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RESEARCH

In the land of tin men? Warrior stelae, mobility, and interaction in western Iberia during the Late Prehistory

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Abstract

The warrior stelae, also called southwestern stelae or western stelae, emerge as one of the most characteristic manifestations of the Bronze Age in Iberia. Since the earliest findings more than a century ago, these monoliths have received great attention from scholars, becoming the subject of an intense debate, without a consensus having been reached on their meaning and sense. A slow but steady trickle of new findings, as well as the implementation of new approaches to their study, has only enriched these discussions in recent years. One of the most successful lines has been the spatial analysis focused on the relationship of these monuments with routes, transit areas, and resources of great value. It is within this line that this article explores the potential relationship that the stelae may have had with a critical mineral resource: the tin ores distributed in western Iberia, which is the highest concentration of this mineral in Europe. To do this, a detailed spatial analysis has been conducted in order to explore if the uneven density of these monuments across western Iberia may be linked with the presence of tin ores or, alternatively, with the control of the routes that allowed the circulation of this mineral by land.

Keywords Warrior stelae · Statue-menhir · Late Bronze Age · Western Iberia · GIS · Spatial analysis · Multivariate statistics

Introduction

Western Iberia is home to a remarkable group of monuments dating from around the Late Bronze Age (c. 1400/1250–850 BC): the so-called warrior stelae, also known as variously southwestern or western stelae. Materially, they are monuments consisting of shaped stones, commonly flattened into a slab-like form, with a rich iconography centered on engravings of weapons and other objects of prestige. Although, since the first discoveries more than a century ago, they have become an essential source of information for this period in the region, their study has posed many problems. Certainly, the main one has been the "absence" of clear archaeological contexts, either because they are located isolated in the landscape—without associated materials—or because they have been reused in historical times, appearing outside of their original position (Celestino Pérez and López-Ruiz 2016: 160). This "decontextualization" (see critical review in Díaz-Guardamino Uribe 2010: 31–35; Díaz-Guardamino Uribe et al. 2019) has made research traditionally focused on the mere iconographic analysis of the engravings to approach their chronology and functionality, a complex issue that has been much debated.

New findings, fieldwork, and new methodologies have helped to revitalize the study of these monuments in recent years, opening new avenues of research. It can be pointed out four main approaches. The most important has been the iconographic line mentioned above. Throughout the study of graphic motifs, the focus has been on three key aspects: the chronology, the meaning, and the supra-regional connections with Europe and the Mediterranean, delving into issues such as acculturation and, more recently, cultural hybridization. With all the problems that this approach implies, it has been the most fruitful line of analysis, constituting the core of our knowledge regarding the warrior stelae (Celestino Pérez 2001; Harrison 2004; Díaz-Guardamino Uribe 2010;

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Araque 2018). In the early 1990s, a second approach was taken into consideration: the spatial analysis, focusing on the relationship of the stelae with the landscape (Ruíz-Gálvez Priego and Galán Domingo, 1991; Galán Domingo 1993; Galán Domingo and Ruiz-Gálvez Priego 2001), more specifically, on the connections between these monuments and pathways, passage zones, and valuable resources. Without ruling out a funerary dimension, already argued by the first approach, the main contribution was to explore the role of stelae as territorial markers. This line has been obviously reinforced with the generalization of GIS-based spatial analysis (Celestino Pérez and Salgado Carmona, 2011; Fábrega-Álvarez et al. 2011; Costa Caramé 2013; Pavón Soldevila et al. 2018; Díaz-Guardamino Uribe et al. 2019; Celestino Pérez and Paniego Díaz 2021).

A third approach springs from a critique of what was described as "a strongly diffusionist approach" and "some disproportionate emphasis on the quest for the oriental parallels" (García Sanjuán 2011: 537). Their funerary role and their function as territorial markers are accepted but interpreting them within the logics proper to the previous monumental and iconographic substrates in the region (García Sanjuán et al. 2006; García Sanjuán 2011; Díaz-Guardamino Uribe 2010; Bueno Ramírez et al. 2019). In recent years, the analysis of the materiality of the supports and engravings has been added, resorting to high-resolution digital photography (Díaz-Guardamino Uribe and Wheatley 2013; Jones et al. 2015; García-Arilla et al. 2021) and petrological analyses (Blas Cortina 2010; Merino et al. 2020; Díaz-Guardamino Uribe et al. 2020; Araque et al. 2023). This has allowed us to begin to delve deeper into two key issues: the study of the geological provenance of the stone supports and the synchrony/diachrony of the engravings that make up the iconographic program of the stelae.

Despite the significant advances achieved, we continue to face unresolved issues. These include, among others, establishing the reason behind the preferential distribution of stelae within a specific area of western Iberia. While this has been argued to be related to different issues—such as the control of routes, fords, and transit zones related to transhumance (Galán and Ruiz-Gálvez 2001)—other possible causes has been ignored. This is the case of the mineral resources. And more specifically, its relationship with the tin sources. Although it is true that this relationship has already been argued by some scholars (Barceló 1989: 205; Bendala 2000: 70-71; Díaz-Guardamino Uribe 2010: 64; Mederos Martín 2012: 445-449; Araque 2018; Rodríguez-Corral et al. 2019), this has not yet been explored in detail through spatial analysis.

This article focuses on exploring the potential relationship between the stelae not only with the tin sources but also the suprarregional interchange of this resource. At first glance, some evidence seems to point in this direction. Firstly, the emergence of these monuments coincides with the rise of bronze metallurgy and the exploitation of the tin ores in the region. Secondly, its distribution seems to overlap with the areas that hold most of this mineral resource. And thirdly, there seems to be archaeological evidence indicating Atlantic-Mediterranean interactions in the territory where the statue are located (Vilaça 2008). To carry out this study, in addition to the stelae, the analysis has been extended to the so-called statue-menhirs-shaped stones, conventionally flattened into a tubular or slab-like form, carved with anthropomorphic details. While both stelae and statue-menhir are closely related spatially and ichnographically, the statues-menhir are dated to earlier times, some of them being reused later as warrior stelae. Their inclusion in the analysis allows us to explore the spatial behaviors of the stelae in relation to the previous iconographic substrate in the region.

Background

The purpose of the spatial analysis carried out in this paper is to detect the existence of eventual regularities in the location of both the stelae and the statues-menhir known nowadays in western Iberia and explore whether their distribution and intensity (density) could have been related to the presence of tin sources in the area. To do this, we first compiled a database with the location and main characteristics of a total of 123 stelae and 20 statue-menhirs located in western Iberia (Fig. 1). This information was gathered by consulting the works carried out by different authors who have analyzed different aspects of these monuments in detail (Celestino Pérez 2001; Harrison 2004; Díaz-Guardamino Uribe 2010; Celestino Pérez and Salgado Carmona 2011; Vilaça 2011; Araque 2018), also including the findings of the last few years.

All published locations of the monuments have been reviewed and checked on cartographic maps for accuracy. It should be noted that a number of these coordinates had to be corrected either because they used an old frame references (taking the Madrid Meridian as basis) or because they did not coincide with the location of the finding. The original location of a number of these engraved monoliths is not known precisely, as they are old findings and/or there are conflicting references. In these cases, we used the nearest geographical point for which reliable information was available (parish, municipality, plot, etc.). On other occasions, although the exact location of the find is known, they have appeared outside their primary context, reused in constructions from the Iron Age, historical, or contemporary period. In these cases, this location has been considered as the original. Authors such as Galán (1993: 31) or Costa (2013) assume that the weight of these monoliths made their displacement far from their original positions

