Mapping procurement areas of lithic resources and mobility patterns: A GIS-based approach to the early colonization of Western Mediterranean islands

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Abstract:

Is it possible to define based on the circulation of chert and obsidian the patterns of mobility and the procurement strategies of lithic resources among the first inhabitants of the Western Mediterranean islands of Corsica and Sardinia?

This paper tackles this question through the following research objectives: 1) To build, through bibliographic research, a systematic database including all published data concerning the presence of chert and obsidian artefacts in Sardinian-Corsican sites dated to the Pre-Neolithic and the Early Neolithic; 2) To create a specific cartography on the geographical distribution of these lithotypes across the two studied islands. Data have been geo-referenced with the QGIS 3.20 open-source software, both to make them visible on the map and to introduce the fundamental variables of space-territory into the research; and 3) To define mobility patterns for the supply of chert and obsidian based on the available results of provenance analyses, using QGIS to draw the movement lines from the findspot to the source with the principle of the minimum effort: that is, through the development of a Least Cost Path Analysis (LCPA). This is to say that the tracing of the probable routes followed by humans will be based on the calculation of the shortest distances from the raw material sources to their findspots based on orography and topographic variables.

The results on the procurement areas and mobility patterns to perform specific tasks, as lithic procurement, will contribute to the debate on resource management and landscape knowledge of early human groups colonizing insular environments.

Keywords: lithic raw materials; procurement strategies; mobility patterns; GIS; Corsica; Sardinia

1. Introduction and background

This paper deals with the procurement of lithic raw materials among the first human groups to settle in the Western Mediterranean islands of Corsica and Sardinia. Our specific

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aim is to develop a hypothesis for the procurement strategies of chert and obsidian in early chronologies and for the mobility patterns associated with the pursuit of this activity.

Several studies developed in recent decades confirm the possibility of defining human mobility based on the distribution of raw materials. Although only large-scale surveys of obsidian circulation have been conducted in the Western Mediterranean islands to date (De Francesco *et al.* 2012; Freund & Batist 2014; Tykot 2011; Tykot & Ammerman 1997; Vaquer 2007), the presence in Sardinian-Corsican archaeological sites of lithotypes - obsidian and chert - whose sources are known paves the way for future small-scale studies of raw material procurement and circulation, as well.

Obsidian is the mobility marker par excellence since its origin is restricted to few, well-known and localized sources (Lugliè *et al.* 2007). Chert, instead, is more ubiquitous and common, available as primary and secondary lithologies at various localities. It is thus a good indicator for preferential selection and management of resources, for example, in terms of quality rather than proximity, when fine-grained chert procured from distant sources is preferred to poor-quality local chert (Fernandes *et al*. 2015; Luedtke 1992; Masson 1983).

In this research the lithic procurement will be investigated in relation to the earliest evidence of human presence in Corsica and Sardinia, that is, from sporadic occurrences in the Pre-Neolithic to the first systematic colonisation in the Early Neolithic, addressing the following research questions:

1. Is it possible to define based on the circulation of raw materials the mobility patterns of the pioneering populations of Corsica-Sardinia while performing a specific task such as lithic procurement?

2. Is it possible to derive from available data on palaeoenvironment, subsistence strategies, type and location of settlements, circulation of chert and obsidian and patterns of mobility, the procurement strategies of lithic resources?

To answer these questions, particular attention has been devoted to the interplay among humans and landscape by georeferencing and querying the data spatially with a GIS software. Patterns of mobility have been traced with the principle of minimum energetic cost (Least Cost Path Analysis), rather than as the crow flies.

1.1. Sardinian-Corsican Geography and Palaeoenvironment

Corsica and Sardinia (Figure 1) have at different times been united into a single landmass and have maintained a condition of permanent insularity ever since the Oligocene-Miocene, around 21 million years ago (Bonifay *et al.* 1998; Lugliè 2018; Sartori 2001).

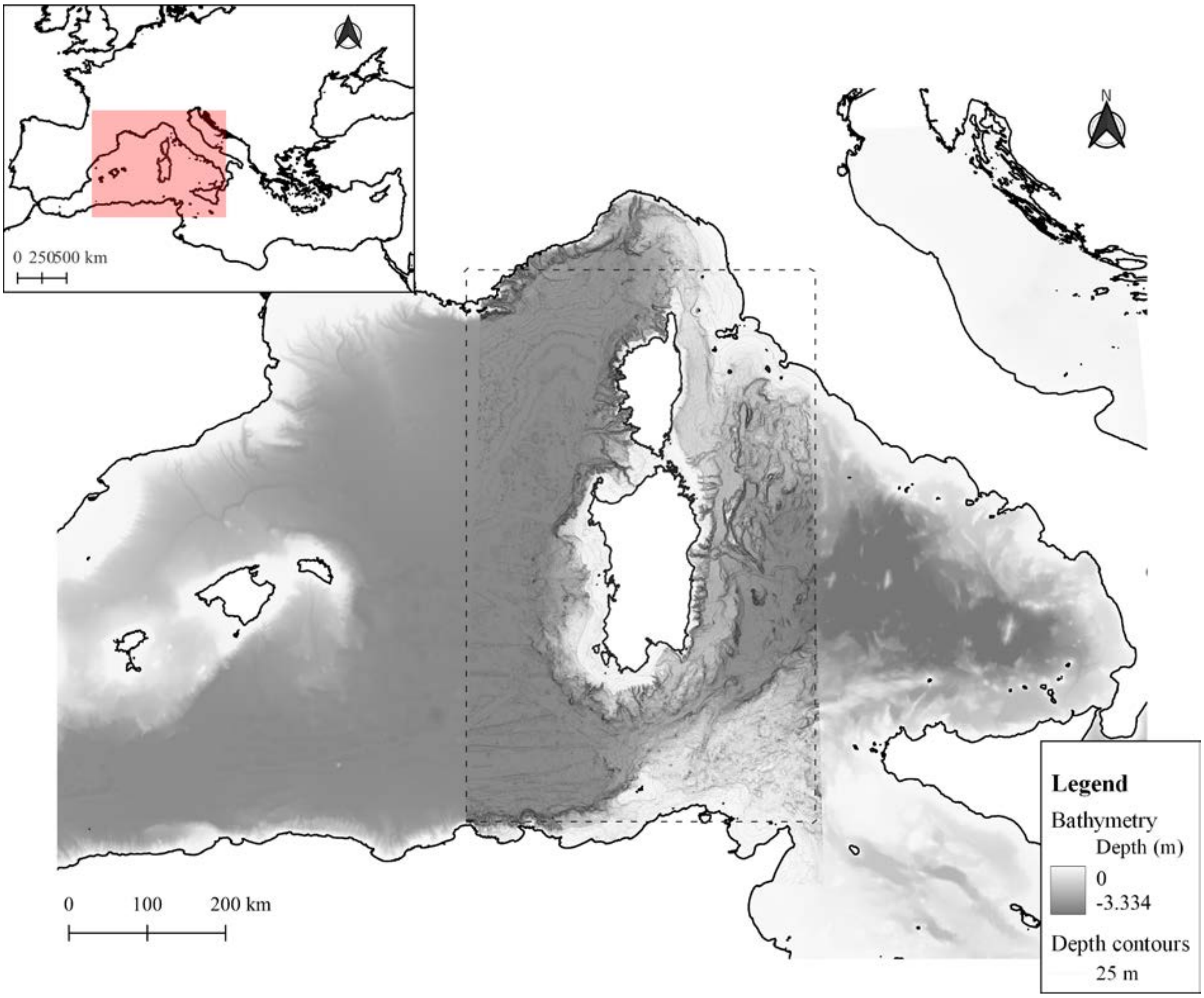

Figure 1. Location of Corsica and Sardinia islands within the western Mediterranean. Constructed with QGIS 3.20.

Very few palaeoenvironmental data about the Late Pleistocene and Early Holocene of this region are currently available.

Fully glacial conditions were reached for the last time at ca. 30.000 BP (Paterne *et al.* 1986). The sea dropped to a maximum of -120 m below its current level at ca. 17-18 ka BP (Fairbanks 1989) and Sardinia-Corsica were thus merged into a single landmass (Antonioli & Vai 2004; Orombelli *et al.* 2005; Shackleton *et al.* 1984), populated by the same fauna: massive presence of *Prolagus sardus*, herds of *Megaloceros cazioti* as the only large mammal and absence of dangerous or competitive carnivores. The only attested predators were the *Cynotherium Sardous*, possibly the *Vulpes vulpes Inchnusae*, and indeterminate mustelids, all rather small (Bonifay 1998; Mussi & Melis 2002).

With the end of the glaciation and the onset of the Holocene the megafauna disappeared (Klein Hofmeijer & Sondaar 1993; Vigne 2000). As the climate warmed, aside from the cold parenthesis of the 8.2ky event (Alley & Ágústsdóttir 2005), the sea level gradually began to rise, and the Corsican-Sardinian block was separated by a seaway of 10 km wide: at ca. 9 ka BP the two islands were thus formed (Shackleton *et al.* 1984).

From 8 ka BP onwards, the Mediterranean basin began to be populated by drought-tolerant faunal taxa (Pittau *et al.* 2012) and plant species pertaining to the thermo- and meso-Mediterranean maquis, together with *Celtis sp.* and *Pinus laricio* in mountain forests (Costa *et al.* 2003). The landscape of both islands was dominated by *Erica* maquis and scrublands at low elevations, while in Corsica forests prevailed at high elevations. The prolonged dominance of *Erica* especially in eastern Sardinia and southern Corsica attests for warmer-drier summers and cooler-moister winters than today, accompanied by high natural fire activity to which this species is extremely well-adapted (Melis *et al.* 2018).

1.2. Early peopling of Corsica-Sardinia

Sound knowledge of Sardinian-Corsican prehistory is rather recent. Although the first discoveries and research date back to the late 19th century, it was not until the 1960s that archaeological excavations were conducted with a methodological approach in Corsica (Atzeni 1966; Bailloud 1969; Gagnière *et al.* 1969) and Sardinia (Atzeni 1962; Lilliu 1961; 1967).

1.2.1. Palaeolithic

The timing of the first human settling on the islands is currently debated. The first systematic peopling is to be dated to the Neolithic, but occasional settling has occurred before, possibly during the Late Pleistocene and indisputably in the Early Holocene-Mesolithic; while other authors state it could even be dated to the Middle Pleistocene-Palaeolithic (Bini *et al.* 1993; Bini 1999; Martini 2017; Mussi & Melis 2002).

At present, however, there are no consistent radiometric dates that support a Pleistocene peopling of the islands. In Corsica, one single site has been cautiously attributed to the Palaeolithic, but dating only refers to weak clues of human presence (Bonifay *et al.* 1998). In Sardinia not only are dates available relative, but sometimes based on dubious stratigraphic correlations or on evidence whose significance is debated (Hofmeijer & Sondaar 1992; Sondaar *et al.* 1986), and most findings are out-of-context (Martini 2017).

