Review Article

Jean-Francois Berger*

Geoarchaeological and Paleo-Hydrological Overview of the Central-Western Mediterranean Early Neolithic Human–Environment Interactions

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Abstract: Climate change is still a subject of debate for archaeologist-neolithists. Its exact chronology, internal pattern, variations in space and time, and impacts on sites and ecosystems and on coastal dynamic and river systems have yet to be assessed. Only a strict comparative approach at high chronological resolution will allow us to make progress on the causality of the socio-environmental processes at work during Neolithisation. Post-depositional impacts on the Early Neolithic hidden reserve also remain underestimated, which has led to the perpetuation of terms such as “Macedonian desert” and “archaeological silence” in the literature on the Neolithic. Off-site geoarchaeological and paleoenvironmental approaches provide some answers to these questions and opens up new research perspectives.

Keywords: Mediterranean, Early Neolithic, bioclimatic mobility, post-depositional processes, fluvial dynamic

1 Introduction

The relationship between human societies and the environment was always present during processes such as Neolithisation, leading to mobility, exchanges/diffusions of goods and techniques, and phases of adaptation to new living conditions and to a new, riskier type of diet for the first farmers. Within this schema, the integration and reality of cultural and ideological resistances appear difficult to measure (they are sometimes identifiable in material culture, or in the economy, but are almost impossible to evaluate in their relation to nature). It creates different behaviours and functioning of socio-environmental systems according to the fronts of colonisation and the influence of ecological conditions (Aubán, Barton, Gordó, & Bergin, 2015; Berger, 2006; Bonsall, Macklin, Payton, & Boroneant, 2002; Dubouloz, Moussa, & Berger, in press; Gronenborn, 1999; Krauß, Marinova, De Brue, & Weninger, 2018; Price, Bentley, Luning, Gronenborn, & Wahl, 2001). Understanding the socio-environmental perspectives of Neolithisation in Europe is a complex collective and pluridisciplinary task requiring consideration of different time and space scales, which nevertheless faces existing gaps, not always sufficiently taken into account by the proposed archaeological models. Even if the Mediterranean basin is apparently considered as homogenous, its

* Corresponding author: Jean-Francois Berger, Environnement, Ville et Société-Institut de Recherche en Géographie, CNRS, UMR 5600 EVS-IRG, University of Lyon, Lyon Cedex, 69362, France, e-mail: jean-francois.berger@univ-lyon2.fr
biogeographical and climatic characteristics are quite diverse from east to west or from north to south and explain the varied living conditions and agro-pastoral potentials during the Early Neolithic (EN). Moreover, environmental conditions have varied greatly from the beginning of the Middle Holocene (MH) with the changes in the Earth’s insolation and its derivative effects (southward shift of the African monsoon, the aridification of the Mediterranean, the cooling of the middle latitude zones, ice-melting forcing steps, and associated profound changes of the coastal configuration). Controversial theories place this Early Holocene (EH) to MH transition at around the 6200 BCE (or 8.2 ka) event, with the phenomenon of the Mediterranean’s neolithisation (Brooks, 2006). This article provides an overview of several current socio-environmental challenges of the EN in the central-western Mediterranean basin by:

1. tracing the spatial dynamics of the climate in the western Mediterranean by emphasising the dynamics of watercourses and fire, which accelerate or slow down the Neolithic spread;
2. discussing the main rapid climate change (RCC) times and patterns from the different proxies’ timing and their possible impacts on the spread and development of the Neolithic;
3. presenting the post-glacial ice-melting forcing steps and the associated profound changes of the Mediterranean coasts for the seafaring Neolithic spread; and
4. discussing the hidden EN reserve and the post-depositional impacts of river and coastal systems (from north Aegean to southern France), which imply constraints for the archaeological models of socio-environmental interactions.

Finally, this article also proposes methodological and reflective directions for the coming years, highlighting certain key points for a better understanding of this period.

2 State of the Art and Major Issues

Despite the increasing number of paleoenvironmental studies performed over the past 30 years and a greater accuracy of proxy data thanks to the development of new analysis tools, it is still difficult to acquire homogenous latitudinal and longitudinal regional climate and environmental data at this macro-regional scale, which complicates socio-environmental and causality approaches (Finné, Woodbridge, Labuhn, & Roberts, 2019). Constant references to Global Climate records such as polar ice and marine archives are made in the literature, while continental and coastal archives are systematically criticised for their discontinuities and gaps, although the data come from sites as close as possible to the territories exploited by the Neolithics. Divergent information from different proxy records and chronological uncertainties are often major limitations to our understanding of abrupt climatic changes and their impact on the less-documented continental environments during the Neolithisation period. Our first focus will be on the large-scale rapid climate changes (RCCs, around 6200 and 5600–5100 BCE) from temperate to semi-arid tropical zones. These have to be included in any socio-environmental analysis, with reasoned discussion of their impact on Early Neolithic (EN) societies. We should in particular work to better document their variability in space and time and investigate their chronological patterns. Current data show opposing effects depending on latitude, and these effects on hydrosystems, ecosystems (versus vegetation, soils, and fire signal) and populations are still difficult to identify and remain a highly challenging task for the near future. Magny, Bégeot, Guiot, and Peyron (2003) first proposed a tripartite hydrological pattern for the 6200 BCE event, with opposing hydrological signals between the central and southern Mediterranean. We have confirmed and complemented this pattern (Berger & Guilaine, 2009; Fletcher, Goñi, Peyron, & Dormoy, 2010; Vannière et al., 2011). We also have to consider a climatic latitudinal frontier between the 40th and the 42nd north Parallels in the western Mediterranean, probably located more to the south in Near East areas. Recent Mediterranean quantitative climatic data also suggest an east-west opposition in Mediterranean climate history (a “see-saw effect”), as observed during the last millennium (Roberts et al., 2012), probably associated with east Atlantic-west Russian cycles (Benito, Macklin, Zielhofer, Jones, & Machado, 2015; Figure 1). EN societies were apparently dependent on RCC effects on the continental and littoral ecosystems and on progressive multi-secular regional climatic-environment trends that permanently changed their living conditions,
pointed questions on climate determinism and societal forms of adaptation (Berger & Guilaine, 2009; Berger et al., 2016; Botić, 2017; Budja, 2015; Flohr, Fleitmann, Matthews, Matthews, & Black, 2016; Glais, López-Sáez, Lespez, & Davidson, 2016; Krauß et al., 2018; Rohling, Marino, Grant, Mayewski, & Weninger, 2019; Sánchez et al., 2012; Weninger et al., 2014). What scale of observation or integration should we implement now? What new approaches should be used? What new archives or markers should be adopted to better identify these complex relationships? The constraints are above all chronological (the necessity to

Figure 1: Sea-Saw and EA/WR effects in Mediterranean. (a) Mean annual surface salinity in the Mediterranean Sea (after Soukissian et al., 2017), (b) wet/dry Mediterranean winter in 1838 after dendroclimatological data (after Luterbacher et al., 2006), and (c) east Atlantic/W.Russia atmospheric configuration (after Benito et al., 2015).
synchronise intra-site finds with paleoclimatic and environmental chronologies), but are also taphonomic (conservation of archaeological and natural archives) because large parts of the landscapes remain undocumented or without information. Thus, a large part of the Neolithic socio-environmental discourses and models still remain hypothetical.

