Antarctic Research, Vol. 7,No. 2,99～117,December 1996

Petrological characteristics of the sedimentary volcaniclastic rocks of the Fossil Hill Formation (eocene) in King George Island, West Antarctica*

Xue Yaosong (薛耀松), Shen Yanbin (沈炎彬) and Zhuo Erjun (卓二军)
Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

Received June 30, 1996

Abstract The Fossil Hill Formation of the type section composed chiefly of the sedimentary-volcaniclastic breccia and tuffites can be divided into two cycles of sedimentation. The thermal fluid was active in the coarse volcaniclastic deposits of the lower cycle, it led to the formation of laumontite, analcite, albite and regularly hybrid mineral of interlayered chlorite and montmorillonite, which are absent from the upper cycle, and to the transportation and concentration of some of trace elements between the coarser tuffites and the overlying fine tuffite bed at the upper part of this cycle. So-called "rain print" and "mud crack" actually are non-sedimentary originally, they were formed respectively by shedding of the small zeolitized concretions on the bedding plane and tectonic pressed stress. The evidences indicate that the Fossil Hill Formation of the Fossil Hill section was deposited in an intermontane lake affected by both volcanic action and seasonal flood under the condition of worm and moist climate.

Key words Antarctica, King George Island, Fossil Hill Formation, sedimentary volcaniclastic rocks.

1 Introduction

The Mesozoic-Cenozoic strata made up of volcanic and sedimentary volcaniclastic rocks are very developed in the Fildes Peninsula, King George Island (KGI), Antarctica. The strata were first named as the Fildes Peninsula Group belonging to Cenozoic (Hawkes, 1961; Barton, 1964, 1965). Since Chinese geologists went into the scientific examinations on this area, they have been doing a large number of the investigations on geology of the Fildes Peninsula (Liu and Zheng, 1988; Li *et al.*, 1992; Jin *et al*, 1992) and on palaeontology, such as sporo-pollen, leaves and trace fossils in the fossiliferous sedimentary-volcaniclastic rocks. Thus the stratigraphic sequence from Late Cretaceous to Early Tertiary was established over there and the paleoclimate and paleogeographic environment during the deposition were also discussed (Shen, 1994). The Fossil Hill is the main area in King George Island, where the Eocene fossiliferous strata are cropping out.

---

* This work was supported by National Natural Science Fundation of China.

However, the characteristics, texture, structure and alternation of the sedimentary-volcaniclastic rocks have not yet been described and discussed in detail. Based on the studies of the thin sections and the results of X-ray diffraction analysis and quantitative spectral analysis, this paper will discuss the above-mentioned questions of the Fossil Hill Formation sedimentary-volcaniclastic rocks in the Fossil Hill section and propose some new understandings and interpretations. The samples were collected by Shen Yanbin, a member of 4th Chinese National Antarctic Research Expedition.

2 Geological background

The Antarctic Peninsula and South Shetland Islands belong to a magmatic arc of the western margin of Antarctic Plate in Mesozoic-Neogene time. Since Pleistocene, both of them were separated due to the expansion of the Bransfield rift valley (Gonzaler-Ferran, 1982; Lu and Wu, 1989). In the Fildes Peninsula of King George Island the strata of the volcanic and sedimentary-volcaniclastic rocks of the the Fildes Peninsula Group can be divided ascendingly into five formations, they are the Half Three Point Formation, Jasper Hill Formation, Agate Beach Formation, Fossil Hill Formation and Block Hill Formation respectively, the first one is referred to Late Cretaceous while others are of Early Tertiary in age (Shen, 1994).

The Fossil Hill section, where lies the typical Fossil Hill Formation, is sited about 1400 m on the NNW of Great Wall Station (Fig. 1). There the strata consist of sedimentary-volcaniclastic breccia and tuffites, leaf and sporo-pollen fossils, bird ichnites and other trace fossils are rich in some horizons. Two thin coal beds are intercalated at the upper part of this section (Shen, 1990, 1994) . The sedimentary-volcaniclastic breccia overlies the volcanic rocks of the Agate Beach Formation unconformably but the top of this formation is not seen at the Fossil Hill section, with the cropped thickness of 12. 5 m. The Fossil Hill Formation of the Rocky Cove section is unconformably overlain by agglomerate of the Block Hill Formation, whereas its base boundary is not seen. Based on the petrological characteristics, fossil assemblage and regional distribution, it is considered that the sedimentary-volcaniclastic strata of the Fossil Hill section only correspond to the lower part of the Eocene Fossil Hill Formation (Shen, 1994).

Covacevich and Lamperein (1972) divided the strata of the Fossil Hill section into 4 units in petrological stratigraphy, from the base to the top they are: (4) unweathering andesite and basalt with the thickness of 380 m; (3) agglomerate, 10 m in thickness; (2) greyish brown, coarser tuffaceous sandstone, 8 m in thickness; (1) brownish grey, coarsed tuffaceous sandstone intercalated with reddish brown fine tuffaceous sandstone with bird ichnites and other trace fossils, 1 m in thickness. The 4 units can be referred to 3 types in petrographyic facies, in which the Unit 4 is the volcanic rocks of Agate Beach Formation while the sedimentary-volcaniclastic rocks of Units 3 to 1 can be referred to the Fossil Hill Formation. The stratigraphy and paleontology of the Fossil Hill Formation in the typical section have been studied and described in detail (Shen, 1994). The stratigraphic sequence and sample-taking positions are shown in Fig. 2.

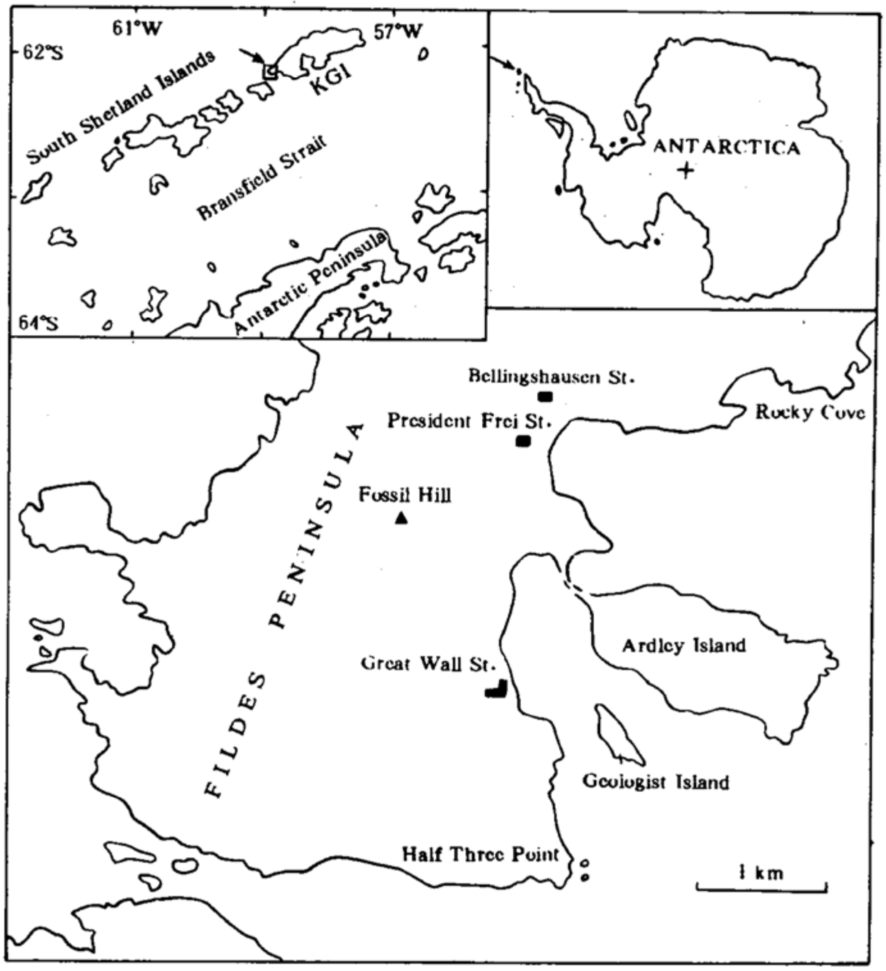


Fig. 1. Location of the Fossil Hill section in the Fildes Peninsula, King George Island, Antarctica.

