# The older volcanic complexes of S.Miguel, Azores: Nordeste and Povoação

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**Abbreviated Title**

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**Abstract**

The oldest part of S. Miguel is to the east of Furnas. Previous research argued that these volcanics belong to a construct called the Nordeste Volcano, a heavily eroded shield which not only extends to the east coast of the island but also underlies Furnas Volcano in the west. On the basis of geomorphological mapping, we argue that Nordeste comprises two volcanic systems: an older Nordeste construct (the Nordeste Volcanic System); and the younger Povoação Volcano which straddles the Nordeste shield on its western margin. The Nordeste Volcanic System consists of the

Lower Basalts which constitute the overwhelming majority of its subaerial products which are exposed in coastal cliff sections. Above the Lower Basalts is a surficial drape of Ankaramites and the Upper Basalts. There is no evidence of large explosive trachytic eruptions from Nordeste Volcanic System. Povoação Volcano comprises an early shield construct, after which the volcano experienced caldera collapse. Post-caldera deposits are poorly exposed, but include basaltic, mugearitic and trachytic lavas intercalated by cut and fill sequences. Radiometric dating has yet to resolve fully the absolute ages of the Nordeste and Povoação volcanic systems, but morphology indicates that the former is much older than the latter.

S. Miguel Island, Azores, is made up of three central volcanoes, each of which has been active in the last 1000 years, and these volcanoes are linked by rift zones of predominantly monogenetic basaltic activity (Fig. 1). Sete Cidades is the central volcano that forms the western end of the island and last erupted about 500 – 600 y BP (Booth *et al.* 1978, Moore & Rubin 1991; Queiroz *et al.* 2008; Queiroz *et al*. 2015 – this volume). A basaltic rift zone separates Sete Cidades from Fogo, the central volcano which dominates the middle of the island. This basaltic rift zone with numerous scoria cones is called the Picos Fissural Volcanic System (Ferreira *et al.* 2015 - this volume). The most recent eruption in the Picos Fissural Volcanic System was in 1652. Fogo last erupted in 1563 with a trachytic sub-plinian central eruption, followed a few days later by a basaltic eruption on the lower northwest flank (Wallenstein *et al.* 1998). Between Fogo and Furnas, the easternmost of the active central volcanoes, lies the Congro Fissural Volcanic System, a rift zone of predominantly scoria cones. Furnas last erupted with a sub-plinian eruption in 1630 (Cole *et al.* 1995, Guest *et al.* 1999).

To the east of Furnas is the oldest part of the island first described by Zbyszewski *et al.* (1958), with according to Moore (1990) volcanic rocks ranging in age from

100,000 years to over 4 Ma. As discussed below, however, Johnson *et al.* (1998) argue that the age range is much younger. Moore (1990) categorises all these older volcanics as belonging to Nordeste volcano. It is the purpose of this paper to provide more understanding of this oldest part of the island demonstrating that the Nordeste volcano is in fact two separate distinct volcanic systems - Povoação and the older Nordeste - that make up the eastern part of the island.