Several authors have pointed out that, in the absence of reliable evidence, claims on the settlement of the Corsican-Sardinian block prior to the Holocene should be cautious (Cherry 1992; Luglié 2009a; Romagnoli & Martini 2012).

1.2.2. Mesolithic

The chronology obtained by absolute dating for the Mesolithic in Corsica-Sardinia covers a timespan of about two millennia, from the 9th millennium to the third quarter of the 7th millennium BCE included (Luglié 2017). Only about 30 sites as a total are currently known, scattered across the 8.722 km^2 territory of Corsica and the 24.090 km^2 of Sardinia.

Given the availability of only small terrestrial fauna and the coastal distribution of the settlements, subsistence strategies had to be focused on the hunting of small game and marine resources as well as on the gathering of fruit, vegetables, tubers, berries, and roots (Magdeleine & Ottaviani 2000). It should thus be better said that these early settlers were not actually hunters, but rather trappers, as well as fishers (Costa *et al.* 2003; Costa 2004).

Mesolithic sites must have been inhabited occasionally and for short periods by mobile groups, probably travelling from the peninsular coast (Luglié 2009a).

1.2.3. Early Neolithic

After a void of about 500 years, from around 5700 cal. BCE onwards in both Corsica and Sardinia evidence of Neolithic settlements starts to appear. The gap is chronological as well as behavioural and genetic (Luglié 2014; 2017).

Human settling in the Neolithic was systematic, and eventually led to the colonisation of the most favourable habitats. It was characterised by open-air settlements with buildings (though coexisting with older housing forms such as cave dwellings and shelters), a new economy based on production, the use of pottery and a different selection and management of lithic raw materials (Lugliè 2017).

The arrival of Neolithic people in Corsica-Sardinia came along with the deliberate introduction of domesticated species of both plants and animals. It seems likely that the dense vegetation cover led to a delay in the spread of agricultural economy (Lugliè 2017; Revelles *et al.* 2019), and instead to the development of pastoralism along with the persistence of hunting (Atzeni 1987; Depalmas *et al.* 1998), fishing and the collection of shellfish (Lugliè 2009b). The Pre-Neolithic economy was thus partly maintained, although accompanied by the emergence of novel technologies and long-distance connections.

The Early Neolithic covers ca. a thousand years, roughly corresponding to the VI millennium BCE (Lugliè 2009b; 2017). The accomplishment of the neolithization - with a fully productive economy and an articulated society based on permanent settlements - is to be dated to the Middle Neolithic, from the 5th millennium BCE onwards.

2. Materials

Published data on 26 Pre-Neolithic (PN) and 109 Early Neolithic (EN) archaeological sites were used for this research, of which 12 PN + 27 EN in Corsica and 14 PN + 82 EN in Sardinia, dated both by absolute methods and typological seriation. These archaeological sites are all those known on the islands for the relevant chronologies, according to the literature reviewed.

The geographic area that was considered includes the entire Corsican-Sardinian block, with islets and archipelagos, thus excluding the Tuscan islands. For the geo-referencing of both archaeological sites and raw material sources, geographic coordinates were used when available.

3. Methods

3.1. Data collection: bibliographic review and database

A bibliographic review was carried out on papers published as conference proceedings, books and communications related to Pre-Neolithic and Early Neolithic archaeological sites in Corsica-Sardinia and, when available, on the description of lithic complexes and on the location of raw material sources. The reference bibliography is updated to the year 2021.

Alongside the bibliographic review, a specific database was constructed in Microsoft Access compiling all the relevant information: that is, the type of site and its location, together with dating methods and data on palaeoenvironment, when given (Tables 1 and 2); the amount and composition of the lithic assemblage (Table 3); and, if available, the number of obsidian and chert items and the results of provenance analyses (Tables 4, 5, 6 and 7) (See Supplementary File 1 - Appendices).

Table 1. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of the site (1/2).

SITE	TYPE OF SITE	REGION	AREA	AGE	PHASE	DATING METHODS	FACIES (ceramic)
Strette XIV and XX (A Petra - Barbaggio) *	small shelter	Corsica	NE	range 5600-5000 cal BCE | layer XXb: 6480 ± 480 BP | 6420 ± 300 BP (very high standard deviation)	Early Neolithic	C14 on wood charcoal and chrono typology of ceramics	Cardial Ware (and poinçonnée?)

Table 2. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of the site (2/2).

ARCH LEVEL	COORDINATES REF	X	Y	H_A.S.L. (in m)	REFERENCE	NOTES
layer XIV	map + Google Maps. APPROX	42.69	9.33	20 or 44 QGIS	Costa et al. 2000 | Tykot 2002 | Costa et al.2002	The distance from the coast was the same in the EN as it is now. From autumn to spring the nearby River Strette swells and regularly floods the site. However, it is likely that the position of the river has changed over time and that the site was not as prone to flooding in the Early Neolithic period.

Table 3. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of the lithic assemblage.

SITE	TOTAL ITEMS IN ASSEMBLAGE
Strette XIV and XX (A Petra - Barbaggio) *	1036 (local rocks between 75 and 83%: quartz, rhyolite, granitoids, serpentinites; high quantity of obsidian; chert)

Table 4. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of obsidian artefacts in the lithic assemblage (1/2).

SITE	OBSIDIAN	% IN ASSEMBLAGE	N° IN ASSEMBLAGE	N° ITEMS ANALYSED
Strette XIV and XX (A Petra - Barbaggio) *	Yes	11%	117	10

Table 5. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of obsidian artefacts in the lithic assemblage (2/2).

ANALYSES	SOURCE	OUTCROP (SUBSOURCE)	TECHNOLOGY	TYPOLOGY
EMP (Electron Microprobe)	Monte Arci	9 SB2; 1 SC. No SA, no SB1.	Introduced as finished products. No evidence of knapping on site.	Poor typological variability. Mostly simple flakes. Few blades and retouched (sharp armatures).

Table 6. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of chert artefacts in the lithic assemblage (1/2).

SITE	CHERT	% IN ASSEMBLAGE	N° IN ASSEMBLAGE	N° ITEMS ANALYSED
Strette XIV and XX (A Petra - Barbaggio) *	Yes	5%	50	N/A

Table 7. Example of an entry in the database of EN archaeological sites in Corsica and Sardinia, focused on the characteristics of chert artefacts in the lithic assemblage (2/2).

ANALYSES	SOURCE	TECHNOLOGY	TYPOLOGY	NOTES
visual characterisation?	Sardinia (probably)	Few evidence of knapping aimed at obtaining flakes with direct percussion (hard hammer) or knap on anvil. Most of the artefacts introduced as finished products	Poor typological variability. Mostly unretouched flakes. Few blades and retouched (sharp armatures).	Introduced pieces with high technical investment vs. local pieces with low investment. Probable satellite site, inhabited by small groups originating from a permanent site.

3.2. Cartography: building the map and georeferencing

A new blank project was created in QGIS 3.20, the latest released version of the Geospatial Foundation's (OSGeo) Open-Source Geographic Information System. The datum WGS84 was chosen as the Project Coordinate Reference System (CRS) and it was associated with UTM projection, zone 32N (EPSG: 32632).

Digital Terrain Models (DTMs) representing the current morphology of the islands' terrain were downloaded from the geo-portal of Sardinian Region and from the geoservices website of France, respectively as 60 raster layers obtained from level curves and elevation points of the geo-topographic database of Sardinia scaled to 1:10.000 (DBGT10K) (RAS 2021a) and as 35 raster layers divided among Haute-Corse and Corse-du-Sud from the gridded DTM of the French territory at medium scale (RF 2021a).

The vector layer for Europe coastlines was downloaded from the European Environment Agency (EEA 2021). Corsica and Sardinia were isolated as two separate polygons using the "Clip" geoprocessing tools. The DTMs were merged and the two resulting rasters (one for each island) were clipped using the "Clip raster by Mask Layer" tool and the polygons as masks. Two DTMs for the landmasses of Corsica and Sardinia were thus obtained. Contour lines were also shown every 25 m and 100 m indicating the exact elevation of the terrain above sea level.

The General Bathymetric Chart of the Oceans (v. 2020) was downloaded for the Western Mediterranean (GEBCO 2021); the waters off Sardinian-Corsican coasts were then modified to show isobaths every 25 and 100 m under the sea level.

Two vector layers of natural Sardinian water streams were combined, one from the DBGT10K (RAS 2021b) representing in detail the course of the main rivers' basins and the other from the ISPRA (2021) depicting the entire national hydrographic network. The latter was filtered according to the fluvial order classification, limited to "1-2" (Horton 1945; Strahler 1954). The indication of navigability was also filtered, and navigable rivers were indicated with different colours and thicknesses on the map.

The vector layer for Corsica water streams was downloaded from the geo-catalogue (RF 2017) and was then filtered to depict the sole watercourses of natural origin. All resulting streams were thus filtered again to show only those with permanent flow. The width of the rivers was depicted on the map with a different line thickness depending on whether they were 15-50 wide or less than 15 metres. According to the attribute table, none of these water streams was navigable.

Even though there are several natural surface water bodies in the Corsican territory, particularly lakes in the mountains and ponds on the coast, they were not represented on the map due to their small size (<0.50 km^2) (Donta *et al.* 2005). The same applies to Sardinia but, as there is a natural lake of significant size (Lake Baratz, about 800 m diameter), it was shown in the map through filtering of the polygon vector layer of the bodies of water (SP_ACQ) downloaded from the DBGT10K. Ponds, marshes, and lagoons were excluded, as their current presence is unstable (RAS 2019).

Subsequently, palaeocoasts were drawn: only the depth and morphology of the seabed were considered, thus excluding possible vertical tectonic movements, such as uplift or subsidence. The lines of four approximate palaeo-coasts were drawn by isolating the relevant isobaths on the bathymetric DEM, following the chronology of sea-level rise as described in the literature: one at -35 m at 7 ka BCE (Shackleton *et al.* 1984) plus two for 5 ka BCE, at -10 or -5 m (Allegrini-Simonetti 2000), framing the Early Neolithic; and one at -45 m at 9 ka BCE (Pasquet & Demouche 2012), maximum threshold of the Pre-Neolithic according to absolute dates. In the absence of reliable dates, palaeocoastlines were not represented prior to this threshold, despite the sites attributed to the Palaeolithic.

The final step in the construction of the cartography was the geo-referencing of archaeological sites and raw material sources. As virtually no coordinates were given in the literature regarding the sites, a first attempt to locate them was made via Google Maps, using the simple search tool by name or a combination of satellite images, photos and maps given in reference papers plus manual searching. Coordinates were exported and saved as .csv UTF-8 comma-delimited text files in simple databases composed by the name of the site and the longitude-latitude in decimal degrees. They were then loaded in QGIS as point vector layers.