3 Characteristics of the sedimentary-volcaniclastic rocks

The sedimentary-volcaniclastic rocks of the Fossil Hill Formation consist of volcanic rubbles (>2 mm), volcanic sands and volcanic dusts(<0. 063 mm). On the whole they show two sedimentary cycles from coarse to fine, i. e. Cycle I from Bed 1 to Bed 3 and Cycle Ⅱ from Bed 4 to Bed 6 (Fig. 2). The thin-bedded rhythmites which are composed respectively of sand-sized to clay-sized volcaniclastic materials are especially developed in Bed 2. The coarser volcanic debris chiefly are basaltic lithoclasts and plagioclase crystallinoclasts with a few of augites, while the matrix consists of fine volcanic dusts. The content of volcanic materials is more than 90% in all. The plagioclase crystallinoclasts and the volcanic dust matrix of the tuffites of the lower cycle are commonly subjected to zeolitization, smectitization and chloritization. A few of quartz grains may be found in the middle to upper parts of this section. Except that the detritus of some horizons of the upper cycle may come from the weathering and disintegrating products of the volcanic rocks, most of the debris can be determined to come from primary volcaniclastic deposits which might be carried through no long distance into the basin. According to Sun

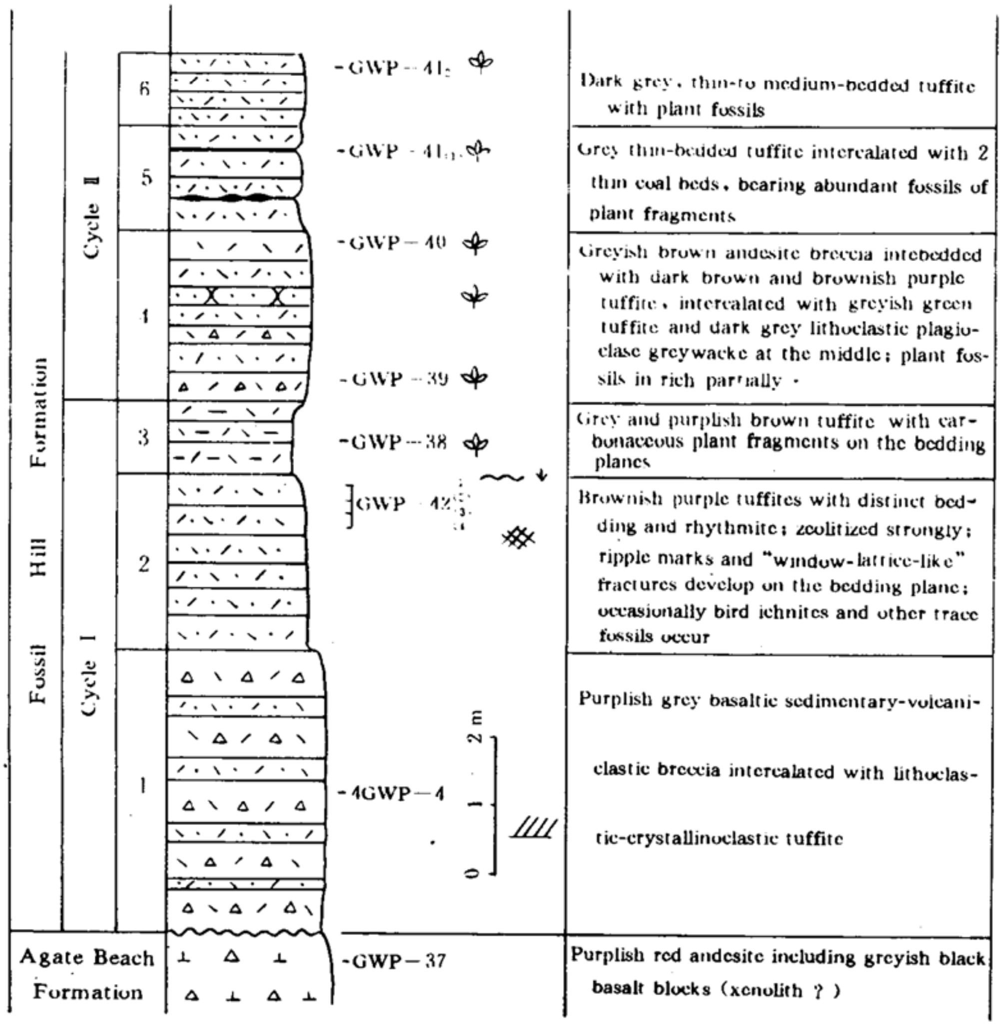


Fig. 2. Stratigraphic column of the Fossil Hill Formation in Fossil Hill, the Fildes Peninsula, King George Island with the sample-taking positions.

Shanping's classification on volcanic and volcaniclastic rocks (Qiu, 1985), the Fossil Hill Formation is mostly composed of sedimentary-volcanic breccia and tuffites intercalated with a few of detrital rocks formed by normal sedimentation.

The thin coal beds intercalated in the upper part of the tuffite sequence at the Fossil Hill section have been studied in coal petrography and geochemistry by Li and Shen (1994). This paper is to discuss the petrological characteristics of the sedimentary- volcaniclastic rocks sampled from the Fossil Hill section. The main petrological types are described as follows:

3. 1 Sedimentary-volcaniclastic breccia

It is dark purplish grey in colour and is mostly composed of basalt and basaltic andesite rubbles commonly with melted and eroded margin, 2～15 mm in size, more than 50% in content. The matrix of the basaltic rubble looks like being subjected to strong chloritization. The intergranular pores are filled with sand-sized volcanic lithoclasts, plagioclase crystallinoclasts, a few of augite and volcanic dust (Pl. Ⅰ -1) . But, the botryoidal chlorite envelopments and the fillings of coarse crystalline zeolite occur commonly in remainder intergranular pores (Pl. Ⅰ -2). Excepting the chloritized matrix, the phenomena that chlorite coats lithoclasts and crystallinoclasts or extends along the fractures are frequently seen in the thin sections. The compression is obvious. It is considered that the alteration of the matrix might finish in diagenetic stage before induration because consolidation could lead the porosity and permeability of the rocks to reducing so that complete alteration of the matrix would be difficult.

The sedimentary-volcaniclastic breccia is usually interbedded with the coarse-sand-sized lithoclastic-crystallinoclastic tuffite, slight showing normal gradation but without distinct bedding plane, to form a subsequence of roughly bedded, coarse sedimentary-volcaniclastic rocks. The rubbles of the basal part of this subsequence are coarser and complex while the upper part of this subsequence consists mostly of finer sedimentary-volcaniclastic breccia, and cross-beddings occur in partial horizon (Shen, 1994). The above-mentioned textures and structures suggest a sedimentary condition of current transportation through a short distance and rapid deposition. It might be a deposition of diluvial fan; but the coarse sedimentary-volcaniclastic breccia at the basal part was probably formed by debris flows.

3. 2 Tuffites

It consists of sand-sized and/or silt-sized plagioclase crystallinoclasts, basaltic lithoclasts, a few of augite crystallinoclasts and ferriferous minerals, and clay-sized volcanic dust matrix; the contents of volcaniclastic material usually are more than 90% (Pl. Ⅱ - 2), even all debris come from volcanic material. Due to sorting they often respectively make up greyish brown, sand-sized lithoclastic-crystallinoclastic tuffite, silt-sized crystallinoclastic tuffite (every layer 1～3 cm in thickness) and dark purplish red, clay-sized tuffite (i. e. mudstone-like tuffite) (every layer 1～15 mm in thickness), to form thin interbedding even lamination and to show distinct and level bedding plane (Pl. Ⅲ -1c, 2 and 3). These rocks have been defined as tuffaceous sandstone, tuffaceous siltstone and tuffaceous mudstone, however their materials mostly come from volcanic debris, without or less normal terrigenous detritus.

In the coarser tuffites the basaltic lithoclasts may have a considerable content, commonly occupying 1/3 to 1/2 of sand-sized debris, in which the plastic-deformed basaltic lithoclasts are often visible. The plagioclase crystallinoclasts mostly show melted-eroded texture, both they and matrix are usually zeolitized in the lower cycle. Several neighbouring zeolitized plagioclase crystallinoclasts and zeolitized matrix including them bear identical direction of extinction, it looks like mosaic texture of coarse-crystalline zeolite including and replacing plagioclase crystallinoclasts, named as "inclusive-mosaic texture" by this paper (pl. Ⅱ -5a and 5b) . The X-ray diffraction patterns of some samples of the zeolitized tuffite show sharp diffraction peaks of laumontite and indistinct peaks of plagioclase, indicating that complete zeolitization could occur in some horizons.

In the tuffite composed chiefly of silt-sized volcanic debris, lithoclasts decrease while plagioclase crystallinoclasts and volcanic dust matrix increase relatively. Although the "inclusive-mosaic texture" formed by zeolitization occurs, too, the zeolite crystals are smaller (finely crystalline).

