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On a coal specimen possibly associated with the classical Mio-Pleistocene São Jorge leaf bed site, Madeira Island, Portugal

Carlos A. Góis-Marques [a,b,c,d,*], Pedro Correia [e], Miguel Menezes de Sequeira [a]

[a] Madeira Botanical Group (GBM), Faculdade de Ciências da Vida, Universidade da Madeira, Campus da Penteada, Funchal, Portugal
[b] BIOPOLIS Program in Genomics, Biodiversity and Land Planning, CIBIO, Vairão, Portugal
[c] CIBIO, InBIO Laboratório Associado, Universidade dos Açores, Ponta Delgada, Portugal
[d] Instituto Dom Luiz (IDL), Laboratório Associado, Universidade de Lisboa, Lisboa, Portugal
[e] University of Coimbra, Geosciences Center, Department of Earth Sciences, Coimbra, Portugal

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ABSTRACT

Due to the unusual presence of coal seams within a volcanic island, the São Jorge lignite, located in the north side of Madeira Island, was since the early 19th century a magnet for naturalists. In 1854 the site was visited by Sir Charles Lyell and Georg Hartung, where both discovered a leaf-bed associated with the lignite. This finding provided key proofs to Lyell's uniformitarian theory of the formation of volcanic islands and the long-term existence of laurel forests in Macaronesia. Despite its historical importance, lignite specimens from São Jorge remain unknown to date. Recently, the study of Funchal Natural History Museum (MMF, Madeira Island, Portugal) collections revealed a coal specimen associated with the classical site of São Jorge. Here we provide a critical analysis of this specimen using historical and palaeobotanical approaches. We show that this coal is not a lignite from São Jorge and that it was not collected in *ca.* 1905. Historically, the São Jorge site was covered by a landslide until 1917, making it inaccessible. Furthermore, the coal is either a bituminous coal or anthracite and contains typical rhizomorph fossils of extinct Lycophytes known as *Stigmaria ficoides* (Sternb.) Brongn., as already indicated in the old MMF record books. The coal is most likely a late Carboniferous (Pennsylvanian, 323.4–298.9 Ma) specimen from the early 20th century British coaling industry on Madeira Island, imported from the UK, which, at some point, was erroneously labelled as originating from the 7–1.8 Ma São Jorge outcrop in Madeira.

1. Introduction

During the 19th century, Madeira Island was visited by various naturalists with an interest in its volcanic geology (*e.g.,* Mitchell-Thomé, 1976 and references therein). One of the most visited outcrops was the São Jorge lignite, a sedimentary deposit located in the northern part of the island, in the stream Ribeira Grande of São Jorge (formerly known as Ribeira do Meio), near the locality of Ilha in Santana (Fig. 1A, B; Góis-Marques, 2013; Góis-Marques et al., 2014, 2018). The unusual presence of sediments with low rank coal within a volcanic setting was known since the early 19th century (Bedemar, 1837; Mouzinho de Albuquerque, 1837), leading to the mention of this locality in the geological literature (Macaulay, 1840; Smith, 1841), and even to a chemical analysis published in Smith (1841) where he states that '*Professor Johnstone considers it to be the dried relict of an ancient peat bog, and its lustre, compactness and rhomboidal fracture to be due to the action of the basalt which overlies it*' (Smith, 1841, p. 354).

