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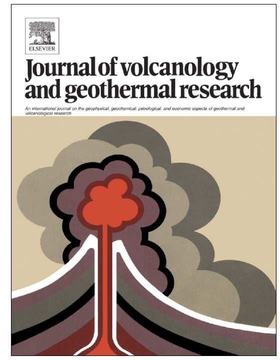


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# ORIGIN OF THE TERM *NUÉES ARDENTES* AND THE 1580 AND 1808 ERUPTIONS ON SÃO JORGE ISLAND, AZORES


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## ABSTRACT

In this paper we: provide a brief account of the 1580 and 1808 eruptions on São Jorge in the Azores, which produced Pyroclastic Density Currents (PDCs); discuss the first recorded use of the term *nuées ardentes* to describe these PDCs; trace how this term was introduced into the scientific literature and discuss its adoption by Alfred Lacroix (1863-1948) to describe the 'glowing clouds' produced by Mt. Pelée (Martinique) in 1902. The 1580 and 1808 eruptions on São Jorge are important because they provide early descriptions of PDCs. Documentary evidence of the eruptions and their impacts suggest that the 1580 PDC was a hotter flow, whereas the 1808 PDCs were cooler and more moist. Contemporary accounts describe the 1580 PDC as a 'globe of fire', mixed with 'caustic smoke' and moving at speed towards the bottom of the slope. In contrast, the 1808 PDCs comprised humid ash, were not incandescent and it is likely that the flows were cooler than that produced in 1580. Since the eruption of Mt. Pelée in 1902, it has been widely accepted that the term *nuées ardentes* was introduced by Lacroix (1904), being based on his description of the pyroclastic flows that he witnessed. Lacroix acknowledges that the Portuguese expression, *ardente nuvem* was first used in contemporary accounts of the São Jorge PDCs. This was first translated as *nuée ardente* and introduced into the scientific by the French geologist Ferdinand Fouqué (1828-1904), who was also Lacroix's father-in-law. Indeed, Lacroix provides an account of the 1580 and 1808 eruptions of São Jorge in his 1904 work *La Montagne Pelée et ses Éruptions*. The seminal work of Frank Alvord Perret (1867-1943) on the 1929-32 eruptions of Mt. Pelée and his description of *nuées ardentes* probably helped reinforce the association between the term and Mt. Pelée.

**KEYWORDS**

*Nuées ardentes,* São Jorge (Azores), 1580 eruption, 1808 eruption

## INTRODUCTION

'Pyroclastic density currents are laterally moving buoyantly expanding mixtures of hot gases and fragmental particles (ash, lapilli, blocks and boulders). They were first called *nuées ardentes* or glowing clouds' (Cole et al., 2015, pp. 944). In many accounts, it is generally accepted (e.g. Rittmann, 1962; Macdonald, 1972; Francis, 1993) that the term was first introduced by Alfred Lacroix (1904) in a description of the catastrophic eruption of Mt. Pelée, Martinique, in 1902. Indeed, Peter Francis states 'It is a little surprising .... that similar phenomena had not been recognised prior to 1902. Since they are not uncommon and must have been observed on many occasions in the past.' (Francis, 1993, pp. 133). This is despite the fact that Lacroix in his seminal work on the Mt. Pelée 1902 eruption states 'in a note dated April 6 1903, for the first time, I employed the expression *nuées ardentes* (our italics and translation)'. On return to Paris he learned that such phenomena had been described on São Jorge in the Azores during eruptions of 1580 and 1808 (Lacroix, 1904, pp.170).

In this paper we: provide a brief account of these historic Azorean eruptions; discuss the first recorded use of the term *nuées ardentes* to describe Pyroclastic Density Currents (PDCs); trace how this term was introduced into the scientific literature and discuss its adoption by Lacroix in order to describe the glowing clouds of Mt. Pelée in 1902.

