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6 Cretaceous and Cainozoic Magmatism of the Senegal Basin (West Africa): A Review

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1 Introduction

Extensive basic magmatism affects the westernmost part of West Africa, and events occurred from the late Cretaceous up to the Quaternary. The various occurrences are scattered in the Cap-Vert in an area 100 km long extending from Dakar to the east of Thiès and represent the only visible part of a larger magmatic province. This province also includes the Leona dome evidenced by drilling and offshore volcanism in the Dakar and Cayar Seamount areas (Fig. 1).

Permian to Jurassic tholeiitic dolerites, occurring as large dykes and sills, are ubiquitous in the Precambrian and Palaeozoic formations bounding to the east and south the Senegal Basin. In the basin itself, their presence in the Palaeozoic terranes

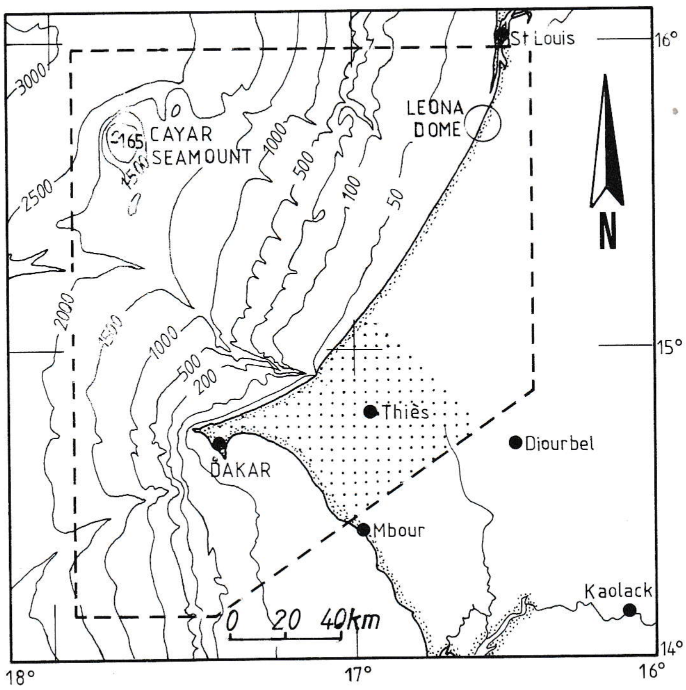

Fig. 1. Location map of the Senegalese volcanic province. *Stippled area* indicates the onshore zone of volcanic outcrops. *Dashed line* is the inferred limit of the volcanic province

underlying the Mesozoic cover is inferred from gravimetric and magnetic anomalies and the occurrence of an early Mesozoic thermal event (Liger 1980; Reyre 1984). They belong to a larger magmatic province extending throughout West Africa (Black and Girod 1970; May 1971; Bertrand 1983a). This extensional, fissural tholeiitic magmatism is connected with the initiation of the rift phase of the opening of the Central Atlantic. It will not be discussed any further in this paper, a contribution in the present volume (Bertrand this vol.) being devoted to this subject.

Since the beginning of the century, the volcanism of the Cap-Vert area has been investigated by many authors; the main contributions are those of Chautard (1906, 1907), Combier (1934, 1935, 1952), Gorodiski (1952), Tessier (1952, 1954), Debant (1963), Faure et al. (1967), Fraudet (1970), Crevola (1974, 1975a–c, 1978, 1980a and b), Uchupi et al. (1976), Meagher et al. (1977), Cantagrel et al. (1978a), Dia et al. (1987). After Chautard's account of the volcanic rocks of the Dakar area, our knowledge progressed slowly during half a century. In this period, however, new occurrences of volcanic rocks were recognized during mapping and drilling. A major discovery, made during oil prospection in 1957, was that of the Cretaceous Leona alkali syenite dome. In the 1960's, detailed work was carried out on the Mamelles Quaternary volcanism and that of the Thies area. In the last decade decisive progress has been made in the study of this province:

Table 1. Whole rock K/Ar ages of volcanic rocks from the Cap-Vert Penisula (Cantagrel et al. 1978a)

1	Mamelles, cone sheet	Doleritic hawaiite	1.05 ± 0.20 Ma
2	Almadies, lava flow	Doleritic hawaiite	1.10 ± 0.06
3	Almadies, Wakome, lava flow	Basanite	1.10 ± 0.05
4	Ouakam, chilled block in base-surge deposits	Basanite	1.00 ± 0.10
5	Ouakam, lava flow	Doleritic hawaiite	1.40 ± 0.20
6	Point K, lava flow	Doleritic hawaiite	1.50 ± 0.10
7	Point K, lava flow	Doleritic hawaiite	2.90 ± 0.30
8	Ile des Madeleines, lava flow	Doleritic basanite	6.90 ± 0.20
9	Ile des Madeleines, lava flow	Basanite	5.30 ± 0.30
10	Pointe de Fann, lava flow	Basanite	7.90 ± 0.40
11	Cap Manuel western coast, lava flow	Basanite	7.65 ± 0.40
12	Cap Manuel eastern coast, lava flow	Olivine melilite nephelinite	8.50 ± 0.40
13	Diack, plug	Basanite	7.80 ± 0.50
14	Diack, plug	Doleritic basanite	10.30 ± 0.50
15	Lam-Lam, dyke	Basanite	12.0 ± 1.50
16	Sene Sérère, lava flow	Basanite	13.0 ± 0.50
17	Ravin des Voleurs, dyke	Basanite	13.3 ± 0.60
18	Gorée, lava flow	Doleritic basanite	13.50 ± 0.40
19	Cap des Biches, sill	Basanite	20.90 ± 0.60
20	Rufisque, sill (?)	Olivine nephelinite	21.5 ± 2
21	Anse des Madeleines, sill	Olivine nephelinite	30.7 ± 2
22	Bandia, dyke	Olivine nephelinite	35.5 ± 1.50

5, 6 and *7* are samples of the same flow. The discrepancy in age is attributed to an alteration of sample 7.

- marine geophysical data demonstrate an important offshore extension of inland known volcanism;
- a detailed survey of the numerous outcrops, along with petrographic and volcanologic studies, was carried out;
- radiometric age determinations and new stratigraphic results provide a fairly good chronological framework.

Detailed mineralogical, geochemical and isotopic investigations are now needed in order to define the mantle melting conditions which then permit more relevant comparisons with other intraplate volcanic areas, especially those of the Eastern Central Atlantic (Canary and Cape-Verde Archipelagoes).

Stratigraphic results and radiometric age determinations (Hebrard et al. 1969; Cantagrel et al. 1976, 1978, this paper, Table 1) show a long period of discontinuous magmatic activity starting in the late Senonian and ending in the early Pleistocene. The Cretaceous magmatism should be distinguished from the Cainozoic one because of its petrographic features and its geodynamic significance. Following Combier (1934, 1935), the Cainozoic volcanism is usually divided into a Tertiary and a Quaternary volcanism, because of the existence of a stratigraphic reference layer: a ferruginous lateritic crust formed during a long period of rock weathering between the two magmatic events.

After an overview of their regional geological setting, the Cretaceous magmatism and the Tertiary and Quaternary volcanisms are successively described.

2 Geological Setting

2.1 Geodynamic Framework

The Cretaceous and Cainozoic magmatisms are located between the Senegal River and the Gambia River latitudes, on the African continental slope and outer continental shelf. Three large magmatic areas can be distinguished: Dakar or Cap-Vert, Cayar seamount and Leona. They determine prominent positive gravity anomalies, as shown in Fig. 2 (Meagher et al. 1977). Other positive gravity anomalies, located near the southern Mauritanian coast, may also be ascribed to volcanic structures (Wissmann 1982). The sedimentary cover is more than 8 km thick in this part of the West African passive margin. It overlies a transitional continental crust, a typical oceanic crust appearing from the 18° meridian westward. Crustal thinning has been inferred by Liger (1980), Liger and Roussel (1979), van der Linden (1981) and Roussel and Liger (1983). They interpret gravity or magnetic data as a rapid seaward rise of the Moho attributed to a pre-Jurassic rifting. The numerous, roughly N-S trending faults with a west downthrow which parallel the coastline (Fig. 3), are usually interpreted as listric growth faults of a passive margin. We interpret these faults as the probable extension of fractures bounding tilted crustal blocks and cutting through the sedimentary cover.

