

EXCURSION GUIDE FOR FIELD TRIP V1 *ISLAND OF SAO MIGUEL*

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1. TECTONIC AND GEOLOGICAL SETTING

The archipelago of the Azores (Portuguese spelling « Açores ») consists of nine islands situated between lat. 37° and 40° N and long. 25° and 31° W, in the area where the E-W Alpine fracture zone meets the mid-Atlantic ridge (MAR). Their main regional trend, oblique to the MAR, is approximately WNW-ESE. These two main fracture zones and related transform faults seem to control the fundamental structural features of the Azores islands and, in general, of the Azores plateau, for which two main tectonic models have been proposed, depending on the assumed position of the central rift with respect to the islands :

- (1) The rift is supposed to go across the archipelago, splitting into two branches, one of which leaves Flores and Corvo towards the West and the other passing through some of the other islands (Krause and Watkins, 1970).

- (2) According to the second model (Machado, Quintino and Monteiro, 1972), the ridge is split into short segments, each of them corresponding to one of the islands, except for Santa Maria, Flores and Corvo, i.e., each of the former islands was formed according to the ocean floor spreading model.

Many fracture zones can be traced in the islands from the alignment of volcanic cones and other morphological features, and beyond the islands through bathymetric expression in the area of the plateau. The positions of the recorded submarine eruptions also fit into the linear tectonic trend of the region.

As in other volcanic areas, radial and ring structures are common and mostly control the evolution of the central volcano.

For the mid-Atlantic islands, the Azores show the highest seismicity in historic times, which fits in the tectonic models proposed for the archipelago, as the islands are connected one to another by ridge-to-ridge transform faults.

Some of the tectonically active fractures have been confirmed or detected from the study of earthquakes, but a reliable tectonic model of the Azorean region certainly requires an adequate net of seismographic stations in the islands, which does not yet exist.

Variations of sea level have been reported in most of the islands and confirmed at least in Santa Maria, where fossiliferous calcareous rocks of marine origin outcrop at 90 metres a.s.l. These variations have been ascribed to eustatic fluctuations but it is not clear that this is the only cause.

Landforms of the islands are dominated by the main volcanoes and a swarm of cinder cones that surround the central volcanic formation.

Petrology. The Azores islands are formed by volcanic rocks, mostly basalts, with some minor sedimentary deposits. The volcanics range from alkali-basalts to highly differentiated rocks of rhyolitic affinities. Santa Maria, São Jorge, Pico and

Corvo are entirely basaltic, but more evolved terms, mainly trachytes, occur in the others. Oversaturated rocks, such as pantellerites and comendites, are found in Terceira and San Miguel. The low $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (1 to 1.5) places the Azores in a petrological potassic province such as the Atlantic islands Gough, Tristan and Jean Mayen, (Schmincke & Weibel, 1972).

The alkaline trend is dominant in the Azores but a parallel line of tholeiitic affinity is also suggested from interpretation of analytical data (Assunção and Canilho, 1970). A gap for the intermediate volcanics is referred to by the same authors but it is not clear that a bimodal distribution can be considered for the rocks of the Azores before additional data are available.

The strongly alkaline character in Terceira and São Miguel is an exception for islands so close to the mid-Atlantic ridge, as has been already emphasized (Ridley, Watkins and MacFarlane, 1974).

In the geological maps of the Azores, andesites are common in all the islands but this classification has been later revised (Assunção and Canilho, 1970) and such intermediate rocks, more alkaline and undersaturated than calc-alkaline intermediate volcanics, have been considered as alkaline basalts (mugearites and hawaiites).

