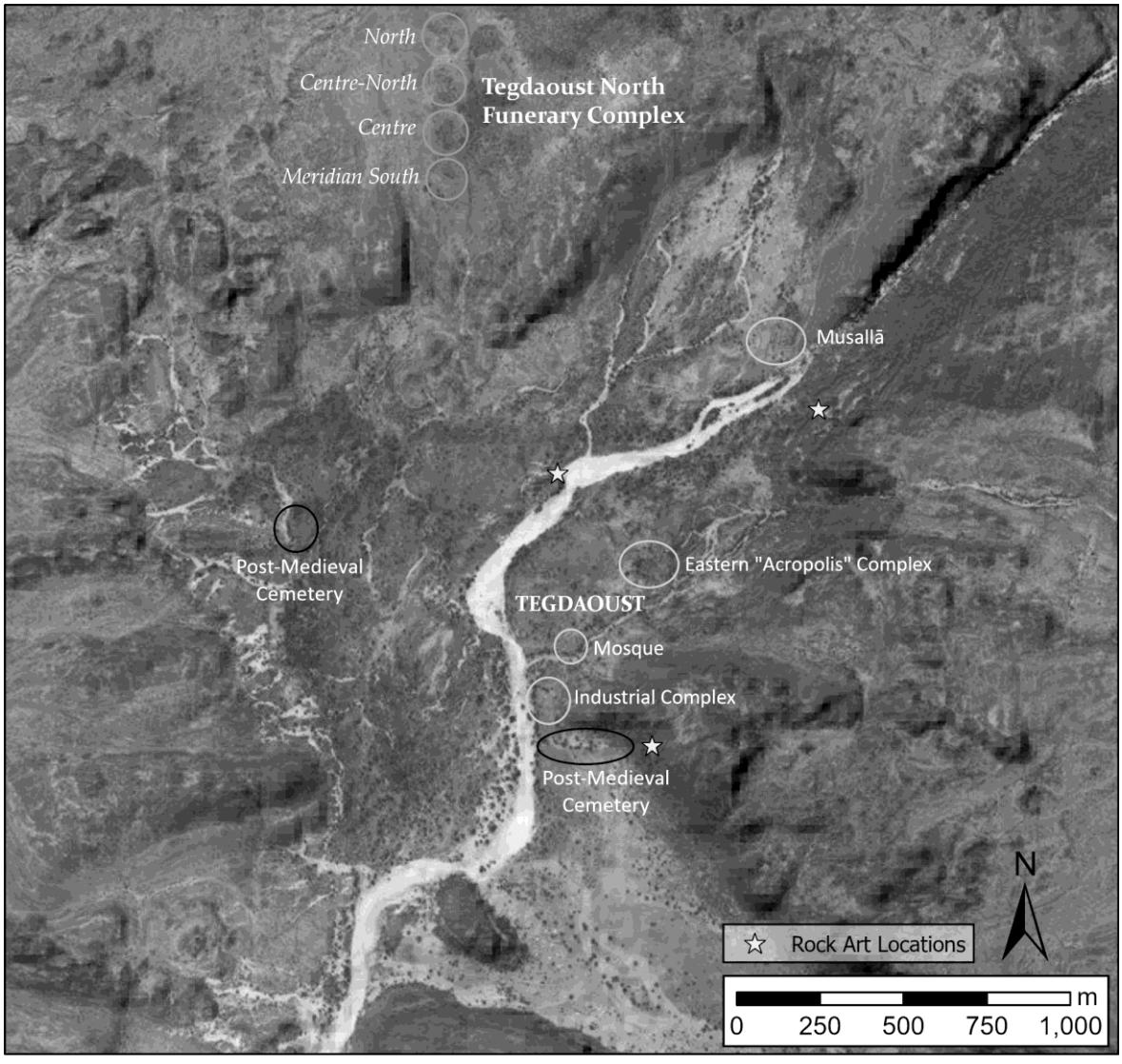


Figure 3. Cultural landscape of Tegdaoust, showing a protracted history of occupation from pre-Islamic to post-medieval times. Distribution data from Devisse (1970), basemap ©ESRI and ©Bing. Map by authors.

To the south, we find peripheral quarters and a small tenth century mosque with rectangular prayer room, a *sahn* or central courtyard, and an elaborate mihrab oriented south/southeast, which further suggests Maghrebi or Andalusian influences (Robert 1970: 481). These hypostyle congregational mosques became common in Saharan urban centers by the 9th–10th centuries, and minarets are conspicuously absent from southern Saharan localities (Nixon 2020). To the south of the small wadi, an industrial activity complex—devoted to metalworking and local pottery manufacture—was located on a secondary tell, and more recent cemeteries were documented in that area (Robert 1970; Vanacker 1979).

Tedgaoust-Nord, a large Islamic necropolis comprising over 100 quadrangular enclosures in 4 main clusters (see Figure 3 above), is located on the northern plateau overlooking the Nouadache Cirque, along a path used until recently by salt caravans (Robert 1970: 474). While a number of features are visible on VHR satellite imagery, the excavation team reported that the partly crumbling stone constructions barely stood above the current ground level. The clearest signs of the Islamic nature of the cemetery come from the presence of two mihrabs, one in the centre-north cluster, and the other on the eastern wall of a rectangular enclosure within a larger rectangular enclosure that forms part of the northern cluster (Robert 1970: 476).

The presence of imported glass goblets, oil lamps and enamelled pottery at Tedgaoust and other localities in the northern Sahel illustrate the dynamic nature of trans-Saharan trading networks connecting Islamic North Africa and the Sahel (McIntosh and McIntosh 1988: 111; Mattingly 2017). Moreover, we cannot neglect the role that slavery played in trans-Saharan exchange networks, with access to slave labour and the commodification of enslaved populations often being important socio-economic dynamics in the consolidation of political power and the maintenance of regional hegemony across the region (DeCorse 2001; Gronenborn 2001; MacEachern 2001; Stahl 2004). Prosperity and suffering are both important dimensions to consider in narratives around human experiences during this period.

1.2. The pre-Islamic roots of trans-Saharan trade networks

Nevertheless, this ‘Arab stimulus’ model downplays the agency and transformative endogenous processes that Sahelian communities experienced prior to the advent of Islam in the region. With the expansion of metal-using peoples into the Middle Niger in the second half of the first millennium BC, the region experienced an increasing degree of settlement nucleation, articulated around the fluvial system. Jenné-jeno, at the core of a productive

floodplain environment, reached 25ha by *c.*300 AD, exporting rice in exchange for stone and metals that were lacking in the Inland Niger Delta (McIntosh and McIntosh 1984). The site continued to expand during the second half of the first millennium AD, with a growing engagement in long-distance trade illustrated by the presence of copper and gold objects, as well as a potash glass bead of Asian origin (Brill 1995), with settlements increasingly exhibiting a regionally homogeneous material culture, which may hint at the statecraft dynamics of the Empire of Ghana (McIntosh and McIntosh 1988: 115–116).

Furthermore, Garrard (1982) drew the attention of Africanist archaeologists to the fact that Carthage and Alexandria minted a growing number of gold coins from the end of the 3rd century AD, with gold coinage production levels at Carthage remaining high even after the Arab conquest in 695, suggesting a maintenance of existing trans-Saharan trade networks, perhaps articulated regionally by Garamantian communities in southern Libya and by sedentary societies in the Niger Bend (MacDonald 2011; Mattingly 2011). A potential source might have been the Sirba goldfields, given the extensive collection of grave goods found at the nearby site of Kissi in contexts dating to the first half of the first millennium AD, which included glass beads of Central Asia origin and imported brass objects from Roman North Africa (Magnavita 2009; Fenn *et al.* 2009; Robertshaw *et al.* 2009). Thus, archaeometric data indicate that pre-Islamic trans-Saharan connections extended not just to the Mediterranean rim, but reached the trade networks around the Indian Ocean (Magnavita 2017). Moreover, the considerable number of Roman imports in the Fazzan region of the Central Sahara has further emphasised the scale of these trade flows, and highlighted the crucial intermediary role that Garamantian elites played in the control and manipulation of resources and channels of influences across the Sahara (Daniels 1970; Liverani 2000; Mattingly 2003).

Indeed, while the pre-Islamic Sahara was never a fully integrated unit, this immense region was more interconnected than often credited. In fact, the development of agricultural communities on Saharan oases, which involve high initial and recurrent labour inputs, was likely supplemented from the start by trade-derived income, a process that would have facilitated and encouraged transformative cultural exchanges, often involving the spread of agricultural products, ideas, and technologies (Mitchell 2005; Horden 2012; Wilson 2012; Mattingly 2013, 2017). The appearance of rock art depicting chariots and horses from the first millennium BC across vast swathes of the Sahara illustrates the potential for increased regional mobility (Mauny 1979; Barich *et al.* 1986; Muzzolini 1995; Gallinaro 2013; Mattingly 2017).

Therefore, trans-Saharan trade is perhaps best conceived as an asymmetric network of interdependent subsystems articulated through a challenging but permeable desert frontier, by means of intermittent but substantial and profitable exchange flows from the first millennium BC, consolidating and expanding from the second half of the first millennium AD (McIntosh and McIntosh 1988: 124; Scheele 2010; Mattingly 2011; Wilson 2012; MacDonald 2013).

In this context, the visual prominence of dry-stone structural features in the semi-arid upland environments of the Sahara and the northern Sahel provides a conducive avenue for archaeological remote sensing research that enhances our understanding of trans-Saharan connectivity through time. This affordable and non-invasive approach allows the ethically-informed survey, documentation, and analysis of cultural landscapes across underexplored and/or politically unstable territories (Sadr and Rodier 2012; Biagetti *et al*. 2017; Rayne *et al*. 2017; Davis *et al*. 2021; Linares-Matás and Lim 2021; Linares-Matás 2022). In this paper, we contextualise the multi-scalar landscape affordances for connectivity of the medieval Islamic entrepôt of Tedgaoust (southern Mauritania) and present the preliminary characterisation and regional distribution of pre-Islamic funerary tumuli in the Rkiz massif. We argue that the location and regional relevance of Tedgaoust as a node of trans-Saharan trade systems emerged from pre-existing endogenous networks of seasonal mobility and interaction between highland and lowland areas that preceded the advent of Islam in the region. These connections were often articulated along the Taskast wadi linking Tamchakett and Dhar Tagant.

2. Methodology

2.1. Multispectral remote sensing for environmental analysis

The analysis of multispectral satellite imagery was used to infer environmental conditions in the landscape. Both 11-band Landsat-8 (30m-resolution ground sampling distance (g.s.d.)) and four-band (Red, Green, Blue, and Near Infrared (NIR)) Planetscope (3m g.s.d) imagery were used. In order to locate potential bodies of water in the study area (a 140,000km² area between Ouadane and Audaghoust including the Taskast Wadi), a mosaic of Landsat imagery was downloaded from Planet as non-orthorectified scenes, calibrated to at-sensor radiance. The mosaic was composed of images taken during the height of Mauritania's rainy season, in September and October, to maximise the chance of locating accumulations of standing water. A Modified Normalized Difference Water Index (MNDWI) raster was calculated from this mosaic, using following spectral bands: Band 3 (Green) and Band 6 (Short-Wave Infrared (SWIR)) in a formula, MNDWI = (Green - SWIR) / (Green + SWIR). This index is a way of highlighting the presence of open water in multispectral imagery (Xu 2006).

Landsat-08 imagery was also used to create a Normalised Difference Vegetation Index (NDVI) of the Tegdaoust area using Band 5 (Red) and Band 6 (NIR), and the formula, NDVI = ((NIR - Red)/(NIR + Red)). This is a standardised measure of vegetation biomass "greenness", or vigour (Tucker 1979). Two comparative mosaics were created using images from the dry season in April 2020, and from the wet season in September 2020, and two NDVI rasters were generated accordingly. The range values of the NDVI rasters were automatically classified using the "Natural Breaks (Jenks)" method (Jenks 1967), and divided into ten value range classes. In the September 2020 NDVI raster, the class representing the highest NDVI values (0.36–0.57) was isolated, and used to guide visual prospection for archaeological features, along with modern settlement and agropastoral activity—very high-resolution open imagery hosted on Bing Maps and Esri was used for this purpose.