Our second focus will be on the variation in the density of Neolithic occupation, which has been discussed from local to regional scales, and highlights the temporal variations of the Neolithic settlement (Borrell, Junno, & Barceló, 2015; Downey, Haas, & Shennan, 2016; Flohr et al., 2016; Shennan, 2013; Weninger et al., 2006). The recurrent and synchronous cultural gaps across southern Europe at the Meso-Neolithic boundary (Aubán, Puchol, Barton, McClure, & Jordó, 2016; Berger & Guilaine, 2009; Biagi & Spataro, 2002; González-Sampériz et al., 2009) generate much discussion about the demographic regime shift among human populations. This episode also called the “archaeological silence” could be associated with undated or inaccurately dated levels or sites (because excavated a long time ago, they were documented by an insufficient number of 14C dates, and/or they were biased by regional historiography or by taphonomy processes). In this imbroglio of situations and contexts, some EN sites appear much more dated than others and will therefore have greater weight in statistical analyses, such as summed radiocarbon probability density (SPD) or chronocultural approaches. However, prehistoric investigation is of course a process involving the addition of unsystematic efforts (Alday et al., 2018), and a very different image may be presented when associations are made with intense soil explorations from rescue archaeology. Among them, strong constraints on occupations in river, wetland, and delta/estuaries environments involve societal adaptations, and specific strategies are required to identify them. As large river deltas served as bridgeheads for further Neolithisation of the hinterland, they represented areas with a predilection for Neolithic diffusion, particularly through the Balkans and central Europe (Biagi, Shennan, & Spataro, 2005; Dubouloz et al., in press; Van Andel & Runnels, 1995). However, the deltas were not then established, and they began to develop after 5000 BCE when the rate of fluvial sediment input overtook the declining rate of sea-level rise (Anthony, Marriner, & Morhange, 2014; Brückner, Vött, Schriever, & Handl, 2005). EN sites were still probably positioned set back from the current coastline, along the paleo-estuaries, and are now typically under several metres of alluvium in the apexes of the deltas. The progradation of the deltas strongly modified the coastal morphology of the EN period, mainly in the paleo-estuaries axis, and buried or destroyed the first Neolithic sites, which are absent from most of the large Mediterranean deltas (Rhône, Pô, Ebro, Tiber, and Moulouya in the Western Mediterranean and all those of Northern Greece). This may explain why the archaeological maps of the EN show settlements only from the hinterland in many regions, sometimes more than 100 km away from estuaries (Macedonia, Ebro basin, Rhone, and Po deltas), thus greatly complicating the archaeological analyses and the coastal settlement restitutions.

Climate-environmental and hydro systems changes induce taphonomic biases disturbing our vision of the occupation of the Late Mesolithic-Early Neolithic transition (Alday et al., 2018; Berger, 2011; Berger & Guilaine, 2009), with some regions revealing inconsistent patterns or a documentation originating mainly from karstic environments. These historiographic and taphonomic aspects are too often neglected or minimised by the Neolithicists community and seem very difficult to correct because of a lack of technical, financial, or time support, as we shall demonstrate later.

3 Tracing the Spatial Dynamics of the Climate in the Western Mediterranean and the Neolithisation Process

The Holocene climate is divided into two main periods with different drivers: the external solar and orbital forcings predominate during the EH, and although the total energetic contribution is small, in the context of deglacial climatic instability, solar variability may be amplified by meltwater from sea ice sheets and oceanic circulation processes. The mid-to-late Holocene is more dependent on internal oceanic forcing (combined with solar cycles) with an amplification via North Atlantic Oscillation-like atmospheric circulation patterns (Bond et al., 2001; Debret et al., 2007; Fletcher, Debret, & Goñi, 2013). The sixth millennium BCE, which corresponds mainly with the western, southern, and central European neolithisation, is a
particular climatic period of transition from one state to another. It is also disturbed by a combination of forcings including the highest rate of change in annual insolation (Zhao et al., 2010), a prolonged period of decrease in the residual atmospheric $^{14}$C (Stuiver & Braziunas, 1993), and a very large Bond Event in the North Atlantic area (Bond et al., 2001). This climate event is particularly interesting because it occurs during the Holocene climate optimum, and it is synchronous with the end of the post-glacial marine transgressive maximum (at the end of the main polar ice sheet melting), with many impacts on coastal settlement systems that we can hardly measure today.

Two main approaches for the reconstruction of paleo-environments and paleoclimates predominate: (1) classical quantitative proxy data on the scale of the site, which depend on the quality of the archiving (including speleothems, marine and lake sequences, and pollen modern analogous methods) and (2) statistical methods using radiocarbon dates summed from various archives (SPD). Paleoclimatic records are evenly distributed in the northern borderlands of the Mediterranean region (with the exception of the Balkans), whereas the southern and eastern borderlands of the Mediterranean basin remain very poorly documented and often present chronologies that are too coarse (Berger & Guilaine, 2009; Finné et al., 2019) to provide a better understanding of regional patterns and trends, in comparison with local climate variability and biomes mobility. This skewed spatial distribution complicates temporal and spatial comparisons among archaeological, landscape, and paleoclimatic data.

### 3.1 Latitudinal Comparison of River and Pedogenic Activity in Western Europe and Mediterranean

In respect to approach 2, the reconstruction of environmental changes by SPD and the sedimentary classification of river systems (activity and stability phases) was initiated by Macklin (1999) using British rivers. Since that time many river syntheses have since been carried out in central to western Europe (Hoffmann, Erkens, Gerlach, Klostermann, & Lang, 2009; Starkel, Soja, & Michczyńska, 2006) and in the Mediterranean basin, integrating the Maghreb, southern Italy, NW Greece, and the Near East, by proposing patterns of evolution on a multi-secular scale (Benito et al., 2015; Berger et al., 2016; Rossato, Fontana, & Mozzi, 2015; Zielhofer & Faust, 2008).

