The geology of Saint Helena, Ascension Island and Tristan da Cunha

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The British Overseas Territory of Saint Helena, Ascension Island and Tristan da Cunha is made up of some of remotest islands on earth. It spans a huge distance of 3,642km and runs along the Mid Atlantic Ridge in the South Atlantic Ocean. All the islands are volcanic, but are formed by hotspots rather than being part of the ridge itself. (Fig. 1 shows the location of the territory.)

Hotspots are places where anomalously hot mantle rises in a plume and burns a hole in the overlying crust, creating an active volcano. The most famous examples are the Hawaiian islands, which have left behind a series of islands and seamounts, as the Pacific Plate has moved over the hotspot. Their cause is not fully understood, with some scientists arguing it may be due to convection within the mantle and others that the plume could be caused by the remnants of subducted plates finally melting near the mantle/core boundary.

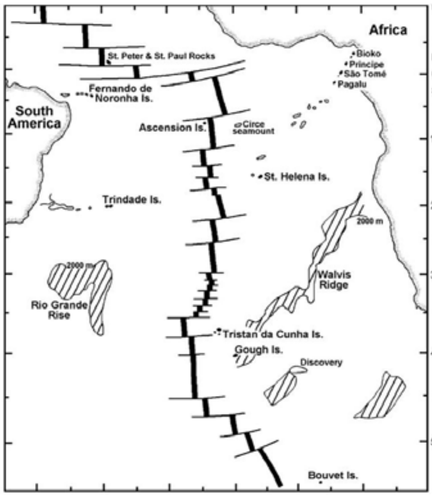

Fig 1. Location map of the territory, showing the submarine ridges and chain of islands, which were created by the hotspots. Taken from Weaver (2002).

The hotspot that created Tristan da Cunha was probably involved in the spitting up of the super continent of Gondwanaland, some 135mya. Flood basalts exist in modern day Parana, Brazil, Etendeka and Nambia, and were erupted when the two places were connected, but began to split apart. As the south Atlantic has spread apart, a series of ancient Tristan da Cunha's were formed, their eroded stumps are now the shallower areas of the Walvis Ridge and Rio Grande Rise. Similarly, the Saint Helena hotspot could be responsible for the Cameroon Line, which includes seamounts and the islands of Pagalu, Sao Tome, Principe and Bioko. However, Ascension Island is different and has no chain of seamounts or islands. In fact, Ascension lies on the South American plate, while the hotspot is on the other side of the Mid Atlantic Ridge under the African plate, and the magma flows along the ridge to reach Ascension Island. The chemistry of the lava on each island is different, showing each hotspot derives from a different source. The Tristan lavas contain the chemical signature of sediments, which perhaps adds weight to the subducted plate idea. The Saint Helena lavas do not contain this signature and the Ascension lavas show they have been heavily mixed by lavas from the Mid Atlantic Ridge (Weaver's website).

Tristan da Cunha

Tristan da Cunha is the remotest part of the territory. Gough Island, lying at a latitude of 40° 19′ S, is the most southerly of the islands and is thought to be formed by its own Gough Hotspot. The other three islands - Nightingale, Inaccessible and Tristan da Cunha - all lie close together, further to the north, and were formed by the Tristan hotspot. Apart from six scientists living on Gough, all the inhabitants of Tristan da Cunha live in the capital 'Edinburgh of the Seven Seas', on the main island of Tristan da Cunha, which has a population of 382. The island is the world's most isolated inhabited island

Fig 2. The welcome sign to Tristan da Cunha - the world's most remotely inhabited island.

Fig 3. Arriving at Tristan da Cunha by ship.

Fig 4. The geographic subdivisions of Tristan da Cunha. Taken from Hicks (2012), who adapted it from Google Earth.

(Fig. 2) and is only approachable by ship, because there is no airfield (Fig. 3). Tristan's nearest neighbour is St Helena, four days by ship to the north, and the nearest airport is a week away by ship in Cape Town, South Africa.