## THE 1580 AND 1808 ERUPTIONS ON SÃO JORGE

### *Historic Volcanic Activity in the Azores*

The Azores were uninhabited when first settled by the Portuguese in the mid-15$^{th}$ century and the first historic records of eruptions date from this period. There have been historic eruptions on five of the nine inhabited islands of the Azores archipelago (Fig. 1) on: Faial; Pico; São Jorge; São Miguel and Terceira (Gaspar et al., 2015). In addition, there have been a number of submarine eruptions the most recent of which is Serreta (1998-2001), being located off the west coast of Terceira. Historic eruptions from the central volcanoes have been trachytic and have included the first observed eruption of Furnas volcano on São Miguel in 1439-43, the final dome forming phase of which was witnessed by the early Portuguese settlers who arrived soon after the main explosive phase of this eruption (Queiroz et al., 1995). The most recent eruption of Furnas occurred in 1630 and was of sub-Plinian dimensions causing around 195 fatalities (Cole et al., 1995; Guest et al., 2015). The largest explosive central eruption in historical times was the 1563 sub-Plinian event of Fogo Volcano, that is also located in São Miguel (Walker and Croasdale, 1971; Booth et al., 1978; Wallenstein et al., 2015).

Most eruptions since the 15$^{th}$ century have been both effusive and basaltic and are associated with fissure zones. The 1563 Pico do Sapateiro basaltic eruption occurred at the NW base of Fogo along the line of the Picos Fissural Volcanic System, which is located between Fogo and Sete Cidades central volcanoes on São Miguel. Lava from this eruption reached the north coast of the island. Basaltic fissure eruptions occurred on the island of Pico: in 1562-64, forming the Mistério da Prainha; in 1718 at São João and in 1720, when lava formed the Mistério da Silveira. In the Azores, *Mistério* (literally, mysteries) is the term used for young, rough and rugged lava terrain (Scarth and Tanguy, 2001, pp. 154). There were also basaltic fissure eruptions on the Capelo peninsula of Faial in 1672-73, and on the island of Terceira in 1761 when lava extended towards the north coast causing damage to the village of Biscoitos. Unusual fissure eruptions were: the 1652 eruption in the Picos Fissural Volcanic System of São Miguel, which formed three small trachytic domes (Ferreira et al., 2015); the Santa Luzia flow erupted in 1718 on Pico, that has the appearance of a basaltic aa flow, although the early stage of the eruption was more evolved being mugearitic in composition (Cappello et al., 2015) and the first phase of the 1761 eruption on Terceira Island, that formed the Mistérios Negros domes which are trachytic (Pimentel et al., 2016). The most significant submarine eruption in historic times was that of Capelinhos on Faial in 1957-58. This was a basaltic Surtseyan eruption that built up a series of cones above sea level and eventually formed an isthmus protruding from the west end of Faial (Anon, 1959; Cole et al., 2001). The phreatomagmatic ash and associated seismic activity of this eruption had a deleterious impact on the people of Faial and their economic activities (Coutinho et al., 2010).

The 1580 and 1808 eruptions of São Jorge were basaltic and associated with fissures aligned with the WNW-ESE tectonic trend of the island. The eruptions occurred on the slopes above the coastline between Velas and Urzelina (a distance of around 7 km) on the SW coast of São Jorge (Figs. 1 and 2a). These eruptions were distinct in that, in addition to effusion of basaltic lava, they were associated with phreatomagmatic activity and the generation of PDCs that swept down the steep scarp slopes of the island to the sea (Fouqué, 1873; Madeira, 1998, 2005; França et al., 2010). These PDCs caused fatalities in both eruptions.

*The 1580 eruption*

The description of the eruption that follows is based on the account by a priest Gaspar Frutuoso (1522-1591). It was published in his multi-volume work, *Saudades da Terra* which was written in manuscript form between 1586 and 1590, with his account of the 1580 eruption being published three centuries later by Ernesto do Canto (1880, pp. 188-190). *Saudades da Terra* remained in manuscript form until the late nineteenth century, being published from 1873 onwards (Luz, 1996) and did not become widely available outside

Portugal until well into the Twentieth Century. Frutuoso did not directly witness the eruption but his account appears to be based on eyewitness testimonials (Madeira, 1998). According to Madeira (1998), later accounts of the eruption by Monte Alverne (1695) and Araújo (1801) also appear to be based on Frutuoso's description. The record is incomplete and the dates and locations of certain events are unclear. Some accounts published in the 19th century (e.g. references quoted by Canto, 1880, pp. 190-193 and Fouqué, 1873) provide both differing dates and sequences of events, though neither author provides sources for this information (Madeira, 1998) and in line with Madeira we retain Frutuoso's sequence because it was written shortly after the eruption and is, therefore, almost contemporaneous.

