Volcanic Hazard Assessment of Tristan da Cunha

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Volcanic Hazard Assessment of Tristan da Cunha

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Volcanic hazards, eruptive activity, hazard assessment.

Front cover

The Settlement plain viewed from the cliffs above Pigbite.

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Executive Summary

This report provides an assessment of the volcanic hazards of the Overseas Territory of Tristan da Cunha, which was carried out by the British Geological Survey on behalf of the Foreign and Commonwealth Office and the Department for International Development. The assessment is based upon fieldwork undertaken during a visit to the island in January and February 2001.

Tristan is a large oceanic volcano, which rises more than 5500 metres from the sea floor to reach an altitude of 2060 metres above sea-level. It has the form of a shield volcano, the outer flanks of which have been truncated by very high sea cliffs formed by marine erosion. The volcano is composed mainly of basanitic and tephritic lavas, although tephri-phonolites and rare phonolites also occur. Parasitic scoria cones occur around the flanks of the volcano, and scoria deposits intercalated within the older lavas attest to localised explosive activity from parasitic cones throughout the volcano's growth above sea level.

New radiometric dates acquired during the assessment, indicate that the volcano grew above sea level (i.e. the top 2 km) between about 140,000 and 20,000 years ago, largely by the voluminous eruption of lavas. This appears to have culminated in outpourings of relatively fluid lavas from the summit region of the volcano during a phase of activity between about 35,000 and 20,000 years. Little activity has occurred on the upper flanks of the volcano since that period, except for the occasional eruption of parasitic scoria cones, the last of which occurred almost 11,000 years ago.

The coastal strips, found in the northwest of the island around the Settlement and Patches areas, and in the south around Seal Bay Plateau and Stonyhill Point, are young constructional features. They each have a basement of relatively young lavas on which superficial alluvial fan deposits have accumulated. Young parasitic volcanic centres have erupted on the coastal strips over the past few thousand years, the most recent of these being the lava dome and flows that were extruded close to the Settlement in 1961-62. Radiocarbon dating of peat samples collected from the volcanic deposits of these areas indicates that there have been 7 such parasitic eruptions on the two coastal strips within the past 3,000 years approximately.

The coastal strip around the Settlement is constructed in the landslide scar formed by a large-scale sector collapse of the volcano's flanks. The collapse produced a submarine debris-avalanche deposit on the seafloor to the northwest of the island, which is estimated to have a volume of about 150 cubic kilometres. The age of this major flank-collapse is uncertain, but it most probably occurred during the past few tens of thousands of years. There is some evidence that the youngest lavas infilling the landslip scar were erupted after the main rise in post-glacial sea levels had taken place, which would imply an age of less than about 6,000 to 8,000 years.

The main volcanic hazards are considered to be those that would be associated with future eruptions on the coastal strips, should there be any. Based on past activity, such eruptions would likely produce parasitic scoria cones, and small lava domes or tholoids with associated lava flows. The hazardous effects of such eruptions are described in the report. On the basis of newly acquired radiometric dates, it is estimated that there is a 25% probability of an eruption occurring on one or other of the two coastal strips during the next 100 years. Assuming an equal chance of an occurrence on either coastal strip, the probability of an eruption occurring in the next 100 years on the strip around the Settlement or Patches area is halved to 12.5%; which is equivalent an eruption on average every 800 years.

An eruption from the upper flanks or summit region of the volcano is considered to be highly unlikely. If, however, a parasitic eruption were to occur on the northwestern flank, this could pose a hazard to the Settlement area below. Based on available geological evidence however, the probability of such an eruption occurring is roughly estimated to be less than 1 in 60,000 per year.

Some concerns have been expressed by members of the population regarding the residual fumarolic activity on the 1961-62 eruptive centre, and whether this might indicate the possibility of renewed volcanic activity from this centre in future. A detailed appraisal of the 1961-62 eruption is given in the report. The fumarolic activity is extremely weak and of very low temperature, and shows no obvious involvement of magmatic fluids. The activity is typical of that caused by the heating of meteoric water (infiltrating rain water) by residual heat within the old vent area, and as such should not be a cause for concern.

The hazard of rockfalls from the cliffs behind the Settlement was investigated. The rockfalls result from the piecemeal disintegration of a well-jointed volcanic plug exposed in the cliffs. Currently this occurs sporadically, producing small blocks, which accumulate close the foot of the cliff. Under current conditions these rockfalls are not considered to be directly hazardous to the Settlement itself. More intensive rockfalls associated with volcanic tremors in 1961 produced much larger blocks, a few of which rolled down slope from the foot of the cliffs, but still stopped well short of the Settlement. Rockfalls of this size could occur again in this area in the event of future volcanic tremors, although the topography provides some protection and any large blocks are likely to roll towards the NNE, obliquely away from the Settlement.

Almost every volcanic process is characterised by seismic signals that can be used to gain diagnostic information on the level of activity. The 1961-62 eruption was typical in this respect, by being preceded by several months of ground tremors that were felt by the population. It is highly likely that there would have been a more prolonged period of seismic activity prior to the felt tremors that preceded the 1961-62 eruption of Tristan. These earlier and weaker seismic signals would have been detectable had the island be monitored by seismometers. Seismic monitoring of Tristan is therefore strongly recommended, as this would maximise the warning time of an impending eruption. The report therefore provides technical specifications and preliminary cost estimates for the installation a seismic monitoring network on the island.

In the event of a future eruption on Tristan, it may be necessary to evacuate the island. A preliminary plan is therefore provided in the report, and recommendations are made for equipment that should be procured to facilitate such an evacuation if it were to be enacted.

1 Introduction

This report provides an assessment of the volcanic hazards of the Overseas Territory of Tristan da Cunha, undertaken by the British Geological Survey on behalf of the Foreign and Commonwealth Office and the Department for International Development.

The assessment is based upon fieldwork carried out during a visit to the island in January and February 2001. In the course of this visit the geology of the island was examined and mapped, in order to elucidate the sequence and style of eruptions that have occurred during the relatively recent history of the volcano and to assess the hazards associated with these events.

2 Objectives of the assessment

The overall objectives of the assessment were:

- To assess the volcanic hazards of the island
- To formulate an evacuation plan
- To make recommendations for a seismic monitoring network.

The specific hazard of rock falls from the cliffs behind the Settlement was also investigated, as this was considered to have been a threat due to instability caused by precursor ground tremors in the months prior to the 1961-62 eruption.

The overall objective of the investigation is to assess the hazards of the volcano. It should be noted however, that there appears to have been some misunderstanding between BGS, DFID and the FCO as to the definition of the word *volcano*. In drafting the Project schedule, BGS used the term to encompass the entire island, since this is a single large volcano. During the visit to the island however, it became apparent that the term *volcano* is used in local parlance in a very restrictive sense to denote the small parasitic centre that erupted close to the Settlement in 1961-62. It is strongly believed however, that little can to be gained by concentrating investigations on the 1961-62 eruption centre, and that the entire island (which in geological terms is the volcano) must be assessed in order to understand the hazards that might affect the Settlement. The term volcano used in this report therefore relates to the entire island. The survey undertaken during the visit was therefore wide-ranging, although a detailed investigation of the 1961-62 eruption centre (*sic* volcano) has been included within the overall assessment.

3 Working methods

3.1 PREPARATION PRIOR TO FIELDWORK

At the planning stage, a topographic map and the available aerial photographs of the island were procured from the Ordnance Survey and RAF respectively. The published map of the island has no coordinate system, and the position of the island was only known roughly. Information does exist however on several geodetic survey stations in the vicinity of the Settlement, which were precisely surveyed by the Royal Navy using global positioning systems (GPS). This information was obtained from the Hydrographic Office.

The original aerial photographs have a nominal scale of 1:80,000, which is too large to be of use for the interpretation and mapping of volcanological and geological features. They were therefore converted into digital images by scanning and then processed in Imagestation^{TM} to produce a series of distortion-free ortho-rectified photographs at a working scale of 1:20,000. A digital terrain model was also produced together with photographs on which metric contours were superimposed. A Universal Transverse Mercator grid was also placed on the photographs with the aid of the Royal Navy's geodetic information. Permission to base this work on the original aerial photographs was granted by the Crown Copyright Administrator of the Ministry of Defense.

A preliminary interpretation of the aerial photographs was carried out with the aid of a stereoscope, and a simplified map of volcanological features was produced for use in the field.

3.2 LITERATURE REVIEW

Relevant literature on the volcano was reviewed. The main work is the volcanological report of the Royal Society expedition, which visited the island in 1962 during the course of the last eruption (Baker *et al.*, 1964). This provided a considerable amount of detailed information, including a geological map of the island. Subsequent fieldwork during the present investigation indicated that the Royal Society report was generally reliable, although in some need of reinterpretation in the light of modern ideas on volcanology and rock classification. Several other useful papers were reviewed which describe the petrology of the volcanic rocks within a modern framework (Le Roex *et al.*, 1990; Harris *et al.*, 2000). Professor Anton Le Roex, of the University of Cape Town, also provided the writer with a large number of unpublished rock analyses from the island.

Potassium-argon radiometric whole-rock ages from Tristan have been published by Baker *et al.* (1964) and by McDougal and Ollier (1982). The dates published by Baker *et al.* are too imprecise to be of use, and without doubt highly erroneous. They have therefore been ignored by the current investigation. Some of the dates published by McDougall and Ollier contradict field relationships observed during the current investigation. Most are considered misleading; and given the presence of excess argon and abundant xenocrysts in all the rocks dated during the present assessment, the whole-rock dating method used by McDougall and Ollier is likely to have yielded ages that are older than the rocks themselves. A few of McDougall and Ollier's dates however generally accord with observations and radiometric ages obtained during the current investigation.

The work of Holcomb and Searle (1991) provides important information on the bathymetry and morphology of the seafloor surrounding Tristan. This indicates that a large-scale sector collapse and submarine avalanche has occurred off the northwest flanks of the volcano in the area of the Settlement.

Chevalier and Verwoerd (1987) provide a structural and volcanological interpretation of the island. This was based on a brief visit to the island in 1984, aboard the South African research vessel Agulhas, bound for Gough Island. Whilst the structural interpretations of Chevalier and Verwoerd may have some credence, their descriptions and interpretations of the volcanic deposits is considered to be inaccurate and misleading. Of particular relevance to the current hazard assessment is the point that Chevalier and Verwoerd describe pyroclastic flow deposits formed by the collapse of eruption fountains from the summit of the volcano. Such deposits, if they existed, would have serious implications for hazard assessment; however, during the course of the present study, no such deposits were observed and no evidence was seen for pyroclastic flow activity.

3.3 FIELDWORK

Fieldwork was undertaken during the period 23 January to 23 February.

Aerial photographic interpretations were used as a basis for the fieldwork. Salient volcanic features identified on the photographs were checked in the field and the photogeological map modified in the light of new information obtained on the ground.

The report of the Royal Society expedition also provided detailed information, which helped focus the work of the assessment. Information in the Royal Society report was generally found to be reliable, although in some need of reinterpretation in the light of modern ideas on volcanology and rock classification.

During the course of fieldwork, a series of samples was collected for radiometric dating. These included three samples of peat taken from seams within scoria deposits on the coastal strip near the Settlement and Patches areas, which were dated by the radiocarbon method; and eight samples of lava that were dated by the argon-argon (Ar/Ar) step-heating method.

Due to the low cloud base, which is the norm rather than the exception on Tristan, it was only possible to visit the upper flanks of the volcano on a limited number of occasions. As a result, more effort was generally expended in examining the geology of the coastal strip of the Settlement area. This included a detailed examination of the 1961-62 eruptive centre.

The very high cliffs around the entire island are prone to rockfalls, especially during periods of heavy rain. The hazard is also likely to intensify as a result of ground tremors associated with volcanic activity, as happened in the build-up to the 1961 eruption. The cliffs around the Settlement were therefore examined with respect to the hazard of rockfalls, and also for evidence of debris avalanches caused by the mass failure and collapse of larger volumes of material.

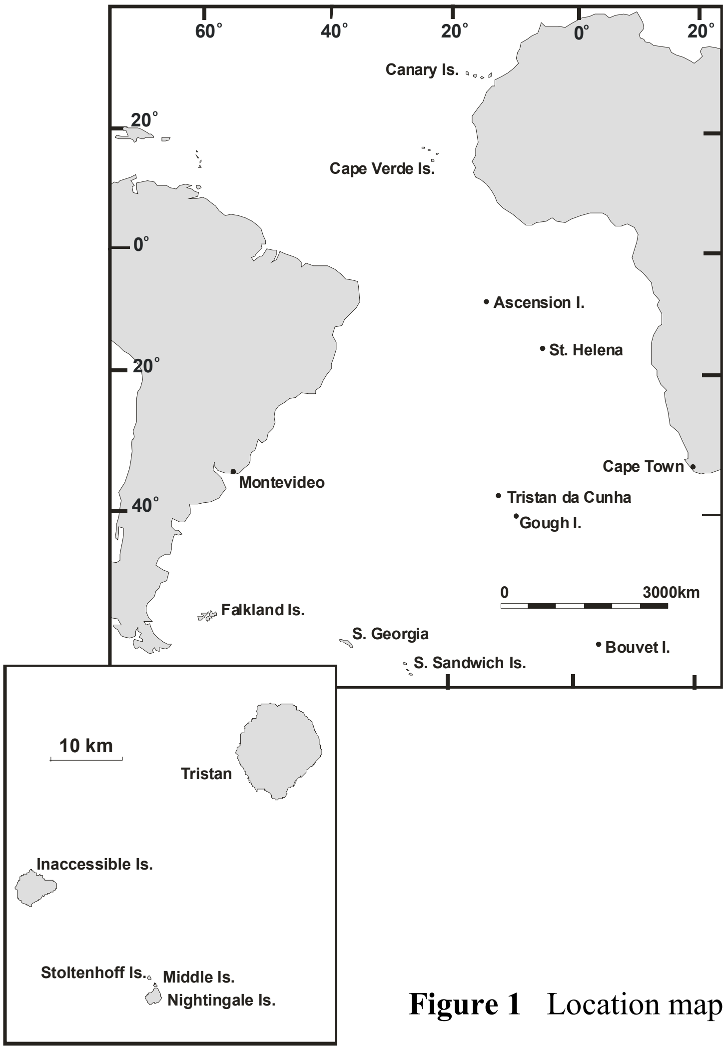

Figure 1 Location map of Tristan

4 Global setting of Tristan da Cunha

Tristan da Cunha (hereafter called Tristan) is a volcanic island situated in the South Atlantic at 37° 05 S, 12° 17' W, approximately 1750 miles west of Cape Town.

Tristan, together with Inaccessible and Nightingale islands and a number of smaller islets, forms part of the Tristan da Cunha group, which lies on a submarine plateau situated on the eastern flank of the Mid-Atlantic Ridge near its junction with the aseismic Walvis Ridge.

Bathymetry indicates that the Tristan da Cunha group rises from water depths of about 3500 metres and that the three main islands represent the uppermost parts of very large, separate volcanoes. Inaccessible and Nightingale islands are surrounded by extensive platforms of shallow water, indicating that they are probably the eroded remnants of once larger volcanic centres, whereas Tristan is virtually a perfect cone both above and below sea-level.

It is generally accepted on geophysical and petrological grounds that the Tristan da Cunha group represents the surface volcanic expression of a mantle plume or hotspot (an area of deep-seated mantle upwelling) (Bowin et al., 1984; Duncan, 1981). In such a model it is proposed that the Walvis Ridge formed over the past 130 million years (McDougal and Duncan, 1988) and represents the locus of volcanism produced as young ocean floor of the African Plate, generated at the Mid-Atlantic Ridge, migrated northeastwards over the stationary mantle plume. The Tristan group represents the area of active volcanism currently located over the plume at the southwest end of the Walvis Ridge.

