Received 25 May 1982

Preliminary note on the soils of Madeira (*)

by

R. PINTO RICARDO

Professor of Pedology — «Instituto Superior de Agronomia»

E. M. SILVA DA CÂMARA and A. F. A. SANCHES FURTADO

Research Scientists of the «Centro de Estudos de Pedologia Tropical»

RESUMO

No presente trabalho dá-se uma informação preliminar sobre os solos que predominam na ilha da Madeira, adoptando-se para o efeito as unidades estabelecidas para a Carta de Solos do Mundo da FAO/UNESCO.

O trabalho começa por descrever de uma maneira muito sucinta o território madeirense, considerando-se, além do respectivo enquadramento geográfico, os seus aspectos geológico/litológico, morfológico, climático e vegetacional. Apresenta seguidamente a classificação e as características gerais dos principais tipos de solos que ocorrem na ilha. Por fim define as *associações* em que os diversos solos identificados se agruparam para fins cartográficos, mostrando a sua distribuição geográfica em esboço pedológico elaborado na escala de 1:150 000.

As unidades-solo dominantes na ilha da Madeira são **Regossolos, Litossolos, Rankers, Vertissolos, Xerossolos, Faeosemes, Cambissolos** e **«Amorfissolos»**.

---

* Joint project of the «Centro de Estudos de Pedologia Tropical» («Instituto de Investigação Científica Tropical») and «Centro de Pedologia da Universidade Técnica de Lisboa» («Instituto Nacional de Investigação Científica»), made in co-operation with the «Direcção Regional de Agricultura da Região Autónoma da Madeira» for the field work.

RÉSUMÉ

Dans ce travail on présente une note préliminaire sur les sols plus représentatifs de l' ile de Madeira, tenant compte les unités établies pour la Carte Mondiale des Sols de la FAO/UNESCO.

On y commence par la description sommaire du cadre géographique en rappelant quelques aspects géologiques/lithologiques, morphologiques, climatiques et végétatives. Ensuite, on y fait la classification et on met en évidence les caractères généraux des principaux types de sols qui se trouvent dans l'île. Finalement, on définent les *associations* dans lesquelles, du point de vue cartographique, se groupent les différents types de sols identifiés, au même temps qu'on y présente leur distribution géographique sur une esquisse pédologique à l'échelle de 1:150 000.

Les unités pédologiques dominantes sont les **Régosols**, les **Lithosols**, les **Rankers**, les **Vertisols**, les **Xerosols**, les **Phaeozems**, les **Cambisols** et les **«Amorphisols»**.

SYNOPSIS

This paper concerns with a preliminary information on the predominant soil types of Madeira island, adopting the soil units defined for the FAO/ /UNESCO Soils Map of the World.

Firstly a description of the island environment is made, including brief accounts of the geological/lithological, morphological, climatic and vegetational factors. Classification and general characterization of the prevailing soil types are then referred. Finally, *soil associations* are established for mapping purposes and their territorial distribution is outlined on a preliminary pedological inset sketch (scale 1:150 000).

The main soil units identified are **Regosols**, **Lithosols**, **Rankers**, **Vertisols**, **Xerosols**, **Phaeozems**, **Cambisols** and **«Amorphisols»**.

1. INTRODUCTION

This paper was prepared at the request of the Regional Direction of Agriculture of the Autonomous Region of Madeira, which is interested in having with readiness a general information on the soils of the island of Madeira, in order to enable them to take certain decisions in the field of agriculture with the eventual collaboration of foreign

experts. Besides this immediate intention and despite its general nature, the paper may possibly be useful also as a scientific contribution and for didactic purposes.

The work constitutes a short preliminary information on the predominant soil types of Madeira. Soil survey and the related laboratory studies are still fragmentary, though at an advanced stage; consequently, the classification, characterization and distribution of the soils, presented in a general way in this paper, cannot be considered definitive.

The first section of the paper comprises a very summary description of the environmental conditions of Madeira. Geological, morphological, climatic and vegetational aspects are considered, besides the correspondent geographical setting.

The next section is devoted to the classification and general characterization of the soil types which predominate in the territory. Taking into account the immediate objective underlying the elaboration of the paper, it was thought to be convenient to use the soil units adopted in the Soil Map of the World (FAO/UNESCO, 1974).

Finally, in the remainder of the paper, definitions of soil associations established for cartographical purposes are given, and their territorial distribution is shown by means of a preliminary pedological sketch.

2. ENVIRONMENTAL CONDITIONS

The island of Madeira is located in the Atlantic Ocean, being limited approximately by the 32° 38′ and 32° 52′ parallels (N latitude) and by the 16° 39′ and 17° 16′ meridians (W Greenwich longitude). Its area is about 728 km², the maximum lenght and width being respectively 58 km (W to E) and 23 km (S to N) (RIBEIRO, 1949).

Madeira has a volcanic origin, dating from the Miocene. It is essentially formed by eruptive rocks and pyroclastic materials, the former predominating to a great extent. Sedimentary formations are also found, but in a relatively small proportion (ZBYZEWSKI *et al.*, 1975).

The eruptive rocks are almost exclusively of basaltic nature. They consist mainly of basalts, basanites, basanitoids, hawaiites and

mugearites. Gabbros and essexites, as well as acid rocks of trachytic type, are found occasionally.

Likewise, the pyroclastic materials are essentially of basaltic composition. They comprise mostly volcanic scorias, cinders, ashes and tuffs.

The sedimentary formations occur along the coast, on the valleys and on the «fajãs». They include beach and dune sands, fluvial and marine coarse deposits, fine and coarse colluvia, and calcareous rocks.

It is true to say that the *geology of Madeira is monotonously basaltic* (SJÖGREN, 1972). Thus, it may be considered that the parente material of the predominant soils of Madeira is exclusively of basaltic composition.

