EXCURSION
GUIDES
FOR THE FIELD TRIPS

EXCURSION GUIDE FOR FIELD TRIP V1
ISLAND OF SAO MIGUEL

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1. TECTONIC AND GEOLOGICAL SETTING

The ahchipelago 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 Alpide 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 Na_2O/K_2O 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 tholeitic 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 calk-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 km^2), 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 alignement 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 ahe 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 buy 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, aparently 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 colums 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 excur-

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 phenochrysts. 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 (natrosanidinite). 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.
Betweend 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 o 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) ignimrbites 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 moutain. 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 ebautiful 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.

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EXCURSION GUIDE FOR FIELD TRIP V2
ISLAND OF TERCEIRA

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1. INTRODUCTION

The island of Terceira is 406 km^2 in area and rises to 1021 metres above sea level. It consists of four strato-volcanoes grouped along a prominent fissure zone (Fig. 1). Two volcanoes, Pico Alto and Santa Barbara, are active and the other two, Guilherme Moniz and Cinquo Picos, are believed to be extinct. The fissure zone may be the sub-aerial expression of the Terceira Rift, regarded by Krause and Watkins (1970) as a secondary spreading centre.

Terceira shows a great diversity of lavas and pyroclastics for an oceanic island and is noteworthy for voluminous production of peralkaline salic magma. Of the four volcanoes forming the island; three are composed of both basic and salic rocks and one has only salic rocks exposed. Since the emergence of the island a compositionally bimodal population of rocks has been represented.

The products of over 100 eruptions in the upper Terceira Group have been recognized. These include ignimbrites, pumice fall deposits, salic lava extrusions, strombolian scoria deposits, basaltic lava flows and littoral (surtseyan) basaltic tuffs. Basaltic activity is concentrated along the fissure zone which bisects the island diagonally from NW to SE. Volumetric studies

give the rate of accumulation of new crust along this small spreading centre; 5.46 km^3 of new material has been erupted on the island in the past 23,000 years, of which over 4 km^3 is comendite-pantellerite composition.

The island's economy is dominated by agriculture and dairy farming. Much of the water for the maintown of Angra do Heroísmo (approximately 20,000 population) comes from underground springs or streams in the lava tubes of a 2000-year-old basalt in Guilherme Moniz Caldera. The island has a good system of roads. Almost the entire population lives around a 5 km wide coastal strip (Fig. 2).

2. ERUPTIVE CENTRES

Cinquo Picos, the oldest volcano (Fig. 1), forms the eastern part of the island and is an eroded caldera 7 km in diameter,

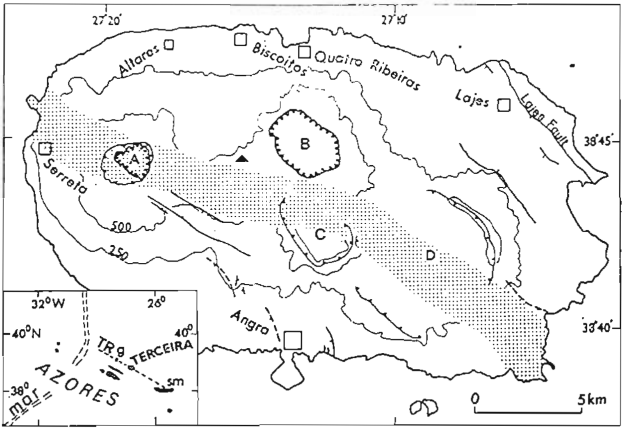

Fig. 1 — Map of Terceira showing fissure zone (stippled). A - Santa Barbara Volcano ; B - Pico Alto Volcano ; C and D old calderas of Guilherme Moniz and Cinquo Picos volcanoes. Faults shown by lines, towns as open sequares. Contours at 250 and 500 m (Δ is site of 1761 hawaiite eruption). Inset are Azores, Mid-Atlantic rift (mar) and Terceira rift (TR), after Krause and Watkins (1970) ; g is Graciosa and sm is São Miguel.

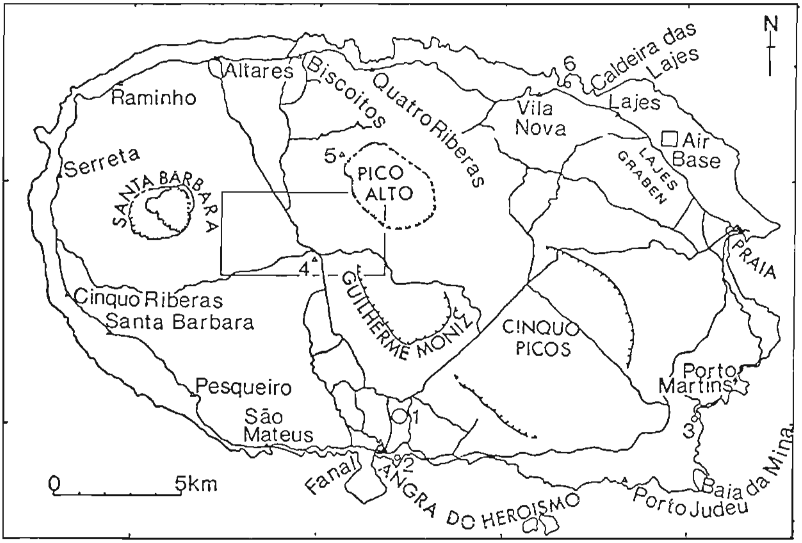

Fig. 2 — Locality map of Terceira. Towns are shown as triangles. Numbered localities are : 1. Vale do Linhares, 2. Castelinho, 3. Salgueiras, 4. Pico da Bagacinha, 5. Pico de Pardelas, 6. Porto do Vila Nova.

the largest in the Azores. Mugearitic lavas are most common with some mildly undersaturated, peralkaline lavas exposed on the flanks. Caldera formation was probably accompanied by exposive salic eruptions as there are erosion remnants of pumice-fall deposits and ignimbrite sheets. The caldera is now floored with young basalts from the fissure zone.

