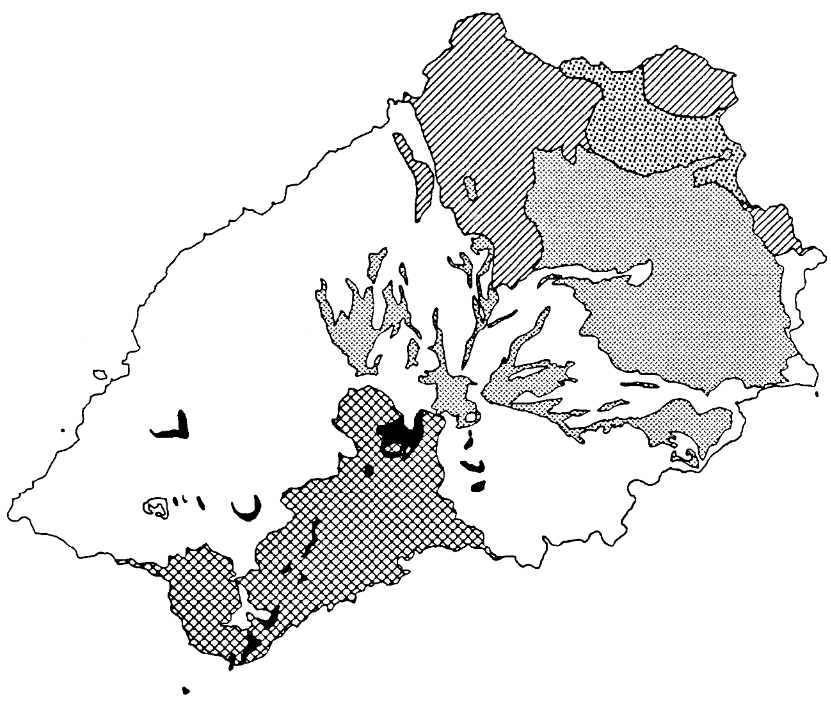
A GUIDE TO THE GEOLOGY OF SAINT HELENA



Barry Weaver

School of Geology and Geophysics,
University of Oklahoma,
Norman, Oklahoma 73019, U.S.A.

FOREWORD

This guide is intended to provide some basic information about the geology of St. Helena for those interested in the natural history of the island. During my two visits to St. Helena in 1988 and 1989 for the purposes of a very esoteric study of the chemistry of the volcanic rocks (about which I shall write nothing here), it was apparent that there was a great deal of interest in the geology of the island, both among Saints and visitors. It was, however, even more obvious that there were many misconceptions about the geological structure and history of St. Helena, not least with regard to the age of the island and the relationship of the origin of the island to plate tectonics. It is hoped that this guide will rectify at least some of those misconceptions, and promote a broader understanding of, and interest in, the geology of St. Helena.

St. Helena is a wonderful place to study volcanic geology, as millions of years of erosion have produced exposures of volcanic rocks of a wide range of types and ages, and displaying numerous types of volcanic features. Unfortunately, it is impossible to be both non-technical and at the same time give an adequate explanation of the geology, and so I have included a bare minimum of geological definitions and terminology as a prelude to a description of the geology of St. Helena. I would hope that the information to be found in this guide could be used by almost anyone to observe the geology of the island, and to come to some understanding as to the islands origin and geological history.

July 1990

Geologising in a volcanic country is most delightful, besides the interest attached to itself it leads you into most beautiful and retired spots.

St. Helena, situated so remote from any continent, in the midst of a great ocean, ... excites our curiosity.

Charles Darwin

The manner of its [St. Helena's] formation, together with the time occupied therein, and the period that has since elapsed in bringing it to its present shape and dimensions, are each subjects affording unusual interest in reading that page of nature's book which throws light upon the ancient geography of the Southern Atlantic Region.

J. C. Melliss

INTRODUCTION

The Island of St. Helena is of volcanic origin, and, as noted by Melliss (1875), "the truth of such an assertion cannot be doubted, even by the most casual observer". However, this single observation prompts a multitude of other questions, not all of which are as simply answered. Why does St. Helena emerge from the vast depth and expanse of the South Atlantic Ocean, 1,200 miles from the nearest mainland? How long has the island been there? What is the origin of the multiple layers seen in the cliffs and hillsides around Jamestown? Why do Lot and Lot's Wife stand in such stark contrast to the surrounding countryside? It is easy to be curious about these aspects of St. Helena, so remarkable is the spectacle of an imposing and beautiful island after a passage of thousands of miles over featureless ocean. It is also difficult to entirely ignore the geology of the island, especially in Jamestown; after all, if you don't go and look at the rocks, it won't be too long before they come and look at you! Some of the best geology is to be seen in the more remote areas of St. Helena, but it is well worth the effort as geologising can indeed be combined with some exhilarating and very rewarding walks. Many types of volcanic structure can be observed on the island, and the geological history of the construction of St. Helena can be quite simply worked out.

Due largely to its remoteness, the geology of St. Helena has been only sporadically studied over the last 200 years. An anonymously published article of 1805 was the first to (albeit briefly) consider the geological structure of the island. The famous naturalist Charles Darwin visited St. Helena for 6 days in July 1836, during the voyage of HMS Beagle which gave Darwin his ideas leading to the publication of *The Origin of Species*. Darwin was an accomplished geologist (in fact, at this time he was primarily a geologist), and his description of the geology of St. Helena, although in error on some points, was a significant contribution, particularly considering the short duration of his visit. Oliver, stationed on St. Helena as a captain with the Royal Artillery, published a short pamphlet in 1869 which describes the geology of the island remarkably well. The well known book by J. C. Melliss, published in 1875, dealt with many aspects of the history and natural history of St. Helena, including the geology. Although Melliss made some good observations, many of his interpretations of the geology are in error; surprisingly, Melliss appears to have been unaware of Darwin's visit to the island, and of his 1844 publication *Geological Observations on the Volcanic Islands* which includes a description of the geology. The American geologist Daly visited St. Helena for just over a month in 1921-1922, and substantially advanced the understanding of the geology of the island, rectifying many of the earlier misinterpretations. His 1927 publication included a geological map of St. Helena which is much superior to previous maps.

Our knowledge of volcanic phenomena and the way in which volcanoes work has increased immensely in recent decades, making these older publications of only limited use in understanding the structure and origin of St. Helena, although they remain of considerable interest for the observations (but not interpretations) recorded in them, and as historical documents of the development of geological thought. Our current, and most comprehensive, knowledge of the geology of St. Helena comes from the work of Ian Baker, who (as a Ph.D. student at Imperial College, London) spent a total of 8 months on the island during 1964 to 1966. Baker mapped out the various exposed volcanic units, applied modern volcanological interpretations to the geology of the island, and did an excellent job of unravelling the geological history of St. Helena. He compiled a detailed geological map, and determined for the first time the absolute ages of rock samples from St. Helena. A copy of Baker's Ph.D. thesis can be consulted in Jamestown Public Library, as can most of the other literature on the geology the island. (A complete bibliography of publications relating to the geology of St. Helena is given at the end of this guide.)

To fully appreciate the origin and evolution of St. Helena, it is necessary to understand some of the broader aspects of the large-scale geological structure of the Earth, and to introduce relevant ideas about the nature of volcanoes. The following sections therefore outline some of the current major concepts and theories in geology, using a bare minimum of essential terminology and definitions.