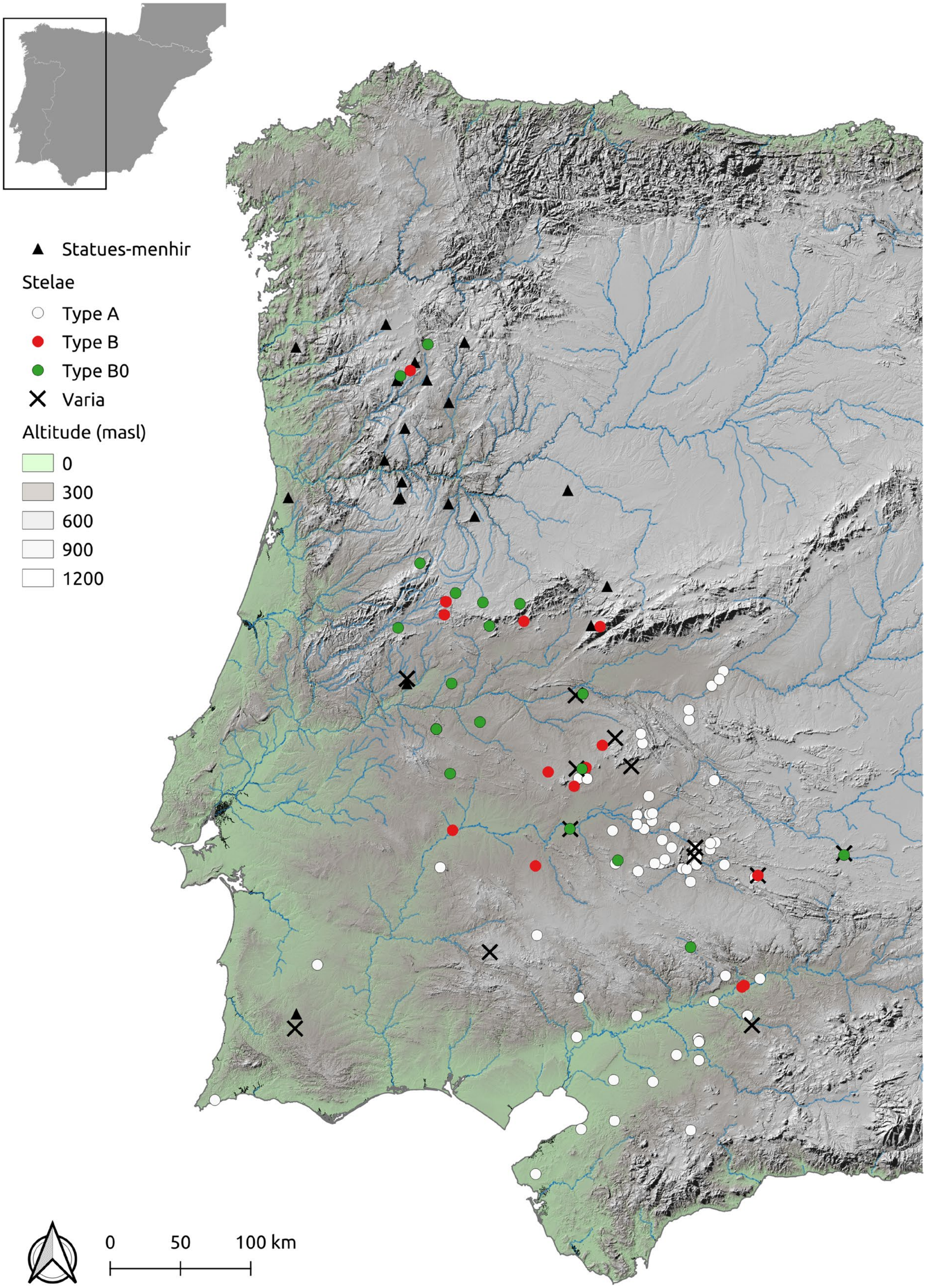


Fig. 1 Location of stelae and statues-menhir in western Iberia

difficult. However, as Celestino Pérez and Paniego Díaz (2021: 77) has pointed out, some of these stelae were founded several hundred meters from their original location. This is the case, for example, of the stela from Cabeza del Buey III (Badajoz), which appeared displaced by more than a kilometer. Be that as it may, while this problem of delocalization may affect at micro- and meso-scale, it should not pose any major problem in a macro-analysis such as the one carried out in this work.

Given the significant internal variability existing within the Iberian stelae, we have decided to analyze them both as a whole and each of the three subtypes defined through their iconography: the so-called type B, type B0, and type A stelae—also denominated in Celestino's (2001) classification as type I-A, type I-B, and type II-IV, respectively (Fig. 2). Type B refers to the so-called basic stelae. They are slabs with graphic motifs typical of the Atlantic sphere: a V-notched shield at the center of the composition and a spear and a sword lying above and below, respectively. Sometimes, conical helmets were added to this iconography. All these artifacts can be traced throughout Atlantic Europe. At some point, these basic stelae began to incorporate objects of Mediterranean origin such as mirrors, combs, or brooches. These are commonly referred to as type B0. Finally, type A stelae are more complex stelae, whose iconography is characterized by the presence of anthropomorphs (Díaz-Guardamino Uribe 2010).

In addition to archaeological data, we collected information regarding the location of 1006 main tin ores known in western Iberia (Fig. 3). To do so, we consulted both previous works (Díaz-Guardamino Uribe 2010; Currás Refojos 2014; Meunier 2019) and databases of the Spanish Instituto Geológico y Minero (IGME) and the Portuguese Laboratório Nacional de Energia e Geologia (LNEG). It should be taken into account that not all of them were necessarily mined during the Late Bronze Age. In this sense, no representative map exists today to illustrate which sources were or were not exploited in prehistoric times. Either this activity leaves very little trace in the landscape or such evidence has been destroyed by the exploitations of later periods. This turns their archaeological identification into a very difficult task. Thus, although there is evidence of exploitation in some areas detected thanks to systematic surveying (Meredith 1998a, b; Rodríguez Díaz et al. 2013; Rodríguez Díaz et al. 2019), we do not know the reality of other parts of our study area (Comendador Rey et al. 2017). Alternatively, our goal has been to create a general distribution map that allowed us to define tin rich areas—in which prehistoric exploitation would have been more likely to occur—in contrast to those other regions with no evidence of tin mineralization.

Using a 100-m resolution elevation map as a basis, we created all the maps (water accumulation, slope, etc.) necessary for the generation of anisotropic cost surfaces and least-cost paths, which were created by using the *r.walk* and *r.drain* algorithms in GRASS GIS 7.8 (GRASS Development Team 2020). Likewise, density estimates for both stelae and statue-menhir as well as for tin sources were generated using the *v.kernel* algorithm with a Gaussian density function. The statistical analyses were carried out in the R software environment, version 4.2.0 (R Core Team 2022), using the "spatstat," "sp" or "raster" packages (Baddeley et al. 2015; Bivand et al. 2013; Hijmans 2022), among others.

Establishing the spatial structure of stelae and statues-menhir

Our first concern was to statistically define the spatial structure exhibited by stelae and statues-menhir in our study area. More specifically, our aim was to determine whether these monuments have a regular—they tend to avoid each other—or clustered distribution—they gravitate towards each other—or if, on the contrary, they are independent of one another. It was especially relevant to rule out this last scenario since it would have implied that stelae and statues-menhir display a complete spatial randomness (CSR) (Baddeley et al. 2015; Bivand et al. 2013). This would have meant that the distribution of such monuments throughout our study area would be totally random and, therefore, only pure chance would explain their location. It would follow

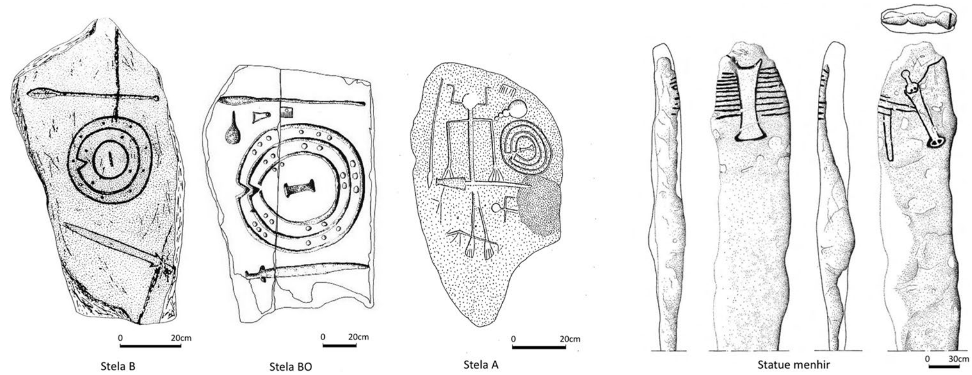


Fig. 2 Types of monuments (from left to right): Cordoba II, Cordoba; Brozas, Cáceres (after Celestino Pérez 2001) Montemayor, Córdoba (after Ferrer Albelda 1999); and statue-menhir from Ataúdes (after Vilaça et al. 2001)

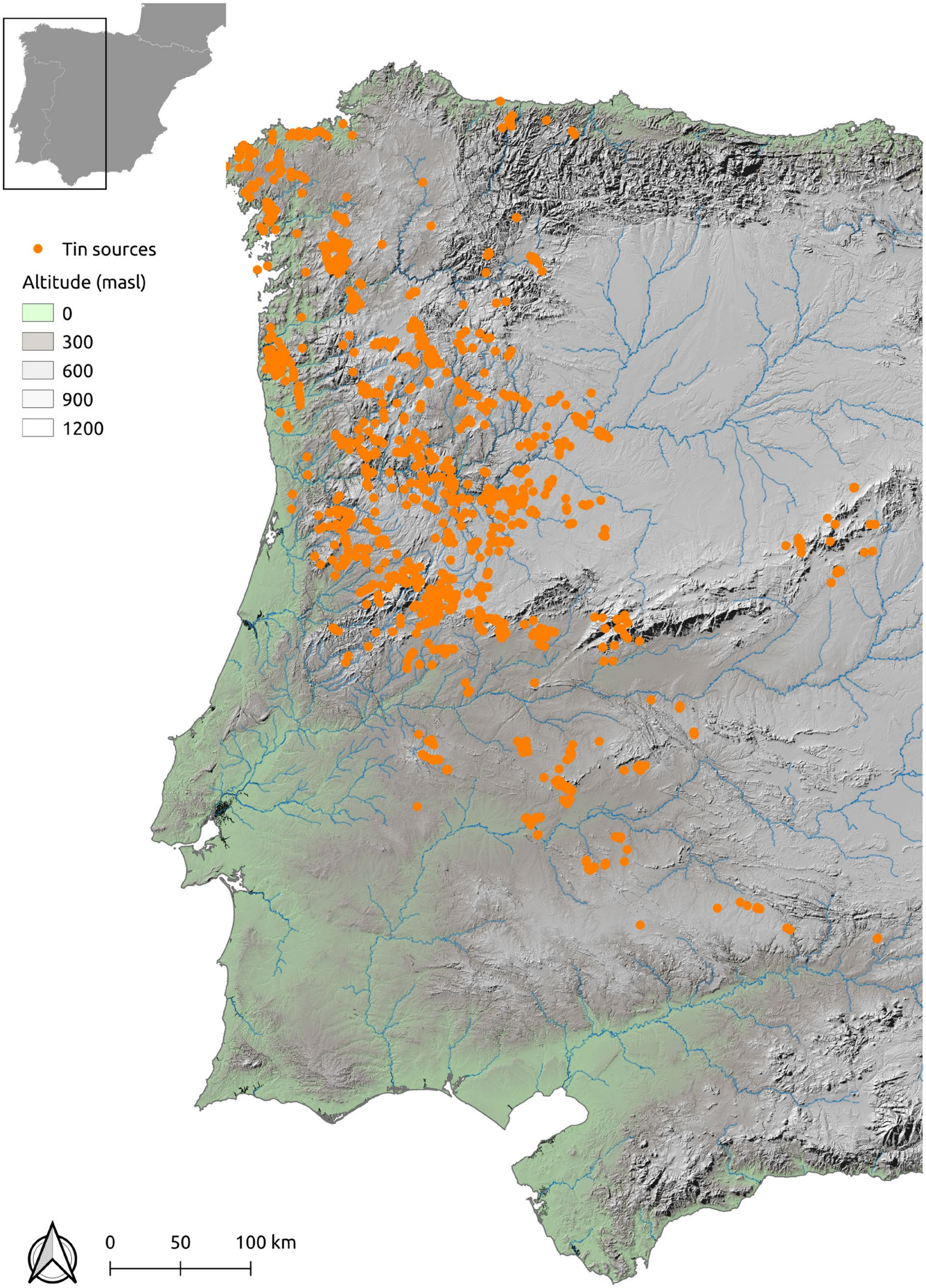


Fig. 3 Location of tin sources in western Iberia (sources: IGME and LNEG)

that all the variables explored in this paper (or any other, for that matter) would lack explanatory power over the spatial arrangement shown by stelae and statues-menhir.

