Quaternary Science Advances 21 (2026) 100314

Contents lists available at ScienceDirect

Quaternary Science Advances

journal homepage: www.sciencedirect.com/journal/quaternary-science-advances

Technological innovations and regional diversity in Western Europe at ca. the MIS 11 threshold: a cladistic approach

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A R T I C L E I N F O

Keywords:
Pleistocene
Cultural evolution
Europe
Ca. MIS 11
Cladistics
Lithic technology
Three-item analysis

A B S T R A C T

The ca: Marine Isotope Stage (MIS) 11 interglacial is considered to be a threshold for behavioural innovations in Western Europe. Innovations both in technology and subsistence are observed, as well as the appearance of Neanderthal anatomical features. Core technologies and Large Cutting Tools reflect changes in behaviours and innovations, with for instance, the onset and diffusion of the iconic Levallois core technology associated with more complex and standardized debitage. Following the severe glacial event of MIS 12, the lithic assemblages yield evidence of both innovations, but the chronology of their appearance remains unclear. For tracking these innovations and generally characterizing the technological and typological features of this period of time, a large database of the available ca. MIS 11 assemblages (from MIS 12 to MIS 10) has been built including a revision of some of the assemblages. In order to unravel the relationship between sites of this period, we applied a cladistic approach using three-item analysis, considering the assemblages themselves as the object of analysis, with an emphasis on core technology. We show how three-item analysis is an efficient method capable of correctly analysing characters from lithic technologies that appear to be intrinsically hierarchical. Our results suggest that Levallois core technology survived during the glacial event of MIS 12 and diversified during the long interglacial of MIS 11. Our results also show the absence of cultural endemism, which may be linked to significant mingling between northern and southern Europe.

1. Introduction

From the point of view of hominin evolution, the long MIS (Marine Isotope Stage) 11 (including MIS 10 at some sites) stands out in Europe, where archaeological remains have highlighted this interglacial as a threshold period, not only in Western Europe, but also in Central Europe (e.g. Berger and Loutre, 2003; Bazin et al., 2013; Ashton et al., 2006, 2011, 2016; Blain et al., 2014, 2015, 2021; Kleinen et al., 2014; Combourieu-Nebout et al., 2015; Goñi et al., 2016; Hrynowiecka and Winter 2016; Oliveira et al., 2016; Sadori et al., 2016; Kousis et al., 2018; Rivals and Ziegler, 2018; Szymanek and Julien, 2018; Palumbo et al., 2019; Brandon et al., 2020; Limondin-Lozouet et al., 2015, 2020, 2025; Dabkowski et al., 2012; 2022; Górecki et al., 2022). Recent data indicate a rapid increase in temperature at the start of MIS 11 (e.g. Loutre and Berger, 2003; Candy et al., 2014; Sherriff et al., 2021; Stefaniak et al., 2022; Tzedakis et al., 2022; Sassoon et al., 2023). This interglacial and its relative stability deeply modified the size of the available territories for hominins (e.g. north-west of Western Europe) and possibly opened ways of dispersing and adapting to new animal and vegetational zones. The establishment of the Strait of Dover is dated to end of MIS 12,

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https://doi.org/10.1016/j.qsa.2026.100314
Received 11 July 2025; Received in revised form 16 January 2026; Accepted 21 January 2026
Available online 24 January 2026

thereby reducing the land link to Britain from the continent to dryland across the southern North Sea Basin during MIS 11 (Gibbard, 2007; Gupta et al., 2007; Hijma et al., 2012). MIS 12 was a severe glacial period and is considered as a major challenge for hominins with an abrupt decrease of human evidence with gaps and hiatuses. The subsequent shrinking of coastal territories and new vegetational zones in the long interglacial of MIS 11 (424 ka to 374 ka), may have encouraged hominin occupation of the interior and mountainous regions, and with increased evidence of occupation in the north-west and south of Western Europe (Hérisson et al., 2016; Hosfield and Cole, 2018; López-García et al., 2018; Moncel et al., 2018a, 2018b; Antoine et al., 2021; Hosfield, 2022; Kot et al., 2022; Rodríguez et al., 2022). European vegetation was key in driving biomass availability for large herbivores and affecting the mobility of human groups and perhaps demographic expansion.

