Quaternary Science Reviews 293 (2022) 107688

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Climate change, migrations, and the peopling of sine-Saloum mangroves (Senegal) in the past 6000 years

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A R T I C L E I N F O

Article history:
Received 3 February 2022
Received in revised form
9 July 2022
Accepted 27 July 2022
Available online 26 August 2022

Handling Editor: Giovanni Zanchetta

Keywords:
West Africa
Climate change
history
human migrations
paleodemography
shell middens
mangroves
radiocarbon

A B S T R A C T

We present a reconstruction of human demography and shell fishing activity in the Sine-Saloum mangrove Delta (Senegal) in the past 6000 years using the summed probability density (SPD) of radiocarbon dates in archaeological shell middens. We explore how this local history relates to the climatic and political history of West Africa. We find that traces of human presence were scarce from 6000 to 2000 yr BP, partly because the geomorphology of the estuary was less favorable to human settlements at that time. A specialized shell fishing population migrated massively to the Sine-Saloum around 2000 yr BP, at the end of the aridification trend that followed the African humid period. This population, likely coming from the northern coast in search of land and resources, fleeing from aridity and the subsequent warfare, found refuge in the coastal mangroves and reached a maximum activity at about 1700 yr BP. This period corresponds to the beginning of trans-Saharan trade, and to a political complexification that would give rise to the Ghana empire. The incoming migration may have occurred in two waves as suggested by two peaks in the SPD curve at 200–400 CE and 600–800 CE and by cultural differences within the Delta. Most sites in the Sine-Saloum islands were abandoned in the early 15th century, before the arrival of Europeans, possibly because intensive shell fishing was not sustainable anymore, or because of the regional political destabilization associated to the fall of the Ghana empire and the beginning of the Mali empire. Shortly after, in agreement with oral traditions, a new population lead by the Manding Guelwars, moved to the Sine Saloum after a military defeat and founded the modern towns. They had a reduced shellfishing activity compared to previous inhabitants, possibly because activities were more oriented to the new trade with Europeans or to a prosperous agriculture in more humid climatic conditions that prevailed from 1500 to 1800 CE.

1. Introduction

The Sine-Saloum area in Senegal hosts one of the most radiocarbon dated archaeological complex in West Africa, providing insights into the history of the demography and its relationship with local and regional environmental and political context.

The Saloum Delta is a vast intertidal wetland covered by

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https://doi.org/10.1016/j.quascirev.2022.107688
0277-3791/

mangrove at the mouth of the Sine and Saloum rivers in Senegal, today registered as a RAMSAR site and a UNESCO World heritage site. One of the extraordinary features of this pristine maze of mangrove islands and channels, is the presence of hundreds of archaeological shell mounds, including some of monumental size (up to 15 m high over ~10 ha) which makes them among the largest in the world (Thilmans and Descamps, 1982). These mounds, waste products of past human shell fishing and processing, are evidence of a millennial activity that is still practiced by Serer-Niominka people who live today in the Saloum Delta (Camara et al., 2017; Cormier-Salem, 2014; Descamps, 1994; Hardy et al., 2016). Little is known, however, about the history of the shell-collecting populations that inhabited the Delta during the last thousands of years.

Historical documents from European travellers or tradesmen, and oral tradition provide some information on people migrations, their economy, and the succession of local and regional political changes over the last five centuries. During his travel to the Saloum islands in the 15th century, the Portuguese Valentim Fernandes described in the village of Diofandor a population dedicated to shell fishing, pottery, and agriculture (Monod et al., 1951). Trade with Europeans, which included gold, salt, leather and slaves, rapidly grew and transformed the economy and political relationships in the region (Barry, 1998; Cormier-Salem et al., 1999). Before the first contact with Portuguese travellers, sources are limited to oral tradition, archaeological evidence, and to Arab travellers' texts who documented the regional context. Mangrove swamps in west African estuaries are thought to have been a refuge in the past millennia for populations running away from wars, kingdom authorities, or climate change (Cormier-Salem, 2014). The Sine-Saloum population in particular has been likely influenced by several migrations related to the rise and fall of west African empires, islam expansion, and trans-Atlantic trade (Barry, 1998; Pélissier, 1966). However, the impact of those events on the Sine-Saloum population cannot be fully assessed without indications about the demographic evolution in the Saloum Delta.

Climate variability likely had also a determinant influence on past human activities and migrations in West Africa. After the African humid period (AHP), which lasted approximately from 12,000 to 5500 years before the present (yr BP), the aridification of the Sahara and the Sahel from 6000 to 3000 yr BP is now well documented, in particular by the sedimentological records of Lake Yoa (Kröpelin et al., 2008), Lake Bosumtwi (Shanahan et al., 2009) and Lake Tislit (Cheddadi et al., 2021), and by a series of marine sediment cores off West Africa (deMenocal et al., 2000; Shanahan et al., 2015; Tierney et al., 2017). The climate variability in the Sahel in the past two millennia has only been recently reconstructed using the isotopic record of the Saloum Delta shell middens (Azzoug et al., 2012a, 2012b; Carré et al., 2019). Saloum shell middens indicate that the climate in the Sahel is more arid today than in any other period, as a consequence of an abrupt decrease of precipitation in the past 200 years (Carré et al., 2019; Gallego et al., 2015). The climate conditions of the past two millennia have therefore always been more favorable than today, with the most humid period recorded in the pre-colonial time from ca. 1500–1800 C.E., within the little ice age (LIA) (Carré et al., 2019). This paleoclimate reconstruction brings new key elements to understand the history of civilizations in western Sahel.

In this study, changes in the frequency of radiocarbon dates in archaeological shell mounds are estimated and used to reconstruct the evolution of the intensity of shell fishing activities and human occupation in the Sine-Saloum mangrove Delta since the first occurrence recorded at 5849 yr BP. Radiocarbon datings from archaeology and paleoclimatology research projects together yield a database of 103 radiocarbon dates from 21 archaeological sites from across the Delta and an opportunity to estimate past human occupation through time. Summed probability density (SPD) of radiocarbon dates has been shown to be a powerful tool to explore past population changes provided potential biases (related to sampling, preservation...etc) are taken into account (Chamberlain, 2006; Contreras and Meadows, 2014; Rick, 1987; Shennan et al., 2013; Surovell and Brantingham, 2007; Williams, 2012). The large changes observed in the shell fishing population over the past millennia in the Delta are discussed in the context of climatic and political changes in the region.