5 Physiography of Tristan

Tristan is a roughly circular island, with a diameter of 12 km, which rises from a water depth of about 3500 metres to an altitude of 2060 metres above sea level.

The island is a near-perfect volcanic cone, the outer flanks of which are truncated by high sea-cliffs, known locally as the Main Cliffs (Plate 1). These are generally 500-650 metres high and descend directly to the shore, or in places to fringing Coastal Strips. Although the cliffs are extremely steep they are nowhere vertical over their full height; there being few sheer drops of more than 300 metres.

The uppermost part of the volcanic cone, above about 850 metres, has steep flanks that slope radially away from the summit with average gradients of 25-30°. Below this height, extending to the edge of the Main Cliffs, the flanks have more gentle slopes, which flatten-out to about 8°. This gives the impression in certain sectors that the lower more gentle slopes form a pedestal upon which the steeper upper part of the cone is superimposed. This has probably given rise to the local names of the Base for the gentler slopes extending from the edge of the Main Cliffs up to about 850 m, and the Peak for the steeper higher slopes up to the summit (Plate 2). Baker et al. (*op. cit.*) and subsequent researchers (e.g. Chevalier and Verwoerd, 1987) point out that this distinction may not be as sharply defined as appears at first sight, especially for example on the eastern flanks of the volcano where there is a gradual increase in gradient from the edge of the Main Cliffs up to the summit. If one accepts that the Main Cliffs have formed by marine erosion and extrapolate the flanks of the Peak and Base beyond them (i.e. seaward), the profile of Tristan does not appear to be dissimilar to those of many other large stratovolcanoes. It is therefore concluded that there is no geological reason for differentiating the Peak and Base from one another.

Numerous parasitic scoria cones, in various states of erosion and preservation, occur on the Base. These range in morphology from degraded scoria mounds in which no original crater features are preserved, to pristine scoria cones with well-defined craters.

Incised drainage channels or gulches radiate off the flanks of the Peak and Base. For most of the time these are dry, because of the porous nature of underlying rocks; although they flood during heavy and prolonged periods of rainfall. The larger streams cascade down the Main Cliffs in very steep, deeply incised, rocky valleys, whereas the smaller streams have hanging valleys and pour over the edge of the cliffs in spectacular waterfalls to the sea below.

Several coastal strips occur between the foot of the Main Cliffs and the sea. The largest is the Settlement coastal strip in the northwest, which is about 7 km (4 miles) long and up to 1.5 km wide (about 1 mile). Another coastal strip, up to 6 km (3.75 miles) long, occurs in the south around Seal Bay Plateau and the adjoining area of Stonyhill Point. A small narrow strip is also found around Sandy Point on the western side of the island. The coastal strips have been subject to marine erosion and are bounded by low cliffs along their seaward edge. The basic structure of the strips appears to consist of near-horizontal lavas, overlain by large coalescing alluvial fans that have formed where streams draining the upper flanks of the volcano disgorge their loads at the mouths of gulches incised into the Main Cliffs. The surfaces of the coastal strips slope seaward. Gentle slopes of a few degrees are found at the coastal edge, but gradients gradually increase inland towards the mouths of the main gulches where the alluvial fans abut against the Main Cliffs and have surface slopes of up to 40°. Young parasitic volcanic centres, including scoria cones and lava flows, occur on the coastal strips; the most notable example being the lava dome and flows erupted near the Settlement in 1961-62.

6 The geology and evolution of Tristan

This section describes the salient features of the geology and evolution of Tristan. It is based on a fuller description given in Appendix 1, which provides more detailed information on key sections and on samples that were used for radiometric dating.

Tristan comprises a single, large volcano composed predominantly of lavas ranging in composition from basanite through tephrite to tephri-phonolite and phonolite, with basanite and tephrite predominating. The form of the volcano approximates to that of a shield volcano, the outer flanks of which have been truncated by the Main Cliffs as a result of marine erosion.

6.1 SUCCESSION OF THE MAIN CLIFFS

The oldest exposed parts of the volcanic edifice are found in the Main Cliffs. These expose a well-stratified sequence of basanite and tephrite lavas, including some highly porphyritic ankaramitic and picritic basanites (Plate 4). Scoria deposits are intercalated within the sequence and represent the remnants of parasitic scoria cones that erupted from time to time on the flanks of the volcano as the lava pile built up. Radiometric dating undertaken during the present study indicates that the age of these lavas ranges from 140 ka for the lowest exposed flows, to approximately 50 ka for lavas at the top of the cliff sequence.

6.2 THE BASE AND PEAK

The Base and Peak, which make up the upper parts of the volcanic edifice, are composed of lavas with intercalated scoria deposits. These dip radially seaward at similar angles to the surface topography, decreasing gradually from about 30º on the upper slopes of the Peak to about 10º or less where the flanks are truncated by the Main Cliffs around the seaward edge of the Base. Compositionally, the lavas of the Base and Peak are predominantly tephritic with minor amounts of tephri-phonolite and phonolite. Relatively young lava fields, with well-preserved flow features cover extensive areas of the flanks. Individual flows can be traced as long narrow features, extending from the upper flanks of the Peak down across the Base to the edge of the cliffs, where they have been cut by erosion. The morphology and long, narrow and sinuous form of individual flows, suggests that they were relatively fluid when erupted. Ar/Ar dating indicates ages for these surface lavas, ranging from 49±7 ka for flows low on the northern flanks of the Base, to 22±8 ka for one of the highest flows on the northwest flanks of the Peak. Based on the radiometric dates obtained, the most extensive lava fields exposed on the flanks of the volcano appear to have been erupted mainly between about 35 and 20 thousand years ago.

Numerous parasitic scoria cones, or the degraded remnants of scoria cones, occur around the Base and lower flanks of the Peak. In addition, a large scoria cone with a well-developed crater occupies the summit of the Peak. These parasitic centres vary in age and state of erosion, although all are heavily vegetated except for the summit cone. Most have craters in various states of preservation, many of which are breached on their down-slope or seaward side. A radiocarbon date of 10770±156 years before present (B.P.) was obtained from a soil overlain by the scoria cone of Big Green Hill (Baker *et al*., 1964). Based on morphology and state of preservation, Big Green Hill is considered to be amongst the youngest of the scoria cones on the Base and Peak.

Several maar craters occur on the Base and Peak. These bear testimony to phreatic and phreatomagmatic activity. They include the three Ponds, on the NNE flank, which are aligned NNE and probably formed as a result of a radial dyke intersecting the water table as it was intruded from below. The summit crater also has features consistent with having been formed by phreatic and phreatomagmatic activity.

Baker *et al.* (1964) maintained that the proportion of pyroclastic material in the volcanic pile increased towards the upper flanks of the volcano, accounting for approximately 25% of the succession on the lower edge of the Base to as much as 75% on the upper parts of the Peak. Observations made during the present assessment suggest that the proportion of pyroclastic material may have previously been over-exaggerated, and that lavas predominate, even on the Peak. Chevalier and Verwoerd (1987) describe pyroclastic flow deposits from the Peak, which they believed were formed by the collapse of eruption fountains produced by explosive activity. Their descriptions of these deposits are scant and vague. Particular attention was paid to this issue during the present study, but no pyroclastic flow deposits were recognised. It is therefore concluded that the descriptions of Chevalier and Verwoerd are erroneous and misleading.

6.3 THE COASTAL STRIPS

The Coastal Strips are relatively young constructional features composed of flat-lying lavas overlain by alluvial and colluvial fan deposits. Young parasitic volcanic centres are superimposed on the surface of these coastal strips, most notable amongst these being the 1961-62 eruption centre.

The Settlement coastal strip consists of a sequence of horizontal lavas, which form a basement on which alluvial and colluvial fan deposits rest. The lavas forming the basement are tephritic in composition and are exposed in the low cliffs along the coastal edge of the strip. The lowest exposed flows consist of pillow lavas with minor hyaloclastite, which were erupted beneath the sea (Plate 6&7). These are overlain by massive and columnar jointed lavas, which were erupted subaerially. The transition from submarine pillow lavas to the overlying subaerial lavas is approximately coincident with the present day high water line. The highest of these basement lavas, sampled at the waterfall at the mouth of Hottentot Gulch, yielded an Ar/Ar radiometric age of 30±6 ka. A seam of peat near the base of the alluvial fan deposits, where they rest on this lava near the mouth of Hottentot Gulch, yielded a radiocarbon age of 2411±48 years B.P. (before present).

The colluvial and alluvial deposits of the Settlement coastal strip have been deposited in a series of coalesced fans, formed by streams draining the Peak and Base disgorging their sediment loads. The fans are now largely inactive, apart from the principal drainage channels that cut across them to the sea. The deposits consists mainly of very coarse, poorly sorted boulder conglomerates, with intercalations of coarse gravels and sands. Beds of fine sand, silt, and clay indicate deposition in ponded water. In places, thin seams of peat are intercalated with these finer sediments. Beds of scoria also occur, usually at or near the base of the alluvial fans. Rockfall debris and the deposits of a small avalanche occur at the foot of the Main Cliffs near the water tank, situated behind the Settlement (Plate 15, 16 & 17).

The young parasitic volcanic centres on the Settlement coastal strip include: the complex of scoria cones around Hillpiece-Burnthill (Plate 10); a cluster of scoria mounds and hornitos at the Patches (Plate 8 & 9), which are associated with thin lava flows; and most notable of all, the 1961-62 lava, situated immediately to the east of the Settlement (Plate 11, 13 & 14).

Radiocarbon dating of a peat seam immediately overlying the scoria deposits of the youngest scoria cone of the Hillpiece-Burnthill complex has yielded an age of 2775±47 years BP. This places an age limit on the last eruption of the complex. The scoria mounds and hornitos of the Patches area are of two types. Several appear to represent vents from which lavas were erupted; whilst others are interpreted as rootless vents formed by explosive activity when the lavas flowed over wet ground or into ponded water. A peat seam, deposited immediately on top of the scoria deposits, has yielded a radiocarbon age of 1624±45 years BP. This provides an age limit for the activity in the Patches area.

The parasitic centre formed during the 1961-62 eruption consists of a tephri-phonolite dome-tholoid complex, from which an extensive lava field was extruded. A detailed description of the 1961-62 eruption is given in Section 7.

Four young parasitic volcanic centres occur on the southern coastal strip around Seal Bay Plateau and Stonyhill Point in the south of the island. Much of Seal Bay Plateau is covered by a young lava flow, which was erupted from a breach in the young-looking scoria cone of Hackel Hill. Three very young eruptive centres and associated lava flows occur around Stony Hill. These include a small scoria cone, which is unnamed on the map, but was christened Kipuka Hill by the Royal Society Expedition. A tephrite lava with well-preserved flow features, which is only sparsely vegetated, was erupted from a breach at the base of the southern flank of the cone. To the north is another small scoria cone, named locally as the Hill-with-the-hole-in. This has a well-preserved crater, in the base of which a deep cylindrical vent is still open to the surface. Based on its state of preservation, this is clearly a very young cone. A tephrite lava flow extends southwards from a breach on the southern flank of the cone, and post-dates the flow that was erupted from Kipuka.

The lava flow from the Hill-with-a-hole-in, is post-dated by the tephri-phonolite lava of Stony Hill. This consists of extensive blocky lava flows that were erupted from a steep-sided tholoid, which form the hill itself (Plate 12). In many respects, both in morphology and composition, the Stony Hill centre resembles the 1961-62 eruptive centre of the Settlement area. The hill itself is composed of very blocky lava dissected by numerous large fissures. The remnant of a small lava spine forms the summit. The pristine morphology of the lava, the lack of weathering and very sparse vegetation, indicate a very young age. The Royal Society expedition suggested that it was erupted about 200 to 300 years ago. This is a subjective estimate, for which there is no firm evidence; although it is obvious from the state of preservation that the eruption of Stony Hill must have occurred recently, and that it was certainly the penultimate eruption to occur on the island.

6.4 SECTOR COLLAPSE IN THE SETTLEMENT AREA

Holcomb and Searle (1991) examined sidescan sonar images (Gloria) of the seafloor surrounding Tristan and recognised a large-scale submarine avalanche extending northwest from the island. The avalanche deposit covers an area about 40 km across. It is about 100 metres thick, and is estimated to have a volume of about 150 cubic kilometres.

The submarine avalanche deposit has a broad fan shape, the apex of which extends back to the Settlement coastal strip. The Main Cliffs backing the Settlement coastal strip are broadly concave and arcuate in plan, consistent with them representing the headwall of the avalanche. Here the cliffs are more than 800 metres high and are very similar in appearance to the headwall scars of large-scale avalanches seen on the Hawaiian Islands. Holcombe and Searle suggested that the Settlement coastal strip probably accumulated as a lava delta within the landslide scar, partly filling it. Observations made during the present survey are wholly consistent with this theory.

The age of the sector collapse that produced the avalanche is uncertain. The Ar/Ar radiometric date of 30±6 ka for the youngest lava forming the basement of the coastal strip, places an upper age on the accumulation of lavas in the landslide scar. However, the peat seam near the base of the alluvial deposits, which rest on the top of this lava, at the mouth of Hottentot Gulch, has yielded a radiocarbon age of only 2411±48 years B.P. On the assumption that there has been little or no intervening erosion, this date may indicate that accumulation of the lavas within the landslide scar was much younger than that suggested by the 30,000 year radiometric date on the lava. The transition from submarine pillow lavas to subaerial lavas in the basement flows of the coastal strip coincides approximately with the present day high-water line; which suggests that they were erupted when the sea-level was approximately at its present elevation; and therefore in post-glacial times. This again suggests a relatively young age for the construction of the Settlement coastal strip, and by inference for the preceding sector collapse. If this hypothesis were accepted, it would indicate that eruption of the lavas forming the basement to the coastal strip probably took place after the main rise in post-glacial sea level, which occurred between about 8,000 and 6,000 years ago.

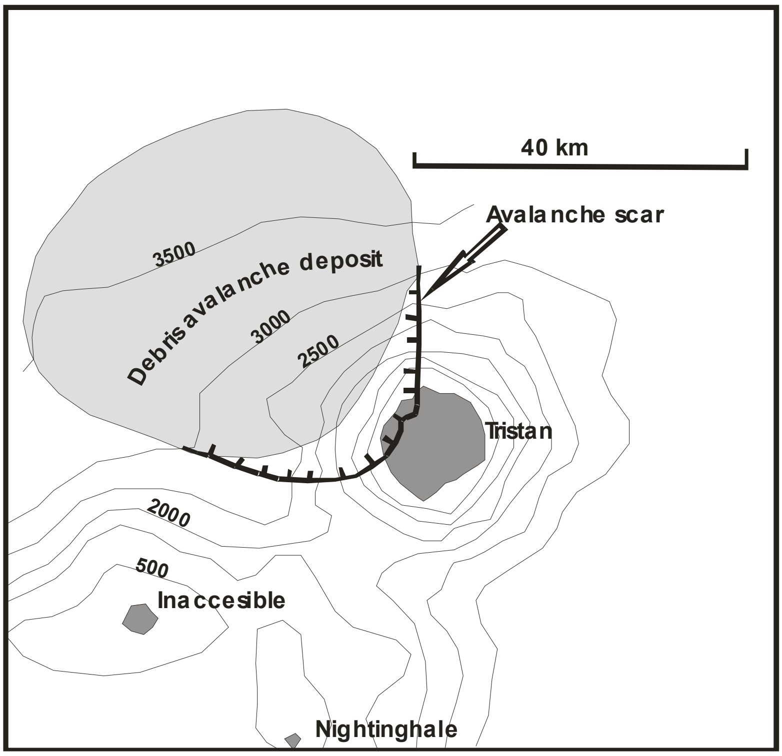

Figure 2 Simplified map of the submarine debris avalanche deposit formed by the collapse of the north-western flanks of the volcano. Isobaths in metres

6.5 SUMMARY OF THE GEOLOGY AND EVOLUTION OF TRISTAN

Tristan is a large volcano, which rises 5.5 km from the sea floor. The uppermost 2 km are above sea level and consists predominantly of lavas ranging in composition from basanite through tephrite to tephri-phonolite and phonolite, with basanite and tephrite predominating.