2.2. Least Cost Pathways

Least cost pathways were generated using a 30m resolution digital elevation model (DEM) of south Mauritania, derived from Shuttle Radar Topography Mission (SRTM) imagery available on the USGS Earth Explorer portal. A distance accumulation raster was created using Tobler's Hiking Function as a cost raster, a function that simulates the performance of a human being walking over terrain (Tobler 1993; Goodchild 2020). A slope raster was calculated using the

DEM, and subject to the following Python-based map algebra expression in ArcGIS Pro 2.8 to generate the cost raster:

*Exp(3.5 * Abs(Tan(("SlopeRaster" * math.pi) / 180) + 0.05)) / 100.*

2.3. Visibility

Projective viewsheds were simulated at regular intervals along a path between Tedgaoust and Tedgaoust Nord, an Islamic funerary complex located on a plateau 2km north of the medieval settlement (Roberts 1970), to simulate what an individual would see when travelling to and from the sites. A least cost pathway was generated using the DEM and methodology outlined in the previous sub-section. Observer points (with simulated heights of 1.75m, the height recommended by Gillings and Wheatley [2001]) were generated at 100m intervals along the path, and projective viewsheds from every point were iteratively calculated. The resulting viewsheds were converted to polygons and smoothed using the Polynomial Approximation with Exponential Kernel (PAEK) technique with a 100m tolerance.

2.4. Inferring tumuli clusters

Funerary monuments in the form of tumuli in the Tegdaoust area were digitised as point features and as polygons in ArcGIS Pro 2.8, using Bing Maps as a basemap—although no metadata is readily available for the Bing Maps service, the local imagery is orthorectified and of a very high (*c.*30cm) ground sampling distance. Where present, the outer tumuli ring features were also digitised as polygons.

Clusters of funerary monuments were inferred using a number of statistical tools. Tumuli were digitised and aggregated into 0.25km² hexagonal cells, then subjected to two independent spatial clustering analyses to confirm if there was indeed clustering— Spatial Autocorrelation (Global Moran's I) (Getis and Ord 1992) and Average Nearest Neighbour (David 1985). Once a non-random and statistically significant degree of clustering was confirmed, both the Kernel Density tool (Silverman 1986) and the 'self-adjusting' (HDBSCAN) algorithm (Campello *et al.* 2013) was used to help group sites into clusters based on cluster probability and stability. A minimum bounding volume in the shape of a convex hull was generated to create a study area of 121km², for the purpose of these calculations.

3. Results

3.1. Vegetation indices for investigating the archaeological landscape of Tegdaoust

A comparative study of the NDVI values of the Tegdaoust area between the dry season in April 2020, and the start of the rains of September later that year, reveals striking differences in seasonal vegetation patterns. During the dry season, the maximum NDVI value is very low at 0.16. However, the landscape is significantly more verdant in September, with a maximum value of 0.57 (Figure 4). Many archaeological sites and tumuli clusters, including Tegdaoust, can be found in close proximity (ie. within 1km) of the areas with the highest NDVI value range class (0.36–0.57) (denoted in purple in Figure 4). While some of the highest values correspond to natural processes, given that they are also found in the central part of seasonal bodies of water, such as small lakes, it is worth noting that a considerable number of areas with high vegetation vigour are hubs of modern agropastoralist activity, in the form of small settlements and crop fields. Local flood-recession farming benefits from productivity enhancement methods, such as the development of stone enclosures of low height that are quite successful in retaining flood-water inputs for longer. This additional provision of moisture maximises the potential of suitable farming areas, creating a positive feedback loop that is clearly reflected in our NDVI assessment. It is conceivable that some of these agronomic adaptations to the highly seasonal environmental conditions prevailing in the area were similar to agricultural practices employed during late medieval times and subsequently built upon by successive generations living in the area.

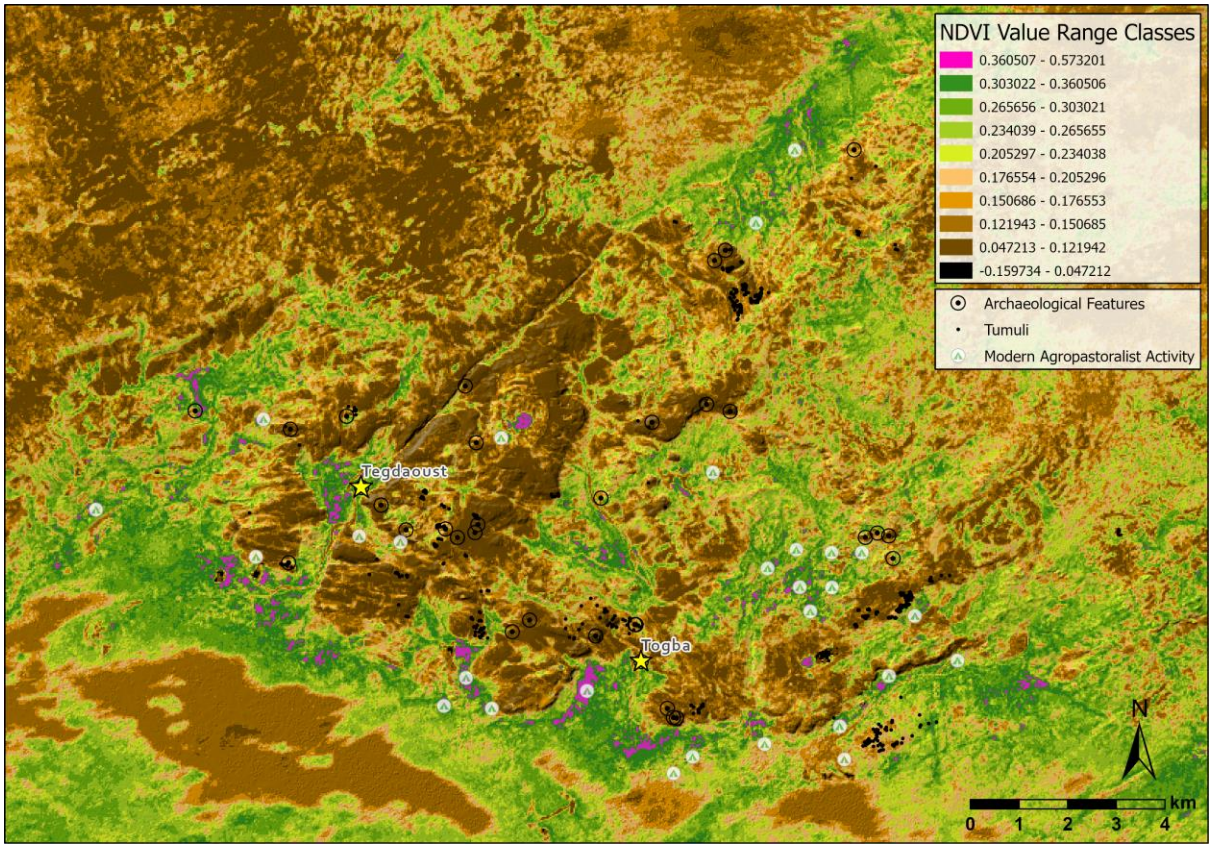


Figure 4: Map with NDVI values showing the distribution of pre-Islamic tumuli, archaeological features and main trading settlements, alongside modern agropastoral sites in the Rkiz Massif region of southern Mauritania. It depicts visually the spatial correlation between high NDVI values and human occupation of the landscape, particularly when pertaining farming productivity. Map by authors, Basemap ©ESRI and ©Bing.

3.2. Least Cost Pathways

The least-cost pathway generated between Oudane and Tegdaoust (Figure 5) highlights the integral role of the Taskast wadi for traversing the medieval trade route, as suggested by Devisse (1989). The Taskast wadi represents a topographically level and easily-traversed route through the vast sand dunes of the Aoukar Desert—inspection of SRTM-derived DEM suggests they range in height from 100m to 150m, and at least 50–60m of relative height along the wadi. This long depression (*c.*150km), modelled by fluvial flows during a humid phase of the Quaternary, could be traversed easily, even by car, in the 1970–1980s (Ould-Khattar 1995). These affordances are especially pertinent given the evidently harsh environmental conditions along most of the travelled path. In this regard, analysis of the MNDWI rasters suggests that there are no permanent or seasonal bodies of surface water in the Majabat Al-Koubra desert—

where Monod (1969) found the Ma'den Ijâfen "lost caravan", a fabulous assemblage comprising numerous brass bars and over three thousand cowrie shells (Christie and Haour 2018). While undoubtedly most caravans reached their destination, this find evokes the potential difficulties associated with traversing the hyper-arid landscapes of the Sahara.

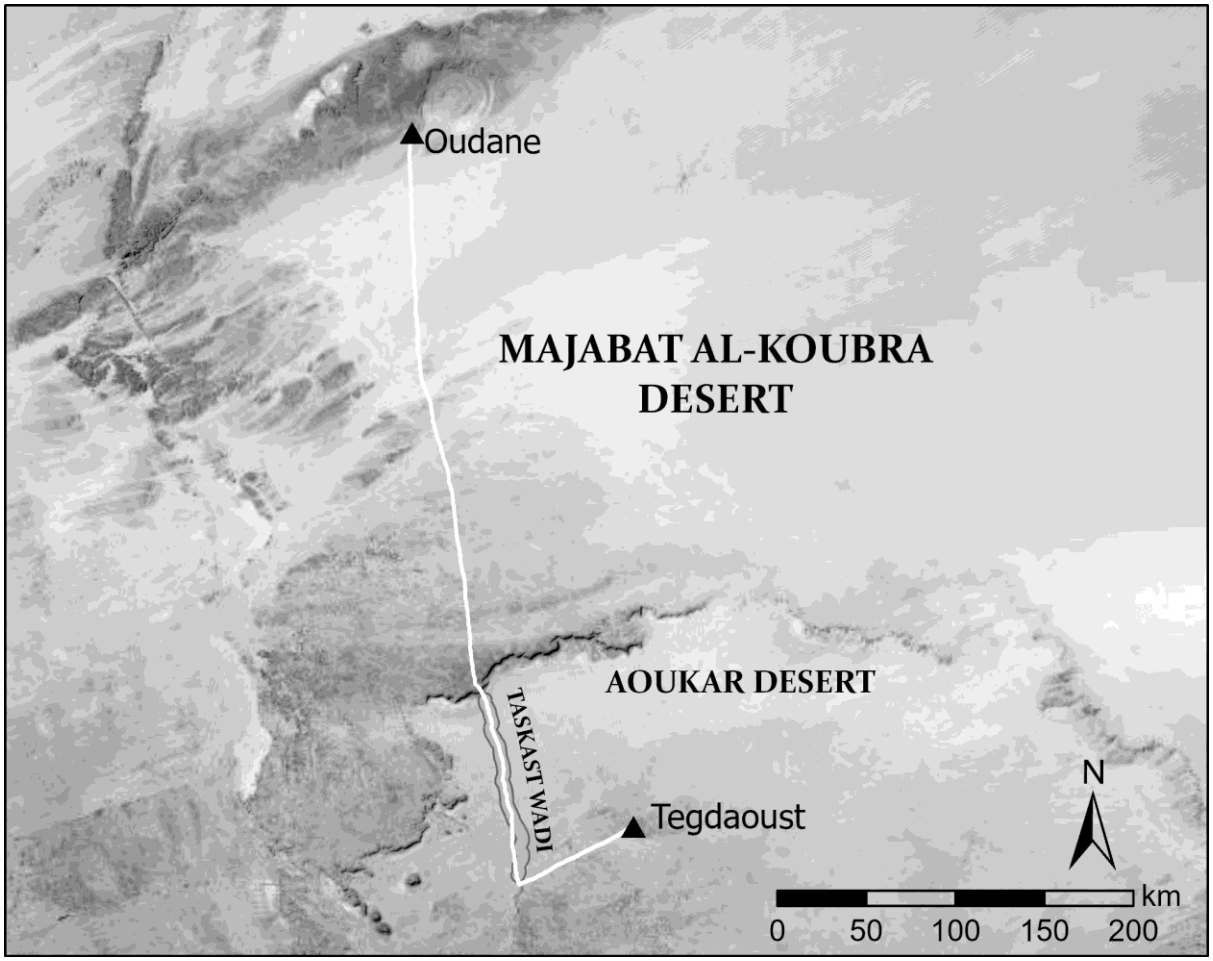


Figure 5. Map showing the simulated least cost pathway between the medieval trading settlements of Ouadane (Adrar region, central Mauritania) and Tegdaoust, across the Majabat al-Koubra desert and the Dhar Tagant escarpment. Note the important role of the Taskast wadi in terms of structuring long-distance mobility in the region. Map by authors, Basemap ©ESRI and ©Bing.

3.3. Visibility analysis around Tegdaoust

In order to investigate the relationship between the medieval inhabitants of Tegdaoust and the Islamic funerary complex of Tegdaoust North, least cost pathways between the town mosque and this cemetery on top of a plateau were calculated, along with viewsheds at 100m intervals. This was done in an attempt to simulate the experience of traversing that landscape. However,

it must be noted that these are suggested optimal routes only based on slope and the time needed to traverse it—the 30m G.S.D DEM used in this study lacks the resolution to discern local scale pathways or hollow ways. A striking pattern emerges along the direct route generated between Tegdaoust and Tegdaoust North (Figure 6)— the traveller ascends the gentle slope to the top of the plateau (from Observer Point (OP) 12 to 15), affording expansive views of the surrounding landscape. However, as they crest the top of the plateau (OP 16), and travel further into the heart of Tegdaoust North (OP 17 to 19), the viewsheds constrict dramatically. This indicates that the top of the plateau is an intimate and private space for mourners, visitors, and those interred within the funerary complex. Our viewshed results, which emphasise lack of intervisibility and a sense of seclusion are consistent with Robert (1970) experiential account, noting how "the solitude of the plateau is certainly compatible with eternal rest". An alternate path was generated—one that assumes that a party of mourners congregate first at a *musalla* to the northeast of Tegdaoust (Figure 6). A similar viewshed pattern is evident, with a constriction of views after the traveller crests the plateau at OP 23 and travels into the funerary complex (OP 24–26), which serves as further evidence for the secluded properties of the plateau.

