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Cycles in stone mining and copper circulation in Europe 5500-2000 BCE: a view from space

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Abstract:	In this paper we ask what relationship existed in European prehistory between the exploitation of high-quality stone sources to produce axeheads and daggers for exchange, and the production, circulation and deposition of copper artefacts. We have collected radiocarbon data on the dates of exploitation of stone quarries, flint mines and copper mines. We have also collected data on the frequency through time of typologically distinctive stone and copper artefacts. By adopting a broad spatial and temporal perspective, the western half of Europe excluding Iberia and peninsular Italy, from 5500 to 2000 BCE, we demonstrate the existence of a general pattern in which the circulation of the first copper artefacts led to a decline in specialist quarry production. This specialist quarry production in turn re-emerged when the availability of copper decreased, before declining again as copper became more generally available in the Bell Beaker phase. Regional variation in this pattern reflected degrees of connectivity with copper exchange networks. While these results are in keeping with previous understandings, they go beyond them in their quantitative demonstration of the patterns and their cyclical nature.
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Cycles in stone mining and copper circulation in Europe 5500-2000 BCE: a view from space

Abstract

In this paper we ask what relationship existed in European prehistory between the procurement of high-quality stones (for axeheads, daggers and other tools) on the one hand, and the early mining, crafting and deposition of copper on the other. We have collected radiocarbon dates for the exploitation of stone quarries, flint mines and copper mines. We have also collected data on the frequency through time of jade axeheads and of copper artefacts. By adopting a broad spatial and temporal perspective – spanning much of the western half of Europe from 5500 to 2000 BCE – we identify a general pattern in which the circulation of the first copper artefacts was associated with a decline in specialised stone quarrying. The latter in turn re-emerged in certain regions when copper use decreased, before declining more permanently in the Bell Beaker phase, once copper became more generally available. Regional variations in these patterns reflected degrees of connectivity among overlapping copper exchange networks. Our results are in keeping with previous understandings, but go beyond them in quantifying these patterns and demonstrating their cyclical nature, with additional reference to likely local demographic trajectories.

Introduction

The production and exchange of flint, higher value ground stone and early metals has long been a major research focus in European archaeology. This paper offers a contrast to previous studies in taking a broadly comparative and strongly quantitative vantage point. We use newly synthesised radiocarbon data on siliceous as well as ground stone mines and quarries, alongside aggregate typological evidence for the circulation of copper artefacts, to examine the way in which the use of high-quality sources for the production of stone tools, axeheads, adzeheads and daggers related to the development of copper production and the local circulation of copper artefacts. Our focus is on the western half of Europe, from the beginning of farming ~5500 BCE to the start of the Early Bronze Age shortly before 2000 BCE[1].

Mining and quarrying to produce large quantities of smaller flint tools as well as axeheads from flint or ground stone, far in excess of local needs, is one of the most characteristic and best-known features of the European Neolithic. In principle, all Neolithic communities were involved and in some way connected via the production and/or exchange of stone tool raw materials. Within this general network of community interactions revolving around raw material and tool procurement, socially differentiated consumption patterns also existed: some stone tools like shoe-last adzeheads, jade axeheads, and later flint and copper daggers

[1] In the following the term flint is used in the sense of French and German “silex”, including all siliceous stone materials suitable for knapping regardless of formation.

can be linked to practices of highly symbolic significance (e.g. Pétrequin et al. 2012). While simple daily tools no doubt comprised the major share of stone artefacts, the demand for special items caused the production of extraordinarily large quantities of favoured materials and therefore can be seen as a driver for the preference of one source over others. The wide distribution of distinct and recognizable flint varieties, for example, indicates how desirable they were even to distant communities, despite the fact that alternative, local raw materials often existed (Kerig 2018).. We do not need to think of the producers as full-time specialists to recognise that the effort that went into producing such large quantities of material for distribution at the major sites was substantial and could involve a degree of specialised production. In the Mons Basin flint-mining region, for example, Collin (2016) shows that some mines provide evidence for a major investment in standardised extraction techniques, and played an important role in raw material provision at an inter-regional scale.

In recent papers (Schauer et al. 2019; Edinborough et al. 2020) we have shown that the main phases of exploitation and supra-regional distribution of many of the major mines were much shorter than the mine's extraction period as a whole and that their rise and demise reflected changing patterns of demand for their products. In Britain the main period of systematic flint-mining and quarrying was ~4000-3500 BCE and the first and strongest demand for axeheads was created by the need for these tools to clear forest among an incoming immigrant farmer population (Edinborough et al 2020), who brought the relevant technologies with them. In southern Scandinavia too, the short phase of underground flint mining coincided with the arrival of incoming farmer groups (Mittnik et al. 2018).

In continental northwest Europe (France, the Low Countries and western Germany), however, the picture was different. Our radiocarbon data do not show any evidence of large-scale shaft-mining for the first 1000 years after the initial arrival of farming, even though it was associated with a major population increase, beginning ~5300 BCE. In contrast, two major mining episodes in these regions, the first ~4200-3800 BCE and the second ~3500-3000 BCE, were both correlated with, but far in excess of, what would be predicted by the regional consumer population size. Schauer et al. (2019) suggested, following others, that the onset of mining was a result of demand prompted by the arrival of the polished jadeitite and similar axeheads (hereafter referred to generically as jade) from the Alps (Pétrequin et al. 2012; cf. Giligny et al. 2012)). The number of large jade axeheads deposited increased over the course of the 5th millennium BCE, reaching a high-point ~4200 BCE contemporary with an inferred population peak, and slightly preceding but strongly overlapping with observable intensities in mining activity. From ~3800 BCE, jade axeheads, mining evidence and inferred population all appear to decline.

In this paper we adopt a broad spatial and temporal scale to ask: what was the relationship between fluctuations in the large-scale production of lithic artefacts for exchange and the local appearance of copper artefacts? We focus on Europe north of the Alps and north and west of the Carpathian basin but include northern Italy, over the period ~5500-2000 BCE. Until late in the period of interest, there was no copper production within most of this region, so the key question is whether the inclusion of parts of our area within the networks of circulation of copper artefacts originally produced in southeast Europe (see below) had an impact on local stone production.

To address this, our focus is on observable patterns of change in copper deposition[2] close to sources of both stone and copper raw materials (see figs 1-8).

Materials and Methods

The paper is based on a variety of different information sources.

1. A georeferenced database of radiocarbon dates for stone quarries or mines, and for copper mines, in the western half of Europe (see SI and map **fig. 1**). As in previous papers (e.g. Schauer et al. 2019), we have used weighted summed probability distributions of the dates as a proxy measure for the intensity of mine exploitation through time.
2. Since large jade axeheads are the most striking example of socially/symbolically important axeheads and have an exceptionally wide distribution, we have used the database and typological attributions in Pétrequin et al. (2012) to show their incidence through time in different regions, following Schauer et al. (2019).
3. Dates from the sources of the flint daggers that are characteristic of specialised production from the later 4th through the 3rd millennium are much less widely available than those for earlier phases, not least because of the open-cast nature of production (e.g. Vaquer and Remicourt 2012). Accordingly, in order to include this production in our analysis, we have used published sources that provide semi-quantitative information on the periods of circulation and frequency of their products, based on their contexts: Grand-Pressigny (Ihuel et al. 2015); the flint daggers of southern Scandinavia (Apel 2001); and sources in southern France (Vaquer and Remicourt 2012), Switzerland (Honegger and de Montmollin 2010), and northern Italy (Mottes 2001).
4. A similar problem of dating sources arises with the early use of copper: many of the early copper sources are unknown, so the few dated mines do not give an adequate picture of early copper exploitation. Moreover, since the earliest known mines are outside our area, in southeast Europe, the mine dates do not necessarily correlate with the circulation of their products in our area of interest; in fact, we know that initially this was not the case (summarised in Rosenstock et al. 2016 and see discussion below). To obtain information on copper circulation, we collected a geo-referenced database of known copper artefacts for the area from Poland to Britain, excluding the Carpathian Basin but including northern Italy, from the earliest known, in the 5th millennium BCE, down to ~2000 BCE, using a variety of sources (see SI and map, **fig 1**), though we do not claim that coverage is complete. Previous typological studies have provided date ranges for different types of copper artefacts, or for the contexts in which they are found, and we have used aoristic methods based on these

[2] By deposition we mean all processes by which copper ended up in the ground, whether intentional or unintentional on the part of the people concerned.

date ranges (cf. Rosenstock et al. 2016) to produce summed distributions of the frequencies through time of all copper artefacts together and of axes, daggers and ornaments separately, for different regions, with a 50-year resolution.
5. A database of radiocarbon dates for non-mine/quarry sites for the period and area concerned has been created and summed probabilities of these dates (SPDs) have been used as a proxy for changing patterns of population within our region (see below).

As always of course, the information derived from these data sources depends on the current state of research in these different domains.

Table 1 summarises the combination of methods that this paper applies to the above datasets.

