Geology of Silhouette island

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The aptly-named island of Silhouette is the eroded remnant of a large volcanic edifice, which probably once towered well above its present level. The volcano, and its sub-volcanic magma chamber which now forms the bulk of the island, was constructed about 63 million years ago (63 Ma) while Seychelles was parting from India (which had been its immediate neighbour for nearly 700 million years) during the later stages of the break up of the old Gondwana supercontinent. This event occurred at the so-called "K/T boundary" when the Mesozoic gave way to the Tertiary geological period and global changes caused the dinosaurs to become extinct. It was also marked by massive outpouring of lavas on the Indian side, forming the "Deccan Traps" which represent one of the largest volcanic (flood basalt) provinces in the world. Boreholes drilled by Amoco in the early 1980s off the western shelf of Seychelles and by Enterprise in 1995 have shown that up to 800 metres of volcanics are also present on the western shelf and at least 900 metres are present on Constant Bank. How these relate to almost contemporaneous magmatic events which gave rise to Silhouette is the subject of current research.

This contribution is intended to present a general overview of the rocks on Silhouette, which include the only terrestrial volcanic rocks within a thousand miles. North Island is of broadly similar age and there are indications that there are more igneous complexes of this age around the margins of the Seychelles Plateau (eg. possibly Fortune Bank).

Geological Setting

Our knowledge of the geology of Seychelles is based on exposed rock on the 0.015% area of the Seychelles Plateau represented by the islands. Recent studies have demonstrated that the granite islands of Mahé and Praslin formed at about 755 million years ago (Jemielita *et al.* in prep.), with some of the pink granites of Mahé may be a little younger (about 700 Ma). These granites were part of the old basement that underlies much of East Africa, Madagascar, and some of western India, and represents the old Gondwana supercontinent at the interior of which was located Seychelles.

Gondwana was a relatively stable continent until the Mesozoic when, at about 150 million years ago, it started to break up in response to a major

reorganisation of the Earth plates. Firstly, a major rift separated Africa from Madagascar + Seychelles + India + Antarctica + Australia. Then, at about 90 Ma, Madagascar parted from India + Seychelles. The isolation of Seychelles was completed at around 65 Ma when India and Seychelles rifted apart, with a major ocean basin forming between them and the Carlsberg Ridge along the median line. This 65 Ma event was accompanied by the outpouring of a very thick sequence of basaltic lavas, well preserved on India as the Deccan Traps, and the origin of Silhouette is linked to these events.

Igneous rocks

Silhouette is an alkaline ring complex, which means that the composition of the magmas which crystallised to form the syenites and related rocks were richer in sodium than more common igneous rocks (although syenites are by no means unusual rocks), and that the rocks formed by magmas being emplaced concentrically (see map in Fig. 1. and cross section in Fig.3.). The geological map (Fig.2.) shows that the bulk of the island is made of syenite with a core of microgranite in the region of Grande Barbe. Only a thin sliver of volcanic rocks is preserved, although undoubtedly there was considerably more of the volacinc pile before its removal by erosion.

The syenites of Silhouette are generally greenish or buff coloured, occasionally with pegmatitic segregations. Petrographically they are dominated by a perthitic alkali feldspar. The dark minerals are mainly a slightly sodic hedenbergite pyroxene, and the alkaline amphibole arfvedsonite. Under the microscope fayalitic olivine is occasionally seen. The principal accessory mineral is aenigmatite.

The microgranite forms the core of the island and is bounded from the syenites by a steep ring fault which has a marked topographic expression in the precipitous cliffs south of Mont Dauban (Fig. 1. and section in Fig.3.). Such ring faults are common features of alkaline ring complexes on this scale. The microgranite is white coloured, and tends to occupy the lower ground inland of Grande Barbe. Mineralogically it comprises of feldspars and quartz with the blue amphibole riebeckite.

