



## **CAPE VERDE AND ITS ROCKS: A HISTORICAL PERSPECTIVE**

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### **ABSTRACT**

*One of the first geological investigations in Cape Verde was made by Charles Darwin in 1832 in the island of Santiago. Darwin was preceded by J.S. Feijó (Brava and Fogo islands, 1784-85), and succeeded by Sainte-Claire Deville (Fogo island, 1848). Systematic investigations in the archipelago began with A. Stuebel in 1863, followed by C. Doelter in 1882, I. Friedlaender in 1912, and J. Bacelar Bebiano in 1932.*

*Geochemistry entered the stage somewhat later, at a first step, in the 1940s and 1950s, using major elements (e.g. Coteló Neiva, Berthois, Burri), later, in the 1970s, using minor and trace elements (e.g. de Paepe, Klerkx), finally, in the 1980s, using stable and radioactive isotopes (e.g. Gerlach et al.). It was in the 1960s that António Serralheiro started his pioneering investigations on the stratigraphy of the archipelago, formerly sketched by Bebiano). The stratigraphical framework created by Serralheiro became the basic support for several fine papers on Cape Verde mineralogy and petrography (e.g. Torre de Assunção, Celestino Silva).*

*In the history of the Petrology and Geochemistry of Cape Verde, the sequence of the papers cited above remarkably reflect the development Geochemistry, both in the scientific content and in the literary style.*

### **RESUMO**

*Os primeiros estudos sobre a geologia de Cabo Verde foram perspicazes, mas pontuais: Feijó (1784-85) na Brava e no Fogo, Darwin (1832) em Santiago, Deville (1848) no Fogo. Muito mais sistemática foi a actividade desenvolvida por Stuebel (1863), Doelter (1882) e Friedlaender (1913), que apresentou os “resultados de uma viagem de estudo no verão de 1912” realizada por todo o arquipélago. Esta importante fase naturalista culminaria com a memória do Eng<sup>o</sup> Bacelar Bebiano de 1932, ainda hoje uma obra de referência obrigatória, e não apenas pelos primeiros mapas geológicos que nela apresenta de todas as ilhas, com excepção do Fogo.*

*A Geoquímica propriamente dita faria a sua aparição mais tarde, em 3 grandes momentos que é possível fazer corresponder a outros tantos saltos qualitativos, tanto nos conteúdos como nos estilos literários: Coteló Neiva em 1940, De Paepe e Klerkx em 1974 e Gerlach et al. em 1988. dão novo salto qualitativo com o recurso à informação isotópica (Sr, Nd, Pb) recolhida na maioria das ilhas. A informação isotópica, hoje bastante utilizada, é obviamente*

*importante. No entanto, porque muito despojado das antigas descrições naturalistas, o discurso científico torna-se por vezes mais afirmativo do que propriamente demonstrativo. Cabo Verde é hoje, do ponto de vista petrológico-geoquímico (e não só), o arquipélago porventura mais interessante da Macaronésia.*

## INTRODUCTION

Though the Cape Verde archipelago remains geologically less known than its companions in Central-North Atlantic (the Azores, Madeira, the Canaries), the specific nature of its alkaline magmatism seems to have been recognized by mid-late 19<sup>th</sup> century. Since then advances in our knowledge of Cape rocks has been spasmodic, yet significant.

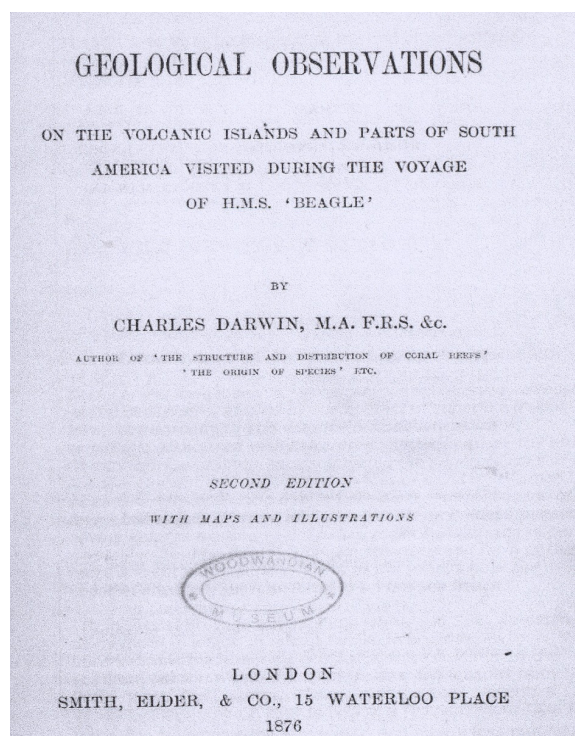
## THE PIONEERS

The first geological investigations in Cape Verde have long been credited to **Charles Darwin**. He visited the island of St. Jago (S. Tiago or Santiago in modern spelling) from 16 January to 8 February 1832, during the celebrated voyage of HSM Beagle. Darwin's first observations (Fig. 1) were made around the capital, Porto Praya (Praia), namely the citadel, Quail Island (Ilhéu de Santa Catarina), and Flag Staff / Signal Post Hill (Monte do Facho).