PLATE TECTONICS

The large-scale geological structure of the Earth's surface is currently understood in terms of the theory of ***plate tectonics*** (developed since the mid-1960's), according to which the upper 75-100 kilometres of the Earth is composed of rigid plates of rock which move over the slightly fluid underlying ***mantle***. Twelve discrete plates compose the surface of the Earth (Figure 1), comprising 7 large, major plates (the African, Antarctic, North American, South American, Eurasian, and Australian-Indian plates) and 5 small, minor plates. The continents are embedded in the plates (Figure 2), and are carried along with them as they move across the surface of the Earth (thus ***continental drift***). Some plates (such as the Pacific plate; Figure 1) are entirely oceanic in character, with no associated continent(s), although most plates carry continental masses (e.g., the African and South American plates; Figures 1 and 2). Greater than 90% of the volcanic and earthquake activity on the Earth occurs in association with the boundaries between plates. At a ***mid-ocean ridge*** boundary new plate material is added to existing plates (Figure 2), which move apart from each other perpendicular to the ridge (e.g., the Mid-Atlantic Ridge is the boundary between the South American and African plates in its southern part (Figure 2), and between the North American and Eurasian plates in its northern part). Mid-ocean ridges are marked by much submarine volcanic activity, and many shallow depth, low magnitude earthquakes. At a ***subduction zone*** boundary two plates converge upon each other (Figure 2), and one plate is destroyed by being subducted into the mantle beneath the other plate (e.g., the small Nazca plate is being subducted under the South American plate along the west coast of South America; Figure 2). Subduction zones are marked by much subaerial volcanic activity (e.g., the very numerous Andean volcanoes), and commonly deep origin, high magnitude earthquakes. At ***transform fault*** boundaries two plates slide horizontally past each other (e.g., the San Andreas Fault in California is a

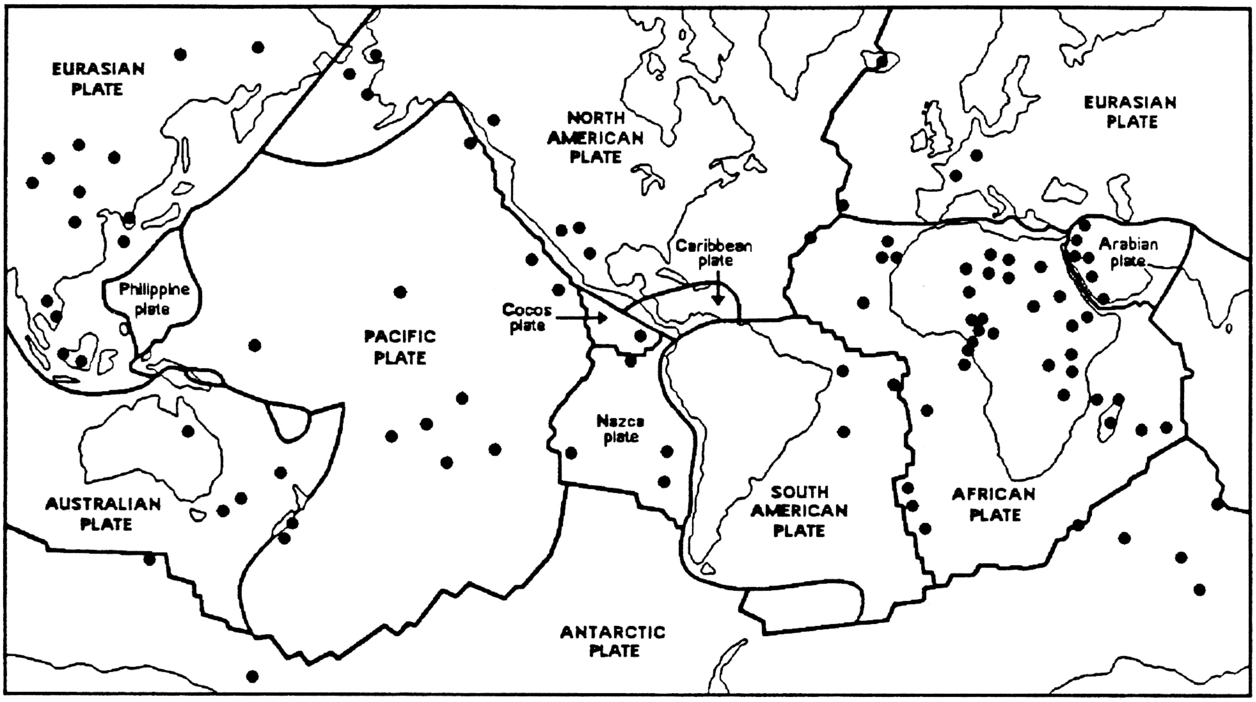


Figure 1. Diagram showing the major (African, Antarctic, Eurasian, Australian-Indian, South American, North American) and minor (Nazca, Cocos, Caribbean, Philippine, Arabian) lithospheric plates of the world. The boundaries between the plates are shown, but mid-ocean ridge, subduction zone, and transform fault boundaries are not distinguished. Also shown are the locations of hot-spots (dots).

transform boundary between the North American and Pacific plates). Transform faults have no associated volcanic activity, but significant, often high magnitude, earthquake activity.

The plates of the Earth are in continual, but slow (rates of centimetres per year), movement. If the motions of the plates across the surface of the Earth are traced back through time, some 200 million years ago the present continents formed a single large continental mass called Pangaea (*"all lands"*; Figure 3). The Atlantic Ocean did not exist at this time, South America, North America, Africa and Europe being joined together (Figure 3). Some 180 million years ago, Pangaea started to break-up into smaller continental masses, and the central part of the Atlantic Ocean started to form (Figure 3). The South Atlantic Ocean initially formed by rifting of South America from Africa some 130 million years ago (Figure 3), while the North Atlantic Ocean did not start to form until some 80 million years ago. Since that time, the Mid-Atlantic Ridge has been fully established, Africa and South America and Eurasia and North America have separated by large distances, and the Atlantic Ocean has increased to its present size (Figure 3). South America and Africa continue to move apart as the Mid-Atlantic Ridge

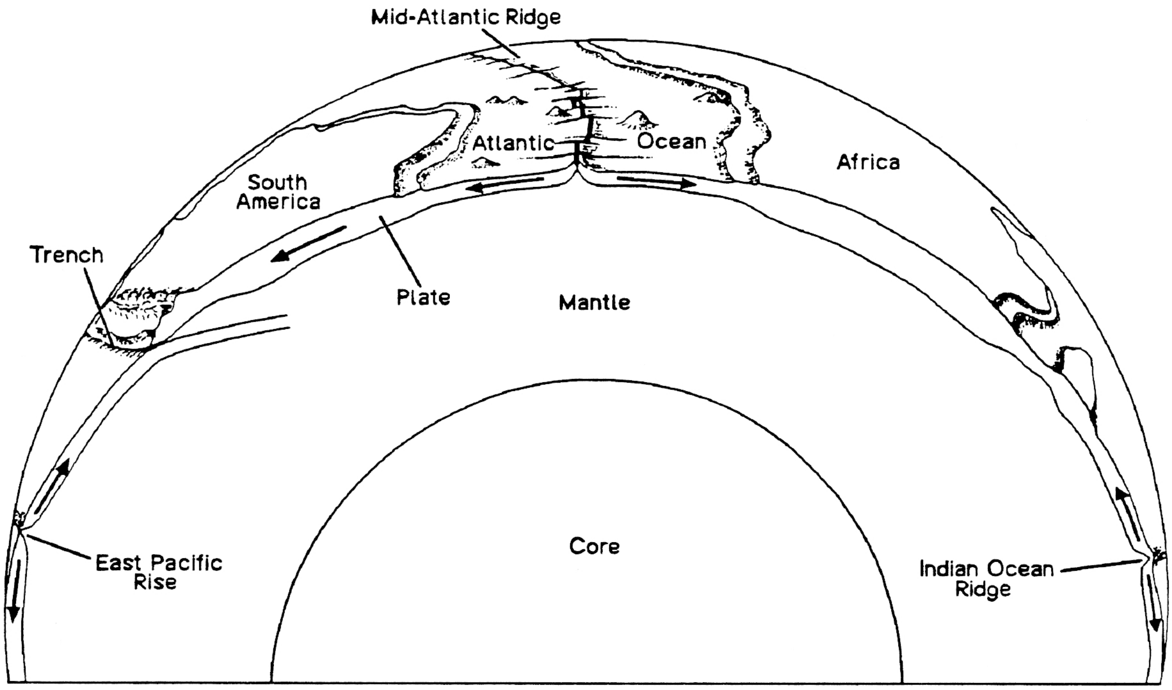
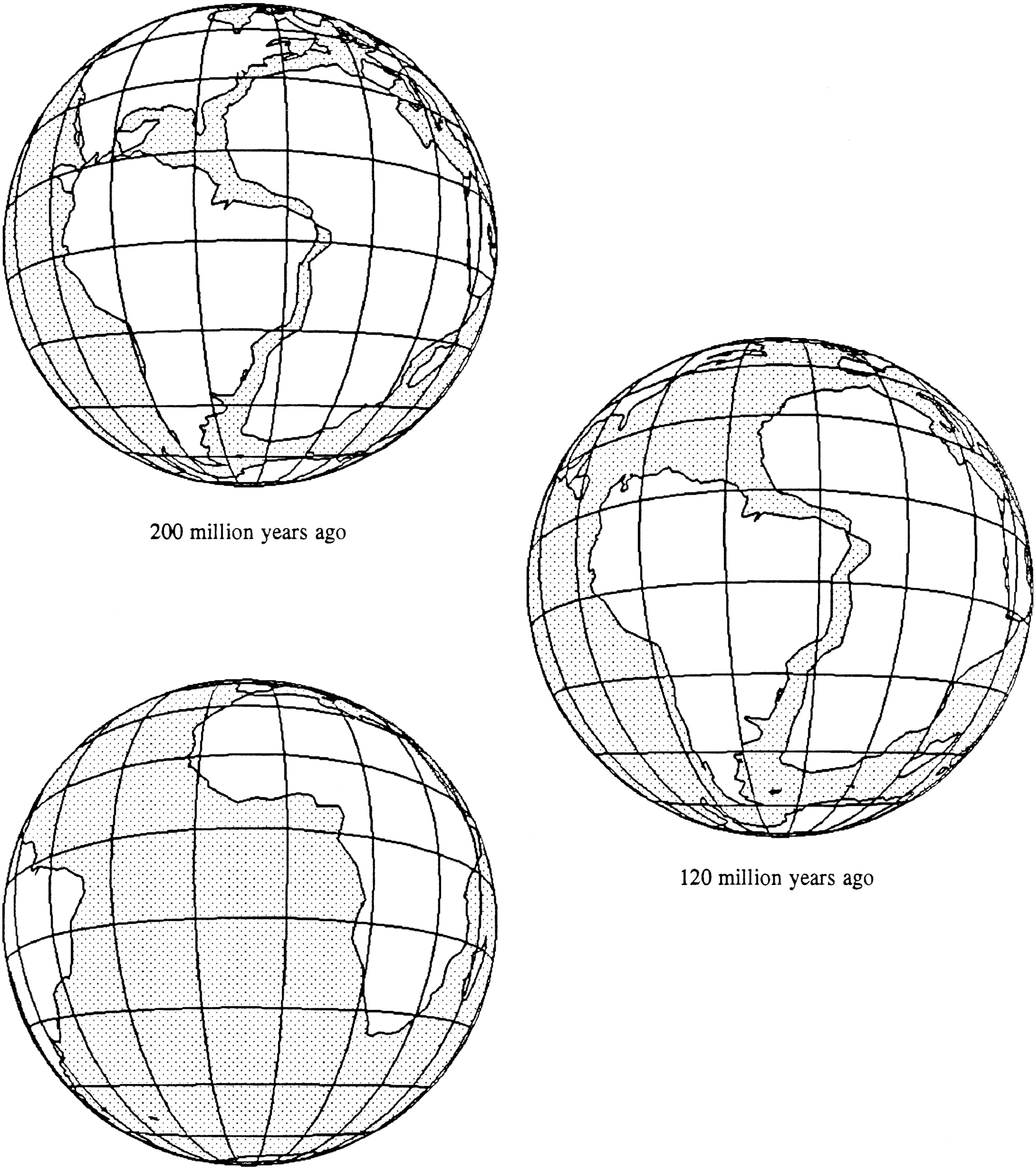