To confirm or rule out CSR, we resorted to a test widely used in spatial statistics for that purpose: Ripley's *K* function (Baddeley et al. 2015). This is generally represented as a graph (Fig. 4) whose vertical axis shows the cumulative and standardized average number of points (in this case stelae or statues-menhir) lying within a given distance (horizontal axis). The cumulative value of the set of real points analyzed in this paper (black line) was compared with those of 999 simulated sets of the same size as the real one, but which do exhibit complete spatial randomness (the dashed red line and its "acceptance interval" with a significance level of 0.05 represented by the gray envelope) (Baddeley et al. 2015). If the values shown by the set of real points (stelae and statues-menhir) were located within the acceptance interval (gray area), these would be consistent with CSR. One of the virtues of this and other similar methods is their multi-scalar perspective, which makes it possible to identify if a given set of points shows different types of distributions at specific scales (e.g., clustered at short distances versus dispersed or even independent at larger scales) (Bevan et al. 2013; Bevan and Conolly 2006).

The results of Ripley's *K* function suggest that none of the four sets of points considered in this paper (type A, B, and B0 stelae and statues-menhir) show a behavior consistent with that of the 999 simulated sets that do exhibit CSR (Fig. 5). However, the distribution of type B stelae is very close to the upper limits of the acceptance interval, while both the type B0 stelae and the statues-menhir show distributions in the smaller radii coherent to those shown by the simulated sets of random points.

On the other hand, the fact that the values shown by the monoliths analyzed in this paper are located above the acceptance interval generated by the 999 sets of simulated point sets, exhibiting CSR could be taken as an indication of stelae and statues-menhir displaying a clustered distribution (the opposite could be said if the values were located below the acceptance interval). Such clustered structure can be deduced—to some extent—from looking to the distribution

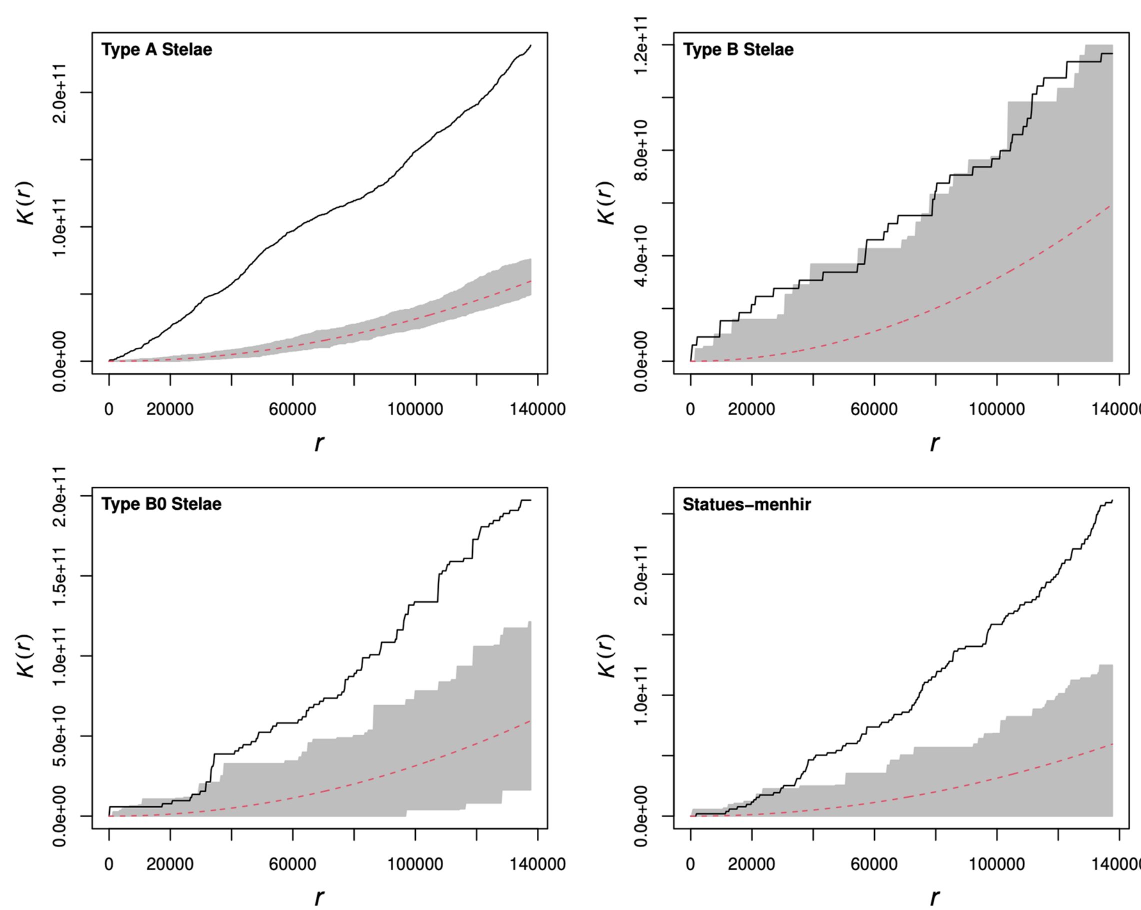


Fig. 4 Homogeneous Ripley's *K* function test of complete spatial randomness for the different types of monuments analyzed in this paper (black line) and against 999 sets of randomly distributed points (gray envelope showing the "acceptance interval")

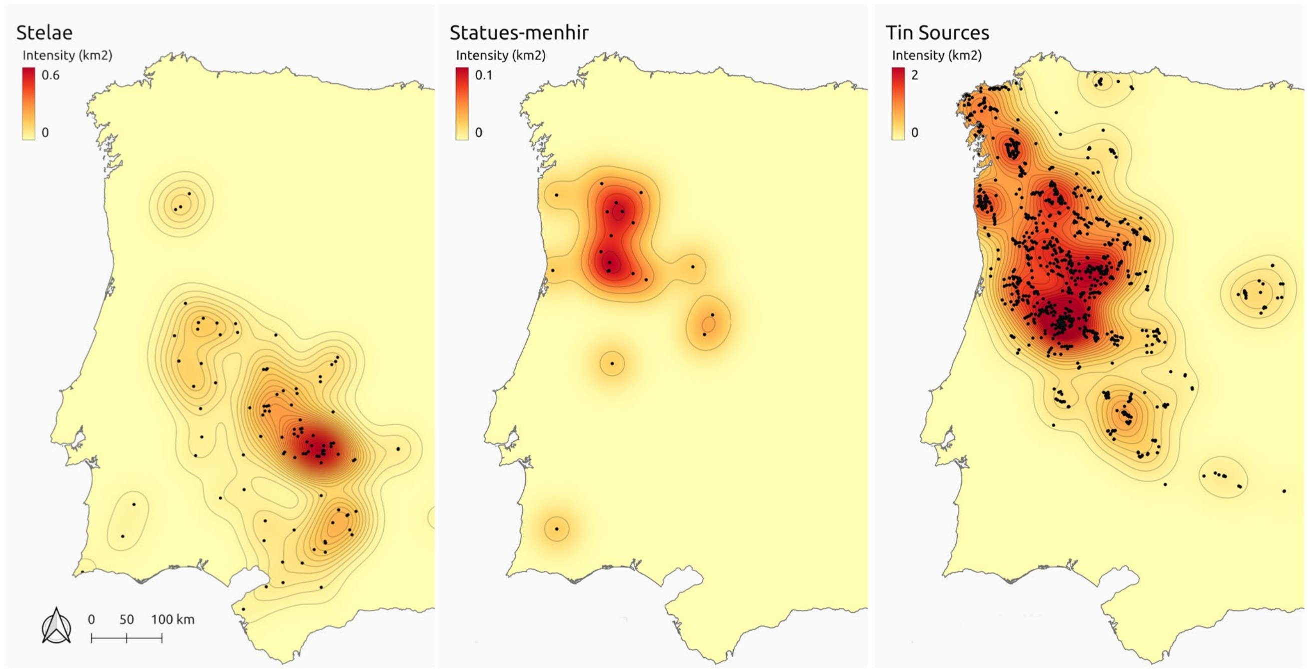


Fig. 5 Kernels maps showing the intensity or density of stelae, statues-menhir, and tin sources within our study area

maps of the engraved monoliths (Fig. 6), which show a tendency for these monuments to cluster in certain regions of the study area.

