AZORES VOLCANO GEOTRAVERSE*

Wes Gibbons 2019

In this Holiday Geology guide we describe a west-to-east drive across the volcanoes of São Miguel, the largest and most easily accessible (and therefore most visited) island in the Azores archipelago. São Miguel lies 2,400km from Barcelona and Newfoundland, and is positioned geologically just east of the Mid-Atlantic Ridge tectonic plate boundary which runs 3,000km north to Iceland and over 10,000km south to Bouvet Island in the South Atlantic. Despite the geographic isolation of the island (the nearest continental landmass is 1,500km away at the Lisbon coast) it is nevertheless well served by flights to the capital Ponta Delgada from both European and North American destinations. You will need to hire a car on arrival and buy a road map before you arrive: *the Azores Tour & Trail (Discovery Walking Guides 2019*) is a good choice.

São Miguel is very green, very volcanic, and very isolated in the Atlantic Ocean.

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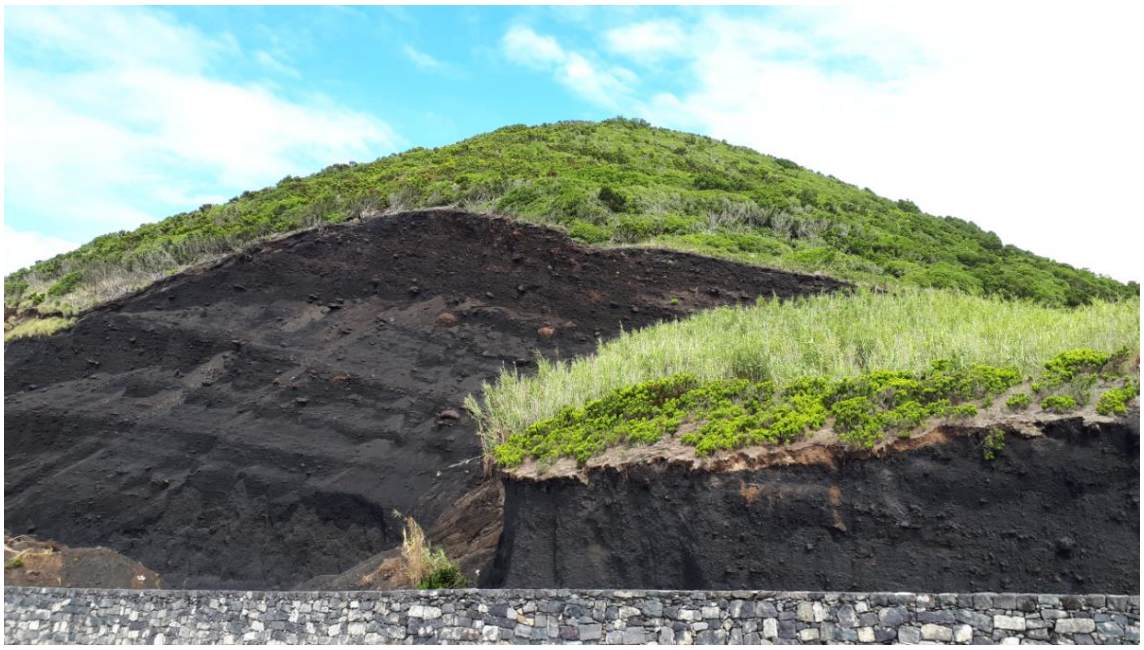
São Miguel is both volcanically and seismically active, geomorphologically very young, and it has a maritime climate subject to severe rainstorms, which together combine to produce a *potpourri* of geological hazards. The geotraverse described here overviews the volcanic geology and its associated dangers, selecting scenic and accessible localities along an attractive, mostly rural route that avoids the more populated strips of the central southern and northern coasts. The driving is fun, but you will need to drive slowly and be comfortable with winding roads that in places are narrow and vertiginous. The route can be completed three leisurely daytrips (1. Ponta da Ferraria to Pinhal da Paz; 2. Ribeira Seca to Vila Franca do Campo; 3. Furnas to Nordeste: see map above), but your choice of day and stop will likely be constrained by the highly variable weather: the volcanic centres of Sete Cidades and Fogo can be shrouded in impenetrable fog. Check out the live webcams on *Spotazores.com* before driving to high ground. Regarding places to stay, our preferred choice would be to spend the first night in Ponta Delgada then be based in the volcanic village of Furnas and day trip out from there.

1. **Ponta da Ferraria**

This coastal locality on the extreme western end of São Miguel exposes volcanic rocks on the west side of the Sete Cidades caldera and is popular with visitors for its thermal baths. From the airport drive 25km northwest along the coastal road to Ginetes and take the turning left to Ponta da Ferraria. After 150m turn sharp right and follow northwards for just over 1km to take a left turning then, 250m further on, park on the left at the Sabrina Island Viewpoint. This is an excellent place to overview the local geology.

Immediately to the north of the car park rises the basaltic scoria cone of Pico das Camarinhas, at the summit of which are three craters aligned along an east-west trending fracture radiating from the Sete Cidades caldera.



Pico das Camarinhas volcanic cone is a typical satellite vent on the flanks of the Sete Cidades volcano and it erupted around 840 years ago. The roadcut exposes crudely layered airfall basaltic scoria with embedded volcanic bombs. Such vents are monogenetic, that is they erupt just once after which the magmatic plumbing system feeding them freezes inside the volcano and blocks later activity. It records just one brief volcanic event in the 800,000-year history of the huge, polygenetic Sete Cidades stratovolcano.