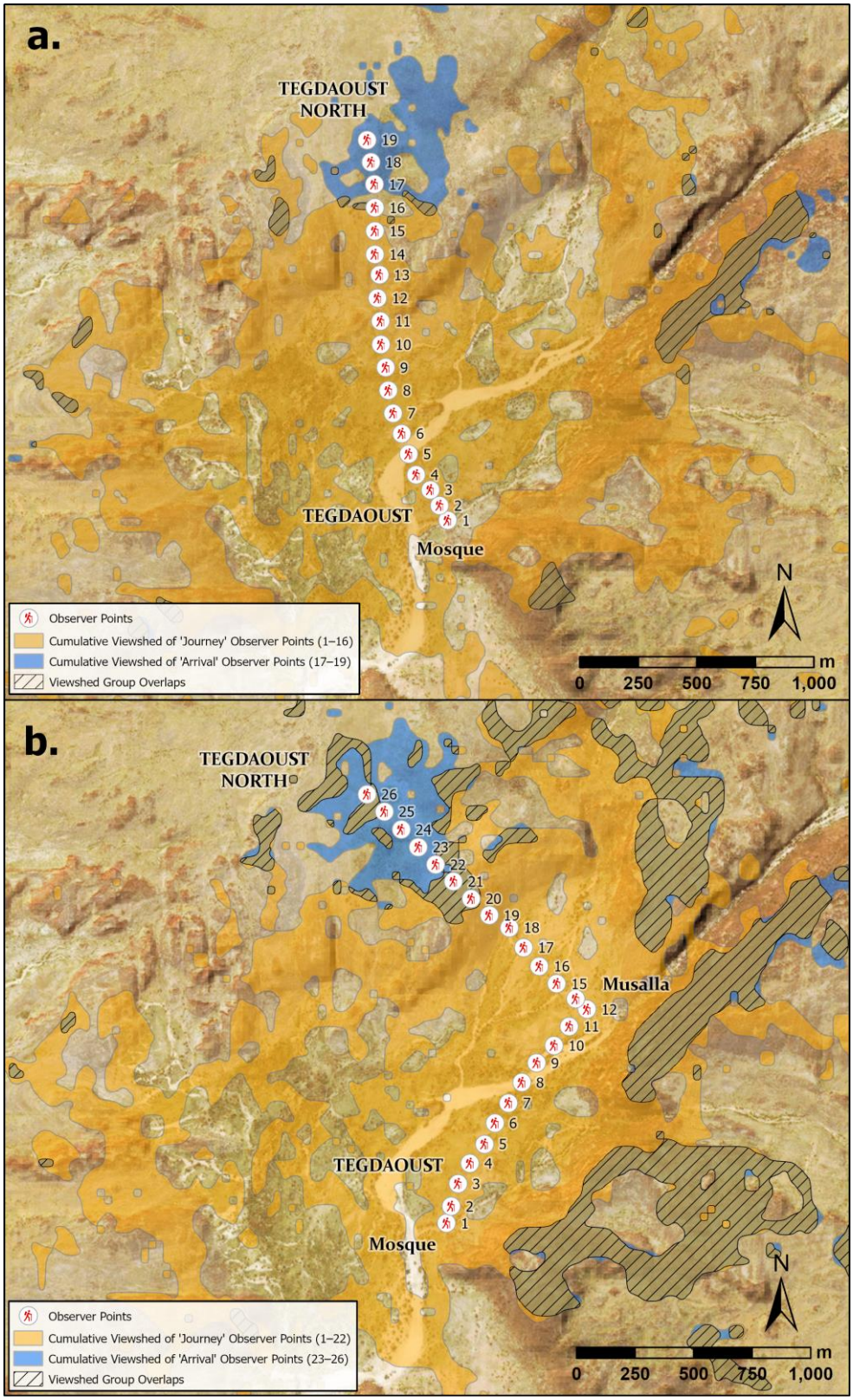


Figure 6: Visual representation of the least cost pathways and cumulative viewsheds when approaching the Islamic funerary complex of Tegdaoust Nord: a) directly from the mosque in the southern periphery of the centre of Tegdaoust; b) via the *musalla* congregational precinct. Map by authors, Basemap ©ESRI and ©Bing.

3.4. Tumuli Clustering

The tumuli in the Rkiz Massif, evidence of pre-Islamic cultural engagement with the regional landscape, were subjected to Average Nearest Neighbour (Ebdon 1985) and Global Moran's I (Getis and Ord 1992) statistical test for spatial clustering, yielding values of -36.6 and 6.087411 respectively— both indicate a less than 1% likelihood that these clustered patterns could be the result of random chance. Informed by the Kernel Density tool (Silverman 1986) and the 'self-adjusting' (HDBSCAN) algorithm (Campello *et al.* 2013), we generated six cluster groups below (Figure 7).

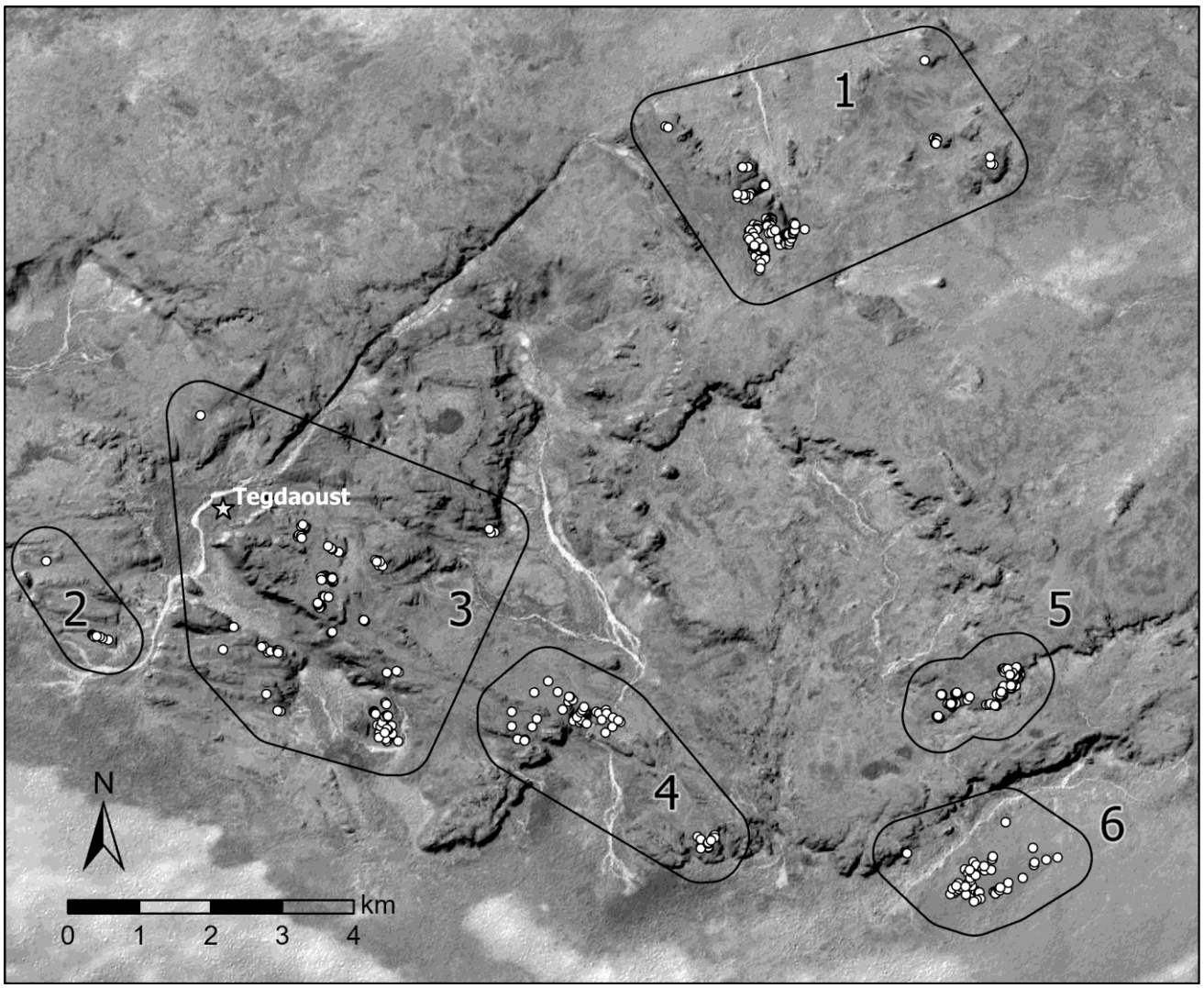


Figure 7: Cluster distribution of prehistoric funerary tumuli in the vicinity of Tegdaoust (Rkiz Massif, southern Mauritania). At least 6 groupings can be identified. Map by authors, Basemap ©ESRI and ©Bing.

4. Discussion

4.1. Analytical phenomenology and Tegdaoust Nord

Ever since the adoption of Geographical Information Systems (GIS) in the mid 1980's for archaeological research, researchers have harnessed its computational abilities in an attempt to model visibility of past humans in the landscape (Lake and Woodman 2003). The most established way of doing so is through the generation of simple binary viewsheds, as we have done in our study, whereby an observer point at a predefined height is defined on a DEM, and individual cells are classified based on whether or not they are visible to the observer (Gillings and Wheatley 2020). It is debatable if this simple approach, as we have implemented it in this study, can fully simulate the phenomenology of a past person existing in this landscape—it does not take into account factors that are inherent to the human sensory experience, like movement and the biological limitations of eyesight, not to mention environmental factors like past vegetation and atmospheric effects (Gillings 2012). These may be addressed in a future study through more computationally complex implementations of viewshed analysis; for example, the use of "fuzzy" viewsheds to simulate the limits of human visual acuity (Ogburn 2006).

Nevertheless, viewshed analysis can provide immediate and tangible results—our implementation of binary viewsheds corroborates quantitatively the impressions from the French archaeological team at Tegdaoust, and provides an opportunity to generate further research questions. For example, while Robert (1970) noted how the solitude of the plateau is certainly compatible with the notion of "eternal rest", underlying logistical connections with the settlement need to be taken into consideration. For example, while the stone was likely obtained from rocky plateau outcrops found in the immediate vicinity, the construction process would have required the procurement, mobilisation, and transport of building materials, such as sands and clays, from the Nouadache cirque. This lowland area would have also been where wells were located, serving as indispensable sources of water for the workers (cf. Robert 1970). It is also not implausible that some materials came from beyond the immediacy of the Nouadache cirque, and geochemical fingerprinting could assist with questions of sourcing and provenance (Wilson and Pollard 2001).

Future research can make use of more complex and phenomenologically rigorous methodologies to further explore the visual experiences of the past inhabitants of the Tegdaoust environs. New viewshed analysis principles and methodologies have arisen that better

represent the experiential component of human-based visibility, like fuzzy/probable viewsheds (Fisher 1994) and visual affordance (Gillings 2012). Furthermore, three-dimensional virtual reality environments are now easily constructed that allows for a more realistic representation of past landscapes, ones that allow for movement and the simulation of vegetation cover and atmospheric effects (Winterbottom and Long 2006; Ruzickova *et al.* 2021). When used in conjunction with high-resolution DEMs created from stereoscopic pairs of satellite imagery, 3D virtual reality produces landscapes that are very analogous with reality (Barbarella *et al.* 2017) .

4.2. Funerary landscapes and mortuary practices

The pattern of a single large cemetery associated with a medieval Islamic trading centre that we see at Tegdaoust is also found at other localities in the Sahara, such as Azuggi (Mauritania) and Gao (Mali), while other sites, such as Tadmekka or Tamdult, possess a number of independent cemeteries relating to the main settlement (Insoll 1996, 2003; Nixon 2020). At Tegdaoust Nord, several phases have been identified on the basis of construction techniques and the varying size and quality of the stones. The Islamic belief on the physical resurrection of the body on Judgement Day effectively prohibits cremation and encourages inhumation, which explains the prevalence of this practice at the cemetery. Most corpses were placed south-facing in a west/east direction without associated grave goods (Robert 1970: 475). However, the centre-north cluster also features two elaborate tombs with grave goods, mostly pottery that resembles the assemblages found in the medieval settlement (Robert 1970: 475). While bones generally show a poor degree of preservation, future aDNA work may determine whether the burials within each enclosure belonged to the same family, as tentatively suggested by Robert (1970). Even though Tegdaoust Nord is a large necropolis, its size and estimated number of burials still fall short of what we might expect if most individuals of the medieval settlement were buried here, given the protracted history of occupation of the settlement - which extended over several centuries- and its estimated population. This pattern therefore seems to suggest that only a selected portion of the population was buried here, perhaps on the basis of status in addition to religious identities.

