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13. *Landslides in the Epicentral Area of the Matsushiro Earthquake Swarm—Their Relation to the Earthquake Fault.*

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1. Introduction

The earthquake swarm which began to be registered on 3rd August 1965 by a seismograph with a magnification of 100,000 at the Seismological Observatory of the Japan Meteorological Agency situated at the southern outskirt of the town of Matsushiro, Nagano Prefecture, central Japan, has now continued on through the two culminated periods, the first around April 1966 and the second from August to September 1966. During the second period of culmination when the crustal deformation was most intensely active, underground water began to well out from many places in the seismic area. The water of some of the wells was of higher salt content. The outpouring was most abundant at the end of September, 1966 and has since gradually decreased.

The present writers[1] have investigated the geology of the main seismic area in and around the town since the beginning of the earthquake swarm by means of field and literature surveys. During the first period of culmination, around April 1966, numerous cracks were formed on the ground north of Mt. Minakami or Minakami-yama, a lava dome in the central part of the present seismic area. Two of the writers[2] studied and explained these cracks as surface manifestation of strike-slip faulting associated with the earthquakes. Subsequently surface evidences of any crustal movements caused by the present earthquake swarm have been watched by them[3]. In order to ascertain geographical distribution of

1) R. MORIMOTO, I. MURAI, T. MATSUDA, K. NAKAMURA, Y. TSUNEISHI and S. YOSHIDA, "Geological consideration on the Matsushiro earthquake swarm since 1965 in central Japan," *Bull. Earthq. Res. Inst.*, **44** (1966), 423-445, (in Japanese with English resumé).

2) K. NAKAMURA and Y. TSUNEISHI, "Ground cracks at Matsushiro probably of underlying strike-slip fault origin, I—Preliminary report." *Bull. Earthq. Res. Inst.*, **44** (1966), 1371-1384, (in English).

3) K. NAKAMURA and Y. TSUNEISHI, "Ditto, II—The Matsushiro earthquake fault", *Bull. Earthq. Res. Inst.*, **45** (1967), in press.

the concealed fault or faults, new cracks which opened during the second period of culmination were mapped with temporary co-operation of one of the writers (R. M.) in the afternoon of 16th September. It happened during the field work at about 17h30 m that they found some cracks of a different kind from those they were mapping, on the mountain slope near Makiuchi. These cracks developed into a landslide 20 hours later, the first surface change causing severe disaster to the inhabitants of the town. After the landslide which occurred on 17th September, two others took place on 25th of the same month at Kirikubo and on 9th October at Nishidaira-yama (Figs. 1-2, Table I).

In this paper, the present writers would like (1) to point out some geological and clay-mineralogical characteristics of the landslide areas, (2) to discribe mode of displacement in the Makiuchi landslide which the writers predicted and observed, and (3) to discuss causes of the landslides in relation to the active faulting and to clay mineralogy.

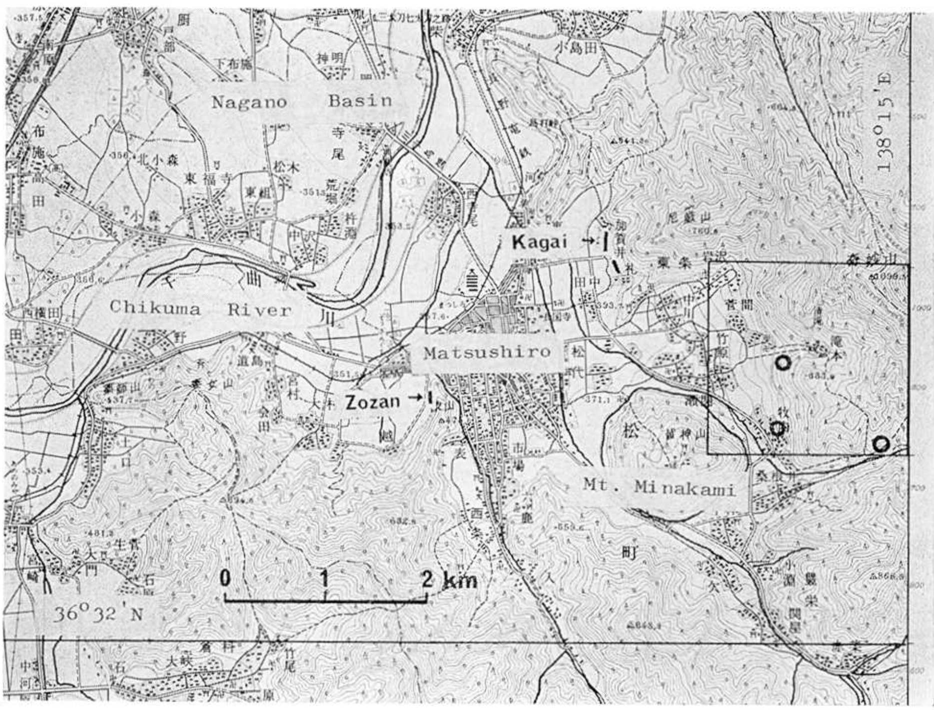

Fig. 1. Index map showing the central part of epicentral area of Matsushiro earthquake swarm. Square indicates the area covered by Fig. 2. Three open circles are the landslides listed in Table I.

Table I Date and dimension of the three landslides.

Locality	Date of occurrence (1966)	Average dip of the slope (°)	width (m)	length (m)	area (m^2)	Volume of the moved mass ($\times 10^4$ m^3)
			of the affected ground surface			
Makiuchi*	17th Sept.	20	160	250	33,000	5-10
Kirikubo**	25th Sept.	20	50	50	2,000	0.3-0.6
Nishidaira-yama†	9th Oct.	25	160	200	27,000	5-10

* Rotational slump and earthflow,
** Rotational slump only,
† Rotational slump and rock fall

A part of the expenses necessitated by this study was defrayed by the special fund for investigation of Matsushiro earthquakes from the Ministry of Education of the Japanese Government to the Earthquake Research Institute. Residents of Makiuchi and officers of the town of Matsushiro and of the Nagano Prefectural Government assisted the writers during their field observations. The Shinano Mainichi Press presented the writers with some useful aerial photographs (Figs. 3 and 7) for this papers. Dr. Tokihiko Matsuda, Associate Professor of the Earthquake Research Institute, joined the writers' discussion. He helped the writers in collecting the clay specimens with Mr. Haruo Takahashi of the same Institute. The writers wish to take the opportunity to express their cordial thanks to all the above-mentioned personnel and organizations.

2. Surface geology and the ground cracks

Surface geology of the area concerning the three landslides is classified into the alluvial fan and the mountain region[4] (Fig. 2). The coalescing alluvial fans in the figure occupy the upper reaches of a broad valley floor where the town of Matsushiro is located. The alluvial fan consists of an irregular mixture of mud, sand and angular rock fragments which were transported to and settled in the present area probably by some mass-movements such as earth or rock flow or avalanche.

The southwestern mountain, Mt. Minakami, shown in Fig. 2 is a lava dome of hornblende bearing augite-hypersthene-andesite which was extruded in the valley probably during the late Quaternary age[5]. The eastern mountain region in the same figure consists mainly of Miocene diorite-porphyrite complex intruded into the fine clastic sedimentary

4) K. NAKAMURA and Y. TSUNEISHI, *loc. cit.*, 2).
5) R. MORIMOTO et al., *op. cit.* p. 432.