Guilherme Moniz Volcano shows comenditic trachyte lavas in the caldera walls and on its southern flanks. The northern flank is covered by the more recent lava domes of Pico Alto Volcano. Comenditic ignimbrite exposed near Angra do Heroísmo perhaps came from Guilherme Moniz, and old hawaiite lavas associated with this volcano are exposed on the S. coast.

Pico Alto Volcano is built on the northern flanks of Guilherme Moniz. No basic rocks at all are exposed. The youngest eruptions were c 1,000 eyars B.P. The volcano has produced at least three ignimbrites of comenditic trachyte composition as well as pantellerite lavas with associated pyroclastic-fall deposits. The oldest rocks on Pico Alto may be $<$ 100,000 years old.

Santa Barbara Volcano is composed mainly of feldsparphyric to aphyric mugearites and hawaiites, capped by olivine hawaiites erupted just prior to the first caldera collapse about 25,000 years B.P. (Self, 1974). Later, comendite lavas and pyroclastic-fall deposits were erupted.

The basaltic fissure zone (Fig. 1) is marked by a line of scoria cones and associated lava flows across the central part of the island and across Cinquo Picos Caldera. The NW part has been most active during the past 50,000 years and previous activity was mainly from the central and SE portion of the zone.

3. GEOLOGICAL HISTORY

The SE part of the island contains the oldest rocks, those associated with Cinquo Picos caldera and the older end of the fissure zone (Fig. 1). This older sequence has been described by Rosenbaum (1974). Elsewhere the exposed rocks are generally of the latest episode of Quaternary activity.

The base of this most recent volcanic group, called the Upper Terceira Group (UTG), is marked by two extensive ignimbrites, the Lajes and Angra Ignimbrites (about 20,000 and 23,000 years old respectively), which together cover a large part of the island and provide a convenient stratigraphic reference horizon. The UTG consists of the products of 116 separate eruptions, including the ignimbrites and pumice fall deposits, lava flows and domes, and various monogenetic, basaltic volcanic forms such as scoria cones, tuff rings and spatter rings.

The products of the various eruptions since the Lajes Ignimbrite are shown on Fig. 3.

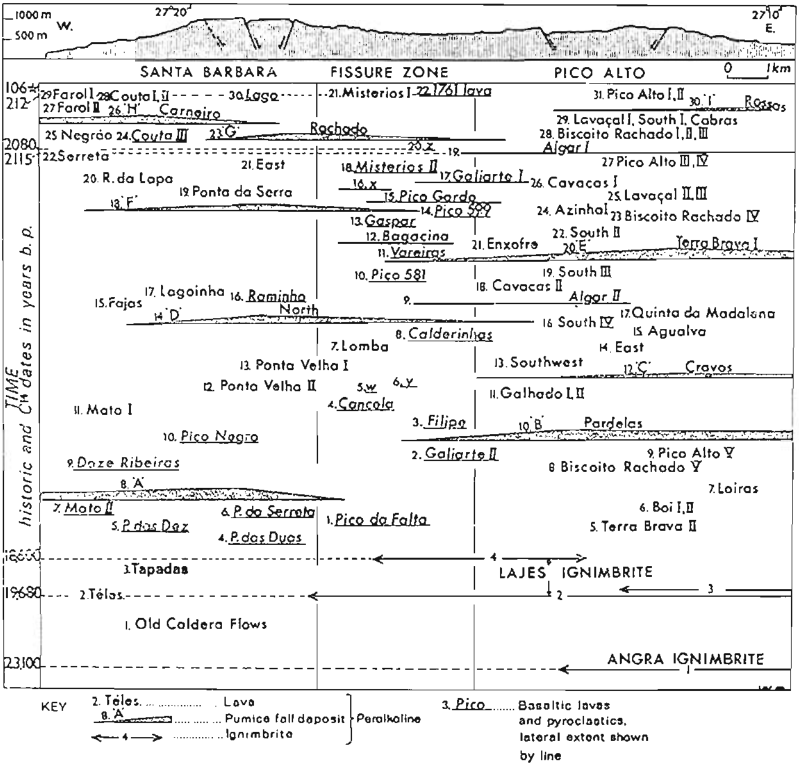

Fig. 3 — Chart showing the volcanic history and formations of the upper Terceira Group. Formations erupted from the three active centres are numbered stratigraphically in three separate sequences and the spatial relations of the formations are also shown. The stratigraphy was interpreted using the 9 main pumice deposits and selected scoria deposits as marker horizons. Formations containing pumice fall deposits are named after the most prominent feature (lava flow or scoria cone). At top : E-W section through the three centres, faults mark calderas. Vertical time scale is arbitrary between dated horizons. Star marks offshore eruption in 1867. Possible age range for Lajes Ignimbrite shown by vertical arrows.

4. PETROGRAPHY AND GEOCHEMISTRY

The petrography of the main rock types is summarized on Table 1 (after Self and Gunn 1976).

The lavas and pyroclastic rocks of Terceira range in composition from porphyritic olivine-augite alkali basalts through hawaiites, mugearites, benmoreites to comenditic trachytes and pantellerites. Hawaiite and comendite are by far the most voluminous types erupted during the recent history of the island. The basic rocks fall into the alkali olivine basalt suite, although some are of «transitional» type (Fig. 4). Geochemically there are two basaltic series: 1) undersaturated, found in lavas of Cinquo Picos and in some recent fissure zone basalts; 2) saturated, found in the younger basalt lavas.