Current genetic data and anthropological analyses show that European Neanderthal characteristics emerged as a regional mosaic of anatomical features between 600 and 400 ka perhaps through local isolation of some groups (Green et al., 2008; Hublin, 2009; Martinón-Torres et al., 2012; Meyer et al., 2016; Demuro et al., 2019; Bergström et al., 2020; Lockey et al., 2022). However, the diversity of anatomical features, such as the Ceprano skull alongside other remains attributed to *Homo heidelbergensis*, suggests a complex European history with local diversification during MIS 11, which may have increased through the expansion of favourable territories for hominins (Manzi, 2016), prior to homogenisation of the Neanderthal metapopulation from MIS 5 (Condemi, 1985; Vandermeersch, 1989; Hublin, 1998).

The greater number of sites located in both north-western and southern parts of Europe (i.e. lithic assemblages with a clear stratigraphic context) helps investigation and description of evidence of new subsistence behaviours and technical innovations (e.g. core technologies and tool kits) (Limondin-Lozouet et al., 2010, 2015; Dabkowski et al., 2012; Wiśniewski, 2014; Mathias et al., 2017; García-Medrano et al., 2015, 2023; Hosfield and Cole, 2018; Moncel et al., 2016, 2018a, 2018b, 2020a, 2021a; 2021b; López-García et al., 2018; Davis and Ashton, 2019; White et al., 2019; De Lombera-Hermida et al., 2020).

For instance, the onset of Levallois core technology and increase in centripetal/discoidal-type debitage are now clearly recorded in different places and dated from the end of MIS 13 to MIS 12–11 (Moncel et al., 2021a,b). These new technologies are associated with the persistence of a diversity of various complex knapping methods depending on several aspects, such as the quality of the raw materials (Gagnepain and Gaillard, 2003; Michel et al., 2013; Ollé et al., 2016; Peretto et al., 2016; Daura et al., 2017, 2018; Romagnoli, 2021; Bahain et al., 2022; Guibert-Cardin et al., 2022). Like biological lineages which can develop anatomical features which then disappear, some innovations can be occasionally rooted in the past, before MIS 12, possibly disappearing during the glacial event of MIS 12 and emerging again during MIS 11.

In some areas there is evidence of networks and of regionalization of traditions with possible regional mobility of human groups associated with specific land-use (Villa et al., 2016; Pereira et al., 2018; Biddittu et al., 2019; Moncel et al., 2020a, 2020b; Ravon et al., 2022; Garcia-Medrano et al., 2022a, 2023). Raw material management and planning are observed in some sites, with not only gathering of local stones but fragmentation of the reduction sequences across the territory. Flint is the main raw material for north-west of Europe, while in the south industries are characterized by the use of various stones and it is admitted that the geological resources could have impacted the technological strategies and the tool kit. For instance, few cleavers are present in the north-west, possibly due to the main use of flint nodules while in the south various cobbles make for the easy production of large flakes (Mourre, 2003).

Bifaces ("Acheulean-type" industries) continue to be made, with origins prior to MIS 12, although some sites lack these tools. There is a diversity of traditions, some reflecting early Middle-Palaeolithic-type behaviours, while different activities (e.g. butchery sites) are proposed to explain the composition of some assemblages. There are changes in shaping methods and morphological products with both thinner, symmetrical handaxes, sometimes resharpened, with a high degree of standardization, or sometimes crudely-made bifacial tools. Such variability could be due to the disruption of MIS 12, with possible local isolation of residual populations (Iovita et al., 2017; Moncel et al., 2018; Barsky et al., 2019; White et al., 2019; Méndez-Quintas et al., 2020; Nicoud et al., 2022; García-Medrano et al., 2023). Changes in subsistence behaviours are also recorded with improved hunting strategies, more complex management of carcasses and manufacturing of bone tools (Yravedra et al., 2010; Conard et al., 2015; Moigne et al., 2016; Rodríguez-Hidalgo et al., 2017; Parfitt et al., 2022; Venditti et al., 2022). These behavioural changes suggest increased cognition with new skills and social interactions that help the diffusion of innovations, and indicating a decrease in the constraints of raw material (Moncel et al., 2015; Shipton and White, 2020). Finally, early fire control (especially from MIS 11 and possible evidence from MIS 13) could have contributed to new hominin abilities to expand territories with behavioural adaptions for better survival in Northern and Central Europe (Kretzoi and Dobosi, 1989; Gowlett and Hallos, 2000; Preece et al., 2006; Lumley, 2015; Davis and Ashton, 2019; Sanz et al., 2020; Ravon et al., 2022; Davis et al., 2025).

