Report on the Mesozoic Volcanic and Intrusive Rocks of the Namibe Basin, Southwest Angola

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1. The Bero Volcanic Complex

The Bero Volcanic Complex comprises a diverse group of quartz latite and tholeiitic basalt lavas, pyroclastic and volcaniclastic deposits, aeolian sandstones as well as intrusive tholeiitic mafic dykes and gabbros. Only the silicic members of this suite have received prior attention being referred to as ñgranitic porphyriesò by Carvalho (1961) who regarded them as being Precambrian in age. Alberti et al.(1992) informally referred to these silicic rocks as the óGiraul Volcanicsô and correlated them with the early Cretaceous Paraná-Etendeka Igneous Province of Brazil and Namibia. We propose the name Bero Volcanic Complex for this igneous suite for the following reasons:

(a) The complete range of lithologies in the suite outcrops only in the Bero River area E of Namibe.

(b) The Bero River area is the location of the basalt lava dated at 130.1±1.9 Ma confirming the early Cretaceous age of the suite.

(c) The name óGiraulô has earlier been informally applied to younger conglomerates by Carvalho (1961) and to a pegmatite field by Gonçalves et al.(2009).

(d) A well-developed tabular stratigraphic succession such as exists in the Etendeka (Marsh et al., 2001) and Paraná (Peate et al.,1992) has proved difficult to document within the volcanic outcrops and the use of the stratigraphic term ócomplexô as opposed to óformationô is preferred until more detailed mapping has been carried out.

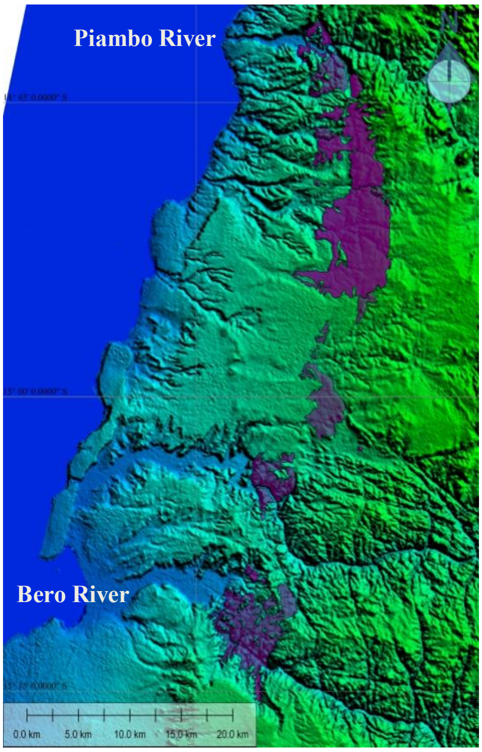


Figure 1: Distribution of the Bero Volcanic Complex (mauve).

Field relationships

The Bero Volcanic Complex outcrops almost continuously within a fault-bounded block up to 7 km wide and extending for over 65 km from the Bero River in the S to the Piambo River in the N (Fig 1). In this area the Bero complex defines the eastern margin of the Namibe Basin. Along its eastern edge the Bero complex is generally down faulted against a variety of Precambrian basement lithologies. To the west the Bero Complex is succeeded by the Cretaceous sedimentary sequence of the Namibe Basin with a faulted contact between the two in many places. The volcanic sequence is also displaced by numerous faults of different orientations and mostly with small throws.

The Bero Complex is dominated by plagioclase-phyric lavas, phyric pitchstones as well as some pyroclastic units, all of quartz latite composition. In the Bero River area the quartz latites are underlain by basaltic lavas. Discontinuous aeolian sandstone lenses are interbedded with and underlie the basalt flows (Fig. 2) but the contact between these underlying aeolian sandstones and Precambrian basement rocks is not exposed. The overall succession of early basaltic flows passing upwards into a quartz latite-dominated sequence is consistent with the general stratigraphic sequence observed in the northern Etendeka (Marsh et al., 2001). A basaltic lava sample NBA-36 collected at 15^{o}09.144ôS; 12^{o}17.704ôE has been dated at 130.1±1.9 Ma by the Cassignol-Gillot K-Ar technique (Delpech, pers.comm. 2010)