2. Material and methods

2.1. The shell middens

Most shell middens in the Sine-Saloum mangroves are almost exclusively composed of *Senilia senilis* shells (bloody cockle), while some are composed of *Crassostrea gasar* (mangrove oysters) shells, or a succession of layers of these species. Pores are mainly filled with sand, charcoal and ashes. The scarcity of artefacts supports the idea that the middens were not permanent villages but working places, possibly seasonally used, and dedicated to the collecting and processing of mollusks. However, the numerous burials mounds found on top of the largest middens (Descamps and Thilmans, 1979) suggest that they played a more complex role in past Saloum societies (Hardy et al., 2016).

The archaeological shell middens of the Sine-Saloum Delta have been extensively surveyed by Thilmans and Descamps (1982) who reported 96 sites (Fig. 1). These authors studied and dated the stratigraphy of three large shell middens, Dioron Boumak (Descamps et al., 1974), Faboura (Descamps et al., 1977), and Bangaler (Elouard et al., 1974). These two latter sites do not exist anymore, used up for construction material. Only a few sites have been dated besides those until 2011 when a new research project started with the aim of reconstructing past climate conditions using shell middens (Azzoug et al., 2012b, 2012a). Eleven additional shell middens were sampled and 65 new radiocarbon dates were produced. In this more recent work, shell middens from most areas of the estuary were randomly sampled, although a preference was given to larger accumulations. Sites are distributed across the whole mangrove area. Since no particular period was targeted and shell middens do not show any visual evidence of their age, sampling biases are minimized. In large shell middens cut by tidal erosion or by human exploitations, several samples were collected for radiocarbon dates along the outcropping stratigraphy. In Dioron Boumak, for instance, samples were collected every meter along the ~11 m high cliff (Azzoug et al., 2012a). Unlike most archaeological shell middens, these sites show little mixing and fast stratified accumulation, as evidenced by the depth-age models obtained in three of those sites (Carré et al., 2019).

2.2. Radiocarbon dates

We completed the synthesis published by Hardy et al. (2016) with 41 new radiocarbon dates, reaching a total number of 103 radiocarbon datings of samples collected from the surface or the stratigraphy of 21 shell middens. Samples are composed of either terrestrial material (mostly charcoal and one bone) or marine material (otolith or mollusc shells including *S. senilis* and *C. gasar*). The concentration of ^{14}C was measured using β radioactivity in the earlier studies, and later exclusively with Atomic Mass Spectrometry (AMS) which yields higher precision and allows for the analysis of small charcoal fragments. New radiocarbon dates of *S. senilis* were measured on the shell hinge, a part that is best preserved from recrystallization and integrates several years of growth. All dates are reported in Supplementary Table 1.

