THE GEOLOGY OF FUERTEVENTURA 8

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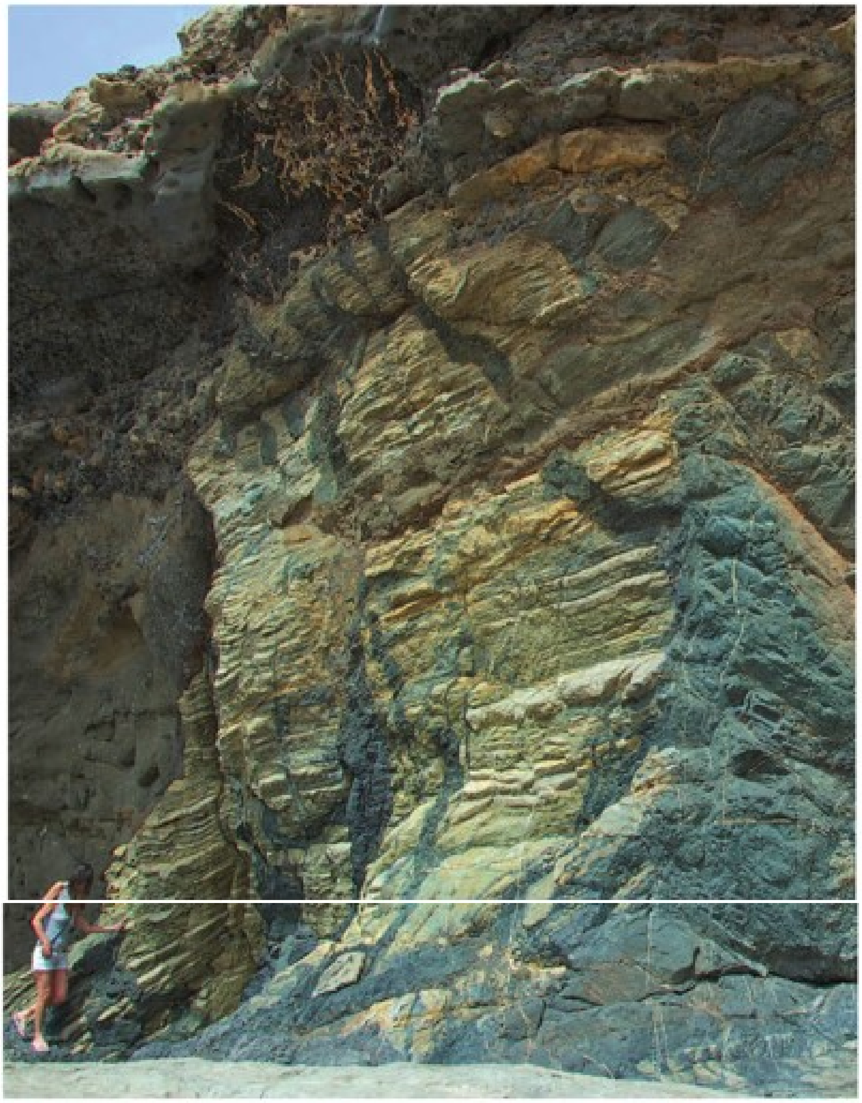

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The Geology of the Canary Islands

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THE ISLAND OF FUERTEVENTURA

As the bathymetry of Fuerteventura and Lanzarote shows (Fig. 8.1), the two islands form a continuous ridge, from the El Banquete seamount in the south to the Isletas north of Lanzarote. The platform between the islands likely formed by marine abrasion during previous glacial periods, when

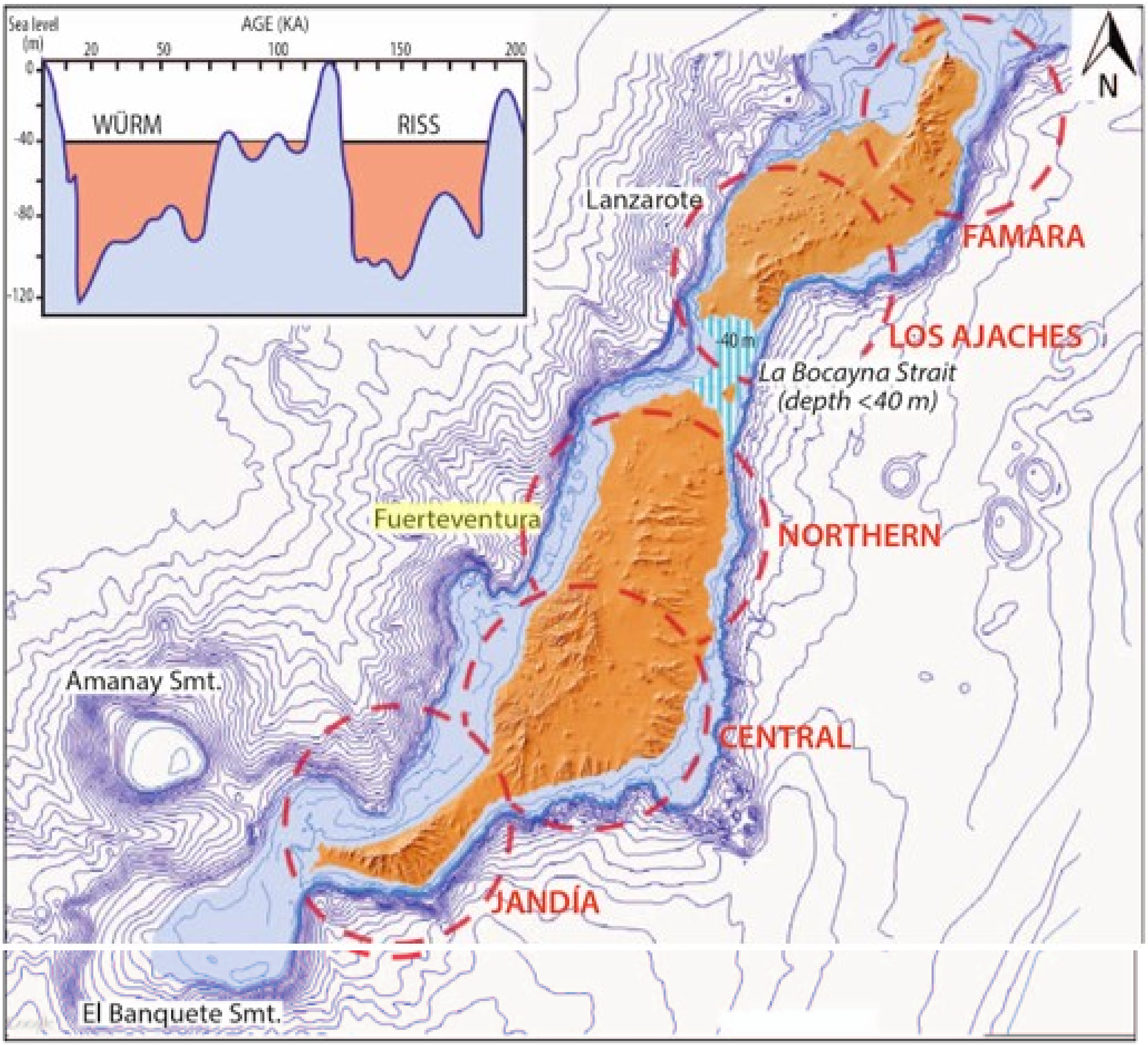

FIGURE 8.1

The islands of Fuerteventura and Lanzarote are separated by a narrow (11 km) and shallow (≤40 m deep) strait, La Bocayna (Bathymetry map from *IDE Canarias visor 3.0, GRAFCAN*). The two islands formed a single island during periods of previous low sea-level standing (eg, during glaciations). The inset illustrates the periods during which the Bocayna strait emerged and both islands were connected, forming a <200-km-long and ridge-like land mass. The red circles indicate the main shield volcanoes.

the sea level dropped by 100 m or more. Thus, the "connected" islands of Fuerteventura and Lanzarote formed by the construction of five overlapping shield volcanoes (red circles in Fig. 8.1) that were aligned in a southwest–northeast direction. Although Fuerteventura and Lanzarote are at present separate islands from a geographical point of view, over considerable periods of geological time the islands were connected and formed a single, elongated, ridge-like land mass more than 220 km long (see inset in Fig. 8.1).

MAIN GEOMORPHOLOGICAL FEATURES

The main geomorphological features of Fuerteventura were originally defined by Fúster et al. (1968a) and comprise: (1) the Jandía peninsula, separated from the rest of the island by an isthmus largely covered with organic aeolian sands (Fig. 8.2A,B); (2) the Betancuria massif, formed by mainly plutonic rocks that have resisted erosion to form a compact group of mountains; (3) the central plain, a 25-km-long depression, interpreted as a fault system (Hausen, 1967) and then later as the scarp of a giant landslide (Stillman, 1999); and (4) the eastern U-shaped valleys separated by elongated and sharp ridges, locally named '*cuchillos*' (knives).