The main island of Tristan da Cunha is a large oceanic strato volcano, meaning it is a volcano rising from the floor of the ocean, made up of alternating layers of volcanic ash and lava flows. If measured from the sea floor, the volcano is 5,500m high, with only the top 40% rising above sea level. The island has a maximum diameter of 12km. Geographically, the island can be arranged into three main zones: (i) the base and peak; (ii) the main cliffs; and (iii) the coastal strip (Fig. 4).

The base and peak. The boundary between the base and peak is not well defined, but the base is the flatter area, while the peak is the steeper area. These areas are crossed by many drainage channels called 'gulches' (Fig. 5). It is heavily vegetated, especially on the base. The rock surface of the base is largely made of lava flows, while the peak is made up of pyroclastic material, which is material that has flown through the air after it was ejected from the main vent of the volcano. Also, on the peak and base are numerous scoria cones. These are produced by fire fountains

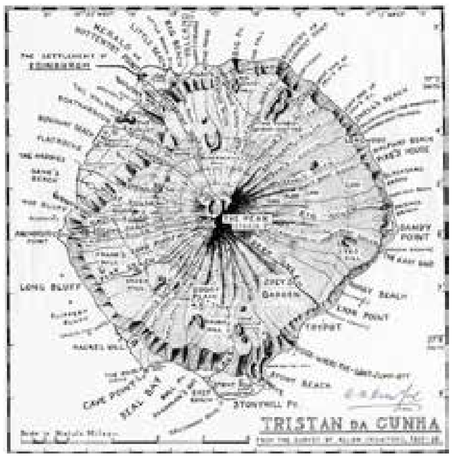

Fig 5. Original 1939 map by Allan Crawford, showing the gulches and place names of Tristan da Cunha.

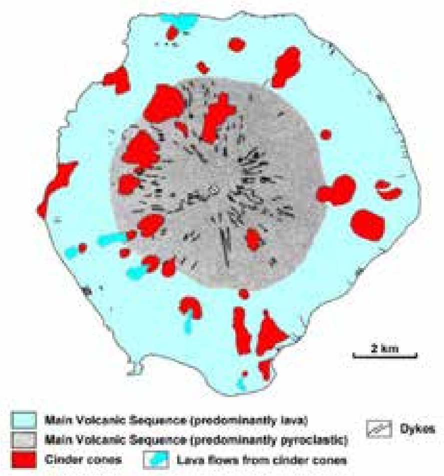

Fig 6. A simplified geological map of Tristan da Cunha. Taken from Barry Weaver's website, originally adapted from Baker et al. (1964).

Fig 7. Fresh snowfalls on Queen Mary's Peak.

Fig 8. The main cliffs behind Edinburgh.

Fig 9. The main cliffs on the southeast side of Tristan.

Fig 10. The red colour in the cliffs marks the location of a former parasitic cone.

erupting out of small side vents and, as the material falls to the ground, these cones are built up. Some of the cones also have their own small lava flows flowing from them (Fig. 6).

The top of the peak is named Queen Mary's Peak. At 2,062m, it is the highest point in the territory. There is a 300m-wide crater at the summit, which contains a lake that is frozen in winter. It is common for the summit to be covered in snow at this time, but snowfall can occur almost anytime. Fig. 7 shows fresh snowfalls that occurred in April 2014, during Tristan's autumn.

The main cliffs. The main cliffs ring the entire island and are 600m high. They have been formed by marine erosion, though near to Edinburgh, they were created by a portion of the island collapsing and breaking off. (Fig. 8 shows the main cliffs behind Edinburgh and Fig. 9 shows the main cliffs on the southeast side of the island.) They are made up of alternating layers of lava flows and pryroclastic material, locally interspersed with parasitic centres. In Fig. 10, the red colour shows where localised eruptions previous occurred.