Modelling least-cost pathways from the settlement to the Islamic burial complex is relevant for understanding how the spatial dimension of local funerary practices intersects with the priorities and anxieties of a global religion. Funerals are community events, typically held in a prayer or gathering space outside a mosque. The *musalla* to the north of Tegdaoust may have

been the main focus of this rite. Since deposition of the deceased is meant to take place as quickly as possible after death, the body is promptly transported to the site acting as burial grounds in a silent and deeply emotive procession, with each person throwing three handfuls of dirt into the grave as a concluding part of the burial rite. While most of the process is part of a shared communal experience, both the initial preparation of the corpse—through careful washing and shrouding (*ghusl*)—and the final resting place become secluded and relatively private spaces, as emphasised for the latter in our characterisation of local landscape binary viewsheds along the way between Tegdaoust Nord and the settlement of the living.

Extensive surveys within a 10km radius of Tegdaoust have failed to locate other comparable funerary complexes dating to this period, with the exception of a small group of five enclosures discovered by Raymond Mauny to the west of the Nouadache cirque (Robert 1970). Changes in funerary practices, such as skeletal remains showing different orientations (from north-south with face to the east to south-oriented ones with their faces heading west), might indicate different phases within a gradual process of Islamic conversion (Robert 1970; Nixon 2020). Selective conversion may have been mediated by commercial interests, since shared religion may have resulted in the establishment of networks of trust, fostering smoother trading transactions with merchants coming from distant lands within the Muslim world (Insoll 2003; Haour 2017). Documenting the incidence of these factors may help explain the "mismatch" between the number of Islamic burials and the temporality of occupation at the urban settlement of Tegdaoust. It would also be interesting to explore how religious identities in the context of changing patterns of conquest and conversion at Tegdaoust and other medieval Saharan trading centres may have been reflected in everyday experiences, such as food consumption, particularly regarding Islamic taboos (e.g. Nixon *et al.* 2011; Brown 2016; Estaca-Gómez *et al.* 2019; Gaastra and Insoll 2020).

Stone funerary monuments, in the form of cairns or tumuli, are ubiquitous across the Sahara and in certain areas of the Sahel (Camps 1961; Gauthier 2015; Linares-Matás and Lim 2021). Although only very few tumuli have been dated using absolute methods, their visual prominence, their morphological diversity, and their extensive spatial distribution provide a way to understand the compositional and relational nature of prehistoric cultural landscapes in the region (di Lernia, 2013; Bokbot 2019; Linares-Matás and Lim 2021; Linares-Matás *in press*). The permanence of their construction material mirrors the continuity of their cultural significance through time, since they appear to have represented meaningful funerary localities

for a long time. Starting in the Neolithic among pastoral communities in the Eastern and Central Sahara, reaching the northern Sahel and the Canary Islands, funerary tumuli were erected across this wide region until the protracted consolidation of Islamisation processes around the seventh to tenth centuries AD, when their popularity became to wane (Camps 1983; Paris 1996; Brooks *et al.* 2009; Paris and Saliege 2010; Carrasco 2018; Cruz and Valenzuela 2018; Alberto *et al.* 2019; Bokbot 2019; Clarke and Brooks 2019). In this regard, the coexistence of at least six clusters of prehistoric tumuli, a large medieval cemetery, and post-medieval tombs in the landscape around Tedgaoust illustrates the sustained cultural significance of the Rkiz highlands (Tamchekett, Hodh El Gharbi) in the socio-economic networks of human communities in southern Mauritania, preceding the development of extensive trans-Saharan connections during the medieval period.

4.3. Shifting patterns of trade and connectivity in southern Mauritania

The favourable climatic conditions of the second half of the first millennium AD, approximately 20% wetter than today, granted human communities greater food security, given the abundance of grain, pastures, and fishing (McIntosh and McIntosh 1988: 94). In the Middle Niger region and in the Senegal River basin, the flourishing sedentary farming communities of the late first millennium AD developed specialised iron smelting techniques and began establishing large, richly-furnished earthen tumuli in clusters, which further suggest wealth concentration in specific urbanised areas, and among certain social elites (Posnanky 1973; McIntosh and McIntosh 1988: 109; Gokee and Thiaw 2020; McIntosh 2020;). At Jenné-jeno Phase III (AD 400–900), the settlement reached 33ha and was increasingly involved in extensive trade networks. These *Markadugu* (towns of commercial and/or spiritual foundation) were able to endure semi-autonomously for centuries, while *Fadugu* ("capitals", understood as settlements of secular state power) represented an alternative pathway towards urbanism in the region (MacDonald and Camara 2012).

Northwest Africa and the western Sahel became increasingly prominent in trans-Saharan routes during the late first millennium AD (Levtzion and Hopkins 2000: 377; Magnavita 2013), with an intensification of established networks of connectivity. Gao, in the Middle Niger, saw a considerable increase in the number of imported trade items, such as glass beads, cowrie shells, copper alloys, carnelian beads and non-local animal species (Insoll 1996; Cisse *et al.* 2013). Similarly, the material culture from Tegdaoust, a commercial settlement in nature with agro-pastoral foundations emerging in a landscape with substantial evidence for pre-Islamic cultural

relevance, highlights the far-reaching nature of trans-Saharan Islamic trade networks, as well as the diverse and heterogeneous composition of the population at the site described by medieval authors (Gomez 2019: 33). Ceramics at the site came from the regions of Ifriqiya, Maghreb, and Al-Andalus, and glass fragments were said to resemble material from Fustat in Egypt (Vanacker 1979: 166–168; 1983: 522). In the second millennium AD, the favourable climatic conditions in the Sahel started to wane, and water concerns quickly came to the fore in these semi-arid environments.

The progressive decline in the water table of wells across the Sahara had a considerable impact on water provisioning due to the diminishing returns of well-digging labour for a non-renewable and increasingly elusive resource, often restricted to geological ecotones between the main landforms of the Sahara (Brooks *et al.* 2003: 71–74; Drake *et al.* 2004: 21; Cremaschi and Zerboni 2009; Mattingly 2017). In this context, it is worth highlighting how the aquifer at Tegdaoust sank at least five meters from the 10th to the 14th century AD (Bernard 1983). Already by the early eleventh century, there is evidence of deeper wells and drainage ditches with protective constructions, illustrating local anxieties regarding increasingly unpredictable fluctuations in hydraulic supply that provided little agricultural benefits (McDougall 1985). Unreliable water supply by the desert edge would have compromised the viability of the formerly thriving trading settlement, further weakened by the Almoravid conquest and the declining presence of long-distance imports, which may attest to the steady disintegration of trust and interaction networks. In this context, Tegdaoust may have been unable to endure as a major Islamic trading hub in the long-term even if major trans-Saharan trade routes had not been diverted towards Oualata (Ould Cheikh 2000). This reorganisation, in a move that bypassed Tegdaoust by avoiding the Aoukar basin, appears to have effectively disrupted the socio-economic foundations of Tegdaoust, with fifteenth century authors noting how the shrinking and languishing settlement no longer resembled the thriving locality that al-Bakri described (Levtzion and Hopkins 2000).

Togba, located 6.75km southeast of Tegdaoust (Figure 8), is a large settlement built by the Tadjakant clan, who migrated from the Adrar region of central Mauritania in the sixteenth century (Laforgue 1941). The site became a prominent post-medieval regional trading centre, particularly involved in the trade of salt, cloth, gold, and slaves (McDougall 1991: 278). Togba featured a lush date palm grove as well as gardens and fields for agricultural cultivation, and possesses an intricate layout comprising multi-roomed rectangular structures, which include

mosques, markets, and residential architecture (Laforgue 1941; McDougall 1991). The limited extent of archaeological excavations limits our understanding of the site, however, and future research would prove to be very informative.

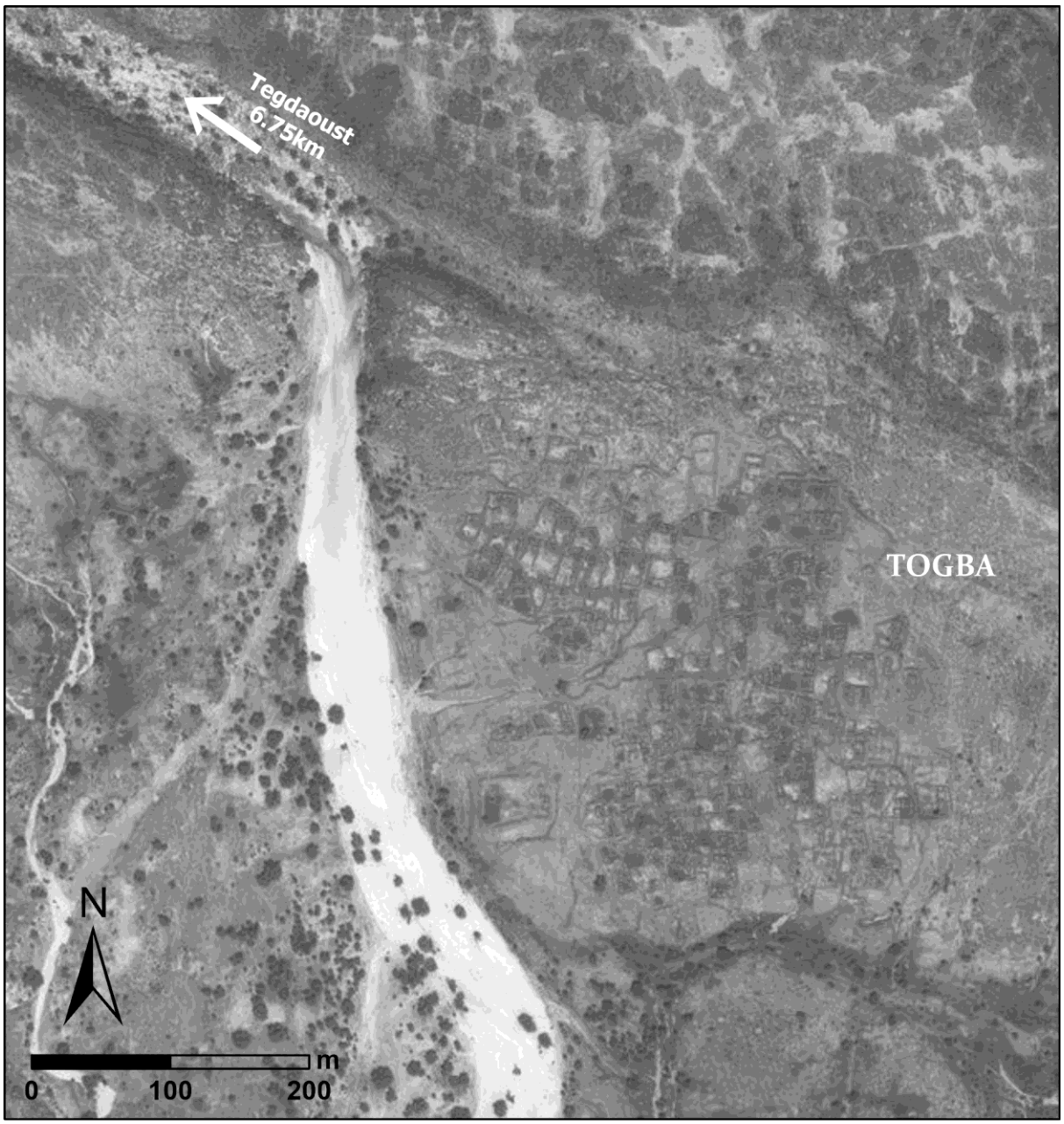


Figure 8. Satellite view of the postmedieval trading settlement of Togba (Rkiz Massif, Hodh El Gharbi, southern Mauritania). Map by authors, Basemap ©ESRI and ©Bing.

5. Conclusions

Understanding processes of connectivity at the intersection between the southern Sahara and the West African Sahel requires a multi-scalar approach to explore local details in a transregional context. The study of changes in trans-Saharan trade network dynamics as evidenced by the settlement biography of Tegdaoust combines spatial analyses, remote sensing methods, analytical phenomenology, and interpretive frameworks rooted on archaeological, palaeoecological, and historical data. Funerary practices, intertwined with manifestations of individual and collective identities, offer an additional perspective for understanding the dimension of cultural changes in southern Mauritania around the time of Islamic conversion. Archaeological research, as a mechanism through which memory is made tangible, aims to become an integral part of contemporary approaches to African history-making. As such, bringing the Mauritanian past to the fore of international imaginaries is also an important contribution towards diversifying global narratives of past human experiences.