Magmatism in Senegal is located near or at the intersection of these major crustal faults with other faults of E-W transform trend, initiated by the Central Atlantic rifting during the Triassic. As already stated by Dillon and Sougy (1974) and by van der

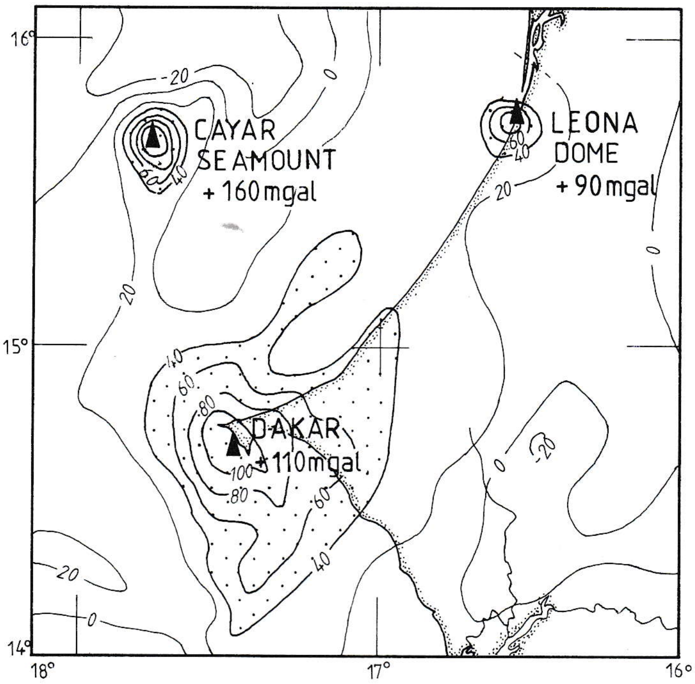

Fig. 2. Gravimetric map of the Senegalese volcanic province: offshore, free-air anomalies; onshore, Bouguer anomalies (after Meagher et al. 1977)

Linden (1981), the magmatism acted along ancient zones of crustal weakness during stress-release periods. Such periods would have immediately followed compressive events taking place in the North African Alpine belt. The Cap-Vert area, devoid of halocinetic deformations, separates the southern Guinea-Casamance field, containing late Triassic to Liassic halite and anhydrite diapirs (Ayme 1965; Templeton 1971), from the northern evaporite basin offshore of Mauritania. The Cap-Vert area was a physiographic high, perpendicular to the trend of the basin, hence appearing during its formation at the onset of the continental breakup. This high transverse zone originated from ancient fractures of the Pangea continental crust propagating as transform faults in the newly spread oceanic crust, after the initial, late Triassic to early Jurassic, rifting (Guiraud et al. 1985). The thinned continental crust of this zone, divided into blocks by transform and marginal faults, became tectonically unstable and liable to later magma influx. The presence of partly contemporaneous volcanic activity in the Cape Verde Archipelago (Grunau et al. 1975; Mitchell et al. 1983) facing the Senegalese volcanic area 500 km offshore, is not fortuitous as it is located on the western prolongation of the same transform faults (Hayes and Rabinowitz 1975).

The relationships between the volcanic areas, the fracture pattern and the location of evaporite basins is shown in Fig. 3. Inland extensions of transform faults are inferred from aeromagnetic and gravity maps (Bureau de Recherches Petrolières 1956; Crenn and Rechenmann 1965; Meagher et al. 1977; Bellion and Guiraud 1984).

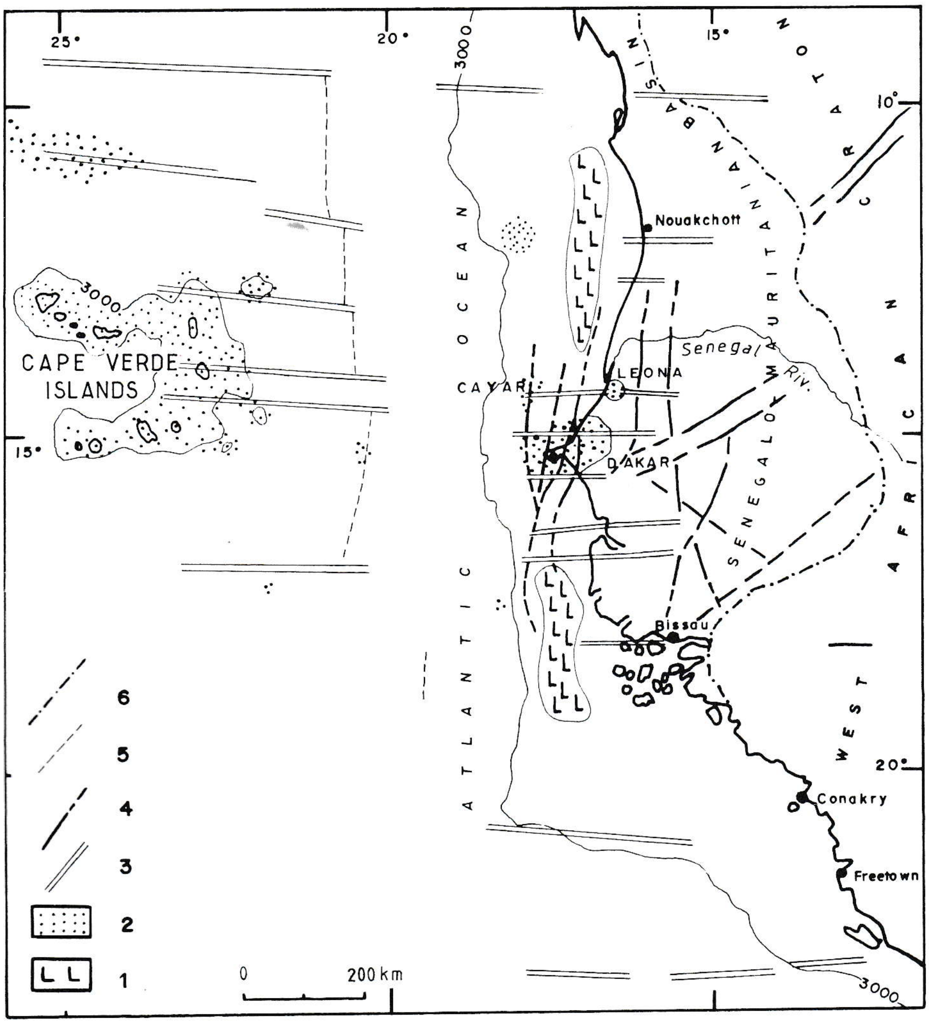

Fig. 3. Geological and structural setting of the Cap-Vert volcanic province (after Bellion and Guiraud 1984, modified). *1* Triassic-Liassic evaporite basins; *2* Aerial and submarine volcanic outcrops; *3* Inferred transform faults; *4* Faults; *5* Western limit of the Jurassic magnetic quiet zone; *6* Eastern boundary of the post-Palaeozoic Senegal-Mauritania Basin

2.2 Structure and Stratigraphy of the Senegal Basin

The Senegal sedimentary Basin (De Spengler et al. 1966; Castelain 1965; Jansa and Wiedmann 1982; Wissmann 1982; Bellion and Guiraud 1984; Bellion 1987), also known as the Senegal-Mauritania Basin, is the westernmost and largest marginal basin off West Africa: 340000 km^2, 1400 km from north to south, and 500 km in its maximum width at the latitude of Dakar, for its onshore part. Because of an important sandy cover (Oligocene to Present), our knowledge concerning the structure and the stratigraphy of the basin is mainly based upon data from oil and water exploration drillings.

The overall structure of the basin is that of an "Atlantic type" passive margin half-basin with: (i) a sedimentary infilling which becomes thicker seaward, and consists of superposed prograding elementary wedges; (ii) a very weak, commonly westward, dip of the layers, with a more or less progressive slope of the substratum in the same direction; (iii) an apparent transgressive character of the deposits westward and eastward, which is linked with oceanic spreading and subsidence.

The pre-Mesozoic basement which slopes gently westward in the onshore part of the basin, is downthrown to the west along north-south fault between the 15° W and 16° W meridians. It lies at a supposed average depth of 6000 m underneath Dakar and at more than 8000 m under the continental shelf of Casamance (Fig. 4).

