PART IV. THE EFFECTS OF THE ERUPTION OF 1961 ON THE VEGETATION OF TRISTAN DA CUNHA

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[Plates 43 to 47]

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1. Introduction

Volcanic eruptions affect vegetation in various ways according to the nature and quantity of the material ejected. Lava, pyroclastics and gases all cause damage in different degrees, varying with the type of eruption. Lacroix (1908) recognized four types of volcanic activity, viz. Hawaiian, Strombolian, Vulcanian and Pelean. The Hawaiian type is characterized by the production of a great deal of lava but little pyroclastic material. At the other extreme, the Pelean type produces great explosions with copious pyroclastics but little lava.

In Hawaii, the damage to the vegetation caused by eruptions is due largely to burial by the lava flows (MacCaughey 1917; Skottsberg 1941; Britten 1956). However, in volcanic areas such as the Lesser Antilles, Papua and the Philippines, where there have been paroxysmal eruptions, damage resulted principally from the force and heat of the blast and the great quantities of pyroclastics thrown out (Anderson & Flett 1902; Anderson 1908; Taylor 1958; Brown, Merrill & Yates 1917).

Not only is the volume of solid material ejected by volcanoes often very great but the volume of gases released is also enormous (Bullard 1962). Many volcanic gases are toxic to plants, some extremely so, such as hydrogen fluoride and sulphur dioxide.

The greatest damage to the vegetation of Tristan as a consequence of the recent eruption is due neither to lava-flows, which covered only a small area, nor to pyroclastics, which were produced in small quantity, but to fumes, which affected the vegetation over a wide area. Sections 2 to 5 are devoted to the direct effects of the eruption. Various aspects of the damage caused by fumes are discussed in detail.

Little can be said at this stage of the plant colonization of the eruptive centre (§7). The study of such an invasion will of necessity cover a considerable period of time. Detailed investigation should yield valuable information about the competition between alien and indigenous species, especially with regard to the capacity of various plants of these groups to occupy a fresh habitat. Study of the vegetation of the volcano at Stony Hill, which is structurally and topographically very similar to the new eruptive centre, may well make an informative comparison with the colonization of the new lava field.

By February 1962, various plants, which had been damaged by the fumes, were beginning to recover. The information given in §6 has been supplemented by the observations made by Mr H. G. Stableford, of the Colonial Office, who visited Tristan from 8 September to 3 October 1962 and from April till December 1963.

2. Direct effects

2·1. *Landslides and rockfalls*

Small landslides have taken place on the Main Cliffs behind the volcano and in Hottentot Gulch, destroying *Phylica* bush and *Blechnum palmiforme* scrub. A large rockfall from the Main Cliffs immediately behind the Village has exposed an old volcanic neck (figure 33). The plant colonization of the scree formed from this rockfall should be compared with the invasion of the new lava field.

The severe injury or death of the vegetation of the Main Cliffs from Hottentot Gulch to Big Point (figure 33) may well reduce the power of soil binding by the roots of various species, notably *Phylica arborea*, with the result that the heavy rain and strong winds characteristic of the climate of Tristan may cause more landslides. On the morning of 3 February 1962, a small landslide was observed to take place on the Main Cliffs, higher than but immediately to the east of quadrat 1 (figure 33). Heavy rain, perhaps that of 7 February (12 mm), or that of 12 February (37 mm) turned the loosened material into mud which flowed down the slopes in a narrow strip, nowhere more than 2 m wide or 0·75 m deep (figure 34, plate 43).

2·2. *Fires*

Small, widely spaced areas of *Phylica* bush, up to 2 m high, on the slopes behind the volcano, were set alight by pyroclastics. Figure 5 shows the location of the main areas. Pyroclastics were found as high as 300 m on the Main Cliffs. At a slightly higher altitude, *Blechnum* scrub, which could not be examined because of its inaccessible position, was seen to have caught fire. *Phylica* seedlings were discovered under bushes in these areas which had been burned (§6·1). Although there is pyroclastic material scattered between the base of the volcano and the eastern end of the Village (figure 33), the grassland did not appear to have been burned. The cottage nearest the volcano was set on fire by a pyroclastic and plants of *Phormium tenax* in the garden were also burned.

The *Phormium* plantation at the Mission Garden (beside the western lobe of the lava field) (figure 33) caught fire due to contact with the lava. Fire, sweeping through the plants, left the bases of the clumps, in many cases, undamaged. Nearby, the grassland on the slopes of the former sea-cliffs was burned, but by February 1962 had largely recovered.

2·3. *Lava and ash*

About twenty acres of grassland and beach sand have been covered by the lava-flows. Julia Point, a promontory rich in marine algae (Baardseth 1941; Christophersen 1946) lay in the path of the lava and has been obliterated (figure 33). The damage caused by ash fall and accumulation is very localized, the covered ground (about ten acres) being confined to the lower slopes of the Main Cliffs immediately behind the volcano (figure 33).

The ash, which lay nowhere to a depth of more than 30 cm, did not accumulate at all evenly because of the steeply sloping, irregular nature of the ground. Moreover, strong winds and heavy rain quickly dispersed the ash into hollows.

The very minor effect of the ash differentiates the recent Tristan eruption from many other eruptions which have damaged vegetation. At Paricutin (Eggler 1948, 1959) and Barcena (Brattstrom 1961), both in Mexico, Mont Pelée in Martinique, and the Soufrière in St Vincent (Anderson 1908; Anderson & Flett 1902), Fayal in the Azores (Macado, Parsons, Richards & Mulford 1962), Krakatoa in Indonesia (Ernst 1908; Backer 1929; Docters Van Leeuwen 1936), Taal in the Philippines (Brown *et al.* 1917) and Komagatake and Minami-dake, both in Japan (Yoshii 1932; Tagawa 1964), the amounts of ash liberated were very great and the vegetation suffered severely as a result of burial, mechanical injury (defoliation, loss of branches) and fire.

2·4. *Toxic fumes*

The damage to the vegetation caused by toxic fumes is by far the most extensive of the direct effects of the eruption (figures 32 and 33).

There is little or no mention of the toxic action of fumes in the accounts listed immediately above. The few reports which deal with this subject show that fumes can damage vegetation even at a great distance from volcanoes. During the 1955 eruption of Kilauea in Hawaii the vegetation 30 to 50 km away from the vents suffered injury from fumes (Britten 1956). Griggs (1915) states that after the 1912 eruption of Katmai in Alaska rains bearing sulphuric acid in such concentration as to destroy gardens occurred as far as 480 km away from the volcano. During the 1783 eruption of Laki, Iceland, a bluish haze spread over the entire country and stunted the grass crop (Thorarinsson 1954).

The fumes released by the new Tristan volcano did not affect the vegetation at a distance of more than about 9·5 km from the volcano. It is possible that the volume of harmful gases released by the volcano accounts for this, but it may well be that the topography and size of the island, and the meteorological conditions were more important. The fumes may have been blown out to sea without passing over the island, except for those parts of the Main Cliffs nearest the volcano.

3. Area of vegetation affected by the fumes

3·1. *General*

The primary factors which determined the area of fume-damaged vegetation were the nature and volume of the toxic gases released by the volcano. Several secondary factors in combination have governed the shape of the area, which is markedly asymmetric about the