## Nordeste Volcanic System

Previous Work

Fernandez (1980) mapped the Nordeste Volcanic System and identified a 1300 m thick exposed sequence and subdivided it into the Trachytes and Tristanites, Upper Basalts, Nordeste Ankaramites and Lower Basalts (Table 1), which together comprise a mildly alkaline suite of volcanic products (Fig. 2). K-Ar dating by Abdel-Monem *et al.* (1975) produced a date of 4.01 Ma for what is considered to be the oldest exposed lava of the Lower Basalts, a date of 1.86 Ma for a lava of the Upper Basalts and dates ranging from 1.28 – 0.95 Ma for the trachytes and tristanites.The complex is cut by a sequence of dykes ranging in composition from ankaramite through alkali basalt to hawaiite in composition. Johnson *et al.* (1998) measured the palaeomagnetism of a hawaiite dyke showing it to be normally magnetised (Brunhes) whereas the Upper and Lower Basalts are reverse magnetised (Matuyama) and therefore older and not related to the magmatism of the dyke. The work of Fernandez (1980) focuses on petrology and does not define the boundaries of the Nordeste Volcanic System. The lowermost exposed basalts are low in $K_2O$, $Na_2O$ and $TiO_2$ compared with the rest of the sequence and are transitional in character between mid-ocean ridge basalts and alkali basalts. The Nordeste  Volcanic System is interpreted by Moore (1990) as being an eroded shield which underlies Furnas Volcano in the west and extends to the east coast of S. Miguel Island. Though grouping all these volcanics as one zone, Moore recognises the complexity by interpreting Povoação as a caldera which is not centred on the main Nordeste massif. Johnson *et al.* (1998) in a palaeomagnetic study of the lava flows of S. Miguel, carried out new $^{40}Ar/^{39}Ar$ dating of the Nordeste Volcanic System. These dates of Johnson *et al.* (1998) give a much younger range than the dates of Abdel-Monem *et al.* (1975) which form the basis of the chronology used by both Fernandez (1980) and Moore (1990). According to Johnson *et al.* (1998) lava from the Lower Basalt Sequence at the base of the Porto de Nordeste cliff gives a mean age of 0.878 Ma. Comparing this with the much older age of 4 Ma quoted by Abdel-Monem *et al.* (1975), who employed K-Ar dating. Younger dates ranging from 0.82 to 0.85 Ma for the Lower Basalts were also obtained by Johnson *et al.* (1998) from the Praia do Lombo Gordo cliff sequence. Johnson *et al.* (1998) argue that K-Ar dates are less reliable than those determined by $^{40}Ar/^{39}Ar$.

The dates of the Upper Basalt sequence provided by Johnson *et al.* (1998) range from 0.78 – 0.82 Ma. If this is the case then the basic magmatism of the Nordeste Volcanic System occurred over a period ranging from 0.78 to 0.88 Ma, i.e. a period of ~0.1 Ma, as opposed to ~2.15 Ma as suggested by Fernandez (1980). The palaeomagnetic data of Johnson *et al.* (1998) show that all the samples analysed from the Lower and Upper Basalts are reversely magnetised (Matuyama) whereas the two ankaramites and one dyke sampled are normally magnetised (Bruhnes) and therefore younger. A younger age for the Nordeste Volcanic System is provided by K-Ar dates of  0.90 Ma and 0.92 Ma obtained from two lavas in cliff sections to the south at Água Retorta (Forjaz personal communication in Johnson *et al.* 1998). The cliffs to the south of Água Retorta (Fig. 3) lie on the downthrow side of a major WNW-ESE fault, the Tronqueira fault (see Fig. 4) and therefore may only represent the upper part of the Nordeste Volcanic System. A summary of the differing age ranges proposed for the Nordeste Volcanic System is presented in Table 1.

## Tectonics

The Nordeste Volcanic System is cut by two major fault trends – NNW/SSE and WNW - ESE and a minor trend NE - SW (Carmo *et al*. 2005; Carmo *et al.* 2015 - this volume). The NNW - SSE trend is clearly shown in the northeast part of the island with faults controlling the orientation of sea cliffs on the coast. A major WNW-ESE fault, the Tronqueira fault (Carmo *et al.* 2015 - this volume), cuts the Nordeste Volcanic System forming a distinctive scarp along the southern margin of the Serra da Tronqueira to the north of Água Retorta (Fig. 5b). From the height of the scarp the fault had a throw of at least 400 m and together with smaller parallel faults has downfaulted the Nordeste Volcanic System to the south. This fault cannot be traced in the Povoação caldera suggesting that it predates the formation of the Povoação Volcano whose lavas are piled up against it. In the Água Retorta area there is a graben developed which has the Tronqueira fault as its northern boundary (Carmo *et al.* 2015 – this volume).

