Chapter 1

Volcanic geology of São Miguel Island (Azores Archipelago): introduction

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The Azores is an archipelago in the Atlantic Ocean composed of nine volcanic islands. The islands are dispersed along a general WNW–ESE trend crossing the Mid-Atlantic Ridge in the area where the Eurasian, African and North American lithospheric plates meet. While Corvo and Flores lie to the west of the Mid-Atlantic Ridge and emerge from a present-day relatively stable geological setting, the other islands are located in an important seismic and volcanically active zone corresponding to the boundary between the Eurasian and African tectonic plates. Volcanic activity has occurred in historic times on the islands of Faial, Pico, São Jorge, São Miguel and Terceira, and there have also been several recorded submarine eruptions (Weston 1964).

São Miguel is the largest and most volcanically active island of the archipelago. In the last 5 ka several eruptions took place on the three active central volcanoes – Sete Cidades, Fogo and Furnas – and in the basaltic fissure systems of Picos and Congro. Although details of the first settlement of the island in the fifteenth century are uncertain, there is evidence that Furnas was in eruption at the time the first settlers arrived, some time between 1439 and 1443 (Queiroz *et al.* 1995). The historian Gaspar Frutuoso (1522–1591?) provided the first geological descriptions of the Azores in his work 'Saudades da Terra', giving important details about the earliest volcanic and seismic events. In the sixteenth and seventeenth centuries there were two explosive trachytic eruptions of sub-Plinian scale on São Miguel: Fogo 1563 and Furnas 1630. The last eruption on land occurred in the Picos Fissural Volcanic System, in 1652, and involved the extrusion of lava domes.

The first systematic study of the São Miguel volcanoes was published by Zbyszewski (1961), together with a geological map of the island (Zbyszewski *et al.* 1958, 1959). The 1970 work on São Miguel by George Walker and his colleagues (Walker & Croasdale 1971; Booth *et al.* 1978) played a significant role in developing an understanding of silicic explosive eruptions. At this time there was also, for the first time, consideration of the hazards posed by these volcanoes (Booth *et al.* 1983). A new geological map of the island and accompanying report was produced by Moore (1991*a*, *b*).

In 1993 Furnas Volcano was selected as one of the European Union *Laboratory Volcanoes* and this facilitated its detailed investigation, with studies ranging from geological history through styles of eruptive activity to aspects of hazard assessment, management and vulnerability (Duncan *et al.* 1999). This project was financed by the Research & Development Environment Programme of the Commission of the European Communities (CEC-DGXII) and followed the European Volcanic Project launched by the Steering Committee of the European Science Foundation's Volcanological Network. It involved researchers from Portugal, the UK, Iceland, Italy and Spain, and was the basis for the development of several international research projects that extended to the other São Miguel volcanic systems and even to other islands. These studies were focused on physical volcanology and the development of instrumental networks for monitoring seismic activity, ground deformation and water and gas geochemistry.

John Guest was the leader of many of these projects and was also the supervisor of several doctoral and master's theses. His experience, dedication and friendship inspired the 'school' of volcanology that was developed in the Azores and which is now of international standing: the Centro de Vulcanologia e Avaliação de Riscos Geológicos (Centre for Volcanology and Geological Risk Assessment) at the University of the Azores. He was also enthusiastic about and largely responsible for the publication of this memoir, which brings together the results of more than two decades of scientific work on the geology of São Miguel, and represents an insight into the pure and applied volcanic geology of the island within the broader context of the Azores archipelago. John Guest sadly died during the preparation of this volume, which stands as a deserved tribute to the scientist and friend who helped to build Azorean earth science as a centre for high level volcanological research and monitoring.

The first section, *Geological setting*, places São Miguel in the volcanic and tectonic contexts of the Azores and discusses its position astride the triple junction between the African, North American and Eurasian plates. **Miranda *et al.* (2015)** provide an overview of the regional tectonic setting based on geophysical and geodetic data. **Madeira *et al.* (2015)** focus on active tectonics of the eastern branch of the Azores Triple Junction, as reflected in the central and eastern islands. The range and distribution of seismic and volcanic activity in the Azores region are discussed by **Gaspar *et al.* (2015*b*)**, the authors characterizing earthquakes with a magnitude >7 and the volcanic eruptions ranging from Hawaiian to explosive sub-Plinian in style that took place in historic times (broadly the last 550 years). A review of magmatism in the Azores is presented by **Zanon (2015)**, in which the petrology of the alkaline suite of magmas, their petrogenesis and the

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evidence they provide of a geochemically heterogeneous mantle underlying the Azores is described.

The second section, on *Volcanic history*, begins with an account by **Carmo *et al.* (2015)** that provides an analysis of the tectonic structures of São Miguel and discusses its dynamics in the context of Eurasian and African plate boundary evolution. Detailed geological accounts of the two central volcanoes, which topographically dominate the island, are presented by **Queiroz *et al.* (2015)** for Sete Cidades and **Wallenstein *et al.* (2015*b*)** for Fogo; the authors reconstruct the history of the volcanoes paying special attention to caldera-forming events and the recent intra-caldera sub-Plinian and phreatoplinian eruptions. A brief account of the volcanic history of Furnas by **Guest *et al.* (2015)** is an update of an early paper by Guest *et al.* (1999) in which new information is presented. The geology of the basaltic fissure systems that link the central volcanoes is described by **Ferreira *et al.* (2015)**. The older volcanic deposits in eastern São Miguel have not yet been mapped in detail, but a preliminary account by **Duncan *et al.* (2015)** identifies the main volcanic features of the Povoação Volcano and the Nordeste Volcanic System that occupy this part of the island.

The section on *Geological hazards and risk assessment* considers the hazards posed by this geologically active island and explores measures undertaken in order to mitigate them. The hazards posed by volcanic activity on São Miguel are investigated by **Gaspar *et al.* (2015*a*)**. The topography of the island is young and in many places unstable, and landslides commonly occur following heavy rainfall and/or seismic activity, and this is evaluated by **Marques *et al.* (2015)**. Diffuse discharge of gases in parts of the island presents a threat to the health of the inhabitants, this being considered by **Viveiros *et al.* (2015*a*)** for CO_2 and by **Silva *et al.* (2015*b*)** for radon. **Wallenstein *et al.* (2015*a*)** discuss the vulnerability and resilience of the population of São Miguel in relation to both the hazards and possible responses that assist in their mitigation.

Volcano monitoring describes the current procedures in place for monitoring seismic and volcanic activity. **Silva *et al.* (2015*a*)** demonstrate how seismic activity on the island and offshore is recorded, analysed and the information used to inform the civil authorities. Ground deformation is an important tool for monitoring geothermal and magmatic systems and **Okada *et al.* (2015)** provide an interpretation of recent data. **Cruz *et al.* (2015)** investigate variation in the hydro-geochemistry of mineral waters on São Miguel, while the systems in place to monitor soil degassing of CO_2 on Fogo and Furnas are described by **Viveiros *et al.* (2015*b*)**.

The final section on *Natural resources* begins with a review by **Coutinho *et al.* (2015)** of the hydrogeology of São Miguel, while **Rangel *et al.* (2015)** present recent data on the use of geothermal resources. It is emphasized that basaltic lava flows, ignimbrites and hydromagmatic tuffs are often used as raw material for building, whereas scoriaceous pyroclastics are used in road construction.

This volume represents a step in bringing current understanding of volcanism of São Miguel together within one volume. We hope it provides a stimulus in the development of new research that will improve understanding of the genesis and evolution of the Azores.

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