This rather simple overall pattern becomes more complex southward because of the presence of about ten salt diapirs which pierce the sedimentary cover of the continental shelf of Casamance. Their upward motion started in the early Cretaceous and still continues. Northward, near the front-line of the continental shelf, the Basin is disturbed by several horsts and grabens, delineated by roughly north-south trending faults: the Ndiass and Dakar horsts, which are separated by the Rufisque graben, the submarine high off Mbour, the Guiers dome Rkiz ridge at the latitude of Saint Louis. This block-faulting and uplift tectonics occur in several episodes in response to Alpine orogenic events from the late Cretaceous to the late Miocene.

Two main discontinuities affect the sedimentary cover. The oldest, early to middle Senonian in age, is visible offshore of Guinea (Dumestre and Carvalho 1985), Casamance and Dakar area (Fig. 4). The youngest, dated as Oligocene, is found all over the basin and is characterized by an important erosion gap, either onshore or offshore (D2 discontinuity).

The sedimentary sequence begins with evaporites, such as halite, gypsum and anhydrite of Triassic-Liassic ages. According to Templeton (1971), their deposition coincides with the birth of the basin of the rift stage of the Central Atlantic, and with an important phase of tholeiitic magmatic activity. These evaporites were reached through drill-holes into some diapiric structures of the continental shelf of Casamance.

The Jurassic (Callovian-Portlandian) consists of a 2000 m-thick sequence of carbonates. This sedimentation, linked to a very strong subsidence, represents the main stage in the upbuilding of the backbone of the continental platform. This stage develops up to the late Aptian with a higher occurrence of detrital elements, probably since the Berriasian.

From the latest Aptian to the Lutetian, a more extensive clastic sedimentation occurred in the basin. It is represented by fine argillaceous and organic matter-bearing deposits at the Albian or the Turonian, or by chemical to biochemical deposits since the Paleocene. The alkali syenite dome of Leona, near Saint Louis, was emplaced before the deposition of the "aquiferous sands of Senegal" during the Maastrichtian.

After the phase of the end of the Lutetian, which represents the major tectonic episode in the basin's history, and the general withdrawal of the sea which locally remained in the Casamance gulf, the Senegal Basin experienced an essentially continental evolution, from the late Eocene to the Present. Such evolution is characterized by an intense ferralitic weathering and by volcanic events which occurred in the Cap-Vert area, with two climaxes at the Miocene and the Quaternary.

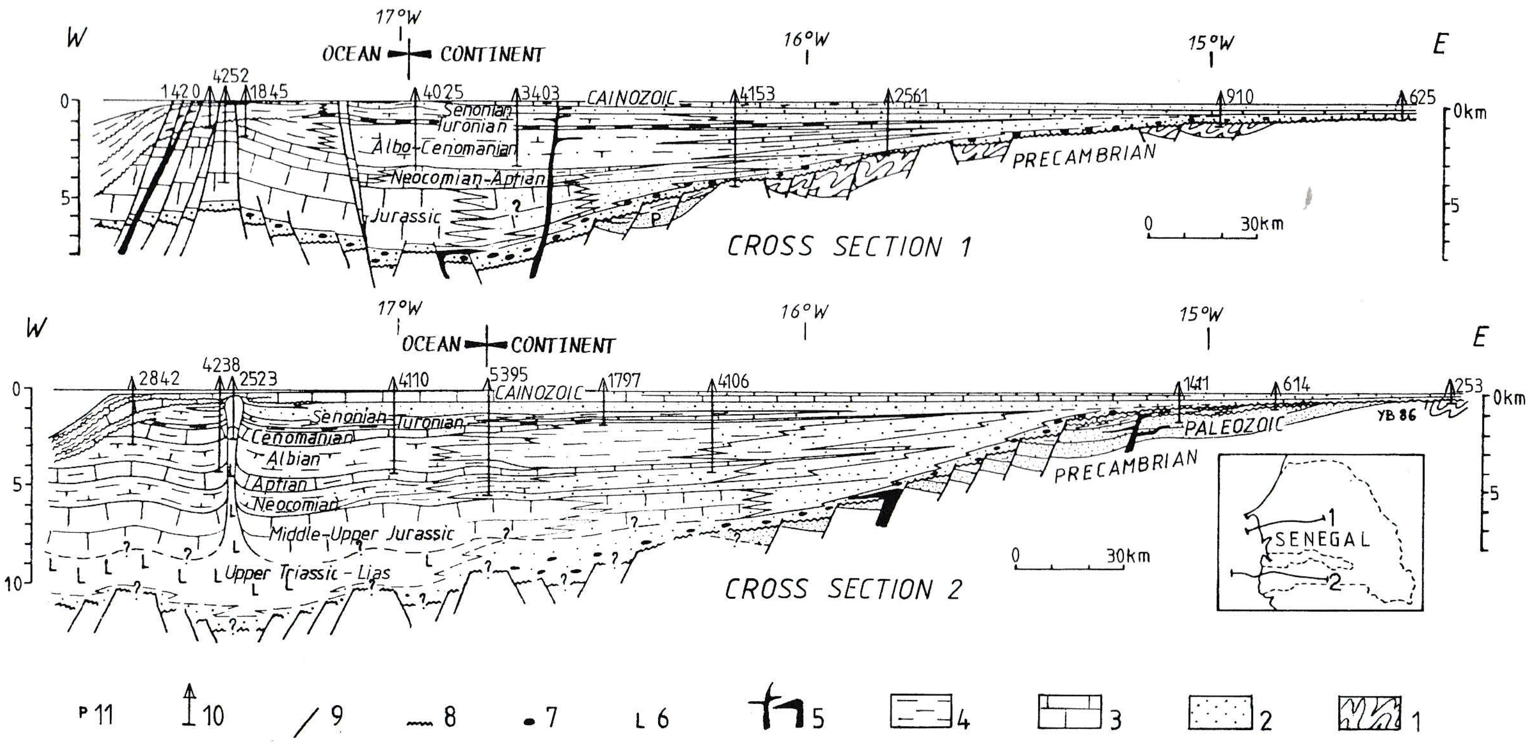

Fig. 4. Semi-interpretative geological cross sections of the Senegal Basin constructed from borehole data (after Bellion 1987). *1* Metamorphic rocks; *2* Sand, sandstone; *3* Limestone; *4* Clay and shale; *5* Igneous rocks (intrusive or lava-flow); *6* Evaporite; *7* Conglomerate or coarse-grained detrital rocks; *8* Unconformity; *9* Fault; *10* Borehole (total thickness in meters); *P* Palaeozoic

3 Cretaceous Magmatism

The Cretaceous intrusion of Leona is located 30 km to the SSW of Saint Louis town. It does not crop out but its presence is revealed by prominent positive circular gravity (90 mgal) and magnetic highs (Bureau de Recherches Petrolières 1956; Crenn and Rechenmann 1965).

The domal structure was reached at a depth of 463 m by the Leona 1 (La 1) oil exploration drilling (S. A. P. 1957). A thermally metamorphosed dolomitic limestone, probably Neocomian in age, with alkali microsyenitic breccia injections, was found under the Maastrichtian aquiferous layer (Fig. 5). These features can be considered as demonstrative of a magmatic stoping mode of emplacement. The alkaline character of the syenite is inferred from the petrographic description of Bodin (in Société Africaine des Petroles 1957a, b) who mentions sodic amphibole and pyroxene but no nepheline. Since the Leona 2 (La 2) drilling, 8.5 km southeast of La 1, shows the aquiferous sands unconformably overlaying Senonian layers, probably Campanian, the intrusive body is supposed to have been emplaced during the early Maastrichtian. According to Liger (1986) this Leona dome, 7 km wide at the top and 14 km wide at a depth of 7 km, sits almost entirely within the sedimentary layers. In Fig. 5, the intrusive body is less wide.