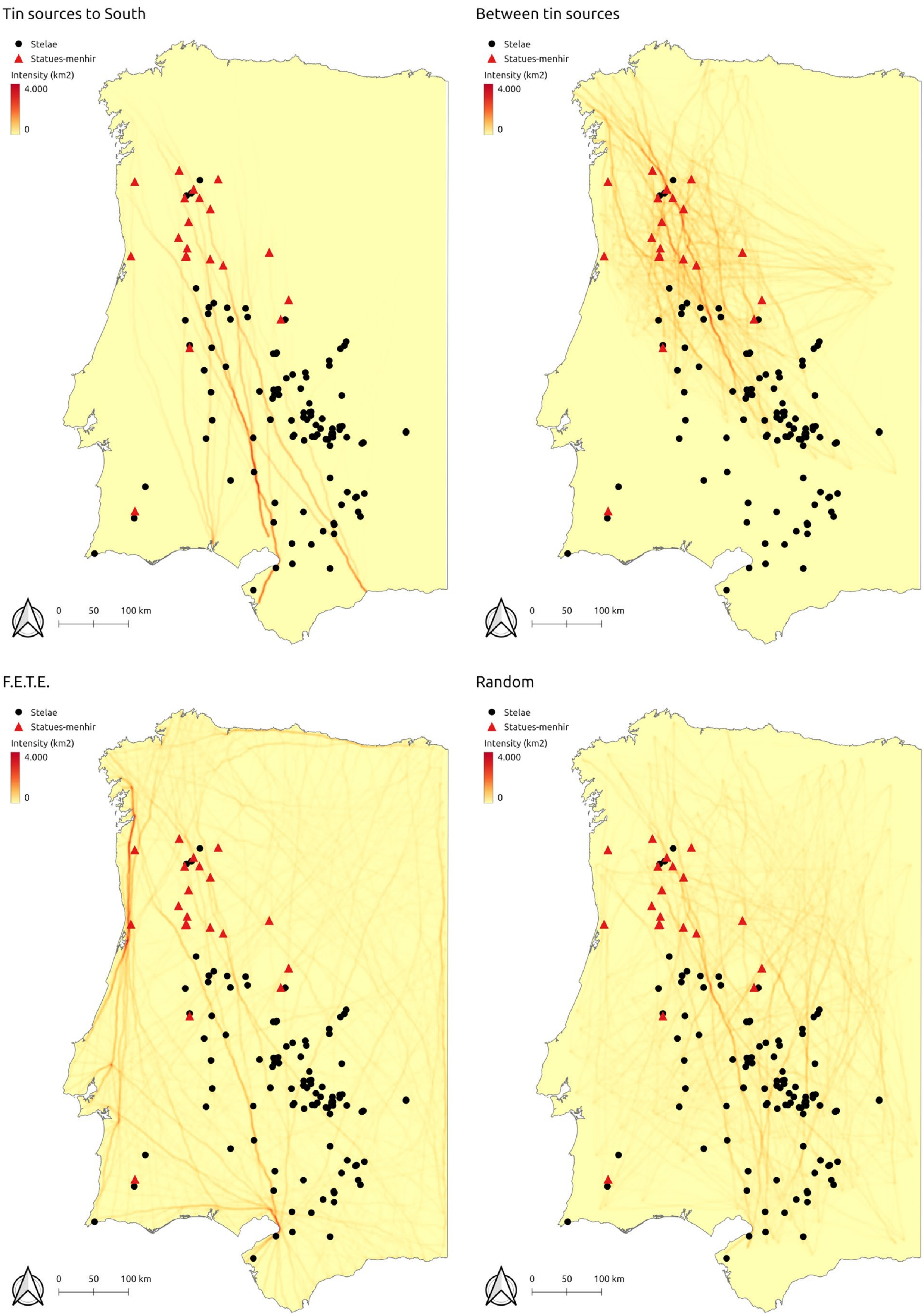
Nevertheless, we applied the Hopkins-Skellam test to statistically confirm that stelae and statues-menhir do show such clustering tendency. This test makes it possible to find out whether a given set of points has a clustered distribution by comparing it—once again—with 999 sets of points randomly distributed across the study area. The assumption is that if a set of points (stelae or statue-menhir) are randomly distributed across a given space, then the statistical distribution of distances from these points to their nearest neighbors will be the same as the distribution of distances to any other random point (Baddeley et al. 2015).

The Hopkins-Skellam produces an index (A) and a p value. If A is equal to 1, the distribution of our set of points should be considered random; if A is lower than 1, the distribution will be clustered; and if it is greater than 1, the distribution will be regular or dispersed (Baddeley et al. 2015). The values well below 1 shown by type A (A: 0.022, p value: 0.001), type B (A: 0.113, p value: 0.002), and type B0 stelae (A: 0.088, p value: 0.001) and by statues-menhir (A: 0.225, p value: 0.003) confirm that these monuments are clearly clustered around specific areas of the Western Iberia. More specifically, the stelae are located in the southwest quadrant of the Iberia (hence the name they have received for many years: stelae of the southwest). These monuments can be mainly found in the eastern half of Extremadura and at its confluence with Andalusia and Castilla la Mancha, as well as in the Guadalquivir Valley (Andalusia) and the Beiras region, in Portugal. The statues-menhir, for their part, are mainly located in the Portuguese territory north of the Douro River (Fig. 7).

Analysis of the spatial distribution of stelae and statues-menhir as a function of the intensity of tin sources and transit routes

Once it has been positively established that the stelae and the statues-menhir analyzed in this paper tend to cluster, it is only logical to think that their uneven distribution was caused by one or—more probably—several variables acting together. Thus, our next goal was to determine whether the existence of tin ores is among the variables that might explain what seems to be a preferential arrangement of these monuments around specific regions within our study area.

The intensity or density maps of stelae, statues-menhir, and known tin mineralization in western Iberia seem to point towards a significant overlap between tin-rich areas and those places where a higher concentration of statues-menhir has been documented (Fig. 8). Regarding the stelae, such overlapping seems less evident, although those monuments of this kind located further to the northwest are near important stanniferous areas. A simple linear regression analysis of the intensity kernels generated for tin sources, stelae, and statue-menhir confirms the picture we have just described:


Tin sources to South
Stelae
Statues-menhir
Intensity (km2)
4.000
0
0 50 100 km
Between tin sources
Stelae
Statues-menhir
Intensity (km2)
4.000
0
0 50 100 km
F.E.T.E.
Stelae
Statues-menhir
Intensity (km2)
4.000
0
0 50 100 km
Random
Stelae
Statues-menhir
Intensity (km2)
4.000
0
0 50 100 km

◂**Fig. 6** Intensity of routes crossing the study area according to the different strategies used for their calculation: routes from tin sources to the south; routes connecting tin sources with each other; routes From Everywhere to Everywhere (F.E.T.E.); routes connecting random points within the study area

the relationship between tin ores and statue-menhir seems to be moderately relevant (*r*: 0.652), while it is virtually negligible for the stelae (*r*: 0.110).

However, given the complexity of the dynamics we are dealing with, we deemed it necessary to carry out a more detailed and robust analysis of this relationship between tin, stelae, and statues-menhir. Three main proxies were used to try to measure such association: (a) the intensity/density of tin sources in the vicinity of the monuments (measured in number of sources or ores per square kilometer); (b) the cost (in hours) of walking from the nearest tin source; and (c) the intensity/density of potential land routes in the vicinity of stelae and statues-menhir (measured in routes per square kilometer).

The first of the variables (*a*) is—at least in theory—self-evident: as we have described above, if there is indeed a relationship between monuments and tin sources, the former would be "attracted" by the latter. Thus, we should expect to find a greater intensity of engraved monoliths in those points, where there is also a greater density of ore. The other two variables (*b* and *c*) account for the possible existence of indirect, less obvious relationships. Thus, the stelae or statues-menhir may be located not in the strict vicinity of ore-rich areas, but in nearby territories easily accessible from these sources (e.g., within a day's journey on foot). Similarly, the intensity of potential land routes was explored in the light of the hypotheses suggesting that the location of many of these monuments could have been linked not to the control of tin sources as much as of the routes that make possible the circulation of ore (and that of other goods and raw materials), especially towards the main enclaves in the coast of Southern Iberia.

To test the relationship, in terms of travel cost by foot, between tin sources and the rest of the study area, an anisotropic cost surface was created using the algorithm *r.walk* in GRASS GIS and subsequently converting the result from seconds to hours. In turn, the possible relationship of stelae and statues-menhir with overland mobility patterns along western Iberia was tested by computing a dense network of more than 80,000 least-cost paths, which were calculated following different strategies:

- Routes between tin sources and some of the main enclaves located on the southern coast of the Peninsula, where dynamics of interaction and presence of Mediterranean agents are documented at an early date (the current provinces of Cádiz, Málaga, Sevilla and Huelva).
- Routes between major tin sources.
- Routes "From Everywhere to Everywhere" (F.E.T.E.) connecting points distributed at regular intervals on our study area (White and Barber 2012).
- Routes connecting points randomly distributed throughout the study area.

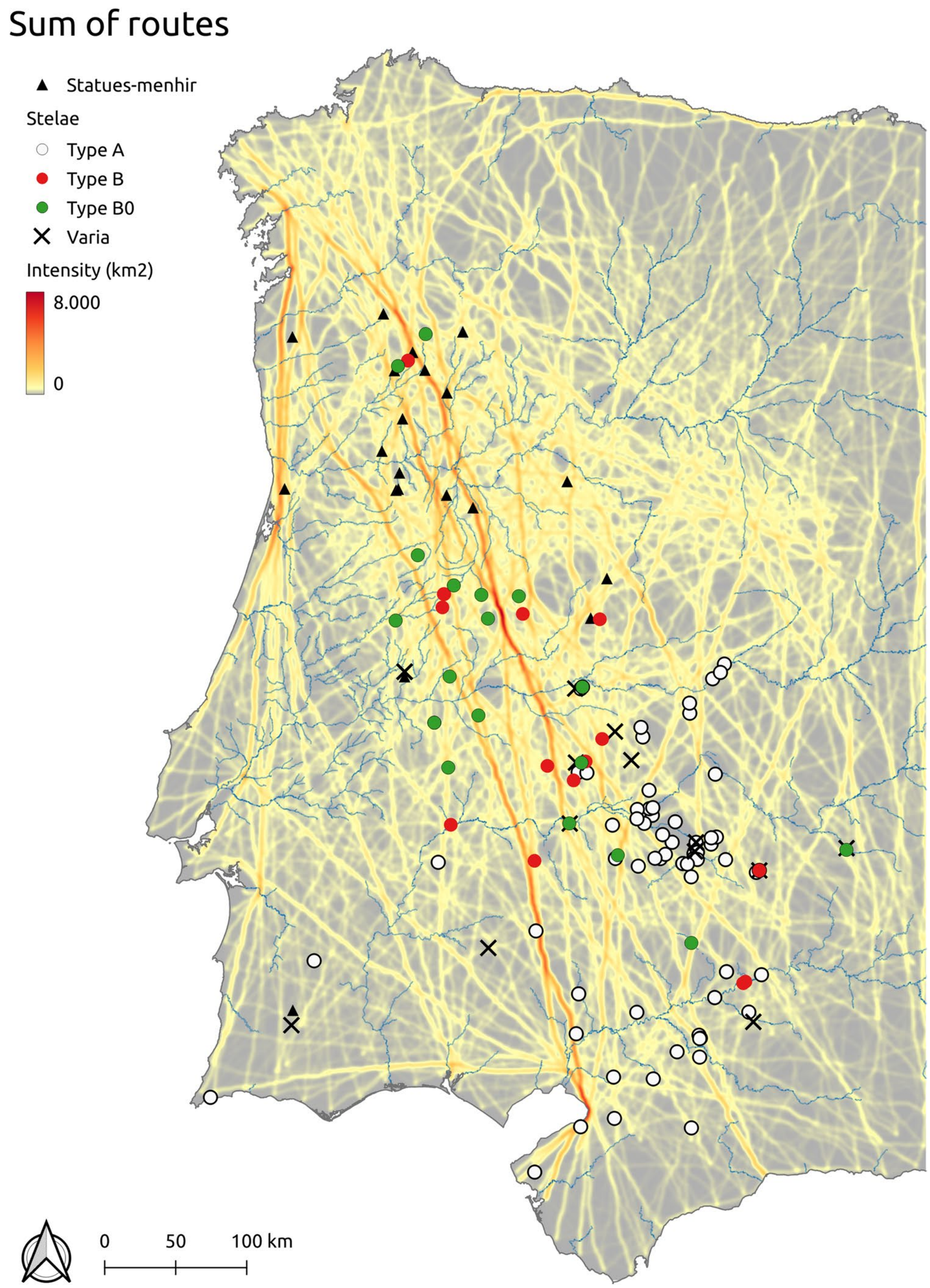
The routes calculated for each of these strategies were subsequently merged, and a kernel raster map was created showing the intensity (that is, the number of routes per square kilometer) existing on each point of our study area (Fig. 9). Besides, a map displaying the sum of all the routes generated for this paper was created to show the location of the monuments in the framework of the general mobility patterns within Western Iberia (Fig. 10).