GEOLOGICAL STRUCTURE AND VOLCANIC STRATIGRAPHY

THE BASAL COMPLEX CONCEPT

Since the early geological study of Hartung (1857), which described a basal "syenite and trapp formation, crossed by an extraordinarily dense swarm of dykes", most of the research on Fuerteventura has been focused on this peculiar and intriguing geological feature. The oldest sequence of the island comprises mafic plutonic rocks, submarine sediments, and volcanics that act as the host rock to a dyke swarm in which the dyke intensity reaches 90% or more in places. This type of formation, which also crops out on La Palma and possibly on La Gomera, was formerly considered to mark a common basement in the archipelago (hence, the term basal complex; Fig. 8.2C,D). Following this concept, the basal complex was defined as a formation comprising all the rocks that lie unconformably below the subaerial volcanic sequences. However, part of the subaerial rocks are frequently included in the basal complex too (eg, Gutiérrez et al., 2006), rendering this stratigraphy confusing (Fig. 8.2C).

The finding of Cretaceous fauna in the marine sediments of Fuerteventura's basal complex (Rothe, 1968) suggested some similarities with the sequence characteristic of constructive plate margins, such as the ophiolite complex of the Troodos Massif in Cyprus (Gastesi, 1973). However, as documented by Robertson and Stillman (1979), these early interpretations of uplifted blocks of oceanic basement were problematic because the igneous rocks are considerably younger than the oceanic sediments and a direct link is not evident.

As Staudigel and Schmincke (1984) demonstrated, the "basal complexes" likely represent the seamount stage of growth of the islands and must be present in the entire archipelago, although they only crop out in the islands that went through important uplifting and central erosion, such as Fuerteventura and La Palma. The older (Cretaceous) submarine sediments on Fuerteventura are

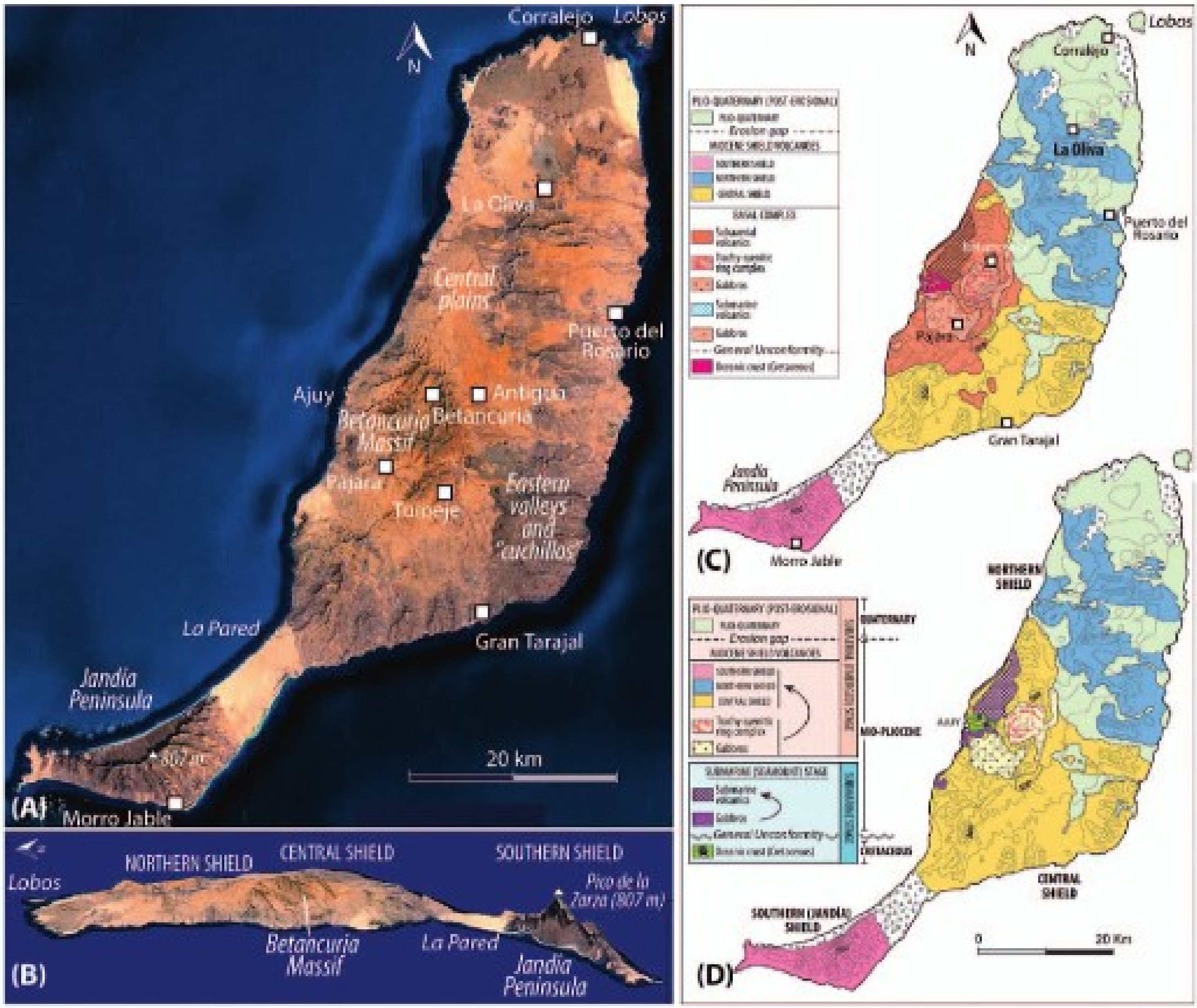

FIGURE 8.2

(A) *Google Earth images* of Fuerteventura. The island is 98 km long and, thus, longer than Tenerife (84 km). Most of the roads are reasonably flat, and it is easy and fast to travel across the island. (B) *Google Earth* profile of Fuerteventura, with vertically exaggerated scale to outline the main geomorphological features. (C). Simplified geological map of Fuerteventura using the concept of a "basal complex." (D) Another approach is to geologically separate the three main temporal units that form the island: (1) the oceanic crust (allochthonous); (2) the submarine (seamount) volcanism of Fuerteventura; and (3) the subaerial volcanism of Fuerteventura. The definition of a "basal complex" has led to confusion in the past, because the subaerial volcanism is then divided into two parts. One part is then included in the "basal complex," whereas the other is not, which creates a "discontinuous" impression, although processes may well have been gradual during the emergence of the island.

part of the oceanic crust and were uplifted by the igneous activity to within the island edifice. In fact, Hansteen and Troll (2003) report contamination signatures in magmas from Gran Canaria that show sedimentary input while also displaying shallow-level crystallization, implying that such an uplifted complex might exist within Gran Canaria island and may even be a feature common to many of the Canary islands.

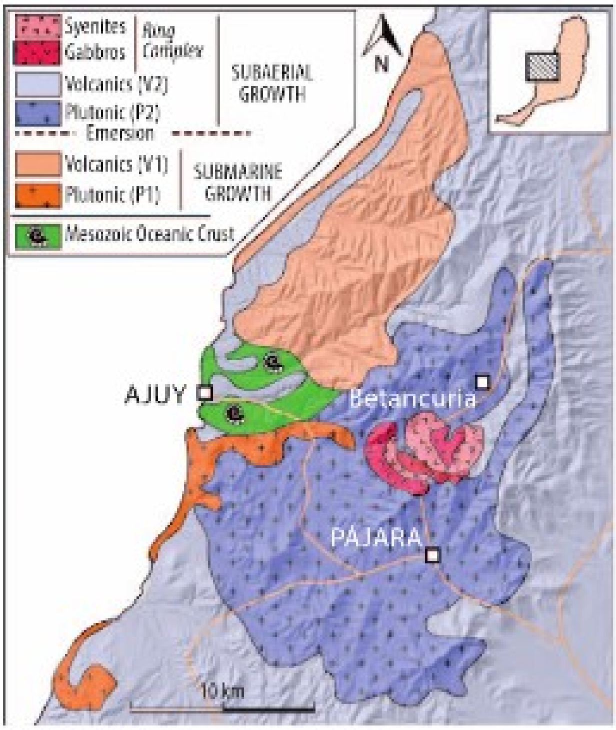

FIGURE 8.3

Geological sketch map of the Betancuria Massif. Note that the older plutonic rocks (P1) correspond to the magma chambers feeding the submarine volcanic suite (V1), whereas the younger plutonic group (P2) fed the subaerial volcanism (V2). Modified from Gutiérrez et al. (2006).

Stillman et al. (1975) synthesized the evolution of Fuerteventura as "a history of transition from normal ocean-floor sedimentation at the foot of the eastern Atlantic continental rise to the build-up of a discrete oceanic island". Therefore, if the "allochthonous" oceanic crust is considered unrelated (see Fig. 8.2D), then what remains are the characteristic formations of construction of an oceanic island, such as the seamount stage and the onset of subaerial volcanism, making the use of the term "basal complex" arbitrary and likely redundant (Carracedo et al., 2001). Consequently, the volcanic stratigraphy of Fuerteventura can be broken down into four progressively younger units: (1) the uplifted (Mesozoic) oceanic crust; (2) the submarine (and transitional) volcanics; (3) the subaerial Miocene shields; and (4) the posterosional volcanic rejuvenation. Note that the older plutonics (P1 in Fig. 8.3) represent the chambers feeding the submarine volcanics (V1), whereas the P2 plutonics relate to the younger surface volcanics (V2).

