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MECHANISMS BY WHICH THE LANDSLIDE WAS CAUSED IN THE "SHIRASU" PUMICE FLOW REGIONS, JAPAN

By

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Abstract

Mechanisms by which the landslide was caused in the "Shirasu" pumice flow regions are roughly grouped into the following three : (1) the progressive change of the natural environment accompanied by the qualitative and structural changes of the social basement ; (2) natural agencies in the natural environment, as seen in the landslides due to columnar joint, scouring and others in places where none of the development is accompanied; and (3) unnatural agencies accompanied by the development, as seen in the landslides of the disturbed "Shirasu" and the weathered "Shirasu" pumice flow due to the defective handling for the drainage and prevention of water, undercutting, mechanical vibration and others in places where the development is in progress.

The result of an out-door test which was carried out for three models set up in different conditions against artificially prepared shower shows the followings : the filled "Shirasu" is weak in its stability for the moving water ; but, in contrast, the "Shirasu" pumice flow with a coating on the crown of slope with a vertical cut does not easily collapse ; and the undercutting and the presence of the pipe-like structure are liable to cause the landslide.

Introduction

So-called "Shirasu", having widely been used in earth sciences, cvil engineering, pedology, disaster prevention and industrial utilization, is that which was named in a narrow sense for pumice flow or pumice flow deposit, prevailing over South Kyushu, Japan, those which came mainly from Aira and Ata caldera volcanoes (ŌBA and others, 1967). For this reason, the "Shirasu" has often been called "Shirasu" pumice flow (ŌBA and others, 1983, 1984) or "Shirasu" pumice flow deposit (ŌBA and others, 1980). In this paper, "Shirasu" pumice flow or simply "Shirasu" will be used in convenience.

Even if any kind of disaster happened, it would be impossible to establish any countermeasure if mechanism by which the disaster was caused could not be disolved. It is most important to do at first that the mechanism by which the disaster was caused is made clear up (ŌBA and others, 1976a).

It has been greatly significant to make clear physicochemical nature of the "Shirasu" pumice flow and mechanisms by which landslide disasters frequently occurred in every

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heavy rain season throughout over the whole "Shirasu" pumice flow regions in the past. Physicochemical features of the "Shirasu" pumice flow and a fundamental distinction between the primary "Shirasu" (ŌBA and others, 1972) and/or the "Shirasu" pumice flow and both the filled "Shirasu" and the weathered "Shirasu" have been discussed (ŌBA and others, 1980).

This paper is an outgrowth of research presented by the present authors as "Physicochemical features of the "Shirasu" pumice flow deposits, and its related landslides in South Kyushu, Japan" at the Third International Symposium on Landslides held in New Dehli, India in 1980 (ŌBA and others, 1980). Major attention will be given in this paper to mechanisms by which the landslide was caused in the "Shirasu" pumice flow regions and their characteristic patterns.

Mechanisms by Which the Landslide was caused

The whole of various technical names for landslide, landslip, sand and mud flow or fall, earth-fall, failure or collapse of slope and others will be represented by a simple term "landslide" in convenience in the present paper, except for illustrations of each examples.

Mechanisms by which the landslide was caused in the "Shirasu" pumice flow regions are roughly grouped into the following three: (1) the progressive change of the natural environment accompanied by the qualitative and structural changes of the social basement; (2) natural agencies in the natural environment; and (3) unnatural agencies accompanied by the development.

Landslides due to the Progressive Change of the Natural Environment accompanied by the Qualitative and Structural Changes of the Social Basement

In 1971, landslide disasters occurred contemporaneously owing to the heavy rainstorms accompanied by tyhoon at many places in the outskirts and secluded areas, where the landslide has so far scarecely taken place, of the "Shirasu" pumice flow regions.

As a result of field investigations, it became clear that in accordance with the progression of the economic development of Japan various developments as seen in road- and land-constructions had been carried out not only in the outskirts around cities, but also in the secluded areas, where it had been thought that the natural environment had been preserved as it is, and, in accompanying with this, the disruption of the natural environment had progressively increased. Thus, many landslides have become to occur even in the secluded areas.

Such a fact shows that "the disruption of the natural environment in accompanying with the qualitative and structural changes of the social basement" (ŌBA, 1972) had increased while man was not aware of it at all, and, as a result, many landslide disasters have become to occur contemporaneously and suddenly on some occasions in an unexpected place or region someday. The progessive change of the natural environment caused by the qualitative and structural changes of the social basement is significantly noted as one of

major mechanisms by which the landslide was caused in the "Shirasu" pumice flow regions (ŌBA, 1976a, b).

A in Fig. 9 shows, as an example, a place where three persons were killed owing to the landslide of the "Shirasu" pumice flow in the heavy rainstorms accompanied by No. 19 tyhoon in 1971. It was observed there that opened cracks of about 1 cm in width are developed nearly parallel to the extension of the road in front of the slope where the landslide took place, and that they attain downward throughout both the surface soil and alternation of loam and pumice overlying the "Shirasu" pumice flow.

Landslides due to Natural Agencies in the Natural Environment

Comparing with the disturbed "Shirasu", represented by the filled "Shirasu" whose original welded texture is fractured due to an unnatural agency (ŌBA and others, 1980), the primary "Shirasu", i. e., the "Shirasu" pumice flow, naturally, has much larger physical stability on a reason that an original welded texture is present. However, the "Shirasu" pumice flow is also liable to occur the landslide parallel to the vertical plane and form the vertical cliff. This comes from the following reasons.

When the "Shirasu" pumice flow was formed from "nuée ardente", shrinkage cracks parallel to three dimensional planes roughly perpendicular to each other, i. e., joints, among which columnar joint is most common, developed in the process of its slow cooling. The typical columnar joint can be observed in the strongly welded "Shirasu" pumice flow, i. e., welded tuff, which is in general gradationally changed into the weakly welded tuff, i. e., the "Shirasu" pumice flow (ŌBA, 1973).

Both the "Shirasu" pumice flow and the welded tuff are liable to be splitted off parallel to their joint planes, particularly to dominant columnar joint plane. Accordingly, if the open-cut is done by natural agency or unnatural agency for them, it results that they are easily splitted off roughly parallel to the dominant vertical joint plane toward the open-cut face to which the internal stress in the natural ground is released. Thus, the slope of the "Shirasu" pumice flow is liable to fail parallel to the vertical plane and form the vertical cliff.

For landslides which were caused by natural agencies in the "Shirasu" pumice flow regions where none of the development is accompanied, the following patterns will be pointed out.

