# 7. *A Study of Landslides.*

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**1. Introduction.** Landslides frequently accompany destructive earthquakes. One of the most conspicuous examples in Japan associated with a destructive earthquake is that which occurred at the time of the Zenkôzi earthquake of 1847, at Iwakurayama (Kokuzôyama), Nagano prefecture. Enormous quantities of earth slid down and filled the valley of the Saigawa (river), damming up the river water with consequent flooding in its upper course, a recent example, although on a greatly reduced scale, being the Tôge landslide of 1932.

When as in the case of the Iwakurayama landslide, the damm was broken at last after 20 days, during last several days of which it was rainy, the water flooded the Zenkôzi plain, a number of houses in the plain being swept away and destroyed.

The destructive earthquakes of Akita in 1914 and of North Idu in 1930 were also accompanied by a number of landslides. People were killed and houses demolished.

Not all landslides however are associated with earthquakes. In many parts of the earth's surface, land is now sliding or creeping, although very slowly. Landslides belonging in this cathegory seem as a rule to be related in some way to precipitations, except for such cases as when the landslide is attributed to the caving in of old mines, as at Ube, in Yamaguti prefecture[1].

Whatever the cause, landslides damage or destroy property and take toll of human lives, so that it is important to study its phenomena scientifically, as so little has yet been done in the matter.

The other names for "landslide" sometimes used are "mud flow", "solifluction", "rockslides"[2], according to their apparent types. Prof. A. Heim[3] tried to distinguish more than 20 different types of landslides. It seems to the author, however, that several of the types distinguished by Heim may be the same phenomena observed under different conditions.

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[1] Landslide of Ube occurred on Sept. 23, 1933.

[2] VANDERWILDT, *Journ. Geol.*, 42 (1934), 163.

[3] A. HEIM, "*Bergsturze und Menschenleben*", (Berlin 1932).

It may be somewhat interesting in this connection to note that, in Japan, such words as "Kue", "Nuke", "Boke", etc., forming parts of the names of certain villages, mean "landslide" or "cave-in". In several region, we notice also in the names of villgaes, "——kubo", "Rondi", "Ronda", etc.,[4] which may indicate some reference to landslides.

**2. Landslides on topographical maps.** To investigate the geographical distribution of landslides we use topographical maps of 1/50000 scale. It is however not easy to find traces of landslides on these maps. Some form of indication is needed. In this connection, Mr. H. Honma[5] pointed out that the configuration of the contour lines have certain characteristics in regions of landslides, as shown in Figs. 1a, 1b. Profiles of landslides are generally characterized by a cliff with a gentle but irregular slope, as in the case pointed out in our previous report.[6] But such characteristics in the configurations of contour lines due to landslides may not always be noticeable in 1/50000 topographical maps. Areas that have been disturbed by landslides are rarely so large that their irregular contour lines can be noticed in 1/50000 topographical maps. In maps of this scale a characteristic in the configurations of the contour lines is noticeable only if the horizontal dimensions of the area of the landslide exceed half a kilometre, with considerable vertical displacement.

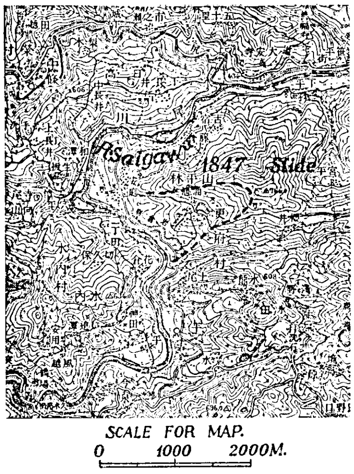

Fig. 1a. Characteristic feature of contour lines in the area of landslide.

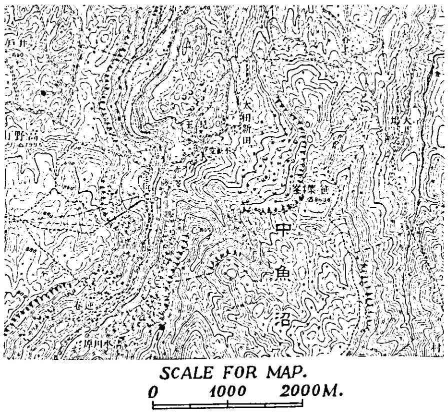

Fig. 1b. Characteristic feature of the contour lines in the area of the landslide.

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[4] K. NAKAMURA, *Tirigaku-Hyôron*, 8 (1932), 848, (in Japanese).
T. TERADA and N. MIYABE, *Bull. Earthq. Res. Inst.*, 10 (1932), 192, (in Japanese).

[5] H. HONMA, *Tuti-to-Midu Iinkwai Hôkoku*, No. 4 (1930), 13~21, (in Japanese).

[6] T. TERADA and N. MIYABE, *loc. cit.*

We also notice in topographical maps that marks, as shown in Fig. 2, represent cliffs. Some of these cliffs are undoubtedly landslides, but, others may have been formed by washing away of the superficial covering by precipitations, exposing the steep base rock.

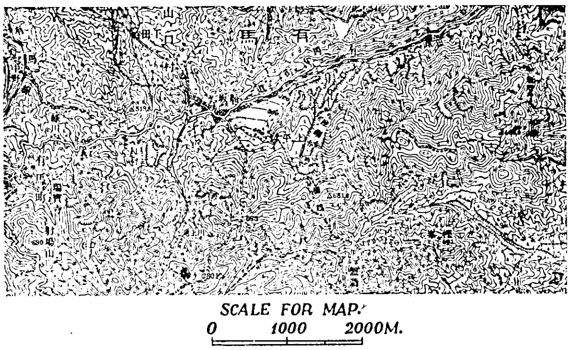

Fig. 2. Marks of cliffs, representing landslides.

The actual areas of landslides therefore cannot be determined from map study alone. To measure the areas of landslides, nothing surpasses actual field observation, but their large number renders it impossible to observe them all in the field. In the present investigation, therefore, the distribution of landslides is studied by means of the marks (see Fig. 2) in 1/50000 topographical maps.