## The volcanic construct

The Nordeste Volcanic System is highly eroded and dissected compared with the active central volcanoes of Sete Cidades, Fogo and Furnas whose subaerial portions date from the last 200,000 years. The less eroded edifice of the Povoação Volcano can be seen banked up against the older Nordeste Volcanic System (Fig. 4). If the dates determined by Johnson *et al.* (1998) are of the correct order of magnitude, then the age gap - in the range of 600,000 years - between the Nordeste Volcanic System and the younger central volcanoes - is much smaller than was previously thought, and raises the question that on geomorphological grounds the Nordeste Volcanic System appears to be much older than the other centres. An older age, however, for the Nordeste Volcanic System is supported by a recent investigation into high levels of mitochondrial DNA diversity within Oxychilid land snails from S. Miguel (Harris *et al.* 2013). Harris *et al.* demonstrate that most of the lineages diverged in the early

Pliocene or Pleistocene and argue that these results are more consistent with the older age of the island of about 4 Ma, this is in line with the date of Abdel-Monem *et al.* (1975) as presented in Table 1.

The Lower Basalts sequence forms a shield which comprises the overwhelming majority of the subaerial products of the Nordeste Vocanic System. The lava pile is exposed in the cliffs between Algarvia on the north coast and Água Retorta on the south east corner of the island (Fig. 3). The angle of slope from the current peak of the Nordeste Volcanic System, Pico da Vara (1130 m asl), to the top of the coastal cliffs is about 9˚. It should be noted that the current summit will be lower than the original summit as a consequence of erosion, but there is no evidence of caldera collapse of this construct. Cliff sections reveal that the Lower Basalts sequence is made of relatively thin lava flows which are typically of *aa* type with massive portions up to 3 m in thickness. At the foot of the cliff just south of the Porto de Nordeste at Ponta do Arnel (Fig. 3) the pile of lavas can be seen to cover scoria cone deposits at the base of the pile. The cliffs along the coastline each side of Ponta do Arnel are formed by a well defined fault (Figs. 4, 5a). Ponta do Arnel is formed of younger lavas (post the Lower Basalts sequence) which have spilled over the cliff. The Lower Basalt sequence is also well exposed at Praia do Lombo Gordo. At this locality about 50 m above the base of the cliffs a thin layer (75 cm) of weathered orange scoria forms a well defined horizon in the sequence of lavas.

Inland, the volcanic system is highly vegetated and exposures are limited. The Nordeste Ankaramites and Upper Basalts sequences form a surficial drape on the construct of the Lower Basalts. Johnson *et al.* (1998) consider that the Nordeste Ankaramites and the Upper Basalts may be at least in part contemporaneous. The small volume of trachytes and tristanites represent the last stage in activity. This indicates that storage of magma occurred for a sufficient time to allow for fractionation to generate trachytic magmas. There is no evidence, however, that the Nordeste Volcanic System gave rise to major trachytic explosive eruptions.

The Nordeste Volcanic System has been subjected to considerable erosion and the complexity of this is a reflection of its age. There are several exposures where debris flow deposits may be seen within the Nordeste Volcanic System. Just to the west of Lomba da Fazenda debris flow deposits with clasts of ankaramite are overlain by ankaramite lava suggesting that the debris flow was generated during the emplacement of the Nordeste Ankaramites sequence. This indicates that erosion and generation of debris flows was occurring during the emplacement of the Nordeste Volcanic System. The Ribeira do Guilherme (Figs. 3, 5a) is a major valley cut into the Nordeste products which enters the sea just north of the village of Nordeste. Near to the mouth of the river a fill of alluvium comprising rounded cobbles and boulders of lava crops out on both sides of the valley at *c.*120 m asl (Fig. 6). The boulders are up to 2 m in size and this, taken together with the poor sorting of the deposits, indicates high energy deposition. The fill perches on the sides of the lava sequence and originally filled the valley up to this level.

The history of cut and fill is well illustrated on the south east flank of the Nordeste Volcanic System. More than 10 m of very poorly sorted debris flow deposit with rounded lava clasts up to 1 m in diameter forms the base of the cliff section just south of Água Retorta. In the current valley, just north of Fagundas locality, torrent gravels can be seen overlying lava. It is clear that there has been a well developed sequence of cut and fill.