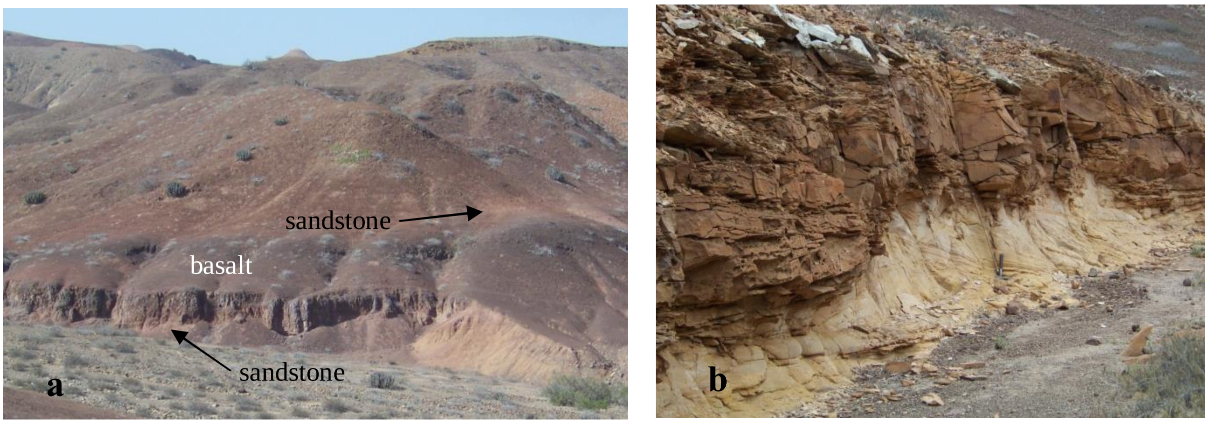


Figure 2: Aeolian sandstones (a) interbedded with Bero basalts and (b) underlying basalts in the Bero River area.

To the N of the Bero River both basalts and aeolian sandstones are absent and quartz latites lie directly on pre-Bero Complex rocks. Three types of contact between the quartz latite sequence and underlying rocks have been observed: (a) quartz latite lying directly on Precambrian basement in at least 3 localities [letto Cambandge, letto Ngola just S of Manome trig beacon, and at 14^{o}52.8ôS; 12^{o}22.6ôE]; (b) quartz latite lying on a coarse conglomerate of uncertain age dominated by boulders and cobbles of reddish granite [Piambo River area - Fig. 3]; and (c) quartz latite lying on coarse gabbro [Piambo River area]. In the Piambo and Bero River areas where the Bero Volcanic Complex is overlain by the early Cretaceous sedimentary sequence which includes thick evaporites the quartz latite pitchstones and glassy pyroclastic rocks are extensively altered. These alteration products have reddish and creamy-yellow colours and superficially resemble fine aeolian sandstones or thinly laminated fine grained sandstones.

Figure 3: Irregular contact between highly altered quartz latite pitchstone (pink and cream colours) and coarse conglomerate of reddish granite boulders.

Intrusive rocks are represented by mafic dykes and gabbros with a horizontal sheet-like form. The dykes are identical in composition to the basalt lavas and are observed intruding quartz latites in many localities. On the assumption that these dykes fed surface lava flows, such flows must originally have overlain the quartz latite sequence. Nowhere has basalt been observed overlying quartz latite, suggesting some post-Bero erosion, which removed the basalt flows from the succession prior to the start of the Namibe basin sedimentation. Such erosion is consistent with abundant evidence for significant topographic relief on the Bero Volcanic Complex prior to sedimentation such as the the fine-grained sediments which wrap around and envelop remnant hills of Bero basalt in the Bero River area (Fig. 4) and the conglomerate-filled valleys cut into Bero quartz latites in the Mariquita area (Fig. 5)

Figure 4: Pale-grey fine-grained sediments overlying and lapping onto Bero basalts, Bero River