“The island of St. Jago extends in a NNW. and SSE. direction, thirty miles in length by about twelve in breadth. My observations (...) were confined to the southern portion within a distance of a few leagues from Porto Praya. The country, viewed from the sea, presents a varied outline: smooth conical hills of a reddish colour (...), and others less regular, flat-topped, and of a blackish colour (...) rise from successive, step-formed plains of lava. At a distance, a chain of mountains, many thousand feet in height, traverses the interior of the island. There is no active volcano in St. Jago, and only one in the group [archipelago], namely at Fogo. The island since being inhabited has not suffered from destructive earthquakes.” (Darwin, 1844/1876, p. 3).

Being the fine investigator that Darwin was, his careful observations were

accompanied by effective interpretations. He did both with great satisfaction and there is no doubt that his first acquaintance with a volcanic island was a most striking experience.



**Fig. 1:** Frontispiece of Darwin's (1844/1876) paper.

“The lowest rocks exposed on the coast near Porto Praya, are highly crystalline and compact; they appear to be of ancient, submarine, volcanic origin; they are unconformably covered by a thin, irregular, calcareous deposit, abounding with shells of a late tertiary period; and this again is capped by a wide sheet of basaltic lava, which has flowed in successive streams from the interior of the island (...). Still more recent streams of lava have been erupted from the scattered cones, such as Red and Signal Post Hills. The upper strata of the square-topped hills are intimately related in mineralogical composition, and in other

respects, with the lowest series of the coast-rocks, which they seem to be continuous (Darwin, 1844/1876, p. 3-4).

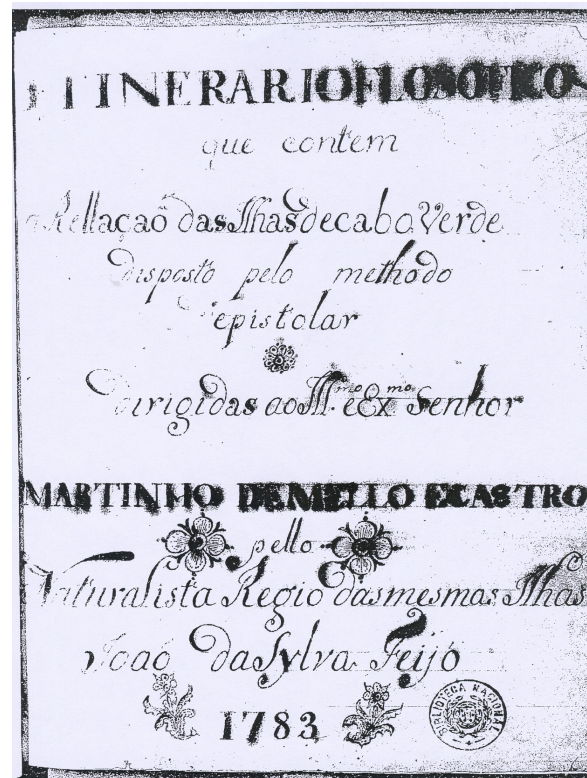
The geology of St. Jago is very striking, yet simple: a stream of lava formerly flowed over the bed of the sea, formed of triturated of recent shells and corals, which it has baked into a hard, white rock. Since then the whole island has been upheaved. But the line of white rock revealed to me a new and important fact, namely that there had been afterwards subsidence around the craters, which had since been in action, and had poured forth lava. It then first dawned on me that I might perhaps write a book on the geology of the various countries visited, and this made me thrill with delight. That was a memorable hour to me, and how distinctly I can call to mind the low cliff of lava beneath which I rested, with the sun glaring hot, a few strange desert plants growing near, and with living corals in the tidal pools at my feet” (Darwin’s autobiography, in Pearson & Nicholls, 2007, p. 240).

Although Darwin was a brilliant pioneer, he was not *the* pioneer. He has been preceded by **João da Silva Feijó** in 1783-85, and was succeeded by **Saint-Claire Deville** in 1848; both studied the nearby island of Fogo, and both were dealing with volcanic eruptions of 1785 and 1847, respectively.

The Naturalist Feijó had been a disciple of the celebrated Domenico Vandelli at the University of Coimbra. At the time, he was in Cape Verde on a Viagem Filosófica (“philosophical journey”), charged by the Portuguese Government to gather every kind of data pertaining to a naturalist inventory of the archipelago (Fig. 2). As a result Feijó was able to give us a first hand scientific description of a volcanic eruption, with a delicious baroque flavour.

“It seems that the Providence, for the passion I have for the study of Mineralogy, kindly wanted to make my wishes come true, showing me the awful spectacle of a volcanic eruption in the course of my philosophical travels: up to then it appeared

to me that by the lesson of the most celebrated contemplators of Nature I had acquired enough ideas to understand the nature of subterranean Physics, and to discourse on the different produces which constitute the study of Mineralogy, principally volcanic; yet my presumptions faded away at sight of the touching picture that she [the Providence] made me see in the last eruption of Pico do Fogo, which took place on 24 January 1785.” (Feijó, in Ribeiro, 1960, p. 239-240, translation from the Portuguese).



**Fig. 2:** Frontispiece of Feijó’s (1783) “Itinerarios F(i)losoficos”.

The geologist Sainte-Claire Deville is a somewhat different case. According to Ribeiro (1960), he was able, in a 2-day exhaustive tour, to clearly delineate the island structure, its main components, and the recent eruptions. Deville’s acquaintance with volcanoes, namely Vesuvius, surely allowed him to appreciate the great interest of the island of Fogo.