Generation of debris flows has continued and the history of cut and fill carries on to the present day.The Ribeira Despe-te Que Suas on the northwestern edge of the Nordeste Volcanic System clearly experiences major episodic discharge. A new road bridge was built to replace the one destroyed by fluvial activity in 1987 and the river bed which is sometimes dry contains large boulders and cuts a 10 m fill which is poorly sorted with a mixture of rounded and angular clasts and this bears testimony to the high energy discharge which can take place.

The instability of the cliffs constitutes a current hazard. On the coast to the south of Pedreira locality houses at the foot of the cliff are built on a small platform made of debris flow and debris avalanche deposits. Two of these houses were damaged by debris flows after heavy rainfall in 1998. On the side of the track is a shrine to a man killed by blocks falling in 1961.

Marine terraces

A flat feature at around 150 m asl can be observed on aerial photographs formed above the current sea cliffs on the north coast from São Pedro do Nordestinho to Lomba da Fazenda and on the east coast between Nordeste village and Pedreira (Fig. 4). This we interpret as a possible marine terrace. On the ground this terrace is less clearly visible and has been partially dissected by erosion.

The terrace is cut into lavas of the Upper Basalts and, therefore, must be younger than 1 Ma. Marine terraces are likely to form at marine high stands but correlating levels is a complex challenge on volcanic islands that may experience significant vertical earth movements and which vary spatially (Moore 1987). An extensive range of marine terraces has been documented in the Canary Islands by Meco *et al*. (2007). These terraces of Miocene-Pliocene age (4 – 9 Ma) range in altitude up to 120 m above current sea level. Only the terraces at the lowest heights (less than 20 m asl) could be aligned with higher sea levels before the advance of northern hemisphere ice sheets (c. 5 Ma). Meco *et al.* (2007) argue that the range in elevations is a consequence of progressive seaward tilting of the islands caused by the younger volcanic edifices to the west generating increased lithostatic load on the crust. In the Azores, on Santa Maria, the oldest island in the archipelago, Serralheiro & Madeira (1990) describe a sequence of Pliocene-Quaternary marine levels from 160 m asl down to the youngest at 5 m asl. This sequence was formed after Santa Maria ceased to be volcanically active in the Middle Pliocene. On the island of Flores, Azevedo & Portugal Ferreira (1999) report marine terraces, which formed at different stages during the volcanic history of the island. The oldest and highest terrace at *c.*250 m asl formed between 500,000 and 250,000 BP. There is also a terrace at *c*.100 m asl with a suggested age of 300,000 BP. Azevedo & Portugal Ferreira (1999) argue that Flores experienced intensive volcano-tectonic uplift during the growth of the volcanic island. Episodes of localised uplift and subsidence in developing volcanic islands frustrates regional correlation of terrace levels.

The terrace feature on Nordeste is not definitive and no *in situ* marine deposits have been identified. But as illustrated by the example on Flores, volcano-tectonic uplift of 100 m is not unrealistic. The significant erosion and dissection of Nordeste Volcanic System may explain the lack of preservation of any deposits.

At São Pedro do Nordestinho there is a substantial river terrace that cuts the possible marine terrace feature. No *in situ* fluvial material was found, but a large number of rounded cobbles and boulders occur in walls or where they have been cleared from fields into piles of rocks. A smaller river terrace occurs on the east coast at Pedreira, where a valley cuts through the marine terrace.

**Povoação Volcano**

Moore (1990) notes that the Povoação caldera is cut into the Nordeste shield on its southern side. The centre of the Povoação caldera is located 7 km SSW from Pico da Vara, the current summit of the Nordeste shield. The northern outer flank of the

Povoação caldera stretches from the rim down to the north coast. Povoação is much less dissected than Nordeste and appears to be morphologically younger (Fig. 4). We propose that Povoação is a volcano in its own right and younger than the Nordeste Volcanic System.

Measured from its footwall, the Povoação caldera is an oval shaped bowl 6 x 3.5 km (long axis E-W); the rim is highest on the north side and dips down to the coast on the south (Fig. 4). The town of Povoação is located on the coast where the rivers that drain the caldera have cut through the rim to the sea. The caldera fault, which is interpreted to run at the foot of the caldera slope can be traced just inland from the coast (Fig. 4). The oval-shaped morphology with the long axis parallel to the coast and the fact that the depression is not open to the sea, does not support it being either an erosional feature or a sector collapse, because such a collapse would be elongated perpendicular to the coast.