A special feature of Silhouette is the presence of volcanic rocks. Between Pointe Ramasse Tout and Pointe Zeng Zeng (Figs. 1. and 2.) is a narrow sliver of volcanic rocks which comprises a series of thin sheets of light-coloured porphyritic rhyolite and trachyte separating black trachytic ash flows and breccias. The sheets are nearly vertical or steeply westwards-dipping towards the syenite complex. The contact between the syenite and the volcanics appears to be intrusive, implying that the syenite was intruded into a cover of volcanic rocks, suggesting that the whole complex formed at, and just beneath, the surface. The total thickness of these volcanics (Fig. 2.) is about 100 metres, but as the top of the section is not seen the original thickness was almost certainly considerably greater.

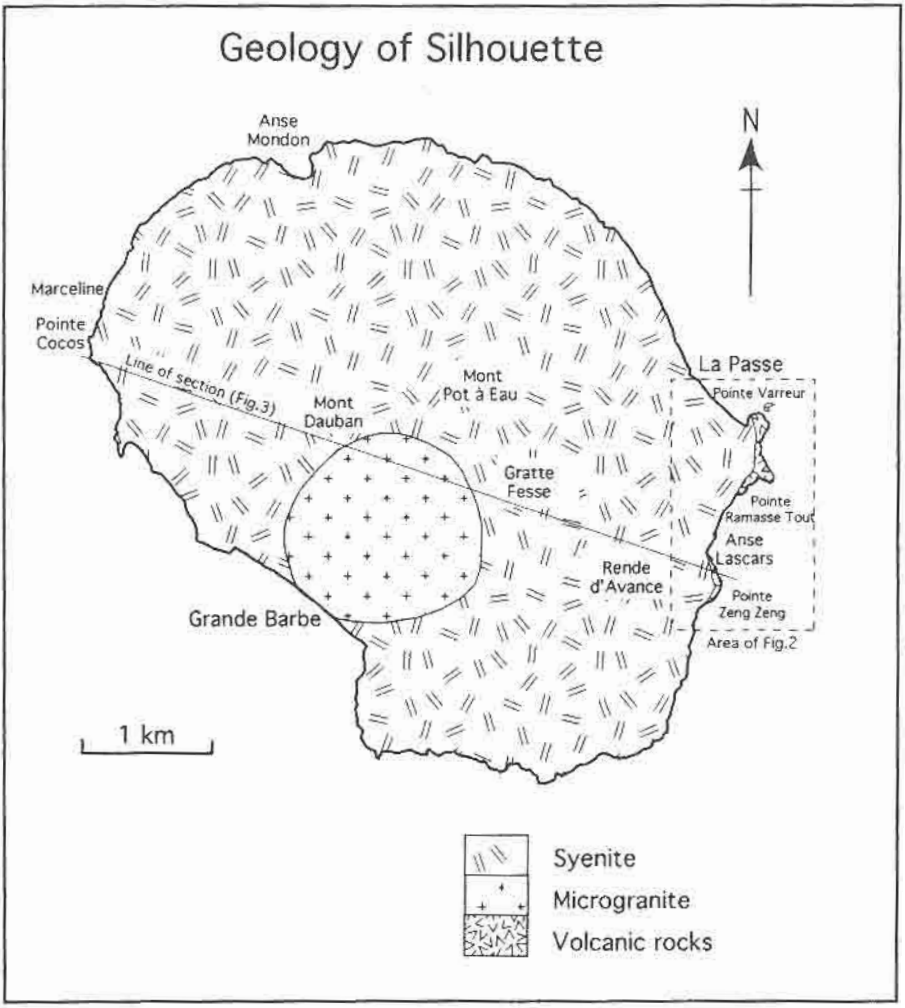

Fig. 1. Map of the major geological units of Silhouette island showing the ring structure of the syenite and microgranite. Inset shows the location of the detailed map of the volcanic section (Fig.2.) and the section line (Fig.3.) is also indicated.