The eruption began on 30th April following two days of felt earthquakes, with between 30 and 50 being experienced each day. Two vents opened less than 2 km SE of Velas, above the Ponta da Queimada lava delta on the top of the lower slope of the scarp (Fig. 2b). Two scoria cones were formed at the Ribeira do Almeida eruption site. The eruption column is described as being so high that its top was 'out of sight'. On 1st May, basaltic lava was erupted from the cones and flowed down the steep scarp slope for about 800 m and reached the sea. On the shore is the Ponta da Queimada lava platform (Fig. 2b), and the 1580 lavas extended the 'delta' to the west, these being the most recent volcanic deposits associated with this landform.

After a further six hours and later on 1st May, another area of volcanic activity began with the opening of a vent ca. 1.3 km further to the SE among vineyards near to Queimada. At the time, this was an important agricultural area selling some 1500 barrels of wine every year, but the majority of the vines were destroyed. The lavas continued to flow for two days contributing to the Ponta da Queimada lava delta at the coast. Today the western end of the runway of São Jorge airport is built on this flow field. Eruptive activity then began further to the east of Velas at Ribeira do Nabo (Fig. 2b). This eruption site at the Ribeira do Nabo, generated a basaltic lava flow field that exceeded a kilometre in width. SE winds deposited tephra over the Rosais area which is NE of Velas (Fig. 2a). Continued ash fall prevented people from leaving the church and, after three days, the build-up of ash meant that the doors could only be opened by digging out the tephra. The ash is described by Frutuoso as causing breathing problems (Canto, 1880, pp. 189) and this would indicate that the ash was fine grained.

According to Frutuoso, sometime later fifteen men returned by boat to collect possessions from a farm building in vineyards that were being threatened by the eruption (the date of this event is not recorded, but Madeira (1998) suggests that it occurred in May) and its location is also not stated in Frutuoso's account. Madeira (1998) considers that the most likely location of the farm building is on the western end of the Ponta da Queimada lava delta below the Ribeira do Almeida cones (Fig. 2b). Some men stayed in the boat whilst others went into the farm building to collect their possessions. A large cloud then engulfed the house. Some of the men startled by the shadow ran towards the boat followed by the cloud 'and the air of the cloud burned all of them, with skin falling from their bodies' (Canto, 1880, pp. 189 our translation). Frutuoso refers to this phenomenon as 'nuvens de fogo' - clouds of fire (Canto, 1880, pp.190). Those who remained in the house were killed and others were severely injured. A contemporary Latin account refers to this phenomenon as *fumi nubibus flammarum globi* - a globe of flame and smoke (Canto, 1880, pp. 192 our translation). This is the only direct record of the generation of what appears to have been a 'glowing' PDC during the 1580 eruption, but parish registers refer to 10 fatalities from the 'terrible cloud burning like hell' (Canto, 1880, pp. 192, our translation). After this disaster limited evacuation from the island was permitted and the eruption lasted for some four months.

*The 1808 eruption*

The fullest account of the 1808 eruption is by Father João Inácio da Silveira, parish priest of Santo Amaro and is published in the local journal, *O Jorgenese,* on 6th May 1871. This was reproduced by Ernesto do Canto (1884, pp. 437-441) with additional notes by Dr João Teixeira Soares. These accounts form the basis of the description of the eruption that follows.

Following a week during which several earthquakes occurred, on the night of 30th April, eight earthquakes were felt. Before the sun set, one was so large that it shook the people of Urzelina from their beds. During Mass on the morning of Sunday 1st May, a loud noise was heard accompanied by a strong earthquake and the congregation fled from the church. The congregation and other people who had evacuated their homes observed a dark cloud rising to a great height from the ridge above Urzelina. The loud bang was followed by a continuous roar marking the onset of the 1808 eruption. Dark clouds rose to a 'great height' and ash fell over the parishes of Urzelina and Manadas. From the vents on the ridge there was a continuous roaring. Houses were covered by ash which reached a depth of around 1 m.  Vents were active throwing incandescent bombs weighing up to 3.78 kg over a distance of 1.2 km.