The mudstone-like tuffite is composed of clay-sized volcanic dust ($\leqslant 5\ \mu m$ in size) and a number of silt-sized lithoclasts and plagioclase crystallinoclasts, occasionally the porous plastic-deformed lithoclasts can be also seen in the thin sections. The results of X-ray diffraction analysis of 9 samples of the mudstone-like tuffite in Beds 2, 3 and 4 indicate that their mineral compositions are somewhat different (Table 1) . 6 powdered samples of the mudstone-like tuffite in Bed 2 have a mineral assemblage of laumontite, analcite, albite, andesine and a few of smectite and chlorite from X-ray diffraction patterns (Fig. 3), but the mineral composition of $<2\ \mu m$ fractions obtained through the extraction after the samples to be immersed mostly is regularly hybrid mineral of interlayered chlorite and montmorillonite (Ch/M RHM), only a few of albite (Fig. 4).

Table 1. Mineral assemblages of 9 samples of the mudstone-like tuffite from Fossil Hill by X-ray diffraction analysis

Order	Bed No.	Sample No.	Main mineral composition
1	4	GWP-40A	Smectite, andesine (and/or labradorite), a few of quartz
2	4	GWP-39	
3	3	GWP-38	
4	2	GWP-42(1)B	Regularly hybrid mineral of interlayered chlorite and montmorillonite, laumontite, albite, andesine
5	2	GWP-42(1)C	
6	2	GWP-42(1)E	
7	2	GWP-42(3)A	
8	2	GWP-42(3)	Regularly hybrid mineral of interlayered chlorite and montmorillonite, laumontite, analcite, albite, andesine
9	2	GWP-42(4)	Regularly hybrid mineral of interlayered chlorite and montmorillonite, analcite, albite, andesine, augite

The matrix of the coarsed tuffites shows the nature of chloritization under polarizing microscope, probably that is reflection of this hybrid mineral. However, the X-ray diffraction patterns of the powdered samples of Beds 3 and 4 show distinct peaks of andesine (and/or labradorite ?) and week peaks of quartz while the patterns of $< 2\ \mu m$ fraction have very sharp 14.03～14.73 Å peaks of smectite and weak peaks of andesine, relatively clear peak of quartz occurs only in the diffraction pattern of sample GWP-38.

In addition, fine-silt-sized plagioclase crystallinoclasts in some samples of the mudstone-like tuffite appear in lamina and its major axes are parallel to the lamination under microscope; a few of carbonaceous plant fragments parallel to the lamination can be seen in the thin sections of some samples (Pl. Ⅲ-3). It suggests the characters of current transportation and sedimentation in water.

3.3 *Lithoclastic plagioclase greywacke*

It is dark grey, with sand-like texture, showing rough broken surface. The exami-

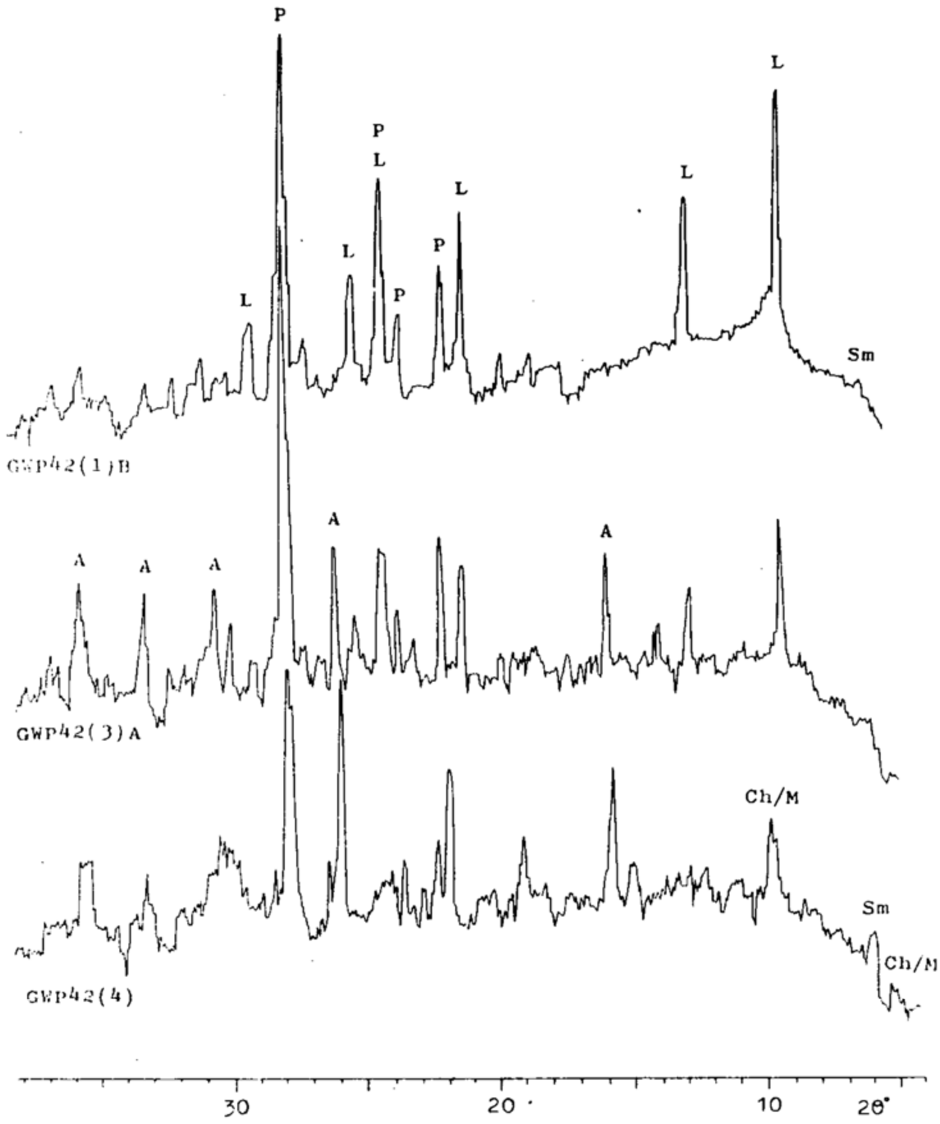


Fig. 3. X-ray diffraction pattern of three powdered tuffite samples from Bed 2 of the Fossil Hill Formation. P--albite; L--laumontite; A--analcite; Sm--smectite; Ch/M--Ch/M RHM.

nation of the thin sections results in that plagioclase grains, 0. 5～1. 5 mm in size, are dominant, with a content of some 65% in sand-sized grains, others are a few of basaltic lithoclasts and augite; the intergranular pores are filled with silt-sized plagioclase and clay-sized matrix, whereas some of remainder pores may be filled with chlorite and zeolite. Sand-sized plagioclase grains mostly bear rounded, melted-etched outline and were zeolitized in various degrees, and they often broke due to compression between the grains (Pl. Ⅱ-1). The silt-sized plagioclase in the matrix might be chloritized along the fractures of crystal. Excepting high abundance and relatively even grain size of plagioclase, there appear the remains of matrix of primary volcanic rock on the surface of some of plagioclase grains (Pl. Ⅱ-1). It suggests that they might come from the weathering and eroding products of volcanic rocks and then were transported through a short distance into the basin to accumulate. This type of rocks, therefore, essentially do not belong to

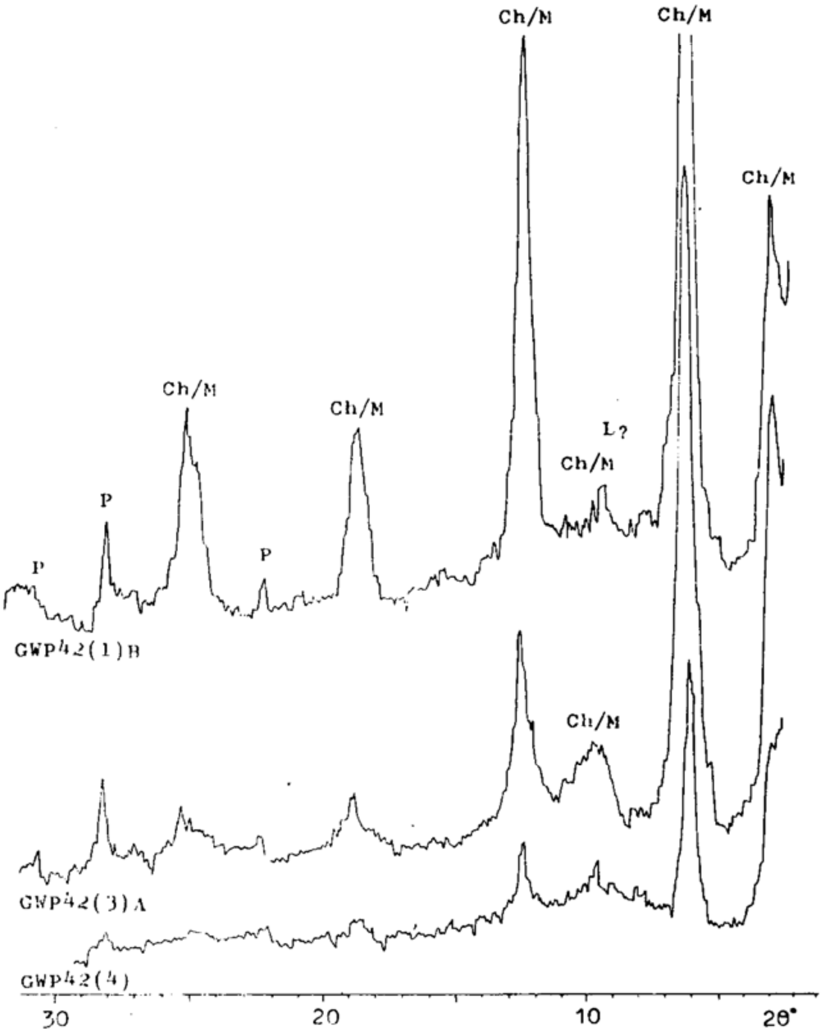


Fig. 4. X-ray diffraction pattern of $< 2\mu m$ fraction (removing ferric oxide) of three tuffite samples from Bed 2 of the Fossil Hill Formation. Ch/M--Ch/M RHM; P--albite, L? --laumontite ?.

volcaniclastic or sedimentary-volcaniclastic rock. It had been identified as tuffaceous sandstone (Li and Shen, 1990) or basaltic crystallinoclastic tuff (Li *et al.*, 1992).