The São Jorge lignite gained further interest when Sir Charles Lyell (1797–1875) and Georg Hartung (1821–1891; see Góis-Marques et al., 2021), whilst exploring the geology of Madeira Island, visited the site on 18 January of 1854 (Góis-Marques et al., 2014). The exploration of the site led them to find a leaf-bed with dicotyledonous leaves and ferns (Lyell, 1854, 1855; also see Góis-Marques et al., 2014 for an historical account). The collections gathered at São Jorge were studied by Heer (1857), Bunbury (1859) and Heer in Hartung and Mayer (1864). These plant fossils were crucial to support Lyell's uniformitarian views on how oceanic islands were built and to disprove the catastrophic theories of the 'craters of elevation' proposed by Leopold von Buch (1774–1853) (Wilson, 2007; Góis-Marques et al., 2014). Furthermore, these plant fossils were even mentioned in the first edition of the 'Origin of Species' as evidence of oceanic islands acting as refugia for the extinct European flora (Darwin, 1859, p. 107). After Lyell, other geologists tried to visit the site, but unfortunately were unsuccessful, as a landslide covered the outcrop *ca.* 1865 (*e.g.,* Starkie Gardner, 1882; Johnson, 1885; Ackermann, 1909a; Gagel, 1912).

Today, the São Jorge lignite and associated plant fossils are still one of the most important geological and terrestrial palaeontological

* Corresponding author at: Madeira Botanical Group (GBM), Faculdade de Ciências da Vida, Universidade da Madeira, Campus da Penteada, Funchal, Portugal.
E-mail address: c.goismarques@gmail.com (C.A. Góis-Marques).

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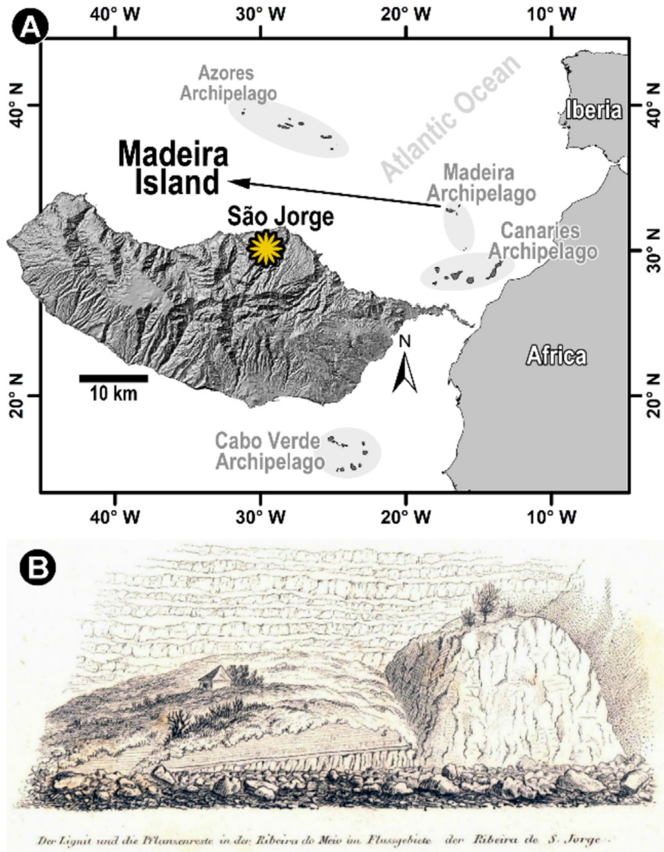

Fig. 1. Madeira Island and the São Jorge outcrop. A, Geographical location of Madeira Island and the São Jorge outcrop; B, drawing of the São Jorge outcrop by Georg Hartung published in Heer (1857) with the translated legend '*The lignite and plant fossils in Ribeira do Meio stream, in the riverside areas of Ribeira de São Jorge stream*'.

sites in Madeira Island and for the Macaronesian archipelago as a whole (*e.g.*, Anderson et al., 2009; Fernández-Palacios et al., 2011; Góis-Marques, 2020). The inferred age of the São Jorge sedimentary deposit ranges from 7 to 1.8 Ma, and is the oldest and best-preserved fossil evidence of a Temperate Stink-Laurel forest (dominated by *Ocotea foetens* (Aiton) Baill., Lauraceae) (dominated by *Ocotea foetens* (Aiton) Baill., Lauraceae; see Capelo et al., 2005) in Macaronesia (Góis-Marques et al., 2018). Interestingly, the São Jorge outcrop had two associated lignite layers (Heer, 1857; Hartung and Mayer, 1864), an upper layer 25 cm thick and a lower lignite of unknown thickness. Despite its importance, lignite specimens from São Jorge are currently unknown (Góis-Marques et al., 2014, 2018). The possible existence of an *ex-situ* São Jorge lignite would be a unique palaeoecological window to a now inaccessible location, as it would enable the geochemical, palynological and macrofloral study of the source vegetation that gave rise to it (*e.g.*, Steart et al., 2007; Worobiec et al., 2021).