A giant bomb of scoriacious lava lying in the road shows in close-up (right) a pumiceous texture of bubbly vesicles left as empty cavities after frothy gas escape during eruption. Note also (e.g. by the finger) the small "xenoliths" of white feldspar and dark mafic crystals (mostly pyroxenes) that have become incorporated into the magma prior to eruption.

The lava emanating from Pico das Camarinhas flowed over the adjacent sea cliff to form a triangular basaltic apron ("fajã") at sea level. A special feature of this basaltic apron is the presence of a "littoral cone", a pseudocrater without magmatic plumbing but formed instead by explosions resulting from the entrapment of steam beneath the hot lava. Such delicate landforms are rarely preserved in such an erosive environment.

Fajã foreshore of the Ponta da Ferraria basaltic lava flow erupted from Pico das Camarinhas forming a delta capped by the brown-weathering conical pseudocrater of the littoral cone (centre). To the right of the cone are the white-painted thermal bath buildings.

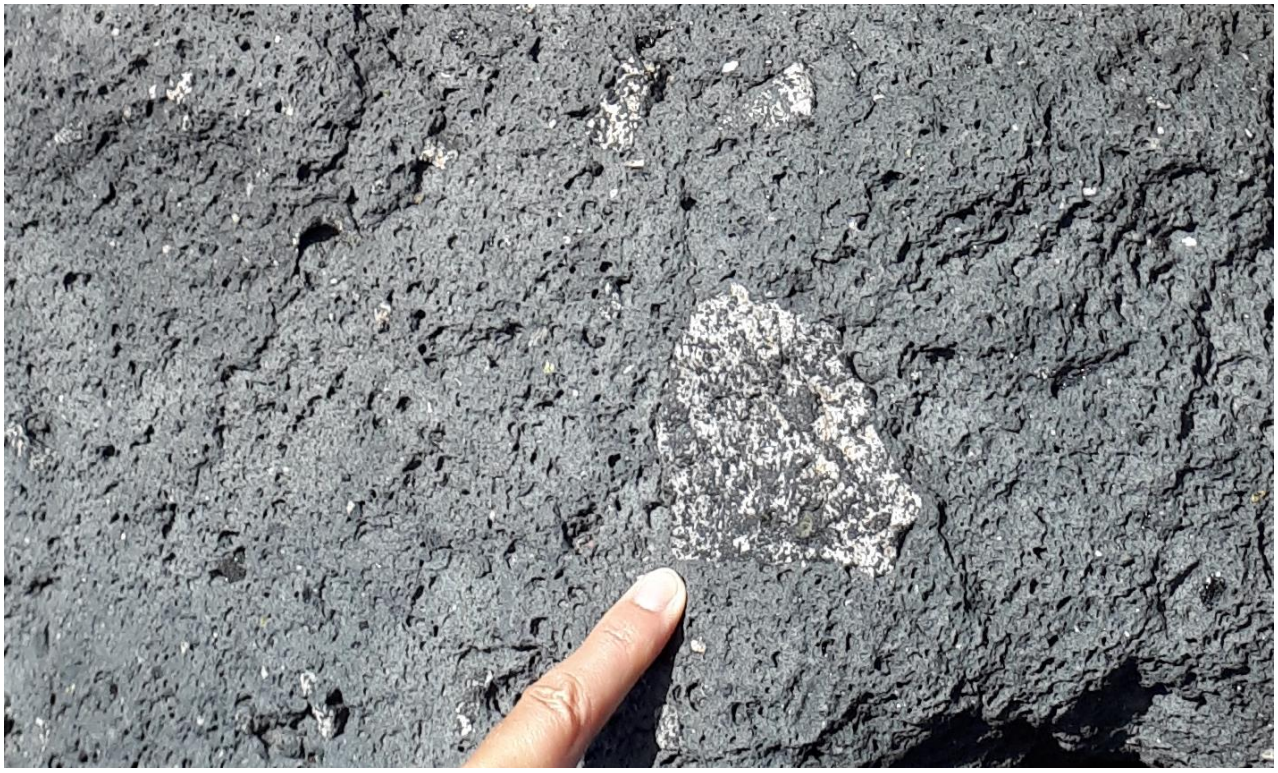
The “Sabrina Island” of this viewpoint does not now exist. It was erupted as a Surtseyan-type vent two km or so off the coastline in June 1811, an eruption witnessed by Captain Tillard, who commanded the British frigate Sabrina. The loose, scoriacious and ephemeral basaltic island was soon lost to wave erosion, disappearing below sea level in October that same year.

Now drive carefully or walk down the steep zig-zag road to the shoreline area where a series of information posts lead you anticlockwise around the exposures. Start by walking northeast, with the fossilised sea cliffs on your right. These cliffs expose a splendid cross-section through eruptive products of the Sete Cidades volcano. Successive eruptions have produced layers of brown weathering trachytic and commonly pumiceous ignimbrite interlayered with darker basalts, some of which show a top reddened by deep weathering and soil formation prior to the next eruption. There are also near-vertical thin basalt dykes that cut through the sequence, exposing the magmatic plumbing system that fed eruptive vents which once lay above.

View north from the fajã basaltic shoreline delta looking towards Ponta do Escalvado. The 840-year old fresh lava in the foreground shows a clinkery top typical of “aa” flows. Behind in the cliff face several thin dykes can be seen cutting vertically through the Sete Cidades volcanic strata which comprise alternating layers of brown trachytic rocks and darker (but sometimes brown/red-weathering) basalt.