When we compare the activity–stability curves of Western Europe and the Near East and NW Africa along a latitudinal transect from $52^\circ$ to $35^\circ$ N. (Figure 2), integrating more robust data (southern England, Rhine, Rhône, and Medjerda rivers) with less robust data sometimes associated with gaps (eastern Mediterranean, southern Italy, Corfu island, Morocco), we observe discrepancies from one curve to another, mainly due to the heterogeneity of some paleohydrological radiocarbon databases (biases are difficult to correct), and the effect of climate tripartite subdivisions of Eurasia and the «see-saw» effect, which resulted in spatio-temporal variations in the North Atlantic atmospheric system. The Holocene fluctuations observed in fluvial archives (around 6200 and 7300 BCE) correspond to RCC planetary climate events. They systematically appear in the fluvial archives of the NW Mediterranean basin (contrasting with the Rhone river), and in the rivers of southern England and Germany (Figure 2), and all except the 6200 BCE event are recorded in the Atlantic Iberian river basins. Tunisian, Moroccan, and southern Spanish fluvial archives do not exhibit a fluvial response at this time, probably because it has not yet been identified or at least not in the same way (Depreux et al., 2021). In the two Spanish basins (Guadalete and Jarama rivers) intensively studied by Wolf and Faust (2016), EH-MH pedosedimentary archives are weak, and a general lack of absolute chronology is observed, which is particularly damaging for the discussions concerning the Neolithic period. The SPD for the entire $^{14}$C data confirms a lack of absolute chronology in the Jarama river basin from 5400 to 3300 BCE and in the Medjerda river basin (Tunisia) between 9800 and 4700 BCE, where there is a very slow and fine aggradation trend (Zielhofer & Faust, 2008). In the slightly better documented Moulouya basin, recent geoaarchaeological studies by Depreux et al. (2021) complement Zielhofer’s data and document a chronological hiatus between 6600 and 5400 BCE despite extensive and systematic surveys. We can question whether this situation results from the absence of $^{14}$C material or from the destruction of the sedimentary and archaeological archives synchronous with the EN, probably because of a deep and long entrenchment of the river systems. The question of water supply for the first Neolithic communities in this southern part of the Mediterranean basin must also be considered, when all the rivers cut deeply,
simultaneously, and durably into their beds. The ecological changes, and thus the resources available, observed are also very important and undoubtedly require adaptations (Depreux et al., 2021). Further detailed fluvial geomorphology work is required to confirm this trend.

### 3.2 Timing of Mid-Holocene Climate Events and Neolithisation in the Sixth Millennium BCE

It is possible to observe the effect of a latitudinal reversal in bio-hydroclimatic functioning on both sides of the 40/41° N parallel during the sixth millennium BCE. Between 5700 and 5500 BCE, a synchronous active
hydrological signal can be observed in the western Mediterranean and Atlantic Europe (Figure 2, Berger et al., 2016). The opposition between the western and eastern parts of the Mediterranean should be considered as a see-saw effect although the river data from southern Italy and the Near East lack the accuracy to confirm this hypothesis (Benito et al., 2015).

The chronology of this plurisecular RCC is still developing, with references to this phase including the “5800–5300 BCE arid event” (Sánchez et al., 2012), the “5100 BCE event” (Aubán et al., 2015), the “Cerin event” from 5550 to 5250 BCE (Magny, 2004), the “5400 BCE event” (Fletcher & Goñi, 2008), the “5600–5300 BCE event” (Berger et al., 2016), the “SPL6–7 event” (5600–5100 BCE) (Haas, Richoz, Tinner, & Wick, 1998), the “ice-rafted debris-5b event” (Bond et al., 2001), and the “Vistula flood event” (5600–5100 BCE) (Kalicki, 1991; Starkel, 1995). These temporally variable events probably correspond to the same climato-environmental event, but in different contexts and with different markers and archives (terrestrial/marine). The recent southern Mediterranean overview of Sánchez et al. (2012) confirms a large impact from an arid phase in tropical areas from 5800 to 5200 BCE (Figure 3(1), orange areas), in phase with the chronology of the river systems. We have actualised their initial synthesis from North Africa to southern France, the western Alps, Italy, and western Balkans, and we could trace the classical reversal in the climatic line from the Hispanic peninsula to northern Greece, around the 40th/41st north parallel, which confirms the river records, and the opposite functioning climate on both sides of the western Mediterranean during the millennium of the Neolithisation. In the western Alps area and northern Italy, a synthesis of robust climatic-environmental data from the Austrian to French Alps and Apennine mountains of northern Italy integrates the speleothem, lakes, upper timberline, and glaciers variations, and documents a regional millennial wetter and colder trend period from 8200 to 5200 BCE, with two maxima during the periods 6200–5600 and 5450–5250 BCE (Figure 3(2)).

The association with proxy data suggests a combined external/internal forcing over several centuries, which could have a strong impact on the first farmers in central to western Mediterranean. For example, the period 5600–5500 BCE represents an important date in the European Neolithic that corresponds with the EN-MN transition (Starcevo-Körös-Cris-Linear Band Keramic/Vinca cultures in Central Europe, and Impressa/Cardial in western Mediterranean), but very few socio-environmental discussions have been initiated on this subject (Berger, 2006; Berger et al., 2016; Dubouloz et al., in press; Gronenborn, 2010). This period also corresponds to a significant acceleration in the rate of spread of the Cardial Neolithic in western Mediterranean (from Italy to Morocco/Portugal) (Zilhão, 2014), the causes of which are still under discussion (Aubán et al., 2016).

### 3.3 Tracing the Spatial Dynamics of Fire Activity in the Western Mediterranean

Due to different orbital parameters of the Earth, the Northern Hemisphere received more solar energy in summer and less in winter at the beginning of the Neolithic period. The seasonal cycle was thus amplified, leading to hotter and drier summers and more severe winters (except in the monsoon-affected areas in the southern Mediterranean). This strong seasonal contrast favoured the natural fire regime, and fires opened up large areas of forests, which was conducive to the opportunistic extension of agricultural and pastoral lands in the EN (Berger & Guillaume, 2009). This spatial schema at the western Mediterranean scale also appears in the fire regime, as described in the synthesis in the study by Vannière et al. (2011). At continental-to-regional scales, coherent patterns of fire activity are evident throughout the Holocene period, and they have been explained in terms of large-scale climatic controls. A comparison (Figure 4) of the fire activity in two latitudinal compartments of the western Mediterranean from 40° to 45° N (orange square) and from 35° to 40° N (red square) provides an opportunity to compare their temporal evolution in parallel. The curves of the fire regimes show an opposite trend between 6000 and 3500 BCE, with low fire activity in the south and high fire activity in the North. This represents the contrast between the maximum of humidity in the southern Mediterranean and North Africa during the African Humid Period, with a low fire regime maintained, and a dryer period in northern Mediterranean areas that was favourable to a high fire regime in
Figure 3: (1) Map with the different paleoenvironmental records documenting paleohydrological and paleoenvironmental variations in the western Mediterranean basin and North Africa. Light blue/orange areas show wet/dry conditions, respectively, obtained in each paleorecord at this time interval (5850–5200 BCE; modified after Sánchez et al., 2012). (2) Synthesis of robust climatic-environmental data from the Austrian to French Alps and Apennine mountains between 8000 and 5000 BCE, (a) Glacial transgression in Alps mountains (Holzhauser, Magny, & Zumbühl, 2005), (b) Central Alpine subfossil trees at the treeline (Nicolussi et al., 2009), (c) phases 11 and 12 of Lake transgressions in north Alps and Jura (Magny, 2004), and (d) Monte Corchia cave speleothem-CC26 illustrating a long discontinued wet period by a $d^{18}O$ decrease (Zanchetta et al., 2007). The vertical blue bands illustrate the coolest and wettest periods in the area of the western Alpine arc.
densely forested areas. When the trend reverses from 3000 BCE, in connection with a rapid shift of the African monsoon system and an increasing aridity in the southern part of the Mediterranean basin (green curve), which is associated with high Saharan dust inputs (Bout-Roumazeille et al., 2013; De Menocal et al., 2000), the fire regime becomes higher in the south and lower in the north, with the north becoming more humid. In the western Mediterranean, the fire signal then shows an inverse dynamic on both sides of the 40° north parallel, as demonstrated by other proxy data. The opening up of the forest by a high fire regime, under climatic control, appears to be a major opportunity for the first farmers from NE Europe to the NW Mediterranean to expand their agricultural and grazing areas with less effort, during a period favourable to the forest closure (Berger & Guilaine, 2009; Davis & Stevenson, 2007). Robust studies of the fire signal in North Africa (37°–32° N), which are required to complete this latitudinal scheme in the western Mediterranean, are still lacking.