### 3. Geographical distribution of traces of landslides.

Several examples of the distribution of cliffs, typical of which will be found in Fig. 2, are shown in Figs. 3, 4.

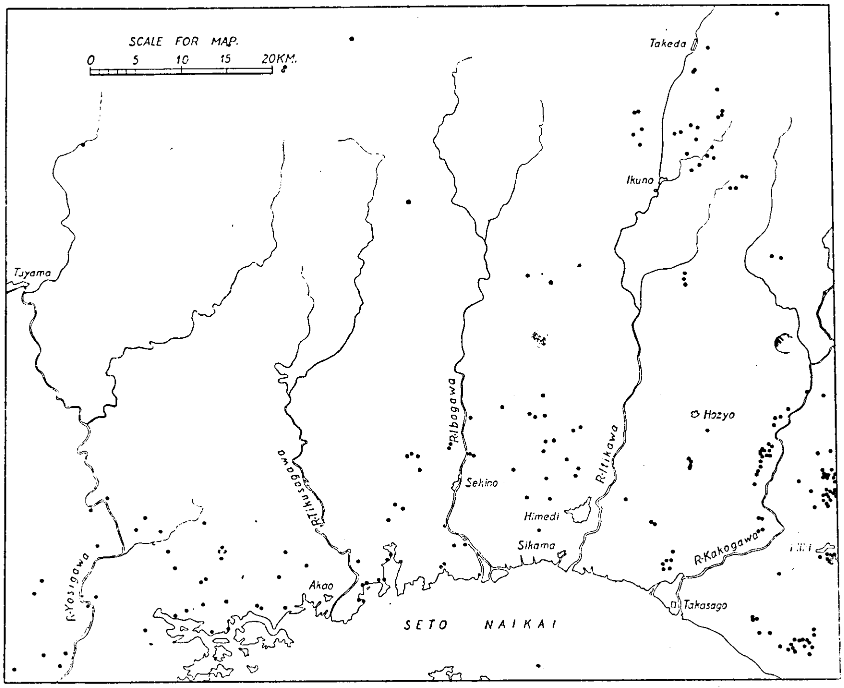

Fig. 3. Distribution of marks of landslides in the neighbourhood of Himedi.

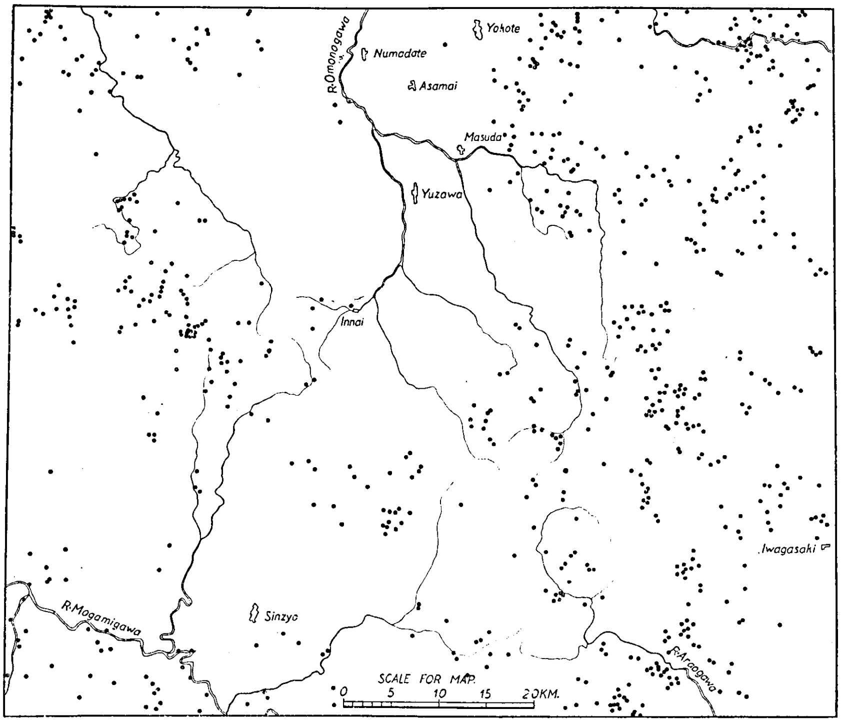

Fig. 4. Distribution of marks of landslides in the neighbourhood of boundaries of Akita, Yamagata and Iwate prefectures.

The following facts are elicited from these figures:

(i) Geographical distribution points to certain regions or zones of landslides.

(ii) Not all landslides occur in regions of steepest slope.

(iii) Not always are geological faults associated with zones of landslides.

(iv) Landslides sometimes seem to be restricted to regions of particular rocks, which however may differ with the locality.

In the distribution of landslides in Sikoku, Prof. Terada has pointed out[7] that landslides depend not only on meteorological causes and the mechanical properties of the rocks forming the surface layers of the regions, but also on movements of the earth's crust. The facts just referred to (elicited from the figures) do not seem to contradict Prof. Terada's statements.

The presence of a number of shallow ponds is also a notable feature of regions of landslides. These shallow ponds were no doubt formed as the result of irregular deformation of or of damming up streams by the earth mass that slipped down, the same as the hollows known as "——

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7) T. Terada, Read at April, 1930, Colloquium of the Institute, but not yet published.

kubo", referred to in a previous paper[8]. Examples of these ponds are found in regions of landslides in the neighbourhood of Hirosima, Gozyô

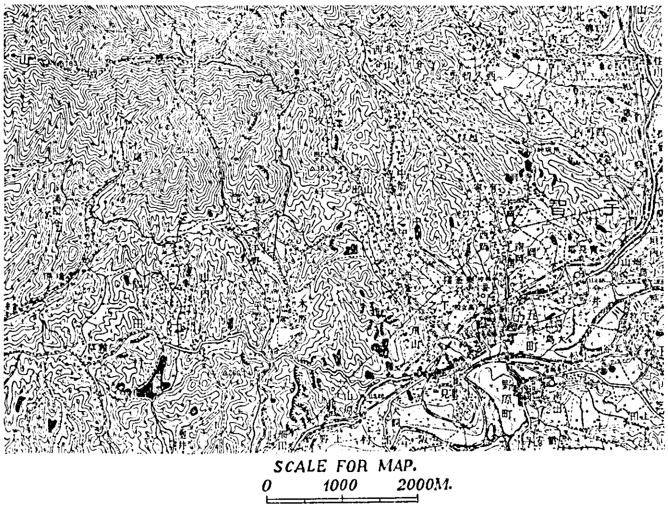

Fig. 5. Distribution of small ponds in association with landslides.