Figure 2. Cross-section through the Earth, showing details of the internal structure. Plates are produced at mid-ocean ridges (e.g. Mid-Atlantic Ridge, East Pacific Rise), and move laterally away from the ridge, to be ultimately subducted into the mantle (e.g. the Nazca plate is being subducted under the South American plate; a deep ocean trench marks the point where a plate starts to be subducted). The continents are embedded in the plates, and move with them. The diagram is not drawn to scale.

spreads at a rate of approximately 4 centimetres per year. Geologically, the Atlantic Ocean is a young feature (the Earth is 4,500 million years old), and the oceanic crust of the Atlantic Ocean is nowhere greater than 180 million years old (new ocean crust is being formed at the Mid-Atlantic Ridge, and becomes older away from the ridge to east and west). This contrasts with the continents of Africa and South America, which are much more ancient, and composed of rocks formed as long as 3,500 million years ago.

HOT-SPOTS

A small, but significant amount of volcanic activity on the Earth occurs distant from plate boundaries, and is unrelated to movement or interaction of the plates. Such activity is a result of the presence of localised areas of high heat flow (***hot-spots***) in the Earth's mantle. Hot-spots originate deep in the mantle (at depths of at least 700 kilometres), and hot jets of deep mantle material rise upwards and cause volcanic activity where they meet the plates. Over 100 hot-spots have been identified globally



200 million years ago

120 million years ago

Present day

Figure 3. The locations of the African and South American plates and continents at 200 and 120 million years ago, and at the present day. At 200 million years ago all of the present continents were joined together, forming Pangaea. By 120 million years ago North America had separated from Africa and Eurasia, and South America and Africa had started to separate. Since then, the South Atlantic Ocean has opened to its present size by sea-floor spreading associated with the Mid-Atlantic Ridge. All views are from 16°S, 6°W (the centre of the diagrams), the present latitude and longitude of St. Helena.

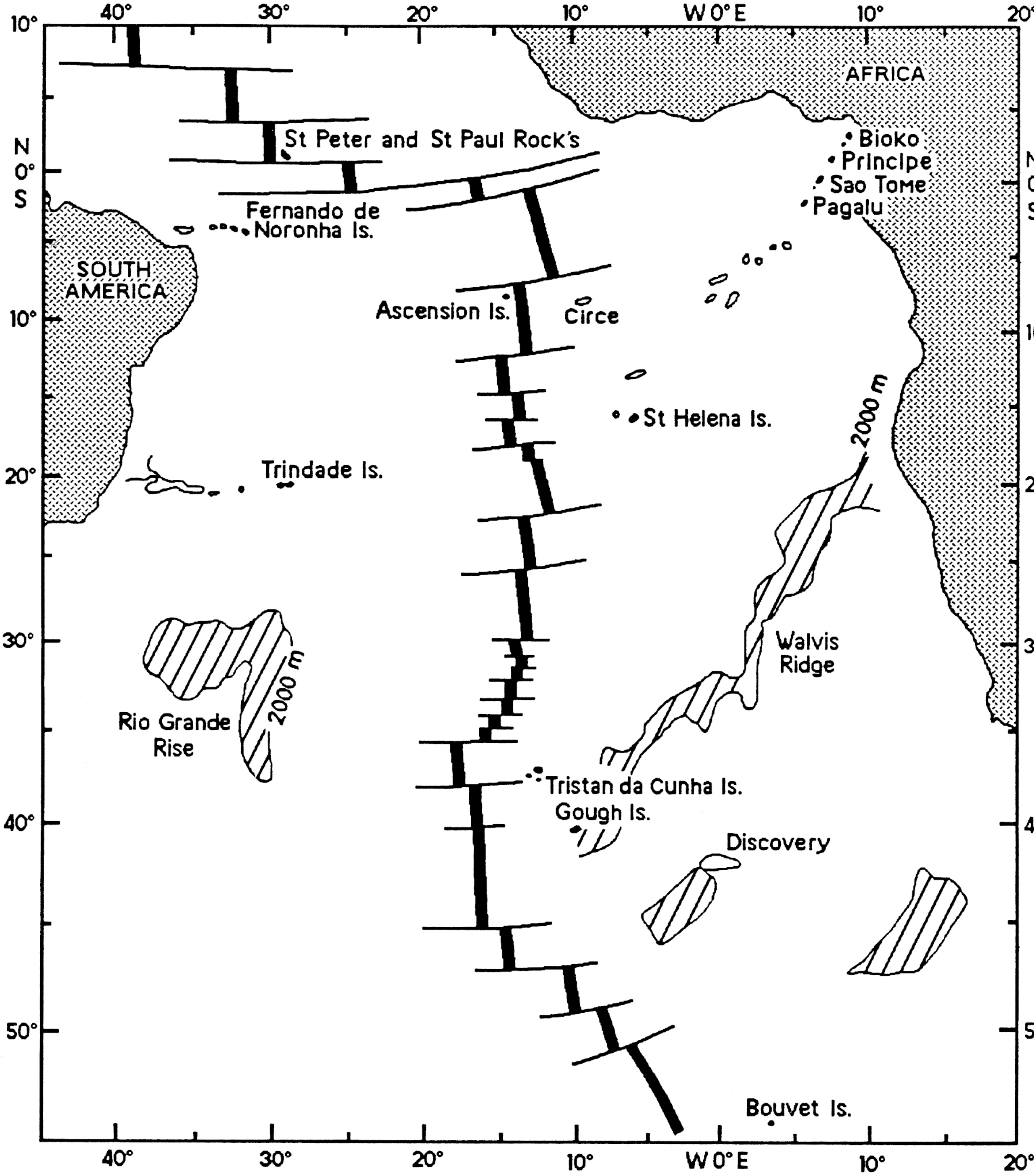


Figure 4. Generalised geological structure of the South Atlantic Ocean, showing location of the Mid-Atlantic Ridge and major E-W fracture zones which offset the ridge, hot-spot related volcanic islands and seamounts, and oceanic crust shallower than 2000 metres water depth.