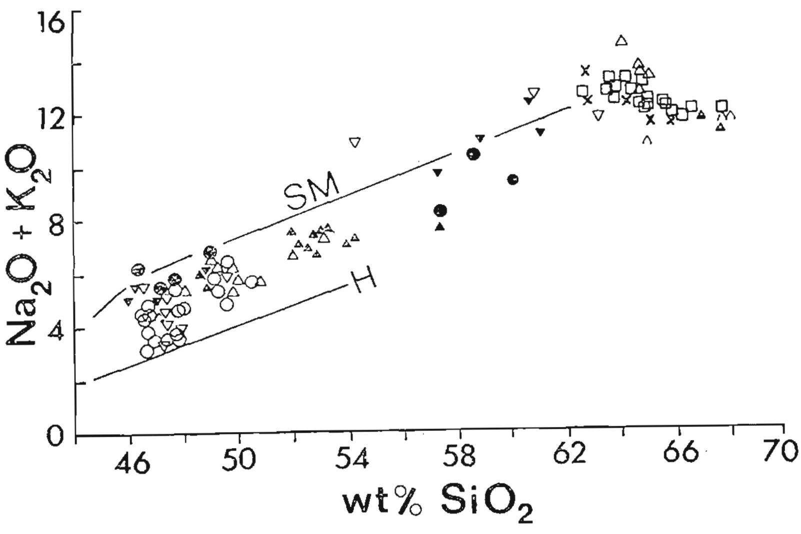

Fig. 4 — Alkali/Silica diagram for Terceira rocks from Self and Gunn (1976). Two other trends shown are H, Hawaiian alkali/tholeiite divider and SM, São Miguel rocks (Schmincke, 1973).

EXCURSIONS

Day 1. 10th August : Sunday.

THEME : IGNIMBRITES OF TERCEIRA

There are at least 6 comenditic ignimbrites on Terceira. The two youngest are the Lajes (19,000 y BP) and the Angra (23,000 y BP), (Fig. 5). The extent of the ignimbrites is shown in Fig. 5 (after Self, 1976). Although the Terceira ignimbrites

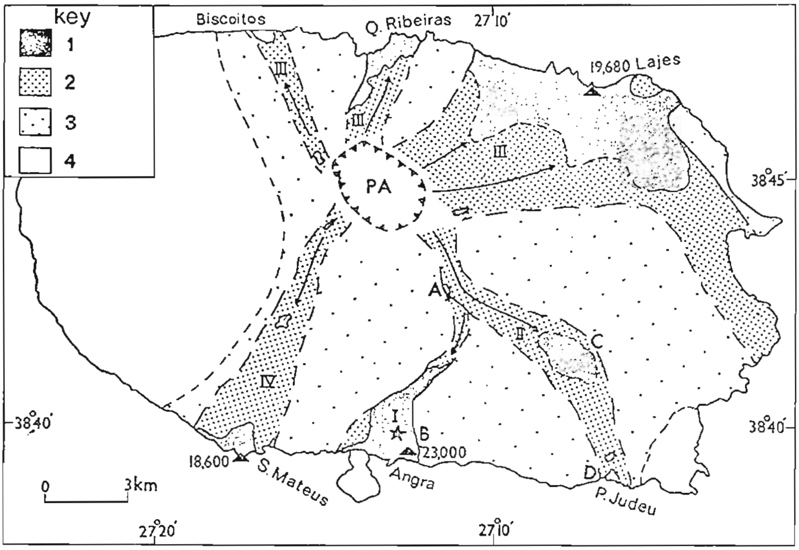

Fig. 5 — Map of the Lajes and Angra Ignimbrites (after Self, 1976). Key : 1) outcrop of thick ignimbrites ; 2) area covered by thin ignimbrite and/or ground surge beds ; 3) co-ignimbrite ash fall deposit ; 4) areas which have no recorded deposits of this eruptive sequence. I is the main outcrop of the Angra Ignimbrite. II-IV are the main outcrops of the Lajes Ignimbrite. Triangles mark the sites of C^{14} datable carbon. PA is Pico Alto Caldera. Arrows mark the main routes used by the pyroclastic flows. The map does not show any volcanics younger than the ignimbrites.

show internal grading corresponding to the eruption sequence of Sparks et al. (1973) (see Figure 6), they do not have underlying pumice fall deposits and the ignimbrite eruption may not be followed by dome extrusion.

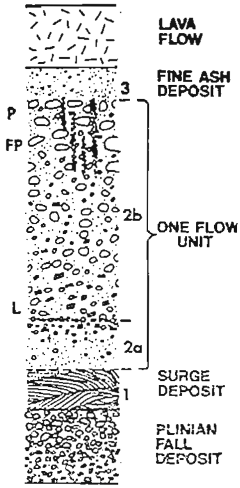

Fig. 6 — Schematic diagram showing the deposits of an ignimbrite-producing eruption episode. P - pumice concentration zone. L - lithic concentration zone. FP - fossil fumarole pipes. Deposits of fine co-ignimbrite ash (3) occur above the flow unit. Modified from Sparks and others, 1973.

9:30 am. Arrive at Lajes Airport, Terceira from São Miguel.

Stop 1. Lajes Ignimbrite and older ignimbrites on coast near Lajes (Caldeira das Lajes). 2000 year old basaltic lava flow.

Stop 2. Lajes Ignimbrites : unusual clast grading due to uphill flow near Vila Nova.

