STUDIES IN THE LICHENS OF THE AZORES. PART 2 - LICHENS OF THE UPPER SLOPES OF PICO MOUNTAIN. A COMPARISON BETWEEN THE LICHEN FLORAS OF THE AZORES, MADEIRA AND THE CANARY ISLANDS AT HIGH ALTITUDES

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The lichen flora of the upper slopes of Pico, the major mountain in the Azores, is described between altitudes 1200-2300 m. Two distinct floristic zones are recognised: an upper, species poor, zone from 1500-2300 m above the inversion layer and a lower, more species diverse, zone from 1200-1500 m dependent on the persistence of the cloud layer. 49 species are reported, 14 of which are new records for the Azores, including two which are newly described: *Ochrolechia azorica* and *Stereocaulon macaronesicum*. The lichen communities above the cloud layer, dominated principally by species of *Stereocaulon* and *Placopsis gelida* are compared with those of other documented floras of Macaronesian islands at high elevations. The paucity of species on the upper slopes of Pico is considered to be primarily the result of the isolation of the Azores, the recent nature of the substrate and severity of the climatic conditions.

PURVIS, O.W., C.W. SMITH & P.W. JAMES 1994. Estudo dos líquenes dos Açores. Parte 2 - Líquenes das encostas de altitude da montanha do Pico. Comparação entre as floras de líquenes de altitude das ilhas dos Açores, Madeira e Canárias. *Arquipélago.* Ciências Biológicas e Marinhas 12A:35-50. Ponta Delgada. ISSN 0870-6851.

Descreve-se a flora de líquenes das encostas altas do Pico, a maior montanha dos Açores, entre os 1200 - 2300 m de altitude. Reconhecem-se duas zonas florísticas distintas: uma elevada, entre os 1500-2300 m, acima da camada de inversão, pobre em espécies, e uma zona baixa, entre os 1200-1500 m, com maior diversidade específica, dependente da persistência da faixa de nuvens. Registaram-se 49 espécies de líquenes, 14 das quais são novas ocorrências para os Açores, incluíndo duas que se descrevem de novo: *Ochrolechia azorica* e *Stereocaulon macaronesicum*. Compara-se a comunidade de líquenes acima da faixa de nuvens do Pico, dominada principalmente por *Stereocaulon* e *Placopsis gelida*, com as floras documentadas de altitude de outras ilhas da Macaronésia. Considera-se que a escassez de espécies de líquenes nas encostas de altitude do Pico é, em primeiro lugar, o resultado do isolamento recente dos Açores, mas também da natureza recente do substracto e das severas condições climatéricas.

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INTRODUCTION

The lichen flora of the Azores has been relatively poorly studied and, except for a few papers on the discovery of particular species, there has been little attempt to describe the predominant lichen communities (PURVIS & JAMES 1993). There are few published records of lichens collected on the upper slopes of Pico. However, DEGELIUS (1941) reported that Dr H. Persson collected *Cladonia pyxidata*, *Erioderma wrightii* Tuck. (as *E. leylandii* (Taylor) Müll. Arg.) and *Pseudocyphellaria crocata* in a small crater at *c*. 1350 m. In addition, *Stereocaulon flavireagens* Gyeln. (= *S. macaronesicum* Purvis & P. James, see below) was reported as occurring from 600-2000 m. More recently, APTROOT (1989) recorded *Coelocaulon aculeatum* and *Placopsis gelida* from near the summit at 2200 m.

By contrast the lichen floras at higher elevations in Tenerife (TOPHAM & WALKER 1982) and Madeira (ARVIDSSON & WALL 1985) are better known. Even so, with the exception of Las Cañadas del Teide (TOPHAM 1982), no attempt has been made to describe the predominant lichen communities specifically occurring in these areas.

The objective of this paper, the second in this series, is to list the dominant lichens and describe the major communities occurring on the upper slopes of Pico emphasising the saxicolous and terricolous communities. An account of the corticolous lichen flora of the relict scrub forests at lower altitudes is in preparation.

The study area

Pico is a major island, *c*. 15 by 45 km, within the central group of the Azores (Fig. 1). The principal physical feature of the island, the active volcano Pico (2351 m), is by far the highest mountain in the Azores (Fig. 2), none of the other islands reaching half its height. Its cone rises abruptly from the sea, the slopes on the north and east exceeding an angle of 40°. The principal cone terminates in a shallow caldera, *c*. 3 km wide and 60 m deep, from the centre of which a secondary cone, symmetrical in shape, comprising scoriae and lava, rises over 60 m above the crater rim. There are signs of continuing volcanic activity as at the summit the ground is warm in places and there are holes from which hot vapours issue (TUTIN 1953).

Though the peak often appears concealed by cloud when viewed from lower altitudes this does not imply that the summit is cloud-capped. In fact the upper third of the mountain often rises well above the main cloud layer and is exposed to the full impact of the sun. Tradewind-induced, orographic clouds commonly form at 900 - 1370 m on the northern slopes with a thinner layer, at 1370 - 1520 m on the southern side creating a rain shadow effect. Throughout the warmer months the cloud base tends to ascend during daylight hours, and the afternoon and evenings are usually less cloudy than during the early morning (ANON 1945).

The climate of the Azores is oceanic with comparatively small seasonal fluctuations in temperature and rainfall at sea level. Annual precipitation is c. 1054 mm at sea level in Faial (the adjacent island to Pico) increasing about 16% for every 100 m increase in altitude (SJÖGREN 1978) up to a more-or-less well-developed inversion layer. However, rainfall is very low towards the summit above the cloud layer. The mean high temperatures in the Azores range between 15-23°C at sea level and the diurnal variation rarely exceeds 7°C (ANON 1945), but it would be much more variable above the inversion layer. The adiabatic lapse rate is 5°C per 1000 m, suggesting a temperature at the summit of between 3-11 °C. Above 1600 m frosts may occur in any month of the year, though they are very rare in summer. In the three coldest months, January to March, frosts occur regularly above 1860 m, occasionally down to 1200 m and very rarely as low as 600 m. Snow can persist on the upper slopes in sheltered, shaded places until mid summer (TUTIN 1953).