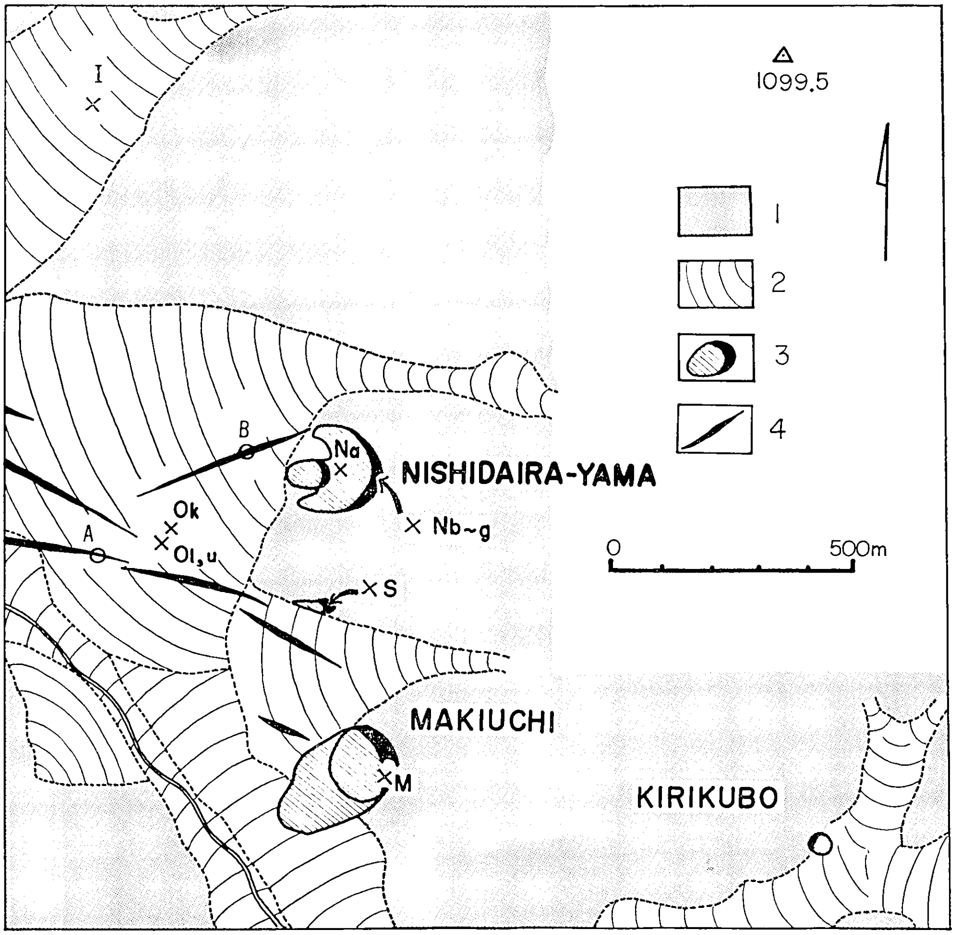

Fig. 2. Distribution of landslides and "fissure zones".

1. Mountain region, including its talus slope
2. Alluvial fan
3. Landslide, backward cliff and rotated and flowed earth
4. "Fissure zones"

A and B: Localities where displacement of the ground along "fissure zone" has been daily measured.

I, M, N, O, and S: Sampling localities (Table III)

rocks of the same age and overlain with Pliocene lava flows. The lower skirts of the mountain region are covered with thin talus debris.

The difference between the two classified regions is explained as follows in terms of historical development of the topography: The mountain region has been an area of erosion and weathering since the development of the deep valley now buried beneath the alluvial lowland including the valley floor where the town of Matsushiro is situated. A period of rapid rise of the base level of erosion followed after the valley cutting. Supply of much debris from the mountain region resulted in the present day lowland topography partly occupied by coalescing alluvial fans. This is evident from the extensive development of the ria-shoreline like boundary between the mountain region and the lowland (drowned mountain slope into the lowland) and also from thick alluvial deposits.

Therefore, the alluvial fans are younger depositional ground surfaces, whereas the mountain region has been a source area for supplying debris to the former.

In the case of the Matsushiro earthquake swarm, no remarkable surface changes had been brought about owing to the small intensity of each shock, except for those found at Kagai, Nuruyu, Zozan (Fig. 1), etc., where groups of cracks were formed by slow underground slip or rotation of shallow mass owing to the accumulated effect of vibration by the successive earthquakes. During the first culmination, April 1966, other kinds of ground cracks appeared on the narrow zone north and northeast of Mt. Minakami and were reactivated during the second culmination.

Groups of ground cracks which had appeared on the surface in the meizoseismal area of the present earthquake swarm till the beginning of September 1966 are generally classified into the following two schemes according to their modes of occurrence[6] although individual cracks are similar tension-cracks.

1) The first type is represented by the group of cracks whose overall distribution and displacement on the surface are quite conformable with the topographic relief, e.g. the general trend of distribution of cracks is parallel to contour lines of the surface.[7]

2) The second type is represented by the group of cracks whose distribution and displacement are quite independent of the surface inclination.[8]

Localities where ground cracks of the first type are distributed are scattered in the meizoseismal area. They appeared at the foot of the mountain slopes just drowned into the alluvial plain. The topographically lower side of the cracks moved downwards without exception.

The groups of ground cracks of the second type, on the contrary, were formed in the narrow straight area arranged *en echelon* passing

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6) K. NAKAMURA and Y. TSUNEISHI, (I) *loc. cit.*, 2).
7) B_1-type of Nakamura and Tsuneishi, *ibid.*, 3).
8) A-type of Nakamura and Tsuneishi, *ibid.*, 3).

through the central part of the meizoseismal area in the directions of WNW-ESE and of ENE-WSW partly shown in Fig. 2 as thick lines. This group of cracks was called a fissure zone in the previous paper[9].

The "fissure zones" consist actually of short parallel tension-cracks arranged *en echelon*. Pattern of the echelon arrangement is the same throughout respective zone and indicates the left-lateral and right-lateral movement of the ground along the zones of WNW-ESE and ENE-WSW trends, respectively. Displacement along the "fissure zones" has a vertical component also. The northern side of the "fissure zones" of WNW-ESE direction and the southern side of the zone of ENE-WSW direction moved down respectively relatively to the opposite side of each zone. The nature of these fissure zones formed on the ground north of Mt. Minakami may reasonably be interpreted as the surface manifestation of a new left-lateral movement of some underlying fault in the besement rocks. The narrow elongated area where these cracks were found seems to define the geographical distribution of the concealed earthquake faulting.

The fact that a number of mineral springs oversaturated with carbon dioxide began to well out from some places through these cracks, means that some of these cracks might have cut through the basal rocks down to the depths of some 400-500 m. Because, similarly oversaturated water welled out from that depth through bore holes at a neighbouring hot spring in Matsushiro (e. g. Kagai, Fig. 1).