In the field it is possible to see the fragmental nature of the breccias with inclusions of many angular fragments, typically with light coloured rims. Under the microscope many samples have an ignimbritic texture of glass with fiamme structure and matrix felsic minerals enclosing lithic and crystal fragments (Plate 1.). The lithic (or rock) fragments include pyroxene- and labradorite-bearing volcanics indicating the presence of basalt flows which are not exposed, but are presumably located beneath these volcanics. The matrix has a streaky form which is known as fiamme structure (Plate 1.) and is typical of ignimbrite (glowing avalanche) eruptions. The fiamme are glass fragments which have been flattened and welded due to the intense heat of the material as it accumulated around the volcanic vent. Glass itself forms when the molten lava cools very rapidly on eruption into the atmosphere. Ignimbrites form during the explosive eruption of a combination of solid material, lava and gas in a dense cloud.

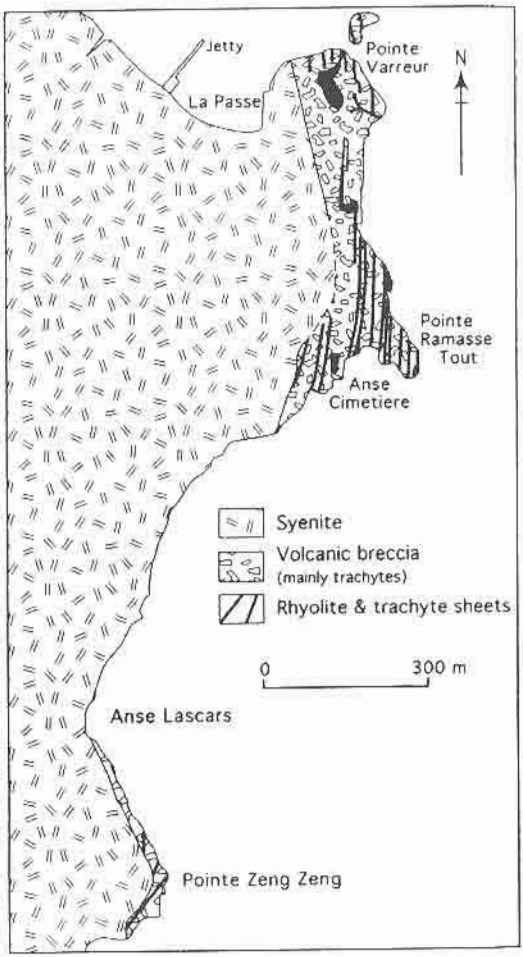

Fig. 2. Map of the coastal volcanic outcrops in the vicinity of La Passe.

Silhouette formed in a manner quite similar to the famous explosive eruption of Mount St Helens in the western USA in 1980. Ignimbrite eruptions are amongst the most rapid and unpredictable, making them the most dangerous of all volcanic eruptions; 63 million years ago Silhouette was not the quiet paradise of today! The evidence suggests that the eruption occurred on land rather than in the sea. The very limited outcrops make it difficult to determine the original form of the Silhouette volcanic complex. The most likely scenario is that an eruptive centre