Pico is the most recent island in the Azores and evolved 250,000 years ago. The last major volcanic activity on Pico occurred in 1718 when there were large and frequent eruptions on the

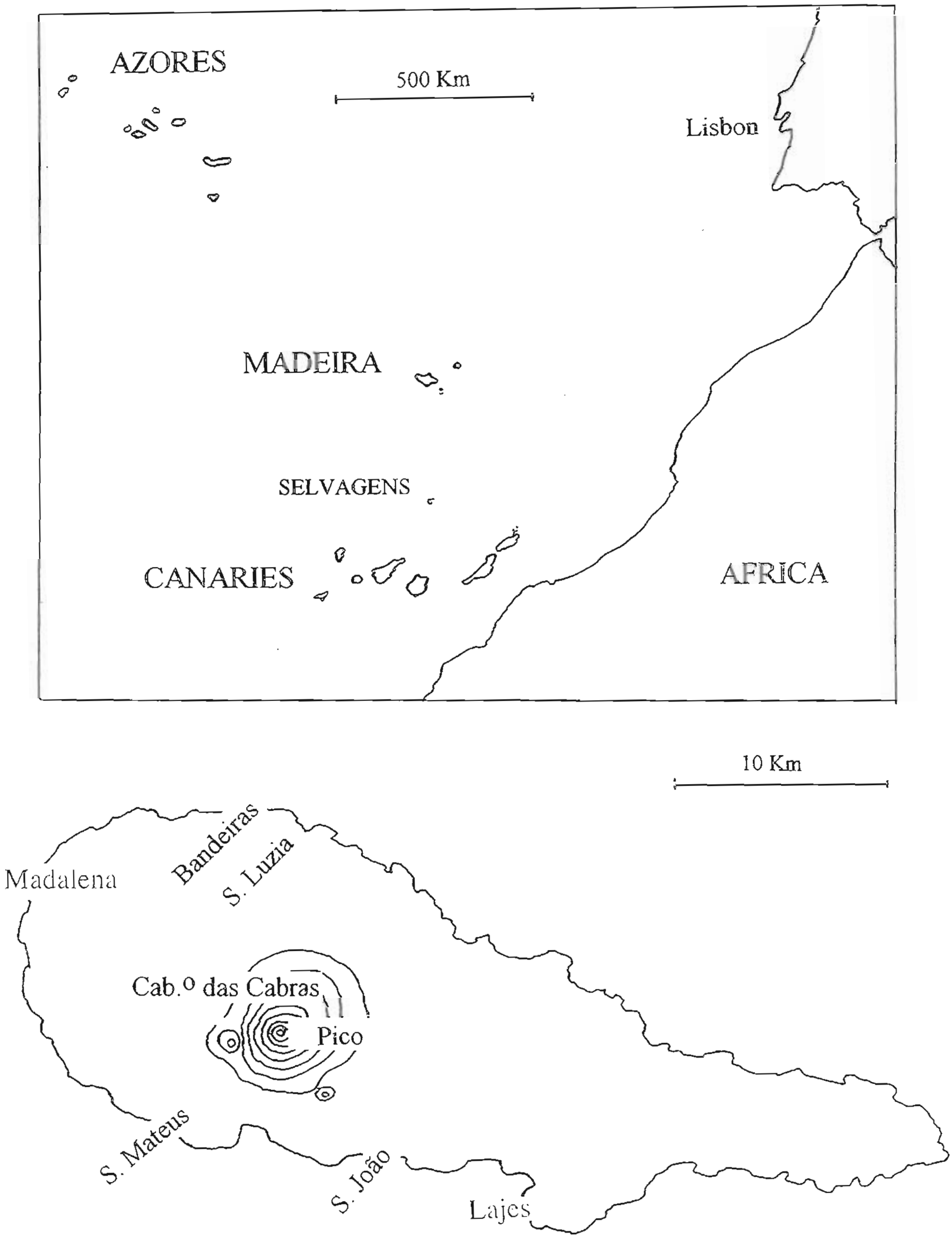

Fig. 1. Atlantic islands with Pico enlarged below.

Fig. 2. Pico from air showing characteristic cloud formation around mid flanks and exposed upper cone.

southern side of Pico, especially between S. Mateus and S. João, and S. Luzia and Bandeiras, with many lava flows and the building of several large cinder and scoriae cones. In 1720, a massive lava flow occurred at Soldão near Lages (ANON 1945). The lavas are basaltic and include much unstable pyroclastic material.

The vegetation above 1200 m falls into two broad zones. The lower of these two zones supports the upper remnants of the Juniperion brevifolii alliance at 1200 m and gives way to a *Calluna vulgaris-Daboecia azorica-Thymus caespititius* zone above 1500 m (SJÖGREN 1973). This Callunetum is a ± open, species-poor community and grows on steep and rather unstable slopes of volcanic debris interspersed with little-weathered and nearly bare lava. Near the summit *Calluna* has a creeping, wind-swept habit and never grows more than a few centimetres high. The rocks at the summit are in many places covered with the arctic-alpine liverwort *Gymnomitrium adustum* Nees (TUTIN 1953); *Andreaea alpina* Hedw. is also present at its only location in the Azores (E. Dias, pers. comm.).

MATERIALS AND METHODS

Two of the authors (Purvis and Smith) climbed the upper slopes of Pico on 4 May 1993 from the beginning of the trail at 1200 m at Cabeço das Cabras on the WNW side of Pico. The trail rises steeply along the western slope, the path veering to the south at 2200 m from where the ascent of the rest of the summit cone was made on the south side. The lichen vegetation was sampled at approximately 150 m intervals.

Observations and measurements of lichens were made following procedures outlined in PURVIS et al. (1992). A list of lichens recorded is given (Table 1); author citations follow BRUMMIT & POWELL (1992) and are presented in full (Table 1); full author citations are also given for lichens the first time they are mentioned in the text but which are not indicated in Table 1. Higher plant nomenclature follows SJÖGREN

(1973, 1984) and that for lichens conforms to recent taxonomic papers. A small number of crustose species remain to be identified which will be referred to in future papers. Material is deposited in BM; some duplicates at University of Hawaii (HAW) and additional specimens at the Department of Agricultural Sciences, University of Azores, Terceira.

Chemical analyses were performed using standard methods of thin layer chromatography (CULBERSON 1972, WHITE & JAMES 1985). Two solvent systems TDA (Toluene : dioxan : acetic acid; 180:45:5) and G (Toluene : ethyl acetate : formic acid; 139:83:8) were routinely used.

RESULTS

Lichen flora of the upper cloud zone, 1200-1500 m

At the beginning of the trail at 1200 m scattered, stunted remnants of the native forest belonging to the Juniperion brevifolii alliance (SJÖGREN 1973) exist as an elfin forest up to 2 m tall. *Erica azorica* and *Calluna vulgaris* scrub is dominant with scattered *Juniperus brevifolia*, *Ilex perado* ssp. *azorica* as well as a ground flora comprising several grasses including *Deschampsia foliosa*,