« Lorsque, vers le milieu du canal qui sépare les îles de Santiago et de Fogo, on

découvre pour la première fois cette dernière île, on est en même temps frappé de la simplicité de ses formes et de la majestueuse élévation du Pic qui la couronne. Le Pic de Ténérife, quoique plus imposant par sa masse, repose sur un ensemble de montagnes extrêmement étendu, qui en dérobe même à la vue la plus grande partie ; tandis que, vu du nord-est, le cône du Fogo a sa base au niveau même de la mer, et s'élève d'un seul jet, et presque par une pente continue, jusqu'à une hauteur de 3000 mètres.

En approchant, on distingue derrière le cône, une crête aigue, dont le point culminant rivalise en hauteur avec lui et qui l'entoure comme un rempart demi-circulaire, détruit du côté qui regarde la mer : analogie remarquable de structure avec le massif du Vésuve, qui saisit dès l'abord et qu'un examen plus approfondi ne fait que confirmer (Deville, in Ribeiro, 1960, p. 9).

### THE CLASSICS

Systematic investigations in the archipelago, and not just single islands, began with **A. Stuebel** in 1863, followed by **C. Doelter** in 1882, **I. Friedlaender** in 1912 and **J. Bacelar Bebião** in 1932. Unfortunately, the vast amount of data (descriptions, drawings and maps, rock samples) gathered by Stuebel has not been published. The result is that Doelter, Friedlaender and Bebião remain the three classics on the geology of Cape Verde.

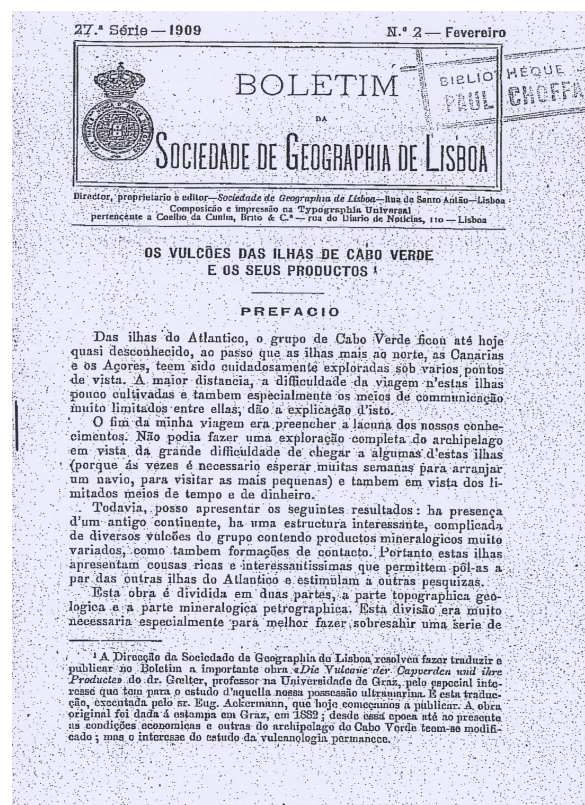
The purpose of Doelter (Fig. 3) was to fill a gap in the knowledge of the Central-North Atlantic islands, inasmuch as Cape Verde was then a remote archipelago.

“Among the Atlantic islands, the Cape Verde group remains almost unknown, while the northern islands, Canarys and the Azores, have been carefully studied under diverse points of view. The greater distance, the difficulty of travelling in these poor cultivated islands, and mainly the scarce means of transport between them, are a good explanation for that.

The purpose of my travel was to fill the gap of our knowledge. I could not make the

exploration of the whole archipelago, due to the difficulty to reach some of the islands (sometimes it is necessary to wait many weeks before getting a ship that visit the smaller ones), and also due to the limited resources in time and money” (Doelter, 1882/1909, p. 49, translation from the Portuguese edition).

Doelter divided his study in two parts, respectively “geologic and topographic”, and “mineralogical petrographic”. In the first part, he presents the results of a careful field survey made in the four islands he visited (Sto. Antão, S. Vicente, Maio, S. Tiago); yet some of the geological interpretations appear somewhat surprising, e.g. the presence, in Maio, of an “old continent” with “gneisses and crystalline schists” and “old limestones” of a probable “Palaeozoic rather than Mesozoic age”.



**Fig. 3:** Frontispiece of Doelter's (1882) paper, in the Portuguese translation.

“When we move from Monte Batalha to the northeast, we found near the aforementioned phonolite fragments of older rocks, like syenite, gneiss, etc. Further on,

on the northeastern slope of Monte Branco, limestones can be seen transformed into dolomite (...).

The hills of Monte Forte and partly of Monte Branco are made up of phonolites; on the slopes we found layered rocks that can be regarded as phonolite-bearing tufs. There are also lava streams which have flowed from Monte Forte eastwards and southwards. Finally, south of Monte Penoso, an elevated massif of stratified sedimentary rocks stretches down to the eastern coast.

Monte Branco, as well as part of Monte Grande, are made up of limestone layers dipping 20° to 30° to the east. These limestone layers are often cut by small veins of augite-rich basalts, yet no contact [metamorphic] action has been produced (...).