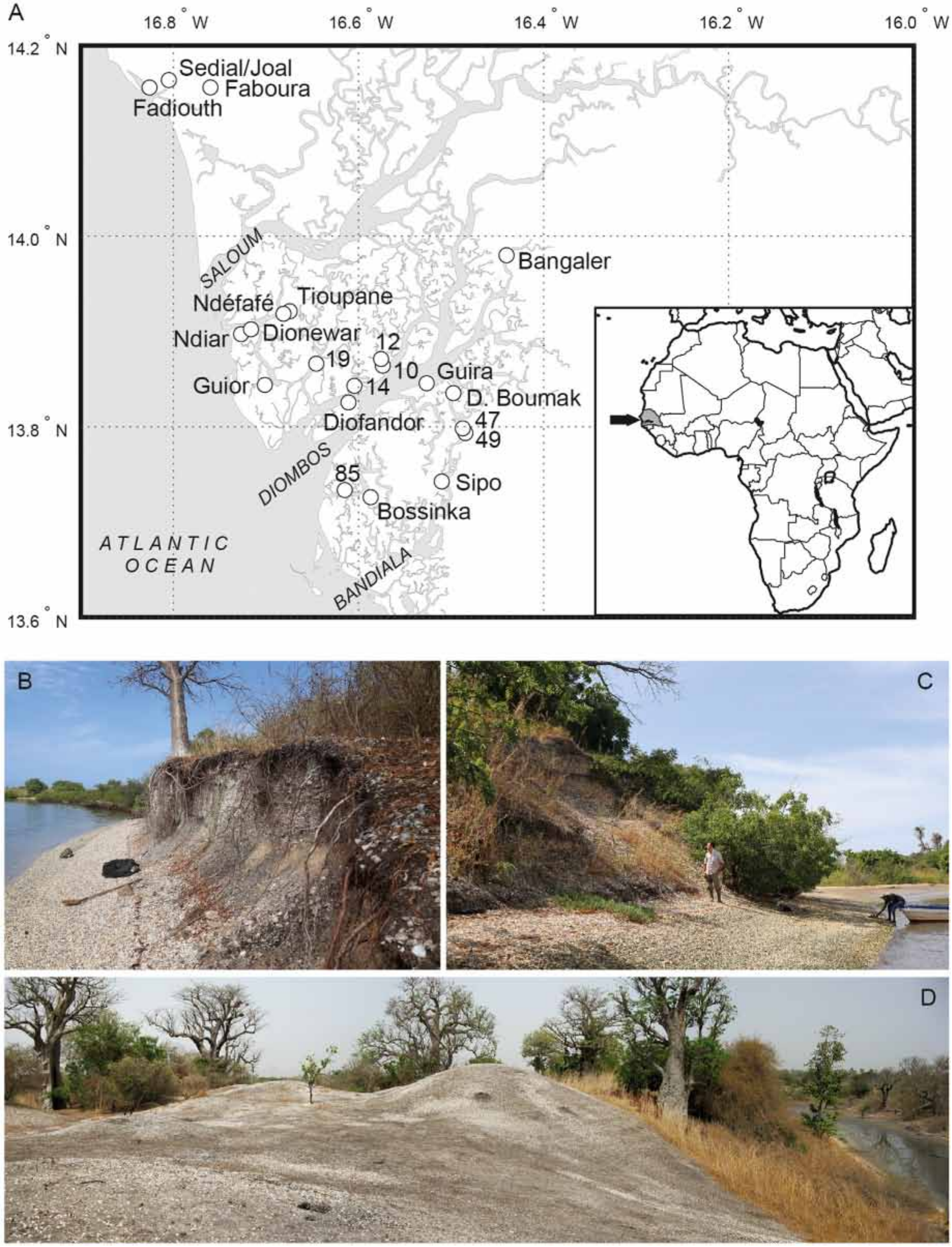

Fig. 1. (A) Map of the Sine-Saloum study area, Senegal. Location of the shell middens dated and listed in Supplementary Table 1 (white circles). Pictures of some representative shell middens: Site 85 (B), Bossinka (C), and Tioupane (D). Numbers used in some site names are from Thilmans and Descamps (1982).

2.3. Calibration

Radiocarbon dates were all calibrated using the R package rcarbon (Crema and Bevan, 2020) with the calibration curves IntCal20 (Reimer et al., 2020) and Marine20 (Heaton et al., 2020). For otolith and mollusk shell samples, it must be considered that the conditions in the estuary are not fully marine. Today, the Saloum Delta is an inverse estuary during the dry season: the sea water enters the Delta with tides and becomes hypersaline landward because of evaporation (Pagès and Citeau, 1990; Savenije and

Pagès, 1992; Mikhailov and Isupova, 2008; Carré et al., 2019). The estuary recovers a normal salinity gradient during the rainy season (July–September) with salinities ranging approximately from 15 to 30 in the mangrove area where mollusc live (Carré et al., 2019). Oxygen isotopic values in archaeological shells showed that the salinity was lower in the past, especially from 1500 to 1800 C.E. (Carré et al., 2019). Shell calcium carbonate was thus precipitated from dissolved inorganic carbon (DIC) that is partly marine and partly terrestrial. As marine and terrestrial carbon have different carbon isotopic composition ($\delta^{13}C$), their proportions were estimated from the $\delta^{13}C$ values measured in shell samples (Supplementary Table 1), since *S. senilis* shells precipitate aragonite in isotopic equilibrium with DIC $\delta^{13}C$ without significant fractionation as observed from modern $\delta^{13}C$ DIC and shell measurements (Carré et al., 2019). The ratio of marine carbon versus terrestrial carbon was calculated assuming a $\delta^{13}C$ value of 0‰ (V-PDB) for marine carbon and a $\delta^{13}C$ value of −22‰ (V-PDB) for terrestrial carbon issued from the degradation of mangrove organic matter. This latter $\delta^{13}C$ value was estimated considering a value of −31‰ for dissolved organic matter of mangrove (Dittmar et al., 2006) and a fractionation of 9‰ between dissolved CO_2 and carbonate ions HCO_3^- (Zeebe and Wolf-Gladrow, 2001) used in shell aragonite precipitation. The contribution of terrestrial carbon was generally less than 20%, with a maximum value of 54% (Supplementary Table 1). When a $\delta^{13}C$ value was available, the calibration of mollusk shells was thus performed using a mix of IntCal20 and Marine20 ($\Delta R = 0 \pm 50$) calibration curves in the R package rcarbon. Throughout the text, yr BP ages refer to calibrated years before present (using conventionally 1950 CE as the present). For the more recent period (the last 2000 years), the Current Era (CE) scale is used.

2.4. Summed Probability Distribution (SPD)

Summed Probability Distribution (SPD) have been widely used to estimate past changes in human demography through time and space (Rick, 1987; Chamberlain, 2006; Williams, 2012; Shennan et al., 2013). One of the most important bias that may arise from this technique is the overrepresentation of some periods or sites where archaeological efforts were concentrated (Chamberlain, 2006; Surovell and Brantingham, 2007; Contreras and Meadows, 2014). To minimize this bias, some radiocarbon dates have been excluded from the SPD calculation using the following criteria. For each site, samples with close radiocarbon dates and similar depths were considered redundant and only one of the replicates was kept, with a preference for terrestrial carbon source and/or better precision. The SPD was finally built from 73 radiocarbon dates (50 terrestrial and 23 marine). Probability distributions from radiocarbon date calibration were calculated and summed using the rcarbon package (Crema and Bevan, 2020). SPDs were first calculated separately for marine and terrestrial samples and then summed. A 100-yr moving average of the total SPD was calculated. The confidence interval was defined by the 0.025 and 0.975 quantiles of values in the 100-yr windows. Three additional SPD curves were built to evaluate the effect of sample selection and of the use of mixed curve calibration of marine samples: (1) all the dates available were included (no sorting) and only the Marine13 calibration curve was used for marine samples (no mixing) (Fig. S1a), (2) only the selected subset of dates was included (sorting) and only the Marine13 calibration curve was used for marine samples (no mixing) (Fig. S1b), and (3) all dates were included (no sorting) but mixed Marine20 and IntCal20 curves were used for marine samples when possible (mixing) (Fig. S1c).

3. Results

The oldest human presence in the Sine-Saloum was evidenced *ca.* 5800 Cal. yr. BP in the site Sipo, a ~2 m thick shell midden on top of a sandy beach ridge in the southern area (Fig. 1). After this first occurrence, dates are scarce until the beginning of the Current Era, and mainly concentrate between 0 and 1500 CE (Fig. 2). A sharp decline is observed in the 15th century. This decline is also accompanied by a strong turnover in the sites that cannot be seen in the SPD curve. A large number of sites are abandoned in the 13th and 14th century. The last five centuries are only represented by one site, Diofandor, in our record (Fig. S2). These main features are robust regardless the data selection or the calibration method (Fig. S1).