1. Define different regions within our overall study area: Central Europe, Southern France/circum-Alpine Europe, Southern Scandinavia, Northwest continental Europe, Britain.
2. Within each region define the combined 200 km radius hinterlands of all stone quarries/mines and copper mines for which we have radiocarbon dates.
3. For each region sum the probabilities of all radiocarbon dates from mines/quarries to obtain a measure of the regional intensity of mine exploitation through time.
4. Use all geo-referenced radiocarbon dates within each region's combined hinterland to produce a summed probability distribution (SPD) as a regional population proxy.
5. Within each region use the geo-referenced location of large jade axeheads from the Pétrequin et al. (2012) database and their typological attributions to plot the changing frequency of large jade axeheads through time.
6. Within each region use the geo-referenced location of copper artefacts of different types and their known chronological distribution to plot their distribution through time.
7. Use information from the literature on the chronology of flint dagger production to plot a semi-quantitative picture of their distribution through time for each region.

Table 1: Method summary

Our published studies (e.g. Schauer et al. 2019) suggest some relationship between periods when mines and quarries were being exploited and the size of the regional population around each extraction site. Accordingly, for each study area, we obtained a population proxy based on the summed probability distribution (SPD) of all non-mine radiocarbon dates, following the method described by Schauer et al. (2019; and see Timpson et al. 2014); the probabilities of these dates within 200 km of the mining sites in each region were binned and summed.

	Radiocarbon dates			Artefacts		Copper find classes		
Region	Stone sources	Copper sources	200km Hinterland	Jade axeheads	Copper finds	Copper axeheads	Copper daggers	Copper ornaments
All	738	111	23184	1456	1739	686	339	534
CEU	173		4179	81	601	192	135	226
SCAN	62		2452	7	112	85	2	25
SEU	77	45	5933	779	528	53	108	252
NEU	240		4498	643	206	38	99	49
GB	186	66	7711	68	361	348	10	3

Table 2. Counts of radiocarbon dates, jade axeheads and copper finds of each type for each of five regions, plus all regions. Note that the total number of copper finds is sometimes slightly greater than the sum of the axeheads, daggers and ornaments, due to the inclusion of low-frequency artefacts for which a type is outside of these classes, uncertain or not given. Note also that the total number of copper finds (All) is slightly less than the total when all the regions are summed because of a small amount of overlap in the circles defining the different regions. Though shown on the plots, stone daggers are not included in this table as we do not have precise counts of each type in each region. CEU Central Europe; SCAN Southern Scandinavia; SEU Southern France/circum-Alpine Europe; NEU Northwest Europe; GB Great Britain. In the case of Britain the dates from the Ross Island mine in Ireland (O'Brien 2004) are included because it was the source of the metal for the early copper artefacts in Britain (Bray and Pollard 2012). The early copper artefacts from Ireland are not included in this study.

In the plots that follow, we present the changing frequency of three categories of radiocarbon date – stone mines, copper mines and all non-mine dates – and four artefact types – large jade axes, and copper axes, daggers and ornaments – within each of five regions, plus all regions combined (**table 1**), based on the combined 200 km hinterland circles around all dated stone and copper sources within the region. The 200 km hinterland SPDs, which are considered a proxy for changes in regional population, are present in all plots. Our rationale for choosing this 200km spatial focus is that, since the deposition locations of the great majority of products from a given stone source fall within a 200 km radius of the source (e.g. Schauer et al. 2020) (with the exception of jade axes, treated separately here), and areas more than 200 km away from a source would be unlikely to be exerting a direct demand on source production in any case, this is where the impact of the circulation of copper would be felt. The SPDs of stone sources within the region are plotted against this hinterland. Each stone source SPD is a 95% envelope created by sampling no more than 5 dates per site, repeated 1000 times. This prevents certain well dated sites, such as Grime's Graves in Britain, from distorting the SPD. Where available (Southern Europe (SEU), Britain (GB), and all regions together (ALL)) we repeat this process for all dated copper sources within the region, again including no more than five dates per site, repeated

1000 times to create a 95% envelope. This sampling procedure was not required for the hinterlands due to the very large sample size in each.

Plotted against these radiocarbon SPDs are the changing relative quantities of jade axeheads, copper finds and estimated stone dagger frequencies within 200km of each stone or copper source, where the latter occur within our region, based on the application of aoristic methods to their known chronological ranges, as described above. Each of these three lines is scaled to its own maximum on the *y* axis, so that the changing relative quantity of each material type can be compared. In a second plot for each region, the copper finds are divided into three categories (axeheads, daggers and ornaments) to show the relative frequency of each within that region. In these plots, the *y* scale is shared between the three shape classes, with the maximum y value determined by the maximum value in any of the three classes. These counts are plotted against the same hinterland, stone source and copper source SPDs shown in the previous plots.

Results

Central Europe (CEU)

Fig 2A shows the results for the area of Central Europe defined by the combined 200 km radius of the 19 stone sources in this region. The first major rise in mine and quarry activity coincides with the arrival of LBK farmers ~5400 BCE. There is then a very rapid drop at the end of the LBK ~4900 BCE, in keeping with the general evidence for a decline in exchange at this time (Zimmermann 1995). The pattern then fluctuates before reaching a low point ~4000 BCE. Mining activity then stays low until ~3500 BC when it increases and remains high until ~3000 BCE, after which it drops again before rising again in the second half of 3rd millennium, at the beginning of the local Early Bronze Age. Imported large jade axeheads appear in the region after the first increase in local stone extraction, peaking ~4200-3800 BCE, declining sharply thereafter. However, the total number is only 81, an order of magnitude less than in Circum-Alpine and Northwest Europe, which are nearer the source. The period of diminished mining activity sees a rapid rise in the number of copper items deposited (cf. Bartelheim 2013; Bartelheim et al 2002; Rosenstock et al. 2016, figs 13-15), with a peak at ~3800-3400 BCE, which then declines gradually as local flint mining activity increases again. Copper item frequency reaches a low just before 3000 BCE, after which it rises again into the Early Bronze Age.

After the initial rise in population with the arrival of farming there does not appear to be any correlation between stone quarrying/mining and the hinterland population proxy in Central Europe. This is also true for the relationship between copper frequency and the population proxy, at least until the end of the sequence after 2500 BCE when both increase together. The 4th millennium copper peak in Central Europe is dominated by axeheads; the first half of the 3rd millennium sees a steady rise in the incidence of copper ornaments, while from 2500 BCE there is a very rapid increase in daggers (**fig 2C**), associated with the Bell Beaker culture. There are no known early copper mines as yet in this region. While there are indications that copper smelting took place in the lower Inn valley at the end of the 5th

millennium (Höppner et al. 2005), results of metal analyses of early objects, including those of the so-called *Mondsee* metal characteristic of the 4th millennium, point to sources in southeast Europe (Frank and Pernicka 2012; Bartelheim 2013).

Southern Scandinavia (SCAN)

The pattern for southern Scandinavia (**fig 3A**) shows a short-lived peak in flint-mining, coinciding with the introduction of agriculture by incoming farmers and the associated population increase (Mittnik et al. 2018; Warden et al. 2017). Only seven large jade axeheads have been found in the region and it seems clear from the dates of currency of the types concerned that most if not all must have been heirlooms by the time the first farmers arrived here. The end of the major mining phase coincides with the well-known episode of copper import and deposition (of axeheads and to a lesser extent ornaments; **fig 3C;** Klassen 2000, 2004), which also now includes evidence of local casting ~3800-3500 BCE (Gebauer et al. 2020). This phase, which corresponds with the local population peak, was over by ~3200 BCE.

Some flint mine activity continued until ~2500 BCE but there is no indication of a resurgence in flint mining. In fact, the end of copper imports occurs shortly after the start of a decline in the population proxy that continues until after 3000 BCE. A massive local production of flint daggers produced by bifacial techniques then began ~2350 BCE with the start of the local LN I period (Lomborg 1973; Apel 2001), dated by their contexts. There are no known mine dates for this period. **Fig 3A** includes a semi-quantitative representation of the *floruit* of dagger types I-III, characteristic of the LN I period (n=8063, table 9.2, Apel 2001). Copper items also began to reappear in southern Scandinavia in the LN I period (Vandkilde 1996).

Southern France and Circum-Alpine Europe (SEU)

As in other regions, the growth of mining and quarrying in this area is associated with the arrival of farming from ~5500 BCE (**fig 4A**) and a resulting population increase. A possible downturn after ~4700 BCE is followed by a major but short-lived peak, ~4300-4000 BCE, which also corresponds to an increase in the population proxy. This is also the peak for the frequency of large jade axeheads, whose source lies in this region. They show a steady increase through the 5th millennium, followed by a rapid decline. This decline is paralleled by the increasing number of copper items deposited, maintaining a peak from ~3800 to 3400 BCE, when it drops rapidly to a low that continues to just after 3000 BCE. From then until ~2500 BCE there is a rapid increase in the incidence of copper finds. Shortly after 4000 BCE, we see the first radiocarbon dates for copper mines, in northern Italy (Maggi and Pearce 2005).

