A prehistoric jade axe from Galicia (Northwestern Iberia): Researching its origin

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Abstract:

The Vilapedre axe (Lugo, Northwest Iberia) has been traditionally considered by archaeologists as evidence of prehistoric long-distance contacts along the Atlantic Coast of France and Spain. This artefact - as other “Tumiac type” axes (long polished blades, generally butt-perforated) - would have been produced in Brittany during the Neolithic (5th millennium BCE) using jadeitite as raw material, a green-coloured rock for which there are sources in the western Italian Alps. In this paper, we have traced the possible archaeological origin of this artefact back by examining the personal files of one of its first owners, Santiago de la Iglesia. Furthermore, we have conducted a mineralogical (X-Ray Diffraction, XRD) and an elemental analysis (Scanning Electron Microscopy with Energy Dispersive X-ray Detection, SEM-EDX) of both the Vilapedre axe and geological samples from several places at the Alps where prehistoric quarrying of greenstones has been reported. The aims were physicochemically characterizing the axe to provide information about its possible geological source. During our analyses, we have found significant compositional similarities between the Vilapedre axe and one of the geological samples coming from the Alps (Alp06). The results are therefore consistent with the alleged Alpine origin of this artefact. The presence of this axe in Northwest Spain, together with other evidence, such as the presence of objects of Iberian origin in Breton monuments, strongly suggests the existence of contacts between both regions of the Atlantic façade during the Neolithic onwards in which seafaring would undoubtedly have played an important role.
Keywords: Jade Axes; Archaeometric analytical method; SEM-EDX; XRD; Lithics Archaeometry; NW Iberia

1. Introduction

In 1908, Santiago de la Iglesia, a doctor and scholar interested in the prehistory and archaeology of Galicia (NW Iberian Peninsula), published a detailed account of his personal collection of archaeological artefacts (de la Iglesia 1908). The Vilapedre axe, a finely polished, butt-perforated greenstone axe head, stands out among the objects of such collection. The immediate parallels for this artefact, the so-called Tumiac axes, are found not in the Iberian Peninsula, but in Brittany (France), where they were produced during the local Neolithic (around the middle of the 5th Millennium BCE). More interestingly, the sources of the raw materials used for making such axes (jadeite, omphacitite or fine-grained eclogite) are located in the Italian Alps, hundreds of kilometres away from both Brittany and Galicia (Pétrequin et al. 2012a).

For more than thirty years, the presence of this Tumiac type axe in Northwestern Spain has been listed by archaeologists as evidence for long-distance connections along the Atlantic facade of Western Europe during the Early Neolithic (Cassen et al. 2012; Fábregas Valcarce 1981; Fábregas Valcarce & Vázquez Varela 1982; Pétrequin et al. 2012b). The similar macroscopic features of the Vilapedre axe and Alpine natural samples (Errera et al. 2012) led one of us (P. P.) to argue for an origin in the South of Monviso massif (Cottian Alps), in the primary outcrops of Vallone di Porco, between 1700 and 2400 m a.s.l., or from the Pò river moraine -circa 400 m high (Pétrequin 2017).

In this paper, we have traced back the possible archaeological origin of this artefact by examining the personal files of one of its first owners, Santiago de la Iglesia. Furthermore, we have conducted a mineralogical (X-Ray Diffraction, XRD) and chemical composition analysis (Scanning Electron Microscopy with Energy Dispersive X-ray Detection, SEM-EDX) as well as a macroscopic analysis of the Vilapedre axe together with geological samples from the Alps, selected among the potential sources where prehistoric quarrying has been documented (Pétrequin & Pétrequin 2007; Pétrequin et al. 2012c). Our main objectives were:
- To characterize, from a macroscopic and analytical point of view, the composition of the Vilapedre axe and the geological samples.
- To compare the results obtained for both the archaeological and geological samples in order to elucidate the possible origin of the Vilapedre axe.

1.1. State of the art regarding the definition and analysis of Jade

The origin of the name jade seems to be that of the Spanish “piedra de ijada” (“loin stone”; Harlow et al. 2015) and it has been applied to different rocks, such as Na-pyroxenites, serpentinites, nephrites or minerals such as fibrolite, etc. Here, the term is used mainly for Na-pyroxenites. The “Na-pyroxenites” can be referred as jadeitites when they are composed mainly of jadeite, omphacitites when the omphacite is the predominant mineral, mixed jades when approximately equivalent amounts of jadeite and omphacite are present and “Na-pyroxene + garnet rocks” if garnets also occur (Giusteto & Compagnoni 2014).

Morimoto et al. (1988) reviewed the nomenclature of the pyroxene group of minerals according to the premises of the International Mineralogical Association; such review was slightly modified by Rock (1990) later on, who classified them based on their mineral formula. Morimoto and colleagues highlighted the Ca-Mg-Fe pyroxenes as one of the main subgroups: these can form a quadrilateral system (named Quad), whose vertices are occupied by diopside (CaMgSi$_2$O$_6$), hedenbergite (CaFe$^{2+}$Si$_2$O$_6$), enstatite (Mg$_2$Si$_2$O$_6$) and ferrosilite (Fe$_{2}^{2+}$Si$_2$O$_6$). These authors proposed a classification of the Na-pyroxenes based on a ternary diagram (Figure
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1), where the aforementioned group (Quad) is placed in one of the vertices, while the jadeite (NaAlSi$_2$O$_6$) and the aegirine (NaFe$^{3+}$Si$_2$O$_6$) are located in the other two. Omphacite (Ca, Na) (Mg, Fe, Al) Si$_2$O$_6$, is located to the centre left of this diagram and it is usually considered a mineral, since it has its own crystalline structure (Morimoto et al. 1988). It is a major constituent of eclogite, usually forming from the metamorphism of basaltic rocks during high-pressure to low-temperature metamorphism.