Recent efforts to locate historical palaeobotanical specimens in Madeira Island's public collections resulted in the discovery of a coal allegedly from the São Jorge historical site. However, the collecting date, lack of collector data, labels, and overall morphology and texture needed further analysis.

In this short contribution we aim at illustrating and critically studying a possible single specimen of lignite from the São Jorge outcrop, and call attention to the need for historical and taxonomical knowledge when evaluating historical specimens that have missing data in their associated labels.

2. Material and methods

Palaeontological and geological collections held in the Funchal Natural History Museum (MMF) were searched for palaeobotanical specimens collected in the Madeira Archipelago. Amongst the geological collections, a catalogued specimen of coal, apparently collected on Madeira Island was detected. The overall morphology of the specimen (Fig. 2) was studied under a binocular stereomicroscope. General and detailed photographs were taken with a Nikon D5500 camera with an attached Nikon AF-P DX Nikkor 18–55 mm f/3.5–5.6G lens using a copystand with illumination. Information contained in the labels and in the old MMF collection record books was examined. The coal specimen (Fig. 2) was analysed and compared with the historical descriptions of the São Jorge lignite (Góis-Marques, 2013; Góis-Marques et al., 2014; Góis-Marques, 2020) and fossil content with relevant literature (Sauveur, 1848; Renier et al., 1938; Teixeira, 1944; Boureau et al., 1967; Gómez-Alba, 2007; DiMichele et al., 2022).

3. Results

A specimen with the collection number MMF 1942, stored in a paper box (Fig. 2A) was found associated with two labels (Fig. 2A), one stating the collection number and the locality 'São Jorge, Ribeira do Tabaco' (see Fig. 2A, upper label), and a second label stating that the specimen was collected *ca.* the year of 1905 at '*Madeira, Ribeira do Tabaco, São Jorge*' (see Fig. 2A, lower label). MMF 1942 is a piece of coal with a wire around it containing an almost illegible label with the number 1942, measuring *ca.* 9.5 × 7.0 × 3.0 cm (Fig. 2B–D), it is dark, compact, and it presents conspicuous fractures and traces of additional mineral deposition (possibly pyrite; Fig. 2C, D). Its upper glossy surface has circular- to oval-shaped structures arranged in a helical fashion (Fig. 2B, E). The old collection registry books from the MMF state the same as the labels, without the name of the collector or a date of collection, but adding an interesting note: '*Lenhite (com Stigmaria ficoides), Ribeiro do Tabaco, São Jorge, Madeira*' adding a note: 'Veja Carlos Teixeira, Antr. Cont. Por. Bol. Soc. Geo. Port. …Fasc. I e II, p. 12, figure 3', a reference to see Teixeira (1944, p. 12, fig. 3), an image of *Stigmaria ficoides* collected in mainland Portugal.

4. Brief discussion

According to the labels and the historical registry book, the specimen MMF 1942 could correspond, as far as it is known, to the only surviving lignite specimen from São Jorge, as today the São Jorge fossiliferous outcrop is no longer exposed (Góis-Marques et al., 2018). Unfortunately, a definite collection date or collector name is unknown for MMF 1942. However, comparing the labels' information with the known historical information (Góis-Marques, 2013, 2020; Góis-Marques et al., 2014) and the analysis of specimen itself reveals that it cannot be a lignite collected from the classical site of São Jorge, Madeira.