Keeping the ocean on your right locate the basalt arch (image below) beyond which is a hot sea bathing area where water emerges with a temperature of over 60°C. From here climb the path back towards the thermal centre (which has a cafe), passing further exposures of xenolithic basalt as well as the famous littoral cone (climbing of which is strictly banned). Drive back up the steep incline to the car park then on for 250m back to the right turn. Here, before turning right, pause to admire the hill to the left, rising from the right side of the road to your left: this is a dome of trachyte. The trachytic magma has followed the same radial fracture as the later Pico das Camarinhas basalt magma, illustrating how the same major fractures can be reutilised through time as conduits for the various magmas being erupted from the main volcanic centre. Return to the main road and continue northwards for a few kms more to pass the turnoff to Sete Cidades and after this reach the Miradouro do Escalvado viewpoint and car park on the left.

Natural arch eroded in the Ponta da Ferraria basalt, which is thought to be around 20m thick (west side of headland looking south). At only 840 years old, this lava flow is geologically very young. In contrast, for example, some of the lavas exposed in the cliffs behind and south of the fajã have yielded an age of around 74,000 years.



Xenoliths such as the one above are sometimes seen in the basalt exposures. Most of them are rich in pale feldspar and probably originally crystallised as plutonic igneous rocks within or adjacent to the magma chamber and plumbing system that fed the Sete Cidades eruptions.

2. Miradouro do Escalvado

The view from here, a former lookout for the whaling industry, offers a panorama of the northwest coast. The cliffs below the lookout expose more of the Sete Cidades volcanic sequence, with its alternating basaltic and trachytic eruptive rocks. Beyond, seen in the image below, is the coastal town of Mosteiros, built between the two main NW-SE trending "graben" faults that run through the Sete Cidades Caldera. One kilometre to the east of Mosteiros (top right below) rises the 361m-high Pico de Mafra volcanic cone, built above one of the great fissures running through the Sete Cidades caldera. The basalts erupted from this post-caldera vent flowed down to the sea to form the Mosteiros lava delta. Like the similar example of the Ponta da Ferraria lavas, all these young, post-caldera basalts are thought to have been erupted from a magma chamber lying around 15km below, at the boundary between crust and mantle (see *Magma Evolution of the Sete Cidades Volcano, São Miguel, Azores* by Beier et al., 2006, in the Journal of Petrology, Vol 47, pp 1375–1411, https://academic.oup.com/petrology/article/47/7/1375/1456666).

View northwest from the Mirador do Escalvado across cliffs exposing the Sete Cidades trachytic/basaltic volcanic sequence to the coastal town of Mosteiros, to the right of which rises the Pico de Mafra basaltic cone. Basalts from the Pico de Mafra flowed down to the coast to form the lava "fajã" delta on which Mosteiros is built.

Drive back southeast a short distance and turn left into the Sete Cidades road which quickly climbs to over 400m asl, passing the Mirador da Lomba do Vasco and the 490m peak of Seara (left) to enter the circular caldera. The Seara peak is thought to have formed around 3,580 years ago by an explosive eruption involving the interaction of hot magma and cold groundwater (known as "hydromagmatic" or "phreatomagmatic" eruptions). Pale layers of explosively eruptive rocks are exposed in road cuts on the left and can be seen sloping gently away from the volcanic caldera centre to the southeast. There are several places from which to enjoy views over the circular caldera, but in this guide we will restrict ourselves to what we consider the best: the Boca do Inferno. To reach this, drive down through verdant scenery inside the volcano to Sete Cidades and cross the crater lakes (blue lake to the left, green lake to the right). The road now climbs, passing viewpoints, firstly over the Lagoa de Santiago (right), then another, the Mirador do Cerrado das Freiras (left) which overlooks the blue and green lakes, to eventually reach a road junction at 600m altitude on the southern side of the caldera.

Here consider making a stop at the popular (and therefore commonly tourist-congested) Visto do Rei viewpoint on the right. Our route however runs left (signposted Pico do Carvão), with the road climbing the southeastern crater wall for another 2-3km to reach a car park on the right opposite a gate on the left. Park here and continue on foot.

3. Lagoa do Canario and Miradouro do Boca do Inferno

Leaving the car, cross the road carefully to pass through the gate and after a short distance take the footpath to the left leading down through forest to the Lagoa do Canário.

The Lagoa do Canária fills a volcanic crater produced by explosive contact between groundwater and hot magma ("phreatomagmatic"). Such craters are known as "maars" and are typically flat-floored and shallow (in this case reported to be only up to 3m deep). Exposures of fragmental layered rocks produced by eruptive debris ("tephra": inset lower right) falling back into the crater can be examined in places along the shoreline. The crater lies just to the southeast of the Sete Cidades caldera rim and directly on one of the two main NW-SE graben faults that run through the volcanic centre.

Return through the forest to the main track, turn left and continue for 500m north to locate the ridge path running out to the Mirador Boca do Inferno which offers a panoramic view over the Sete Cidades Caldera and the opportunity for tourist selfie photos:

View looking northwest over the Sete Cidades caldera from the path leading down to the Mirador Boca do Inferno. In the foreground is the Lago de Santiago crater, formed by an explosive maar eruption that deposited stratified pumice, lapilli and ash layers, and to its left is a similar eruptive centre now occupied by the Lago de Rasa. Behind and to the right is the major vent now filled by the Lago Azul, from which the steep cliffs of the caldera wall rise to a peak of 845m above sea level. This broadly circular outer wall forms the most prominent geomorphological landform and defines the 5km-wide caldera, which is the combined product of a series of three paroxysmal eruptions dated as happening around 36,000, 29,000 and 16,000 years ago. Continued eruptions since this time have shaped the scenery of the caldera interior, producing minor craters (such as Santiago and Rasa above), lava domes, scoria cones and lava flows on the caldera sides, as well as surtseyan eruptions offshore.

