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Darwin, Hooker and Arruda Furtado and the palaeobotany of Azores: Rediscovering the first collections

Carlos A. Góis Marques *, Miguel Menezes de Sequeira

Madeira Botanical Group (GBM), Centro de Ciências da Vida, University of Madeira, Campus da Penteada, 9000-390 Funchal, Portugal

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ABSTRACT

The historical investigation of the palaeobotany of the Azores Islands led to the recent rediscovery of the leaf fossils initially collected by Arruda Furtado in the late 19th century. Advised by Sir Charles Darwin and Sir Joseph Dalton Hooker to search for plant fossils, Arruda Furtado found the first specimens in São Miguel Island, and sent them to the UK for further identification. A recent search at the Natural History Museum, UK, revealed that from a total of sixteen specimens, only one specimen survived. In the same tray, two undescribed specimens from Furnas (São Miguel) were found. Here we describe and identify them as *Woodwardia radicans*, *Laurus azorica* and an unidentified fern. The taphonomy indicates that these fossils were preserved in a trachytic tuff, possibly related to the explosive episodes of the Furnas volcano, indicating that they could be late Pleistocene to Holocene in age. This report aims to highlight the potential of future palaeobotanical studies of the Azores Islands.

1. Introduction

Throughout the mid-19th century, the Azores Archipelago (Portugal) attracted several foreign naturalists, especially after Darwin's 1859 publication of the Origin of Species (Arruda, 1998). The most prominent local naturalist was Francisco de Arruda Furtado (1854–1887), who corresponded with several other naturalists, including Charles Darwin (Arruda, 2002). The reconstruction of the history of science is a useful exercise, especially when the correspondence letters are available. These letters can give us important clues about the first collected specimens and indicate the whereabouts of old unpublished collections.

Plant fossils from the Azores Archipelago are poorly known and understood, although the presence of megafossil sites are continually reported since the early 19th century; these include the presence of gymnosperm logs buried in pyroclastic deposits (e.g. Webster, 1821; Boid, 1835; Drouët, 1857; Hartung, 1860; Guppy, 1917). These findings were used as proof of the existence of monumental trees in Azores (Borges, 2007). Charcoal, wood, peat and palaeosols have been used for radiocarbon dating of volcanic events (e.g. Moore, 1991; Madeira et al., 1995, 1998; Guest et al., 1999).

Leaf fossils were reported in five islands (i.e. Faial, Pico, Terceira, S. Miguel and S. Jorge), corresponding to several fossil-beds dating from Plio-Pleistocene or more recent (Teixeira and Pais, 1976; Anderson et al., 2009), but they were rarely studied in detail (e.g. Bensaúde, 1892; Trelease, 1897; Agostinho, 1949; Forjaz, 1960; Diniz, 1962; Forjaz and Monjardino, 1964; Forjaz et al., 1970; Madeira, 1998).

This paper presents a brief historical review of the first leaf fossils reported by Arruda Furtado and describes a small unreported collection from Furnas (São Miguel) discussing their ecological and palaeoecological importance, and suggests future perspectives of palaeobotanical studies in the Azores.

2. Materials and methods

The search for the 19th century historical references included the analysis of books, papers and correspondence dealing with geology and botany. Some possible collections emerged from the literature, and an enquiry was undertaken at the Natural History Museum, London (NHM) and the Leeds City Museum, Leeds (LCM), both in the UK, in an attempt to locate these collections.

Specimens were photographed (using a Canon SX500is) with low light to enhance venation patterns. Extant specimens were collected and photographed (Nikon D700) for comparison of the leaf architecture. Leaf descriptions follow Ellis et al. (2009). The systematic taxonomy follows the criteria used by Silva et al. (2005) and Press and Short (1994).

3. Results

Two sets of results are presented. The first deals with the historical review, and the second with the collections' fate.

* Corresponding author. Tel.: +351 291 705 000.
E-mail addresses: c.goismarques@gmail.com (C.A. Góis Marques), sequeira@uma.pt (M. Menezes de Sequeira).