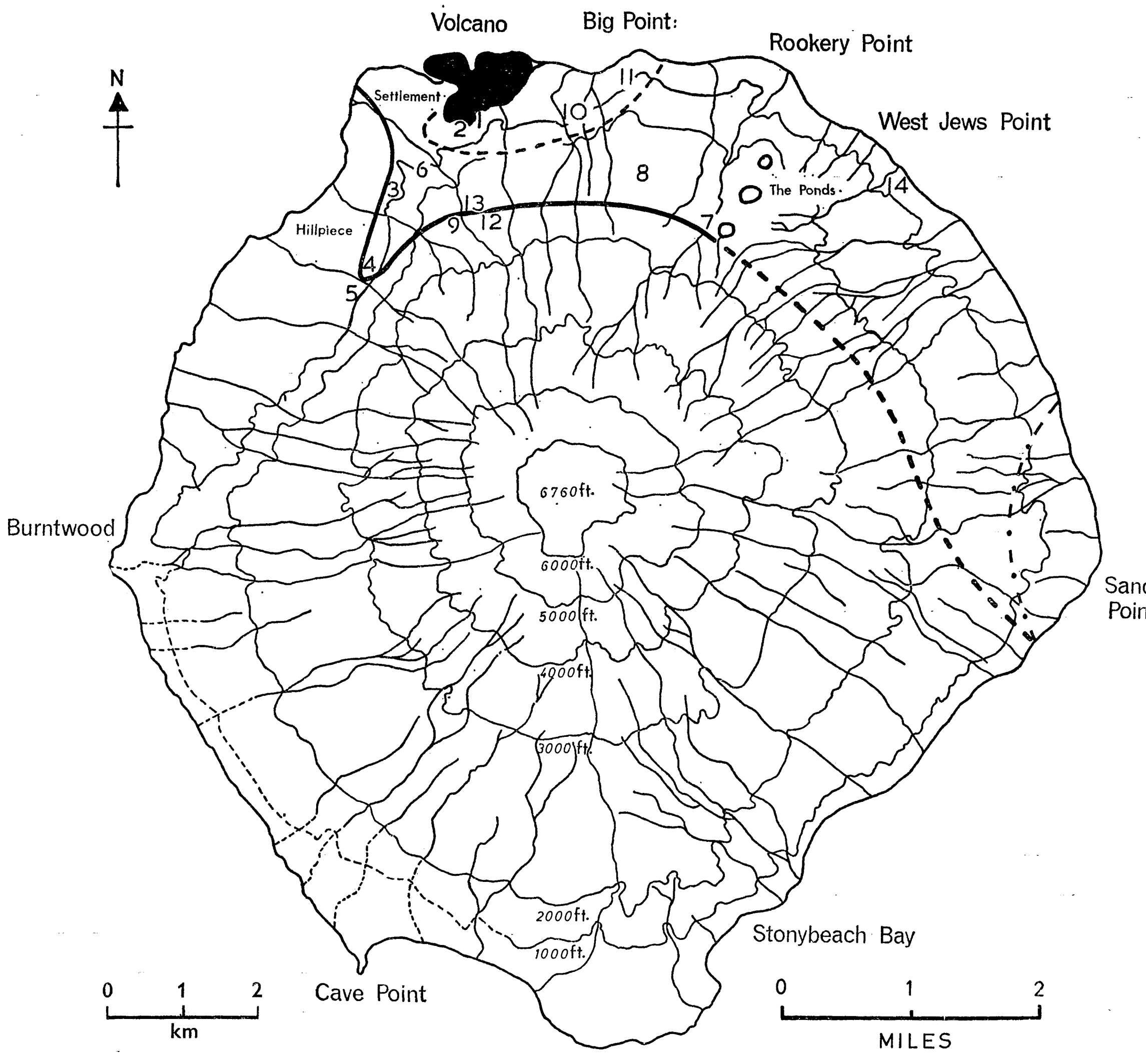

FIGURE 32. The area of fume-damaged vegetation, March 1962. The new eruptive centre is shown in black. The thick (continuous and dash) line delimits the area of fume-damaged vegetation. Between the Settlement, Hillpiece and the Ponds it is accurately placed because the ground was thoroughly covered on foot. Between the Ponds and Sandy Point it is approximately placed because no visits could be made to that region. The dot-dash line shows the area observed from a helicopter of H.M.S. *Protector*. The thin dash line shows precisely the area of maximum fume damage. Numbers 1 to 14 indicate localities studied in detail.

volcano. These were the direction of the prevailing wind, the position of the volcano in relation to the topography of the island and to the vegetation belts, and the sensitivity of the dominant plants to the fumes.

The extent of the affected vegetation is shown on figure 32. The area is about 22 sq. km, which represents about a quarter of the planar area of the island. The fume-damaged vegetation was studied by making detailed examinations in the localities indicated by numerals 1 to 14 on figure 32, and by sailing along the coast of the island in order that the vegetation of the Main Cliffs could be scanned carefully, with the aid of binoculars when necessary. The Base above Sandy Point was examined from the helicopter of H.M.S. *Protector*. Damaged *Phylica* trees could be seen clearly. Photographs taken by those members of the expedition who landed at Sandy Point confirm this observation.

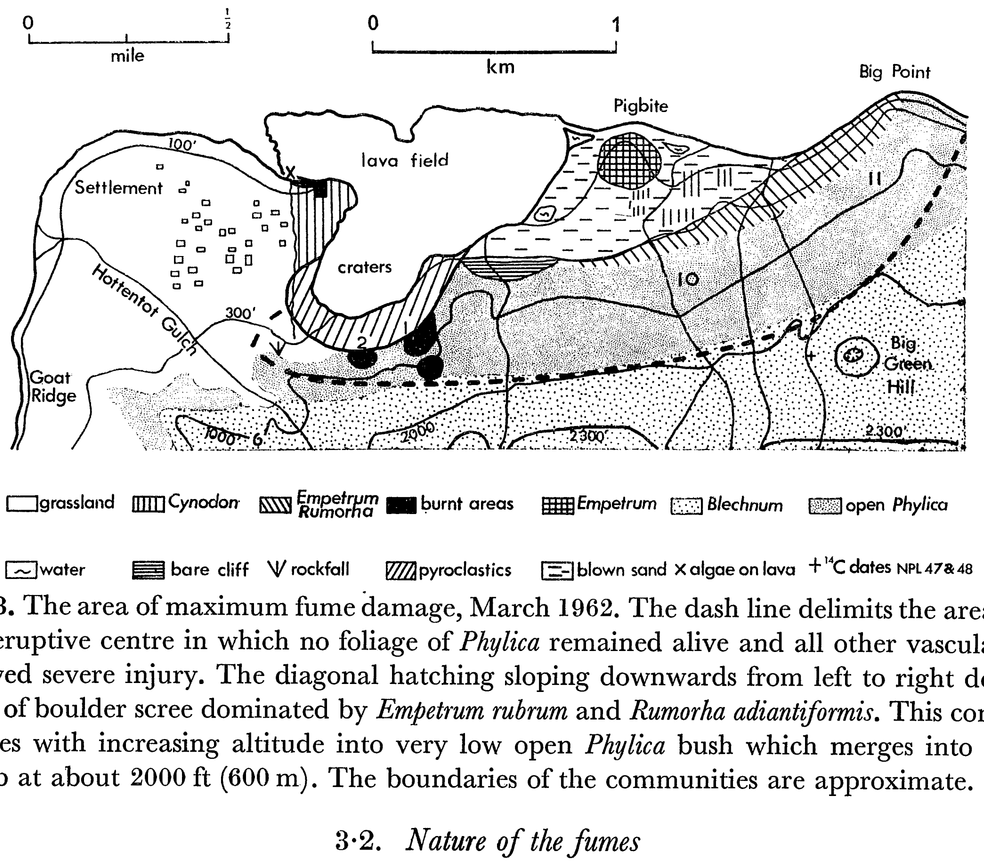

FIGURE 33. The area of maximum fume damage, March 1962. The dash line delimits the area around the eruptive centre in which no foliage of *Phylica* remained alive and all other vascular plants showed severe injury. The diagonal hatching sloping downwards from left to right depicts an area of boulder scree dominated by *Empetrum rubrum* and *Rumorha adiantiformis*. This community grades with increasing altitude into very low open *Phylica* bush which merges into *Blechnum* scrub at about 2000 ft (600 m). The boundaries of the communities are approximate.

3·2. *Nature of the fumes*

Volcanic gases are often released in very great volume. The following estimations are used to exemplify this statement but not to imply that direct comparisons can be made with the new Tristan volcano, which is of a much smaller size than any of the three volcanoes mentioned.

Bullard (1962, p. 41) states, 'The total volume of gases evolved during an eruption is stupendous. Alfano & Friedlander (1928) calculated that the volume of gas in the 1906 eruption of Vesuvius from the size of the conduit, and the velocity of emissions, and state "it appears that not only the volume but also the weight of gases must be many times greater than the total mass of ash and lava". It has been estimated that 13600 metric tons of water were released daily by the Mexican volcano, Paricutin, during the year 1945 (Fries 1953). Zies (1938) calculated that the fumaroles of the Valley of Ten Thousand Smokes, in Alaska, during 1919, gave out 1250000 tons of hydrochloric acid and 200000 tons of hydrofluoric acid. These gases made up less than 1 % by volume of the total gases released.

Mason (1952) gives a list of the various gases which have been identified as components of volcanic emanations; he states (p. 123), 'Water is always the major constituent generally making up 80% of the whole volume; CO_2, H_2S, SO_2, HCl and NH_4Cl are often abundant; and HF, N_2, CH_4, B_2O_3, CO and H_2 have been recorded in lesser amounts'.

Unfortunately, no analyses could be made of the gases evolved by the new volcano either during the early stages of the eruption or during the stay of the expedition. Sulphur dioxide and hydrogen sulphide were recognized by their distinctive odours, the former being most noticeable around the peripheral crater, and the latter only from the fumaroles in the valley behind the volcano. However, a study of the fumarolic minerals associated with the new parasitic volcano (Baker *et al.* 1964) has established the existence of sulphates, fluorides, native sulphur, chlorides, carbonates and borates, in approximate order of abundance. From this it would seem likely that the major component of the fumes, after water vapour, was SO_2 with smaller amounts of H_2S (the sulphates predominate over native sulphur) and probably H_2SO_4. HF was probably next in abundance and was probably followed by HCl and CO_2. The boron was very minor in amount and was probably present as H_2BO_3. NH_4Cl was probably also present (one ammonium-bearing mineral was found).

3·3. *Liberation of the fumes*

The few reports there are of the emission of fumes by the volcano during the period in which the island was left unoccupied, and the observations made by members of the expedition are summarized below.

During the evacuation of the island on 10 October 1961, sulphur was smelt one km out to sea. Occasional puffs of sulphurous smoke from the volcano were observed from H.M.S. *Leopard* on 13 and 14 October 1961. A photograph taken on 20 October 1961 by Captain M. T. Scott of the M.V. *Tristania* and published in the National Geographic Magazine (Wheeler 1962), shows a large yellowish brown cloud pouring down the western side of the volcano towards the Village. On 27 October 1961, Captain H. Klein, of the *Straat Magelhaen*, reported that a sulphurous smoke haze lay over the Settlement and that the odour of sulphur could be detected 8 km out to sea.

Harris & Le Maitre (1962) observed the volcano in an active phase on 16 and 17 December 1961 but make no mention of the smell of fumes. They state (p. 3), 'The cone continuously emitted a whitish smoke from its summit and flanks. Every few minutes it puffed forth a cloud of white smoke, accompanied by an audible bang, and blocks and bombs were thrown 100 ft. into the air', and referring to the peripheral cone 'This vent also belched forth mushroom-shaped clouds of smoke but of a yellowish colour'. During February and March 1962, fumes could only be smelt in the immediate vicinity of the peripheral cone and various fumaroles.

It is evident that the liberation of gases was most active during the period October 1961 to January 1962 but was much reduced by February and March 1962. Fumes were still being given off during December 1963 (Stableford, private communication).

3·4. *Position of the eruptive centre*

The eruptive centre formed immediately at the foot of the 600 m high Main Cliffs which skirt the north eastern end of the Settlement Plain. Its position is such that the fumes, blown along the face of the Main Cliffs and onto the Base, came into contact with the semi-natural *Phylica* bush of the Main Cliffs and the *Blechnum* scrub of the Base.