4 Major structures of the tuffites

4.1 *Graded rhythmite*

The Fossil Hill Formation is mostly composed of the tuffites made up of sand-sized, silt-sized and clay-sized volcanic debris which often formed thin-bedded graded rhythmites, especially developed in Bed 2 (Pl. Ⅲ-1c, 2 and 3). The sand-sized lithoclastic and crystallinoclastic tuffite layers, mostly 1 ~ 30 mm in thickness, usually show normal graded bedding and level and distinct basal plane. Sometimes, small loading structure can be seen in the thin sections, even the mudstone-like tuffite might intrude upwards into overlying coarser tuffite layer (Pl. Ⅱ-4). In some of the coarse tuffite layers the base part may appear as reversed gradation, about 1～2 mm thick, and contain a number of the grains of ferric oxide, while the top surface of the underlying mudstone-like tuffite is dark brownish red which was formed due to impregnation of ferric oxide, therefore nearly opaque under microscope (Pl. Ⅲ-2 and 3). It suggests a sedimentary interval before next low-density flow deposition.

4. 2 Ripple mark

Small ripple marks are visible on the top surface of the tuffite rhythmites at the uppermost part of Bed 2 (Pl. Ⅳ-1). It is lingual in form with wide and even crest plane, 16～19 mm in wave length (L) and 1. 5 mm in wave height (H), L/H value from 11 to 13. 5. It suggests a shallow sedimentary environment with a rapid velosity of water flow.

4. 3 "Window-lattice-like" fractures

Two suits of fractures meeting nearly at right angles are very developed on the bedding surfaces of the mudstone-like tuffites (2～6 mm in thickness) , which are intercalated in the coarse tuffites of Bed 2, to form "window-lattice-like" structure (Pl. Ⅲ-1a and 1b). A suit of the fractures is continuative in straight lines, and another suit is faulted and somewhat moved as en echelon joints (Pl. Ⅲ-1b). The small lattices mostly assume square, partially short rectangle, 2～5 mm or 5～10 mm in side length. The fractures uaually curve and link at the top and base of the mudstone-like tuffite layers (Pl. Ⅲ-1c), so that the small lattices have dome-like top and base. They are easy to be peeled off from the bedding plane, leaving corrugated marks (Pl. Ⅲ-1b).

This structure had been described as "mud crack" (Liu and Zheng, 1988; Shen, 1990; Li *et al.* , 1992). However, in natures it is obviously different from mud crack: (1) the straight fractures breaking up the mudstone-like tuffite layers into small squares are not similar to the polygonal fractues of mud crack; (2) the fractures are fine without fillings; (3) in two mudstone-like tuffite layers which are respectively as the apical and basal plates of a coarse tuffite layer, the fractures are identical in direction but the domes of the small squares may be reverse, showing a relationship of mirror image (Pl. Ⅲ-1a and 1b). It is considered that the formation of this fracture structure might be relevant to process of tectonic stress after the diagenesis.

4. 4 Small concretions on the bedding plane

A few of small spheroidal concretions, about 1 mm in diameter, are scattered on the bedding planes of some of the fine tuffite layers (Pl. Ⅳ-5). They have been crystallized to form a irregular spheroid with strong reflection, rude surfaces, not being dyed in the solution of alizarin red; a number of crystal fragments with feature of minus relief under polarizing microscope can be seen in the powders of the concretions. It may be zeolite. After the concretions fell off, a few of small hollows which have been considered as "rain print" in the field works would be left on the bedding plane. However, these irregular small hollows are obviously diffrent from rain print in feature. The recent rain prints on the surface of mud deposits appear to be shallow dished hollows in shape with ring swelling and divergent structure at its margin, just like lunar craters.

4. 5 No zeolitized remainder mottles

The fine tuffites consist mostly of volcanic ash <30 μm in size, with a few of dark volcanic lithoclasts and plagioclase crystallinoclasts. When they were zeolitized, the zeolitization took place in impregnation, whereas no zeolitized parts of the rock appear to be dark remainder mottles with the caky and ginger-like shapes like concretions, ranging from 0. 5 to 8 mm in diameter (Pl. Ⅳ-3). Under polarizing microscope the remainder mottles contain more opaque lithoclasts, showing positive relief as a whole, but other parts appear to be lighter colour and minus relief; there is a clear zeolite ring around the remainder mottle. This structure is frequently visible in the fine tuffite intercalations of Bed 2 (Pl. Ⅲ-1c).

4. 6 Calcitized lumps

Calcitization is poor developed in the Fossil Hill Formation tuffites, only a few of minor, irregular calcitized lumps occur at the top part of Bed 2. Allotriomorphic, finely crystalline calcite replaced the zeolitized plagioclase-crystallinoclasts and matrix to form small lumps scattered between zeolite crystals. It is clearly determinable by the dyeing method of the solution of alizarin red (Pl. Ⅳ-4).

5 Distribution of trace elements

7 samles including the andesite (GWP-37) of the top part of the Agate Beach Formation and the fine tuffites of Beds 2, 3 and 4 of the Fossil Hill Formation are analysed by spectrometry. The analytical results (Table 2) show that the composition and content of the trace elements of the fine tuffites are consistent with that of the andesite, without obvious anomaly except for high content of Sr in individual tuffite sample (Fig. 5). The content of La of all of the analysed samples is lower than the analysable sensitivity 0.1×10^{-6}); the values of Sc and Cr of the andesite are relatively higher than the fine tuffites of the Fossil Hill Formation. The content of B in all samples is less than 1×10^{-6}, it suggests that not only the geologic background value of B is very less, but also the sedimentary environment was out of all relation to seawater.

Table 2. Spectrometric results of trace elements of Agate Beach Formation andesite and the Fossil Hill Formation mudstone-like tuffites from Fossil Hill, King George Island ($\times 10^{-6}$)

Sample No.	La	Yb	Y	Cd	Sc	Tl	B	Sr	Ba	Mn	Ti	V
GWP40	-	1.20	12.6	0.16	22.0	-	<1	310	110	575	3760	204
GWP 39	-	1.68	10.8	0.13	30.1	-	<1	394	154	859	3895	165
GWP 38	-	2.30	18.7	0.18	33.3	0.31	<1	639	154	733	4930	219
GWP42(1)B	-	1.57	11.4	0.14	26.0	-	<1	254	82	593	4280	204
GWP 42(3)A	-	1.21	11.4	0.12	27.5	-	<1	597	116	804	3470	147
GWP 42(4)	-	12.4	12.3	0.11	28.2	-	<1	6410	199	929	3565	158
GWP 37	-	1.67	13.3	0.19	39.7	-	<1	374	122	797	4833	109

Sample No.	Zr	Ga	Cu	Pb	Zn	Sn	Cr	Ni	Co	Mo	Ge	Nb
GWP40	67.2	13.8	95.3	4.03	57.2	4.74	16.9	10.4	24.1	0.86	0.82	6.43
GWP39	75.8	11.6	122.4	3.79	129.8	2.70	23.5	10.3	21.9	0.85	0.72	6.47
GWP38	136.6	18.1	226.5	7.13	89.5	2.62	18.6	10.0	28.7	0.90	2.06	5.77
GWP 42(1)B	82.3	19.8	135.7	5.76	50.4	2.13	17.2	8.0	16.1	0.67	1.37	5.42
GWP42(3)A	80.8	17.5	88.7	6.23	57.2	2.27	12.0	8.8	18.4	0.74	1.06	5.63
GWP42(4)	69.5	18.5	194.5	4.50	37.6	2.43	17.2	7.8	19.9	0.78	0.86	5.14
GWP 37	86.7	11.7	152.3	5.42	96.5	2.35	38.5	10.1	21.5	0.61	0.80	5.08