3. The Makiuchi Landslide

a) *Sequence of the events:*

During their mapping of "fissure zones", the writers found a new one trending in a WNW-direction in the Makiuchi area on the way to their inn. This was toward the evening of 16th September, one day before the disaster, and at the two-forked path seen in Fig. 3, though at that time cracks were less predominant than those appearing on the photograph.

According to their previous observations about the "fissure zones" of WNW-ESE trend, the expected sense of displacement to be shown by these cracks was exclusively north side down and left-lateral. But the sense of displacement displayed by these fresh cracks was south side down and right-lateral. Arcuate arrangement of cracks was revealed by hasty mapping and the writers recognized these fresh cracks almost

9) K. NAKAMURA and Y. TSUNEISHI, *ibid.*, 2).

Fig. 3. An aerial view of the ground cracks formed at the head of the impending landslide at Makiuchi. Photograph was taken by Mr. Sakurai of the Shinano Mainichi Press from a plane 50 m above the land two hours before the visible sliding which started at 14h05 m, 17th September 1966. Upper right of the rural road is cut by one of these cracks to make a step, where several persons are standing. Fig. 4. is a close-up of this part.

intuitively as those usually found at the head of a landslide in its initial state.

To make sure how the opening of the cracks progressed, they began to survey the opening as soon as possible. Distribution of vertical and horizontal displacement along the cracks combined with oral communication from village people clearly indicated that a slow landslide was just taking place there. The writers marked a horizontal lines as makeshift bench marks on the stone wall along the road traversing the head of the expected landslide (Fig. 4) and made the first measurement with a portable auto-level under the head-lights of their car. The rate of vertical displacement there during the daytime was roughly estimated about 1 cm per hour from observations orally communicated by village

Fig. 4. A rural road was cut through by one of the cracks along which the anticipated landslide was going to occur. Displaced height was about 80 cm, 20 minutes before the visible sliding started. Horizontal lines were marked for levelling on the stone wall at the left side of the road.

After taking this photograph, one of the writers (R. M.) asked the woman in the photo whether she found any swelling place on the downslope or not. She replied without fear that her own appleyard swelled. He felt an impending danger and said the all eyewitnesses to escape at once from the depressed road.

Fig. 5. A panoramic view of the semi-circular cliff at the head of the Makiuchi Landslide about 10 minutes after its first visible movement. The underground water which was previously concealed is shown running down in the middle of the cliff. To the left of the water, many inclined striation are seen on the cliff. These are probably formed during the slide. The curved surface of the cliff still preserved its perfect crescent-like shape at that moment. Top of the head broke down at the second collapse, 30 minutes later (Fig. 6 and Fig. 7 below).

people. The writers were afraid lest the earth mass as defined by the cracks should begin to move fast or collapse downwards. An anticipated area of damage was preliminary estimated. Inclination of the slope was about 20°. On the downslope of the dangerous cracks there are houses of village people. A large amount of underground water welling out from the uppermost cracks was flowing down in the new cracks. It rained. Number of felt earthquakes was a few hundreds a day.

Under the above-mentioned circumstances, the writers decided to advise the officers of the town hall to evacuate the inhabitants from the dangerous area and to control the water flowing into the cracks in order to miminize or to retard the impending disaster. The officers and people accepted the writers' advice. The inhabitants were evacuated at midnight. No visible landslide did take place in the morning of next 17th September. Legality and validity of "last night's evacuation" were discussed, while slow but still faster invisible sliding had continued on.

Around the noon, new swelling at the down slope below the arcuate cracks was reported and observation and mapping were quickly made (Fig. 9). The average velocity of downward movement measured by the writers at an observation point (Figs. 4 & 9) became more than twice as much compared with that on the previous day.

Visible sliding began at 14 h05 m, in the presence of a crowd of people :

At first small fragments of rocks and pieces of dry mud on the lower mulberry and appletree yards began to roll down from a number of upthrusting small cliffs or growing front of steps with a sound as if it had begun to shower. Cracks successively opened in the direction of mass movement without much disturbance. Mulberry and appletree yards of the upper slope slid down and tilted as a whole leaving a clean spoon-shaped scar on the mountainside, with a sound similar to surf heard at the sea shore. A crescent shaped cliff was formed at the head of the slide (Fig. 5). The moving mass gradually broke into several blocks, being cut by vertical cracks to make blocks behind. This first movement continued for several minutes only. Collapses along the newly formed cliff started at once

Fig. 6. An aerial view of the landslide at Makiuchi, an hour after its occurrence. Underground water pouring out from the curved scar at the head of the collapsed area is dammed up behind the ridge of the rotated mass. Mulberry trees intermingled with slid earth draw the flowage patterns to wards the front, similar to a big surface pattern of ropy lava flow. Smaller embayed portion at the top of the cliff collapsed secondly, about 30 minutes after the sliding down of main mass. Photo. by Mr. Sakurai, Shinano Mainichi Press, around 15h, 17th September 1966.

