Active Volcanoes of the World

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Volcanoes of the Azores

Revealing the Geological Secrets of the Central Northern Atlantic Islands

Springer

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Foreword

The Northern Mid-Atlantic Ridge (MAR) between 33°N and 41°N exhibits a gradient in seafloor depth, from 3500 m just north of the Hayes Transform (near 33°N) to less than 1000 m near 39°N. Together with this depth gradient, the MAR is characterized by a broadening with a funnel shape, best represented by the 2000 m bathymetric contour. This large bathymetric structure representing a prominent submarine topographic high is called the Azores platform. The maximum bathymetric expression of this platform is given by the emergence of a group of nine volcanic islands, forming the Azores archipelago.

The Azores platform represents a tectonic peculiarity as it is located at the triple junction between the American, Eurasian and African plates. In this context, the tectonic evolution of this region and the nature of the boundary between the Eurasian and African plates have always been contentious, with several models proposed to describe the overall plate kinematics, but this issue is still being debated.

Another highly disputed subject is related to the origin of the Azores platform and its islands. The geochemistry of the Azores lavas (either from land or from submarine samples) shows incompatible trace element enrichment coupled with high Sr–Nd–Pb radiogenic isotope ratios (a typical signature of oceanic island basalts) and has been used to suggest the existence of a compositional mantle anomaly beneath the Azores. Additionally, this geochemical enrichment was found to correlate with other geophysical characteristics, such as negative gravity anomaly, anomalously low S-wave velocities in the 100–200 km depth range or crustal thickness 60% higher than normal, all of them suggesting high magma productivity. These observations and inferences led to the generation of alternative models by suggesting the existence of a thermal anomaly in the mantle ("hotspot"), a volatile enrichment anomaly ("wetspot") or the presence of a mantle plume. To date, origin, size, depth and accurate location of this mantle anomaly are still a matter of debate.

The chapters included in this book provide a comprehensive and multidisciplinary overview of the geoscientific knowledge of the Azores platform. The scientific core themes of this volume encompass the geophysical, geochemical and petrological subjects, addressing not only the two aforementioned main controversial issues in the Azores, but also related topics such as hydrogeology and palaeontology. Additionally, Chapter "A Portrait of the

Azores: From Natural Forces to Cultural Identity" by Beier and Kramer deals with the Azorean cultural identity that has been strongly conditioned by the forces of nature, expressed in this region mainly by earthquakes and volcanic eruptions. Since the first permanent settlements in the Azores in the fifteenth century, about thirty volcanic eruptions, both on land and offshore, have been documented. Besides, the Azores are located in an area of elevated seismic activity. The majority is usually expressed through microearthquakes; however, periodically, the Azores are shaken by moderate to strong earthquakes that have caused destruction and negative economic impact. Cumulatively, more than 5000 people have perished and this, undoubtedly, impacted on the socio-economic and cultural development of these Portuguese people living isolated and enclosed by volcanoes in the middle of the Atlantic Ocean.

The six following chapters constitute the geophysics section in this book. The second Chapter "The "Azores Geosyndrome" and Plate Tectonics: Research History, Synthesis, and Unsolved Puzzles" by Vogt and Jung addresses the anomalous morphological, geological and geophysical framework present in the so-called Azores Triple Junction. It integrates and compares these characteristics with those present in a broader and more regional context such as the encompassing Mid-Atlantic Ridge, in a way to clearly understand the peculiarities existent in the Azores. These anomalies are identified through water depth and gravity/geoid variation, crustal thickness, upper mantle seismic structure, plate boundary morphology and rock geochemistry. The authors also review the evolution of the present-day understanding of the Azores and discuss the implications of their findings for other geologically recent plate boundaries. Chapter "The Contribution of Space-Geodetic Techniques to the Understanding of the Present-Day Geodynamics of the Azores Triple Junction" by Fernandes et al. focuses on the major contributions obtained with Space Geodesy (Global Navigation Satellite Systems (GNSS) and Interferometry Synthetic Aperture Radar (InSAR) techniques) in the Azores through a review of the published results since the late 1980s. Global Navigation Satellite Systems (GNSS) have been applied to modelling and understanding large-scale processes such as the relative movements and angular velocities of the three tectonic plates but, more recently and as a result of denser distribution of GNSS stations throughout most Azorean islands, more detailed studies concerning intra-island deformations have been carried out. Both techniques addressed have been contributing significantly to better understand the tectonic dynamics and the volcanic processes occurring in the Azores. In Chapter "Crust and Mantle Structure Beneath the Azores Hotspot—Evidence from Geophysics", O'Neill and Sigloch assess the geophysical constraints on crustal and mantle structure beneath the Azores hotspot discussing the possible existence of a traditional mantle plume. The data obtained through surface wave models, suggesting a shallow origin (250–300 km of the mantle) to the Azores hotspot or, alternatively, that the plume is waning, contrast with recent finite-frequency body-wave tomography which indicates that the Azores plume may extend to the core–mantle boundary. The authors suggest a common origin under West Africa for the Azores, Canary and Cape Verde hotspots. Chapter "The Tectonic Evolution of the Azores Based on