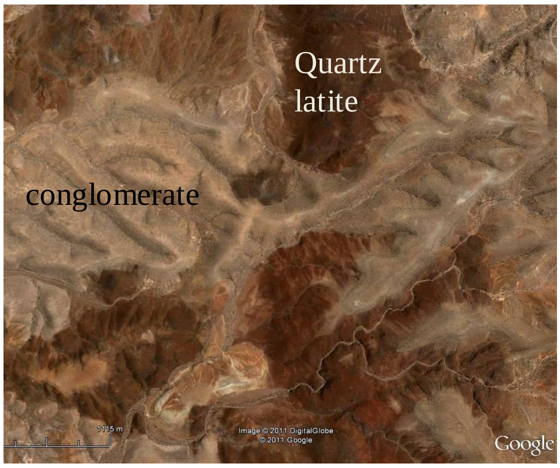


Figure 5: Google earth image showing valley-confined conglomerates (grey) cutting across Bero quartz latites (red brown).

The gabbros are more enigmatic. An extensive sill-like gabbro body outcrops along letto Menguari and SE towards letto Chaliue to the west of the volcanic sequence and appears to be overlain by it. In the Piambo River at 14^{o} 42.05'S; $12.^{o}$ 21.79'E coarse gabbro outcrops at river level and is overlain with a more-or less horizontal contact by a thick quartz latite. The gabbro exhibits only slight fining of grain size towards the contact. The gabbros analyzed to date are identical in composition to the basalts and the mafic dykes, i.e. they crystallized from high-Ti Khumib-type magma. The current view is that the gabbros represent mafic magmas intruded into or below the package of quartz latite lavas while the latter were still hot, hence their coarse grain size.

Geochemistry

The overall composition of rocks from the Bero Volcanic Complex is summarised in the Total Alkalies – Silica (TAS) classification plot (Fig.6) of Le Maitre (2002). Collectively the Bero rocks define a bimodal suite, typical of magmatism associated with continental rift tectonic settings. Mafic lavas, dykes and gabbro plot in the basalt and basaltic andesite fields and are separated by a silica gap from the quartz latites which plot at the junction of the trachydacite, dacite and rhyolite fields. To obviate the ambiguity inherent in the TAS classification of these rocks Erlank et al. (1984) proposed that similar rocks in the Etendeka Igneous Province of Namibia should be collectively referred to as ‘quartz latite’ and this nomenclature will be followed here.

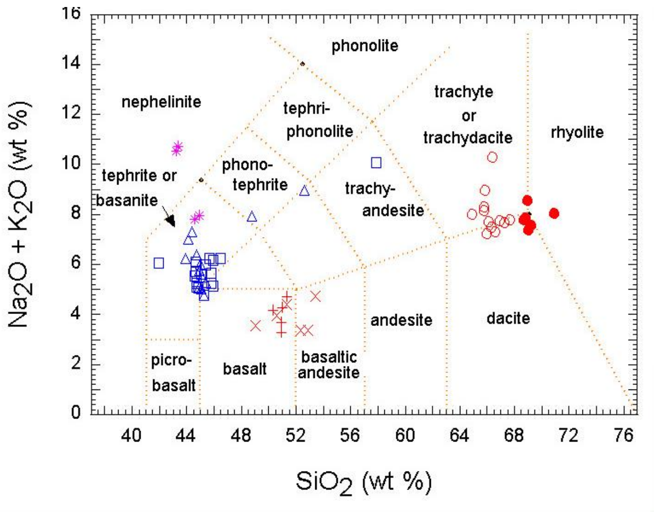
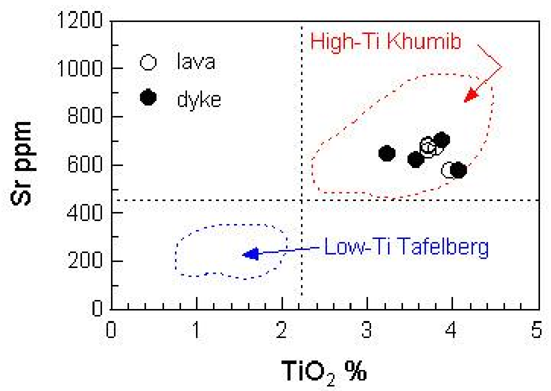


Figure 6. Total alkalies – Silica classification plot of Namibe basin volcanic rocks. Red dots and circles – Bero quartz latites Red crosses – Bero basalts and mafic intrusions. Blue symbols – Bentiaba Basanite Formation with triangles = plugs and squares = lava flows. Mauve stars are the Chapéu Armado nephelinite.