For sites not found, a different procedure was followed. When maps were found in the literature, these were georeferenced and then added to the project as raster layers, thus enabling the location of sites to be drawn manually directly on QGIS as point vector features (Figure 2).

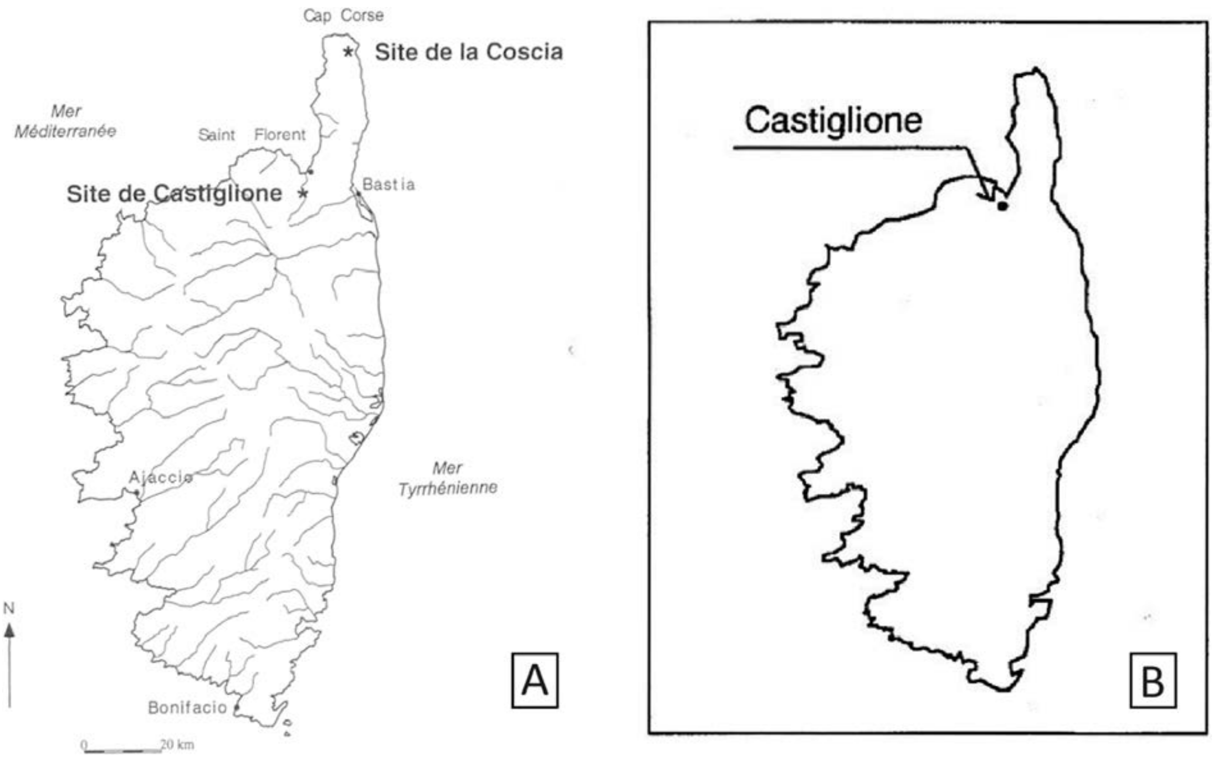

Figure 2. Example of maps found in the literature and georeferenced on QGIS to be used as a reference for the location of the site of Castiglione, Corsica (Bonifay *et al.* 1998: fig. 1 (A); Salotti *et al.* 2000: fig. 1 (B)).

In case it was a cave or shelter site, the regional caves layer was used as a reference (RAS 2021c; RF 2021b). Current municipalities and mountains were used as landmarks to confirm the correct location whenever possible. The “Sample raster values” tool was then used to extract the elevation of each site expressed in metres above sea level and approximated to the integer.

3.2.1. Locating raw material sources

Based on current data, the only sources of both obsidian and chert among the two islands are in Sardinia (Bonifay *et al.* 1998; Costa *et al.* 2003; Leandri & Fernandes 2020; Magdeleine & Ottaviani 2000). In the entire Western Mediterranean only four obsidian sources have been located to date, all belonging to island environments within Italy: Lipari, Palmarola, Pantelleria and Sardinia (Tykot 1995: 61-77).

The first comprehensive survey of Sardinian obsidian sources was undertaken in 1958 (Puxeddu 1958), while their complete chemical characterisation dates to only thirty years ago and was conducted by R. H. Tykot through major and minor element composition analysis combined with visual examination. As a result, nine geo-chemically different obsidian sources were located in Sardinia, all from the Mount Arcu volcanic complex, of which only four are of archaeological interest (i.e., were found in archaeological sites): SA, SB1, SB2, SC (see Tykot 1992; 1995: 83-87; 1996; 1997; 2002; for recent analysis see De Francesco *et al.* 2012).

On the other hand, regarding chert, several potential sources are known, scattered throughout Sardinia. The most frequently mentioned is the Perfugas basin in the northern Anglona region; nearby, there are outcrops in the municipalities of Laerru and Usini; or at the Montiferru massif near the west coast of the island and in the Campidano plain south-west, not far from Mount Arci (Bressy-Leandri 2012).

In the Central Campidano, chert deposits alternate with marine sediments in a small alluvial terrace of the Riu Serri along the slope of the Sedda Su Cardu hillock in Santa Maria Is Acquas locality; pebbles transported by floods can also be found in this area (Mussi & Melis 2002). Other chert-bearing formations are known but without considerable knappable qualities (Leandri & Fernandes 2020).

All sources were located in QGIS through the sole georeferencing of maps found in the literature: for the sources of obsidian, the maps provided by Tykot (1995: fig. 29) and Lugliè (2017: 42); while for the sources of chert, the sole map of Bressy-Leandri (2012: 41).

3.3. Least Cost Path Analysis (LCPA)

For the archaeological sites for which sources of obsidian or chert were known, analyses were applied to reconstruct the lowest energy cost routes for procuring the raw material. To do so, the “Least Cost Path” command of QGIS was used: this analysis calculates the easiest route between two points based on a cost surface in which each cell is given a value based on criteria defined by the user, and that value represents the cost of moving across the cell in space. Here we took the land slope as the sole criterion for the construction of the cost surface (i.e., we used the DTMs) as it was the only detailed and reliable data on the palaeo-landscape of the islands.

Since orography was taken as the only relevant factor, both streams and bodies of water and the sea were excluded from the calculation of movements. For the routes in which the crossing of the sea was necessary - i.e., for all displacements from Corsica to Sardinia - it was decided to consider as the most probable path the shortest route as the crow flies from the Corsican palaeo-coast to Sardinian palaeo-coast, drawing a simple straight line.

For all movements from Corsica to Sardinia, the Least Cost Path was therefore constructed in two stages: 1) from the settlement to the coastal location at the shortest distance as the crow flies from Sardinia; 2) from the corresponding nearest Sardinian dock to the raw material source. Regarding the submerged stretch of land between the current coastline and the paleo-coasts, as this was a virtually unknown part of the territory from the point of view of slope, no routes were drawn there.

Two maps of land gradient were constructed on the basis of Corsican and Sardinian DTMs using the simple QGIS “Slope” tool. The slope map was then used as the cost surface or “friction surface” layer (Gustas & Supernant 2017) for the calculation of the LCPA.

Archaeological sites were considered as start-points and raw material sources as endpoints. As regards chert, the precise coordinates of the outcrops were not available, just the areas as polygon layers; since the LCPA constructs paths using points, the centroids of the polygons were calculated using the appropriate QGIS command and were then used as endpoints for the analysis. On the other hand, in the case of obsidian, the outcrop areas were known and vectorized as polygons but also as precise point coordinates, which were several for each geochemical type; all known coordinates were thus used as endpoints for the software to trace the route to the nearest one.

4. Results

Two maps were obtained on QGIS representing all known archaeological sites to date in Corsica-Sardinia, respectively for the Pre-Neolithic (Figure 3) and the Early Neolithic (Figure 4). A different pattern is visible in terms of quantity and location of settlements: while there is little evidence of human presence during the PN, the number of settlements increases sharply in the EN, especially in Sardinia.

As results in the database, out of these sites, only a total of 11 PN and 38 EN archaeological levels have yielded obsidian or chert in their lithic assemblages, with an absence of information regarding the rest of the sites. The presence of these lithotypes is rather rare and usually in such small quantities as to be insignificant in the PN, while it increases strongly in both amount and frequency with the EN. The results of the bibliographic review will be examined elsewhere in depth, while the outcomes of the LCPA will be addressed here.

Four maps were obtained representing the likely routes taken by humans for the procurement of lithic raw materials, respectively: for the Mesolithic (Figure 5); for the procurement of obsidian from Corsica during the EN (Figures 6, 7, 8, 9); for obsidian within EN Sardinia (Figures 10 and 11); and for chert in both islands during the EN (Figure 12). All distances are calculated for the outward journey from the settlement to the source and must be doubled to get the full calculation of the km travelled to get the raw material and back to the place of departure.