3·5. *Prevailing wind and the dispersal of the fumes*

Figure 32 shows that the area of damaged vegetation is markedly asymmetrical about the eruptive centre. To the east, damage extends as far as Sandy Point, about 9·5 km away, while to the west it extends no further than Hillpiece, only 2·5 km away. The asymmetry is due to the prevailing westerly winds which blew the fumes eastwards round the island.

During the stay of the expedition the dispersal of the fumes was observed. When the wind was from the west, the fumes were seen to rise obliquely from the volcano and pass along the face of the Main Cliffs towards Big Point (figure 12, Part I). On the day the expedition arrived, 27 January 1962, and again on 6 February 1962, the fumes were observed to reach as far as Big Point.

Only twice did a haze of fumes lie over the Settlement and the fumes were never seen to reach the level of the Settlement Plain. On the infrequent occasions when the wind blew from the east, the fumes travelled no further than the east side of Goat Ridge and then dispersed up Hottentot Gulch (figure 33). The contrast between fume damage to *Phylica* bushes on the west and east sides of Goat Ridge was very marked. Many more bushes on the east side were affected than on the west side. It seems that Goat Ridge was a partial barrier to the dispersal of fumes to the west.

The interaction of topography and wind direction in influencing the dispersal of fumes is well illustrated by White Island, a constantly fuming volcano, off the northern coast of the North Island of New Zealand. The topography and prevailing wind are such that the fumes are blown to the south-east of the island, where no vegetation occurs. The vegetation, consisting of *Metrosideros* forest, is only to be found on those parts of the island least affected by fumes (Hamilton & Baumgart 1959).

4. Nature of fume damage

4·1. *General*

Many of the gases which have been recognized as components of volcanic emanations are toxic to plants (see § 3.2). Hydrogen fluoride and sulphur dioxide need only be present in very small quantity for very short periods to cause damage to foliage. The majority of species (various grasses, cereals and vegetables) studied by Zimmerman & Crocker (1934) were injured by fumigation with sulphur dioxide at a concentration of one part per million for 1 h. Hydrogen sulphide, hydrochloric acid and carbon monoxide must be present in much greater concentrations for much longer periods to injure foliage (Thomas 1951).

The widespread damage to vegetation caused by the fumes released by the Tristan volcano is similar to the destruction caused by pollution of the atmosphere resulting from the release of gas by smelters (Zimmerman & Crocker 1934; Katz 1939; Daubenmire 1959). The economic importance of the injury to plants as a consequence of atmospheric pollution is of such a magnitude that a great many investigations of gas damage have been carried out. The literature is voluminous, Katz (1939), Thomas (1951), Carr (1961) and Peace (1962) give reviews of the subject.

Sulphur dioxide was very probably the gas principally responsible for damage to the vegetation of Tristan. The injured plants show symptoms comparable with sulphur dioxide damage, described in detail by Katz (1939). However, Katz stresses the need for caution in diagnosing gas damage. On page 431 he states, 'Numerous markings closely resembling those of sulphur dioxide may be attributable to other causes, such as winter injury, drought, insects, fungi and various physiological disorders'.

The sudden, deleterious change in health of the wide variety of plants, both native and introduced on Tristan, at a time when the atmosphere contained toxic gases released by the volcano, and the shape of the area of affected vegetation and the position of the area relative to the volcano and the prevailing wind, make it clear that the damage is due to fumes. Nevertheless, in order to dispose of all other possible causes of injury, some discussion is necessary.

Winter injury needs no consideration because of the time of damage which took place during the spring and summer. Moreover, the winter on Tristan is so mild that the vegetation of the lowlands and the Main Cliffs scarcely ceases growth. The extreme minimum temperature recorded at the Settlement is 3·0 °C. Field observations showed that the injury was due neither to fungal infection nor to insect pests. Dried specimens of various damaged plants have been examined by the mycologist, Dr H. J. Hudson, who agrees with this assessment.

The 5 in. gauge used for recording rainfall at the meteorological station, which is situated at the north western end of the Settlement, was left standing when the island was abandoned on 9 October 1961. Lt. Cdr A. B. Crawford, the meteorologist on the Expedition, on reading the gauge on 2 February 1962 found that it registered 218 mm (8·6 in.). The mean rainfall for the four-month period October till February for the years 1942 to 1949 and 1952 to 1961 was 506 mm (19·9 in.), a figure more than double the amount recorded for October 1961 to February 1962. It is very important to decide whether the deficiency of rainfall was enough to affect the vegetation to such an extent that confusion of drought damage with fume damage was possible.

The effect of the deficiency of rainfall on the vegetation is thought to have been slight for the following reasons. First, because of the small size of the island, it is very probable that the deficiency of rainfall affected the whole island. However, outside the area marked on figure 32, the vegetation showed no sign of injury. The vegetation of the low-lying areas between Cave Point and Stony Beach and of the Settlement Plain west of Hillpiece and of the Main Cliffs between Hillpiece and Sandy Point westward round the island (figure 32) was in a completely undamaged condition. Secondly, the temperatures are sufficiently low (mainly in the range 12 to 18 °C) and the humidities sufficiently high (around 80 %) to have lessened the effect of the deficiency. Thirdly, the selective nature of the damage to the plants, particularly the cultivated species in the Settlement, is strong evidence against the deficiency of rainfall being the cause of any serious injury (§ 5·3).

4·2. *Injury to certain species*

4·21. *Phylica arborea* Thouars

Phylica arborea is one of the dominant species in the lower parts of the fern-bush vegetation which encircles Tristan up to an altitude of about 750 m (§4, Part II).

When fully grown under favourable conditions, *Phylica* forms a small tree, 6 m high at the most. The trunks are often procumbent for much of their length (figure 6 in Wace & Holdgate 1958). Young plants are shrubby (figure 34). The evergreen leaves are light green in colour and lanceolate in shape, with acute tips, entire, strongly re-curved margins and very short petioles (figure 41, plate 44). They are about 10 to 15 mm long and 3 to 6 mm wide. Leaves of such a size are designated nanophylls by Raunkiaer (1934). Both surfaces of the leaves have a covering of simple, long hairs, that of the adaxial surface being present only in young leaves, while that of the abaxial surface is dense and persistent.

The fumes damaged *Phylica* bushes so severely as to kill the foliage and branches. Dead leaves were persistent on the stems. In all but a few of the plants examined, affected leaves were completely brown with no patchiness in colour whatever (figure 41, plate 44). No yellowish or green colour could be seen. The uniform nature of the fume damage contrasts with that of *Blechnum palmiforme* and *Phormium tenax* (§§ 4·22 and 4·23) the leaves of which were often affected only along the margins and at the tips (figures 40 and 43, plates 44 and 45).

TABLE 31. ESTIMATION OF DAMAGE TO *PHYLICA*

The amount of dead foliage on one hundred *Phylica* bushes at nine localities was estimated.
* Only fifty bushes counted. † Only thirty-five bushes counted.

quadrat	distance from volcano	altitude (m)	aspect	slope	0 %	1–25 %	26–50 %	51–75 %	75–99 %	100 %
6	0·8 km SSW	*ca.* 330	NW	45°	0	0	0	2	9	89
3	1·2 km SSW	*ca.* 240	N	45°	0	54	20	7	12	7
4	2·0 km SSW	*ca.* 240	NW	44°	0	93	5	2	0	0
5	2·4 km SSW	*ca.* 300	NW	42°	100	0	0	0	0	0
2	0·4 km S	*ca.* 240	E	53°			complete damage			
1	0·4 km ESE	*ca.* 210	W	46°						
10	1·2 km E	*ca.* 240	N	44°			all foliage dead			
11	2·0 km ENE	*ca.* 240	NW	44°						
8	2·4 km ESE	*ca.* 690	N	*ca.* 20°	0	0	0	0	5	95
7*	3·2 km ESE	*ca.* 720	N	20°	0	5	4	7	18	16
14†	5·2 km E	*ca.* 150	NE	*ca.* 40°	0	15 < 50 %		16 > 50 %		4

In the area of maximum fume damage (figure 33) all the foliage on the *Phylica* bushes was dead; no branch escaped damage. With increasing distance from the area of maximum fume damage, more and more bushes were only partially injured, and more and more escaped damage. It was characteristic of partially injured bushes that whole branches were completely damaged while other branches of the same size and in juxtaposition on the same plant were free from observable injury (figure 41, plate 44). Damaged plants ranged from those with only one living branch to those with only one dead one.

In order to make some estimation of the intensity of the damage at varying distances from the volcano, areas of 5 m square of vegetation (*Phylica* bush where possible) were studied in detail. Visual assessments of the amount of brown foliage on each of a hundred *Phylica* plants in and around each quadrat were made (table 31). The areas of *Phylica* bush were chosen, as far as possible, for similarity of aspect, slope, size of bush and canopy cover.

The list of species, together with the cover-abundance of each species, from quadrats 1 to 8, 10 and 11 (*Phylica* bush) and 9, 12 and 13 (*Blechnum* scrub) are given below. Figure 34 shows diagrams which illustrate the community structure and soil profiles of five of the *Phylica* quadrats. *Phylica* is quite absent from the region in which quadrats 9, 12 and 13 are situated, consequently, *Blechnum* scrub had to be studied instead.

To the west of the volcano, *Phylica* with dead foliage was not found more than 2 km away. At quadrat 4, only two bushes had more than 50% of the foliage affected. At quadrat 5, 2·4 km away, there was no damage comparable with that recognized elsewhere, but the yellowish colour of some of the leaves may have represented fume damage.