The Leona anorogenic intrusion can be compared with other intrusions of the same type occurring during Cretaceous times within the North Atlantic passive margins. Along the West African coastline another intrusive body crops out in Los Archipelago: the anorogenic subvolcanic ring complex of nephelinic syenite of Los, offshore of Conakry, studied by Lacroix (1911) and Millot and Dars (1959), emplaced during Albo-Senonian times (105–80 Ma, Lazarenkov and Sherif 1975). Because of the internal dip of the primary magmatic structures in the external islands, a funnel-shaped complex is assumed by Moreau et al. (1986b). In the Baltimore Canyon Trough on the eastern U. S. continental margin, the Great Stone Dome, a pre-Cenomanian mafic intrusion, has been recognized (Schlee et al. 1979; Folger et al. 1979;

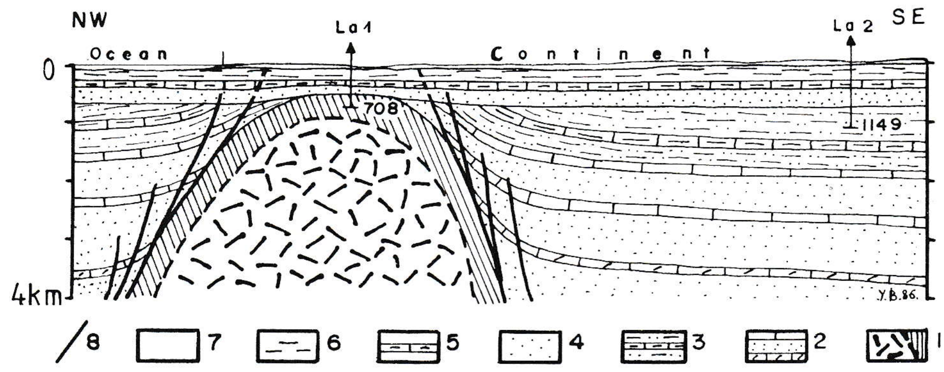

Fig. 5. Schematic section of the Leona dome (after Bellion 1987). *1* Syenite intrusion and its brecciated aureole of contact metamorphism; *2* Limestone, dolomite, sandstone and clay of the lower Cretaceous; *3* Clay and sand of the middle and upper Cretaceous; *4* Maastrichtian sand; *5* Paleocene clay and limestone; *6* Eocene clay and marly limestone; *7* Quaternary sand; *8* Fault

Sheridan et al. 1979; Klitgord and Behrendt 1979). Its shape and relationships with the surrounding sedimentary layers resemble those of the Leona dome. In the Maio island of the Cape Verde Archipelago the occurrence of a mid- to late Cretaceous magmatic phase of alkaline character has been inferred by Stillman et al. (1982) from the occurrence of clasts of both subaerial and plutonic alkaline rocks in the upper Cretaceous Coruja formation.

These magmatic events may be related to the rearrangement of plate motions known as the "mid-Cretaceous revolution" (Olivei et al. 1984; Jansa and Pe-Piper 1985). During this period (from 115 Ma to 85 Ma), the African plate starts its northward motion toward the Eurasian plate, the Equatorial Atlantic begins to open up and alkaline magmatism is widespread in both oceanic and continental intraplate environments.

4 Tertiary Volcanism

The Cap-Vert volcanic area is marked by a triangle-shaped (100×90 km) prominent gravity anomaly (110 mgal), centered upon the southwest coast of the peninsula head (Fig. 2), and by conspicuous magnetic anomalies. This volcanic area consists of the Tertiary and Quaternary volcanics, which are locally superposed.

On land, the Tertiary volcanism characterized by alkaline and strongly undersaturated lavas, is represented by numerous small occurrences which are scattered in the Cap-Vert, Ndiass horst and Thies areas (Fig. 6). Some lavas and tuffs have been found in many wells and drillings. Offshore of Dakar, to the south, some rocks shoals associated with local magnetic anomalies have been referred to as Tertiary volcanic outcrops (Horn et al. 1974).

During the bathymetric and geophysical surveys off Cayar, the focus was put on the Cayar seamount volcanic area (Seibold and Hinz 1974; Uchupi et al. 1976; Meagher et al. 1977). The Cayar seamount, which is located 60 km to the NNW of Dakar, rises from a bottom of 1700 m to a depth of 185 m, its basal diameter being 15 km (Fig. 7). Two other small seamounts are connected with it. This volcanic area is marked by an elliptic gravimetric anomaly of 160 mgal and also by important magnetic anomalies. The volcanic rocks have not been sampled until now.

4.1 Stratigraphy and Age of Volcanism

An approximate idea of the age of the volcanic events is suggested by the stratigraphic context. The youngest formations cross-out by dykes are middle-Eocene in age. The Anse Bernard tuffs in Dakar contain *lepidocyclina*-bearing limestone blocks of Oligocene age. Moreover, almost all the exposures, which are very often of small extent and deeply weathered, are capped by an iron crust, the age of which is probably end-Pliocene. On land, the Tertiary volcanics are thus emplaced between the late Eocene and the end of the Pliocene.

The age of emplacement of the Cayar seamount may be estimated from seismic-reflexion data correlated with results of oil exploration drillings (Seibold and Hinz 1974; Meagher et al. 1977). The D2 discontinuity, which is now properly dated from

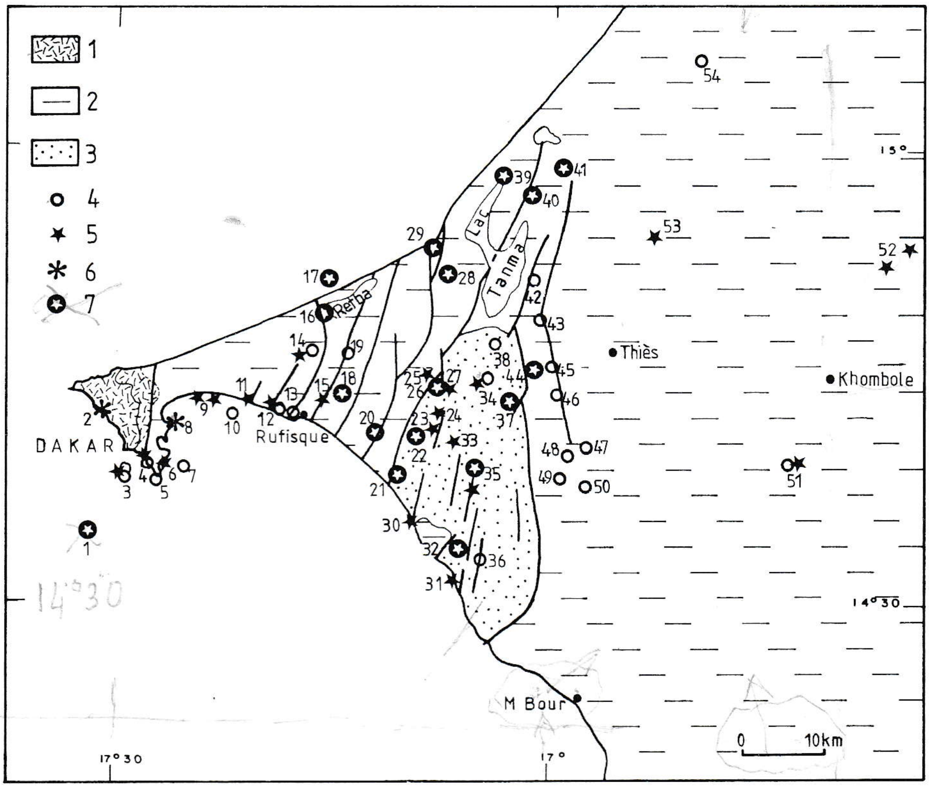

Fig. 6. Location map of Cap-Vert volcanic outcrops (after Crevola 1975a–c and 1978). **1** Quaternary volcanism. In *dashed line* the inferred extension of volcanism under the superficial sands; **2** Tertiary basement; **3** Mesozoic basement; **4** *Dyke, sill or lava flow*. Ile des Madeleines *3*; Anse des Madeleines *4*; Cap Manuel *5*; Ile de Gorée *7*; Banc de la Résolue *10*; Cap des Biches *12*; Diokoul *13*; Niakoul Rap *14*; Sangalkam *19*; Ouobine *34*; Khazabe *36*; Sène Sérère *38*; Fouloume *42*; Bellevue *43*; Ravin des Voleurs *45*; Keur Mamour *46*; Kissane *47*; Thiéo *48*; Bandia *49*; Thiéo 2 *50*; Diack *51*; Taïba *54*. **5** *Volcanic tuff* (*sill, dyke or pipe*). Ile des Madeleines *3*; Anse des Madeleines *4*; Anse Bernard *6*; Dakar-Marine boreholes *9*; Mbao *11*; Cap des Biches *12*; Niakoul Rap *14*; Santhiaba *15*; Gandoul *23*; Yeba *24*; Mbirdiam *25*; Sandock *27*; Toubab Diallao *30*; Cap de Naze *31*; Paki *33*; Ouobine *34*; Ndiass *35*; Diack *51*; Bare Diam and Beaufi *52*; Lam Lam *53*. **6** *Base surge tuff of maar volcano*. Mamelles *2*; Bel Air *8*: **7** *Oil exploration drilling cutting through volcanic rocks*. Such drillings are too numerous in the westernmost part of the peninsula (Dakar area) to be shown on this map. Cap-Vert Marine (CVM 1) *1*; Retba 1 (Rt 1) *16*; Dakar Marine 1 (DKM 1) *17*; Kabor 1 (Ka 1) *18*; Bargny 1 (By 1) *20*; Yenn 3 (Ye 3) *21*; Dougar 2 (Do 2) *22*; Sebissou 1 (So 1) *26*; Tamna 1 (Ta 1) *28*; Cayar 1 (Cr 1) *29*; Popenguine 1 (Pp 1) *32*; Ndiass 1 (DS 1) *35*; Pout 2 (Pt 2) *37*; Gadiaga 1 (Gd 1) *39*; Mont Rolland 1 (Rd 1) *40*; Mont Rolland 2 (Rd 2) *41*; Pout 1 (Pt 1) *44*