Jadeite has a density ranging between 3.30 and 3.36 g/cm$^3$ (though some New World jades have densities as low as 3.0), omphacite’s minimum is 3.33, while eclogite shows higher values than all the others (Errera 2014). However, it is worth noting that, sometimes, jadeitites and eclogites can display lower densities if retromorphism was important (chlorite and albite neoblastesis, etc.).

Jadeitites and mixed jades can be found in different regions of Asia and America. In Europe, jadeite sources are found - for example - on the islands of Syros and Tinos (Cyclades, Greece), in the Monviso and the Voltri Group and in the western Italian Alps (Bröcker & Enders 2001; Compagnoni et al. 2007, 2012; Giustetto & Compagnoni 2014; Harlow et al. 2015; Pétrequin et al. 2012c, 2017a), and also in Norway and Brittany (Lozano et al. 2018). However, so far, there is no evidence of metaophiolite exploitation in the European Neolithic outside the Monviso and Voltri group areas (also in val Susa, but to a very lesser degree), where such activities have been documented by two authors of this paper (P.P., M.E.). Prehistoric quarrying of other greenstones (fine-grained eclogites) has been documented in the Baetic range, in Southern Spain (Lozano et al. 2018). Regarding our study area –Northwestern Spain–, the occurrence of jadeite minerals has also been described but only as a minor pseudomorph after plagioclase in granitic veins of decimetric width existing among the granodioritic orthogneiss of the Malpica-Lamego line (Gil Ibarguchi 1995).

Jadeitite and mixed jades have been the subject of many analytical studies, including geological and physicochemical (Cameron et al. 1973; Cisowski et al. 2004; Clark et al. 1969; Compagnoni et al. 2007; D’Amico et al. 1995; Delaitte et al. 2010-2011; Errera et al. 2012; Franz et al. 2014; Gil Ibarguchi 1995; Harlow 1993; Harlow et al. 1994, 2011, 2012a, 2012b, 2014, 2015; Hirajima & Compagnoni 1993; Kempe & Harvey 1983; Knaf et al. 2017; Lü et al. 2014; Macke et al. 2010; McClure 2012; Medaris et al. 1995; Mendoza et al. 2015; Morimoto et al. 1988; Ou Yang et al. 2011; Pétrequin et al. 2012a, 2017a; Seitz et al. 2001; Taube et al. 2004; Theye & Seidel 1991), archaeological (Cassen et al. 2012; Harrison & Orozco 2001; Pétrequin et al. 2012a; Rodriguez Ramos 2011; Rodriguez Ramos & Pagán Jiménez 2006; Surmely et al. 2001) and archaeometric, on Asian (Bishop et al. 1985, Chang et al. 2010; Cook, 2013; Franz et al. 2014; Harlow et al. 2012b; Ou Yang et al. 2011; Rösch et al. 1997; Wang 2011; Wen & Jing 1992; Yang et al. 2004), American (Foshag & Leslie 1955; García-Casco et al. 2013; Harlow et al. 2006; Lange 1993; Ruvalcaba-Sil et al. 2008) and European samples (Coccato et al. 2014; Compagnoni et al. 2007, 2012; D’Amico 2005, 2012; D’Amico et al. 1995, 2003; Domínguez-Bella et al. 2004; Domínguez-Bella et al. 2012, 2016; Errera et al. 2012; Giustetto et al. 2018; Giustetto & Compagnoni 2014; Lozano et al., 2018; Odriozola et al. 2015; Pétrequin 2017; Pétrequin & Errera 2017; Pétrequin et al. 2012c; Querré et al. 2008; Rapp 2001; Riqc-de Bouard & Fedele 1993; Spišiak & Hovorka 2005). In all these approaches, information is provided regarding the nomenclature, the main and accessory minerals of jadeitite and mixed jades, the techniques used for their analysis and archaeometric information such as the identification of the source areas and the evidence of circulation of the artefacts made of this raw material.
1.2. Alpine jades in prehistoric Western Europe

Jade has been highly valued for adornments or tools in Europe since prehistoric times: polished axes made from Alpine rocks such as jadeitite, omphacite or fine-grained eclogite travelled across Western Europe during the 5th and 4th Millennia BCE over distances up to 1700 km (Figure 2). From the Italian Alps, where primary and mainly secondary deposits of these rocks were exploited in the massifs of Monviso and Voltri Group during Neolithic times (Pétrequin et al. 2012c), the long-distance transfers reached the Atlantic seashore and Great Britain in the West, Denmark to the North, the Black Sea shores and the Turkish coast to the East and finally Malta to the South (Pétrequin et al. 2012a, 2017b; Sørensen et al. 2017).

The choice of the Alpine jades by the prehistoric communities of Western Europe may be explained by the rarity of these precious raw materials and by their physical characteristics: a remarkable tenacity, a light-catching colour and fine-grained structure, allowing bright and sometimes extraordinarily polished surfaces (Pétrefquin et al. 2017a). An added value might lay on the difficulty of quarrying at Monviso, between 1700 and 2400 m a.s.l. (Pétrefquin & Pétrefquin 2007, Pétrefquin et al. 2006, 2012d).