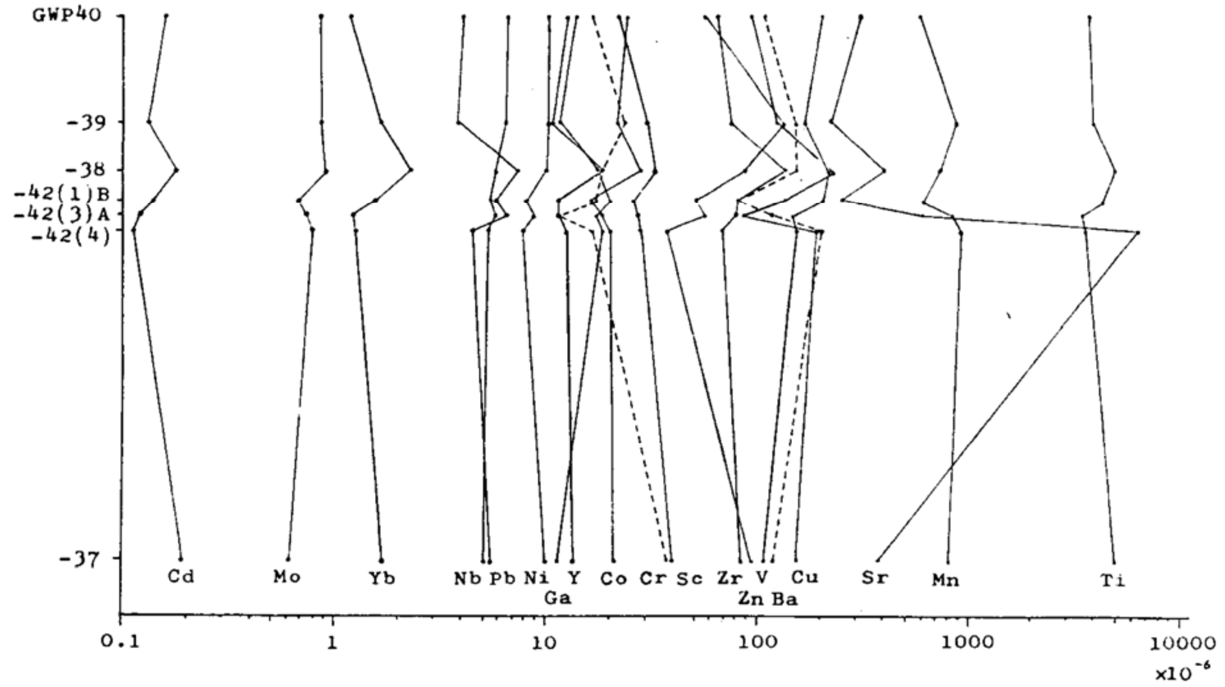


Fig. 5. Curves of trace elements based on spectral analyses to the andesite and the mudstone-like tuffites of the Fossil Hill section, King George Island.

A number of the trace elements of the fine tuffite sample (GWP-38) of Bed 3, such as Yb, Y, Cd, Sc, Tl, V, Zr, Ti, Cu, Pb, Co and Ge, show its highest values in the Fossil Hill section, but the lowest abundances of Cd, Yb, Y, Cr, Co, Mo, Cu, Pb and

Zn occur at the top part of Bed 2 (GWP-42) (Fig. 5). It might bear a relationship to the transportation and concentration of some elements at the boundary between Bed 2 and Bed 3. Bed 2 consists mostly of the coarse volcanic debris, abundant interlayer fluid contained in it could flow easily, which led to strong zeolitization but high concentration of trace elements had not been carried into this bed, in contrast some of trace elements might be dissolved and transported into the overlying fine tuffite which is the apical plate of the coarse tuffite.

6 Discussion

In the Fossil Hill section the strata merely correspond to the lower part of the Fossil Hill Formation, composed mostly of the sedimentary volcaniclastic rocks. On the whole it shows two cycles from rude to fine, with clear bedded and graded features. The lower part of Cycle I chiefly is the sedimentary volcaniclastic breccia deposited in alternation with the rude tuffites, but the bedding is poor developed. It suggests a sedimentary condition of rapid deposition in the intermontane basin formed after the volcanic eruptions of Agate Beach age. In the overlying beds, especially in Bed 2, the rhythmites are developed, which might originally be a deposition of diluvial fan formed by seasonal floods. The upper part of this section is rich in leafage, stem and sporo-pollen fossils, and contains a few of quartz sands, in which the thin coal beds originally belonging to allochthony deposition may occur partially (Li and Shen, 1994). It suggests that "normal sedimentation" entered into the later depositions. The plant fossils indicate a condition of worm and moist climate at that time (Li and Shen , 1990; Li, 1994) . Although the fine tuffites mostly are brownish red, brownish purple and dark brown in colour which resulted from impregnation of ferric oxide under oxidational condition, the fact that clay minerals except for smectites are absent from the strata suggests that the volcanic debris (or volcanic rocks) of the source regions were not subjected to chemical weathering for a long time. It can be assumed that the Fossil Hill Formation was deposited in a intermontane lake with the nature of intermittent and rapid depositions which might be affected by both volcanic eruption and seasonal floods.

Smectitization is the most wide-ranging diagenetic alteration in the Fossil Hill Formation of the Fossil Hill section. Most of the fine volcanic ashes had altered into smectite. However, the results of X-ray diffraction analyses to < 2 μm-sized fraction of the fine tuffite intercalations of Bed 2 indicate that the finest volcaniclastic material had altered into regularly hybrid mineral of interlayered chlorite and montmorillonite, and the content and crystallinity of them seem to be increasing upwards based on the intensity and shape of the diffraction peaks (Fig. 4). The <2 μm-sized fractions of the fine tuffites of Beds 3 and 4 mostly are purer smectite instead of this hybrid mineral. It is considered that the hybrid mineral of interlayered chlorite and montmorillonite in Bed 2 did not result from progressively burying of the deposits, it might be formed by the hot fluid which entered into the pores and reacted with the fine volcanic ash sediments. Their formation may be earlier than the zeolitization because the fine matrix could be often zeolitized.

The zeolitization is an important alteration, too. It is especially developed in the ruder tuffites of the lower cycle. A few of the fine veins of zeolite (only 10 ~20 μm in width) can be seen in the sample GWP-42(3)B, they usually cut through the beddings of the zeolitized crystallinoclastic-lithoclastic tuffites and the mudstone-like tuffites with "window-lattice-like" structure, even through zeolitized plagioclase-crystallinoclasts and volcanic lithoclasts. It can be said that the zeolites were formed in various stages: the zeolitization of the crystallinoclastic-lithoclastic tuffites might finish in diagenetic stage but the zeolite veins occurred obviously after diagenetic stage. In the upper cycle, only a few of zeolite fillings can be visible in some of intergranular pores of the greywacke, whereas the zeolitized plagioclase grains might come from the weathering products of volcanic rocks, they were already zeolitized before redeposition. No distinguishable diffraction peaks of zeolites appear in the diffraction patterns of the mudstone-like tuffites of the upper cycle. The evidences indicate that the zeolitization of the upper cycle is very poorly developed, obviously in contrast to the strong zeolitization of the tuffites of the lower cycle.

In addition, the X-ray diffraction patterns of the mudstone-like tuffites of Bed 2 show strong and sharp 3. 18 Å peak of albite and weak 3. 21 (3. 22) Å peak of andesine (Fig. 3), while the diffraction patterns of three samples, GWP-38, GWP-39 and GWP-40 A bear a feature of twin peaks, 3. 21 (3. 20~3. 22) Å and 3. 18 (3. 17) Å, in which the former is somewhat stronger. It is characteristic of diffraction of andesine (and labradorite ?). The evidences indicate that there are more albite in Bed 2 and only andesine in the overlying tuffites. The Mesozoic to Cenozoic volcanic actions of the Fildes Peninsula mostly were the eruptions of basic to mediosilicic magma which should produce basic to neutral plagioclases. Therefore, we consider that the albite of the tuffites of Bed 2 probably are a secondary mineral. The formations of the albite and analcite in the lithoclastic-crystallinoclastic tuffites might result from sodium separation from andesine when it was laumontitized. However, the diffraction pattern of the sample GWP-42(4) shows the existence of analcite, albite and andesine, without laumontite, it is difficult to identifing whether Na came from the Laumontitization of the neighbouring tuffite layers or it was carried by allogenic hot fluid. The former is more possible based on the distribution of trace elements.