THE UPLIFTED (MESOZOIC) OCEANIC CRUST

As described by Robertson and Stillman (1979), the composition of this fragment of oceanic crust is tholeiitic and, hence, characteristic of mid-ocean-ridge basalts, which are otherwise very rare in

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➔ **The following image shows an extraction from an geological information board at „Ajuy Beach" :**
(included in this document by Harry K. Hahn)

➔ Note the information about the **- old oceanic sediments - :**

A characteristic sequence of the ocean sediments shows fine-grain rhythmic deposits, with alternating green and white banding (Fig. 8.4). The green layers are mainly formed by chlorite in shale and clay deposits, while the white bands show high quartz contents, indicating a continental origin because quartz is not usually present in volcanic rocks of the Canary archipelago. In places, heavy mineral-enriched layers occur ("zircon sands"), implying highly dynamic transport conditions. These rhythmic deposits were likely formed by many repetitive turbidity events from Africa, and we emphasize that the presence of igneous and sedimentary oceanic crust is unrelated to the Canarian magmatism. Instead, the Canary ocean island volcanism was the cause for the uplift of these older rock sequences. →

Secondary Impacts in this area, caused by the Permian-Triassic-Impact are probably the cause for this uplift of the older rock sequences__ **comment by Harry.K.Hahn**

- ➔ The **quarz bands** in the old ocean sediments can help to indentify the impact event ➔ the **zircon** can help to analyse the **true (252Ma) age** of the impact.

SUBMARINE GROWTH

An interesting and unusual feature that can be inspected on Fuerteventura is the transition from submarine to the subaerial volcanism.

The earliest volcanic manifestations are thick sequences of basaltic pillow lavas and hyaloclastites resting on an erosive unconformity over the Mesozoic sedimentary crust (Fig. 8.5A,B). Plutonic activity coeval with the generation of the submarine volcanic sequence (see Fig. 8.3) comprises alkaline rocks that crop out along the western coast south of *Ajuy*, such as pyroxenites, nephelinites, and carbonatites (Fúster et al., 1980; Le Bas et al., 1986; Demény et al., 1998). Carbonatites, igneous rocks with more than 50% carbonate minerals, are rare in the Canaries and likely formed on Fuerteventura by liquid immiscibility from a CO_2-rich alkaline silicate magma (Fig. 8.5C).

The submarine succession forms a 2-km-thick sequence (Gutiérrez et al., 2006) that includes intermediate to shallow depth volcanics, as indicated by the vesicularity of pillow lavas (Fig. 8.5B). Units A to F in Fig. 8.5A are progressively shallower, with unit F documenting a shoaling phase through the presence of coral reefs that likely correspond to the first stage of emergence (Fig. 8.5D). Transitional units overlie the submarine sequence and are topped by subaerial volcanic and sedimentary rocks (Miocene to recent, Figs. 8.3 and 8.5A).

THE SUBAERIAL GROWTH OF FUERTEVENTURA

The initial stages of subaerial volcanism erupted large volumes of basaltic effusive lava, constructing an island that was considerably larger and higher than that of today, probably reaching elevations similar to those of present-day Tenerife (eg, Javoy et al., 1986). After this intense eruptive phase (the shield-building stage, lasting only a few Ma, perhaps), in which growth of the edifice through volcanic activity outpaced destruction through erosion and during which most of the volcanic edifice formed, eruptive rates and frequency drastically decreased. Magmas became more evolved (siliceous and thus more viscous), contributing to an increase in volcano height. In fact, Stillman (1999) suggests that a peak as high as the present Mount Teide on Tenerife existed in the central part of the island and was rapidly denuded in less than 2 million years (Ma).

Volcanism then declined and, finally, the island entered extended periods of volcanic inactivity, during which mass wasting through giant landslides and erosion outpaced volcanic growth. This caused the island to become deeply eroded, eventually exposed a window into submarine volcanics

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FIGURE 8.6

Approximately 2 km south of *Pájara*, in the region east of the km 11 road sign on FV-605, the transitional and subaerial volcanic units unconformably overlie the submarine sequence crossed by the feeder dykes of thousands of submarine and subaerial eruptions. These now form an extremely dense northeast–southwest striking dyke swarm (see also Figs. 8.18, 8.33 and stops 2.2 and 2.3). Google Earth image.

and the roots of the subaerial volcanoes, particularly in the central and northern parts of the island. There, a succession of plutonic intrusions (pyroxenites, gabbros, and syenites) represents the frozen magma reservoirs that fed the Miocene volcanoes of Fuerteventura (see Fig. 8.3).

For instance, the Miocene gabbro-pyroxenite pluton near *Mézquez* (P2 in Fig. 8.3) is interpreted as part of the feeder zone to the subaerial volcanism and is a 3.5 × 5.5-km shallow-level intrusion. The intrusion was, to some degree, controlled by the regional east–west extensional tectonic setting that affected Fuerteventura during the Miocene (eg, Stillman et al., 1975; Stillman, 1987; Stillman and Robertson, 1977; Fernández et al., 1997), which may have facilitated rapid magma production and consequent ascent and eruption.

The massive and successive plutonic intrusions (Fig. 8.7) and the extraordinary number of dykes caused intense alteration, analyzed in detail by Le Bas et al. (1986) and Hobson et al. (1998).

Emplacement of the plutons at high levels in the crust caused hydrothermal metamorphism, likely due to fluid circulation along the dykes because the intensity of metamorphism correlates with the density of dykes. Hence, most of the rocks of the submarine complex were affected by fluid overprint, but notably to variable degrees (Javoy et al. 1986).

Migmatites crop out in a 200-m-wide aureole at the contact between two gabbroic intrusions and the basaltic dyke swarm (Figs. 8.7 and 8.8). Migmatites form under extreme temperature and/or pressure conditions during progressive metamorphism, where partial melting occurs in pre-existing rocks. Incipient melting leads to segregation and crystallization of a leucosome, the lighter-colored part of migmatite, which on Fuerteventura displays a banding of syenitic veins alternating with and migrating through basaltic or pyroxenitic host rocks (zebra structure, Fig. 8.8B).

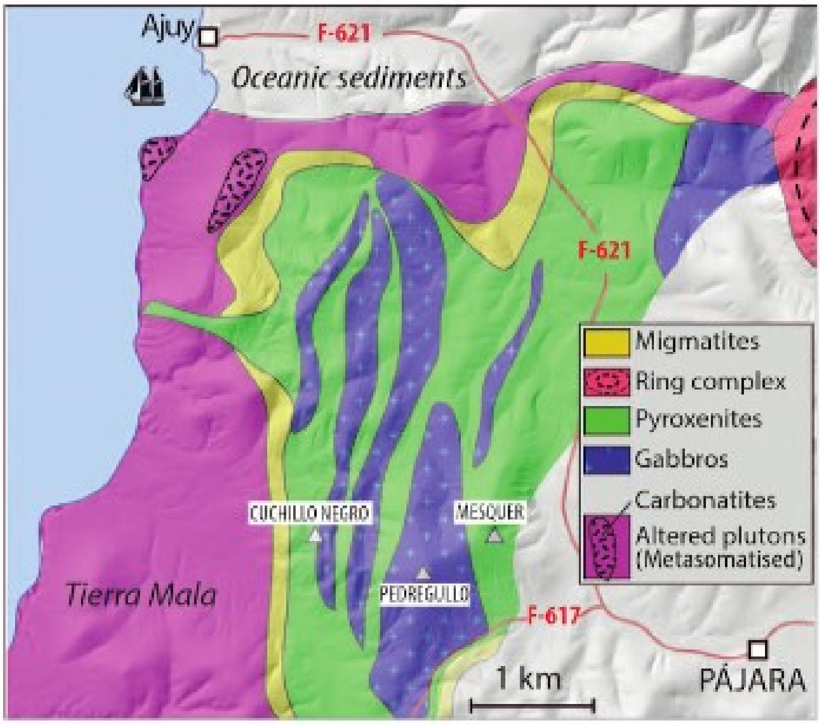

FIGURE 8.7

Geological sketch map of the Betancuria Massif showing a suite of plutonic intrusions (gabbros, pyroxenites, and syenites) in the area between *Pájara* and *Mesquer*. The migmatites (zebra rock see Fig. 8.8) probably formed through the heating and partial melting, and associated internal segregation within the basalt country rocks during intrusion of the associated pyroxenite plutons. Melting in the aureole likely occurred in the presence of abundant fluids (after Le Bas et al., 1986; Hobson et al., 1998).