the Eocene-Oligocene boundary, is raised and pierced by the seamount (Fig. 7). The arrangement of the three later series of Miocene age is modified around the dome by presenting successive levels. In contrast, the Plio-Quaternary beds are not disturbed. These data suggest a pre-Pliocene emplacement which lasted during the whole Miocene.

Further precisions were obtained by means of radiometric age determinations performed on 22 samples of volcanic rocks. The radiometric ages range from

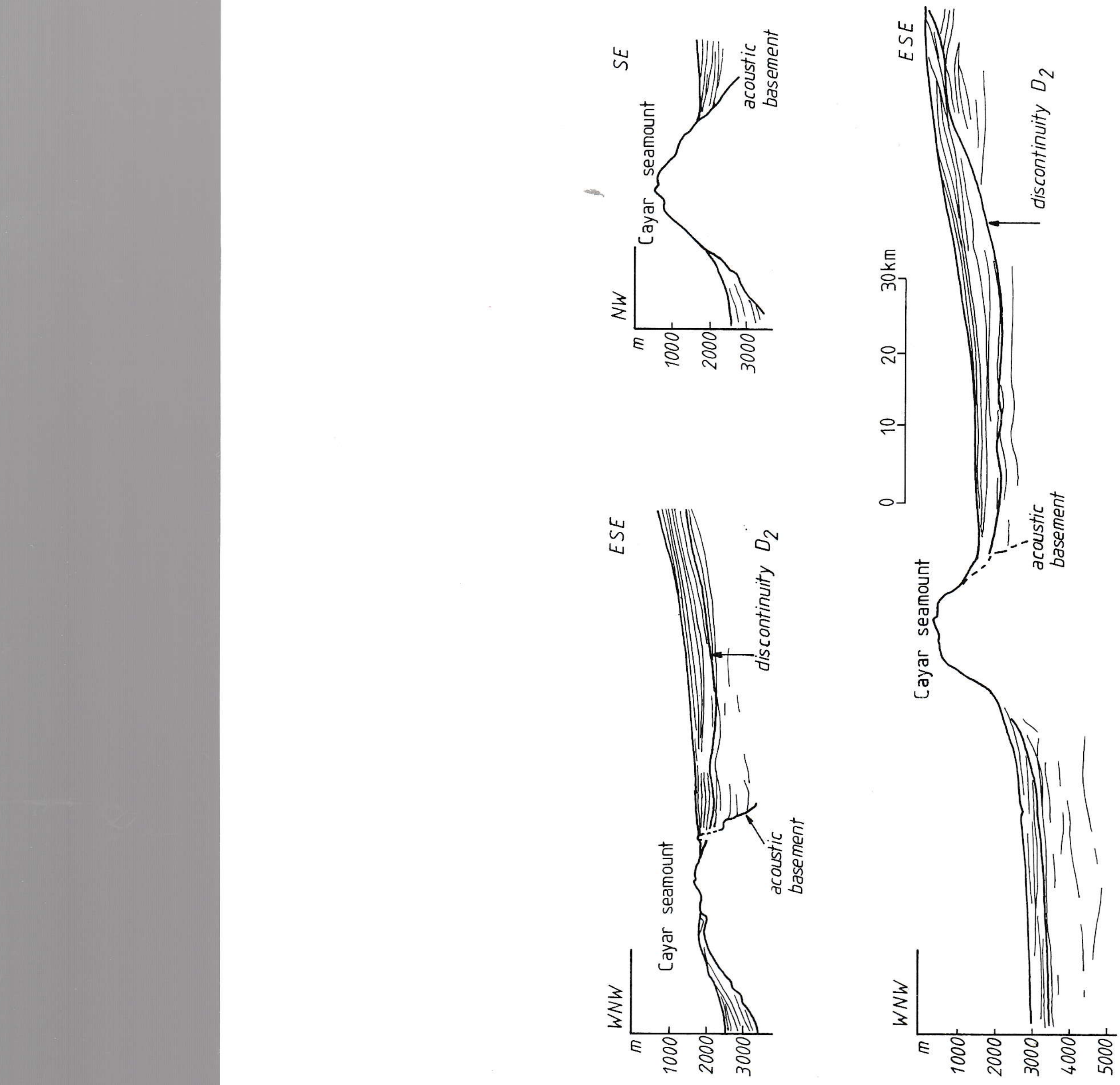

Fig. 7. Seismic-reflexion profiles from the Cayar seamount volcanic area (after Seibold and Hinz 1974)

35.5 ± 1.5 Ma to 5.3 ± 0.3 Ma (Table 1) (Cantagrel et al. 1978a, b), i.e. from the late Eocene to the Mio-Pliocene boundary. However, the main volcanic stage seems to be Miocene in age. The volcanic activity begins in the Thies area by the intrusion of the olivine nephelinite of Bandia (35.5 ± 1.5 Ma). In Dakar, the first volcanic event occurred during the Oligocene: the olivine nephelinite sill of Anse des Madeleines is dated at 30.7 ± 2 Ma; the detrital *Lepidocyclina*-bearing limestone blocks of Oligocene age, set in the tuffs of the Anse Bernard pipe, contain angular fragments of basalt which already bear witness of a volcanic activity.

These data show neither a migration of volcanism inside the volcanic area of Cap-Vert nor any magmatic evolution through time.

4.2 Types of Occurrence and Volcanic Activities

Because of an important erosion and lateritic weathering occurring at the end of the Tertiary and during middle to late Quaternary, no aerial volcanic edifice can be observed any longer, and the existence of lava flows is not absolutely certain.

Most of the Tertiary remains are small subsurface intrusions, sometimes linked with volcanic tuffs. However, three intrusive masses are more important and present noticeable gravity anomalies: those of Niakoul Rap and Ndiass, which are composed of doleritic gabbro with an ophitic texture, and the one of Diokoul, composed of olivine nephelinite. These intrusions are clearly linked with the submeridian faults in several places. For instance, the Thiès cliff fault is dotted with intrusions, and the tuff and lava intrusions of Mbao-Rufisque stretches in a N 20-N 30 direction which corresponds to the main local fracture trend (Brancart 1975).

In the Dakar area, very thick (30 to 40 m) but little extended tongues in the Cap Manuel, Gorée Island and Madeleines Islands are generally considered as flows, because of their beautiful columnar jointing, sometimes differentiated into two columns. However, their base and top cannot be observed. Without any doubt, these remains belong to an important dismantled volcanic center active during several millions of years.

The volcanic tuffs play an important part among the products of Tertiary volcanism. The way they were emplaced has remained controversial for a long time: lahars, interbedded submarine tuffs, intrusive tuffs (Hubert and Lenoble 1927; Combier 1935; Tessier 1952 and 1954). In fact, their structural and petrographic characteristics and their relationships with the surrounding rocks show that they are intrusive tuffs which were emplaced as sills, dykes and pipes by a fluidization process (Crevola 1978). Some other tuffs, which are deeply weathered or have been found to occur in wells and drillings, seem to be of similar origin. Sills and dykes of tuffs are very abundant in Dakar town, where they were described on the coastal cliffs (Combier 1935; Crevola 1978) and found in many foundation works (Tessier 1954). Two large pipes, those of Anse Bernard (400 × 300 m) in Dakar and of Toubab Diallao (400 × 50 m), well exposed in coastal cliffs, show characteristic structures of pipe infilling (Mac Callum et al. 1975): steeply dipping beds undisturbed by blocks, "descended" blocks of sedimentary rocks which are younger than the wall rocks. So the Anse Bernard pipe contains *Lepidocyclina* limestones from the Oligocene which are no longer exposed. The Diack plug can be regarded as a jagged lava lake set in a maar at the top of a pipe.