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3.1. Historical review

In 1881, on his own initiative, Arruda Furtado (based in S. Miguel) corresponded with Darwin (1809–1882), sharing views about evolution and island biology, and asking Darwin for scientific guidance (Arruda, 2002). In a letter dated the 12th September 1881, Darwin encourages Arruda Furtado to locate plant fossils, following the advice given by Joseph Dalton Hooker (1817–1911):

> "*Sir J. Hooker tells me one very interesting fact, which is well worth your investigating, namely that huge trunks of Cypresses (Cupressus) have been found there [he does not say in which island] buried in the ground; yet the Cypress is extinct in the islands. He thinks that the remains of other plants might be found in the same sites (…).*"

Darwin to Arruda Furtado (Arruda, 2002, pp. 114).

Hooker, interested in unique island floras (Williamson, 1984), most probably knew about these buried trunks from the literature of the Azores Islands (e.g. Webster, 1821; Hartung, 1860). The research for these sites by Arruda Furtado soon led to the discovery of a new fossil plant site in São Miguel Island, Mosteiros leaf-bed (Fig. 1), as mentioned in the letter to Darwin dated the 21st November 1881 (Arruda, 2002, pp. 117). Chronologically, the next letters were from W. T. Thiselton-Dyer (1843–1928), based in Kew gardens (UK), on 19th December 1881 (Arruda, 2002, pp. 150) reporting the identification of some leaf fossils as *Laurus canariensis* (=*L. azorica*) and *Notelaea* (=*Picconia*) *excelsa*. Following this letter, Arruda Furtado replied on the 19th March 1882 (Arruda, 2002, pp. 152), stating that he was going to send him all of his specimens. On a letter dated 5th April 1882 (Arruda, 2002, pp. 155), Thyselton-Dyer reported that he had received the fossils and that he was sending them to the Ecological Department of the British Museum (now NHM). Arruda Furtado received an acknowledgment letter from this Museum on the 29th June 1882 (Arruda, 2002, pp. 156).

Later, Arruda Furtado sent other plant fossils to Louis Compton Miall (1842–1921) based at the Museum of the Literary and Philosophical Society of Leeds (now LCM). The correspondence between Miall and Arruda Furtado was started through Thomas Edward Thorpe (1845–1925) in 1880 during a scientific visit to the Azores Islands (Arruda, 2002). Miall acknowledges the receipt of the fossils in May 1882 (Arruda, 2002, pp. 97).

3.1.1. Collections and specimens

Three historical Azores plant fossils were found in the NHM collections; only one (no. V152; Plate I,1) can be referred to the original Mosteiros collections by Arruda Furtado in 1881. This specimen consists of faint and fragmentary leaf impressions and branches in a pyroclastic matrix. The other two specimens (V19878 and V19879) are from a new locality at Furnas (Plate II, 1 and 2), as the hand-written label states that they are "from a spot near to the boiling spring of Las Furnas about 500 yards distance west". These consist of leaf impressions in a trachytic tuff. The date of collection of the Furnas fossils, and the name of the collector, are unknown; these specimens are from the Geological Society of London, received by the NHM in 1911. The collection sent to Miall was not possible to locate in Leeds collections.

3.2. Systematic palaeobotany

Class FILICOPSIDA Pichi-sermolli, 1958
Order FILICALES Engler and Prantl 1898–1902
Family BLECHNACEAE Newman, 1844
Genus *Woodwardia* Sm., 1793