The production and distribution of Alpine axes has been intensively analyzed in the framework of two research projects of pan-European scope funded by the French National Research Agency (JADE and JADE-2 programs). The results led to the identification of more than 2000 Alpine axes longer than 13.5 cm (Pétrefquin 2017), the geological origin of many...
being traced mainly through spectroradiometric (Errera et al. 2007, 2012) or macroscopic and XRD analyses (Pétrequin et al. 2012c).

![Distribution of long Alpine jade axes in Western Europe](image)

**Figure 2.** Distribution of long Alpine jade axes in Western Europe (white circles). Green circles: Butt-perforated Tumiac axes, as Vilapedre (green star). Red circles: Tumiac axes. Data base: P. Pétrequin. Mapping: E. Gauthier. NASA - Shuttle Radar Topography Mission (SRTM 3 arc-seconds) version 2.1, USGS., ESRI Basemap Data (licence MSHE C.N. Ledoux).

### 1.3. Alpine jades in the Iberian Peninsula

For a long time, it was assumed that, with the partial exception of Catalonia, the Iberian Peninsula was barely reached by the jade network (Ricq-De Bouard 1996). Outside the Catalanian lands, the few axes of alleged Alpine origin known in Iberia seemed to endorse such a view. However, this impression has significantly changed after the research conducted in the framework of the JADE projects, leading us to identify over forty presumably Alpine axes in Spain and Portugal (Fábregas Valcarce et al. 2017). The Alpine origin of the rocks used for making these artefacts has been suggested by means of spectroradiometric analysis in twelve of the Catalanian samples (Vaquer et al. 2012). Two other pieces from the Spanish Meseta were characterized as jadeitite by using XRF analysis; this same technique, together with XRD and
μ-Raman Spectroscopy, reported –respectively– jadeite and other related rocks for another two axes from Western Andalusia (Domínguez-Bella et al. 2016; Odriozola Lloret et al. 2016). In a recent work, Villalobos and Odriozola (2017) analyzed five axes from the Spanish Meseta using Raman and UV-VIS-NIR. Their results suggest an Alpine origin in Monviso and Voltri Group. Finally, an axe from Portugal was identified also as jadeite through XRD and UV-VIS-NIR Spectroscopy (Odriozola Lloret et al. 2015).

As elsewhere in Europe, most Iberian specimens come from insecure contexts, isolated findings or old private collections (Domínguez-Bella et al. 2016; Fábregas Valcarce et al. 2012, 2017; Odriozola Lloret et al. 2016). In the Northeast of the Iberian Peninsula, though, some of the Alpine axes came from burials (sepulture 83 of Can Badosa, Caserna de Sant Pau) ranging from the end of the 5th to the mid-4th Millennium BCE (Molist & Gibaja 2012; Pétrequin et al. 2012a; Vaquer et al. 2012). In the rest of the Iberian Peninsula, no secure contexts have been reported for genuine Alpine axes, although the presence of local imitations (namely, “Cangas” type axes) in passage-graves suggests that these artefacts may have been deposited there at least from the first half of the 4th Millennium BCE, therefore providing an ante quem yardstick for their Alpine models (Fábregas Valcarce et al. 2012).

1.3.1. Vilapedre: An Alpine axe in Galicia (Northwestern Iberian Peninsula)

The existence of the Vilapedre axe (Figure 3: left) was revealed in 1908 by Santiago de la Iglesia in a paper where he stated that the axe, “made on beautiful sea-green jasper”, was “found in the Vilapedre parish (Vilalba)” (de la Iglesia 1908: 62), a council located in the Northern part of the Lugo province (Galicia) (Figure 4: top left). As usual, this artefact lacks a clear archaeological context, thus making imperative that –in addition to ascertaining its Alpine origin– a thorough research of the circumstances of the find ought to be undertaken. This was done in order to rule out a recent arrival to Northwestern Spain of the axe as a result, for example, of the trade in antiquities (see Domínguez-Bella et al. 2016 or Odriozola et al. 2016 for similar problems with other Iberian axes).

According to Santiago de la Iglesia, the axe and other objects in his collection were donated to him by Manuel Mato Vizoso, a scholar from Vilalba, who wrote extensively about the history of this council. De la Iglesia gave no specific information about the exact spot within the Vilapedre parish where this piece was found. Meanwhile, Mato Vizoso’s personal documents kept in the archives of the Real Academia Galega do refer to his “inspection” of several mounds and hillforts located in the vicinities of Vilalba (Mato Vizoso 1872?). This circumstance – together with the documents lacking any reference regarding the purchase or trade of archaeological artefacts from other scholars– seems to reinforce the idea of the Vilapedre axe having a local origin.

However, the documents do not clarify if Mato Vizoso –like Santiago de la Iglesia– personally carried out any excavation in mounds or if he merely inspected the remains of those monuments looted or destroyed by local peasants. The latter seems to be the case of a mound in the Guitiriz council (Lugo), where he recovered pottery, a mill, and other remains “left there by those who conducted the excavations”. Less clear is the case of, among others, an unidentified mound located in Vilapedre, where several pottery sherds “were recovered inside the chamber”, these “were torn up, finding inside nothing but black, compact soil”.