1. Landslides of the "Shirasu" Pumice Flow due to Scouring

The slope or cliff in the "Shirasu" pumice flow regions geologically consist, in general, of the "Shirasu" pumice flow, the weathered "Shirasu" pumice flow, alternation of loam and pumice, and surface soil in ascending order in most cases, as shown in Fig. 1. The surface soil occupies the upper most of loam of the alternation in many cases. In the following explanations, therefore, the alternation will be treated as that which includes the surface soil in convenience.

When the slope of the "Shirasu" pumice flow (Fig. 1, a) is scoured by water action at the

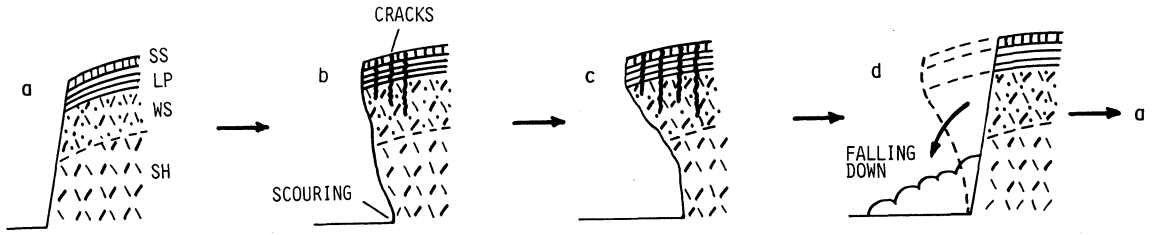

Fig. 1. Regression cycle by scouring on the slope of the "Shirasu" Pumice flow. When the slope of the "Shirasu" pumice flow (a) is scoured by water action at the foot, geologic constituents, such as the weathered "Shirasu" pumice flow and alternation of loam and pumice and surface soil, of the upper portion of the slope become unstable (b), and cracks roughly parallel to the face of the slope in both the alternation of loam and pumice and the surface soil (c), thus it results to cause landslide (d). After that time, the slope recoveries again into an initial state (a). Abbreviations.–SH, "Shirasu" pumice flow ; WS, weathered "Shirasu" pumice flow ; LP, alternation of loam and pumice ; SS, surface soil. In the following illustrations, the surface soil is included in the alternation of loam and pumice in convenience.

foot, geologic constituents of the upper portion of the slope naturally become unstable (Fig. 1, b), and cracks roughly parallel to the face of slope, toward which the internal stress in the natural ground is released, occur in the alternation of loam and pumice (Fig. 1, c), thus it result to cause the landslide (Fig. 1, d). After the time when the landslide occurred, the face of slope recoveries again into an initial state (Fig. 1, a). In the natural environment, such a circulation is uninterruptedly and repeatedly continued. The present authors call it "regression cycle by scouring".

2. Landslides of the Alternation of Loam and Pumice followed by Flowing Away of the Weathered "Shirasu" Pumice Flow

When the weathered "Shirasu" pumice flow is encountered with water, it becomes soon to flow away, and, as a result, the alternation of loam and pumice overlying the weathered "Shirasu" pumice flow, as Fig. 2 shows, becomes to form a roof-like overhanging cliff. The alternation of loam and pumice, accordingly, becomes physically very unstable and falls

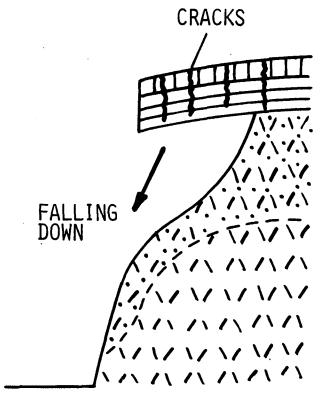

Fig. 2. Landslide of the alternation of loam and pumice followed by flowing away of the weathered "Shirasu" pumice flow.

down along cracks developed within it.

3. Landslides of the Weathered "Shirasu" Pumice Flow followed by Falling Down of the Alternation of Loam and Pumice

Surface soil and loam, those which are composed mainly of humic and clayey substances in general, usually overlay the weathered "Shirasu" pumice flow. They play a role to keep from percolation of water into the weathered "Shirasu" pumice flow. When they are eroded away and/or denudated away or fall down by water action, however, the weathered "Shirasu" pumice flow is immediately exposed in the air. Thus, when it is encountered with rain water, as Fig. 3 shows, it becomes easily to occur the collapse.

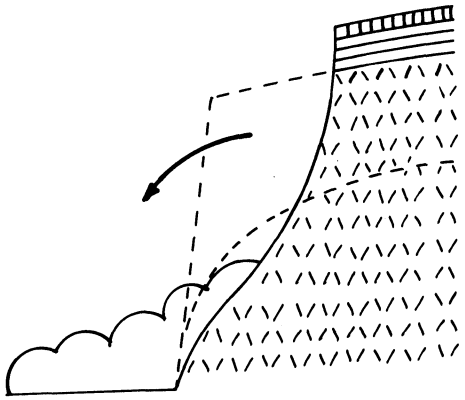

Fig. 3. Landslide of the weathered "Shirasu" pumice flow followed by falling down of the alternation of loam and pumice.

4. Landslides of Talus Deposit overlying the "Shirasu" Pumice Flow

In the "Shirasu" pumice flow regions, talus deposit usually overlays the surface soil or loam on the slope. If the slope is scoured at its foot, as Fig. 4 shows, naturally, it becomes

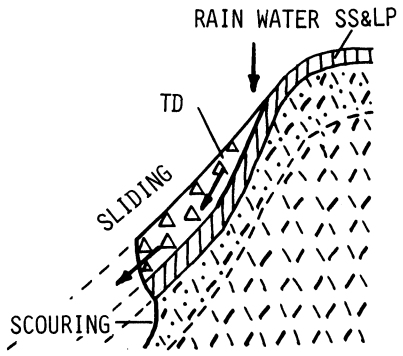

Fig. 4. Landslide of talus deposit overlying the "Shirasu" pumice flow. When the slope is scoured at the foot and rain water percolates downward through the talus deposit and stays over the impermeable layer, it becomes to cause the landslide of the talus deposit. Abbreviations.—TD, talus deposit ; SS & LP, surface soil and alternation of loam and pumice.

physically unstable. When there has much rain, rain water percolates downward through the talus deposit and stays over the clayey surface soil or loam, those which play a role of an impermeable layer, thus the talus deposit results to cause the failure accompanied with a sliding.

5. Landslides of a Mixture of Pumice, Sand and Mud accompanied by the Flush Down Water

When a large amount of materials such as welded tuff and pumice fall deposit falls down along the face of slope, a natural dam-like landform may happen to be formed by falling down-materials which are deposited at a peculiar place in a narrow valley or gully on the fore-slope. In such a case, if surface water or percolated water stay in a naturally formed dam and exceed some limit of capacity, the naturally formed dam is destroyed, and a mixture of block, sand, mud and water rushes down and is intermingled with talus deposits and other brittle sediments on the way, thus disaster may happen to cause.