These heterometric tuffs are composed of vesicular and nonpalagonitic basaltic elements, and of sedimentary rocks from the surrounding formations cemented by fines, calcite and sometimes barite. Basaltic amphibole and biotite phenocrysts can be found either in basaltic elements, or freely in tuff, or making up hornblendite xenoliths. These petrographic characteristics show the importance of juvenile fluids in the magmatic processes.

4.3 Petrographic Features of the Lavas

Tertiary lavas are olivine nephelinites (six occurrences, among which one of olivine melilite nephelinite in Cap Manuel) and basanites (many occurrences) (Table 2). These rocks are generally aphanitic and contain lherzolite xenoliths or xenocrysts. However, some coarse-grained ophitic olivine gabbros and porphyritic olivine nephelinite can be found ("pyroxenolite" of earlier authors).

The Tertiary lavas constitute a sodic, moderately to strongly alkaline magmatic suite which is not differentiated (Fig. 8). They are similar to strongly basic rocks of other intraplate volcanic areas, particularly those of the Canary and the Cape Verde Islands.

Coarse-grained pegmatitoïdes (Lacroix 1928) are associated in places with the most basic rocks, with gradual transitions. They appear as veins or, sometimes, as huge stratiform pods inside the host lavas. As they display the same columnar jointing, one

Table 2. Selected chemical analyses of volcanic rocks from Cap-Vert peninsula (1 to 4, Crevola, unpublished data; 5 to 7, Quin and Fraudet 1975; 8 and 9, Debant 1963)

	1	2	3	4	5	6	7	8	9
SiO_2	38.90	40.48	41.82	45.42	44.00	47.50	50.70	47.45	49.25
Al_2O_3	10.27	12.47	10.69	12.58	13.00	13.85	16.70	16.00	15.90
Fe_2O_3	5.57	4.92	4.99	2.04	4.49	3.80	3.02	3.90	3.20
FeO	7.01	6.38	7.63	8.52	8.62	9.07	6.67	6.65	8.10
MnO	0.19	0.19	0.15	0.17	0.19	0.31	0.15	0.14	0.14
MgO	13.14	11.34	13.28	12.10	10.00	7.52	4.52	8.35	7.40
CaO	15.37	14.62	12.60	11.77	10.76	10.19	9.84	6.85	8.75
Na_2O	3.27	3.15	3.10	3.08	3.62	3.46	4.13	5.25	4.20
K_2O	1.02	0.92	0.82	0.81	1.22	0.99	1.23	1.85	0.85
TiO_2	2.13	2.53	1.84	1.86	2.07	1.82	1.85	1.80	1.35
P_2O_5	1.02	0.91	0.64	0.48	0.60	0.53	0.61	0.68	0.39
L.O.I.	2.03	1.61	2.18	0.73	2.14	0.34	0.32	1.05	1.25
Total	99.92	99.52	99.77	99.56	100.71	99.38	99.74	100.10	100.81
Na_2O/K_2O	3.20	3.31	3.78	3.80	2.80	3.49	3.35	2.84	4.94

Tertiary volcanism:
1 Olivine-melilite nephelinite, eastern coast of Cap Manuel, Dakar; *2* Olivine nephelinite, Thieo; *3* Basanite, western coast of Cap Manuel, Dakar; *4* Basanite, Sene Serere; *5* Fine-grained basanite, Diack; *6* Medium-grained doleritic basanite, Diack; *7* Coarse-grained pegmatitoid, Diack.
Quaternary volcanism:
8 Aphanitic basanite, Mamelles volcano; *9* Doleritic hawaiite, Sicap Liberté, Dakar.

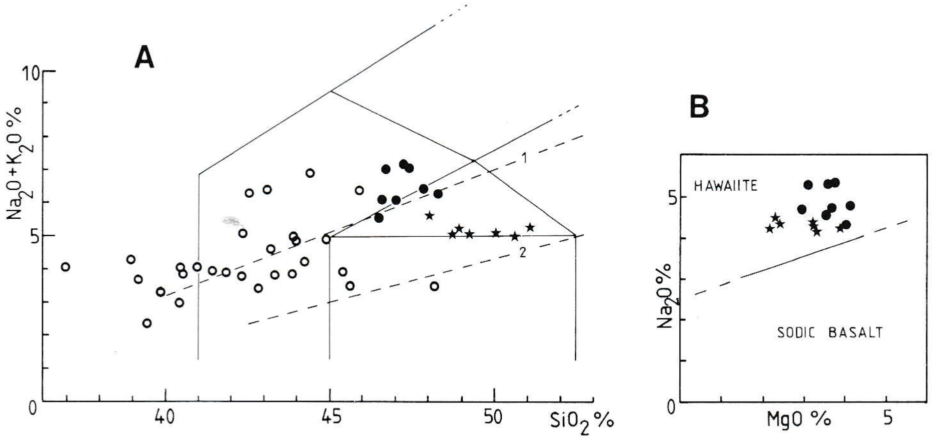

Fig. 8 a, b. Geochemical diagrams of Cap-Vert volcanic area. **A** Alkali-Silica diagram with A.T.S. fields (Le Bas et al. 1986a). *Solid circle* Quaternary basanite; *star* Quaternary dolerites; *open circle* Tertiary lava except pegmatitoidic type. *1* Boundary between moderately and strongly alkaline lavas (Saggerson and Williams 1964); *2* Boundary between alkaline and tholeiitic basalts (Mac Donald and Katsura 1964). **B** Na_2O/MgO diagram for sodic basalts (Middlemost 1975)

can assume a simultaneous emplacement. They are more acid, less undersaturated and more alkaline than the host lavas (example, Table 2), and they show an aegirine-riebeckite/arfvedsonite-aenigmatite late paragenesis. Three occurrences are noticeable because of the importance of pegmatitoides and their gradual transition toward the host lavas: Gorée and Madeleines Islands (Combier 1952) and Diack (Fraudet 1970; Quin and Fraudet 1975).

The strong basic character and the high Mg-number[1] (65 < Mg-number < 70 for the most basic rocks) of the lavas, the great number of small intrusive occurrences, the lack of any evolved product and the frequent presence of xenoliths and xenocrysts show that the Tertiary lavas correspond to the incoming at the surface of a primitive magma, which did not undergo any differentiation in a magma chamber.

5 Quaternary Volcanism

The Quaternary volcanism, which is confined to the head of the Cap-Vert peninsula, extends on land over an area of 50 km^2 (Fig. 6). It consists of a main complex volcanic edifice, the Mamelles volcano, of minor adjacent vents and of several sets of flows and tuffs which are interbedded among generally azoic aquiferous sands. The Tertiary substratum of the Quaternary sands and interbedded flows outcrops to the south in Dakar town, and gradually slopes northward to a depth of 80 m under the northern boast (Fig. 9). The Quaternary flows continue offshore beyond the northern coast.