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Conclusions

This thesis approaches the study of the prehistoric and medieval archaeological record of southeastern Mauritania, from the Early Tichitt period (*c.*1900 BC) to the abandonment of Tegdaoust in the fifteenth century, through a remote sensing perspective. The papers presented here integrate quantitative methods and transdisciplinary theoretical developments to characterize and assess diachronic cultural trends in terms of regional settlement dynamics, the nature of funerary landscapes, and supra-regional connectivity in a transitional zone between the southern Sahara and the West African Sahel.

Archaeological research, as a mechanism through which memory can be made tangible and intelligible, aims to become an integral part of contemporary approaches to African history-making. As such, bringing the Mauritanian past to the fore of international imaginaries represents an important contribution towards diversifying global narratives of past human experiences. My research contributes to the efforts of a series of consolidated and emerging projects aiming to monitor endangered heritage in Africa at a pan-regional scale, with an explicit focus on regional training to facilitate the research initiatives of local archaeologists and international collaborations. These include *Endangered Archaeology in the Middle East & North Africa* (EAMENA; Rayne *et al.* 2017) and *Mapping Africa's Endangered Archaeological Sites and Monuments* (MAEASaM; https://maeasam.org/). Ethically sensitive remote sensing research represents an opportunity to engage responsibly in developing more nuanced and collaborative studies that highlight local innovativeness and resilience and challenge negative stereotypes about the African past, as well as the continent's present and future (Smith 2014).

The analytical characterization and theoretical conceptualization of funerary landscapes and settlement patterns provides a coherent research agenda into the spatio-temporal dynamics of

socio-political organization at a supra-regional scale (Mattingly *et al.* 2019; Sterry and Mattingly 2020). I propose that emerging differences in Tichitt Tradition social and political organization in southeastern Mauritania during the Late Holocene can be explained through reference to the non-linear dynamics of Complex Adaptive Systems (Gronenborn *et al.* 2017; Kinahan 2018), as they unfolded within the cultural milieu of pre-colonial African polities. Increases in social complexity and household interconnectivity can become structured in either a centralized or a polyfocal and heterarchical manner, depending on the relative weight of narratives of firstcomer primacy (Kopytoff 1987) and the relevance of alternative sources of political and ritual power independent from lineage-based seniority (McIntosh 1999). Combining these insights with the pastoral-centered pathways to social complexity embedded within the Mobile Elites theory (MacDonald 1998) and Munson's (1980) application of Carneiro's circumscription theory of state formation provides a robust interpretive framework for understanding the origins and socio-economic and political development of the Tichitt Tradition and its expansion into Mali. In particular, I see the Internal African Frontier as most applicable for understanding the degree of architectural and material culture homogeneity associated with the settlement of the Mauritanian *dhars* by agropastoral communities through demographic expansion during the Early Tichitt once cereal cultivation became a staple socio-economic activity. This process was undertaken by splinter groups, but they were most likely not blindly venturing into unknown lands, instead agropastoral colonization would have been informed by first-hand landscape knowledge derived from seasonal pastoral mobility, in the context of herders accessing pastureland. A similar dynamic likely underpinned the later expansion of Tichitt Tradition communities to Dhar Tagant and Mali. This process of agropastoral expansion unfolded within former hunter-herder communities, for which cattle and associated material culture represented the main source of public wealth and prestige, in accordance with the Mobile Elites theory (MacDonald 1998). In the context of climate change,

the control of both agropastoral means of production (fields and herds), as well as relevant material embodiments of this wealth (hachettes, stone arm rings) appears to have fueled increasing socio-political complexity, territoriality, and conflict, as witnessed through developments in weaponry, settlement walls, and investment in mortuary architecture. The arrival of Lybico-Berber communities appear to have intensified this process (cf. Munson 1971). In any event, the archaeological record of southeastern Mauritania, examined in this thesis, further illustrates how the earliest development of social complexity in the West African Sahel was predominantly endogenous in origin and preceded the local adoption of iron metallurgy, first documented around 800 BC at Walaldé (Senegal) and Djiginyai (Mauritania, Dhar Néma; Deme and McIntosh 2006; MacDonald *et al.* 2009). Earlier metallurgical processes may have been present within Tichitt Tradition society, however, given how surface surveys have documented copper remains at several Dhar Tichitt sites (Vernet 1993; Alpern 2005). The review conducted by Alpern (2005: 60) includes ingots and finished objects, such as weapons (arrowheads, daggers, lance tips), small tools (awls, burins, hatchets, hooks, pins) and personal ornaments (earrings, pendants, rings). These remains derive from local copper mining and smelting in Guelb Moghrein, near Akjoujt (western Mauritania; Lambert 1971; Vernet 2000), with tantalising unpublished evidence suggesting that this practice may extend into the early second millennium BC, but more contextual research with robust dating is still required (MacDonald, pers. comm.).

From a methodological perspective, the open availability of very high resolution (VHR) satellite imagery and the remote visual prominence of drystone architectural components in arid upland ecosystems has led to high degrees of identification success rates for settlements and funerary monuments. Moreover, the potential to accurately delineate site and feature sizes favours the formation of reliable empirical datasets. These characteristics make above-ground remote sensing methods particularly conducive for archaeological research in the southeastern

Mauritanian highlands. At the same time, the low chronological resolution currently available for southeastern Mauritania does not yet allow for a definitive corroboration of all the interpretations and theoretical developments presented here, particularly in relation to the temporality of site growth and size rankings. Satellite imagery shows a palimpsest, representing the final site layout at the time of abandonment, but without precise dating it is unfeasible to model individual settlement dynamics, including abandonments of individual compounds or neighborhoods or within site instances of shifting sedentism, which precludes the determination of landscape patterns throughout southeastern Mauritania according to different temporal phases (e.g., Early, Classic, Late Tichitt), beyond the data for Dhar Tichitt collected by Munson (1971). Understanding the spatio-temporal dynamics of site use, including any phases of compound construction and modification, will be a crucial next step in refining the quantitative approaches presented here for the study of large prehistoric settlements.

Despite inherent limitations such as restricted chronological control and an inability to identify smaller elements of material culture, remote sensing approaches hold great potential for documenting the archaeological record of arid landscapes. Integrating multiple lines of enquiry in future multidisciplinary and collaborative research, both remotely and on the ground, represents an important step in this process. Ethical considerations and a self-reflective attitude must be at the forefront of archaeological research in relation to opportunities and challenges for remote collaborative engagement with local communities, especially where conflict or other factors impose restrictions on fieldwork (di Lernia 2015). The archaeological record of southern Mauritania is intrinsically linked with historical trajectories in Mali, with Tichitt Tradition sites found in both countries, each incorporated to a different international heritage project (Mauritania within EAMENA and Mali within MAEASaM). The future inclusion of thousands of archaeological sites documented over the course of the present DPhil thesis into the EAMENA project database has already been agreed upon, and conversations to discuss

whether they should also be included in the MAEASaM project database due to cultural affinities with the Malian archaeological record are ongoing. Both of these databases are available to international researchers as well as relevant national and regional authorities, which will facilitate and promote the monitoring, investigation, and safeguarding of cultural heritage in the region.

In these conclusions, I first present a discussion summary of the main contributions of the thesis to our understanding of Tichitt Tradition funerary landscapes and settlement patterns in southeastern Mauritania, followed by the presentation of several avenues for future research encompassing remote sensing approaches as well as future fieldwork initiatives.

1. The Funerary Record of southeastern Mauritania

The remembrance of the dead is a ubiquitous dimension of most human societies (Sherratt 1990). In the highlands of southeastern Mauritania it is illustrated by the documented presence of >9,000 stone cairns and tumuli. The adaptive emphasis on architectural forms that circumvented the need to excavate the sandstone bedrock and made use of durable local materials enabled funerary monuments to simultaneously become embedded memories and conspicuous visual cues guiding the daily rhythms of the living.

Funerary practices provide insights into socio-economic dynamics, such as labor mobilization, that reflect the attitude of the living towards the dead, since each society has a specific logic of resource expenditure and spatial patterning in mortuary practices informing who is to be memorialized, how, and where (Morris 1991). The establishment of formalized disposal areas for the dead enables the establishment of "genealogies of place" through the transmission of property ownership and access rights (Renfrew 1976; Chapman 1981), and/or contributing to the creation of "places to be remembered" across territorial thresholds (di Lernia 2013), thereby structuring mobility and exchange flows of beings and things (Posnansky 1982).

A shift in emphasis from a household-centered mortuary tradition, associated with the presence of skeletal remains in a compound at the site of Akreijit (Dhar Tichitt), to a more corporate, collective locus of identity represented by the memorialization of the dead through funerary monuments *outside* settlements unfolded within the highlands of southeastern Mauritania during the late second and the first millennia BC. The protracted development of monumental funerary landscapes involves the conspicuous material and spatial co-constitution of social memory and cultural identity. These dimensions can be analyzed through factors, such as the topographic placement, local visibility, and size of monuments, particularly when these variables can be contextualized in large and dense clusters such as the tumulus fields present in the Saharo-Sahelian borderlands.

Two main socio-political pathways — centrality and liminality — constitute the underlying centripetal forces leading to the formation of funerary monument clusters in southeastern Mauritania. The first instance was rooted in the cosmological and political centrality of nucleated living spaces, with dense tumulus clusters found on the immediate periphery of some large settlements, such as Dakhlet el Atrouss (Dhar Tichitt) or Guelb ed Dâmi (Tagant Plateau). In particular, the very large size of several tumuli at Dakhlet el Atrouss I may indicate the temporary coalescence of social power in the hands of a restricted number of lineages within a political landscape where multiple competing lineages were investing in the materiality of ancestor remembrance. Such potential for centripetal dynamics within large agropastoral communities, coupled with evidence for cultural and demographic interactions between Tichitt Tradition societies from southeastern Mauritania and those from the Middle Niger region of Mali, may offer interesting insights into later state formation processes in the West African Sahel.

In the second pathway, political liminality was the key variable, with clustering occurring along or at one end of major mobility and communication routes, as evidenced in the Dhar Tagant

near the entrance of the Taskast wadi and likely also reflected in the extensive monumental landscapes of Tabarit (western Tagant). This trend may be indicative of more decentralized or more actively negotiated social dynamics and regional boundaries in the western and southern margins of the Tagant Plateau during the main phases of monument construction. The emergence of these tumulus fields is therefore better understood through processes of spatial translocation and socio-economic transformation among the agro-pastoral communities of the Late and Terminal Tichitt Tradition (1,000 BC to AD 100), a trend resembling the earlier adaptive pathways of pastoral groups in the Tadrart Acacus highlands of southwestern Libya in the face of increasing aridification within the Central Sahara (di Lernia 2013).

Variability between tumulus size may attest to asymmetries in the scale of labor mobilization networks at the household levels, in terms of material assets or social capital (Becker and Martin 1982). At the same time, small-scale societies are able to mobilize relatively large pools of labor beyond kin groups for ritualized monument construction through collective action, sustained by reciprocal, trust-based networks (DeMarrais and Earle 2017). Nonetheless, even though collective action could smooth inter-household wealth variability, differences in the actual mobilization of social capital as labor could instead have reinforced pre-existing asymmetries.

The Gini coefficient values obtained for the Dhar Tichitt tumuli clusters (< 0.35) show remarkable consistency in their measure of socio-economic differentiation to those obtained for household compounds at large regional settlements, such as Dakhlet el Atrouss I and Akreijit. These levels of socio-economic differentiation were predominantly sustained through endogenous sources and dynamics of wealth accumulation and distribution, given the so-far limited number of imported prestige goods known from the Tichitt Tradition. 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, within the opportunities and constraints afforded by Saharan climate cycles. At Dakhlet el Atrouss I, statistical analyses of compound size asymmetry have also documented marked intra-site variation at the compound cluster level (Paper 2). The two large funerary monuments within the site may have played a key role in shaping socio-economic differentiation at this regional centre, particularly if they are proven to represent lineage-based collective burials.

Meanwhile, the Tabarit tumulus fields, in the western Tagant, seem to exhibit a greater degree of burial size differentiation (Gini coefficient > 0.4), with lower energy investment per tumulus on average, which may indicate a greater range of social agents actively involved in burial rituals. Tumulus placement could be a further reflection of intra-cluster socio-economic differentiation, given how smaller tumuli are generally found in lower elevations within the Tabarit tumulus fields. Nevertheless, the scale of interpersonal, material, and knowledge-based networks relevant for labor and resource mobilization can vary over time. Expenditure can increase over time to offset expectations of "diminishing returns" that require a disproportionate increase in investment relative to social gains (Tainter 1988). It can also decrease once the emphasis shifts from the need to forge a more cohesive community to a less costly maintenance and renewal of social relations (Sawchuk *et al.* 2018). These changing trends become particularly important when characterizing the material biographies of extensive and intergenerational tumulus fields, palimpsests of memory where multiple temporalities or even logics of deposition may have coalesced in space. As such, the pattern of larger monuments in higher topographic elevations and smaller monuments in lower parts of the local landscape may instead primarily represent a temporal trend of decreasing labor investment, if more prominent areas were monumentalized first and the tumulus field expanded downslope from the more elevated "cluster cores". Regrettably, information pertaining to the chronology of monument construction, the nature, quantity, and diversity of grave goods, if any, as well as

osteological and anthropological data from the skeletal remains themselves, is still missing for most of the prehistoric funerary record of southeastern Mauritania.