The calcitization in the tuffites is very weak in contrasted with the strong calcitization but without determinable zeolitization in the Late Cretaceous tuffites of the Half Three Point area (Xue, 1994). A number of laminated, ferrodolomitized rock masses occur in the Block Hill Formation in the southern Geologist Island. They are composed of xenomorphic, rudely-crystalline to finely-crystalline ferrodolomites including a large number of remainder volcanic ashes (Pl. I -3a and 3b), not dyeing in the solution of alizarin red but dyeing into blue in the solution of potassium hexacyanoferrate, containing FeO up to 4. 23%, CaO 10. 85%, MgO 4. 92% and insoluble residue of 55. 4%. They should primarily be one of carbonated tuffites formed before the magma eruption of the Block Hill age, probably to be synchronous deposit with the Half Three Point Formation.

References

Barton, C. M. (1964): Significance of the Tertiary fossil floras of King George Island, South Shetland Islands. In: Antarctic Geology, Ed. by Adie, R. J., North-Holand Publishing Company, Amsterdam, 603～608.

Barton, C. M. (1965): The geology of the South Shetland Islands, III. The stratigraphy of King George Island. British Antarctic Survey, Scientific Reports, (44), 1～33.

Covacevich, V. and Lamperein, C. (1972): Ichnites from the Fildes Peninsula, King George Island, South Shetland Islands. In: Antarctic Geology and Geophysics, Ed. by Adie, R. J., Universitetsforlaget, Oslo, 71～74.

Gonzalez-Ferran, O. (1982): The Antarctic Cenozoic volcanic provinces and implication in plate tectonic processes. In: Antarctic Geoscience, Ed. by Craddock, C., The University of Wisconsin Press, Madison, 687～694.

Hawkes, D. D. (1961): The geology of the South Shetland Islands 1. The petrology of King George Island. Falk. Isl. Depend. Sur. Sci. Rep., (26), 1～28.

Jin Qingmin, Kuang Fuxiang, Xing Guangfu, Sun Nangui, Feng Ningshen and Sun Yijian (1992): Volcanism and magmatic evolutions of Fildes Peninsula, King George Island, Antarctica. Jiangsu Science and Technology Publishing House, Nanjing, 1～98 (in Chinese and English).

Li Haomin (1994): Early Tertiary Fossil Hill flora from Fildes Peninsula of King George Island, Antarctica. In: Stratigraphy and palaeontology of Fildes Peninsula, King George Island, Antarctica, Ed. by Shen Yanbin, Science Press, Beijing, China, 133～171(in Chinese).

Li Haomin and Shen Yanbin (1990): A primary study of Fossil Hill flora from Fildes Peninsula of King George Island, Antarctica. *Acta Palaeon. Sinica*, 29(2), 147～153.

Li Xiaoyan and Shen Yanbin (1994): Preliminary study on the genesis of Tertiary coal from Fildes Peninsula of King George Island, Antarctica based on petrographical, chemical and organic geochemical characteristics. In: Stratigraphy and Palaeontology of Fildes Peninsula, King George Island, Antarctica, Ed. by Shen Yanbin, Science Press, Beijing, China, 251～261 (in Chinese).

Li Zhaonai, Zheng Xiangshen, Liu Xiaohan, Shang Ruxiang, Jin Qingmin and Wang Bixiang (1992): Volcanic rocks of the Fildes Peninsula, King George Island, West Antarctica. Science Press, Beijing, China, 1～227 (in Chinese and English).

Liu Xiaohan and Zheng Xiangshen (1988): Geology of volcanic rocks on Fildes Peninsula, King George Island, West Antarctica. *Antarctic Research* (Chinese Edition), 1(1), 25～35.

Lu Wenzheng and Wu shuigen (1989): The Bransfield Trough—a Cenozoic rift. *Antarctic Research* (Chinese Edition), 1(4), 28～35.

Qiu Jiaxiang (1985): Petrology of magmatic rocks. Geological Publishing House, Beijing, China, 1～340 (in Chinese).

Shen Yanbin (1990): Progress in stratigraphy and palaeontology of Fildes Peninsula, King George Island, Antarctica. *Acta Palaeontologica Sinica*, 29 (1), 129～139.

Shen Yanbin (1994): Subdivision and correlation of Cretaceous to Paleogene volcano-sedimentary sequence from Fildes Peninsula, King George Island, Antarctica. In: Stratigraphy and Palaeontology of Fildes Peninsula, King George Island, Antarctica, Ed. by Shen Yanbin, Science Press, Beijing, China, 1～36 (in Chinese).

Xue Yaosong (1994): Characteristics and sedimentary environment of volcanic debris rocks of Upper Cretaceous Half Three Point Formation from King George Island, Antarctica. In: Stratigraphy and Palaeontology of Fildes Peninsula, King George Island, Antarctica. Ed. by Shen Yanbin, Science Press, Beijing, China, 97～108 (in Chinese).

Explain of the plates

(The samples are collected from the Fossil Hill section except for those to give clear indication on the sampling area)

Plate I

1. The basaltic, sedimentary-volcaniclastic breccia of Bed 1 intercalated with the lithoclastic-crystallinoclastic tuffite. 4GW-4; microphotograph from the thin section under polarizer. The scale bar is 0. 5 mm.

2. The walls of intergranular pores between the volcanic debris are coated with botryoidal envelopes of chlorite (Ch), whereas the remainder pores are filled with zeolite (Z) in which there are the remains of plagioclase (P). 4GW-4. The scale bar is 0. 1 mm.

3a and 3b. Ferrodolomitized tuffite. A large number of the crystallinoclasts and lithoclasts are included in the ferrodolomite spars, and there are a few of pyrite crystals. 3a, a microphotograph of the thin section under single nicol; 3b, the same field under X-nicols with 3a. The scale bar is 0. 1 mm. The sample come from the Block Hill Formation of Geologist Island.

Plate II

1. Plagioclase and lithoclastic greywacke. The plagioclase (P) have fine fractures and are subjected to zeolitization in varying degrees; the matrix remains of primary volcanic rock (a) coat the surface of some of the plagioclase; some of the plagioclase are cracked (c) under pressure of pyroxene (b). GWP-39-40; microphotograph from the thin section under single nicol. The scale bar is 0. 5 mm.

2. The microphotograph of the tuffite, GWP-39, from the thin section under single nicol. The scale bar is 0. 5 mm.

3. The microphotograph of the tuffite, GWP-38, from the thin section under single nicol. It shows laminated structure due to varying content of silt-sized plagioclase crystallinoclasts , and there are a number of carbonaceous plant fragments parallel to the lamination. The scale bar is 0. 5 mm.

4. The laminated, fine tuffite are pressed and intruded into the overlying lithoclastic-crystallinocstic tuffite. GWP-42(3)A; microphotograph from the thin section under single nicol. The scale bar is 0. 5 mm.

5a and 5b. Zeolitized crystallinoclastic tuffite. GWP-42(2)A; 5a is microphotograph from the thin section under single nicol, while 5b shows that some of zeolitized plagioclase crystals have identical direction of extinction under X-nicols in the same field with 5a. The scale bar is 0. 1 mm.

Plate III

1a and 1b. The "window-lattice-like" fracture structure respectively on the upper plane and basal plane of the same layer, showing that they are identical in direction. GWP-42(4); photographes of the sample. Each lattice of the bar is 1 mm.

1c. The Photograph of the vertical polished section of the above-mentioned sample shows graded bedding of the ruder tuffite layer. The remainder mottles after zeolitization occur in the fine tuffite layers (a).

2. Brownish purple, fine tuffite intercalated with zeolitized lithoclastic-crystallinoclastic tuffite. GWP-42 (3)A; polished section. Each of the small lattices is 1 mm.

3. The zeolitized lithoclastic-crystallinoclastic tuffite interbedded with mudstone-like tuffite contains fine rubbles of volcanic rocks and shows reserve-graded lamina at its basal part. GWP-42(1)C; polished section. The magnification is the same with photo 2.

Plate IV

1. The cast of the ripple mark on the basal plane of the ruder tuffite layer. GWP-42(1)A. Each of the small lattices of the bar is 1 mm.