Table 1

Alphabetical list of lichen species of upper slopes of Pico mountain

1 *Amygdalaria pelobotryon* (Wahlenb.) Norman
2 *Baeomyces rufus* (Huds.) Rebent.
3 *Biatora* sp.
4 *Bryophagus gloeocapsa* Nitschke ex Arnold
5 *Buellia* sp.
6 *Caloplaca* sp.
7 *Cladonia azorica* Ahti
8 *C. cervicornis* (Ach.) Flotow
9 *C. diversa* Asperges
10 *C. merochlorophaea* Asah.
11 *C. pyxidata* (L.) Hoffm.
12 *C. stereoclada* des Abb.
13 *C. subcervicornis* (Vainio) Kernst.
14 † *Coelocaulon aculeatum* (Schreber) Link
15 * *Epigloea soleiformis* Döbbeler
16 * *Epilichen scabrosus* (Ach.) Clem.
17 § *Erioderma leylandii* (Taylor) Müll. Arg.
18 *Gyalidea hyalinescens* (Nyl.) Vezda
19 *Gyalideopsis muscicola* P. James & Vezda
20 *Hypotrachyna endochlora* (Leighton) Hale
21 * *Lecanora polytropa* (Hoffm.) Rabenh.
22 * *Lecidea hypnorum* Lib.
23 * *Lecidella scabra* (Taylor) Hertel & Leuckert
24 * *Leptogium lichenoides* (L.) Zahlbr.
25 *Micarea peliocarpa* (Anzi) Coppins & R. Sant.
26 *Moelleropsis nebulosa* (Hoffm.) Gyeln.
27 *Mycoblastus caesius* (Coppins & P. James) Tønsb.
28 * *Ochrolechia azorica* Purvis, P. James & Brodo
29 *Parmelia saxatilis* (L.) Ach.
30 *Peltigera lactucifolia* (With.) Laundon
31 *P. melanorhhiza* Purvis, P. James & Vitik.
32 *Placopsis gelida* (L.) Lindsay
33 *Platismatia glauca* (L.) Culb. & C. Culb
34 * *Porpidia cinereoatra* (Ach.) Hertel & Knoph
35 * *P. crustulata* (Ach.) Hertel & Knoph
36 * *P. macrocarpa* (DC.) Hertel & Scwab
37 * *P. musiva* (Körber) Hertel & Knoph
38 * *P. platycarpoides* (Bagl.) Hertel
39 * *P. tuberculosa* (Sm.) Hertel & Knoph
40 § *Pseudocyphellaria crocata* (L.) Vainio
41 *P. intricata* (Del.) Vainio
42 *Rhizocarpon obscuratum* (Ach.) Massal.
43 *Stereocaulon azoreum* (Schaerer) Nyl.
44 *S. leucophaeopsis* (Nyl.) P. James & Purvis
45 *S. macaronesicum* Purvis & P. James
46 * *Toninia thiopsora* (Nyl.) H. Olivier
47 *Trapeliopsis flexuosa* (Fr.) Coppins & P. James
48 *Verrucaria* cf. *papillosa* Ach.
49 *V.* cf. *nigrescens* Pers.

* = new record for Azores
† = recorded by APTROOT (1989), not refound during this survey
§ = recorded by DEGELIUS (1941), not refound during this survey
The numbers refer to the species numbers indicated in Fig. 3.

Holcus lanatus and *Anthoxanthum odoratum*, the club-moss *Diphasiastrum madeirense* (J.H. Wilce) J. Holub and the moss *Racomitrium lanuginosum* (Hedw.) Brid. Macrolichens are scarce and virtually all epiphytic; *Platismatia glauca* and *Hypotrachyna endochlora* are the dominant foliose species, whilst *Cladonia azorica* is locally frequent on the ground in sheltered areas. Crustose species are also rather rare, much wood being in fact devoid of lichens, though *Mycoblastus caesius* and *Trapeliopsis flexuosa* are relatively frequent on wood and *Gyalideopsis muscicola* widespread on tufts of *Hypnum* spp. on *Erica*. *Stereocaulon azoreum* and *S. macaronesicum* are the dominant colonists of pebbles and small lava outcrops with *Placopsis gelida* and *Gyalideopsis hyalinescens*.

At higher elevations (1340 m) the ground flora becomes significantly more sparse than at the start of the trail: a *Calluna vulgaris*-*Daboecia azorica* heath land with *Deschampsia* and scattered *Erica*. The most diverse lichen habitat observed on the trail was associated with a spatter cone where over half of the species recorded were found (Fig. 3, Table 1). The outside of the cone supported a wide range of mainly crustose species, including *Baeomyces rufus*, *Gyalidea hyalinescens*, *Moelleropsis nebulosa*, *Placopsis gelida*, *Rhizocarpon obscuratum*, several species of *Porpidia*, *Stereocaulon leucophaeopsis* and *Toninia thiopsora* as well as a few macrolichens: *Cladonia* species, *Peltigera lactucifolia*, *Stereocaulon azoreum* and *S. macaronesicum*. Within the sheltered interior of the cone, the infrequent phanerogam *Ranunculus cortusifolius* occurs together with an extensive assemblage of lichens, most of which are typical at lower altitudes within the laurisilva and which were not found elsewhere on the trail, including the macrolichens *Cladonia subcervicornis*, *Leptogium lichenoides*, *Peltigera melanorrhiza* and *Pseudocyphellaria intricata* as well as a range of crustose species including an unidentified species of *Buellia*, *Lecidella scabra*, *Porpidia platycarpoides* and *Verrucaria* cf. *papillosa*.

Lichen flora above cloud zone, 1500-2300 m

At 1520 m, a *Calluna/Thymus* heath with scattered, dwarf *Erica* clumps but few or no

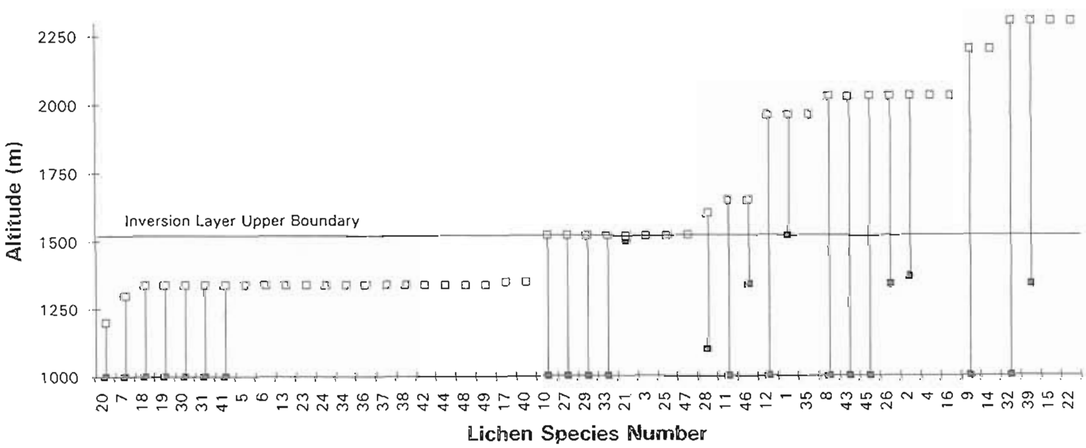

Fig. 3. Distribution of lichens on upper slopes of Pico.

grasses supported few epiphytes, notably *Platismatia glauca* and *Parmelia saxatilis* with an unidentified species of *Biatora* and fertile specimens of *Ochrolechia azorica*. Saxicolous species present include *Amygdalaria pelobotryon, Baeomyces rufus, Lecanora polytropa, Parmelia saxatilis, Placopsis gelida*, rust-coloured specimens of *Porpidia crustulata* as well as *Stereocaulon azoreum* and *S. macaronesicum*.