Magnetic Data" by Miranda et al. reviews the progress made in the geophysical research of the Azores, based on geophysical observations complemented by numerical modelling, and presents an updated interpretation scheme for the genesis and evolution of the Azores Triple Junction. Whereas on land investigations with detailed topographic maps, aerial photographs and satellite imagery as well as rock samples are straightforward and allow the study of geological structures at all scales, at sea things are quite different and have only advanced recently with technological developments. Mitchell et al. (Chapter "Volcanism in the Azores: A Marine Geophysical Perspective") present and discuss the Azores sea bottom morphology obtained through different types of sonar data (GLORIA, TOBI and multibeam bathymetric data). The studied sonar datasets allowed them to view and understand the topographic structures of the ridges (that constitute important extrusive structures in the Azores region) and interpret the morphologies in terms of the volcanic and tectonic features present on them. Fontiela et al. (Chapter "Characterisation of Seismicity of the Azores Archipelago: An Overview of Historical Events and a Detailed Analysis for the Period 2000–2012") give an overview of the existing historical and instrumental seismic catalogues, describe the seismicity of the region since early 1915 and analyse the features of the observed seismicity in the period 2000–2012, which is typically characterized by high number of events with relatively low magnitude.

Chapters "The Marine Fossil Record at Santa Maria Island (Azores)" and "Surface and Groundwater in Volcanic Islands: Water from Azores Islands" deal with direct observations or measurements. Ávila et al. (Chapter "The Marine Fossil Record at Santa Maria Island (Azores)") describe the unique exposure of sedimentary rocks containing marine fossils in the Azores. These outcrops on Santa Maria Island are interpreted as the result of tectonic processes. The authors also discuss the need and importance of preserving this palaeontological heritage. The magmatic origin of the Azores is first approached by Larrea et al. (Chapter "Petrology of the Azores Islands") with a detailed compilation of mineralogy and major element chemistry of xenoliths and volcanic rocks. These geochemical data are used to give an overview of the petrology of these igneous rocks, namely insights into magmatic evolution paths/processes and depth of melting, in a geochronological context (where appropriate temporal data are available), to better understand the origin of the specific geochemical characteristics present in each island. In Chapter "Melting and Mantle Sources in the Azores", Beier et al. detail the geochemistry of igneous rocks (mainly from land but also including submarine samples) by reviewing the trace element and radiogenic isotope (Sr–Nd–Pb–Hf systems) data. The alkaline character of the lavas and the large compositional range from basalts to trachytes identified in the volcanoes is emphasized, and elemental and isotopic comparisons inter-islands are made. These findings are used to address the mantle source characteristics (composition, degree of heterogeneity and temporal evolution) of the magmas from the Azores islands as well as their chemical evolution and the processes involved during magma ascent and differentiation. The geochemistry study is complemented by Moreira et al. (Chapter "Noble Gas Constraints on the Origin of the Azores Hotspot") which discuss the origin

of the Azores archipelago by making comparisons between the different islands and integrating the findings in a wider regional scheme along the MAR between 28°N and 53°N. Antunes and Carvalho (Chapter "Surface and Groundwater in Volcanic Islands: Water from Azores Islands") characterized surface waters (lakes, springs and rivers) and revealed the degree of direct input by volcanic activity. The authors constrained by the volcano-tectonic activity that influenced today's geomorphological characteristics and emphasize the importance of volcanic lakes as a freshwater resource.

The final Chapter "Where to Go? A selection and Short Description of Geological Highlights in the Azores" by Kueppers et al. describes a selection of geological outcrops from each of the Azores islands that the authors considered worthwhile visiting, to get an overview of prominent geological features. Some of the selected outcrops have been subject to detailed geological descriptions and are regularly visited by researchers and students, and data from the peer-reviewed literature, wherever available, are used to complement the descriptions and integrate them in a larger regional geological context.

I am happy to see such a compilation of national and international chapters that cover a wide range of geoscientific questions about the Azores.

Alfragide, Portugal

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