Stop 3. Lajes and four older ignimbrites in cliff section at Porto da Vila Nova. (Lunch stop). Return to Lajes

and Praia de Vitória. Brief stop to look at Lajes Fault Scarp. Cross island by main road.

Stop 4. Lajes Ignimbrite, proximal facies. Quarry in 2,000 year-old hawaiite lava where it flows out from Guilherme Moniz caldera, exposes underlying ignimbrites where they are thin but welded. (Locality A, Fig. 5). Subplinian pumice fall deposits B and E from Pico Alto Volcano.

Stop 5. Angra Ignimbrite ; Vale das Linhares Quarrys ; non-welded Angra Ignimbrite ; a benmoritic ignimbrite ; comendite lava flows.

Stop 6. São Mateus : Lajes Ignimbrite : distal facies ; here the ignimbrite flowed across a basalt lava delta and into the sea.

Stop 7. Pre-23,000 year ignimbrites in the cliff section at Angra Harbour and the Castelinho (Fig. 7).

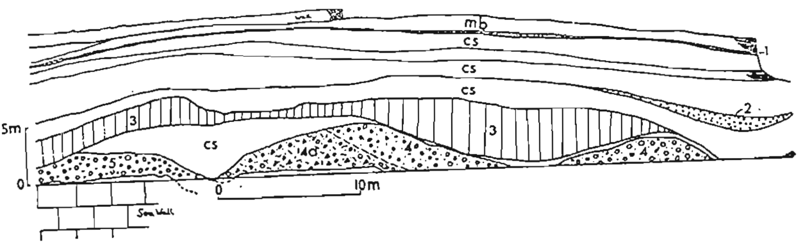

Fig. 7 — The section at Angra Harbour. 1. Angra Ignimbrite. 2. « Basaltic » Ignimbrite. 3. Fanal Ignimbrite. 4. Castelinho Ignimbrite. 4a. Mudflow in 4. 5. Porto das Pipas Ignimbrite. mb = Monte Brasil tuff. cs = condensed ash-fall sequence.

End of day.

Day 2. 11th August: Monday.

THEME: BIMODAL VOLCANISM ON THE TERCEIRA RIFT: BASALTIC AND PERALKALINE ROCKS

8:00 am, or earlier (for reasons of good visibilitay), leave Angra for drive to Cimo de Santa Bárbara (lookout at top of Santa Bárbara volcano), via São Mateus, Pesquiero, Santa Bárbara, Cinquo Riberas.

Stop 1. Santa Bárbara Caldera: overlook of double caldera filled with comendite domes (Fig. 8a).
Source of pumice fall deposits C, D and F.

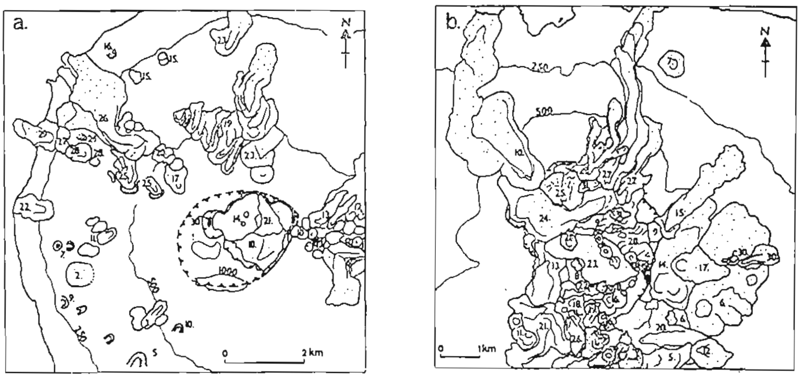

Fig. 8 — Peralkaline lavas of a) Santa Barbara and b) Pico Alto. New calderas: black triangles; old calderas: open triangles. Adventive basalt scoria cones: close stipple. Contours at 250 and 500 m. Numbers correspond to Fig. 3.

Stop 2. Serreta: pantellerite-comendite domes and coulées: thick sub-plinian pumice fall deposit (H): youngest explosive silicic volcanism on Terceira.

Stop 3. Proceed around coast road to Biscoitos (lunch): young alkali olivine basalt lava flow delta; thin

ignimbrite; comendite lava flows of Pico de Pardelas dome.

Stop 4. The Terceira Rift on land: Pico de Bagacina — Biscoitos Negros region. Wild upland region across which we will walk for most of afternoon: features to be seen are:

1761 Scoria cones and hawaiite flows; youngest on-land eruption.
Scoria cones and deposits; young comendite pumice fall deposits.
Biscoitos Negros: pantellerite domes, probably only 500 years old.
Benmorite and mugearite lava flows.
Gaping fissures.
Spatter ring (Pico de Gaspar) and ramparts.

Finish at Pico da Bagacina; excellent section through scoria cone.
Return to Angra do Heroísmo.

End of day.

There is a possibility of an evening trip for small numbers of people interested in investigating the basalt lava tubes in the 2000 year old Algar do Carvão flow at Cabrita (Guilherme Moniz caldera).

Day 3. 12th August: Tuesday.

THEME: CALDERAS

Depart Angra at 9 am. Drive to Pico de Bagacina and proceed East through young pantellerite flows from Pico Alto Caldera. Depending on weather, stop 5 may be visited first.

Stop 1. Furnas do Enxofre. Geothermal prospect? Pantellerite domes of Pico Alto.

Stop 2. Rim of Guilherme Moniz Caldera. Drive across Guilherme Moniz caldera floor.

Stop 3. Algar do Carvão scoria cone and lava flow. This 2000 year old hawaiite is one of the longest lava flows on the island, reaching both the N and S coasts. Fig. 9 shows some of the larger basaltic lava flows from the fissure zone.