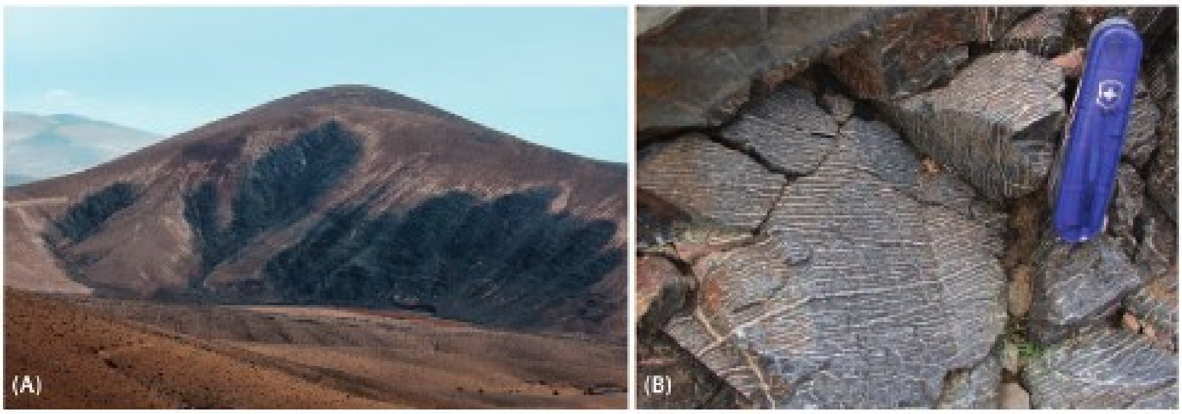

FIGURE 8.8

(A) The black pyroxene pluton of *Mesquer*. (B) Veining in migmatite (zebra rock) in the aureole to the pyroxenite in Bco. de La Arena. Partial melting with concurrent deformation of the basaltic protolith has resulted in feldspathic leucosomes that are present as felsic segregation veins.

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THE MIOCENE VEGA DE RIO PALMAS RING COMPLEX

This trachytic–syenitic ring complex, the last stage of the preserved plutonic history of Fuerteventura, intrudes the submarine and transitional volcanic groups and its top cuts across subaerial lavas (Figs. 8.9 and 8.10). Thus, the felsic ring complex likely represents the magmatic

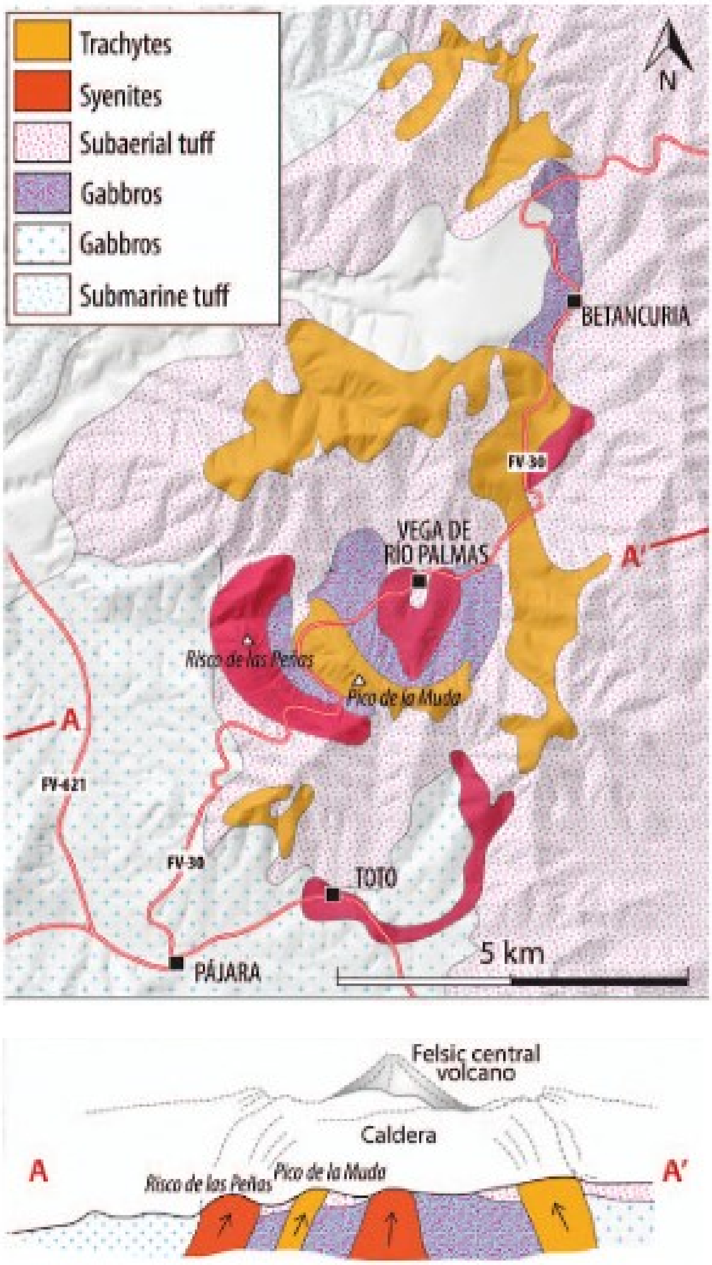

FIGURE 8.9

Geological map and west–east cross-section of the ring dyke complex of *Vega de Río Palmas*. Note the central intrusion is encircled by three concentric ring intrusions (modified after Muñoz, 1969). The upper volcanic structure in the cross-section is inferred from geological evidences (see text for details).

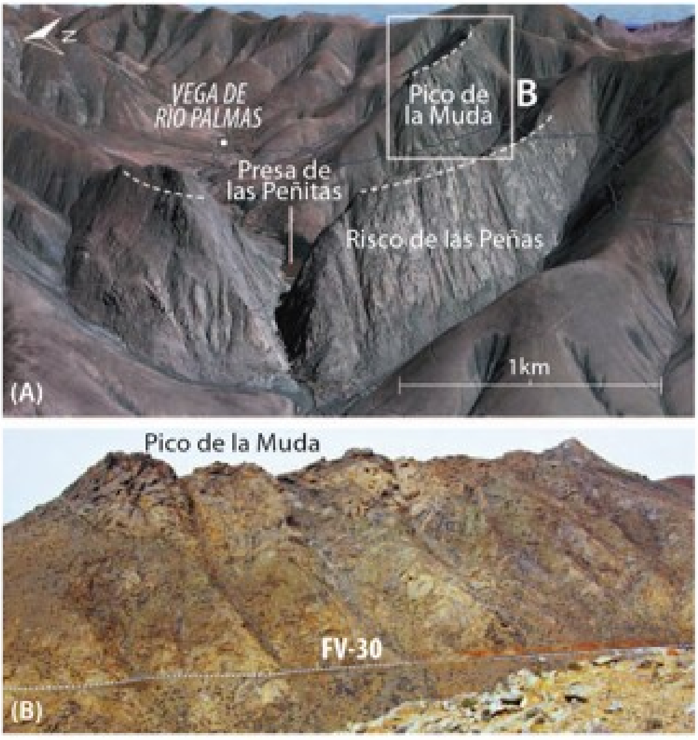

FIGURE 8.10

(A) *Google Earth* image of the ring complex of *Vega de Río Palmas*. (B) Outcrop along the raod at *Risco de la Muda*, a semi-circular trachyte intrusion of the central ring complex.

conduit to a felsic volcanic complex similar to the Las Cañadas−Teide complex on Tenerife, or the Vallehermoso complex on La Gomera, or indeed the Tejeda Caldera on Gran Canaria (see cross-section in Fig. 8.9). The Fuerteventura felsic volcano may have reached elevations of 3000 m or higher above sea level, as suggested by stable isotope data from the dykes (Javoy et al., 1986; Stillman, 1999). Subsequent erosion, probably including massive landslides, removed approximately 3500 km^3 of lavas and volcaniclastics, stripping the western sectors of Fuerteventura down to the rocks of the pre-shield phase (Stillman, 1999).

THE MIOCENE SHIELD VOLCANOES

The subaerial growth of the island gave rise to three large, overlapping shield volcanoes, the central, northern, and southern (Jandía) shields (Figs. 8.11 and 8.12). This volcanic disposition seems to be characteristic of ocean islands, and is seen on the island of Hawaii (Mauna Kea, Mauna Loa, Hualalai, and Kilauea), Tenerife (Teno, Central, Anaga), La Palma (Taburiente, Cumbre Vieja), and Lanzarote (Ajaches, Famara). The explanation for such a frequent arrangement of overlapping

FIGURE 8.13

View from Mña. de la Muda onto El Aceitunal. This part of the island belongs geologically to the northern shield. In the foreground, the small village of *La Mantilla*. To the right, one can see the central plain, and in the far distance the central shield can be seen.