The labels and the old collection registry book state the locality as 'Ribeira do Tabaco'. The use of this toponym is unusual for a specimen collected in the 20th century, as it was first mentioned by Mouzinho de Albuquerque (1837) but later authors used 'Fajã do Taboado' or more often 'Ribeira do Meio' (see Góis-Marques, 2013). Furthermore, the specimen is unlikely to have been collected *ca.* 1905, as stated in the second label (Fig. 2B). After the publication by Hartung and Mayer (1864), subsequent authors stated that the locality was no longer available to collect. Starkie Gardner (1882) is the first to state that a landslide *ca.* 1865 covered the outcrop. Other works such as Taylor (1882), Johnson (1885), Brown (1901), Ackermann (1909a, b, c, d) and Gagel (1912) also confirmed that the lignite beds of São Jorge were no longer exposed. Interestingly, Mourão Pitta (1889) states, without giving details, that the site was prospected with the intent of exploration, but soon abandoned due to the very limited extension of the deposit. According to Silva and Menezes (1940–1946), the site was again

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exposed in 1917, possibly by the natural erosion of the valley or an attempt to explore the site, but Cockerell (1928) later states that it was no longer possible to collect plant fossils in this locality, which has been inaccessible ever since.

Furthermore, in the MMF historical registry book it is stated '*Lenhite (com Stigmaria ficoides)*…' meaning 'lignite with *Stigmaria ficoides*'. However, the São Jorge lignite has an inferred Mio-Pleistocene age of 7–1.8 Ma (Góis-Marques et al., 2018). This age is incompatible with the presence of the Palaeozoic *Stigmaria*, a rooting system of extinct arboreous lycopsids characteristic of the Mississippian up to the late Permian (*ca.* 358.8–251.9 Ma; but see DiMichele et al., 2022 and references therein). The analysis of the surface of the specimen MMF 1942 reveals circular to oval 'marks', helically arranged with *ca.* 3–4 mm in diameter (Fig. 1B, E). This morphology and arrangement are characteristic of the rhizomorph fossil *Stigmaria ficoides* (Sternb.) Brongn. (compare to de Sauveur, 1848, pl. LXV; Renier et al., 1938, pl. 34; Boureau et al., 1967, fig. 459a-b; Gómez-Alba, 2007, pl. 38, fig. 1;) and in accordance with the identification stated in the registry book. Furthermore, each 'mark' corresponds to a rootlet scar in (quasi-)transversal section, with an outer rim, corresponding to the outer limit of the rootlet cortex, and an inner rim corresponding to the vascular bundles (*e.g.,* Boureau et al., 1967; DiMichele et al., 2022).

The exact geographical origin of the coal specimen MMF1942 is currently unknown. *Stigmaria* fossils are found in numerous Westphalian-age coalfields throughout Europe and North America (C. Cleal, personal communication). However, during the mid-19th to early 20th century, several English companies imported coals from Wales and Durham to Macaronesian islands (Fig. 3A–C; Office of Naval Intelligence, 1900, 1909; Bosa, 2004), including Madeira Island, which were used mainly to fuel steamboats (Fig. C, D; see Correia, 2022 and references therein). Coal from the Rhondda Valley in South Wales was well suited to steamboats (C. Cleal, personal communication, 2025) and was, at the time, advertised as the optimal fuel for powering these vessels (see Fig. 3D). The specimen MMF1942 might be an early 20th century imported coal sample from the UK and kept because of the *S. ficoides* fossil, and later wrongly curated as having been collected in São Jorge, Madeira Island, the only locality where coals (lignite) were known to occur. Although beyond the scope of the present paper, further refinement of the coal's age could be achieved through petrographic and palynological studies (see Scott, 2017).