The logic behind this computation is quite straightforward: those places with a higher intensity of routes per square kilometer (hotspots) would have had the potential to act as significant nodes in the overland transit network. Consequently, it would be precisely in the vicinity of those areas where one should expect to find sites and monuments originally intended to control, either effectively or symbolically, the transit of people and objects through a given territory. This approach has already proven to be quite successful in measuring the transit association of different types of archaeological sites, such as paleolithic sites (Díaz Rodríguez 2019), prehistoric mounds (Carrero-Pazos 2018; Rodríguez-Rellán and Fábregas Valcarce 2017), rock art (Rodríguez-Rellán and Fábregas Valcarce 2015), and even the statues-menhir themselves (Fábrega-Álvarez et al. 2011). In our case, the fact that many of the areas identified as having a higher transit intensity coincide with the layout of significant historical routes—Via de la Plata, Roman roads, and traditional cattle trails (España-Chamorro 2019; Fernández Centeno and Moreno Manso 2017; Rodríguez Martín 2008)—may be seen as a confirmation that the simulated mobility networks generated are, to a certain extent, representative of the traditional paths existing within our study area.

Once we created the maps displaying the different variables of analysis taken into consideration for this paper, our goal was to determine whether the uneven intensity showed by stelae and statues-menhir depends on any of the variables considered.

The existence of such dependence was explored by means of the Kolmogorov-Smirnov and Berman tests (Baddeley et al. 2015). These make it possible to determine whether there are statistical differences between the values of a given variable (e.g., "intensity of tin sources") observed in the exact location of stelae and statues-menhir and those displayed by the very same variable in any other random point within our study area. The existence of a statistically significant difference is essential for considering

Fig. 7 Intensity of routes across the study area considering the sum of the more than 80,000 routes generated for this paper



that the location of the engraved monoliths is dependent on a specific variable.

For this purpose, we created a simulated set of points composed of the same number of elements than our real population of stelae and statues-menhir but distributed in a completely random manner throughout the study area. This process was subsequently repeated a given number of times (999, in this case). We chose to calculate the difference between the real and simulated sets of points using three different tests (Kolmogorov-Smirnov, Berman's Z1 and Berman's Z2), since each of them has certain strengths and weaknesses compared to the others (Baddeley et al. 2015). In this sense, we have opted for the very strict option of considering as relevant only those variables for which significant differences has been unanimously highlighted by all three tests (Table 1), even if it entails an increased risk of underestimating the importance of some of the variables.

The results suggest that—when analyzing the stelae as a single, undifferentiated group—these monuments show a dependence on the variables "intensity of tin sources," "walking costs from tin sources," "intensity of routes between tin sources," and "intensity of random routes."

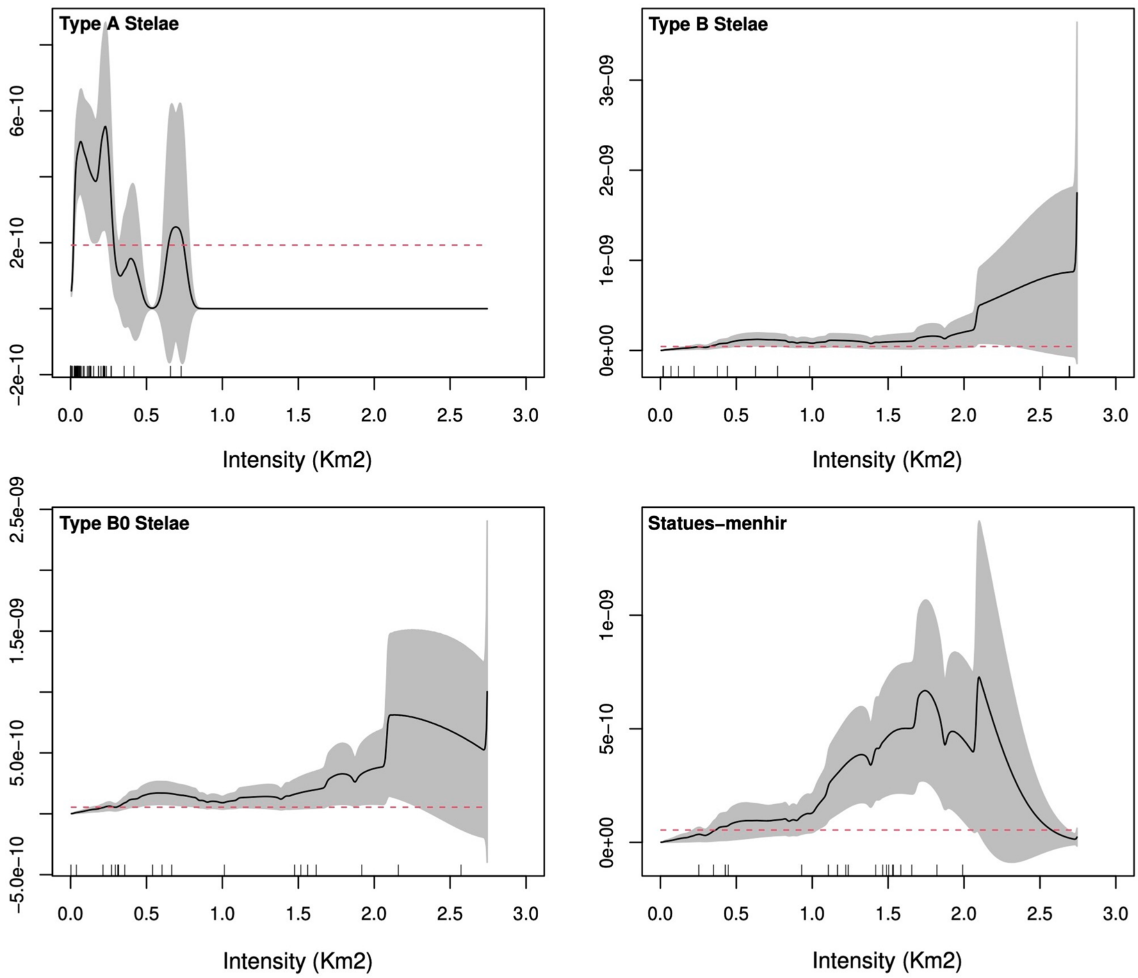


Fig. 8 Relative distribution estimate of the intensity of stelae and statues-menhir as a function of the density of tin sources across the study area (measured in ores per square kilometer)

Meanwhile, the rest of the variables considered ("intensity of routes between tin sources and the south," "routes F.E.T.E.," or "sum of all the routes") show significant differences according only to one or two of the tests conducted (Table 1).

Curiously, if we analyze the stelae divided into groups created according to their traditional typological classification as mentioned above, we observe the emergence of quite heterogeneous patterns. For instance, type A stelae show only a significant dependence on the variable "intensity of random routes." None of the other tin-related variables are significantly different in the locations of these monuments compared to randomly selected points within our study area. On the other hand, the intensity of both type B and B0 stelae across western Iberia shows a significant dependence on the variables "intensity of tin sources," "walking costs from the nearest tin source," "intensity of routes between tin sources," and in the case of type B stelae on "intensity of random routes" and "random routes" (Table 1).

Meanwhile, the intensity of statues-menhir seems to be dependent on the variables "intensity of tin sources," "walking costs from the nearest tin source," "intensity of routes between tin sources," and "sum of all routes." Other two variables—"intensity of routes connecting tin sources to the south" and "intensity of random routes"—show significant differences according only to two of the three tests (Table 1).