Redundant datings have been identified mainly in Dioron Boumak, Faboura, Guior and NDiar. Since most dates excluded as redundant were from obtained marine material, this process mainly affected the SPD derived from marine samples. The most prominent effect is to drastically reduce the peak between ca. 700 CE and 1300 CE (Fig. S1). Using mixed calibration curves for shell samples yields better defined peaks in the marine SPD curve. The use of the mixed calibration is *a posteriori* supported by a better agreement between the terrestrial and the marine SPD curves, especially when using the selected dates (Fig. S1).

The high frequency variability in the SPD curve is not considered as a significant signal. Only the changes observed in the 100-year smoothed SPD curve are thus discussed here (Fig. 2). Within the main occupation period (200–1500 CE), the SPD curve shows two peaks at 200–400 CE and at 600–800 CE, followed by an intermediate level plateau from ~900 to ~1400 CE. Sites are distributed in the whole mangrove area, with a higher concentration around the central axis of the Diomboss (Fig. 1, S2). Joal Fadiouth, at the northern end of the Sine-Saloum, is one of the oldest occupation and is still inhabited today by a shellfishing community (Hardy et al., 2016), suggesting a possible 3000 years long occupation in this area.

4. Discussion

4.1. Radiocarbon dates, shellfishing, and population density

Summed probability density of ^{14}C dates from archaeological sites may yield powerful insights into the past dynamics of human population but is also prone to several potential biases (Williams, 2012). All the archaeological sites known in the Sine-Saloum mangroves are shell middens, the age of which cannot be estimated before dating. Since the first objective of the sampling was to build a long paleoclimatic record, the sampling effort was not focused on a specific period but rather intended to cover a period as large as possible, so that sites were chosen as diverse and disperse as possible, with a preference for long sequences. A bias related to the site selection process is thus not considered significant here. For diverse reasons, some sites have been more dated than others. This overrepresentation has been corrected for (see section 2.3) so that sampling bias would be minimum in the final SPD.

The record might be also possibly biased by the destruction of some shell middens used up for construction material during the 20th century. This exploitation preferentially affected sites accessible by roads on the periphery of the Mangrove, while sites in the core of the mangrove area were better preserved. Faboura and Bangalère for instance, dated in the 1970s, do no longer exist. Only sites within the mangrove could thus be sampled during the more recent dating campaign. This selective destruction would create a

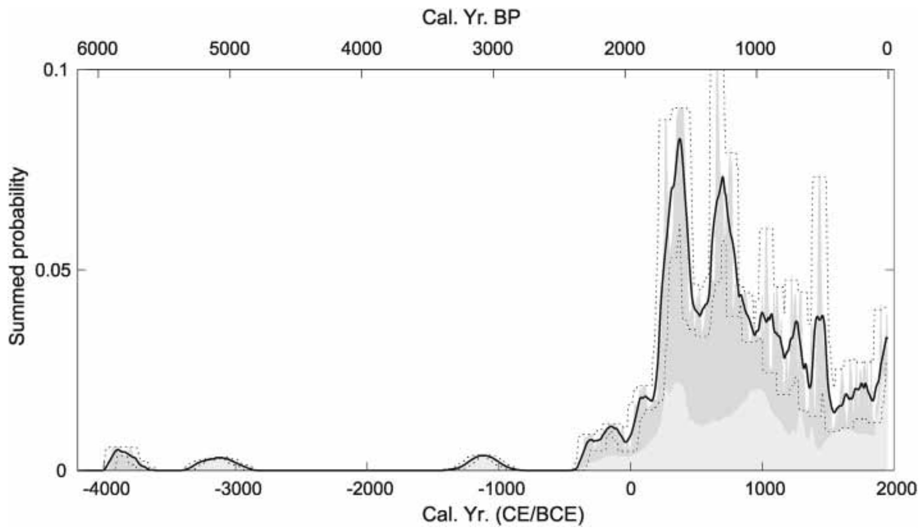

Fig. 2. SPD curve of selected radiocarbon dates from shell middens of the Sine-Saloum Delta. The SPD of terrestrial samples (dark grey) is added to the SPD of marine samples (light grey) calibrated using mixed IntCal13 and Marine13 calibration curves. 100-yr moving average is shown (black line) with the 95% confidence interval (dotted lines).

bias in the SPD if shell mounds from outside or within the mangrove had a different age, which is not supported by dates from Faboura and Bangalère.

The total sample size determines the uncertainty of the SPD and the reliability of its variations. The 21 sites dated here are only a fraction of the 96 shell middens reported by Thilmans and Descamps (1982). Some of these sites were dated in their stratigraphy and showed different occupation periods, yielding also a diachronic dimension that adds to the SPD. Using a Monte Carlo statistical resampling approach, Michczyńska and Pazdur (2004) determined that a minimum number of 14 dates per millennium is required to have a meaningful signal, and 56 dates per millennium are required for statistical variability to be less than 20% (considering a mean ^{14}C dating error of 115 years). Williams (2012) reached a similar result finding that a minimum of 500 dates is needed over a period of 40,000 years (i.e. ~13 dates per millennium). In our record, radiocarbon dates are very scarce before the Current Era. Although ancient sites may have been more subject to erosion or human exploitation, this scarcity can only be interpreted as a period of very low human activity. Detailed changes within this period cannot be resolved with this dataset. Radiocarbon dates are here concentrated in the past 2000 years, with ~30 dates per millennium (~50 dates per millennium before selection), above the minimum suggested by these earlier statistical studies. In addition, the 100-year moving average removes a large part of the variability related to stochastic sampling. The 95% confidence interval associated to the moving average curve provides an indication of the statistical significance of the SPD variations (Fig. 2). We thus conclude that the broad phases observed in the SPD in the last 2000 years are statistically robust.

4.2. Shellfish exploitation and population size

Senilia senilis is still very abundant today, has a high growth rate, and is the main mollusk species collected in the Sine-Saloum. The species lives in the first centimetres of the sediment on intertidal mudflats, where it is manually collected by women during low tides. *Crassostrea gasar*, an oyster species that lives attached to mangrove roots is also easily collected from a small boat at low tide, and is the second most used species. Mollusks are such an easy and reliable protein source in the Sine-Saloum, that it seems very likely that this resource has been part of the economy of any human group living in or close to the mangrove area. Inhabitants of the mangrove today collect mollusks for their own consumption and accumulate shells in temporary fishing sites as well as in their villages (Camara et al., 2017; Hardy et al., 2016).