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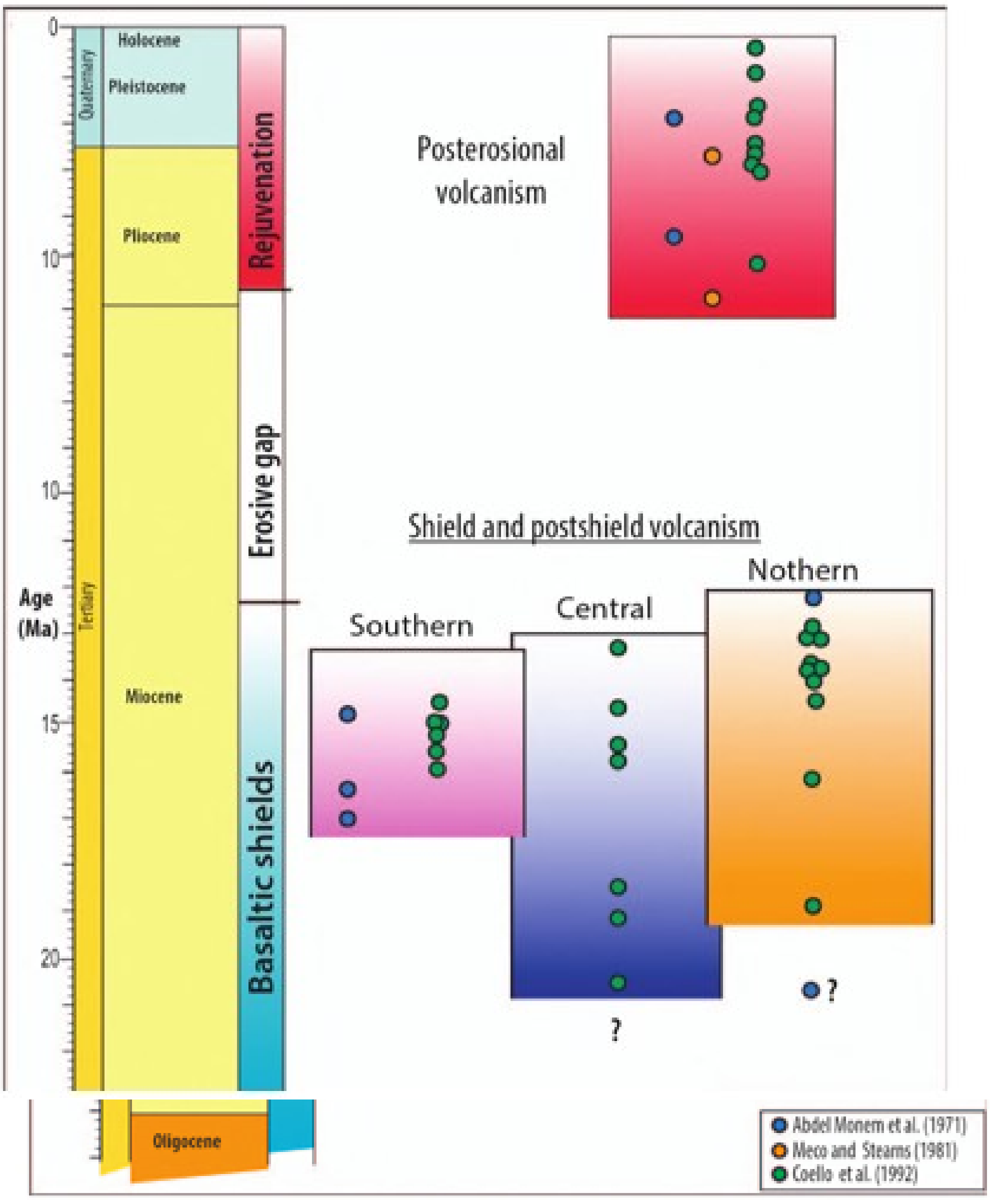

FIGURE 8.14

Simplified stratigraphy of Fuerteventura, based on radiometric ages from Abdel-Monem et al. (1971), Meco and Stearns (1981), and Coello et al. (1992).

THE PLIOCENE TO RECENT POSTEROSIONAL REJUVENATION

After a long period without volcanism, basaltic eruptions resumed in the northern half of the island approximately 5 Ma ago. The considerable duration of the erosional hiatus (Fig. 8.14) produced an extensive coastal abrasion platform, now seen as the unconformable contact of the Miocene to

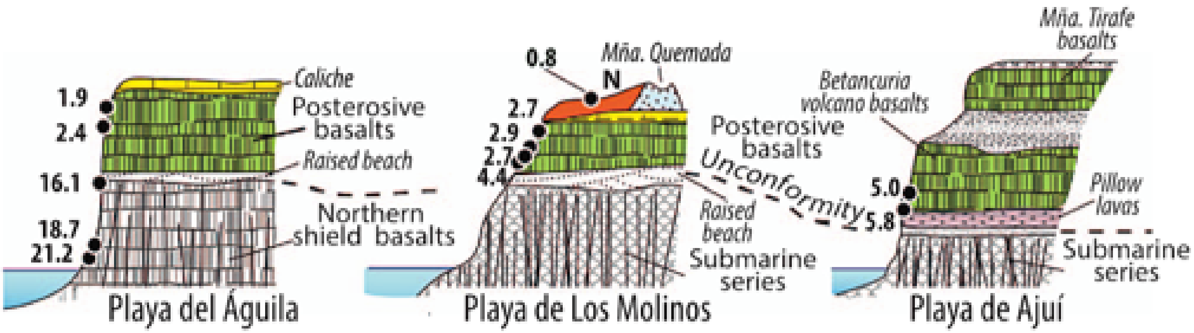

FIGURE 8.15

Geological sections along the western coast of Fuerteventura, indicating the age, polarity, and relationships between the Miocene submarine and subaerial volcanism (after Fúster and Carracedo. Ages from Abdel Monem et al., 1971; Meco and Stearns, 1981 and Coello et al., 1992).

Pliocene volcanism (Fúster and Carracedo, 1979). Marine erosion and correlative coast retreat formed a cliff that extended along most of the western coast, where post-erosional volcanism is overlying the 20-m raised beach and the older Miocene and pre-Miocene formations (Fig. 8.15).

PRE-BRUNHES ERUPTIONS

The initial Pliocene eruptions are scattered in the central part of the island and along the coast around *Ajuy*. This episode of rejuvenation volcanism has been divided according to the Brunhes/Matuyama boundary at approximately 0.78 Ma (Fúster and Carracedo, 1979). Initially, Fúster et al. (1968a) divided the pre-Brunhes eruptions (their "Series II") into two subseries (B1 and B2). The former corresponded to exclusively effusive eruptions forming small shield volcanoes and lavas that were flowing even in very gentle slopes, adapting to the post-erosive topography, such as the Cercado Viejo volcano near *Casillas del Ángel* (Figs. 8.16 and 8.17A), and the still preserved cinder cones, such as the "Volcanes de Tetir" at the center of the island (Figs. 8.16 and 8.17B). The younger and more explosive subseries B2 occurs mainly in the southeast of the island, east of *Pájara* (Figs. 8.16 and 8.17C), and in the north near *Corralejo*, forming the "Malpaís de la Arena" and "Malpaís del Bayuyo" (Figs. 8.16 and 8.17D).

BRUNHES ERUPTIONS

These recent volcanoes are well preserved, frequently forming extensive lava fields, impractical for farming, and locally known as *malpaíses* (badlands). The greatest concentration of recent volcanoes occurs in the northern part of the island (see Figs. 8.16 and 8.17D).

THE INTRUSIVE FACIES OF FUERTEVENTURA

Dykes on Fuerteventura are extraordinarily abundant, particularly in the Betancuria massif, where they reach more than 90% of the rock mass in places (eg, Stillman 1987). Intrusions are so tightly

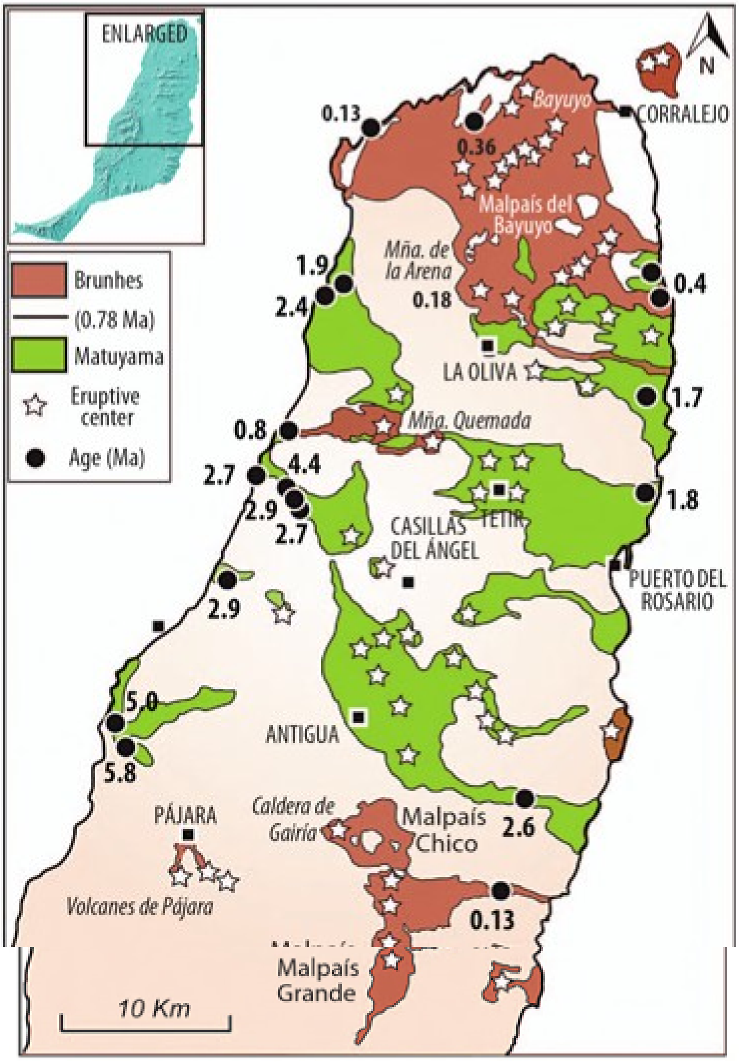

FIGURE 8.16

Post-erosional volcanism in Fuerteventura can be separated into two age groups on the basis of geomagnetic polarities by using the Matuyama/Brunhes limit at 0.78 Ma (ages as in Fig. 8.15).

packed there (see Fig. 8.6) that only small screens of the host rock can be observed in many localities (eg, Figs. 8.18 and 8.19). Most dykes are approximately 0.5–1 m thick; the greater number is basaltic and a small fraction is trachytic to phonolitic. Usually they are intensely overprinted and original minerals have frequently disappeared.