No one can be quite sure about the age of the limestones; they dip eastward and westward. The limestones can be either Palaeozoic or Mesozoic, but are by no means related to the Tertiary or more recent layers which are horizontal everywhere (...). Gneisses occur near the eastern coast; north of the village of Maio we found many blocks of a garnet-bearing gneiss which seems here to constitute the base" [of the sequence]. (Doelter 1882/1909, p. 167-167, translation from the Portuguese edition).

In the second, "mineralogical petrographic" part, Doelter divided the "eruptive rocks" in two age groups, respectively "older" and "younger". The "older eruptive rocks" comprise foyaite, syenite, diorite and diabase. The "younger eruptive rocks" include leucitite, phonolite, tephrite, basanite, plagioclase-bearing basalt, nepheline-bearing basalt, limburgite, and pyroxenite. The description of a typical foyaite from S. Vicente is a good example of Doelter's approach and style.

"A typical foyaite can be found about ½ mile southwest of the port of S. Vicente. It is a coarse-grained rock which forms an isolated, small hill a few meters high; the syenitic rock is cut by thin veins of basalt. With the naked eye we can see crystals of orthose, augite and nepheline; with a lens

we see small cavities filled with minute crystals of analcime. Under the microscope we recognize somewhat clouded sections of orthose and plagioclase, the last one exhibiting twin streaks; nepheline frequently appears as transparent crystals, and also in sections surrounded by orthose, yet sometimes appears altered.

Augite is present only in veinlets and pieces, not in regular crystal sections; it has a dark grey colour and a slight pleochroism. Hornblende is less common, in brown pleochroic sections rendered visible by cleavage.

Pyroxene melts easily to the red-hot heat and forms a magnetic, vitreous matter of a dark green colour.

Magnetite is seldom observed. Titanite does not appear in my microscopic thin sections . (...) Mr. F. Kertscher has performed the chemical analyses the rock and the feldspar." Doelter, 1882/1909, p. 174-175, translation from the Portuguese edition).

Three decades after Doelter, the vulcanologist Immanuel Friedlaender (Fig. 4) visited Cape Verde (islands and islets). He has since become well-known not only for his comprehensive field investigations (descriptions and interpretations), but also for having discovered the first fossils in the archipelago, specifically the Mesozoic "Aptychus" at Maio. Friedlaender acknowledged Doelter's work, but did not hesitate in correcting some views of his illustrious predecessor.

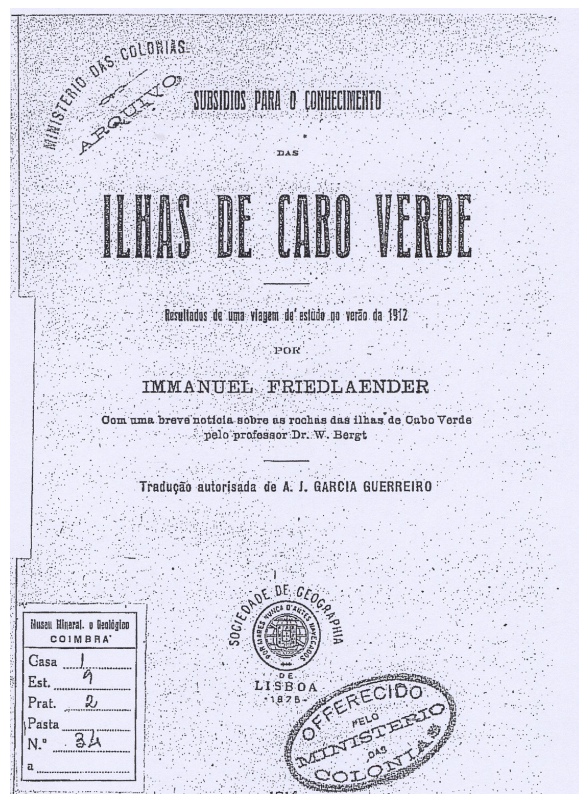
"The island of Maio has already been visited in 1881 by Doelter, who recognized there the existence of ancient crystalline rocks as well of a sedimentary limestone where he was not able to find any fossil.

Doelter mentions, among these ancient rocks, a gneiss that I have partly found not only at the same isolated places indicated by him but also and most plentiful at the former, small quay eastward of Porto Inglês, on the mouth of Ribeira Preta.

I made sure, by information gathered at the village, that this gneiss has been carried in the past from Brazil as ship ballast (...). So,

this gneiss must be excluded from the list of ancient rocks of Maio.

On the great valleys and on the slope of the mountain chain, we found a vast amount of remains of (...) crystalline rocks alike to syenite and diorite (...). These ancient rocks are cut in many places by basaltic veins. They are overlain by the ancient limestones mentioned by Doelter.



**Fig. 4:** Frontispiece of Friedlaender's (1913) paper, in the Portuguese translation.

At Morro, these limestone layers strike SW-NE and dip about 20° north-eastward. They are sometimes overlain by layers of varied shales and marls (*margeligen Tonschiefer*). In the Morro limestone layers I have found fossils, namely the *Aptychus* described by Dr. Hennig. I immediately realized the existence of fossils in these limestones. After sending the entire caravan in search of them, the first well preserved *Aptychus* was found by Eng. Fonseca" (Friedlaender, 1913/1914, p. 60).