The density of radiocarbon dates in shell middens primarily reflects the intensity of the shellfishing activity in the Sine-Saloum, and indirectly the size of the population living in the area, assuming that shellfishing intensity and population size are linked. Because of the multiple use of the mangrove ecosystem (Piqué et al., 2016), the abundance and easy access of *Senilia senilis*, and the economic importance of this resource, it can be reasonably assumed that changes in shellfishing intensity are linked on a first order to population size, but it also depends on the economic strategies chosen by the groups. Those strategies may change through time with climatic conditions or cultural evolution. Hence, shellfishing intensity may overestimate population size in periods when the mollusk extraction effort is intensified for trade, or underestimate it when efforts are reallocated in other kinds of resources or activities.

Ancient shell middens in the Sine-Saloum are almost exclusively composed of shells. Because remains of artefacts or settlements are scarce, these sites have been considered as work site dedicated to the processing of shells, the flesh of which is dried or smoked and then transported to be consumed elsewhere (Camara et al., 2017; Descamps, 1994; Hardy et al., 2016). The monumental size and the fast accumulation rate of some middens such as Dioron Boumak suggest an industrial activity aimed for trade rather than for domestic consumption (Descamps et al., 1974; Descamps and Thilmans, 1979). This hypothesis, however, also bears uncertainty. First, these very large mounds are only a handfull among the 96 reported sites and the possibly hundreds of unreported ones (Thilmans and Descamps, 1982). It also must be noted that these very large sites generally bear numerous funeral tumuli sometimes containing rich artefacts (Descamps and Thilmans, 1979), which suggest an intermediate type of use in between the temporary fishing sites and the permanent villages observed today. Finally, the hypothesis is fundamentally based on the idea that the shell production exceeded the needs of the local population, based on an analogy with the modern population size rather than on archaeological evidence of past population size. Additional quantitative evidence on traded products and past food production strategies including fish, cattle, and crops, are required to test this hypothesis.

Although no simple relationship exists between shellfishing intensity and population size due to changing practices, we consider here, based on the available information, that they are broadly positively linked, so that the SPD can be considered as a reliable qualitative indicator of population presence, activity and size in the Sine-Saloum mangrove area. While possibly amplified by trade-oriented extraction, the broad SPD peak observed between ~200 and ~1400 CE, very likely represents a maximum population size. This is supported by the larger number of sites (not only the number of datings) and the larger spatial coverage during this period (Fig. S2).

4.3. The influence of sea level and coastal geomorphology

The availability of land for shell middens and of mollusk resources depends on the geomorphology of the Sine-Saloum, which has strongly evolved during the Holocene. The relative sea level was about 1–2 m higher than today during the Nouakchottian marine transgression period from approximately 6500 to 4000 yr BP. This event has been well dated and described in Mauritania and Senegal (Ausseil-Badie et al., 1991; Barusseau et al., 1995; Elouard, 1968; Faure et al., 1980). For the combined effect of high sea level and a stronger flow of the Saloum River in the African humid period (AHP), the Sine-Saloum was a macrotidal estuary, with large shallow and intertidal areas and relatively open and high energy environments (Ausseil-Badie et al., 1991). Some early beach barriers, like the one in Sipo where the oldest shell midden was found, created protected area where *Senilia senilis* could grow and be gathered. However, the absence of mangrove islands and channels reduced greatly the availability of the mollusk banks and the terrain to build shell middens.

After sea level reached its modern value 4-3ka (Faure et al., 1980; Nizou et al., 2010) and after the AHP, new beach barriers and a littoral spit formed *ca.* 3.5 to 2.5ka. Fluvial and aeolian sediments then accumulated in the barred estuary to progressively form the islands and channels that constitute the modern mangrove Delta (Ausseil-Badie et al., 1991; Diara and Barusseau, 2006). The Delta geomorphology was similar to the modern one *ca.* 1500 BP.

Although the geomorphological and ecological conditions were more favorable to shellfishing in the past 2000 years than before, these changes cannot fully explain the SPD. Dense *S. senilis* banks were present from 6000 to 2000 yr BP as attested by vast natural Nouakchottian deposits (Debenay and Bellion, 1983), by their presence in beach barrier sand (Ausseil-Badie et al., 1991), and by a few archaeological shell middens. Although mangrove islands were not available in early times to establish camp sites, these islands were not indispensable for human to use mollusks. Numerous mid-Holocene *S. senilis* shell middens were found around the Banc D'Arguin in Mauritania (Barusseau et al., 2007; Vernet and Tous, 2004). The large shell middens of Faboura and Bangalère, accumulated between 1900 and 600 yr BP, were built respectively on substrate dated of 4700 yr BP (Ausseil-Badie et al., 1991), and on pre-Holocene substrate (Barusseau et al., 1995; Elouard et al., 1974). If geomorphological conditions were the primary factor determining the presence of shellfishing people in the Sine-Saloum, we would expect a progressive increase of radiocarbon date frequency in the past 6000 years, following the progressive formation of the Delta. Instead, human presence and shell fishing abruptly increases from insignificant level before 2000 yr BP to an absolute maximum 300 years later. This pattern could only be explained by the sudden arrival of a large human population who migrated and settled in the Sine-Saloum approximately 2000 years ago.

4.4. The influence of climate change

In the Sahel and the close-by Sahara, climate largely determines the availability of resources and agriculture productivity and is therefore a primary driver of human societies' strategies, success, and movements (Brooks et al., 2005; Magadza, 2000). In this section, we examine how past climate and environmental changes in west Africa in the past 6000 years may be related to the peopling of the Sine-Saloum reflected by shell middens SPD.