This threshold in Western Europe, corresponding to the end of the Lower Palaeolithic (and Acheulean) and the beginning of the Middle Palaeolithic, is at present under-investigated, in particular in regard to why and how innovations appeared and were transmitted among populations (Derex et al., 2016; Grove, 2016). The reasons underlying these behavioural changes, pushing back the roots of the Neanderthal world, have yet to be identified: was this behavioural evolution rooted in previous traditions and how is it possible to observe that in MIS 11 sites? Was it due to arrivals of new populations or the onset of Neanderthals from *Homo heidelbergensis* (and Middle Pleistocene hominins) with innovations? Is the higher number of sites reflective of increased population, rather than explained by taphonomy and better preservation? If so, was this conducive to early regional networks and the diffusion of innovations, or was it due to environmental adaptation to changes in climate?

Before we can answer these questions, we need to give a historical perspective to these technological changes by analysing the relationships between MIS 11 sites in order to reflect the cultural evolution of the period. Such a perspective raises questions on filiation, reinvention or introduction of new lithic strategies, loss or acquisition of technological behaviours or tools, and impact and constraints of environmental parameters such as the availability of raw materials and the role of geography. In order to resolve the general problem of the history of lithic innovations during MIS 11, several more specific sub-questions can be addressed:

- Evidence of Levallois core technology is dated to the transition of MIS 13/12 (i.e. Boëda, 1993, 1994; Moncel et al., 2020b; White et al., 2011, 2024) and exists in different assemblages during MIS 11 and MIS 10. If an early date is accepted, did this technology persist through to MIS 11, but is archaeologically difficult to identify due to the low population during MIS 12? Or was there reinvention (in situ?) after MIS 12? During MIS 11, as this technology is observed in different places, did it appear in one place and spread, or appear independently in several places?
- Discoid-type cores sensu latu (s.l.) and centripetal cores are often considered to be the origin of the Levallois method. As increased complexity is recorded in centripetal and discoid-type core technologies during MIS 11 (hierarchy in the debitage with bifacial discoid cores sensu stricto (s.s.), prepared platform, productivity), can we use these trends to estimate a degree of filiation and/or cultural evolution of human groups, and their roots in the past?
- For the heavy-duty component, can regional or chronologically constrained clusters of sites be identified, with relationships

recognized by the mode of “façonnage”, the intensity in shaping for some assemblages and the composition of the tool kit?

In this study, we use a cladistic approach based on the presence of technological innovations, to identify cultural groups and relationships between as many lithic assemblages as possible that broadly date to around MIS 11. A few sites from other periods were also added in order to discuss the temporality of the cladogram. The work is based on a large database of the most significant sites in Western Europe (SOM 1, 2) with chronological data, archaeological context, together with cultural data and technological details for each site. We apply a cladistic analysis using three-item analysis (3ia thereafter; Nelson and Platnick, 1991) on characters based on the technological data and innovations on both flaking methods, Large Cutting Tools (LCTs) and small tools, for each site. The principle of cladistic analysis is not to choose a priori one character that would be the only relevant one for reconstructing cladistic relationships. The process of bringing different types of characters into congruence is the procedure that makes it possible to show a posteriori that a given character is relevant for resolving the relationships between given sites, i.e. synapomorphic. This implies that a character may be relevant for certain relationships, but not all.

As a detailed discussion of typological terminology is beyond the scope of this paper, for the LCTs, we refer to the large shaped tools (sensu Kleindienst, 1962) using commonly accepted terms for the Lower Palaeolithic, such as choppers/chopping tools or pebble tools, as well as typical Acheulean forms such as bifacial handaxes, cleavers, picks, or knives (e.g., Bordes, 1961; Kleindienst, 1962; Leakey, 1971; Isaac and Isaac, 1977; Sharon, 2007).

Using a precise quantification of three-item statements (3is thereafter) and the computation of several analytical tools such as the retention index (Kitching et al., 1998) for character and character states using analytical tools (Rineau and Zaharias, 2025), the resulting cladogram is discussed to quantify the link between clades and characters in order to answer the question of the historical development of lithic innovations at the onset of MIS 11.

2. Materials and methods

2.1. Archaeological sites database

Our study is based on a large data set of 47 layers from 42 archaeological sites in Western Europe from France, Italy, Iberian Peninsula and England, to which we have added some sites from Germany, Ukraine and Hungary (see tables). The sites include various biomes and landscapes with open-air locations on the North European plain (southern England and northern France) and both open-air and cave sites in southern basins and valleys. The largest quantity of sites is however mostly located in Western Europe, explained by either better preservation of sites, historically more excavations or a higher density of human occupation in this part of the continent at this time. We are conscious of biases in this database due to the limited amount of qualitative and quantitative data published for some sites, and by variability in methods used to study them. These factors may affect the representativeness of the dataset and should be taken into account when interpreting the results.