In summary, our analyses suggest that the uneven intensity showed by stelae and statues-menhir across the study area may be dependent on, among many other factors, variables such as the intensity of tin sources per square kilometer, the cost of walking from tin ores, or the intensity of routes emerging on the framework of different mobility strategies. Furthermore, most variables—except from "walking costs from the nearest tin source"—show positive Berman's *Z* scores (Table 1). This implies that both stelae and statues-menhir show distributions with higher means than those observed among the simulated, randomly distributed sets of points within our study area. The fact that the only exception

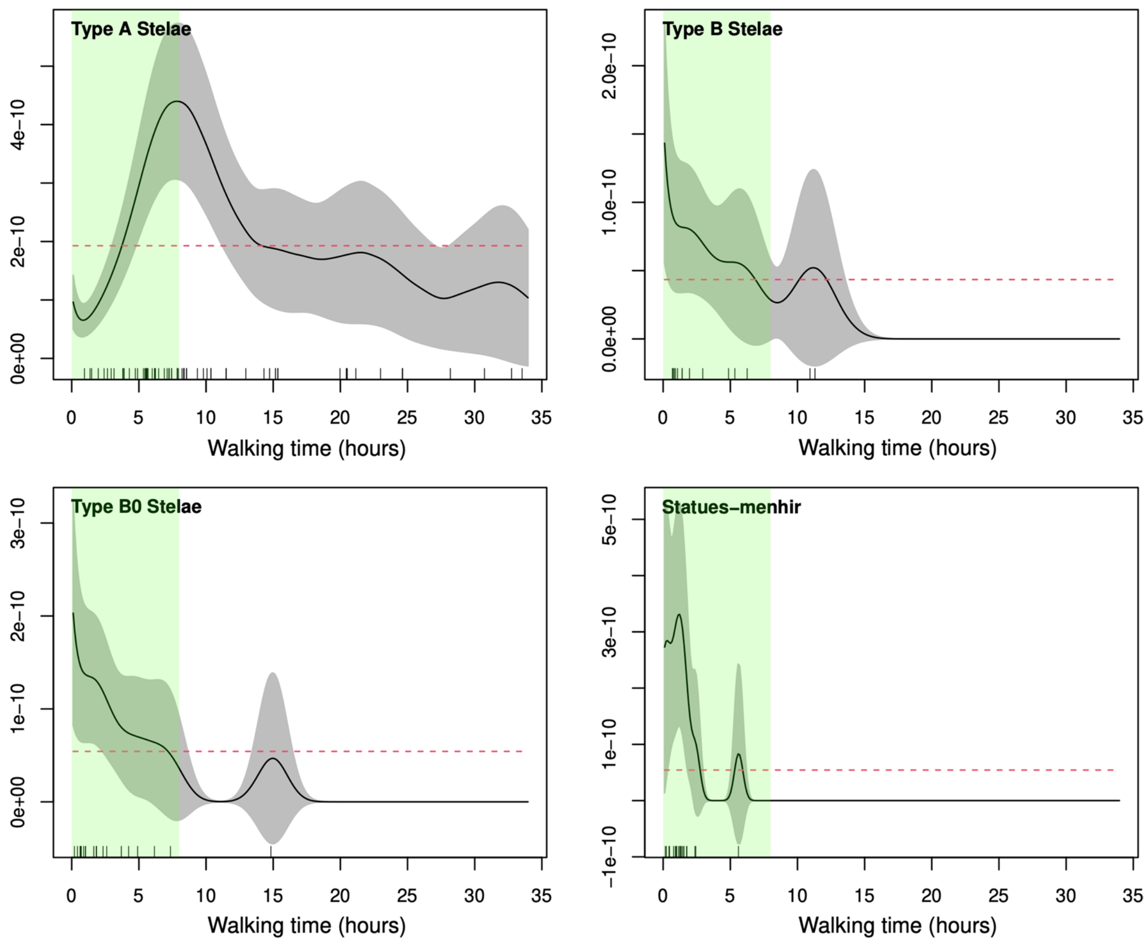


Fig. 9 Relative distribution estimate of the intensity of stelae and statues-menhir as a function of the variable "walking costs from the nearest tin source" (measured in hours from the nearest tin ore). The green square marks the 8-h isochrone

to this dynamic is the walking cost from tin sources is quite interesting, considering the hypothesis according to which these monuments may be located on points readily accessible from the tin sources.

To further explore how the intensity of the monuments across the study area depends on the variables identified as statistically relevant according to the Kolmogorov-Smirnov and Berman tests, we carried out a relative distribution estimate of stelae and statues-menhir as a function of some of the variables described above. The graphical outcome (Figs. 8 and 9; SM_01) displays, on its vertical axis, the estimate of how the intensity of the different monuments (black line with its 0.05 confidence interval) depends on the value of a particular variable, represented on the horizontal axis (Baddeley et al. 2015).

Figure 8 displays the relative distribution estimate of the intensity of stelae and statues-menhir as a function of the density of tin sources across the study area. The graphs clearly show the existence of different patterns depending on the type of monument being analyzed. type A stelae are grouped around very low densities of tin (between 0 and 1 sources per square kilometer). Meanwhile, type B and B0 stelae show a much more variable distribution, although the estimate suggests a higher intensity of monuments on those areas with higher ore densities (above 2 and even 2.5 sources per square kilometer). Lastly, the statues-menhir exhibit a "normal-like" estimate distribution, with sites mainly clustered in areas with moderate densities of tin (between 1 and 1.7 sources per square kilometer).

The relative distribution estimate of the intensity of stelae and statues-menhir as a function of the variable "walking costs from the nearest tin source" is shown in Fig. 9. The four plots in this figure suggest that the engraved monoliths tend to display their higher density within the 8-h isochrone from the nearest source of tin (green square). This applies to all monuments, but it is particularly eloquent for type B and B0 stelae and—even more so—for statues-menhir, which are located entirely within an 8-h walking radius from the nearest source of tin. The reason for highlighting the 8-h isochrone derives from the fact that eight is the approximate

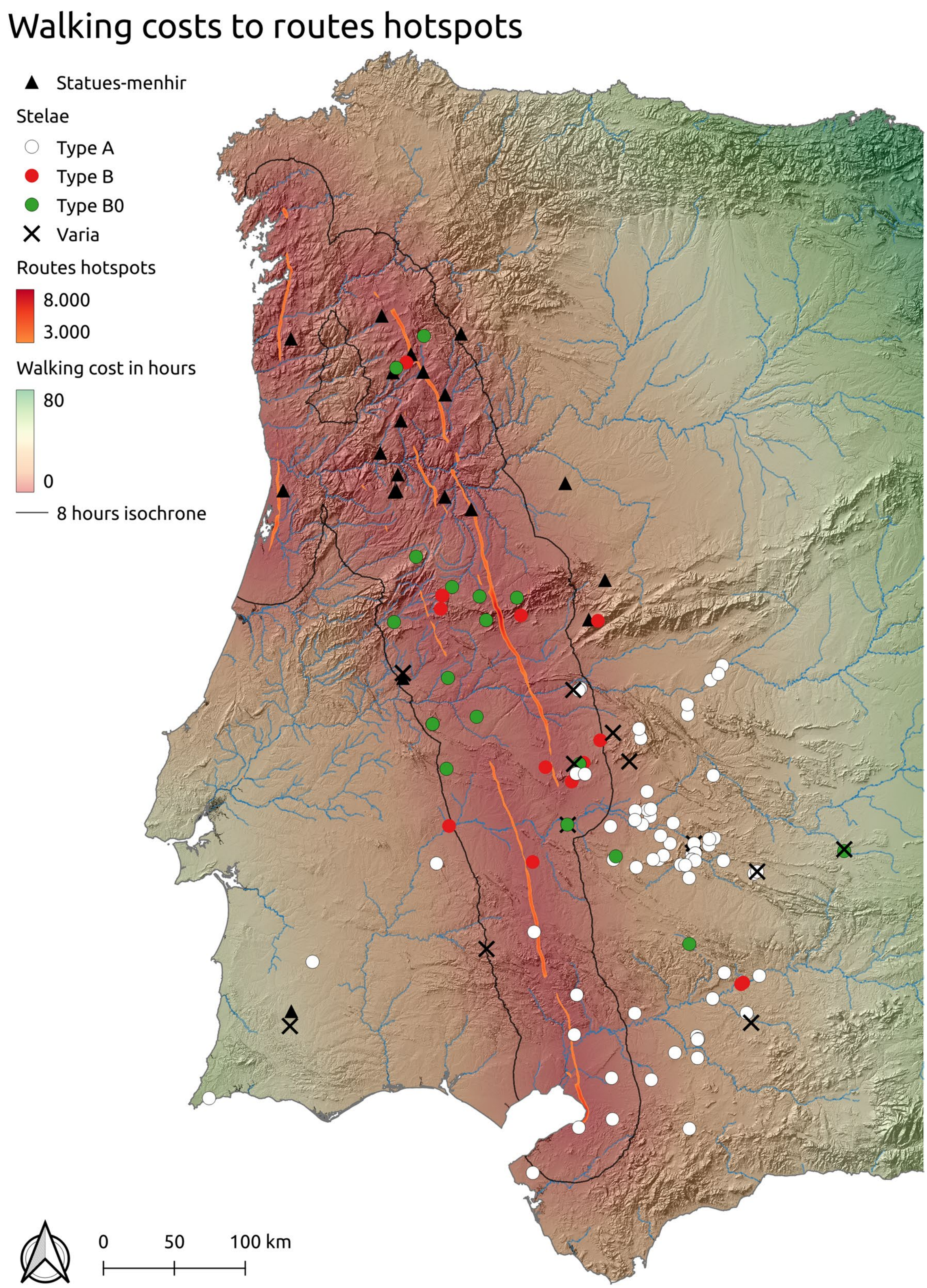


Fig. 10 Location of stelae and statues-menhir in western Iberia regarding the walking costs from the route hotspots identified in our calculations

Table 1 Results of the Kolmogorov-Smirnov (KS), Berman, and area under curve tests for all the monuments and variables taken into account in our analysis (*significative at 0.05 level)