The island was originated mainly through the activity of a set of great volcanoes which have been extinct for a long time. They had an initial explosive stage, leading to the formation of the central core of the island; that stage was then followed by relatively quiet outflows of basaltic lava which, little by little, contributed to the enlargement of the island to its present shape.

A relatively recent volcanic activity also affected the general landform of the territory, mostly along the coastal zone where it was particulary intense. It was indeed an important phenomenon, but its effect on the landscape had little expression.

From the morphological point of view, there stands out in Madeira a high central region corresponding to the original volcanoes. It is a region showing intensive erosion with the landform exhibiting well-marked differences due to dissimilar resistance of the lithological materials. In this region one can observe rugged mountain--massifs with abrupt slopes, and high plateaus more or less flat and of different development.

Some mountainous belts extend to the ocean. When the mountains do not reach the coast, the landscape outside the central region is normally characterized by more or less steep slopes in some places and by relatively gentle slopes in other places («achadas», «lombadas» or «lombos»). In all situations, the slopes are deeply incised by abrupt valleys which constitute the basic drainage network of the island. Small cones of volcanic scorias are scattered on these landforms, mainly on the southern coastal region.

The coastline is normally developed as imponent escarpments, which can reach heights of the order of 500-600 m. However, they are

more frequent and large on the northern coast than on the southern coast.

The highest elevation of the island (Pico Ruivo), with 1,861 m, is located in the central region near its mid-zone. The altitudes higher than 1,000 m represent about a third of the island surface and form along the E-W direction a ridge which raises a natural barrier between the southern and the northern regions.

Streams which run through the island are numerous. They generally have steep slopes and an intermittent and torrential regime. In winter their flow is plentiful and impetuous, having a high transportation power for solid detritus; in summer, on the contrary, the streams of the northern region have very little water and those of the southern one are pratically dry.

Springs are also numerous, being supplied by the infiltration water that the peculiarity of the geological formations allow to accumulate in vast natural deposits. They are more frequent and have a more copious and regular flow in the northern region than in the southern one.

Madeira is subject to the trade-winds which blow over the territory during most of the year. This fact, as well as the geographic position of the island and its general morphology, determine that the climate of the northern part be very different from that of the southern one. On the other hand, the climate is strongly influenced by the orographic conditions.

From a general point of view the climate of Madeira (MACHADO, 1970) is predominantly temperate, with oceanic characteristics; it varies from dry to humid and from moderately to excessively rainy, as the altitude increases. However, above 1,500 m, it gets cold (although at the limit of the temperate climate) and dry again. Moreover, for similar altitudes, the northern region is more rainy and colder than the southern one. Another peculiar aspect of the climate of Madeira is the occurrence of a cloud zone at variable altitude, but with a lower limit of about 500 m in winter which is somewhat higher in summer; the high mountain tops may be unclouded, especially in summer.

According to the Thornthwaite's classification, the climate varies from semiarid (D) — only in three limited areas of the southern coast — to perhumid (A) towards the high central region of the island. The climatic belts, which on the northern coast begin with

the humid climate (B_2 type, at least), are spread as more or less narrow strips roughly parallel to the coastline and nearly following the orography. Thus, the climate becomes progressively moister and colder with the altitude: DB'_3da', $C_1B'_3da'$ or $C_1B'_3sa'$, $C_2B'_2sa'$, $B_1B'_2sa'$, $B_2B'_2sa'$, $B_3B'_2ra'$, $B_4B'_1ra'$ and AB'_1ra' or AB'_1sa'.

After Köppen's classification, the larger part of the island has a mild temperate rainy climate (humid mesothermal climate) with dry and cool summer (Csb); for a narrow strip at the southern coast, it is still a mild temperate rainy climate but with dry and hot summer (Csa).

The mean annual temperature decreases with increasing altitude, varying from about 19°C (on the southern coast) or 17°C (on the northern coast) to about 9°C on the plateaus and on high peaks of the central region. The mean annual relative humidity increases from about 70 % on the coast to approximately 90 % in the cloud zone, usually decreasing again towards the higher altitudes where it reaches about 75 %. The mean annual rainfall increases remarkably with altitude, going from 500 mm (on the southern coast) or 1,000 mm (on the northern coast) to about 3,200 mm on the uplands of the central region.

The vegetation of the island (DANSEREAU, 1966; SJÖGREN, 1972) is deeply influenced by the anthropic factor. The area with the original floristic associations is very reduced, since the intensive and disordered human activity has led to a marked destruction and/or degradation of the native plant communities.

At present, one finds predominantly in Madeira an agricultural zone, exotic forests, the autochthonous forest, a shrub community of indigenous species and a native scrub-grassland formation.

The agricultural zone is mainly confined below 550/600 m. The most important crops are bananas, sugar cane, vineyards, fruit trees, cereals and several horticultural species. They are generally grown on small plots established on artificial terraces built on more or less steep slopes.

The exotic forests are essentially of pine and eucaliptus. They are chiefly found in the southern region of the island, between about 200/250 and 1,100/1,200 m.

The autochthonous forest is a temperate laurel rainforest. It is a dense and evergreen formation with tall trees (reaching the height of *ca.* 30 m), being dominated to a great extent by *Laurus azorica*

(Seub.) Franco and also including *Ocotea foetens* (Ait.) Baill., *Clethra arborea* Ait. and *Prunus lusitanica* L.

The typical shrub community is a dense formation of high shrubs. It is dominated by *Erica arborea* L., *Laurus azorica* (Seub.) Franco of shrubby structure, *Myrica faya* Ait. and *Vaccinium maderense* Lk.

Both the laurel rainforest and the shrub formation are distributed mainly above 300/400 m, climbing to altitudes of about 1,600 m. They are confined almost exclusively to the steep slopes of the mountainous areas and of the valleys, occurring mainly in the northern part of the island where they may occupy areas of some extension. Normally they lost their original constitution except in recondite places inaccessible to the human activities.