2. GEOLOGICAL SUMMARY OF S. MIGUEL

S. Miguel, the largest islands of the archipelago (757 km²), consists of four volcanoes with summit calderas, from W toward E: Sete Cidades, Água de Pau, Furnas and Povoação. The range formed by the latter three volcanoes rises to the height of 1105 meters (in Pico da Vara) and trends approximately E-W, but the massif of Sete Cidades, separated from the eastern area by a low narrow zone — «Região dos Picos» — formed by recent basalts, is oriented according to the regional

trend, i.e., approximately WSW-ESE. That Sete Cidades trend is controlled by fracture alignment is supported by the linear positions of the recorded submarine eruptions, parallel to the SW coast of the island.

From field relationship and some available radiometric data, it is possible to establish the following eruptive sequence (Zbyszewski, 1974) : Nordeste basalt complex (4 m.y.), trachytes of Povoação, Furnas and Água de Pau, with intercalations of basaltic eruptions, basalts of Sete Cidades and Picos, and the historic recorded eruptions which were trachytic (explosive) and basaltic (effusive).

The basaltic basement of S. Miguel — lavas and pyroclasts — are mostly covered by trachyte material, mainly from explosive eruptions related to the formation of the summit calderas. The basalts, uncovered by erosion, outcrop along the bottom of the streams and also on the coastal cliffs around the island. In exploratory drillholes for geothermal energy, basaltic material of subaerial eruptions was traced as far as 700 m below sea level. Young basalts occupy the saddle-like area of Picos, between the massifs of Água de Pau and Sete Cidades. This area coincides with the rift segment that, according to the tectonic models, comes across the island.

Ignimbrites (welded ash flow tuffs) occur in two main zones, related to Água de Pau and Povoação volcanoes.

These rocks, that have been referred by Schmincke & Weibel (1972) are being mapped at present and will be seen during the trips.

Between the Água de Pau and Furnas massifs, there occurs a remarkable maar — Lagoa do Congro — and adjacent to it, but at a different level, a smaller one — Lagoa dos Nenúfares — which seems to be the result of phreomagmatic activity.

3. VOLCANIC ACTIVITY

The following eruptions have been recorded in historical times, that is, since the settlement of S. Miguel, in the 15th century :

- 1444. On the first voyage to S. Miguel, after the discovery of the island, a great abundance of floating ejecta was reported along the coast of S. Miguel, but their origin is uncertain.
- 1563. Lagoa do Fogo (Água de Pau volcano). A huge plinian eruption of the central volcano was followed by an effusive basalt eruption of Pico do Queimado in the northwest slope of the massif, which buried part of the Ribeira Seca village.
- 1630. Plinian eruption of Pico do Gaspar, a secondary volcano inside Furnas Caldera. This eruption, of which there are reports from different sources, apparently the most harmful known in the Azores, caused much damage and many casualties. It corresponds to the last trachytic activity of S. Miguel. The ash falls reached considerable distance.
- 1638. Submarine eruption a few miles west of S. Miguel. Different reports apparently coincide with respect to the description of the eruption : explosions with columns of water and abundant ejecta of variable sizes, from ash to big blocks, and the formation of a small islet that disappeared within a few days.
- 1652. Pico do Fogo, situated about 3 km NW of Lagoa town. As mentioned in the 5th stop of the excursion.

sions, the last eruption in S. Miguel was in Pico do Fogo, forming a basalt cinder cone.

- 1682. Submarine eruption a few miles from the island, farther away than the eruption of 1638. It is reported as an explosive eruption, with abundant pumice, that covered a large area in the sea around the focus.
- 1811. Submarine volcano with formation of Sabrina islet which reached the length of 2000 meters and the height of 90 meters above sea level, after two phases of volcanic activity, mostly explosive, separated by three months of quietude. The new-born islet was soon destroyed by the action of waves.

4. EXCURSION ROUTES

The excursions are planned as follows : —

— 1st day

1st stop: — Rosto de Cão. Palagonite tuff cone partly partly destroyed by marine erosion.

2nd stop: — Basaltic lava flow. There is a sand beach adjacent to the basalt outcrop.

3rd stop: — Basaltic lava flow. There is a sand beach abundant coarse elements, including large size bombs. A white or light coloured rock is common as angulose inclusions in the basaltic pyroclasts.