However, as noted above in the case of southern Scandinavia, the radiocarbon-dated stone mines and quarries do not accurately reflect the importance of specialised stone dagger production on both long blades and bifacially-worked pieces in this region after ~3500 BCE. This is because of problems with finding and dating the specific source sites; so the periods of use of the sources must be inferred from the contexts of the products. Thus, the period from ~3500 to ~3000 BCE across this region was a time of growing production and wide distribution of flint daggers (Vaquer and Remicourt 2012). These came from specialised sources in western and southern France, especially Grand-Pressigny (Ihuel et al. 2015) and Forcalquier (Vaquer and Remicourt 2012; Honegger 2006), based on long blades, and northern Italy, especially the Monti Lessini, based on bifacial techniques (Mottes 2001; Borrello et al. 2009). Their occurrence increases again from ~3000 to ~2800 BCE maintaining a high level until ~2500 after which they rapidly decline (dotted line, **fig 4A**).

After 3000 BCE there is much more evidence of local copper mining, including in southern France, where copper items, especially ornaments, from local sources are frequent (Mille and Carozza 2009), coinciding with a peak in the radiocarbon mining record. Local mining continues into the Bell Beaker period but seems to tail off thereafter. In southern Europe, axeheads and ornaments are equally frequent during the first copper peak, unlike further north, while the second peak is largely made up of small ornaments and secondarily by daggers (**fig 4C**).

Northwest Europe (NEU)

The pattern for continental northwest Europe (**fig 5**) is different in several respects from the other regions so far examined. As pointed out in the introduction, the arrival of farming in the late 6th millennium BCE did not lead to a visible commencement of mining and quarrying , though the majority of flint finds can be accurately sourced to areas where shaft mining would later take place. Shaft mining did not start until ~4200 BCE, only reaching a peak ~4000-3800 BCE, just as the population began to decline. The deposition of large jade axeheads in the region also declined precipitously at this time. This had been rising steadily through the 5th millennium, peaking at ~4200-4000 BCE when local flint mining started. Local flint mining then rose to a second peak in ~3300-3100 BCE before fading away. This second peak does not seem to be associated with a population increase. The period from ~3100 BCE, especially ~2800 to ~2400, is characterised by the exploitation of the Grand-Pressigny flint sources for specialised production of large numbers of long flint blades for daggers that were widely distributed (red dotted line in **fig 5A**, based on Ihuel et al. 2015. Deposition of copper objects first occurred after 3500 BCE but these are almost exclusively small ornaments using very little metal (Mille and Bouquet 2004). There may have been a drop in numbers of copper items ~2700-2500 BCE but the situation changed after 2500 BCE with a major increase, dominated by daggers (**fig 5C**), associated with the appearance of the Bell Beaker culture, coinciding with the demise of Grand-Pressigny production.

Britain (GB)

Britain (**fig 6**) is located even further from the centres of innovation than southern Scandinavia. After a peak in stone mining and quarrying associated with the arrival of the first immigrant farmers, stone extraction activity declined steadily through the 4th millennium as population also decreased. As in Central Europe and southern Scandinavia the number of jade axeheads in Britain is small compared with the regions nearer to the sources and the date distribution of types suggests that many were heirlooms by the time farmers arrived in Britain ~4000 BCE. There are indications of a short-lived upturn in local mining ~3000 BCE and another ~2600-2400 BCE. The latter corresponds to the exploitation of the flint mine at Grime's Graves (Healy et al. 2018). However, although it is contemporary with Grand-Pressigny, there is no indication that it was a centre of specialised blade production (Saville 1981); indeed, there is no evidence that Grand-Pressigny blades were ever imported into Britain. Grime's Graves came to an end with the arrival of Bell Beaker immigrants (Olalde et al. 2018) and the beginning of copper mining at Ross Island in Ireland (O'Brien 2004), whose products, including the first daggers, circulated in Britain (Bray and Pollard 2012). **Fig 6C** shows the very large number of axeheads associated with the earliest copper exploitation dates in Britain, especially in eastern Scotland (Needham 2004). However, from ~2250 to 2000 BCE flint daggers also circulated in Britain in Bell Beaker contexts (Frieman 2014) (**fig 6A**).

Discussion

From ~5500 to ~2500/2000 BCE, over the period spanning the arrival of farmers to the beginning of the Bronze Age, it is possible to identify two broad trends in the social and symbolic dimension of materials and artefacts across the western half of Europe. The first is a shift from the value attached to high-quality stone artefacts (especially jade) that characterised the period up to ~4000 BCE, to a new system based on the value attached to copper (and gold, not considered here). The second is a shift in social importance from axeheads to daggers (and also halberds, considered in this paper, see Horn 2014).

Klassen et al. (2012) proposed that the decline in the circulation of large, socially important jade axeheads during the 4th millennium BCE was the result of competition from copper, which was beginning to circulate more extensively in regions close to the Alpine jade sources. The sources continued to be exploited, but for smaller utilitarian axeheads which had a much more local circulation. The same is true of the quarries for axeheads of pelite-quartz in the Vosges hills of eastern France (Pétrequin and Jeunesse 1995). At ~4000 BCE these quarries reached a peak of production in terms of both the quantity of axeheads being produced and their length but they declined in both respects from ~3850 BCE, while the spatial scale of their distribution also decreased, especially to the east. The North Alpine foreland lake settlements now show evidence for the local production of copper artefacts (ibid., 111-12) with people reverting to local stone sources for the production of smaller work-related axeheads. Pétrequin and Jeunesse (1995, 117-8) suggest that in the north Alpine region both stone axeheads and metal prestige goods declined in the mid-4th millennium BCE, as a result of a demographic decline provoked by a climatic downturn.

However, the period ~4500-3500 BCE is not the only one for which a relationship has been postulated between specialised stone tool production and the production and circulation of copper in the western half of Europe. From the late 4th millennium until ~2000 BCE there was a new interest in the highly-skilled production of high-quality stone artefacts produced at restricted sources and widely exchanged, for axeheads, for example at Krzemionki in Poland (Balzer 2002), but also now for daggers. Examples include those made on long flint blades and bifacially-worked pieces from a variety of sources found widely in the Circum-

Alpine region (see e.g. Pellegrin 2012, Ihuel et al. 2015, and below). These are usually regarded as a response to the introduction of copper daggers (e.g. Honegger 2006), which occurred earlier further east, for example in the late 5th millennium Carpathian Basin (e.g Csányi et al. 2009; and see below). The connection is obvious in material choices where stone resembles metal, in technical choices, and in design, where, for example, elements of metal artefacts were transformed into elements of flint daggers (e.g. Frieman 2012).

In Central Europe the exploitation of special hard stone sources and the widespread exchange of their products began in the LBK Early Neolithic with the production and distribution of shoe-last adze- and axeheads whose main source was in northwest Bohemia (Přichystal 2015; Nowak 2008). In southern and western Europe from ~5000 BCE we see the growing importance of the production and exchange of the large, high-quality Alpine jade axeheads already discussed that reached its apogee in the mid-late 5th millennium BCE (Pétrequin et al. 2012). At the beginning of the 4th millennium BCE, the circulation of copper from southeast European mines that had begun ~5000 BCE (Radivojević et al. 2010) expanded north and west of the Carpathian Basin, as seen in the patterns mapped by Bartelheim et al. (2002) and Rosenstock et al. (2016; cf. Radivojević and Grujić 2018). Moreover, it is clear from the presence of crucibles and the existence of specific local types that the know-how to melt and cast copper was also transmitted (e.g. Strahm 1994).

In our results, we see a number of significant transformations that conform well with these patterns (2016). As deposition of copper from the southeast European mines, mainly in the form of axes, increased in Central Europe, there was an abrupt and massive decline in stone quarrying and in the circulation of large jade axes (**fig 2**). Stone mining and quarrying temporarily resumed from ~3500-3000 BCE, coincident with a temporary decline in copper deposition, after which stone mining reaches a low at ~2900 BCE. Concurrently, with the beginning of the Corded Ware phase, there was an increase in copper deposition, but now mainly in the form of small ornaments requiring little metal, in contrast to the dominance of axeheads in the previous phase. Axeheads were an important element of Corded Ware grave goods but without exception these were of stone (Maran 2008). The Bell Beaker phase from ~2500 BCE saw a rapid rise in the deposition of copper, reflecting the presence of copper daggers in many Bell Beaker burials, linked with the introduction of a 'dagger practice' (see below).