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[1] $100 \times Mg/Mg + Fe_t^{2+}$

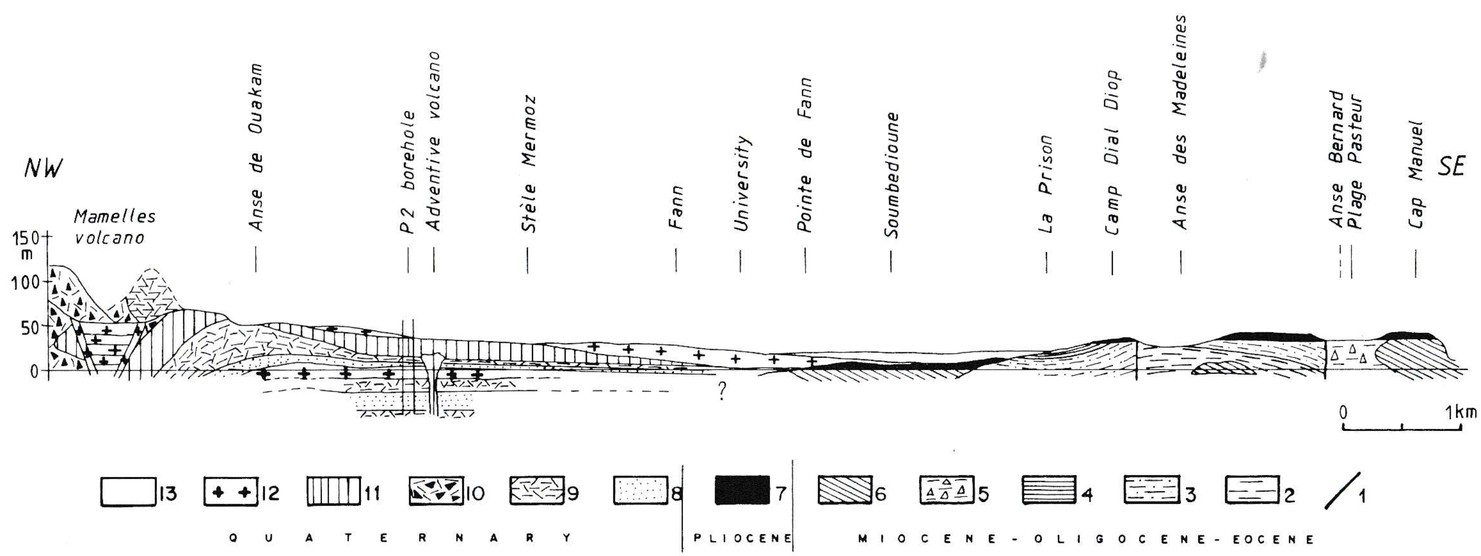

Fig. 9. Geological section of the southwest coast of the Cap-Vert peninsula (after Crevola 1975a–c). Dips of sedimentary layers are exaggerated because of the choosen vertical scale. *1* Fault; *2* Formation des Madeleines: Paleocene marl and marly limestone; *3* Limons de l'Hôpital: lower Eocene dolomitic silicified clay; *4* Formation de la Prison: lower Eocene clay (Attapulgite); *5* Middle Eocene marly limestone of Anse Bernard and Miocene volcanic tuff of Anse Bernard and Plage Pasteur; *6* Oligo-Miocene olivine-melilite nephelinite and basanite of Cap Manuel; *7* ferruginous lateritic crust; *8* to *13* Quaternary deposits: *8* sands; *9* base surge deposits; *10* volcanic breccia; *11* basanite; *12* dolerite; *13* Recent sand and silt

5.1 Stratigraphy and Age of Volcanism

Surface observations and data from water and oil exploration wells drilled in the head of the peninsula allowed us to establish the following synthetic lithostratigraphy (Crevola and Gaye 1979a and b; Crevola 1980a). From base to top, one can distinguish (Fig. 10):

a) *the basal sands unit*, with ferruginous fine gravels and some shells remains, which overlies the marly or marly-calcareous Paleogene substratum, locally intruded by Miocene tuffs;
b) *the lower volcanic unit*, consisting of an altered vesicular basalt flow and of a tuff layer;
c) *the lower sands unit*, 10 to 60 m thick, with quartz gravels intercalations;
d) *the middle volcanic unit*, the outlets of which are unknown. This unit consists of a thick coarse-grained dolerite flow which overlies tuffs and, locally (Fort A, Terme Sud), some basaltic flows separated by tuffs and sandy layers. The radiometric datings yielded an age of 1.5±0.10 Ma for the dolerite flow;
e) *the middle sands unit*, a few meters to 15 m maximum thickness;
f) *the upper volcanic unit*, or Mamelles unit, is formed by the products of the Mamelles volcano and of its secondary vents. With an age of about 1 Ma, it con-

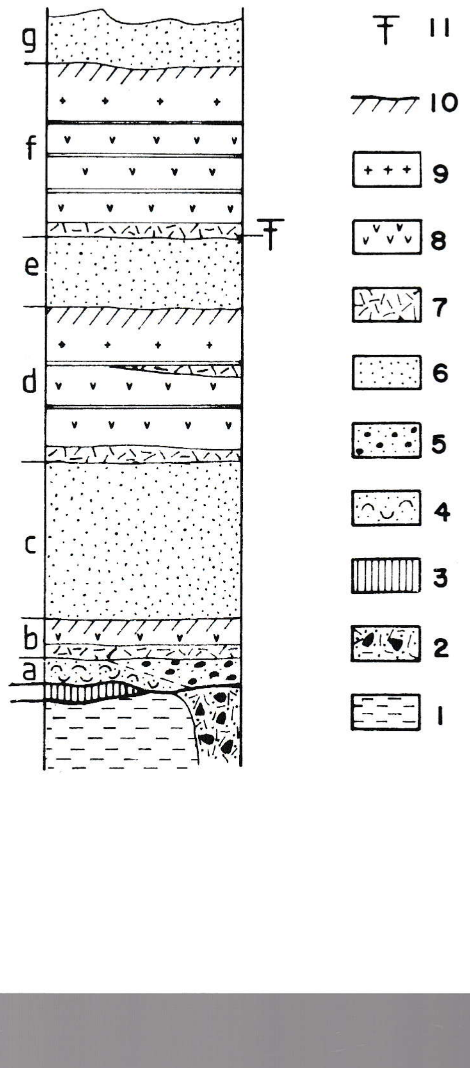

Fig. 10. Synthetic lithostratigraphic column of the Cap-Vert peninsula Quaternary deposits (after Crevola 1980a). *1* Paleogene clay or marly limestone; *2* intrusive tuff-breccia; *3* ferruginous lateritic crust; *4* shelly sand; *5* sand with ferruginous gravels; *6* sand; *7* bedded volcanic tuff; *8* basanite; *9* dolerite; *10* weathered fringe of lava flow; *11* fossil plants

sists of about ten successive basaltic flows overlying bedded tuffs and overlain by a dolerite flow. The total thickness of the flows can reach 50 m. The tuffs fossilize a paleosoil and its flora (Hebrard 1973);

g) *the upper sands unit*, or Pikine and Cambérène Recent dunes unit. It is worth noting that the lateritic crust which separates the Tertiary and Quaternary volcanisms disappears under the sea at Dakar University (Fig. 9), and that no drilling has effectively cut through the basal sands and the lateritic crust before reaching the sedimentary Paleogene or the Miocene tuffs. The age of the three oldest units is not exactly known, although they are older than 1.5 Ma.

5.2 Types of Volcanic Activities

Phreatomagmatic activity generating base surge deposits is generalized during the Quaternary. It originates from the intrusion of basaltic magma within aquiferous sedimentary layers, notably Tertiary marly limestones and Quaternary sands. It initiates the middle and the upper volcanic cycles and it can generate other tuff units interbedded among the flows or isolated in the sands such as Bel Air's. The bedded tuffs emplaced by a base surge mechanism (Moore 1967; Fisher and Waters 1970; Boucarut and Crevola 1972; Crevola 1974) are characterized by their fine grain size which increases toward the vent, their antidune-type sedimentary structures and their cross-bedding. They have a mixed composition containing basaltic elements, often palagonitic, and sedimentary elements from the Tertiary substratum and the Quaternary sands. They show several ash layers with accretionary lapilli.

Both volcanic units – middle and upper – show the same petrographic types and the same evolution through time. Thus, the middle unit could have been emplaced during a volcanic cycle similar to that of the Mamelles volcano.