Above this altitude to the summit, epiphytic species become extremely rare, though *Ochrolechia azorica* was recorded on *Calluna* up to 1600 m. The higher plant vegetation also becomes progressively more sparse, above 1900 m it is reduced to prostrate mats of *Calluna/Thymus* with *Racomitrium. Daboecia* is rare on the extensive, unstable areas of clinker-like a'a' lava (Fig. 4). The lichen communities above this altitude are characterised by an increasingly stunted assemblage of *Stereocaulon* species together with the less conspicuous crustose *Amygdalaria pelobotryon*, *Placopsis gelida*, *Porpidia crustulata*, and *P. tuberculosa*. All these species are confined to the more stable pahoehoe lava, the clinkery a'a' lava being virtually devoid of lichens probably the result of its unstable nature. The muscicolous *Bryophagus gloeocapsa* and saxicolous *Epilichen scabrosus* were noted in the shelter of a boulder on a single occasion at 2030 m and several species of *Cladonia*, mostly rather poorly developed, are also confined to this habitat; foliose lichens were absent. At 2300 m, at least 50% of the rock surfaces are bare. Here the terricolous *Epigloea soleiformis* and *Lecidea hypnorum* were present in association with the psoromic acid-containing strain of *Cladonia cervicornis*.

DISCUSSION (with a comparison for other Macaronesian island groups)

There are essentially three distinct distributions of lichens on the upper slopes of Pico; (1) those which are confined to below the inversion layer

Fig. 4. Wind-blasted *Thymus caespititius* / *Daboecia azorica* heath near summit of Pico.

(30 taxa represented), (2) those found only above the inversion layer (7 taxa represented); and (3) those occurring over the whole range (12 taxa represented) (Fig. 3). The greatest diversity of lichens occurs at lower elevations, particularly at the spatter cone (Fig. 3) where there is the greatest range of habitats including sheltered, moist niches on stable rock surfaces. This area also lies within the area of frequent cloud cover, experiences a more consistently humid environment, and is subject to lesser extremes of temperature than above the cloud layer. Several species which are typically epiphytic within the relict cloud forest below, are here saxicolous, such as members of the normally foliose Lobarion community, including species of *Leptogium*, *Peltigera* and *Pseudocyphellaria*. Above this zone the phanerogamic flora becomes increasingly stunted with a corresponding reduction in lichen diversity and a paucity of macrolichens, probably as a consequence of the extremely inhospitable environment above the cloud layer. Interestingly, there are very few species from lower elevations that exist above the inversion layer, a reflection of ecological factors such as low rainfall, exposure to widely different temperatures, and high insolation all of which create an inhospitable environment for lichen growth except, perhaps, in shaded situations. The lichen flora above the inversion layer towards the summit is extraordinarily poor in species and includes as dominants a small number of crustose and fruticose lichen pioneers having cyanobacterial photobionts in external cephalodia, viz. *Amygdalaria pelobotryon*, *Placopsis gelida*, *Stereocaulon azoreum* and *S. macaronesicum*, as well as the saxicolous *Porpidia crustulata* and *P. tuberculosa*; *Epilichen scabrosus* and *Lecanora polytropa* are rare. Many of these species occur within a fairly broad altitudinal range from above the cloud layer to towards the summit (Fig. 3). Moreover, this flora shows a close resemblance to that of oceanic mine spoil heaps with abundant scoriae resulting from the smelting of ore material. The flora above the inversion layer on Pico probably represents a more widely distributed, cosmopolitan element than the lichen flora occurring below the cloud layer; terricolous species are restricted to sheltered habitats, such as shaded rock crevices and beneath boulders. There is a notable absence of *Herteliana taylorii* and *Rhizocarpon hochstetteri* above the cloud zone, two particularly frequent saxicolous species in the cloud forest below. The sparse flora observed above the upper cloud base on Pico contrasts dramatically with similar peaks of other Macaronesian islands e.g. Tenerife and Madeira.

Tenerife, situated near the centre of the Canary Islands archipelago in the mid-Atlantic, west of southern Morocco, is dominated by the dormant volcano, Pico del Teide (3718 m high), considerably higher than Pico. It is one of the younger of the Canary Islands having been formed about 5 million years ago. The top of the cloud base occurs at a higher level than on Pico, at above 1970 m; the peak itself is often above the upper limit of the north easterly trades. From the caldera, Cañadas del Teide (2250 m) to the summit (3550 m), TOPHAM (1982) reports 50 species though additional collections were made by previous authors (PITARD & HARMAND 1912, KLEMENT 1965, FOLLMANN & SÁNCHEZ-PINTO 1981). However, the summit of the peak of Teide was reported as very poor in species, only *Lecanora polytropa* being collected. A contributing factor to this scarcity of lichens might be the deleterious effect of sulphurous gaseous emissions from volcanic fumaroles. At the level of the Teide 'crater' floor, which lies at a similar altitude to that of the summit of Pico, the lichen cover is often very local in crevices or sheltered niches, areas away from surfaces exposed to excessive insolation, persistent drought or wind blast, factors deleterious to most forms of plant life. Precipitation primarily occurs as snowfall in the winter months and the position of the meltwater and seepage flows is clearly of the greatest importance to the saxicolous flora. Significantly, the most diverse habitats occur on shaded, north-facing cliffs. Major crustose lichen genera recorded including brightly coloured (*Acarospora*, *Caloplaca*, *Candelariella*, *Dimelaena*, *Rhizocarpon* (*geographicum* group) or pruinose species (*Acarospora*, *Aspicilia*, *Buellia*), including several macrolichens such as *Lasallia* and *Umbilicaria*, all species with photo-protective mechanisms to shield photobionts from excessive levels of illumination.