Up to the later 4th millennium BCE, the pattern in the Circum-Alpine region roughly corresponds to that in Central Europe. Quarrying and the circulation of large jade axes decreased as southeast European copper began to circulate in the North Alpine region and copper circulation declined with the disappearance of those contacts after 3500 BCE. However, there are two significant differences. First, in northern Italy, local copper mining and smelting appear in the early 4th millennium (Maggi and Pearce 2005), most probably as a result of earlier Balkan-Carpathian connections (Dolfini 2013), though there is little sign of its impact on metal deposition. The situation changes after 3000 BCE, when our data show a big increase in radiocarbon-dated copper mining activity, including its expansion to southern France, as well as a significant rise in the deposition of copper items (**Fig 4**; cf. Cattin 2009;

Mille and Carozza 2009; Peruchetti 2017). This record is dominated by the presence of small ornaments, and secondarily by daggers.

The presence of the latter points to a second significant difference between Central and Circum-Alpine Europe, the existence of a ‘dagger practice’ that is not found in Central Europe until the Bell Beaker phase, based on the technical innovation of copper daggers. The first cast copper daggers appear in burials at the end of the 5th millennium in the Carpathian Basin(e.g. Csányi et al. 2009) and represent a technological innovation that Hansen (2013, 151) links with improved casting through the use of arsenical copper. Early daggers are very widely but thinly distributed, from the Black Sea to southern France but are rarely found north of the Carpathian Basin or, further west, north of the Danube (Hansen 2013, fig 22); an early example is dated to the 38th century BCE at the Pfyn culture lake village of Reute in southwest Germany.

Müller (2013) suggested that daggers represent an innovation in male equipment associated with individualised competition that, with a couple of rare exceptions, was not taken up until the Bell Beaker period in areas to the north. In Circum-Alpine Europe, on the other hand, they seem to have rapidly acquired a major social significance much earlier. This is clearly indicated by the appearance of copper daggers in rich burials such as Fontaine-les-Puits in southern France (Rey et al. 2010), dated to ~3500-3250 BCE and the early phase of the Remedello culture in northern Italy at the same time (de Marinis 2013).

North Italian flint artefacts were already reaching areas north of the Alps by the early 4th millennium, but, as the first copper daggers appeared, specialised flint dagger production on a large scale using high-quality raw materials began in Italy and in southern and western France. The products were very widely distributed. In western Switzerland, Honegger (2006, 52-3; Honegger and de Montmollin 2010) identifies an initial phase, ~3500-3000 BCE, after the first copper daggers had appeared, when flint daggers had a high social value because they were rare and came from distant sources (e.g. Honegger and de Montmollin 2010). After ~3000 BCE copper production also began in southern France (Ambert 1995). This is also the period of circulation of the well-known Remedello copper dagger type (de Marinis 2013) whose social/symbolic significance is indicated by numerous representations on Alpine statue-stelae (e.g. de Saulieu 2004).

Nevertheless, in western Switzerland ~3000-2700 BCE, copper objects were still uncommon and imported flint daggers, especially from Grand-Pressigny, increased in frequency and were occasionally recycled when broken to make other types of object (Honegger 2006). From ~2700 BCE copper was much more frequent yet the import of Grand-Pressigny flint daggers, and the production of local imitations, reached its highest level, two to three times higher than previously (**fig 4A** & **5A**); recycling of flint daggers also increased as they gradually lost their prestige value to copper. There were no more flint daggers in the subsequent Bell Beaker phase (Honegger 2006, Honegger and de Montmollin 2010).

While we cannot be certain of the relation between circulation and deposition of these different materials, it seems likely that the massive production of flint daggers was compensating for the fact that copper production was insufficient to meet the local demand for what were indispensable items in the context of the dagger practice. In northern Italy, for example, ~2900-2500 BCE, flint daggers imitating the form of the Remedello copper daggers were much more common than the latter (de Marinis 2013).

Northern France and the Low Countries lay outside the sphere of early connection with copper circulation networks originating in southeast Europe, with only a very small number of copper ornaments appearing in the late 4th millennium (**fig 5C**), at the time of the second peak of flint mining. However, this is when production of blades began at Grand-Pressigny, using a unique *chaîne opératoire* based on indirect percussion (Pelegrin 2012). These products acquired an increasingly broad circulation from ~3100 BCE, reaching a peak in both distance travelled and quantity produced in 2650-2450 BCE (**fig 5A**). Just as axeheads obtained by exchange from special sources could have both a social and a utilitarian value, so too could the Grand-Pressigny blades. Linton's (2016) use-wear study reveals patterns of use similar to locally-sourced materials; the implication is that they were carried around and used for day-to-day activities. Their success, Honegger (2006, 51) suggests, was due at least partly to the fact that Grand Pressigny was in a region without local copper sources. Its production ceased with the appearance of Bell Beakers and copper daggers, as **figure 5A**&**C** shows, presumably a result not only of the increasing scale of copper production but also because the region was now connected through the Bell Beaker network to the metal sources.

Although itself outside the area of copper circulation, Grand-Pressigny was in contact with the newly emergent south-central European sphere where copper was circulating and daggers had become a key male status indicator. This was not the case in Britain, where flint-mining and quarrying were mainly accompaniments to the initial stages of farming (**fig 6A**). A 3rd millennium phase of mining at Grimes Graves, contemporary with the main phase of exploitation at Grand-Pressigny, has no evidence of specialised flint dagger production (Saville 1981), and the lack of Grand-Pressigny blades in Britain, given their wide distribution in France and adjacent areas, is striking. The demise of Grime's Graves around ~2400 BCE may have been linked to the arrival of Bell Beaker immigrants in Britain, introducing copper and copper metallurgy, as well as the dagger-focused status system embodied by their use as grave goods. In contrast, copper axeheads were never placed in Beaker burials, despite their overwhelming numbers in other contexts and overall (**fig 6C**). Interestingly, however, flint daggers briefly replaced copper ones in British Beaker graves around ~2250 BCE, prior to the deposition in burials of bronze knives and daggers in the Early Bronze Age (Frieman 2014; Needham 2005; Parker Pearson et al. 2019, 185-7). Given the large number of copper axeheads deposited in Britain during this period it seems unlikely that this can be accounted for by a lack of available copper; more probably it was a funerary fashion.

In Scandinavia too, the short period of flint mine production was associated with the arrival of farming (**fig 3A**). Its decline may be associated with the end of initial large-scale forest clearance but it also coincided with the imported of copper objects from the south, and the arrival of the know-how to cast metal and produce local forms (Gebauer et al. 2020), a phase that finished around ~3200 BCE. It was the appearance of Bell Beakers in southern Scandinavia that connected the region to the male dagger practice (cf. Sarauw 2009), as in

Britain, and indeed Central Europe. Yet, unlike Britain and Ireland – where the Ross Island mines were producing copper from 2450 BCE – southern Scandinavia had no local sources. The result was, in effect, a repeat of the Grand-Pressigny phenomenon but ~600 years later; the massive local production of flint daggers, though here using bifacial techniques. This served to meet a new demand, beginning ~2350 BCE (Apel 2001), as copper items began to reappear (Vandkilde 1996). Production continued until ~1500 BCE although from ~2000 BCE onwards increasing quantities of copper and bronze items were imported from the south.

Conclusion

At the broadest scale of the western half of Europe as a whole (**Figs 7** and **8**), the overall picture is of gradually rising population following the arrival of farming, albeit with local demographic fluctuations. Yet fluctuations in stone quarrying and mining, as well as in copper deposition, still stand out prominently, so are unlikely to be due exclusively to changing population. Declines in stone quarrying and the circulation of large jade axeheads correspond with a rise in the deposition, and presumably circulation, of copper, resulting from the establishment of networks connecting the majority of the regions examined with the copper mines of southeast Europe and associated with the spread of casting technology; the items deposited were mainly axes. This peaked ~3500 BCE and then declined. Following Pétrequin et al. (2012), we interpret this as reflecting a decline in demand for prestigious, high-quality stone axeheads brought about by the novel attraction of copper axeheads, and to a lesser extent ornaments, which had become more accessible as a result of the westward spread of copper circulation. Given this metal's desirability and extensive use, it seems unlikely that the decline in copper deposition and evidence of local casting in Central Europe at the end of the 4th millennium was created by declining demand; more likely it was generated by a decline in availability as a result of a breakdown of the relevant exchange networks and perhaps decreased production at the southeast European ore sources (Radivojević and Grujić 2018). In any case, the decline is correlated with increased activity at stone quarries around 3000 BCE. Although copper ornaments increased in frequency in the following centuries, by this time Central Europe was in the Corded Ware sphere, where the significant item of male equipment was the stone shafthole 'battle-axe', though a very small number of copper ones are known (discussed in Maran 2008). This situation only changed with the Bell Beaker culture.

Circum-Alpine Europe was very different from Central Europe because it took up the dagger practice much earlier, in the later 4th millennium, associated with the innovation of copper daggers spreading from further east. The social significance of the new dagger custom, combined with the limited availability of metal at this time, led to huge demand for high-quality flint daggers. Their production involved specialised techniques and their circulation was on a massive scale. It continued until the Bell Beaker phase.