The early to mid-Holocene in Africa is known as the African humid period. In response to seasonal insolation changes, the west African monsoon was intensified and shifted north (Braconnot et al., 2000; Joussaume et al., 1999; Kutzbach and Liu, 1997) while the mediterrannean winter rainfall system was also intensified and shifted south (Cheddadi et al., 2021). As a consequence, rainfall was increased from the Gulf of Guinea to the Mediterranean coast, lakes and watersheds were active, and the Sahara was covered by vegetation (Bartlein et al., 2011; Jolly et al., 1998; Kröpelin et al., 2008; Watrin et al., 2009). The end of the AHP, once thought to have occurred abruptly *ca.* 5500 cal yr BP (deMenocal et al., 2000), was more likely progressive as shown by a broad range of indicators including pollen records (Cheddadi et al., 2021; Kröpelin et al., 2008), wetland radiocarbon dates (Lézine et al., 2011), and leaf wax deuterium records (Niedermeyer et al., 2010; Shanahan et al., 2015; Tierney et al., 2017). These records indicate an aridification trend approximately from 6000 to 3000 yr BP (Fig. 3). This transition from a productive environment to the extreme aridity of the

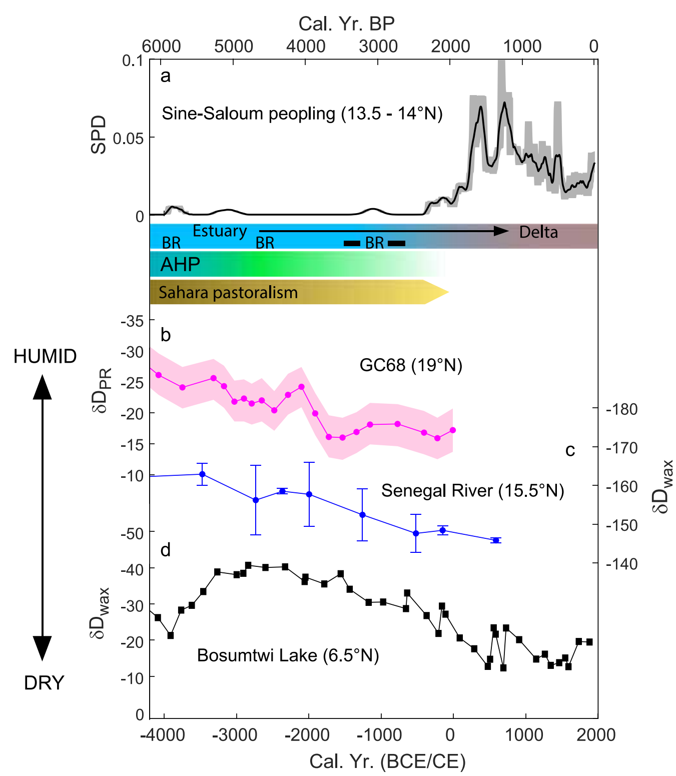

Fig. 3. Sine-Saloum peopling and regional climate in the past 6000 years. (a) SPD 100-yr moving average of the Sine-Saloum. Indicated below are the evolution of the Sine-Saloum Delta (BR indicates the formation of Beach Ridges), the intensity of the African Humid Period (AHP), and the period of pastoralism in the Sahara. The precipitation trend in West Africa is indicated by (b) the record of Deuterium of precipitation in GC68 marine core collected off Mauritania (Tierney et al., 2017), (c) the leaf wax deuterium record from GeoB9508 marine core off the Senegal River (Niedermeyer et al., 2010), (d) the leaf wax deuterium record of the Bosumtwi Lake, Ghana (Shanahan et al., 2015).

Sahara Desert represents the largest Holocene environmental change on Earth (Jansen et al., 2008; Wanner et al., 2008).

Human societies have been profoundly affected by this environmental change across all northern Africa. The Sahara, widely occupied by diverse human groups living from hunting, fishing, and pastoralism during the AHP (Holl, 2004; Lhote, 1970; Paris, 1993; Smith, 1980; Sutton, 1977), was progressively abandoned as aridity increased (Brooks, 2006; Maley and Vernet, 2015; Manning and Timpson, 2014; McIntosh and McIntosh, 1983; Vernet, 2002). While in the eastern Sahara, people found refuge in the Nile valley, possibly giving rise to the ancient Egypt civilization (Kuper and Kröpelin, 2006), in central Sahara, pastoralists migrated to the Sahel, following the southward migration of Savanna and pasturage (McIntosh and McIntosh, 1983; Smith, 1979). The progressive decline of the Saharan population at the end of the AHP has been well demonstrated by radiocarbon dates density in all the regions of the Sahara (Manning and Timpson, 2014; Vernet, 2002). Interestingly, the population of the West African Atlantic coast has an opposite dynamics and tend to grow at the end of the AHP to reach a maximum 3.5 to 3ka (Manning and Timpson, 2014; Vernet and Tous, 2004). The reliability of marine resources was likely a factor of resilience and the Mauritanian coast may have become a momentary refuge. Between 3 and 2ka, the shellfishing groups of Mauritania abandoned also their sites and seem to move south towards Senegal, as aridity kept increasing (Vernet and Tous, 2004). A final abrupt aridification occurred in the Sahel around 2 ka to reach the modern semi-arid landscape (Lézine, 1989).

The abrupt rise of shellfishing population in the Sine-Saloum around 2ka coincides with the end of the aridification after the African humid period (Fig. 3), and the end of shellfishing activities in Mauritania. Human occupation patterns in West Africa suggest that environmental changes forced large migrations in search of vegetal resources in the Sahel and marine resources on the Atlantic coast. We hypothesize that a human group migrated and found refuge in the Sine-Saloum around 2ka as a consequence of the increasing scarcity of land in the Sahara and Sahel and the subsequent increasing competition for resources. They immediately organized an intensive exploitation of *S. senilis*, which is evidenced by the high accumulation rate of the middens (Azzoug et al., 2012a; Descamps et al., 1977, 1974) and by the rapidly decreasing size of the shells (personal observation) which indicates a strong gathering pressure on the species. This observation suggests that they were already specialized or at least knowledgeable in this activity, and testifies therefore a possible origin from northern Senegal and Mauritanian coast (Vernet and Tous, 2004). An ancient shellfishing population collecting *S. senilis* was also present in the estuary of the Senegal River since at least 5ka (Mbow, 1997; Michel et al., 1967). Potteries found in middens of the first millennium BCE were decorated with impressed cord-wrapped stick (Mbow, 1997), a technique observed soon after in the Sine-Saloum sites (Thilmans and Descamps, 1982), suggesting a cultural filiation. Shellfishing activity did not end *ca*. 2ka in the Senegal River Delta as it did in Mauritania. It seems thus that the shellfishing Mauritanian population, moving South, may have triggered also a migration from the Senegal River Delta to the Sine-Saloum.