The coastal strip. If you look at Fig. 11 (a photograph from NASA), you will notice the island has an unusual shape. This is because, between 34 and 25 thousand years ago, the northwest part of the island fell off, in a process called sector collapse (Hicks, 2012). The loss of the part of the island then resulted in further eruptions, which produced the coastal strips. Edinburgh is situated on the coastal strip (Fig. 12) and it is the only place on the island where permanent habitation and crop cultivation is possible. The lava that forms the coastal strip erupted from the 'Hillpiece' (Figs. 13 and 14). This is now partly eroded away by the sea, showing the flat area of the coastal strip would once have been larger. The coastal strip also hosts the potato patches. Potatoes are the only crops grown on the island and are said by the islanders to be the best in the world. Potatoes were once used as the currency on the island and the earliest stamps were issues in 'potatoes' rather than pennies. (Fig. 15 shows the potato patches, and Fig. 16 shows potatoes being loaded onto our ship, so we could transport them to Saint Helena.) Near the patches are a series of mounds called hornitos. These were formed when lava flowed over ponded water, producing phreatic eruptions, which are eruptions caused by steam. (Fig. 17 shows horintos and the bus stop at the potato patches and Figs. 18 to 22 show other general scenes around the settlement of Edinburgh.)

Fig 11. A NASA image of Tristan.

Fig 12. A photograph of 'Edinburgh of the Seven Seas', taken from the top of the 1961 lava flow.

Fig 13. The Hillpiece, the eruptive centre of the settlement coastal strip, seen from the land.

The coastal strip of the settlement is not the only coastal strip on Tristan. There are two other smaller areas to the south the island, around Hackel Hill and Stony Hill (Fig. 5). In both places, lava has erupted from these hills, creating the flat coastal areas. The eruption at Stony Hill occurred just 200 to 300 years ago.

The 1961 eruption. Tristan has been settled for just 200 years and the most dramatic moment in the island's history happened in 1961, when an eruption occurred right next to the settlement, forcing the entire population to be evacuated to the UK. Two months before the eruption, there was gradually increasing seismic activity, with numerous rockfalls behind the settlement. Surface deformation occurred, causing cracks in buildings and buckling pipes, doors and window frames. On 9 October 1961, a mound began to form and the eruption started the next day. The lava was extremely viscous, more like toothpaste than treacle and its chemistry constituted a tephri-phonolite. This lava extruded from the dome in a blocky flow, which grew the dome to 147m, and blocks and cinder were seen rolling from it. A cone then formed on the seaward side of the dome and from it flowed a blocky flow followed by two a'a flows, which reached the sea. In the final stages of the eruption, a second dome with blocky lava extruded from the cone. (Fig. 23 shows a diagram of the eruption and Fig. 24 shows a photograph of the lava flow - the white circular mark on the cliff is due to a recent rockfall.)

As it turned out, the eruption only caused minor damage to the settlement, with just one building being badly damaged. This has since been restored (Fig. 25). However, the main landing beach, where the islanders launched their boats, was destroyed by the lava flow, making life on the island impossible. Meanwhile, the population (who had been evacuated to Southampton) were not finding it easy to adjust to life in the UK. There was a particular fear of crime and the population was becoming homesick. The last straw came when one of the older men was mugged, and the population decided it wanted to return home to Tristan. However, the British Government was reluctant to allow them to return, but after much arm twisting from a former administrator of the island, permission to return was granted in 1963. Additionally the British Government spent one million pounds building a new harbour, enabling the islanders to support themselves by fishing. At the time, the desire of the islanders to return to their remote volcano took the British public by surprise and several newspapers even commented (unfairly) that the action felt like a criticism of the way of life in the UK. (Fig. 26 shows a plaque that commemorates the 50th anniversary of the evacuation.)

The most recent eruption. The 1961 eruption was not the most recent eruption in the Tristan group of islands. In July 2004, earthquakes measuring 4.8 on the Richter Scale were recorded in Tristan and pumice washed up on the beaches. The eruption occurred from a seamount only 250m below the surface, near to Nightingale Island. (Fig. 27 shows the position of Nightingale Island relative to Tristan and Inaccessible Island and Fig. 28 shows a photograph of Nightingale Island. Fig. 29 shows Sub Antarctic Fur Seals resting in a cave in the volcanic tuff on the island and Fig. 30 shows the landscape of the island with its nesting albatrosses.) Nightingale Island is also where the freighter, MS Oliva, ran aground on 16 March 2011, spilling tons of heavy fuel oil into the ocean. This damaged the islands penguin population, which was

Fig 14. The Hillpiece, seen from the sea.