The form of the volcano approximates to that of a shield volcano, the outer flanks of which have been truncated by marine erosion that has produced the high cliffs surrounding the island.

The oldest exposed part of the volcanic pile, seen in the Main Cliffs, consists of a layered sequence of basanitic and tephritic lavas with local intercalations of scoria deposits that were erupted from parasitic cones on the flanks as the volcanic pile grew. These lavas and scoria deposits were erupted between about 140 ka and 50 ka.

The upper flanks of the volcano, making up the Peak and Base, are mainly composed of tephritic lavas with minor tephri-phonolites and phonolites. These were erupted between 49±7 ka and 22±8 ka. Lava flows with well-preserved flow-features cover extensive areas of the flanks of the Base and Peak These were erupted from the summit region mainly between about 35 and 20 ka. Parasitic eruptions also produced numerous scoria cones, which are preserved in various states of erosion around the Base and lower flanks of the Peak. Big Green Hill appears to be the youngest of these cones, and was erupted around 10770 years B.P. This was probably the last eruptive event on the Base and Peak.

The coastal strips, found around the Settlement and Patches in the northwest, and Seal Bay Plateau and Stonyhill Point on the south side of the island, are relatively young constructional features. They are made up of basements of horizontal lavas, overlain by colluvial and alluvial fan deposits. The lavas forming the basement to the Settlement coastal strip show an upward transition from submarine pillow lavas to massive and columnar jointed lavas that were erupted under subaerial conditions. The transition between these two types of lava coincides approximately with the present day high water mark, suggesting that they were erupted after the major rise in post-glacial sea levels, which was largely accomplished by about 8000–6000 years ago.

The Settlement coastal strip has been constructed in a landslip scar, formed by a major sector collapse of the volcano's flanks. This collapse produced an avalanche deposit on the seafloor to the northwest of the island, which is estimated to have a volume of about 150 cubic kilometres. The age of this collapse is uncertain, but it is considered to be relatively young, and is constrained by the age of the youngest basement lavas of the coastal strip, which could be as young as 8000-6000 years (see previous paragraph).

Young parasitic volcanic centres occur on the coastal strips. These include tephritic scoria cones and lavas, and tephri-phonolite tholoids and flows. Three such parasitic eruptions have occurred on the Settlement coastal strip within the past 2770 years, the last being in 1961-62. Another four have also occurred at Seal Bay Plateau and Stonyhill Point, probably over a similar time period, with the eruption of Stony Hill having taken place during the last few hundred years. On this evidence, it is considered that over the past three thousand years approximately, the coastal strips have been affected by parasitic eruptions on average every 400 years.

7 The 1961-62 eruption

A detailed description of the 1961-62 eruption is provided in the Royal Society report (Baker et al., 1964). This forms the basis of the following summary, which is augmented by observations made during the current assessment.

7.1 PRECURSOR SEISMIC ACTIVITY

During the week beginning 6 August, about 2 months before the eruption, slight earth tremors were felt in the vicinity of the Settlement and also at Sandy Point on the east side of the island. These increased slightly in intensity and frequency over the following 3 weeks, although there was an apparent lull in activity at the end of August.

Felt tremors recommenced in early September with greater frequency and intensity, and there were reports of 'many minor rumblings and subterranean thumpings'. These events were monitored at the Settlement by taking the precise time of each tremor and gauging intensity according to an improvised scale increasing from A to D: This scale is reported by the Royal Society expedition to have been roughly equivalent to the following intensities of the Modified Mercalli Scale: A = 3, B = 4, C = 5 and D = 6.

Parties were also dispatched to other parts of the island to monitor events. Tremors were felt at both ends of the Settlement and on the edge of the Base above the Settlement. No tremors were felt at Stony Beach, situated 11 km from the settlement on the south coast of the island, nor on Nightingale Island when observations were made there at the end of September. Tremors were felt at Hillpiece, situated about 1.5 km south-west of the Settlement, at least one of which was believed to have been of greater intensity than that felt at the Settlement.

Seismic activity reached a climax during the first 5 days of October, when the number of recorded shocks actually decreased, but were all sufficiently intense to merit a 'D' grading.

Rock falls were concurrent with tremors of 'D' grade. In total about 60 rockfalls were recorded, particularly from near the top of the 600 m high cliffs behind the Settlement. These usually involved the fall of soil and loose talus and sometimes 'considerable' volumes of underlying rock. The intrusive volcanic plug exposed in the cliffs immediately behind the Settlement was the site of the greatest falls, where as many as 20 falls per day occurred at the climax of tremoric activity.

Surface deformation began to manifest itself in October. Small surface cracks developed in the eastern part of the Settlement on 8 October and the water supply system was severed as a result of the buckling of the main supply pipe. The fractures generally had a north-south trend, and where they passed through houses, the doors and windows became difficult to open and close. On the following day the fractures had closed and windows and doors operated as usual. On 9 October a large crack roughly parallel with the Main Cliffs opened about 300 yards east of the Settlement. The ground began to swell on the southern side of this crack and within two hours a fractured mound about 30 feet in diameter and 20 feet high had developed. At this stage no surface volcanic activity was associated with this feature.

7.2 ERUPTIVE ACTIVITY

At 2 am on the 10 October, a red glow was observed on the newly formed mound, confirming the start of the eruption, and by daybreak a small lava dome approximately 50 metres in diameter and 20 metres high had developed. Phreatic activity (steam explosions caused by the heating of groundwater) also occurred in a boggy area about 200 metres to the west of the mound; but within two days this ceased.

The lava dome grew rapidly by the extrusion of material on the summit region and the avalanching of blocks down the flanks. Swellings were also observed on the flanks and these intermittently 'burst' and scattered fragments. The development was also reported of 'blow holes' that ejected debris. By the 14 October the dome had reached a height of about 75 m above the surrounding ground and covered an area of about 1.25 hectares. At this stage the dome began to extend northwards (seaward) and transform into an elongated flow-dome or tholoid.

The Royal Society report states that 'no actual lava was observed, although there was a virtually continuous fall-out of red hot clinker and rock from the summit', whilst at night red hot lava was seen streaming down the sides. This last description seems improbable given the morphology of the lava and in the light of information from well-studied dome eruptions at other volcanoes. Instead, the observations and descriptions are compatible with the extrusion of highly viscous, near-solid blocky lava on the summit region of the dome, and the continuous avalanching of this unstable material down the flanks, which at nighttime appeared incandescent and gave the impression of being fluid.

Over the following weeks, observations were made from various passing ships. On 21 October it was reported that the main beach was almost covered by lava and that the 'erupting cone' was nearly 120 metres high. By 27 October the flow had extended 100 metres into the sea and was also extending westwards towards the Settlement. Photographs taken at this stage show lava issuing from the tholoid and descending down a steep incline into the sea.

On 16 December two geologists, P.G. Harris and R.W LeMaitre (who later formed part of the Royal Society expedition) visited Tristan aboard HMS Jaguar, but were unable to land because of sea conditions. By this stage the lava field extended 360 metres (400 yards) beyond the former coastline and was about 900 metres (1000 yards) wide at its seaward margin. They reported that the tholoid had a height of 480 feet (146 metres) and had been breached by a collapse on the seaward side. At the head of the resulting U-shaped depression, a small cone (the Central Cone) had developed from which a stream of blocky lava ran towards the sea. Activity was said to be more violent than any observed previously, with steam being emitted from the summit of the cone and explosions every few minutes ejecting blocks and bombs to heights of 100 feet, accompanied by the emission of red flames or liquid (*sic*): Flames are very unlikely to have been emitted and it is most probable that this represented hot incandescent molten lava. A second small cone with a crater was also active against the cliff at the back of the original dome and was the site of explosive emission of steam and ash. This was known as the Peripheral Crater. Examination during the present assessment indicates that this was an explosion crater, which appears to have formed mainly by phreatic activity, which produced a relatively wide, but shallow crater surrounded by a low cone composed of moderately well-sorted, subangular to subrounded lithic ejecta with some scoria.

By the time the Royal Society expedition arrived on 27 January, activity had diminished greatly, except for a few weak explosions from the Peripheral Crater, but within a few days a second dome began to grow. This was extruded from a breach on the seaward side of the Central Cone and formed a low north-south trending ridge. This grew rather slowly during February and March, reaching a height of 482 feet (147 metres) above sea level on 19 March, just prior to the departure of the expedition. Temperature measurements of red-hot material within a fracture on the dome, taken with an optical pyrometer, indicated a temperature of 890°C. Fumarolic activity (venting of steam and other gases) declined throughout February and March, by which time the main area of fumaroles was confined to the central cone and to scattered steam vents across the lava field.

The area covered by the lava was estimated by the Royal Society expedition to be 700,000 square yards (586057 square metres), although subsequent marine erosion has reduced this. The total volume of material erupted was estimated to be 26 million cubic yards (19.9 million cubic metres). The duration of the eruption is not precisely recorded, although the account given by the expedition implies that extrusion of lava probably ceased in mid-March. If a duration of 160 days is assumed, the average rate of extrusion would have been 1.44 cubic metres per second.

7.3 COMPOSITION OF THE 1961-62 LAVA

The Royal Society expedition referred to the 1961-62 lava as a trachyandesite, although three chemical analyses presented in the expedition report (Baker et al., 1964) indicate a strongly alkaline and undersaturated composition, with between 9-10% normative nepheline, which is not compatible with such a classification. Furthermore, petrographic descriptions report the presence of leucite, which would again be impossible to reconcile with the term trachyandesite. Le Roex et al. (1990) published an additional analysis of the 1961-62 lava and drew attention to the discrepant rock classification scheme used by the Royal Society expedition. Using the more modern IUGS TAS classification (Le Maitre et al., 1989) the lava is more correctly classified as a tephritic-phonolite, in keeping with its undersaturated composition.

7.4 MORPHOLOGY OF 1961-62 ERUPTIVE CENTRE

The 1961-62 eruptive centre comprises two main parts. These are the source region, consisting of the dome-tholoid complex, and a lava field, which comprises three different lobes.

The source region is composed of the initial tholoid, which is now preserved as a steep sided arcuate (U-shaped) ridge composed of blocky lava and scoria. This initially had an elongated dome-shaped form, but at an early stage in the eruption underwent collapse and was breached on its seaward side. During this early stage the central cone and peripheral crater developed. The peripheral crater is located at the southern end of the tholoid where it abuts against the Main Cliffs, and appears to have been the site of mainly phreatic activity. The Central Cone is located about 80 metres north of the peripheral crater. It is constructed of blocky lava and lesser amounts of scoria, and was the vent from which more fluid lavas issued and descended down the northern flanks of the tholoid to produce the lava field that grew out into the sea. Three main flows make up the lava field. The Central flow was erupted first and consists of a blocky lava composed of very coarse jagged and slabby blocks. This was followed by the eruption of the Eastern flow and finally the Western flow, both of which are composed (on the surface) of loose blocks which are generally more equant in shape and noticeably less coarse than those of the Central flow. The Western and Eastern flows have well-developed concentric pressure ridges (ogives) and levees which indicate the direction of flow.

The second dome was extruded from the Central Cone during the final stages of the eruption. It is composed of coarsely blocky and slabby lava, with a series of small spines located around the southern (back) side of the vent.

7.5 CURRENT OBSERVATIONS AND INTERPRETATION OF THE 1961-62 CENTRE

Examination of the 1961-62 parasitic volcanic centre as part of the current assessment indicates that the report of the Royal Society expedition provides an accurate description of its morphology, which accords well with the sequence of eruptive events chronicled at the time.

The tripartite morphology of the centre, namely the initial dome-tholoid complex, the lava field and the second (final) dome most probably reflect variations in rates of extrusion, crystallinity and viscocity of the lava.

The initial dome-tholoid complex is consists of a very coarse blocky lava, which from eyewitness accounts appears to have been extruded in an almost solid state. The time taken for the magma to reach the surface is unknown, although judging from precursor tremoric activity it would appear to have resided at a shallow level for several months at least before finally breaking out onto the surface, and may have taken a considerably longer time rising from deeper levels. During ascent to the surface the initial magma would have been subject to cooling and crystallisation, a process that would have been further promoted by stagnation in the near-surface environment. The lava that first erupted onto the surface is therefore likely to have had a higher degree of crystallinity than later material, thus explaining the extrusion of a near-solid blocky lava that formed the initial steep-sided dome-tholoid.

Once the eruption was initiated and a conduit opened to the surface, magma could ascend more freely and thus reach the surface more quickly in a less crystallized and more fluid state. This may explain the change in eruption to that of the more fluid lavas, which flowed from the breached tholoid and formed the extensive lava field that grew out into the sea.

The second dome formed at the end of the eruption. This small dome probably represents the final extrusion of residual, degassed and relatively crystallized (and therefore more viscous) magma. The report of the Royal Society expedition supports this view by stating that at the time of the eruption the lava of the final dome was more crystalline than earlier lavas.

7.6 RESIDUAL THERMAL ACTIVITY

Present day fumarolic activity is confined to three small areas, which fall on a vaguely arcuate line around the summit rim of the original tholoid. These locations include the pinnacle forming the highest point on the western rim of the tholoid, a second small area on the rim of the peripheral crater, and a third area a short distance to the east of this. The activity consists of very weak, low temperature steam seepages from crevices and cavities. Flow rates are very low to almost imperceptible, with only minor condensation occurring and no audible noise. Depending on weather conditions, diffuse wisps of steam are visible at times emanating from fractures around the pinnacle, and a small pall of steam sometimes hangs over the area on windless humid days. Steam seepages in the two eastern areas range in temperature from ambient to warm, with maximum values estimated to be no more than about 35-40°C. These steam seepages have ferns and moss growing within them, attesting to their low-temperature. Temperatures are slightly higher around the pinnacle, although are variable from day to day, possibly being modulated by the weather. For example, on one windless, humid day the largest fumarolic vent was almost too hot for prolonged exposure to the hand, suggesting temperatures of around 60°C, whereas a day later, under sunny, windy conditions the steam seepages were hardly perceivable. A very slight, almost imperceptible odour of hydrogen sulphide is occasionally apparent in the fumaroles around the pinnacle, but not in the other two areas. Hydrothermal alteration is very limited, consisting of ochreous to white encrustations on rock surfaces, which probably consist of sulphates such as gypsum-anhydrite and jarosite. Pervasive alteration of the ground around the fumaroles is very weak or absent.

Minor concern has been expressed by members of the population about the fumarolic activity, as to whether it might indicate the possibility of future or renewed volcanic activity. In the writers experience the fumarolic activity is extremely weak, of very low temperature and of restricted extent. As such it is not unusual for a young parasitic volcanic centre, and if anything is rather less intense than that which might normally be expected around a young lava dome. The virtual absence of sulphurous gases, especially sulphur dioxide; the complete lack of sulphur precipitates; and the very weak and generally non-pervasive hydrothermal alteration are also taken as indicators of the lack of involvement of any reactive magma tic fluids. It is concluded that the fumarolic activity is typical of that caused by the heating of meteoric water (infiltrating rain water) by residual heat within the old vent area, and as such should not be a cause for concern.