Further south, in the Rkiz Massif (Tamchekett, Hodh El Gharbi), I have documented at least six clusters of prehistoric stone tumuli, a common funerary architecture solution in North Africa, the Sahara, and the West African Sahel until the protracted consolidation of Islamization processes around the seventh to tenth centuries AD (Camps 1983; Bokbot 2019). Their spatial co-existence with a large medieval cemetery and post-medieval tombs in the landscape around Tedgaoust illustrates the sustained cultural significance of the region in the socio-economic networks of human communities prior to the development of extensive trans-Saharan connections. The medieval Islamic trading center of Tegdaoust is associated with a single large cemetery (Tegdaoust Nord). Corpses were placed south-facing in a west/east direction, mostly without associated grave goods, although two elaborate tombs have associated pottery assemblages (Robert 1970: 475). The *musalla* to the north of Tegdaoust may have been the main focus of pre-burial Islamic funerary rites, with a silent procession transporting the body to its resting place. The Tedgaoust North burial ground was located in a relatively secluded and private part of the landscape, as shown by the loss of intervisibility in local landscape binary viewsheds generated along the way between the cemetery and the settlement of the living. Gradual and selective conversion, perhaps mediated by commercial interests, may help explain why the number of burials at the Islamic cemetery is lower than expected given Tegdaoust's size and its temporality of occupation.

2. Settlement Dynamics

The highlands of southeastern Mauritania present an extraordinary archaeological record for documenting the emergence, consolidation, and reorganization of prehistoric settlement dynamics. Their study is relevant because these trends include several alternative pathways

towards the increasing social complexity at the Saharo-Sahelian interface that command interest in terms of validating the creativity and ingenuity of indigenous African communities and of expanding archaeological perspectives in the global comparative study of past human experiences.

A key dimension for the study of Tichitt Tradition settlement dynamics consists in charting their diachronic trajectory, i.e. understanding how and why the system changed over time, and discussing the role of relevant variables in these processes (Paper 4). My interpretation assesses and incorporates insights from three theoretical frameworks: a) resilience theory for exploring trends over time; b) the Internal African Frontier (*sensu* Kopytoff 1987) for explaining the nature of cultural patterns across space; and c) the structural role of mobility and migration in articulating social resilience in dryland ecosystems, particularly in contexts of resource unpredictability and climate change.

Resilience Theory

The most relevant feature of resilience theory through the lens of Complex Adaptive Systems to consider in these conclusions is the non-linear nature of the adaptive cycles of human societies. Holling and Gunderson (2002) describe the adaptive cycles of human societies as comprising four main states, which represent different possibilities of becoming within a system and not progressive stages of development. The first two states—growth (r) and conservation (K)—represent the fore loop, with protracted periods of energy accumulation and transformation through increasing connectedness. The other two states—release (Ω) and reorganization (α)—are generally shorter periods of energy release as the system unravels and reconfigures, thus offering opportunities for creative innovation and the emergence of cultural solutions with greater adaptive fitness.

The oscillating nature of Saharo-Sahelian climate has long shaped large-scale population and ecosystem dynamics in the region, with human mobility and behavioural flexibility intertwined with wider environmental trends. The Pre-Tichitt phase, characterized by ephemeral sites mostly consisting of material culture scatters and low architectural investment, is consistent with the signature of highly mobile communities. This period would correspond to an initial, local reorganization phase following the arrival of groups who migrated southwestward into southeastern Mauritania from the drying Central Sahara at the onset of the Late Holocene.

The fore loop would correspond to the growth and progressive consolidation of human groups in the Tichitt-Oualata escarpments of southeastern Mauritania. These landscapes offered an ecological niche capable of sustaining a thriving agropastoral economy based on cattle-keeping and pearl millet cultivation throughout the second millennium BC (Early Tichitt and Classic Tichitt phases). This territorial consolidation led to the formation of permanent agglomerations with numerous thick-walled drystone architectural features, with several population clusters constituting very large settlements (>50ha). The following five-tiered settlement division captures the diachronic diversity of Tichitt Tradition settlement sizes:

- Rank 1 sites are larger than 75 ha or possess more than 250 compound enclosures.
- Rank 2 sites: between 25 and 75 ha or possessing more than 100 compound enclosures.
- Rank 3 sites: ranging in size from 5 to 25 ha.
- Rank 4 sites: comprising those between 1 and 5 ha.
- Rank 5 sites: isolated or small groups of enclosures over less than 1ha.

Increasing aridification across the Sahel and the suggested arrival of Berber communities in the region during the Late Tichitt period (*c.* 1000–400 cal. BC) are correlated with a considerable decline of permanent human settlement in the Tichitt-Oualata region, corresponding with the systemic unravelling of a release state. This regional demographic

decline was accompanied by substantial population relocation, with the archaeological record indicating that both western Mali and the wider Tagant region experiencing a population influx. In Dhar Tagant, the late first millennium BC and early first millennium AD witnessed a process of population size growth and an increasing socio-economic reliance on certain resources and techniques, particularly ironworking, as landscape knowledge networks and material entanglements became more established. This pathway, named Terminal Tichitt, represents a new fore loop encompassing a growth state (r) and a series of conservation (K) pathways.

Frontier Dynamics

Frontier dynamics constitute a fundamental dimension for understanding the genesis and socio-political pathways of many African polities. Kopytoff (1987) suggests that their production and reproduction is intrinsically tied to processes of immigration and territorial colonization. These processes are sustained in sparsely populated landscapes by social mechanisms favouring conflict-resolution through group fission and splintering, leading to the formation of agricultural pioneer fronts. Senior members from lineages with successful claims to territorial precedence have the power to grant land, enabling the establishment of social relationships and alliances based on the control over people.

An important tenet of Kopytoff's Internal African Frontier model is its emphasis on how the reproduction of a novel frontier settlement would mirror the ideological and material structures of the source community, in a conservative but decentralized fashion. At the same time, Ogundiran (2014) highlighted how interstitial communities in polity frontiers could also become sources of greater adaptive diversity, creativity, and spontaneity. The adaptive cycles discussed above enable a seamless integration of these two perspectives, with reference to the archaeological record of southeastern Mauritania. Early Tichitt agropastoral communities fulfil the main four criteria sustaining the formation of internal frontier zones (Kopytoff 1987):

- a widely shared social tendency towards human mobility, anchored in seasonal agropastoral strategies, social fission, and agricultural migratory expansion;
- the existence of microregional boundaries within cultural and geographical entities;
- the absence of comprehensively enforced means of centralized control;
- the existence of considerable structural homologies between communities interacting along and across those frontiers.

Thus, a conservative reproduction of material and ideological forms is likely to lead to settlements exhibiting high systemic coherence within maturing fore loop phases in social contexts favoring the formation of internal frontiers. This pattern is clearly attested among Classic Tichitt Tradition sites. On the other hand, as socio-economic strategies reconfigure and systemic coherence rapidly decreases during release and reorganization phases, we would expect interstitial sites to adaptively experiment with novel solutions.

The dynamic frontier conditions in the prehistoric sequence of the highlands of southeastern Mauritania appear to have significantly contributed to the formation of the initial cultural background for widely shared traits of pan-African political culture, in line with Kopytoff's (1987: 15) intuition of the relevance of Saharo-Sahelian Neolithic communities in this process.

Mobility and Migration

Mobility, migration, and interconnectivity represent critical dimensions for the security, resilience, and survival of agropastoral communities facing disruptive climate change in the Saharo-Sahelian borderlands both today and in the past. This pattern is apparent in Tichitt Tradition settlement dynamics, most evidently during its growth phase in the early second millennium BC and in the aftermath of its release phase during the late first millennium BC and the first millennium AD (Paper 4). In particular, migration appears to have played a fundamental role as a coping mechanism for Tichitt Tradition communities in the face of

intense aridification trends. These processes of relocation from the Tichitt-Oualata escarpments set the scene for processes of reorganization elsewhere, including the Tagant region to the west, while further south, in present-day Mali, this diaspora may have become a demographic catalyst for different pathways towards socio-political complexity, including the rise of early Sahelian empires and the consolidation of heterarchical urban communities across the West African Sahel (MacDonald *et al.* 2009; MacDonald 2015).

In the Tagant, the regional diversity of settlement dynamics was anchored in divergent manifestations of the translocal management and connectivity of people *through* spaces of mobility and the movement of places *alongside* people, a cornerstone of social resilience in the Sahel. In dryland ecosystems, community life is not spatially static and settlements can recurrently experience small-scale shifts as well as larger scale relocations, a concept labelled "shifting sedentism" in nearby Senegal (Canós Donnay 2016). This paradoxical principle of cultural landscape stability through social and settlement fluidity may prove particularly useful for understanding the nature of the most extensive site in the North Tagant, a polyfocal settlement encompassing over 180ha that comprises households with variable degrees of spatial integration but with very limited layout structure and no evidence of civic architecture or public spaces. In the absence of any kind of chronological control, it is unclear how many of these enclosures were occupied simultaneously, and whether demographic agglomerations were permanent or predominantly seasonal.

As places move, the circulation flows of people, things, and other beings play a paramount role in the constitution and reorganization of cultural landscapes. In southeastern Mauritania, the introduction of ironworking and the arrival of Berber groups in the first millennium BC led to the creation of novel identities and the reconfiguration of political relationships. In some instances, the emergence of ritually charged professions could have offered more opportunities for small-scale exchange between smaller and more autonomous households. On the other

hand, the harnessing of ritual affordances and tensions associated with ironworking within pre-existing dynamics of first-comer seniority generated centripetal forces towards settlement nucleation and socio-political centralization. These manifested themselves in the rise of large walled settlements during the Terminal Tichitt phase, such as T150 in Dhar Tagant or Guelb ed Dâmi in the northern Tagant Plateau, which may hint at processes of increased inter-community competition and conflict.

A translocal resilience framework anchored in the management and connectivity of people *through* spaces, and the movement of places *alongside* people, creates opportunities for exploring expressions of power *through* places, rather than merely *over* them, thus further contributing to reconciling ideas of interstitial communities in African landscapes as loci of both conservatism *and* creativity.

Furthermore, the interplay between the dynamics of social organization and landscape agency—encompassing from topography to climate change—shifts analytical emphasis on vulnerability and risk-management from individual units towards multi-scalar and interconnected networks. Social resilience thus becomes:

1) **embedded** within complex systems;

2) **extended** through flows connecting and mobilizing places, beings, and things;

3) **embodied** and constituted by participating agents; and

4) **enacted** through interactive social processes and practices.

Amidst increasing aridification during the first millennium BC, the importance of remembrance and control of communication routes, particularly in liminal areas, grew alongside seasonal mobility requirements. This process is illustrated in southeastern Mauritania by the clustering of funerary monuments in the westernmost area of the Tagant Plateau (Paper

3), as well as near the Taskast wadi entrance, one of the main axes of mobility across the Hodh basin (Paper 1).

In contrast, the second half of the first millennium AD witnessed very favorable climatic conditions. The abundance of rains and grains underpinned the growth of human communities in the west African Sahel, granting them greater food security. In the Middle Niger region and in the Senegal River basin, sedentary farming communities, and settlements such as Jenné-jeno, were increasingly involved in extensive trans-Saharan trade networks (McIntosh 2005). Contemporarily, the centralized Sahelian empire of Ghana/Wagadu rose to power in western Mali and southeastern Mauritania. Towards the end of the first millennium AD, the material culture from the medieval entrepôt of Tegdaoust (southeastern Mauritania), which includes ceramics from Ifriqiya, Maghreb, and Al-Andalus, illustrates greater connectivity between North and West Africa (Insoll 2003; Mitchell 2005). Nevertheless, the progressive decline in the water table of wells across the Sahara in the early second millennium AD had a considerable impact on water provisioning at Tegdaoust (Robert 1970). Unreliable water supply by the desert edge and the reorganization of trans-Saharan trade routes towards Oualata compromised the viability of the formerly thriving trading settlement. Analyzing processes of connectivity enables us explore local details of cultural processes in a transregional context, such as the waxing and waning of international exchange dynamics in southeastern Mauritania against the backdrop of Islamic conversion.