The arrival of people in the Sine-Saloum also roughly coincides with the spread of rice cultivation in West Africa (Linares de Sapir, 1971; Linares, 2002; McIntosh and McIntosh, 1981). It is thus possible as well that the new settlers came in search of fields for rice cultivation since West African mangroves have long been a highly productive environment for rice (Cormier-Salem et al., 1999; Linares, 2002; Pélissier, 1966), and collected mollusks as a complement during the dry season. Determining who these people were, where they came from, and the exact cause of their migration will, however, require a more detailed archaeological characterization of the shell middens in the Sine-Saloum.

In the past 2000 years, the changes in the SPD does not present any clear relationship with climate variability (Fig. 4). Soil erosion related to agriculture intensity in the region, as indicated by the dust fraction in marine sediments, constantly increases during the past 2000 years, with a strong acceleration with recent industrial agriculture (Mulitza et al., 2010). The two large peaks in radiocarbon dates density around 300 and 700 CE are not related to any climatic event. Aridity conditions reconstructed by mollusk shell oxygen isotopes show instead little variations until approximately 1500 CE when precipitations increased and the environment became less saline (Carré et al., 2019). The Sine-Saloum was much less occupied during the humid period that lasted from ~1500 to 1800 CE (Fig. 4). We could expect people to invest more in agriculture during a wet period and rely less on shellfishing. Combined with overexploitation of S. senilis, indicated by the small size of shells in the middens (pres. obs.), the benefit-cost balance of shellfishing may have become too low for this activity to be pursued, especially in a context of higher crop productivity. It is however difficult to draw a causal relationship between these circumstances because of the chronological uncertainty. Most shell middens were abandoned in the 14th century, when climate was starting to improve, but before rainfall had reached its optimum. This abrupt decrease in shellfishing population in the 14th century

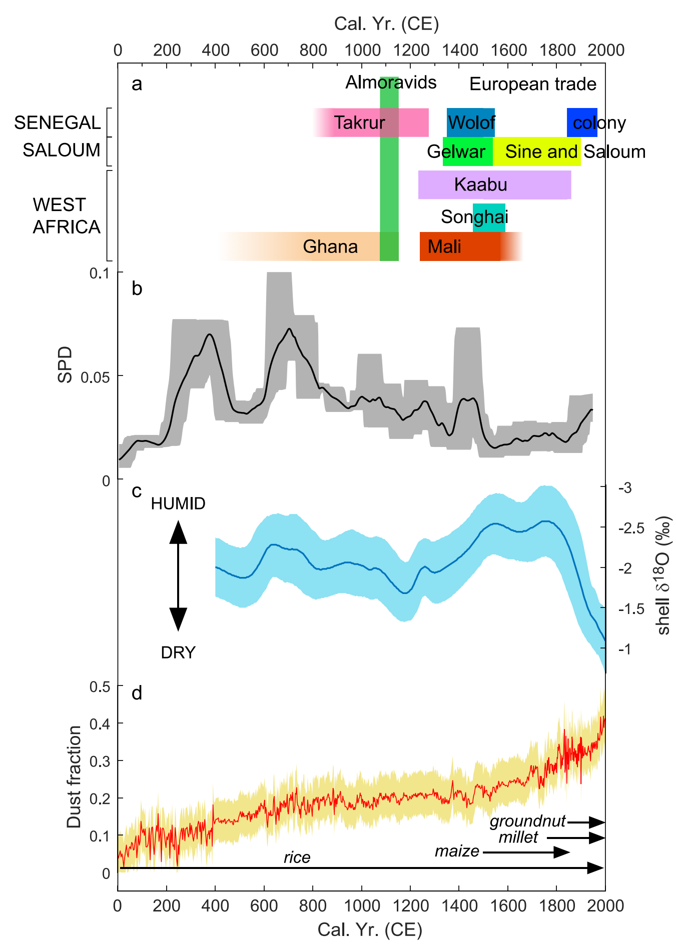

Fig. 4. Sine-Saloum peopling and regional context in the past 2000 years. (a) Schematic chronology of main political structures in Senegal and West Africa. (b) SPD 100-yr moving average of the Sine-Saloum. (c) Precipitation changes in the Saloum basin reconstructed from shell oxygen isotopes (Carré et al., 2019). (d) Dust fraction in GeoB9501 marine core collected off the Senegal River, related to soil erosion and agriculture practice (Mulitza et al., 2010).

(it artificially appears in the 15th century in Fig. 4 because of the effect of the 100-yr smoothing, but is better seen in Fig. 2, S1, and S2) may therefore rather be related to local or regional political troubles.

4.5. The influence of regional conflicts

The decreasing water resources across the Holocene and the subsequent migrations likely triggered conflicts, warfare and political evolution in the whole region. Evidence of these conflicts are however hard to identify in the archaeological record. Changes in the structure of villages in the sequence of the Tichitt tradition in southern Mauritania seem to indicate a period of warfare in the middle of the first millennium CE (Munson, 1980). Shortly after, trans-Saharan trade would start and become progressively a essential element of West African economy (Fauvelle-Aymar, 2013). From −300 to 500 CE, the trade favoured a socio-economic transformation in the Sahara and the Sahel with the apparition of cities, increasing exchanges and political complexity, that would lead to the rise of the Ghana Empire (Holl, 1985; McIntosh and McIntosh, 1983; Munson, 1980). The shellfishing people settled in the Sine-Saloum during this phase of regional scale transformation, and likely took part to these new trade relationships using dried mollusks, as attested by the industrial scale of shellfishing, and possibly crops.