In southern Scandinavia the loss of contact with southeast European copper networks in the late 4th millennium did not lead to any response in flint production. Mass-production of flint daggers began here a thousand years later, when southern Scandinavia became connected to the Bell Beaker network and its practice of depositing metal daggers in burials but was too far away from its copper sources. Prior to this, like Central Europe, it was part of the Corded Ware sphere, with its stone shafthole 'battle-axe' focus.

Similarly, it was Bell Beaker immigrants who introduced the dagger practice to Britain and Ireland as well as the first metallurgy, though here it resulted in the extensive production and deposition of flat axeheads in non-burial contexts characteristic of the British and Irish record. Nevertheless, despite the local copper sources, Britain too had an episode of flint dagger production, albeit much shorter and much smaller in scale than the massive long-lived production in southern Scandinavia.

In sum, by adopting a broad spatial and temporal perspective to the available evidence, we have quantified, confirmed and enlarged earlier claims that the circulation of the first copper artefacts was associated with a decline in specialised stone production. This new evidence also demonstrates a contrast between Central Europe north of the Danube and Circum-alpine Europe, with daggers an important focus of male status in the latter and specialised flint daggers compensating for insufficient supplies of copper equivalents. With the appearance of Bell Beaker culture across the western half of Europe, the link between daggers and male status became universal and copper procurement and consumption expanded.

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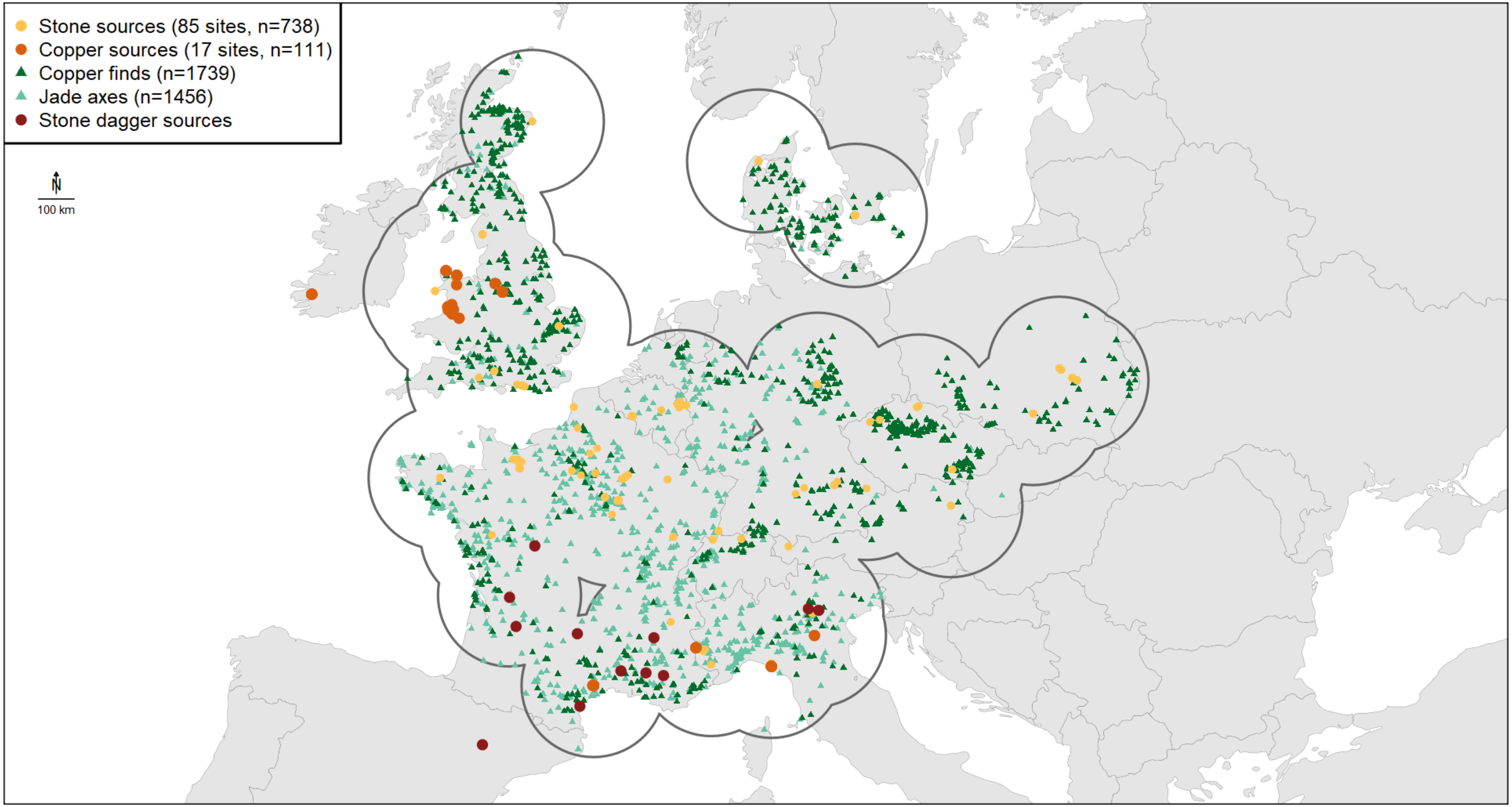

Fig 1. Map of sampled area, showing the total area covered by the 200km hinterland, which extends from the centre of each included stone or copper source

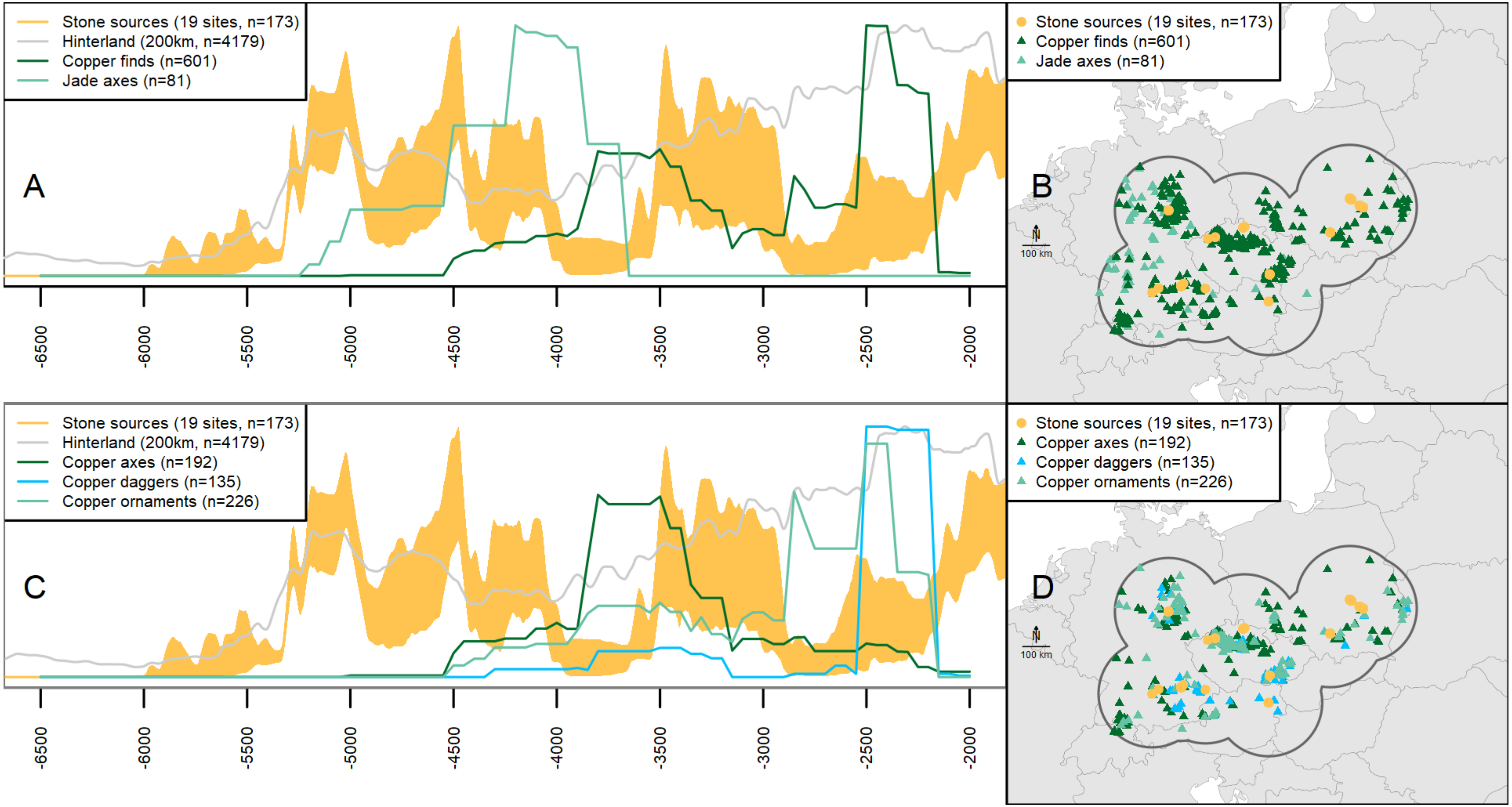

Fig 2. Central Europe (CEU). A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. Each stone source SPD is a 95% envelope created by sampling no more than 5 dates per site, repeated 1000 times. This is not necessary for the population proxy as the number of dates is very large, B. Map of the distribution of stone sources, jadeitite axes and copper finds and the composite 200 km hinterland of all the stone sources. C. As A but without the jadeitite axes and with the copper items differentiated by type. D. As B but with copper items differentiated by type. The known copper mines in this region all fall after the cut-off date of 2000 BCE.