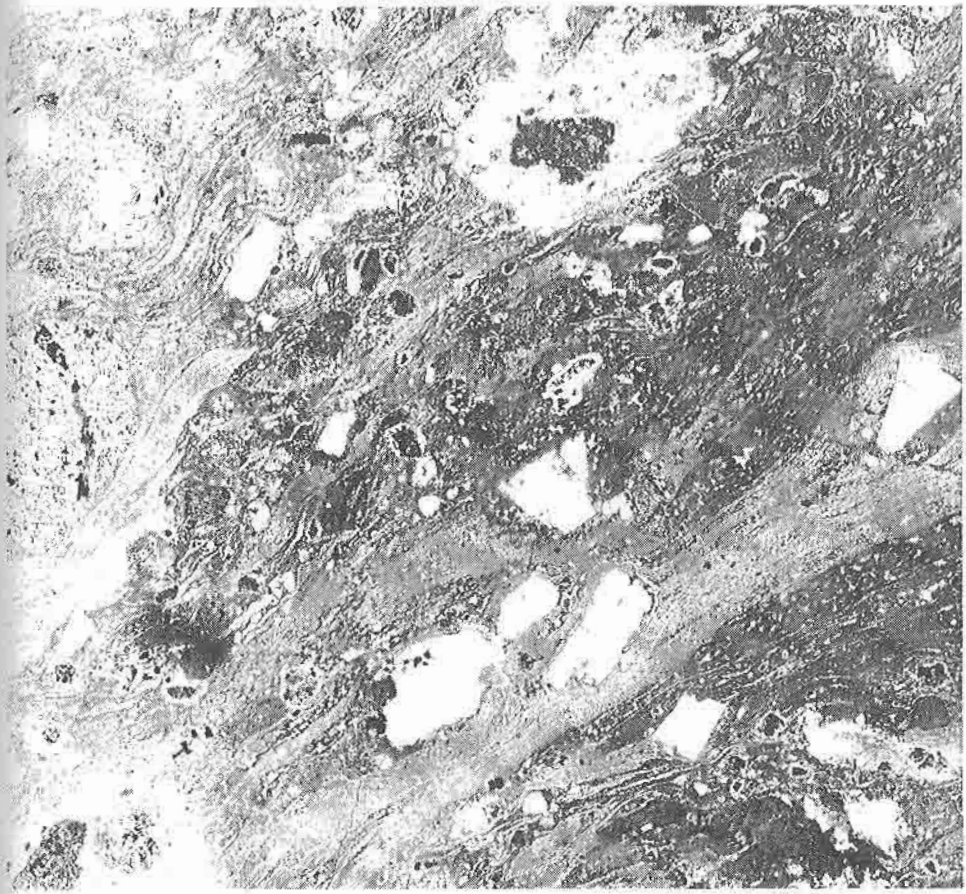

Plate 1. Thin section through a trachytic breccia, Pointe Ramasse Tout, Silhouette. The white crystals are feldspars (sanidine) and the other light and dark coloured rounded patches are lithic (rock) fragments. The streaky matrix is due to the welding of glass fragments and some show flame-like form (fiamme) typical of ignimbritic eruptions. Width of field of view is 12 mm and the picture was taken in cross polarised light.

(and probably a crater) existed south-east of La Passe, but this has now almost entirely been eroded away and submerged. The volcano would have erupted many times, with alternations between explosive eruptions of ash and quieter eruptions of lava flows. A magma chamber also probably existed beneath the Grande Barbe microgranite which finally collapsed into the chamber along the ring fault.

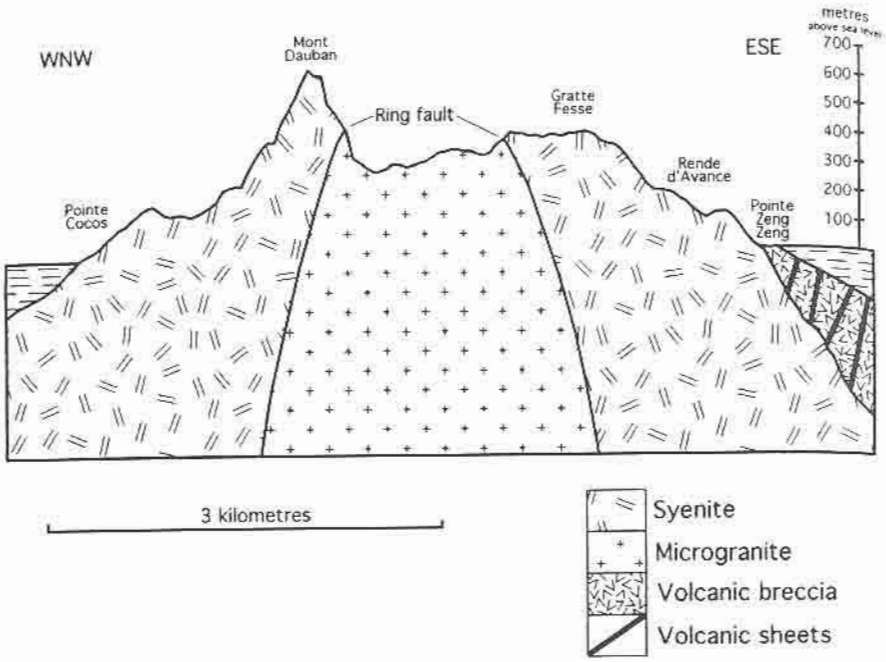

Fig. 3. A topographic and geological cross section through Silhouette along the line indicated in Fig. 1. The ring fault that surrounds the microgranite centred on Grande Barbe forms a marked topographical feature but its subsurface orientation is not well constrained. It is postulated that the small outcrop of volcanics south of La Passe projects offshore, and the volcanic sheets within the breccia appear to dip steeply towards the plutonic centre.