To the east of the volcano, all the bushes at quadrat 11, 2·0 km away, were completely damaged. At quadrat 7, 3·2 km distant from the volcano, 34 out of 50 trees were found

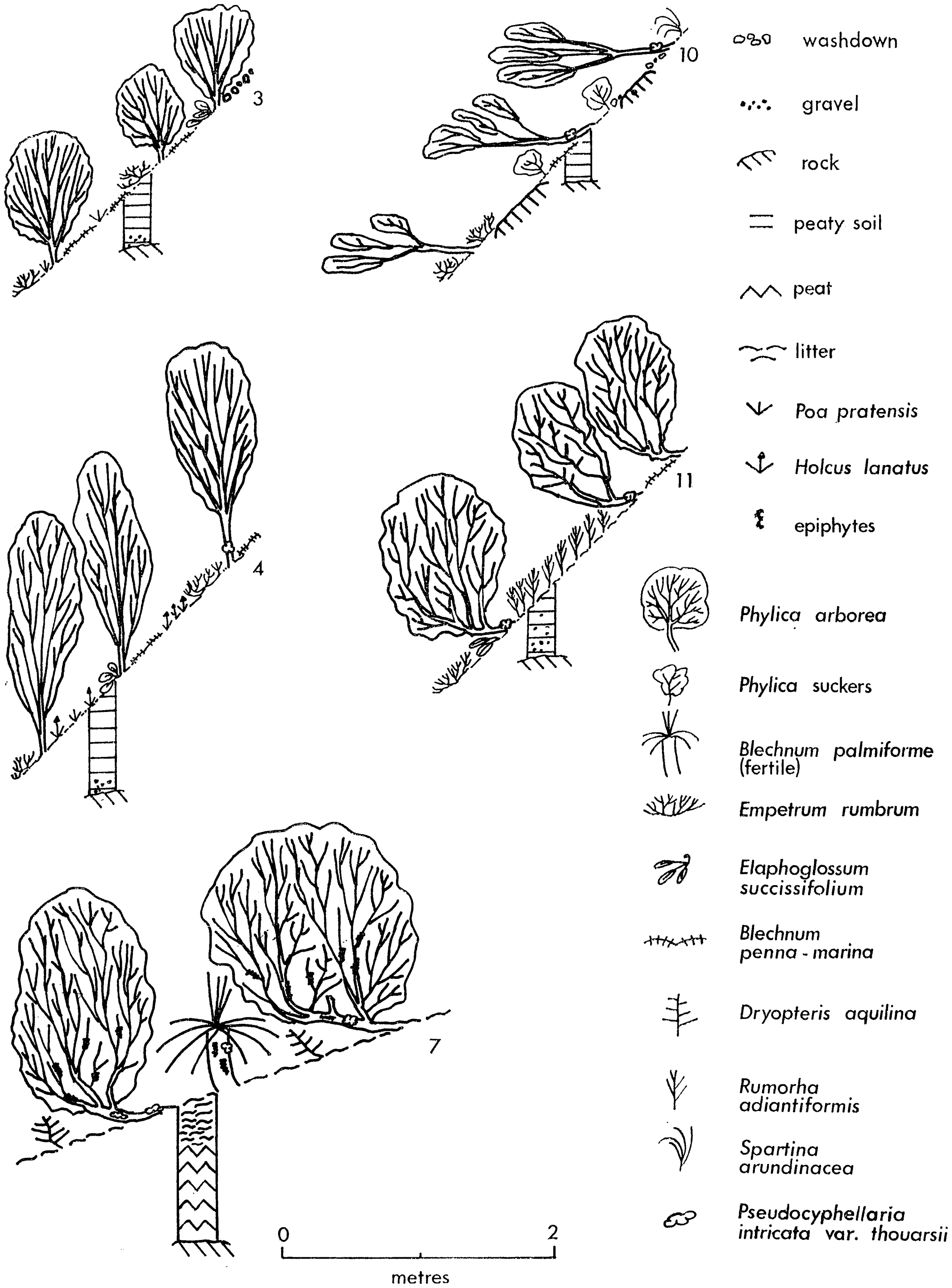

FIGURE 34. Profile diagrams. The vertical and horizontal scales are the same. The numbers refer to localities shown on figure 32.

FIGURE 35. Mudflow on the slopes behind the volcano. Ash covers the ground on both sides of the mud.

FIGURE 36. Burnt *Phylica* bushes of quadrat 1. Seedlings of *Phylica* were found growing through the ash which covered the ground.

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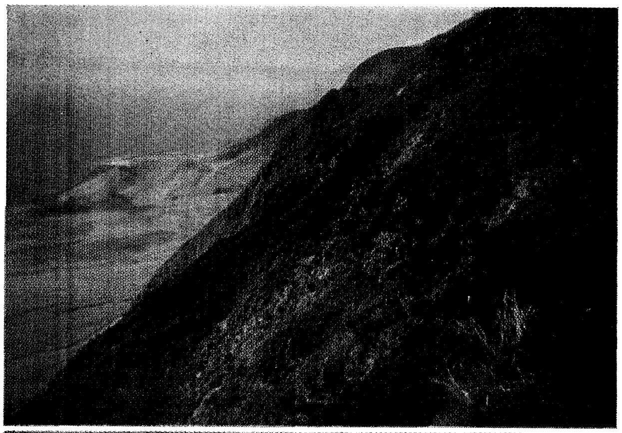

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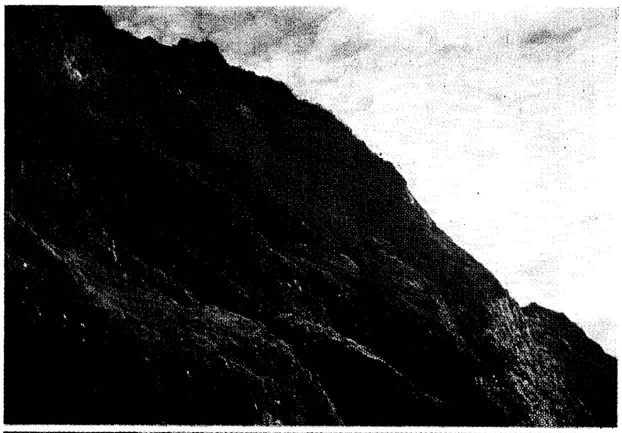

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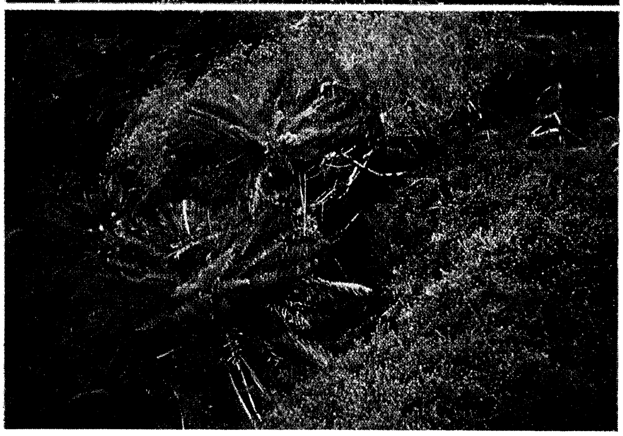

FIGURE 37. The Main Cliffs from the edge of the Base at Burntwood. Hillpiece in the distance. Undamaged semi-natural *Phylica* bush.

FIGURE 38. The Main Cliffs behind the volcano. All vegetation badly damaged by the fumes.

FIGURE 39. *Blechnum palmiforme* scrub of quadrat 12. Plants free of damage.

FIGURE 40. Very badly fume-damaged plants of *Blechnum*. East side of Big Green Hill.

FIGURE 41. Badly fume-damaged bush of *Phylica* near Big Green Hill. A few branches on the left have escaped injury.

FIGURE 42. Undamaged *Empetrum rubrum*, right, contrasting with *Blechnum*, left, and *Phylica*, background, both badly injured. East side of Big Green Hill.

FIGURE 43. Fume-damaged *Phormium tenax*. Margins and tips of the leaves as well as peduncles dead.

FIGURE 44. A tree of *Persea americana* defoliated by the fumes. Numerous new shoots sprouting from the trunk and main branches. Undamaged tree of *Metrosideros* sp., right background.

FIGURE 45. A tree of *Leucadendron argenteum* killed by the fumes. Many of the leaves have fallen.

FIGURE 46. A pine very badly affected by the fumes. New shoots growing from a few of the branches.

FIGURE 47. *Cynodon dactylon* spreading over rubble of pyroclastics close to western edge of main cone.

FIGURE 48. The lower slopes behind the volcano. *Rumex frutescens* growing from undamaged rhizomes.

to be more than 75% affected. The area marked 14 on figure 4 is 5·2 km away from the volcano. Because of the rough nature of the terrain and the scarcity of bushes, only 35 plants were examined. Of these, 20 were more than 50% affected. As mentioned above (§3·1) *Phylica* trees were damaged at Sandy Point, about 9·5 km away from the volcano. It is evident that at comparable distances from the volcano, *Phylica* bushes to the east were much more severely damaged than those to the west.

The gradually diminishing effect of the fumes in all directions from the area of maximum fume damage contrasts with the fume damage resulting from the Kilauea eruption in 1955 (Britten 1956). In this case the vegetation was damaged in the immediate vicinity of the vents and 30 to 50 km away, the intervening areas remaining free of harm.

4·22. *Blechnum palmiforme* (Thouars) C. Chr.

Blechnum palmiforme is one of the dominant species in the fern-bush vegetation which encircles Tristan up to an altitude of about 750 m (§4, Part II). It is particularly abundant in the upper reaches of this vegetation.

