EXCURSION GUIDE FOR FIELD TRIP V2
ISLAND OF TERCEIRA

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1. INTRODUCTION

The island of Terceira is 406 km² 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 km³ of new material has been erupted on the island in the past 23,000 years, of which over 4 km³ 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,

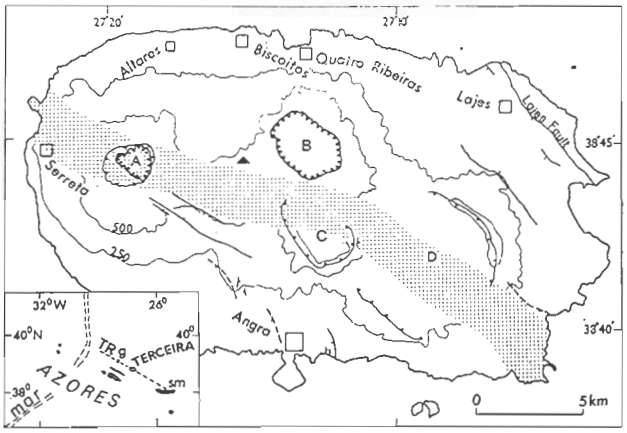

Fig. 1 — Map of Terceira showing fissure zone (stippled). A - Santa Barbara Volcano; B - Pico Alto Volcano; C and D old calderas of Guilherme Moniz and Cinquo Picos volcanoes. Faults shown by lines, towns as open sequares. Contours at 250 and 500 m (Δ is site of 1761 hawaiite eruption). Inset are Azores,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

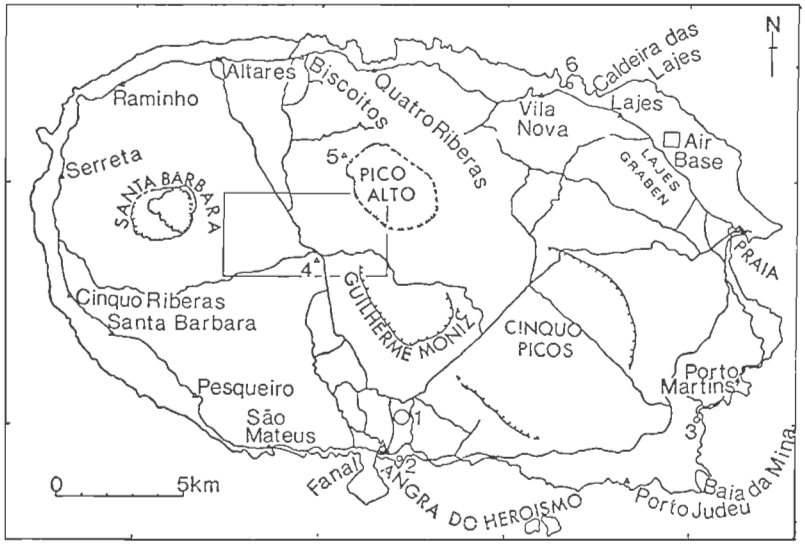

Fig. 2 — Locality map of Terceira. Towns are shown as triangles. Numbered localities are : 1. Vale do Linhares, 2. Castelinho, 3. Salgueiras, 4. Pico da Bagacinha, 5. Pico de Pardelas, 6. Porto do Vila Nova.

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.