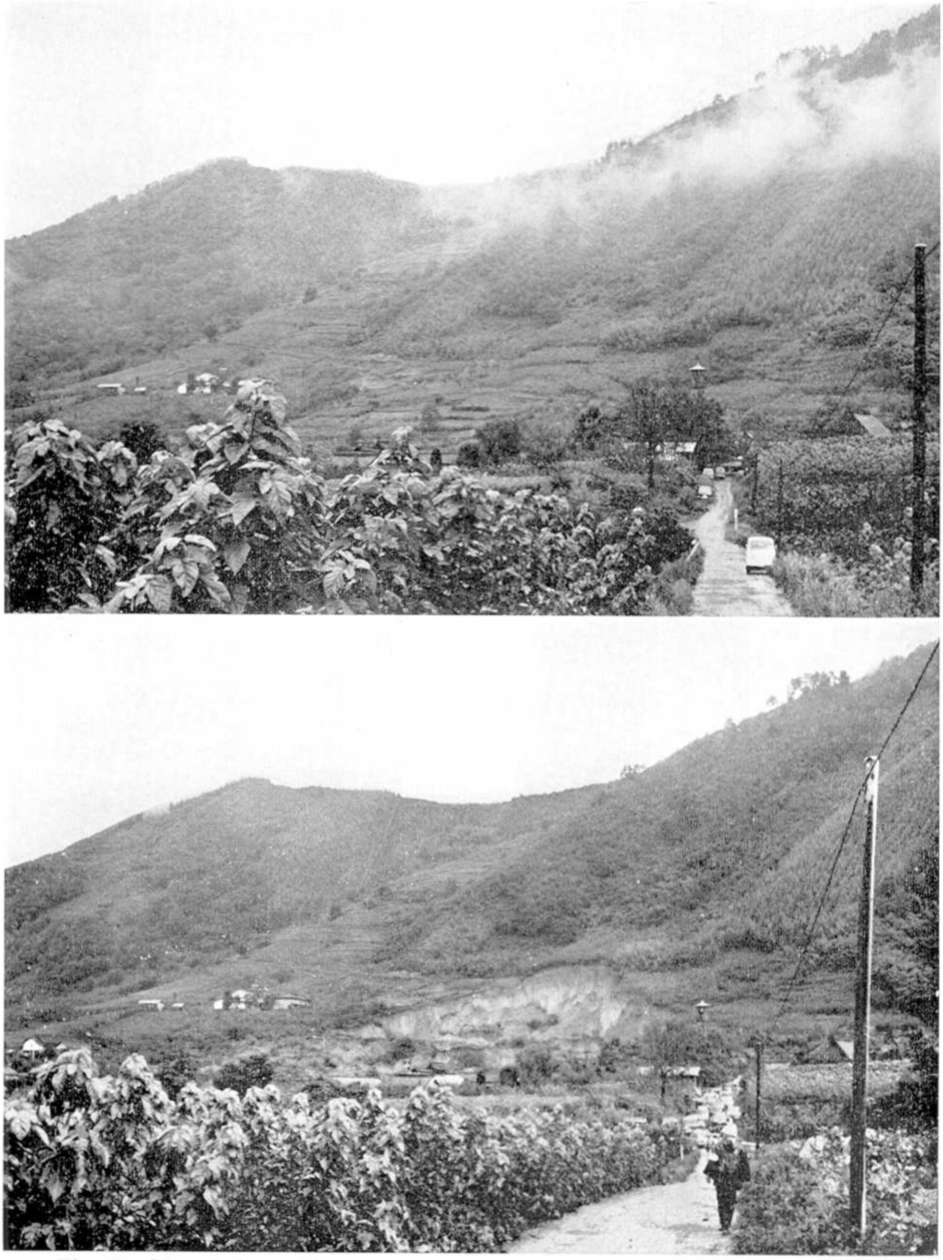

Fig. 7. Site of the Makiuchi Landslide viewed from a point about 1,000 m southwest of the spot before and after the event. Upper photo was taken at 13h30m, and the lower at 15h30 m, 17th September.

to make talus cones beneath there. At about 14h40 m a remarkable collapse took place in the central rim of the cliff (Fig. 6), which caused a second movement to start appearing as slumping behind and swelling up in front. The swelled up mass collapsed and flowed downwards. This continued for about 20 minutes with the velocity of ten to twenty centimetres per second. Most of the destroyed houses were collapsed down by the earth flow during this second movement (Fig. 6). The cross-section of the moved mass is shown in Fig. 8.

Appropriate work of preventing the water pouring into the cracks was done by the firemen of the town during the night of 16th September and probably retarded the starting of rapid sliding. This must have decreased the velocity of moving earth, and would have protected the inhabitants from the anticipated danger due to dashing water and earth if it had occurred.

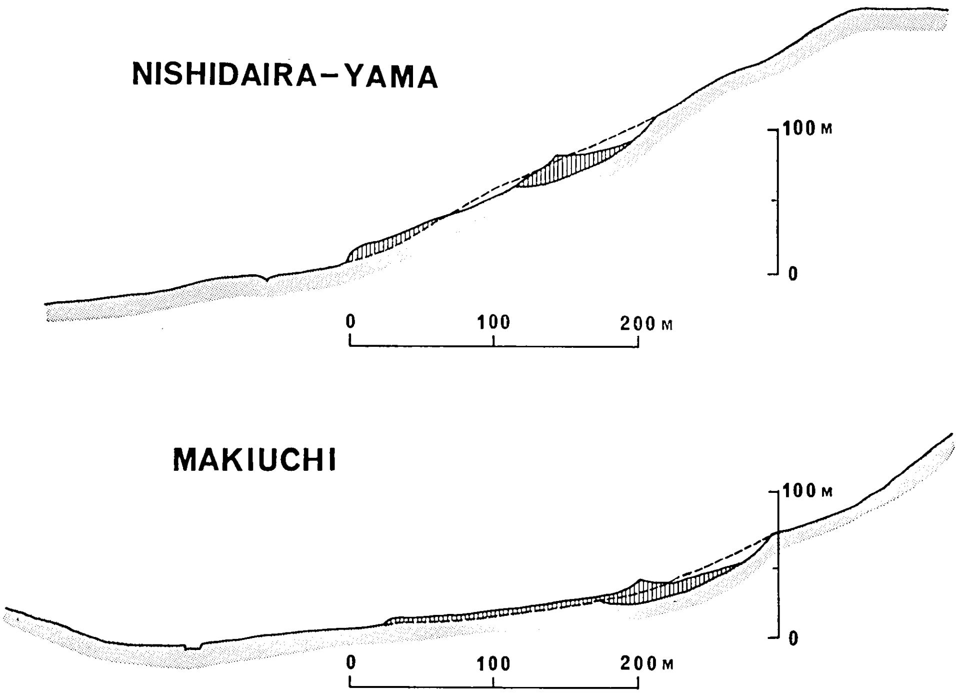

Fig. 8. Cross-sections of the sites of two landslides at Makiuchi and Nishidaira-yama. Higher parts of the moved masses show rotational slumps whereas the lower parts represent flowed masses which bear flowage pattern on their surface (Fig. 6) at Makiuchi, and rock fall and avalanche at the Nishidaira-yama.

b) *Movement before the main event :*

A part of the semicircular crevice which later developed into an amphitheatre-like curved cliff, had already appeared on the slope in the night from 14th to 15th September, according to village people. This means that a slow landslide had already started along the slope, whose movement itself was not recognized with naked eyes at that time.

Since the evening of the 16th the vertical component of the diplacement was measured three times by the writers at a road side (Figs. 3, 4 & 5) near the southeastern rim of the anticipated slid area. The results of these measurements suggest that the movement of the land-