Blechnum palmiforme has the habit of a dwarf tree fern. The plants, which can attain a height of 1·5 m at the most, were usually 1 m high in those areas where *Blechnum* scrub was studied. The pinnate, coriaceous fronds can reach a length of 70 cm but are frequently about 50 cm long. The pinnae are up to 8 cm long and have strongly recurved margins. Young trophophylls are light green in colour but become darker with age. Sporophylls, of which there are ten at the most simultaneously, are held stiffly erect from the centre of the crown of up to fifty trophophylls. They are golden green in colour. The rachides and undersides of the pinnae of the trophophylls have a dense covering of golden brown ramenta, as do the sporophylls except for the undersides of the pinnae which are occupied by sporangia. In the most severely fume damaged state, the upper parts of the rachides and all but a few of the basal pinnae of the trophophylls were killed. Dead tissue was brown in colour (figure 40, plate 44). Less severely injured trophophylls had the affected areas scattered round the margins of the pinnae. Sporophylls showed damage confined to the distal ends of the pinnae, the junction between the dead shrivelled tissue and healthy tissue being abrupt.

Almost all the damaged plants were producing new fronds by February 1962. However, on the slopes between quadrat 8 and Big Green Hill (figures 4 and 5, Part I) and on top of the Main Cliffs behind the volcano, the fronds, old and young alike of some of the plants were badly damaged. In a few cases even the youngest, unexpanded fronds were completely injured and withered. Figure 40, plate 44 shows a stand of *Blechnum* near Big Green Hill. The badly damaged fronds contrast markedly with the healthy ones shown in figure 39.

4·23. *Phormium tenax* J. R. & G. Forst.

Phormium tenax (New Zealand flax) is cultivated in quantity in the Settlement. The stout plants, grown close together, act as windbreaks. However, the principal use is for thatching the cottages of the islanders. The very fibrous leaves, which can reach a length of over 2 m, are very suitable for such a purpose. Particularly luxuriant specimens of *Phormium* were seen on Nightingale Island. On the main island plants are to be found away from the Settlement only at Stony Hill.

Table 32. Quadrat lists from *Phylica arborea* and *Blechnum palmiforme* communities

Cover-abundance figures follow the Domin scale. Vascular plants not found in the quadrats but occurring within 3 m of the edges of the quadrats are indicated *. Alien plants are shown †. No cover-abundance figures are given for bryophytes or lichens, all of which indicated ×. Micro-lichens were not collected.

Bryophytes occurred as epiphytes on *Phylica* and *Blechnum* in quadrats 5, 7, 8, 12 and 13, as did the two species of *Hymenophyllum* in the latter three quadrats and the lichen *Pseudocyphellaria intrictata* var. *thouarsii* in all quadrats except 2 and 3.

	on the Cliffs								on the Base				
quadrats (5 m square)	1	2	3	4	5	6	10	11	7	8	9	12	13
altitude (m)	210	240	240	240	300	330	240	240	720	690	750	750	690
aspect	W	E	N	NW	NW	NW	N	NW	N	N	N	N	N
slope (degrees)	46	53	45	44	42	45	44	44	20	20	*ca.* 5	15	*ca.* 5
soil depth (cm)	16	15	33	38	18	27	15	32	112	36	90	70	70
height of dominant (m)	1·0	1·5	1·0	2·0	2·0	1·5	1·0	2·0	1·5	2·5	1·0	1·0	1·0
Phylica arborea Thouars	7	8	7	7	8	8	7	7	8	9	—	—	—
Blechnum palmiforme (Thouars) C. Chr.	—	—	—	—	*	*	—	—	6	3	9	8	10
Empetrum rubrum Vahl	4	4	5	7	4	+	5	3	*	—	5	5	—
†*Holcus lanatus* L.	—	—	2	5	5	6	2	+	*	*	2	4	—
Carex thouarsii Carmichael	—	1	1	*	1	—	+	+	+	—	+	2	—
Nertera granadensis (Mutis) Druce	—	—	+	+	1	—	—	—	—	1	3	2	—
†*Rumex acetosella* L.	—	—	—	—	—	+	—	—	*	*	—	3	—
Scirpus thouarsianus Schult.	—	1	1	+	—	+	—	+	—	+	—	—	—
†*Poa pratensis* L.	1	3	3	3	—	5	—	—	—	—	—	—	—
Spartina arundinacea (Thouars) Carmichael	—	4	—	—	*	*	3	—	—	—	—	—	*
†*Chrysanthemum leucanthemum* L.	—	—	—	1	—	2	—	—	—	—	—	—	—
Scirpus sulcatus Thouars	—	—	—	—	1	—	—	—	+	—	—	—	—
†*Agrostis* sp.	—	4	—	—	—	—	—	—	—	—	—	—	—
†*Gnaphalium luteoalbum* L.	—	—	—	—	—	1	—	—	—	—	—	—	—
Centella asiatica (L.) Urb.	1	—	—	—	—	—	—	—	—	—	—	—	—
†*Plantago lanceolata* L.	—	—	—	+	—	—	—	—	—	—	—	—	—
Uncinia compacta R. Brown	—	—	—	—	—	—	—	—	*	—	3	4	1
Deschampsia sp.	—	—	—	—	—	—	—	—	—	—	—	2	—
Lagenophora nudicaulis (Comm. ex Lam.) Dus.	—	—	—	—	—	—	—	—	—	—	2	—	—
Uncinia brevicaulis (Thouars) Thouars	—	—	—	—	*	—	—	—	—	*	—	—	*
Hydrocotyle capitata Thouars	—	*	—	—	—	—	—	—	—	—	—	—	—
†*Cynodon dactylon* (L.) Pers.	*	—	—	—	—	—	—	—	—	—	—	—	—
†*Mariscus congestus* (Vahl) C.B.Cl.	—	*	—	—	—	—	—	—	—	—	—	—	—
†*Rumex obtusifolius* L.	—	—	—	—	—	—	—	*	—	—	—	—	—
Carex insularis Carmichael	—	—	—	—	—	—	—	*	—	—	—	—	—
Blechnum penna-marina (Poir.) Kuhn.	3	5	6	6	5	4	4	4	1	3	—	1	1
Dryopteris aquilina (Thouars) C. Chr.	—	—	—	—	—	1	—	—	4	7	—	2	1
Elaphoglossum laurifolium (Thouars) Moore	—	—	—	—	4	—	—	—	—	—	3	—	—
Histiopteris incisa (Thunb.) J. Sm.	—	—	—	—	—	—	—	—	—	1	+	—	—
Elaphoglossum succissifolium (Thouars) Moore	4	1	3	4	5	—	1	4	—	—	—	—	—
Hymenophyllum aeruginosum (Poir.) Carmichael	1	—	—	+	1	1	—	2	—	—	—	—	—
H. peltatum (Poir.) Desv.	—	—	—	1	—	1	—	—	1	—	—	—	—
Rumohra adiantiformis (Forst. f.) Ching	—	—	—	—	—	—	4	9	—	—	—	—	—
Blechnum australe L.	—	*	—	—	—	1	—	*	—	—	—	—	—
Elaphoglossum obtusatum (Carm.) C. Chr.	—	—	—	1	—	—	—	—	—	—	—	—	—
Lycopodium diaphanum Sw.	—	—	—	—	2	—	*	—	—	—	—	—	—
Gymnogramma cheilanthoides (Sw.) Kaulfuss	—	—	—	—	*	—	—	—	—	*	—	*	—
Adiantum poiretii Wikstr.	—	—	—	—	—	*	—	—	—	—	—	—	—

