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PHYSICOCHEMICAL FEATURES OF THE "SHIRASU" AND STABILITY OF THE FILLED SHIRASU AND THE WEATHERED SHIRASU

By

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Abstract

The so-called "Shirasu" pumice flow deposit, which was formed from "nuée ardente" erupted from caldera volcanoes and is widely distributed over South Kyushu, Japan, is characterized by the following physicochemical features: (1) the welded texture is present in the non-weathered Shirasu in a natural state; (2) a great portion of the Shirasu is composed of volcanic glass; (3) constitutent materials of the Shirasu are quite poor in sorting; (4) most volcanic glasses are vesiculated ones; and (5) large amounts of pumice are comprised.

Both of the filled Shirasu and the weathered Shirasu are very much weak in their stability for the running water. This fact comes from such a reason that their original welded texture is fractured by man-work or lost due to natural agency. The reason that landslide disasters of unusual patterns occurred repeatedly in the Shirasu regions in the past, is clearly originated in these natures of the Shirasu.

Introduction

So-called "Shirasu" is widely distributed over South Kyushu, Japan (Fig. 1). The Shirasu was formed from "nuée ardente" erupted from caldera volcanoes, and is defined essentially to be pumice flow deposit in a narrow sense or pyroclastic flow deposit in a broad sense (ŌBA and others, 1967a). Its name has widely been used not only in earth sciences, but in many fields of technology such as civil engineering, pedology, disaster prevention and industrial utilization.

Since 1967, landslide disasters have frequently occurred and many people have been killed in every heavy rain season throughout over the whole Shirasu regions. Therefore, it has been a great social problem. For this reason, the authors have engaged in the study on the Shirasu to make clear its physicochemical nature and the cause of its related landslide. Major attention will be given in these respects. Some of this study was presented by the authors at the International Symposium on Landslides held in New Delhi, India in 1980 (ŌBA and others, 1980).

The Shirasu is, in most cases, overlain by alternation of loam and pumice (Fig. 3). The Shirasu came from Aira caldera volcano (MATSUMOTO, 1943) (Fig. 4), symbol A in

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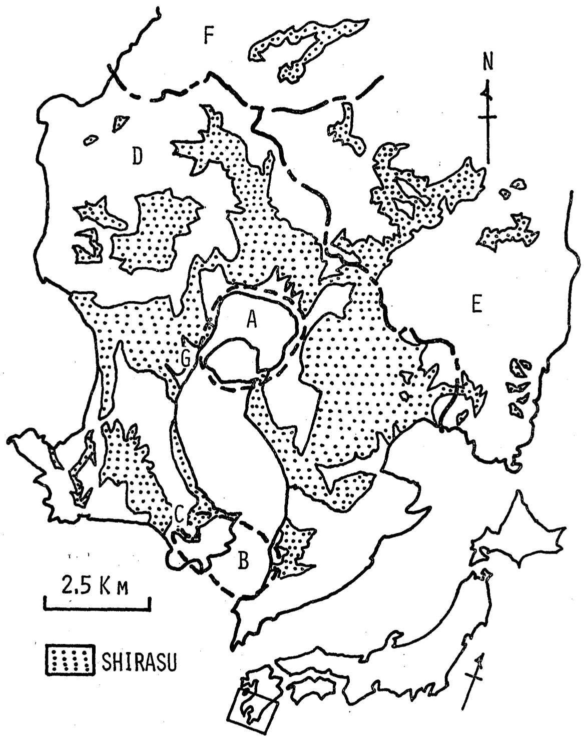

Fig. 1. Distribution of the Shirasu, pumice flow deposit, and locations of caldera volcanoes in South Kyushu, Japan. Caldera volcanoes: A, Aira; B, Ata; C, Ikeda. D, Kagoshima Pref.; E, Miyazaki Pref; F, Kumamoto Pref. G, Kagoshima City.

Fig. 1, Ata caldera volcano (Matsumoto, 1943), symbol B in Fig. 1, Ikeda caldera volcano (Ui, 1967), symbol C in Fig. 1, and from other unknown sources. The Shirasu from Aira and Ata caldera volcanoes have been called Aira Shirasu and Ata Shirasu respectively (Ōba and others, 1967 a, b). Aira and Ata Shirasu are correlated to Ito and Ata pyroclastic flow deposits (Aramaki, 1965; Aramaki and Ui, 1966). In 1967, the genetical consideration was discussed by Ōba and others (1967b). There are still many pyroclastic flow deposits from unknown sources of eruption in South Kyushu.