(Figure 1). Hot-spots are stationary in the mantle, and the plates move relative to them at rates of centimetres per year. A hot-spot may, by chance, coincide with a plate boundary (e.g., Iceland, where the Iceland hot-spot coincides with the Mid-Atlantic Ridge; Figure 1), but in general hot-spot activity occurs in the interior regions of plates (Figure 1). St. Helena represents the top of a huge hot-spot

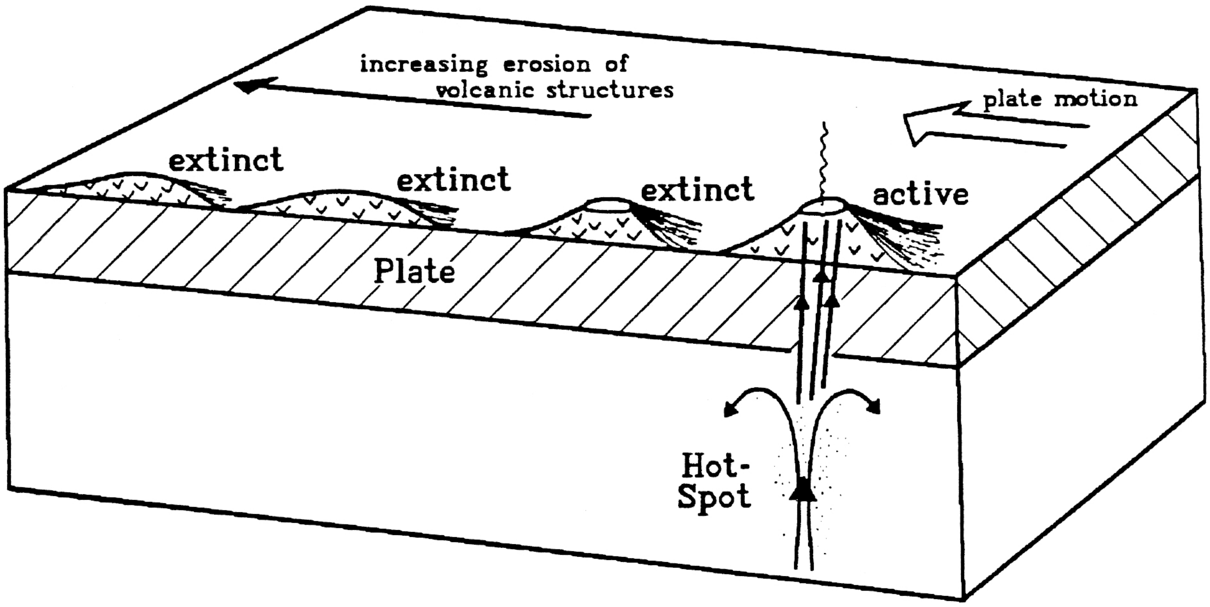


Figure 5. Diagram illustrating the development of a volcanic island and linear chain of extinct seamounts in association with the movement of a lithospheric plate over a hot-spot.

related volcanic cone constructed on oceanic crust of the African plate in the interior part of the plate (Figure 4), some 800 kilometers distant from the Mid-Atlantic Ridge boundary between the African and South American plates (Ascension Island lies on the other side of the Mid-Atlantic Ridge, and stands on oceanic crust of the South American plate, although located only 120 km to the west of the ridge; Figure 4). The various South Atlantic Ocean islands (Ascension, the Tristan da Cunha group (including Gough), St. Helena, Trindade and Fernando de Noronha; Figure 4) each represent the volcanic products of independent hot-spots. These islands ***were not*** formed at the Mid-Atlantic Ridge and subsequently carried away from the ridge by the motion of the plates, as is wrongly stated in numerous TV natural history documentaries.

Hot-spots may be very volcanically active for a period of time, and then cease activity for some time (the time periods involved may be of the order of millions of years). When a hot-spot is active, eruption of magma on to the surface of the overlying plate builds a large volcanic cone (Figure 5). However, as the plate moves over the stationary hot-spot the point of volcanic activity shifts, and a new volcanic cone is initiated at a different location on the plate (Figure 5). The original volcano ceases activity and becomes extinct, and starts to subside and be eroded (Figure 5); eventually it disappears beneath sea-level and becomes a ***seamount***, a fate which inevitably awaits St. Helena, but in 10 to 15 million years time!. (This might be the case with Bonaparte Seamount, although this volcano - related also to the St. Helena hot-spot - may never have emerged above sea-level.) In this way, over millions of years, a linear chain of extinct volcanic seamounts is built on a plate as it moves over a hot-spot, with a volcanically active island marking the location of the hot-spot (Figure 5). St. Helena is not related to a well defined seamount chain, but it does lie on an extension of the trend delineated by the islands of the Cameroon line (Bioko [formerly Fernando Póo], Principe, São Tomé, and Pagalu [formerly Annobon]; Figure 4), the volcanic activity of which appears to be have been initiated by the St. Helena hot-spot. Given the average rate of motion of the African plate over the last 7 million years, the current location of the (presently inactive) St. Helena hot-spot is approximately 150 kilometres to the southwest of the island of St. Helena.

NAMING VOLCANIC ROCKS

Magma (molten rock) is produced in the deep interior of the Earth by the melting of the solid rocks of the mantle. Once formed, magma ascends towards the surface. At some point, the magma cools, crystallises, and solidifies to form an ***igneous rock***. Magma reaching the surface is erupted as a ***lava flow*** which crystallises to form a ***volcanic rock***, whereas magma which becomes trapped at depth in the Earth crystallises to form a ***plutonic rock***. The rocks occurring on St. Helena are dominantly volcanic igneous rocks, but some plutonic igneous rocks are found. There are many different varieties of volcanic igneous rocks, each variety being named according to the chemical composition of the rock (most simply expressed by the content of silica, SiO_2) and the types of minerals present in the rock. There are, unfortunately, a huge number of names used in the classification of igneous rocks. Luckily, we need use only a few names in describing the volcanic rocks of St. Helena. ***Basalt*** is the dominant rock found on the island, has relatively low silica (roughly 45 percent by weight), and is mostly made up of the minerals ***olivine***, ***pyroxene***, and ***feldspar***. ***Trachybasalt*** has more silica and feldspar than basalt, while ***trachyandesite*** has more silica and feldspar than trachybasalt. ***Trachytes*** and ***phonolites*** are quite similar in composition, both having relatively high silica (roughly 60 percent by weight) and being composed mostly of feldspar. This scheme of names is something of a simplification, but follows the classification used by Baker in describing the geology of St. Helena.

TYPES OF VOLCANIC ERUPTION AND VOLCANIC STRUCTURES

Volcanoes may erupt magma either relatively passively (eruption of a lava flow), or explosively (eruption into the air of a cloud of gas and variably sized volcanic fragments which fall back to the surface to form ***pyroclastic rocks***). An individual volcano may erupt both passively and explosively during its lifetime. The type of eruption depends mainly on the chemical composition of the magma erupted. Eruptions of basalt tend to be passive, and the lava flows rapidly away from the point of eruption due to its relatively low viscosity. ***Shield volcanoes*** are built dominantly from basaltic lava flows, and have shallowly dipping sides to the volcanic cone. Eruptions of trachyandesite or trachyte tend to be explosive, and build ***stratovolcanoes*** with more steeply dipping sides to the volcanic cone. Being constructed mostly of basalt, the volcanic cone forming St. Helena is a shield volcano, the average dip of the submerged sides of the cone being about 4°. There are, however, some pyroclastic rocks on St. Helena which are evidence of intermittent, minor explosive volcanic activity.