Age and geochemistry

The fact that Silhouette was much younger than the granite basement of Seychelles was first recognised by Baker in 1963 and then demonstrated by Baker & Miller (1963). They obtained ages of 34 to 62 Ma using the K-Ar (potassium-argon) dating technique on an altered pyroxene from a syenite at Roche Marceline (Fig. 1:). Samples of fresher material were analysed again by the K-Ar method (Dickin *et al.* 1986) and five samples representing all rock types in the complex yielded an average age of 63.8 Ma. An independent method (the whole rock Rb-Sr isochron technique) was also applied by Dickin *et al.* (1986) which gave an age of 63.2±1.0 Ma. The very good agreement between these methods gives us confidence that Silhouette formed about 63 million years ago and that the ages of Baker and Miller are too young. Nearby North Island has been shown by the Rb-Sr method to have been emplaced at 60±4 Ma (Yanagi *et al.* 1983), within error of the age of Silhouette.

The volcanics can be related to the syenites of Silhouette through their chemical compositions. The volcanic breccias are compositionally trachytes, and chemical analyses of Silhouette trachytes and syenites are virtually indistinguishable. The sheets of porphyritic rhyolite are more siliceous and correlate well with the composition of the Grande Barbe granite. The isotopic fingerprints of the igneous rocks of Silhouette, as described in the paper by Dickin *et al.* (1986), suggest that the magmas have a primitive mantle-like source and have undergone little contamination by old continental crust.

Correlations within and beyond Seychelles

North Island, only some seven kilometres to the north of Silhouette and lying on the same bathymetric level. is similar to Silhouette in that most of the island is made up of an almost identical syenite. There are, however, differences in that there are no volcanic rocks evident on North Island but its range of compositions is much wider, including alkaline gabbros. As discussed above, their ages are also similar.

The discovery of trachytic tuffaceous material of approximately the same age in the Seagull Shoals-1 and the Owen Bank-1 wells drilled by Amoco (Khanna & Pillay 1986) suggests that there was similar volcanic activity elsewhere. Other igneous centres dating from this time have been postulated from the offshore geophysical record. The largest is Fortune Bank which has a concentric structure in its magnetic and gravity responses, but is considerably larger than Silhouette. Most of these centres that have been recognised are located towards the periphery of the Seychelles Plateau. A regional review of the available age data has been presented by Plummer (1995). Since that review, the drilling on Constant Bank has revealed a great thickness of basic volcanic rocks (>900 metres) and the indications are that these are of generally similar age, but they are probably not related to a central alkaline centre like Silhouette.

In India, the Deccan province of basalts covers more than 500,000 km^2 of western India, centred on Bombay. These were erupted around 65 Ma, and it is interesting that Seychelles was connected to India in the very region where these eruptions occurred, and that the rift of Seychelles from this part of India occurred at this time. We have speculated (Devey & Stephens 1992) that these Deccan basalts may have also covered at least some of Seychelles at that time and have since been eroded. The evidence is based on a remarkable correlation in the geochemistry of some dykes found on Praslin (including the dyke forming the spectacular waterfall at Cascade) with certain of the early Deccan lavas (Devey & Stephens 1991).

Summary

Silhouette is an alkaline plutonic-volcanic ring complex in which almost all of the volcanic cover has been removed. The volcanism was generally explosive in the form of ash flow eruptions. These events occurred approximately 63 million

years ago, during or soon after one of the world's greatest volcanic eruption events, the Deccan Traps of India. There is a growing body of evidence to suggest that considerable volcanic activity occurred on the Seychelles Plateau at this time including some of the Deccan Traps. Silhouette is very important to geologists as a tiny fragment of this volcanism is preserved and is accessible for study.

Acknowledgements

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