Fig 15. The potato patches.

Fig 16. Potatoes loaded onto our ship for transporting to Saint Helena.

Fig 17. Hornitos, behind the Patches bus stop, formed from phreatic eruptions, as lava flowed over ponded water.

Fig 18. Tristan's new harbour built since the 1961 eruption.

Fig: 19. The governor's residency.

Fig: 20. The pub - The Prince Philip Hall.

Fig 21. A typical Edinburgh street.

Fig 22. A shipping crate.

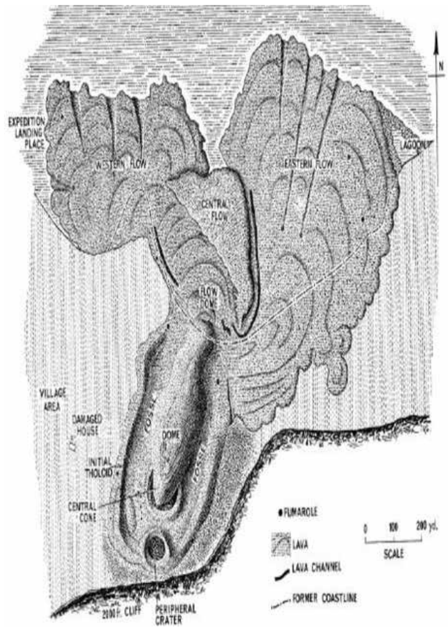

Fig 23. A diagram of the 1961 eruption. Taken from Baker et al. (1964).

Fig 24. The lava flow from the 1961 eruption. The white circular mark is due to a recent rockfall.

Fig 25. The restored house, with the 1961 lava flow in the background.

Fig 26. A plaque commemorating the 50th year anniversary of the Tristan evacuation.

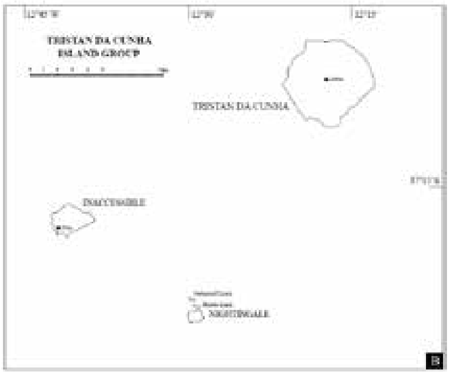

Fig 27. The Tristan da Cunha groups of islands. Taken from Hicks (2012).

Fig 28. Nightingale Island.

Fig 29. Sub Antarctic fur seals on Nightingale Island, resting in layers of tuff.

Fig 30. The landscape of Nightingale Island, with a nesting albatross.

transported to Tristan for cleaning, but luckily they were not wiped out. The other island close to Tristan da Cunha is Inaccessible Island. (Fig. 31 shows a pod of Killer Whales approaching Inaccessible Island. Nightingale and Inaccessible are both 35km from Tristan da Cunha, while Tristan's other Island Gough Island lies 395km to the south, and was not visited on this trip.)

Saint Helena

Even though Saint Helena is less remote than Tristan da Cunha, it is still an incredibly remote island, because it has no airport. However, one is being built and is due to open in 2016. Saint Helena's remoteness made it the ideal location for the British to imprison Napoleon Bonaparte. The island is the UK's second oldest possession after Bermuda and was originally settled by English colonists in 1659. The capital of Saint Helena is Jamestown.

Formation of Saint Helena Island. Like the Tristan Islands, Saint Helena has been formed by a hotspot. In Fig. 1, a chain of islands and a submerged ridge can be seen extending from the island into Cameroon. However, the hotspot is not currently under Saint Helena and lies somewhere to the southwest. The island is an extinct volcano that has not erupted in the last 7myrs and it was once very much larger than today. The current maximum height of the island is just 820m, but it was once between 1,200m and 1,500m high, with 20km^3 of rock having been removed by erosion. (Fig. 32 shows a NASA image of the island with the deep erosional valleys cut into it.) Also, unlike Tristan, the volcano is a shield volcano, rather than a strato-volcano. This is because it is made from less viscous lavas that have flowed quicker and further, so have not built up a high cone. By volume, the island of Saint Helena only represents the top 5% of this shield volcano; the remaining 95% is below sea level and the volcano sits on an ocean floor that is 4.4km deep. The basal diameter of the volcano is 130km.