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Besides this unidentified monument, Mato Vizoso mentioned very few mounds located in the Vilapedre parish. In his papers and notes, he only referred “three mounds distributed in a South to North axis” located close to the small villages of Fraguas and Garea, and near to the limits between the parishes of Vilapedre and Lanzós. According to his description, it is likely that these are the mounds known nowadays as Bouza or Veiga da Garea. Three of them (Bouza 1 to 3) display an N-S distribution, and they are also located near to the two aforementioned towns and to the limit with Lanzós (Figure 4: bottom). These monuments show evidence of having been looted, but —unfortunately— Mato Vizoso did not specify if the Vilapedre axe was recovered in any of them.

The looting of funerary mounds has been a very frequent practice in Northwest Spain for at least the last 300 years. As a result, probably less than the 2% of the more than 3.000 Galician catalogued mounds are intact nowadays. The 20 monuments located in the Vilapedre parish are not an exception, most of them showing eloquent evidences of this kind of damage. Moreover, there are references to the existence of at least another nine mounds that were destroyed in the last 50 or 60 years (Figure 4: top right), most of them due to farming activities. Any of these or other unknown archaeological sites could be the place from where the Vilapedre axe was originally recovered, probably by local peasants from whom Mato Vizoso would have bought it or—otherwise— being found by Mato Vizoso himself in the course of his “inspections” of local monuments.
The Vilapedre axe, together with other artefacts, was probably donated to Santiago de la Iglesia by Manuel Mato Vizoso in the decade of 1890. Thus, in 1896, de la Iglesia publishes one of the objects of his collection, a bronze dagger found in a mound in San Martín de Lanzós (Vilalba), coming from Mato Vizoso. A year later, in 1897, de la Iglesia made a four day trip
to different places in Northern Galicia, including Vilalba and, during this trip, he was in contact with Manuel Mato Vizoso and it may be in this moment when Mato gave him the artefacts. After de la Iglesia’s death in 1931, his collection was donated to the Santiago de Compostela University, in whose Department of History it is kept today.

2. Materials and methods

2.1. The archaeological specimen

The Vilapedre axe (Figure 3: left) is a butt-perforated greenstone axe whose surface has a glossy aspect due to an intense, fine polish. It has an elongated, narrow triangular shape, an acute proximal end, sides almost rectilinear and a convex edge. Its cross-section is thin, with an oval –almost lenticular– outline and the preserved length is 12.9 cm, its width 5.4 cm and its thickness 1.2 cm. The proximal perforation has a rather uncommon biconical section with a maximum and minimum diameter of 8 and 3 mm, respectively.

The raw material of the Vilapedre axe (hereafter MPVV) has a density –measured using a hydrostatic balance– of 3.33 g/cm³ (dt: 0.00; C.V.: 0.11 %) compatible with a mixed jade and other greenstones.

It is a rock with thin, discontinuous, whitish, partly wavy bands arranged parallel to the schistosity of the raw material (Figure 5). Due to the existence of a slight patina generated after millennia, the current colour is neither the observable on a fresh break, nor that showed by the rock extracted at the original source. The original colour (under the patina) is a pale-milky to light-bright-green, suggestive of the presence of slightly translucent omphacite. The examination under x2 and x10 magnifications revealed the following characteristics:

- narrow fissures clogged with a medium bright-green raw material
- some whitish inclusions forming a “crown” around small reddish black nodules (rutile?) (Figure 5);
- deformed garnets (determined by microscopic comparison with natural reference samples) with a blurred contour and ranging between 1 and 3 mm in size (Figure 5). The most characteristic examples marked with a white hexagon and
- other small garnets (0.2 to 0.4 mm) displaying hollow cores (Figure 5)
Figure 5. Macroscopic detail of the Vilapedre axe and of several Alpine geological samples. White hexagons: deformed garnets. White circles: hollow-core small garnets. Vilapedre images are shown at different scales. Photos P. Pétrequin and O. Lantes.
2.2. Geological samples

The petrological features and archaeometric data of many prehistoric jade axes suggest that the raw materials on which they were made might have originated in the Western Alps slopes (either from primary outcrops, secondary deposits in riverbeds and alluvial plains, or out of Tertiary conglomerates). Moreover, there are clear archaeological evidences of prehistoric quarrying in this area, mostly in the Monviso massif, including large concentrations of axe rough-outs, hammer-stones and flakes (Pétrequin et al. 2007, 2012d).

Different geological samples of jade were collected from Monviso, taking into account macroscopic similarities with the raw material of the Vilapedre axe and, above all, the evidence—in those specific spots—of prehistoric activities related to the exploitation of Alpine jades and the production of axe-heads, eight of them coming from the Cuneo district, and another (Alp30) from Alexandria. These criteria make sure that the sampling was carried out in the most important outcrops where prehistoric activity has been detected so far (Table 1, Figures 6, 7). Naturally, we cannot rule out further surveys leading to the discovery of other sources whose composition might have higher similarities to Vilapedre’s, but presently the geological samples included in this paper offer a reliable representation of those areas of Monviso where prehistoric activities have been reported.