Fig. 6. Distribution of small ponds in association with landslides.

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[8] T. TERADA and N. MIYABE, *loc. cit.*

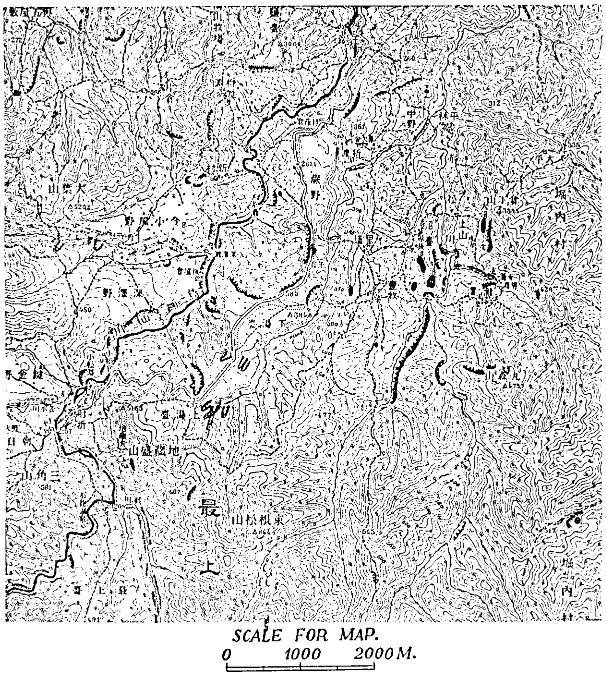

Fig. 7. Distribution of small ponds in association with the landslides.

(Wakayama Pref.), etc. (Figs. 5~7).

### 4. Geographical distribution of recent landslides.

In the preceding paragraph, landslides not shown by marks denoting cliffs in the maps were excluded. Many landslides however are not marked in topographical maps. These may belong in either of the following two groups:

i) Old landslides that cannot be represented by simple marks, or in which the characteristic features of the contour lines cannot be recognized owing to obliteration of all topographical features.

ii) Recent landslides not yet marked in topographical maps.

As to the former group no reference to it is possible here in the absence of any account of them excepting the studies of geologists.

The landslides belonging in the latter group are reported in the newspapers. The localities of landslides with areas exceeding 10000 square metres, collected from newspapers reports during 1931~1933, are given in Table I.

It will be seen from this table that, so far as reported, recent landslides have been most frequent in the prefectures of Nagano and Niigata.

In Fig. 8, the geographical distribution of these recent landslides is shown, together with those of marks of landslides referred

Table I.

| No. | Locality<br>Prefecture, County, Village | Date | Extent |
|---|---|---|---|
| 1 | Niigata, Higasi-Kubiki, Hisisato, Busuno | 1931 Apr. 5 | $5\times10^4$ m$^2$ |
| 2 | 〃 , 〃 , 〃 | 〃 8 | 9·9 |
| 3 | 〃 , 〃 , 〃 , Kamibuna | 〃 〃 | 5 |
| 4 | 〃 , 〃 , Osima, Syôbu | 〃 〃 | 2·6 |
| 5 | 〃 , 〃 , Hisisato, Maogi | 〃 11 | 2 |
| 6 | 〃 , , Koide-mati | 〃 16 | — |
| | Siduoka, ———, Kobutano-yama | 〃 21 | — |
| | Toyama, Higasi-Tonami, Higasi-Yamami | 〃 25 | 1 |
| | Siduoka, Takata, Itô | 〃 24 | 3 |
| 7 | Niigata, Higasi-Kubiki, Matudai, Aizawa | 〃 16 | 1 |
| 8 | 〃 , 〃 , Urata, Kurokura | May 1 | 5 |
| | Siduoka, Iwata, Kômyô, Huneaki | 〃 2 | — |
| | Tiba, ———, Kiyosumi-yama | 〃 3 | 1 |
| 9 | Niigata, Nisi-Kubiki, Nôdani, Maseguti | June 4 | 5 |
| | Toyama. , Yamakadumi, Tôhukuzino | 〃 9 | 1 |
| | Saga, Kisima, Yamaguti, Nisi-ku | 〃 20 | 10 |
| 10 | Niigata, Higasi-Kubiki, Matudai, Aizawa | July 11 | — |
| 11 | Nagano, Kami-Minuti, Odagiri, Yamada | 〃 23 | 1·5 |
| 12 | 〃 , 〃 , Nisi-Mamabe | 〃 23 | 9·5 |
| 13 | 〃 , Tiisagata, Kanau, Kamamurata | 〃 24 | (300 m. in length) |
| | Hyôgo, Akasi, Tarumi, Nadami | 〃 29 | 1 |
| 15 | Nagano, Kita-Azumi, Nakatuti | Aug. 4 | 2 |
| 14 | Niigata, Nisi-Kubiki. Kanaya, Nakanomata | 〃 3 | — |
| | Osaka, Minami-Kôti, Kokubu | Oct. 12 | 1 |
| | Saitama, Titibu, Otaki, Otigawa | 〃 4 | 4 |
| | Osaka, Naka-Kôti, Katagami, Tôge | Oct. — | 100 |
| | Isikawa, Suzu, Saikai, Sasanami | Dec. 20 | 5 |
| 16 | Nagano, Kita-Azumi, Nakatuti | 1933 Mar. 17 | 12 |
| | Yamagata, Mogami, Araki, Osawa | Apr. 11 | 2 |
| 17 | Niigata, Naka-Onuma, Tazawa, Togura | 〃 9 | 50 |
| 18 | 〃 , Higasi-Kubiki, Yamahira | 〃 14 | 5 |
| | Wakayama, Nisi-Muro, Inaki | 〃 24 | (60 m. depress.<br>1000 m. upheaval) |
| 19 | Niigata, Naka-Kubiki, Miduhara, Ozawa | 〃 29 | 22 |
| | Nagano, Sarasina, Akesina | June 9 | — |
| | Hukusima, Iwaki, Ono, Yagyû | July 5 | (1400 m. depress.) |