Madeira is situated about 450 km north of the Canaries and 600 km west of the coast of Morocco. The highest mountain, Pico Ruivo, reaches 1860 m, significantly lower than Pico but like Pico having a similar, though less extreme pattern of an early clear cloudless summit followed by the development of orographic misty cloud during late morning between altitudes of 500 and 1300 m. The resulting precipitation maintains the water flow in the levadas which are a feature of the upper slopes of Madeira. Thus, compared with Tenerife, the climate in Madeira is much more humid and would therefore be expected to be generally favourable to lichen colonisation and growth. In fact above 1500 m, a wide range of predominantly crustose species were reported (e.g. KALB & HAFELLNER 1992) but also several macrolichens including *Hypogymnia tubulosa* (Schaerer) Havaas and *Leptogium resupinans* Nyl. (ARVIDSSON & WALL. 1985). Personal observations of the authors along the track from Achada do Teixeira to Pico Ruivo confirm that, unlike the situation in the Azores on Pico, *Erica* (*E. arborea*) grows to about 1.5 m tall right to the summit, where the *Lobarion* persists at sheltered bases. Species present include: *Leptogium burgessii* (L.) Mont., *Leptochidium albociliatum* (Desm.) M. Choisy, *Leptogium corniculatum* (Hoffm.) Minks, *Lobaria pulmonaria* (L.) Hoffm., *L. scrobiculata* (Scop) DC., *L. virens* (With.) Laundon, *Massalongia carnosa* (Dicks.) Körber, *Nephroma laevigatum* Ach., *Pannaria mediterranea* C. Tav., *Parmeliella jamesii* S. Ahlner & P.M. Jørg, *Peltigera collina* (Ach.) Schrader, *P. membranacea* (Ach.) Nyl., *Psoroma hypnorum* (Vahls) S. Gray, *Polychidium muscicola* (Swartz) Gray and *Pseudocyphellaria crocata* (L.) Vainio. The tree canopy is dominated by *Hypogymnia maderensis* (Tav.) Hawksw., *Platismatia glauca* (L.) Culb. & C. Culb. and *Pseudevernia furfuracea* (L.) Zopf with occasional *Alectoria sarmentosa* (Ach.) Ach., *Hypogymnia tubulosa* (Schaerer) Havaas, *Letharialla canariensis* (Ach.) Krog, *Ochrolechia androgyna* (Hoffm.) Arnold and *O. szatalaënsis* Vers. Conditions here appear to favour growth of lichens over mosses. A further factor influencing the composition of lichen communities within the cloud zone is that of grazing. On Pico Ruivo the ground flora has few or no grasses whereas on Pico they are an important component up to *c.* 1340 m, including several introduced species for cattle grazing. Burning, selective scrub clearance and disturbance from grazing have had a dramatic impact on the vegetation of Pico with a reduction in the number of shrubs and consequent decrease in the availabilty of substrates for lichens, or else terricolous lichens may become smothered by invasive grasses. An analagous situation was observed by one of us (Smith) in Hawaii Volcanoes National Park where scrubland at *c.* 1200 m had 20 years ago an almost continuous groundcover of *Cladina skottsbergii*, *Stereocaulon ramulosum* and a species of *Stereocaulon* attributed to *S. vulcani*. Following the introduction of the alien grass *Andropogon virginicus*, lichens were unable to compete and virtually disappeared. However, neither burning nor clearance of elfin scrub appears to have been carried out at higher levels (above 1500 m) on Pico as this area has little or no agricultural value. Towards the summit of Pico Ruivo, poorly vegetated areas on clinker-like pyroclastics are much more reminiscent of those on the higher slopes of Pico and support far fewer lichen species, including *Epilichen scabrosus* (Ach.) Clem., *Placopsis gelida* in many forms, *Stereocaulon vesuvianum* Pers., *S. leucophaeopsis* (Nyl.) P. James & Purvis, *Trapelia involuta* (Taylor) Hertel and *Trapeliopsis wallrothii* (Flörke ex Sprengel) Hertel & G. Schneider, contrasting sharply with the the smoother, stable andesitic formations more frequent at slightly lower levels which support a far more diverse lichen flora which merits closer examination.

Explanations for the differences in the composition of the lichen floras seen on the mountain summits of these Atlantic islands may be due to one, or more probably, a combination of factors. These include: climatic, in which fluctuations in temperature and the amount and persistence of moisture regimes are important; the degree of exposure and presence of shelter, e.g. shrub cover; variations in niche structure; the physical and chemical nature of the substrate; the distance from nearest land masses acting as sources for inoculation either through wind or dispersal by birds along migratory routes; and their age and the last period and intensity of volcanic activity which could result in the local extinction of particular species or the local deleterious effect of volcanic gases.

Concerning climate, in view of the more southerly location of Madeira and the Canaries and their proximity to the African mainland, it might be expected that their climate would be significantly warmer than the Azores. However, the Azores are on the southern edge of the warm North Atlantic Drift, Madeira is at the commencement of, and the Canaries within, the south-westward drift of the Canary current. Thus, in spite of lying some 600 miles to the south, the temperature of the surface water of the western Canary Islands is similar to that in the Azores and that of the eastern Canaries is cooler mainly due to the upwelling of cold water that occurs off the African coast between Tangier and Cape Verde. Thus the surface waters of the Azores is usually 3 to 5° warmer than the average of the ocean in these latitudes, while that of the Canaries is between 2 and 4° colder than the average warmth of surface waters at these latitudes.

The only notable continental influence on the climate of the three island groups is the hot, dry dusty weather that often accompanies easterly and south-easterly winds. This influence is strongest in the Canaries when dry easterly winds may bring dust from Africa during all seasons of the year. It has weakest impact in the Azores, but in Madeira dry easterly winds occasionally occur between July and September. However, very little dust, if any, falls on the peak of Tenerife at heights above 2730 m. Pico del Teide is often above the upper limit of the north easterly trades and a definite westerly current is common at heights exceeding 2420 to 2730 m. The Azores, situated in the mid-Atlantic (Fig. 1) with dominantly westerly winds is also not on major bird migratory routes. The chances of air-borne lichen propagules arriving on Pico must therefore be smaller than on similar mountains in Tenerife and Madeira. Furthermore, in view of its younger age there has been less time for colonisation.

It is probable therefore that a combination of factors, including variation in niche diversity, particularly in relation to the type and stability of rocks as well as the predominant wind patterns and the closer proximity of Teneriffe and Madeira to the north-west African coast might explain the richer diversity of lichens observed above the cloud layer on these islands as compared with the lower diversity in the Azores. However, the lichen flora of the north-west African coast is relatively poorly documented making such comparisons difficult. In the case of Madeira the more humid climate at upper altitudes must also play an important role in enabling the colonisation and growth of a greater range of species. However, it is to be expected that a more intensive study of high ground on Pico would reveal further species, particularly on the more stable surfaces of cliffs beneath the summit cone, though access is here difficult. A fuller analysis of the lichen floras, including a detailed study of primary (sexually reproducing) and secondary (asexually reproducing) species, occurring in a wider range of habitats on these and other islands will be necessary to establish their relationships and possible origins.

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APPENDIX

Ochrolechia azorica **Purvis, P. James & Brodo**

Thallus tenuis vel sat crassus, albus vel cinereus; soralia granulata, dispersa, discreta, interdum irregularia, 0.3-0.8 mm in diam.; apothecia 0.5-1(-1.5) mm diam., discis dilute luteo-aurantiacis vel testaceis, epruinosis vel leviter pruinosis, marginibus aequatis, laevibus haud prominentibus, thecio 200-230 µm alto, hypothecio *c.* 130 µm crasso, strato algaro infra hypothecium continuo, cortice plerumque distincto, radiato; ascosporae 55-70(-75) x 25-31 µm. Thallus acidum variolaricum continens, apothecia acidum variolaricum et gyrophoricum continentia.

Typus: Azores: Pico, NW slopes of Pico, *c.* 3 km S. of road EN3, through Cerrado de Sonicas, S. of track leading to aerial, alt. 1000-1150 m [site 24], 11 April 1992, O.W. Purvis & P. James (BM - holotypus) (Fig. 5).