The last paroxysmal explosive eruption here took place around 16,000 years ago, enlarging the caldera to its present dimensions. However, the volcanic centre continues to be highly active: over the last 5,000 years alone Sete Cidades has erupted at least 17 times which, when compared to Fogo (10 times) and Furnas (5 times) volcanoes, makes it the most active volcanic caldera centre in the Azores during this recent period.

4. Carvão aqueduct and the Miradouro do Pico do Carvão

Return to your vehicle and continue southeast, stopping on the right after 2km to view the Carvão aqueduct on the left.

View from behind the Carvão aqueduct (left) northwards to a strombolian basaltic scoria cone, one of many that have erupted from fissures that slice through the area between Sete Cidades and Fogo volcanoes. This part of São Miguel is known geologically as the Picos Fissural Volcanic System.

Return to your vehicle and continue less than 1km to park at the Miradouro do Pico do Carvão.

View southeast from the Miradouro do Pico do Carvão across basaltic volcanic cones of the Picos Fissural Volcanic System, which occupy the narrow waist of land between the northern (left) and southern (right) shores to the east of Sete Cidades. The Picos Fissural Volcanic System is geologically very young and most of the more than 200 cones show craters aligned in a northwest-southeast direction (as in the central example above), reflecting the orientation of the fault lines through which they have erupted.

5. Reserva Florestal do Pinhal da Paz and Picos Fissural Volcanic System

Return to your vehicle and continue south for 5km to locate the road leading east towards Serra Gorda which, rising to nearly 500m, is one of the most prominent basaltic peaks in the fissure system. Navigate your way anticlockwise around Serra Gorda, joining the road connecting Ponta Delgada with São Vicente Ferreira before turning east (right) again then south (right) and east (left) to locate the small road on the left which leads to the car park at the Reserva Florestal do Pinhal da Paz. From here walk for 20-30 minutes northeast through beautiful forest tracks: one can spend hours enjoying this park, but make sure you leave before they close the gates as the place is strictly out of bounds after this. Head for the viewpoint on the northern edge of the park, which is reached after a steep climb to the concrete tower-capped summit of one of the local basaltic "picos". The tower may be ugly but the view afforded from the top certainly is not.

The panorama from the tower-top viewpoint in the Reserva Florestal do Pinhal da Paz takes in the narrow central waist of the island, from the southern ocean behind the forested basaltic peak of Cruz (top right) to the wide sweep of northern coast running out to Ribeira Grande (top centre), the second largest settlement on São Miguel and one lying on the northern side of Fogo volcano. In this image the distant land surface in the background rises from Ribeira Grande to nearly 1,000m above sea level at the cloud-capped summit of Fogo. In the centre of the image is the dark forested peak and adjacent village of Pico da Pedra. Behind and to the right of Pico da Pedra (in the ground between Pedra, Cruz and Fogo) is the dark forested peak of Pico da Queimada, site of an eruption in 1563 that sent a lava flow north to the coast at Ribeira Seca, our next location to be visited.

Cruz basaltic vent (right) with Pico da Queimada (left centre) and the northwestern slopes of Fogo volcano rising behind.

6. Ribeira Seca and 1563 basaltic eruption

Return to your vehicle and navigate your way to the main road running northeast towards Ribeira Grande. Just before reaching the coast west of Ribeira Grande, turn right at a roundabout signposted to Ribeira Seca and *fontanario Sec. XVI.* This road leads in 200m to the church of São Pedro, in front of which, by the Fontanario Café, one can view the geohistorical monument of a fountain partially overwhelmed by the 1563 lava flow.

Fluid basaltic lava (pahoehoe-type) erupted in the summer of 1563 and is preserved here flowing around and freezing against the visible remnants of a street fountain in Ribeira Seca. The lava originated from the 375m-high Pico da Queimada (formerly known as Pico do Sapateiro) satellite vent 3.5km to the SSW on the western flank of the huge Fogo stratovolcano. The eruption emerged from a NW-SE oriented fissure cutting through a trachytic dome and left a crater up to 100m wide. That year was dangerous in São Miguel: a few days previously in late June-early July the central vent in Fogo had burst into activity, producing a sub-Plinian eruption accompanied by major earthquakes and much destruction. Today the volcano is dormant, but continued outgassing of CO_2 remains a problem in this area: a short walk east from the fountain (by the Cantinho da Ribeira) runs the Ribeira Seca. This narrow stream passes through a zone in places known to register dangerously high levels of CO_2. Concentrations approaching 15% CO_2, which can lead to death by asphyxiation, have been measured less than 1km upstream from here and are reported to have killed a local farmer.

7. Lagoa do Fogo and 1563 trachytic eruption

Continue driving northeast from São Pedro church for 1km and turn right into the road (signposted Lagoa do Fogo) that climbs southeast from Ribeira Grande up the northern slopes of Fogo volcano. This area shows abundant geothermal activity, with the road initially passing a geothermal power station currently producing around 40% of Sã Miguel's electrical consumption from wells tapping a hot reservoir (240°C) typically at depths of 1-1.5km (see *The role of geothermal in the energy transition in the Azores, Portugal* by António Franco & Carlos Ponte in the European Geologist 2019). The route then climbs past the tourist attraction of Caldeira Velha, where geothermal manifestations at surface include hot pools, to reach the car park (left) just before a viewpoint looking southeast over the Lagoa do Fogo. Park then walk to the viewpoint.