B in Fig. 9 shows the cliff where seven persons were killed owing to the rush down of an avalanche of pumice, sand and mud accompanied by the flush down water in the heavy rainfalls on June 22, 1975.

Geologic constituents of the cliff are, as shown in a schematic model of geologic profile

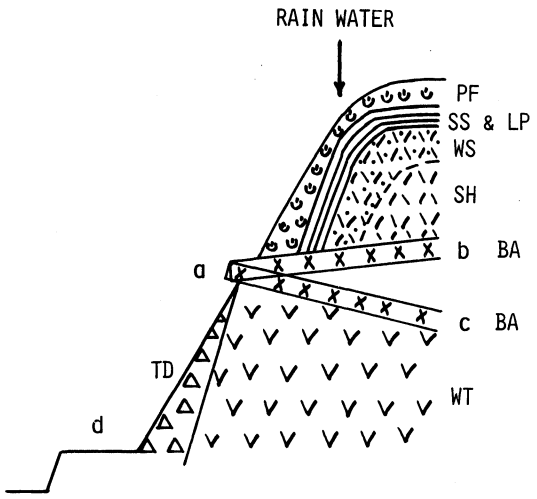

Fig. 5. Schematic model showing geologic profile of the cliff, located at Ushine-fumoto, Tarumizu City, Kagoshima Prefecture, Japan, where the rush down of an avalanche of pumice, sand and mud accompanied by the flush down water occurred in the heavy rainfalls on June 22, 1975. After ŌBA (1976). An overhanging lava flow of basaltic andesite (a–c), dipping downward the side of inland, played a role of a natural dam (a) for water which percolated through pumice fall deposit. The avalanche of pumice, sand and mud rushed down and captured the talus deposit composed mainly of pumice on the fore-foot of the cliff, and jumped over a national road (d) and attacked houses. Abbreviations.–WT, welded tuff ; BA, basaltic andesite ; SH, "Shirasu" pumice flow ; WS, weathered "Shirasu" pumice flow ; SS & LP, surface soil and alternation of loam and pumice ; PF, pumice fall deposit ; TD, talus deposit. Denotations.–a–b & a–c, overhanging basaltic andesite ; d, national road.

in Fig. 5, strongly welded "Shirasu" pumice flow, i. e., welded tuff, basaltic andesite, weakly welded "Shirasu" pumice flow, weathered "Shirasu" pumice flow, alternation of loam and pumice, surface soil, and pumice fall deposit in ascending order.

Rain water percolated downward through the pumice fall deposit. Percolated water flowed down along the plane of the clayey surface soil and loam, those which played a role of an impermeable layer, and stayed within the pumice fall deposit on an overhanging plate-shaped lava flow of basaltic andesite (Fig. 5, a–c) which played a role of a natural dam. At that time when field investigation was done, it was obscure that the plate-shaped lava flow of basaltic andesite is wethere it dips upward (Fig. 5, a–b) or downward (Fig. 5, a–c) the side of inland. Later, it was ascertained by means of seismic prospecting to be the downward dipping which is liable to form a natural dam in this case.

Thus, a great amount of an avalanche composed mainly of pumice rushed down in accompanying with the flush down water. At that time, talus deposit composed mainly of pumice on the fore-foot of the cliff was captured by the avalanche, and all of them jumped over a national road and attacked houses along the road.

Mechanism by which the avalanche of pumice accompanied by the flush down water occurred, is explained as follows :

(a) there was the overhanging lava flow which played a role as a natural dam for water-reservoir on the steeply inclined slope ;

(b) there was the loose pumice fall deposit in an unconsolidated state on the steeply inclined slope at an angle of almost 37° in spite of 35° at the maximum angle of repose, and, accordingly, the pumice fall deposit had been an unstable condition that it is liable to fall down at any shock ;

(c) there were geologic constituents impermeable against percolated water beneath the pumice fall deposit ;

(d) vegitation on the slope had been not so good to be preserved; and,

(e) there had the heavy rainfalls.

Such a disaster owing to the avalanche composed mainly of pumice in accompanying with the flush down water is significantly noted as a typical example showing that it was caused by a composite condition of geologic and geomorphologic natures.

Landslides due to Unnatural Agencies accompanied by the Development

Since before and after 1961, the cityward concentration of population had increased and works of various developments in the "Shirasu" pumice flow regions surrounding urbanized areas have progressively been proceeded along with the progression of the economic development in Japan, while the disruption of the natural environment has become to be promoted acceleratedly. As a result, a large number of landslide disasters has become to occur frequently and successively at every heavy rain season in almost all places of the "Shirasu" pumice flow regions since before and after 1967.

At that time, there had gone on the heated discussion about whether landslide disasters

were caused owing to natural agency such as the heavy rainstorm accompanied by tyhoom in a local place or unnatural agency related to such developments as represented by housing land construction, and this subject had been one of major problems in society. It is obvious that landslide disasters were caused owing to an unnatural agency from such a fact that they had increased in proportion to the progression of the regional development and an increase of the developed area in space.

In the meantime, it is true that at that time there was the following easygoing way of thinking about the development in the "Shirasu" pumice flow regions : that is, it is easy to cut off hills of the "Shirasu" pumice flow, and to transport the cut off-"Shirasu" materials into low grounds or valleys to fill ; and, in such a way, when flatted lands for housing are constructed, housing lands will become possible to serve at a low cost to people who wish to live in urbanized areas. It was also true that such a thinking had widely been believed among many people.

What it is easy to cut just means what it is liable to collapse. Apparently, there was a fundamental misunderstanding that man ignored characteristic features of the "Shirasu" pumice flow itself, and man treated the "Shirasu" pumice flow as the same as the common soil and sand in spite of quite difference in its essential nature.

C and D in Fig. 9 show the face of slope where the landslide occurred at the time when there had the heavy rainfalls at a place where the housing land construction was moving in the "Shirasu" pumice flow region in 1970. C in Fig. 9 shows gullies formed on the face of slope composed of the filled "Shirasu" and, in part, the weathered "Shirasu" pumice flow. D in Fig. 9 obviously shows that the reinforced concrete wall built on the filled "Shirasu" is easily destroyed even if it is physically so strong.

When disaster happened once, an enormous outlay will be required for the restoration. If characteristic features of the "Shirasu" pumice flow had fully been investigated in advance, and if the most appropriate design and construction on the basis of their data for the disaster prevention had been applied at first, and, in such a way, if no any disaster occurred until the end, it would have finally resulted into the same thing as that great profits were provided. That is, it can be said that the disaster prevention is the most valuable and best way to be invested.