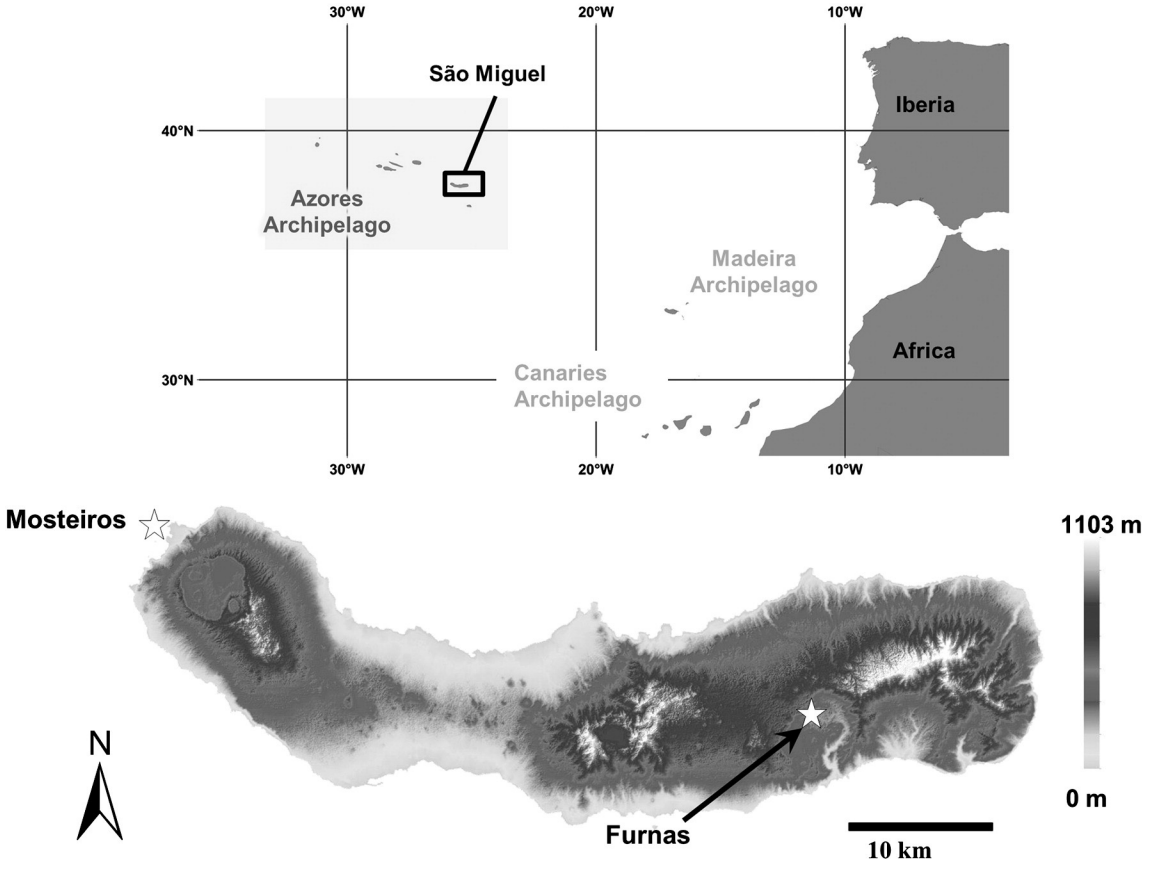

Fig. 1. Geographical location of Azores Archipelago and São Miguel Island. The stars indicate the leaf bed sites mentioned in this report.