Charles Darwin visited Saint Helena in 1836 on the return leg of his around the world voyage on the Beagle. Writing about the island he remarked: *"St. Helena, situated so remote from any continent, in the midst of a great ocean ... excites our curiosity".*

He also made a very good first attempt at describing the geology of the island. He described a basal sequence of submarine lava flows, underlying a series of basaltic lava flows, which is indeed the case. He also correctly considered the trachyte stocks that form Lot and Lot's Wife to have intruded after the cessations of eruptions. However, he hypothesised that the volcano had one eruptive centre, centred on the Sandy Bay area and geologists now know Saint Helena had two eruptive centres (Fig. 33).

Northeast volcanic centre. The northeast eruptive centre is the oldest eruptive centre on the island. The oldest rocks from this centre are the submarine breccia as Darwin correctly identified. This is between 14 and 15myrs old and is up to 400m thick, consisting of small boulders up to 1.5m across of basalt and trachyte, with a green-brown coloured matrix. Approximately 14mya, the island emerged from the waves and, from 11 to 14mya, subaerial lava flows were deposited on top of the marine breccia. A good place to see these is in Jamestown itself. If looking at the town from the sea, these lavas form the left hand side of the valley (Fig. 34). (Note that the terms "northeast volcanic centre" and "southwest volcanic centre" are adapted from Weaver, 2002).

Southwest volcanic centre. Eleven million years ago, the eruption from the northeast volcanic centre stopped, apart from some localised flows 9mya, and the eruptive activity switched to the southwest volcanic centre (Fig. 33). Initially these eruptions were centred on the Sandy Bay area (Fig. 35), but the present day amphitheatre is not the ancient crater as Darwin hypothesised, rather than an erosional feature. The lava of the lower shield is up to 600m thick and is aged from 10 to 11myrs old. It is formed by four distinct units, each consisting of a lava flow overlain by a pyroclastic layer. The lower shield lavas can be seen outcropping in the Sandy Bay and the Gates of Chaos (Fig. 35).

The lava flows of the main shield are 800m thick, mainly made of basalt, and cover the greatest area of the island. Sedimentary layers between the lava layers are common. A very good place to see the lava layers is by climbing Jacob's Ladder in Jamestown, which is on the right hand side of the valley, if looking from the sea. Jacob's Ladder is the 'must see' tourist attraction in Jamestown and has 699 steps. It was originally built to link Jamestown with the former fort on Ladder Hill (Figs. 36 and 37). Another good place to see the lava flows of the Main Shield is the Heart Shaped Waterfall (Fig. 38).

Fig 31. A pod of killer whales approaches Inaccessible Island.

Fig 32. A NASA photograph of St Helena from space.

Fig 35. Sandy Bay and the Gates of Chaos. The bedrock is lava from the lower shield.

Fig 34. Jamestown as viewed from the sea, with lavas from the northeast eruptive centre on the left side, and lavas from the main shield of the south west volcanic centre on the right side.