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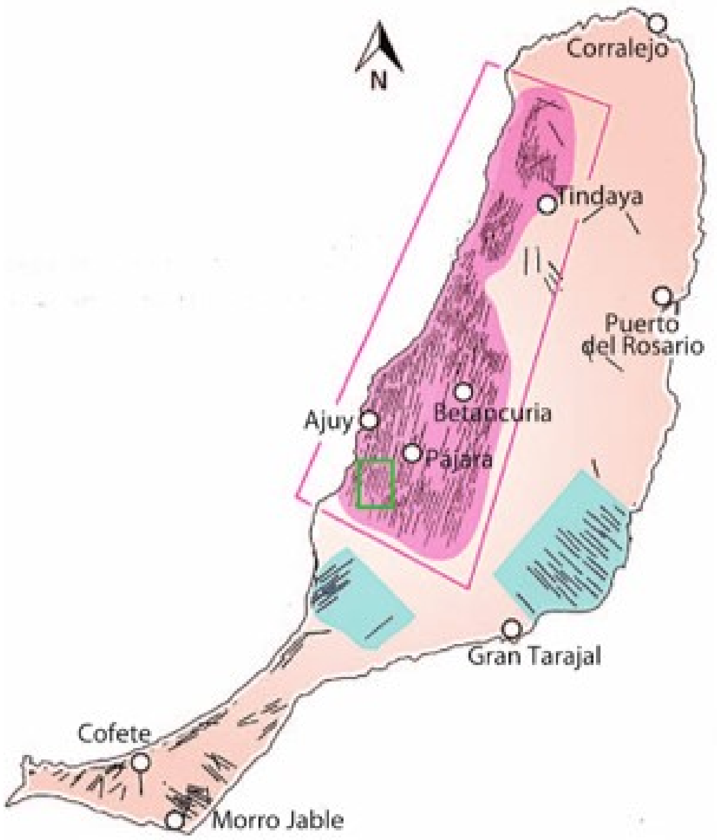

FIGURE 8.18

The extremely dense dyke swarm in the Betancuria Massif (pink) represents the former feeder system to the submarine and early subaerial volcanism of the island. Dyke swarms in blue correspond to the later subaerial shield-stage volcanism. The green rectangle refers to Fig. 8.6. Modified from Fúster et al. (1968).

However, Fúster et al. (1968a) already pointed out that the "dyke complex" is not a stratigraphic unit *per se*, because the dykes cross different stratigraphic formations simultaneously. Today, we know that similar dyke swarms occur in the active rifts of ocean islands accessible through *galerías* or in the deeply eroded structures of rift zones, such as the northeast rift zone on Tenerife (eg, Carracedo et al., 2011b; Delcamp et al. 2012) or in the Taburiente caldera on La Palma (Staudigel et al., 1986).

Such a high dyke density as seen on Fuerteventura is nevertheless best achieved in an extensional regime. Otherwise, the successive intrusions will progressively increase compressive stresses, hindering and eventually preventing new injections. Because it is very likely that the dyke complex on Fuerteventura fed the numerous eruptions that constructed the submarine and subaerial structure of the island, the origin of the required extensional regime is likely different from a constructive plate margin. Two different options have been considered, which are a fracture propagating from the Atlas to the Canaries (Anguita and Hernán, 1975, 2000) or doming from a mantle plume (Holik et al., 1991, Carracedo et al., 1998).

Thirth option : the required extensional regime for the dense dyke swarm was caused by an ejecta lobe coming from the proposed Ø ~13,5 x 10 km (oblique) Ajuy Impact Crater → see my explanation
The impact of this „ejecta lobe" caused an acceleration (flow) of this part of Earth's crust (→ the Betancuria Massif and surrounding area), causing the extensional regime & the dykes.
Comment by Harry.K.Hahn

FIGURE 8.19

(A) Dyke swarm intruding Miocene submarine volcanics, Playa del Valle. (B) Pliocene lavas resting unconformably on the Miocene dyke complex, Bco. de Malpaso, Playa de Ajuy. (C) Densely packed dykes leaving only small screens of the submarine host rock near *Pájara.* (D) Sills in steeply dipping oceanic sediments. These must have intruded prior to uplift and deformation of the oceanic sedimentary rocks in Cueva de Caleta Negra, near *Ajuy*. Images in (A), (B), and (D) courtesy of S. Wiesmaier.

Although there is no significant evidence against a mantle plume accounting for the origin for the Canaries, there are fundamental constraints against the tectonic influence of the nearby Atlas region since the early Miocene. As pointed out by Gutiérrez et al. (2006), the Atlas deformation postdates the construction of Fuerteventura. From the Oligocene to early Miocene, the Africa–Eurasia convergence was mainly absorbed across the ALKAPECA domain (Alborán, Kabylies, Peloritan, and Calabria) and the Iberian–Balearic margin. The Atlas system deformation occurred late in the Miocene and, more specifically, during the Pleistocene and early Quaternary (Frizon de Lamotte et al., 2000), and therefore most probably after the formation of the intrusive complex of Fuerteventura.

FELSIC INTRUSIONS

Outcrops of trachyte and phonolite intrusions are scant on Fuerteventura and generally present as plugs or domes. The most spectacular one is the Tindaya mountain, a Miocene 400-m-high elongated and eroded ridge towering over the Esquinzo plain. Tindaya is a classic case of relief inversion that results from millions of years of differential erosion (Fig. 8.20). The trachyte of the Tindaya quarry is a popular ornamental building stone in the Canaries, and its decorative value is based on the abundant and colorful "Liesegang rings" (see Day 4, Stop 4.1).

Another noteworthy trachyte intrusion crops out in a cliff of Cuchillo del Palo, on the Jandía peninsula. There, a trachytic dyke intrudes the basaltic lavas of the southern shield, expanding into a dome as the intrusion approaches the surface (Fig. 8.20B).

FIGURE 8.20

(A) Montaña Tindaya is a large eroded Miocene trachyte plug (image courtesy of *Foto aérea de Canarias*). (B) Trachyte dome with its feeder dyke exposed at Cuchillo del Palo on the Jandía peninsula.

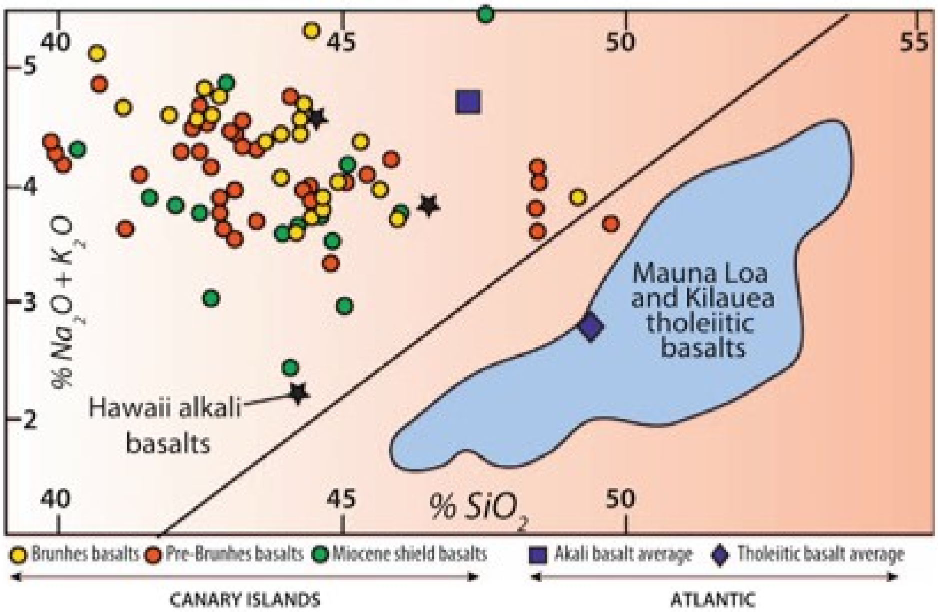

FIGURE 8.21

Simplified TAS diagram of rocks of different basaltic units of Fuerteventura (after Fúster et al., 1968) and comparative data from other Atlantic basalts and of Hawaii alkali and tholeiitic basalt compositions (after Clague and Sherrod, 2014). The data demonstrate the ocean island character of the basaltic rocks of Fuerteventura.