*(to be continued.)*

Table I. (*continued.*)

| No. | Locality<br>Prefecture, County, Village | Date | Extent |
|---|---|---|---|
| 20 | Niigata, Higasi-Kubiki, Osima, Syôbu | July 9 | $1{\cdot}1\times10^4\,\mathrm{m}^2$ |
| 22 | Nagano, ———, Simosuwa, Tomibe | 〃 11 | (100 m.) |
| 21 | Nagano, Higasi-Sarasina, Nobusato, Yamabuse | 〃 10 | 5 |
|  | Ibaraki, Nisi-Ibaraki, Minami-Yamaguti | 〃 16 | 2·1 |
|  | Toyama, ———, Kurobe valley | 〃 19 | 20 |
|  | Nagano, Higasi-Sarasina, Kôhu | Oct. 2 | 0·5 |
| 23 | Niigata, Nisi-Kubiki, Kinoura | Nov. 19 | 10 |
| 24 | 〃 , 〃 , 〃 | 〃 21 | 4 |
|  | Isikawa, Kasima, Kita-Otani | 〃 24 | 2 |
|  |  | Dec. 2 |  |
| 26 | Niigata, Nisi-Kubiki, Saikai, Maki | 〃 17 | 3 |
| 27 | Nagano, Kita-Azumi, Nakatuti | 1933 Jan. 14 | 3 |
|  | Kyôto, ———, on the Miyadu-wan | Feb. 2 | (90 m. crack) |
|  | Nara, Yosino, Totugawa | Mar. 18 | 1·8 |
| 28 | Niigata, Higasi-Kubiki, Oguro | Apr. 4 | (150 m. crack) |
| 29 | Nagauo, Kita-Azumi, Aizome | 〃 6 | 3 |
| 30 | Niigata, Naka-Kubiki, Miduhara | 〃 9 | 10 |
| 31 | 〃 , Higasi-Kubiki, Yasuduka | 〃 9 | 0·3 |
|  | Isikawa<br>Toyama }, ———, Ameda pass. | 〃 10 | 1 |
|  | Tottori, Iwami, Gamô, Arai | 〃 20 | 50 |
| 32 | Nagano, Kita-Azumi, Kita-Koya | 〃 14 | 1 |
|  | Toyama, Simo-Sinkawa, Higasi-Huse | 〃 18 | 5 |
| 33 | Niigata, Higasi-Kubiki, Hisisato | May 4 | 8 |
|  | Nara, ———, Nara Park | July 21 | (100 m. crack) |
|  | Toyama, Simo-Sinkawa, Katakaiya | Aug. 1 | 6 |
|  | 〃 , Higasi-Tonami, Riga | 〃 20 | 5 |
|  | Nagano, Tikuma, Hadamura | 〃 6 | — |
|  | Yamaguti, ———, Ube, Hudiyama | Sept. 23 | 100 |
| 34 | Nagano, Kita-Azumi, Nakatuti | Dec. 30 | 1·1 |

to in the preceding paragraph, and from which it is interesting to note that the zones of recent landslides differ considerably from those of the old, the reason for which is not apparent; all that we can do being to speculate that the zones of active landslides may have migrateed.

The frequency of landslides in Nagano and Niigata prefectures

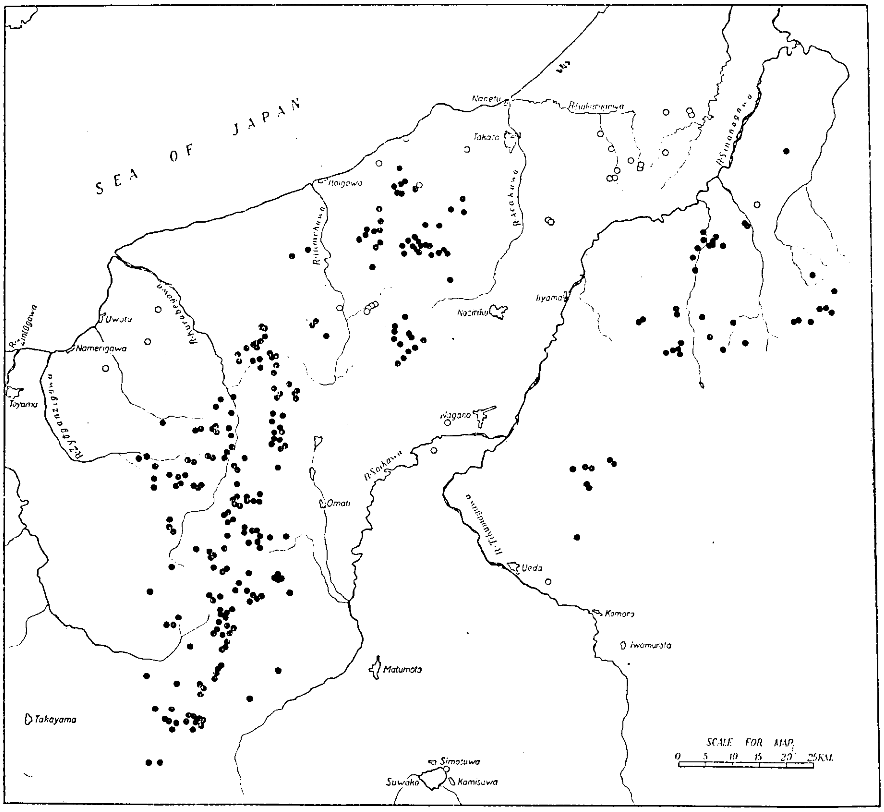

Fig. 8. Distribution of recent landslides (denoted by ○) and that of the marks of cliffs in the prefectures of Niigata, Nagano and Toyama.

seem to be related to some way to the geological structure of these districts, which are said to be in the zone of compression[9]. In the zone of tension, that is, in the Kwantô districts and those along the northern Pacific, earthquakes are frequent.