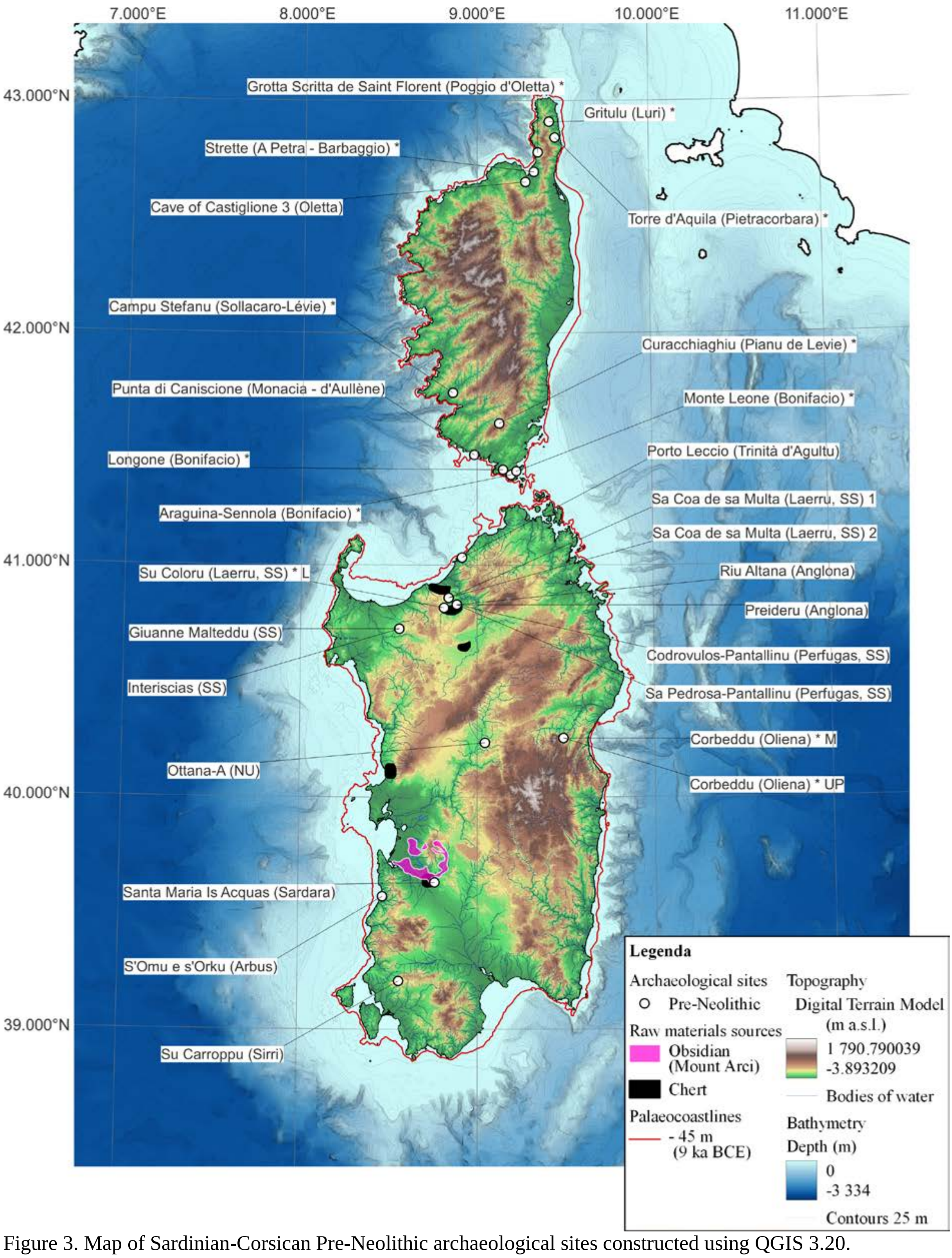

Figure 3. Map of Sardinian-Corsican Pre-Neolithic archaeological sites constructed using QGIS 3.20.

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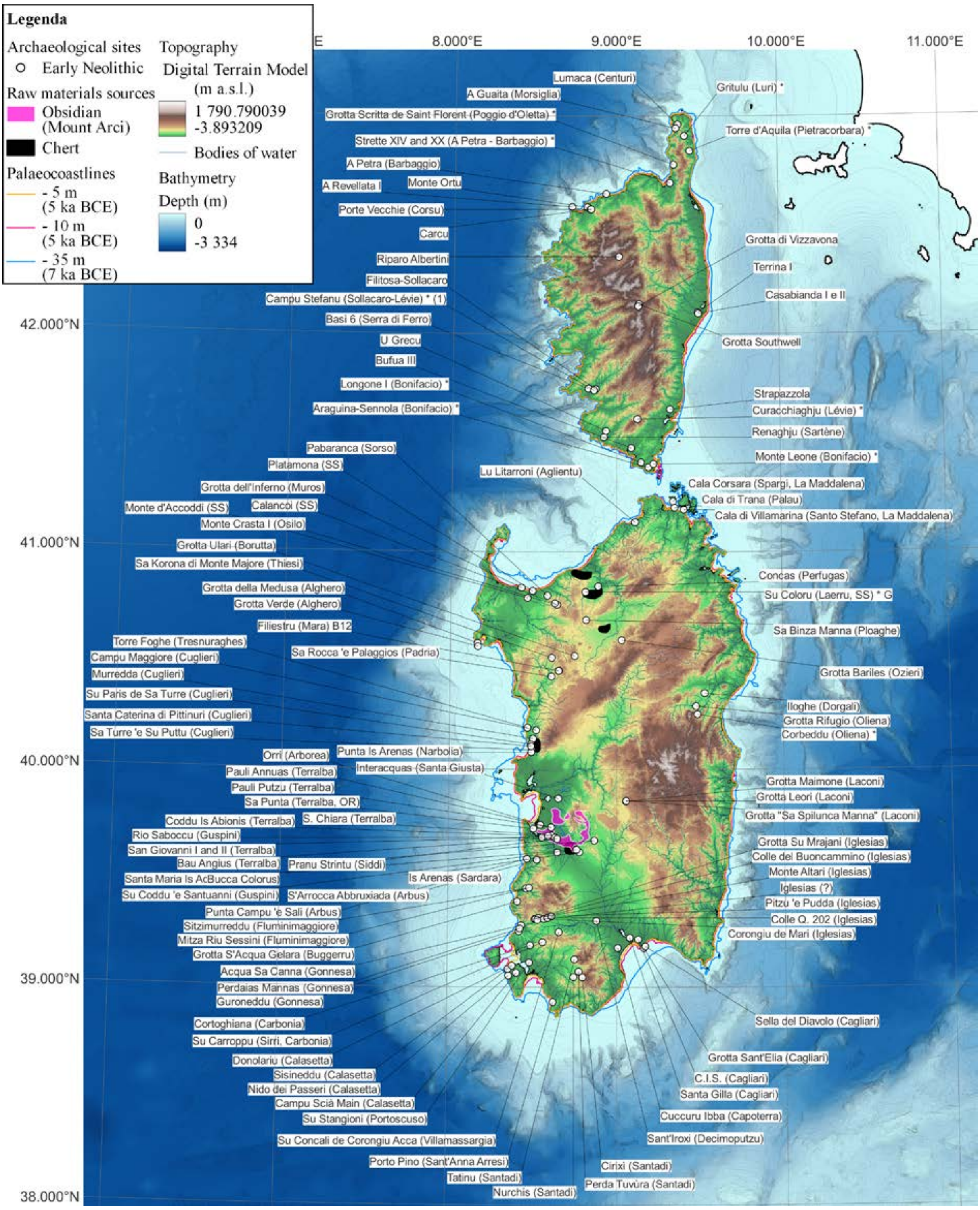

Figure 4. Map of Sardinian-Corsican Early Neolithic archaeological sites constructed using QGIS 3.20.

4.1. Least Cost Paths during the Pre-Neolithic

As a result of scarce available data, a map was obtained for Mesolithic mobility patterns for the provisioning of chert, referring to a total of three settlements: Campu Stefanu and Punta di Caniscione in Corsica and Porto Leccio in Sardinia, whose chert artefacts were sourced to the Perfugas basin (Figure 5).

From Corsican settlements, the LCPs follow the course of rivers and skirt the eastern coast to reach the southern tip of the island, the ending point for the analysis. Punta di

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Caniscione is located along the hypothetical route, in what appears to be a strategic position. Two possible least-cost choices were then available for crossing the sea at 9 ka BCE when the sea level was -45 m under the present (Pasquet & Demouche 2012) (Figure 5).

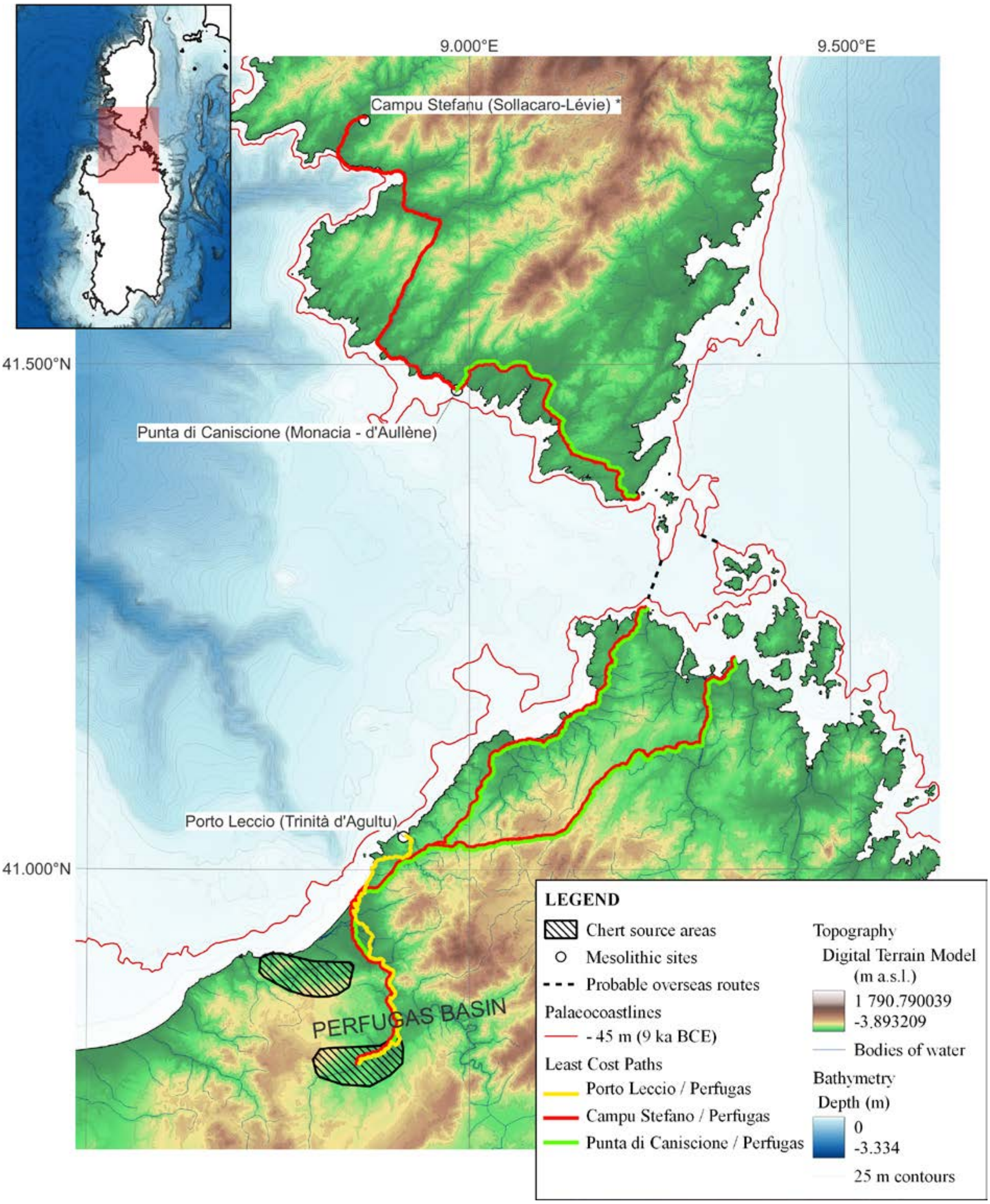

Figure 5. Least Cost Paths from Corsican and Sardinian Mesolithic archaeological sites towards the sources of chert, constructed with QGIS 3.20.