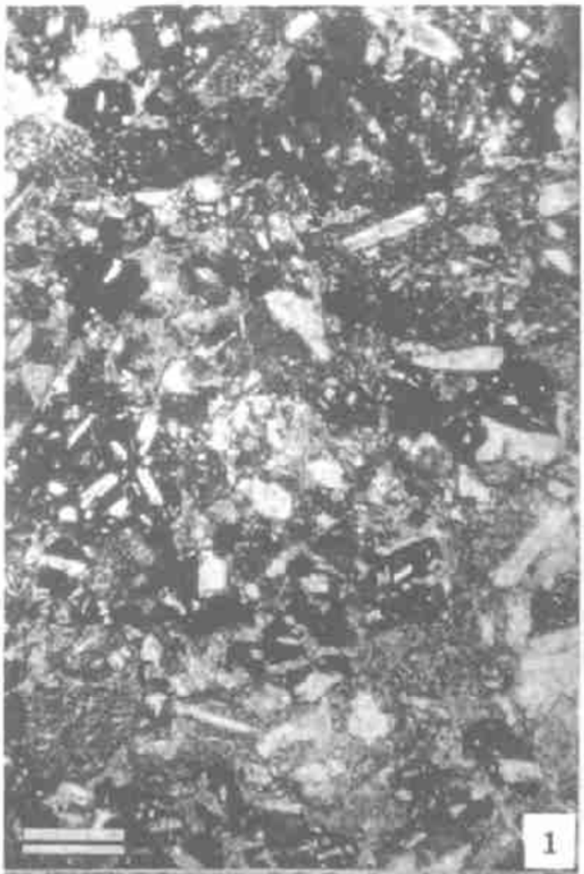
2. Trace fossil (?) on the bedding plane of the tuffite. GWP-42(1)B.

3. The remainder mottle structure on the bedding plane of the tuffite after zeolitization. GWP-42(2)C.

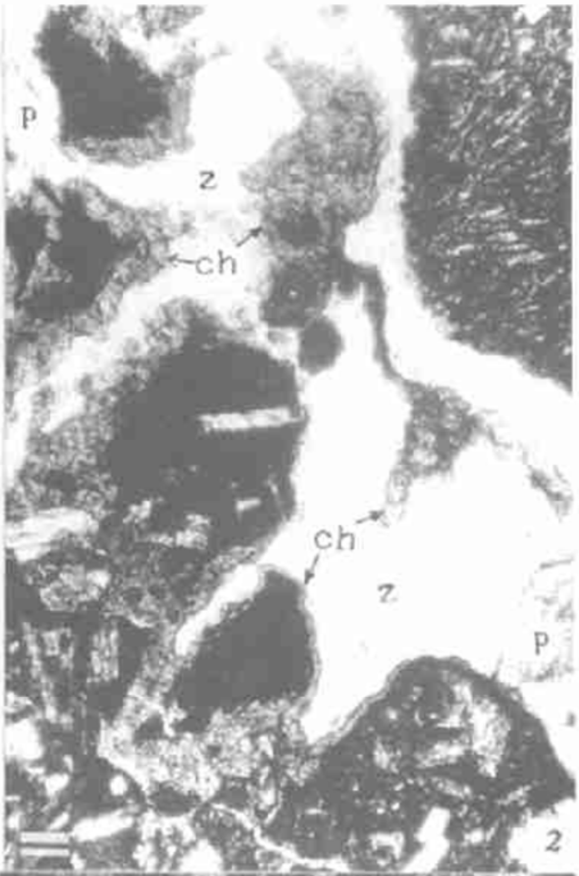
4. The calcitized lumps (a) in the zeolitized lithoclastic-crystallinoclastic tuffite layer, and small zeolitized concretions (b) on the bedding plane. GWP-42(3) E; polished section vertical to the bedding, dyed by the solution of alrizarin red at its left.

5. The photograph shows the zeolitized small concretions (a) on the bedding plane of the above-mentioned sample and a few of irregular hollows (b) after the concretions fell off.