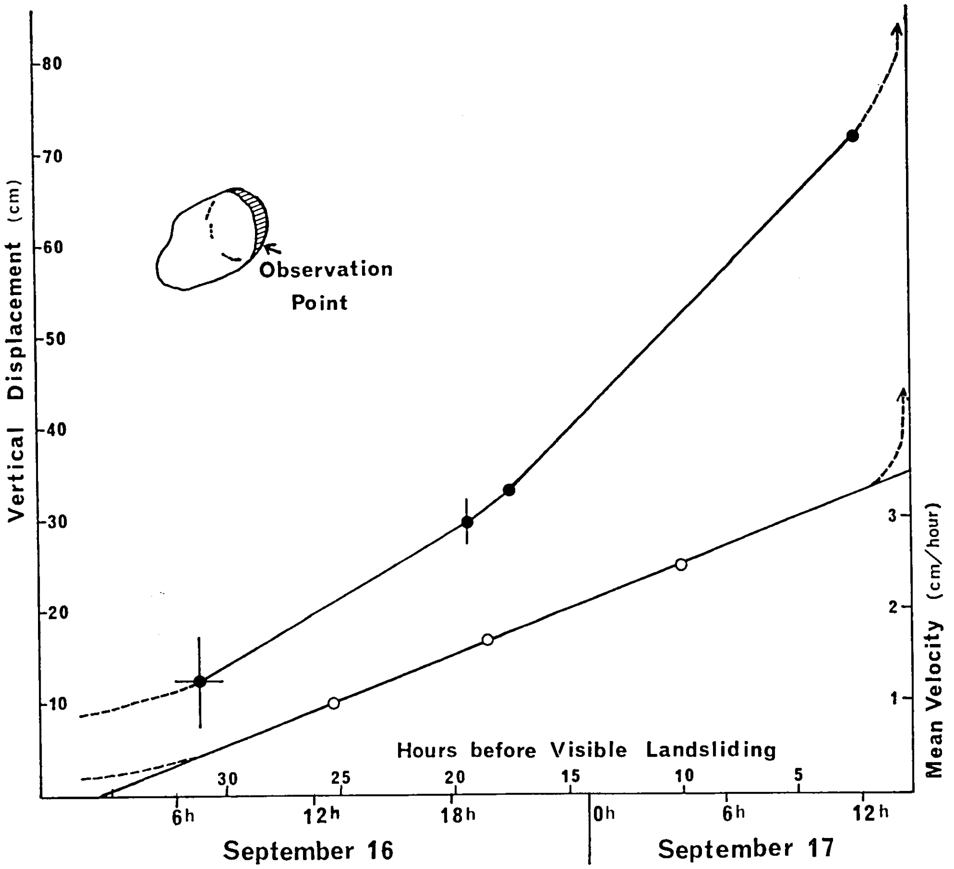

Fig. 9. Vertical components of displacement and mean velocity of the sliding mass prior to visible landslide at Makiuchi, observed at a southeastern margin of the collapsed area.

slide, at least near the observation point, would be divided into three stages; the 1st stage of small but increasing acceleration, 2nd stage of small constant acceleration, and the 3rd one of catastrophe.

The upper curve of Fig. 5 shows *time-vertical displacement relation* at the observation point. Solid circle of extreme left is a value estimated after communication from village people. Vertical and horizontal lines attached to circles indicate possible range of error. Second circle from the left is a value measured by the writers. The other two circles represent values obtained from levelling by the writers.

The lower curve of the same figure shows *time-mean velocity relation* derived from the upper curve. Three open circles plotted on the lower curve lie on a linear line. This fact means the constant acceleration of observed displacement and the constant resisitance against sliding:

$$0.10\,\mathrm{cm}\cdot\mathrm{hour}^{-2}=7.7\times10^{-9}\,\mathrm{cm}\cdot\mathrm{sec}^{-2}\,.$$

The acceleration in the direction of actual movement, or in the direction of maximum inclination of the slope is,

$$7.7\times10^{-9}/\sin 20^\circ=2.0\times10^{-8}\,(\mathrm{cm}\cdot\mathrm{sec}^{-2})\,.$$

During visible landslide, the mean velocity must have been greater than that linearly extraporated and would have changed something like the dotted curve. This means that the resistance against sliding dropped just before the visible sliding.

If the velocity line is linearly extrapolated into the period before measurements, it becomes zero in the morning of the 16th. Actually, however, cracking started in the morning of the 15th, indicating that the velocity was not zero in the morning of the 16th. This is expressed by another dotted line on the left. In this first stage, registance against sliding must have been greater but decreasing.

4. Characteristics in geology of the slid areas

After occurrence of the landslide at Makiuchi, there took place several similar surface changes, among which the greater two are listed in Table I together with that at Makiuchi. Among these, the Kirikubo landslide showed rotational slump only. The cross-section of the Nishidaira-yama landslide is shown in Fig. 8. Beside these, two arcuate groups of cracks appeared as an initial stage of landslides at the south of Nishidaira-yama and at a few hundred metres south of loc. I in

Fig. 2. No more opening movement of the two groups have been recognized since the appreciable decrease of nearby welling water. A small mud-flow also started from a mountain slope between Makiuchi and Nishidaira-yama landslides (S in Fig. 2). This occurred in the morning of 18th September, the volume of the material concerned being estimated at about 500 m^3.

The mud-flow and the three actual and two suspended landslides occurred exclusively on the middle and lower skirt of the mountain region (Fig. 2) where basal rocks are covered with talus debris less than a few metres in their thickness. The basal rocks at the three localities are all deeply altered porphyrite or fine-grained diorite*. But at Nishidaira-yama, a part of the basement rock consists of pebbly mudstone or sandstone** which lies on the depression of the diorite and is overlain by thin talus debris. In this mudstone, fresh and nearly horizontal slicken-sides which seemed to have been formed by the present movement were frequently observed.

No landslide occurred on the slope of alluvial fan deposits even where they are deposited at the slope (about 20°) just adjacent to the site of landslide (Fig. 8). Taking the mode of formation of the present topography into account (Chap. 2), it may be concluded that the alluvial fan area has been immune from disturbance or that the area is more stable against gravity force than the above-mentioned mountain slopes.

These differences between the two areas are also reflected on the association of clay minerals collected from the displaced areas and from the alluvial fan deposit adjacent to the slid place.

Localities of the three landslides are exclusively situated on the "fissure zones" or on their extension: Makiuchi and Kirikubo are on the southeastward extension of the "fissure zones" of WNW-ESE direction and Nishidaira-yama on the WSW-ENE "fissure zone" which might have been opened under the same stress distribution. The mountain skirt of the same geological condition as that of above-mentioned displaced areas is extensively developed in the meizoseismal area. But no surface changes of this type were found on these mountain slopes out of the "fissure zones" and their extension. Thus the skirt of the mountain region composed of deeply weathered basal rocks which were disturbed to make cracks by the movement of some concealed earthquake faults, satisfies necessary geologic conditions giving birth to these landslides.

* Specimens of them are designated as Nc, Nd, Ng, S, and M in Table II.

** Specimens Na, Nb, Ne, and Nf (ditto).

Table II Samples collected for the clay mineralogy.

The Makiuchi Landslide	Mu	altered diorite 3 m from the surface		from a southern cliff formed by the present landslide
	Ml_1	〃 } 6.5 m 〃	less weathered part	
	Ml_2	〃	more 〃	
Mud flow of Sezeki of 18th September	Sa_1	〃	low ↑ degree of alteration	from a cliff newly formed by the collapse to form the mud-flow
	Sa_2	〃		
	Sb	〃	↓ high	
The Nishidaira-yama Landslide	Na	unconsolidated mudstone	grey black	from cliffs newly formed by the landslide
	Nb	unconsolidated pebbly sandstone	grey brown	
	Nc	altered diorite	light yellow — low ↑ degree of alteration	
	Nd	〃	yellowish brown	
	Ng	〃	white — ↓ high	
	Ne	pebbly fine sandstone	grey	
	Nf	〃	〃	
Alluvial fans	Ou	matrix of fan deposits	brown — 30 cm below the surface	from the same exposure
	Ol	〃	〃 — 50 cm 〃	
	Ok	〃	〃 — 20 cm 〃	
	I	〃	light brown — 50 cm 〃	

5. Clay minerals

Kinds of constituent clay minerals collected from the displaced areas are considered to be one of the factors in bringing about a landslide. Clay minerals play a part of greasy media in sliding. The properties characteristic to their own crystal structures often make themselves a main activator of severe landslide in the field of gravity force. Such examples were described by two of the writers in the cases of the landslide at the Town of Imaichi[8] and the earth-flow at Sôunzan, Hakone volcano[9]. Specimens of clay were collected from various parts of the collapsed areas as well as from the adjacent stable slope of alluvial