Thallus thin to moderately thick, ± continuous, smooth, only irregularly fissured through cracking of underlying substrate, membranous, white to grey-white, spreading, often encircling twigs and small branches; prothallus absent or inconspicuous, white, sorediate. Soralia *c.* 0.3-0.8 mm diam., scattered and widely dispersed, rarely 2- to 3-confluent, rounded, excavate, appearing ulcerose with a ± ragged rim, sometimes becoming erumpent, convex-efflorescent, concolorous with thallus or pale yellow-grey; soredia ± coarsely granular, 0.1-0.15 mm diam. Apothecia 0.5-1(-1.5) mm diam., occasional, mostly discrete and widely dispersed, rarely 2- to 3-contiguous, sessile throughout; disc pale yellow-orange or flesh-coloured, smooth to ± scabrid, ± translucent, not or very sparingly white-pruinose, concave at first becoming ± plane; margin persistent, thick, smooth, ± tumid, even or occasionally angular through mutual pressure. Pycnidia rare, 0.2-0.4 mm diam., low-conical with a flattened apex.

Photobiont cells green, 9-10 µm diam., forming a distinct and continuous algal layer, 20-50 µm tall beneath hypothecium with scattered, subcontinuous radiating clumps in the outer margin just proximal to a rather well-developed cortical region; photobiont layer, thalline margin and medulla densely granular, granules dissolving in K. Thecium 200-230 µm tall, ± colourless, pale grey-brown, semi-opaque and densely granular for upper ca. 90 µm, partly dissolving in K leaving a thin layer of crystals ca. 10-15 µm below upper edge (surface of disc), non-granular below, paraphyses densely branched and anastomosed. Hypothecium ca. 130 µm thick, pale yellow-brown, ± unchanged in K, granular inclusions absent. Asci cylindrical-clavate, (1)2- to 4-spored, uniformly thin-walled. Ascospores 55-70 (-75) x 25-31 µm, ellipsoid, ovoid or rarely ± weakly reniform, colourless, simple, wall uniformly thin, 1.5-2 µm thick. Conidia bacilliform, 4.5-5.5 x 1 µm.

Chemistry: apothecial and thallus cortex and soralia K-, C+ yellow, KC+ yellow; apothecial disc K-, C+ red, KC+ red, Pd-. Contains variolaric acid in the apothecial and thallus cortex and soralia, variolaric and gyrophoric acids (with a trace of lecanoric acid) in the apothecial disc, and lichesterinic and protolichesterinic acids in the thallus and/or apothecia.

Apparently restricted to decorticated wood above an altitude of *c.* 1000 m on Pico where it occurs principally on *Erica azorica* in the uppermost zone of the Juniperion brevifolli alliance and at higher elevations (to at least 1600 m) on dead stems of *Calluna vulgaris* in the Callunetum in very exposed situations. Associated species present include: *Cladonia azorica*, (crustose primary thallus), *Lecanora farinaria* Borrer, *L.* aff. *strobilina* (Sprengel) Kieffer, *L. symmicta* (Ach.) Ach. agg., *Loxospora elatina* (Ach.) Massal., *Micarea peliocarpa* (Anzi) Coppins & R. Sant., *Mycoblastus fucatus* (Stirton) Zahlbr. (= *M. sterilis* Coppins & P. James, *Parmelia saxatilis*, *Pertusaria pulvinata* Erichsen, *Sphaerophorus globosus* (Huds.) Vainio, *Thelotrema lepadinum*

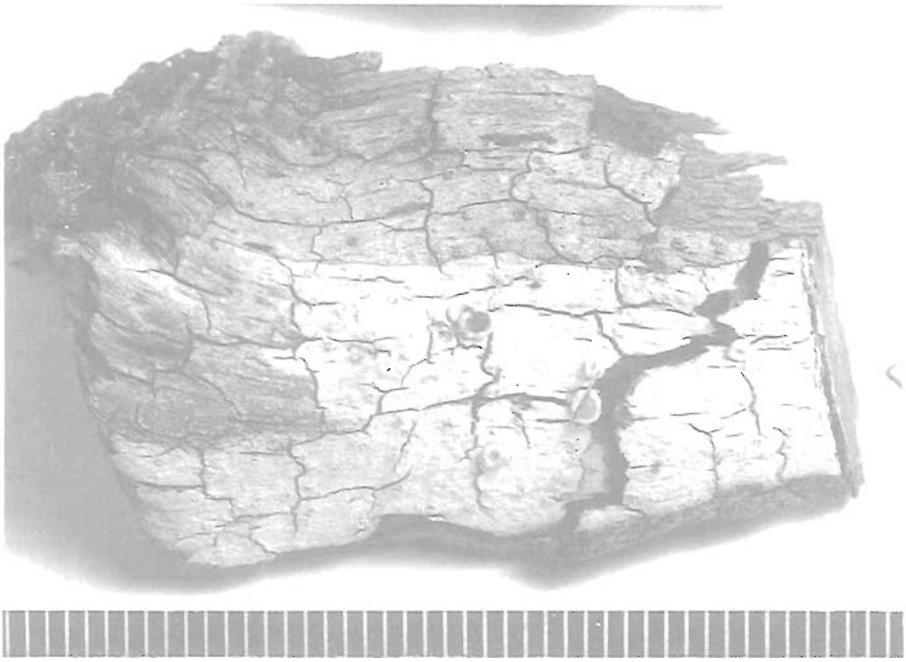

Fig. 5. *Ochrolechia azorica* (part of holotype). Scale in mm.

(Ach.) Ach. and *Trapeliopsis flexuosa* (Fr.) Coppins & P. James.

Ochrolechia azorica is characterised by the small, scattered, punctiform, ulcerose, marginate soralia containing granular soredia; the soralia resembling those of *Caloplaca ulcerosa* Coppins & P. James and *C. obscurella* (Lahm ex Körber) Th. Fr. The thin, even, smooth, white thallus, margins of the sessile apothecia and soralia contain variolaric acid (C+ yellow); in addition the disc contains gyrophoric acid (C+ red). In longitudinal section the apothecia have a distinct and continuous photobiont layer below the hypothecium with scattered, somewhat radiately arranged photobiont clusters in the outer apothecial margin proximal to a well-developed cortical region. In this arrangement of the photobiont *O. azorica* resembles certain species in the *O. tartarea* aggregate, e.g. *O. subpallescens* Vers., as well as some in the *O. parella* aggregate e.g. *O. pseudopallescens* Brodo, and so this character alone can be used definitively assign *O. azorica* to one or the other group. In the *O. tartarea* group, the apothecial margin disc is characteristically smooth, as is that of *O. azorica*, but variolaric acid is only usually present in traces and the thallus is almost always C+ red (gyrophoric acid or one of the hiascic complex of acids). Variolaric acid is a major constituent of the *O. parella* and *O. upsaliensis* groups but species in these complexes have notably scabrose and densely white-pruinose apothecial discs. *O. alboflavescens* (Wulf.) Zahlbr. in the *O. parella* group has rounded, well-delimited soralia, but has larger apothecia with pruinose-scabrid discs and a more uneven, darker coloured thallus. In the *O. upsaliensis* group, the apothecial discs are notably scabrose and devoid of gyrophoric acid. The key to placing *O. azorica* must therefore rest on the fatty acid chemistry. In containing both protolichesterinic and lichesterininc acids, our new species has the same chemosyndrome as several members of the *O. parella* group (e.g. *O.*

pseudopallescens* and *O. alboflavescens*) unlike any species in the *O. tartarea* or *O. upsaliensis* groups (BRODO 1991), and we can therefore confidently relate it to that complex.