Breutelia tenuifolia (Mitt.) Par.	—	—	—	—	×	—	—	—	—	—	×	×	×
Campylopus introflexus (Hedw.) Brid.	—	×	—	×	—	×	—	—	—	—	—	—	—
C. vesticaulis Mitt.	—	—	—	—	×	—	—	—	—	—	×	×	—
Campylopus sp.	—	×	—	—	—	—	×	—	—	—	—	—	—
Cyclodictyon laete-virens Hook. and Tayl.	—	—	—	—	—	—	—	—	—	×	—	—	—
Dicranoloma harioti (C.M.) Par.	×	—	—	×	×	—	—	—	—	—	×	—	—
Drepanocladus uncinatus (Hedw.) Warnst.	—	—	—	—	—	—	—	—	—	—	×	—	—
Eustichia longirostris (Brid.) C.M.	—	—	×	×	—	—	—	—	—	—	—	—	—
Hypnum cupressiforme Hedw.	—	×	—	—	—	—	—	—	—	—	—	—	—
H. elatum Dix.	—	—	—	—	—	×	—	—	—	—	—	—	—
Polytrichum juniperinum Hedw.	×	×	×	—	—	×	×	—	—	—	—	—	—
Ptychomnion densifolium (Brid.) Jaeg.	—	—	—	—	×	—	—	—	×	—	×	×	—
Rhacomitrium crispulum (H. f. & W.) H. f. & W.	—	—	—	—	—	—	×	—	—	—	—	—	—
Rhynchostegium isopterygioides Card.	—	—	—	—	—	—	—	—	—	×	—	—	—
Rigodium crassicostatum (Dix.) Bartr.	—	—	—	—	—	—	—	—	—	×	—	—	—
Syrrhopodon atlanticus Dix.	—	—	—	—	—	×	—	—	—	—	—	—	—
Thuidium curvatum Mitt.	×	×	×	—	×	—	—	×	×	—	×	×	—
Adelanthus magellanicus (Ldgb.) Spr.	—	—	—	—	×	—	—	—	—	—	—	—	—
A. unciformis (Mitt.) Schiffn.	—	—	—	—	—	—	—	—	—	—	×	×	—
Anastrophyllum incumbens (Lehm. et Ldgb.) Arnell	—	—	—	—	×	—	—	—	—	—	—	—	—
A. crebrifolium (Tayl.) Steph.	—	—	—	—	—	—	—	—	—	—	×	—	—
Anthoceros sp.	—	—	—	×	—	—	—	—	—	—	×	—	—
Bazzania skottsbergii (Steph.) Fulf.	—	—	—	—	×	—	—	—	—	—	—	—	—
Calypogeia cf. *peruviana* Nees.	—	—	—	—	—	—	—	—	—	×	—	—	—
Cephaloziella tristaniana Arnell	—	—	—	—	—	—	—	—	—	—	×	—	—
Clasmatocolea vermicularis (Lehm.) Grolle	—	—	—	—	—	—	—	—	—	×	—	×	—
Drepanolejeunea tristaniana Arnell	—	—	—	—	—	—	—	—	×	—	—	—	—
Frullania stipatiloba J. & St.	—	—	—	—	—	—	—	—	×	—	—	—	—
F. tristaniana Arnell	—	—	—	—	—	—	—	—	×	—	—	—	—
Isotachis striolata Steph.	—	—	—	—	—	—	—	—	—	—	—	×	—
Jamesoniella grandiflora (Lehm. et Ldgb.) Spr.	—	—	—	—	×	—	—	—	—	—	—	×	—
Lepidozia procumbens Mitt.	—	—	—	×	×	×	—	—	—	×	×	×	×
Lophocolea anomoda (Mont.) Steph.	—	—	×	×	—	—	—	—	—	—	—	—	—
L. cunninghami Steph.	—	—	—	—	—	—	—	—	—	×	×	×	—
L. puccioana Steph.	—	—	—	—	—	—	—	—	—	—	—	×	—
L. chiloensis Steph.	—	—	—	—	×	—	—	—	—	—	—	—	—
L. submuricata Hery.	—	—	—	—	—	—	—	—	×	—	—	—	—
Metzgeria sp.	—	—	—	—	—	—	—	—	×	—	—	—	—
Microlejeunea ulicina Spr.	—	—	—	—	—	—	—	—	×	—	—	—	—
Mylia chiloscyphoides Ldgb.	—	—	—	—	—	—	—	—	—	—	×	—	×
Neohodgsonia mirabilis (H. Perss.) H. Perss.	—	—	—	—	—	—	—	—	—	×	—	—	—
Pagiochila infuscata Mitt.	—	—	—	—	×	—	—	—	—	—	—	—	—
P. fuscobrunnea Steph.	—	—	—	—	—	—	—	—	—	—	—	—	
Radula fernandeziana Steph.	—	—	—	—	×	—	—	—	—	—	—	—	—
Riccardia savaiteri (Steph.) Evans	—	—	—	—	—	—	—	—	—	×	×	—	—
Symphogyna hymenophylla (Hook.) Nees & Mont.	—	—	—	—	—	—	—	—	—	—	—	—	×
Telaranea sejuncta (Ångstr.) Arnell	—	—	—	—	×	—	—	—	—	—	—	—	—
Cladonia sp.	—	—	—	—	×	—	—	—	—	—	—	—	—
litter	—	—	—	—	—	—	—	—	9	6	8	7	10
rock	—	7	—	—	—	4	7	—	—	—	—	—	—
washed down stones	—	—	6	3	—	4	6	—	—	—	—	—	—
volcanic ash	8	—	—	—	—	—	—	—	—	—	—	—	—
larger pyroclastics	2	—	—	—	—	—	—	—	—	—	—	—	—
number of species in quadrat	10	14	13	19	26	18	11	10	15	16	23	21	9

Without exception, the plants of *Phormium* in the Settlement were badly damaged by the fumes. Young and old leaves alike were affected. The damage was confined to a more or less broad zone along the margins and at the tips of the leaves. Injured areas had a bleached appearance (figure 43, plate 45). Inflorescence, which had been growing at the time of damage, were severely injured in such a way that the peduncles and unopened flowers had withered, and the former assumed a drooping instead of the normal erect position (figure 43, plate 45). In some cases, almost all the peduncle was affected, while in others only the upper part was damaged, with an abrupt junction between the dead and surviving tissue. A small patch of *Phormium*, growing at the foot of the bare Main Cliffs shown on figure 33, was very severely damaged. What little green tissue remained was confined to the lowermost parts of the leaves.

4·24. *Various angiosperms and pteridophytes*

Within the area of maximum fume damage, all species of vascular plants, without exception, were affected by the volcanic gases. Figure 33 shows the major plant communities within this area. Brief descriptions of the damage to vascular plants of the grassland, various other communities and of the understories of *Phylica* bush follow.

Blechnum penna-marina and *Empetrum rubrum* occur abundantly under open *Phylica* bush (table 32). In many cases, the pinnate, dark green fronds of *Blechnum penna-marina*, which reach a length of no more than 10 cm in the areas investigated, showed damage confined to the tips and margins of the pinnae. The fronds of plants growing in and around quadrats 1 and 2 (figure 33) were turned completely brown.

Injured plants of *Empetrum* had leaves yellowish or brown in colour, instead of the normal dark green. Only a few plants in the vicinity of the volcano and in the community at Pigbite (figure 33) were completely affected. Plants with much foliage remaining green could be found at quadrats 10 and 11, and in the *Empetrum–Rumohra* community on the slopes at the foot of the Main Cliffs, east of the volcano (figure 33). Fronds of the fern *Rumohra adiantiformis* (Forst.) Ching in this community had the tips of the fronds brown and shrivelled. As far away as the area marked 14 on figure 33, where there is well-developed *Blechnum penna-marina* sward, the plants of *Blechnum* showed symptoms of fume damage. However, *Empetrum* plants appeared to be very little affected.

On the slopes and rock faces in the region of quadrats 1 and 2, *Agrostis* sp., *Acaena sarmentosa* (Thouars) Carm., *Carex thouarsii* Carm., *Centella asiatica* (L.) Urb., *Chevreulia sarmentosa* (Pers.) Blake, *Gnaphalium luteoalbum* L., *Hydrocotyle capitata* Thouars., *Mariscus congestus* C. B. Cl., *Poa pratensis* L., *Spartina arundinacea* Carm., *Scirpus thouarsianus* Schult., *Asplenium obtusatum* Forst. f., and *Elaphoglossum succissifolium* (Thouars) Moore were brown and withered. It was only near quadrats 1 and 2, that *Cynodon dactylon* (L.) Pers. showed symptoms (bleached, withered leaves), which were probably due to fume damage. At Pigbite and in the grassland between the Village and the western side of the lava field (figure 33), *Cynodon* appeared little, if at all, damaged.

4·25. *Bryophytes and lichens*

Bryophytes and lichens, especially, are well known to be sensitive to atmospheric pollution (Vareschi 1936; Jones 1952; Barkman 1958). Because of the similarity between pollutants and volcanic gases, notably sulphur dioxide, it is probable that these plants are equally sensitive to volcanic fumes.

In the region of maximum fume damage (figure 33) neither bryophytes nor lichens were abundant either on rocks or as epiphytes on the low, shrubby *Phylica* bushes. No liverworts occurred in quadrats 1, 2, 10 and 11, and bryophytes were found to be much more abundant on the Base than on the Main Cliffs (table 32). On the slopes immediately behind the volcano, *Polytrichum juniperinum* Hedw. was the only common moss. Others present included, *Thuidium curvatum* Mitt., *Hypnum cupressiforme* Hedw., *Dicranoloma harioti* (C.M.) Par., and *Campylopus introflexus* (Hedw.) Brid. The large, foliose lichen, *Pseudocyphellaria intricata* var. *thouarsii* Wainio, was the only epiphyte on the *Phylica* bushes of the area of maximum fume damage.

In the field, difficulty arises in assessing the health of bryophytes and lichens, because of the diminutive size of many of the plants and their ready ability to change shape or colour or both, according to the moisture available. The scarcity of bryophytes and lichens in the area of maximum fume damage made it still more difficult to assess the state of these plants. Little more can be said than that none of the species examined showed any signs of growth.

Polytrichum juniperinum is a species of sufficiently large size and was of frequent enough occurrence to make observation fairly easy. In all specimens examined, the leaves had turned yellowish or brown except for a few of the apical ones, and even some of these retained their original green colour only partially. During September 1962, Mr H. G. Stableford made a small collection of healthy, actively growing shoots of this species from the lower slopes of the Main Cliffs close to the volcano.

Outside the area of maximum fume damage, and on the Base in particular, bryophytes and lichens appeared to be growing and undamaged.

5. Selective effect of the fumes

5·1. *General*

The selective effect of atmospheric pollution on plants is well known. Tolerances to sulphur dioxide varying widely from species to species have been described by numerous authors including Zimmerman & Crocker (1934) and Katz (1939). Selective effects of volcanic emanations on vegetation have been reported from various areas of the world.

In his account of the vegetation of New Zealand, Cockayne (1928, p. 192) briefly describes a community called solfatara manuka shrubland. He indicates *Leptospermum ericoides* A. Rich., *Cyathodes fasciculata* (Forst. fil.) Allan, (*Leucopogon fasciculatus* A. Rich) and *Lycopodium cernuum* L. as being tolerant of fumes. In the vicinity of sulphur springs in Java, the shrubs *Agapetes vulgaris* Jugh. and *Rhododendron retusum* Benn were found to be completely covered by a yellowish deposit from sulphurous fumes (Holtermann 1907). These species must be highly resistant to the fumes. The fumes released by the 1929 eruption of Komagatake, Japan, killed *Betula platyphylla* var. *japonica*. *Quercus crispula* proved resistant (Yoshii 1932).

After the 1957 eruption of Manam volcano in New Guinea, selective killing of certain tree species, notably *Albizzia* and *Canarium* spp., took place (G. A. Taylor, private communication). Howard (1962) has made a thorough survey of the fumaroles of the Lesser Antilles and the reaction of the vegetation to fumes. Certain species, e.g. *Clusia* spp., *Lycopodium* spp., *Pitcairnia* spp., were found to be markedly more tolerant of fumes than others, e.g. *Cyathea* spp., *Peperomia* spp., and *Weinmannia* spp. The fumes released during the 1954 glacier burst of Grímsvötn, Iceland, were especially harmful to *Sorbus aucuparia* L. (Thorarinsson 1954).