As already stated, a number of geologists have studied the phenomena of landslides, the localities of which are shown in Fig. 9, and the literatures given in Table II.[10]

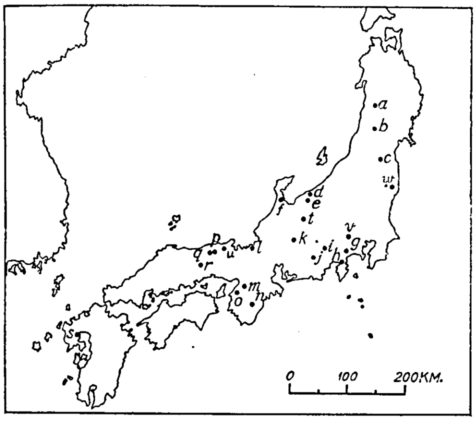

Fig. 9. Distribution of the landslides reported by the geologists.

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[9] T. Tokuda, *Tiriguku-Hyôron*, 1 (1925), 341, (in Japanese).

[10] Much of these literatures are collected in the resume:—"Abstracts of literatures on landslides", N. Miyabe, (Tokyo 1932), (in Japanese).

Table II. References of Landslides.

| No. | Date | Locality | N.B. | Author. | Reference. |
|---|---|---|---|---|---|
| a.) | 1914 | Akita pref., (on the bank of the Omonogawa) | Eqk. | A. Imamura | Rep. Imp. Earthq. Inv. Comm., 82 |
| | | | | Y. Aomi | 〃 |
| | | | | R. Ohasi | 〃 |
| | | Yamagata pref., Araki-mura | | —— | Kisyô-Yôran, 1932, IV. |
| b.) | 1932 | Hukusima pref., Handa Mine | — | K. Jimbo | Rep. Imp. Earthq. Inv. Comm., 49 |
| c.) | 1987- | | — | E. Tamura | 〃 38 |
| | | | | K. Inoue | Tisitugaku-Zassi, No. 89 |
| | | | | K. Jimbo | 〃 10 |
| | | | | T. Ogawa | Tigaku-Zassi, No. 159 |
| | | | | H. Inouye<br>D. Satô | 〃 〃 〃 |
| | | | | 〃 | 〃 〃 No. 160 |
| d.) | 1918<br>1933 | Niigata pref., Tutuisi | — | K. Nakamura | Tisitugaku-Zassi, 36 |
| | | | | I. J. R. | Tetsudô Saigai Kizi (1918) |
| e.) | — | Several landslides in Niigata pref. | | K. Nakamura | "Yamakudure" |
| f.) | 1892- | Isikawa pref., Kue-mura | — | J. Ohikata | Rep. Imp. Earthq. Inv. Comm.. 49 |
| g.) | 1923 | Kanagawa pref., Hatano | Eqk. | N. Yamasaki | Rep. Imp. Earthq. Inv. Comm., 100 |
| | | | | T. Terada<br>N. Miyabe | Bull. Earthq. Res. Inst. 10 |
| h.) | 1930 | Siduoka pref., Omi-mura | Eqk. | —— | Kensin-Zihô, Vol. 5. No. 1 |
| i.) | 1898 | Yamanasi pref., Gokai-mura | — | K. Jimbo | Rep. Imp. Earthq. Inv. Comm., 38 |
| | | Siduoka pref., Kanaya tunnel | — | 〃 | 〃 〃 |
| j.) | 1912 | Siduoka pref., along the Tenryûgawa | — | T. Wakamidu | Tigaku-Zassi, 24 |
| k.) | 1904<br>1932 | Gihu pref, Tozawa | — | T. Kamiya | Tikyû, 19 |
| l.) | 1898 | Hukui pref., Utiura-mura | — | T. Iki | Rep. Imp. Earthq. Inv. Comm, 21 |
| m.) | 1932 | Osaka pref., Katagami-mura | — | M. Matuyama | Tikyû, 17 |
| | | | | A. Takata | Doboku Sikenzyo Hôkoku |
| | | | | K. Nasu | Bull. Earthq. Res. Inst. 10 |
| | | | | N. Miyabe | 〃 〃 |
| n.) | | Wakayama pref., Totugawa | — | Cf.T.Wakimidu | Tigaku-Zassi 24 |
| o.) | 1932 | Wakayama pref., Higasi Nogami | — | F. Kishinouye | Bull. Earthq, Res. Inst. 11 |
| p.) | 1897<br>1922 | Hyôgo pref., Teragi-mura | — | H. Okada | Rep. Imp. Earthq. Inv. Comm., 38 |
| | | | | K. Tanahasi | Umi to Sora |
| | | | | M. Matuyama | Tikyû, 17 |
| q.) | 1933 | Tottori pref., Gamô-mura | — | M. Katuya | Sinrin-Tisui Kisyô Ihô, 14 |
| r.) | 1907 | Okayama pref., Nariho-mati | — | T. Tyûsa | Tisitugaku-Zassi, 40 |
| s.) | 1913-<br>193 | Nagasaki pref., | — | —— | Bull. Geotech. Comm., Vol. 2. |

*(to be continued.)*

Table II. (*continued.*)

| No. | Date | Locality | N.B. | Author. | Reference. |
|---|---|---|---|---|---|
| t.) | 1912 | Nagano pref., Hiyeda-yama | — | M. Yokoyama | Tigaku-Zassi, 24 |
| u.) | 1903 | Hyôgo pref., Okusatu-mura | — | J. Ohikata | Rep. Imp. Earthq. Inv. Comm., 47 |
| v.) | 1970 | Tokyo pref., Hibara-mura | — | Y. Otuki | Tigaku-Zassi, 19 |
| w.) | 1921 | Hukusima pref., Taira Colliery | — | S. Tokunaga | Tisitugaku-Zassi, 28 |

There are two cases of landslides in Karahuto (Sagharene) reported by H. Saitô, though they are not shown in the map of Fig. 9.