	Covariate	K-S		Berman				AUC
		D	*p* value	*Z*1	*p* value	*Z*2	*p* value	
Stelae (all types)	Intensity of tin sources	0.2595	1.28e−07*	2.111	0.0347*	4.2546	2.09e−05*	0.6130
	Walking cost from tin sources	0.2441	8.62e−07*	− 3.1556	0.0016*	− 4.4022	1.07e−05*	0.3853
	Routes from tin sources to the south	0.2525	3.06e−07*	1.7156	0.0862	5.3952	6.84e−08*	0.6380
	Routes between tin sources	0.2165	1.95e−05*	2.0375	0.0416*	4.124	3.72e−05*	0.5942
	Routes F.E.T.E.	0.1322	0.02712*	− 1.5746	0.1153	− 1.7061	0.0879	0.4554
	Routes random	0.2917	1.62e−09*	4.3777	1.20e−05*	6.7502	1.48e−11*	0.6755
	Sum of routes	0.2259	7.01e−06*	1.6886	0.0912	4.1935	2.75e−05*	0.6088
Type A stelae	Intensity of tin sources	0.1938	0.0082*	− 2.5154	0.0118*	0.29186	0.7704	0.5101
	Walking cost from tin sources	0.1701	0.0288*	− 1.1829	0.2369	− 0.49239	0.6224	0.4839
	Routes from tin sources to the south	0.1979	0.0065*	0.967	0.3335	1.6624	0.0964	0.5649
	Routes between tin sources	0.2184	0.0018*	− 1.0537	0.2920	0.3994	0.6895	0.5136
	Routes F.E.T.E.	0.1544	0.0604	− 1.3898	0.1646	− 1.3898	0.1646	0.4255
	Routes random	0.2604	9.74e−05*	3.4085	0.0006*	4.3989	1.09e−05*	0.6508
	Sum of routes	0.1456	0.0888	0.1997	0.8417	1.3369	0.1812	0.5459
Type B stelae	Intensity of tin sources	0.4741	0.0007*	5.3533	8.64e−08*	4.2502	2.14e−05*	0.8081
	Walking cost from tin sources	0.4865	0.0005*	− 2.2633	0.0236*	− 4.2292	2.35e−05*	0.1974
	Routes from tin sources to the south	0.5297	0.0001*	1.8067	0.0708	4.3745	1.22e−05*	0.8075
	Routes between tin sources	0.5402	6.73e−05*	5.6252	1.85e−08*	3.909	9.27e−05*	0.7470
	Routes F.E.T.E.	0.4068	0.0065*	0.7679	0.4425	0.7703	0.4411	0.7005
	Routes random	0.5611	2.81e−05*	2.5103	0.0120*	4.1491	3.34e−05*	0.8003
	Sum of routes	0.5891	8.08e−06*	3.4973	0.0004*	4.7918	1.65e−06*	0.8476
Type B0 stelae	Intensity of tin sources	0.6239	4.75e−08*	5.3143	1.07e−07*	5.0995	3.41e−07*	0.8274
	Walking cost from tin sources	0.5225	1.31e−05*	−2.6043	0.0092*	− 4.9041	9.39e−07*	0.1857
	Routes from tin sources to the south	0.6409	1.60e−08*	1.4687	0.1419	5.1799	2.22e−07*	0.8373
	Routes between tin sources	0.6000	2.04e−07*	2.4302	0.0150*	4.5703	4.87e−06*	0.7929
	Routes F.E.T.E.	0.1681	0.5669	− 0.8758	0.3811	− 0.87554	0.3813	0.4513
	Routes random	0.3575	0.0085*	1.7215	0.0851	2.8613	0.0042*	0.6856
	Sum of routes	0.4319	0.0006*	1.3025	0.1928	3.6623	0.0002*	0.7385
Statues-menhir	Intensity of tin sources	0.6931	4.05e−10*	7.5648	3.89e−14*	6.0705	1.28e−09*	0.8730
	Walking cost from tin sources	0.7059	1.51e−10*	− 2.5555	0.0106*	− 5.51	3.59e−08*	0.1422
	Routes from tin sources to the south	0.5144	1.93e−05*	0.7397	0.4594	3.8248	0.0001*	0.7470
	Routes between tin sources	0.6002	1.10e−06*	8.241	< 2.2e−16*	5.3778	7.54e−08*	0.8557
	Routes F.E.T.E.	0.2298	0.2064	1.0603	0.2890	1.06	0.2891	0.5149
	Routes random	0.2470	0.1463	2.6366	0.0083*	2.2544	0.0241*	0.6459
	Sum of routes	0.4181	0.0011*	4.4004	1.08e−05*	3.6651	0.0002*	0.7344

annual average of daylight hours representative of all western Iberia. Therefore, the space traveled during this range of time may be considered as a rough estimate of the maximum distance covered by foot in a day's journey (assuming, of course, that people did not travel by night).

The Supplementary material accompanying this paper includes the relative distribution estimate plots of the intensity of stelae and statues-menhir as a function of the density of routes per square kilometer calculated following the different strategies described above (SM_01). Again, the results differ significantly depending on the specific type of monument under consideration. Type A stelae, for example, peak in intensity around those areas with a lower density of routes. This seems to be true for all the strategies taken into consideration except for the random routes, where these monuments show a greater dispersion, including some specimens in medium densities (between 500 and 600 routes per square kilometer).

Type B and B0 stelae show, in general, a more pronounced dispersion than type A, although almost all their numbers seem to be in places where the density of routes per square kilometer belongs to the lower half of the range of values found within our study area. However, it should be noted that the relative distribution estimate plots calculated for type B and B0 stelae tend also to identify (albeit with considerable uncertainty) peaks around the middle values of path densities (SM_01). Finally, the statues-menhir are perhaps the monuments with the highest number of their specimens located in places with high densities of routes per square kilometer, as shown by the peaks of the estimates located in the upper quartiles of density.

Based on the relative distribution estimate analyses, it can be concluded that both stelae and statues-menhir tend to be located in places within the study area where a medium or low density of land routes per square kilometer exists. This is true regardless of the strategies used to calculate the routes. If we had to choose the strategy for which there is a greater number of monuments located in areas with particularly important route densities, this would probably be the "intensity of random routes." On the other hand, neither stelae nor statues-menhir seem to be in places with important densities of routes connecting tin sources with each other or with points in southern Iberia (SM_01). Still, even if these values are not as higher as expected, we should bear in mind that positive Berman's *Z* scores pointed out that such monuments show distributions with higher means of these variables than those they would achieve if they were located at random points.

So far, we have seen how stelae and statues-menhir show a tendency to cluster around specific areas of the western half of the Iberian Peninsula. Furthermore, several tests have shown us that these variations observed in the intensity of engraved monoliths across our study area may depend on some of the variables explored in this article (Table 1). However, it is quite possible that such dependence, albeit real, is so weak that the variable or variables in question do not actually have any discriminatory power in explaining the spatial arrangement of these monuments.

Thus, the last step was to establish the discriminatory power of the different variables considered as relevant in the light of the results of the tests described in the previous pages. This was achieved by means of the receiver-operating characteristic curve (ROC) and the area under such curve (AUC). The ROC generates a graphical outcome (not showed in this paper), while the AUC generates a numerical index between 0 and 1 which denotes the discriminatory strength of the variable: values close to 1 or 0 indicate strong discrimination, while values close to 0.5 suggest no discriminatory power at all (Baddeley et al. 2015).

The results of the AUC (Table 1) suggest that no variables show a real strength or effect on the intensity distribution when analyzing stelae as a whole, single group. This is true even for those variables which have been pointed out as significant by the Kolmogorov-Smirnov and Berman tests. The same can be said of the type A stelae when analyzed separately, since none of the variables considered in this article have shown to have sufficient discriminatory power either.

The picture changes substantially when we examine the results of the remaining monuments. The AUC suggests that all the variables considered in this paper would have had a significant effect on the intensity distribution of type B stelae (even those for which the Kolmogorov-Smirnov and Berman's *Z*1 and *Z*2 are not unanimous in highlighting their significance) (Table 1). For some of them, the discriminatory power is, as a matter of fact, quite important. This is the case for "sum of routes" (0.84), "walking cost from tin sources" (0.19), "intensity of tin sources" (0.80), or "intensity of random routes" (0.80). For type B0 stelae, the variable that shows the greatest discriminatory strength is "intensity of routes from tin sources to the south" (0.83), which was considered as statistically significant by only two of the three tests applied (KW and Berman's Z2). In addition to this, two other variables show a statistically relevant strength regarding the intensity of occurrence of type B0 stelae: "walking cost from tin sources" (0.18) and "intensity of routes between tin sources" (0.79).

Lastly, the AUC suggests that five of the variables considered in this article show some discriminatory power in explaining the uneven intensity of statues-menhir: "intensity of tin sources" (0.87), "intensity of routes between tin sources" (0.85), "walking costs from tin sources" (0.14), "sum of routes" (0.73), and "intensity of routes from tin sources to the south" (0.74).

All in all, four of the variables considered in this paper ("intensity of tin sources," "walking costs from tin sources," "intensity of routes from tin sources to the south," and "intensity of routes between tin sources") shown a significant strength in explaining the intensity of distribution of type B and B0 stelae and also of statues-menhir. Meanwhile, "sum of routes" shows strength for type B stale and statues-menhir, "intensity of random routes" does it only for type B stelae, and "intensity of routes From Everywhere to Everywhere" does not show a significant discriminatory power in any of the monuments considered.

Discussion

The results of the spatial analyses carried out on the set of stelae and statues-menhir known to date in western Iberia have allowed us to observe how these monuments, far from presenting a homogeneous distribution, tend to concentrate around different regions within our study area: the Southwestern quadrant of Iberia, for the stelae, and the Portuguese territory north of the Douro River, for the statues-menhir. However, both types of monuments are being documented with increasing frequency outside their core areas (Bueno

Ramírez et al. 2019), as exemplified by the presence of stelae in Alto Támega (Northern Portugal) and Ourense (Galicia, Northwest Spain) or even statues-menhir in southern areas (Rodríguez-Corral 2015; Santos-Estévez et al. 2017). This circumstance has led some authors to avoid using terms such as "southwestern stelae" to refer to these manifestations (Celestino Pérez and López-Ruiz 2016).

The analytical outcomes described above suggest that internal heterogeneity of the stelae should be considered. Two different behaviors seem to emerge, which correlate to the main groups identified within the typological classifications of these monuments: type A stelae and type B stelae (the latter grouping together type B *sensu stricto* and type B0 stelae). The differences between these two groups can be detected in their geographic distribution (Fig. 1), in which the course of the Guadiana River may have played some role. This could be concluded from the fact that most of the type A stelae (76%) are located south and east of this river, while—on the contrary—most of the type B and B0 stelae (78%) are located north and east of the Guadiana (a ratio that rises to 100% in the case of the statues-menhir). This uneven geographical distribution would have obviously affected the connection that these monuments may have had with the tin-rich areas, which are mostly located in the Iberian Massif, to the north of the Guadiana River (Fig. 1). This seems to be backed by the results of the statistical tests carried out for this article. The intensity or density of type B and B0 stelae and of statues-menhir has been shown to be dependent, to a degree, on variables related to the presence of tin, such as "intensity of tin sources" or "walking costs from tin sources." In sharp contrast, type A stelae show no relationship with these or—in fact—with almost any of the variables considered in our analyses.