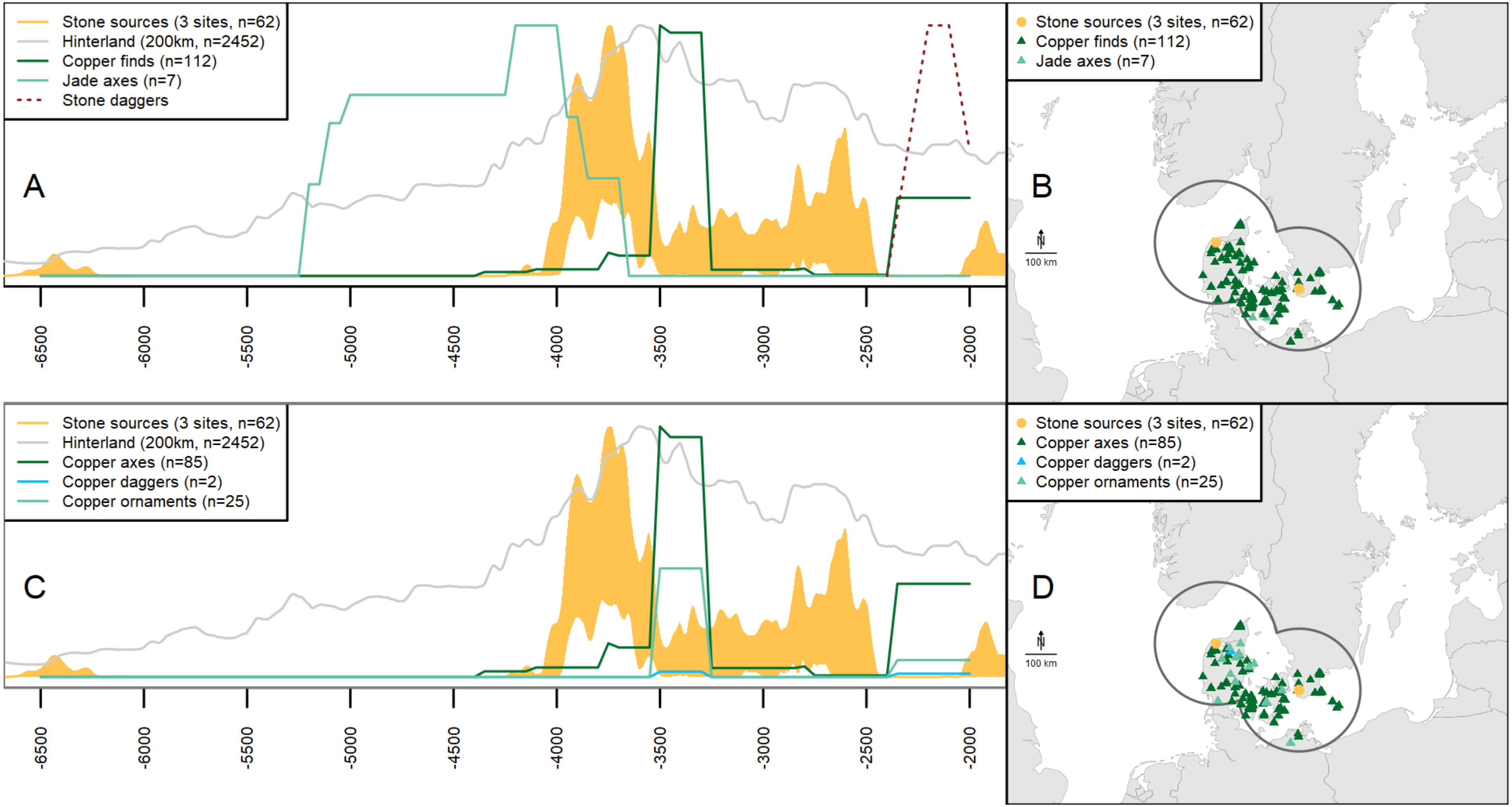

Fig 3. Scandinavia (SCAN). A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity, the approximate number of Late Neolithic I flint daggers, and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. B. Map of the distribution of stone sources, jadeitite axes and copper finds and the composite 200 km hinterland of all the stone sources. C. As A but without the jadeitite axes and flint daggers and with the copper items differentiated by type. D. As B but with copper items differentiated by type.

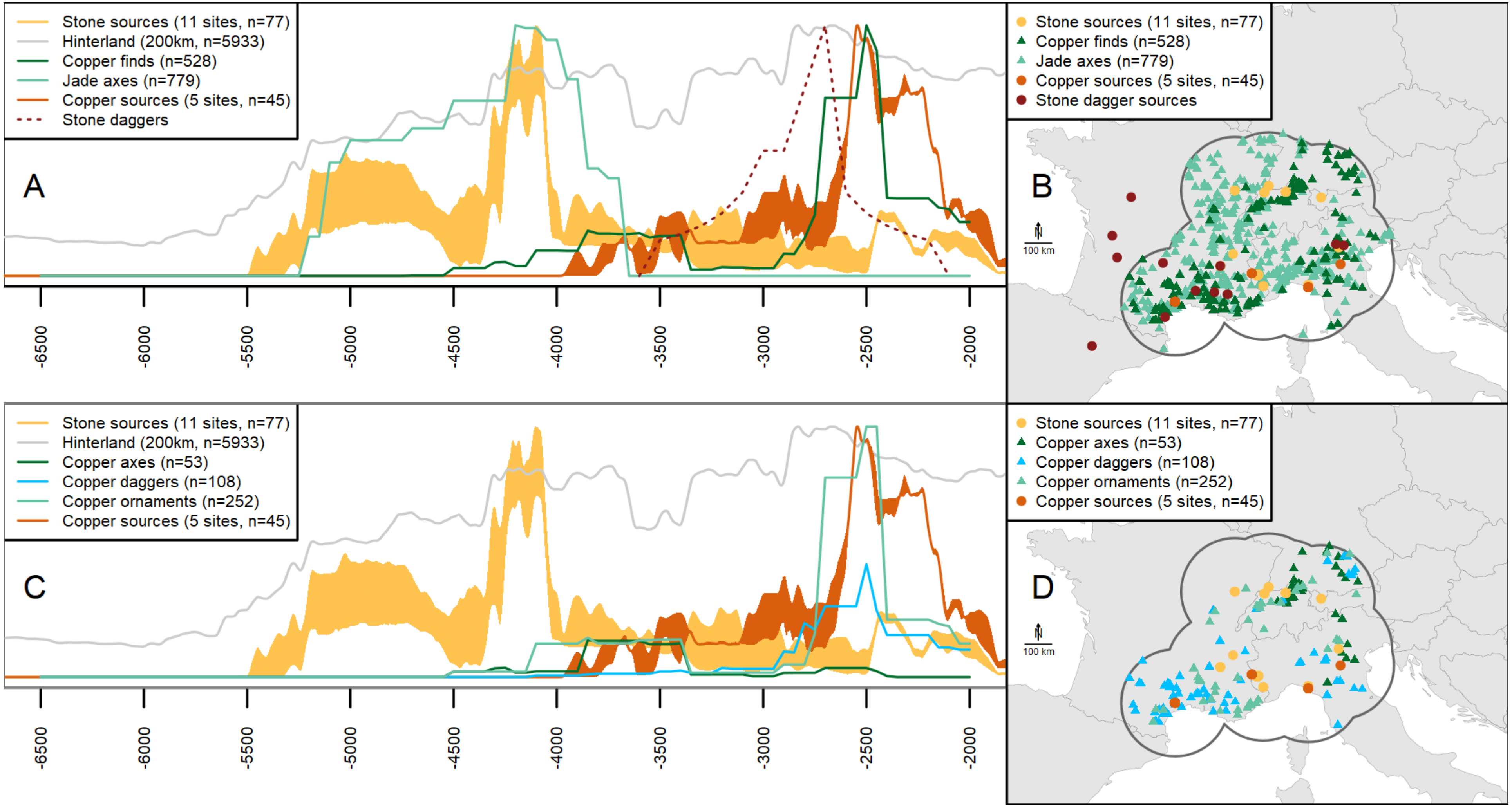

Fig 4. Southern France / Alps (SEU). A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity, copper mining activity, a semi-quantitative estimate of the frequency of flint daggers, and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. B. Map of the distribution of stone sources, copper mines, jadeitite axes, copper finds and the composite 200 km hinterland of all the stone and copper sources. C. As A but without the jadeitite axes and flint daggers and with the copper items differentiated by type. D. As B but with copper items differentiated by type.