Erupted magmas cool quickly, and crystals do not have time to grow to large sizes. Commonly, therefore, lava flows are fine grained, and the individual minerals comprising the rock cannot be easily identified by the naked eye. If magma is stored at depth in the Earth in a ***magma chamber*** for a long time prior to eruption, crystals forming in the magma can grow to moderate sizes. These crystals (***phenocrysts***) are carried in the magma when it is erupted, and rapid cooling of the lava flow produces a texture of phenocrysts set in a fine-grained matrix. Lava flows displaying such a texture are termed ***phyric***, whereas fine-grained lava flows lacking phenocrysts are termed ***aphyric***. The majority of lava flows on St. Helena are aphyric, but some are phyric, and contain easily visible phenocrysts of the minerals olivine, pyroxene, and feldspar.

At depth in the Earth magma is under considerable pressure, and gases are dissolved in the magma. Under lower pressure at, or close to, the surface, the gases separate from the magma as gas bubbles (if there is a lot of gas and the magma is very viscous, this can lead to an explosive eruption).

As the erupted magma flows over the surface, the gas bubbles are concentrated towards the top and bottom of the lava flow. When the flow solidifies, the bubbles are preserved in the rock as empty circular or elliptical cavities called ***vesicles***. Lava flows with a high concentration of vesicles are termed ***scoriaceous***. Typically, the basalt lava flows on St. Helena show the development of scoriaceous tops and bottoms to the flows, with non-vesicular, or ***massive***, centres to the flows.

A lava flow may change thickness substantially as it moves across an irregular ground surface away from its point of eruption. Where the flow crosses a depression in the ground surface it will pond and thicken, and where it encounters a small elevation it will either flow around it or thin over it. It is common for lava flows to change thickness substantially over distances of only tens or hundreds of metres. This can be commonly seen on St. Helena; most of the lava flow sequences exposed in cliffs and hillsides show individual flows thickening and thinning along their length, often by large amounts.

Volcanoes are not continuously active; the time intervals between successive eruptions of lava may be short (tens or hundreds of years), or rather longer (thousands or tens of thousands of years). If there is a long time between eruptions, the top of a lava flow will cool and be weathered to form a thin soil, such that vegetation can be established. A subsequent lava flow will bury and burn the vegetation, and evidence for the roots of trees will be preserved as casts in the lava flow. Tree root casts are not uncommon in flows on St. Helena (see Melliss (1875) and the letters from Denholm in the 2 December 1988 and 3 November 1989 issues of the *St. Helena News*), and most such casts may be of the indigenous Ebony tree. Drainage channels (streams) will be eroded into the side of the volcano during periods of quiescence between eruptions, with volcanic debris eroded from the upper part of the volcano deposited as sediment in these channels. A later lava flow will cover and trap the sediment, and bake it (a basalt lava flow is very hot, with a temperature of around 1200°C) and dehydrate it to form a hard ***sedimentary*** rock. Many such layers of red- to orange-coloured baked sedimentary rock (composed dominantly of clay minerals) can be seen between lava flows on St. Helena, particularly good examples occurring in the cliffs by West Rocks and in the cliffs on the west side of Lemon Valley Bay.

Magma stored in a magma chamber located deep in the volcanic structure is transported to the surface either via cylindrical conduits (***pipes***), or via sheet-like tensional cracks (***dykes***) in the overlying rocks. Dykes are usually almost vertically inclined sheets which intersect the surface as a linear ***fissure***. Magma is fed from the magma chamber through the dyke to the surface, and erupted as a lava flow from the fissure. At the cessation of the eruption, the magma remaining in the dyke solidifies, leaving a sheet of rock. Many of the lava flows on St. Helena were fissure fed, and consequently dykes are commonly seen cutting through lava flows; most of these dykes originally fed lava flows which have since been removed by erosion.

FINDING THE AGE OF VOLCANIC ROCKS

The ages of volcanic rocks can be found in two ways, either in a relative sense ("this lava flow is older than that one, but younger than that one"), or in an absolute sense (where the time of eruption, in years before present, can be stated). ***Relative age dating*** is easy; if one lava flow lies on top of another, the upper one is the younger, the lower one the older. Similarly, dykes are emplaced into pre-existing rocks (lava flows), and are always younger than the enclosing rocks. ***Absolute age dating*** is much more useful, but much more complicated. Determination of the absolute age of a rock is based on a laboratory measurement of the abundances of certain radioactive elements in the rock. As radioactive elements decay at a constant (and known) rate, measurement of the amount of a radioactive element remaining in a rock can be used to calculate the age of the rock. As it is both time consuming and costly to undertake absolute dating of rocks, usually only small numbers of samples with well known relative ages are dated in this way. Sufficient absolute age dates (obtained by Baker, Gale and Simons, 1967) are available for St. Helena rocks to define the timing of volcanic activity on the island. On this basis it is known that the island originally emerged above sea-level something over 14 million years ago, and that volcanic activity persisted for a total period of some 7 million years.

THE GEOLOGY OF SAINT HELENA

Geological Structure

St. Helena lies some 800 kilometres to the east of the Mid-Atlantic Ridge (Figure 4), the island itself representing only the top 5% of a large shield volcano built on 40 million year old oceanic crust of the African plate. The volcanic cone has a present height of over 5000 metres (the surrounding oceanic crust of the African plate is at a depth of 4400 metres beneath sea-level), and an average basal diameter of 130 kilometres. The dimensions of this volcanic structure far exceed those of any continental volcanoes. The base of the cone is not perfectly circular, but is somewhat elongated in a NE-SW direction (mimicked by the shape of the island itself). Nothing is known about the structure or age of the submerged part of the volcanic cone. The present volume of the volcanic cone above sea-level is approximately 60 cubic kilometres; however, erosion over the last 7 million years has removed at least 20 cubic kilometres of volcanic material.

St. Helena has a geological structure typical of oceanic islands produced by hot-spot activity. Darwin (1844) thought the geology to be relatively simple; he described a basal sequence of submarine lavas underlying a basaltic series of lavas (forming an incomplete ring around the island), in turn overlain by a feldspar-rich upper series of lavas forming the central, higher elevations of the island. Darwin correctly considered the phonolite stocks (e.g., Lot and Lot's Wife) and dykes to have been intruded after the cessation of eruptions. Melliss also recognised the general time progression from basaltic lavas to more feldspar-rich lava flows, but thought (wrongly) that eruption of lava flows was always preceded by eruption of "first mud, then rubble", the former being represented by the sedimentary layers, the latter being the sporadic pyroclastic layers. Both Darwin and Melliss considered that *all* of the lava flows were erupted from a volcanic centre originally located in the vicinity of the present Sandy Bay area, and that the large amphitheatre structure here represented the remains of a very large volcanic crater. By contrast, Daly (1927) correctly identified the presence of two ancient volcanic centres on St. Helena. He related the older lavas in the northeast of the island to what he termed the Northeastern Massif, with later eruptions forming the Main Massif of the larger part of the island being centred in the Sandy Bay area. Daly correctly considered the Sandy Bay amphitheatre to be purely an erosional feature.

Baker verified the existence of the deeply eroded remains of two ancient volcanic centres on the island. The earlier, smaller volcanic centre in the northeast of the island was centred on the area around the present Knotty Ridge, and was active for some 3.5 million years, starting at something over 14 million years ago. The later, larger volcanic centre in the southwest of the island (in the Sandy Bay area) was also active for about 3.5 million years, and Baker subdivided the activity of this centre into three phases (Figure 6). There is no evidence for any volcanic activity in the last 7 million years. The general chronology of events in the volcanic evolution of St. Helena is outlined in Table 1. Baker produced a detailed map of the geology of St. Helena, a simplified version of which is given in Figure 6. Only the main volcanic units (described below) are indicated on the map in Figure 6; Baker's detailed geological map of the island (and very detailed maps of particular areas) is to be found in his thesis.