The route calculation starts again on the present Sardinian coast as two divergent paths climb up the tributaries and the main river basins up to 300 m to cross the Limbara plateau.

The Perfugas basin is eventually reached by climbing up the river Coghinas towards its source; the same path is followed from the Sardinian settlement of Porto Leccio.

The distance covered from Corsica towards the outcrops of chert in northern Sardinia would thus be 177-185 km from Campu Stefanu and 123-131 km from Punta di Caniscione, even though another chert outcropping area is available at the mouth of the Coghinas at shorter distances.

Within Sardinia, Porto Leccio is the only Mesolithic assemblage partially sourced to Perfugas, at a 45 km distance. Nevertheless, most of its chert is a local hydrothermal variety, gathered in the close alluvial deposit (Lugliè 2009a; Tozzi 2012), just as the rest of the archaeological chert recovered in Sardinian PN sites appear to be local.

4.2. Least Cost Paths during the Early Neolithic

As regards the LCPs for obsidian supply from Corsica in the EN (Figures 6, 7, 8 and 9), the sites of Basi and Renaghju in the south-west follow the same route as Mesolithic Campu Stefanu and Punta di Caniscione to reach the shore. The others - Lumaca, a Guaita, Torre d'Aquila and Strette, which are instead located in the Corsican cape - all follow a route along the western coast at a very close proximity to the sea and zero slope, also joined by the path descending from the mountain settlement of Curacchiaghju along the river De Spinu. The dock in southern Corsica is again reached by passing through the valley traced by watercourses (Figure 6).

Several routes were then proposed to cross the Bonifacio strait, as during the EN the palaeocoastline was at -35 m at 7 ka BCE (Shackleton *et al.* 1984) and around -5 or -10 metres at 5 ka BCE (Allegrini-Simonetti 2000) (Figure 7).

Once in Sardinia, the LCP again makes ample use of river valleys, but it also reaches 700 m a.s.l. to cross the Campeda plateau instead of circumventing it (Figure 8). The nearest outcrop of type SB1 is then reached at 235 m a.s.l., while type SB2 and SC obsidian appear to be more easily procured in the valley, and SA is last reached on the southern slopes of Mount Arci at about 200 m a.s.l. (Figure 9).

Thus, to procure obsidian directly from its source at Monte Arci, human groups living in Corsica should have had to face a minimum journey of 370 km and a maximum of 577 km, without considering the crossing of the Bonifacio strait between the two islands.

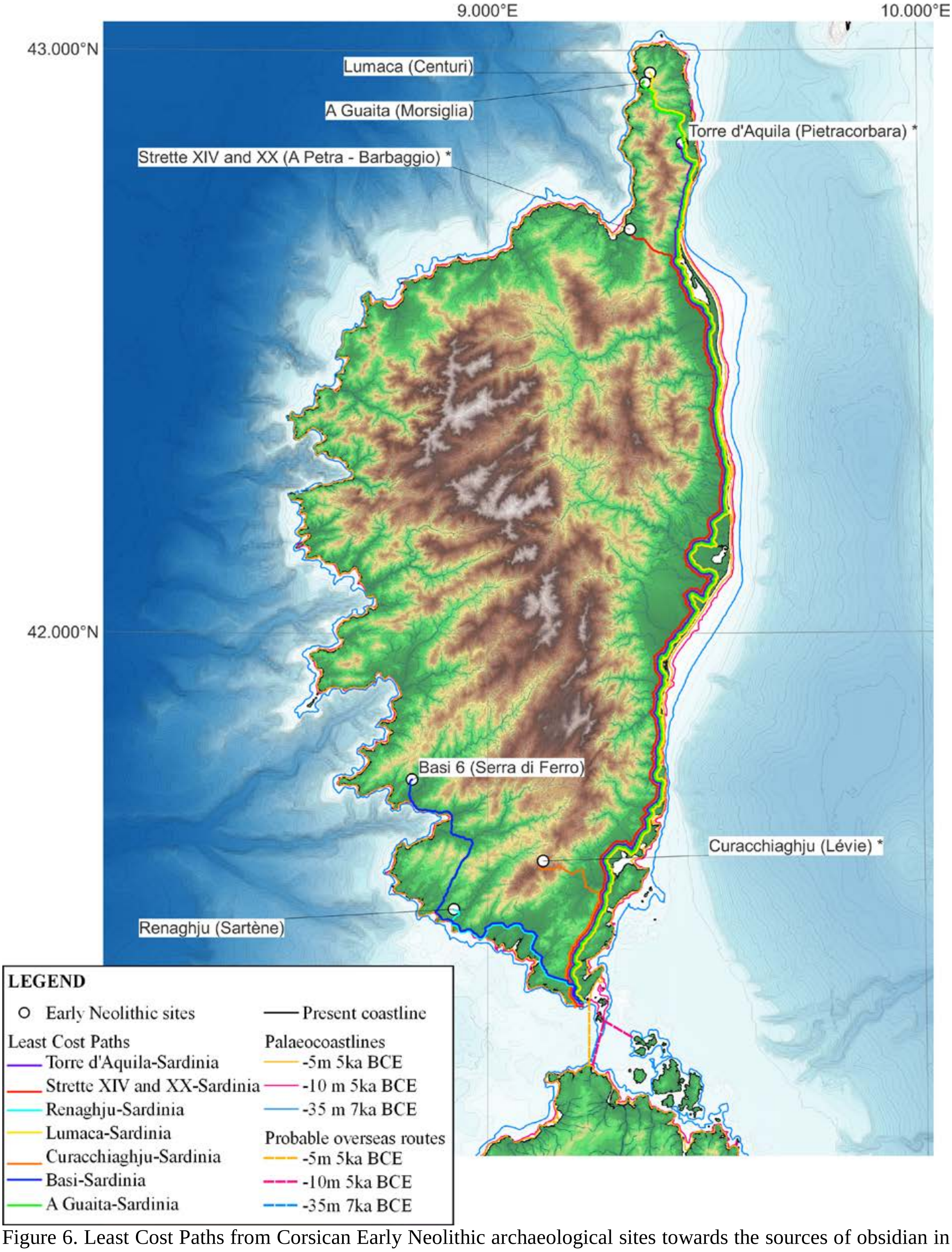

Figure 6. Least Cost Paths from Corsican Early Neolithic archaeological sites towards the sources of obsidian in Sardinia. Constructed with QGIS 3.20.

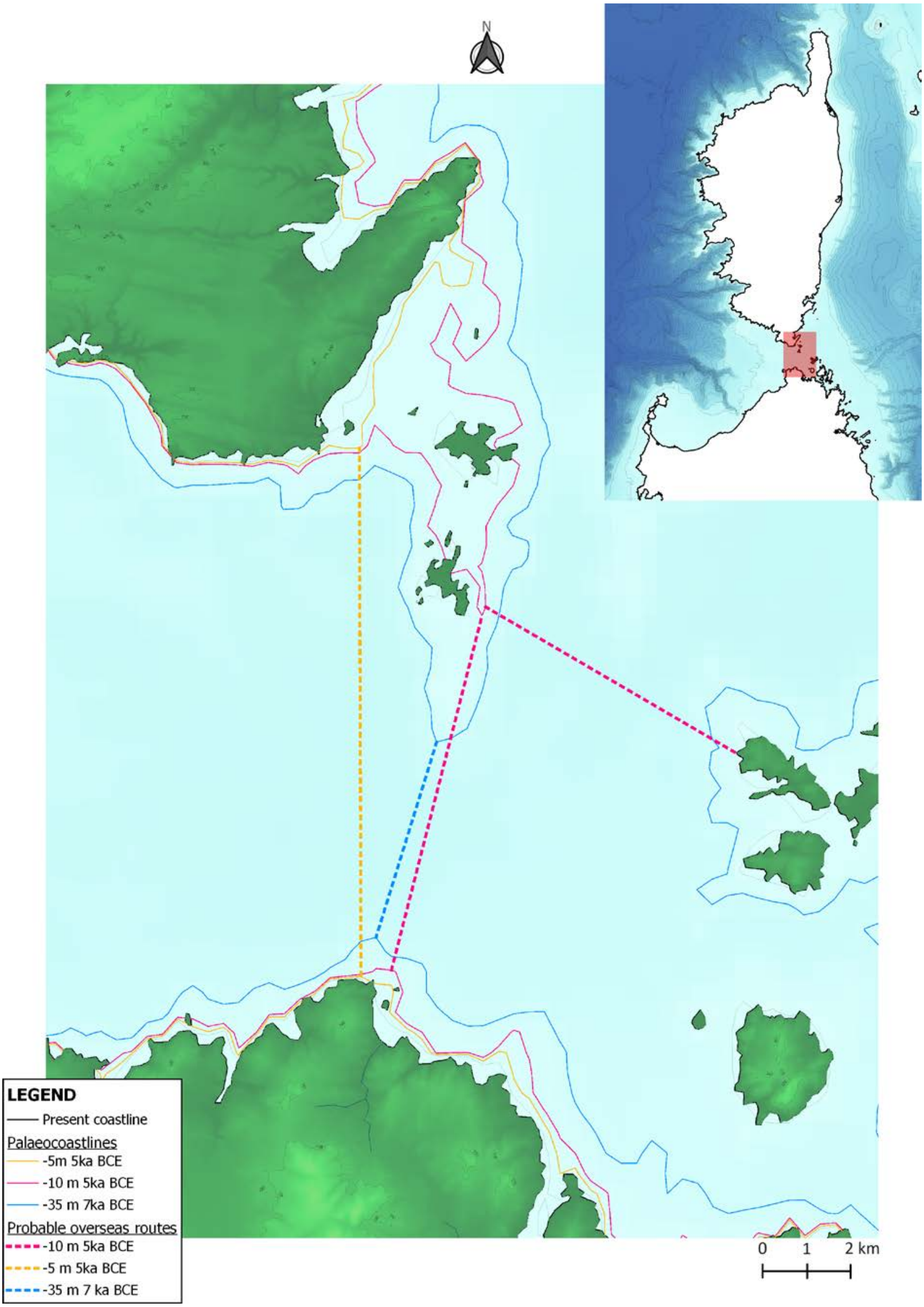

Figure 7. Detail of the probable overseas routes from Corsica to Sardinia during the Early Neolithic, constructed following the shortest distance as the crow flies according to palaeocoasts with QGIS 3.20.