The lavas that make up the early shield construct of Povoação are exposed in the sea cliffs to the west of Povoação village. There is good exposure of pre-caldera material in the sea cliff that extends eastwards from the town of Povoação for 1.5 km to a small headland. This coastline appears to be fault controlled. The sequence dips westwards and there are a number of faults which mostly downthrow to the west. At the headland are crudely bedded agglutinates and thin lavas. These are overlain by basic lavas intercalated with a thick scoria/breccia sequence. Pale grey dykes of intermediate composition trending NW-SE cut the sequence and one dyke feeds a lava flow or sill. At the west end of the sequence there appears to be a vent system with a cone overlain by basaltic lavas. This is illustrated in Fig. 7. The deposits as described above appear to be vent facies (actual vent material or proximal deposits) and this may indicate the fault here was active prior to caldera formation. This vent facies material may have formed along a fissure system. By the mouth of the river at

Povoação welded ignimbrite, the Povoação Ignimbrite, from Furnas Volcano (Duncan *et al.* 1999) lies on top of the sequence. It needs to be emphasised that the Povoação Ignimbrite though well exposed in the Povoação caldera was erupted from Furnas Volcano about 30, 000 BP (Guest *et al.* 1999).

The post-caldera deposits are poorly exposed. Products from Furnas Volcano, the Povoação Ignimbrite and younger tephra, form the uppermost sequence emplaced within the caldera. On the sides of interfluves within the Povoação caldera horizontal basaltic, mugearitic and trachytic lavas are exposed intercalated with cut and fill material. On the northern wall of the caldera, Moore (1990) recognises more than 100 m thickness of trachytic pyroclastic flow and fall deposits which preceded caldera collapse. It is likely that there was more than one eruption associated with the collapse.

A large volume of orange trachytic pyroclastics are found in places mantling the eroded edifice of the Nordeste Volcanic System and reworked in the valleys cut into the Nordeste shield. The alluvium which filled the Ribeira do Guilherme has a matrix rich in weathered yellow ash and lapilli. In a quarry by the church at Pedreira (Fig. 3) orange ash can be seen overlying a well developed soil on top of Nordeste Volcanic System lavas and scoria. A dyke cuts the lava and scoria sequence but not the soil and orange ashes. On the high ground between Faial da Terra and Água Retorta mantling orange ashes with scattered lapilli crop out, in places these are reworked and in one exposure a rotten ignimbrite occurs at the top of the sequence. The topography of the down faulted block of the Nordeste Volcanic System, south of the Tronqueira fault, has a subdued relief as it is mantled by the orange pyroclastics. These pyroclastics clearly postdate Nordeste but these deposits have not been located at the top of the Povoação caldera fill which would be expected if they had been derived from the younger Furnas or Fogo volcanoes. We propose that these trachytic pyroclastics that postdate Nordeste, but appear to be older than Furnas, are the products of the Povoação caldera forming eruptions and may correlate with the products described by Moore (1990, see above).

## Conclusions

The research reported in this paper argues that the previously defined Nordeste Volcano is two separate volcanic constructs, the Nordeste Volcanic System, and the younger Povoação Volcano. The edifice of the Nordeste Volcanic System is more highly dissected than that of the Povoação Volcano and, morphologically, the edifice of Povoação can be seen to wrap around the Nordeste Volcanic System. The Nordeste Volcanic System is made up of predominantly basaltic lavas, together with the products of intense erosion which occurred both during and after the activity of the volcano. No evidence has been found of caldera formation on the Nordeste Volcanic System and no products of major trachytic explosive activity have been identified. Povoação Volcano has an early lava shield followed by explosive trachytic activity and caldera collapse. It is proposed that the large volume of orange trachytic ash that mantles part of the Nordeste Volcanic System is interpreted as possible products of the Povoação caldera forming eruptions.  The caldera fill is largely obscured by products from the younger Furnas Volcano to the west. The age gap between the Nordeste Volcanic System and the other volcanic centres of S. Miguel remains to be resolved. The recent dating work of Johnson *et al*. (1998) suggests that this age gap may be only a few hundred thousand years as opposed to the 3 Ma as previously thought. Such a short time gap does not agree well with the morphological evidence and recent work on the diversity within Oxychilid land snails (Harris *et al.* 2013) that suggests that the Nordeste Volcanic System is much older than the other centres.