Plate 1 The island of Tristan. Note the high cliffs surrounding the volcano. The summit region is obscured by cloud.

Plate 2 The Peak looking up from the edge of the Base at Burntwood.

Plate 3 The Settlement plain viewed from the cliffs above Pigbite. This shows the 1961-62 lava with the Settlement beyond.

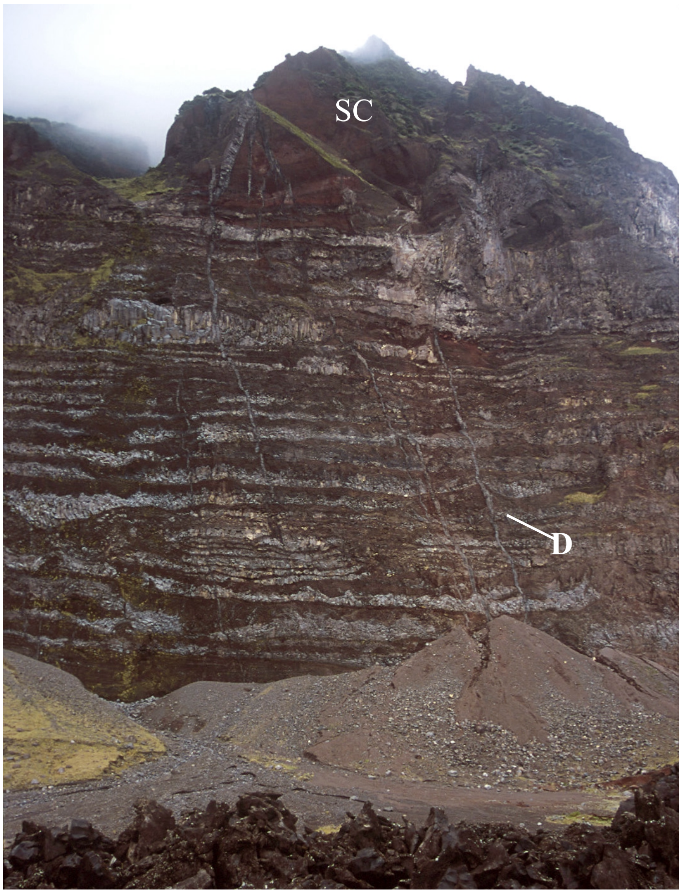

Plate 4 The base of the Main Cliffs at Pigbite. The section consists of a sequence of stratified lavas, both massive and autobrecciated, intruded by dykes (D). Scoria cone deposits (SC) are locally intercalated within the sequence

Plate 5 The Main Cliffs southwest of the Settlement. This shows a sequence of white pumiceous tuffs and tuffaceous sediments at the base of the lava sequence.

Plate 6 & 7 Tubular pillow lavas (PL) on the foreshore near the harbour. These form a basement to the Settlement coastal strip. The transition from submarine pillow lavas to subaerial lavas (SAL) coincides approximately with the present day high-water line.

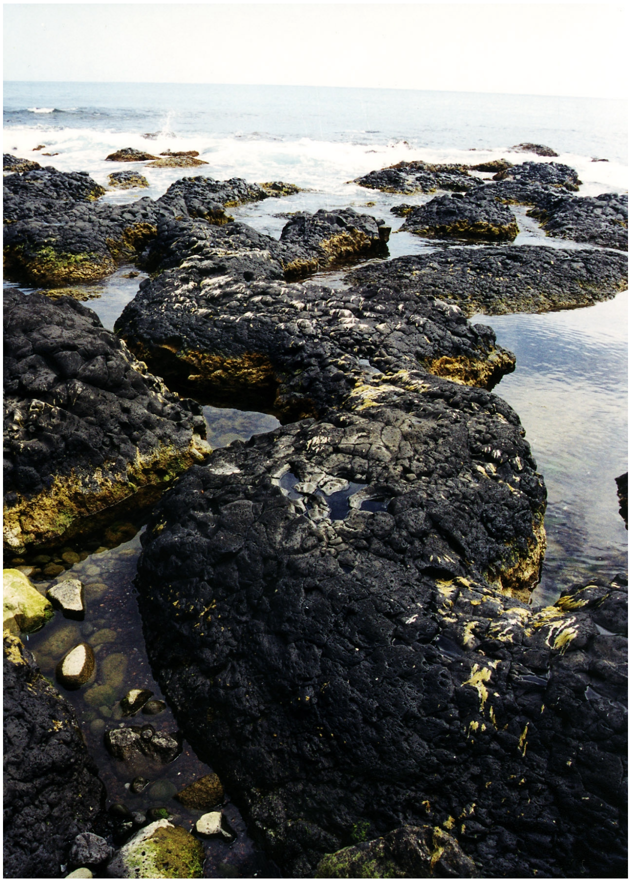

Plate 8 The coastal strip around the Patches area looking south-westward to Burntwood. In the foreground young scoria mounds and hornitos can be seen. These have yielded a radiocarbon age of 1624 ± 45 years. The Main Cliffs behind the coastal strip are over 800 metres high, and represent the landslip scar of a major sector collapse of the volcano's flanks.

Plate 9 Hornitos and scoria mounds on the coastal strip around the Patches.

Plate 10 The Hillpiece scoria cone on the Settlement coastal strip.

Plate 11 The 1961-62 lava and dome, backed by stratified lavas of the Main Cliffs.

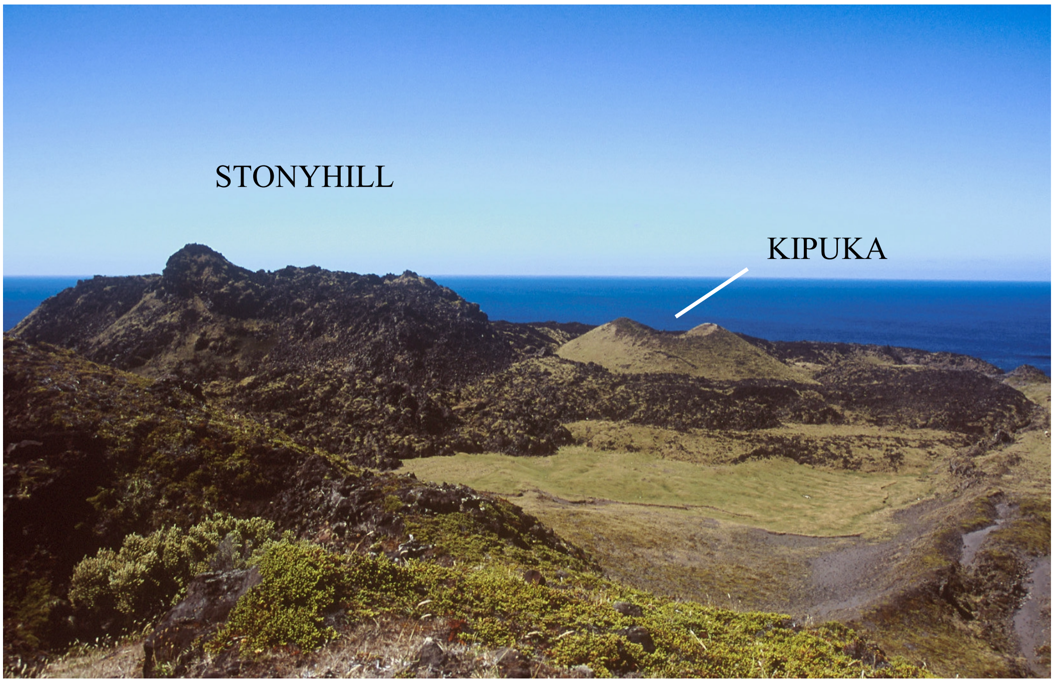

Plate 12 The tephritic scoria cone of Kipuka, surrounded by the young tephri-phonolite lava erupted from the tholoid of Stonyhill.

Plate 13 The 1961-62 eruption centre viewed from the Main Cliffs, looking towards the Settlement. The dome-tholoid complex (DT) was the source of the lava field (LF). The peripheral crater at the back of the dome was the site of largely phreatic explosive activity. Minor explosive activity occurred from the Central Cone (CC).

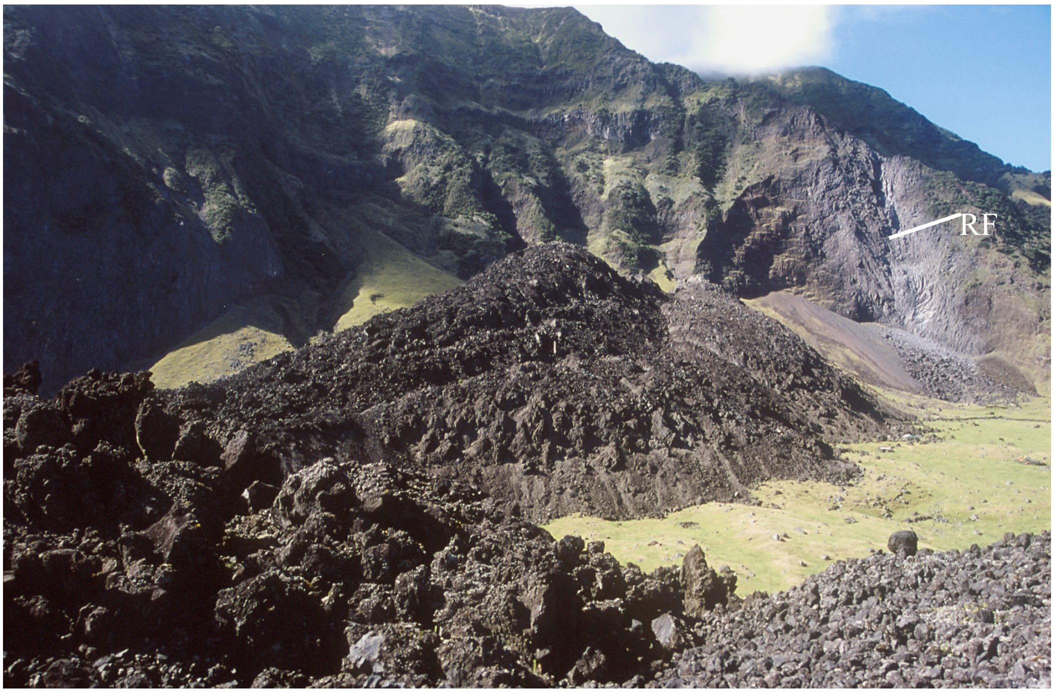

Plate 14 The dome-tholoid complex of the 1961-62 eruptive centre viewed from the lava flow (foreground). The area of rockfalls (RF) behind the Settlement can be seen.

Plate 15 Avalanche deposits forming a low ridge behind the Settlement. This is an ancient deposit which extends from the base of the Main Cliffs to the south-easterly corner of the Settlement.

Plate 16 & 17 The site of the rockfalls in the cliffs behind the Settlement. Most of the fallen debris has accumulated at the base of the cliff, although during the 1961 volcanic tremor, a few large blocks rolled down the slope. The source of the rockfalls is a well-jointed intrusive volcanic plug of tephrite exposed in the cliff (margins marked by dashed line). Plate 16 shows the low ridge formed of older avalanche deposits (AD) on which the water tank stands. The south-eastern corner of the Settlement is further to the right of the photograph.

8 Hazards

As a general premise to volcanic hazard assessment, it is anticipated that future activity on Tristan will be broadly similar in style to the past eruptions of the volcano. The assessment therefore concentrates on the hazards that would be posed by eruptions of the type that have occurred during the recent geological history of the island. An estimate of the probability of future eruptions is also made, based on the radiometric ages of the most recent eruptive events acquired during this study. In addition to primary volcanic hazards, the specific hazard of rockfalls is also assessed, as this posed a threat to the Settlement at the time of the last eruption.

8.1 PRIMARY VOLCANIC HAZARDS

This investigation has shown that the upper part of the volcano, now above sea level, has grown over the past 140,000 years; and that the last outpourings of lavas from the Peak occurred between about 35,000 and 20,000 years ago. Parasitic scoria cones and their eroded remnants occur around the Base and lower parts of the Peak, but the youngest of these (Big Green Hill) appears to be almost 11,000 years old. It would appear therefore, that huge volumes of material, principally lavas, were erupted on a regular basis between 140,000 years and 20,000 ago, but that very little has occurred subsequently. The complete lack of residual thermal manifestations on the Base and Peak, such as fumaroles and hot springs, also point to the main volcanic edifice itself having been in a long period of repose. It is tempting to conclude that the volcano may be passing into extinction, as it is carried away on the crustal plate from the underlying (stationary) mantle plume, which has been the root cause of the volcanism of the island (see Section 4).

With respect to hazards, it is important to note that the current investigation found no evidence for pyroclastic flow activity on the Peak, as suggested by Chevalier and Verwoerd (1987). All the activity appears to have consisted of the effusion of lavas, with localised explosive activity from parasitic scoria cones.

Volcanic activity in the recent geological past has been confined entirely to the coastal strips, where two distinct types of parasitic eruptions have occurred. The hazard assessment given in the following paragraphs will concentrate on these two styles of eruption, because they are the most likely form of activity to occur, in the event of a future eruption.

The most common type of activity has been that of explosive eruptions that have produced tephritic scoria cones, some of which have been accompanied by the eruption of small lava flows. These include the eruption of the Hillpiece - Burnt Hill scoria cone complex, and the hornitos and scoria mounds around the Patches. An eruption of this type within a few kilometres of the Settlement could be hazardous due to the deposition of ash and the ejection of volcanic bombs. Ash can cause the collapse of roofs through loading and corrosion, and even small amounts can damage mechanical and electrical equipment through abrasion and corrosion. It can also cause disruption to radio communications. In terms of health effects, ash causes respiratory problems, particularly in people who are predisposed to bronchial problems, such as asthma sufferers, who form a high proportion of the population of Tristan. Even thin dustings of ash on pasture can cause fluorinosis in sheep and cattle, which is often fatal. Thin ash has also been known to cause severe abrasion to the feet pads of sheep dogs, of which there are many on Tristan. The impact of falling bombs can cause severe damage and injury.

The other type of activity that should be considered with respect to hazards, is the extrusion of tephri-phonolitic lava domes or tholoids accompanied by the effusion of more extensive lava fields. The 1961-62 eruption was of this type, as was the penultimate eruption that produced the Stonyhill parasitic centre in the south of the island a few hundred years previously. Such lavas are unlikely to pose a direct threat to life and limb because they move very slowly, although they could destroy property, infrastructure, crops and pasture. Growth of a lava dome or tholoid near the Settlement, as happened in 1961-62, would pose a serious hazard. Dome eruptions can produce explosions, lateral blasts, hot avalanches and pyroclastic flows which are extremely hazardous; although the 1961-62 eruption was not accompanied by such phenomena, except for small explosions which did not eject bombs to any distance and left the Settlement unscathed.

A parasitic eruption of either type on the coastal strip near the Settlement would pose a hazard to the population. As a general guide it is suggested that an eruption in the sector bounded by Pigbite Gulch in the east and Big Sandy Gulch in the west would probably necessitate an evacuation. Parasitic eruptions elsewhere are unlikely to pose a direct hazard to the population, although if they were to occur on the Settlement between Hillpiece and Burntwood, or on the coastal strip between Seal Point and Stonyhill Point, they would deprive the population of important areas of cultivation and grazing. The sustainability of the population in the longer term would therefore be affected by such eruptions.