Constituent Materials of the Shirasu

Each of these Shirasu, in particular, Aira Shirasu and Ata Shirasu are apparently different in both mineral and chemical compositions in each source of eruption. Concerning of a standpoint of civil-construction, however, it may be quite all right to regard that these Shirasu are almost the same in composition. For this reason, mineral and chemical compositions of the Shirasu will be represented by those of Aira Shirasu which is most widely distributed and most typical one among the whole Shirasu.

1. Mineral Composition

As shown in Table 1, the Shirasu is mainly composed of volcanic glass, plagioclase, hypersthene and augite, and a small amount of hornblende and magnetite. Besides, it is accompanied by zircon, apatite and other iron-oxide minerals as accessories. Fig. 5 shows a microphotograph of some of its constituent minerals. It is noted that volcanic glass occupies about 85–87 volume % among major minerals. This fact is to

Table 1. Volume ratios (%) of constitutent minerals of the Shirasu (Aira Shirasu)

Sample No.		78NK3	78NK6	66112707*
Location of analyzed sample		Kagoshima City	Sendai, Kagoshima	Kajiki, Kagoshima
Analyst		K. Inoue	K. Inoue	K. Yokoyama
Grain size (mesh)		60–120	60–120	32–115
Felsic minerals	Volcanic glass	87.6	87.2	84.6
	Plagioclase	6.8	7.3	9.1
	Quartz	0.5	0.7	4.2
Mafic minerals	Hypersthene	0.7	1.0	1.6
	Augite	0.2	0.2	0.1
	Hornblende	0.2	0.1	tr.
	Opaque minerals**	3.9	3.3	0.5
	Others	0.1	0.1	tr.

* Recalculated from weight % (Ōba and others, 1967a).
** Magnetite and other iron oxide minerals are included.

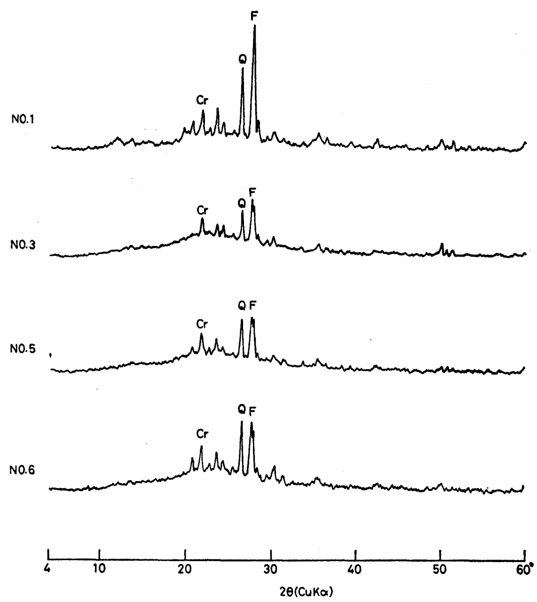

Fig. 2. X-ray powder diffraction patterns for the non-weathered Shirasu. F, Feldspar; Q, Quartz; Cr, α-cristobalite. CuKα 30 KV, 15 mA. No. 1 and No. 2 correspond to those in Table 2.

be regarded as being significantly important to consider the nature of the Shirasu. As seen from x-ray powder patterns (Fig. 2), no clay mineral is contained in the non-weathered Shirasu, while α-cristobalite (2θ 21.8°) is detected.

2. Chemical Composition

As shown in Table 2, the Shirasu is characterized in chemical composition by the fact that it is mostly composed of silica, about 70% in weight, and has the dominance of soda over potash and of lime over ferrous iron oxide throughout the whole analyzed samples (ŌBA and others, 1967a), though FeO contents of No. 1 and No. 2 are not presented. The fact that a great portion of the Shirasu is, roughly speaking, occupied by silica, is also important to consider the nature of the Shirasu.