## 5. Factors governing the occurrence of landslides: Descriptions of landslides.

There are many factors governing the occurrence of landslides, as revealed by a number of investigations and observations. From these data we can distinguish several common characteristic in the phenomena. Some authors have tried to classify landslides into groups, according to types as exhibited in their manner of sliding, or to the physical character of the earth's crust of the region, or to the direct or indirect causes of the landslide, etc.[11]

As to the phenomena of landslides, the following points may be enumerated, a number of which of course have already been noticed by earlier investigators:

(a) While some landslides move with great velocity others do so very slowly. Attempts have been made to classify them according to these velocities, which however is very difficult, owing to the wide range through which their speeds vary as shown in the following Table III.

Table III. Velocities of Landslides.

| Locality | Velocity | Observer |
|---|---|---|
| Karahuto, Kurasi (West coast) | 10 m./day. | H. Saitô |
| Karahuto, Siritori (East coast) | 40~25 cm./day. | H. Saitô |
| Hyôgo pref., Teragi-mura | 27~25 cm./year. | M. Matuyama<br>I. G. R. |
| Kagosima pref. Yosimatu | 300~10 cm./day. | N. Nasu<br>M. Matuyama |
| Osaka pref. Katagami-mura | 3 cm./day. (max.) | (Rep. by J. Ohikata) |
| Isikawa pref. Kue-mura | 30 m./hour. (max.) | |
| Kirchenstock, Switzerland (I) | 3~1 cm./month. | A. Heim. |
| (II) | 100~10 cm./month. | |

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[11] A. Heim, *loc. cit.*
T. Wakimidu. *Tigaku-Zassi*, 24 (1912), 379, 379, (in Japanese).
K. Jimbo, *Rep. Imp. Earthq. Inv. Comm.*, 98 (1902), (in Japanese).
K. Watanabe, "*Doboku-Tisitugaku*", (Tokyo 1928).
K. Nakamura, "*Yamakudure*", (Tokyo 1934).

It may also be noticed that, as in the case of the Tôge landslide in Osaka[12], the velocities of sliding fluctuate with the quantity of precipitation.

(b) As already stated, the character of the rocks composing the surface of the earth seem to be related to landslides. Investigations so far show that the rocks in regions of frequent landslides are chiefly shales, especially sandy shales, agglomerates, and andesites, as will be seen from the following Table IV.

Table IV. Rocks Composing the Surface Layers in the Region where the Landslides occurred.

| No. | Locality | Rock | N.B. |
|---|---|---|---|
| a) | Akita pref. Senpoku | Sandy Shales. | W. |
| c) | Hukusima pref. Hand Mine. | Agglomerate, Shale, Sandstone etc. | |
| d) | Niigata pref. Tutuisi | Shale. | W. |
| f) | Isikwaa pref. Kue | Mudstone, Sandstone (Tertiary).<br>Fragments of Schists and Granite. | W. |
| i) | Yamanasi pref. Gokai-mura | Agglomerates, Shales. | |
| | Siduoka pref. Kanaya tunnel | Shale<br>Sandstone | |
| j) | Siduoka pref. along the Tenryûgawa | Clay Slate, Slate.<br>Black Mudstone. | |
| k) | Gihu pref. Tozawa | Sand, Gravel, Clay, | W. |
| l) | Hukui pref. Utiura-mura | Sandstone, Mudslate etc.<br>Andesite, Gabbro, Conglomerate etc. | |
| m) | Osaka pref. Katagami-mura. | Andesites | W. |
| p) | Hyôgo pref. Teragi-mura | (Diluvium) | |
| r) | Okayama pref. Nariha | (Triasic)<br>Shale | W. |
| t) | Nagano pref. Hiyeda-yama | Andesites etc. | W. |
| u) | Hyôgo pref. Okusatu-mura | Andesites. | |
| v) | Tôkyô pref. Hibara-mura | Mudstone. | |
| — | Several landslides in Karahuto. | Sandy Shale, (Tertiary)<br>Sandstone, Shale. | |

The mark "W" in the column of "N.B." denotes that the rocks are decomposed by weatherings.

(c) Although the classification of landslides according to their apparent types is, as already stated, not so easy as according to differences in their velocities, it is possible to distinguish several different types of landslides in extreme cases. These types are

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[12] A. TAKATA, *Doboku-Sikenzyo Hôkoku*, No. 23 (1932), (in Japanese).
N. NASU, *Bull. Earthq. Res. Inst.*, **10** (1932), 694, (in Japanese).
M. MATUYAMA, *Tikyû*, **17** (1932), 323, (in Japanese).

(i) Slides of superficial layers of the earth's crust.

(ii) Streams or flows of masses of earth or rock fragments.

(iii) Relatively slow movements of fairly large masses of earth, generally bounded by zones of cracks.

(iv) Fall of great masses of rock fragments.

Of these types of landslides, the last three seem to show the same mechanism in their movements, and Type (ii) is generally associated with Type (iii). The landslide at Tôzaki, near Tutuisi, Niigata prefecture, is a typical example of Type (iii), while that at Tyausuyama, near Nagano, exemplifies Type (iii) associated with Type (ii).