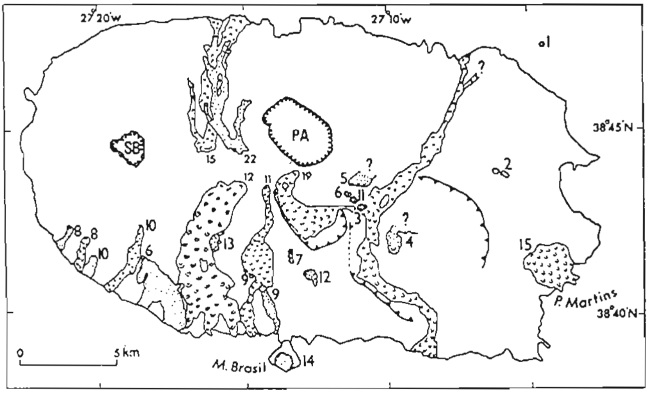

Fig. 9 — Map showing largest fissure zone basalt lava flows (small numbers, see Fig. 3) and 15 post-23,000 year basaltic cones and flows (large numbers, 1-15 are oldest to youngest). Calderas as in Fig. 1.

Stop 4. Cinquo Picos volcano: outlook on caldera rim: old mugearitic lava flows. (Campo do Golfo: lunch).

Stop 5. Pico Alto Caldera, via access road from Bagacina — Biscoitos Road. Pico de Pardelas comendite dome and coulée. Vale do Azinhal: caldera rim. View over caldera-fill domes and flows. Thick pumice fall deposit «B» (Refer to Fig. 8b).

Return to Angra.

End of day.

Day 4. 13th August: Wednesday.

THEME: OFFSHORE ERUPTIONS

am — Monte Brazil tuff ring in Angra do Heroísmo. Examine base surge deposits in outer wall of tuff ring. Tuff ring deposits and crater; compound lava flows and surtseyan tuffs at Fanal, west of Angra.

pm — Free afternoon. Short excursions involving smaller groups may be possible; *or* trip to SE Terceira — older basaltic lava flows and scoria deposits.
Young lava flow at Salgueiros with cognate xenoliths.

Day 5. 14th August: Thursday.

Free day at Angra (effects of great earthquake of Jan. 1st., 1980).

End of Field Trip.

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TABLE 1

PETROGRAPHY AND MINERALOGY OF TERCEIRA

Rock types	Analysed samples	*Major Phenocryst Phases	*Accessory and Groundmass phases	Texture, special features	Eruptive centre Morphology of products	Stratigraphic position
Common types						Young fissure events in
Alkali Olivine Basalt	T0045, 10050, T0059	Plagioclase An 55-65, olivine Fo 65-80), clinopyroxene (augite)	Plagioclase (An 45-60), augite, olivine (rare), magnetite and ilmenite microphenocrysts, apatite.	Phenocryst % varies from 10% — 50% + (picritic) in different flows. Olivine & plagioclase equally important. Variation in groundmass from micro-crystalline to glassy in different flows, mostly undersaturated.	Fissure zone. Cinquo Picos Volcano. Scattered adventive cones & flows. —— Cindercones & thin lava flows, some of great lenght. Off-shore tuff rings.	centre of island. Adventives of various ages. Late Cinquo Picos lavas (but early in island's history).
Hawaiite	T0079, T0056, T0066	Plagioclase An 45-55, clinopyroxene (augite), olivine (as above) magnetite.	Plagioclase (An 40-50), augite, olivine magnetite and ilmenite microphenocrysts.	Generally low phenocryst contents, 5-15%. Often very vesicular. Some aphyric types. Feldspar dominant in groundmass. High % Fe-oxide microcrysts, up to 5%; includes some prominent «big feldspar basalts».	Santa Barbara Volcano, central vent & adventive cones. Fissure zone. Cinquo Picos Volcano. ? Base of G. Moniz Volcano. —— Cindercones & thin flows.	Early pile of Cinquo Picos, therefore some of oldest rocks on Terceira. Later adventives. Early pile of Santa Barbara. Old SE part of fissure & young fissure events in centre of island.
Mugearite	T0047, T0055, T0057, T0087, T0068, T0073, T0072	Plagioclase An 25-40, (some anorthoclase), resorbed olivine and sugite.	Plagioclase, Fe-oxide microphenocrysts, glass.	Includes some «big feldspar basalts»; mostly aphyric types. Highly vesicular, «trachytic» texture of feldspar phenocrysts & groundmass laths. Cinquo Picos types undersaturated.	Cinquo Picos (pre-caldera?). Santa Barbara - central vent & adventive cones. Fissure zone between Santa Barbara & Pico Alto volcanoes. —— Thin flows with associated cinder cones.	Early Cinquo Picos Volcano, early Santa Barbara Volcano, young fissure zone lavas.
Comenditic Trachyte to Pantellerite	T0049, T0051, T0084, T0075, T2068, S0196, T0082, T0052	Anorthoclase, Ab65	Occasional relict olivine, augite, biotite, hedenbergite, aenigmatite, amphibole (arfvedsonite). Fe-oxide microphenocrysts. (Hematite & magnetite as occasional phenocrysts). Cryptocrystaline & glassy groundmass more common but microcrystalline occurs.	Glomeroporphyritic texture common in lavas & pyroclastics. Amost all are porphyritic. Dominance of anorthoclase as phenocryst phase (up to 15% rock). Variation in crystalline state of groundmass. Microperthite feldspar. Devitrification even in young lavas.	Calderas & flanks of three volcanoes. —— Thick coulées, domes, pyroclastic fall deposits & ignimbrites.	Ail ages, including late-stage of Santa Barbara, G. Moniz Volcano, Pico Alto Volcano.
Minor types						
Benmoreites	T0086, S0086, T2067	If present are plagioclase An 20-30	Feldspar, (Plagioclase An 18-22). Fe-oxide microphenocrysts. Remnant pyroxenes.	Mainly aphyric, cryptocrystalline, often dark-coloured lava. (2 types: 1. Undersaturated (Cinquo Picos), 2. Oversaturated, (younger Santa Barbara lavas and fissure zone).	Santa Barbara, fissure zone, Cinquo Picos Volcano. —— Dyke exposures, caldera wall exposures, small thint flows (very small volume).	Early island lavas (undersaturated) in scanty Cinquo Picos exposures. 2 fissure zone flows exposed by small faults. 1 flow at base of Santa Barbara caldera wall.
Undersaturated trachytes	T0041	Plagioclase (An 15-20). Anorthoclase	Feldspar, mainly plagioclase. Cryptocrystalline amphibole in groundmass (aenigmatite?)	Feldsparphyric, light grey lavas. «Trachytic» texture of feldspar laths. Slightly peralkaline in some flows.	Flank of Cinquo Picos Volcano. —— Thick flows, some vesicular.	Limited to oldest volcano, Cinquo Picos.
Xenoliths						
1) Gabbro		Plagioclase (An 65-75), pyroxene (augite), olivine, Fe-oxide.	Apatite, Ti-amphibole	Equigranular and holocrystalline. Ophitic augite/plagioclase. Often highly oxidised.	Basaltic flows. Vulcanian air-fall deposit «A» on Santa Barbara Volcano.	Mostly young eruptions but not confined to any one centre.
2) Syenite		Feldspar (anorthoclase and albitic plagioclase)	Feldspar, aenigmatite-amphibole, minor biotite. Fe-oxide, quartz.	Porphyritic holocrystalline, shows two stages of oxidation.	Ignimbrites from Pico Alto and ? other volcanoes. Vulcanian deposit «A»	In old and young ignimbrite.