Mirador overlooking the Lagoa do Fogo, a lake that fills the summit caldera of Fogo volcano. This is the largest and currently most dangerous of the three central stratovolcanoes on São Miguel, with significant hazards caused by local CO_2 outgassing and by frequent landslides after heavy rain and/or earthquake activity. The unstable volcanic edifice, which rises to nearly 950m above sea level just 5km from the south coast, poses a constant threat to the 45,000 people who live in the Fogo District. A sub-Plinian eruption occurred here in 1563, followed by a hydromagmatic explosion the next year, covering much of eastern São Miguel in trachytic air fall (tephra) deposits. The only human deaths reported as linked to this eruptive phase were two people overcome by gas when visiting the vent area afterwards. Much larger, fully Plinian, eruptions have emanated from here around 15,000, 10,000 and 5,000 years ago. The elongated shape of the crater lake reveals the northwest-southeast orientation of this volcano, which lies in a zone of downfaulting (a volcanic "graben") running out to the coast at Ribeira Grande. Subsidence within this Ribeira Grande graben is estimated to have been around 650m.

8. Ponta do Cintrão

Drive back towards Ribeira Grande and turn right on the by-pass road signposted to Nordeste and Furnas. In 2km you will reach a crossroads to Caldeiras da Ribeira Grande (right) and Ribeirinha (left). Caldeiras offers an optional visit to another tourist hot pool attraction and the opportunity for local walking in this geothermally active area, although our georoute described here takes us left (northeast) towards Ribeirinha (we will see better geothermal phenomena later in Furnas). In 1km turn right into the village and follow signs to Porto de Santa Iria and Ponta do Cintrão. The narrow road leaves the village and runs northeast, passing the scoria cone of Pico da Vinha which rises to the right. Ignore a right fork to Porto de Santa Iria and follow the road as it climbs around the trachytic dome of Cintrão hill to reach the Miradouro da Vigia das Baleias (also marked on maps as the Miradouro da Ponta do Cintrão)

View west across the Ribeira Grande graben from the Miradouro da Vigia das Baleias towards Ribeira Grande which sits in the middle of this volcanic fault zone running northwest from Fogo volcano. The trachytic dome of the Ponta da Cintrão in the foreground is matched by the distant trachytic dome of Rabo de Peixe in the background and marking the other side of the graben.

A short walk south from the Miradouro there are roadside exposures of layered volcanic rocks that include pale pumiceous airfall deposits, brown palaesols, and a prominent dark welded ignimbrite seen in the image below. Look for a coarse pumiceous layer containing a mixture of pale trachytic pumice fragments and small pieces of darker, more basaltic rock. Intrusion of fresh basaltic magma moving upwards into the trachyte magma chamber beneath a central stratovolcano has been suggested to be the root cause behind major eruptions, with the hotter basaltic magma inducing thermal instability and gas release which flashes out of control and promotes explosive ejection. See: Kueppers et al., 2019 at: https://www.researchgate.net/publication/333419637_Biased_Volcanic_Hazard_Assessment_Due_to_Incomplete_Eruption_Records_on_Ocean_Islands_An_Example_of_Sete_Cidades_Volcano_Azores.

Road-cut exposing volcanic rocks and ancient soils (palaeosols) south of the Miradouro da Vigia das Baleias. The pale ashy layer at the top is underlain by a coarse pumiceous layer that has been compared to the pumiceous lapilli airfall layer resulting from an explosive sub-Plinian eruption of Sete Cidades volcano 16,000 years ago (prevailing wind directions here generally blow volcanic ash plumes eastward).

Close-up of the contact between two units in the Ponta da Cintrão roadside exposure. Note the irregular contact between what is interpreted as a grey welded ignimbrite and an underlying pale airfall/palaeosol deposit. This is considered to be a result of erosive action of the hot pyroclastic flow as it moved over the land surface across immature soils forming on older airfall deposits left by previous eruptions from the trachytic volcanic centres on São Miguel.

9. Miradouro de Santa Iria and the tea estates

Drive back to Riberinha and turn left (east). Just outside the village turn right and continue south to pass underneath the by-pass and turn left into the old main road. This contours picturesquely around the volcanic landforms, a taste of old São Miguel, to reach a viewpoint (left) just west of Pico da Trindade where there are views west to Ribeira Grande. At this point you are situated close to the Falca Fault, which defines the northeast boundary of the Ribeira Grande graben. Lagoa do Fogo lies in the volcanic centre of this graben just 6km to the south.

Continue following the old main road which joins the new by-pass at the Miradouro de Santa Iria (left), the most spectacular and easily accessible viewpoint on the north coast of São Miguel. From here one can enjoy the panorama westwards over the Ponta do Cintrão, and across the Ribeira Grande graben and Picos Fissural Volcanic System to the Sete Cidades volcano. Now continue west on the new main road to make a stop at the Chá Porto Formosa estate for a nice cup of organic tea and view from the garden terrace.

View northwest from the organic tea plantation of the Chá Porto Formosa estate. To the right is the flat-topped (uplifted marine-cut terrace?) Ponta Formosa peninsula whereas in the distance on the coast (top left) is the trachyte dome forming the Ponta Cintrão peninsula.

Continue east along the north coast road to the Gorreana tea plantation which is more touristic but has a car park that is convenient for the PRC28 footpath circular walk to the south (http://trails.visitazores.com/en/trails-azores/sao-miguel/cha-gorreana: from the car park cross the main road carefully and follow the signs, although be sure to do this walk clockwise).

10. Congro Fissural Volcanic System and Lagoa do Congro

Continue <2km along the coast road before bearing right (southeast) towards Furnas. The road climbs to over 400m asl and, in a little over 4km, turn right on to the road signposted to Lagoa do Congro. This road runs southwest through the Congro Fissural Volcanic System (CFVS) which lies between Fogo and Furnas volcanoes.