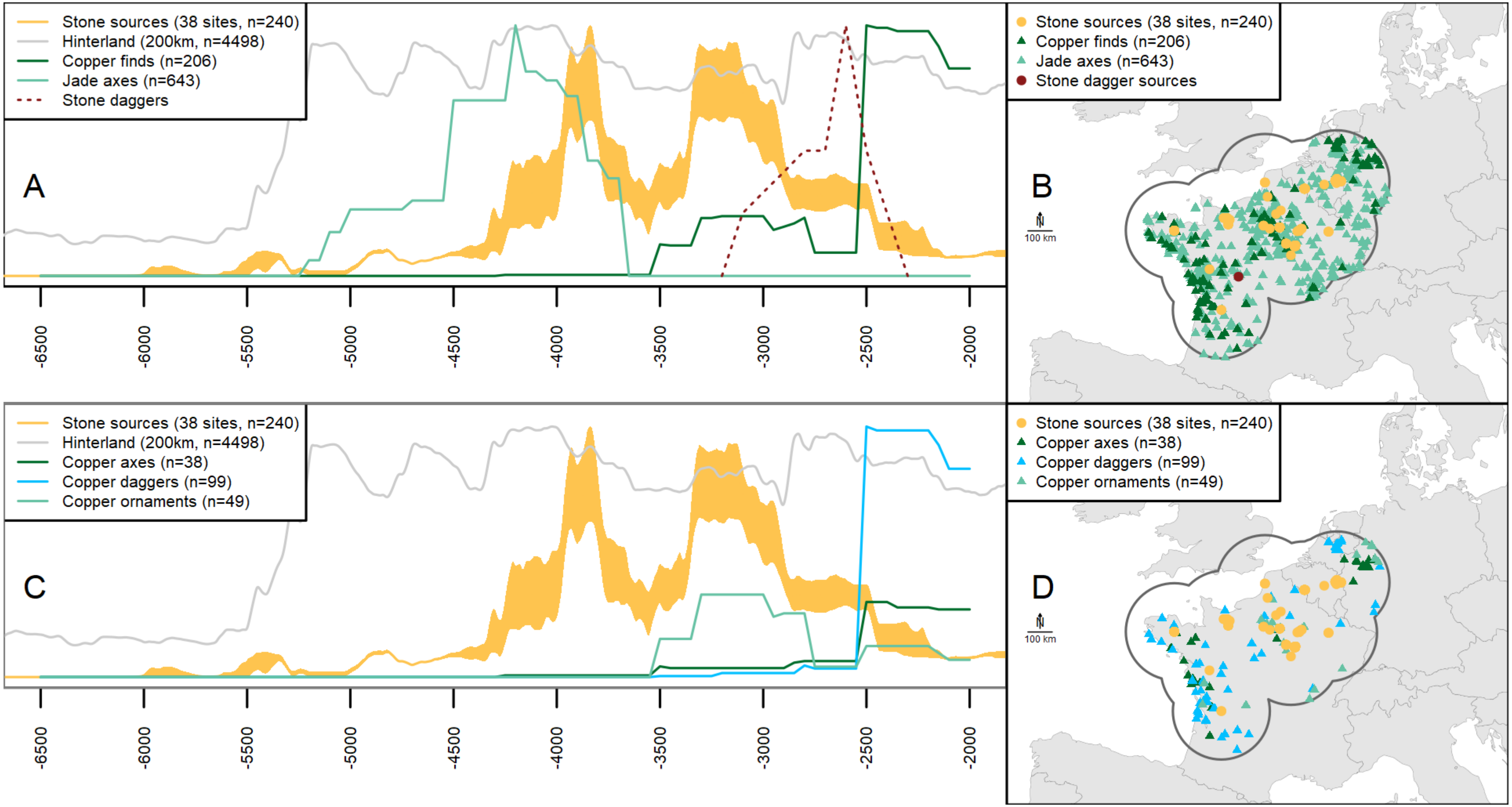

Fig 5. Northwest Europe (NEU). A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity, a semi-quantitative estimate of the production of the Grand-Pressigny flint dagger source, and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. B. Map of the distribution of stone sources, the Grand-Pressigny dagger source, jadeitite axes, copper finds and the composite 200 km hinterland of all the stone sources. C. As A but without the jadeitite axes and flint daggers and with the copper items differentiated by type. D. Distribution of stone sources and of copper items differentiated by type.

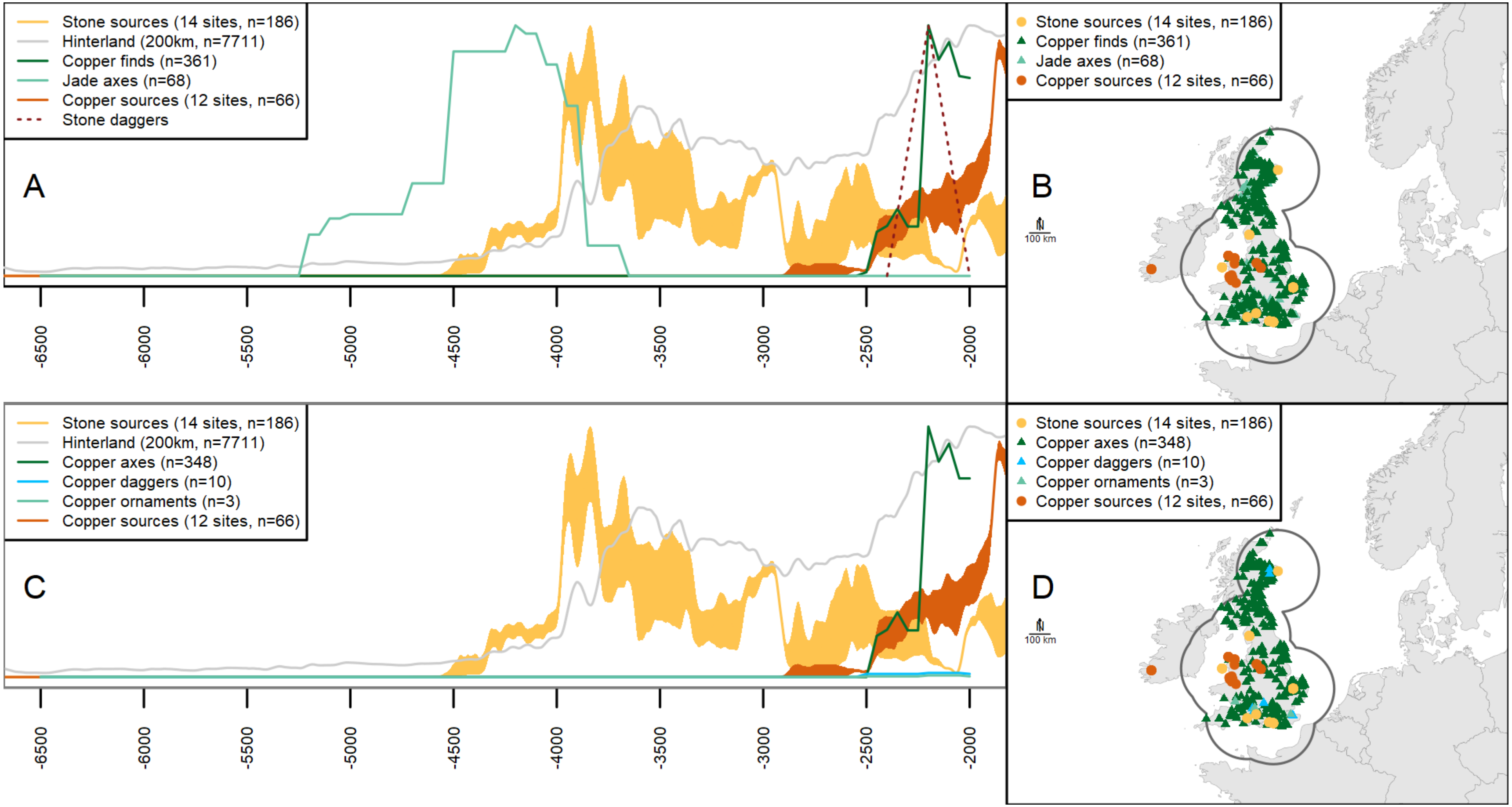

Fig 6. Britain (GB). A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity, the summed probabilities of radiocarbon-dated copper mining activity, and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. B. Map of the distribution of stone sources, copper mines, jadeitite axes, copper finds and the composite 200 km hinterland of all the stone and copper sources. C. As A but without the jadeitite axes and flint daggers and with the copper items differentiated by type. D. Distribution of stone sources and of copper items differentiated by type. For all plots, all information from Ireland is excluded except for the location and dates from the Ross Island mine.