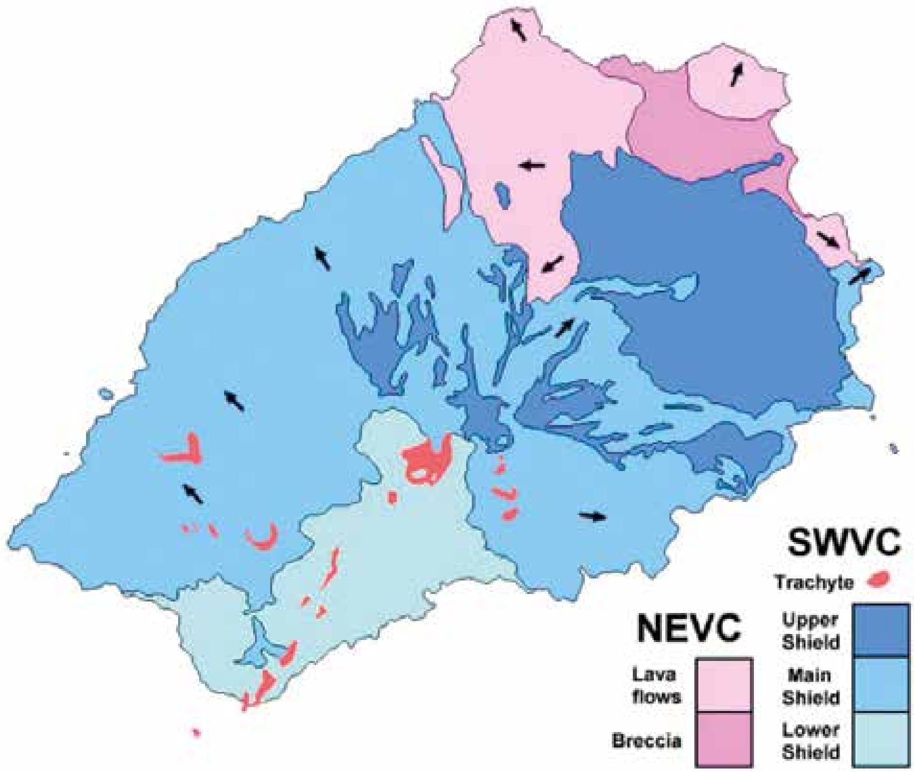

Fig 33. A simplified geological map of Saint Helena showing the northeast volcanic centre and the southwest volcanic centre. Taken from Weaver (2002).

Around 9mya, there was a brief pause in eruptions from the southwest volcanic centre and the eruptive centre moved slightly to the current summit of the island. From here, the lavas of the upper shield were erupted and, in places, these are seen infilling erosional channels cut into the main shield.

Late intrusive and extrusive phases. Around 8mya the eruption of the upper shield lavas had finish, and trachyte, dykes and stocks, as well as some unusual celery-shaped intrusions were emplaced. The most iconic landforms on St Helena - Lot, Lot's Wife and Daughters, the Ass's Ears and Frightus Rock - were all formed this way. They consist of harder rock and have been left exposed as wonderful sculptures after the softer rock had been worm away. (Fig. 39 shows Lot and Lot's Wife and Daughters.) Finally, around 7mya, a small amount of lava was erupted and then all activity ceased. Since then, the sea has been gradually reclaiming Saint Helena, eroding it down until eventually it will become a submerged seamount, showing where the hotspot once used to be. (Figs. 40 to 42 show some general images from around Saint Helena.)

Ascension Island

Unlike Saint Helena, Ascension Island is still an active volcano. It was first discovered in 1501 and, since that time, no eruptions have been recorded. However, the island has only been inhabited since 1815, so activity may have gone unnoticed. Remains of fumaroles from the Devil's Riding School (Fig. 43) and very recent looking lava flows on the Letterbox (Fig. 44) indicate the volcano is still active, but perhaps in its waning stages.

Like Saint Helena, Ascension Island is a shield volcano and rises from an ocean depth of 3.2km. The maximum height of the island – 'The Peak' of Green Mountain - is 859m above sea level. Eruptions have generally been more violent than those on Saint Helena, with vent eruptions rather than fissures. And like Saint Helena, Charles Darwin also visited Ascension Island. He was only there for three days but commented: *"Geologising in a volcanic country is most delightful, besides the interest attached to itself it leads you into the most beautiful and retired spots."*

He also identified that the Devil's Riding School had once been a lake.

The capital of Ascension Island is Georgetown. However, no citizens have the right of residence in Ascension Island, and you must have a job with either the British Government or US Air Force to live there. (Fig. 45 shows a NASA image of the island.) The capital, Georgetown, can be seen on the west coast. The airbase, which is shared by the UK and USA, can be seen in the southwest and the village of Two Boats can be seen in the interior.