Finally, we wish to call attention to the fact that historical plant fossil specimens, such as this one found in the MMF collections, that lack information or were not studied/curated properly, need to be reviewed using a modern integrative approach to avoid future errors. This includes the use of the history of the island's geology and botany, coupled with modern geological, botanical, and palaeobotanical methodologies and reasoning. In fact, research in the last decade resolved or called attention to some problematic palaeobotanical identifications in the Macaronesian Islands. For example, the taxonomic and nomenclatural revision of the São Jorge macroflora (see Góis-Marques et al., 2018 and references therein) clarified previous misidentifications. Similar problems were also found for fossils found in other Macaronesian archipelagos such as the Azores, where leaf fossils were wrongly identified as *Pittosporum undulatum* Vent. (Góis-Marques et al., 2019), an Australian alien species introduced in the mid-19th century (Schäfer, 2021) with some modern authors still accepting it as part of the Azorean fossil

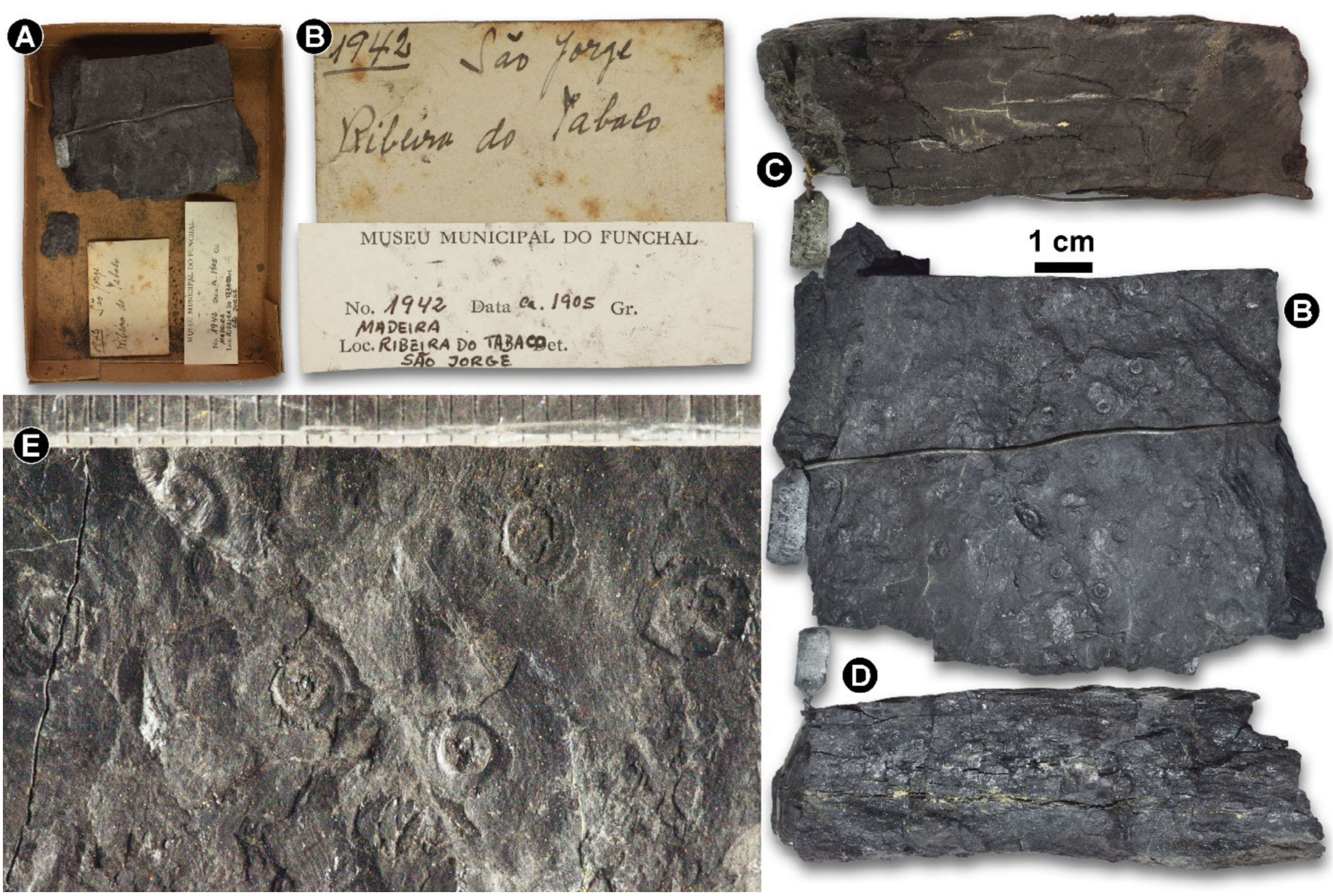

Fig. 2. The alleged São Jorge lignite specimen MMF 1942. A, Curated specimen and respective labels, as found in the MMF collections; B, detail of the labels indicating that the specimen was collected in the classical site of Ribeira do Tabaco, São Jorge, Madeira; B–D, specimen overview, B, upper view (as found in the collections). Note the circular marks (rootlet scars) in the surface of the specimen arranged in a helical fashion, C and D, lateral sides; E, detail of typical *Stigmaria ficoides* rootlet scars.

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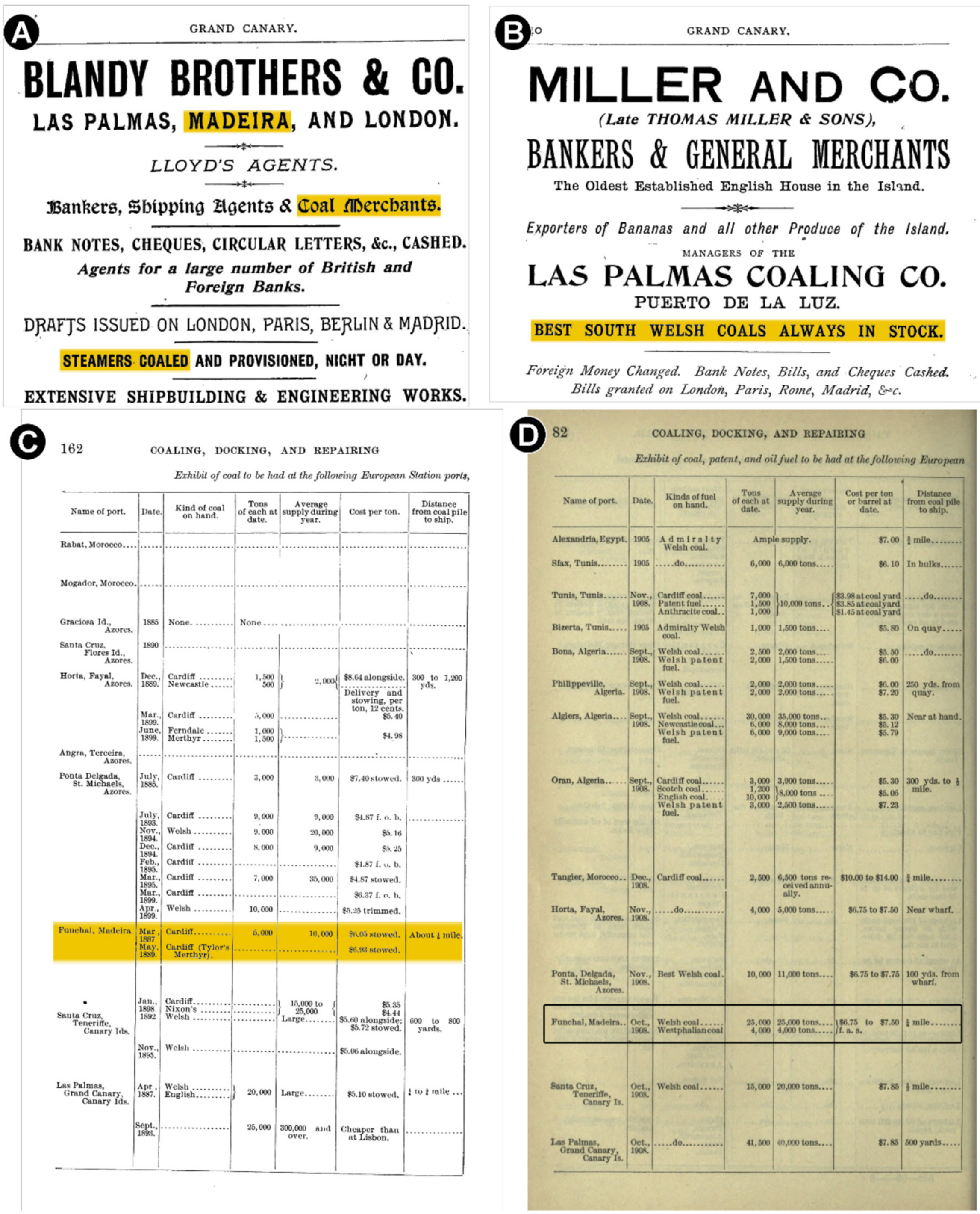
record (Góis-Marques et al., 2024 and references therein), or in the Canary Archipelago, where a 13 Ma tube pumice was misidentified as pine bark (Góis-Marques et al., 2025).