4th stop: — Caloura. Low basalt platform built up by lavas that reached the sea. Trachytes

outcrop along the base of the cliff. Caloura is a favourable zone for vineyards and is known for the red wine produced in the area.

5th stop: — Pico do Fogo. The last volcanic activity in S. Miguel was the explosive eruption in Pico do Fogo in 1652, which is formed by a basalt cinder cone 318 meters a.s.l.

— 2nd day

6th stop: — Ponta das Calhetas (Fenais da Luz). Along the coastal cliff there are good exposures of horizontal basalt flows with columnar jointing, underlying horizontal beds of pumice and other pyroclasts. Sea caves and blowhole caused by marine erosion.

7th stop: — Capelas. Thick section of palagonitic tuffs well exposed along the road cut to Capelas harbour, with occasional «bomb sag» features. Different aspects of typical marine erosion in tuffaceous formations.

8th stop: — Bretanha. In the road cut, close to Pico Vermelho, basalt dyke intrusive in pyroclast deposits.

9th stop: — Road cut on the way to Mosteiros. Alternating beds of basaltic lava flows.

10th stop: — Mosteiros, at the harbour. Fine grain ash deposit with plant fossils.

11th stop: — Mosteiros (Piscinas). Low basalt platform formed by lavas erupted from Pico de Mafra (360 m a.s.l.) that flowed down the cliff and reached the sea. This is an

olivine-rich basalt with coarse olivine phenocrysts. Pot-holes and partially eroded lava tunnels (the «piscinas» = swimming pools) are prominent features of marine erosion.

12th stop: — Pumice quarry in production, in the SE flank of Sete Cidades, about 1 km from the outer rim of the caldera.

13th stop: — Vista do Rei (King's View), on the outer rim of Sete Cidades caldera from where one can see the double lake on the bottom (Lagoa Verde and Lagoa Azul) surrounded by steep walls. Sete Cidades is a composite volcanic edifice with a summit caldera, 5 km wide. Inside the caldera there are five secondary craters which seem to be controlled by a ring structure. A considerable thickness of pumice covering the mountain shows how much material had erupted before the collapse that formed the caldera.

14th stop: — On the way down toward the village, one can see from the road the Lagoa Escura, a small lake on the bottom of one of the secondary craters of Sete Cidades, with almost vertical walls.

— 3rd day

At the village Água de Pau there is a good section in the road cut, of the same basalt cinder as the 3rd stop, with large size bombs, overlying pumice deposits. Between the village and 15th stop, there is, on the

northern side of the road, a well exposed section of a sequence of unconformable pumice beds.

15th stop: — Pumice quarry.

16th stop: — View from the main road to Caloura coastal platform.

17th stop: — Pisões. Outcrop of ash-flow tuff (ignimbrite) underlying pumice beds.

Between stop 17 and stop 18 the road runs parallel to the shore along the base of a cliff formed by pyroclasts, mainly pumice and fine grain yellowish brown tuffs with occasional inclusions of syenite (natrosanidine). Close to the base of the section, lens-shaped beds of rounded pebbles and boulders, badly sorted, outcrop in several places. They are considered as uplifted beach deposits (Zbyszewski et al., 1959).

18th stop: — Ribeira da Praia. Ash-flow tuffs (ignimbrites) outcrop in the road cut, intercalated in other pyroclasts, mainly pumice. They belong to a larger formation of ignimbrites which are cut through by the valley of Ribeira da Praia. They are dark coloured ignimbrites, the same type of rock that was largely used in many of the ancient buildings, including churches, in the area of Ponta Delgada (Hotel São Pedro building for example) and towards the east of the town as far as Vila Franca do Campo and beyond.

Between stops 18 and 19, the road cuts across ash deposits at Água de Alto village,

exploited for making concrete blocks for building purposes.

At Vila Franca you can see the volcanic cone that forms the Vila Franca Islet, 500 metres off the shore.