Table 1. Description of the geological samples. Produced by P Pétrequin and O. Lantes.

| Sample | Region                  | Site                        | Color  | Texture          |
|--------|-------------------------|-----------------------------|--------|------------------|
| ALP1   | Oncino (Cuneo, Piedmont)| Porco, vallone de           | pale green | massive-foliated |
| ALP3   | Oncino (Cuneo, Piedmont)| Porco, vallone de           | green  | granoblastic-foliated |
| ALP4   | Sanfront (Cuneo, Piedmont)| Pô riv., Rocchetta, morain | green  | foliated-granoblastic |
| ALP6   | Revello (Cuneo, Piedmont)| Pô riv.                    | green  | foliated         |
| ALP10  | Martiniana (Cuneo, Piedmont)| Pô riv.                  | pale green | foliated-granoblastic |
| ALP14  | Revello (Cuneo, Piedmont)| Pô riv.                    | pale green | foliated         |
| ALP17  | Sanfront (Cuneo, Piedmont)| Pô riv., Rocchetta, morain | green  | massive-foliated |
| ALP30  | Ponzone (Alexandria, Piedmont)| Fondoferle, Orba riv.   | green  | massive-granoblastic |
Figure 6. Photographs of the Alpine geological samples. See Table 1 for details. A general similarity with a minor variation in range can be observed from a petrographic point of view. Photos R. Fábregas and O. Lantes.

Figure 7. Location of the geological samples. Mapping F. Prodéo, ESRI Data and Maps (licence MSHE C.N. Ledoux et NASA-SRTM).
2.3. Experimental design

Archaeometric analysis is usually a complex task: the sampling of archaeological artefacts for analytical purposes is often restricted, when not directly forbidden, by Heritage authorities. Thus, assays are nearly always limited in terms of size or volume.

We have implemented a micro-sampling design oriented to obtain powder to be submitted to chemical and mineralogical analysis, in a similar way to Marinova et al. (2018). Three independent small areas - previously cleaned by polishing and located in mechanically induced fractures during transport and use - were abraded using a diamond tool (1x2 mm). None of these fractures were near areas of natural alteration. Since these modifications are barely visible to the naked eye, they do not compromise the structural integrity of the piece or its future exhibition. We used X-Ray powder diffraction (XRD) to identify and semi-quantify the mineralogy and Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX) for the determination of the chemical composition of the samples. The geological samples were subjected to the same micro-sampling protocol, choosing “freshly cut” surfaces and avoiding alteration crusts as well.

2.4. Equipment and measuring conditions

2.4.1. X-ray Powder Diffraction (XRD)

We employed a Philips PW1710 diffractometer with a vertical goniometer with Bragg-Brentano geometry θ/2θ, generator with tube of 2,2 kW with Cu anode, graphite monochromator and proportional detector PW1711/10. Some milligrams of the sample, previously crushed, were deposited on a zero-background sample-holder (U-1.2rd, Gem Dugot: Dana Smith, Princeton) trying to get randomly oriented crystal grains. The measurement time for each sample was 3 seconds per step, between 2° and 65° 2θ and a step size of 0,02°. The identification and semi-quantification were conducted on the DIFFRACplus EVA software (Bruker AXS), combined with the HighScore Plus 2011 (PANalytical B.V.). The Reference Intensity Ratio (RIR) (Chung 1974) was used for the semi-quantification.

2.4.2. Scanning Electronic Microscopy coupled with Energy-Dispersive X-ray Spectroscopy (SEM-EDX)

The equipment used was an EVO LS15 microscope, which works in variable pressure mode, coupled with INCA microanalysis and a backscattered electron detector. The measurements were conducted under the following conditions: 100 s for the spectra acquisition; 20,3 s for the photograph scanning, l-probe of 1 to 1,8 nA, 20 Kv of voltage, and an 8,5-mm focus distance. The INCA detector was calibrated for the quantitative analysis using a cobalt standard (Micro-Analysis Consultants, Ltd. Cambridgeshire U.K.). The powder sub-samples (three for each sample, located in different areas) were deposited in a standard SEM sample holder (metallic body covered by an organic sticker) without any SEM-shading. Five analyses were conducted on each sub-sample (a total of 15 analyses per sample). Figure 8 (displaying the sample ALP17, as an example) shows the aspect of the extracted powder and the area analysed in each EDX analysis (rectangle A).
2.4.3. Statistical analysis

The statistical analysis was carried out with the SPSS Statistics software version 20 (IBM®). The main statistical methods used were ANOVA and hierarchical clustering, which were applied to the chemical compositions with the data normalized to the concentration of silicon. We used this normalization for improving the statistical analysis through the removal of the carbon contribution from the sticker at the holder (the analysis area was multigrain and, in the interstices, we received the carbon signal of the sticker of the sample holder). Regarding the cluster analysis, the data were transformed into Z-scores. The intergroup linking was used as clustering method and the Euclidean distance as measure of the interval. The elements included in the analysis were Na, Mg, Al, P, S, Ca, Ti, Fe and Cu, some of them not related to the crystal-chemistry of pyroxenes, as for example P (related to apatite), S (related to sulfides), Ti (related to a Ti-bearing phase) and Cu (possibly related to chalcopyrite - CuFeS2, a sulfide) but they were included to show similarities between samples.