3. Future research perspectives

This thesis strives to renew long-term research endeavors that aim to describe, recognize, and highlight emergent patterns of complexity in the archaeological record of southeastern Mauritania. At the same time, in several regards this research still remains a preliminary effort

which I hope will galvanize students, scholars, and national authorities to devote more time and resources to the study of prehistoric cultural dynamics in Saharo-Sahelian regions.

The pioneering nature of several quantitative analyses conducted in the present thesis in relation to the richness of the West African archaeological record highlight the great potential for comparative studies of socio-economic differentiation using Gini Coefficient assessments on household compound area. An undergraduate dissertation, completed at the University of Oxford in March 2023 by James Chapman and titled "The View From Above: A Spatial Analysis of Population Size and Inequality in the southern Dhar Oualata Region of Mauritania" represents the first extension of this approach, contextualizing a c.50ha settlement from Dhar Oualata with the data from Akreijit and Dakhlet el Atrouss I. It would be exceedingly useful to apply this perspective to a wider range of Tichitt Tradition settlements with stone-walled compounds across different regions: Dhar Tichitt, Dhar Oualata, Dhar Tagant (particularly T150) the Tagant Plateau (especially Guelb ed Dâmi), Dhar Néma, the Malian Lakes Region, and elsewhere in Mali, in order to understand variability over space and time. It would also be very relevant to explore data from Kerma (Sudan) and the Tichitt Tradition comparatively, as well as to incorporate more West African prehistoric sites to global contextualizations of household inequality using econometric methods.

A parallel line of enquiry involves the comparative assessments of Gini coefficient and labour estimates for funerary architecture, using tumuli data from a range of Tichitt Tradition sites, other Saharan contexts, as well as later cases in Mali, such as the Pays Dô tumulus fields associated with the rise of the Malian Empire, from the thirteenth century AD. In addition to calculations based on monument area, it would be relevant to assess the result of applying Gini coefficients on tumuli volume, derived either from monument height measurement in the field or from the analysis of very high resolution Digital Surface Models (DSM), to test whether this approach would contribute towards a better characterization of socio-economic differentiation

in the mortuary arena. Furthermore, the acquisition of a high-resolution DSM (<1 m pixel size) would also enable the precise and detailed modelling of viewsheds and pathways within any given tumulus field, facilitating the applicability of more phenomenologically rigorous methodologies to better represent the experiential component of human perception, including three-dimensional virtual reality reconstructions and environmental simulations. Lastly, the generation of bespoke experimental assessments of the architectural energetics for building prehistoric stone tumuli in terms of person/hours estimates would enable a robust reconstruction of labor mobilization patterns. This is fundamental for addressing questions about the relationship of tumuli size variability, the quality of construction, and catchment areas to asymmetries in labor mobilization energetics (Voutsaki *et al.* 2018).

In addition to more in-depth remote sensing approaches, the analysis of Tichitt Tradition communities may be further complemented through the incorporation of relevant oral histories and ethnoarchaeological insights in order to develop a wider range of testable hypotheses and expand the range of plausible interpretations. The Dogon of Mali live in the Bandiagara Escarpment, which represents one of the closest environmental analogy for approaching prehistoric lifeways in southeastern Mauritania. In this regard, while granaries are ubiquitous features of agricultural life in the Sahel, both in flatlands and on cliffs (Bordier and Min-ha 1998), a structural explanation for the specific nature of raised "pillar granaries" that are so typical of the Tichitt Tradition (Amblard Pison 2006) may come from the ethnographic observation among the Dogon that this feature adapts very well to uneven topography, such as that found on the escarpment scree (Douny 2014). Nonetheless, it is paramount to bear in mind that the origins of Dogon settlement in the Bandiagara were the result a refuge strategy in the context of imperial expansion and violent raiding activities during the second millennium AD, and therefore may not be directly applicable to the socio-political realities of Tichitt Tradition agropastoral communities, particularly during most of the second millennium BC.

The Dogon cultivate the lowlands intensively, and emphasize the relevance of the cliffs as a topographic source of ontological security as they retain rainwater during the dry season and provide a hideout during times of socio-political unrest, particularly when involving communities from other regions. Furthermore, the natural environmental unpredictability and hazards of semi-arid ecosystems in the Saharo-Sahelian ecotone has led to the development of cosmological and material practices as coping mechanisms against experiences of scarcity among the Dogon. Over time, Tichitt Tradition communities also had to deal with increasingly unpredictable climates and greater political instability. Therefore, a theoretical framework resembling how Dogon communities conceptualize container forms as protective devices—with settlement walls, compound enclosures, field boundaries, granaries, and pots conveying a sense of impenetrability and intimate cohesion from threatening external forces (Douny 2014)—may contribute to a better characterization and interpretation Tichitt Tradition settlements and material culture assemblages during phases of greater uncertainty.

Another dimension in which ethnoarchaeological perspectives could contribute to our understanding of Tichitt Tradition sites revolves around intra-site settlement dynamics. The spatial arrangements of many Dogon plateau villages entail a circular expansion from the center or first house, and there is often a public place (*táy gonó*) with a baobab tree that acts as a cultural locus of socialization and from which paths to access compounds radiate (Douny 2014). Besides, the protracted material biographies of settlements are culturally embedded among the Dogon, who recognize that portions of villages become abandoned or occupied at different times (Douny 2014). The layout of a settlement with a protracted site biography can also be affected by clustering dynamics, resulting from gradual processes of administrative merging and spatial coalescence of multiple smaller settlements into a larger one (*synoecism*). This process mimics at the settlement level the clustering of households from a same lineage into a compound (Zeh 2000). In Dogon Country, the village of Tiréli had two main districts

that came together: Sodanga in the northeast and Teri-Ku in the southwest (Douny 2014); similarly, Kopytoff (1999) describes how the Aghem settlement of Wum, in the Cameroonian Grassfields, is composed of several, clearly separated villages that grew physically together into what superficially would seem like a single continuous settlement. If constituent villages had any distinctive material culture that preserved archaeologically, for example if were arranged on the basis of lineage-based economic specializations (e.g., blacksmiths, potters, etc), as documented at pre-colonial Banama settlements in Mali (Zeh 2000), their spatial dynamics may be discernable archaeologically. Therefore, the archaeological contextualization of settlement layouts can the outcome of demographic dynamics difficult to disentangle from satellite imagery alone remote sensing settlement maps, requiring the development of high-resolution intra-site chronologies for complex sites, such as Dakhlet el Atrouss I.

In terms of informing future bioarchaeological research, I would highlight two relevant avenues of research derived from ethnoarchaeological insights. Multiple layers of organic matter—animal dung, millet stalks and chaff—are found within Dogon compounds, particularly in latrines and where animals are kept. This litter is left to decay in order to generate manured compost to be taken to the fields as fertilizer (Douny 2014). Geochemical traces of comparable accumulation processes, if applicable, may still be retrievable from archaeological deposits, as shown by Styring *et al.* (2019) among second millennium AD agricultural communities in northeastern Burkina Faso. Studying mechanisms of intensifying regional production outputs through stable isotope research on crop products to measure manuring and water provisioning would be an interesting avenue of enquiry into agricultural management systems and the growth of socio-economic differentiation in Sahelian West Africa. From a taphonomic perspective, cultural processes documented among the Dogon that may impact the representativeness of faunal assemblages and that may need to be taken into consideration in future zooarchaeological studies of Tichitt Tradition sites include the fact that bones are often

scattered on butchering sites, “where they are eaten by dogs, gathered and thrown in a field as fertilizer, or simply disappear into the soil” (Douny 2014).

Biomolecular approaches also hold considerable potential towards elucidating the degree of cultural and demographic syncretism between Tichitt Tradition communities and incoming Berber populations during the first millennium BC, as well as potential relationships with first millennium AD urban polities in the Middle Niger, as reflected in the funerary record. Additionally, genetic research could help document any dynamics of kinship and social authority at play in the spatial and morphometric configuration of tumulus fields. Lipid residue analyses would inform about whether pottery vessels contained dairy products, ruminant or non-ruminant animal fats, freshwater resources, or vegetal residues. Lastly, stable isotope analyses on faunal and human bone remains could provide a wealth of information in terms of human dietary ecology (particularly using carbon and nitrogen to assess the contribution of animal and freshwater resources to overall subsistence) and mobility, both seasonally and/or in terms of punctuated migration, through oxygen and strontium values.

Integrating desk-based approaches with collaborative, community-centered fieldwork and suitable data-sharing solutions as soon as logistically feasible will undoubtedly improve data resolution, social impact, and capacity building potential for archaeological heritage, an important step towards mitigating perceptions of remote sensing as an aerial panopticon inherently detached from local needs and realities. On 19th October 2022, the UK Foreign and Commonwealth Office updated their recommendations in relation to Dhar Tagant and the Assaba highlands, as well as the western portion of the Adrar Plateau, from advising “against all travel” to “against all but essential travel”. This update came as part of a wider set of recommendation changes which also included lifting the advice against all but essential travel to seven *wilayas* in the western and southwestern portions of the country, including the capital,

Nouakchott. This evidence-based shift in national risk assessment may contribute towards a resurgence of archaeological fieldwork in Mauritania over the coming years.

4. Proposed future fieldwork research initiatives

In this regard, future fieldwork initiatives centered around the Tagant Plateau are being planned as part of an international project involving Prof. Kevin MacDonald, Dr. Nick Gestrich, Robert Vernet, and myself, among others. Ahead of this future fieldwork intervention, a relevant remote sensing contribution to be made in the near future include the processing of survey data for archaeological settlements and funerary monuments in the southern Tagant Plateau and the Assaba highlands, already collected in the context of this doctoral research. The following research priorities are intended to provide guidance for specific field interventions in this remote landscape, taking into consideration the necessarily brief nature of archaeological work in southeastern Mauritania due to logistical reasons, including security and water provisioning.

The first pressing matter includes the targeted acquisition of samples from a variety of sites and intra-site contexts for more AMS radiocarbon determinations, following the recommendations for future research made by Munson (1989). In this regard, understanding the intra-site chronology of Dakhlet el Atrouss I emerges as a paramount question for modelling settlement dynamics and the origins of urbanism in West Africa. How the urbanization process came into being in different parts of Africa, let alone globally, is a complex and very diverse matter, although aspects such as some degree of occupational specialization and division of labor are often mentioned (Childe 1950; Trigger 1972; McIntosh 2005; Chirikure 2021). However, the cultural and spatial manifestations of such specializations differs considerably: Old Kingdom Egyptian towns had areas dedicated to specific activities, Jenné-jenó exhibits some degree of population neighborhood clustering on the basis of labor, while Great Zimbabwe shows no signs of functional specialization being expressed spatially.

Instead, extended households engaged in multi-crafting activities, with specialization perhaps taking place more on a seasonal basis, i.e. temporally rather than spatially (Chirikure 2021). Understanding how Dakhlet el Atrouss I fits in this picture would enhance the contributions of African urbanism to our characterization of global prehistory.

Additionally, it would be rather illuminating to assess the temporal relationship between Dakhlet el Atrouss and other sites in Dhar Tichitt and the largest ones from Dhar Oualata, such as v.372 (Figure 1), to test whether the growth of the latter was the result of a parallel sequence and/or the direct result of southward population migration from the Dhar Tichitt as aridification trends intensified during the second/first millennium BC transition.

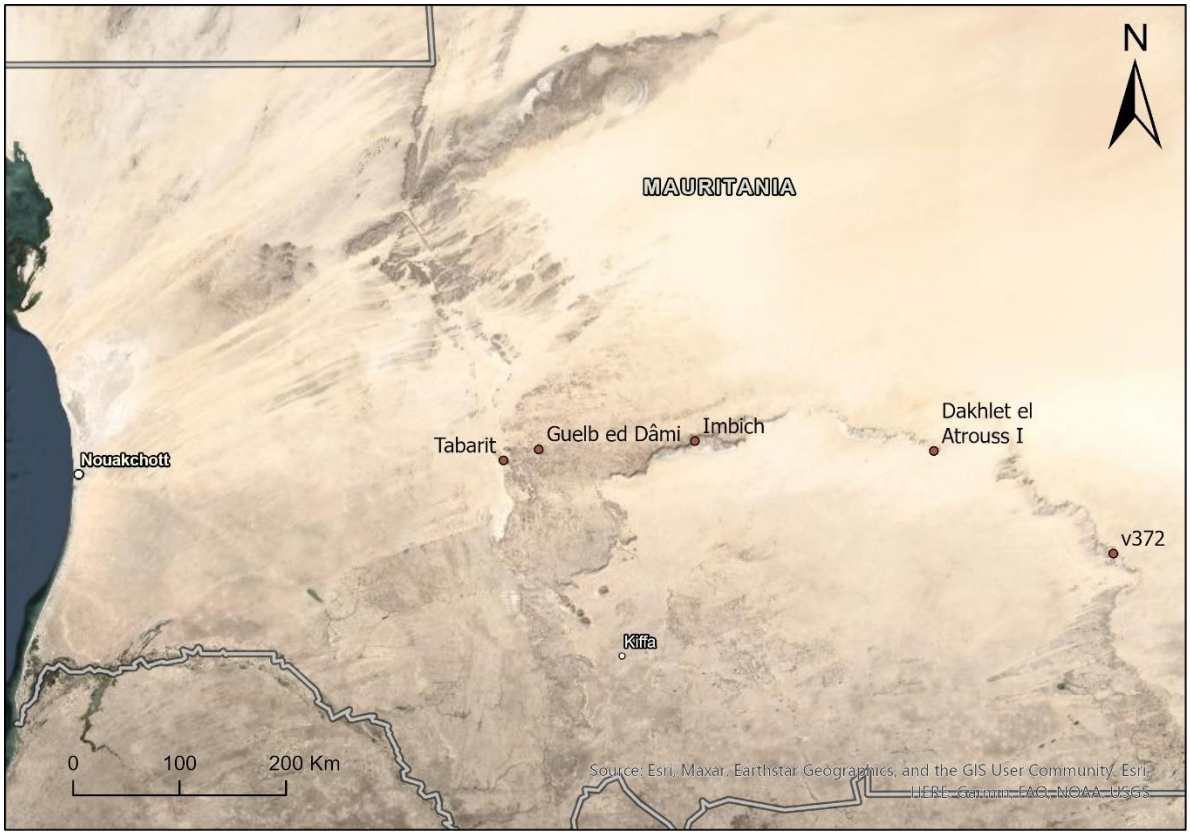


Figure 1. Map of archaeological sites discussed in relation to future fieldwork initiatives.