In the case of the Tôzaki landslide, cracks were formed as shown in Fig. 10, reproduced from Nakamura's book[13]. It will be seen that there is a

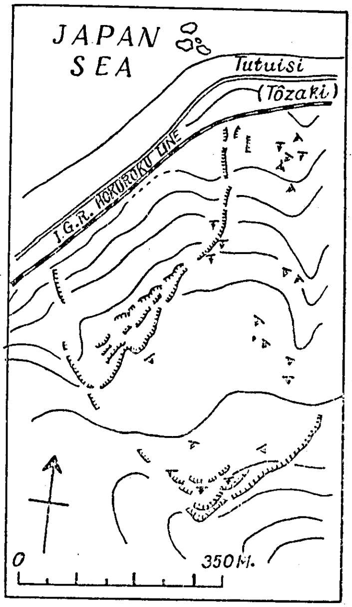

Fig. 10. Distribution of cracks in the Tôsaki landslide (reproduced from Nakamura's book.)

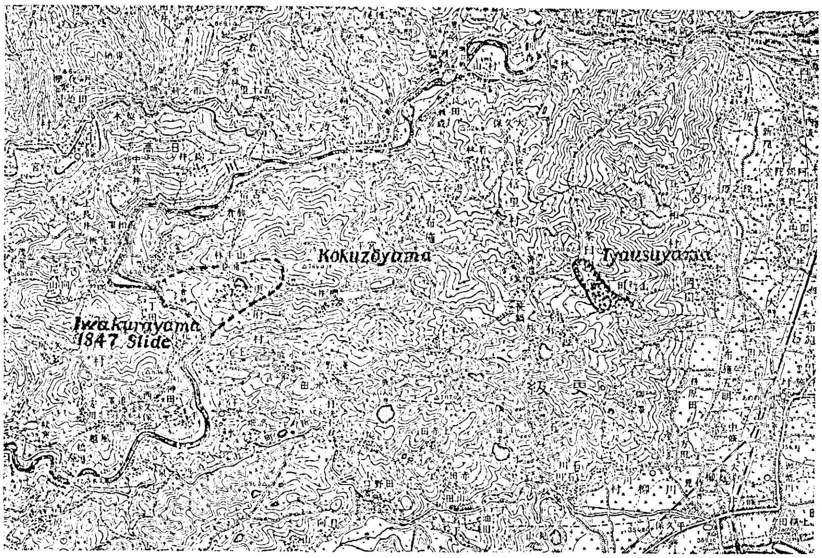

Fig. 11. Map showing the topographical features in the neighbourhood of the Tyausuyama lendslide.

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[13] K. NAKAMURA, *loc. cit.* "Yamakudure",

relatively undisturbed area, surrounded by zones of cracks. It may also be noticed that the undisturbed area is on the whole tilted southward, that is, in the opposite direction to that of sliding. A similar configuration of zones of cracks was also witnessed in the case of Tôge landslide[14].

The topography of the neighbourhood of the Tyausuyama landslide is shown in Fig. 11. The mud flow in the lower part of this landslide is shown in Fig. 12. In the upper part of the landslide, however, we find a block of the surface crust tilted, with zones of cracks of configurations similar to those mentioned above in connection with Type (ii).

Fig. 13 shows the profile of the Tyausuyama landslide schematically. As the part of the earth's surface that is represented by the hachured area in this figure slips down, a cliff is formed at A, and the sliding block is tilted backward against the direction of slip. At the lower end of the sliding block, B, cracks are formed as in the case of the Tôzaki landslide. In this zone, the surface crust is greatly deformed, in consequence of which fragments of rocks and small earth masses are formed, the whole sliding down the slope either as a mud flow or as a rock flow. The velocity of the mud flow or rock flow thus formed may be increased, should considerable quantities of water be mixed as the result of precipitations, since the water added to the mud flow may diminish the friction between the mud particles. In landslide of such type, the surface of slip seems to be, as shown in Fig. 13, nearly spherical, as would be expected from the theory of soil mechanics[15].

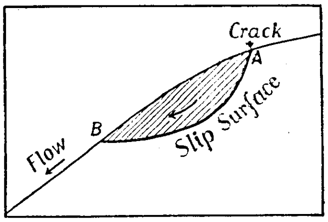

Fig. 13. Schematical profile of the landslide.

Landslides of this type are those of Tôge in Osaka prefecture, of Tôzaki in Niigata prefecture, of Tyausuyama in Nagano prefecture ; and although I have not personally observed them, those of Teragi-mura in Hyôgo prefecture, Kue-mura in Isikawa prefecture, the Gamô-mura in Tottori prefecture, etc.

Landslides of type (i) may differ slightly from those just mentioned in their mechanism of occurrence. The cause here may be loosening of connection between the thin surface layer and the bed rock, since the water held in the boundary layers on the surface.

If the rocks composing the surface crust in a region of considerable steepness are hard, landslides occurring in such a region may belong to Type (iv). The harder rocks composing the region may first be broken

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[14] A. TAKATA, *loc. cit.*, etc.

[15] REDLICH, TERZAGHI, KAMPE. "Ingeniur Geologie", (Berlin 1932),. S. 430.

into small pieces by fissures and joints developing in the rock mass. When such a region is exposed to heavy rain or earthquake, or suffers from some other triggar action, the internal friction is diminished, so that it cannot retain the original form of the slope, resulting in pieces of rock falling down in flows with considerable velocity, forming a cliff at the top of the disturbed area. The mud flow of Nebukawa at the time of the Kwantô earthquake of 1923[16], the Totugawa landslide[17] and several landslides in the Alps[18], may belong to this Type, iv.

Often in landslide of types ii) and iv), mud and rock flows damup valleys, forming ponds or small lakes. Examples are the Hatano landslide[19] associated with the Kwantô earthquake, and several others associated with the Akita earthquake of 1914.

In landslides of type iii), the block of earth that slips along the slip surface deforms considerably, loosening the earth and exposing a larger surface to erosion. The irregular contours and, sometimes, shallow ponds in regions of landslides are formed in this way.