2.4.4. Other determinations

A macroscopic analysis was conducted on the Vilapedre axe and on the geological samples using a stereographic microscope. The rocks were preliminarily identified with Diffrac Plus EVA as a poorly garnet-bearing Na-pyroxenite. Density analysis was conducted following the method proposed for this specific kind of archaeological artefacts by Errera (2014).
3. Results and discussion

3.1. Mineralogy

Except in samples Alp10 and Alp17, where only omphacite was detected (Table 2, Figure 9), jadeite and omphacite were the main minerals identified in the geological samples using XRD. Some of these contain analcime, albite and clinochlore as secondary minerals, which were probably formed during the retrogression of the rocks (also detected by D’Amico et al. 2003). The Vilapedre axe only showed the presence of jadeite (73 %, semiquantification in weight) and omphacite (27 %), confirming it as a mixed jade. From a mineralogical point of view, the results show that ALP06 and ALP03 were the analysed geological samples more similar to our axe, since the three have a similar composition, based exclusively on jadeite and omphacite (Table 2).

Table 2. Mineralogical semi-quantification obtained from X-Ray Diffraction. Besides, optical analysis revealed the presence of garnets (deformed garnets or hollow-core small garnets) in both the archaeological and geological samples. Produced by O. Lantes.

| Sample | Jadeite | Omphacite | Analcime | Clinochlore | Albite |
|--------|---------|-----------|----------|-------------|--------|
| ALP01  | 64      | 19        | 17       | -           | -      |
| ALP03  | 61      | 39        | -        | -           | -      |
| ALP04  | 51      | 45        | 5        | -           | -      |
| ALP06  | 85      | 15        | -        | -           | -      |
| ALP10  | -       | 100       | -        | -           | -      |
| ALP14  | 31      | 21        | -        | -           | 48     |
| ALP17  | -       | 100       | -        | -           | -      |
| ALP30  | 57      | 28        | -        | 15          | -      |
| MPVV   | 73      | 27        | -        | -           | -      |

3.2 Chemical composition

Table 3 shows the results of the EDX elemental analysis (five independent determinations per subsample, five subsamples per sample). We must stress that we were interested in a global composition, so that we measured polycrystalline areas to achieve it. The major chemical components detected during the analyses were Na, Mg, Al, Si, Ca and Fe, while the minor elements identified were P, S, Ti, Cu and K. The major elements are characteristic of jadeite and omphacite. Regarding the minor elements, Ti could appear in this kind of rocks as part of a minor trace phase as rutile or titanite and K as phengite or K-Na paragonite (Harlow et al. 2015). P could appear as part of apatite (one of the accessory minerals in both omphacitite and jadeitite). The presence of S, also rare, could be explained by its role as component of the occasional pyrite, pyrrhotite or chalcopyrite. The occurrence of the latter mineral, together with apatite, has been repeatedly reported in Alpine jades (D’Amico 1995, 2012; D’Amico et al. 2003). The detailed SEM exploration of the Vilapedre axe, in this case in individual grains, led us to detect a very occasional presence of shining crystals or grains, interpreted either as La, Nd and Ce phosphates (monazite) or as zircon (Figure 10), the latter already referred as a trace mineral in Alpine jade (D’Amico et al. 1995, 2003, Petrequin et al. 2012b). Cu is present in small quantities in those samples with secondary minerals, such as oxides and sulphides, and its presence in samples of jadeite and omphacite coming from the Alps has been referred by Coccato et al. (2014).

We conducted an ANOVA test of the global chemical data finding no significant differences between the sub-samples at a general level (Table 3 shows the average of the five determinations in each sub-sample). This points out to a compositional homogeneity and it may be seen as an evidence of the representativeness of our sampling strategy.
Table 3. Elemental composition. Mean value, expressed as the percentage in weight relative to Si, of the five determinations in EDX defined for each sub-sample. The absence of superscripts means that the ANOVA test did not detect significant differences between sub-samples (they belong to the same statistical group). Produced by O. Lantes.