Table III

			M	H	HH	Mix	Q	F	Cr	74 μ>
Samples from	landslide areas	M*u*	±	+	±		++	+	±	30.9%
		Ml_1	±	+	±		++	+	±	8.8
		Ml_2	+	+	+		++	++	+	24.1
		Sa_1	++	+	±	±	++	+	±	15.6
		Sa_2	+	+	±	±	++	+	±	18.0
		S*b*	+	+	±	±	++	+	±	26.5
		N*a*	+++	++			+	±	±	58.2
		N*b*	++				+	±	±	7.8
		N*c*	+				++	+	+	3.2
		N*d*	++				++	+	++	38.4
		N*e*	++				+	±	±	14.7
		N*f*	+				+	±	+	14.5
		N*g*	++	+			++		+	27.4
	alluvial fans	O*u*		+	+		++	++	+	8.6
		O*l*		+	+	+	++	++	++	23.2
		O*k*				+	++	+	+	33.9
		I		+	+	+	++	++	+	39.0

M : Montmorillonite, H: Halloysite, HH: Hydrated halloysite,
Mix : Random mixed layer, Q: Quartz, F: Feldsper,
Cr : Cristobalite
+++: large amount, ++: medium, +: small quantity, ±: trace
% : weight percentage of the finer portion under 74 μ

8) R. MORIMOTO, J. OSSAKA and T. FUKUDA, "Geology of Imaichi District with special reference to the Earthquake of Dec. 26, 1949 (III)", *Bull. Earthq. Res. Inst.*, **35** (1957), 359-375, (in English).

fan (Table II). Their grain size distribution and X-ray analyses data are shown graphically in Figs. 10 and 11. All specimens are illsorted. Some of the specimens collected from the site of landslides show a proportion of the fine part predominance, suggesting advanced weathering.

Results of these observations are summarized in Table III. Montmorillonite was found exclusively from the clayey earth of the disturbed areas, while the mineral was not yet observed in the clay collected from the young fan deposit adjacent to the slid place.

The physical property of both montmorillonite and hydrated halloysite must have given a favourable condition to slipping of the overlying

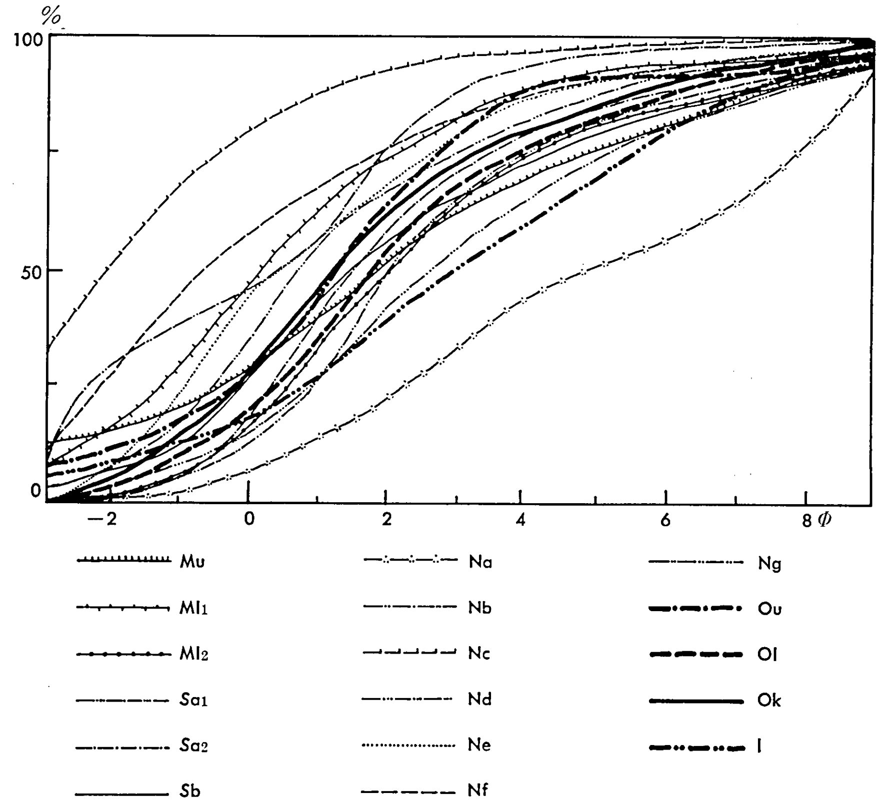

Fig. 10. Cumulative curves of the specimens collected from slid areas and alluvial fan deposits. Localities are shown in Fig. 2.

9) F. KISHINOUYE and J. OSSAKA, "Earth-flow on July 26, 1953 at Sôunzan, Hakone" *Bull. Earthq. Res. Inst.*, 33 (1955), 153-161, (in Japanese).