Unlike Doelter, Friedlaender carried out no laboratory research; yet his booklet contains as Appendix II a short petrographic

report by Prof. Bergt of Leipzig. Bergt's report includes a comparative Table with data from all the islands.

"Three rock collections are at the author's disposal: one, vast and beautiful, by A. Stuebel of 1863, which is in the Geographic Museum of Leipzig; another by the author of 1912; and the third by Friedlaender also of 1912. The ensemble of these independent three collections amount to about 1,400 rock samples, which allow a rather detailed description of all the islands of the Cape Verde archipelago. All the rocks, without exceptions, have been made accessible to microscopic examination.

*The deep rocks (Tiefengesteine), as well as the vein rocks (Ganggesteine), and the younger eruptive rocks (Ergussgesteine) belong (...) to the large group alkaline rocks. They show a great variety in the mineralogical composition, greater than any other already known in the other Central Atlantic volcanic archipelago.*" Bergt, In: Friedlaender, 1913/1914, p. 100).

#### **J. Bacelar Bebiano, 1932**

The third of the classics is J. Bacelar Bebiano, a geologist and mining engineer (and also a soldier and a politician) who made geological investigations in Cape Verde during the periods 1926-27 and 1930-31 when he joined the Missão Geográfica de Cabo Verde. Bebiano's seminal "Geology of the Cape Verde Archipelago" (Fig. 5) is a 275 page monograph which contains field descriptions, many drawings and photos ... and the first geological maps of all the islands except Fogo. It also includes, as Supplement I, a petrographic and chemical study of the main rock types of S. Vicente by Prof. **Amilcar Mário de Jesus**. These maps were original and a most welcome contribution, since Bebiano himself acknowledges that much of the field and laboratory data had already been obtained by his predecessors, namely Doelter and Friedlaender.

"Unfortunately, these valuable works [Doelter's and Friedlaender's] had lacking

the indispensable geographic base, since good maps of the archipelago were not available at that time. Those observers presented geographic and lithologic descriptions, with no attempts to study the genetical relationships between the examined rocks and the magmas that have generated them. In the present work I try to fill that gap.” (Bebiano, 1932, p. 11, translation from the Portuguese).



**Fig. 5:** Frontispiece of Bebiano’s (1844/1876) Memoir.

Bebiano’s concerns about the time relationship between his mapped rock types and rock groups make him not only the last of the classics but also the first of the moderns. His description of S. Vicente is a good example.

“From a geological point of view, the island of S. Vicente is mostly made up of basic volcanic products, where the basaltic lavas predominate over the correspondent pyroclastic series of breccias, lapilli and tufs. To this ensemble I will give the name of “Basaltic Series”. These products have flowed from the crater of the main volcano formerly situated at Porto Grande and part

of the town of Mindelo, and have spread to the coast as flows and layers dipping 6° to 12° (...).

Around the main volcanic centre extends an area containing a great number of dykes of much altered, acidic and basic rocks, which cut the Basaltic Series (...) it will be called “Mindelo Volcanic Series”.

Further away from that crater, the basaltic formations are accompanied by most altered basaltic rocks cut by dykes of a curious calcite-rich rock which can be classified as a limestone. It occurs in large amounts on the left border of Salgadinha River, around K. 4.5 on the road S. Julião – Viana, and thus will be called “Salgadinha Complex”.

[As to plutonic rocks] syenite and diorite occur around a place called Pedras Brancas [white stones]; their whitish colour sharply contrasts with the dark colour of the majority of the island rocks (...).

At Salamansa, Calhau and Viana, to the north and to the east, some craters occur in a remarkable state of preservation, what means that they have been formed during a weaker, post Basaltic Series phase of volcanism”. (Bebiano, 1932, p. 111).

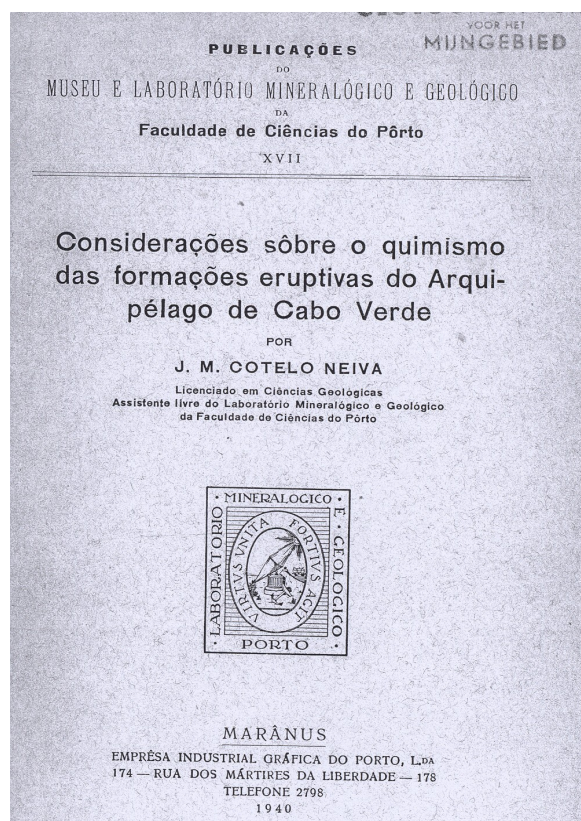
## THE RENOVATORS

Geochemistry would enter the stage somewhat later, as a first step using major elements, later using trace elements, finally using stable and radioactive isotopes. The main reference work remains Bebiano’s monograph.