Table 2. Chemical analyses (weight %) of the Shirasu

	AIRA	SHIRASU		ATA SHIRASU
No.	1	2	3	4
Analyst	M. Yamamoto	M. Yamamoto	N. Ōba & H. Ebihara	N. Ōba & H. Ebihara
SiO_2	72.20	70.07	70.91	65.37
TiO_2	0.27	0.29	0.24	0.64
Al_2O_3	15.00	15.64	14.05	15.44
Total Fe_2O_3	3.28	3.47	-	-
Fe_2O_3	-	-	0.83	3.77
FeO	-	-	0.97	1.65
MnO	0.07	0.07	0.09	0.10
MgO	0.50	0.57	0.54	0.93
CaO	2.23	2.42	2.20	3.51
Na_2O	3.29	3.27	3.31	3.34
K_2O	2.42	2.18	2.56	1.69
H_2O+	n.d.	n.d.	3.14	3.06
H_2O-	n.d.	n.d.	0.55	0.50
P_2O_5	n.d.	n.d.	0.07	0.15
Total	99.26	97.98	99.46	100.15

1, Sample No. 78NK3; 2, Sample No. 78NK6: New analyses determined by a combination of x-ray spectrometry and atomic absorption. 3, Average of 13 analyses; 4, Average of 2 analyses: Determined by a combination of standard and ion exchange resin-chelate titration methods. Data from Ōba and others (1967 a).

Nature and Microstructure of Volcanic Glasses in the Shirasu

What state is volcanic glass which occupies an overwhelming portion of the Shirasu is concerned with a great interest not only for the genetical consideration, but for the solution of substantial problems of the Shirasu landslide.

1. Relationship between Volcanic Glass and the Welded Texture

Non-weathered and fresh Shirasu in a natural state, that is, primary Shirasu, is characterized by the presence of the welded texture. Microphotograph of the welded texture is shown in Fig. 6. Volcanic glass constitutes a major portion of the welded texture, and plays a role to fill intergranular spacings among major and minor minerals and to make mineral grains bind with one another.

2. Microstructures of Volcanic Glasses

As a result that the Shirasu was formed from "nuée ardente" composing of fragments and particles in a molten state which were keeping still high temperature and vesiculating, most volcanic glasses of the Shirasu occur in vesiculated ones that bubbles contained in the volcanic glasses are expanding escaping gases, as shown in Fig. 7 and Gb in Fig. 8. This fact is also important to consider mechanism of the Shirasu landslide.

Volcanic glasses of several 10 to one μ in size, as shown in an electron microphotograph (Fig. 9) and a microphotograph (Fig. 8), occur in such a form as ascicular, fibrous, frothy, sponge-like or bubble-bearing glasses, and transparent or stained glasses, or irregular shaped fragments and splits.

Physicochemical Featrues of the Shirasu

The Shirasu is characterized by the following facts that: (1) the welded texture showing a fact that the Shirasu was subjected to the welding is recognized in the fresh Shirasu in a natural state; (2) a great portion of the Shirasu is composed of volcanic glass; (3) most volcanic glasses are vesiculated ones; (4) as is clear from a fact that materials in size ranging from micrograin of micron unit to pumice block more than 1 m in diameter are comprised, constitutent materials of the Shirasu are quite poor in sorting; and (5) a large amount of pumice characterized by abundant gas cavities is comprised.

These facts clearly show that the Shirasu is essentially different from either common soil or common sand (Fig. 10). These natures are significant to understand why unexpected disasters of various patterns repeatedly happened in the Shirasu regions in the past.

Fundamental Difference between the Primary Shirasu and Both the Filled Shirasu and the Weathered Shirasu

"Disturbed Shirasu" will be used for the Shirasu whose original welded texture was broken up by man-work in the process of construction in this paper. Various field names such as filled Shirasu, discarded Shirasu, stayed Shirasu and others, have been used for the disturbed Shirasu in civil construction fields. In convenience, the filled Shirasu will be used here as a representative for this kind of the disturbed Shirasu. Meanwhile, "weathered Shirasu" will be used for the Shirasu whose original welded texture was lost due to weathering.

1. Difference between the Primary Shirasu and both the Filled Shirasu and the Weathered Shirasu with respect to the Welded Texture

A fundamental distinction between the primary Shirasu and both the filled Shirasu and the weathered Shirasu is that the welded texture is present in the former, on the contrary, not present in the latter two. It may be all right to say that the Shrasu whose welded texture was fractured or lost is just only powder composed mostly of fragmental particles of volcanic glass. Various different behaviors and phenomena seen between them at the time when landslide disaster took place, are essentially due to whether the welded texture is present or not.