The Age of the Volcanic Rocks of Saint Helena

Darwin (1844) wisely made no attempt to estimate the age of the volcanic rocks of St. Helena. Melliss, on the other hand, was rather over-ambitious in his attempts to determine the age of the island. Melliss (1875) states that "Its isolated position, its peculiar fauna, and its very remarkable insular flora, together with its geological character, present strong reasons for placing St. Helena amongst the oldest land now existing on the face of the globe", although the logic of this statement is far from sound. He then embarks on a calculation (based on an estimate of the original size of the island and annual rates of erosion) which suggests the island to be 40,000 years old! (Melliss' figure for the original size of the island is not too much in error, but his figure for an annual erosion rate is a huge overestimate.) Furthermore, from a count of 70 lava flows produced at a rate of one flow a century, Melliss also concluded that the island was constructed in some 7,000 years! Daly (1927) gave some brief consideration to the age of the island. While (again wisely) not stating an age in years, he considered that the balance of fossil evidence suggested the island to date back to at least pre-Pliocene times. We now know that the Pliocene epoch of geological time began 5.3 million years ago, and therefore this was not a bad estimate!

Baker, Gale and Simons (1967) used radioactive dating techniques to determine the age of two dozen rock samples from St. Helena. They established that the volcanic rocks exposed on the island range in age from somewhat over 14 million to about 7 million years old. The ages of the various volcanic units will be outlined below (see also Table 1).

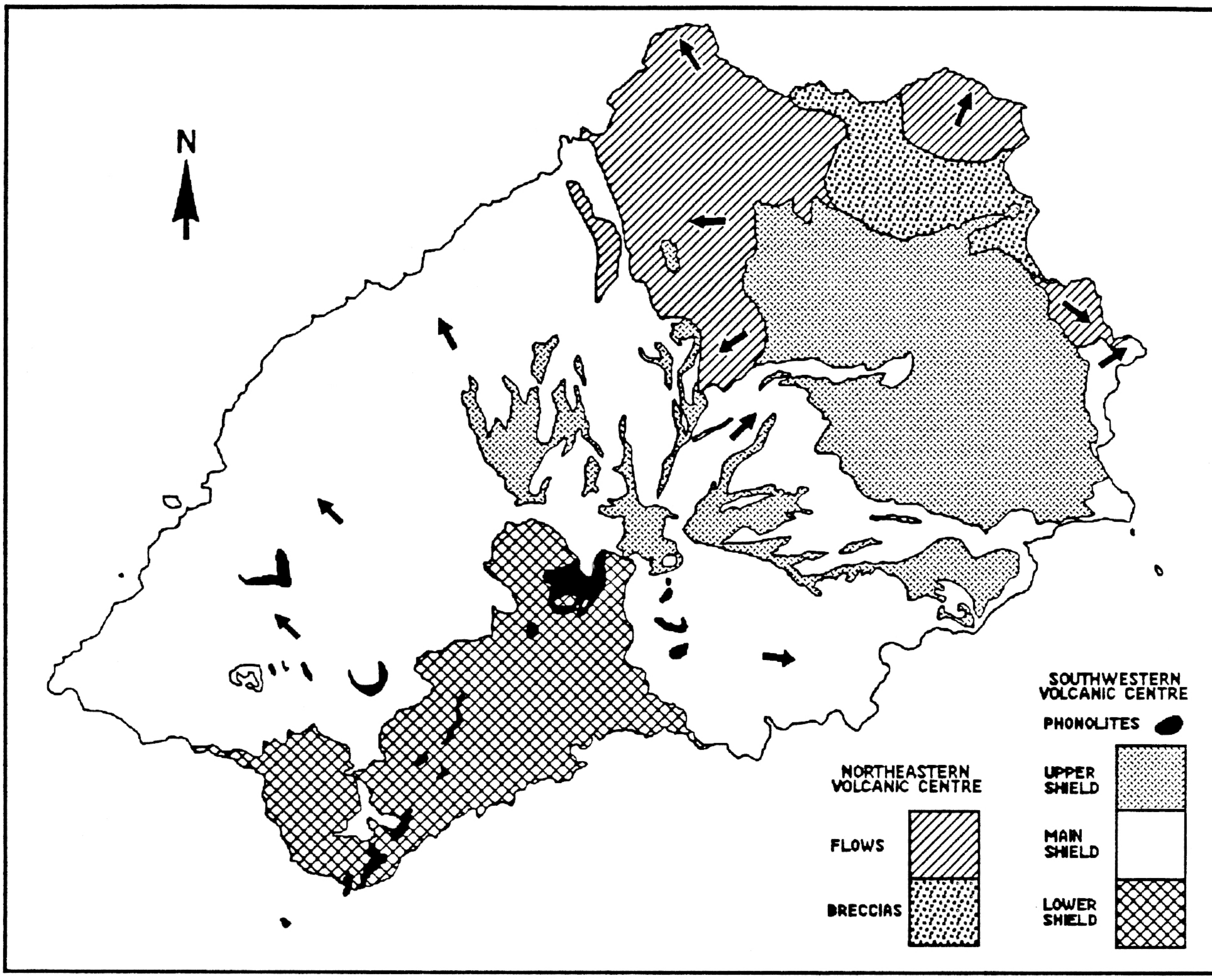


Figure 6. Generalised geological map of Saint Helena, after Baker (1968). Only the major volcanic units are shown. Arrows show the local direction of dip of lava flows.

THE NORTHEASTERN VOLCANIC CENTRE

The oldest volcanic rocks to be seen on St. Helena are those of the Northeastern Volcanic Centre (Figure 6). These rocks are well exposed on the coast eastwards from Munden's Point to just north of King and Queen Rocks, and form the conspicuous peaks of Sugar Loaf, Flagstaff Hill and The Barn.

The earliest rocks of the Northeastern Volcanic Centre formed underwater, and are submarine volcanic breccias (a breccia consists of angular boulders set in a fine-grained matrix). Somewhat over 14 million years ago, and continuing until about 11 million years ago (Table 1), the volcanic activity became subaerial in character, producing basalt lava flows. Thus, the volcanic cone (and the island) did not emerge above sea-level until about 14 million years ago. The age of the submerged part of the volcanic cone, and the time taken in its construction, are unknown.

Table 1. Simplified sequence and approximate timing of the major geological events occurring during the origin and evolution of St. Helena.

Millions of years ago	Northeastern Volcanic Centre	Southwestern Volcanic Centre
	Cessation of volcanic activity	
7		Late Extrusive Phase
		Late Intrusive Phase
8		
		Upper Shield
9	Local lava flows	
		Main Shield
10		
		Lower Shield
11		
	Subaerial lava flows	
14	Emergence of the island above sea-level	
	Submarine breccias	
?	Initiation of submarine volcanic activity associated with the St. Helena hot-spot	

The Breccias

Up to a 400 metre thickness of the submarine breccias of the Northeastern Volcanic Centre are exposed (Figure 6). The breccias are highly altered and relatively soft, and easily eroded. Consequently, exposure of the breccias is poor, and where exposed direct access is generally difficult or impossible. However, the breccias can be seen east of Flagstaff Hill (on the ridge from Flagstaff to the Barn) and in the lower parts of the valleys on either side of Turks Cap. Darwin (1844) recognised that the breccias were of submarine origin and represented the earliest volcanics exposed on the island. The breccias themselves are composed of small (up to 0.5 metres in diameter) angular to subangular basalt and trachyte boulders of a greenish-brownish colour set in a yellow matrix. Abundant dykes cut the breccias. The dykes are generally less than 1 metre thick, and form two distinct sets which strike in direction approximately N-S and E-W. The dykes are more resistant to weathering than are the breccias, and stand out in moderate relief from the enclosing breccias. These dykes acted as feeders to the lava flows of the Northeastern Volcanic Centre, and some may have been feeders to lava flows of the Southwestern Volcanic Centre.

The Lava Flows

Up to 800 metres total thickness of subaerial lava flows of the Northeastern Volcanic Centre are preserved (Figure 6). The original thickness of these flows is unknown. The lava flows are particularly well exposed on the upper elevations of the Barn, in Banks Valley and Rupert's Valley, on Bunker's Hill and Sugar Loaf, and on the coastal path from Munden's Point to Banks Valley Bay. The impressive structure of the Barn is formed by a hard, resistant capping of lava flows above the softer breccias; this is well seen from Turk's Cap and the ridge running to Turk's Cap (the dip of The Barn flows to the NE is also obvious from this vantage point). The directions of dip of the Northeastern Volcanic Centre lava flows (shown on the geological map; Figure 6) indicate that they were erupted from a centre in the general vicinity of the present Knotty Ridge. These flows were predominantly formed by fissure-fed eruptions.