### *Major element Geochemistry*

In 1940, the young **J. Cotelo Neiva**, (he was then a “Free-Assistant” at the University of Oporto), presented a paper (Fig. 6) containing a petrochemical study of the available chemical analyses by calculating and interpreting the correspondent Niggli parameters. The strong influence of Niggli on the mid-20th century European Petrology is well known; it began waning only with the development of trace element and isotope Geochemistry.

Neiva then attempted to relate the chemical characteristics of Cape Verde rocks to the regional fracture pattern as delineated by Bebiano.



**Fig. 6:** Frontispiece of Neiva's (1940) paper.

"I carried out the present essay based chiefly upon the analytical-chemical data gathered from the works by Doelter, Prof. A. Amílcar de Jesus, Eng. J. Bacelar Bebiano, and Prof. A. Lacroix, yet having been guided by the remarkable studies by Prof. Paul Niggli of Zurich, and having also consulted the works by Parga-Pondal." (Neiva, 1940, p. 5, translation from the Portuguese).

"In the following Table I have collected the Niggli parameters of both the analysed groups I created and the not grouped rocks. By using the data from this Table, I made the projections Ls-Fs-Qs (...), as well as the diagrams *al-fm-c-alk* vs *si*, and the diagram *k-mg*.

The conclusions are as follows:

1° - The Cape Verde eruptive rocks are Na<sub>2</sub>O and TiO<sub>2</sub> rich, and often present [normative] nepheline

2° - The Cape Verde eruptive formations are of the sodic type, characteristic of the Atlantic Province.

3° - The projections Ls-Fs-Qs (...) show that Cape Verde rocks are located in the triangle *lon*, the place for the alkaline series magmas. Only two rocks project in the triangle *qon*, the place for calc-alkaline magmas, and specifically in the triangle *lps*, the place for normal gabbroic magmas, yet, by their chemical characteristics (...), I have integrated them in the typical Atlantic magmas.

4° - Through the *k-mg* diagram (...) we can visualize their Atlantic character, as well as the predominance of the melanocratic rocks.

5° - The *al-fm-c-alk* differentiation diagrams (...) show the typical Atlantic differentiation, as well as a great temporal and differential dispersion, specially the basic types, and I have drawn the curve of the differentiation course. It is worth noting that the isophalic point is typically Atlantic.

6° - I admit, as for the differentiation course (...), a fundamental basic magma, from which two magmas derived, one ultrabasic, the other highly acidic, the differentiation being accompanied by a temporal-differential dispersion.

7° - An inter-dependence exists between the chemical characteristics of the Cape Verde eruptive formations and the geographic-geological features of the archipelago, as I verified that rocks displaying a calc-alkaline or Pacific, trend occur in the islands situated along a E-W lineament (Sto. Antão, S. Vicente, Sta. Luzia, S. Nicolau, and Boavista), formed along a fracture having that strike, while the islands formed along a N-S fracture, as well as the others, have no rocks displaying a calc-alkaline trend." (Neiva, 1940, p. 47-53).

Neiva's paper marked the beginning of a series of investigations using Niggli and other major element parameters. In 1950, **L. Berthois**, based upon Niggli's isophalic point, emphasized the similarities between Cape Verde rocks and those of the islands



of Los, as well as those of the East African Rift Valley. Ten years after, C. **Burri** used both Niggli's and Rittman's parameters to stress the individuality of the Cape Verde archipelago. The influence of Niggli can be perceived as late as 1979, when **Matos Alves et al.** published a "mise-au-point" on the island of Santiago.

#### *The stratigraphical basis*

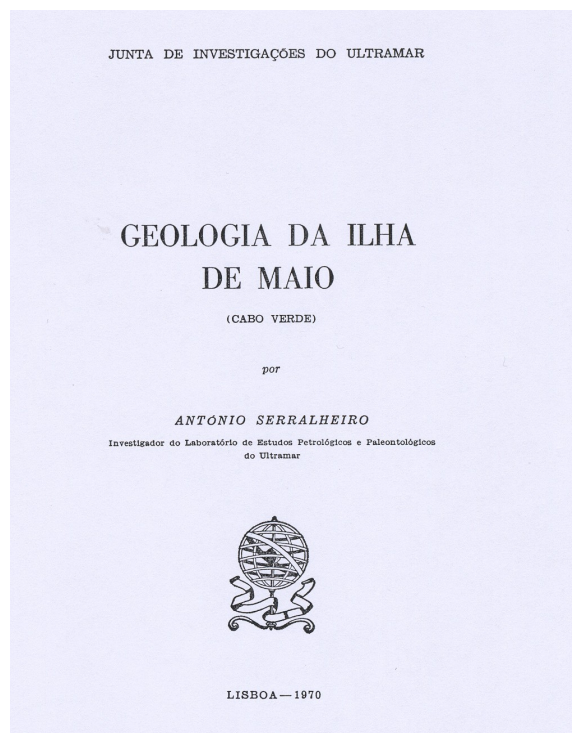
It was in the 1960s that **António Serralheiro** started his pioneering investigations on the stratigraphy of the islands, at first on S. Vicente and Maio (Fig. 7), later, already in the 1970s, on Santiago. Obviously, the stratigraphical basis created by Serralheiro became the basic support for several fine investigations by the Missão Geológica de Cabo Verde researchers, namely by **C. Torre de Assunção** on Petrology and **L. Celestino Silva** on Mineralogy, either as authors or as co-authors. Well-known contributions by Assunção include 1) the description of a wider range of plutonic rocks than had hitherto been suspected, and 2) the definitive identification of Bebiano's "curious limestone dikes" as oceanic carbonatites, indeed even today a most curious, uncommon rock. An interesting feature of Silva's research is that he generally undertook the field work himself to support his mineralogical (and petrographic) analyses.