Furthermore, there are over 500 unexcavated funerary tumuli in the vicinity of Dakhlet el Atrouss I. Targeted fieldwork focusing on a small sample of these tumuli across the site's

hinterland would provide an opportunity to test whether the pattern of single inhumations without grave goods documented for the very few Tichitt Tradition tumuli excavated so far actually holds. Moreover, for a more comprehensive study of Tichitt Tradition funerary practices within the Tichitt-Oualata escarpments and beyond, it would be very interesting to explore whether any burials were conducted on small crevices or natural chambers within the sandstone escarpments, given how Dogon cemeteries (*ɔmo sày* or 'places where the living decompose') tend to be located in the largest natural chambers and cavities of the escarpment, with smaller or distant hollows reserved for culturally threatening deaths (Douny 2014), a practice that would be impossible to detect using satellite imagery.

Within the Tagant region, the area that seems most likely to witness any archaeological fieldwork in the near future, I would particularly recommend field assessments of three archaeological areas: the Imbich depression, the Tabarit tumulus fields, and Guelb ed Dâmi.

1) The Imbich depression is located in Dhar Tagant, and has an average elevation of 137 meters. Within it, we find the "gridded site complex" described in paper 1, which encompasses a range of sites, all boasting unique morphologies within the visible archaeological record of southeastern Mauritania, described in paper 1. Furthermore, there is a *c.* 30ha walled settlement on the plateau, 6-7km to the North but directly overlooking the area, which should itself be the focus of urgent field research, since it is being threatened by severe erosive processes. Architecturally, it resembles the Late Tichitt forms typical of Dhar Tagant, but it would be very beneficial to obtain some radiocarbon dates to confirm and contextualize it (Figure 2). In between, there is a well-structured tumulus field (with at least 80 funerary structures; Figure 3) as well as several smaller sites. Understanding the dating and ceramic assemblages associated with each of these settlements and potential funerary complexes would shed light into the socio-political organisation of Late Tichitt communities during the first millennium BC, a period for which we have very little data

from Dhar Tichitt, including the extent to which Berber communities were present in the area. Moreover, it could also address longstanding questions regarding the role of southern Mauritanian landscapes in processes of Sahelian state formation and expansion, if any of the components of the Imbich gridded site were to be chronologically ascribed to the period between the Ghana empire and the arrival of Islam to the region.

2) The Tabarit tumulus fields are described extensively in paper 3. They represent one of the densest concentrations of funerary architecture in southern Mauritania, so understanding their chrono-cultural attribution constitutes a research priority, through a combination of surface pottery associations – which may provide insights into the temporal depth of ritual practices, as well as through targeted excavations of individual tumulus. This would provide an opportunity to test whether the pattern of single inhumations without grave goods so far documented in the very few Tichitt Tradition tumuli that have been targeted for fieldwork to date is applicable to the Western Tagant region. The presence of any grave goods would be very relevant for understanding changes in burial dynamics over time, as well as aspects of socio-economic differentiation and geographic connectivity with other Saharo-Sahelian communities. Stable isotopes and genetics data from Tabarit inhumations would provide invaluable insights into aspects of dietary ecology, mobility, and population ancestry at a time of considerable demographic and cultural change in the region.

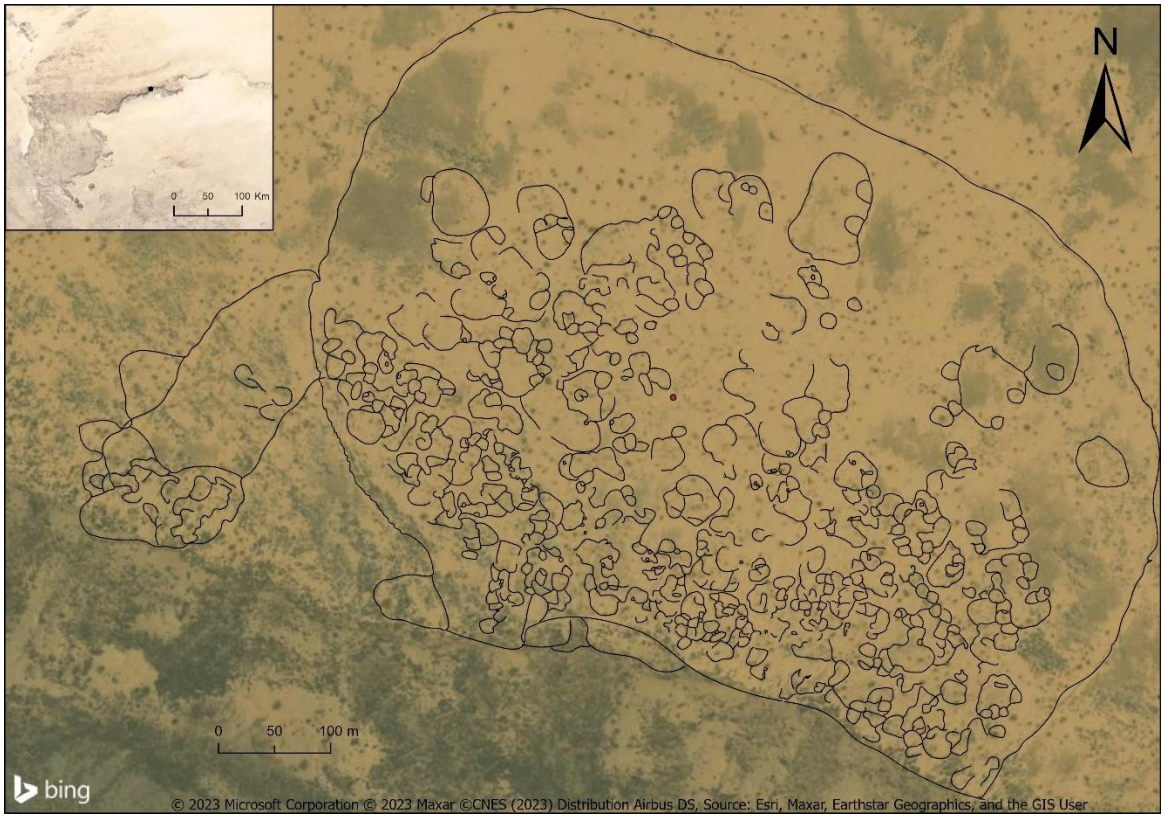


Figure 2. Outline of architectural features of the *c.*30 ha walled settlement overlooking the Imbich depression (with inset map showing the regional location of this geological formation).



Figure 3. Map of the tumulus field in the Imbich depression, located in between the "gridded site" complex and the walled settlement atop the Tagant Plateau. Note encircling enclosures.

3) Guelb ed Dâmi is a large (*c.*25ha) walled settlement in the Tagant Plateau. The site was previously undocumented and remains undated. The layout shows a vertical differentiation of space, reflected in architectural typology (predominance of circular household forms in the upper precinct, predominance of rectangular household forms in the "lower town" – these rectangular forms are often attributed to North African influences).

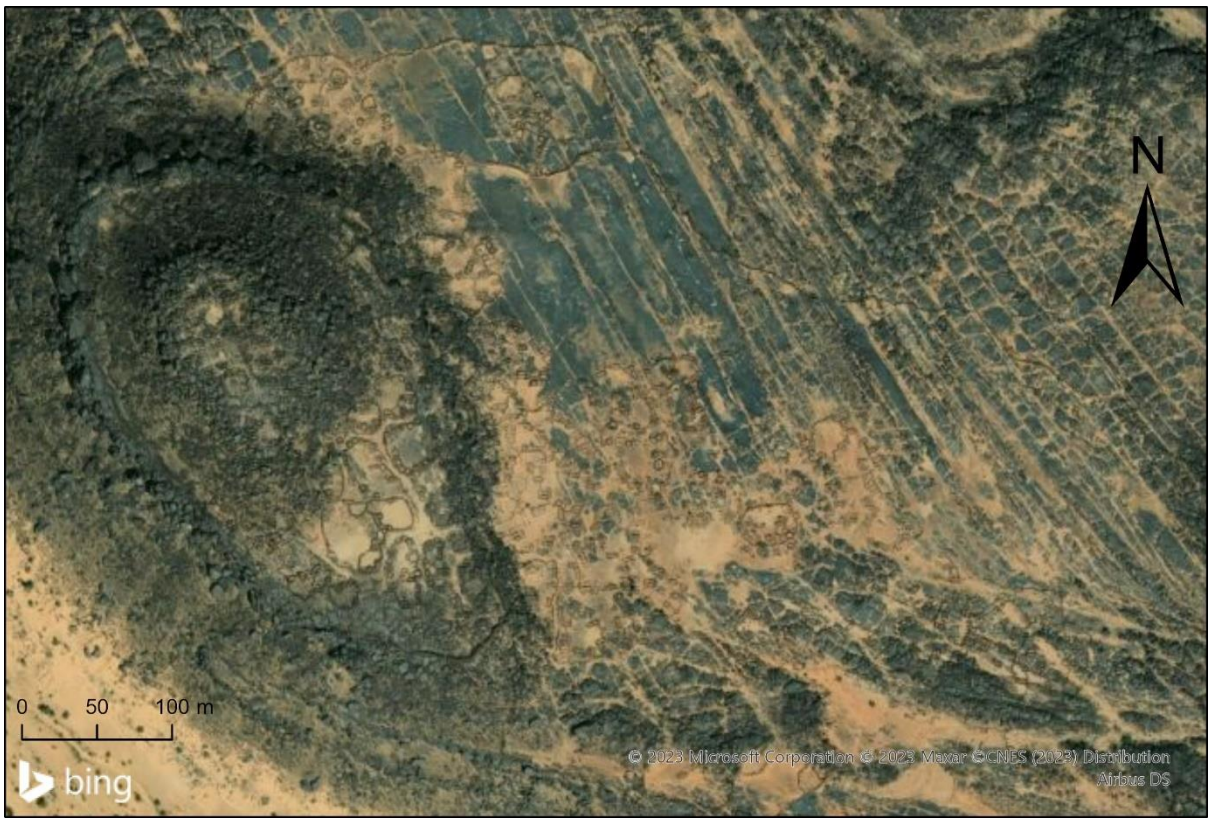


Figure 4: Satellite view of the walled settlement of Guelb ed Dâmi (Tagant Plateau).

Understanding intra-site dating patterns would help contextualize this otherwise atypical site within the Tichitt Tradition sequence or ascribe it to a later date. It would also determine whether the different contexts represent different temporal phases of site occupation and/or whether they were contemporary and thus potentially reflect cultural or socio-economic differences of the inhabitants (i.e. local Sahelian populations, Lybico-Berbers, etc.). Any evidence from additional sources of evidence beyond the reach of remote sensing approaches, such as rock art representations, would further contribute towards answering

this question. Besides, on the other side of the seasonal wadi located next to the site, there is a cluster of funerary monuments. Fieldwork may show whether there is a chrono-cultural association between both archaeological contexts, contributing to discussions regarding the centrality and liminality of funerary architecture in relation to large settlements or communication routes.

A much larger number and range of different projects could be designed and developed, but the ones outlined above constitute some of the lines of enquiry with the greatest *a priori* potential in my opinion. In general, the stark contrast between the richness of the archaeological record of southeastern Mauritania, as described in the present doctoral thesis, and the limited extent of archaeological fieldwork in the area highlights the incredible future research potential of the region, security and logistical issues permitting.

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