(a) Basaltic rocks

Tholeiitic mafic lavas in the Paraná-Etendeka Province are dominated by two types - low-Ti Tafelberg (Etendeka) or Gramado (Paraná) and the high-Ti Khumib (Etendeka) or Uribici (Paraná) types. Figure 7 presents data for the Bero mafic rocks on discrimination diagrams for these two types and demonstrates that all the Bero mafic rocks are equivalent to the high-Ti type. This is consistent with the geographical distribution of the high-Ti types in northern parts of the Etendeka and Paraná provinces.



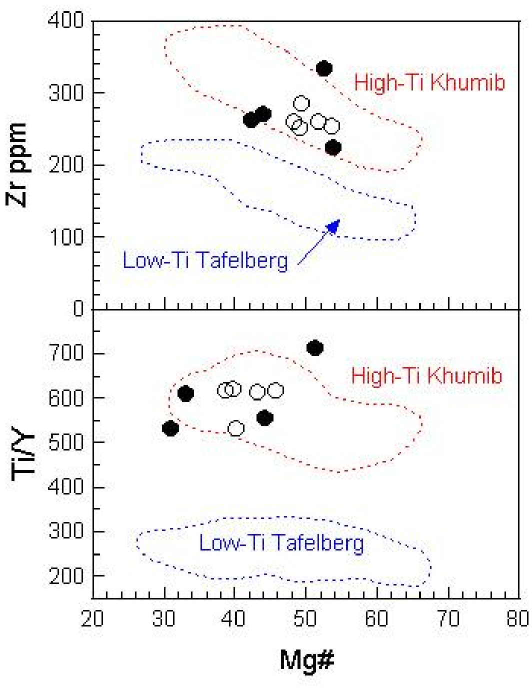
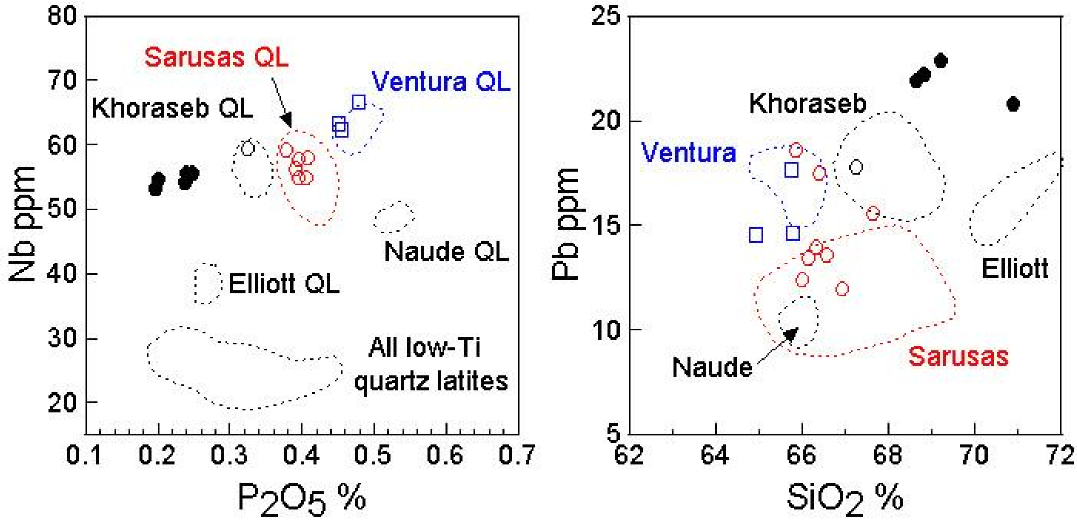


Figure 7: Discrimination diagrams comparing Bero basalts and intrusions to the two main types of mafic lava in the Etendeka Igneous Province. The plots show the overlapping composition of Bero dykes and lavas and their correlation with the high-Ti Khumib type basalts of northern Namibia.