Of the indigenous species of Tristan, *Phylica arborea* and *Blechnum palmiforme* showed symptoms of fume damage most clearly. On the Base, these two dominants alone were affected. There are about forty species of trees, shrubs and herbaceous plants cultivated in the Settlement. Weeds are numerous (Part II, §6). The fumes affected many of the trees and shrubs badly, but did not harm the herbaceous species.

5·2. *Indigenous plants*

Table 31 shows the estimations of damage to *Phylica*. In and around quadrat 8 which lies on the Base, 2·4 km east of the volcano (figure 32), 95 out of 100 bushes were 100% damaged. *Blechnum palmiforme* plants were all severely injured. No other species exhibited any observable damage (table 32). At quadrat 7, 3·2 km away from the volcano, 40 out of 50 *Phylica* bushes were more than 50% affected and *Blechnum* showed clear symptoms of fume damage. As before, no other species appeared injured. Figure 42, plate 44 shows an area just west of Big Green Hill (figure 33). The green foliage of *Empetrum rubrum* presents a marked contrast to the brown, damaged foliage of *Phylica* and *Blechnum*. No *Empetrum* plants appeared to be damaged. Such was the case with all plants of this species on all parts of the Base which were studied.

In the region of quadrats 3 and 4, which are situated on the Main Cliffs southwest of the volcano, only *Phylica* and *Blechnum* were injured by the fumes.

The sensitivity of the dominants, *Phylica* and *Blechnum*, is partly responsible for the shape of the area of fume-damaged vegetation. Nowhere did the effect of the fumes extend beyond the upper altitudinal limit of *Blechnum*. Between quadrats 12 and 7 (figure 32), the boundary of fume damage coincided with the upper limit of *Blechnum*.

5·3. *Cultivated plants*

The Settlement Plain, which is fully exposed to the very strong winds characteristic of of the climate of Tristan, has proved to be an unsuitable habitat for imported trees. Dyer (1938) states that 460 trees and 240 shrubs were planted on Tristan in 1937. The few remaining today are indicated in the list below. In the Settlement, where the cottages and especially the administration buildings and *Phormium tenax* plantations provide some shelter, various trees and shrubs have been planted and grown successfully. At Sandy Point, on the more sheltered side of the island, there are plantations of pines and eucalypts.

The differing effect of the fumes from species to species of the trees and shrubs in the Settlement was very striking. Some species were very badly affected, perhaps killed, while others seemed little, if at all, affected. The very marked damage to *Phormium tenax* has been described (§4·23). Other species which suffered most severely were: *Acacia* sp. (several small trees), *Cupressus macrocarpa* Hartweg (one large tree planted 1937 and two young plants), *Eucalyptus cornuta* Labill (one tree planted 1937), *E.* cf. *globulus* (one young plant), *Leptospermum laevigatum* F.V.M. (one bush planted 1937), *Leucadendron argenteum* R.Br. (two trees), *Persea americana* Mill. (three small trees), *Pinus* sp. (several small trees), *Quercus cerris* L. (one young tree), *Ulex europaeus* L. (one small bush) and *Myoporum insulare* R.Br. (one bush planted 1937).

The trees of *Persea* and *Acacia* were completely defoliated, and the *Leucadendron* trees were almost so, those leaves which remained being withered (figures 44, 45, plates 45 and 46). *Eucalyptus cornuta, Leptospermum,* the pines and the young *Cupressus* plants, all had the foliage persistent but turned completely brown. The large *Cupressus* was in little better state, only a few very small branches surviving. *Eucalyptus* cf. *globulus, Myoporum, Ulex* and *Quercus,* all had badly affected branches.

The following species seemed least affected by the fumes: *Ficus carica* L. (one small tree), *Hibiscus* sp. (one shrub), *Malus sylvestris* Mill. (several trees), *Metrosideros collina* (Forst.) Gray (one tree), *M. excelsa* Sol. ex Gaertn (several trees), *Salix babylonica* L. (several small trees), and *Salix caprea* × *cinerea* (a few young plants). With the exception of *Ficus* and *Hibiscus,* these plants exhibited damage, probably due to the fumes but, in all cases, the injury was slight, e.g. the trees of *Salix babylonica* had a few young, leafless branches which appeared to be dead.

Observations made from the helicopter of H.M.S. *Protector* showed that at Sandy Point *Phylica* trees were damaged and photographs taken by those members of the expedition who landed there showed damaged pines. There is no reason to suppose that this injury was due to any cause other than the fumes.

Various herbaceous plants are grown in the gardens of the Settlement, e.g. *Dahlia* sp., *Calendula officinalis* L., *Tropaeolum majus* L., *Lathyrus odoratus* L., *Canna indica* L. Vegetables such as *Solanum tuberosum* L., *Rheum rhaponticum* L., *Pastinaca sativa* L., *Brassica oleracea* L., and *Cucurbita pepo* L. are cultivated, all but the first in small quantity. None of these plants showed any sign of fume damage, nor did any of the numerous weeds, e.g. *Rumex obtusifolius* L., *Digitaria sanguinalis* (L.) Scop., *Mariscus congestus* C.B. Cl., *Poa annua* L., *Polycarpon tetraphyllum* (L.) L., *Stellaria media* (L.) Vill. and *Verbena officinalis* L.

The selective nature of the damage to the plants in the Settlement gives strong evidence against drought being the cause of any serious injury (§4·1). If the deficiency of rainfall had such a marked effect as to severely injure, and in some cases kill, various tree and shrub species, the herbaceous plants would have been very badly damaged also. The selective damage is best explained by the passage of fumes through the Village, perhaps only for a few hours, at a concentration sufficiently high to injure the foliage of the trees and shrubs. The fumes may not have been present at ground level in concentration great enough to damage low-growing species. Moreover, many herbs in the gardens were just beginning to grow for the new season when the volcano erupted and hence may have escaped injury. However, it may be that some of the weeds, vegetables and garden plants were damaged by the fumes but, by the time of arrival of the expedition, were recovered to such an extent that the injury passed unnoticed.

6. Recovery of the damaged plants

6·1. *Indigenous plants*

With two exceptions mentioned below, no completely fume damaged *Phylica* bushes growing in the area of maximum fume damage or elsewhere showed any sign of recovery during February and March 1962. The observations made by Mr H. G. Stableford (private communication) during September 1962 indicated that any recovery of the bushes in the area of maximum fume damage was certainly not of a substantial nature. It seems probable that many of these are dead. However, caution is necessary in making such an assertion because *P. arborea* has the ability to develop shoots from the widely spread roots. Even bushes with completely dead foliage may be able to recover by suckering from the roots.

Pillans (1942) in his monograph of the genus *Phylica* makes no mention of the development of adventitious shoots in *P. arborea* or any of the 147 other species. None of the previous literature on Tristan botany deals with root suckers of *P. arborea.* Adventitious shoots were most readily observed on bushes growing on the shallow soils of the Main Cliffs.

Two completely damaged *Phylica* bushes growing high on the east facing slopes of Hottentot Gulch were found to have numerous new shoots sprouting from the base of the stems. Elsewhere outside the area of maximum fume damage, as at quadrats 7 and 8, though they showed no such recovery, the majority of completely damaged bushes may survive the injury. They were found to have the tissues at the base of the stems still alive. This was deduced from the ease of peeling of the bark and the appearance of the exposed tissues. However, judged by such a criterion, few of the bushes in the area of maximum fume damage were still alive. The bark peeled off with difficulty and the exposed tissues appeared dry.

Between April and December 1963 Mr Stableford observed much sprouting from the stem bases of young bushes.

As described above (§2·2), small areas of *Phylica* bush were set alight by pyroclastics. Under burned bushes of quadrats 1 and 2 (figure 33), small numbers of seedlings of *Phylica* were discovered. They had pushed their way through a layer of ash 1 cm thick. The largest were no more than 3·5 cm high and still bore cotyledons. The first, very small foliage leaves with the recurved margins and pubescent surfaces characteristic of the species were enough to ensure certain identification. The only seedling to be found elsewhere, occurred under the completely fume damaged bushes of quadrat 11 (figure 33).

Few, if any, of the plants of *Blechnum palmiforme*, even the most severely injured, appeared to have been killed by the fumes. Almost all had started to develop new fronds by February 1962 (figure 40, plate 44), and were continuing to grow during September 1962 (Stableford, private communication).

Blechnum penna-marina (Poir.) Kuhn and *Hydrocotyle capitata* Thouars were the only indigenous species in and around quadrats 1 and 2 (table 32) which were producing new leaves by February 1962. *Elaphoglossum succissifolium* (Thouars) Moore, *Hymenophyllum aeruginosum* (Poir.) Carmichael, *Spartina arundinacea* (Thouars) Carmichael, *Empetrum rubrum* Vahl and *Scirpus thouarsianus* Schult showed no signs of recovery. However, the rhizomes of the first-named species appeared still alive. By September 1962, the last-named species had recovered (Stableford, private communication).

The observations given above suggest that the complete recovery of the plants of the Base and the Main Cliffs outside the area of maximum fume damage will take place rapidly. Even in areas close to the volcano, such as quadrats 1 and 2, where it is probable that *Phylica* bushes are dead, regeneration of this species by seed may take place swiftly. However, the recovery of the plants in the area of maximum fume damage may be retarded as a consequence of soil erosion and continual liberation of fumes by the volcano. The widespread roots of *Phylica* bushes help to bind the shallow soils of the steep slopes of the Main Cliffs. If the bushes have been killed by the fumes, it may be that the loss of stability of the soils will be such that extensive erosion will ensue. The volcano may continue to liberate fumes in sufficient volume to damage plants, at least those growing on the slopes nearest the craters.