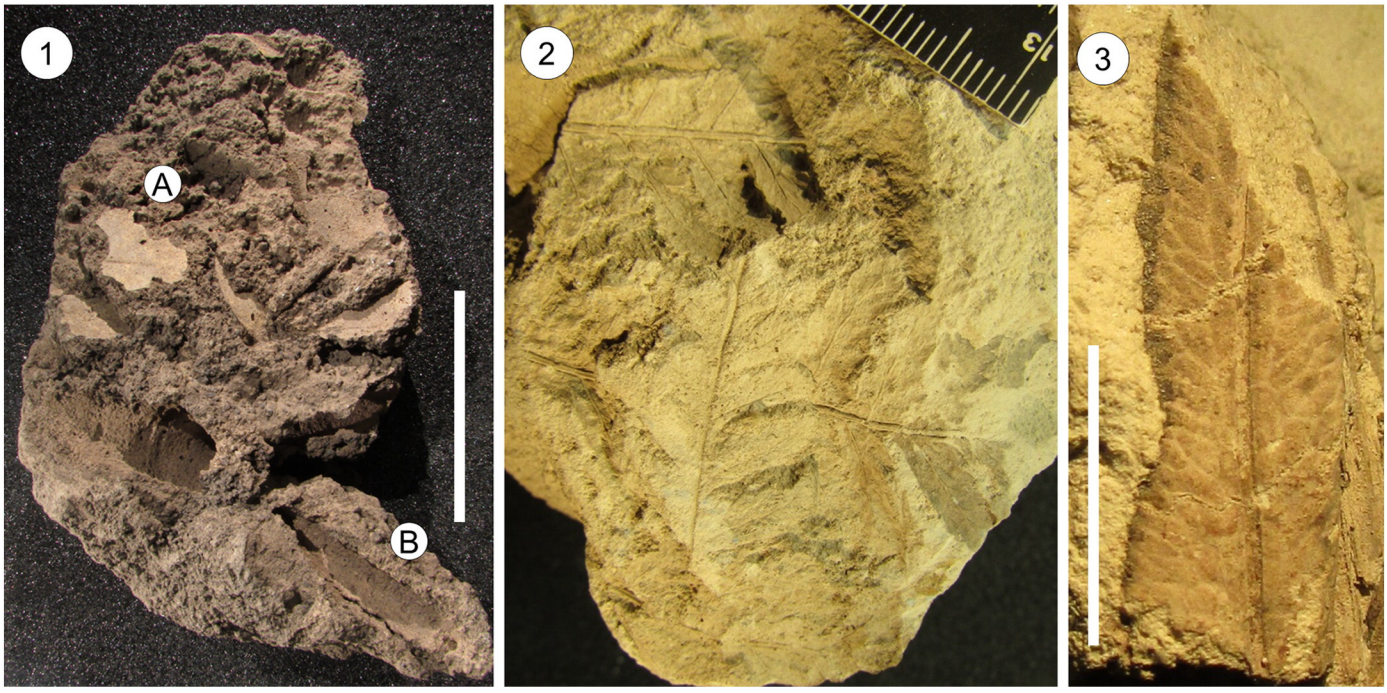

Plate I. 1) Specimen V152 collected by Arruda Furtado; A) partial leaf impressions; and B) stem cast. Scale bar 5 cm; 2) unidentified fern V. 19879 (scale in mm); and 3) *Woodwardia radicans* pinnule fragment in the specimen V 19878 (Scale bar 1 cm).

Woodwardia radicans (L.) Sm., 1793
Plate II, 3

Material: Fragmentary sterile pinnule V 19878.
Description: Single pinnule approximately 2.16 cm × 0.16 cm, with anastomosed venation, and prominent costa.
Remarks: *W. radicans* is native to S. Miguel Island (Silva et al., 2005). The anastomosed venation is specific to this species. This is the first report of *W. radicans* as a fossil for Azores Archipelago. It is also known from the Pleistocene of Madeira Island (Bunbury, 1859; Góis Marques, 2013; Heer, 1857).

Family and genus *incertae sedis*
Plate I, 2

Material: Impression of a single incomplete sterile frond V 19879.
Description: Incomplete sterile frond, at least 2 pinate, as 3 pinnae are parallel to each other suggesting an insertion into a rachis; pinnae fragments with 1–1,5 cm; pinnule attachment sessile, adnate and distichous; costae sinuous. Margin serrate.
Remarks: This fragmentary fern shows characteristics shared with some other fern families (e.g. Dicksoniaceae, Athyriaceae, Dryopteridaceae) native to Azores.

Class MAGNOLIOPSIDA Brongniart, 1843
Order LAURALES Perleb, 1826
Family LAURACEAE Jussieu, 1789
Genus *Laurus* L., 1753

Laurus azorica (Seub.) Franco, 1960
Plate II, 1–4

Material: Several incomplete superimposed leaf impressions in specimens V 19878 and V 19879.
Description: Blade attachment apparently marginal, laminar size nanophyll to notophyll. Margin is entire with acute apex angle, shape acuminate and apparent retuse in one leaf. Base not preserved. Primary venation pinnate. Major secondaries eucamptodromous to brochidodromous with secondary spacing irregular, inconsistent secondary angle and excurrent attachment to midvein. Associated with the axils of the secondary veins there are small projections (domantia). Minor secondaries simple brochidodromous. Intersecondaries present, usually spanning more than 50% of the length of the subjacent secondary and occurring at less than one per intercostal area, proximal course is parallel to major secondaries. Intercostal tertiary vein fabric alternate percurrent with obtuse angle to midvein, with consistent angle variability. Epimedial tertiaries mixed percurrent. Exterior tertiary course looped. Quaternary vein fabric reticulate regular. Quinternary vein fabric regular. Areolation with good development. Freely ending veinlets absent. Marginal ultimate venation apparently looped.
Remarks: The leaf morphology of *L. azorica* agrees with the living specimens (Plate I, 3 and 4), specially the preservation of domantia, which is characteristic of this species.