- 19th stop: — Lagoa do Congro. This is a typical explosion crater (maar) 300 to 400 meters wide, with almost vertical walls of olivine-rich basalt, surrounding the lake on the bottom. There is, adjacent to Congro, a smaller water-filled crater of the same type (Lagoa dos Nenúfares). The Congo crater is situated between the calderas of Furnas and Água de Pau, in the middle of a thick forest (the crater will be observed from the top because of the difficulty of access to the bottom).
- 20th stop: — Lagoa das Furnas. The lake, with a field of fumaroles near the shore line, occupies a depression inside Furnas caldera and is considered by some geologists as a primitive caldera itself (Zbyszewski, 1961).
- 21st stop: — Furnas. This is a composite volcano with a central caldera with a remarkable field of solfataras and hot springs scattered around, the most important in the Azores. There are several adventice cones inside the caldera, in one of which — Pico Gaspar — there occurred in 1630 a violent explosion that caused great damage and many casualties.
- 22nd stop: — Lomba do Cavaleiro. A general view of Povoação caldera can be observed from here.

23rd stop: — Povoação. Trachytes and two main different types of ignimbrites outcrop around Povoação village in the bottom of the caldera and on the cliff along the sea shore. They are: (1) ignimbrites with abundant fiamme in a dark matrix, and (2) ignimbrites with minor fiamme in a light coloured matrix. The latter are well exposed in a quarry where the rock is used as building material.

The Povoação volcano is supposed to be extinct. The caldera, open toward the sea, is deeply eroded by a fan-like net of streams that converge in a main stream before entering the sea, near the town. Return from Povoação to Furnas.

24th stop: — Pico do Ferro. Small trachyte cone on the NE edge of Furnas caldera. There is a general view from here over the whole caldera, including Pico do Gaspar (referred to in the 21st stop) as well as other secondary volcanic cones of Furnas volcano.

— 4th day

Along the route, from Lagoa town up to the 25th stop, on the way to Lagoa do Fogo, well exposed beds of pumice and other pyroclasts can be observed, sometimes separated by horizons of ancient soil rich in carbonaceous material.

25th stop: — Basalt cinder cone with abundant bombs and blocks (which is being used as road building material). Pumice deposits, with

inclusions of syenite, are resting on the basaltic pyroclasts. The occurrence of syenite inclusions in pumice can be seen in several places along the road and seems rather common, especially in the southern flank of Água de Pau mountain.