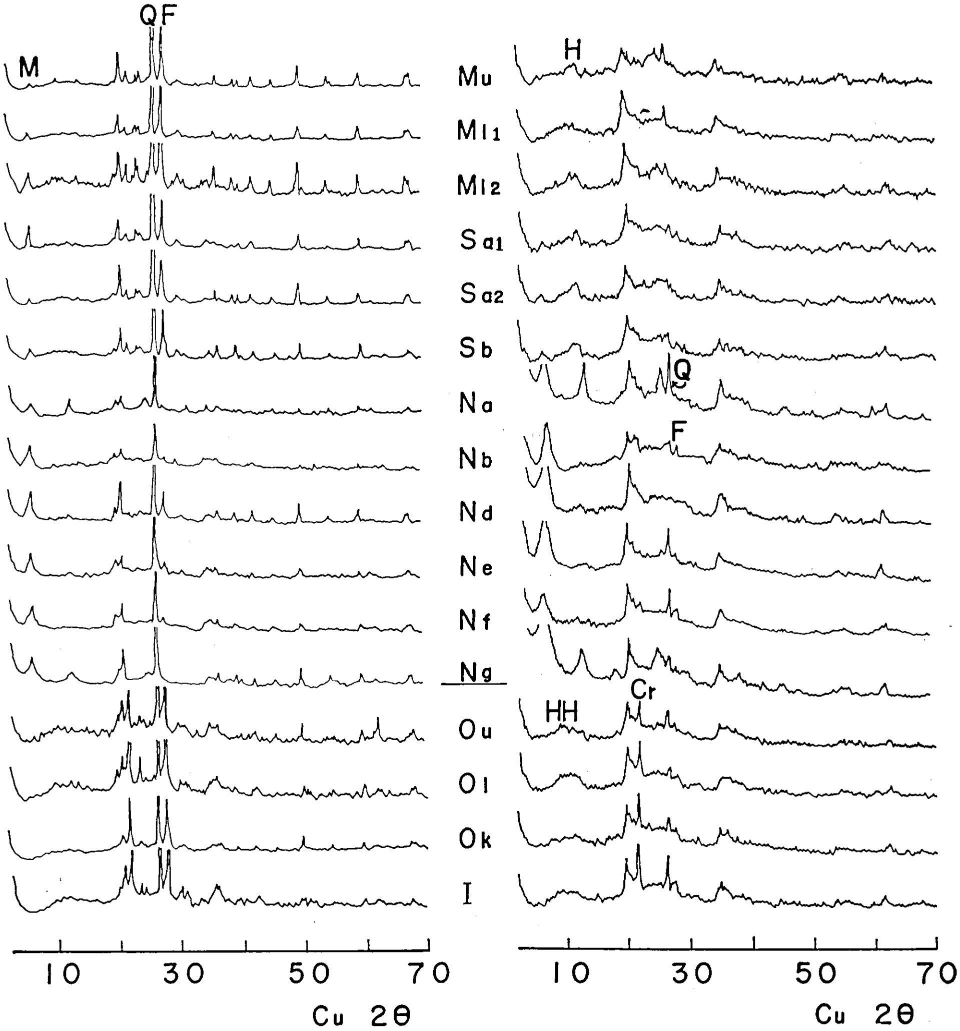

Fig. 11. X-ray diffraction patterns of the specimens collected from slid areas and from alluvial fan deposits. Localities are shown in Fig. 2. The lower four below the line in the centre of the figure are specimens collected from alluvial fan deposits and the rest above the line from slid areas. Refraction patterns of bulk composition and those of decantated finer portion ($<2\mu$) are given on the left- and right-hand respectively.

M: Montmorillonite, HH: Hydrated halloysite, H: Halloysite, Q: Quartz, F: Feldspar, and Cr: Cristobalite.

mass in these slid areas. Formation of montmorillonite is not expected by means of mere weathering process from the surface, but can only be possible in a deeper place where alteration advances without sufficient supply of oxygen[10]. This genetic condition of montmorillonite is quite compatible with the occurrence of the present landslides on the slopes of deeply weathered basal rooks.

7. Discussion and Conclusion

Causes of landslides are generally complicated, because there are many conditions favouring landslides. This applies to the present landslides. In this case, however, their occurrence is quite restricted in place and time: They occurred successively within 25 days following the culminated period of August-September of 1966 in the prolonged seismic activity, in the area where the crustal deformation was most intense. This suggests a quite intimate relationship between causes of the landslides and the earthquakes or resultant crustal movement.

The places where the landslides occurred were selectively in the lower slope of the mountain region (Fig. 2). The region has been an area for weathering and erosion and part of the slope is regarded as a remnant of the original valley wall, the corresponding bottom of which is now buried under the alluvium. On the contrary, area of alluvial fan has been the place of deposition. Thus, the slope is originally less stable for gravity force than the surrounding alluvial fans as indicated by the difference in their mode of formation.

Although it rained during a few days before the occurrence of Makiuchi Landslide, it was quite fine before that of Nishidaira-yama Landslide. The main factor controlling the ground moisture was not a meteoric running water but the underground water plentifully welled out from neighbouring ground surfaces.

The following factors would have decreased the strength of the surface layers and caused the slides in addition to the authigenic instability of the ground:

10) R. MORIMOTO and J. OSSAKA, "Low temperature mud-explosion of Mt. Yaké, Prefs. Nagano-Gifu, central Japan, on 17th June 1962, as an example of endogeneous katamorphism of volcanic rock at the destructive stage of the volcano", *Bull. Volcanologique*, **27** (1964), 3-4, (in English). J. OSSAKA and T. OZAWA,, "The 1962-ejecta from Mt. Yaké, Nagano-Gifu Prefectures, and its mechanism of eruption", *Bull. Volcanological Soc. Japan*, 2nd Series, **11** (1966), 17-29, (in Japanese).

1. Vibration due to numerous earthquakes (This is a widely prevailing condition in the meizoseismal area.)

2. Rupture formed by the movement of underlying fault (This is strongly suggested by the fact that the landslide took place exclusively on the zone of concealed earthquake faulting.)

3. Physical loosening of soil and rocks by saturation of underground water supplied through the rupture (The underground water began to well out a few weeks before the first landslide).

4. Swelling of clay minerals due to sufficient supply of underground water (This is expected from the characteristic crystal structure of montmorillonite and hydrated halloysite which had already been formed in the surface layer of the slid area).

Through the combined effect of these factors, the slope must have gradually been made ready for sliding. However, it is difficult to point out what was a direct trigger in bringing about these visible landslides. No strong earthquakes were registered just before the visible sliding at Makiuchi and Nishidaira. Movement of the underlying fault had almost stopped before the landslide, and no remarkable changes were found in the condition of underground water supply just before the event.

In conclusion, the landslides occurred on the valley wall which has long been weathered since Late Quaternary where clay minerals favourable for sliding had already been formed *in situ*. More direct cause of the slides would be plentifull supply of the underground water to the slid mass through the cracks formed by the movement of a buried earthquake fault.

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13. 松代群発地震震央地域の地辷り
―― その地震断層との関係 ――

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1965 年 8 月に始まった長野県松代付近の群発地震は，現在もその活動を続けているが，これまでに，1966 年 4 月を中心とする時期と，同年 8 月から 9 月にかけてとの 2 回の著しい活動期があった．特に 2 回目の活動期 (8 月～9 月，いわゆる第 3 活動期) には，皆神山北東部を中心とする地

域の地殻変動，(土地の隆起及び南北方向の伸長，地震断層の動きによる地割れの発生・開口など)が著しく，9 月に入ってからは同上地域の山麓各所で地下水が湧出をはじめた．地辷りはこの地域内の数ケ所に，隆起・伸長等の地殻変動が逆向きに転じた後，9 月 17 日からの約 25 日間に発生した．

筆者らは群発地震発生以来地質調査を行い，また 1966 年 4 月からは地震断層研究のために地割れの調査を続けてきた．その野外調査中に地辷り活動の最初のもの(牧内)を事前に発見予測し，その滑落を目撃した．この論文ではこれまでの調査結果に基いて，まず表層地質の特徴および震央域内に生じた地割れの二大別について述べ，牧内地辷り発見以降の経過を記載し，ほかの地辷り地点の地質学的粘土鉱物学的特徴を指摘し，滑落するに至った要因について論ずることにした．

この群発地震は，その個々の地震の規模が比較的小さく，地震動の地表に及ぼす影響がはげしくなかったために，地表で肉眼的に観察される地変が，その初期には，きわめて稀であった．わづかに，温湯・加賀井・象山など沖積低湿地に接する山麓斜面に，その斜面の等高線に平行な地割れが生じたにすぎなかった．これらの地割れはいずれも緩行性の地辷りによるものである．これらの地割れ群とは別に，上述の 1 回目の著しい活動期のころから，皆神山北東の地域に，地割れ群が発生したが，この地割れ群が規則的に雁行する tension crack よりなること，および変位量とその方向の測定から，中村及び恒石は地下に左横ずれの地震断層が，皆神山北東，竹原部落を中心に西北西—東南東方向に生じていることを推定した．