In the "Shirasu" pumice flow regions where various works of the construction are carrying on, when the impervious loam and clayey surface soil by those which the weathered "Shirasu" pumice flow is protected from erosion and digging are denudated away, the weathered "Shirasu" pumice flow whose initial welded texture is disappeared due to weathering is immediately subjected to erosion, and, subsequently, collapses down by rain water.

As seen from the fact mentioned above, most of landslide disasters, which cause during the heavy rain season in the "Shirasu" pumice flow regions where various developments are in progress, occurred at the weathered "Shirasu" pumice flow after the time when the surface soil and loam were denudated away, as well as at the disturbed "Shirasu", or at the alternation of loam and pumice.

Compared to the disturbed "Shirasu", the primary "Shirasu" pumice flow in a natural state keeps much larger physical stability. What differences fundamentally are there between the primary "Shirasu" pumice flow and the disturbed "Shirasu" and/or the weathered "Shirasu" pumice flow were discussed in the former paper (ŌBA and others, 1980).

For landslides caused by unnatural agencies accompanied by various developments in the "Shirasu" pumice flow regions, the following patterns will be pointed out.

1. Landslides of the Weathered "Shirasu" Pumice Flow followed by the Denudation of the Surface Soil and Loam

Both surface soil and loam are composed mainly of clayey substances, and play a role as an impermeable material for the protection of the weathered "Shirasu" pumice flow underbeneath them from erosion and digging by rain water or surfacial running water. As soon as surface soil or loam and/or both of them are denudated away by work of the construction, however, the weathered "Shirasu" pumice flow exposed in the air become loose and flows out right away. Accordingly, this corresponds to a case of the landslide caused by the natural agency in Fig. 3.

2. Landslides of the Weathered "Shirasu" Pumice Flow followed by the Open-Cut of the Slope of the "Shirasu" Pumice Flow, and Subsequent Failure of the Surface Soil and Loam

When the open-cut is done for the slope of the "Shirasu" pumice flow, as shown in I of

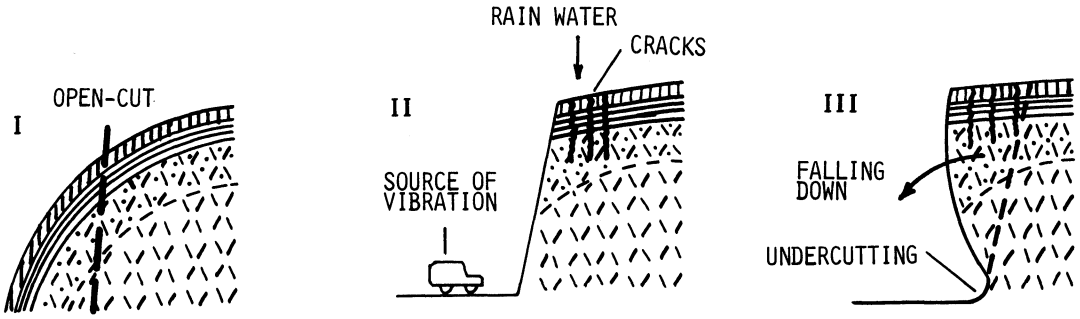

Fig. 6. Landslide of the slope of the "Shirasu" pumice flow at place where the development is moving and the mutual relationships among the "Shirasu" pumice flow, the weathered "Shirasu" pumice flow and the alternation of loam and pumice.

I. When the open-cut is done for the natural ground of the slope, the weathered "Shirasu" pumice flow is exposed in the air. When it is encountered with rain water, gullies are formed, and, subsequently, it is followed by the failure.

II. The internal stress in the natural ground is going to release toward the open-cut face. Thus, it is released in a form that cracks roughly parallel to the open-cut face occur. The open-cut face of the slope where the construction is in progress is always affected by mechanical vibration due to working of busy heavy trucks and civil engineering machines. Thus, opening up, widening and extension of cracks are promoted.

III. When the undercutting is done at the foot of the slope, the weathered "Shirasu" pumice flow is turned into an unstable hanging state, thus it is liable to occur the falling down in the rain time or just after the rainfall.

Fig. 6, the weathered "Shirasu" pumice flow is immediately exposed in the air, thus gullies are formed right away over the whole surface of the slope and the weathered "Shirasu" pumice flow becomes to cause flowing away, and, subsequently, it follows that the alternation of loam and pumice falls down. This corresponds to a case of the landslide caused by the natural agency in Fig. 2.

3. Landslides of the Weathered "Shirasu" Pumice flow due to the Defective Handling for the Drainage and Prevention of Water

As a result that the alternation of loam and pumice is denudated away in the "Shirasu" pumice flow regions where the development such as civil construction is moving, usually and actually workers encounter with the weathered "Shirasu" pumice flow or the disturbed "Shirasu".

In such a case, accordingly, the perfect and effective handling must be done for the drainage set up within the weathered "Shirasu" pumice flow or the disturbed "Shirasu" and for the prevention of water throughout over the whole of their surfaces. If the handling for them is imperfect and defective, as C in Fig. 9 shows, the weathered "Shirasu" pumice flow or the disturbed "Shirasu" will easily be percolated by water and turned into a mobile fluid, thus the rush down will be taken place. At that time, channels or pipes for the drainage will likely be filled by accompanying pumices of various sizes, thus urban areas surrounding places where the development is in progress will be suffered by comming down of overflow water accompanied with a great amount of pumice. Work of the civil construction in a large scale, therefore, should be avoided as much as possible during the period of rainy season in the "Shirasu" pumice flow regions.

4. Landslides of the Disturbed "Shirasu" due to the Defective Handling for the Drainage and Prevention of Water

Physically pressed block of the disturbed "Shirasu" as represented by the filled "Shirasu" whose original welded texture is fractured becomes loose right away by percolation of water (ŌBA, 1976b). Basins for sedimentation and retarding, therefore, should not be set up within the disturbed "Shirasu", but within the natural ground of the primary "Shirasu" pumice flow. D in Fig. 9 shows an example showing that a portion where a conduit is set up within the filled "Shirasu" allowed to be a way for running water on a place where work of the housing land development was in progress.

Whennever the drainageway is set up in the "Shirasu" pumice flow, handling for the prevention of water should perfectly and carefully be done soon after the time when the drainageway was set up not only in the disturbed "Shirasu", but also in the "Shirasu" pumice flow in order to be avoided from a much greater disaster which may happen later.