3.4 RCC Times and Patterns

The duration of the 8.2 event has been discussed in several papers. Its onset very often appears earlier in continental or marine series, around 6400 BCE, depending on the sites studied and continues more than a century after the end of the glacial outburst, i.e., up to 6000 BCE. Rohling and Pälike (2005) evaluated anomalies that lasted for 400 years or more in a compilation of proxy records. They insist on the need to be very careful about attributing any anomaly around 6000 BCE to the 6200 event itself, with there being a repeating pattern of long-term anomalies during the Holocene, amplified by the effects of a glacial outburst. The sharp signals triggered by the meltwater outburst were restricted to a much smaller North Atlantic realm, which is perfectly measured (170 years) by several glacial series compiled by Thomas et al. (2007) (Figure 5(a)). The timescale of the selected proxy records we discuss varies from 300 to 450 years (Figure 5(b–f)). Weninger et al. (2014) recently suggested that the cumulative impact of two events should be

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Figure 4: Fire signal evolution in western Mediterranean region from 6500 to 1000 BCE: a reversal dynamic on both sides of the 40° North is observed during the Neolithic period. (a) Location of the studied windows, the orange rectangle surrounds the fire data of the NW Mediterranean region (N 40–45°), the red rectangle surrounds the fire data of the SW Mediterranean region (N 40–37°), the black dashed line represents a region with a very strong under-representation in proxy data (Maghreb). (b) Evolution curve of the fire signal on the northern (orange) and southern (red) coast of the Mediterranean. The green curve represents the peak of the ‘African humid period’ followed by a strong aridification in North Africa (modified from Vannière et al., 2011). The orange and red curves show an almost opposite trajectory, the dynamic of the fires is maximum in the north of the Mediterranean between 5800 and 3000 BCE, while it is minimum in the south in connection with the humidity of the African humid period.
considered: an aridification that started around 6600/6500 BCE, which is recorded in a large number of marine and continental proxy datasets, and a glacial outburst from 6250 BCE. The expansion of the RCC would therefore be the result of a double forcing: the first being associated with a reduced solar output, as suggested by cosmogenic $^{14}$C and $^{10}$Be records (Daley et al., 2011; Steinhilber et al., 2012), and the second more-pronounced forcing, coming from an abrupt cooling seen over the North Atlantic region with a glacial outburst. A slowdown in North Atlantic Deep Water production associated with the large inertial process of the ocean could explain the prolongation of the 6200 event effects, which appears to exert effects until 6000–5950 BCE.

However, one aspect that has been mentioned by Swiss palynologists (Tinner & Lotter, 2001) remains to be explored in greater depth: the subdividing of the 8.2 ka (alias 6200 BCE) event into three probable sub-phases. Thomas et al. (2007) show a tripartition over the 170 years, with maximum cold in the central part around 6200 BCE. The paleoenvironmental records of three proxy datasets of the Aegean-Balkan world illustrate this same tripartite pattern (Figure 5(b–d)): Lake Maliq in the Albanian mountains, the Sidari

Figure 5: (a) Oxygene isotops ratios for GRIP, GISP2, NGRIP, and DYE 3 cores with 20 years running average, illustrating the drop in temperature in the high latitudes of the northern hemisphere around Greenland over 170 years (Thomas et al., 2007). (b) Pollen-based temperature of the coldest month in Lake Maliq (Albania), from a transfer function of pollen assemblages using the modern analogue technique (Bordon, Peyron, Lézine, Brewer, & Fouache, 2009). (c) Results of SPD analysis of Sidari 1–2 sequences (Corfu Island, Greece) identifying two marked phases of erosion (black curve), separated by a short phase of pedogenesis (brown curve), during a four century phase associated with the 8.2 ka event (Berger et al., 2016). (d) SL21 E-Tripartite oscillation of the Aegean Sea Surface temperatures, close to the island of Crete by variations of the percentage of warm foraminifera species (Rohling et al., 2002). (e) Tripartite variations in temperature restituted by the isotopic records of an Irish speleothem in Crag cave (Ireland) ($^{18}$VPDP) (McDermott, Matthey, & Hawkesworth, 2001). (f) Tripartite variations of the Asian monsoon activity restituted by the isotopic records of Dongge cave, China (Dykoski et al., 2005). A common tripartite pattern (phases 1–3) emerges from this confrontation of several palaeoenvironmental archives, distributed between the tropical and polar zones, which testifies to the same tempo on a hemispheric scale.
small valleys dynamic in Corfu (Greece), and marine core temperatures in SL21 in the southern Aegean Sea. The speleothem data from Crag (Ireland) and Dongge caves (China) confirm this pattern within a shorter 8.2 event (three centuries; Figure 5e and f). These data show each time to be associated with an improvement in environmental conditions lasting about a century in the middle part of the RCC (milder temperatures, more active monsoon or soil stability). This moderation of the 8.2 event centred on 6200–6150 BCE should undoubtedly be considered in the perspective of the Balkan’s Neolithisation (northwards advance through the valleys) and the diffusion of the Impressa from Greece towards the Adriatic zone (Berger et al., 2016; Biagi et al., 2005; Forenbaher & Miracle, 2005). It is therefore now necessary to (1) refine the chronology of the future proxies studied to confirm this hypothesis and (2) to better measure the effects of this climatic tripartition on the functioning of coastal and continental ecosystems from a socio-environmental (causality analysis) and historical (timing of Neolithisation) perspectives.

3.5 The Stages of Post-Glacial Meltwater Forcing and the Profound Changes of the Mediterranean Coasts

Many studies of deltas/estuary paleogeographic evolutions exist across the Mediterranean basin, particularly in the eastern (Greece, Turkey) and western (Spain, France, Italy) Mediterranean. Geomorphological and eustatic control factors (sometimes with tectonic) profoundly changed the coastal configuration due to the global sea-level rise flooding. The Neolithisation period corresponds to the complete melting of former ice sheets that occurred around 6000–5500 BCE (Roy & Peltier, 2018) and to the last ice-melting forcing at the north-atlantic/Mediterranean scale, which resulted in the first postglacial transgressive maximum around 5300 BCE, recorded in the whole western Mediterranean. Coastal plains and deltaic formation then have usually developed through the combined effects of the slowing of post-glacial sea-level rise over the last six millennia (Amorosi, Dinelli, Rossi, Vaiani, & Sacchetto, 2008; Vacchi et al., 2016) and the increase of sediment input caused by both natural and anthropogenic factors (Anthony et al., 2014; Arnaud-Fassetta & Suc, 2015; Figure 7j). Human occupation of the coastal plain, from the late prehistoric times, was most likely constrained by the rapid and constant evolution of this coastal landscape, which can be documented only by systematic and precise core sampling studies, structured in upstream–downstream transects. Introduction of farming dispersal episodes by seafaring pioneering groups is partly constrained by limited knowledge of coastal EN occupation and a lack of precise local paleogeographic reconstructions of Neolithic coastal and human systems in central to western Mediterranean (Arnaud-Fassetta & Suc, 2015; Brisset, Burjachs, Navarro, & de Pablo, 2018; Devillers et al., 2019; Ghilardi, 2021; Melis et al., 2018; Vella et al., 2005).