4. Discussion and future perspectives

As already noted by Diniz (1962), the correspondence between Arruda Furtado and Darwin includes the first reference to leaf fossils in the Azores Islands. It is quite clear that Darwin and Hooker led Arruda Furtado into making important contributions to the Azorean palaeobotany, namely finding fossil logs, which led to the discovery of a new leaf bed in Mosteiros (Fig. 1). The interruption of these studies was most probably due to the premature death of Arruda Furtado on 21st June 1887.

The attempt to re-locate Arruda Furtado's specimens revealed the existence of Azores leaf fossils in the NHM. From the original sixteen specimens sent to NHM, only one poorly preserved specimen survived. In addition, two new specimens, from an unreported leaf-bed from Furnas (S. Miguel), were found. This specimen reduction was also reported in a collection from Madeira Island (Góis Marques et al., in press).

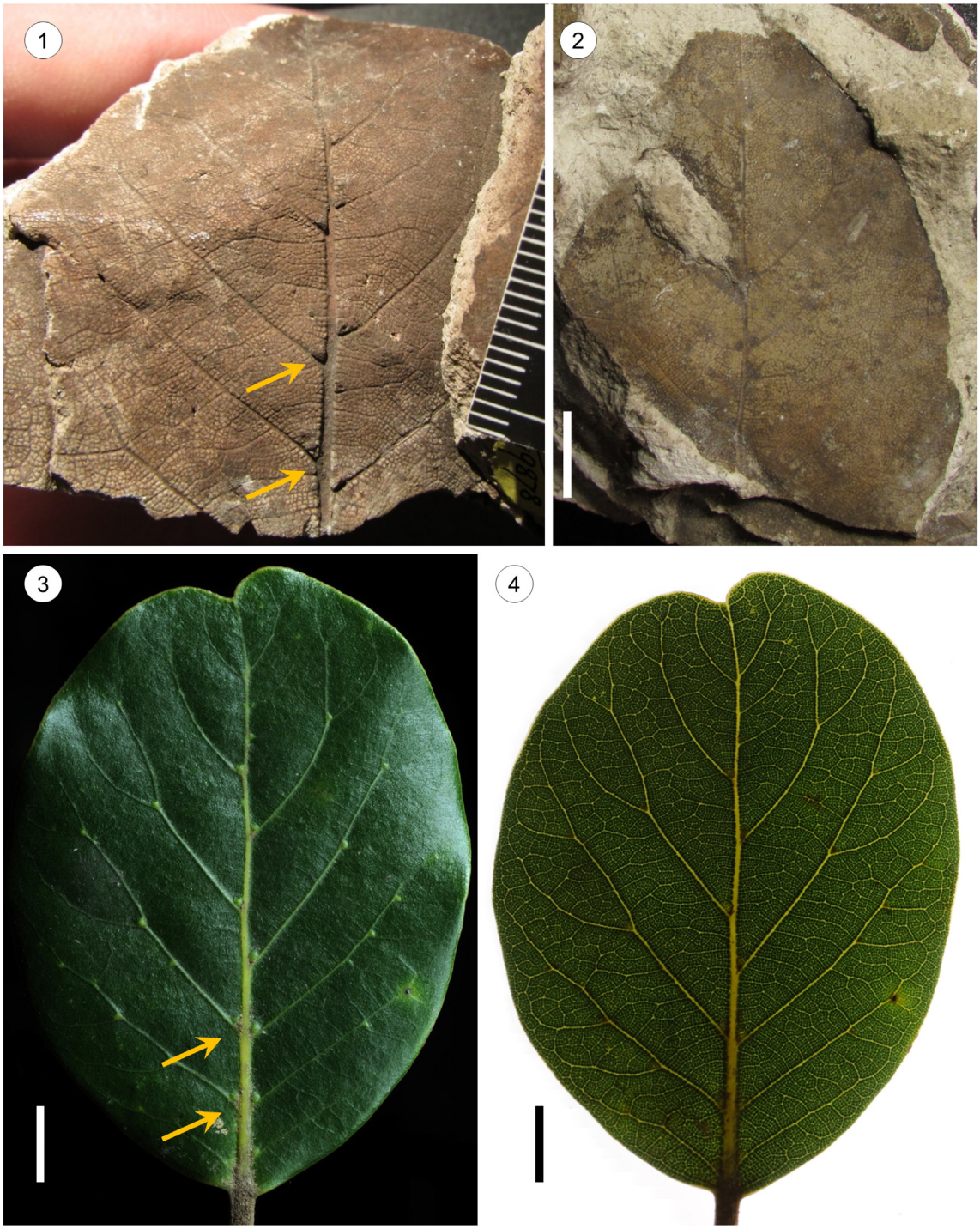

Plate II. *L. azorica*: 1) V 19878 and 2) V 19879 and partial leaf impressions, with exquisite preservation, where the domantia is visible along the axils of the secondary venation (arrows); 3) and 4) photographs of actual leaf of *L. azorica*: 3) low light photography to enhance the domantia (arrows) and 4) showing the leaf architecture; scale bar in mm in 1); scale bar equal to 1 cm in 2) to 4).

The study of these specimens reveals the existence of well-preserved leaves of three extant plants. *L. azorica* fossils were found in other fossil beds from Terceira, Pico, São Miguel, Faial and S. Jorge (see Teixeira and Pais, 1976), but are rarely presented in a taxonomical approach to justify the fossil classification (with the exception of Diniz (1962)). The presence of *W. radicans* is first reported here. From this small collection, it is clear that the presence of a typical composition of a laurel forest, dominated by evergreen broad-leaved trees (*L. azorica*) and understory vegetation, such as ferns (*W. radicans* and unidentified fern), are characteristic of the native Azores Islands' vegetation (Silva et al., 2005).

The geology of the Furnas locality was studied in detail by Guest et al. (1999), illustrating the presence of several palaeosols (dated late Pleistocene to Holocene) containing charcoal fragments. The palaeosols are interbedded with volcanic material of a trachytic composition, including ash deposits that compose the matrix of the studied plant fossils.