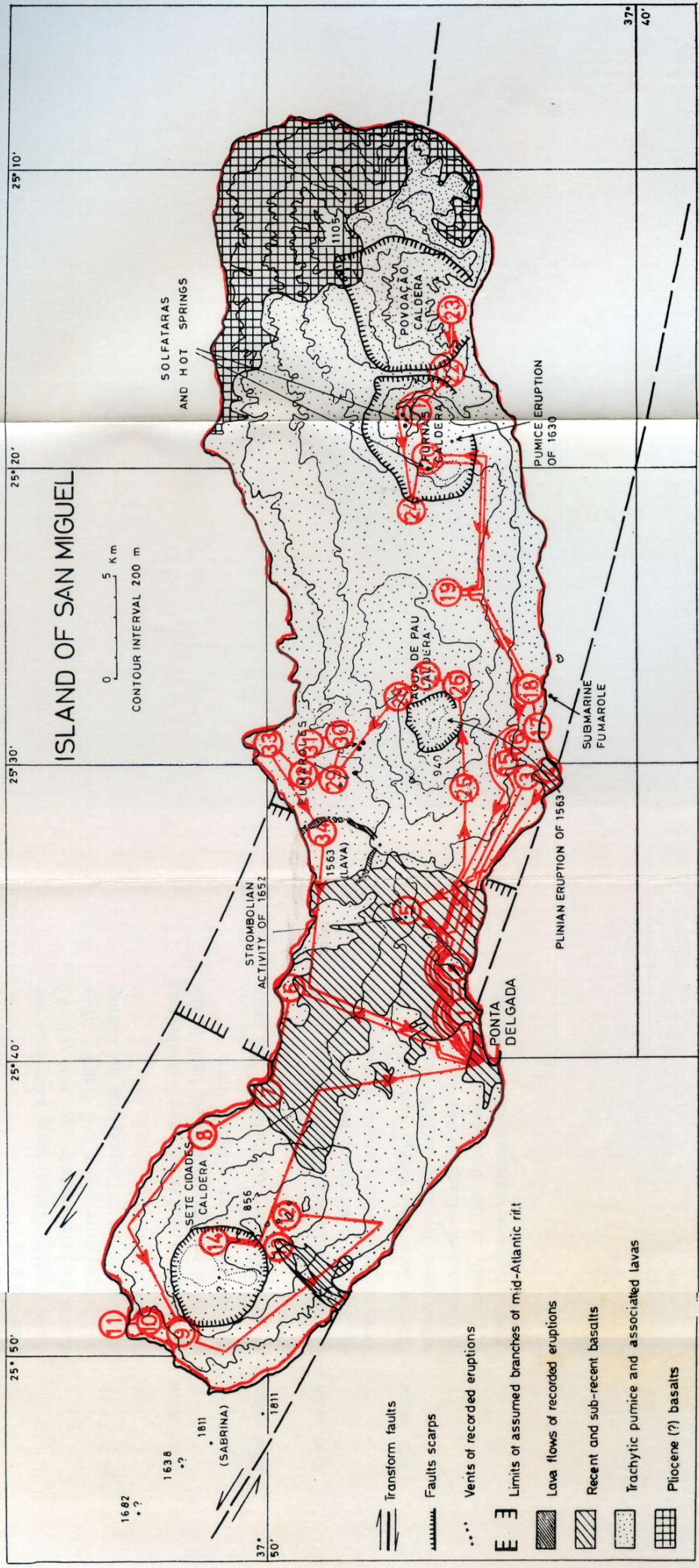
26th stop: — Outcrop of trachyte in the road cut, not far from the top of the mountain. Pumice deposits with inclusions of syenite and also with inclusions of carbonaceous material outcrop near the place.

Between this and the next stop one can see along the route a general scenery over the western side of the mountain, and peculiar erosion features, such as deep cut gullies in the pyroclast deposits.

27th stop: — The highest point of the road that crosses the mountain, close to the top, (949 metres a.s.l.) Pico da Barrosa, where the TV antenna is mounted. There one can observe the typical morphology at the headwaters of the regional drainage.

28th stop: — Going down the road toward Ribeira Grande there is a complete and beautiful view of Lagoa do Fogo (Fire Lake), where a huge plinian eruption occurred in 1563.

29th stop: — Caldeira Velha. Solfatara in the bottom of a deep V valey in the middle of a thick forest. The water's pH = 3.0 and its temperature 90°C (194°F). Because of another solfatara, situated upstream, the flowing water is warm and seems to carry sulphur in suspension.



30th stop: — Caldeiras da Ribeira Grande. These solfataras are located in the bed of a small stream on the northern slope of Água de Pau volcano.

As in Caldeira Velha, these solfataras are also of the acid sulphate type, with pH=3.0 and temperature about 70°C (158°F). They are the second in importance to Furnas in the Azores.

31st stop: — Exploratory drillholes for geothermal energy in two different sites, both in the vicinity of Ribeira Grande town.

32nd stop: — Other exploratory drillholes in the same area.

33rd stop: — Ponta de Santa Iria. This is a place on the top of a cliff from where one has an ample view of the northern coast of the island.

34th stop: — Ribeira Seca. This village was built on the basalt lava flow that, in 1652, buried part of the ancient village of the same name. A fountain of the previous village, unburied by recent excavations, is exposed.

5. SELECTED LITERATURE

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