The best and most accessible exposures of Northeastern Volcanic Centre lava flows are on the Banks to Rupert's coastal path, and at Banks Valley Bay. At the most southwesterly side of Banks Valley Bay (at beach level) a very good example of a vertical dyke cutting the lava flows can be seen, and some of the flows here are quite rich in small crystals; the bronze to olive-green coloured crystals are of the mineral ***olivine***, and the black coloured crystals are of the mineral ***pyroxene***. Walking along the path from Banks towards Rupert's and Jamestown, a sequence of 1 to 3 metre thick lava flows can be seen. These flows typically have scoriaceous tops and bottoms and massive centres. At a number of places 1 to 2 metre thick vertical dykes cut the lava flows; these dykes all strike roughly N-S (e.g., across the path), and stand out somewhat in relief from the flows.

At approximately 11 million years ago volcanic activity associated with the Northeastern Volcanic Centre largely ceased, although there was some limited, sporadic, later activity from this centre (Table 1). A localised sequence of lava flows exposed on Bunker's Hill filled a drainage channel eroded into older Northeastern Volcanic Centre flows, and are approximately 9 million years old.

THE SOUTHWESTERN VOLCANIC CENTRE

Some 11 million years ago the major locus of volcanic activity shifted to the southwestern part of the present island, and a new volcanic centre was initiated (Figure 6). The volcanics erupted from this centre partially buried those of the older centre. The volcanic rocks of the younger Southwestern Volcanic Centre can be divided into three major phases (Table 1; Figure 6); the volcanics of the **Lower Shield** were erupted between about 11 to 10 million years ago, those of the **Main Shield** between about 10 and 9 million years ago, and those of the **Upper Shield** between about 9 and 8 million years ago. Each of these phases produced distinctive associations of volcanic rocks, but basaltic lava flows predominate in all phases. The most extensively exposed volcanics on the island are the lava flows of the Main Shield (Figure 6).

The Lower Shield

Exposure of volcanics of the Lower Shield is restricted to the southwestern part of the island (Figure 6), in the area from Sandy Bay and the Devil's Garden to Castle Rock Plain and Manati Bay. Much of this area is difficult of access, being of steep, scree covered slopes. In addition, many of the rocks are highly weathered and altered, and the volcanic structures and relationships are not always clear. The alteration of the Lower Shield rocks has made them particularly susceptible to erosion, and the general amphitheatre structure of the Sandy Bay area is an entirely erosional feature, and not, as envisaged by Darwin and Melliss, the remnants of a large volcanic crater.

There is as much as a 600 metre thickness of Lower Shield volcanics preserved, consisting of both lava flows and pyroclastics; only the Lower Shield sequence shows the development of voluminous pyroclastic rocks. Baker (1969) subdivided the Lower Shield into four different units, each comprising a sequence of lava flows overlain by pyroclastic rocks. Many of the Lower Shield lava flows are quite strongly phyric, being rich in crystals of olivine and pyroxene. Boulders of this material are very abundant at Sandy Bay and in Broad Gut, and the phyric lava flows can be seen *in situ* on the hillsides surrounding Sandy Bay. Pyroclastic rocks which are extremely rich in crystals of pyroxene can be found in the immediate vicinity of the old flax mill at Fairyland, and, less accessibly, on the higher slopes in the vicinity of the Gates of Chaos. The black pyroxene crystals in these pyroclastics are frequently perfectly formed, and may be up to 5 centimetres in length.

Dykes intruded into the Lower Shield volcanics are very common, and, in a number of places, are extremely prominent. The impressive wall of The Chimney (on the descent to Lot's Wife Ponds) is formed by a dyke which has resisted the erosion that has removed the surrounding altered lava flows. The Ponds themselves are formed by a number of dykes which create natural dams and trap large pools of water. On the path down to Manati Bay from Botley's Lay, a sequence of altered Lower Shield lava flows intruded by many dykes can be seen on the northern face of the hillside south of Devil's Cap. In Manati Bay itself, fresh, unaltered Lower Shield flows and dykes may be examined, the more resistant dykes forming the linear features extending out into the bay. Many of the dykes intruding the Lower Shield lava flows are phyric, containing abundant crystals of olivine and pyroxene.

The Main Shield

The volcanic rocks of the Main Shield cover the greatest area of the island (Figure 6). The entire coastline westwards from Munden's Point through Lemon Valley Bay and South West Point to Man and Horse Cliffs is composed of Main Shield lava flows. Similarly, Main Shield volcanics extend continuously along the coast eastwards from Powell Point to King and Queen Rocks. Good sections eroded through sequences of Main Shield lava flows are therefore seen in a number of valleys, particularly James Valley, Lemon Valley, and Thompson's Valley in the northwest of the island, and Powell's Valley, Deep Valley and Sharks Valley in the southeast of the island.

The total sequence of Main Shield lava flows is at least 800 metres thick, and the flows are dominantly of basalt. Sedimentary layers occurring between flows are relatively common, and easily distinguished from the flows by their orange-red colour and softness. Some of the earliest Main Shield lava flows are quite phyric, containing abundant, sizeable crystals of olivine and pyroxene (e.g., in the vicinity of Hooper's Ridge, Joan Hill and West Point, and in the lower parts of the seaward end of Powell's Valley). The later Main Shield flows are more commonly aphyric. An excellent sequence of Main Shield lava flows is seen on Ladder Hill; a "stroll" up Jacob's Ladder takes one through a 200 metre thick sequence of lava flows, and the individual flows (varying from approximately 2 to 5 metres thick) can be easily identified.

Some localised, small minor intrusions post-date the volcanics of the Main Shield. An excellent example is seen at High Knoll, where a very fine-grained trachybasalt intrusion has fed a lava flow which overlies Main Shield lava flows and extends along the top of Ladder Hill to the vicinity of Signal House.

The Upper Shield

The volcanic rocks of the Upper Shield phase of the Southwestern Volcanic Centre are restricted in occurrence to the central and eastern parts of the island (Figure 6). There may have been a small shift in the centre of volcanic activity between the Main and Upper Shield phases, as the Upper Shield lava flows appear to have been extruded from the vicinity of the present Peaks in the centre of the island. A significant period of time may have elapsed between the Main and Upper Shield phases of volcanism, as many of the Upper Shield lava flows in-fill major erosional channels cut into the earlier volcanics. The Upper Shield flows of the interior of the island are poorly exposed and often badly altered. The best examples of Upper Shield volcanics are to be seen at Turks Cap, Bryan's Rock, at the seaward end of Fisher's Valley, and in the vicinity of the Stone Tops. Interestingly, Darwin (1844) termed some of these flows "the upper or feldspathic series", although he equated this "series" with flows erupted from the volcanic centre of the southwest of the island.

On the walk from Prosperous Bay ascending the southeastern side of Fisher's Valley a sequence of some of the earliest Upper Shield lava flows is traversed (at Prosperous Bay itself occur altered breccias and dykes of the Northeastern Volcanic Centre). The flows here are each approximately 15 metres thick, and 8 such flows can be observed. Occasional, thin ash layers separate some of these flows, and there may have been lengthy periods of time between eruption of the individual flows.

Turks Cap (and the ridge running to Turks Cap where Gregory's Battery and Cox's Battery are located) and Bryan's Rock are formed by thick trachyandesite and trachyte lava flows which are somewhat younger than, and lie above, the flows seen at the seaward end of Fisher's Valley. Three separate, 30-35 metre thick flows are seen forming Turk's Cap itself; here they directly overlie the altered breccias of the Northeastern Volcanic Centre, and probably fill a large erosional channel in the earlier volcanics. A fourth trachyandesite flow is present in the upper part of Fisher's Valley.

The youngest volcanic activity associated with the Upper Shield occurred in the vicinity of the Stone Tops. Baker distinguished this activity from the main part of Upper Shield activity, and termed these later flows the East Flank flows (as they were extruded onto the lavas forming the eastern flank of the Southwestern Volcanic Centre). Great and Little Stone Tops are formed by trachyte flow domes (Darwin wrongly believed Great Stone Top to be composed of basalt). Trachytic lavas are much more viscous than basaltic lavas, and flow only short distances from their point of eruption, tending to swell into domal shapes when they are erupted. The Great Stone Top trachyte is superbly seen from the northern side of Sharks Valley, from the top of the cliffs above Stone Top Bay and southeast of Bencoolen (or White Hill). Here the trachyte occurs upon flows of the Upper Shield which overlie a very thick sequence of Main Shield lava flows. In the seaward-facing cliffs below Great Stone Top, an arcuate shaped intrusive lens of trachyte can be seen which appears to have been the feeder to at least one of the Great Stone Top flows.