EXCURSION GUIDE FOR FIELD TRIP V3
ISLANS OF FAYAL AND PICO

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1. INTRODUCTION

The Azores are situated at the intersection of the mid-Atlantic ridge with the Azores-Gibraltar fracture belt which is part of the Alpine orogenic chain. At this triple junction converge the so-called American, Eurasian, and African plates.

On 6 of the islands there are 9 active volcanoes: the number of independent submarine vents is unknown, but 4 had recorded eruptions since the 15th century.

Seismicity of the islands is considerable, which certainly results from plate movement. According to one of the tectonic models proposed for the area, the mid-Atlantic rift could cross all the islands with active volcanoes (Fayal, Pico, San Jorge, Graciosa, Terceira and San Miguel). Expansion along the rift would be accompanied by shear at the associated transform faults, this shear being responsible for most of the frequent earthquake swarms.

The present tectonic situation is further complicated by the effect of the Alpine movements, which also seem to produce

crustal expansion to the west of a no-strain point at longitude 22° West.

Another tectonic model assumes simply that the mid-Atlantic rift is situated between Fayal and Flores, and is intersected by a minor rift and spreading centre (the Terceira rift) that merges into the Azores-Gibraltar fracture zone.

2. GEOLOGICAL SUMMARY

Fayal is a central volcano with a summit caldera. The older lavas are mostly basalts ; the lava flows produced gentle slopes where adventive eruptions formed small basaltic cinder cones ; exceptionally there are two trachyte domes.

In Recent times explosive trachytic activity produced important pumice fall deposits (and some pumice flows) ; this pumice covers now most of the island. Following the big explosions, the summit of the mountain collapsed, forming the caldera which is about 2 km wide and 500 m deep.

Very recently, basaltic activity has resumed and formed the lava fields and cinder cones of the west ridge, which are not covered by the pumice layers of the central explosions.

Pico volcano is a tall basaltic cone (2351 m high) which accumulated at the western end of a previous linear volcanic ridge. The new central vent formed first a shield volcano and then a big central cone whose steep slopes suggest that the corresponding material is mostly basaltic cinder. In many places, however, the cinder has been covered afterwards by basaltic flows from the main vent.

The western two thirds of the island form thus a conspicuous lava field of Recent age. There are many small cinder cones on the primitive lava shield, as well as along the eastern ridge.

Branches of the mid-Atlantic rift are supposed to exist at the west part of Fayal and at the central part of Pico. These two branches are connected by a transform fault (or fault system) which has exhibited considerable seismic activity. The remarkable grabens of the east slope of Fayal are probably associated with this complex fault. Another transform fault seems to run westwards along the south coast of Pico Island.

3. VOLCANIC ACTIVITY

Since the settlement of Fayal and Pico in the 15th century, the following eruptions have been recorded:

— 1562, effusive activity on the east ridge of Pico, with basaltic lava flows to the north coast.

— 1672, basaltic eruption on the west part of Fayal; lava flows reached the north and south coast of the young lava field.

— 1718, basaltic eruptions on the north and south slopes of th main cone of Pico, with important lava flows, especially to the north coast.

— 1720, activity on the east ridge of Pico with basaltic lava flows to the south coast.

— 1957, basaltic eruption off the west end of Fayal (Capelinhos), starting as strong intermitent submarine explosions, and changing in 1958 to an effusive eruption with many short lava flows; a spatter cone developed inside the cinder and ash ring of the previous explosions.