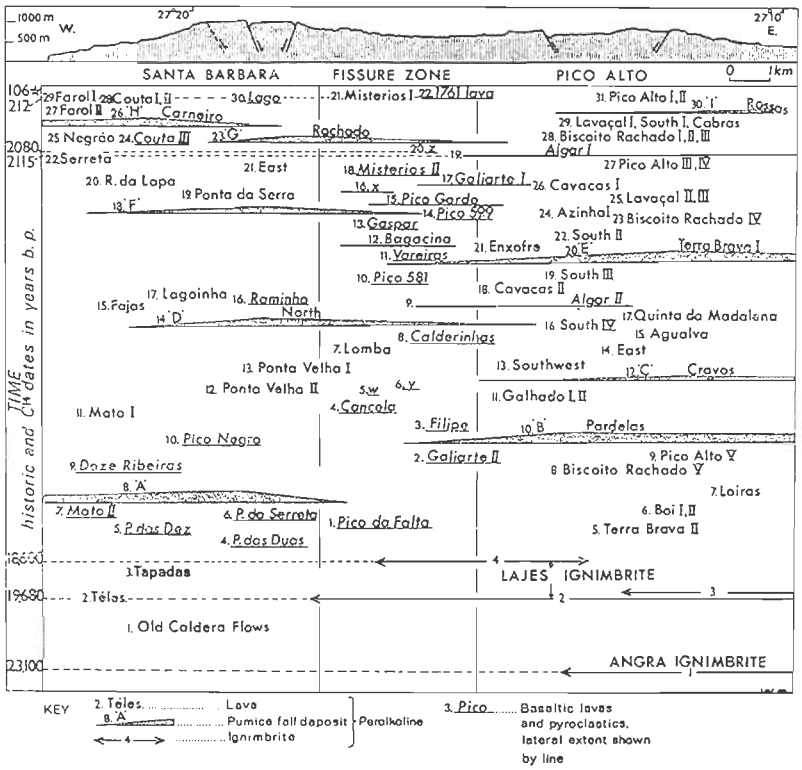

Fig. 3 — Chart showing the volcanic history and formations of the upper Terceira Group. Formations erupted from the three active centres are numbered stratigraphically in three separate sequences and the spatial relations of the formations are also shown. The stratigraphy was interpreted using the 9 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.

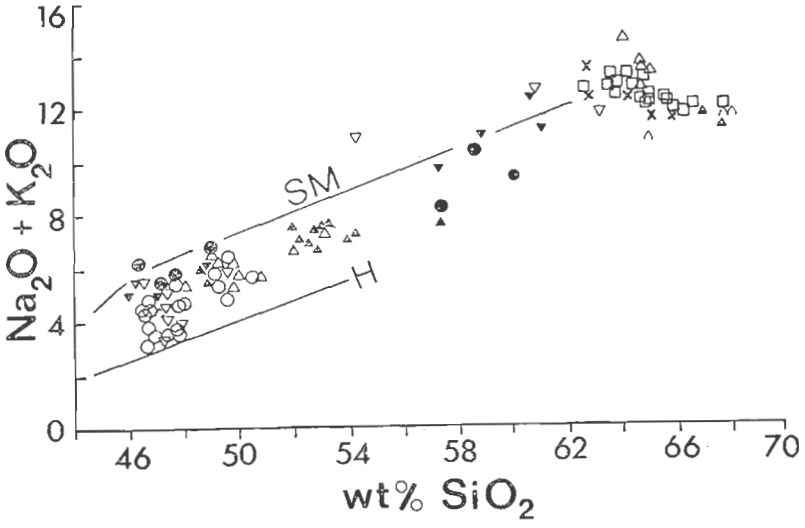

Fig. 4 — Alkali/Silica diagram for Terceira rocks from Self and Gunn (1976). Two other trends shown are H, Hawaiian alkali/tholeiite divider and SM, São Miguel rocks (Schmincke, 1973).