| zone | Na     | Mg     | Al     | Si     | P     | S     | K     | Ca    | Ti    | Fe    | Cu    |
|------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|
| Alp01| 1      | 0.402  | 0.040  | 0.413  | 1.000 | 0.000 | 0.000 | 0.000 | 0.095ab| 0.009 | 0.074 | 0.022 |
|      | 2      | 0.400  | 0.042  | 0.409  | 1.000 | 0.000 | 0.000 | 0.000 | 0.099ab| 0.009 | 0.075 | 0.023 |
|      | 3      | 0.403  | 0.039  | 0.410  | 1.000 | 0.000 | 0.000 | 0.000 | 0.100b | 0.013 | 0.074 | 0.023 |
| Alp03| 1      | 0.339  | 0.108  | 0.309  | 1.000 | 0.000 | 0.000 | 0.000 | 0.178  | 0.014 | 0.187 | 0.000 |
|      | 2      | 0.331  | 0.107  | 0.307  | 1.000 | 0.000 | 0.000 | 0.000 | 0.178  | 0.013 | 0.189 | 0.000 |
|      | 3      | 0.333  | 0.108  | 0.307  | 1.000 | 0.000 | 0.000 | 0.000 | 0.176  | 0.014 | 0.181 | 0.000 |
| Alp04| 1      | 0.321  | 0.098  | 0.330  | 1.000 | 0.000 | 0.000 | 0.000 | 0.084  | 0.001 | 0.114 | 0.019 |
|      | 2      | 0.314  | 0.097  | 0.327  | 1.000 | 0.000 | 0.000 | 0.000 | 0.084  | 0.003 | 0.116 | 0.019 |
|      | 3      | 0.312  | 0.097  | 0.326  | 1.000 | 0.000 | 0.000 | 0.000 | 0.084  | 0.004 | 0.117 | 0.017 |
| Alp06| 1      | 0.382  | 0.036  | 0.351  | 1.000 | 0.000 | 0.000 | 0.000 | 0.098  | 0.024 | 0.240 | 0.000 |
|      | 2      | 0.379  | 0.035  | 0.352  | 1.000 | 0.001 | 0.000 | 0.000 | 0.098  | 0.022 | 0.237 | 0.000 |
|      | 3      | 0.385  | 0.036  | 0.354  | 1.000 | 0.000 | 0.000 | 0.000 | 0.097  | 0.024 | 0.239 | 0.000 |
| Alp10| 1      | 0.221  | 0.184  | 0.227ab| 1.000 | 0.000 | 0.000 | 0.000 | 0.385  | 0.024 | 0.090 | 0.000 |
|      | 2      | 0.219  | 0.185  | 0.225ab| 1.000 | 0.000 | 0.000 | 0.000 | 0.385  | 0.025 | 0.089 | 0.000 |
|      | 3      | 0.229  | 0.189  | 0.231b | 1.000 | 0.000 | 0.000 | 0.000 | 0.383  | 0.023 | 0.091 | 0.000 |
| Alp14| 1      | 0.314  | 0.064  | 0.377  | 1.000 | 0.000 | 0.000 | 0.000 | 0.119  | 0.010 | 0.055 | 0.017 |
|      | 2      | 0.319  | 0.066  | 0.376  | 1.000 | 0.000 | 0.000 | 0.000 | 0.119  | 0.009 | 0.056 | 0.019 |
|      | 3      | 0.314  | 0.064  | 0.378  | 1.000 | 0.000 | 0.000 | 0.000 | 0.118  | 0.010 | 0.056 | 0.017 |
| Alp17| 1      | 0.255  | 0.151  | 0.217  | 1.000 | 0.000 | 0.000 | 0.000 | 0.308ab| 0.021b| 0.263 | 0.000 |
|      | 2      | 0.261  | 0.152  | 0.216  | 1.000 | 0.000 | 0.000 | 0.000 | 0.302ab| 0.016a| 0.255 | 0.000 |
|      | 3      | 0.255  | 0.152  | 0.215  | 1.000 | 0.000 | 0.000 | 0.000 | 0.307ab| 0.014a| 0.260 | 0.000 |
| Alp30| 1      | 0.298  | 0.155  | 0.282  | 1.000 | 0.011 | 0.050 | 0.000 | 0.210  | 0.045 | 0.398 | 0.021 |
|      | 2      | 0.293  | 0.147  | 0.282  | 1.000 | 0.009 | 0.051 | 0.000 | 0.214  | 0.124 | 0.319 | 0.020 |
|      | 3      | 0.299  | 0.150  | 0.285  | 1.000 | 0.011 | 0.049 | 0.000 | 0.213  | 0.122 | 0.313 | 0.020 |
| MPVW | 1      | 0.360  | 0.032  | 0.379  | 1.000 | 0.002 | 0.000 | 0.000 | 0.007ab| 0.072 | 0.111 | 0.137 |
|      | 2      | 0.362  | 0.032  | 0.382  | 1.000 | 0.000 | 0.000 | 0.008ab| 0.071 | 0.100 | 0.140 |
|      | 3      | 0.359  | 0.032  | 0.379  | 1.000 | 0.004 | 0.000 | 0.009ab| 0.070 | 0.111 | 0.131 |

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Figure 9. Example of a diffractogram (zoom between 20 and 40 2θ) of some Alpine samples as examples of various Na-Px compositions. Alp04 (red) and Alp17 (black) samples (superimposed). Orange bars: peaks corresponding to omphacite; red bars: peaks corresponding to jadeite. Alp17 does not show traces of jadeite. Produced by O. Lantes from DIFFRACplus EVA software © PANALYTICAL.
3.3. Similarity between the archaeological artefact and the geological samples

A simple visual examination suggests, or at the very least does not contradict, an Alpine origin for Vilapedre’s raw material, given the existence of several similarities between the geological and archaeological samples. Such macroscopic analysis could also to provisionally suggest a more specific source for the raw material, since the macroscopic traits identified in the Vilapedre axe –in particular the garnets (Figure 5)– are akin to those documented in geological samples from Monviso. Conversely, these seem to be absent in the Voltri Group samples (Pétrequin et al. 2012b; Pétrequin & Errera 2017). The jadeite-omphacite
association observed in the Vilapedre axe, with its characteristic schistose structure, is also well represented in the Monviso samples collected to the south of the massif, regardless of whether they are natural blocks, prehistoric axe rough-outs or debris of the workshops documented in the area, but we ought to bear in mind that the Voltri group display, occasionally, a schistose structure too.

The statistical analysis points to the Vilapedre item being more similar, from a chemical point of view, to the geological sample ALP06, followed by ALP03 (Figure 11). Such results are consistent with the similarities detected at a mineralogical level, therefore suggesting that ALP06—a decimetric block collected in the Pô River at Revello (Piedmont, in the Italian Alps)—could be a raw material similar to Vilapedre’s. In addition to the analytical data, the external aspect (green colour and flakiness) of ALP06 is the closest to MPVV among the samples analysed for this paper. The presence of zircon as trace mineral points also towards an Alpine origin of the MPVV raw material, since zircon has been referred as an important trace mineral in Alpine jade (D’Amico 1995, Pétrequin et al. 2012b), both in Monviso and Voltri. Likewise, apatite and—to a lesser extent—titanium minerals have been frequently identified as minor phases of the Alpine jades (D’Amico 1995). The only difference between MPVV and ALP06, detected in the performed analysis is the absence of K in the latter, maybe included in phengite (Harlow et al. 2015), but this dissimilarity could be due to a lower concentration of this mineral.