John Dabney, the United States Consul, witnessed the start of the eruption from the City of Horta on Faial Island. He described a noise like a cannon shot from São Jorge followed by a dense column of smoke rising to a great height above the island (Webster, 1821). On 3rd May Dabney travelled to Velas on São Jorge to observe the eruption. He learned that the eruption started in the middle of a lake in a fertile pasture on a ridge above Urzelina (Fig. 2b), and formed a crater with an area of ca. 10 ha. In this area, a series of vents developed which became known as the Bocas de Fogo (Fig. 2b). Winds from the NE deposited tephra up to more than 1 m in thickness to the south, in an area between the vent and coast (Fig. 2b), ash also being deposited on the eastern end of Pico Island. Dabney on visiting the second crater that opened on 2nd May, found that at a distance of about 1.5 km from this new vent the 'earth was rent….and as we approached nearer, some of the chasms were 6 feet (ca. 1.8 m) wide' (Webster, 1821, pp. 288).

On the 3rd May activity at the Bocas de Fogo (Fig. 2b) subsided, but in the early morning of 4th May a new eruption opened 1.5 km to the west and this formed an eruption column generating much tephra. The ash was moist and thick and the accumulation of wet ash caused trees to collapse under its weight (Canto, 1884, pp438). The account of Father João Inácio da Silveira (Canto, 1884), records that the two new vents of the 4th May developed along a fissure in the fracture area described by Webster and noted above.

According to the account of Silveira (Canto, 1884), on 11th May another eruption began in the Parish of Santo Amaro, 1.5 km to the west. Two vents became active and generated lava flows, which by the second day covered ca 2.4 ha of land creating a *mistério* and that this lava was moving towards houses which had to be evacuated (Fig. 2b). After a few days of quiescence, eruptive activity returned to the Bocas de Fogo on the 15th May (Madeira, 1998). Winds from the NW caused tephra fall which ruined much pasture land. Many people fled from Urzelina to Manadas, Calheta and Rosais (Fig. 2a) and only the priest remained in the church at Urzelina. 'As the tide rose the volcano became more furious'

(Canto, 1884, pp. 439, our translation). The vents were ejecting bombs. The priest saw lava coming down the hill and rang the church bell; some people arrived and helped to remove valuable items to the *Ermida* (i.e. hermitage) *do Senhor Jesus*.

On 17th May the Vicar of Manadas, accompanied by people from his parish, visited S. Mateus Church at Urzelina (Fig. 2b) to help in the recovery of valuable items. Whilst at work, 'a huge flame rose from the volcano and a burning cloud, *medonha e ardente nuvem* (a fearsome burning cloud – our translation) came down the slopes setting fire to the vineyards, bushes and trees and burning around 30 people as it approached the church' (Canto, 1884, pp. 440, our translation – Fig. 3). The cloud was described as 'covering the sunlight' as if it were night. An account of this event is given by Dr Soares as a footnote: 'After the eruption of lavas and associated damage, there was a short suspension of activity at the craters and this was followed by a sudden and unexpected explosion of a dark cloud that rolled down the hill, close to the ground in a turbulent fashion. It reached the sea with a prodigious force, devastating, burning and killing everything that breathed in its path. Afterwards the area affected resembled a desert' (Canto, 1884, pp. 440, our translation). Dr Soares, in a note written 63 years after the eruption, states that the *nuvem ardente* was a *humid* (our italics) dust (Canto, 1884, pp. 443), thus indicating that the ash was moist.

The Vicar of Urzelina thinking it was his last hour, prepared to receive the sacrament of the Mass when the cloud cleared and the sun shone. He left the church and met the Vicar of Manadas, who was accompanied by the people who had been burned. Those who had minor injuries went home, whilst others were treated in the church or in nearby houses. Burnt skin was hanging from their limbs, bodies were black and swollen, some legs were broken and there was sneezing suggestive of damage to respiratory tracts. Many people requested the Sacrament of Holy Communion. Some people did not recover and their names are listed in footnote 2 by Canto (1884, pp. 440).