The scrub-grassland formation is located in the highlands — either on the plateaus or on more or less steep slopes —, generally above 1,000 m. It contains: a sward of short grasses and other herbaceous species, tending to cover sparsely the ground; a more or less continuous layer of *Pteridium aquilinum* (L.) Kuhn; and, only up to a certain altitude, a few scattered bushes comprising *Erica cinerea* L. and also, sometimes, *Thymus caespititius* Brot. The typical floristic composition of this community is strongly degraded due to overgrazing.

3. CLASSIFICATION AND GENERAL CHARACTERISTICS OF THE SOILS

As mentioned in the Introduction, the FAO/UNESCO System of Soil Classification (FAO/UNESCO, 1974) has been adopted here. Assuming that the present paper will be used by foreign experts, this will enable them to predict easily the main soil characteristics and to derive the essential agricultural potentialities of soils from the names of the soil units. At the same time, a detailed characterization of the various soil types may be omitted in this way without compromising their full identification.

Nomenclature and concepts established for the FAO/UNESCO System have been in general strictly followed here. However, when the identified soil types are not well correlated with the FAO/UNESCO soil units new designations have been provisionally assigned.

The FAO/UNESCO System does not consider the adoption of phases in the case of soils having a cultural profile more or less modified in relation to the natural profile. Nevertheless, this being the general rule in the agricultural zone of Madeira, such soils are considered as *Anthropic phases* of the soil units from which the respective pedons were derived.

Steep slopes were common in the agricultural zone. Consequently, almost whole of the area had to be terraced in order to make cropping possible. Soils of this zone were thus generally subjected to major land displacements. This has implied the truncation of many pedons and the burying of others, as well as the mixing up of the original horizons to a greater or lesser depth. Besides these partially modified pedons, there are others that are modified throughout their depth having been built up, over bare rock (basaltic lava flows) or over very shallow soils, by means of soil materials transported from adjacent favourable places.

It is for soils with such cultural profiles that *Anthropic phases* have been adopted; they show also the inherent modifications due to the application of mineral and organic fertilisers, liming, etc., as well as those modifications that result from the other common agricultural practices. Although the pedons of these soils may be profoundly modified as regards the succession of the original horizons and their structure, besides other particular characteristics, they mantain a particle size distribution and a mineralogical composition similar to those of the corresponding soils in their natural condition. Therefore, from the physico-chemical point of wiew, the *Anthropic phases* will show a general behaviour very close to that of the sois units in the virgin state.

The principal units defined for Madeira, which correspond to the predominant soils types so far observed in the island, are *Regosols*, *Lithosols*, *Rankers*, *Vertisols*, *Xerosols*, *Phaeozems*, *Cambisols* and «*Amorphisols*».

Their general characterization follow.

REGOSOLS

Soils showing no profile development, predominantly composed by coarse loose materials of volcanic scoria (mainly gravel fragments) and having small amount of fine earth fraction dark reddish brown

(moist colour) and with fine to medium texture; the proportion and sizes of coarse elements increase with depth, and later become consolidated forming a kind of cuirass. Considering these particular characteristics of the regosols, they are classified as «*Gravelly*» *Regosols*.

The «*Gravelly*» *Regosols* identify themselves with the volcanic cones. They occur mainly under semiarid (D) and subhumid (C_1 and C_2) climates, and are generally found at altitudes below 400 m.

The few available data on «*Gravelly*» *Regosols* show that these soils have usually low organic matter content; their base saturation degree is high, generally more than 50 %; concerning the reaction, these regosols are predominantly slightly acid to neutral.

The «*Gravelly*» *Regosols* are pratically chemically inert soils, due to their low proportion of coloidal constituents; however, they have a high weatherable mineral reserve. They present high permeability to water and low water holding capacity, thus being dry soils from the physiological point of view. Therefore they are soils with limited agricultural value, however they can carry special crops.

LITHOSOLS

Soils having an incipient or very weakly expressed *solum*, with consolidated hard rock within 10 cm of the surface. Generally they are more or less stony and they are associated to frequent rock outcrops.

The *Lithosols* occur only under semiarid climate (D), being confined to the eastern extreme of the island (Ponta de S. Lourenço). They are soils without agricultural potential.

RANKERS

Soils having OACR or ACR profile, with an umbric A horizon and a more or less shallow to deep development; generally showing a small to high proportion of coarse fragments, which can predominate over the fine earth fraction right from the surface or, more frequently, from a subsurface depth. Thus they can be stony and may, moreover, be covered to a large extent by boulders, stones and rock outcrops.

The *Rankers* occur in Madeira under perhumid and humid climates, mainly in A, B_4 and B_3 climatic types. They are observed in the high plateaus and mountainous belts, seldom being found below 500 m; the respective surface is flat to gently sloping in the plateaus, and steep or very steep in other places.

Normally they have dark brown or dark reddish brown moist colours. They are medium or, sometimes, fine textured soils, having always a high percentage of silt. Their structure is weak and of the subangular blocky type; or there is no observable aggregation. The consistence is soft when the soil is dry, very friable or friable when moist and slightly sticky when wet.

The organic matter content is very high or high in the A horizon, being generally over 8 % and more frequently over 15 %; it decreases with depth and may be about 4 % in the lower part of the profile. C/N ratio varies usually between 11 and 21.

The cation exchange capacity is medium to high, predominantly 15-35 me/100 g, but attaining higher values in the organic horizons. In general the degree of base saturation is very low or, less frequently, low (< 32 %), and the soil reaction is strongly acid (pH 4.5-5.5). The exchangeable aluminium content is less than 3 me/100 g, corresponding to an exchangeable aluminium saturation below 14 % (calculated as *exchangeable Al/cation exchange capacity* and with the values expressed in percentage).

The *Rankers* present a high proportion of original weatherable minerals, having therefore a great mineral reserve. However, their level of available macronutrients is usually low.

They exhibit intensive erosion, showing even on the steep and very steep slopes important soil slipping.

Considering their particular characteristics and conditions of occurrence, they have a poor agricultural potential despite being soils with high organic matter content and abundant weatherable mineral reserve.

VERTISOLS

This unit includes mainly typical *Vertisols* and, also, other related soils which show the charateristic properties of vertisols to a lesser extent. Thus the soil unit comprises *Vertisols and similar soils*, which have as fundamental and more prominent characteristic a clay fraction dominated by smectites.

All of them are dark coloured, with moist chromas of 2.0 or more but less than 4.0. Thus as far as the *Vertisols* are concerned they are *Chromic Vertisols*, however with dark brown or, sometimes, dark reddish brown colours.

The *Vertisols and similar soils* occur in Madeira usually as *Anthropic phases* and frequently as *Lithic phases; Sodic phases* are also present, with exchangeable-sodium percentage seldom exceding 20 %.

Their most common occurrence is under semiarid (D) and subhumid (C_1 and C_2) climates. They are found only in the southern part of the island, in general below 250 m and often below 150 m.

They have strong structure throughout most of the profile, generally fine to coarse blocky structure in the upper horizons and prismatic structure with depth; sometimes, in non-cropped soils, a thin layer of the surface horizon has a very fine strong structure (self-mulching). The consistence when dry is very hard or hard; when wet it is sticky or very sticky, and very plastic and plastic. They are highly compact, develop cracks during dry seasons (wide and deep cracks in the typical *Vertisols*) and show slickensides.

Their organic matter content is no greater than 5.5 % at the surface, decreasing with depth to values that usually vary from 1.0 to 3.0 %; normally with a C/N ratio about 9 to 14, indicating a favourable stage of humification. They have fine texture with a clay content in general somewhat uniform throughout the profile, exceeding 35 % and in most of the soils being greater than 50 % and reaching values of the order of 70-75 %; the clay fraction is dominated by montmorillonite (> 50 %), but it presents always variable amounts of kaolinite (5-40 %) and amorphous iron hydrous oxides too (5-20 %), which in *Vertisols* are less than in the *similar soils* (other mineral species may be present, but their amounts are small — generally not more than 5 %). They are devoid of calcareous accumulations in the *solum*. The cation exchange capacity varies usually from 25 to 50 me/100 g and the degree of base saturation is over 68 %; pH values are mostly in the range of 5.7 to 8.7, normally increasing with depth (the highest values correspond to the *Sodic phases*); exchangeable aluminium is absent. Moreover, these soils have a high level of available calcium and magnesium; they are high to medium in available potassium which, nevertheless, may be low sometimes; and they show variable amount of available phosphorus, ranging between very low and high contents.

Generally, the *Vertisols and similar soils* observed in Madeira have a high natural fertility. However, their physical characteristics and the strong susceptibility to erosion (including mass movements of soil) render their utilization difficult.

XEROSOLS

These are more or less developed soils typical of aridic moisture regime, with ochric horizon and without the characteristics of vertisols and similar soils.

The *Xerosols* found in Madeira are predominantly shallow soils, having a weak ochric A horizon and a cambic B horizon and/or a calcic horizon. Probably they are *Haplic Xerosols* and *Calcic Xerosols*; they include, frequently, *Sodic phases*, as well as *Stony phases* and *Lithic phases*. There are considerable amounts of rock outcrops, boulders and stones covering the surface of the soils.

They occur only under semiarid climate (D), being limited to Ponta de S. Lourenço.

The moist colour of *Xerosols* is generally dark reddish brown or dark brown; the texture is normally medium to fine, with high silt content (sometimes, coarse texture); they may or may not have calcium carbonate accumulations. The soils with medium to fine texture are well structured (usually, subangular and angular blocky structure); their consistence is hard or very hard (dry soil) and very firm or extremely firm (moist soil).

Analytical data are not yet available for the *Xerosols*. Thus, it is not possible to carry out a more detailed characterization at this moment.

Generally, they show significant features of accelerated erosion.

The *Xerosols* have severe risks and limitations for use in agriculture, not only by their own characteristics but also due to the environmental conditions which are associated to them.

PHAEOZEMS

These are soils having a mollic A horizon or, in view of the fact that pratically all the *Phaeozems* observed in Madeira correspond to *Anthropic phases*, more properly they are soils having an anthropic A horizon. Typically, they are *Haplic Phaeozems*.

Concerning soil depth, the unit includes from shallow to very deep soils; on the other hand, they may be more or less stony soils. Thus, there often correspond to them also *Lithic phases* and/or *Stony phases*.

The *Phaeozems* occur in Madeira below about 400 m, mostly under semiarid (D), subhumid (C_1 and C_2) or even humid (B_1 and B_2) climates.

Generally they have dark brown moist colour (sometimes very dark grayish brown or other like dark colours), usually with value and chroma of 3 or less. Texture is predominantly fine, with a high content of silt; structure is subangular and/or angular blocky, strong or less frequently moderate; the aggregates are mostly hard to very hard (dry soil) and firm to very firm (moist soil); when wet, the soil is sticky.

Their clay fraction consists predominantly of kaolin minerals, to which are associated significant amounts of 2:1 minerals (showing some expansibility, or not) and non-crystalline iron hydrous oxides; small proportions of hematite and magnetite are also frequently present. They have a high weatherable mineral reserve.

Usually the content of organic matter is medium (no greater than 7.7 %) which however may become low in the deeper layers, falling to values around 1.5 %; C/N ratio generally between 9 and 13, indicating an advanced stage of humification.

The cation exchange capacity is high (19-36 me/100 g); the degree of base saturation always exceeds 50 % and often attains values of the order of 85 %; usually the soil reaction is medium acid to neutral, with pH values ranging from about 5.4 to 7.3; exchangeable aluminium is absent. Concerning available macronutrients, in general the soils have a low level of phosphorus, a medium or high level of potassium, and high to very high levels of calcium and magnesium.

Phaeozems do not show the current types of erosion, probably because the areas in which the soils occur are protected by their being built-up on artificial terraces. Nevertheless, they frequently exhibit severe mass movements of soil.

In a general way, they are soils having a certain agricultural potential. However, besides the normal dressings of nitrogenous fertilisers as is common practice, they always need phosphatic fertilisation; potassic fertilisation is also often required but at relatively low

levels. Moreover, most of the *Phaeozems* have no lime requirement and consequently liming is unnecessary.

CAMBISOLS

Soils wherein a cambic B horizon is developed, and not having an ardic moisture regime nor the characteristics of *Vertisols* or *Phaeozems*; also without the typical clay fraction of «*Amorphisols*».

They are *Eutric Cambisols*, *Chromic Cambisols* and *Dystric Cambisols*. For cartographic purposes, *Eutric* and *Chromic Cambisols* are grouped together under the designation of «*Saturated*» *Cambisols*; similarly, following the same principle, *Dystric Cambisols* are named «*Unsaturated*» *Cambisols*.

Usually, *Eutric* and *Chromic Cambisols* occur in Madeira as *Anthropic phases*; these phases are also frequent in the *Dystric Cambisols*, however in a lesser proportion. In all types of *Cambisols*, *Lithic phases* also exist but in a low proportion. Sometimes *Stony phases* may be stil observed, mainly in *Eutric* and *Chromic Cambisols*.

The *Cambisols* are not found at altitudes over 700 m; *Eutric* and *Chromic Cambisols* occur mainly below 400 m, whereas *Dystric Cambisols* are only observed pratically above 200 m.

The most common occurrence of *Eutric* and *Chromic Cambisols* is under subhumid climate (C_1 and C_2) as well as, although less frequently, under B_1 and B_2 humid climates. The *Dystric Cambisols* are predominantly found under climate ranging from moist subhumid (C_2) to B_4 humid type.

From the physico-chemical point of view, there are no significant differences between *Eutric* and *Chromic Cambisols*. As regards their morphology, the sole evident diference refers to the moist colour in the subsurface levels of the *solum* — in fact, *Eutric Cambisols* are dark reddish brown with hue 5YR, value generally 3 and chroma 2-4; the *Chromic Cambisols* have a colour with hue 2.5YR or less frequently 10R, value 2.5-3.0 and chroma 3-6, which give a clear perception of red although corresponding Munsell colours may include, besides dark red and dusky red, also dark reddish brown.

Considering other characteristics, *Eutric* and *Chromic Cambisols* usually have fine texture, with a high proportion of silt; strong or less frequently moderate structure, of angular and/or subangular blocky type; hard (dry) and sticky (wet) consistence. Their clay

fraction is normally composed mainly of kaolinite and/or halloysite; it has, also, small but significant amounts of 2:1 clay minerals (usually non-expanding minerals), amorphous iron hydrous oxides and, often, hematite and magnetite. The weatherable mineral reserve is high. Moreover, these soils have an organic matter content seldom higher than about 7 %, which may decrease to 1-2 % in the *solum* with depth; generally a C/N ratio of 10 to 13, indicating a favourable stage of humification; cation exchange capacity medium to high (16-33 me/100 g); degree of base saturation also medium to high, with values in the *solum* normally comprised between 50 and 78 % (hence, the grouping together of these *Cambisols* as «*Saturated*» *Cambisols*); pH value varying predominantly from 5.4 to 6.7 (in general, medium or slightly acid reaction); exchangeable aluminium pratically absent. As far as available macronutrients are concerned, these *Cambisols* are high in calcium and magnesium, usually high or medium in potassium and very low or low in phosphorus.

Dystric Cambisols usually have in subsurface levels dark reddish brown (hue 5YR or, sometimes, 2.5YR) and seldom dark red or dusky red (hue 2.5YR or 10R) moist colours, with value 2.5-3.5 and chroma 2.5-6.0; generally fine texture, sometimes medium (always with high proportion of silt); normally, moderate subangular and/or angular blocky structure; slightly sticky to sticky wet consistence; slightly hard to soft dry consistence in the upper layers, becoming hard or slightly hard subsurfacially. The composition of their clay fraction is similar to that of the other *Cambisols*, and the weatherable mineral reserve is high too. *Dystric Cambisols* are also characterized by an organic matter content usually medium (not exceeding 9 %) in the surface layers, decreasing gradually with depth to values of about 2%; a C/N ratio with values predominantly ranging between 10 and 18, therefore indicating for some these soils a not advanced stage of humification of the organic matter; a cation exchange capacity medium to high (15-35 me/100 g); a degree of base saturation low or very low (whereby, they are denominated «*Unsaturated*» *Cambisols*), in general 12-40 % and rarely 40-50 %; predominantly, a strongly acid reaction (pH 4.5-5.7); a variable amount of exchangeable aluminium in the *solum*, usually with a maximum of about 6 me/100 g, to which corresponds an exchangeable aluminium saturation usually less than 10 % in the surface layers and below 25 % in the subsurface levels. As regards their level of available macronu-

trients, normally they are medium to high in calcium, high in magnesium, medium in potassium and very low in phosphorus.

From the agricultural point of view *Eutric* and *Chromic Cambisols* are rather near the *Phaeozems*, therefore showing a fair fertility. *Dystric Cambisols*, on the contrary, show less productivity; the strongly acid and leached profiles make their agriculture use difficult, frequently implying the necessity of liming and the application of important amounts of fertilisers in most of these soils.

«AMORPHISOLS»

This designation is provisionally adopted to cover several soils having the following distinctive characteristics:

a) OABC or ABC profile, with an umbric A horizon and a cambic B horizon;

b) Typical presence of amorphous aluminium hydroxides (sometimes amorphous alumino-silicate minerals) and often also gibbsite, which strongly marks the behaviour of the clay fraction;

c) Very high weatherable mineral reserve.

The *«Amorphisols»* vary in depth from shallow to deep soils; moreover, they are often stony. Therefore, they occur frequently as *Lithic* and/or *Stony phases*.

No lower category units are distinguished in the *«Amorphisols»*, because their laboratory studies are still at an early stage.

They occur mostly over 400 m, predominantly under perhumid (A) and humid (B_4 and B_3) climates.

Usually, they have a moist colour in the B horizon dark reddish brown, dark red or dusky red (sometimes, it is dark brown); medium or fine texture, being high in silt content; aggregation not evident or, generally, weak subangular blocky structure; consistence usually soft (dry), friable or very friable (moist) and slightly sticky (wet).

Their clay fraction consists predominantly of kaolinite and/or halloysite; also it has typically significant amounts of free aluminium hydroxides (gibbsite and/or amorphous gels), free iron hydrous oxides or oxides (always as amorphous gels and often with added

hematite and magnetite) and 2:1 non-expanding clay minerals. In some cases, amorphous alumino-silicate minerals were identified; although being in general materials with a low silica content, they may probably be classified as allophanes. Therefore, it is admissible that the «*Amorphisols*» include, among others, some *Andosols* or, at least, soils having andic characteristics.

The content of organic matter is high or very high in the A horizon (usually over 7 % and very commonly even over 11 %), decreasing in the B horizon and with depth to about 2 %; the C/N ratio ranges normally from 12 to 22, which implies in many cases an organic matter in a weak state of humification; the cation exchange capacity is medium to high (mostly 10-35 me/100 g, however may be higher in the organic horizons); the degree of base saturation is normally very low, not exceeding 25 % and often being less than 10 %; reaction is predominantly strongly acid, with pH values comprised between 4.5 and 5.5; the exchangeable aluminium content in the *solum* is below 7 me/100 g, corresponding to an exchangeable aluminium saturation which does not exceed 26 %.

Commonly, the «*Amorphisols*» are deficient soils as regards the general macronutrients; in fact, they are usually very low in available phosphorus, low in potassium, low in calcium (exceptionally, medium) and also low in magnesium (although, in some cases, the latter may reach high levels). Therefore they are soils with low natural fertility, despite their high organic matter content and weatherable mineral reserve. Generally they present good physical characteristics.

Intensive erosion is frequently observed in these soils, as also important mass movements.

4. DISTRIBUTION OF THE SOILS

The territorial distribution of the different soil units observed in Madeira is shown on the accompanying map, which is drawn to a 1/150,000 scale. It is a preliminary pedological sketch to which, obviously, corresponds a level of general information.

Soil associations are used as mapping units, due to the general nature of the map. Each of these, as is normal in soil survey and cartography, includes several soil types which may not represent all

of the soils that occur in the respective areas but, of course, only a fraction of no more than 70-80 %.

The legend of the pedological sketch consists of 12 different soil associations, 6 of which include two or three subdivisions. They are composed of one or more soil types, some of them being the dominant soils and the others the associated soils and the inclusions.

In the present section, all of these mapping units are characterized. For each association the corresponding soil types are specified, the aproximate extension of their occurrence is broadly defined, and also complementary informations may be given.

The units are dominated by one or two kinds of soils. Therefore, they have single or complex designations; they take the name of the predominant soil type or else they are named after the two major soils types found in the respective association.

The characterization of soil associations follows.

REGOSOLS (1) *

«*Gravelly*» *Regosols* are the dominant soils in this association, in such a way that they may be considered as their exclusive component. Frequently great consolidated masses of coarse pyroclastic materials, which attain the size of boulders, are exposed.

It is possible that in some areas «*Saturated*» *Cambisols* also occur, but as inclusions.

VERTISOLS (2)

Almost exclusively, this association consists of *Vertisols and similar soils*. Nevertheless the typical *Vertisols*, which occur in a very large proportion, stand out over the other soils.

Anthropic and *Lithic phases* are frequent.

Mass movements of soil are observed regularly in the areas of this association.

XEROSOLS (3)

Xerosols are the dominant soils in this association. «*Gravelly*» *Regosols* and *Vertisols and similar soils* are the principal associated

* The number (or number and a small letter) in parentheses, in this as in the other associations, specifies the symbol of the respective mapping units.

soils. *Lithosols* and rock outcrops are also found in appreciable proportions.

«*Gravelly*» *Regosols* occur only on cones of volcanic scorias. The other soil types are observed out of such areas, predominating among them *Sodic phases* and also *Stony* and *Lithic phases*.

More or less intensive erosion is evident in pratically the whole area of occurrence of this association.

PHAEOZEMS (4a, 4b)

This association consists almost exclusively of *Phaeozems*. Nevertheless, it is subdivided into two units: one, in which «*Saturated*» *Cambisols* and/or *Vertisols and similar soils* may be present but as inclusions (4a); another, which includes these same soils and also abundant rock outcrops (4b).

Pratically, all of the soils occur as *Anthropic phases*. Besides these, *Lithic phases* and also *Stony phases* are often observed.

In general, mass movements of soil are evident.

«SATURATED» CAMBISOLS (5)

This association is essentially composed of «*Saturated*» *Cambisols*; they have also rare inclusions of other soils, mainly *Phaeozems*.

Most of the soils of this unit correspond to *Anthropic phases*. A small proportion of *Lithic phases* and, sometimes, *Stony phases* may also be observed.

«AMORPHISOLS» (6)

This association is almost exclusively formed by «*Amorphisols*». Besides them, *Rankers* may also be found as accidental inclusions.

VERTISOLS AND PHAEOZEMS (7a, 7b)

Vertisols and similar soils, as well as *Phaeozems*, are the dominant soils of this association. It comprises two subdivisions: one (7a), in which the first soil unit — mainly the similar soils of the Vertisols — occur in a proportion two or three times larger than that of *Phaeozems*; another (7b), in which *Phaeozems* are the largely predominant soils.

The soils of this association mostly consist of *Anthropic phases* and *Stony* and/or *Lithic phases*.

Mass movements of soil may be observed frequently.

PHAEOZEMS AND «SATURATED» CAMBISOLS (8a, 8b, 8c)

Phaeozems and «*Saturated*» *Cambisols* are the major soils of this association. The proportion of each soil type is variable, which led to the subdivision of the association into three mapping units. In one of them (8a) *Phaeozems* and «*Saturated*» *Cambisols* are found in approximately equal extents, and only accidentaly other soil types are observed. In another unit (8b) the association is largely dominated by *Phaeozems*, in a proportion of about three to one; moreover, *Vertisols and similar soils* may also occur but in a very small proportion. In the third one (8c), the «*Saturated*» *Cambisols* predominate largely over the *Phaeozems*; generally, «*Unsaturated*» *Cambisols* may also be found as inclusions.

Practically, all of the soils correspond to *Anthropic phases*. *Lithic* and *Stony phases* are also found, in a relatively small proportion in what concerns the «*Saturated*» *Cambisols*, and in a somewhat higher proportion as regards the *Phaeozems*.

«SATURATED» AND «UNSATURATED» CAMBISOLS (9a, 9b)

Cambisols are practically the only soils of this association. It may accidentally include also *Phaeozems* or «*Amorphisols*».

Two mapping units are considered in this association. In one of them (9a), «*Saturated*» *Cambisols* and «*Unsaturated*» *Cambisols* may occur in approximately equal proportions; in the other (9b), «*Unsaturated*» *Cambisals* are the dominant soils.

Most of the «*Saturated*» *Cambisols* correspond to *Anthropic phases*; they also occur in small proportion as *Lithic phases* and, sometimes, as *Stony phases*. As regards the «*Unsaturated*» *Cambisols*, the *Anthropic phases* have a smaller representation; *Stony phases* are pratically absent and *Lithic phases* have only an insignificant occurrence.

«UNSATURATED» CAMBISOLS AND «AMORPHISOLS» (10a, 10b, 10c)

«Unsaturated» Cambisols and/or *«Amorphisols»* are the dominant soil types of this association. Minimal inclusions of *Rankers* or *«Saturated» Cambisols*, as well as rock outcrops occurring with regularity but in small proportion, may also be found.

Three different mapping units are distinguished: in one of them (10a), both *«Unsaturated» Cambisols* and *«Amorphisols»* are in approximately equal extents; in another (10b), *«Unsaturated» Cambisols* are the largely dominant soils; in the third unit (10c), it is the *«Amorphisols»* the soils that dominate.

Lithic phases of both soil types may be observed in small proportion. In the same way, there are *Anthropic phases* too in what concerns the *«Unsaturated» Cambisols*.

«AMORPHISOLS», RANKERS AND ROCK OUTCROPS (11a, 11b, 11c)

This association consists, essentially, of *«Amorphisols»* (to which frequently correspond *Stony* and/or *Lithic phases)* and *Rankers*; sometimes, it may also include a small proportion of *«Unsaturated» Cambisols*. Besides these soils, the association also shows an appreciable amount of *Rock Outcrops*.

There are three different mapping units of this association. In one of them (11a) *«Amorphisols»*, *Rankers* and areas with *Rock Outcrops* are in approximately equal extents; in another (11b) *«Amorphisols»* are the largely dominant soils, occupying the *Rankers* and the *Rock Outcrops* nearly identical areas; in the third one (11c), *Rankers* and *Stony phases* of *«Amorphisols»* are the largely dominant soils, which together add up to an area about three or four times larger than that of *Rock Outcrops*.

The existence of boulders and stones covering the land surface is rather frequent.

It must be still referred that the areas corresponding to this association show in general a more or less intensive erosion, including sometimes considerable mass movements of soil. In the particular case of the zones submitted to severe overgrazing, the permanent devastating effect on the vegetative cover of the ground due to an excessive number of goats and sheep open the way to erosion and accelerate actively the process; this is strongly enhanced by the combined action

of the steep slopes, the high water runoff and the intense winds which blow mostly on the uplands of the central region and on the northern part of the island.

MISCELLANEOUS LAND TYPE (12)

This mapping unit is used for mountainous areas, presently inaccessible, where therefore an orderly and systematic soil survey could not be carried out. The unit occurs over a wide range of altitudes, and thus the corresponding climatic conditions (as well as some other environmental conditions) vary considerably.

Although the unit composition has been based on a very limited number of soil observations, it is acceptable that it may essentially consist of areas having a high density of rock outcrops and/or boulders and stones, as well as having also some soils to wich generally and typically correspond stony phases and very shallow lithic phases. Usually heterogeneous colluvium materials and chaos of boulders, and frequently land-escarpments, must also be found.

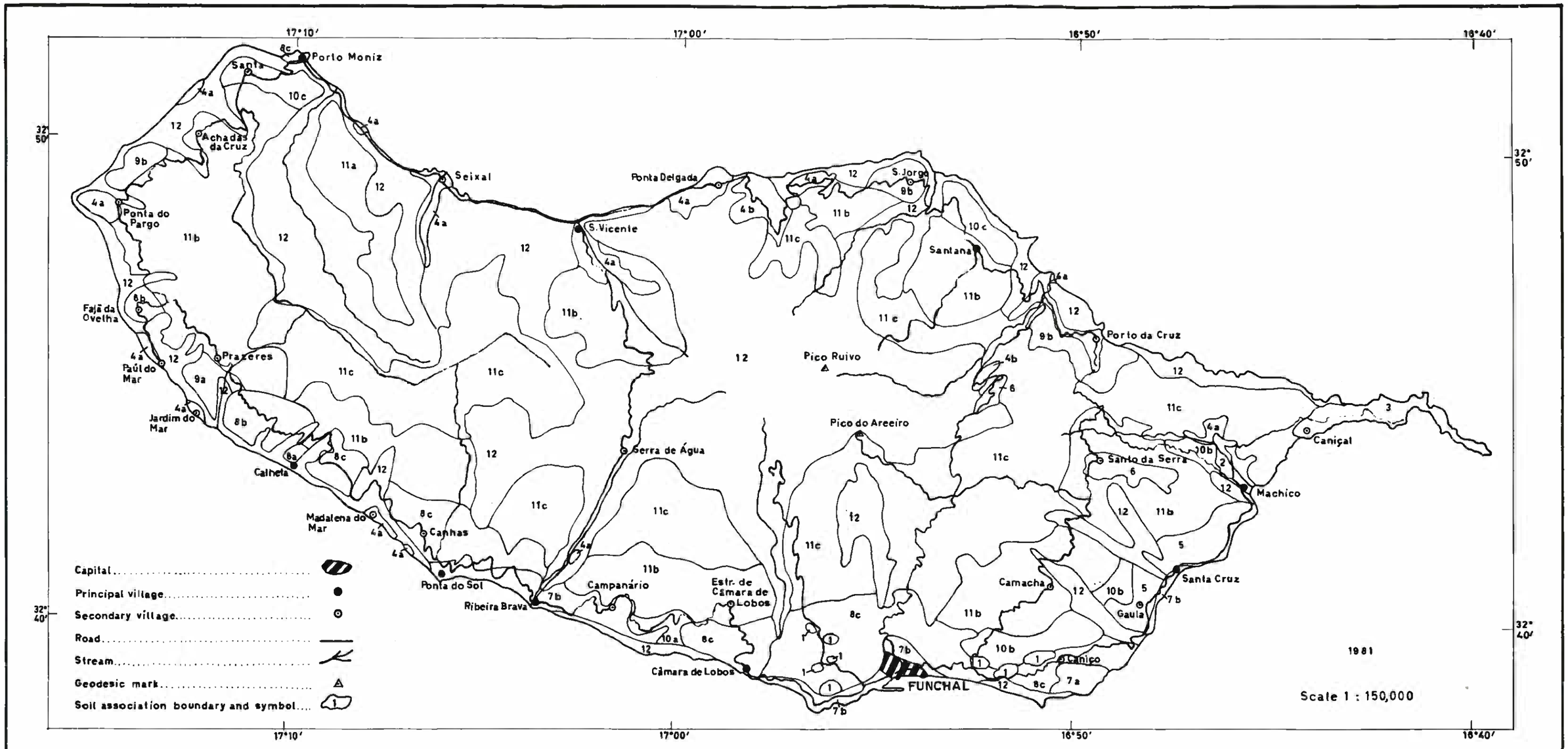
As a consequence of the variety of climate and other pedogenic factors that characterize the unit, the soils the occurrence of which is here admitted (mostly as stony and lithic phases) will obviously belong to different types. Thus, *Phaeozems, «Saturated» Cambisols* and «*Unsaturated*» *Cambisols* will be found at lower altitudes, whereas *Rankers* and «*Amorphisols*» will be found at higher altitudes where, incidentally, the *Miscellaneous Land Type* is most widely represented.

ACKNOWLEDGEMENTS

The autors are grateful to Prof. Edgar C. Sousa for his critical revision of the English text, and to Eng. M. A. Melo Ferreira for his help in drawing up the pedological sketch.

Thanks are also due to staff members of CEPT, CPUTL, «Instituto Superior de Agronomia» and «Serviços Agrícolas da Madeira» who have collaborated in the field work or in the laboratory work, without whom this paper could not have been prepared.

PRELIMINARY PEDOLOGIAL SKETCH OF MADEIRA ISLAND



SOIL ASSOCIATIONS

1 Regosols	4a, 4b Phaeozems	7a, 7b Vertisols and Phaeozems	10a, 10b, 10c "Unsaturated" Cambisols and "Amorphisols"
2 Vertisols	5 "Saturated" Cambisols	8a, 8b, 8c Phaeozems and "Saturated" Cambisols	11a, 11b, 11c "Amorphisols", Rankers and Rock Outcrops
3 Xerosols	6 "Amorphisols"	9a, 9b "Saturated" and "Unsaturated" Cambisols	12 Miscellaneous Land Type

CEPT/CPUTL, 1981

REFERENCES

DANSEREAU, Pierre. 1966 — Études Macaronésiennes — III. La zonation altitudinale. *Naturaliste Canc.*, 93:779-795. Québec.

FAO/UNESCO. 1974 — *Soil Map of the World (1:5000000). Volume I — Legend.* United Nations Educational, Scientific and Cultural Organization. Paris.

MACHADO, M. J. S. Sousa. 1970 — *Balanço Hídrico e Clima da Ilha da Madeira.* Serviço Meteorológico Nacional. Lisboa. (Mimeo.).

RIBEIRO, Orlando. 1949 — *L'Île de Madère. Étude Géographique.* Congrès International de Géographie, Lisbonne 1949. Union Géographique International. Lisboa.

SJÖGREN, Erik. 1972 — Vascular plant communities of Madeira. *Bol. Mus. Munic. do Funchal*, XXVI: 45-125. Funchal.

ZBYSZEWSKI, G. *et al.* 1975 — *Carta Geológica de Portugal (1/50.000). Notícia Explicativa das Folhas A e B da Ilha da Madeira.* Serviços Geológicos de Portugal. Lisboa.

(Concluded on 30 November 1981)