The Mamelles volcano, the only important volcanic center, is a polygenic edifice built up through several stages of activity (Crevola 1975 b). The coastal cliffs provide a remarkable section of its inner parts, allowing the reconstruction of its history as follows (Fig. 11):

a) phreatomagmatic activity with base surges built a maar volcano with a wide crater (1200 m in diameter) made up of bedded tuffs (3, Fig. 11). Two such stages followed one another, with formation of a small spatter-cone (5, Fig. 11) and ring-shaped collapses (10, Fig. 11) between them;
b) strombolian activity, with alternating emissions of bombs and scoria and of thin lava flows built a strombolian cone (6, Fig. 11), the remains of which constitute the western Mamelles. Outpouring of voluminous lava flows take place by perforation at the base of the cone and huge basaltic masses intruded the strombolian scoria (7, Fig. 11). The Mermoz secondary vent, active at this stage, gave birth to a basaltic flow after the outburst of palagonitic tuffs;
c) lava-lake effusive activity in a collapse crater. This crater was filled progressively with thin flows of large phenocrysts-bearing lavas heralding the later dolerites (8, Fig. 11);
d) terminal fissural activity. Some vesicular coarse-grained dolerite cone sheet emplaced, mainly using the earlier collapse surface and feeding thick dolerite flows

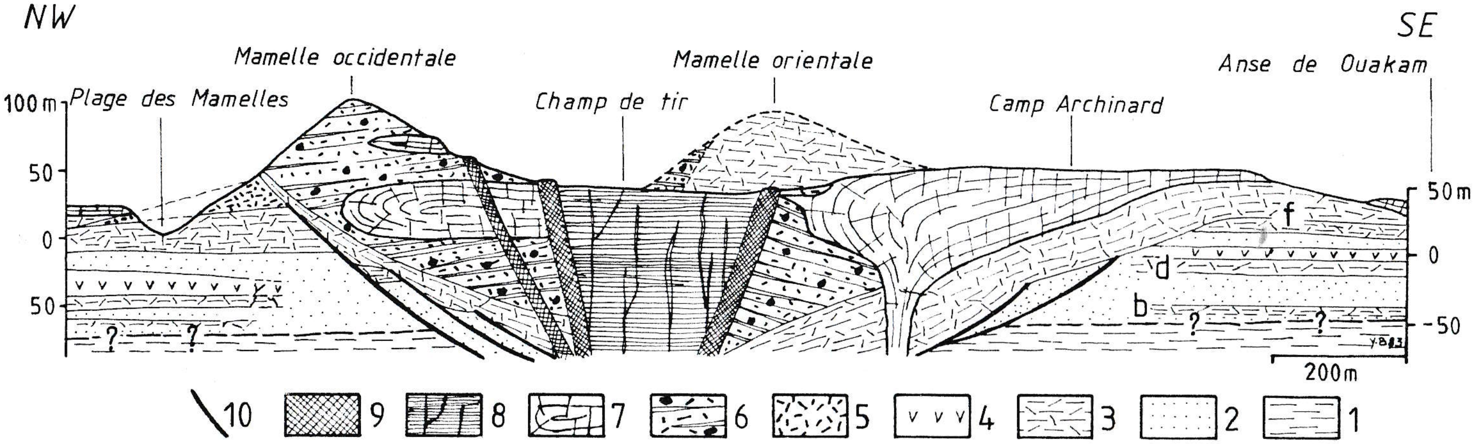

Fig. 11. Semi-interpretative section of the Mamelles volcano (after Crevola, in Bellion and Guiraud 1984). *1* Tertiary basement; *2* sand; *3* bedded tuff (maar volcano); *4* basanite and dolerite lava flows; *5* black slags (spatter-cone); *6* slags, small flows, bombs (strombolian cone); *7* basanite intrusions and flows; *8* thin flows of dolerite in a collapse-crater; *9* dolerite cone sheet; *10* ring faults; *b, d, f*: see Fig. 10

(9, Fig. 11). Besides the Mamelles, other dolerite dykes are well known, especially in the Almadies-Yoff area.

One or several stages of erosion and lateritic weathering occurred after volcanism. To the south of the peninsula head erosion has cut deep into the Quaternary flows and their Tertiary substrate.

5.3 Petrographic Features of the Lavas

The Quaternary lavas, more evolved than the Tertiary ones, are mainly hawaiites: $46.50\% < SiO_2 < 53\%$; $2.7\% < Na_2O/K_2O < 6\%$; $0\% <$ normative nepheline $< 13\%$; $35 <$ D. I. < 45; abundant zoned plagioclases (An 55 to 70), sometimes modal nepheline. In the T. A. S. diagram (Le Bas et al. 1986) they plot mostly in the hawaiite field and a few of them in the basanite field (Fig. 8 and Table 2).

The same types of lava and the same textural evolution (from base to top) characterized by an increase in the phenocrysts size and in the phenocrysts/groundmass ratio are observed in the successive flows of both middle and upper volcanic units, which constitute most of the erupted lavas. The texture evolved thus, from the aphanitic basanites with an abundant groundmass and lherzolite xenoliths from the first flow, to the coarse-grained vesicular doleritic hawaiites, consisting only of phenocrysts, which constitute the last flows. This textural evolution is linked with a slight chemical evolution: increase in the silica content, increase of the Na_2O/K_2O ratio, decrease in the alkalis content and decrease of normative nepheline. Some dolerites show a late alkaline paragenesis with aegirine, arfvedsonite and aenigmatite.

The observed textural and chemical evolution, which occurs twice during the Quaternary, is characteristic of lavas with a long crystallization residence in the magma chamber before coming to the surface.

6 Comparisons with Other Central Atlantic Alkaline Provinces

A brief comparison of the Cap-Vert Cainozoic volcanism with those of the neighbouring alkaline provinces of Canary and Cape Verde Archipelagoes can be proposed on the basis of available data (Grunau et al. 1975; Klerkx and de Paepe 1976; Schmincke 1982; Stillman et al. 1982; Mitchell et al. 1983; Araña and Oritz, this Vol.).

The geodynamic setting appears as broadly similar for the three provinces. Located at the northwestern edge of the African Continent they rest on an oceanic crust (Cape Verde Islands and most, if not all, Canary Islands) or on a transitional crust (Cap-Vert and possibly the easternmost Canary Islands). The alkaline magmatism is connected in both space and time with uplifting of lithospheric blocks bounded by previous weakness zones (north-south to northeast-southwest trending faults of the passive margin and/or east-west trending oceanic faults and their continental equivalents). The uplift took place in several episodes after the Eocene in response to Alpine tectonic compressional events occurring in northwest Africa. It corresponds in the stratigraphic record to several discontinuities among which the D2 discontinuity of Oligocene age is the most important and widespread.

In all three provinces, the Cainozoic magmatism occurs discontinuously from Oligocene up to Quaternary with a peak in activity in the middle to upper Miocene.

However, earlier magmatic events of alkaline character, middle to late Cretaceous in age, have been reported: alkaline clasts from Maio, syenitic intrusion of Leona, plutonic basal complex of Fuerteventura. Contrasting with the older tholeiitic oceanic or continental magmatism, they herald to some extent the subsequent extensive Cainozoic magmatism.

An important difference is of course connected with the geographic location of the Cainozoic magmatism. In the Canary and Cape Verde Islands, it is at first submarine, building up large volcanoes of pillow-lavas and hyaloclastites in which gabbroic to syenite plutonic complexes were intruded. Then the volcanism became subaerial.

In all three provinces, the magmatism is strongly alkaline and mainly undersaturated, olivine nephelinites and olivine-melilite nephelinites being fairly common. However, the volcanic series of the Cap-Vert Province remains weakly differentiated and in some of the Canary Islands mildly alkaline to transitional series occur because of local variations in the mantle-melting processes.

7 Conclusion

The Senegalese part of the West African passive margin experienced three phases of magmatic activity, each of them being connected with a stage of the geodynamic evolution of the Central Atlantic:

i) Triassic to Jurassic tholeiitic extensional magmatism pre-dating and accompanying the incipient Atlantic rifting;
ii) mid to late Cretaceous alkaline magmatism, possible related to a modification of plate motions;
iii) Tertiary and Quaternary undersaturated basic alkaline volcanism, linked to uplifting and block-faulting through reactivation of ancient weakness zones in response to collisional events occurring in the Mediterranean area.

The last of these three phases is the most important and the best documented in the Senegal Basin. Taken together, the volcanic area of Cap-Vert and the Cayar seamount constitute a volcanic province with an average size of $150 \times 150\ km^2$. Stratigraphic data and radiometric ages demonstrate a discontinuous long-lasting activity from the Oligocene up to the middle Quaternary. The Cap-Vert Tertiary and Quaternary lavas constitute a strongly alkaline and sodic, undersaturated and only slightly differentiated volcanic suite. The volcanism is scattered, often intrusive and does not build up any major subaerial edifice.

Though less abundant and widespread and weakly differentiated, the Cap-Vert Cainozoic volcanism is broadly similar to those of the neighbouring Canary and Cape Verde Archipelagoes. The three magmatic phases recognized in the Northwestern African margin occur with similar characteristics on the North American margin, but the Cainozoic magmatism is poorly developed there (Jansa and Pe-Piper 1985).

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