(b) Quartz Latites

Alberti et al. (1992) have previously suggested that the Bero quartz latites (their óGiraul volcanicsô) are the geochemical equivalent of the Chapecó acid rock type of northern Paraná. The Chapecó is now known to consist of a number of geochemically distinct subtypes (Peate, 1997) which have equivalents in the northern Etendeka, and which occur in a consistent stratigraphic sequence in both provinces (Marsh et al., 2001). Geochemical discrimination diagrams for these different quartz latite types are shown in Figure 8 and demonstrate that equivalents of the Sarusas, Khoraseb, and Ventura quartz latites in northern Etendeka are present in the Bero complex. In addition, a fourth type, hereafter the Piambo type, unknown from the Etendeka or Parana, appears to occur throughout the outcrop area of the Bero complex. In the Etendeka the stratigraphic sequence is: Ventura (oldest), Khoraseb, Sarusas (youngest). Currently it is not known whether this sequence is consistent with the distribution of these types in the Bero complex. Sampling carried out in September 2011 was aimed at addressing this question whose answer must await analysis of the collected samples. Additionally, the stratigraphic relationship of the Piambo type to the other quartz latites remains unknown.



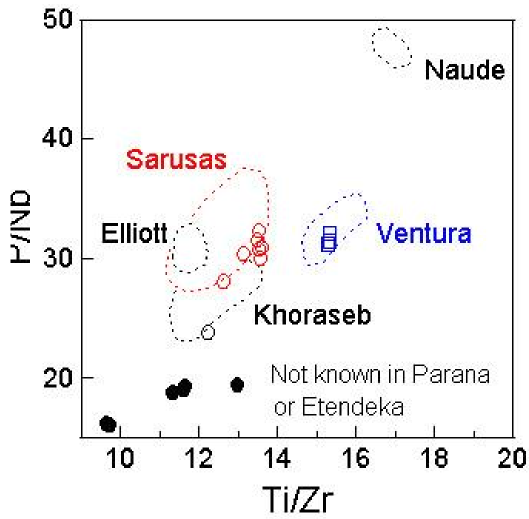


Figure 8: Discrimination diagrams comparing Bero quartz latites with the fields for quartz latite types found in the northern part of the Etendeka Igneous Province. The diagrams indicate the presence of the Sarusas (red) Ventura (blue) and Khoraseb (black circle) types in the Bero complex. Also indicated is the presence of an additional quartz latite type, the Piambo type (black dots), which has not been identified in the Etendeka or in the Paraná.

2. Bentiaba Basanite Formation

Field Relationships

Extensive flows of basanitic lava with a Coniacion-Turonian age occur from the Mariquita River (latitude 14° 47') northwards to the Carunjamba River (latitude 14° 00' - see Fig 9). A sample of a lava flow collected at 14° 07.946'S; 12° 25.156'E has been dated at 88±1.3 Ma

(Delpech, pers.comm.,2010). In most places the Formation is represented by a single lava flow (Fig. 10) but in some places up to 3 flows occur interbedded with red gritty sandstones and conglomerates (Fig. 11) In many exposures the basanites exhibit well-developed columnar jointing. The lack of pillow lavas suggest that flows represent subaerial eruptions. The occurrence of peperites (e.g. at Uau) attests to some interaction with wet sand (Fig 12). Although a detailed volcanological investigation of the flows was outside the scope of the current nvestigation there is evidence from the Caniço valley that some flows were invasive and were able to intrude downwards into their sandstone substrate (Fig. 13) and propagate for short distances.