5. Landslides of a Mixture of Pumice, Sand and Silt due to the Disturbed "Shirasu" Which is left at Places Where the Construction is in progress

The existence of the disturbed soil can not be avoided during throughout the processes

of various works of the civil construction those of which are in progress. It is very dangerous, however, that the disturbed "Shirasu" is left as it is owing to its own characteristic features, particularly, in the rainy season. When handling for the disturbed "Shirasu" is done in an unappropriate way, the rush down of a mixture of pumice, sand and silt will become soon to occur at the heavy rainfall. Therefore, the disturbed "Shirasu" should carefully be treated so that the safety is guaranteed after the construction, and the remaining disturbed "Shirasu" should be transported to a dumping ground officially autholized.

6. Landslides of a Mixture of Block, Sand and Mud due to the Flush Down Water

When blocks, cobbles and others such as sand, mud and timbers, all of those which are derived during work of the development, are deposited and accumulated in a narrow place on the slope or valley, a dam-shaped site may happen be formed there. In such a case, when water stays in the dam-shaped site, and an amount of stayed water exceeds some limit of capacity, the flush down of a mixture of block and others accompanied with a great amount of water may happen suddenly be caused. It is neccessary, therefore, to make effort so that a dam-shaped site is not formed on such a specified slope or valley, particularly, in the rainy season.

7. Landslides of the "Shirasu" Pumice Flow due to the Undercutting

(1) Landslides of the "Shirasu" pumice flow due to the undercutting accompanied by the construction

When the undercutting is done at the toe of the slope of the "Shirasu" pumice flow during works of various constructions, as shown in III of Fig. 6, the weathered "Shirasu"

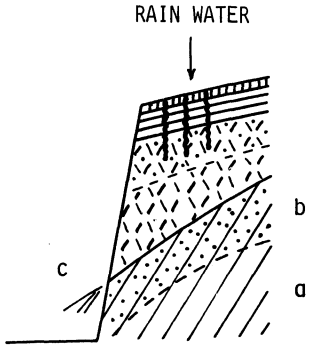

Fig. 7. Landslide of the "Shirasu" pumice flow due to geological structure. When percolated water stays on the boundary plane between the "Shirasu" pumice flow and the underlying geologic constituents which play a role of an impermeable layer, and when the boundary plane is inclined downward the open-cut face, the whole of the overlying "Shirasu" pumice flow, weathered "Shirasu" pumice flow and alternation of loam and pumice may happen very often to cause the landslide. Denotations.—a, hard rocks ; b, clayey and weathered portion of hard rocks ; c, spring which appears when there had the rain or when the place is located under the ground-water level.

pumice flow overlying the "Shirasu" pumice flow is turned into an unstable hanging state, and naturally, becomes unstable mechanically, thus it is liable suddenly to occur the failure in the rain time or just after the rainfall.

The undercutting is severely prohibitted on the Labor Standard Law. Neverthless, if the undercutting is needed to be done in an unavoidable reason, a supervisor skilful in this kind of work should be prepared.

(2) Landslides of the "Shirasu" pumice flow due to undercutting by farmers

In South Kyushu, Japan, the undercutting is frequently done by farmers on the slope of the "Shirasu" pumice flow to use the collected "Shirasu" materials for spreading over house gardens in a transitional custum or for mixing to improve air-permeability in farm clayey soil. The undercutting is sometimes so dangerous that farmers should not do it or they should seak for much safety place to do it.

8. Landslides of the "Shirasu" Pumice Flow due to Geological Structure

When layers or rocks, such as sedimentary rocks, igneous rocks and welded tuff, lie beneath the "Shirasu" pumice flow and clayey substances exist on their weathered portions, and if percolated water is liable to stay on the boundary plane between the "Shirasu" pumice flow and the underlying geologic constituents and the boundary plane is inclined downward the open-cut face of the slope, as Fig. 7 shows, the whole of the "Shirasu" pumice flow and the alternation of loam and pumice may happen very often to cause the failure accompanied with a sliding on the reason that the boundary plane itself plays a role of a sliding plane.

9. Landslides of the "Shirasu" Pumice Flow due to Opening Up of Cracks, parallel to the Open-Cut Face of the Slope, developed by Mechanical Vibration during the Construction in a Broad Sense

As soon as the open-cut is done for the natural ground and a steeply inclined open-cut face is formed, as I and II in Fig. 6 show, the internal stress in the natural ground is going to release toward the open-cut face, and, as a result, it is released in a form that cracks roughly parallel to the open-cut face occur. The open-cut face of the slope where the civil construction is moving is always affected by mechanical vibration due to working of busy heavy trucks and civil engineering machines. In such a case, opening up, widening and extension of cracks which occur within the geologic constituents of the slope are promoted, and sometimes the cracks attain not only into the weathered "Shirasu" pumice flow but also into the "Shirasu" pumice flow throughout the alternation of loam and pumice. When rain water percolates down into the weathered "Shirasu" pumice flow through the cracks, the weathered "Shirasu" pumice flow is pushed out and fails down in part, and, subsequently, it is much more widely exposed in the air, thus it becomes to cause the landslide accerelatedly in a large scale.

It is significantly noted that there is a close relation between an influence of mechanical vibration by which the slope of the "Shirasu" pumice flow is suffered and the disaster owing to the landslide.

10. Landslides of Talus Deposit due to the Open-Cut of the Slope of the "Shirasu" Pumice Flow

When the open-cut is done for the slope where talus deposit overlays the other geologic constituents, and when rain water percolates downward through the talus deposit and stays over the clayey substances, as Fig. 8 shows, the failure accompanied with a sliding is liable to cause.

Out-Door Test for Three Models of the "Shirasu" Pumice Flow in Different Conditions against Artificially Prepared Shower

A and B in Fig. 10 show three models set up for an out-door test which was carried out in 1977 at a place where housing land development was moving in Kagoshima City for comparison of the stability on the "Shirasu" pumice flow with a cement mortar-coating for the protection over the crown of the face of slope close to a nearly vertical cut, model I on the left handed side in A and the foreground in B ; the "Shirasu" pumice flow without a coating on the crown with a V-shaped side-ditch of the face of slope, with the undercutting at the toe, close to a nearly vertical cut, model II on the center ; and physically compacted filled "Shirasu" without a coating on the crown of the face of slope with a gradient of 55°, model III on the right handed side in A and the backside in B, against artificially prepared shower about 200 mm/m^2 for a half hour, corresponding to several times of the heavy rainfall. The out-door test was done with the cooperation of Kagoshima City Government, the Corporation for Development Works and Fire Department of the City.

C in Fig. 10 shows the start of the out-door test. For the face of slope of the model II, falling down occurred at a portion nearby the undercutting at the toe of the slope before the start of the test. Several minutes later, as D in Fig. 10 shows, gullies were formed immediately on the face of slope of the model III.