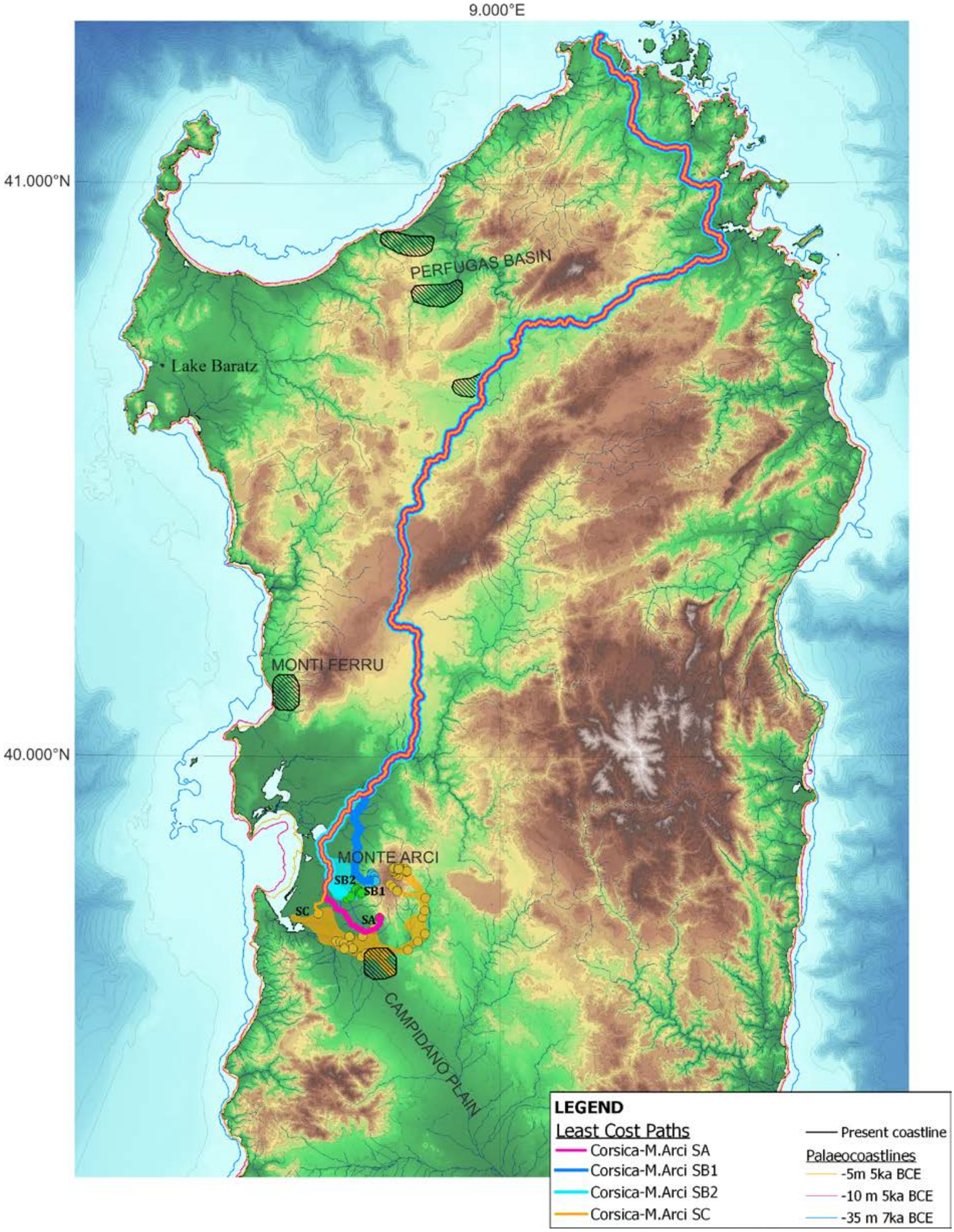

Figure 8. Least Cost Paths from Corsican Early Neolithic archaeological sites towards the sources of obsidian in Sardinia. Constructed with QGIS 3.20.

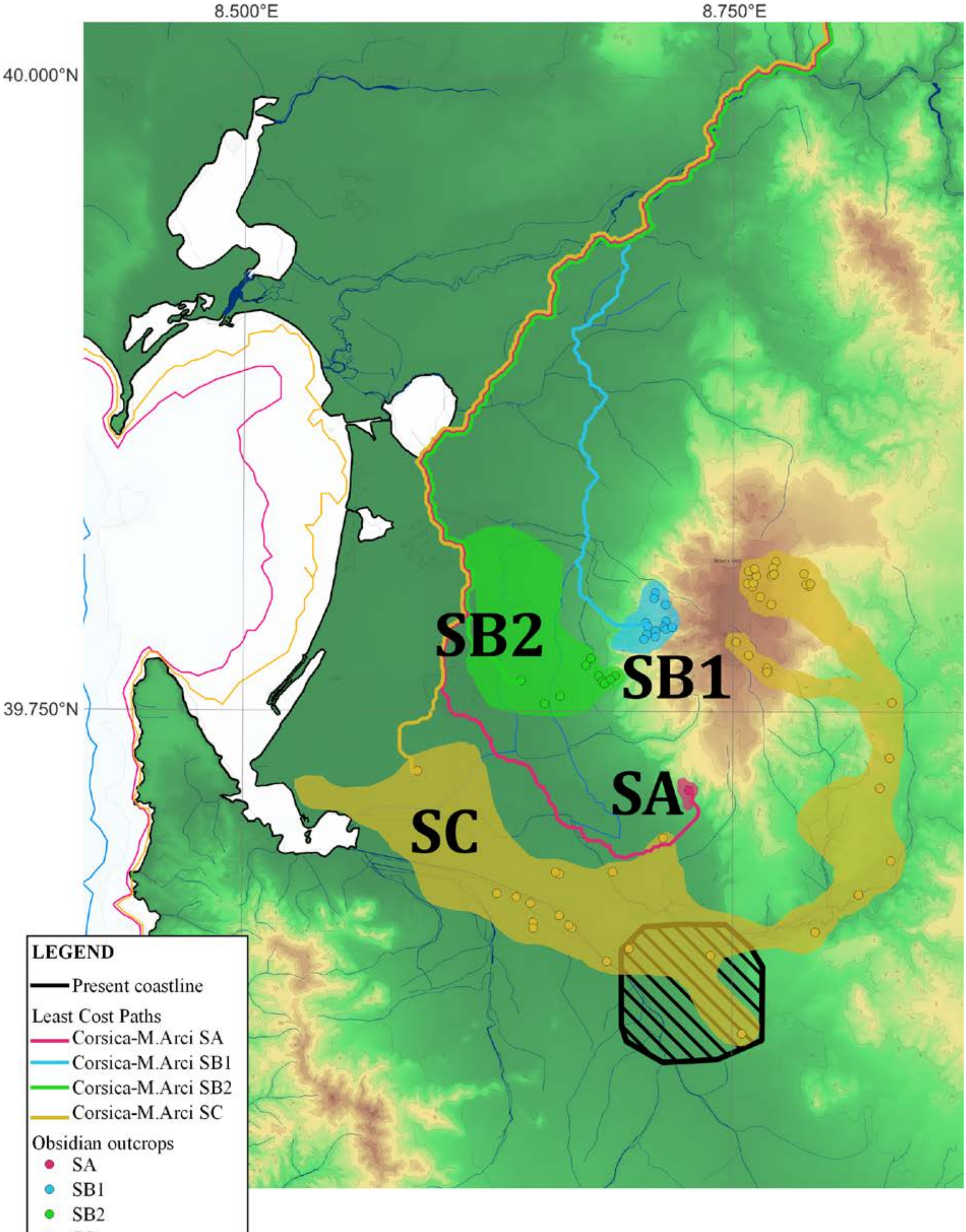

Figure 9. Detail of the Least Cost Paths for the provisioning of Monte Arci's obsidian from settlements in Corsica during the Early Neolithic. Constructed with QGIS 3.20.

The procurement of obsidian from Sardinian settlements during the EN (Figures 10 and 11) obviously involves shorter routes than those from Corsica. The most distant site is Cala Corsara on the island of Spargi, La Maddalena, in the far north of Sardinia. After crossing an arm of sea about 3 km wide, the route re-joins the same path followed when coming from Corsica, namely to the east by circumventing the Limbara massif and then in a south-western direction until it crosses the Campeda plateau and reaches Mount Arci from the west.

The western sites of Sa Korona di Monte Majore and Filiestru also join the Cala Corsara route by crossing the Campeda plateau at the same point. From Santa Caterina di Pittinuri and Su Paris de Sa Turre in the vicinities of Monti Ferru, the route skirts the coast and part of the Gulf of Oristano to reach the sources of Mount Arci again from the north-west (Figure 10).

Routes from southern sites (Acqua sa Canna and Su Carroppu) climb along the course of the Cixerri river to reach the sources from the south. The first SC outcrop to be reached is the southernmost, at about 59 m a.s.l.; but since the route continues towards other sources, SC outcrops to the north are also reached even though they do not appear in the LCPA, whereas the others on the north-eastern peak of the mountain are less accessible. For the SB2 type too the southernmost outcrop is the most easily accessible, at only 17 m a.s.l., whereas the nearest SB1 and SA outcrops are the same as those reached with Corsican routes (Figure 11).

The nearby sites of Coddu Is Abionis, Rio Saboccu and Sa Punta are so close that they could exploit the sole SC type remaining within a local range; but both have also yielded obsidian from other sources. For Coddu Is Abionis it has been suggested that the exploited outcrops were Conca Cannas and Santa Maria Zuarbara (Lugliè 2000), while Perdas Urias would probably be too far, almost 50 km away on foot, although only 19 km as the crow flies. From Rio Saboccu and Sa Punta, the outcrops are reached from the southwest and are the same as those exploited by routes coming from Corsica.

The LCPs within Sardinia for the supply of obsidian in the same period would thus not exceed 294 km, but except for settlements located at a close distance from Mount Arci, would have required to cover at least 63 km to reach the nearest source.

Regarding the supply of chert in the Early Neolithic, which involves the sole sites of A Guaita, Strette, Campu Stefanu and Renaghju in Corsica and Cala Corsara in Sardinia, the routes are the same as previously observed, towards the Perfugas basin. In this case, the maximum distance covered from Corsica to procure chert from the Perfugas basin would have been 340 km, while the minimum 135 km.

Within Sardinia, instead, the maximum distance covered to procure chert is 94 km, without considering the short sea stretch (Figure 12). Nevertheless, most archaeological chert seems to have been procured from local outcrops.