The second peak in the SPD from 600 to 800 CE might correspond to a second migratory movement possibly in relation to the foundation of the Ghana Empire but the archaeological information about the Sine-Saloum and the regional context is scarce in this period. The hypothesis of a second migratory arrival is supported by cultural differences observed between Faboura, which started with the first SPD peak, and Dioron Boumak which started with the second peak. While ceramics at Faboura are similar to those found further North, Dioron Boumak ceramics seem related to those from Casamance (Descamps et al., 1977).

It has been proposed that the Serer population living in the Sine-Saloum today came from the north pushed by the expansion of islam through the influence of Almoravids, and especially from the kingdom of Tukrur in northern Senegal (Sarr and Becker, 1986), one of the first that officially adopted islam in the 11th century (Niane, 1985). Almoravids eventually destabilized and accelerated the collapse of the Ghana empire in the 12th century, which was followed by a regional scale political reorganization. With the rise of the Mali empire, West African Manding population expanded to the Senegambian coast, and the Sine-Saloum mangroves were likely incorporated in the new empire in the 13th century (Meideros, 1980; Niane, 1985). Shortly after, during the 13th and 14th century, most of the main sites of the islands were abandoned, including Dioron Boumak, Faboura, Tioupane. Although the causes of this abandonment are not clear, we speculate it was somehow related to a period of strong political instability in West Africa (Fig. 4).

New settlements were dated in the 15th century. They were fewer and smaller. Shells were large again, indicating that *S. senilis* populations were less exploited during a time and could recover. This peopling turnover is strikingly coherent with the oral tradition of the Sine-Saloum. According to the oral record, the ancestors of the current inhabitants found the islands deserted when they arrived in the Sine-Saloum and the population who had built the large shell middens had disappeared (Cormier-Salem et al., 1999; Pélissier, 1966). After the battle of Troubang (1335 CE) in the civil war of the Kaabu kingdom, the Manding Guelwar aristocratic elite found refuge in the Sine-Saloum area and initiated a dynasty who ruled over the Sine and Saloum kingdoms until the 20th century (Cormier-Salem et al., 1999; Richard, 2012; Sarr and Becker, 1986), first as vassals of the Wolof kingdom, then within the French colony. The alliance and mixing of the Guelwars and the local Serer seems at the origin of the Niominkas, the actual inhabitants of the Sine-Saloum islands.

The first contact with European travellers was likely around 1446 CE (Cormier-Salem et al., 1999; Person, 1985; Thiaw, 2012), after the settling of the Guelwars (i.e. after the had been abandoned and reoccupied). Fernandes visited the Saloum Delta where ships found a safe anchoring site, mentioned the village of Diofandor, and described a population living from shellfishing and agriculture (Monod et al., 1951). In the following period, the trade of salt, iron, spices, ivory and slaves with Europeans deeply affected the economic and political relationships in West Africa (Person, 1985), but the trade routes were still controlled by the Niominkas (Cormier-Salem et al., 1999). The intense trade with Europeans may have contributed to reduce the need of shell fishing. For the last 300 years, the peopling of the Sine- Saloum would be likely better documented by the history of the modern villages, which has not been documented by archaeological methods so far.

5. Conclusions

The millennial history of the Sine-Saloum peopling, as revealed by radiocarbon dates frequency in archaeological shell middens, is closely related to the climatic, environmental and political evolution of West Africa since the middle Holocene. The geomorphology of the estuary was less favorable to human settlement and shellfishing in the mid-Holocene when sea level was higher and mangrove islands had not formed yet. However, traces of human occupation were still scarce between 3000 and 2000 BP, when beach ridges were formed and the Delta islands were close to their modern morphology. The population arrived massively around 2000 BP and reached a maximum shellfishing activity at about 1700 BP. This abrupt increase indicates the settlement of a migrating population in search of resources and land at the end of the aridification trend that followed the African humid period. The Sine-Saloum seems to have been a refuge for people fleeing the Saharan desertification and the subsequent warfare. This period corresponds to the beginning of trans-Saharan trade, and to a political complexification that would give rise to the Ghana empire. The incoming migration may have occurred in two waves as suggested by the double SPD peak at 200–400 CE and 600–800 CE and by cultural differences within the Delta. After that time, the Sine-Saloum peopling seemed primarily driven by political changes, conflicts and the subsequent migrations than by climate change. Most sites in the Sine-Saloum islands were abandoned in the 13th and 14th century, before the arrival of Europeans, likely in relation to the regional political destabilization that followed the fall of the Ghana empire and the beginning of the Mali empire. The Manding Guelwars, defeated in the Trandang battle in 1335 CE, moved and founded the modern towns of the Sine-Saloum in the 14th century. They had a reduced shellfishing activity compared to previous inhabitants, possibly because of a more prosperous agriculture in humid climatic conditions, and maintained their dynasty at the head of the Sine and Saloum kingdoms until the 20th century.

Author statement

Matthieu Carré conceptualized the study, Matthieu Carré, Moufok Azzoug, Abdoulaye Camara, and Rachid Cheddadi participated to field work, Louis Quichaud did the radiocarbon calibrations and the SPD, Diana Ochoa, Jorge Cardich helped with statistics, Matthieu Carré, Abdoulaye Camara, Moufok Azzoug, Alexander Pérez and Rodolfo Salas contributed to the bibliographical synthesis, Matthieu Carré, Julien Thébault, Yoann Thomas,

and Jorge Cardich contributed to funding acquisition. All authors commented on the methodology, read the manuscript and contributed to its preparation.

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.

Acknowledgements

This work was supported by CNRS-INSU through the program LEFE (Les Enveloppes Fluides et l'Environnement), and by the French National Research Agency within the framework of the IROCWA project (ANR-19-CE32-0003-01 grant). We thank the LMC14 staff (Laboratoire de Mesure du Carbone-14), ARTEMIS national facility, (LSCE (CNRS-CEA-UVSQ)-IRD-IRSN-MC) for the results obtained with the accelerator mass spectrometry method. The study received support from CONCYTEC (Peru) with grant n°034-2019-FONDECYT-BM.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2022.107688.

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