According to our results, one could argue that the connection that seems to exist between type B and B0 stelae, statues-menhir, and tin may have materialized in two different ways or with two different intensities. On the one hand, there are monuments located in the immediate vicinity of tin sources of some relevance (with a minimum distance recorded between one and the other of barely 1000 m). In these cases, it could be hypothesized that the "control" exercised over the ores by the communities, groups, or individuals responsible for erecting such monuments could have been direct and perhaps more intense and/or effective. However, most of the engraved monoliths seem to be located not in the strict vicinity of the tin sources, but in relevant points of the territories with comparatively quick and easy access from the ores. The fact that almost the entirety of the type B and B0 stelae as well as the statues-menhir are located within the 8-h isochrone from the tin ores (which, as we discussed above, could be considered a rough estimate of the maximum distance to be covered on foot in a day's journey) may point precisely in this direction. In these cases, one may argue that the "control" exerted by stelae and statues-menhir would not have been over the tin ores themselves, but perhaps over the territories in which these and other potentially significant resources were located.

Another interesting aspect of the analyses is the confirmation of the relationship between stelae, statues-menhir, and the overland transit networks across western Iberia. This association can be inferred in two ways: (a) from the tendency shown by these monuments to be in places where, on average, there is a higher density of routes per square kilometer than that observed at random locations; (b) from the fact that the intensity exhibited by the monuments within our study area shows a statistically significant dependence on the density of existing routes in their immediate surroundings. These results are not surprising at all, given that many studies have highlighted the relationship between these monuments and traditional paths, such as Roman roads or cattle trails (Fábrega-Álvarez et al. 2011; Galán Domingo and Ruiz-Gálvez Priego 2001; García Sanjuán et al. 2006).

The basic stelae (types B and B0) and statue-menhir seem to be associated with routes connecting tin sources with each other and with routes between non-specific origins and destinations, such as routes between random points. The situation is, in principle, less obvious if we focus on the transit routes between tin sources and southern Iberia. This is largely due to the starting premise of using three tests (Kolmogorov-Smirnov, Berman's $Z1$, and Berman's $Z2$) to determine whether the different types of monuments show dependence with respect to the variables analyzed. While this triple filter is aimed at ensuring a high degree of certainty in the results, the fact is that it can ultimately generate the opposite effect, underestimating the dependence of the monuments on the variables under analysis. This could be the case, for example, of the basic stelae. Two of the three tests (Kolmogorov-Smirnov and Berman $Z1$) revealed a significant dependence of these stelae on the variable "intensity of routes connecting tin sources to the south." These two tests, by themselves, could be sufficient to assess some dependence with this variable. It is the AUC analysis that seems to clearly reinforce this idea. This analysis shows a high discriminatory power of this variable "intensity of routes from tin sources to the south" for both the menhir-statues and the basic stelae. This is even more evident in the basic stelae that incorporate Mediterranean elements (BO), showing this variable as the one with the highest discriminatory power.

In relation to the overland transit networks across western Iberia, as with the connection between monuments and tin sources, the behavior of type A stelae is entirely different from the rest of the monuments. While these showed an important dependence on the different route networks, this does not occur with the type A stelae.

In any case, stelae and statue-menhir do not seem to be spatially related to the main hotspots in the transit networks created for this work. The relative distribution estimate of the intensity of stelae and statues-menhir suggests that—except for a few cases—these monuments tend to be in places with a medium or low density of land routes per square kilometer. It is worth pondering if this limited relationship with the main nodes or hotspots within the route networks created for this paper using 80,000 least-cost paths implies that stelae and statues-menhir tended to be associated to a greater extent with secondary routes or with mobility strategies on a smaller scale, as other studies may suggest (Fábrega-Álvarez et al. 2011).

It is also possible that—as with the tin ores—this relationship did exist, but it would have been taken place in a less conspicuous or more indirect manner. Thus, many of engraved monoliths may have not been erected in places allowing them to control the main routes from up close (as if they were some sort of road signs), but in areas that were significant within the territories, these routes traversed. The fact that 78% of type B and B0 stelae and 75% of statues-menhir are located precisely within the 8-h isochrone from these major land hotspots (Fig. 10) may be interpreted as evidence of the stelae working as symbols material at the center of a critical territory due to its strategic resources. In this sense, they must have constituted a socio-material engagement ultimately creating (ideological) meaning or an effect on the landscape.

Conclusions

How can we explain the distribution of these monuments considering the variables analyzed? The contrast observed in the distribution of the monuments seems to reflect divergent behaviors in their relationship with tin sources and the mobility patterns linked to this metal. Two groups can be distinguished in this regard. The first would encompass the statues-menhir and basic stelae (types B and B0) and the second the complex stelae (type A). While the oldest stelae (types B and B0) seem to show similar behaviors to the menhir-stelae—and, therefore, seem to follow the logics of the previous monumental and iconographic substratum—the most recent stelae (A) adopt distributive logics that are far from distributive logics.

This difference in the behavior of the stelae could be reflecting the evolution and transformation over time of their function and meaning. The oldest stelae are the basic ones (types B and B0). Although there is no consensus on the beginning of their chronology, we can place them, depending on the author, in 1400/1200 BC (Díaz-Guardamino Uribe 2010), 1200 BC (Harrison 2004), or 1100/1000 BC (Celestino Pérez 2001; Celestino Pérez and López-Ruiz 2016). Be that as it may, these stelae seem to inherit the spatial behavior of the statue-menhir. In both cases, the monuments are confined to the tin belt, being clearly located within isochrone 8 with respect to the main tin sources. Also, as the analyses have determined, both show a relationship with mobility patterns between tin sources, as well as with routes between tin sources and routes to southern Iberia, although to a lesser extent.

Symptomatically, this spatial correlation seems to extend to graphic motifs. The basic stelae, as Díaz-Guardamino Uribe (2010: 403) has already pointed out, may have emerged as a renewed form of the iconography and ideology of the statue-menhir. In both case, weapons, emblems, and other prestige objects were engraved, working as symbols of power and identity. Likewise, a large group of these stelae (BO) begin to incorporate at some point in their iconography elements of Mediterranean origin, such as mirrors, brooches, or combs. At the same time, deposits from the Late Bronze Age also reveal presence of Mediterranean elements in the region (Vilaça 2008). The appearance of these objects together with other Atlantic objects would therefore be influencing the same idea: the existence of interaction processes between the northwest (area that contains the tin sources) and the southwest of Iberia (area that functions as an interface between the Atlantic and Mediterranean worlds) (Celestino Pérez and Salgado Carmona 2011: 437). The spatial and statistical analyses carried out on the basic stelae seem to reveal a dependence not only between these monuments and the tin sources but also in relation to the transit routes interconnecting the tin sources with each other. Likewise, the results of the analyses may reveal patterns of connectivity with southern Iberia.

However, the type A stelae show different patterns from a chronological, spatial, and iconographic point of view. Depending on the authors, diverse dates have been proposed: 1200–1050 BC (Díaz-Guardamino Uribe 2010), 1000–750 BC (Harrison 2004) or in the 9th and 8th centuries BC (Celestino Pérez 2001; Celestino and López-Ruiz 2016). Be that as it may, their distribution is dated more recently than the basic stelae. Their spatial distribution clearly distances them from the logics of interaction and mobility of the basic stelae. Thus, while the basic stelae reveal a continuity with the previous iconographic substrate (statues-menhir) and a connection with the tin areas, the complex stelae (A) move away from that substrate and do not seem to be spatially related to that mineral resource in any of the analyses carried out. Behind this disconnection, perhaps we should see a change in the connectivity and mobility patterns in western Iberia at the end of the Late Bronze Age.

Two suggestions can be put forward. Firstly, while more than 50% of the total of type A stelae are accumulated in the Zújar Valley (between Andalucía and Extremadura), the basic stelae are absent. This significant concentration of type A stelae could be read in the framework of relations and communication between the south and the north, as Celestino (2011: 435) has proposed. Thus, its apparent dissociation with the tin sources could simply be because "its importance would derive fundamentally from its intermediary role in transit areas and not in direct relation to its exploitation" (Galán Domingo 1993). The fact is that our analysis has not been able to confirm the relationship of the type A stelae with access routes from the south to the tin sources. Secondly, it could be argued that the appearance of type A stelae may have coincided with the loss of importance of the terrestrial route to the tin territories to the detriment of new interaction patterns such as, for example, those from the estuaries of the rivers of the Atlantic coast of Iberia. If this were so, then the fact that the type A stelae (Fig. 2) do not show any connection with tin encourages us to consider other valuable recourses that were also important for the Late Bronze Age and Iron Age communities of the southwestern Iberia, such as livestock or other mineral resources such as silver.

In sum, in the tin areas, the basic type B stelae maintain a clear Atlantic character, showing links (ideological, iconographic and spatial) with the iconographic substrate of the statues-menhir. Likewise, the analyses reveal that their location in these, like the menhir-statues, seems to be related to tin areas—although not in most cases in direct relation to the ores. The incorporation of Mediterranean elements to their iconography (BO) seems to point to processes of interaction with southern Iberia that, according to the results presented, should be encouraged by this critical resource. As a result, those communities that seem to appropriate through their monuments the stanniferous territory begin to use exogenous Mediterranean elements in the construction of their identities. Finally, as we have seen, this reality contrasts with stelae A. Their more complex iconography incorporates more Mediterranean elements than the basic ones. However, this cannot be explained as a process of intensification of previous patterns. On the contrary, it happens within a process of rupture with basic stelae and statues-menhir at different levels. Symptomatically, sometimes, old statues-menhir are reused as support for these type A stelae. As Díaz-Guardamino Uribe has argued, the A format seems to be "more detached from the traditional iconography (statue-menhir) than the B and B0 format stelae" (2012: 409). Similarly, it is not only detached from the sources of tin but also from the potential routes that would connect with those areas rich in that mineral.

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Declarations

Competing interests The authors declare no competing interests.

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