O. azorica appears to be endemic to the Azores, possibly restricted to Pico as this is the only island where the mountains exceed 1000 m. A similar species chemically, *O. szatalaënsis* Vers., which also contains variolaric, but lacks gyrophoric, acid in the apothecia, has recently been observed by the authors on *Erica arborea* on high ground in Madeira on Pico Ruivo. *O. szatalaënsis* further differs from *O. azorica* in lacking soralia and has densely white-pruinose apothecial discs and is so far unknown in the Azores, though is also present in the Canary Is. (BM).

BRODO (1991) draws attention to the fact that very few temperate corticolous species of *Ochrolechia* are widespread. Of approximately 31 species described, only 4 % are definitely known to occur in both Europe and North America. This is all the more surprising in view of the large number of species with asexual propagules. It would seem likely therefore, that recent speciation is relatively rapid in this genus as also in e.g. *Menegazzia*, and it is not inconceivable that *O. azorica* is restricted to Pico, particularly in view of its specialised habitat and the relatively remote location of the Azores. However, in view of our incomplete knowledge of the distributions of crustose lichens on atlantic islands, further study will be necessary to fully test this hypothesis.

Additional species of *O. azorica* examined: Pico: 11 km SE of Madalena, 1-1.5 km S. of road EN-3, Cerrado de Sonicas, cloud forest within sheltered gully and alongside deep craters, alt. 1100 m, 25 April 1993 [site 46], O.W. Purvis & P.W. James; along Pico trail to summit from Cabeço das Cabras on western side of Pico, alt. 1520 m, 4 May 1993 [site 65], O.W. Purvis & C.W. Smith; Along Pico trail to summit from Cabeço das Cabras on western side of Pico, alt. 1600 m, 4 May 1993 [site 65], O.W. Purvis & C.W. Smith.

***Stereocaulon macaronesicum* Purvis & P. James**

Typus. Pico: as *S. flavireagens* Gyeln. 600-1500 m, 7 May 1937, Herman Persson, det. Gunnar Degelius. (UPS-holotypus) (Fig. 6).

Stereocaulo vesuviano similis, sed phyllocladia centris non-fuscis et acidae lichenosae dissimile.

Pseudopodetia forming dense tufts, 5-10(-20) cm across, firmly attached to rock substratum, to 3 cm tall, erect or ± decumbent, robust, ± terete or somewhat flattened, simple or sparingly branched above, apices ± flexuose, grey or pinkish grey-white, ecorticate, without tomentum, surface ± coarsely striate or ridged. Phyllocladia coarsely nodular-granular, 0.3-0.8 mm diam., sparse or crowded, often in scattered, convex, individually rounded, glomerule-like clusters or becoming confluent, ± uniformly white-grey, lacking individual dark centres with a paler rim. Cephalodia apparently absent, though loosely associated, black, irregular tufts of *Stigonema* occasionally present intermingled between phyllocladia. Apothecia rare, 0.3-0.8 mm diam., pale to dark brown, convex, lateral, sessile, mainly attached towards apices of main branches; epithecium brown, thecium 45-60 µm tall, colourless; paraphyses mostly simple, apices sometimes with a dark brown cap; hypothecium pale yellow-brown; asci 8-spored. Ascospores (27-)35-45(-60) x 3-4 µm, narrowly fusiform, often attenuated towards one end, colourless, (1-)3-4 (-5) - septate.

Thallus K+ yellow-red, Pd + red, C- (norstictic and connorstictic acids and two unidentified compounds (rf 3 in TDA and C, red-orange and brown-yellow, Fig. 7).

Stereocaulon macaronesicum is characterised by the combination of its unique chemistry and form and disposition of the phyllocladia; morphologically it resembles *S. vesuvianum* but lacks the characteristic dark centres of the phyllocladia of that species. The pseudopodetia in fresh material are also more obviously tinged pinkish, contrasting with the phyllocladia which are starkly white-grey changing to a dull grey in the herbarium.

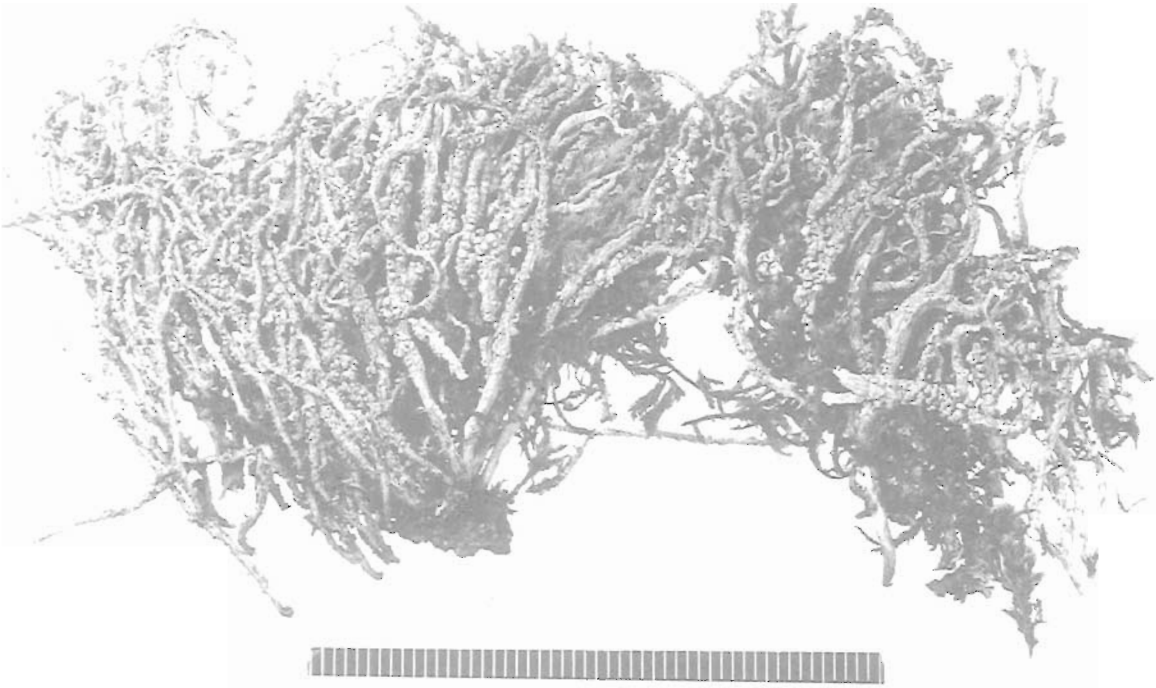

Fig. 6. *Stereocaulon macaronesicum* (part of holotype). Scale in mm.