Dabney (Webster, 1821, pp. 239) provides an interesting account of the impact of the 17th May dilute PDC: 'most of the inhabitants fled; some, however, remained in the vicinity too long, endeavouring to save their furniture and (other) effects, and were scalded by flashes of steam which, without injuring their clothes, took off not only their skin, but also their flesh. About sixty persons were thus miserably scalded, some of whom died on the spot or in a few days after' (our comment in italics). Fouqué (1873) considered that the asphyxiation was caused by inhalation of toxic gases. It is more likely that this relatively cool PDC, not hot enough to burn clothes, but in places at least was still hot enough to flash water to steam, scald victims and asphyxiate them as they inhaled the gases which burned their throats causing swelling.

It is of note that in 1808 the locals used the same term *ardente nuvem* - burning cloud, to describe these bulbous clouds that flowed down the hill, a term which had been first used in the account of the 1580 eruption (Fouqué, 1873). As was the case in the 1580 eruption, the *ardente nuvem* burned victims caught in its path. The term *ardente fogo* was not used in 1808 and there is no description of incandescence in the black cloud. Fouqué argues that on the basis of lack of observed incandescence and the moist nature of the ash that the 1808 flow was cooler than that of 1580. It appears from the records that more PDCs were erupted (Canto, 1884, pp. 443), after which activity gradually decreased.

## DISCUSSION

The 1580 and 1808 eruptions on São Jorge are important because they provide early descriptions of PDCs and are unusual in that the PDCs were generated by basaltic eruptions.

Eruptions of mafic/intermediate magmas can be explosive. Large eruptions of this type typically occur from established summit vents such as the basaltic Plinian eruption of Etna in 122 BC, whose tephra caused significant damage on the southern flank of the volcano including the city of Catania (Coltelli et al., 1998) and the andesitic eruption of Ngauruhoe (Tongariro massif) New Zealand, that generated PDCs as scoria flows (Nairn and Self, 1998; Lube et al., 2007). PDCs from small basaltic eruptions can occur either from phreatomagmatic explosions, from gravitational collapse of scoria cones, or from accumulations of lava at the top of a steep slope (Cole et al., 2015). Behncke et al. (2008) described PDCs generated by explosive activity during the eruption of basaltic magmas from the SE Crater of Etna volcano in 2006. These PDCs travelled up to a distance of 1 km. They argued that explosive activity was triggered by the interaction of magma with wet rock on the flank of the cone. Alternatively, Ferlito et al. (2010) suggested that this paroxysmal event was produced by rapid ground fracturing leading to a drop in confining pressure that was exploited by an injection of primitive, gas-rich magma. The São Jorge 1580 and 1808 events were relatively small eruptions from monogenetic cones. The documented evidence of the eruptions and their impacts suggest that the 1580 PDC was the hotter flow, whereas the 1808 PDCs were cooler and more moist. Based on contemporary accounts, Fouqué (1873, pp. 1199) describes the 1580 PDC as a globe of fire, mixed with caustic smoke and moving at speed towards the bottom of the slope. As described above, the 17$^{th}$ May 1808 PDC comprised moist ash; was not incandescent and the flow was cooler than that associated with the 1580 eruption. The 1580 and 1808 PDCs almost certainly reached the shore but there are no descriptions in the historic documents of them entering the sea. The hotter and incandescent nature of the 1580 eruption and the local topography, might suggest collapse of an active lava flow from the top of the scarp. This is supported by the interpretation of Madeira et al. (1998) who consider that the 1580 PDC erupted from the Ribeira do Almeida site was a block and ash flow. In the case of the 17th May 1808 PDC, the observation of the moist ash-laden nature of the turbulent flow, its relative coolness and the nature of the dark cloud blotting out the sun light, support the proposition of Madeira (2005) that this flow was a surge of phreatomagmatic origin. It is of note that John Dabney records that the Bocas de Fogo vents were located in the middle of a lake (Webster, 1821, pp287) and this raises the probability that ground water was present at shallow depths.

Deposits from the 1580 and 1808 PDCs have not been identified in the field; a prehistoric block and ash flow deposit (radiocarbon date 2880±60 BP) has, however, been located in the Ribeira da Cancela, above Manadas, which supports the occurrence of recent eruption of basaltic PDCs on São Jorge (Madeira et al., 1998).