The lava flows preserved on Boxwood Hill (directly west of Great Stone Top) and Bencoolen (just to the north of Sharks Valley) appear to be somewhat younger than the trachyte flows of the Stone Tops. These flows are rather altered, and not especially well exposed, but in detail they are distinctive from all other flows on the island. An interesting feature of the Bencoolen flows is the occurrence, some 300 metres to the southeast of Bencoolen, of a 4 metre thick dyke which was the feeder to the Bencoolen flows. This dyke trends approximately NE-SW, and stands out in relief from the Upper Shield flows which it intrudes, and displays a number of small offsets along its exposed length.

The Late Intrusive Phase

Late in the life of the Southwestern Volcanic Centre, some 7.5 million years ago, trachyte magma was emplaced into the conduits which had fed the earlier lava flows of the centre (Figure 6). Subsequent erosion of the overlying and surrounding rocks has exposed these trachytes as upstanding masses, as they are more resistant to erosion than are the enclosing altered volcanics of the Lower Shield. Numerous trachyte and phonolite intrusions can be seen, including those forming Lot, Lot's Wife, Speery Island, the Gates of Chaos and White Rocks, Sheep Knoll, High Hill, Hooper's Rock, Writing Stones, the Asses Ears, etc. (Only the larger bodies are shown on the simplified map in Figure 6.) Many of these intrusions were emplaced as essentially cylindrical, pipe-like, bodies (e.g., Lot, Lot's Wife, Sheep Knoll), although numerous dykes of trachyte and phonolite are common. Many thick (up to 15-20 metres) trachyte and phonolite dykes which trend northeast to southwest can be observed in the Sandy Bay area; White Rocks and the Gates of Chaos are fine examples of the thick trachyte/phonolite dykes.

The Lava Flows of the Late Extrusive Phase

A small volume of lava flows preserved in the southern part of the island are somewhat younger than the trachytes and phonolites of the Late Intrusive Phase (these flows are not shown on the map of Figure 6). These flows of the Late Extrusive Phase are seen on White Hill (directly south of Green Hill), on the small knoll on the ridge from White Hill to Sandy Bay Barn, and (the best example) forming Sandy Bay Barn itself. No absolute age dates are available for these flows, but they are clearly younger than the 7.5 million year old Late Intrusive Phase trachytes. In the vicinity of the eastern and southern sides of White Hill, a number of thin dykes can be distinguished which appear to have fed the flows forming White Hill itself. The Late Extrusive Phase flows of Sandy Bay Barn overlie an approximately 300 metres thick sequence of Main Shield lava flows that form the sides of Powell's Valley. A thick (15 metres) trachyte dyke of the Late Intrusive Phase cuts the Main Shield flows in Powell's Valley, but does not intrude the flows forming Sandy Bay Barn, and is therefore older than these flows. These relationships are superbly seen from the path on the northeast side of Powell's Valley from Rock Rose down to Powell's Bay.

AFTER THE VOLCANO

Since the cessation of volcanic activity some 7 to 7.5 million years ago, the island has been formed into its present shape by erosion. Deep valleys have been incised as radial drainage channels from the central part of the island. As much as 20 cubic kilometres of volcanic rock has been eroded from the island over this time, and shed onto the submerged flanks of the volcanic structure. Although difficult to estimate accurately, the island may once have had a maximum height of some 1200-1500 metres. The V-shaped valleys have all been cut by streams, which, at one time, must have been much more active than at present. The climate of the island was undoubtedly considerably wetter in the past; the dense vegetation and greater elevation of the island in the few million years after cessation of volcanic activity would have resulted in much greater precipitation over the island. Once exposed by erosion of Main Shield lava flows, the relatively soft, altered volcanics of the Lower Shield were much more rapidly eroded, resulting in the production of the amphitheatre feature of the Sandy Bay area in the southwestern part of the island. The raised beaches evident at a number of localities around the island are the result of global changes in sea-level during the last 1 to 2 million years.

Although volcanic activity has long since ceased, there are records of occasional earthquakes over the last 250 years; these occurred in June 1756, May 1763, 1780, September 1817 and July 1864. It is not clear if there has been any earthquake activity over the last 100 years. These events seem to have been very low magnitude tremors, as available accounts (e.g., Margaretta Pleydell's account of the 1817 earthquake) suggest very little (if any) structural damage to buildings. However, such tremors could potentially trigger rock falls from cliffs and valley sides. Earthquakes are of frequent occurrence in active volcanoes, where they are related to the movement of magma through the plumbing system of the volcano (swarms of tremors commonly precede eruptions). In the case of St. Helena, the tremors are most likely a result of the very gradual subsidence of the island.

ECONOMIC MINERAL DEPOSITS

Hot-spot related volcanic islands such as St. Helena are typically devoid of economic mineral deposits. The lack of any precious metal deposits has been amply demonstrated by a number of futile, though vigorous, "rushes", most notably the frantic prospecting for gold and silver in Breakneck Valley initiated by Captain Mashborne in 1709. The carnelian (red chalcedony) occurrences near Turks Cap are interesting, and the result of alteration of lava flows. However, although the carnelian has been mined sporadically in the past, it is of no economic significance. Perhaps more unfortunately, the island has little in the way of useful basic mineral deposits or resources. Weathering and alteration of basalts in the Prosperous Plain and Turks Cap areas has produced minor amounts of manganese mineralisation, but these deposits are far from being of any economic value. Beach sands useful in building construction have long since been almost totally depleted, and the gypsum deposits on Prosperous Bay Plain are of little use. The fresh, hard basaltic lava flows do, however, make fine road aggregate!

PUBLICATIONS CONCERNING THE GEOLOGY OF SAINT HELENA

Anonymous. 1805. Description of the island of Saint Helena, containing observations on its singular structure and formation. London.

Baker, I. 1968. The geology of Saint Helena Island, South Atlantic. *Ph.D. Thesis, University of London*, 396 pages.

Baker, I. 1968. Intermediate oceanic volcanic rocks and the 'Daly gap'. *Earth and Planetary Science Letters*, volume 4, pages 103-106.

Baker, I. 1968. Compositional variation of minor intrusions and the form of a volcano magma chamber. *Journal of the Geological Society of London*, volume 124, pages 67-79.

Baker, I. 1969. Petrology of the volcanic rocks of Saint Helena Island, South Atlantic. *Bulletin of the Geological Society of America*, volume 80, pages 1283-1310.

Baker, I. 1969. Small scale arcuate intrusions on Saint Helena, South Atlantic. *Bulletin Volcanologique*, volume 33, pages 369-397.

Baker, I., Gale, N.H. and Simons, J. 1967. Geochronology of the Saint Helena volcanoes. *Nature* (London), volume 215, pages 1451-1456.

Daly, R.A. 1927. The geology of Saint Helena Island. *Proceedings of the American Academy of Arts and Sciences*, volume 62, pages 31-92.

Darwin, C. 1876 (2nd edition). Geological observations on the volcanic islands. Smith, Elder and Co., London, 674 pages. (First edition 1844.)

Melliss, J.C. 1875. St. Helena: A physical, historical and topographical description of the island, including its geology, fauna, flora and meteorology. Reeve and Co., London, 408 pages.

Oliver, J.R. 1869. Geology of Saint Helena. Jamestown, St. Helena.

ACKNOWLEDGEMENTS

There are almost too many people deserving of mention to be acknowledged in a reasonable space. Mike Colucci, my colleague during my first visit to St. Helena, provided that rare combination of enthusiasm, excellent companionship and a strong back and legs for carrying rock samples. In addition, many other people provided field assistance in various ways, including John and Jenny Jefferis, John and Evie Bailey, Pete Lewis, and John Starkey. The friendship and tolerance of a great many Saints for those of us with "rocks in our heads" is also greatly appreciated. Local transport and accommodation in 1989 was generously and graciously provided by Fred Ward, and, of course, Yelka. Geoff Shallcross coerced me into giving talks on the RMS which provided the initial impetus for writing this guide. Our work on the volcanic rocks of St. Helena has been funded by grant EAR-8708376 from the National Science Foundation.