The scenery of the CFVS is characterised by gently rolling cattle farming countryside lying above 400m asl and punctuated by scoria cones produced by monogenetic strombolian and phreatomagmatic eruptions. The whole area is draped by a mantle of trachytic airfall tephra emanating from the Fogo and Furnas central vents on either side. As with the Picos Fissural Volcanic System on the other side of Fogo volcano, the scoria cones here in the CFVS are distributed along faultlines (which here mostly run WNW-ESE). The road curves south to pass several of these cones, firstly Pico Meirinho (left) then Pico da Quebrada and Pico del Rei (right), before turning southeast again to reach a road on the right signposted to Caldeiras. Turn right here, driving gingerly over the rough road surface for 600m and park on the roadside by a small abandoned house (left) where a track runs left (south) towards Lagoa do Congro. Walk along this track for 10 minutes to locate the path (left) leading down to Lagoa do Congro.

Lagoa do Congro is a maar crater suffering from overhyped tourist descriptions so you are unlikely to be alone as the steep slippery path leads down to the lake 120m below (allow 15minutes each way). The crater here was created by an explosive maar eruption around 3,900 years ago. This area between Furnas and Fogo volcanoes is the most seismically active part of Sao Miguel. Several major earthquakes in this area have triggered catastrophic landslides since the area has been inhabited, the worst so far being in 1522, and swarms of seismic activity are common. In 2005, for example, a bout of seismic shaking produced thousands of mostly minor earthquakes centred on the Congro area, with the strongest being magnitude 4.3, and caused over 250 landslides. The extreme instability of this area makes it, at least for this geologist, an unnerving place to choose to live.

11. Ermida de Nossa Senhora da Paz and Vila Franca do Campo 1522 landslide

To overview the location of the devastating 1522 earthquake, and gain an impression of just how geologically dangerous this part of the island is, drive back to the main road and turn right (south) to reach the coast road. Here turn right (west) towards Vila Franca do Campo. The coastal road becomes a modern by-pass which you exit left at a roundabout on the northeast side of Vila Franca do Campo. Drive towards town but then turn right following signs to Ermida de Nossa Senhora da Paz for a challenging drive up the steep, narrow road leading to the chapel overlooking Vila Franca do Campo and the offshore volcanic cone forming the islet of Vila Franca. The volcanic islet was formed by an explosive surtseyan-type eruption and is now partially eroded, with its circular central crater infilled by seawater. See the website: https://www.azoreswhalewatch.com/saomiguelazores/when-magma-and-water-mix-big-boom/

The modern town of Vila Franca do Campo (>11,000 inhabitants) overviewed from the steep slopes of the Ermida de Nossa Senhora da Paz. A major earthquake struck the southern flanks of Fogo volcano on 22 October 1522, with the epicentre believed to be a few kilometres NNW of Vila Franca do Campo. The town, founded in 1472 and until then the capital of São Miguel, was devastated by building collapse and landslides. The most destructive landslide was generated about 450m asl and created a debris flow that buried much of the town and was strong enough to create a small tsunami that destroyed two boats anchored near the islet of Vila Franca seen above. Several thousand people died as a result of this event, and the site of the island capital was moved to Ponta Delgada.

12. Lagoa das Furnas and 1630 eruption

Return to the coastal highway east of Vila Franca do Campo and drive east to where the road turns north towards Furnas, the third of the three active stratovolcanic calderas in São Miguel. In <2km park in the car park on the right: take a ticket after passing the barrier (if full here continue to the paid parking area on the north side of Lagoa das Furnas and do the walk in reverse). The car park lies on the northern edge of a volcanic vent that produced a sub-Plinian eruption in 1630. This eruption, thought to have travelled up from a magma chamber around 5km below ground, left a trachytic lava dome that today forms a hill rising to 383m asl immediately south of the car park. This eruption caused

considerable damage and nearly 200 fatalities due to volcanic explosions, pyroclastic flows, and building collapse. One of the effects of this and other young eruptions here on the southern margin of the Furnas volcanic centre has been to obscure the main volcanic structure. Thus here in the south, Furnas caldera is much less geomorphologically well defined in the landscape than Fogo or Sete Cidades, although that does not at all mean that it is any less active or dangerous.

From the car park cross the road and walk down the track that leads west along the south side of Lagoa das Furnas to pass the chapel of Nossa Senhora das Vitórias and reach the ticketed entrance to the Jose do Canto gardens. The verdant gardens make for an enjoyable stroll, in one direction to the Salto do Rosal and in the other to the fern garden. The walk to Salto do Rosal curves south clockwise to pass the 1630 trachytic dome across the road on the left and enter the valley that drains east from the Congro Fissural Volcanic System. Leaving the gardens, walk clockwise around the lake to its northern end (passing a café/interpretation centre) where an area of intense geothermal activity focussed close to the caldera wall can be enjoyed from the safety of a boardwalk system.

The geothermal ground at the northern tip of the Lagoa das Furnas produces bubbling mudpools, hot springs and active fumaroles accompanied by abundant volcanic gas emissions of carbon dioxide and radon. The natural heat is used for cooking "cozido das Furnas" in hot steam wells.