8.2 ESTIMATED PROBABILITY OF FUTURE ERUPTIONS

Based on radiometric dates obtained during the present investigation, it is possible to obtain broad estimates of the probability of a future eruption on the coastal strips. In Section 6.5 of this report, it was concluded that three parasitic eruptions have occurred on the Settlement coastal strip within the past 2775 years. Another four young parasitic eruptions have also occurred at Seal Bay Plateau and Stonyhill Point, probably over a similar time period, with the eruption of Stonyhill itself having occurred within the last few hundred years. On this evidence, it is considered that over the past three thousand years, the coastal strips have been affected by parasitic eruptions approximately every 400 years on average, the last being in 1961-62. It is therefore estimated roughly that there is a 25% probability of an eruption occurring on one or other of the two coastal strips during the next 100 years. Assuming an equal chance of an eruption occurring on the Settlement coastal strip and the southern strip around Seal Bay and Stonyhill Point, the probability of an eruption occurring in the next 100 years on the Settlement coastal strip is reduced to 12.5%; which is equivalent to a probability of 1 in 800 per year.

Some concern has been expressed by local inhabitants as to the state of activity of the 1961-62 eruptive centre (known as the *volcano* in local parlance). This concern appears to stem from the fact that the centre shows variable levels of fumarolic activity. In the writer's opinion, the fumarolic activity is very feeble and lacks any indication of the involvement of magmatic fluids (see section 7.6). If anything, the steam activity is considerably weaker than that normally seen around many young volcanic centres. It is concluded that the fumarolic activity is typical of that caused by the heating of meteoric water (infiltrating rain water) by residual heat within the old vent area, and as such should not be a cause for concern.

An eruption on the Peak or Base is considered to be highly unlikely. The volcano experienced voluminous outpourings of lava between about 140,000 and 20,000 years, but since then there has been little activity on the higher flanks (Base and Peak); other than sporadic eruptions of parasitic scoria cones, the last of which probably occurred almost 11,000 years ago. If, however, activity were to occur on the northwestern flanks of the Peak and Base, this could pose a hazard to the Settlement. In particular, the eruption of a scoria cone on the northwestern flank of the Base could threaten the Settlement and Patches area below with falling volcanic ejecta. Such an eruption anywhere on the Base is very unlikely, and is considered to have a probability lower than 1 in 10,000 per year (i.e. 1 eruption in 10,000 years). Furthermore, such an eruption would need to occur within a restricted sector, on the northwestern flank of the Base, for it to have direct effect on the Settlement. Assuming there is an equal chance of a parasitic eruption on any sector of the Base, then the probability of an eruption occurring within a 60° sector above the Settlement is reduced six-fold, and is therefore estimated to be less than 1 in 60,000 per year.

8.3 THE HAZARD OF ROCKFALLS AND LANDSLIDES AROUND THE SETTLEMENT

The very high cliffs around the entire island are prone to rockfalls, especially during periods of heavy rain. The hazard is likely to increase if there are ground tremors associated with volcanic activity, as happened in the precursor phase to the 1961-62 eruption.

Rockfalls from the cliffs behind the Settlement were triggered by ground tremors during the weeks preceding the 1961 eruption. The source of these rockfalls is an intrusive volcanic plug exposed in the cliffs about 200 metres SSE of the Settlement, situated immediately behind the spring that is the source of the water supply system. This is less than 200 metres from the 1961-62 eruption site. It is reported that substantial falls occurred during the strongest tremors, which were roughly equivalent to intensity 6 on the Modified Mercali Scale. Occasional rock falls still continue at this location to the present day. Photographs of the location are shown in plates 14, 16 and 17.

The volcanic plug consists of a vertical body approximately 45-50 m wide, intruded into a layered sequence of lavas. The plug is composed of a hard, finely crystalline, tephrite, which shows no signs of weathering or hydrothermal alteration. This is intruded into a stratified sequence consisting of layers of hard massive basanitic lava separated by red-brown oxidised autobreccias. The lavas dip very gently northwards at an angle of about 5-10°. Several basaltic dykes intrude the lavas on either side of the plug.

A large pile of fallen blocks has accumulated at the base of the cliffs immediately behind and encroaching upon the spring. Individual blocks are mostly of the order of a metre or two in size, ranging up to about 8 metres. The ground in front of the pile of blocks is occupied by pasture, which slopes at 5-10 degrees towards the NNE. The pile of fallen material extends outwards (northwards) from the base of the cliffs for a distance of 50-60 metres, although a few scattered blocks have rolled farther down the slope for distances of up to 120 metres, stopping some 90 metres short of the nearest dwelling. Most of these blocks fell during the precursor volcanic tremors in 1961: Prior to that time only a small steeply sloping fan of talus composed of small blocks and finer material is reported to have existed at the foot of the cliff, similar to the small talus fans that occur in many places around the island at the foot of the cliffs. Numerous recently fallen blocks were apparent at the time of assessment and fresh scars in the cliff indicated the locations from where they had fallen. These recently fallen blocks are substantially smaller than those that fell during the 1961 tremors, generally being a few tens of centimetres in size, but ranging up to about a metre. These have accumulated at the head of the boulder pile within 10-15 metres of the foot of the cliff. They show no evidence of having rolled any distance down slope.

The volcanic plug is a strongly jointed rock. Near vertical master joints run parallel with the margins of the plug and curve downwards and inwards towards the interior of the body. The curved joints in the interior also dip steeply northwards at 50-60°, so providing ideal slip planes for large slab-like blocks to slide forward and fall from the free-face of the cliff. Secondary joints that are apparently horizontal (or roughly so) intersect the vertical master joints, so dividing the rock body into rectilinear blocks, many of which are overhanging and therefore unsupported. The rectilinear jointing is reflected in the shape of the larger fallen blocks, many of which are roughly cuboid, whilst some larger ones are distinctly slab-like.

The Settlement itself is situated upon the alluvial fan that spreads out from the point where the ravine of Hottentot Gulch disgorges at the base of the cliffs. The area of rockfalls is located immediately to the east of the alluvial fan, and as a result of this position the Settlement is protected from falling rocks by a marked topographic bevel on the surface of the fan.

The ravine of Hottentot Gulch cuts obliquely eastwards into the cliffs behind the volcanic neck. As a result, the neck is actually located on a spur-like ridge extending down from the Main Cliffs. Smaller rockfalls are also beginning to take place from the volcanic neck off the backside of this ridge; but the material falls into the ravine of Hottentot Gulch and therefore poses no hazard to the Settlement.

The cliffs on either side of the area of rockfalls show no evidence of mass instability in the form of fractures or incipient ground movement along slip planes. Fractures or slip planes are not apparent on the surface of the Base immediately on top of the cliffs; neither do they occur in the ravine of Hottentot Gulch where it cuts into the cliffs behind the volcanic neck. The ravine provides excellent exposure so that if any such planes of weakness were present they should be evident.

A low hummocky ridge strewn with boulders extends NNE along the edge of the alluvial fan, from the base of the cliffs immediately to the most southeasterly house of the Settlement. This is interpreted as an old, small-scale avalanche deposit (Plate 15). The ridge is approximately 180 metres in length and is widest and highest near the cliffs, where it is approximately 60 metres wide and 7-8 metres high. Passing northwards, down the slope towards the Settlement, the ridge narrows and becomes lower. The header tank for the water supply system is situated on the highest part of the ridge near to the cliffs, and the most south-easterly house of the Settlement is built on the northern end of the ridge. This avalanche deposit was produced by a small-scale collapse of the cliffs at the same locality as the volcanic plug that is the source of the more recent rockfall activity.

It is concluded that the rockfalls from the cliffs behind the Settlement occur as a result of the piecemeal disintegration of the well-jointed volcanic plug, with blocks detaching themselves along joints and falling. Currently this occurs sporadically and produces relatively small blocks, which are accumulating close the foot of the cliff, and are therefore not hazardous to the Settlement. There were more intensive rockfalls associated with the 1961 volcanic tremors which produced much larger blocks, a few of which travelled down the slope from the foot of the cliffs for distances of up to 120 metres (although even the boulder which travelled farthest still stopped short of the settlement by about 90 metres). More intensive rockfalls of this kind could occur in the event of future precursor volcanic tremors, although based on previous experience these are likely to run down the slope to the NNE, whereas the Settlement is situated to the NNW and is shielded to some extent by the intervening topographic bevel of the alluvial fan on which the Settlement is situated.

As a final comment on the subject, it should be noted that the 1961-62 eruption occurred very close to the area of rockfalls. A future eruption elsewhere on the island (i.e. at a greater distance) is therefore unlikely to cause such large rockfalls in the vicinity of the Settlement. If, however, ground tremors associated with a future eruption were to cause an escalation in rockfall activity from the volcanic plug behind the Settlement, then, the hydraulic ram pump for the water supply system would be vulnerable, as would livestock and anyone attending them in the pasture immediately in front of the source of the rockfalls.

9 Evacuation plan

This plan provides recommendations to be followed in the event of a volcanic eruption that might necessitate an evacuation.

9.1 PRECURSOR ACTIVITY AND PREPARATIONS

The 1961-62 eruption was heralded by two months of ground tremors that were felt throughout the Settlement. It is therefore assumed that ground tremors would give forewarning of a future eruption near the Settlement. If the island were to be monitored by a seismic network, then precursor activity would be detected before tremors were felt by the population, so providing a longer warning period and possibly an indication of the location where an impending eruption might occur.

The plan assumes that the island will be monitored seismically, as recommended in Section 10, and that escalating seismic activity would therefore be detected well in advance of tremors being felt by the population.

In the event of increased seismic activity the following procedures are recommended:

- The organisation in charge of monitoring seismicity should inform the Foreign and Commonwealth Office (FCO) of the increased seismic activity.
- The Administrator on Tristan da Cunha should be advised by the FCO, who in turn should inform the Chief Islander and Chief of Police. An escalation in seismic activity may not necessarily lead to an eruption. It is therefore recommended that initial seismic activity should not be disclosed to the population at large, so as to avoid unnecessary alarm and panic.
- Should the seismic crisis continue and an eruption be considered possible, a volcanologist should be dispatched to the island by the earliest possible means. Given the remoteness of the island and infrequency of shipping it is important that volcanological expertise be on hand to provide first hand advice. At this stage the general population should be informed of the situation, if they have not already been alerted by ground tremors.
- Provisional arrangements for shipping should be made by the FCO during the precursor phase of activity, in case an evacuation should become necessary.
- In the event of an eruption, the decision to evacuate should be made by the Administrator in consensus with the Island Council, with scientific advice being provided by a volcanologist.
- In the event of an evacuation, a decision should also be made as to whether a skeleton crew remains on island in a care-taking capacity. The purpose of such a crew would be to tend livestock and maintain a presence in order to ward off looters or intruders (which were a problem when the island was evacuated in 1961). Local support would also be needed if volcanological observers were to remain on the island to monitor events. Discussions held with the Administrator and other key officials indicate that a group of about 20 able bodied men should ideally remain on the island in this care-taking capacity.

9.2 EVACUATION PROCEDURES

The population should be evacuated if an eruption directly threatens the Settlement.

Shipping with a capacity to carry 300 passengers would be required to evacuate the island. The destination of the evacuated population is not considered in this report, although presumably the first port of call would be Cape Town, which depending on the ship and sea conditions would take about a week to reach.

People should ideally be ferried to awaiting ships directly from the Settlement, either from the existing harbour or the proposed new harbour.

There are no harbour facilities for ocean-going ships at Tristan. In the event of an evacuation, the population would need to be ferried out to rescue ships in small craft and board via rope ladders or boarding nets. The whole exercise would therefore be very dependent on sea conditions. Launching boats under relatively calm conditions from the harbour is routine, but it is possible (if not statistically probable) that evacuation could be hampered and delayed due to rough seas, particularly during the winter months. Ships may therefore be required to standby for considerable periods before conditions would allow the population to be taken off the island.

Given that rough seas are the norm rather than exception around Tristan, it would be preferable if ships sent to evacuate the island were equipped with a helicopter of suitable capacity. This would give extra flexibility and assurance to rescue operations and would be of considerable assistance for the embarkation of old and infirm people.

Should an eruption directly threaten the Settlement before the arrival of shipping, the population should move to the Patches area in the first instance to await evacuation off the island. Whilst a large proportion of the population could be accommodated in the huts at the Patches, there would be a requirement for tented accommodation, including several large tents for communal use. Fuel, food, mattresses, blankets, medical supplies and communications equipment would need to be moved from the Settlement also.

If the population were moved to the Patches in the first instance, or if the harbour were no longer accessible, boats could be launched from the Bluff at Burntwood. These could be towed to the beach along a motor track, although a bulldozer would be required to flatten out the cobbles on the beach to facilitate launching. Currently however, there are no suitable boats on the island that could be launched from this location and which have sufficient capacity to ferry large numbers of people to awaiting ships. Discussions with islanders experienced in search and rescue and conversant with local sea conditions indicate that the best craft for such work would be inflatable boats with fibre-glass hulls, capable of carrying about 12 passengers. Several craft of this type would be required.

9.3 TELECOMMUNICATIONS

The island maintains good telecommunications with the outside world and passing ships by a number of different methods, including HF radios and three satellite telephones which are maintained and operated by two experienced telecommunication technicians. There are also a considerable number of portable VHF radios on island, which offer line-of-sight communication. Communication in the event of an emergency should therefore not be a problem.

If the population were to be moved to the Patches or elsewhere to await further evacuation, it would be necessary to set-up a temporary communications centre. The satellite telephones and many of the radios are portable and are powered by batteries. A temporary communications centre could therefore be organised using existing equipment, although there would be a need for portable generators with a supply of fuel to recharge batteries.

9.4 POPULATION PROFILE AND MEDICAL CONSIDERATIONS

At the time of the writer’s visit to the island in 2001, the population of Tristan was 284, of which 134 were male and 150 female. In addition there were 11 expatriates, 3 of whom were children.

Of the Tristanian population there were 67 pensioners over the age of 65 years, 29 school children between the ages of 4 to 15 years, and 10 infants under the age of 4 years.

In discussion with Dr Pieter Du Toit, the medical physician on the island at the time, a list was compiled of old people who would need assistance in the event of an evacuation, and of others with medical problems who might need extra vigilance. A plan of the settlement was also drafted and the houses in which these people reside were marked. The detailed list and plan of the settlement were retained on Tristan. Although such details will change with time, the list serves to illustrate the proportion of the population which is more vulnerable and which would need extra care during an evacuation. In early 2001 there was one lady who was housebound and 11 others (7 women and 4 men) who would need assistance to be moved. In addition, there were 13 other people suffering from medical conditions, who might need extra care in a crisis situation.

The medical officer on island should maintain a comprehensive medical kit in readiness for an evacuation. Sufficient stocks of medicines for people with specific medical conditions should also be assembled prior to an evacuation.

A stock of facemasks should also be retained for use in case of suspended ash in the atmosphere. Asthma sufferers, which include about a third of the population of Tristan, would be particularly vulnerable to ashy conditions. In the absence of masks, damp cloths should be worn over the nose and mouth under ashy conditions.

9.5 MISCELLANEOUS CONSIDERATIONS

Many households have dogs, which could not be evacuated. A decision would therefore need to be made as to whether they should be culled in the event of an evacuation. They should not be left to roam, since in the absence of food they would soon resort to killing island's livestock. Alternatively, some dogs could be spared if a skeleton crew were to remain on island.