In the NW Mediterranean, studies have recently increased in the number and quality, and the publication of numerous local to micro-regional studies (for the large deltas) now makes it possible to better understand the transition period between the end of the retrogradation phase and the beginning of deltaic progradation. Thus, we can cite: the mouth of the Arno, Po, and Tiber rivers in Italy (Amorosi et al., 2008, 2017; Fontana et al., 2017; Rossi, Amorosi, Sarti, & Potenza, 2011), Posada river (Sardinia) (Melis et al., 2018), Rhone River (Arnaud-Fassetta & Suc, 2015; Vella et al., 2005), Herault and Argens rivers (Devillers, Excoffon, Morhange, Bonnet, & Bertoncello, 2007; Devillers et al., 2019), Eastern Provence and French Riviera rivers (Dubar, 2003; Sivan, Dubar, & Court-Picon, 2010), Corsica rivers (Ghilardi, 2021) in France, and Llobregat river (Daura et al., 2016) and Pego-Oliva basin (Brisset et al., 2018) in Spain. During the transgressive period (until 4500 BCE), the retrogradational coastal system, led by the rapid sea-level rise, could produce a wave-dominated delta morphology, which migrate more or less deeply into the estuaries according to their initial morphology. But very few studies are based on numerous cores and present a sufficient absolute/exact chronology and bio-sedimentological studies to precisely reconstruct the coastal paleogeography of the sixth millennium BCE, which interests us here. From 6200 to 5300 BCE, the backward shoreline migration reached a maximal inland position leading to the disappearance of the former
inner lagoon (Figure 7c, d, g, and i). This timing is very similar in numerous recent western Mediterranean records. The maximal inland marine position transgression has been dated to around 5500–4900 BCE.
(Viñals & Fumanal, 1995) in the Pego vicinity (Xàbia, Spain), 5500–5200 BCE in the Valencian gulf (Spain) (Carmona & Ruiz, 2011), around 5500 BCE in the Posada coastal valley in Sardinia (Melis et al., 2018) (Figure 7c),

(caption on next page)
and around 5000 BCE in a series of deep estuarine sequences from St-Maximin to Nice (French riviera) (Dubar, 2003). This evolution has been also constrained from 5700 to 5000 BCE in the vast Po deltaic system (Amorosi et al., 2017, Figure 7f and g) and from 5800 to 5000 BCE in Tuscan deltas (Amorosi, Rossi, Sarti, & Mattei, 2013). Approximately during the period 5700–3600 BCE, the high-level prism of the Rhone delta developed, generally prograding towards the Mediterranean (Arnaud-Fassett & Suc 2015). Approximately in the sixth and fifth millennium BCE, the deltaic plain (598 km²) only occupied a third of its current surface (Figure 7h).

A qualitative shift has been established in two recent coastal studies, which proposed a grid pattern of numerous cores and a robust age-depth model to elucidate a detailed and more complex image of the morphology and dynamics of past coastlines and lagoons during the last 8,000 years. They allow us to better perceive the changes in the paleo-landscape and ecosystems and thus to examine the constraints exerted on the last hunter-gatherers and the first farmers. Firstly, a first local progradation is observed in the deep Herault embayment, with two deltaic lobes around 6000 and 5500/5000 BCE, during the last period of sea flooding (Figure 7d, Devillers et al., 2019). This first alluvial progradation gradually filled the estuary with advances of the mouths, several shallow lagoons, and sandbars. The early growth of the fertile alluvial plain inside the Herault estuary was coeval with the development of local Neolithic agriculture by the early Impressa farmers, located in a surrounding plateau (Guilaine, 2017). Secondly, in the Pego-Oliva basin (Valencia, Spain), the alternation of pulse and pause of the relative sea level during the retrogradation phase modifies the coastal ecosystem’s productivity and location strategies (Brisset et al., 2018). Five transgressive phases have been recorded at Pego-Oliva in 7550 (no. 1), 7150–7050 (no. 2), 6800–6700 (no. 3), 6500–6250 (no. 4), and 6150–5350 BCE (no. 5). Phases 4 and 5 may be strongly correlated with the meltwater pulses identified in the North Atlantic (Nesje, Dahl, & Bakke, 2004), confirming their connection with global EH climatic changes. Amorosi et al. (2008) also mention alternation of pulse and pause for the Po river and in other deltas of the northern Adriatic coast (albeit with less precision). Brisset et al. showed that the acceleration of marine transgression caused the disappearance of the lagoon in 6200 BCE and reached a maximum inland position by 5300 BCE. Sea-level rise was translated into the loss of human settlement areas, reduction of hunting territories and shellfish productivity, and modification of coastal
ecosystems during the last rapid stage of the marine flooding (6100–5300 BCE). A vertical rate of sea-level rise of 1 cm/year has been estimated, corresponding to a horizontal shoreline displacement rate of 360 m per century, rapid enough to be perceived by human communities. This local environmental mutation, consecutive to the global sea-level rise, probably extended and repeated in the Mediterranean region and therefore needs to be spatially confirmed. For the same authors, it negatively impacted the Late Mesolithic subsistence and settlement patterns, probably driving to a significantly lower occupational intensity (even depopulation) of this coastal area, coinciding with spatial re-organization of the settlement networks, which would still need to be confirmed from a taphonomic point of view. It is certain that the high reduction of lagoon spaces during marine pulse episodes strongly reduces coastal biodiversity and probably limits local densification of the settlement (Figure 7), but the intertidal and supra-littoral marine environment still offers exploitable alternative food resources, which does not exclude the occupation of the coastline during the acceleration phases of flooding.