About a half hour later, as E in Fig. 10 shows, many largely digged gullies were formed over the whole face of slope of the model III and it was followed by flowing away of the

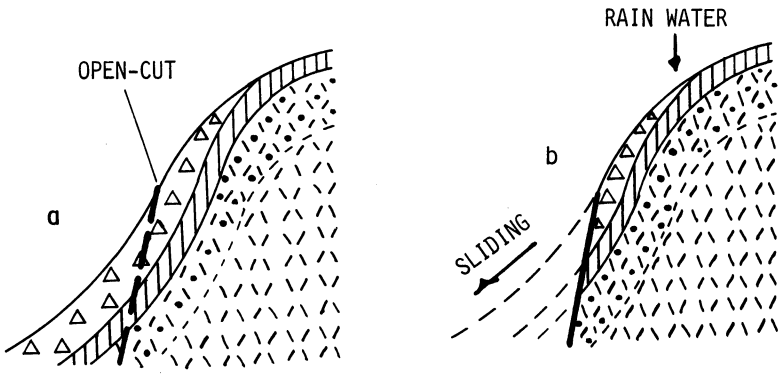

Fig. 8. Landslide of talus deposit at place where the development is moving. When open-cut is done for the slope where talus deposit overlays the other geologic constituents (a), and when percolated water through the talus deposit stays over the clayey substances, the failure accompanied with a sliding is liable to occur (b).

"Shirasu" materials in a state of mobile fluid. For the model II, a one largely digged gully and a few gullies were formed along the pipe-like structure, which was named in convenience by the present authors for "fossil fumarolic pipe" (YOKOYAMA, 1970) which was formed at the time when initially the "Shirasu" pumice flow deposited as "nuée ardente", that which exist within the "Shirasu" pumice flow on the face of slope, and it was followed by falling down of the "Shirasu" pumice flow in a much larger scale at the upper portion of the undercutting. In contrast with the model III, no any erosion and digging occurred on either the face of slope and the top in the model I.

As a result of the out-door test, the following facts were ascertained :

(1) the disturbed "Shirasu" represented by the filled "Shirasu" whose original welded texture is fractured is significantly weak in its stability for the moving water, and, accordingly, the slope protection for the prevention of water is required ;

(2) in contrast, the "Shirasu" pumice flow with a coating for the protection over the crown of the face of slope with a nearly vertical cut does not easily collapse in order to the presence of its own original welded texture ;

(3) the undercutting at the toe of the face of slope of the "Shirasu" pumice flow is liable to cause the vertical collapse due to the dominant columnar joint plane which is present essentially in the "Shirasu" pumice flow itself ; and,

(4) the presence of the pipe-like structure within the "Shirasu" pumice flow was noted throughout the out-door test on the reason that the pipe-like structure is liable to make a way for the moving water, and, accordingly, it is liable to cause the collapse of the face of slope.

Summary

Mechanisms by which the landslide was caused in the "Shirasu" pumice flow regions are roughly grouped into the following three : (1) the progressive change of the natural environment accompanied by the qualitative and structural changes of the social basement, as seen in the spreading of the development represented by the land construction even in the secluded areas during the progression of the economic development ; (2) natural agencies in the natural environment, as seen in the landslides due to columnar joint originated from shrinkage crack, scouring by water action at the toe of slope, weakness of stability of the weathered "Shirasu" pumice flow for moving water, peculiar combined geologic and geomorphologic natures and others in places where none of the development is accompanied ; and (3) unnatural agencies accompanied by the development, as seen in the landslides of the disturbed "Shirasu" and the weathered "Shirasu" pumice flow due to the denudation of the surface soil and loam, the defective handling for the drainage and prevention of water, undercutting, peculiar geologic structure, cracks developed during mechanical vibration and others in places where the development is in progress.

An out-door test was carried out for three models set up in different conditions against artificially prepared shower. As a result, the following facts were ascertained : the filled "Shirasu" is significantly weak in its stability for the moving water ; but, in contrast, the

"Shirasu" pumice flow with a coating for the protection on the crown of slope with a vertical cut does not easily collapse ; the undercutting at the toe of slope is liable to cause the vertical collapse ; and the pipe-like structure, if present, is liable to cause the landslide.

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References

ŌBA, N. (1972) : Geological study on disasters owing to No. 19 and No. 23 tyhoons in 1971 in the Shirasu regions. In "Researches on regional features of disasters in West Japan" by the Grant in Aid for Specified Scientific Researches in the 1971 fiscal year of the Ministry of Education of Japan, p. 63 (in Japanese).

ŌBA, N. (1973) : Microstructure and physicochemical features of the "Shirasu". Civil Construction Engineering (Sekō-gijutsu), vol. 6, p. 67–72 (in Japanese).

ŌBA, N. (1976a) : Mechanisms of the landslides due to rainwater ; with reference to the Shirasu regions, South Kyushu, Japan. Civil Construction Engineering (Sekō-gijutsu), vol. 9, p. 82–89 (in Japanese).

ŌBA, N. (1976b) : Shirasu (2). Jour. Res. Assoc. Powder Technology, Japan, vol. 13, p. 387–395 (in Japanese).

ŌBA, N., TOMITA, K., and YAMAMOTO, M. (1980) : Physicochemical features of the "Shirasu" pumice flow deposits, and its related landslides in South Kyushu, Japan. Proceed. Intern'l Symposium on

Landslides, New Dehli, India, 1980, vol. 1, p. 13–18.

ŌBA, N., TOMITA, K., YAMAMOTO, M., ISTIDJAB, M., BADRUDDIN, M., SUDRADJAT, A., and SUHANDA, T. (1983) : Geochemical comparison of volcanic products of Krakatau Group and Aira caldera-Sakurajima Volcano. Paper presented at Symposium on 100th Year Development of Krakatau and its Surroundings, August 23–27, 1983, Jakarta, Indonesia, 11p., with figures.

ŌBA, N., TOMITA, K., YAMAMOTO, M., ISTIDJAB, M., SUDRADJAT, A., and SUHANDA, T. (1984) : Geologic significance of granitic fragments found from pumice flow of 1883 eruption at the Krakatau Group, Indonesia. Abstracts of Papers presented at Fifth Congress on Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA V), April 8–13, 1984, Kuala Lumpur, Malaysia, p. 24.

ŌBA, N., TSUYUKI, T., and EBIHARA, H. (1967) : Mineral and chemical compositions, and genesis of the Shirasu (I). Jour. Japanese Assoc. Mineralogists, Petrologists and Economic Geologists, vol. 58, p. 81–97 (in Japanese with English abstract).