The database is made of sub-datasets. The first informs on all the contextual and technological information on the archaeological sites and levels, using published and unpublished data, including some of our own reviews of the material. The main references are also listed on the database (SOM 1). The description lists the context of the occupations as primary, where remains are found within the sedimentary deposits, and secondary, when remains have been reworked and not in original deposits. Chronologically, we have focused on the ca. MIS 11 event and we have enlarged the database to key-sites from the end of MIS 13/beginning MIS 12 to MIS 10 (e.g. Cagny-la-Garenne I-II, TD10.1 Gran Dolina, Áridos I, Cueva del Ángel, Cueva de Bolomor, Ambrona, Torre in Pietra and La Micoque) (Santonja et al., 1980, 2001; Fernández Peris et al., 2008; Yravedra et al., 2010; Méndez-Quintas et al., 2020). In order to test the hypothesis of past filiation of some innovations, we have included the French sites of Cagny-la-Garenne I and II dated to MIS 13/12 for the early Levallois evidence (Moncel et al., 2020b). Environmental proxies have been recorded to provide chronology (mammalian biostratigraphy, geology, malacology, palynology) and to reconstruct the climatic context (temperature - warm, mild, cool or cold).

For the location of each site, the geographical coordinates (longitude, latitude, altitude), topography (fluvial, fluvial without terrace information, hill, lake, mountain, plateau, lake-shore, valley, valley-edge), general location (inland, continental, coastal) and type of site (cave, open-air, shelter) have been recorded. Also included are data regarding the size of the excavations and density of the material, to help explain any biases in the record and the paucity of some assemblages.

A large corpus of data refers to the archaeological patterns: presence of fire and main features, human remains (number and types of remains), raw materials (types, distance - local, semi local and exogenous), lithic remains (number, main technological activity flaking and/or shaping, fragmented and/or complete operative chains), hard and/or soft hammerstones, function of the site (butchery site, camp, workshop), subsistence data, duration (long-term, short-term, seasonal) and faunal remains (herbivore and carnivore types). In this database, we have avoided cultural attribution, as for instance Clactonian, Acheulean and Middle Palaeolithic-type. These attributions are often questioned depending on the size of the excavated area, the type and date of the excavation (old surveys on open air surfaces) or the kinds of criteria selected, and are therefore not suitable for defining homologies in the context of cladistics (see Fig. 1).

This study is based on additional sub-databases, in which we have divided detailed technological patterns into two main fields: flaking (cores and flakes) and shaping processes (Large Cutting Tools-LCTs- and small retouched tools on flake) (Figs. 2 and 3).

Core technology includes data on each raw material, (if known) number and ratio of various technological and metrical parameters, as for instance, core size, number of flaking faces (unifacial, bifacial, trifacial and multifacial), number and organization of removals. We have also included some features considered as marks of technological complexity such as hierarchical organization of removals and type/preparation of striking platform. Due to the diversity of approaches, the database has included first a long list of terminologies found in the literature for core structure. In order to simplify and harmonize, we have reduced the terminology to this following list: Unipolar, Bipolar, Alternate flaking (including S.D.D.A.”Surfaces de debitage alternées”- and “Clactonian” debitage), Orthogonal (orthogonal to multifacial, cores with more than two flaking surfaces), Centripetal, Discoid (s.l and s.s with pseudo-Levallois products) and Levallois (i.e. Boëda, 1993, 1994; Peresani, 2003; Baena et al., 2017; White et al., 2024). The definition of Levallois core technology is generally well-established (Boëda, 1993, 1994) despite the use of this term being sometimes questioned for early examples using proto-Levallois, pre-Levallois, prepared cores, or simple prepared cores (White and Ashton, 2003; Moncel et al., 2021a,b; White et al., 2024). It has been questioned as to whether Levallois evidence exists in the UK before MIS 9/8, a late arrival being related to a warming event (White et al., 2024), as is possibly the case in Central Europe (Wiśniewski, 2014). “Prepared core technology”, being sometimes related to Levallois, has also been called into question by White et al. (2024).

For products of debitage, we have recorded data by each raw material, and (if known) number of remains and ratios, sizes, type of flakes among the reduction processes, platform (prepared and/or non-prepared), number and organization of removals, and cortical extension.

The light-duty component (i.e. flake-tools) has been recorded (number and ratio) by each raw material, the type of flake-tool, type of support, size, type and extension of retouch.

Finally, the LCTs were described first in general with types of raw