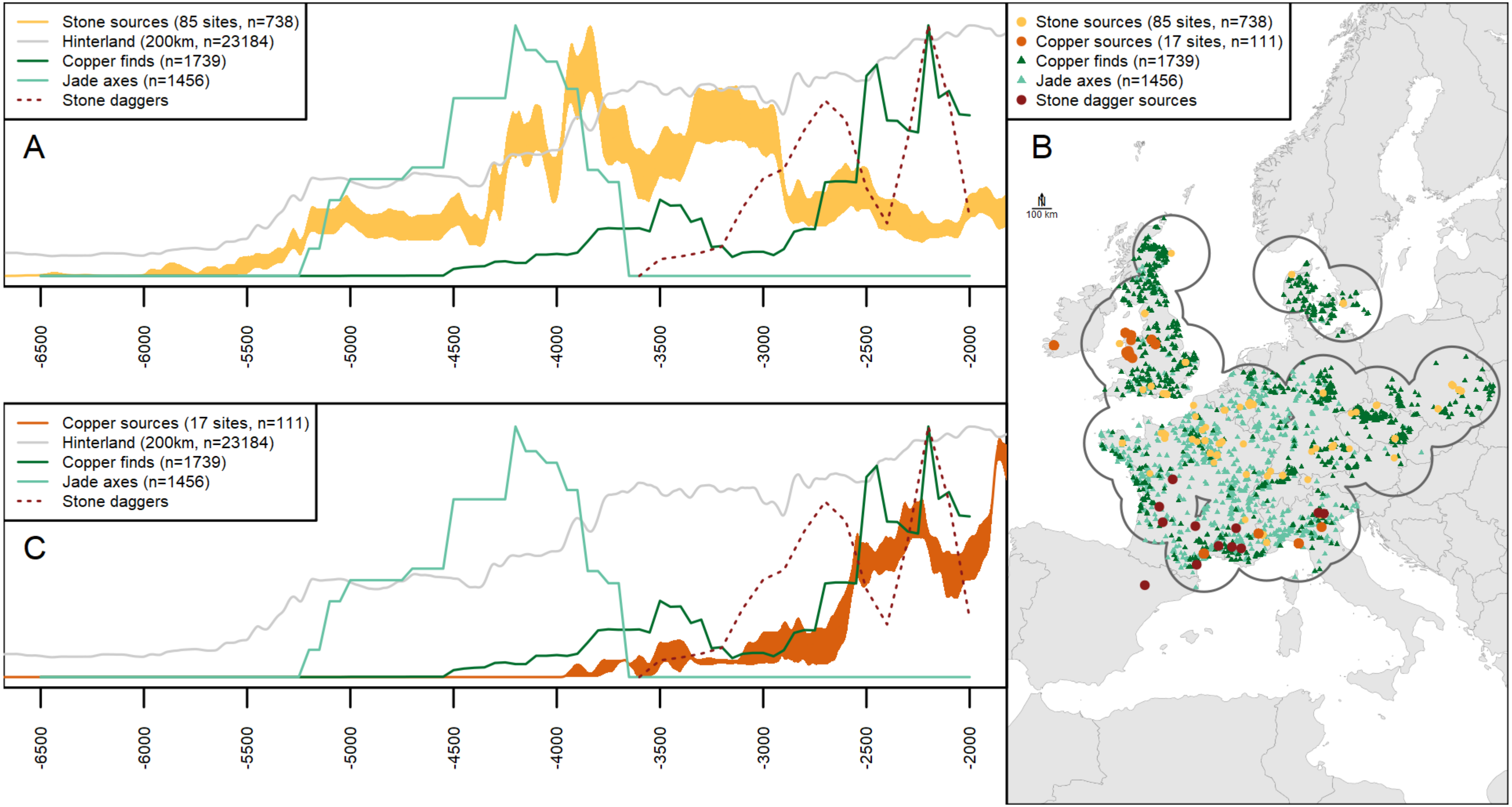

Fig 7. All regions treated as a single European-sized hinterland, A. Chronological patterns in the deposition of copper items, based on the aoristic distribution of different dated types, against the aoristic distribution of different dated types of jadeitite axes, the summed probabilities of radiocarbon-dated stone mining activity, a semi-quantitative estimate of the frequency of flint daggers, and the summed probability of all non-mining dates within 200 km of the stone and copper mines as a population proxy. B. Map of the distribution of stone sources, copper mines, jadeitite axes, copper finds and the composite 200 km hinterland of all the stone sources. C. As A but with the stone source SPD replaced by the SPD of radiocarbon dates from copper mines that fall within the period, constructed on the same principle as the stone source SPD.

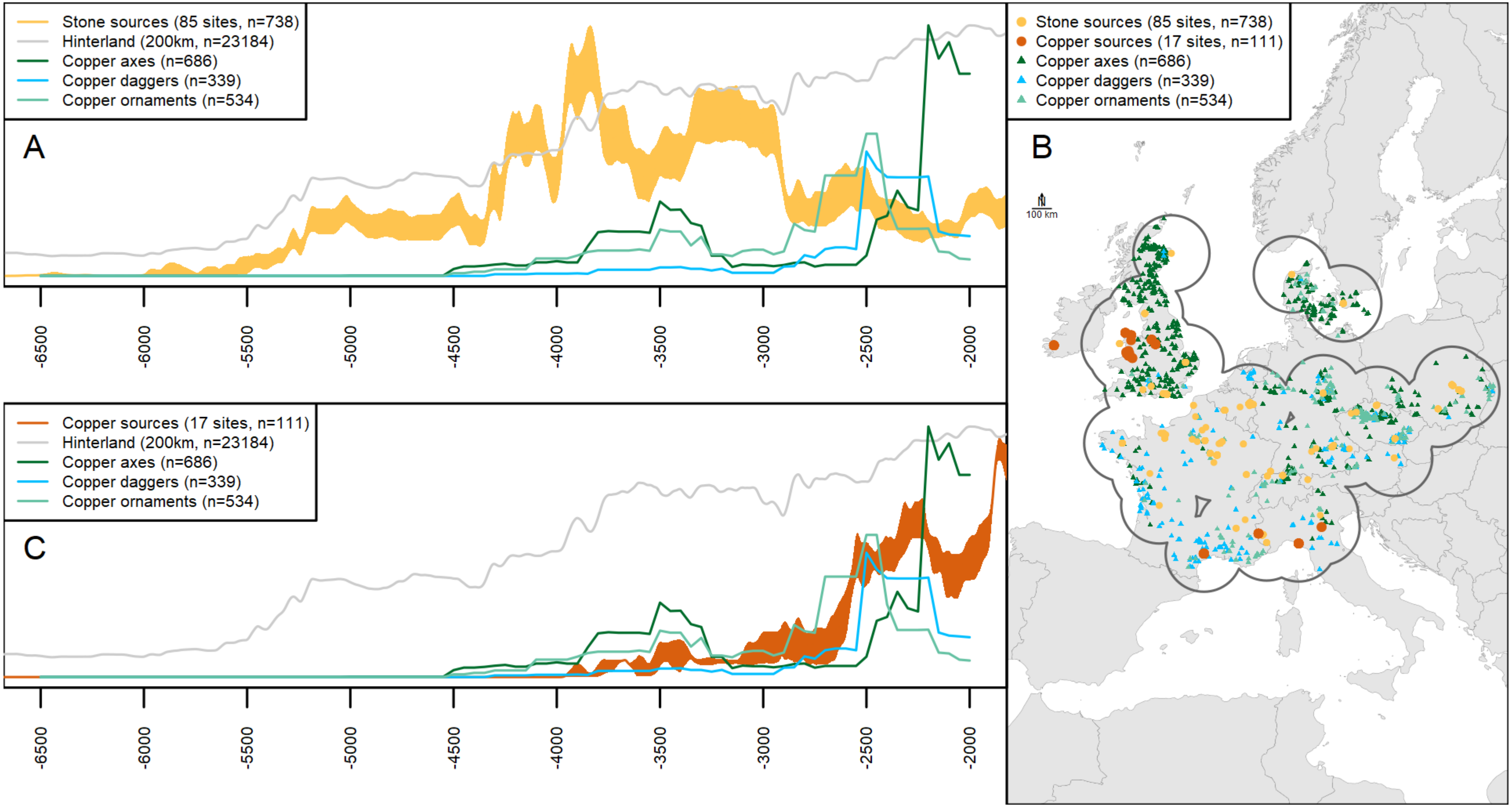

Fig 8. All regions treated as a single European hinterland. A. Chronological patterns in the deposition of different types of copper items, based on the aoristic distribution of different dated types, against the summed probabilities of radiocarbon-dated stone mining activity, and the summed probability of all non-mining dates within 200 km of the mines as a population proxy. B. Map of the distribution of stone sources, copper mines, different types of copper finds and the composite 200 km hinterland of all the stone sources. C. As A but with the stone source SPD replaced by the SPD of radiocarbon dates from copper mines that fall within the period, constructed on the same principle as the stone source SPD.