ŌBA, N., YAMAMOTO, M., TOMITA, K., and INOUE, K. (1980) : Physicochemical features of the "Shirasu" and stability of the filled Shirasu and the weathered Shirasu. Rep. Fac. Sci., Kagoshima Univ., no. 13, p. 1–9.

ŌBA, N., YAMASHITA, H., and YAMAMOTO, M. (1972) : Mineral and chemical compositions of the Secondary Shirasu. Jour. Japanese Assoc. Mineralogists, Petrologists and Economic Geologists, vol. 67, p. 84–89 (in Japanese with English abstract).

YOKOYAMA, S. (1970) : Geomorphology of the Ito pyroclastic flow desposit to the north of the Aira caldera. Geographical Review of Japan, vol. 43, p. 464–482 (in Japanese with English abstract).

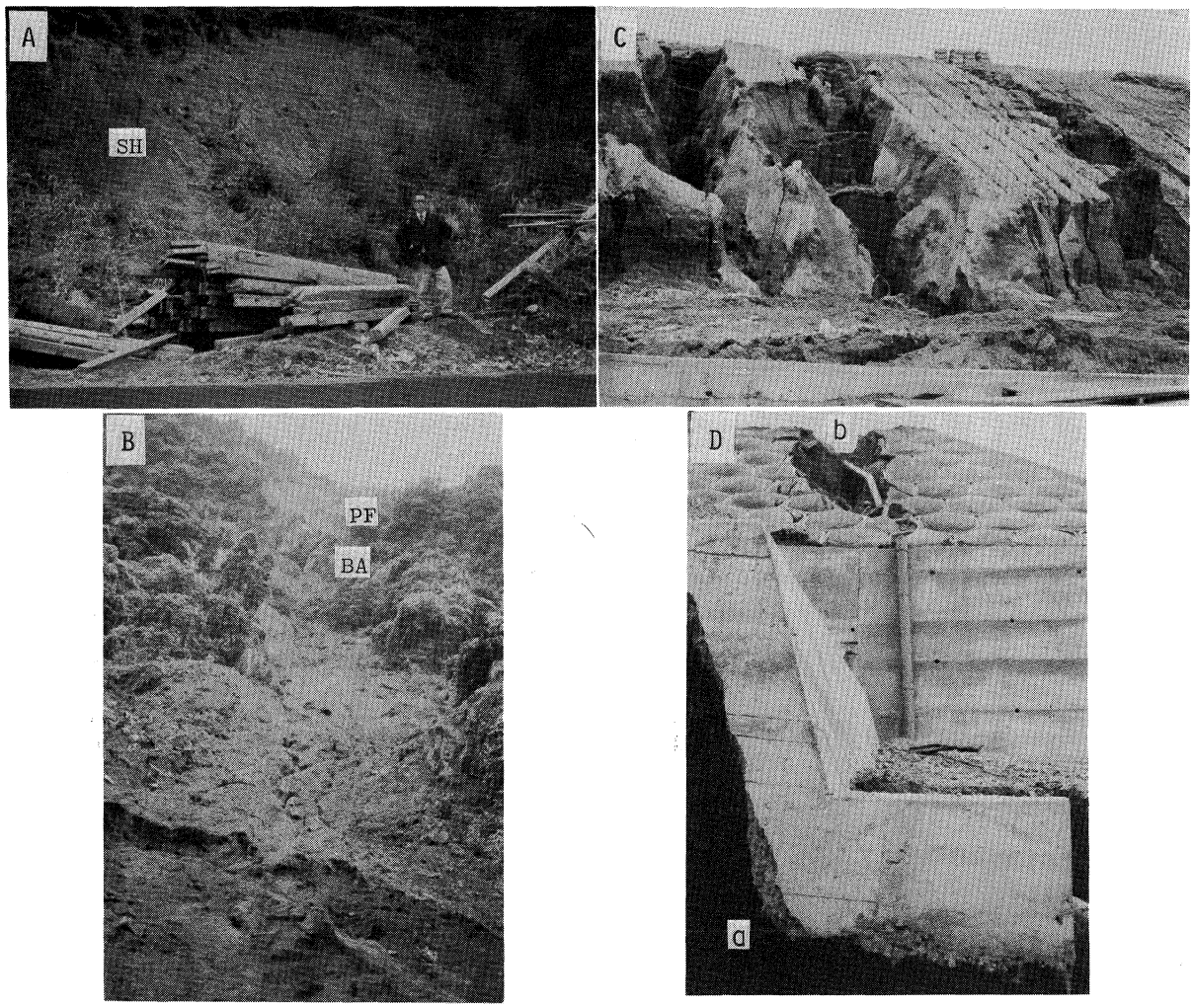


Fig. 9. Various patterns of the landslides in the "Shirasu" pumice flow regions.

A. An example of the landslides due to the progressive change of the natural environment accompanied by the qualitative and structural changes of the social basement. Three persons were killed here owing to the landslide of the "Shirasu" pumice flow (SH) in the heavy rainstorms accompanied by No. 19 tyhoon in August 1971. Kihoku-cho, Kimotsuki-gun, Kagoshima Prefecture, Japan. Photo taken by N. ŌBA.

B. An example of the landslides due to natural agencies in the natural environment. Photo shows the steeply inclined cliff where seven persons were killed owing to the rush down of an avalanche of pumice, sand and mud accompanied by the flush down water in the heavy rainfalls on June 22, 1975. An overhanging portion on the upper side shows a plate-shaped lava flow of basaltic andesite (BA) (see a–c in Fig. 5) which played a role of a natural dam for water which percolated through pumice fall deposit (PF). Ushine-fumoto, Tarumizu City, Kagoshima Prefecture, Japan Photo taken by N. ŌBA on June 25, 1975.

C. An example of the landslides due to unnatural agencies accompanied by the development. Photo shows the face of slope where the landslide occurred at the time when there had the heavy rainfalls at a place where the housing land construction was moving in the "Shirasu" pumice flow region. Many largely digged gullies were formed on the face of slope composed of the filled "Shirasu" and, in part, the weathered "Shirasu" pumice flow. Photo taken by N. ŌBA on April 14, 1970 at Harara Housing Land in construction, Kagoshima City, Japan.

D. The reinforced concrete wall built on the filled "Shirasu" is easily destroyed even if it is physically so strong. Note the facts that the filled "Shirasu" of the foundation where the reinforced concrete wall is based was perfectly flowed away (a), and that a portion where a conduit is set up within the filled "Shirasu" (b) allowed to be a way for running water owing to the defective handling for the prevention of water. Photo taken at the same place as C.