#### **THE MODERNS**

Both the mineralogical and chemical data so far available had provided adequate evidence of the highly alkaline nature of the whole Cape Verde magmatism. The investigations of the Belgian **P. De Paepe** and **J. Klerkx** in the 1970s may be credited to constitute first step in the modern knowledge of the archipelago. *The expression "modern knowledge" is here taken as that arising from the Plate Tectonics approach (directly or otherwise) to geological problems.*

#### *Minor and trace-element Geochemistry*

Working on the island of Maio in 1974 and using chiefly REE data, they have convincingly shown the MORB character of the tholeiitic basalts associated with the Mesozoic limestones. The rapid growth of trace element geochemistry was becoming more and more useful in the framework of Plate Tectonics, so De Paepe et al. (1974) were able to present (Fig. 8) a sound, mobilistic view on the early stages in the evolution Cape Verde ocean plateau.

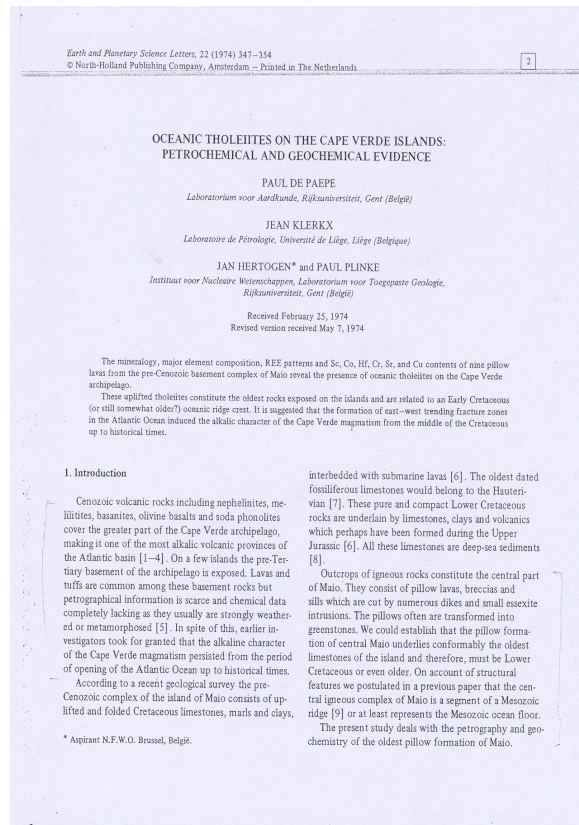


**Fig. 7:** Frontispiece of Serralheiro's (1970) Memoir.

"The present study deals with the petrography and geochemistry of the oldest pillow formation of Maio. The knowledge of these volcanics is of primary importance for understanding of both the magmatic evolution of the Cape Verde archipelago and the history of the eastern part of the central Atlantic Ocean.

(...) The mineralogy, major element composition, REE patterns and Sc, Co, Hf, Cr, Sr, and Cu contents of nine pillow lavas from the pre-Cenozoic basement complex of Maio reveal the presence of oceanic tholeiites on the Cape Verde archipelago. These uplifted tholeiites constitute the oldest rocks exposed on the islands and are

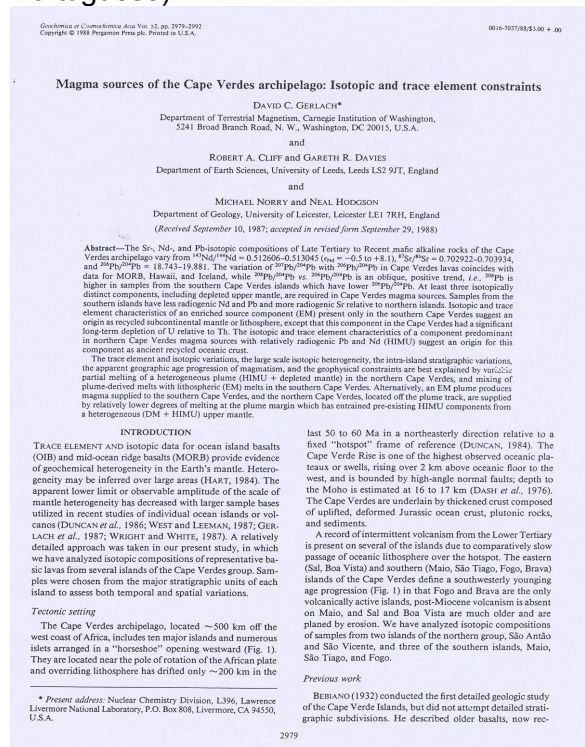
related to an Early Cretaceous (or still somewhat older?) oceanic ridge crest. (...) It is probably that the tholeiitic magma phase was a relatively short event as compared with the strongly alkaline magmatism initiating in the middle of the Cretaceous. During the fast period of ocean spreading, which ended by the middle of the Cretaceous, large-scale transverse faults developed. Due to these tectonic features the Cape Verde ridge became inactive. The formation of these pre-Cenozoic faults was, therefore, the main cause of the drastic change in the magmatical [sic] regime. Strongly undersaturated alkaline magma came easily up along these deep-seated fracture zones, from depths of more than 80 km, and capped the island during the Tertiary and Quaternary Era." (De Paepe et al., 1974, p. 347-348 and 353).