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

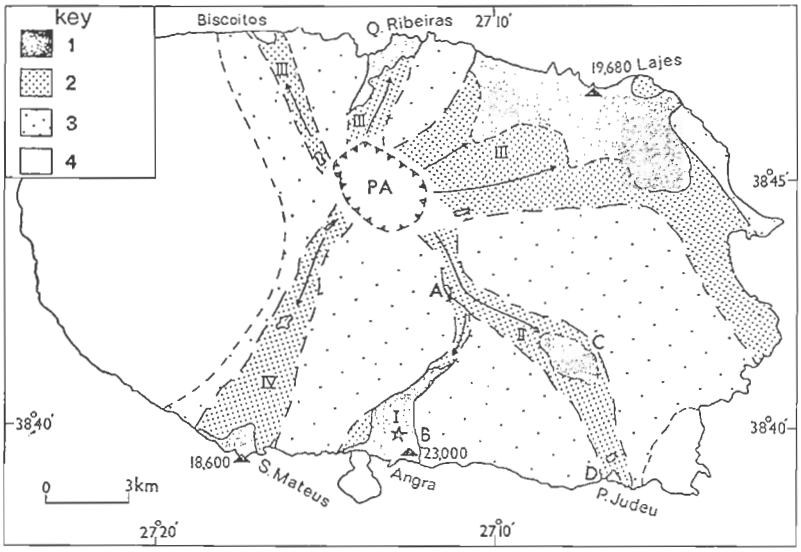

Fig. 5 — Map of the Lajes and Angra Ignimbrites (after Self, 1976). Key : 1) outcrop of thick ignimbrites ; 2) area covered by thin ignimbrite and/or ground surge beds ; 3) co-ignimbrite ash fall deposit ; 4) areas which have no recorded deposits of this eruptive sequence. I is the main outcrop of the 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.

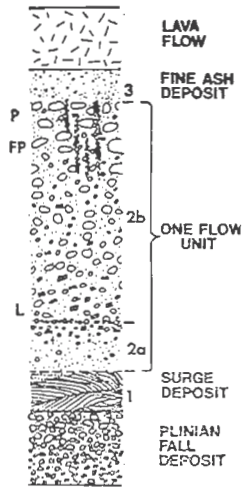

Fig. 6 — Schematic diagram showing the deposits of an ignimbrite-producing eruption episode. P - pumice concentration zone. L - lithic concentration zone. FP - fossil fumarole pipes. Deposits of fine co-ignimbrite ash (3) occur above the flow unit. Modified from Sparks and others, 1973.

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).

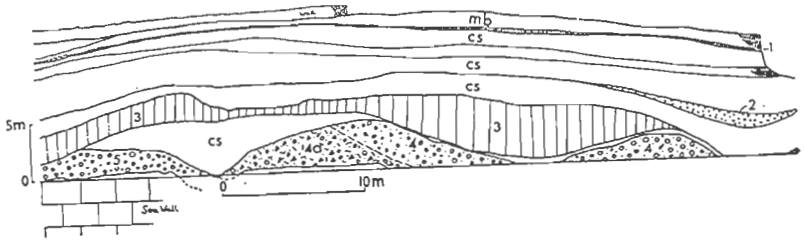

Fig. 7 — The section at Angra Harbour. 1. Angra Ignimbrite. 2. « Basaltic » Ignimbrite. 3. Fanal Ignimbrite. 4. Castelinho Ignimbrite. 4a. Mudflow in 4. 5. Porto das Pipas Ignimbrite. mb = Monte Brasil tuff. cs = condensed ash-fall sequence.

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.

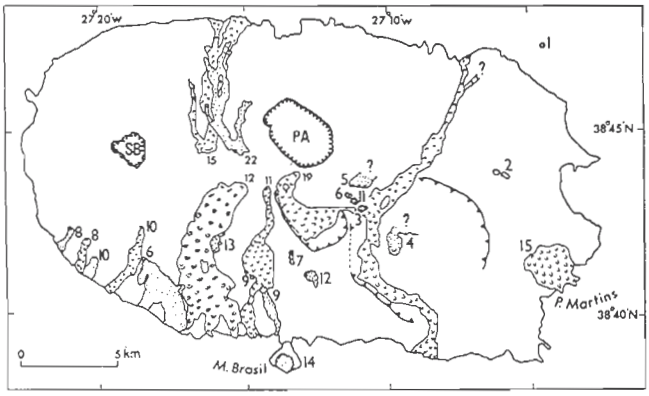

Fig. 9 — Map showing largest fissure zone basalt lava flows (small numbers, see Fig. 3) and 15 post-23,000 year basaltic cones and flows (large numbers, 1-15 are oldest to youngest). Calderas as in Fig. 1.

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.