2. Stability of the Filled Shirasu and the Weathered Shirasu for Running Water

Most landslide disasters in the Shirasu regions have been caused by running water accompanied by heavy rain. The filled Shirasu is very much liable to break down as compared with the primary Shirasu when it is encountered with water. This phenomenon depends fundamentally on the following reasons: (1) the filled Shirasu is that whose original welded texture is fractured; (2) volcanic glass which occupies an overwhelming portion of the Shirasu does not play a role to be binding or cementing material for itself; and (3) most volcanic glasses are vesiculated ones such as bubble-bearing glass (Fig. 7 and Gb in Fig. 8) and fibrous aggregates with inter-openings (Fig. 9). Accordingly, when the filled Shirasu is encountered with the running water, it very easily becomes a mobile fluid. In addition to these, (4) a large amount of pumice of various sizes is comprised; and (5) the Shirasu is quite poor in sorting of its constitutent materials. Therefore, disasters which occur in the Shirasu regions result in much more greater ones as compared to those in the non-Shirasu regions. The reason that the weathered Shirasu whose original welded texture was lost due to natural agency is also very weak in its stability on the running water, is basically almost the same as in the filled Shirasu.

On such a reason, even if the disturbed Shirasu was compacted by man-work or a rolling machine and looks a compacted one at a glance, when it is saturated by water, it becomes loose right away. Actually, physically pressed block of the disturbed Shirasu becomes loose very easily for a short time by percolation of water, just like melting of cubic sugar put in water.

Fig. 11 shows two models which were set up for out-door test which was carried out in 1973 for making comparison of the stability of the primary Shirasu, on the left handed side, and physically compacted filled Shirasu, on the right handed side, against artificially prepared shower about 100 mm/h, corresponding to that of several times of the heavy rainfall. Fig. 12 shows the start of the out-door test. As is clear from Fig. 13, it was proved that the primary Shirasu is high in its stability for shower, and, in contrast, the compacted filled Shirasu is very easily eroded away in a short time.

Therefore, when the disturbed Shirasu is encountered with the running water, it is very liable to become losse and rushes over in a form of fluid. Besides, drainages and weep holes are clogged by pumices. Thus, it is explained that landslide disasters in the disturbed Shriasu resulted in much more greater ones than the firstly presumed extent of damage.

Summary

The subjects having been discussed, will be summarized as follows. The so-called Shirasu is characterized by the following distinguished physicochemical features: (1) the welded texture is present in the fresh Shirasu in a natural state, i. e., the primary Shirasu; (2) a great portion of the Shirasu is occupied by volcanic glass; (3) most volcanic glasses are vesiculated ones; (4) the Shirasu is quite poor in sorting of its constitutent materials; and (5) a large amount of pumice is comprised.

Meantime, the filled Shirasu and the weathered Shirasu are very weak in their stability as compared to the primary Shirasu when they are encountered with the running water. Fundamentally, this comes from the reason that their original welded texture is fractured by man-work or lost due to natural agency. It can be said that

the reason that landslide disasters of unusual patterns occurred repeatedly in the Shirasu regions in the past is clearly originated in these natures mentioned above.

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Figs. 3-8

Fig. 3. The Shirasu is, in most cases, overlain by alternation of loam and pumice. h, Surface humic soil; l, Loam; p, Pumice; ws, Weathered Shirasu; ss, Secondary Shirasu. Note cross-bedding and graded bedding. ps, Shirasu; primary Shirasu. Note non-stratified massive exposure. Taken by T. Fukuda in 1974.

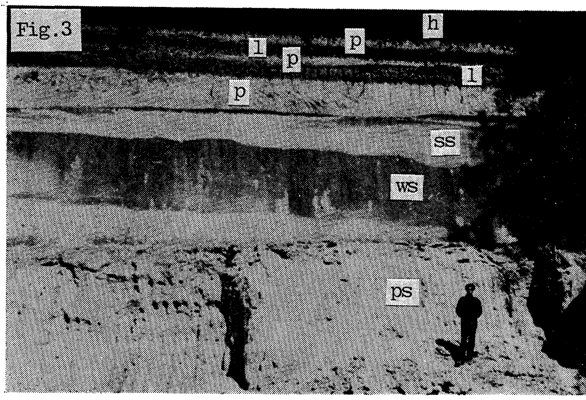
Fig. 4. Aerial veiw of Aira caldera seen from southeast. A, Aira caldera; B, Sakurajima Volcano; C, Kagoshima City. After guide book of Volcanological Society of Japan, 1962. Taken by a photographer of Mainichi Newspaper Co.