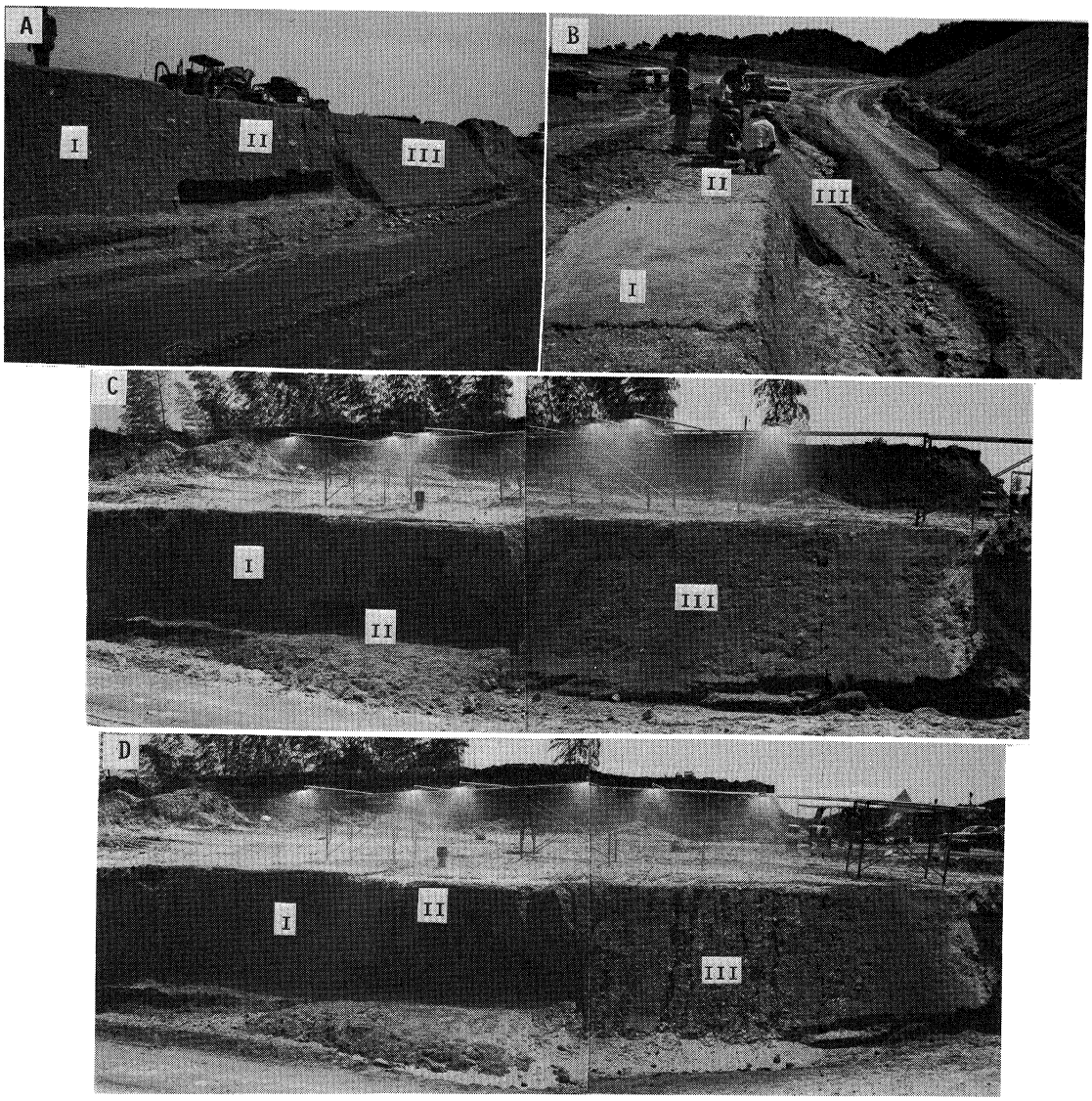
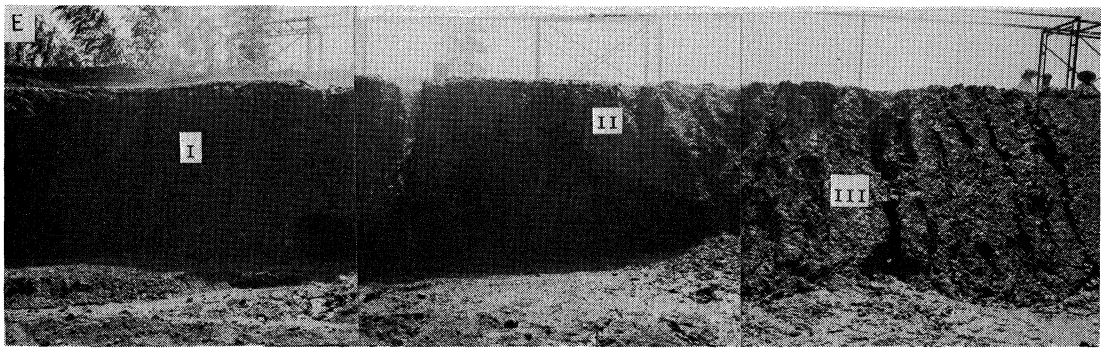


Fig. 10. Out-door test for three models of the "Shirasu" pumice flow in different conditions against artificially prepared shower about 200 mm/m^2 for a half hour.

A & B. Models set up for the out-door test for comparison of the stability on the "Shirasu" pumice flow with a cement mortar-coating of 5–7 cm in thickness over the crown of the face of slope 5 m long by 2 m wide close to a nearly vertical cut, model I on the left handed side in A and the foreground in B ; the "Shirasu" pumice flow without a coating on the crown, with a V-shaped side-ditch of 30 cm in width and 20 cm in depth parallel to the extension of the top, of the face of slope 5 m long by 2 m wide, with the undercutting at the toe, close to a nearly vertical cut, model II on the center ; and physically compacted filled "Shirasu" without a coating on the crown of the face of slope 7 m long by 2 m wide with a gradient of 55°, model III on the right handed side in A and backside in B.

C. Start of the out-door test. Falling down occurred at a portion nearby the undercutting of the model II before the start of the test.

D. Several minutes later, gullies were formed immediately on the face of slope of the model III.



E. About a half hour later, many largely digged gullies were formed over the whole face of slope and it was followed by flowing away of the "Shirasu" materials in the model III. A one largely digged gully and a few gullies were formed along the pipe-like structure within the "Shirasu" pumice flow on the face of slope, and it was followed by a much larger scale of falling down of the "Shirasu" pumice flow at the upper portion of the undercutting in the model II. No erosion and digging occurred on either the face of slope and the top in the model I.