2 回目の活動期に入って，これらの地割れ発生地区では地割れの開口量も著しくなり，炭酸ガスに過飽和の地下水の湧出が始まった．昭和 41 年 9 月 16 日夕刻，上記 2 名に森本も加わって，横ずれ断層によると推定される地割れの野外調査の帰路，この地震断層の南東延長に当る牧内部落の背後山地の斜面に新鮮な地割れ群を発見した．この新らしい地割れ群の方向は西北西で，断層起源の地割れの多くと同じであったが，変位の方向は逆で，北上り，右ずれであった．地辷りによる地割れ群ではないかとの危惧をいだいたので，懐中電灯を使ってさらに詳しく調査した結果，地辷り地上端に生じている地割れと判断された．すなわちこの地割れは西方すなわち斜面の下方に開いて弓なりに分布し，その北翼は右横ずれで南下り，南翼は左横ずれ北下りの変位を示す雁行配列をしているうえ，頂部は開口し，すでに数 10 cm の落差をもっていた．

前日はかなりの雨で，また当夜も降雨がつづいていた．湧出地下水が，弓形の割れ目中を流下し，地辷りまたは土石流発生の可能性が十分にあった．上記 3 名は直ちに，ジープのヘッドライトのもとで，地割れを横切る農道に沿った石垣に標をつけて即席の水準点とし，自動水準儀を用いて比高を測定したのち，松代町役場地震対策本部に，その危険を報告，地辷りによる被害の及ぶ面積の予想を示し，住民の避難を勧告，湧水及び雨水の地割れへの浸入を防ぐ必要のあることを伝えた．中村は，さらに町役場吏員と共に第 2 回の測量を行った．住民よりの聞き込みによる 16 日日中の地割れの垂直移動量は 1 時間約 1 cm であったが，約 2 時間の間をおいた 2 回の測量による垂直移動量は 1.7 cm/毎時となっていた (第 9 図)．町役場当局は，この結果に基き筆者等の意見を入れ，住民の避難をきめ地割れへの湧水及び雨水の浸入をできる限り少なくする応急措置をとった．第 3 回の測量は翌 17 日昼近く中村及び恒石によって行なわれた．前夜来の湧水の処理は，地辷りの発生を時間的におくらせ，落下速度を減じ土石流の発生を防止したものと推定される．急速な滑落を伴う地辷りは，17 日 14 時 5 分頃，衆人監視のもとに始まった．11 棟の家屋が破壊されたが，人畜の生命の被害は皆無であった．この経験に基いて地元ではこれ以后，地辷りの事前発見のためのパトロールの必要が強調され，その結果，地辷り発生初期を指示する地割れが附近の山麓の数ケ所で発見された．10 月 9 日西平山に発生した地辷り (Table I) も数日前からその発生を示す地割れが発見されていた．9 月 25 日には桐窪で単純な廻転を主とする地辷りが発生している．

筆者らの目撃，事前の測定結果と聞き込みから，牧内地辷りの動きは次のようである．14 日から 15 日に至る夜半に動きがはじまって地割れが発生し，16 日朝頃までは次第に滑動に対する抵抗力が減少しながらも非常にゆっくり動いていた．その後 16 日から 17 日 14 時頃迄は全体として同一抵抗力のもとで (等加速度) すべり，回転のための斜面下方のもり上りも生じた．その後抵抗力が激減して 14 時 5 分の急速な滑落に至ったと考えられる (第 9 図)．急速な滑落は数分間でおわり斜面は回転運動の結果，ほぼ水平になってとまった．頂部にはなめらかな三ケ月形の滑落崖が生じた (第 5 図)．ただちに崖ぞいに小崩壊が続発したが 14 時 40 分頃崖の中央部で大きな崩落があり崖

は第6図，8図でみるように中央部がさらにえぐりとられて後退した形となった．同時に崩落土塊の衝撃と重みによって再び回転運動がはじまり，前面は盛上りつつ，せり出しては崩れ落ちた．崩れおちた土は厚さ数m，幅約 150 m にわたり 10～20 cm/sec 程度の早さで流れ，10 数分間つづいた．この第2回の動きが被害をうけた家屋の多くをたおしたのである．滑落崖下には回転運動によって生じた逆傾斜面にかこまれて凹地が生じ，崖から流下するかっての地下水によって池ができた．18 日，この水は自衛隊によって安全に排水された．

牧内地辷り及びそれ以後に発生した桐窪・西平山の地辷り地点は次のような特徴を持った場所である．

1．この付近は，表層地質的には侵食地域である山地とその麓をおおう堆積地域の扇状地に2大別される．地辷りは例外なく山地の斜面下部におこっている．ここはひん岩～閃緑岩を主とする基盤岩より成り場所によってはその上が数 m 以下のうすい崖錐によって被われている．基盤岩の変質はかなり進み軟化(粘土化)している．これに対し扇状地は，比較的新らしい時期におそらく泥流状物質の堆積によって生じ，その現在の表層部は大小の角礫の間が砂泥の基地でうめれた地層よりなっている．

2．急速な滑落を伴った地辷りは，例外なく地下の横ずれ地震断層の動きによってできたと考えられる地割れ群の分布地域及びその延長上で発生している．地表付近に破壊を伴う変形がおこっていることと地辷りとの密接な関係を示すものであろう．

谷の斜面にあって長く風化作用を受けた細粒閃緑岩あるいはひん岩よりなる基盤岩は，震央地域に広く分布しているが，上記地割れ群発達地帯以外の地域では，同じ地質条件であっても，この種の地辷りは発生しなかった．地辷り地域及び，それに隣接する扇状地堆積物より採取した試料について，小坂および角田は滑落に関係する粘土鉱物の同定に当った．この結果第 3 表に示すように，地辷り地の粘土鉱物にはモンモリロナイトが発見されているのに，扇状地堆積物にはモンモリロナイトがまだ発見されていない．両地域の試料採取地点は，地表からの深さに差があるけれども（第 2 表），両地域成立の地史的な相異を考慮すれば構成粘土鉱物の相異は，地辷り発生地では風化がより深く進行しており，滑落に好都合な状況にあったものと判断される．これまでの，森本及び小坂による今市及び箱根早雲山の地辷り粘土及び崩壊堆積物の研究によれば，モンモリロナイト及び加水ハロイサイトの存在が滑落に関係している．また焼岳の昭和 37 年 6 月 17 日の噴出物の研究において述べたように，モンモリロナイトは，地表のような，酸素の供給の十分な条件のもとでは生成されない．地辷り発生の直前に震度 III 以上の地震はなく，雨も，西平山の地辷り発生までの数日はなかった．

以上の諸事実と，それに基いた筆者らの考察は，つぎのように要約できる．これらの急激な滑落を伴った地辷りの発生した場所には，今回の地震群が起こる以前より，長年月にわたる深層風化によってモンモリロナイト及び加水ハロイサイトなどの粘土鉱物が生じていた．そのような場所の表層部の岩石に，地下の地震断層の動きによって割れ目が生じ，その割れ目を通して，多量の地下水が供給された．上記の粘土鉱物は結晶構造上，供給された地下水を吸収膨潤し，滑落を容易にする状態になったと考えられる．滑落の直接の原因は，多量の地下水の供給であろうが，地下水に上昇の通路を与えたのは，地震断層の動きによって生じた地下の割れ目であろう．

牧内地辷り発生まえまでは，多くの人々の関心が，地震動による被害の発生に注がれて，地辷りに対する注意がほとんど払われなかった．牧内地辷りが発生してからは多くの機関による地辷り調査がいっせいに行われるようになったからそれらの報告は，いづれ発表されるであろう．

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