**Fig. 8:** Frontispiece of De Paepe et al.' (1974) paper.

Interestingly, the Portuguese geophysicist **F. Machado**, as early as in 1967, had speculated, based on Berthois' paper, that "the Cape Verde islands and

perhaps the Canaries may be a relic of volcanism within an ancient rift that would mark the opening of the Atlantic" (Machado, 1967, p. 24, translation from the Portuguese).



**Fig. 9:** Frontispiece of Gerlach et al. (1988) paper.

**Isotope Geochemistry**

The systematic, rather than occasional, use of isotopes (Sr, Nd, Pb) started in the late 1980 with the well-known paper (Fig. 9) by **Gerlach et al. (1988)** dealing with the islands of Fogo, Santiago, Maio, S. Vicente, and Sto. Antão). This is an important step in the knowledge of the archipelago. Indeed, it had just been recognized that trace element and isotope data from mid-ocean ridge basalts (MORB) and ocean island basalts (OIB) provide evidence of geochemical heterogeneities in the Earth's mantle. Any adequate sampling of ocean island rocks must take into account both their place (geographic) and time (stratigraphical) position. It is worth noting the highly "scientific" (as opposed to "naturalistic") style adopted by Gerlach et al.

The Sr-, Nd-, and Pb-isotopic composition of Late Tertiary to Recent mafic alkaline rocks of the Cape Verde archipelago vary from  $^{143}\text{Nd}/^{144}\text{Nd} = 0.512606\text{-}0.513045$  ( $\epsilon\text{Nd} = -0.5$  to  $+ 8.1$ ),  $^{87}\text{Sr}/^{86}\text{Sr} = 0.702922\text{-}0.703934$ , and  $^{206}\text{Pb}/^{204}\text{Pb} = 18.743\text{-}19.881$ . The variation of  $^{207}\text{Pb}/^{204}\text{Pb}$  with  $^{206}\text{Pb}/^{204}\text{Pb}$  in Cape Verdes lavas coincides with data for MORB, Hawaii, and Iceland, while  $^{208}\text{Pb}/^{208}\text{Pb}$  vs.  $^{206}\text{Pb}/^{204}\text{Pb}$  is an oblique, positive trend, i.e.,  $^{208}\text{Pb}$  is higher in samples from the southern Cape Verdes islands which have lower  $^{206}\text{Pb}/^{204}\text{Pb}$ . At least three isotopically distinct components, including depleted upper mantle, are required in Cape Verdes magma sources. Samples from the southern islands have less radiogenic Nd and Pb and more radiogenic Sr relative to northern islands. Isotopic and trace element characteristics of an enriched source component (EM) present only in the southern Cape Verdes suggest an origin as recycled subcontinental mantle or lithosphere, except that this component in the Cape Verdes had a significant long-term depletion of U relative to Th. The isotopic and trace element characteristics of a component predominant in northern Cape Verdes magma sources with relatively radiogenic Pb and Nd (HIMU) suggest an origin for this component as ancient recycled oceanic crust.

The trace element and isotopic variations, the large scale isotopic heterogeneity, the intra-island stratigraphic variations, the apparent geographic age progression magmatism, and the geophysical constraints are best explained by variable partial melting of a heterogeneous plume (HIMU + depleted mantle) in the northern Cape Verdes, and mixing of plume-derived melts with lithospheric (EM) melts in the southern Cape Verdes. Alternatively, an EM plume produces magma supplied to the southern Cape Verdes, and the northern Cape Verdes, located off the plume track,

are supplied by relatively lower degrees of melting at the plume margin which has entrained pre-existing (HIMU components from a heterogeneous (DM + HIMU) upper mantle (Gerlach et al., 1988, p. 2979).

Since the paper by Gerlach et al., the number of studies on Cape Verde petrology and geochemistry has been growing rapidly. They typically share 1) a most generous use of trace element and isotopic analyses, 2) plume-based discussions on magma sources in the mantle, and 3) an austere, somewhat esoteric literary style.

### CONCLUSION

In his well-known book of 1976 on the Macaronesia archipelagos, **R. Mitchell-Thomé** could write "... the literature and geological mapping is much less impressive than those relating to the Azores and Madeira. We would further remark that it is chiefly the Portuguese geologists who have interested themselves in these islands, a very different case from the Canaries, which have attracted an international group of workers". (Mitchell-Thomé, 1976, p. 247).

Following the post-independence political opening of the archipelago, the situation has since somewhat changed, yet in absolute rather than relative terms within Macaronesia. This is a most surprising situation, since the Cape Verde Islands are no less interesting – and not only from a petrologic-geochemical point of view – than the islands of the Azores, Madeira and the Canaries.

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