4 The Hidden Early Neolithic Reserve and Post-Depositional Impacts in River and Coastal Systems

Another fundamental aspect of the EN socio-environmental approach is the validation of settlement patterns on which diffusion and interaction models are based. We need to measure and know the effects of the post-depositional processes that are responsible for the state of the archaeological archives we use (which we call a taphonomic approach), in the different sedimentary environments (coasts, deltas, inland fans, floodplains, etc.), whose main impacts and processes have been presented earlier in this article. We previously proposed a first overview of the major taphonomic stresses with erosion and/or sediment masking the archaeological layers, leading to a lack of knowledge about the EN phase (Berger, 2011; Berger & Guilaine, 2009). This needs to be chronologically and spatially extended as it now becomes an essential element for evaluating the validity of the working hypotheses for an objective view of Neolithisation. However, only a few Mediterranean regions have recently benefited from systematic geoarchaeological studies or in-depth soil explorations resulting from rescue archaeology. Some areas remain mainly documented by caves-rockshelters settlements (Slovenia karst, main parts of Ebro, parts of Aude or Ardèche/ Cêze basins, etc.). Post-depositional impacts are sometimes clear and easy to read on a local scale on a stratigraphic section, being evidenced by truncations of the deposit, slump, and mixture of archaeological deposits, and erosion of part of earlier deposits by torrential flows (Berger & Guilaine, 2009; Berger et al., 2016; Mlekuž, Budja, Payton, & Bonsall, 2008; Schudlenrein, 2001; Zielhofer et al., 2012). They can also be detected by radiocarbon dating of stratified series when the lithology is apparently continuous, or when it presents depositional palimpsests, and then reveals temporal discontinuities, which are taphonomic evidence for mixing or chronological hiatuses (Aubán, Barton, & Ripoll, 2001; Biagi & Spataro, 2002; Bonsall et al., 2002; González-Sampériz et al., 2009). At a higher spatial scale (that of the landscape units), they can be totally invisible and yet be repetitive (absence by destruction, burying, or non-occupation), and then only a rigorous geoarchaeological examination of the landscape morphologies and of all the recent pedosedimentary formations allows us to discuss the origin of this recording gap (Ammerman et al., 2008; Berger, 2011), caused by the profound transformations that have taken place in the earth’s surface formations over the past 8 millennia.

Rescue archaeology continue to make new discoveries about the Neolithic in the areas where they are deeply buried, and because of technical and economical limits, we are still not yet able to explore the vast hidden reserves of the great Mediterranean estuaries and deltas other than by geological coring. It should also be kept in mind that often these deep archaeological archives are not prescribed by the culture and heritage services and are therefore not excavated (they are considered as too deep and therefore protected from future constructions or are technically too costly to undertake). A quick overview focusing on the northern Mediterranean contexts is really informative.
These Neolithic diffusion corridors along “waterways” with rich and thick alluvial soils represent the best documented hypothesis in the academic literature (Biagi et al., 2005; Davison, Dolukhanov, Sarson, & Shukurov, 2006; Rowley-Conwy & Owen, 2011), in particular along the Danube-Rhine river axis (Bocquet-Appel, Naji, Vander Linden, & Kozlowski, 2012; Sherratt, 2004). In this model of demic diffusion, the pioneer farmers preferred to occupy the floodplains of rivers and lakes in south-eastern Europe, where the populations eventually reached “saturation” point, causing divisions and diffusion of Neolithic groups to the next alluvial plain towards central Europe (Dubouloz et al., in press; Sherratt, 2004; Van Andel & Runnels, 1995). However, this theoretical model is difficult to compare with the field reality in the southern Balkans/northern Aegean regions, since the major river ways that would have favoured the movement of the first pioneers towards the interior are empty of sites from the EN period (especially in their downstream parts). In fluvial environments, very thick Neolithic tells or sites located on old river levees have a chance of being detected during pedestrian or aerial surveys (Van Andel & Runnels, 1995; Ghilardi et al., 2012).

4.1 The Dynamics of North-Central Mediterranean Coastal and Lower River Plains in EN

We will focus first on the northern part of the Aegean where there are still many questions about the first Neolithic settlements. The EH is often lacking because few core drillings exceed 10 m in depth (Brückner et al., 2005; Glais, Lespez, Vannière, & Lopez-Saez, 2017; Vött, Brückner, Handl, & Schriever, 2006), which means that the reference horizons are not reached because of the depth of the paleovalleys in the axis of the estuaries. The vast estuaries and deltas of the Macedonian coast and western Thrace are very important for understanding the first wave of the Neolithic in Europe (Figure 6a and b). Several authors have discussed the importance of these North Aegean hydrographic axes of Neolithic penetration towards the interior (Ammerman et al., 2008; Gatsov & Nedelcheva, 2009; Lichardus-Itten, Demoule, Pernicheva, Grebska-Kulova, & Kovačev, 2006; Nikolov, 1990; Pavuk & Cochadziev, 1984; Todorova & Bancov, 1993), but no consensus has been reached to explain the lack of information on the EN. Here, we come up against the strong taphonomic constraint that still annihilates the detection of EN sites in deltaic and alluvial plain contexts despite numerous attempts to locate them (Berger, 2017; Lespez et al., 2013). This is the origin of a recurrent archaeological gap in north Greece, in what we call the “Macedonian Desert,” with the exception of Nea Nikomedia and more recently Dikili Tash. For the Maritsa river, regional researchers consider two possibilities, either that this axis was used but there is no archaeological evidence to verify this or that the middle and downstream parts of this valley were never occupied by the EN (Nikolov, 2007). In reality, only the upstream basin of the river (on the eastern slope of the Pirin mountains) bears witness to an EN presence (Dobriniste, Elesnica, Belica, Bacevo). This absence could be explained by the combination of an upwelling of the river aquifers and a greater frequency of floods and thick alluvial deposits in the axis of the alluvial plain, which would hide the reality of the Neolithic occupation in the middle and lower basins (Boyadzhiev, 2009; Chohadzhiev, 2007). The same hypotheses are put forward to explain the total absence of sites in the lower Strymon/Struma valley, where an important series of EN sites is distributed within the middle and upper basins (between Kovacevo and Siskovci), but sites are totally absent from the lower basin (Figure 6a). However, in this last area, deep geo-archaeological explorations have reconstructed a vast fluvio-lacustrine system whose filling thickness is greater than 20 m (Glais et al., 2017), and in which only the formations attributable to the recent Neolithic have been recognised at depths between 8/10 m (Figure 6e).