## ORIGIN OF THE TERM *NUÉES ARDENTES*

The visit by the French geologist Ferdinand André Fouqué (1828-1904) to the Azores led to him to make significant contributions to volcanology. Following his initial account of the volcanic geology of the Azores (Fouqué 1867), his research on the 1580 and 1808 eruptions on São Jorge (Fouqué 1873) and his use of the term *nuée ardente* represents an early contribution to the understanding of the generation and emplacement of PDCs. The term *nuée ardente* is credited by Fouqué as a direct translation of the Portuguese *ardente nuvem,* which was coined by locals who witnessed events in 1580 eruption and was subsequently adopted by witnesses of the 1808 eruption. Though it should be noted that *ardente nuvem* refers to a burning cloud and this was clearly the impact of the flow on the victims who were in its path whereas *nuée ardente* translates as glowing avalanche (Francis 1993). In interpreting the cause of death and injury by asphyxiation of those caught by the cloud, Fouqué recognised the similarity of their fate with those of some of the inhabitants of Pompeii during the eruption of Vesuvius in AD79, arguing that this would explain how the Roman inhabitants, including robust males, clearly died in agony in a manner which is difficult to explain solely from the fall of tephra.

Since the eruption of Mt. Pelée in 1902 it has been widely accepted in the literature, that the term *nuées ardentes* was introduced by Lacroix (1904), being based on his description of the pyroclastic flows that he witnessed. In the *Encyclopedia of Igneous and Metamorphic Petrology* it states that 'the term *nuée ardente* was first introduced by Lacroix' (Bowes, 1989, pp. 396). Lacroix (1904) adopted the term to describe the glowing ash clouds erupted by Mt. Pelée in 1902, but on returning to France he became aware that the term had been used to describe the phenomenon observed in the 1580 and 1808 eruptions of São Jorge, for which Frutuoso used the term *nuvens de fogo* (clouds of fire) in his account of the 16$^{th}$ century eruption (Canto, 1880, pp. 190). Lacroix acknowledges that the Portuguese term was first translated as *nuée ardente* by Fouqué (1873), and so entered the scientific literature. Indeed Lacroix provides an account of the 1580 and 1808 eruptions of São Jorge in *La Montagne Pelée et ses Éruptions* (Lacroix, 1904, pp. 364-66). The seminal work of Perret (1935) on the 1929-32 eruptions of Mt. Pelée and his description of *nuées ardentes* probably helped reinforce the association between the term and Mt. Pelée.

In succeeding years, the contribution of Fouqué was largely forgotten in international literature.  We draw attention to two exceptions. This first was a reference in a paper delivered by Marjorie Hooker entitled, *Origin of the term Nuée Ardente,* presented at a meeting of the Mineralogical Society of America (Hooker, 1965). Hooker notes that Fouqué derived the term *nuée ardente* from the Portuguese term *nuvem ardente* and introduced it into the geological literature. The second instance is a short account by Maurice Krafft (1993, pp. 170-71). The issue came to the fore once more when Alwyn Scarth visited the Azores in researching his book, *Volcanoes of Europe,* (Scarth and Tanguy, 2001) and became aware of the 1580 and 1808 eruptions of São Jorge. Scarth clearly explored the link between Fouqué's account and Lacroix's adoption of the term. He notes as Krafft (1993, pp. 171) did, that Lacroix married Fouqué's daughter and 'the term only came into common volcanological usage when it was revived by Alfred Lacroix (1863-1948), see Lacroix (1904, pp. 170). It (seems) likely (that) he learned the term from his father-in-law' (Scarth 2002, pp. 115).

Descriptions of the 1580 and 1808 *ardentes nuvens* during eruptions of São Jorge represent important early descriptions of PDCs and explain the origin of the term *nuées ardentes.*

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## FIGURES

Fig. 1. Azores: Location map.

Fig. 2a. Fig. 2a. S. Jorge north of Calheta showing the positions of the 1580 and 1808 eruptions (based on: Forjaz and Fernandes, 1970, 1975; Forjaz et al., 1970).

Fig. 2b. Detailed sketch map of the eruptive activity of 1580 and 1808 eruption (based on Madeira, 1998 and 2017 personal communication).