13. Pico do Gasper 1439-1443 eruption and Caldeiras geothermal field

Walk back to the car park: this can be done by continuing clockwise around the lake although, given the road traffic, it is more peaceful to return the way you came. Then drive north for 1km up the east side of Lagoa das Furnas and turn right into a narrow road signposted to Lagoa Seca to follow a scenic backroute into Furnas which first runs north, with another trachytic dome forming a hill on the right. This is the Pico do Gasper, which erupted in 1439-43, just after the island had begun to be settled and was witnessed by a priest sent to investigate. Ignore a first turn to the right but take the second one, curving into an easterly direction to follow the north side of the Pico do Gasper and then turn left at a T-junction. The road first runs northeast but then doubles back heading northwest with views to the right over Furnas and the northern caldera wall behind the town. After curving right (northwards), as the road enters the outskirts of Furnas take the first road on the right (east) which leads past a cemetery (left) then curves left (northeast) to a fork where you bear right (east). In 350m fork left (opposite a campsite entrance) and cross a stream to reach a T junction where you turn right. In 500m the road curves left, immediately after which take the road (left) signposted to Ribeira Grande and Caldeiras, the steam rising from which you can see ahead to the left. Drive past the Caldeiras geothermal ground (right) and, as the road curves left, take the road to the left which climbs to a car park from which you can visit the Caldeiras hot springs on foot. This locality also offers the opportunity to sample geothermally cooked corn on the cob:

The geothermal field at Caldeiras lies on the eastern margin of the central crater of Furnas volcano. The steam and abundant CO_2 emissions that characterise this area presumably result from geothermal activity concentrating within heavily fractured rock at this crater margin. Enhanced levels of CO_2 have been measured in many places within the village. View looking southeast across the steaming ground towards the Pico das Caldeiras, an area of trachyte dome intrusion on the southeast side of Furnas volcano.

14. Miradouro do Pico do Ferro

From the car park rejoin the main road, turning left towards the village and after 250m slow down to take the sudden right turn to the Ribeira Grande road which leads north then curves left to start the sinuous climb up the caldera walls. After c.4km turn left into the road signposted Miradouro do Pico do Ferro and drive to the viewpoint car park.

View southeast over the Furnas volcanic caldera from the Miradouro do Pico do Ferro. The lake infills the western side of the caldera, with the trachyte dome produced during the 1630 eruption forming the circular hill on the far side of the water. Another rounded trachyte dome (this one produced in the 1439-1443 eruption) forms the Pico do Gaspar (top centre left), to the left of which lies the town of Furnas situated in the low ground of the central crater. The caldera walls are well developed to the west (right side of image), north (viewpoint) and east (not in image), but are poorly expressed in the south due in part to repeated recent eruptions. Note the geothermal ground alongside the lake immediately below the viewpoint, a hot spot for radon and CO_2 emissions close to the main caldera wall. An explosive sub-Plinian eruption similar to that of 1630 is the most likely future volcanic event in Furnas.

15. Miradouro do Salto do Cavalo

Return to the main road and turn right, back towards Furnas, for 300m and take the left turn signposted Salto do Cavalo. This high road runs along the top of the northern caldera wall, passing a series of basaltic scoria cones on the left then turning east to reach the Miradouro do Salto do Cavalo.

The Miradouro do Salto do Cavalo offers another grand panorama across the Furnas caldera, this time from the northwest side and at a height of 805m asl. The steep northern wall (right) of this caldera is well displayed from this angle and defines the edge of a catastrophic eruption that took place here around 30,000 years ago.

The town of Furnas nestling in the lower ground that marks the central part of the main caldera, with the Lagoa de Furnas beyond. Since the major event forming the outer caldera wall (e.g. behind the lake) 30,000 years ago, the caldera has seen multiple eruptions. For example the dark wooded cliff slopes just to the right of Furnas result from a younger event that took place sometime around 11,000 years ago. Each of the major explosive eruptive events that created the Furnas caldera led to ground subsidence as the overpressured magma below was evacuated explosively, producing lower central ground ringed by curving caldera walls. Such eruptions are typically followed by partial infilling of the volcanic depression by degassed magma rising more passively to form trachytic domes such as Pico do Gaspar on the southern side of the caldera. The end result is a complex of nested depressions overprinted by later volcanic events and all developed over many thousands of years, so that the resulting geomorphology can be far from simple to interpret.

16. Miradouro do Salto da Farihna

Continue following the road from the viewpoint, taking the left fork towards Nordeste (the road to the right here descends to the coast inside an adjacent but older volcanic centre called the Povoação caldera: see the map on page 1) and descend northwards to enter the village of Salga where a refreshment stop may be enjoyed by the church in the Café o Priólo. From here continue north to turn right into the old Nordeste coast road and in a short distance take the road left to Miradouro do Salto da Farihna and park at the end after a steep descent to the coast. Leave the vehicle and, after enjoying the basaltic cliffline views at the coast, walk down the road which descends southeast into the valley and exposes (right) a series of lavas in a continuous roadcut:

Several basaltic lava flows are exposed in the road-cut leading down to the Salto do Farinha coastal valley which has been cut by a stream draining from the north side of the Furnas caldera. The basalts are exposed as cliffs on the opposite side of the valley (image above) but are best observed in the road-cut (left and top). Red palaeosols (lower left) represent time gaps during which the top of the latest flow was subjected to weathering before being covered by the next flow. The basalts typically show a broken, rubbly base overlain by more massive lava, and are commonly vesicular (scoriaceous), with locally intrusive contacts. This sequence probably belongs to a pile of basalts that erupted during the early build-up of the Furnas volcano, similar to Fogo and Sete Cidades volcanoes which both sit upon an older basement of basalt erupted before they became centralised trachytic stratovolcanoes.

17. Parque Natural da Ribeira dos Caldeirões

Return to the main road and continue east (left) to meet the coastal by-pass just south of Achadina. Here stay on the old coast road, which weaves its way around the stream system that drains the north side of the Povoação caldera to reach the Parque Natural da Ribeira dos Caldeirões. This tourist location offers walks upstream to a waterfall, and extensive exposures of basaltic rocks in the parkland area downstream, where there are particularly good examples of spheroidal weathering and porphyritic textures.