Morphs in exposed situations, such as on boulders above the adiabatic zone, form more adpressed, compacted tufts, to 2 cm tall, with more decumbent and richly branched pseudopodetia; the phyllocladia are more densely crowded, becoming flattened and shield-like, often coalescing and forming a ± continuous cracked crust over the surface of the pseudopodetium, curving upwardly at the margins. Such Azorean specimens were previously referred to as *S. vulcani* f. *maunae-loae* (Magn.) Lamb (holotype of *S. mauna-loae* Magnusson - Hawaii, Mauna Loa, above the rest house, alt. 3400 m, 14 November 1922, *C. Skottsberg* 1729, UPS!), a habitat form later considered by LAMB (1977) to be comparable with f. *umbonatum* (Wallr.) Lamb of *S. vesuvianum* var. *nodulosum* (Wallr.) Lamb. However, as intermediates may be found amongst the Azorean specimens of *S. macaronesicum*, no formal taxonomic distinction is made here of the stunted material which is here considered as an ecotype.

The Azorean collections of Herman Persson that we consider as *S. macaronesicum*, were labelled by Magnusson and Degelius *as S. flavireagens* Gyeln. (isotype - Hawaii, Glenwood, On lava, alt. 1200 m, E. Schnell, UPS!). It should be noted, however, that Magnusson obviously had some doubts about his naming of these collections as he originally ascribed the name of *'S. oceanicum'* to some of the specimens, though this name was never formally validated. Notwithstanding, LAMB (1977) considered this Azorean material to be referable to *S. vulcani* (Bory) Ach. (Réunion island - holotype PC-Thuret!; isotype UPS!) in which he also included *S. flavireagens* (Lamb 1977) and its two forms, *S. flavireagens* f. *cinerascens* Magnusson (holotype - Hawaii, E. Maui, Haleakala, along Halemau trail, 5 August 1938, O. Selling, UPS!) and f. *densum* Magnusson (Hawaii, top of Hualalai, alt. 2600 m, 25 November 1922, *C. Skottsberg, 1569*, UPS!), as synonyms. Thus, in using the name *S. vulcani*, Lamb allies the Azorean material with that from Hawaii and

Réunion island. Our examination of the type material of *S. flavireagens* from Hawaii including its forms *cinerascens* and *densum* as well as that of *S. maunae-loae* (type cited above), although mostly in a poor and fragmented condition and morphologically rather similar to *S. macaronesicum,* shows that this Hawaiian material has a simpler chemistry of atranorin, norstictic and connorstictic acids only. Furthermore, the type material of *S. vulcani*, unlike *S macaronesicum* and *S. flavireagens*, has phyllocladia with conspicuously darkened centres surrounded by a paler rim and a chemistry besides atranorin, of norstictic acid (trace), stictic acid and a suite of accessory substances, including menegazziaic acid, features suggesting that the type material of *S. vulcani* is, in fact, closely related to the *S. vesuvianum* agg. Unfortunately, only immature apothecia are present in type material examined, though their lateral, more-or-less sessile position towards the tips of the podetia further suggests that *S. vulcani* may be referable to *S. vesuvianum* s.str. The above observations confirm that *S. macaronesicum* is therefore a Macaronesian species so far only known in the Azores (all main islands) and in the Canary Islands (Tenerife) and furthermore that the Hawaiian material which has been named as *S. vulcani* or *S. flavireagens* is not the same as *S. macaronesicum.*

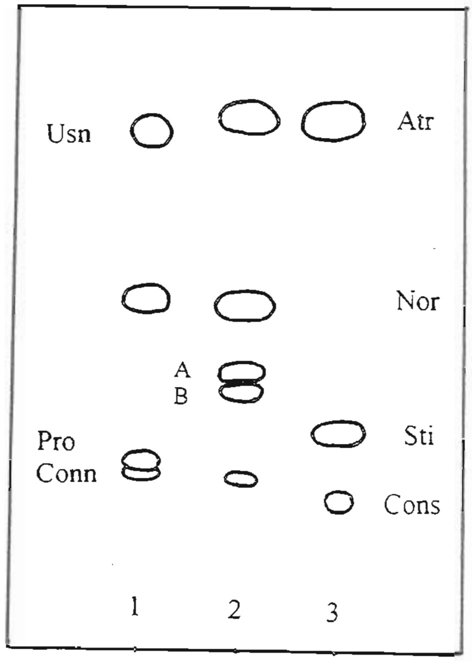

Fig. 7. TLC chromatogram run in solvent G. 1 = control, 2 = *S. macaronesicum* (holotype) and 3 = *Stereocaulon vesuvianum.* Atr = atranorin, Conn = connorstictic acid, Cons = constictic acid, Pro = protocetraric acid, Sti = stictic acid, Usn = usnic acid, A = red-orange and B = brown-yellow unidentified substances.

There is a second Macaronesian endemic *Stereocaulon* in the Azores: *S. azoreum* (Schaerer) Nyl. which has finely granular phyllocladia and elegant, richly branched, often richly fertile pseudopodetia with terminal apothecia; it is unique amongst species of *Stereocaulon* in containing both lobaric and stictic acids. A further species, *S. atlanticum* (Lamb) Lamb (= *S. meyeri* Stein ssp. *atlanticum*), described from the Azores (S. Jorge), has smooth pseudopodetia with terminal, capitate soralia, shortly stalked, sacculate cephalodia and contains stictic acid, norstictic acid and atranorin as well as accessory substances of the stictic acid complex; this species has also been recorded from central and South Africa as well as tropical America and belongs to subsect. *Aciculisporae* which includes the widespread species, S. *ramulosum* (Sw.) Räusch.

Additonal specimens examined: **Azores**: - **Faial**: Praia do Norte (on lava, covering large patches), 8 July 1928, O.C. Schmidt [as *S. flavireagens* f. *cinerascens*] (UPS); 3 May 1997, Herman Persson [*as S. flavireagens* Gyeln.] (UPS). - **Pico**: Along Pico trail to summit from Cabeço das Cabras on western side of Pico, alt. 1200-1960 m, 4 May 1993 [site 65], O.W. Purvis & C.W. Smith (several specimens-BM); liten crater, c. 1350 m, Herman Persson [as *S. flavireagens* Gyeln., redet. *S. vulcani* var. *maunae-loae* (H. Magn.) Lamb] (UPS); Toppen, 9 May 1937, Herman Persson [as *S. flavireagens*] (UPS). - **St Jorge**: between Calheta and Topo, 15 May 1937, Herman Persson [as *S. flavireagens*, redet. *S. vulcani*] (UPS). - **Terceira**: Terra do Morião, 19 April 1937, Herman Persson [as *S. flavireagens* Gyeln., redet. *S. flavireagens* f. *cinerascens* by Lamb] (UPS); Terra do Morião, 19 April 1937, Herman Persson [as *S. flavireagens* Gyeln., redet. *S. vulcani* (Bory) Ach. by Lamb] (UPS). **Canary Islands**: Tenerife, Hartung, between basaltic rocks, Hepp *Flechten Europa* 2, pro parte with *S. vesuvianum* [No. 652. *Lich. Helvet. exs. Schaer. et Hepp*, as 2. *S. denudatum* ß *vesuvianum*. (UPS, BM)].

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