A decision would need to be made prior to the implementation of an evacuation as to the amount of personal belongings that evacuees could take with them. This would depend upon the capacity of ships involved in the evacuation, and on other factors such as sea conditions and the speed with which the evacuation needs to be undertaken.

9.6 REQUIREMENT FOR ADDITIONAL EQUIPMENT

In order to maintain flexibility during a volcanic crisis it is recommended that additional equipment be procured. In particular this would be required if the population had to be evacuated to the Patches in the first instance. In addition, suitable boats would be required to ferry people should the harbour not be accessible or sea conditions require evacuation from an alternative landing site. The following equipment is recommended:

- Three inflatable fibreglass hulled inshore rescue boats with the capacity to carry 12 passengers each, supplied with suitable outboard motors.
- Fifteen family-size tents.
- Three large communal tents (mess tents etc).
- Three portable petrol generators.
- Additional water bowsers.
- A supply of drums and jerry cans for transporting fuel.

10 Recommendations for seismic monitoring

Almost every volcanic process is characterised by seismic signals that can be used to gain diagnostic information on the level of activity. The 1961-62 eruption on Tristan was typical in this respect and was preceded by two months of ground tremors that were felt by the population. The ground tremors would undoubtedly have been preceded by a more prolonged period of weaker and deeper seismic activity, that could not be felt, but would have been detectable had the island been monitored by seismometers.

Seismic monitoring of Tristan is therefore strongly recommended, in order to maximise the warning time of an impending eruption, so allowing preparedness measures to be implemented at the earliest stage possible.

Plans are currently being made under the auspices the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty Organisation (CTBTO), for an international monitoring station to be installed on Tristan for the detection of seismic waves coming into the island, through the surrounding seas. Such a station is a requirement of the treaty and it will be built. At the present time, however, there is no agreement on open access to data collected by such a station, and there is not likely to be instantaneous access, which would be required for volcanic monitoring when precursory seismic crises occur.

Seismic data from the IMS station will not be available locally, but will be transmitted via a satellite link to the International Data Centre (IDC) in Vienna. It will be protected from any possibility of tampering to meet the requirements of the treaty.

Despite the need for the IMS station to remain independent, there are considerable benefits that could accrue to a volcano monitoring seismic network on the island. These include:

- The establishment of a robust satellite communications link, probably with spare capacity for hire.
- Continuous mains power will become available
- Cable routes may be shared
- First-line maintenance capability through training islanders is likely
- If more than one station were established by the IMS (two or three are possible), then additional sharing of cable routes, radio masts and transport provisions for maintenance should be possible.
- Sharing of a central laboratory facility in the Settlement for collection, recording and onward transmission of data should be possible.

At this stage it is not possible to make detailed plans. However, it is recommended that 5 radio-linked monitoring stations be established around the island with a sixth on Nightingale Island, should this prove to be feasible. Such a network would have modest redundancy to allow for station downtime in relation to the detection of seismic precursors. It would not, however, provide redundancy for the accurate location of the sources of seismic activity. For ease of access and maintenance, a less extensive network, containing fewer stations on the Settlement side of the island could be considered. This would also be cheaper to install and maintain, but would not provide data sufficient for location of the sources of seismic events; although it would be sufficient to provide warning of volcanic unrest prior to an eruption.

For logistical purposes, it is proposed that the data collection and recording centre be established in the Settlement and that the data be transmitted there, by radio, from the outstations. Radio repeater stations would be required to achieve this. Onward transmission of data by satellite is recommended so that diagnostics on equipment performance, data analysis and software upgrades, can be performed remotely by experienced seismologists. In parallel, a local data analysis capability (including training) could be implemented.

Based on the logistics researched during the course of fieldwork, preliminary locations for seismic stations and radio repeater sites are recommended as follows: Three-component sensors should be installed near the Settlement and Round Hill. The other 4 stations, at Big Green Hill, Stone Castle, Sandy Point and Nightingale should be equipped with a single, vertical component sensor, which is cheaper and easier to maintain. At least two repeater stations are required to relay signals from the opposite sides of the island to the data collection centre at the Settlement. The proposed sites for these are at Franks Hill and Round Hill. The latter is also one of the proposed seismometer sites. Radio reception will need to be checked at these sites in the field prior to implementing such a plan. Batteries charged by solar panels would power Field stations.

A minimum level of spares should be held on Tristan to cover one 3-component station, one vertical component station, and one radio repeater station. These would need to be augmented as rapidly as possible following the onset of local seismic activity and, possibly, following the first year of operation when the impact of bad weather on the system has been tested. A spare data logger is also recommended for the base station.

The budgetary costs of the system proposed above are given below, at 2001 prices. These costs are for equipment only and do not take into account the costs of installation, long-term maintenance and data interpretation.

Equipment Costs for 6 station seismic network on Tristan Da Cuhna.

Item	**Number**	**Item cost (£k)**	**Sum Cost (£k)**
Three component seismometer	2	4	8
Single component seismometer	4	1.4	5.6
Digitizer	6	2.6	15.6
Radio RX/TX pairs	8	1.7	13.6
Line monitor units	6	1	6
Field station hardware (solar panels, batteries, antennae, mountings etc)	8	2	16
Seismic data logger	1	10	10
GPS clock	1	6	6
220V UPS	1	1.5	1.5
Seismic analysis facility	1	5	5
Total			**87.3**

Recommended spare equipment.

Item	**Number**	**Item cost (£k)**	**Sum Cost (£k)**
Three component seismometer	1	4	4
Single component seismometer	1	1.4	1.4
Digitizer	2	2.6	5.2
Radio RX/TX pairs	3	1.7	5.1
Line monitor units	1	1	1
Field station hardware (solar panels, batteries, antennae, mountings etc)	2	1.5	3
Seismic data logger	1	10	10
Total			**29.7**

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Appendix 1 The Geology of Tristan

The geology and volcanic evolution of Tristan is best described under the headings of the main physiographic units, namely the Main Cliffs, the Base and Peak, and the Coastal Strips. In addition, brief sections are included on intrusions, residual thermal activity and large-scale sector collapses that have produced major submarine avalanches.

1 The Main Cliffs

The oldest exposed rocks on Tristan are a thick sequence of basic lavas and scoriaceous deposits which outcrop everywhere around the island in the Main Cliffs. These range in composition from highly porphyritic ankaramitic basanites through to sparsely porphyritic and aphyric tephrites, although basanites and tephrites predominate.

The sequence consists mainly of massive and columnar jointed, grey lavas separated by red-brown scoriaceous fragmental layers, most of which represent the autobrecciated tops of lava flows. The overall appearance is one of a well-layered sequence which is apparently horizontal; although the strata are actually broadly parallel with the surface of the Base and dip radially seaward at a low angle. Baker *et al.* (1964) consider these lavas to have been erupted from a central vent and to have formed a broad, low-angle shield volcano.

Individual lava flows range from about a metre to more than 10 metres in thickness and can normally be traced laterally in the cliffs for several hundreds of metres, and in some examples for more than a kilometre. Some flows are much less extensive, and local thickening in channels is common. The fragmental layers intercalated between the lavas consist of oxidised, red-brown, highly vesicular, agglutinated autoclastic breccias which contain fragments of ropy lava and in places preserve the remnants of broken pahoehoe surfaces.

The lava sequence is replaced locally by thick scoria deposits. These are interpreted as the remnants of parasitic scoria cones that erupted from time to time on the flanks of the volcano as the main lava pile built up. In cross-section they consist of prisms and irregular masses of oxidised scoria, which vary from being lithified to poorly consolidated, and from being internally massive to well-stratified. Stratification can dip in any direction, depending on the orientation of the section with respect to the original parasitic cone. The deposits of these parasitic centres thin away from their source vents and become conformable with the lavas with which they are intercalated.

A distinctive sequence of rocks outcrops in the base of the cliffs a short distance east of the Settlement, on the east side of the alluvial fan of Hottentot Gulch (UTM 738798 5893747). Here the lavas of the cliffs are underlain by a subaqueously deposited sequence of volcaniclastic rocks approximately 20 metres thick. Creamy white tuffaceous and pumiceous deposits occur in the lower part of the sequence and can be traced for almost a kilometre southeastwards along the base of the cliffs. These include a sedimentary melange up to 12 metres thick composed of coarse clasts of white tuffaceous sandstones, siltstones and fine-ash tuff, supported in a tuffaceous matrix. This is overlain by white pumice deposits containing altered tubular pumice lapilli. The upper part of this volcaniclastic packet includes tuffaceous sandstones and siltstones, mass-flow breccias and palagonitised scoria deposits, displaying proximal turbidite facies. This volcaniclastic sequence is volumetrically insignificant compared with the lavas of the cliffs, but it bears testimony to the occurrence of subaqueous conditions in what otherwise appears to have been a subaerial lava pile; and more significantly, from a volcanological point of view, indicates the occurrence of limited explosive volcanism of silicic composition.

McDougall and Ollier (1982) measured whole-rock potassium-argon (K/Ar) radiometric ages on several samples from the Main Cliffs behind the Settlement. These gave ages in the range 150±10 Ka to 110±30 Ka (Ka signifies a thousand years). During the course of the present study, the ages of several samples were measured by the more precise step-heating argon-argon (Ar/Ar) technique. Samples from the cliffs at Pigbite, a short distance to the east of the Settlement, gave ages of 141±8 ka for a lava at the base of the section (sample PDTDC17), and 80±7 ka for approximately 400 metres (two thirds of the height) up the cliffs (PDTDC40). Further constraints are placed on the age of the lavas exposed in the Main Cliffs by an Ar/Ar age of a well-featured lava covering the surface of the Base immediately at the top of the Pigbite section. This sample (PDTDC49) yielded an age of 49±7 Ka. In Section 3.2 of the report it was indicated that the dates obtained by McDougal and Ollier using the conventional whole-rock K/Ar method are likely to too old. It is therefore concluded here, on the basis of the Ar/Ar dates acquired by the present study only, that the age of the lavas exposed in the Main Cliffs, at least in the Pigbite area, range from about 140 ka at the base, to about 50 ka at the top.

2 The Base and Peak

The Base and Peak are composed of lavas with intercalated autobreccias and scoria deposits which dip radially seaward at similar angles to the surface topography, decreasing gradually from about 30º on the upper slopes to about 10º or less where the flanks are truncated by the main sea cliffs.

The lavas are mainly tephritic in composition, although rare flows of tephri-phonolite and phonolite also occur. The majority are fine-grained aphyric and sparsely microporphyritic rocks.

The interpretation of aerial photographs and follow-up confirmation in the field indicate that the flanks of the Base and Peak are covered by extensive lava fields, which despite their almost completely vegetated state still preserve original morphological features, such as flow-fronts, levees and in some cases concentric pressure ridges or ogives. Relatively young flows probably cover all the flanks of the Base and Peak; although their presence in the northeastern sector is unproven, due to cloud cover on the aerial photographs and because this part of the island was not visited during the assessment. Individual flows with prominent levees can be traced as long narrow features, extending from high on the flanks of the Peak across the Base to the edge of the Main Cliffs. These linear flows control the courses of many of the gulches. The longest are up to 4 km in length, which is contrary to the Royal Society expedition report (Baker *et al.*, 1964), which stated that lavas exposed on the Base could not be traced for more than a quarter of a mile (400 m). The morphology of these young lavas on the surface of the Base and Peak suggest that they were relatively fluid when erupted.

The well-preserved flow features suggest that the lava fields on the flanks of the Peak and Base are relatively young. McDougall and Ollier obtained a K/Ar age of 30±0.30 ka (sample T12) on one such lava from Gypsy Gulch on the south-western flank of the Base. They also report a K/Ar age of 20 ka for a dyke intruded into the sequence near the summit of the Peak (at 1980 m.), although no precision was quoted for the measurement. Five additional Ar/Ar ages have been obtained from these relatively young lava fields during the present study. Tephrite flows forming a lava field low on the northern edge of the Base have yielded an age of 49±7 ka. Well-featured tephrite lavas on the western flanks of the Peak have yielded ages of 31±4 ka and 24±7 ka and one of the highest flows on the northwest flanks of the Peak produced an age of 22±8 ka. An age of 33±7 ka was obtained from a tephrite lava erupted from high on the eastern flank of the Peak.

Numerous parasitic scoria cones, or their degraded remnants, occur around the Base and lower flanks of the Peak. In addition, a large scoria cone with a well-developed crater occupies the summit of the Peak. These parasitic centres vary in age and state of erosion, although all are heavily vegetated except for the summit cone. Most have craters in various states of preservation, many of which are breached on their down-slope or seaward side. Lava flows have been erupted from many of the cones, either through breaches in crater rims or lower on the flanks. The oldest parasitic centres preserve few original morphological features and consist of degraded piles of scoria in various states of burial by younger lavas. There are other examples which appear to post-date the younger lavas of the flanks, such as Red Hill, Big Green Hill and Little Green Hill. A radiocarbon age of 10770±156 years B.P. (before present) was obtained by Baker et al. (1964) from soil immediately overlain by the scoria deposits of Big Green Hill. From this it was suggested that this relatively young-looking scoria cone probably had an age of about 10000 years.

Several maar-like craters occur. The three Ponds, situated on the NNE flank, are good examples. These consist of deep, cylinder-shaped craters, which are occupied by lakes and surrounded by slightly raised, low-angle cones of debris. Although the material of the cones is very poorly exposed, it appears to consist of lithic breccias. Given their NNE-trending alignment, it is most probable that the craters formed as a result of phreatic explosive activity, produced when a radial dyke was intruded into the volcano and intersected the water-table close to the surface.

The crater of the summit scoria cone is also occupied by a lake. The cone itself is a large structure, approximately a kilometre in diameter, with a large crater approximately half a kilometre across from rim to rim and about 50-60 metres deep. The rim of the crater is composed of beds of poorly consolidated and agglutinated scoria, which dip radially away at low angles. These deposits are not very thick and appear to be largely missing from the southern rim of the crater. The crater itself has steep sides, except in the south, and is incised in older, massive lavas. In most respects the structure is more akin to a maar than a scoria cone. It was probably blasted through pre-existing rocks by phreatic or phreatomagmatic activity, with a final stage of magmatic explosive activity producing the scoria ramparts around the rim of the structure.

Baker *et al.* (1964) maintained that the proportion of pyroclastic material increased relative to lava in the higher parts of the volcanic pile. They estimated that pyroclastic rocks accounted for approximately 25% of the succession on the lower parts of the Base, but increased to as much as 75% on the upper parts of the Peak. Observations made during the present assessment suggest that the proportion of pyroclastic material may have been over-exaggerated. From the present investigation, the Base and Peak are considered to be primarily composed of lavas and intercalated autobreccias. Scoria deposits are intercalated within the succession locally and were produced from the parasitic cones, which are scattered around the Base and lower flanks of the Peak. The higher flanks of the Peak expose frost-shattered lavas separated by areas of unconsolidated sandy and gravely solifluction deposits. It is possibly Baker *et al*. mistook these solifluction deposits for pyroclastic material, so overestimating the importance of the latter on the flanks of the Peak.

Chevalier and Verwoerd (1987) describe pyroclastic flow deposits from the Peak, which they believed were formed by the collapse of eruption fountains produced by explosive activity. Their descriptions of these deposits are scant and vague. If such activity were to have taken place, this would have serious implications for the assessment of hazards. Particular attention was therefore paid to this point during the present study, but no deposits of this type were recognised, not even in the area where Chevalier and Verwoerd reported their presence. It is therefore concluded that the descriptions of Chevalier and Verwoerd are erroneous and misleading. No evidence whatsoever was seen during the present study for pyroclastic flow activity.