The surface of Ascension Island. Ascension is much hotter and more arid than either Tristan da Cunha or Saint Helena. There is little vegetation and most of the bedrock can be seen. The western part of the island is covered by basaltic lava flows, while the central and eastern parts are covered by trachyte/rhyolite flows. The island also has 56 scoria cones, which have been produced by fire fountains (Fig. 46). Fig. 47 shows one of these cones behind the church in Georgetown. The sheer number of these gives Ascension a very 'other planet' feel. Some of them have small lava flows emanating from them. (Fig. 48 shows a lava flow, flowing from the Broken Tooth Scoria Cone, and Fig. 49 shows a lava flow near the airbase.)

Fig 36. Looking up the 699 steps of Jacob's Ladder. This is a great place to observe the lava flows of the main shield.

Fig 37. The author, James Cresswell, reaching the top of Jacob's Ladder in Jamestown.

Fig 38. The Heart Shaped Waterfall flows over lavas of the main shield.

Fig 39. Lot and Lot's Wife and Daughters are trachyte intrusions.

Fig 40. The centre of Jamestown. The site has been proposed as a World Heritage Site due to its British Georgian architecture.

Fig 41. The tomb of Napoleon.

Fig 42. The residence of the governor and the giant tortoise, who is the island's oldest inhabitant.

Fig 43. Fumaroles in the Devil's Riding School.

Fig 44. The Letterbox - a trachyte dome surrounded by a ring of scoria.

Fig 45. A NASA image of Ascension Island.

Fig 47. A scoria cone behind the church in Georgetown.

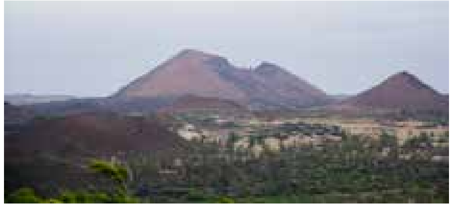

Fig 48. A lava flow flowing from the Broken Tooth scoria cone.

Fig 49. A lava flow near the shared UK and USA airbase.

Fig 50. A lava tube.

Fig 51. Obsidian.

Fig 52. The Devil's Riding School.

Fig 53. The Devil's Eyeballs.

Interesting Facts about the Territory of Saint Helena, Ascension Island and Tristan da Cunha

- It was formed in 2009 from the former Saint Helena and Dependencies, with each island group now having equal status.
- Tristan da Cunha is the most remotely inhabited island on earth and has a population of just 388.
- The entire population of Tristan da Cunha was evacuated to the UK after the volcano erupted in 1961, and then returned home in 1963.
- Tristan's Gough and Inaccessible Islands are World Heritage Sites.
- St Helena is the UK's second oldest colony, originally settled in 1659.
- Napoleon Bonaparte was exiled to Saint Helena from 1815, until his death in 1821.
- The territory stretches 3,642km from Ascension Island in the north to Gough Island in the south.
- The highest point in the territory is Queen Mary's Peak on Tristan da Cunha, with an elevation of 2,062m.
- The territory has the largest Exclusive Economic Zone of any British Overseas Territory, which includes large stretches of the Mid Atlantic Ocean Ridge that may one day be an important site for undersea mining.
- In Saint Helena and Ascension Island, the currency is the Saint Helena pound which has the same value as Sterling, whereas, in Tristan da Cunha, the currency is Sterling.
- At present, the only airfield in the territory is RAF Ascension Island, which is jointly run by the UK and USA. It has regular flights to RAF Brize Norton in the UK and to the Falkland Islands.
- The last operating Royal Mail Ship, RMS St Helena, runs to and from Cape Town, linking Saint Helena to the world. It occasionally also visits Tristan da Cunha, Ascension Island and the UK. It will continue to run until Saint Helena's airport is open.
- Tristan's main links to the outside world are South African fishing boats.