6·2. *Cultivated plants*

The numerous cultivated plants grown in the Settlement are listed above (§5·3) and *Phormium tenax* is given special mention (§4·23). During February and March 1962, *Phormium* was not making any recovery. However, Mr Stableford (private communication) found that during September 1962 the plants were producing vigorous new growth. Of the badly fume damaged trees and shrubs the following were recovering by February 1962: *Acacia* sp., *Eucalyptus cornuta*, *Persea americana*, *Pinus* sp. New shoots were appearing from the trunks and main branches of a few of the *Acacia* trees, the *Eucalyptus*, two of the *Persea* trees and one of the larger pines (figures 44, 46, plates 45 and 46).

It appears that the *Leucadendron* trees, the *Leptospermum* and the *Ulex* bush are dead (Stableford, private communication).

6·3. *Lowland grassland*

The rhizomatous grass, *Cynodon dactylon*, is one of the few species in the area of maximum fume damage (figure 33), which appeared to have suffered little set-back as a result of the eruption. Indeed, many of the plants may have continued to grow throughout the eruption.

Figure 33, shows the area of grassland, dominated by *Cynodon*, adjacent to the western side of the lava field. The dense sward of *Cynodon* extends right to the edge of the lava, and does not appear to have caught fire, nor did the plants show any other sign of being harmed by the presence of the lava. In some places, shoots could be found growing vigorously between the blocks of fresh lava. Eggler (1948) lists *Cynodon dactylon* as one of the species unaffected by the very close proximity of lava flows, which were a year old at the time of the investigation.

The area covered by rubble of pyroclastics just to the west of the volcano (figure 33) is being colonized actively by *Cynodon* (figure 47, plate 47). For a short distance immediately behind the peripheral cone, the ground has an almost complete cover of pyroclastic material, ranging from ash and lapilli to much larger fragments of bombs. *Cynodon*, the only living species present, has succeeded in growing up through as much as 15 cm of fine debris. Eggler (1948) states that *Cynodon* was the most abundant species on the $2\frac{1}{2}$ year-old ash fields, deposited by the volcano Paricutin. The species survived burial by up to 50 cm of ash.

The lowermost slopes of the Main Cliffs immediately behind the volcano have a covering of ash (figure 33). Apart from *Cynodon*, few other species showed signs of growth, viz. *Centella asiatica* (L.) Urb., *Poa pratensis* L. and *Rumex frutescens* Thouars. These species were almost certainly killed back to soil level and owe their recovery to their rhizomes.

TABLE 33. DIATOMS FROM BIG WATRON AND THE NEW LAVA

Species marked * were found in the gatherings from both localities, the remainder only from Big Watron.

Achnanthes coarctata Breb.
**A. lanceolata* (Breb.) Grun.
  *var. *rostrata* (Ostrup) Hustedt
**A. minutissima* Kutz.
  var. *cryptocephala* Grun.
**A.* nov.sp.
Cymbella helvetica Kutz.
  var. *compacta* Ostrup.
C. ventricosa Kutz.
Denticula tenuis Kutz.
Diatoma hiemale (Lyngbye) Heiberg.
Diploneis peterseni Hust.
Frustulia rhomboides (Ehr.) de Ton.
  var. *saxonica* (Rab.) de Ton.
F. vulgaris Thw.
Gomphonema angustatum (Kutz.) Rab.
  var. *linearis* Hust.
G. constrictum Ehr.
**G. longiceps* Ehr.
  *var. *subclavata* Grun.
  fo. *gracilis* Hust.
**G. parvulum* (Kutz.) Grun.
  var. *subelliptica* Cl.
  nov.var.
Hantzschia amphioxys (Ehr.) Grun.
Navicula cincta (Ehr.) Kutz.
N. contenta Grun.
  var. *biceps* Arnot.
N. cryptocephala Kutz.
N. gregaria Donk
N. mutica Kutz.
N. perpusilla Grun.
N. rhyncocephala Kutz.
N. rostellata Kutz.
N. variostriata Krasske
N. bryophila Petersen
  var. *lapponica* Hust.
**N. radiosa* Kutz.
**Nitzschia amphibia* Grun.
N. fonticola Grun.
N. frustulum (Kutz.) Grun.
N. linearis W. Sm.
N. palea (Kutz.) W. Sm.
  var. *tenuirostris* Grun.
Neidium bisulcatum (Lagerst.) Cl.
Melosira granulata (Ehr.) Ralfs.
**M. roeseana* Rab.
Meridion circulare Ag.
Pinnularia appendiculata (Ag.) Cl.
P. fasciata (Lag.) Hust.
P. gentilis Donk.
**P. kneukeri* Hust.
**P. borealis* Ehr.
**P. major* (Kutz.) Cl.
**P. subcapitata* Greg.
**P. viridis* (Nitz.) Ehr.
**Rhopolodia gibberula* (Ehr.) Müller
Surirella ovata Kutz.
S. angustata Kutz.
**Fragilaria bicapitata* A. Mayer
F. capucina Desmazieres
**F.* nov.sp.
**F. construens* (Ehr.) Grun.
  var. *venter* (Ehr.) Grun.
Amphora ovalis Kutz.
  var. *libyca* Ehr.
Anomoeoneis serians (Breb.) Cl.
  fo. *thermalis* (Grun.) Hust.
Cocconeis placentula Ehr.
Synedra ulna (Nitzsch) Ehr.
**S. affinis* Kutz.

The diatoms were determined by Mr J. B. Carter who will describe the new species of *Achnanthes* and *Fragilaria* and the new variety of *Gomphonema parvula* elsewhere.

7. PLANT COLONIZATION OF THE ERUPTIVE CENTRE

Due to a special circumstance the first plant colonization of the new lava took place very rapidly. The western lobe of the lava field (the third flow) lies parallel to the former sea-cliffs (figure 33). For a length of some 100 m blocks of new lava rest against the cliffs. A stream, called Big Watron by the islanders, falls over the cliffs and splashes on to the blocks of lava, which, being constantly wet, have developed a growth of a filamentous green alga. No other plants were to be seen elsewhere on the new lava during February and March 1962.

A photograph taken by Harris & Le Maitre (1962) during a visit on 16 and 17 December

1961 shows the third flow about 50 m away from Big Watron, which must have been cut off soon afterwards, probably during the latter part of December or the early part of January 1962 at the latest. When discovered on 19 February 1962, the green alga had been present on the blocks for a week at least. The colonization of the new lava had taken place within 7 weeks at the most.

The alga which formed the conspicuous growth is a species of *Stigeoclonium*, perhaps *S. tenue* Kuetzing. The material which was collected on 6 March 1962 has filaments 1 to 2 mm long. This species was not found amongst a gathering of algae from the rocks of Big Watron, which yielded *Oedogonium* sp., *Zygnema* sp., *Spirogyra* sp. and a species of *Nostoc*, perhaps *N. fuscescens* F. E. Fritsch. Abundant diatoms were found amongst the gatherings of filamentous algae, the most frequent in descending order being, *Gomphomena loniceps* Ehr., *Achnanthes lanceolata* var. *rostrata* (Ostrup) Hustedt, *Fragilaria* nov.sp., *Gomphonema parvulum* (Kutz) Grun. and *Achnanthes* nov.sp. (table 33).

By April 1963 further colonization of the new volcano had taken place (Stableford, personal communication). At least eight species of angiosperms were growing on the western side of the main cone (table 34). Mosses had invaded three areas (the place described above and two on the western slope of the main cone). Details of the mosses which include *Funaria hygrometrica*, new to the archipelago, will be published elsewhere.

Table 34. Angiosperms collected from the new volcano by Mr H. G. Stableford

Cerastium holosteoides	*Poa annua*
Chrysanthemum leucanthemum	*Rumex acetosella*
Cynodon dactylon	*Scirpus thouarsianus*
Gnaphalium luteoalbum	*Trifolium* cf. *dubium*

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FIGURE 35. Mudflow on the slopes behind the volcano. Ash covers the ground on both sides of the mud.

FIGURE 36. Burnt *Phylica* bushes of quadrat 1. Seedlings of *Phylica* were found growing through the ash which covered the ground.

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FIGURE 37. The Main Cliffs from the edge of the Base at Burntwood. Hillpiece in the distance. Undamaged semi-natural *Phylica* bush.

FIGURE 38. The Main Cliffs behind the volcano. All vegetation badly damaged by the fumes.

FIGURE 39. *Blechnum palmiforme* scrub of quadrat 12. Plants free of damage.

FIGURE 40. Very badly fume-damaged plants of *Blechnum*. East side of Big Green Hill.

FIGURE 41. Badly fume-damaged bush of *Phylica* near Big Green Hill. A few branches on the left have escaped injury.

FIGURE 42. Undamaged *Empetrum rubrum*, right, contrasting with *Blechnum*, left, and *Phylica*, background, both badly injured. East side of Big Green Hill.

FIGURE 43. Fume-damaged *Phormium tenax*. Margins and tips of the leaves as well as peduncles dead.

FIGURE 44. A tree of *Persea americana* defoliated by the fumes. Numerous new shoots sprouting from the trunk and main branches. Undamaged tree of *Metrosideros* sp., right background.

FIGURE 45. A tree of *Leucadendron argenteum* killed by the fumes. Many of the leaves have fallen.

FIGURE 46. A pine very badly affected by the fumes. New shoots growing from a few of the branches.

FIGURE 47. *Cynodon dactylon* spreading over rubble of pyroclastics close to western edge of main cone.

FIGURE 48. The lower slopes behind the volcano. *Rumex frutescens* growing from undamaged rhizomes.