5. Conclusions

The coal specimen MMF1942 is not a lignite from the Mio-Pleistocene classical site of São Jorge, Madeira Island. Rather it is a coal specimen of higher ranking, possibly a bituminous coal or anthracite from the Carboniferous Period, confirmed by the presence of the characteristic fossil *Stigmaria ficoides*. The coal specimen was most probably obtained from coal imports from the UK (possibly Wales) that happened during the mid-19th to early 20th century, as stated in the label (*ca.* 1905), and kept due to the presence of *S. ficoides*. Upon later integration into the MMF collections, it was erroneously labelled as collected in the São Jorge lignite locality. Either way, the specimen MMF 1942 is still valuable, as it could be the evidence of the coaling English industry that once flourished in Madeira Island, which is now long gone (Correia, 2022).



Name of port.	Date.	Kind of coal on hand.	Tons of each at date.	Average supply during year.	Cost per ton.	Distance from coal pile to ship.
Rabat, Morocco						
Mogador, Morocco						
Graciosa Id., Azores.	1885	None.	None			
Santa Cruz, Flores Id., Azores.	1890					
Horta, Fayal, Azores.	Dec., 1889.	Cardiff Newcastle	1,500 500	2,000	$8.64 alongside. Delivery and stowing, per ton, 12 cents.	300 to 1,200 yds.
	Mar., 1899.	Cardiff	5,000		$5.40	
	June, 1899.	Ferndale Merthyr	1,000 1,500		$4.98	
Angra, Terceira, Azores.						
Ponta Delgada, St. Michaels, Azores.	July, 1885.	Cardiff	3,000	3,000	$7.40 stowed.	300 yds
	July, 1893.	Cardiff	9,000	9,000	$4.87 f. o. b.	
	Nov., 1894.	Welsh	9,000	20,000	$5.16	
	Dec., 1894.	Cardiff	8,000	9,000	$5.25	
	Feb., 1895.	Cardiff			$4.87 f. o. b.	
	Mar., 1895.	Cardiff	7,000	35,000	$4.87 stowed.	
	Mar., 1899.	Cardiff			$6.37 f. o. b.	
	Apr., 1899.	Welsh	10,000		$5.25 trimmed.	
Funchal, Madeira	Mar., 1887	Cardiff	5,000	10,000	$6.05 stowed.	About 1/4 mile.
	May, 1889.	Cardiff (Tylor's Merthyr).			$6.93 stowed.	
Santa Cruz, Teneriffe, Canary Ids.	Jan., 1898 1892	Cardiff Nixon's Welsh		15,000 to 25,000 Large	$5.35 $4.44 $5.60 alongside; $5.72 stowed.	600 to 800 yards.
	Nov., 1895.	Welsh			$5.06 alongside.	
Las Palmas, Grand Canary, Canary Ids.	Apr., 1887.	Welsh English	20,000	Large	$5.10 stowed.	1/4 to 1/2 mile
	Sept., 1893.		25,000	300,000 and over.	Cheaper than at Lisbon.	