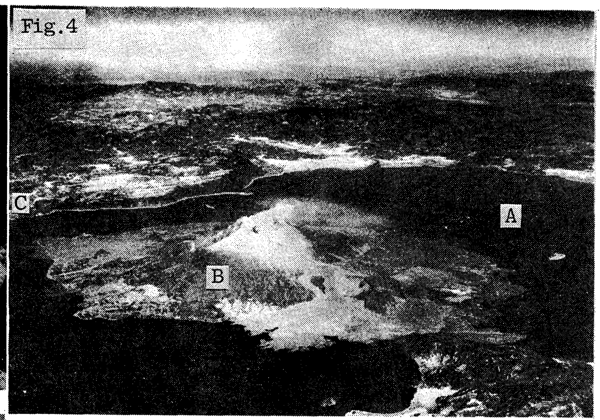
Fig. 5. Microphotograph showing constitutent minerals of the Shirasu. Pl, Plagioclase; Q, Quartz; Hy, Hypersthene; Mt, Magnetite; Gt, Irregular shaped transparent colorless-brown colored volcanic glass; Gb, Vesiculated volcanic glass. Note bubbles showing expanding and escaping gases within volcanic glasses.

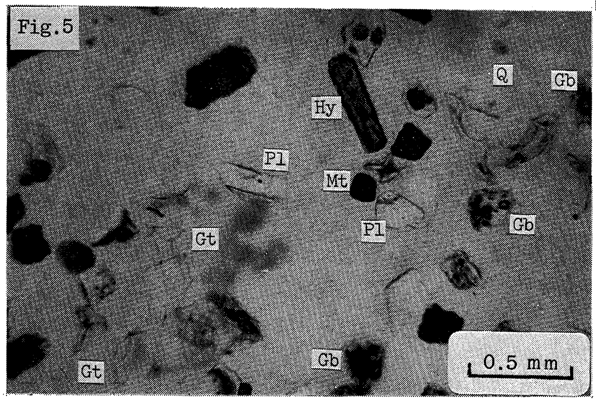
Fig. 6. Microphotograph showing the welded texture of the non-weathered Shirasu in a natural state. W, Welded texture.

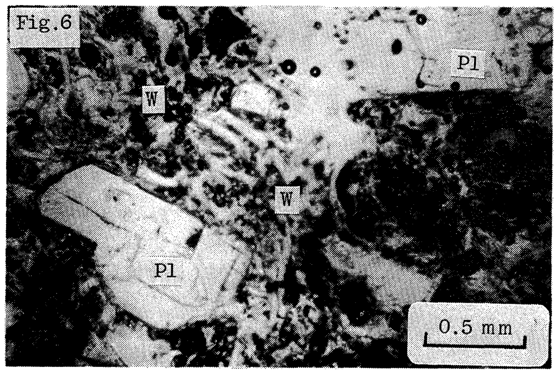
Fig. 7. Microphotograph of vesiculated volcanic glass. Note bubbles expanding and escaping gases within volcanic glass.

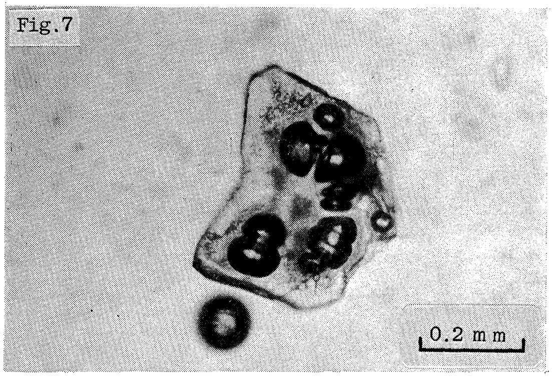
Fig. 8. Microphotograph showing irregular shaped volcanic glasses of the Shirasu. Gt, Transparent volcanic glass; Gf, Fibrous volcanic glass; Gb, Vesiculated volcanic glass in a state of expanding and escaping gases.