Macaronesia gave refuge to the last pristine forests of Europe (e.g. Dias, 2007; Menezes de Sequeira et al., 2007). It has been established that anthropogenic influences since the colonisation of the Azores Islands over the past six hundred years have had a destructive effect on native flora of the Islands (Dias, 2007). Although there are historical accounts

of the presence of luxurious forests in the Azores (Dias, 2007), the only way to reconstruct the past vegetation is through palaeontological studies. Recently there has been an emphasis for using palaeontology as a tool for ecological and conservational studies (e.g. Louys, 2012; Seddon et al., 2014). This is due to the uses of palaeontology to understand and predict how ecosystems reacted in the past and how they will in the future (Seddon et al., 2014). It is clear that the Azores present an ideal situation to test long term biodiversity changes and how these island ecosystems recovered from recurrent volcanic events. In addition to this, generally there is a lack of palaeobotanical perspectives in studies from the Azores (the recent contribution by Connor et al. (2012) being an exception). The presence of several fossil plant beds and palaeosols in several islands is a unique opportunity to explore palaeobotanical and palaeopalynological data (e.g. Forjaz et al., 1970; Teixeira and Pais, 1976; Madeira et al., 1995, 1998).

Further prospecting in Azores Islands will conclusively lead to the discovery of new fossiliferous outcrops including mega and macrofloral elements. Some plant fossils are reported in-situ (Diniz, 1962); it is expected that other organisms, such as insects and birds, will appear in these lithological units.

These sedimentary and fossiliferous volcanic deposits present the potential for supplementary fieldwork, not only to collect further macrofossils, but also for palynological studies which could assist and lead to the description of additional taxa. It is widely suggested in the literature that palaeobotanical studies in the Azores Islands and other Macaronesian islands continues, as this enables a further study and understanding of the biogeographic origin, dynamic, and evolution of these specialist insular floras (e.g. Anderson et al., 2009; Fernández-Palacios et al., 2011; Fernández-Palacios, 2013). The founding interest and study by Darwin and Hooker to understand the origin and evolution of insular ecosystems are not lost, but instead entombed, waiting for palaeontologists to discover them in both the field and in forgotten collections.

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