Fig. 3. Photograph showing the path followed by the PDC on 17$^{th}$ from Bocas de Fogo to Urzelina.

# HIGHLIGHTS

The 1580 and 1808 eruptions on São Jorge Island (Azores)

Early descriptions of PDCs

Alfred Lacroix, Mont Pelée and the first use of the term, *nuées ardentes*

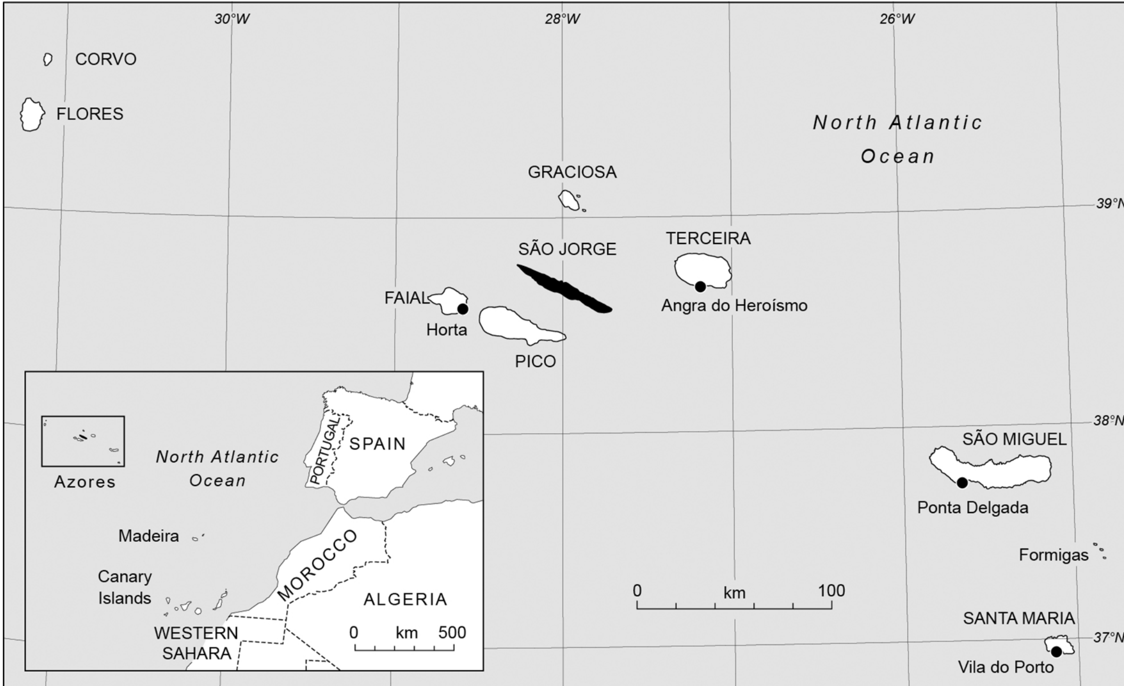
30°W
28°W
26°W
CORVO
FLORES
North Atlantic Ocean
GRACIOSA
39°N
SÃO JORGE
TERCEIRA
FAIAL
Horta
Angra do Heroísmo
PICO
38°N
SÃO MIGUEL
Ponta Delgada
Formigas
0
km
100
SANTA MARIA
37°N
Vila do Porto
Azores
North Atlantic Ocean
PORTUGAL
SPAIN
Madeira
MOROCCO
Canary Islands
ALGERIA
WESTERN SAHARA
0
km
500