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**Table 1**: *Outline stratigraphy of the Nordeste Volcanic System based on Fernandez (1980) showing dates of both Abdel-Monem et al. (1975) and Johnson et al. (1998).*

| Sequence | Lithology | Thickness | Age (1) | Age (2) |
|---|---|---|---|---|
| Trachytes and Tristanites | Short stubby flows and small plug like intrusive | Thin | 0.95 Ma<br>1.28 Ma | |
| Upper Basalts | Relatively thin commonly aphyric alkali basalts and trachybasalts | ~150 m | 1.86 Ma | 0.78 - 0.82 Ma |
| Nordeste Ankaramites | Two widespread thick flows of ankaramite and plagioclase ankaramite | ~200 m | | |
| | *Unconformity* | | | |
| Lower Basalts | Conformable sequence of lavas ranging from ankaramite to alkali basalt to trachybasalt | ~1000 m | 4.01 Ma | 0.88 Ma |

(1) K-Ar dates of Abdel-Monem *et al.* 1975
(2) Ar-Ar dates of Johnson *et al*. 1998

**Figure captions**

Figure 1. General location map of S.Miguel and the Nordeste Volcanic System

Figure 2. Total Alkalis Silica plot showing compositional range of volcanics of the Nordeste Volcanic System (data from Fernandez 1980).

Figure 3. Location map of the Nordeste and Povoação area.

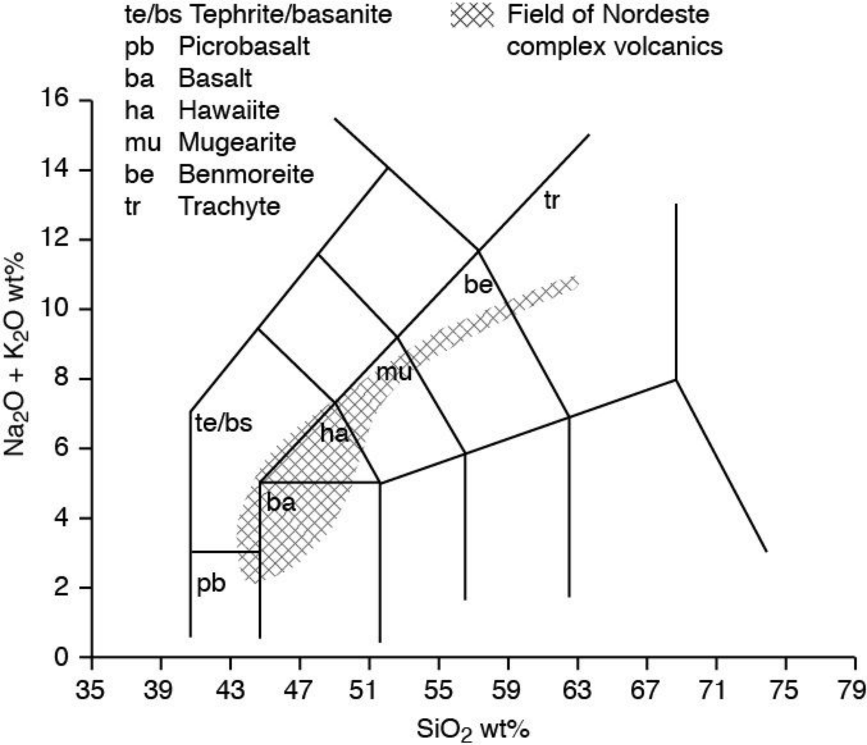
Figure 4. Digital Elevation Model of Nordeste and Povoção Volcanic Systems, showing geomorphological relationships and tectonic features. Tr is Tronqueira Fault. The volcanic limits (thick black lines) represent the boundaries of the geomorphological expression of the volcanic constructs of Furnas, Povoação and Nordeste Volcanic Systems. The younger, less dissected, edifice of Povoação can be seen banked up against the older Nordeste Volcanic System. The volcanic limits do not represent geological boundaries as such, for example products from Furnas Volcanic System drape over the adjacent Povoação caldera rim. Some tectonic information from Carmo *et al.* (2015 – this volume) is included in this figure.