3 The Coastal Strips

The two main coastal strips, situated around the Settlement, and the area around Cave Point and Stoney Hill Point are of similar structure. The third coastal strip at Sandy Point is little more than a narrow sandspit backed by cliffs and will not be dealt with further in this description.

3.1 SETTLEMENT COASTAL STRIP

The Settlement coastal strip is backed on the landward side by the Main Cliffs, which are generally between 600 and 800 metres high. In plan, the cliffs themselves define two broadly arcuate areas in which the coastal strip nestles. In effect the strip is almost separated into two sub-areas, joined by a narrow coastal strip around Little Sandy Gulch. The largest area is centred on the Patches and extends from Burntwood in the south and Little Sandy Gulch in the north. A smaller extends north and west of this, from Little Sandy Gulch to Pigbite, and includes the area of the Settlement itself.

The arcuate areas defined by the Main Cliffs are interpreted as landslip scars, formed during a major sector collapse of the volcano's flanks, as described in section 4 of this appendix. Subsequent to the collapse, the Settlement coastal strip was constructed within the scar of the landslip.

The seaward edge of the is bounded by relatively low sea cliffs, mostly less than 15-20 metres high, but locally reaching about 50 metres in the area around Hillpiece

The Settlement coastal strip is made up of a basement sequence of horizontal lavas, overlain by alluvial and colluvial fan deposits. A number of relatively young parasitic volcanic centres are superimposed on the ., including the lava dome and flows of the 1961-62 eruption. In addition, rockfall and avalanche deposits occur near the Settlement. The geology of the Settlement coastal strip is therefore described under the following headings:

Basement lavas

Alluvial – colluvial fan deposits

Parasitic volcanic centres

Rockfall and avalanche deposits

Basement lavas of the Settlement coastal strip

The lavas forming the basement of the are exposed along the sea cliffs and the intertidal zone of the foreshore. They consist of fine grained aphyric to sparsely microporphyritic tephrites, which exhibit two contrasting modes of occurrence. In the intertidal zone they take the form of pillow lavas. These are well-displayed, for example, around the harbour and on the foreshore of Runaway Beach. They exhibit classic tubular pillows, with branching and budding structures, and concentrically arranged vesicles elongated in the direction of flow. Pillow margins and interpillow areas display hackle jointing and brecciation typical of hyaloclastites.

The pillow lavas are overlain by lavas with features typical of subaerial extrusion. These are horizontally stratified, massive and columnar jointed flows that form the sea cliffs. Individual flows range from about 5 to 15 metres in thickness and can be traced laterally in the cliffs over distances of several kilometres. They are sparsely vesicular, exhibit flow-banding and flow-folding, and have oxidised scoriaceous zones between flows. No more than three or four flows were recognised within the subaerial pile exposed along the entire coastline. The transition from pillow lavas to massive subaerial lavas appears to be abrupt and coincides with the present-day high-water line. This implies that the sea level has not changed significantly since eruption of the lavas; unless there have been fluctuations and the current sea level now fortuitously coincides with the transition from submarine pillow lavas to subaerial lavas. The topmost lava of the sequence, where it is exposed at the mouth of Hottentot Gulch, yielded an Ar/Ar radiometric age of 30±6 ka (sample PDTDC53).

Alluvial-colluvial fan deposits

The Settlement coastal strip is almost everywhere covered by colluvial and alluvial deposits. These have been deposited in a series of coalesced fans, formed where streams draining the Peak and Base deposit their sediment loads at the mouths of gulches as they disgorge onto the . The deposits consists mainly of very coarse, poorly sorted boulder conglomerates, with intercalations of coarse gravels and sands. Locally, seams of fine sand, silt, clay and peat testify to ponding of water. Beds of scoria also occur within these deposits, usually at or near the base of the alluvial fans. A sample (PDTDC54) taken from a seam of peat near the base of the alluvial fan deposits, where they rest on the basement of lava near the mouth of Hottentot Gulch, yielded a radiocarbon age of 2411±48 years B.P.

Parasitic volcanic centres

Young parasitic volcanic centres, including scoria cones and lava flows, occur on the Settlement coastal strip. These include: the Hillpiece – Burnthill complex of scoria cones; a series of scoria mounds and hornitos at the Patches; and most notable of all, the 1961-62 dome and lava flow immediately to the east of the Settlement.

The Hillpiece – Burnthill complex consists of a cluster of scoria cones and craters in various states of preservation. The large cones of Hillpiece and Burnthill are thought to be the oldest, as they are relatively degraded compared with others in the complex. Hillpiece has been eroded by the sea, and in the cliffs on the seaward side there is a marked angular discordance in the sequence. Dark red-brown to black scoria deposits of the cone rest with strong angular discordance on older yellow coloured deposits. It was not possible to examine these lower deposits, but from their ochreous colour and bedforms (examined with binoculars) they appear to be palagonitised deposits, possibly representing the remnants of a tuff cone formed by a pheatomagmatic eruption in shallow water.

A small cone with a well-preserved crater is superimposed on the south side of the Hillpiece – Burnthill complex. In terms of superposition and preservation, this cone is the youngest of the complex. The southern flank of this youngest cone is cut by Sandy Gulch. This exposes scoria deposits and lavas from the cone, overlain by scoriaceous gravels, sands, silts and clays, including varved deposits considered to be lacustrine in origin. A clayey peat band occurs at the base of the sediments and rests directly on the scoria of the cone. A sample of peat (PDTDC33) has yielded a radiocarbon age of 2775±47 years BP (before present). This places an age limit on the last eruptive event of the Hillpiece-Burnthill complex.

Scoria mounds and hornitos occur in the Patches area. These take the form of small, steep-sided cones and mounds that are partially buried by younger fluvial and fluvio-lacustrine deposit. Down-slope, on the seaward side of the scoria mounds and hornitos, the surface is covered by clastic lavas with small tumuli, which extend to the cliffs edge. These surface lavas rest directly on the massive lavas exposed in the sea cliffs. The scoria mounds and hornitos are composed of apparently structureless, unconsolidated scoria, with rare zones of agglutinated scoria. Rare spindle bombs are found within the hornitos. The hornitos and scoria mounds are interpreted as having two possible origins. Some may have formed over the source vents from which the associated lavas were erupted; although most probably represent rootless vents formed by explosive activity when the lavas flowed over wet ground.

The youngest deposits in the Patches area surround and partly bury the scoria mounds and hornitos. They consist mainly of scoriaceous gravels overlain by soil. One section exposed in a small drainage channel exposes laminated clays at the base of the gravels, which appear to have accumulated in a small lacustrine basin between two scoria mounds. At the base of these clays, a thin peat rests directly on the deposits of the scoria mounds. A sample of the peat, PDTDC32, yielded a radiocarbon age of 1624±45 years BP. This appears to have been deposited immediately after the formation of the scoria mounds, and thus provides an upper age for the eruption that produced the scoria mounds and hornitos of the Patches area.

The youngest parasitic centre on the Settlement coastal strip is that of the 1961-62 eruption. This consists of a tephri-phonolite dome-tholoid complex, approximately 145 metres high, from which a lava field was extruded in three different lobes. A more detailed description of the 1961-62 eruption is given in Section 7 of the report.

Rockfall and avalanche deposits

A steep pile of large boulders has accumulated at the base of the Main Cliffs, near the water tank behind the Settlement. The boulders have accumulated as a result of piece-meal falls from a well-jointed intrusive plug of tephrite. Minor rockfalls occur sporadically at the present time, but the majority of the boulders accumulated during the precursor tremors prior to the 1961-62 eruption.

The water tank is located on a low hummocky ridge strewn with boulders, which extends northwards from the base of the cliffs as far as the most south-easterly house in the Settlement. The ridge is approximately 180 metres in length and is widest and highest near the base of the cliffs, where it is approximately 60 metres wide and 7-8 metres high. Passing down the slope towards the Settlement, the ridge narrows and becomes lower. The water tank is situated on the highest part of the ridge near the base of the cliffs, and the most southeasterly house of the Settlement is built on the northern end of the ridge.

The ridge appears to be a relatively old feature, being almost completely covered in pasture, although it post-dates the alluvial fan on which the Settlement is built. The deposits of the ridge are exposed in a few places near the water tank and consist of weakly consolidated, poorly sorted debris, containing a high proportion of reddened vesicular lava clasts similar to the scoriaceous breccias exposed in the cliff adjacent to the intrusive plug. The nature of these deposits and the hummocky form of the ridge are typical of debris avalanche deposits. The lower part of the cliffs at this locality has a scalloped-shaped indent or scar, consistent with the avalanche having collapsed from this sector.

3.2 SEAL BAY PLATEAU AND STONYHILL POINT

The coastal strips around Seal Bay Plateau and Stonyhill Point appear to have originally been one, but have been virtually separated into two areas by marine erosion, producing the embayments of Seal Bay and Deadman's Bay. Both areas have similar structure, consisting of flat-lying lavas, which are exposed in low sea cliffs, overlain by colluvial fan deposits. The surfaces of the fans are gently inclined near the coast, but steepen inland towards their apexes where they bank-up against the Main Cliffs. Several young scoria cones and lava flows are superimposed on the surface of the coastal .

Much of Seal Bay Plateau is covered by a lava flow, which was erupted from the breached scoria cone of Hackel Hill. This flow is sparsely vegetated and is well-exposed around Cave Point. Here it consists of a very fine-grained, almost black, highly vesicular tephrite with a rubbley-scoriaceous upper surface. Based on its well-preserved morphology, this is considered to be a young flow in geological terms.

Three very young eruptive centres and associated lava flows occur around Stony Hill. The oldest of these is a small scoria cone, which is unnamed on the map, but was christened Kipuka Hill by the Royal Society Expedition. A sparsely vegetated tephrite lava flow, with well-preserved flow features occurs to the south. This was erupted from a breach at the base of the southern flank of the cone.

To the north is another small scoria cone, named locally as the Hill-with-the-hole-in. This has a well-preserved crater, in the base of which a deep cylindrical vent a metre or two in diameter is still open. Based on its state of preservation and the fact that the vent is still open, this is clearly a very young cone. A tephrite lava flow extends southwards from a breach on the southern flank of this cone. This lava post-dates the flow erupted from Kipuka, thus testifying to the relative ages of the two eruptive centres.

The lava from the Hill-with-a-hole-in, is post-dated by the tephri-phonolite lava of Stony Hill. This has the form of a tholoid, surrounded by more extensive flows of low aspect-ratio. In many respects, both in morphology and composition, the Stony Hill centre resembles the 1961-62 eruptive centre of the Settlement area. The hill itself is composed of very blocky lava cut by numerous large fissures. A small lava spine occurs on the summit. The pristine morphology of the lava, lack of weathering and the very sparse vegetation, indicate a very young age. The Royal Society expedition suggested that it was erupted about 200 to 300 years ago. Although this is a subjective estimate, for which there is no firm evidence, it is obvious from the state of preservation that the eruption of Stony Hill must have occurred recently, and that it was almost certainly the penultimate eruption on the island.

4 The sector collapse in the Settlement area

Holcomb and Searle (1991) examined sidescan sonar images (Gloria) of the seafloor surrounding Tristan and recognised a large-scale submarine avalanche extending northwest from the island. The sonographs depict a broad area, 40 kilometres across, with a distinctively speckled appearance, characterised by small patches of sonar backscatter. This is of similar appearance and scale to sonographs of large-scale submarine debris slides that have been studied around the Hawaiian islands. Individual speckles on the sonographs are inferred to represent hillocks on the surface of the avalanche deposit, of the order of 10's of metres in width. The deposit covers an area about 40 km across. The isobaths also shows the form of the debris slide and indicate that the deposit is about 100 metres thick. On this basis Holcombe and Searle estimated that the avalanche deposit has a volume of about 150 cubic kilometres.

The submarine slide deposit has a broad fan shape, the apex of which extends back to the Settlement coastal strip. The Main Cliffs backing the Settlement area are broadly concave and arcuate in plan, consistent with them representing the headwall of the avalanche. Here the cliffs reach their highest, of more than 800 metres. The cliffs, shown in Plate 8 are very similar in appearance to the headwall scars of large-scale avalanches seen on the Hawaiian islands. Holcombe and Searle suggested that the Settlement coastal strip probably accumulated as a lava delta within the landslide scar, partly filling it. Observations made during the present survey are wholly consistent with this explanation.

The age of this avalanche event is uncertain. The Ar/Ar radiometric date of 30±6 ka for the youngest lava forming the basement of the Settlement coastal strip , places an upper age on the accumulation of lavas in the landslide scar. However, the peat seam near the base of the alluvial deposits at the mouth of Hottentot Gulch rests on the scoriaceous top of this lava and has yielded an age of only 2411±48 years B.P. On the assumption that there has been no intervening erosion, this date would suggest that construction of the within the landslide scar may have been much younger. The transition from submarine pillow lavas to subaerial lavas in the basement lavas of the , coincides approximately with the present day highwater line; which suggests that the lavas were erupted when the sea level was approximately at its present level, and therefore in post-glacial times.

5 Intrusive dykes and volcanic plugs

Numerous dykes and less commonly plugs intrude the volcano. These are compositionally similar to the lavas. Most of the dykes belong to a radial swarm, centred on the Peak, although Baker et al. (1964) also mapped a number with concentric orientations with respect to the Peak. The radial dykes are mostly vertical in attitude although some consist of branching and irregular anastamosing lenses, and others have sill-like offshoots. Vertically inclined dykes belonging to the radial swarm are seen everywhere in the Main Cliffs intruding and cross-cutting the horizontally layered lavas. Dykes belonging to the radial swarm are also exposed in the deeply incised gulches on the flanks of the Peak, where they form prominent wall-like features that are resistant to erosion. Some of these wall-like dykes are sufficiently large to be seen clearly on aerial photographs.

6 Residual thermal activity

The only residual thermal activity seen on the entire island during the present study consists of very weak, low-temperature fumaroles and steam seepages on the summit area of the 1961-62 lava dome. This is described in more detail under section 7.6..

Chevalier and Verwoerd (1987) also reported observations of fumaroles and warm ground south of the summit of the island. They do not however, say whether they actually visited this area or only observed it from the summit. The Royal Society Expedition did not recognised any residual thermal activity on the island, even though most localities were visited. Likewise, local guides, who know the ground very well, maintain that there is no such activity on the Peak, and that Chevalier and Verwoerd had probably mistaken mist or cloud for fumarolic steam.

The lack of residual thermal activity on the island is remarkable, given the clear evidence for a number of volcanic eruptions during the relatively recent past. It is tempting to conclude from this that the volcanic system is on the wane, although other factors, such as a very high water table in the volcanic edifice may be a reason also.