Figure 1

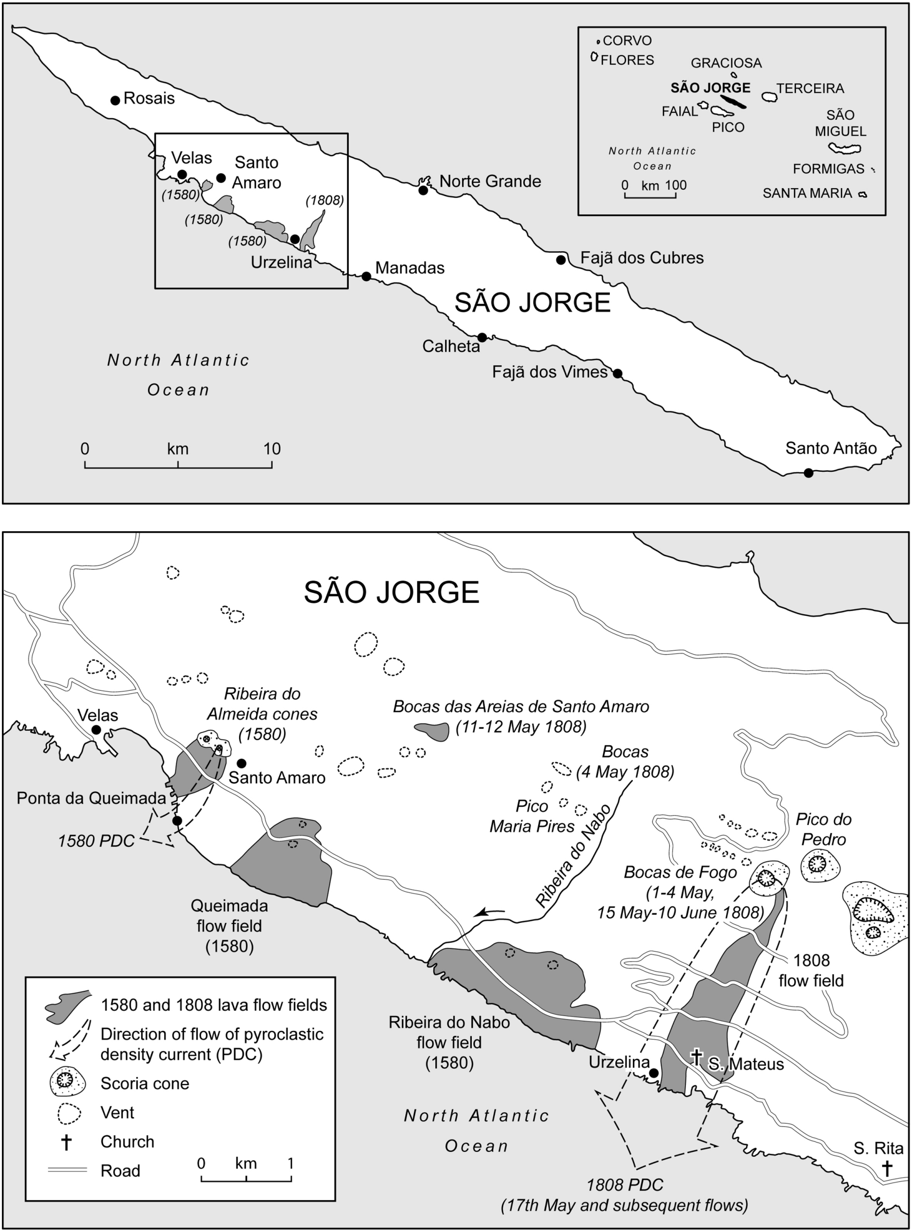
CORVO
FLORES
GRACIOSA
SÃO JORGE
TERCEIRA
FAIAL
PICO
SÃO MIGUEL
North Atlantic Ocean
0 km 100
FORMIGAS
SANTA MARIA
Rosais
Velas
Santo Amaro
(1580)
(1580)
(1580)
(1808)
Urzelina
Norte Grande
Manadas
Fajã dos Cubres
SÃO JORGE
Calheta
Fajã dos Vimes
North Atlantic Ocean
0 km 10
Santo Antão
SÃO JORGE
Ribeira do Almeida cones (1580)
Bocas das Areias de Santo Amaro (11-12 May 1808)
Velas
Santo Amaro
Bocas (4 May 1808)
Ponta da Queimada
1580 PDC
Pico Maria Pires
Ribeira do Nabo
Pico do Pedro
Bocas de Fogo (1-4 May, 15 May-10 June 1808)
Queimada flow field (1580)
1808 flow field
1580 and 1808 lava flow fields
Direction of flow of pyroclastic density current (PDC)
Scoria cone
Vent
Church
Road
0 km 1
Ribeira do Nabo flow field (1580)
Urzelina
S. Mateus
North Atlantic Ocean
S. Rita
1808 PDC (17th May and subsequent flows)

Figure 2

Figure 3