ROCK COMPOSITION

Lavas of Fuerteventura are monotonous from a petrological point of view. Both shield and post-erosive stage rocks are basalts of alkaline character (Fig. 8.21). The more silicic types plot near the boundary with tholeiitic basalts in a TAS diagram and recent eruptions (Series IV of Fúster et al., 1968a) also comprise alkali basalts, very similar in chemical composition to the older formations of the island.

As a general remark, the majority of lavas on Fuerteventura show a low degree of silica saturation and high alkali content. These lavas are even less silica-saturated than the Hawaiian lavas or average Atlantic alkali basalts in general (Fig. 8.21).

YOUNG SEDIMENTARY FORMATIONS

Sedimentary formations, not commonly exposed in the western islands, are a significant geological feature in the eastern islands, particularly on Fuerteventura, Lanzarote, and the iconic Maspalomas sand dunes on Gran Canaria. Specifically, the extensive aeolian sand deposits are relevant for their climatic implications and the definition of raised beaches, which helped enormously in defining the volcano-stratigraphy of the island.

AEOLIC SANDS (JABLES)

Deposits of light-colored sand (locally known as *jables*, from the French *sable*) are frequent in the eastern Canaries (see also Chapter: The Geology of Lanzarote). Thick sand deposits cover extensive areas of Fuerteventura (Fig. 8.22). The sand is formed by a complex aeolian system supplied by Pliocene and Pleistocene marine deposits, partially covered by carbonate crusts (calcrete). Sands are formed mainly by a Mio-Pliocene biogenic component comprising skeletal calcareous algae, shell fragments, and foraminifera that thrived on Fuerteventura during a period of equatorial climate (ie, lacking annual seasonal cycles) that extended from approximately 9–4 Ma (Meco et al., 2007). The closing of the Panama isthmus at approximately 4.6 Ma then initiated the cold Canary current that brought a drastic change in climate to the Canaries. Climate became colder, arid, and with marked annual seasonal cycles (see also Chapter: The Geology of Lanzarote, Fig. 7.9). This led to "mass extinction" of the marine equatorial fauna in the Canaries and provides the source of the *jables* and, hence, the spectacular beaches of Fuerteventura.

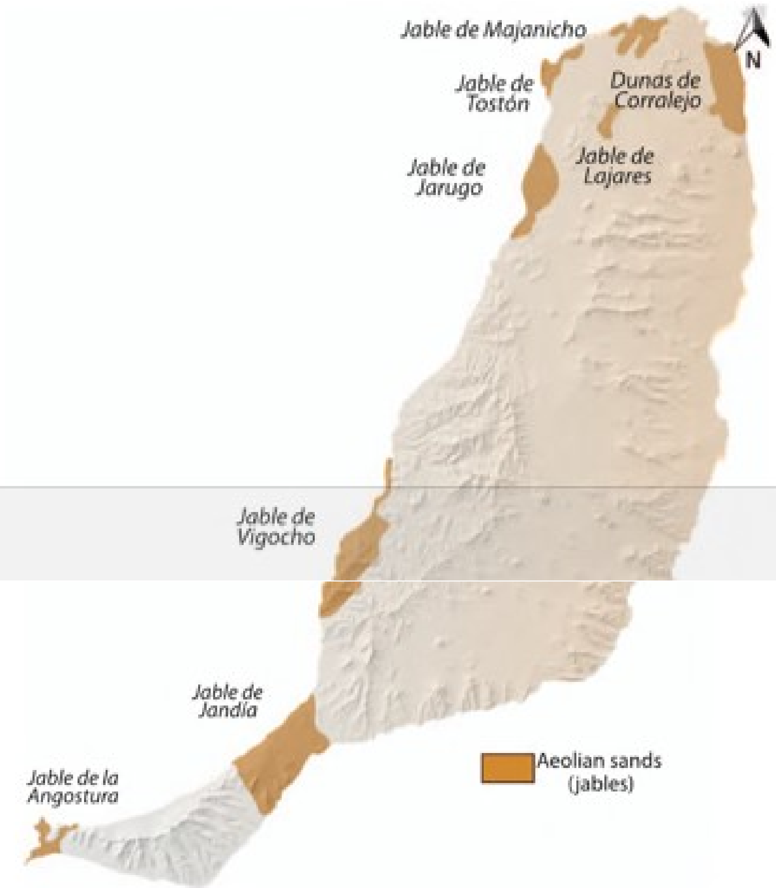

FIGURE 8.22

Distribution of aeolian sand deposits (jables) on Fuerteventura. Notably, the eastern (leeward) coast largely lacks this type of deposit.

555 is missing

However, this volcanic stratigraphy proved nontransferable to the western Canaries that are still in the shield stage of evolution and where equivalent raised beaches are lacking. Therefore, Carracedo et al. (1998) proposed applying the same volcano-stratigraphic units used in the Hawaiian Islands, separating the shield and post-erosional stages. Important advantages of this classification are that it is applicable to the entire archipelago, has a genetic connotation, and allows correlation of similar volcanic processes among the different islands and thus across geological time (see '*La Canaria*' concept in chapter: The Canary Islands: An Introduction, Fig. 1.34).

GEOLOGICAL ROUTES

Fuerteventura presents a number of features that are unique within the Canarian archipelago. First, it is the oldest island; in its western part, large sections of uplifted oceanic sediments and the submarine seamount stage of growth are exposed. Moreover, erosion and landslides removed the greater part of the Miocene island, exposing the deeper plutonic structure of the Miocene Fuerteventura edifice, such as the different magma reservoirs now preserved as plutonic intrusions and the feeder dykes of thousands of submarine and subaerial eruptions that formed very dense dyke swarms in a number of places.

Because of the low and smooth topography, roads on Fuerteventura are mostly flat, making traveling across the nearly 100-km-long island easy and fast (note that Tenerife is only 98 km long). Tourist resorts are disperse, with the northern *Corralejo* area and the southern Jandía peninsula (*Morro Jable*) being the main tourist hot spots. For this reason, the starting point for the day trips on Fuerteventura are not fixed (Fig. 8.24).

DAY 1: OCEANIC SEDIMENTS AND PLUTONS

Drive to *Pájara* and then follow FV-621 to *Ajuy* (Fig. 8.25). Approximately 1–2 km before reaching the coast, you will see numerous dykes on your left in the road cuts that show striped sedimentary rocks between the dyke intrusion. Note the ratio of dykes to sedimentary country rock. More than 60% of the rock mass here are dyke intrusions. From here, make your way to *Ajuy* and to the
than 60% of the rock mass here are dyke intrusions. From here, make your way to *Ajuy* and to the
larger car park near the beach.

Stop 1.1. Playa de Ajuy *(N 28.3991 W 14.1545)*

At the northern end of the beach, uplifted sediments are intruded by dykes (Fig. 8.26). The sedimentary rocks comprise dominantly siliciclastic lithologies here and show rhythmic banding for most parts. These sedimentary rocks are, in turn, overlain unconformably by Pliocene beach conglomerates, alluvium, and wind-blown materials, indicating a drop in sea level since the Pliocene and a rather stable situation thereafter. Note the massive gray phonolite dyke that bends within the sediments but is truncated by the younger (Pliocene) lava flows.

Stop 1.2. Zebra rocks in Bco. del Aulagar, Las Arenas (N 28.3841 W 14.1503)

This first outcrop should be followed by a hike up the barranco (approximately 40 min to an hour each way) to inspect dykes and a pyroxenite intrusion with spectacular partial melting textures in their aureoles (zebra rock, Fig. 8.27). For this, walk up the Bco. del Aulagar, which you can access at the southern end of the beach via a dry river bed.

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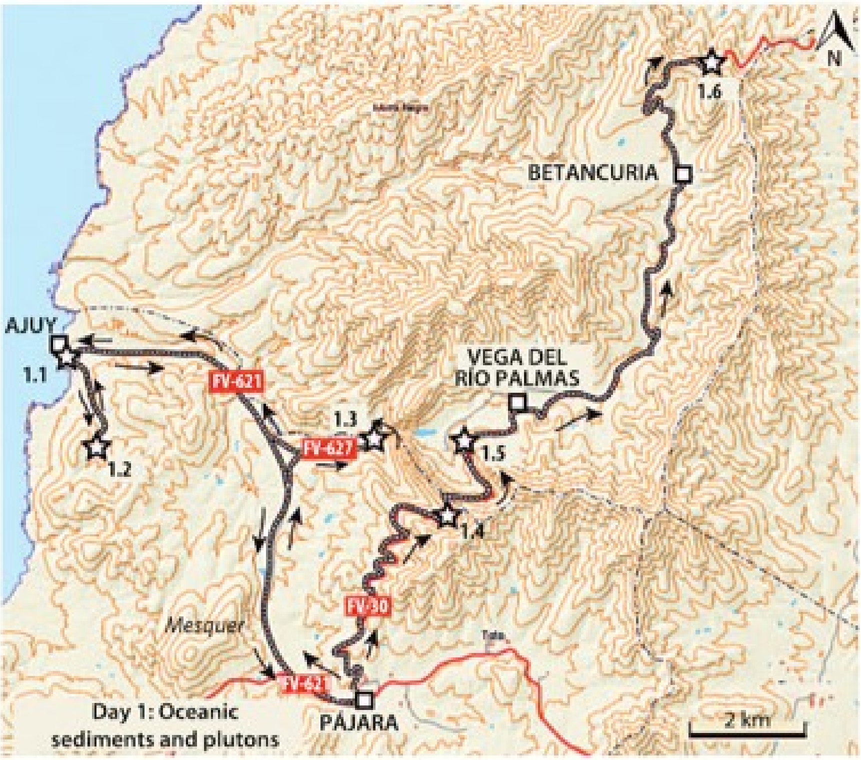

FIGURE 8.25

Map of the central western part of Fuerteventura (the Betancuria massif), with the stops for Day 1 marked. The day is mostly dedicated to the uplifted oceanic sediments and the plutonic core of the island that is exposed in the *Ajuy*, *Pájara*, and *Betancuria* area. Map modified from IDE Canarias visor 3.0, GRAFCAN.

is probably a function of flow differentiation that moves solid inclusions to the center of the active flow during magma transport in a confined fracture (see also Day 5, chapter: The geology of Tenerife).