Appendix 2 Details of samples for radiometric dating

RADIOCARBON DATING:

PDTDC32:

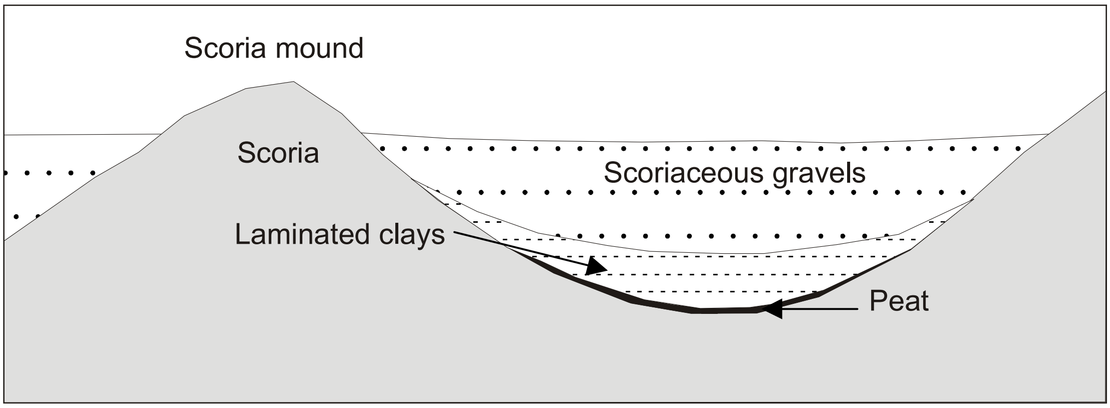
GPS UTM coordinates 0736880 5891900

GPS coordinates do not correlate precisely with map. Map coordinates 736660 5891840.

SRR-6664 1624±45 (BP)

Locality situated in small deeply incised gulch immediately south-east of scoria mounds and potato patches and 15-20 metres upstream from small bridge made of concrete "sleepers".

The stream bed passes between two small scoria mounds, both of which are exposed in the walls of the gulch. These are composed of medium to coarse, poorly-sorted scoria. In the trough between the two mounds the scoria is overlain by a thin peat 2-3 cm thick which is overlain by pale to mid-brown laminated clays and silts up to about 75 cm thick. The laminae mantle the underlying surface of the scoria. The clays are in turn overlain by up to 2 metres of stratified, medium to fine gravels composed of scoria and lithic clasts. These dip gently westwards towards the sea and appear to be alluvial gravels of the main colluvial fan.



PDTDC33:

GPS UTM coordinates 0737580 5892480

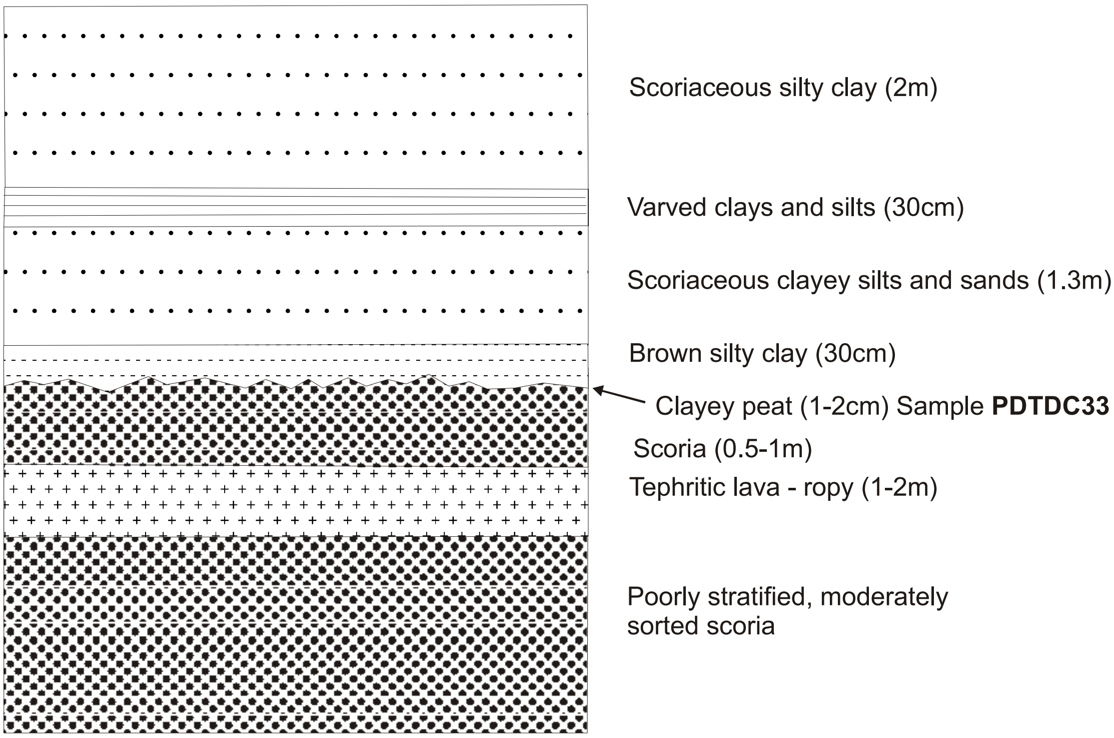
GPS coordinates do not correlate precisely with map. Map coordinates 737420 589254.

SRR-6665 2775±47 BP

Locality situated in Sandy Gulch, 30-40 metres downstream of small well-preserved scoria cone on the west side of Burnt Hill.

Sample PDTDC33 of peat – peaty clay.

Succession consists of a thick sequence of poorly-stratified scoria with a thin tephritic lava (1-2m) overlain by coarse, black scoria 0.5-1.0 m thick. A thin seam of peat-peaty clay (1-3 cm) immediately overlies the scoria. The sample was collected from the peaty seam. This is overlain by 30 cm of brown silty clay, overlain by 1.5 metres of silty clays and sands with scoria clasts, overlain by 30 cm of laminated silts and clays, overlain by 2 metres of clays and silts with scoria clasts, capped by soil.



PDTDC54:

GPS UTM coordinates 0738576 5894202

GPS coordinates do not correlate precisely with map. Map coordinates 0738480 5894320

SRR-6666 2411±48 BP

Locality situated in Hottentot Gulch, 60 metres upstream from dry waterfall at mouth of gulch.

Sample PDTDC54 of peat – peaty clay collected from very near base of deposits of the main alluvial fan of Hottentot Gulch where they rest on top of the uppermost lava exposed in the cliffs and around the Harbour.

The succession consists of the following: Massive lava- the uppermost of two flows exposed around the coastal cliffs. The unconsolidated, clinkery, rubbley top of this flow is full of cavities and is overlain by a thick alluvial sequence exposed in the wall of the gulch. Clayey gravel 10-30cm thick rests directly on the autobrecciated top of the flow. This is overlain by 20 cm of planar and cross-bedded lithic sands and fine gravel infilling a channel which is in turn overlain by 15 cm of coarser scoriaceous gravel, overlain by less than 10 cm of buff coloured silty-clayey sand with a clayey top which grades up into a thin clayey peat 1-2 cm thick. This peaty clay band becomes richer in organic content at the top. The sample was taken from this peaty layer. The peat is overlain by 1.3m of matrix-supported boulder gravel with large boulders supported in a clayey gravel matrix. This is overlain by a 6 m thick stratified sequence of bedded sands and gravels, overlain at the top by boulder gravels which form the surface of the alluvial fan over a wide area.

A few metres upstream the boulder gravels infill a channel which cuts down through the sequence to rest directly on the unconsolidated rubbley top of the lava. Further upstream on the opposite (south) side of the gulch the bedded sequence is exposed on the other side of the palaeo-channel.

ARGON – ARGON DATING

PDTDC17: BASANITE LAVA

GPS UTM coordinates 0741426 5894518

Lowest outcropping lava on beach at base of cliffs between Pigbite and Big Point

AGE: 141±8 ka

Massive, columnar jointed basanitic lava with scoriaceous – autobrecciated top, approximately 7 metres thick. Sample collected from fallen columnar jointed block. Medium-fine grained rock, apparently fresh, with microphenocrysts of plagioclase, clinopyroxene and olivine with oxidised rims.

PDTDC37: TEPHRITE LAVA

GPS UTM coordinates 0738401 5888679

GPS co-ordinates could be wrong – in the deeply incised gulch only 5 satellites were received. According to the map the UTM co-ordinates should be 0738200 5888660.

AGE: 24±7 KA

Sample of relatively young lava at base of Peak exposed in Third Gulch. This is one of a series of flows whose features (flow-fronts, levees etc) can be seen on aerial photographs and which originate higher on the Peak.

The sample was collected from a dry waterfall in the floor of the gulch. The outcrop was very fresh and unweathered. The rock is a fine grained, mid-grey, tough lava with clinopyroxene phenocrysts up to about 3 mm, and laths of plagioclase generally about 1 mm in size up to about 2 mm.

PDTDC40: Tephrite lava

GPS UTM Coordinates 0741406 5894087.

GPS co-ordinates could be wrong – on the cliffside only 5 satellites were received. According to the map the UTM co-ordinates should be 0741360 5894120.

AGE: 80±7KA

Outcrop where Pigbite path crosses gulch, situated at 400 m about 2/3 of the height up the main cliff from the base. (About 400 m above PDTDC17).

The outcrop is fresh and waterworn. Sample collected from massive coarsely vesicular part of the flow. Large, widely spaced vesicles (no secondary minerals). Most elongated up to 6 cm long, although occasional large undeformed spherical vesicles up to 10 cm.

The rock is a fine compact grey rock with very sparse microphenocrysts of clinopyroxene up to 3 mm and very rare plagioclase up to 5mm.

PDTDC47: TEPHRI-PHONOLITE LAVA

GPS UTM Coordinates 0740033 5888527

Sample of well-featured lava flow forming first rocky outcrop high up on flanks of Peak (GPS 1552m) on interfluve ridge on south side of Third Gulch.

AGE: 31±4 KA

The outcrop is virtually fresh and frost shattered. Pale-mid grey microporyritic rock with abundant plagioclase (1-3 mm), euhedral amphibole and hexagonal biotite?

PDTDC49: TEPHRITE LAVA

GPS UTM Coordinates 0741130 5893403

Sample of well-featured basaltic lava taken from Plantation Gulch. According to the map the coordinates should be 0741180 5893420.

AGE: 49±7 KA

Water worn outcrop in bed of gulch. Fine, mid-grey micropporhyritic basaltic rock with pyroxene microphenocrysts up to 5 mm.

PDTDC52: Tephrite lava

GPS UTM Coordinates 0740496 5890110

Sample of lava forming the slope of the upper flank of the Peak. According to the map the coordinates should be 0740370 5890060**.**

AGE: 22±8 KA

Fine, mid-grey microporhyritic basaltic rock with pyroxene microphenocrysts up to 3 mm and plagioclase laths.

PDTDC53: TEPHRITE LAVA

GPS UTM Coordinates 0738521 5894216

Sample of lava on top of dry waterfall at mouth of Hottentot Gulch. According to the map the coordinates should be 0738420 5894360**.**

Age: 30±6 ka

Fine, mid-grey aphyric lava with some small vesicles. Sample taken from massive central part of uppermost of the two lavas which extend around the low coastal cliffs from east of the harbour. In most places spheroidally weathered. Some spheroidal weathering in the outcrop, but the sample was taken from a massive unweathered part.

PDTDC56: TEPHRITE LAVA

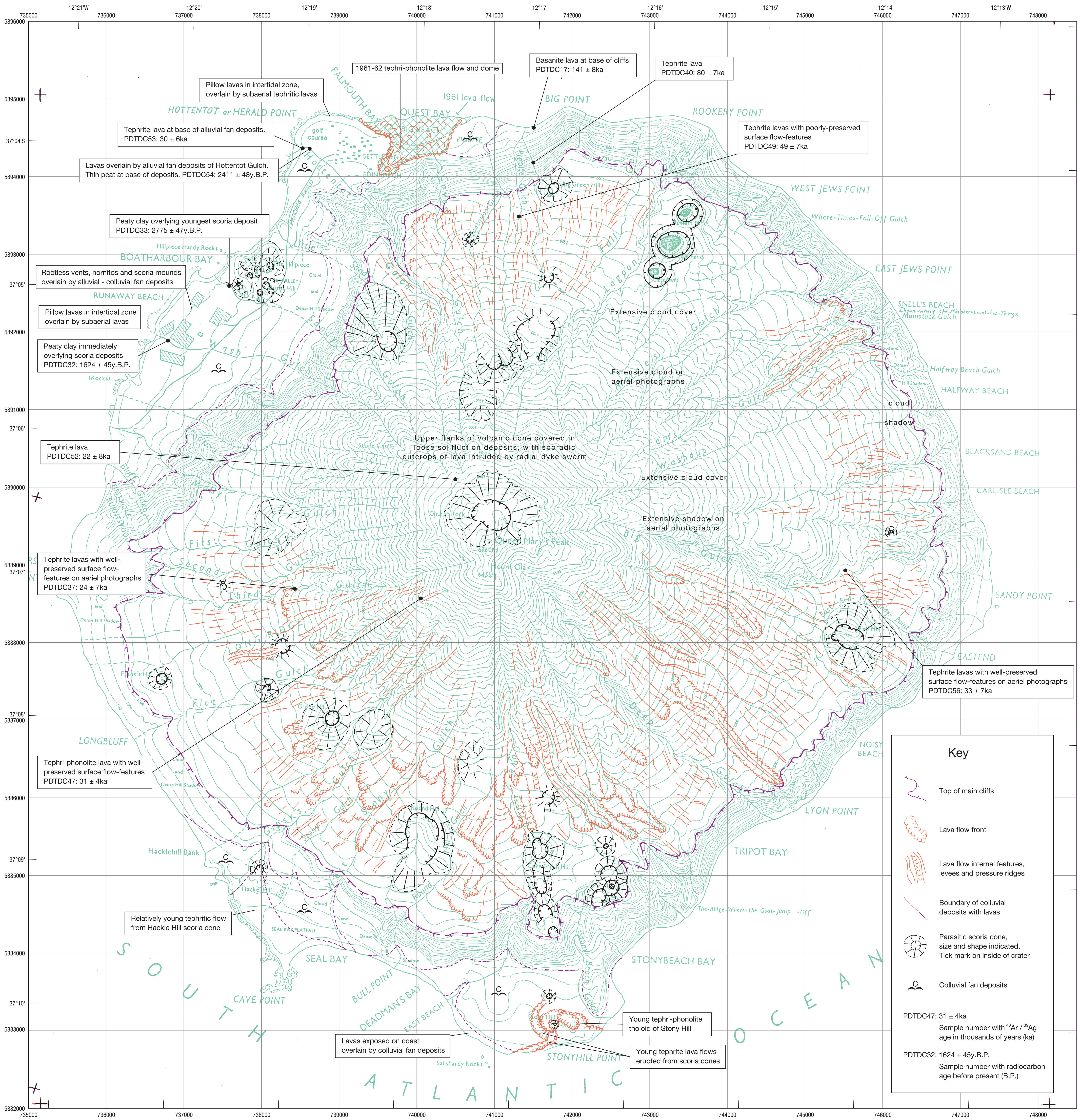
GPS UTM Coordinates 0745485 5888933

Sample of young? lava in bed of Big Gulch, north of Red Hill. According to the map the coordinates should be 0745400 5888880**.**

AGE: 33±7 KA

Fine, mid-grey flow-banded lava. Microporphyritic with phenocrysts of pyroxene and amphibole. Abundant cognate xenoliths of microgabbro and rare olivine aggregates? Outside of gulch on south side, vegetated but well-featured young lava flows with levees, ridges, flow-fronts.

TRISTAN DA CUNHA - VOLCANIC FEATURE MAP



Geological Survey by P. N. Dunkley.
Cartography by P. Turner and S.E. Wood, and digital photogrammetry by D. G. Tragheim, British Geological Survey, 2002

The topographic map is the Ordnance Survey 1:20,000 sheet, SD 2965 Tristan da Cunha reproduced with the permission of Her Majesty's Stationery Office (© Crown Copyright 1997) Ordnance Survey licence number GD272191/2002.
Contour vertical interval at 100 feet.
Projection: UTM Zone 28 South (18°W-12°W), WGS84 datum and ellipsoid.

1000m 500 0 1 2 3 4km

Scale 1:25,000

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL