Antarctic Research, Vol. 7, No. 1, 70~78, June 1996

The pedogenic groups and diagnostic characteristics in the Fildes Peninsula of King George Island, Antarctica*

Zhao Ye (赵烨) and Li Tianjie (李天杰)

Institute of Resources and Environmental Sciences, Beijing Normal University, Beijing 100875, China

Received November 5, 1995

Abstract Based on the analysis of the soil-forming factors, pedogenic processes and the soil properties in the study area, this paper is to propose the soil geographico-genetic classification of maritime-climatic Sub-Antarctic regions. The soils of the Fildes Peninsula were classified into 3 soil-orders, 4 suborders and 13 soil groups, and then the relationship between the soil distribution and the environment was discussed.

Key words Antarctica, Fildes Peninsula, soil geographico-genetic classification, diagnostic soil characteristics, environment.

1 Introduction

It is important to study the soil geographico-genetic classification and soil diagnostic characteristics of the ice-free regions in Antarctica, which can help us to understand the characteristics of Antarctic modern physical environment, the biogeochemical processes in cold environment and the processes of the regional environment change.

2 Soil-forming environment

The Fildes Peninsula is in the southwest part of King George Island in Antarctica, and it is located at latitude 62°10′S~62°13′S, longitude 58°53′W~59°01′W, the area is about 36 km^2. The whole peninsula almost consists of the laminar basaltic lava, volcaniclastic rock and volcanic sedimentary rock of Tertiary system, and the rock is basic rock. The glacial deposition is vague in the peninsula, but the denudation is strong, and so the parent materials of the soils are the weathering eluvium of basic rock. The Fildes Peninsula is a hilly area at an elevation of less than 200 m, there are two wavy platforms (i. e. 40 ~50 m above sea level and 110~120 m above sea level), but in the east coastal area there are 4~6 stages of sea terraces which are mostly covered with gravel and sands.

The climate of the Fildes Peninsula belongs to the subantarctic oceanic type, the an-

* This research was supported by the National Natural Science Foundation and State Antarctic Committee of China.

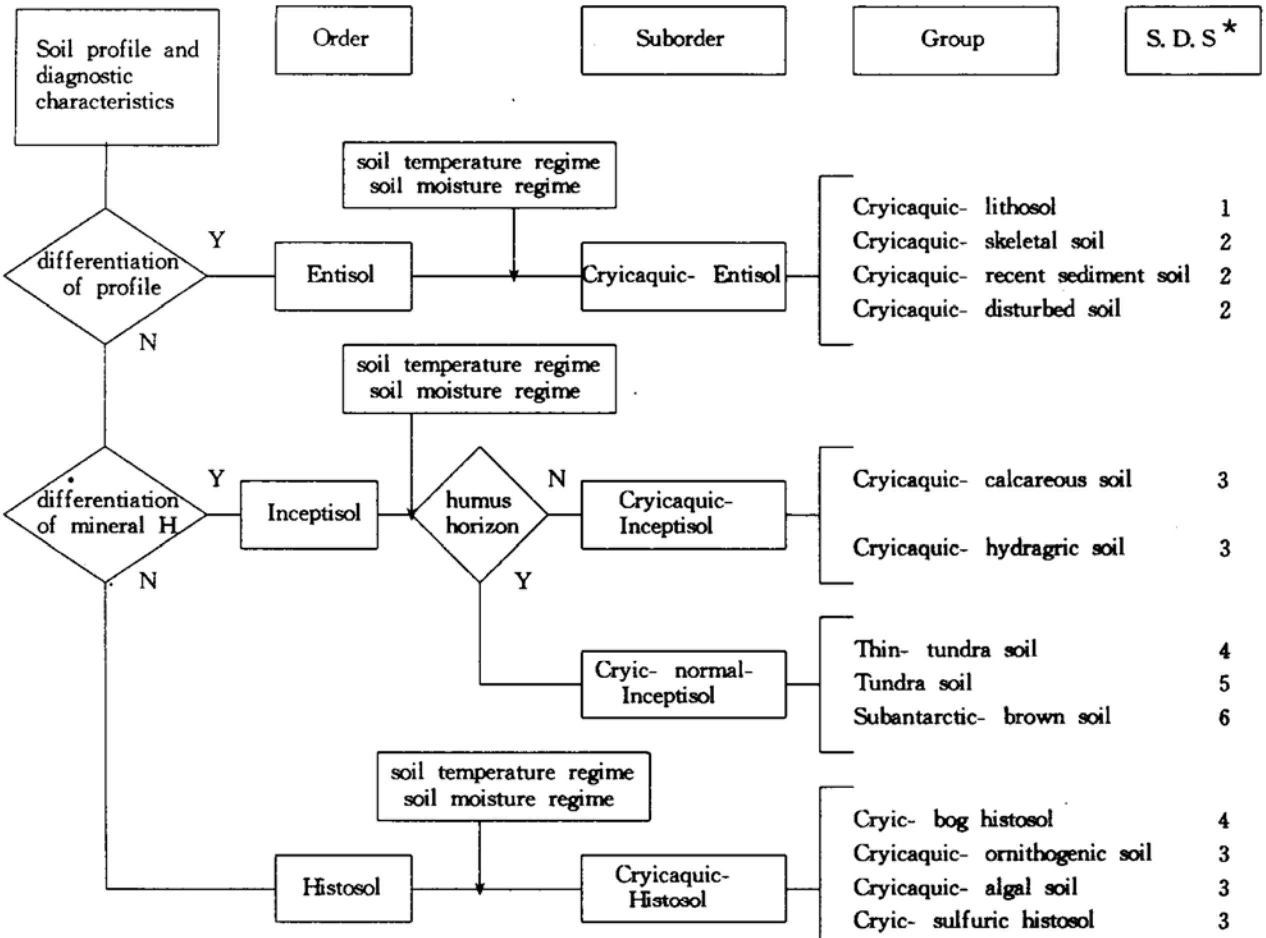
nual average temperature is about -2.1°C, the annual average precipitation is about 630 mm, the annual average relative humidity is about 90% (Zhao *et al.*, 1993). During one year there are 4 months in which the mean monthly temperature reaches 0°C to 5°C and the mean monthly temperature seldom falls below -10°C in winter. It is measured that the temperatures of the surface soils can reach more than 10°C during summer, and so there exist strong freeze-thaw processes, the permafrost occurs at depths of 40～70 cm in most soils. The mud-rock flow related with the freeze-thaw processes, strong wind erosion, and water or snow erosion-accumulation all have a great influence on the soil forming and development.

The component of plant community is simple, and the dominant species are cryptogams bryophyta, lichens and algae (Chen *et al.*, 1993). But there are some Deschampsia antarctica (angiosperms) occasionally on the gently north-facing slopes and north-west-facing slopes. The bryophyta occur extensively in the wet habitat on flat or gently sloping ground where the freeze-thaw disturbances are relative weak. the groundmasses are gravelly or sandy-skeletal accumulation materials. The covered bryophyta may reach 100% in some favorable areas. In the Fildes Peninsula the covered bryophyta banks have a thickness of 7～15 cm (or 40 cm at most). The production rate of the maritime Antarctic moss bank is 162～350 $g \cdot m^{-2} \cdot a^{-1}$(dry wt). Lichens occur extensively on the surface of bedrock and gravel. The foliose lichens occur only on the bedrock in the coastal areas; Usnea and Usnea antarctica are the dominant species of fruticose lichens, Usnea communities are widely and extensively developed in the study area; but Usnea antarctica communities are mainly developed in the coastal area. It has been estimated that the production of fruticose lichens in maritime Antarctic area is 30～150 $g \cdot m^{-2} \cdot a^{-1}$(dry wt)(Bonner and Walton, 1985). The algal communities are abundant in the basement of runoff, in the depression and in the habitat of sea birds, seal and penguin rookeries, the algal cover degree may reach 30%～50%, and the algal bank has been formed in some depressions. In late summer, the surface of firn snow is red or green or yellow in color caused by snow alga communities. As a result: the plant community of study area has a relative high production (Samford, 1988), and many organic substances enter into the soils, which give the nourishment to the bacteria, eumycota and protozoa in the soils of the Fildes Peninsula, the number of bacteria in the soil is 10^5～10^6/g (Xiao *et al.*, 1994). But the earthworm was not found in the soils. In the coastal area there are many seals, penguins and other oceanic birds, these oceanic animals bring much nutrient to land, the soil development are deeply affected, and the particular histosol is formed in the study area.

3 Soil geographico-genetic classification system

In the ice-free areas of Antarctica, the soil forming processes include the intense physical weathering and relative weak biochemical processes, and special soils are formed. At the same time, the regional differentiation of Antarctic physical environment and the different histories of regional environment change make the regional diversity of the soil properties. There have been various pedological classifications, but a number of problems are posed for the particular Antarctic soils: (1) The classification of soils in the maritime Antarctic region has not received much attention; (2) Soil Taxonomy and F.A.O. classification that base on the precise morphological and analytical parameters often cut through the natural soil groupings in Antarctica; (3) There have been no complete analytical soil data in Antarctica, which makes it impossible to recognize the horizon that conforms to the definition of an epipedon and diagnostic horizon (Buol, 1980; Campbell and Claridgn, 1987; Bockheim and Ugolini, 1990). The traditional soil genetic classification that base on the relationships among pedogeneic processes and contributing soil-forming factors is particularly useful to Antarctic soils (Campbell and Claridgn, 1987). Therefore, this paper sets up the soil geographico-genetic classification of maritime sub-Antarctic regions, the fundamental principles are: The soil-forming environment, soil-forming processes and soil characteristics should be synthetically analyzed; the order and suborder are classified, based on the differences of soil profile, the characteristics of the organic horizon, the stage of soil development, the soil temperature regime and soil moisture regime; the group is classified based on the component of soil and morphological characteristics of soil. The quantitative criteria of Soil Taxonomy are not used in the classification. As a result, the soils of the Fildes Peninsula are classified into 3 soil-orders, 4 suborders and 13 soil-groups (Table 1).

Table 1. Soil geographico-genetic classification system of maritime sub-antarctic region.



* S. D. S: soil development stage.

4 Major genetic soils and diagnostic characteristics

4. 1 Entisol —Cryicaquic-Entisol

The soils, developed recently, have no mollic epipedon or differential profile. Based on the genetic characteristics and component of the soils, Cryicaquic-Entisols may be classified:

(1) Cryicaquic-lithosol. It includes the bedrock and the product of frost physical weathering, these soils occur extensively in Davis Highland and Lune Hill. The strong denudation makes the top soil and plasma of the soils to be lost, but there are lichens and algae on the soils, and the biological staining is very clear(Zhao *et al.* , 1993).

(2) Cryicaquic-skeletal soil. Although there are lichens and algae on Cryicaquic-skeletal soil, the macroscopic marking of soil-forming processes are vague. The results of chemical examination show: the releasing, leaching and biological accumulation of the chemical elements on the soil surface are very clear. For example, the coefficient of biological accumulation of S, K, Ca, P, B in the soil are 162, 26, 19, 11, 3 separately.

(3)Cryicaquic-recent sediment soil. It includes the recent alluvial soil, marine soil and drift soil. The biological activities are weak in these soils, and the content of organic carbon in the surface soil is less than 0. 30%. These soils occur mainly on the coastal terraces, the depressions arounding lakes and foreshore depressions of ice-cap and firn snow.

(4)Cryicaquic-disturbed soil. The frequent frost-thaw cycles make the gravel and fine soil grain of the surface soil layer and subsoil layer to separate, and the polygon soil, mud-stone flow and stone-polygon are formed in the Fildes Peninsula. There are few plants on the soils because of the unstable ground, the content of organic carbon in the surface soil is less than 0. 30%, the porosities of the central area of stone-polygon are 38%~45%. So, the differentiation of the profile is vague.

4. 2 Inceptisol—Cryicaquic-Inceptisol

The biological activities is so weak in Cryicaquic-inceptisol, there are no clear accumulation of organic matter in the soils, and the content of organic carbon in the surface soil is less than 0. 30%, but there are clear differentiation in the mineral-soil horizons.

(1)Cryicaquic-calcareous soil. These soils are developed on the calcareous parent material, there are few lichens and mosses on the ground, so the soils have no organic soil-layers. During summer, leaching and the resistance of the permafrost horizon make the soils very aquatic, and the leaching-quantities of $CaCO_3$ are different in the profile. For example, Profile S48:Site 250m east of Horatio Peak, altitude 102 m, there are few lichens and mosses on the ground, the parent material is the weathering product of basalt which contains siliceous amygdaloids:

0~8 cm: Very dark gray(5Y 3/1), loamy texture, but the surface soil is gravelly sand soil. there are cellular-porous structure, pH=7. 71, the content of organic carbon is 0. 19%, the content of $CaCO_3$ is 1. 09%, X-ray diffraction analysis and SEM(scanning electron microscope) show: there are some calcites in the clay, and there are SiO_2 illuviating on the surface of calcites.

8～32 cm: Dark olive gray (5Y 3/2), loamy texture, the content of water in the soil is 32%, pH=7.98, the content of organic carbon is 0.21%, the content of $CaCO_3$ is 4.30%.

32～40 cm: Dark grayish brown (2.5Y 4/2), light loamy texture, moisture-saturated soil, pH=8.12, the content of $CaCO_3$ is 6.15%, the density is 1.57 $g \cdot cm^{-3}$, there are a thin yellow-brown redox horizon on the frozen soil horizon.

40～42 cm: Frozen soil horizon.

The Cryicaquic-calcareous soils occur mainly on the southern part of the Fildes Peninsula.

(2)Cryicaquic-redoximorphic soil. There is a periodically stagnating horizon in the subsoil layer on the gentle slopes, the stagnating horizon goes down as the summer-thawing layer deepens, which makes the oxidation processes to replace the reduction processes in the subsoil layer, and the Fe, Mn of the subsoil are clearly migrated, the rust streak-spot horizon is formed in the subsoil layer, as shown in Profile S17: Site 200 m southwest of Shanhaiguan Peak, altitude 124 m, the profile is in the middle part of gently-slope platform, There are a few of lichens and mosses on the ground, the parent material is the eluvium and slope-wash of basaltic andesite.

0～5 cm: Olive (5Y 4/4), coarse-sand texture and fragmental structure, pH=7.26, the content of organic carbon is 0.32%, there is no calcareous reaction in the soil. The content of Fe in the soil is 4.620%, the content of Mn in the soil is 0.124%.

5～29 cm: Olive (5Y 5/4), coarse-sandy loam texture and loosely grained structure, pH=7.30, the content of organic carbon is 0.20%, there is no calcareous reaction in the soil. The content of Fe in the soil is 4.110%, the content of Mn in the soil is 0.096%.

29～38 cm: Pale yellow (5Y 7/4), sandy loam texture and loosely grained structure, there are some yellow-brown spots in the layer, there is no calcareous reaction in the soil. The content of Fe in the soil is 4.520%, the content of Mn in the soil is 0.032%.

39～45cm: Olive (5Y 4/3), frozen soil layer.

Cryicaquic-redoximorphic soils occur mainly on the gently slopes in the middle part of the Fildes Peninsula.

4.3 *Inceptisol-Cryicnormal Inceptisol*

Cryicnormal Inceptisols are the zonal soils of maritime sub-Antarctic region. In the soils the accumulation of organic matter is strengthened by the mosses, lichens and Deschampsia antarctica, there are a clear humus horizon in the soil. Based on the stage of soil development and the soil characteristics, the soils can be classified.

(1)Thin-tundra soils. The short soil-forming age and the erosion make these soils to be in the initial stage of soil development, the top layer often is biomass and bio-relict. the subsurface horizon is the thin humus horizon. So the solum is composed of A-horizon and C-horizon. In the study area the thin-tundra soils and Cryicaquic skeletal soils often form the particular soil complex.

(2)Tundra soils. Affected by the mosses and lichens, these soils have a relative long soil-forming process and a clear humus horizon. The Fe, Mn and clay of the soil are clearly migrated, the X-ray diffraction data show that the clay minerals consist mainly of montmorillonite, chlorite and illite. The soil characteristics are as follows: Profile S52. Site 150 m northwest of West Lake, altitude 43 m, the profile is on the platform, the cover degree of mosses and lichens is 40%~60%, the parent material is the weathering relict of basaltic andesite.

0~10 cm: Very dark grayish brown (2. 5Y 3/2), sandy loam texture and micro-granular structure, the density of the soil is 1. 43 g • cm^{-3}, there are a few of fungi in the soil, there is no calcareous reaction in the soil, pH=6. 94, the content of organic carbon is 1. 32%, the content of clay(<2 μm) is 6. 31%, the SiO_2/Al_2O_3 of the clay is 3. 15.

10~23 cm: Dark grayish brown (2. 5Y 4/2), light-loam texture and loose block structure, the density of the soil is 1. 45 g • cm^{-3}, there is no calcareous reaction in the soil, pH=7. 48, the content of organic carbon is 0. 79%, the content of the clay(<2 μm) is 6. 78%, the SiO_2/Al_2O_3 of the clay is 3. 32.

23~40 cm: Gray (5Y 5/1), light-loam texture and fragmental structure, the density of the soil is 1. 62 g • cm^{-3}, there is no calcareous reaction in the soil, pH=7. 82, the content of organic carbon is 0. 31%, the content of the clay(<2 μm) is 11. 04%, the SiO_2/Al_2O_3 of the clay is 3. 72.

40~52 cm: Gray (5Y 5/1), light-loam or sandy loam texture and fragmental structure, there are much gravel in the soil, and there are some dark-red or brown-red coating on the gravel surface, the content of clay is 9. 18%, the SiO_2/Al_2O_3 of the clay is 3. 86.

Tundra soils occur mainly on the platform of the middle area and southern area of the Fildes Peninsula.

(3) Subantarctic brown soils. On the Fildes Peninsula, the development of subantarctic brown soil has been limited by the landform and the wind force. but there are some developed subantarctic brown soils in the ice-free area of nearby peninsulas and islands. There are thickly Deschampsia antarctica in small areas on the gently north or northwest slopes of the Fildes Peninsula, and the thin subantarctic brown soils are formed under the mulcher. The humus horizon whose thickness is 3~8 cm has much the rhizotaxis of Deschampsia antarctica, the soils are olive brown (2. 5Y 4/4 dry), loam texture and block structure. The subsoil layer consists of mesic rhizotaxis, and the soils are pale-brown (10YR 6/3 dry), light-loam texture and block structure.

4. 4 *Histosol—Cryicaquic-histosol*

Cryicaquic-histosols are formed by the mosses, alga and oceanic animals. Based on the patterns of the biological activities, the soils are classified.

(1) Cryicaquic bog-histosols. The soils have been developed by the mosses on the sandy-gravel terraces or the flat bedrock surfaces. Samford (1988) pointed out that the

accumulation rate of the moss-peat is 89～158 $g \cdot m^{-2} \cdot a^{-1}$, it is very difficult to decompose the moss-relict in maritime sub-Antarctic regions, the decomposition rate is less than 0. 01 a^{-1}. Therefrom, the constituent of the soil is the fibrous or mesic-fibrous peat. For example Profile S45: Site the coastal terrace in the northwest part of the Ardley Island, altitude 17 m, the parent material is marine sandy gravel, the entire terrace is covered by the mosses.

0～5 cm: The moss-growth layer.

5～15 cm: Dark brown (10YR 3/3), fibrous matter, the density of the soil is 0. 42 $g \cdot cm^{-3}$.

15～32 cm: Very dark brown (10YR 3/2), mesic-fibrous matter, the density of the soil is 0. 69 $g \cdot cm^{-3}$, there are a gravel interbeded stratum in bottom.

32～43 cm: Dark grayish brown (10YR 4/2), the soils are the mixture of silt and mesic-fibrous peat. the density of the soil is 1. 15 $g \cdot cm^{-3}$, the ignition loss of the soil is 15%.

43～50 cm: Sandy gravel frozen layer, the ignition loss of the soil is less than 3%.

Cryicaquic histosols occur mainly on the Ardley Island.

(2)Cryicaquic ornithogenic soil. It is a particular histosol of the coastal ice-free areas of Antarctica. Cryicaquic ornithogenic soils often occur on the penguin rookeries i. e. the steep fragmental slopes on the coast or bedrock coast. The accumulation of penguin-dung may form the Cryicaquic ornithogenic soil that have the high content of Fluorine the accumulation of penguin feather may also make Cryicaquic ornithogenic soil to assume the protein fibrous, as seen in Profile S78. Site on the east coast of the Ardley Island, altitude 4 m, the rookeries of Ardley penguin, there are some milky-white, yellow-red muddy liquid in the penguin nest. The profile is in the interval of bedrock, there have been accumulation of penguin-dung.

0～3 cm: The loose granular structure. It is the recent dung accumulation horizon.

3～8 cm: Olive gray (5Y 4/2), block or stratified structure, the density of the soil is 0. 71 $g \cdot cm^{-3}$, the ignition loss of the soil is 29. 2%.

8～11 cm: Dark olive gray (5Y 3/2), loam texture and block structure, the ignition loss of the soil is 20. 1%. there are much gravel in the soil.

11～26 cm: Dark gray (5Y 4/1), gravel layer.

(3)Cryicaquic alga-peat soil. The soils are formed by the algae in the bottom surface of runoff or shallow lakes. Owing to the short soil-forming age and the limited productivity of algae, the thickness of the organic horizon is less than 5 cm, the color is dark olive gray (5Y 3/2), and the component of the soils is the round platy peats.

(4)Cryicaquic-sulfuric histosols. During the summer, there are many seals metabolizing in some coastal sandy or loam terraces, and the soils have been formed by the metabolism of seals, the surface soil is compacted, and there is clearly gleization in the subsoil layer. For example Profile S77: Site on the coastal sandy terrace in the Shimen Peninsula, altitude 2. 8 m, there are more than 100 seals living in summer.

0～3 cm: Black (5Y 2/2), sandy-loam texture and block structure, the ignition loss of the soil is 17. 2%, there are some yellow-milk liquid in the depressions.

3～10 cm: Black (5Y 2/2), sandy-loam texture and block structure, the ignition loss of the soil is 14.5%, there are some H_2S and mesic feather of seals.

10～36 cm: Dark olive gray (5Y 3/2), sandy texture and fragment structure, there are much frost-cracked gravel.

The Cryic-sulfuric histosols occur only on the small areas of the west coastal terraces in the Fildes Peninsula.

5 Relationship between soil distribution and environment

The results of the soil survey and analysis show: the soil distribution in the Fildes Peninsula are controlled by the parent material, landform and bioclimatic factors, and it is closely related to the processes of the ice-retreating and the coastal terrace develop-

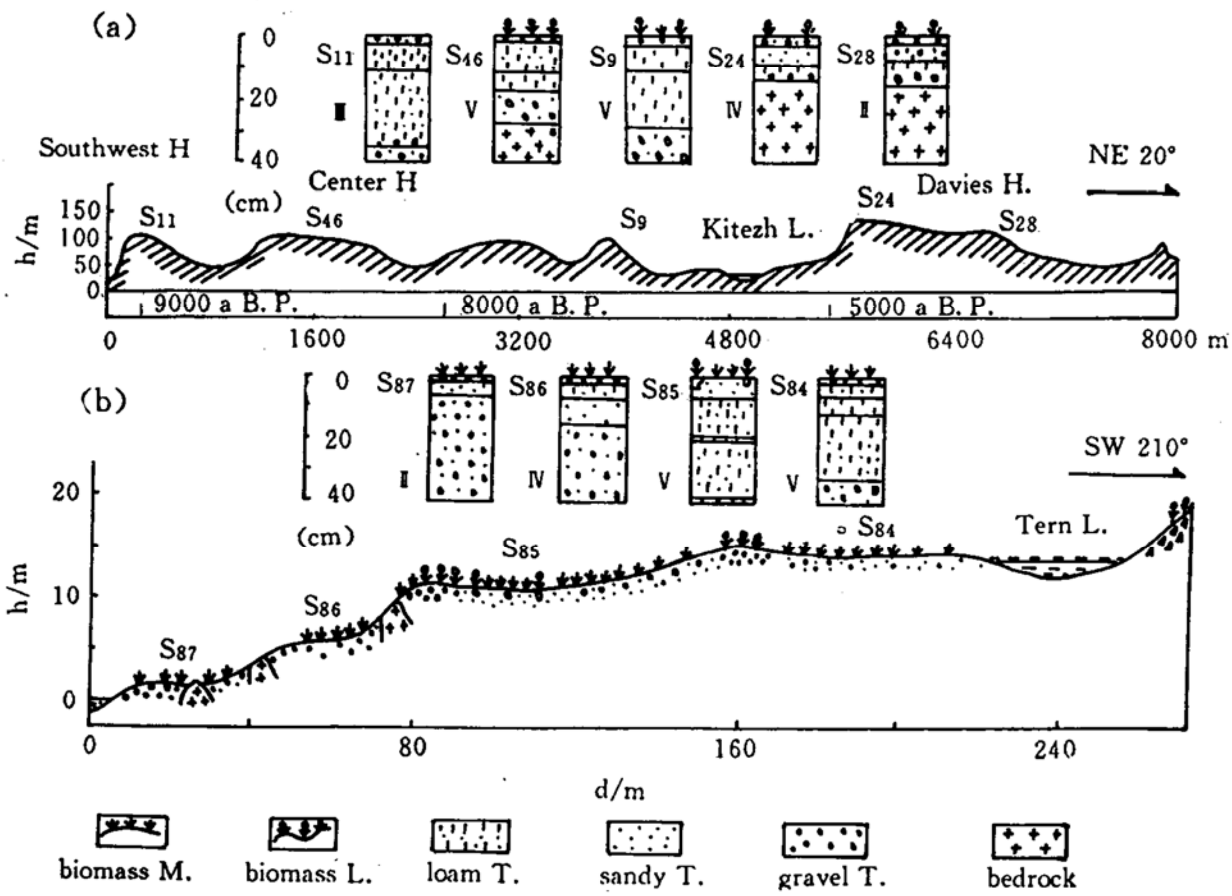


Fig. 1. Map showing the relationship between soil, soil development stage and environment in the Fildes Peninsula. S11: Cryicaquic calcareolls soil; S46: Tundra soil; S9: Tundra soil; S24: Thin-tundra soil; S28: Cryicaquic skeletal soil; S87: Cryicaquic-recent sediment soil; S86: Thin-tundra soil; S85: Tundra soil; S84: Tundra soil.

ment. As in Fig. 1 it is showed that the soil development stage is identical with the regional ice-retreating processes (Xie and Cui, 1992) to a certain extent. The soils on Southwest Highland and Center Highland where the icecap retreated early are often in development stages 3, 4 or 5, and the soils consist mainly of tundra soils and cryicaquic calcareous soils, the soil layer is relatively deeper, the texture is finer and the subsoil is loam texture. But the soils on Davies Highland where the icecap retreated recently are in development stages 1 or 2. the soils consist of cryicaquic-lithosols, cryicaquic-skeletal soils and thin-tundra soils. the soil layer is often thin, the texture is coarse (sandy or gravel texture). In the coastal terraces where the parent material and bioclimatic factors are similar, the different soil-forming ages make the soil development stage very different. For example, in east coastal area, the soils on T1 terrace consist only of the moss biostrome and sandy subsoil layer i. e. the soil profile is O--AC; on the T2 terrace the soil profile consists of O-horizon, A-horizon and C-horizon; But on the T3 or T4 terraces, the soil profile consists of O-horizon, A-horizon, B-horizon and C-horizon, as shown in Fig. 1b. Therefore the soil development has been affected deeply by the regional environment change.

Acknowledgments We are grateful to Pr. Zhang Lansheng, Pr. Lin Pei and Pr. Campbell I. B. for their helpful discussion, and the ninth Chinese National Antarctic Research Expedition for soil survey assistance.

References

Bockheim, J. G. and Ugolini, F. C. (1990): A review of pedogenic zonation in well-drained soils of the Southern Circumpolar Region. *Quaternary Research*, 34, 198.

Bonner, W. N. and Walton, D. W. H. (1985): Key environment Antarctica. Pergamon Press, Oxford.

Buol , S. W. (1980): Soil genesis and classification. 2nd ed. Ames Iowa: The Iowa State University Press.

Campbell, I. B. and Claridgn, G. G. C. (1987): Soils weathering processes and environment. Elsevier Press, New York.

Chen Fudong, Li Xuedong and Hiroshi Kanda (1993): An investigation of the Bryophtes in Fildes Peninsula of King George Island, Antarctica. *Antarctic research* (Chinese Edition), 5(1), 46.

Samford, M. (1988): Natural history of the Antarctic Peninsula. Columbia University Press, New York.

Xiao Changsong, Liu Dali and Zhou Peijin (1994): The survey of total number of bacteria and fungi isolated from the Fildes Peninsula in Antarctica. Antarctic research (Chinese Edition), 6(4), 67.

Xie Youyu and Cui Zhijiu (1992): The environment events on King George Island since the Last Glaciation. *Antarctic research*, 3(2), 56.

Zhao Ye, Yan Junfang and Li Tianjie (1993): An analysis on the spectral characteristics of the ground in the Great Wall Station area, Antarctica. *Remote sensing information*, 4, 9.