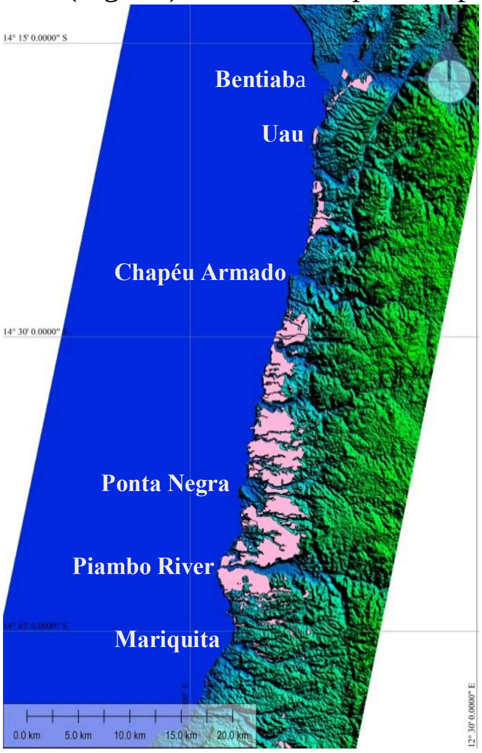


Figure 9: Distribution of Bentiaba basanites (pink) between Mariquita and Bentiaba

Associated with the lava flows are óplugsô accompanied in places by short dykes and these probably represent the eroded vents from which the flows were emplaced. They form positive erosional features in the landscape (Fig. 14). South of Mariquita, in the Bero and Giraul river valleys no lava flows are associated with the basanite plugs. In the S wall of the Giraul valley at Tumbue (15° 03.72ôS; 12° 16.23ôE) a basanite dyke is abruptly truncated by Campanian sediments (Fig.15) suggesting of a period of erosion which may have removed any surface lava flows associated with these intrusions. Most of the

Figure 10: Single columnar-jointed basanite flow, south wall of Piambo River valley

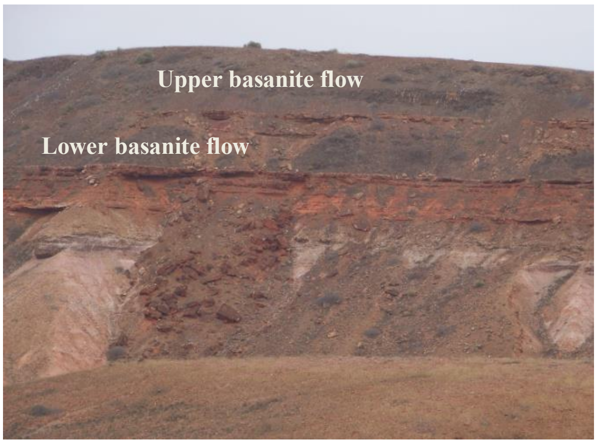


Figure 11: Two basanite flows with sedimentary interbed, Ponta Negra River

óplugsô intrude the Cretaceous sequence of the Namibe basin, but at least 3 plugs have been positively identified as intruding Precambrian basement to the east of the main basin boundary fault. In total some 22+ óplugsô have been positively identified; many are conspicuous on Google earth images but some are not, so it is likely that many more exist. Most plugs are small, have a simple structure and appear to be filled by lava and sometimes with associated pyroclastic breccias. A few óplugsô are much larger and have more complex features. For example, the one located at the mouth of the Piambo River consists of a variety of pyroclastic breccias with juvenile and accidental clasts as well as cored and ribbon bombs, dykes, short, irregular lava flows and small lava domes. The deposits within the plug carry ubiquitous mantle-derived spinel peridotite xenoliths and megacrysts. The Ponta Negra ‘plug’ is dominated by pyroclastic rocks and both airfall and surge facies have been identified. The Piambo Mouth and Ponta Negra outcrops occur at the same stratigraphic position as the regional basanite flows and clearly represent the volcanic superstructure of basanite eruptive systems, whereas many of the smaller plugs represent sub-volcanic erosion levels.

Figure 12: Basanite flow and associated peperite, Uau

Figure 13: Snout of invasive basanite flow, Caniço

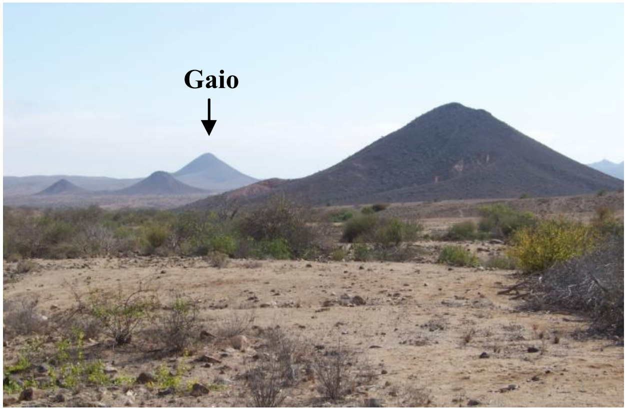


Figure 14: Basanite plugs forming prominent hills in landscape, Gaio area.