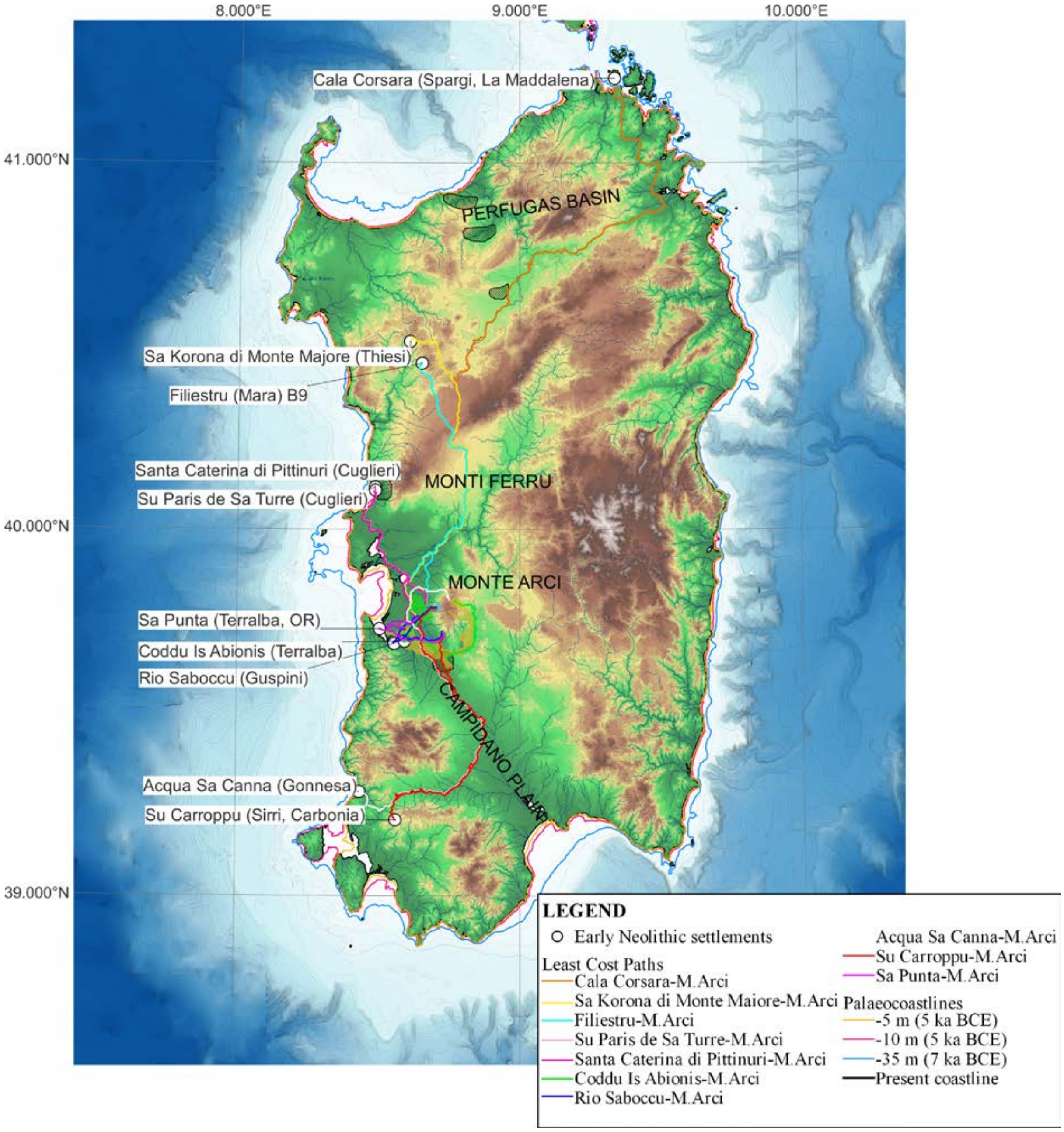

Figure 10. Least Cost Paths from Sardinian Early Neolithic archaeological sites towards the sources of obsidian in Mount Arci, constructed with QGIS 3.20.

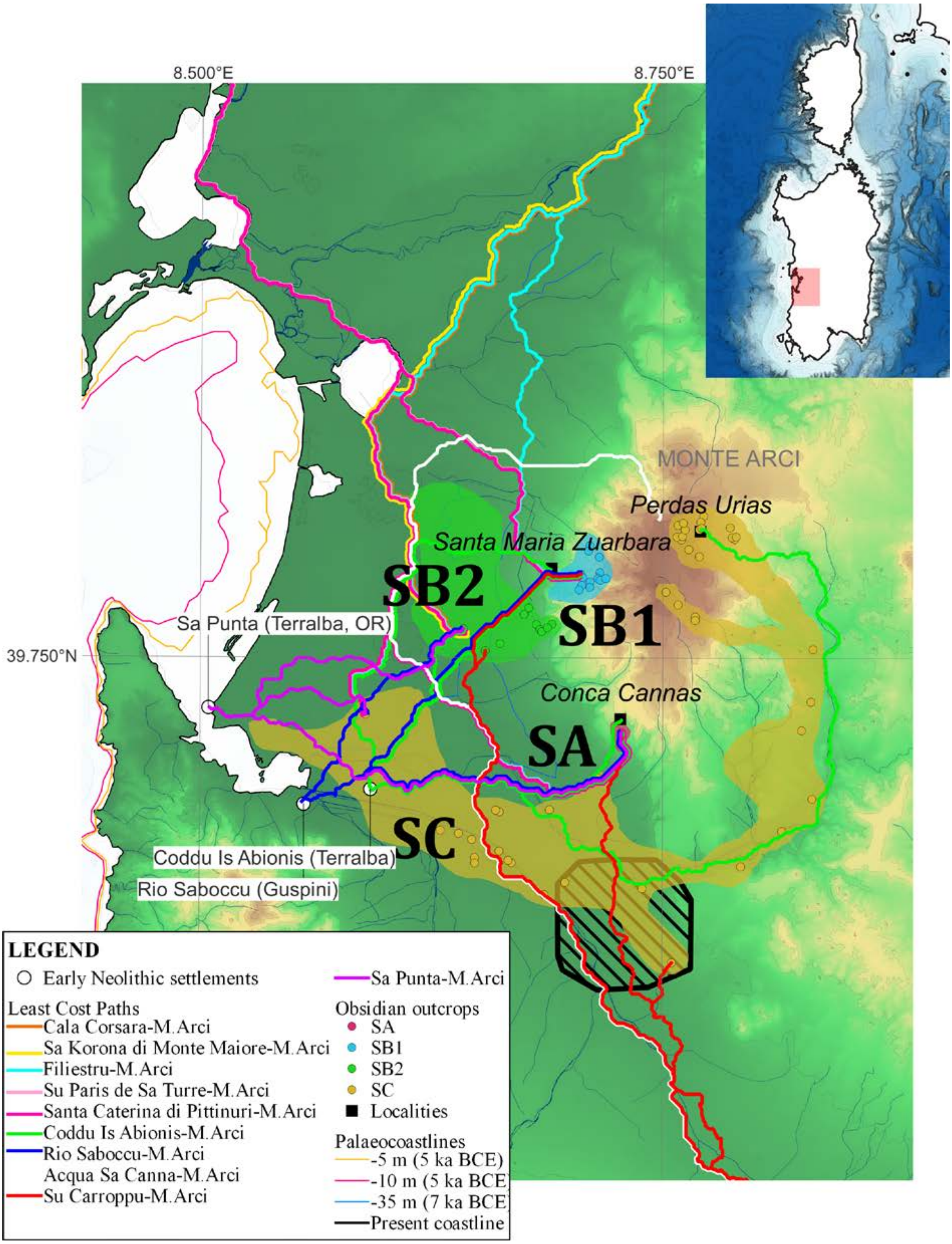

Figure 11. Detail of the Least Cost Paths for the provisioning of Monte Arci's obsidian from settlements in Sardinia during the Early Neolithic. Constructed with QGIS 3.20.

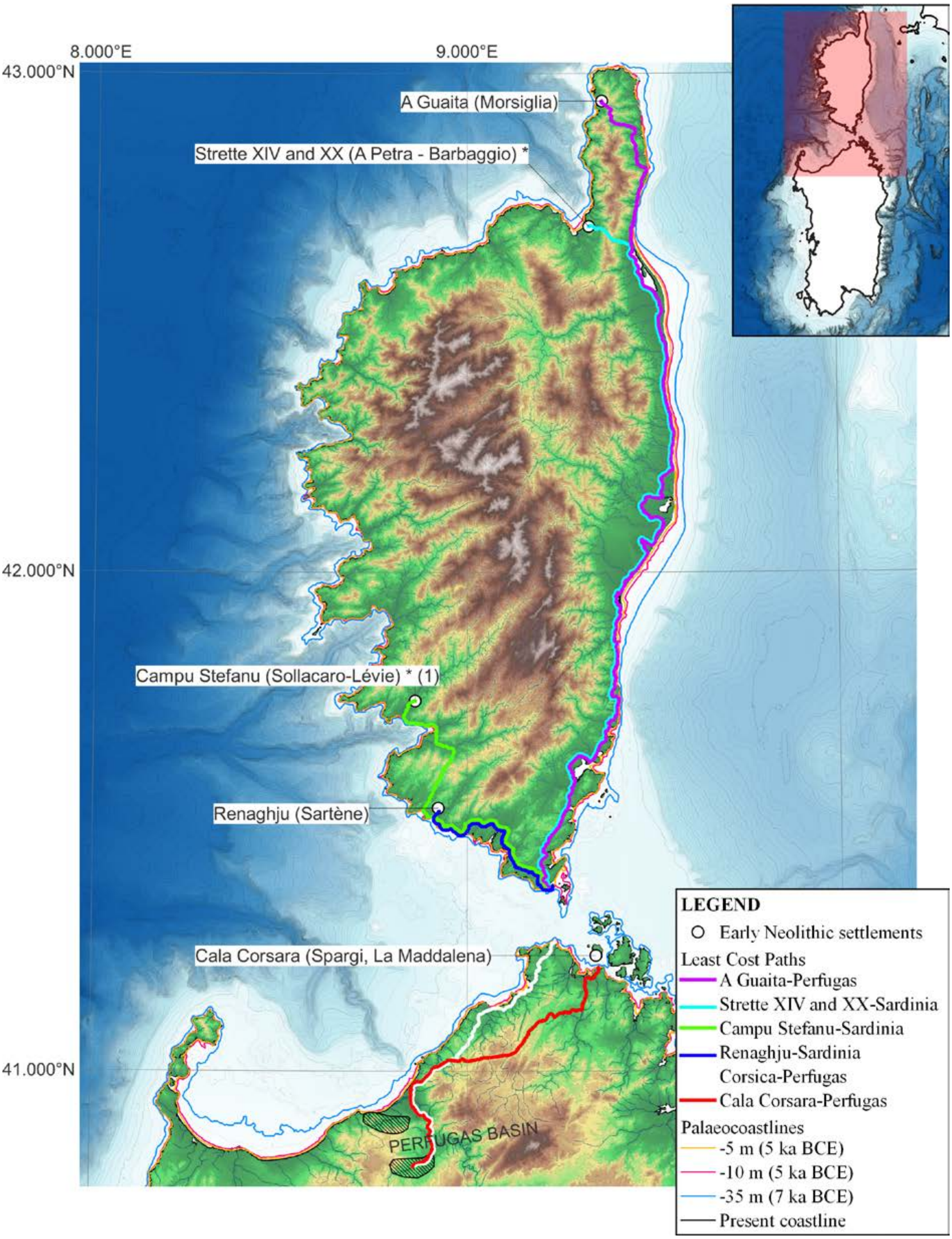

Figure 12. Least Cost Paths from Sardinian and Corsican Early Neolithic archaeological sites towards the sources of chert, constructed with QGIS 3.20.