4. EXCURSION ROUTES

The excursions are planned as follows: —

Fayal Island (1st day)

1st stop: — Flamengos. Pumice and ash flows from the big explosive phase of Fayal volcano; the material is being excavated for use in road works.

2nd stop: — Largo Jaime Melo. View on the graben of the actual active transform fault.

3rd stop: — Caldeira. Sumit caldera formed by subsidence, which followed the pumice eruptions of Fayal volcano; during the 1958 effusive phase of Capelinhos eruption, a minor explosion and fumarolic activity were recorded at the bottom of the caldera.

4th stop: — Cedros. Pumice deposits produced by the central vent Plinian explosions and Péléan type pumice flows of Fayal volcano.

5th stop: — Ribeirinha. Oldest lavas of Fayal (probably Pleistocene).

6th stop: — Espalamaca. Actual active transform fault separating the African and American plates; grabens associated with the fault system; view of San Jorge and Pico (including the disrupted Madalena rocks).

Pico Island (2nd day)

7th stop: — Santa Luzia. Lava flows of the 1718 eruption and sea erosion on young flows.

8th stop: — Santo António. Olivine basalt flows with large phenocrysts ; scarps of the eastern volcanic ridge.

9th stop: — Lages. Limit of branch of the mid-Atlantic rift ; lavas of Pleistocene age.

10th stop: — Mato da Silveida. Lavas of the 1720 eruption and transition to older lavas.

11th stop: — Bocas de Fogo : Empty vents (funnels) of the 1718 eruption ; close view of the steep central cone.

12th stop: — Frei Matias Caves. Interior of pahoehoe lava flow with basaltic stalactites.

13th stop: — Madalena. Active transform fault ; islets corresponding to previous palagonite ring cut by the sliding of the fault.

Fayal Island (3rd day)

14th stop: — Castelo Branco. Trachyte dome ; pumice fall deposits of the Plinian eruptions of Fayal volcano.

15th stop: — Arieiro. Lava flows of the 1672 eruption ; fissure marked by line of cinder cones along the western ridge.

16th stop: — Capelinhos. Spatter cone inside cinder and ash ring, both formed during the 1957-58 eruption ; palagonite tuffs in old cliff line.

17th stop: — Fajã. Recent lavas with olivine nodules ; possible scarp of mid-Atlantic rift.

18th stop: — Praia do Norte. Fractures of the strong earthquakes of 1958; houses rebuilt after the seismic catastrophe.

19th stop: — Varadouro. Thermal springs ; lava of the 1672 eruption and cliff cut on the main cone.

20th stop: — Lomba. Flamengos valley with young cinder cones ; graben of active transform fault.

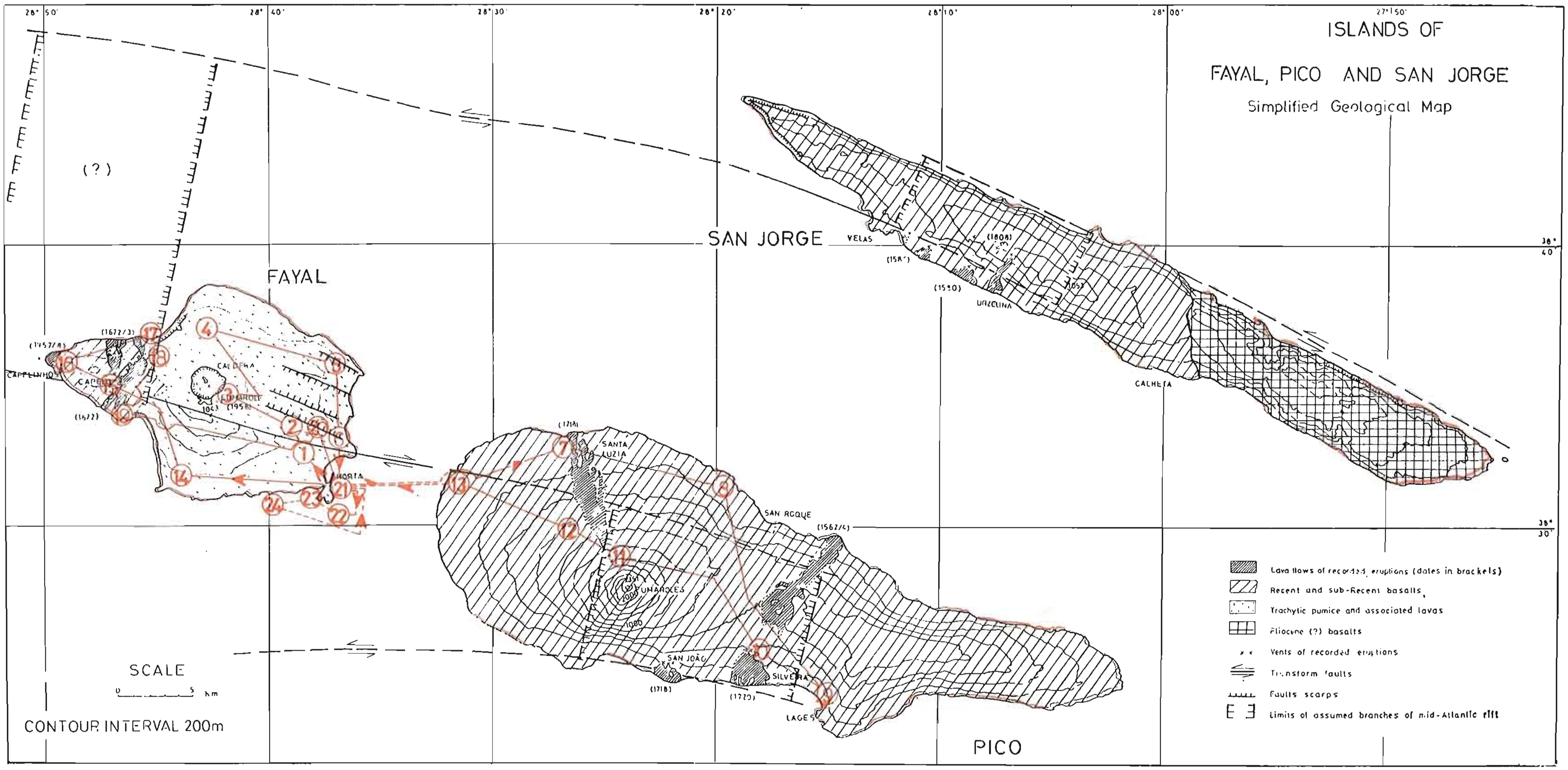
21st stop: — Monte da Guia. Palagonite tuff cone with double crater ; south slope of main volcano.