Continue upstream until you reach a natural terrace and some young trees above the terrace. Keep on the southern track (right) and continue for approximately 10 min through basaltic dykes until you reach the first zebra rock exposure (Fig. 8.27). The zebra rock is in part white to cream-colored in the contact aureoles to the large pyroxenite intrusions that form the dark hills to your left (east). The zebra veins represent frozen partial melt and are made up of evolved syenitic/phonolitic compositions, providing an elegant mechanism for the generation of felsic ocean island magmas. Continue in a southerly direction along the stream bed.

At the junction with Bco. de Las Arenas (N 28.3891 W 14.1498), you can either continue southward to gradually leave the contact aureole again or turn toward the southeast to approach the pyroxenite intrusions. Unfortunately, the pyroxenite is not very fresh, but the large pyroxene crystals are readily visible. A bit further up this southeastern arm of the stream system, a cream-colored "kinky" dyke of felsic composition occurs in the pyroxenite, likely exploiting cooling fractures in the pyroxenite host rock.

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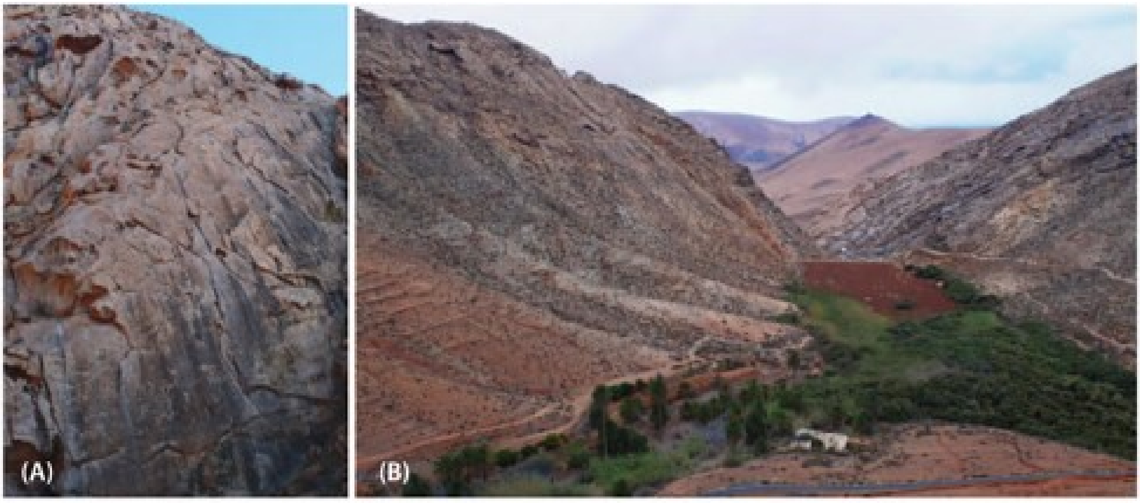

IGURE 8.28

A) The outermost (syenitic) ring of the Vega de Río Palmas intrusive complex. (B) Las Peñitas dam is now ompletely filled with sediment. In the far distance, the darker pyroxenite pluton of Mesquer is visible.

Stop 1.4. Mirador Risco de las Peñas (N 28.3797 W 14.0953)

'ou are now on top of the Vega de Río Palmas ring dyke. Here, you can inspect the syenite again nd take a stroll onto its upper exposures. Locally, pegmatitic domains are present. At this site, quirrels are plentiful, but they should not be fed.

Walk toward the exposed rocks along the available path for a few hundred meters to inspect a arger gabbroic mass that is resting in the syenite and hosts many syenite veins. This is a fallen lock from the roof, consistent with the notion of a previous caldera collapse. Assuming these abbro blocks are from the gabbroic Toto ring dyke, then the Vega de Río Palmas ring dyke is the ounger of the two ring intrusions (see Fig. 8.9).

Return to your car and continue northward through mainly dykes of the basal complex. Continue for approximately 2 km to *Mirador las Peñitas* for our next stop.

Stop 1.5. Mirador las Peñitas (N 28.3870 W 14.0924)

Looking west, you can now view the Rio de la Vega ring dyke from above (and from inside)! Note the path taken earlier in the day is visible from here (see Figs. 8.10; 8.28B). The curvature of the intrusion is quite apparent from here also, and so is the geometry of a steep arcute sheet (ie, the bell jar–shaped geometry of the ring dyke).

Note the squirrels! The Barbary ground squirrel (*Atlantoxerus getulus*) was introduced to Fuerteventura from North Africa as a household pet in 1965. After some escaped, they found a natural environment similar to their homeland but without predators. Their numbers have increased to an estimated 300,000 and they are now a threat to the island's endemic flora and fauna.

Continue on FV-30 for approximately 11 km to *Mirador de Corrales de Guise*.

Stop 1.6. Mirador de Corrales de Guise (600 masl, at Guanche statues) (N 28.4407 W 14.0561)

This vantage point is at an altitude of 600 m on FV-30 and offers spectacular views onto the beautiful scenery of Betancuria's landscape to the south and also over northwest Fuerteventura and all the way to Lanzarote (Fig. 8.29).

A pronounced dyke in the near hillside is visible (strike approximately 40° and with a dip to the west). Looking north, in the flat part in the distance beyond the near hillside, note the reddish cinder cone (Mña. Bermeja, from the Spanish *Bermejo*, a type of bright red color). Moreover, in the far distance, a ridge-like trachyte intrusion (Tindaya) and, to the east, lava remnants of the northern shield complex (Miocene 11–9 Ma) are visible (eg, Rosa del Taro, Mña. del Campo; Fig. 8.29).

Looking southeast toward *Betancuria*, you can see rounded hills made up mainly of basal complex dyke intrusions that are also partly exposed in the lower ground.

The two giant bronze statues are a tribute to Guise and Ayose, the native kings of Maxorata and Jandía, the two separate kingdoms of Fuerteventura in the pre-Hispanic era. The larger north of the island was known as Maxorata and the smaller south was known as Jandía, with a dividing wall that was erected on the isthmus of *La Pared*.

This is the last stop of the day. Make your way back to your base, either in the north or south of the island. Note that we will be back in *Ajuy* tomorrow morning.

END OF DAY 1.

DAY 2: THE SOUTH

Make your way to *Pájara* and then again to *Ajuy* (*Puerto de la Peña*), and park again at the beach.

Day 2 will be dedicated mainly to inspect the transition from submarine to subaerial volcanism and the plutonic intrusions of that period (Fig. 8.30).

Stop 2.1. Ajuy, *Caleta Negra (N 28.4001 W 14.1572)*

We shall now inspect the post-basal complex sequence in the cliffs on the northern end of the beach. Follow the steps up the cliff (Fig. 8.31). Above the steep dipping basal complex sediments and dykes, there is a semihorizontal unit of beach conglomerates. On the steps, the large phonolite dyke from Day 1 appears here as a sill, exploiting the boundary between these major rock units. The beach is approximately 14 masl and has calcareous organic sediments resting on its top section, which are dominantly of aeolian origin. The fossils here are approximately 3 Ma old (ie, Pliocene in age).

There are gastropods and shells to be seen, as well as insect nests (from wasps for instance) mixed with volcanic detritus and rock pebbles of various sources.

Continue through the hardened sand deposits along the coastal walk. After a few minutes you will encounter basaltic rocks on top of the aeolian sandstones, which are Pliocene lavas that were flowing toward the sea. The pillow lavas observed a little further along the path imply that at this time, this site was at sea level (Figs. 8.31 and 8.32). They are, in turn, overlain by regular subaerial lavas.

Continue on the path until it descends. You will soon encounter hyaloclastite breccias and pillow lavas mixed with sand, suggesting a lava delta of some definition. Here, please take a look

FIGURE 8.29

Panorama view from *Mirador los Corrales de Guise* onto the northern half of Fuerteventura. In the foreground is the "smooth" relief of the Betancuria massif. In the distance and in darker color are the remains of the northern shield volcano.