5. Discussion and Conclusions

Several difficulties were encountered in the development of a LCPA for the procurement of chert and obsidian in Pre-Neolithic and Early Neolithic Corsica-Sardinia. The absence of precise coordinates of both archaeological sites and geological outcrops strongly affected the construction of the cartography. The few provenance analyses available narrowed the scope of the LCPA, especially with regard to the provisioning of chert.

The paucity of data on palaeo-environmental proxies - vegetation, climate, bodies of water and watercourses (width, presence of fords, regime, past navigability) - reduced the LCPA to the sole variable of slope as the only complete and reliable one. As slope does not change over a few millennia, results do not allow us to distinguish PN (Mesolithic) and EN LCPs from the point of view of the itinerary, but rather for the presence or absence of routes, the choice of raw materials and the number of displacements. Yet, these routes are to be understood as a sum of cumulative actions over time (Tykot 1996) whose timescale could have reached the order of generations (Williams-Thorpe 1995).

5.1. Mesolithic lithic procurement and mobility patterns

Data on the provisioning of chert point to movements from Corsica towards Sardinia and vice-versa during the Mesolithic (it is not known whether periodic, occasional, or frequent), or contacts among human groups of both islands, even if we were to exclude long displacements such as those traced by the LCPA.

Movement could also have taken place solely by sea, or along the coast, without penetrating inland except for a few tens of kilometres, thus corroborating the thesis that Mesolithic settling in Corsica and Sardinia was sporadic and never reached inland areas. Nevertheless, several factors suggest that travel took place (if not solely, also) by land. These factors are (1) the presence of occupational deposits (although not necessarily traceable to a stable settlement) at locations considerably distant from each other or in inland areas; (2) the very procurement of raw materials, which shows that the sources were known and used, even at some distance, although in small quantities and against a strictly local procurement.

If the occupation of mountainous inland areas is doubtful in Pre-Neolithic Sardinia due to the lack of reliability of the stratigraphic sequence in Ottana-A and Grotta Corbeddu, it is not the case for Corsica where the Curacchiaghju deposit is considered reliable for the Mesolithic (Lugliè 2018).

Thus, it seems likely that the territory was beginning to be explored in this period, although perhaps not systematically; and a certain degree of knowledge of it had already been reached, at least of the coastal and sub-coastal areas in Sardinia and some mountainous regions in Corsica. Human groups did not necessarily maintain mobility restricted to the sole coastal areas, even in case they reached the islands during seasonal or occasional settlements for the exploitation of punctual resources; thus, their mobility range was wider than previously assumed (Costa *et al.* 2003; Lo Vetro & Martini 2016; Lugliè 2009a).

Given the predominantly fishing-hunting and gathering economy of Mesolithic settlers and the type of settlements, which lack evidence for the emergence of a sedentary lifestyle (e.g. spatial structuring systems, remains of buildings) and mostly exploit available habitable places in the landscape - caves or shelters - the presence of Perfugas chert in Corsica could rather be the result of sporadic movements within the islands than of a displacement towards Sardinia aiming specifically at obtaining chert.

The latter is, in fact, a typical strategy for communities organized as “collectors” *sensu* Binford (1979), which live in relatively sedentary base camps and settle specialized groups for the obtention of resources: such a strategy would have been needed in this case, as the journey was hundreds of kilometres long and would have required at least several days to be completed. In addition, there was the crossing of the sea stretch between Corsica and Sardinia and therefore the need of a boat; which, however simple, would have had to be either built or stored in situ near the coast. Furthermore, there are no remains of chert (nor obsidian) in Corsica that would quantitatively justify systematic long journeys.

The long distance to the source and the stretch of sea to cross could suggest that chert passed among different human groups, rather than having been collected by the same group that then brought it to the settlement. Yet, it seems unlikely that the supply of chert occurred indirectly, in the context of informal exchanges among communities, because the settling of the islands in the Mesolithic must have been occasional and spread over long periods of time.

Instead, it seems probable that groups moved occasionally throughout Corsica and Sardinia in the framework of a “foraging” strategy, i.e., exploiting the resources immediately available in the vicinities of the camp and possibly collecting some useful raw materials found along the way, such as chert or obsidian.

In any case, we are dealing with such a small number of evidence of Perfugas chert in Corsican Mesolithic settlements (in total, 2 items at Campu Stefanu, 6 from Porto Leccio and “a few” for Punta di Caniscione) (Cesari *et al.* 2011; Le Bourdonnec *et al.* 2014; Tozzi 2012) as to be better understood as an epiphenomenon, that is, a sporadic and therefore anecdotal presence.

5.2. Early Neolithic lithic procurement and mobility patterns

The use of chert and obsidian in Corsican-Sardinian settlements becomes significant with the Early Neolithic.

According to Tykot, the general island’s low population density in the Early Neolithic, combined with a relatively high mobility for a still incipient level of food production (especially herding), suggest direct obsidian supply from Mount Arci rather than a “down-the-line” exchange model (Renfrew 1969; Tykot 2002). However, strategies would have differed depending on the distance from the source. A distinction must be made between settlements in the immediate vicinities and the rest of the island, where obsidian was probably obtained through exchange (Tykot 1996).

Mount Arci does seem to be a pole of attraction for human communities, probably due to raw materials availability: in fact, as many as 16 Early Neolithic settlements have been located in a radius of 25 km around the massif. It is indeed likely that the procurement of obsidian was mediated when conducted from settlements far from the source, but mostly because direct access would have required long distances to be covered, either in the case of procurement embedded in other subsistence activities (Binford 1979) or if the displacement was for the sole purpose of obtaining the lithotype (Arroyo 2009; Gould 1978).

This is consistent with the subsistence strategies of these early settlers (i.e., the permanence of hunting-gathering alongside a mostly pastoral economy): human groups were dispersed over the territory of the islands, but were very much interconnected thanks to a degree of mobility that paradoxically seems to increase in the EN compared to PN. The circulation of raw materials thus occurred over much longer distances and was likely the result of indirect procurement (as frequent informal exchange habits were in place among communities), together with occasional embedded provisioning and direct, purposeful exploitation in the vicinities of the source.

In fact, the higher presence of obsidian and chert in EN settlements compared to the PN points to more intensive exploitation of the sources, which cannot be dismissed as the result of embedded procurement strategies alone. Furthermore, the decrease of obsidian artifacts as one moves away from the source agrees with a down-the-line procurement model.

The same discourse applies to the procurement of chert. Yet, this lithotype has a much more ubiquitous presence throughout the territory of Sardinia and, according to the literature, it was mostly obtained within a local provisioning range. In Corsica, instead, where natural chert outcrops are lacking, the down-the-line informal mode of procurement is likely to have been in place from most distant sources. It is instead unsure whether direct procurement from the source as an embedded strategy during foraging activities was also in place from Corsica towards the near sources of chert in northern Sardinia during these chronologies.

6. Limitations

This research has a number of limitations that we have addressed elsewhere (Corona *et al.* 2022) but some of which it will be useful to mention here. First, results should not be considered as representative of the totality of the archaeological sites for the periods examined, but as an analysis of currently published data. The reliability of the observations is higher for sites where provenance analyses were carried out on enough evidence to be statistically significant, if not for the whole assemblage.

We are aware that this study does not address the likely possibility that nodules of obsidian and chert were moved by slope and water, to be collected at unknown secondary sources. As the presence of watercourses was not calculated in the analysis, LCPs not only follow rivers by overlapping the flow channel but also cross them horizontally via the lower gradient terrain: the itinerary could thus change significantly were waterways considered as variables, either as obstacles or facilitators of movement. The lack of environmental proxies also forced us to analyse only movement by land without considering coastal navigation, even though it could be frequent. As regards mobility patterns, the relocation of settlements on the ground to improve the accuracy of the analysis could also benefit future research.

These are thus not final results, but a premise for future developments, in a geographical context in which this type of analysis and research had not yet been implemented.

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Data accessibility statement

All data used for this paper are available within the paper and quoted and integrated in the reference section.

List of supplementary files

Supplementary file 1
"Supplementary file 1. Appendices - Databases.docx"
Appendices 1-8. Databases.

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Mappatura delle aree di approvvigionamento delle risorse litiche e dei modelli di mobilità: un approccio tramite GIS alla prima colonizzazione delle isole del Mediterraneo occidentale

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Abstract:

È possibile ricostruire tramite la circolazione della selce e dell'ossidiana i modelli di mobilità e le strategie di approvvigionamento delle risorse litiche dei primi abitanti delle isole di Corsica e Sardegna, localizzate nel Mediterraneo occidentale?

Questo lavoro affronta la questione con i seguenti obiettivi di ricerca: 1) Costruire, tramite ricerca bibliografica, un database che includa tutti i dati attualmente pubblicati sulla presenza di manufatti in selce e ossidiana nei siti sardo-corsi datati a Pre-Neolitico e Neolitico Antico; 2) Creare una cartografia sulla distribuzione geografica di questi litotipi nelle due isole prese in esame. I dati sono georeferenziati con il software open-source QGIS 3.20, sia per renderli visibili su mappa sia per introdurre nella ricerca le variabili fondamentali dello spazio e del territorio; e 3) Ricostruire i modelli di mobilità per l'approvvigionamento di selce e ossidiana sulla base dei risultati delle analisi di provenienza dei reperti litici (se disponibili), utilizzando QGIS per tracciare le linee di movimento dal luogo di ritrovamento alla fonte della materia prima secondo il principio del minimo sforzo energetico: ovvero, sviluppando una Least Cost Path Analysis (LCPA). Ciò significa che il tracciamento dei probabili percorsi seguiti dall'essere umano si baserà sul calcolo delle distanze più brevi dalle fonti delle materie prime ai loro punti di ritrovamento, in base alle variabili orografiche e topografiche.

I risultati di questa ricerca, incentrata sulle aree di approvvigionamento e i modelli di mobilità per svolgere un'attività specifica come lo sfruttamento delle materie prime litiche, contribuiranno al più ampio dibattito sulla gestione delle risorse e sulla conoscenza del paesaggio da parte dei primi gruppi umani che colonizzarono ambienti insulari.

Parole chiave: materie prime litiche; strategie di approvvigionamento; modelli di mobilità; GIS; Corsica; Sardegna