![Figure 11. Dendrogram of samples. -1, -2, -3: independent sub-samples obtained for each sample. In all cases, sub-samples corresponding to the same sample are grouped together. This suggests a very similar and homogenous composition of the subsamples. Produced by O Lantes from SPSS Statistics software version 20 (IBM®).](image-url)
3.4. Vilapedre as evidence of prehistoric contacts between two Atlantic land ends?

Parallels for the Vilapedre axe cannot be found elsewhere in the Iberian Peninsula, but in Brittany (France): research has shown the Gulf of Morbihan acting as a powerful attractor for large polished blades within the distribution network of Alpine jades. Such artefacts were often re-polished to create specific regional models: the so-called “Carnacean axes”, whose most emblematic examples—the Tumiac type—are butt-perforated (Figure 3: right). Between the mid-5th Millennium and approximately 4300 BCE, this coastal area of France delivered some repolished Alpine pieces towards the Paris Basin, Germany and—as we suggest in this paper—the northwest of the Iberian Peninsula (Cassen et al. 2012; Pétrequin et al. 2012b).

The presence of a Tumiac axe in Northwestern Spain has been repeatedly mentioned as an evidence of the existence of links between the French and Iberian western outposts, starting at least from the early 4th Millennium BCE (Cassen et al. 2012; Pétrequin et al. 2012b), an hypothesis that is also supported by the presence of other Iberian artefacts (namely variscite beads from Palazuelo de las Cuevas and Encinasola) amidst the grave-goods at several sepultures of Western France, most of them found in the gigantic Carnacean tumuli around the Morbihan gulf—Tumiac in Arzon, Mané er Hroëck in Locmariaquer, and Saint-Michel in Carnac—(Cassen et al. 2012; Querré et al. 2008, 2012, 2015). Recent approaches (Cassen et al. 2019) have added Tumiac axes made on calcium amphibole/actinolite to the possible list of artefacts exchanged between these two regions.

The peculiar spatial distribution of some of these objects, with few or no examples in regions between Brittany and Galicia (Figure 2), has led several authors to point out the possibility of direct contacts by sea between these two areas, which would provide interesting insights on the possible development of relatively advanced seafaring techniques in Southwest Europe as early as in the 5th millennium BCE (Cassen et al. 2019).

4. Conclusions

The mineralogical, chemical and macroscopic analyses have identified ALP06—a decimetric block collected in the Pô River at Revello (Piedmont, in the Italian Alps)—as the closest to Vilapedre’s raw material among the geological samples analysed for this paper. Such similarity, together with the fact that the selection of samples was conducted considering all the archaeological data available for the potential source areas known in Western Europe to this day, points out that it could be the probable raw material employed for manufacturing the Vilapedre axe, perhaps from blocks close to Revello or others located in areas with similar features, including primary sources higher up in the mountains. That said, other potential sources appearing in the future may make further geological analyses necessary to tighten with greater accuracy a precise location.

The determination of an Alpine origin for the Vilapedre axe is a significant contribution to the study of the Prehistory of the Atlantic Façade, since it links two of its major “land-ends” and stepping stones (Brittany and Galicia) within an exchange network that—from the Italian Alps—reached most part of Western Europe. Although other Alpine axes had been previously documented in the Iberian Peninsula, Vilapedre is the only clearly Carnacean axe of Morbihan style found so far in the area. As other authors have repeatedly noted, this circumstance reinforces the traditional hypotheses suggesting the existence of contacts between Brittany and Galicia since, at least, the Neolithic period. Such a view is endorsed by the striking similarities in certain artefacts, such as the unusual concentration of Cangas-type perforated axes in NW Iberia, the Castelic pottery found in the passage-grave of Dombate or the presence of West Iberian variscite in Breton tumuli; noteworthy is, too, the so-called “The Thing” carved on Dombate’s uprights—also in other NW Iberian dolmens— that has been related to motifs found in Breton megaliths (Cassen et al. 2012; Fábregas Valcarce et al. 2012).
It is also remarkable the current absence of parallels for Vilapedre and other perforated Tumiac axes in other regions of Spain or Portugal, namely in the whole Cantabrian strip, perhaps hinting at the existence of direct sea contacts between Brittany and Galicia. Such a peculiar distribution of material items seems to persist in later, Chalcolithic times, for Bell Beakers are very well represented in Galician territory, while extremely scarce in neighbouring Cantabrian regions and, again, quite present in Brittany with, furthermore, clear coincidences as to the design and decorative techniques of the vessels (Blas & Rodríguez 2015; Prieto & Salanova 2009).

With the necessary caveats linked to the difficult context of the piece, we would like to propose the path followed by the Vilapedre axe: from the extraction and manufacture, probably in the Western Alps, to its circulation towards the Paris basin and then to Brittany, where the final polishing and perforation would have taken place. Finally, having lost its original function as a working tool and becoming an item with a strong social or religious significance, the Vilapedre axe would have departed the Gulf of Morbihan to reach the northwest of the Iberian Peninsula, after completing a journey of more than 1.400 km.

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