Fayal sea trip (4th day)

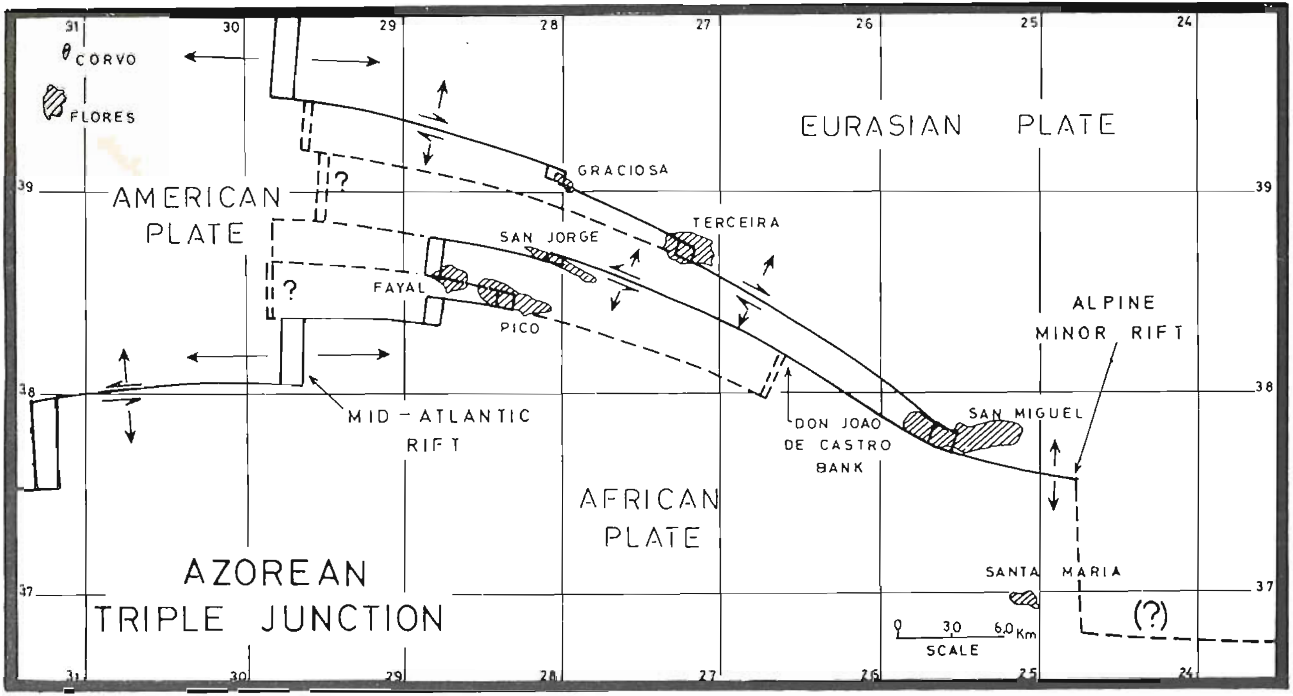
22nd stop: — Monte da Guia. Double crater of palagonite tuff cone.

23rd stop: — Porto Pim. Young lava flows and sand isthmus of Monte da Guia (used as a beach).

24th stop: — Feteira. Sea caves made by wave erosion under young lava flows.



ISLANDS OF
FAYAL, PICO AND SAN JORGE
Simplified Geological Map
28° 50'
28° 40'
28° 30'
28° 20'
28° 10'
28° 00'
27° 50'
38° 40'
38° 30'
(?)
SAN JORGE
VELAS
(1580)
(1808)
URZELINA
CALHETA
FAYAL
CALDEIRA
CAPELINHO
HORTA
(1672)
SANTA LUZIA
SAN ROQUE
(1562/4)
(1718)
SAN JOÃO
(1720)
SILVEIRA
LAGES
PICO
SCALE
0 5 km
CONTOUR INTERVAL 200m
Lava flows of recorded eruptions (dates in brackets)
Recent and sub-Recent basalts
Trachytic pumice and associated lavas
Pliocene (?) basalts
Vents of recorded eruptions
Transform faults
Faults scarps
Limits of assumed branches of mid-Atlantic rift



EURASIAN PLATE
AMERICAN PLATE
AFRICAN PLATE
AZOREAN TRIPLE JUNCTION
CORVO
FLORES
GRACIOSA
TERCEIRA
SAN JORGE
FAYAL
PICO
SAN MIGUEL
SANTA MARIA
DON JOAO DE CASTRO BANK
MID - ATLANTIC RIFT
ALPINE MINOR RIFT
(?)
0 30 60 Km
SCALE
31
30
29
28
27
26
25
24
39
38
37

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