Geo-archaeological exploration of the vast Axios/Vardar-Aliakmon delta (Macedonia) by Ghilardi et al. (2012) has made it possible to reconstruct the paleogeography of the Nea Nikomedia tell close to a large embayment, but on the periphery of the river axes. It has allowed delimiting of a vast and unexplored Neolithic reserve, set back from a large bay that is now filled in by deltaic progradation (Figure 6b and c). Systematic core sampling by Ammerman et al. (2008) on and around the tells of the MN (Figure 6a)
demonstrated a real EN potential in Makri and from the second half of the EN (6000 BCE) in Krovili. In Korinos, an EN archaeological horizon was recognized at a depth of more than 8 m (Besios et al., 2001). Ammerman et al. (2008) are adamant about the destructive effects of 8000 years of marine transgression on pre-Versilian coastal archives (as in Lafroudoua), while Lespez et al. (2013) demonstrate the near impossibility of working on this period without the use of deep coring campaigns. The deep geoarchaeological explorations carried out by Lespez et al. (2013) around the Dikili Tash tell revealed an EN archaeological level, contemporary with those known in western Thessaly and Macedonia (around 6500–6200 BCE) at a depth of nearly 10 m (Figure 6d). The analysis of the location of EN sites occurs at very small scales (western Turkey, Aegean, southern Balkans) in relation to the current soil map (Rosenstock, 2002) and is quite revealing of approaches classically focused on current landscapes and on documentation not discussed in a taphonomical perspective and therefore only represents “the surface of the iceberg” (Berger, 2011; Van Andel & Runnels, 1995). These results are based on a database, which naturally favours the large tells because of their very high visibility, without taking into account flat sites that are clearly disadvantaged and statistically under-represented. The regional spatial analysis of Rosenstock (2002) shows the preference of visible EN sites for Mediterranean red soils. Its cartography (Figure 6f) illustrates source effects that unbalances the regional geostatistical analysis, firstly by an over-representation of Greek sites (from Peloponnese to Macedonia), especially in Thessaly (Gallis, 1989), secondly by over-representation of tells compared with flat sites (especially in the Balkans) because of their high visibility, and thirdly because of the almost general absence of tells and flat sites in Holocene floodplains that appear to be largely under-mapped in the regional cartography (Lespez et al., 2013). In the most-prospected areas such as Thessaly, the variety of soils exploited is, however, wider (Demoule & Perles, 1993; Gallis, 1989). The results observed in the four main river corridors from the Aegean coast (Evros/Maritsa, Nestos/Mesta, Strymon/Struma, Axios/Vardar) towards the south of the Danube basin are still very explicit, as they illustrate once again the absence of EN sites in the thick alluvial deposits of the Holocene floodplains up to several tens of kilometres inland. The known sites are always located on high points at the margins of valleys (Ghilardi et al., 2012; Figure 6c).

### 4.2 North-Western Mediterranean Coastal Dynamics in EN

The same situation, with similar geomorphological contexts, can be observed in the north-western Mediterranean, and the connection among coasts, deltas, and hinterlands still remains problematic in most areas. The tremendous coastal sedimentary volumes, corresponding to the last phases of the retrogradation and the beginning of the deltaic progradation, have rarely resulted in positive archaeological findings. It is undoubtedly a whole part of the coastal settlement systems that still eludes us during a period marked by a sharp regional decline in population density (Berger & Guilaine, 2009; Biagi & Spataro, 2002). Ammerman et al. (2008) have demonstrated the positive effect of multiplication of coring campaigns in northern Greece. Very few EN sites were identified in Mediterranean submerged like the PPNB site off the Carmel shore (Israel) (Galili & Weinstein-Evron, 1985) or in Leucate-Corregre (Languedoc coast), the submerged EN Cardial site discovered during dredging operations of a lagoon (Guilaine, Freises, & Montjardin, 1984). In the French Riviera, under the modern-day city of Nice, intensively documented by rescue archaeology, Sivan et al. (2010) were even been able to identify on two occasions remains of the MN under 15 to 18 m of alluvium during the very first stages of the deltaic progradation phase in the apex part of two small deltaic plains: under the SNCF station and under Garibaldi Square (Figure 7a and b). Archaeological programmes rarely offer the opportunity for extensive coastal coring (as the costs are substantial). Rescue archaeology presents itself as a more useful tool to detect the Neolithic presence in these coastal sedimentary environments, constantly prized by regional planning policies. The intensification of geoarchaeological studies should be carried out opportunistically at this time to increase our knowledge.

The markers of occupations not recognised locally by archaeology can also appear indirectly (by pollen indicators for example) and can thus bridge certain regional occupation gaps. In the Loup and Cagnes rias fillings, the horizon corresponding to the first step of Neolithization (Impressa-Cardial complex) is situated...
between 20 and 12 m in depth, which makes its study particularly difficult other than by a series of cores. Traces of agro-pastoral exploitation of these deep coastal valley floors (with cereal pollen) were thus identified by palynology from 6000 BCE in two different watersheds (Guillon, Berger, Richard, Bouby, & Binder, 2009), i.e., two centuries before the first regional archaeological evidence of EN Impressa (Binder et al., 2018). In Piantarella (S Corsica), the first signs of agriculture are evidenced ca. 5450 BCE with the development of pastoralism (identification of NPPs) with deforestation, quickly followed by cereal cultivation. The paleoenvironmental results clearly prove human occupation in an area where EN archaeological information is lacking (Ghilardi, 2021). Further south, in the Posada River coastal plain (Sardinia), pollens of cereal cultivation are clearly identified around 5500 BCE, with no associated nearby Cardial site (Melis et al., 2018). Coastal geoarchaeology and paleobotany in the case of Sardinia–Corsica and the French Riviera help to better define land use practices related to the first stages of the EN period. They represent an additional contribution in areas with archaeological information deficits.

4.3 The Fallacies of the EN Continental Locations from the Landscape to Micro-Regional Scales

At regional scales, recent quantitative studies carried out in SE France have identified the majority of EN sites in caves and rock shelters, with a scarcity of open-air sites, which is even more explicit when applied to surface sites (Berger et al., 2019). We will discuss this artificiality of the databases in the well-documented context of the MRV. The same observation is made in the lower Ebro basin (Alday et al., 2018) where a ratio of 1 open-air site for 4.5 cave and rock shelter sites is identified. No EN sites are identified in the delta and lower Ebro alluvial valley, even in areas with very wide floodplains (Figure 7d). In the Friuli Plain (NE Italy), another bias linked to taphonomic processes can be observed, that of a strong heterogeneity of the implantations according to geomorphological units (Fontana & Pessina, 2007). Thirty sites have been identified, including four only in the apexes of the coastal deltaic plains and 26 on the Pleistocene lateral fluvial ridges of the megafans of the Alpine fluvial systems protected by the Holocene entrenched trend and on top of narrow cataglacial fluvial ridges with well-developed leached brown soils. Despite the explanation proposed by the authors (detailed geo-archaeological surface survey and soil fertility activity on the alluvial ridges), the systematic absence of sites in the large floodplains of North Italy remains suspect and cannot be generalised without systematic mechanical surveys, as in the French Riviera or the Rhone Valley, where the taphonomic filter has been demonstrated (see Figure 8e and f). The study of the main EN sites of the Po plain and its main southern Alpine tributaries also reveals the recurrent archaeological gap in the Po delta and its major riverbed axis as far as Lombardy, and even beyond (Starmini, Biagi, & Mazzucco, 2018), with EN sites being mainly identified in the alluvial fans and terraces of the Alpine tributaries or Apennines (Figure 7f).