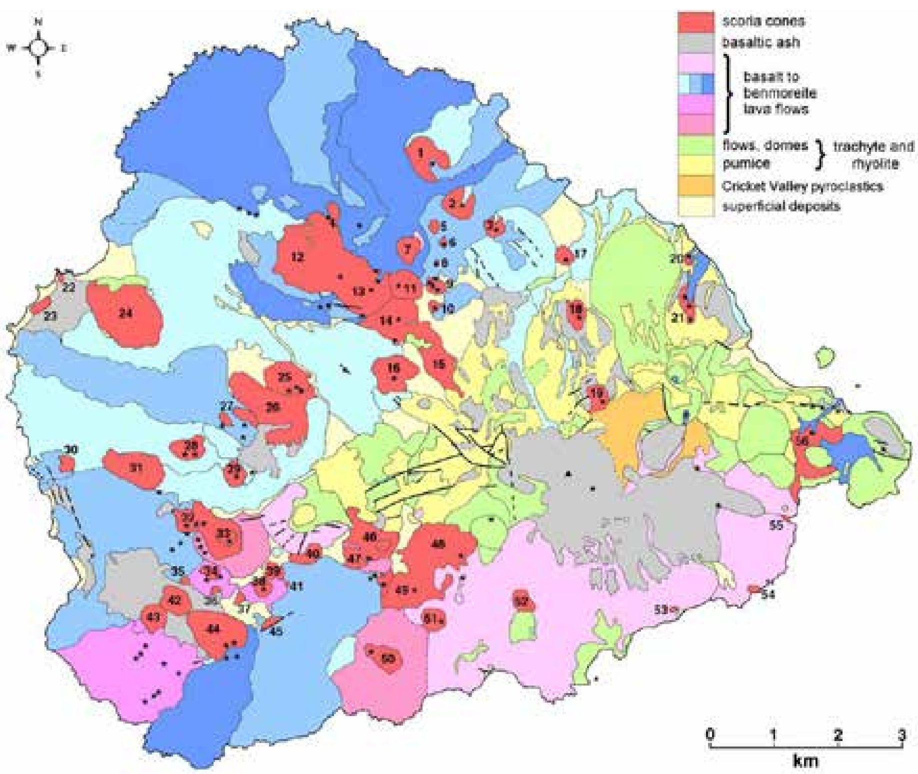

Fig 46. A simplified geological map of Ascension Island. Taken from Weaver (2002).

The island also has several lava tubes, formed where the sides and top of the lava flow have solidified and the lava inside has flowed away, leaving a hollow tube (Fig. 50). At the base of some of the rhylotic lava flows in the centre of the island, the volcanic glass, obsidian, can be found. This formed when the solidifying lava flow collapsed into a glass (Fig. 51).

Devil's Riding School. One of Ascension's great landmarks is the Devil's Riding School, which was originally described by Charles Darwin. The circular feature, resembling a riding school, was formed first by a basaltic lava flow doming up (Fig. 52). Trachyte magma then erupted through the up-domed basalt flow. The eruption caused the dome to subside and a lake to form. In the bottom of the lake, small round balls of rock, called the Devil's Eyeballs, formed through sedimentary processes (Fig. 53).

Future eruptions

Will any of these islands erupt again? Tristan da Cunha will erupt again one day. The most recent eruptions have been from small side vents, and regular drills are carried out so the population could evacuate to the potato patches if, for example, the dome near the settlement re-erupted. However, if a large eruption occurred from the summit of the Queen Mary's Peak, it could be much more hazardous for the population, which cannot easily be evacuated due to the lack of an airfield. Tristan produces viscous lavas, which can lead to violently explosive eruptions, if pressure builds up. Such an eruption will probably occur at some point in the future, but it is not possible to know if that will be in tens, hundreds, thousands or even millions of years. The worst type of eruption could create a caldera from the island, generating a huge tsunami in the South Atlantic.

Saint Helena is extinct and will not erupt again. Ascension could erupt again, but any future eruptions are likely to be small eruptions from scoria cones. In fact, this is how the most recent eruptions have been.

Want to go?

The photographs that accompany this article were all taken me when I visited the territory in April 2014. Itineraries of future trips can be seen at: http://www.geoworldtravel.com/mid-atlantic.phpWeaver, B. Website: http://mcee.ou.edu/bweaver/Ascension/sh.htm.

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