Exposures of basaltic rocks in the Parque Natural da Ribeira dos Caldeirões include fine examples of perfectly shaped ("euhedral") black pyroxene crystals (right). This "porphyritic" texture, characterised by large crystals embedded in a finer matrix, is produced when minerals begin to crystallise deep in the magma chamber but their growth is interrupted by magma movement towards the surface which leads to rapid cooling and freezing of the magma around the earlier grown crystals.

18. Ponta do Arnel and Nordeste

Continue along the road to join the main northern by-pass which slashes across deeply river-dissected scenery via a series of bridges, such as that crossing the valley of the Ribeira Despe-te Que Suas just east of Algarvia. These valleys are dangerously susceptible to large debris flow events that are testimony to the more advanced state of erosion that characterises the northeast corner of the island. We are now crossing the inactive Nordeste Volcanic System, the oldest of all the volcanic strata found on the island, and the landscape is correspondingly more deeply eroded.

Drive through Nordeste and, a short distance south, park at or near the small parking area on the left overlooking the Ponta do Arnel lighthouse, from where there are fine views over the fault-controlled coastline and the ocean beyond.

Ocean view from the car park overlooking the Ponta do Arnel peninsula capped by a lighthouse (right) which contrasts with the sharp, straight cliffline running northwards to Nordeste (left). In this part of the island the coastal scenery clearly reflects the position of a steep fault running NNW-SSE and which defines the cliffline morphology. The cliff exposes "Lower Basalts" of the Nordeste Volcanic System. In contrast, the Ponta do Arnel headland protrudes eastwards into the ocean due to the fact that basaltic lava younger than the Lower Basalts has cascaded over the cliff faultline and built a small delta oceanward.

19. Agua Retorta, Faial da Terra, Povoação and Ribeira Quente

Return to Furnas on the slow but scenic southern route via Povoação. The route passes the village of Pedreira and the unstable coastline to the south, cut into the Lower Basalts and known for destructive rock avalanches. At Agua Retorta the road turns inland, heading westwards parallel to a major WNW-ESE structure called the Tronqueira Fault, which creates a prominent scarp that defines the southern edge of the Sierra da Tronqueira. Make a stop in Faial da Terra, where the instability of this treacherous and fault-controlled coastline is demonstrated by frequent rockfalls. Here we are in the transitional area between the Nordeste Volcanic System and the Povoação caldera, the semi-circular trachytic, ignimbritic slopes of which are deeply dissected by a stream system converging on the coastal town of Povoação.

Finally, turn left just before Furnas, heading south towards the coast for a stop in Ribeira Quente. This village has the dubious distinction of being considered as one of the most geologically hazardous places in the Azores. Apart from being located so close to Furnas volcano, the area is especially prone to rainfall-induced landslides, as demonstrated by a catastrophic event that occurred here on October 31 1997. Heavy rain falling on already saturated and slippery volcanic soils resulted in a series of landslides which moved blocks up to 3m in size, damaging road, bridges and houses and killing 29 people. In recent years progress has been made in researching and understanding these geological threats to life and property on São Miguel, and awareness has been raised in the general population. Everyone needs to understand that it is not a question of whether volcanic eruptions, earthquakes and landslides will hit the island again, but why, when and where.

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http://barcelonatimetraveller.com/

Background to Holiday Geology Guides

The author and geologist Wes Gibbons has always had an interest in writing short geoguides aimed at inquisitive tourists, offering them the opportunity to learn about the landscapes and rocks of scenically attractive places. His argument is that there is so much more to know about rocks and Earth history than the superficial descriptions offered by tourist guidebooks, which rarely even scratch the surface of Deep Time.

His first attempt in this direction produced *The Rocks of Sark* (1975), published jointly with John Renouf of Manche Technical Supplies in Jersey, a venture that taught a youthful Wes to always be the one responsible for the final proof reading. In 1976 Wes moved from Sark to begin a PhD supervised by Greg Power (Portsmouth University) and Tony Reedman (British Geological Survey). Living in a former Post Office in the village of Greatham on the Hampshire-West Sussex border, Wes decided to pass his spare time preparing a guide to the geology of the Weald in southeast England. He sold the idea to the publishers Allen and Unwin who commissioned other authors to develop a mini-series: *The Weald* (1981), *Snowdonia* (1981), *Lake District* (1982), and *Peak District* (1982).

His next field-based guidebook surfaced in 1985, fruit of several years research work in Corsica (*Corsican Geology: a field guidebook* by Gibbons and Horák). Two years later Wes launched the Holiday Geology series, using a simple, inexpensive format later described as “a single A3 laminated sheet …. folded into three and (with).. six portrait panels … filled with a lively mix of colour photos, maps, sections and text” (review by Nigel Woodcock in Geological Magazine, 2000). The first two Holiday Geology guides were *Scenery and Geology around Beer and Seaton* (1987) and *Rocks and Fossils around Lyme Regis* (1988). The Holiday Geology concept attracted the attention of the British Geological Survey who went on to expand the series to over 20 titles.

Following his retirement in 2004 to live in Barcelona with Teresa Moreno, Wes maintained his interest in publishing field guides by writing the text to *Field Excursion from Central Chile to the Atacama Desert* (Gibbons and Moreno 2007), *The Geology of Barcelona: an Urban Excursion Guide* (Gibbons and Moreno 2012), and *Field Geotraverse, Geoparks and Geomuseums* (in central and southwest Japan: Gibbons, Moreno and Kojima 2016). His most recent publishing project, the most ambitious so far aimed at a general readership, has produced the book *Barcelona Time Traveller: Twelve Tales* (2016, Spanish translation 2017: Bimón Press Barcelona) and the resurgence of the Holiday Geology concept, although this time in virtual format linked to the *Barcelona Time Traveller* webpage.