Name of port.	Date.	Kinds of fuel on hand.	Tons of each at date.	Average supply during year.	Cost per ton or barrel at date.	Distance from coal pile to ship.
Alexandria, Egypt.	1905	Admiralty Welsh coal.	Ample supply.		$7.00	3/4 mile
Sfax, Tunis	1905	do	6,000	6,000 tons	$6.10	In hulks
Tunis, Tunis	Nov., 1908.	Cardiff coal Patent fuel Anthracite coal	7,000 1,500 1,000	10,000 tons	$3.98 at coal yard $3.85 at coal yard $1.45 at coal yard	do
Bizerta, Tunis	1905	Admiralty Welsh coal.	1,000	1,500 tons	$5.80	On quay
Bona, Algeria	Sept., 1908.	Welsh coal Welsh patent fuel.	2,500 2,000	2,000 tons 1,500 tons	$5.50 $6.00	do
Philippeville, Algeria.	Sept., 1908.	Welsh coal Welsh patent fuel.	2,000 2,000	2,000 tons 2,000 tons	$6.00 $7.20	250 yds. from quay.
Algiers, Algeria	Sept., 1908.	Welsh coal Newcastle coal Welsh patent fuel.	30,000 6,000 6,000	35,000 tons 8,000 tons 9,000 tons	$5.30 $5.12 $5.79	Near at hand.
Oran, Algeria	Sept., 1908.	Cardiff coal Scotch coal English coal Welsh patent fuel.	3,000 1,200 10,000 3,000	3,900 tons 8,000 tons 2,500 tons	$5.30 $5.06 $7.23	300 yds. to 1/2 mile.
Tangier, Morocco	Dec., 1908.	Cardiff coal	2,500	6,500 tons received annually.	$10.00 to $14.00	3/4 mile
Horta, Fayal, Azores.	Nov., 1908.	do	4,000	5,000 tons	$6.75 to $7.50	Near wharf.
Ponta, Delgada, St. Michaels, Azores.	Nov., 1908.	Best Welsh coal.	10,000	11,000 tons	$6.75 to $7.75	100 yds. from wharf.
Funchal, Madeira	Oct., 1908.	Welsh coal Westphalian coal	25,000 4,000	25,000 tons 4,000 tons	$6.75 to $7.50 f. a. s.	1/4 mile
Santa Cruz, Teneriffe, Canary Is.	Oct., 1908.	Welsh coal	15,000	20,000 tons	$7.85	1/2 mile
Las Palmas, Grand Canary, Canary Is.	Oct., 1908.	do	41,500	40,000 tons	$7.85	500 yards

Fig. 3. The origin of the coal and the coaling industry in Madeira and the Macaronesian archipelagos. A and B, extracts from the Office of Naval Intelligence (1900, 1909) reports, stating that the coal provided in Madeira Island was from the UK (Madeira Island highlighted). Note that in all other Macaronesian Islands, the coal also originated from the UK; C, publicity from the Blandy Company as merchants of coal in Madeira Island (highlighted), extracted from Brown (1901); D, publicity from Miller and Co. as merchants of coal in Gran Canaria, highlighting that they sell the "best South Welsh coals", extracted from Brown (1901).

CRediT authorship contribution statement

Carlos A. Góis Marques: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Pedro Correia:** Writing – review & editing, Writing – original draft, Investigation. **Miguel Menezes de Sequeira:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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