Figure 5.
a) View looking north with the northeast coast showing the cliffs along the coastline each side of Ponta do Arnel which are formed by a well defined fault. The Ribeira do Guilherme, which is considered to be fault controlled (Carmo *et al.* 2015 – this volume) is the major valley entering the sea at the northern end of the fault controlled line of cliffs.
b) The east coastline of S. Miguel with the village of Água Retorta in the middle of the photograph with the cliffs at Ponta do Arnel stretching to Nordeste village on the far right. The cliffs are cut largely into the lava pile of the Lower Basalts. To the right of Água Retorta village the fault controlled scarp of the Serra de Tronqueira can be clearly seen. The summit of the Nordeste Volcanic System, Pico da Vara, can be seen rising above the clouds. (Photographs by Paulo Melo)

Figure 6. Deposit of the alluvial fill material perched on the side of the valley of the Ribeira do Guilherme near Nordeste village.

Figure 7. Coastal cliff section immediately east of the mouth of the river at Povoação village. The cliff exposes pre-caldera deposits showing what appears to be vent material (A) overlain by thin basaltic lavas coastal section (B). On top of the sequence lies the massive welded Povoação Ignimbrite (C) erupted from Furnas Volcano to the west.

31°50'
24°30'
40°00'
36°40'
N
Corvo
Flores
Graciosa
São Jorge
Terceira
Faial
Pico
São Miguel
North Atlantic Ocean
100 km
Santa Maria
Azores
SPAIN
PORTUGAL
North Atlantic Ocean
Madeira
MOROCCO
ALGERIA
Canary Islands
WESTERN SAHARA
500 km
Lagoa Azul
SETE CIDADES CALDERA
Ribeira Grande
Nordeste
SÃO MIGUEL
Furnas
POVOAÇÃO CALDERA
Lagoa do Fogo
FOGO CALDERA
Lagoa das Furnas
FURNAS CALDERA
Airport
PONTA DELGADA
Povoação
Vila Franca do Campo
0
km
10



te/bs Tephrite/basanite
pb Picrobasalt
ba Basalt
ha Hawaiite
mu Mugearite
be Benmoreite
tr Trachyte
Field of Nordeste complex volcanics
16
14
12
10
8
6
4
2
0
$Na_2O + K_2O$ wt%
35 39 43 47 51 55 59 63 67 71 75 79
$SiO_2$ wt%
te/bs
pb
ba
ha
mu
be
tr

SÃO MIGUEL
Fenais da Ajuda
Achada
S. Antonio
Lomba da Fazenda
S. Pedro
Algarvia
Maia
Lomba da Maia
Nordeste
R. Despe-Te Que Suas
Rio Guilherme
Pico da Vara (1103m)
Ponta Arnel Harbour
Pedreira
Lombo Gordo Beach
Furnas
Lagoa das Furnas
Água Retorta
Fagundas
Faial da Terra
Povoação
Ribeira Quente
Towns and villages
River
Road
Peak
0
km
5
Corvo
Flores
Graciosa
São Jorge
Terceira
Faial
Pico
São Miguel
North Atlantic Ocean
100 km
Santa Maria
40°00'
36°40'
31°50'
24°30'


Nordeste
Povoação
Furnas
Tr
Caldera rim
Inferred caldera rim
Volcano limit
Inferred volcano limit
Fault
Inferred fault
Margin marine terrace
4190000
4185000
4180000
640000
645000
650000
655000
660000
665000


C
B
A