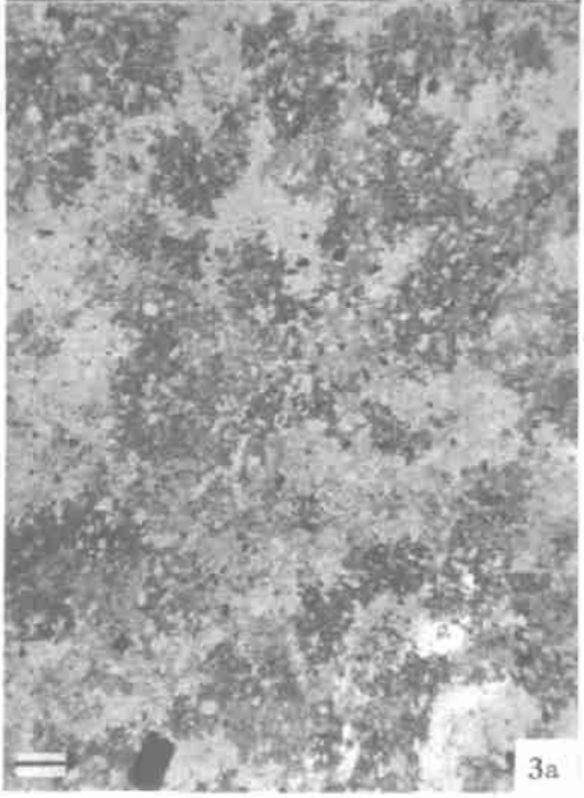
Plate I



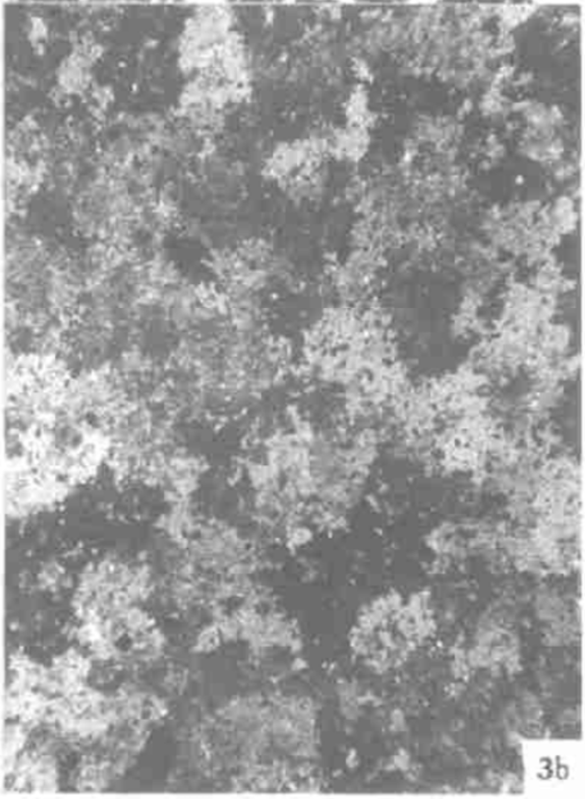
1



2

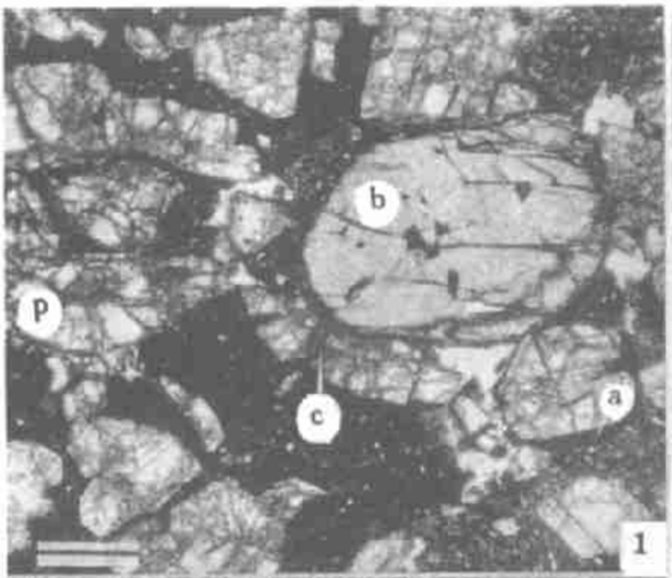


3a

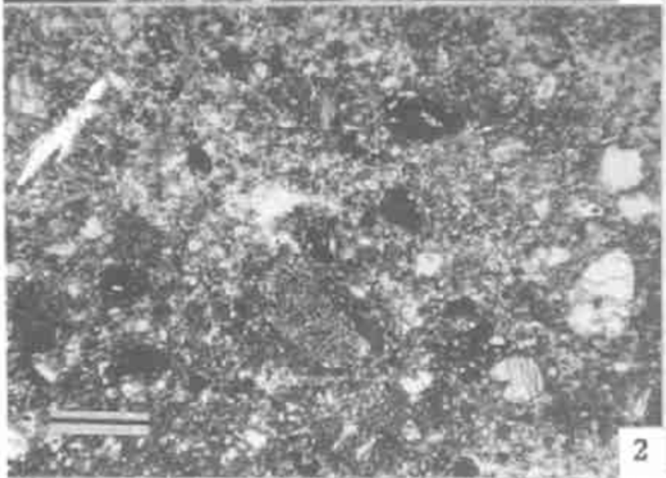


3b

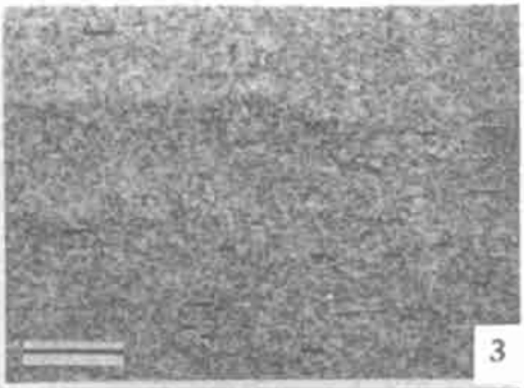
Plate I



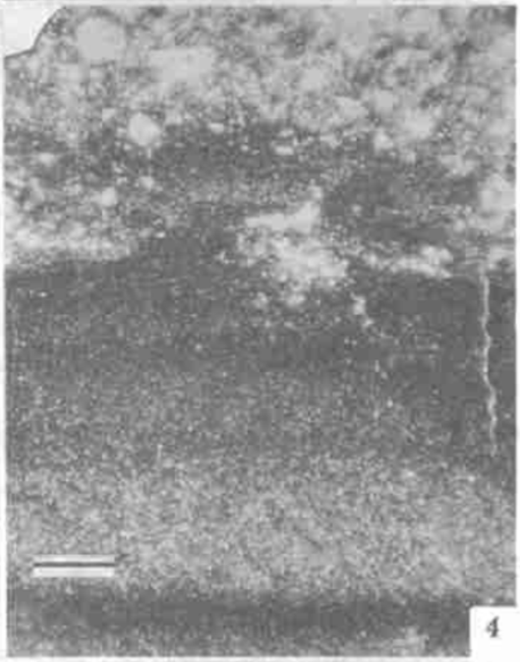
1



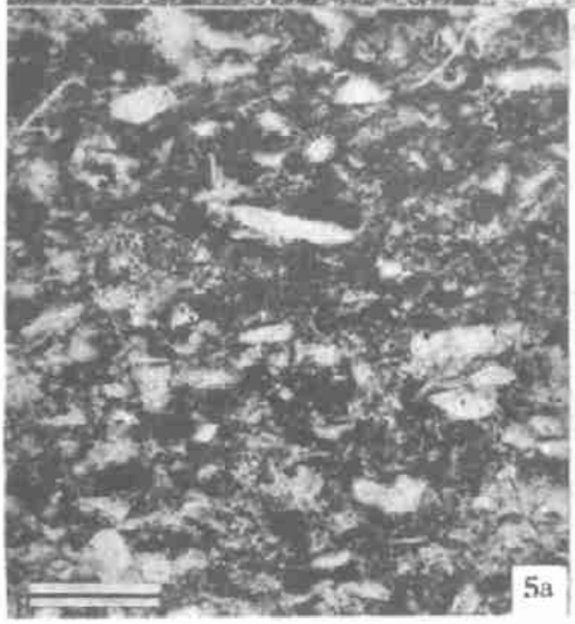
2



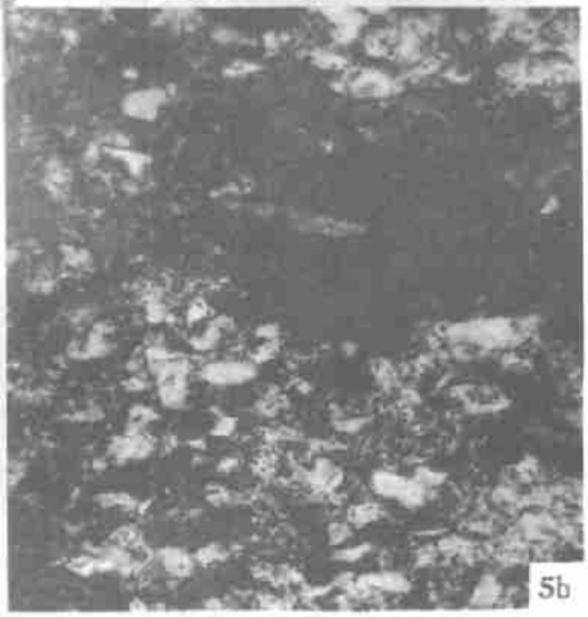
3



4

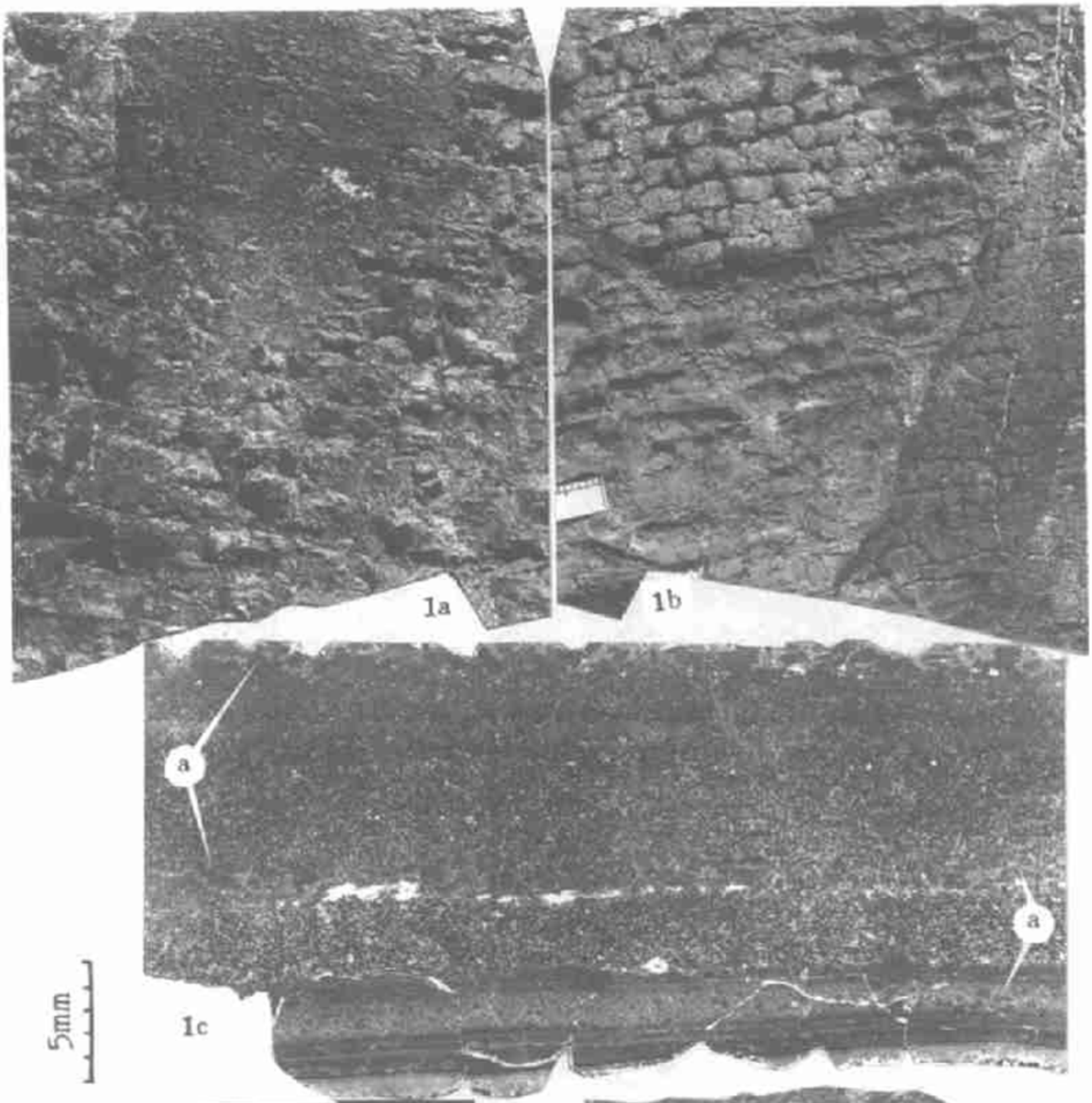


5a



5b

Plate Ⅱ



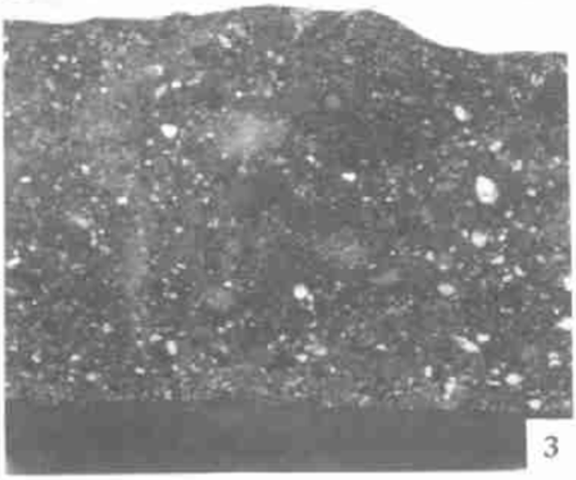


Plate Ⅳ