We have now learned the origin of this chronical under-representation of the EN, through the combined effect of recent discoveries made during rescue excavations and systematic core-drilling campaigns. These clearly demonstrate, in both parts of the N. Mediterranean, the inadequacy of the resources traditionally mobilised to identify sites from this period (mainly pedestrian and focused on caves/rockshelters surveys), and the strong potential of buried EN sites that may be reworked or destroyed in active sedimentary zones. The same observation has been made on the scale of southern France, where the Cardial was for a long time strongly under-represented in the floodplains and confined to karstic zones, until the rescue archaeological corrections (TGV line) that offered the opportunity to observe continuous trenches through the main pre-alpine tributaries of the Rhone river (Berger, 2011). The Rhone-Saone confluence in Lyon (Figure 8a and b) and the Tricastin plain data (Figure 8a and c) explain the links between hydrogeomorphological river evolution and EN locations, and their state of fossilization. Three taphonomical categories can be observed in the floodplains. First, areas where the river activity and its lateral mobility have completely destroyed the fluvial archives of the EN period during the late Holocene (green arrows in Figure 8b and c). Second, areas
where the surface floodplain has not evolved from the EN period (red dash line) on EH pseudo-terraces contexts associated with more or less leached mature soils and where their remains could be partially disturbed by surface processes (pedoturbation, agriculture, etc.) or only preserved as hollow structures in truncated areas. Third, areas where the fluvial archives and EN associated sites are buried under alluvia from 1 to 5 m (red arrows) in lateral floodplains and fans contexts. Then, the MRV floodplains represent a
large hidden reserve for the EN period despite the fluvial destruction of one third to one half of its original surface area. The database of the Tricastin-Valdaine micro-regions (1,000 sites for 1,000 km²) explains the taphonomical effects and allows the building of predictive models by GIS geostatistics. Black circles located in the vast alluvial fans of the Tricastin plain illustrate taphonomical corrections carried out in active Holocene sedimentation sectors (humid depressions, floodplains, and alluvial fans) thanks to numerous deepest mechanical trenches (Figure 8d and e). When we extrapolated by modelling (Verhagen & Berger, 2001), from 38 known sites, we estimated 167 surface sites and 1,628 buried sites for the Cardial-Epicardial period (for seven centuries) (Figure 8f). We observed a ratio between known and estimated sites of 1:47, and a potential density of 1.83 sites/km². The quantitative geostatistics created by GIS reveal a maximal predictivity in the floodplains and alluvial fans (light green unit, Figure 8d). Today, in one of the best archaeological surveyed regions in Europe, we have knowledge on less than 2% of the predicted sites for the EN Cardial-Epicardial period (Berger, 2011). The inventory of the sites identified in MRV shows a real pre-eminence of open-air sites buried in the alluvial plains between the beginning of the Cardial and the Prechassean (Figure 8g) (Berger, 2015). By combining three kinds of contextual informations (open air surface, buried, and cave-rock-shelter sites) from the MRV database of the Leverhulm project, the SPD analysis (Berger et al., 2019), four successive trends of 150 to 250 years are recorded, which reflect both post-depositional impacts and changes in settlement strategies in the EN (see Figure 8h). In the past, many flat sites were neglected because they were systematically buried, sometimes very deeply, on the edges of the low Mediterranean and Balkan alluvial plains. This hidden Neolithic remains little explored and still holds secrets for us!
5 Conclusions

The sometimes simplistic arguments of pro-deterministic searchers are based almost exclusively on a synchrony of climatic and socio-cultural processes (Rohling et al., 2019; Weninger et al., 2014), which remains a necessary element, but are insufficient for the basis of a theory-of-causality, without an in-depth study of the socio-economic evolution and estimation of the effects of the mobility of populations and biomes and post-depositional impacts estimation on EN sites (Berger et al., 2016; Flohr et al., 2016). In absolute terms, and in order to free oneself from purely theoretical visions, climate impacts must be first identified in the functioning and evolution of terrestrial and coastal ecosystems (vegetation, fauna, water resources, seasonality, PANN-TANN, etc.) at the scale of the archaeological generation (25 years). They must then be able to identify the human reactions and responses of their socio-environmental systems to rapid changes in living conditions (e.g., daily practices, type of food, local reorganisation of the habitat, changes in the distribution of the geographical space on a local or regional scale, widening of food spectrums, adaptation of techniques). Unfortunately, we are far from being able to illustrate the chains of phenomena listed earlier, because problems with the scale and precision of analyses and chronologies, but also of data availability often limit our possibilities. The geomorphological and paleo-environmental restitution of ecosystems, at the periphery of Neolithic sites, is a direction that is already underlined by a «new Archaeology» heritage (Asouti & Hather, 2001; Berger et al., 2020; Butzer, 1982), which has yet to be generalised and refined. The broadening of our EN observation focus, by integrating latitudinal or longitudinal bioclimatic flip-overs on multi-secular scales, is necessary to find other small-scale explanatory frameworks. Better documenting the climate-environmental variability in space and time becomes a necessity to explain spatial variations in biotops and settlement systems. Current climate and ecological models can help. Detection of alternation of pulse and pause of the relative sea level and their combination with postglacial ice-melting steps and RCC events during MH period become a crucial aim to understand the push factors for the spread of the Neolithic in a more precise, socio-environmental way.

We also need to rethink the methods and approaches to coastal occupation, which are strongly impacted by the speed of sea level rise, which skews, to a large extent, the coastal settlement systems up to the changeover period between retrogradation and progradation (between 5500 and 4000 BCE). More coring campaigns are needed, particularly in the best protected areas of Mediterranean estuaries, very limited fetch for wind and waves (like along the protected submarine Baltic coast) to guide the possible mechanical surveys and identify the traces of EN versus Late Mesolithic buried occupations, which are still often confined to caves and rockshelters and which only represent a part of their initial settlement systems.

We also have to accept simply reasoning with deficient information at this time of technical limitations to document the hidden reserve and to occasionally focus on indirect data (geoarchaeology, paleobotany, sedimentary DNA, residual archaeological traces, etc.) to partially fill in the cultural gaps that still exist and to perfect the models (Lespez et al., 2016, Ghilardi, 2021). We cannot be restricted to proposing circular logic based on the most visible or easily accessible data in the extra-littoral zones, which unfortunately often remain incomplete. In the Ligurian-Provençal arc, for example, these indirect data (pollen indicators, Guillon et al., 2009) thus seem to demonstrate an earlier diffusion tempo of the Impressa than what the currently published archaeological data seems to indicate (Binder et al., 2018) (around 6000/5900 BCE). The Impressa settlement seemed focused firstly on alluvial coastal plains, more suitable for the cultivation of cereals. This local, earlier arrival of Impressa could be consistent with its chronological spread from the south-eastern Italian Ligurian coast (Guilaine, 2017). Geoarchaeology and preventive archaeology excavations have also demonstrated the greater densification of continental Cardial-Epicardial settlements in the axis from the Rhône valley to the south of the Jura massif (Berger, 2006, 2011), far from the first peri-Mediterranean models.

Modelling is another field of research in the socio-environmental sphere that can help to understand cultural trajectories and their responses to internal (society) and external (climate/environment) hazards (Aubán et al., 2015; Banks, Antunes, Rigaud, & d’Errico, 2013; Bocquet-Appel et al., 2014; Dubouloz et al., in press; Lemmen, Gronenborn, & Wirtz, 2011), but it faces problems of oversimplification, homogenisation of various data, and homogenisation of archaeological hiatuses in some landscape units. Predictive modelling
is a complementary tool to predict the depositional mode of sites, i.e. to envisage the conditions of recognition of sites for future surveys, from the local to the micro-regional level, based on a generalisation of geomorphological knowledge and combining geophysical, geomatic, and buried/surface archaeological information (Berger, 2011; Carozza, 2011).

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