Figure 15: Basanite plug (left) and dyke (right centre) truncated by overlying Campanian sediments, south wall of Giraul River valley.

Geochemistry

The TAS classification diagram (Fig.6) indicates that most the “basanites” as a group are variable in composition and plot in the basanite/tephrite field. Differentiates of the basanites are insignificant and range up to trachyandesite in composition. Amongst the basanites MgO varies from 5 to 12% MgO, indicative of a significant amount of differentiation which can be modelled by fractionation of olivine and salite (Fig 16) both of which are phenocrysts in the more primitive samples. This differentiation trend extends to very evolved compositions with MgO < 2% and the more evolved samples are aphanitic. Despite the compositional range, the basanites and their differentiates represent a single magma system, which was tapped by numerous pipe-like eruptions. This is indicated by the constantcy of incompatible element ratios (Fig. 17).

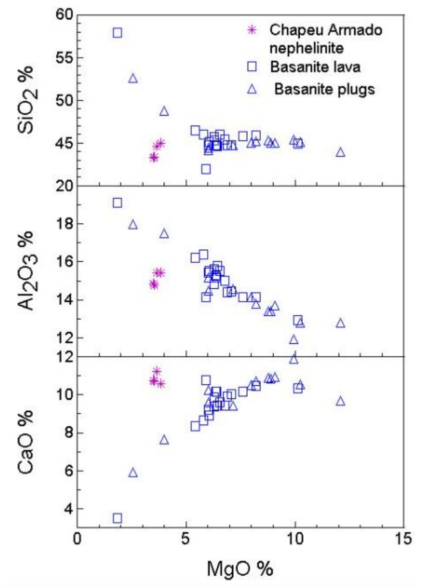


Figure 16: Major oxide variation in basanites consistent with fractionation of salite and olivine.

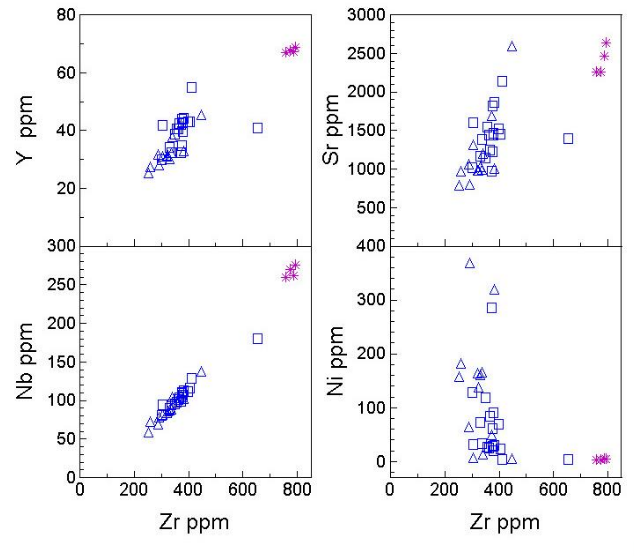


Figure 17: Variation of some trace elements in basanites. Constant Zr/Nb and Zr/Y indicates a genetic relationship and Sr and Ni variations are consistent with olivine+salite fractionation