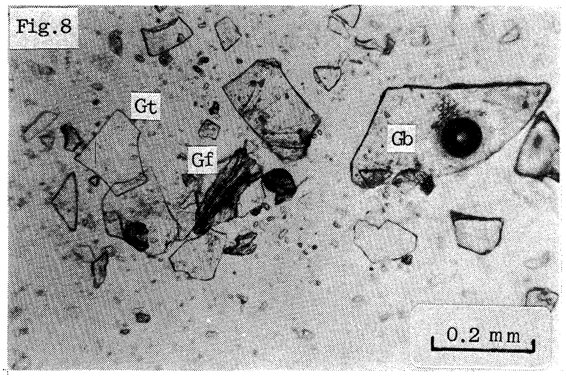












Figs. 9-13

Fig. 9. Scanning electron microphotograph of typical fibrous volcanic glasses. Taken by Shimazu Seisakusho Ltd.

Fig. 10. Microphotographs of grains of river sand (A) consisting mostly of stable rock-forming minerals and constitutent substance of loam (B) composing of clay minerals.

Fig. 11. Models with the face of slope with a gradient of 45° set up for out-door test for comparison of the stability of the primary Shirasu, on the left handed side, and physically compacted filled Shirasu with sodding, on the right handed side, against artificially prepared shower about 100 mm/h.

Fig. 12. Start of the our-door test.

Fig. 13. After about 30 minutes, there was scarecely change on the face of the primary Shirasu, and, in contrast, the compacted filled Shirasu became loose and rushed out in a form of fluid.

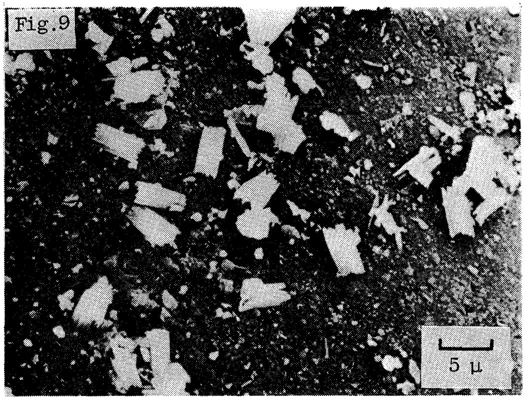


Fig.9
5 μ

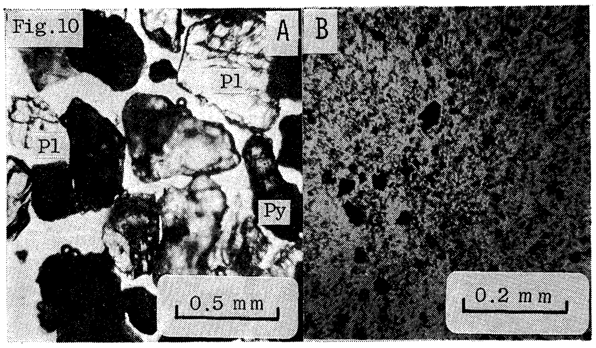


Fig.10
A
B
Pl
Pl
Py
0.5 mm
0.2 mm

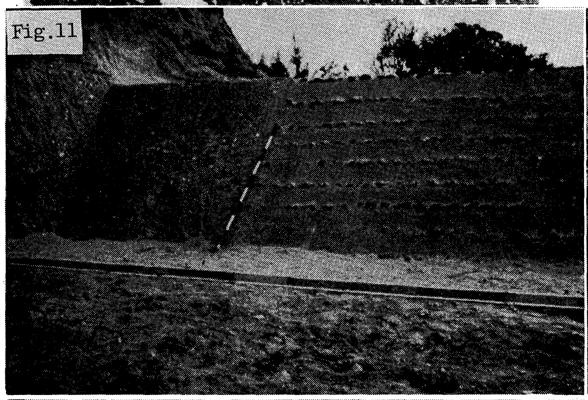


Fig.11

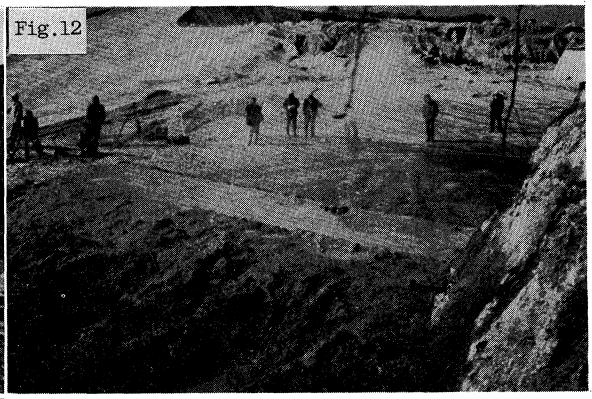


Fig.12


Fig.13