3. Chapéu Armado Nephelinite

Nephelinite lavas, dykes, and pyroclastic breccias occur on the prominent hill (hereafter Chapéu Armado) which lies 2 km SE of the fishing village of Chapéu Armado. The geological structure of the nephelinite volcano is revealed on the eroded eastern slopes of the hill (Fig. 18) where the regional Cretaceous sequence extending to some 40-70m above the Bentiaba Basanite Formation. is exposed. Chapéu Armado is capped by a thick layer of pyroclastic breccia overlain by slightly amygdaloidal nephelinite lava flows with vertical columnar jointing. Some plugs of nephelinite intrude the lavas and several vertical nephelinite dykes intrude the Cretaceous sedimentary sequence and the Bentiaba Basanite flow below the summit lavas. Extensive scree cover prevent the structure of the volcano to be fully explored, but the variable altitude of the basanite flow across the east face attests to considerable faulting and deformation of the wall-rock stratigraphic sequence. The pyroclastic breccia below the summit lavas is poorly sorted with volcanic, sedimentary and granitic clasts up to 15 cm set in a coarse altered gritty matrix. The breccia is several metres thick and its lower contact is obscured by scree. The lavas also enclose many crustal xenoliths. The age of the nephelinite is unknown but is stratigraphically younger than the 88 Ma Bentiaba basanite. The presence of nephelinite boulders in the Miocene beach deposits reported by Beetz (1933) indicates that it is pre-Miocene in age.

Geochemistry

Dykes and lavas of nephelinite have a narrow range in composition (Figs. 16 and 17) except for a significant difference in Na_2O content between lavas and dykes. On the TAS classification diagram (Fig. 6) the lavas plot in the nephelinite field but the dykes, with lower total alkalies (due to lower Na_2O), plot in the tephrite field. Figures 16 and 17 shows that for both major oxides and trace elements the nephelinites plot away from the basanite evolution trend and they are not genetically related to the basanite magma system.

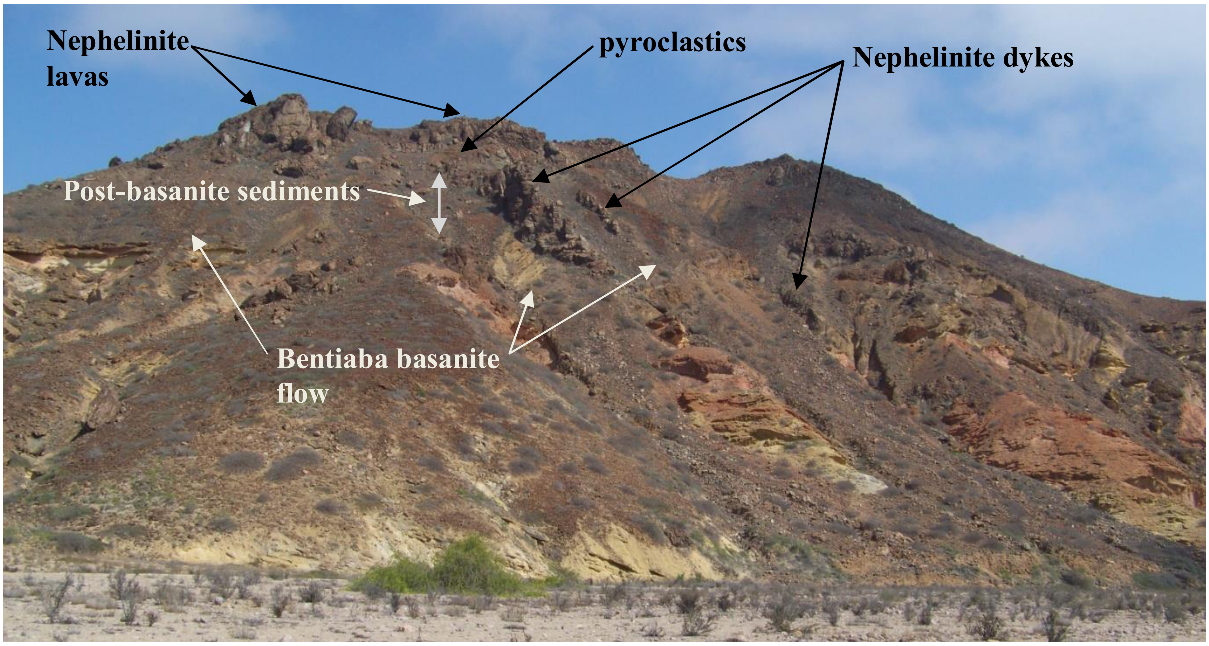


Figure 18: Eastern face of the Chapéu Armado volcano showing the features described in the text

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