(d) Landslides are closely related to the amount of precipitation, as will be discussed in detail later.

(e) In the case of some landslides, explosive shocks are felt and loud noises heard in the neighbourhood.

In the rockslide at Durango, Colorado, U.S.A., explosive shocks are reported to have been felt in the neighbourhood[20]. Similar noises were also reported to have been heard at the time of the Hiedayama landslide of 1905[21]. Such noises or shocks are supposed to have been produced by the crushing of rocks under the ground, In the case of Kue landslide[22], crunching, grinding noises were heard as the earth mass slid down, believed to have been caused by the crushing of the rock and the earth mass.

It may also be worthy of note that the topographical feature of the northern part of Bandaisan volcano which lost the northern half of its cone as the result of the 1888 explosion, closely resembles that of a landslide. The cones of several volcanoes exhibit features similar to that formed by landslides.

(f) In several landslides the odour of sulfur has been noticed as also flashes of light. The sulfur odour may in most cases be a psycho-

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16) T. Matuzawa, *Rep. Imp. Earthq. Inv. Comm.*, 100 B (1925), (in Japanese).

17) Cf. T. Wakimidu, *Tigaku-Zassi*, 24 (1912), 379, (in Japanese).

18) A. Heim, *loc. cit.*

19) T. Terada and N. Miyabe, *loc. cit.*

20) Vanderwildt, *loc. cit.*

21) M. Yokoyama, *Tigaku-Zassi*, 24 (1912), 609, (in Japanese).

22) J. Ohikata, *Rep. Imp. Earthq. Inv. Comm.*, 49 (1904), (in Japanese).

logical illusion or it may be due to pulverization of sulfides.[23]

The origin of light flashes seen at times of landslides is not yet understood. Many geologists[24] think it is due to frictional electricity as the rocks grind against each other when they flow down. Lights in association with landslides were reported to have been observed at the time of the North Idu earthquake of 1930[25].

**6. Correlation between landslides and precipitations.** As already stated, a number of landslides occurred in Niigata prefecture in the years, 1930～1933. We shall now compare the frequencies of these landslides with the quantity of precipitation for the corresponding period, the result being quite similar to those already obtained by K. Nakamura[26].

The annual distribution of the frequency of these landslides during 1930～1933, which is given in Fig. 14, shows that in Nagano and Niigata prefectures landslides occur most frequently in April, while there is another maximum of frequency in July. Upon comparison with the curve showing the annual variation in precipitations in Fig. 15, the second maximum landslide frequency in July suggests some relation to the heavy summer rains.

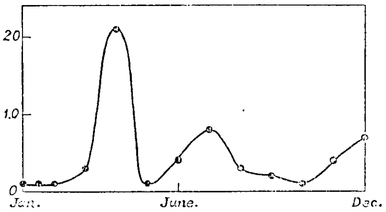

Fig. 14. Annual variation in frequency of landslides (1931-1933).

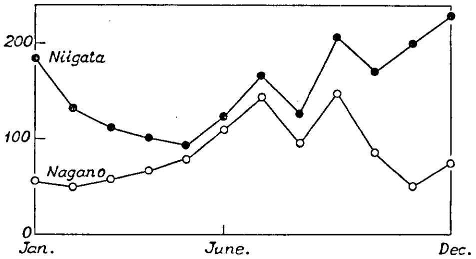

Fig. 15. Annual variation in monthly mean precipitations at Nagano and Niigata.

In Fig. 16, are shown the daily values of precipitation during January 1931～December 1933, together with marks denoting the occurrence of landslides. Fig. 16 shows several cases of landslides having been preceded by heavy rains. It must, of course, be remarked that the values of the precipitation are those observed in the cities of Nagano, Takata, and Niigata, so that they may not represent the actual amounts of precipitation in the regions where the landslides occurred, although these stations lie very close to them. Of landslides accompanying heavy rains, those that occurred in Higasi-Kubiki Gun, etc, that is, the

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[23] VANDERWILDT, *loc. cit.*

[24] A. HEIM, *loc. cit.*

[25] K. MUSYA, "*Luminous phenomena accompanying the destructive earthquakes,*" (Tokyo 1931).

[26] K. NAKAMURA, "*Yamakudure*", *loc. cit.*

eastern region of the district under consideration, are generally associated with precipitation maxima at Niigata and Takata or Niigata, Takata, and Nagano, while those that occurred in Nisi-Kubiki Gun, in Niigata prefecture and Nagano prefecture, that is, in the western region, are associated with the precipitation maxima at Takata and Nagano or Nagano alone.

Landslides that occurred in March April and May are generally not connected with the heavy rains. These landslides may be, as mentioned already, caused by the melting of the snow accumulated during the preceding winter.

Landslides have also occurred some time after the atmospheric temperature rose several degrees above freezing point[27].

If the heat that melts the snow is supplied by conduction alone, the quantity of snow melted in unit time per unite area will is estimated roughly by

$$s\rho v = \lambda(\theta - \theta_0),$$

$$\text{or} \quad \rho v = \frac{\lambda}{s}(\theta - \theta_0),$$

where $(\theta - \theta_0)$ is the temperature difference between the snow and the surroundings, $\lambda$ the conductivity, $s$ the specific heat of the melted snow and pv the melted mass of the snow. Should radiation be an important factor in the supply of heat, another term, which is a function of $T$, should be added. The quantity of the melted snow during $t_2 - t_1$ is therefore nearly

$$\int_{t_1}^{t_2} \frac{\lambda}{s}(\theta - \theta_0)dt \doteqdot \frac{\lambda}{s}(\theta - \theta_0)(t_2 - t_1).$$

Taking $0{\cdot}5 \times 10^{-3}$ and 80 cal. for the numerical values of $\lambda$ and $s$ respectively, the quantity of melted snow for a temperature difference of 10 degrees and a duration of 1000 hours is estimated to be 2200 g., which corresponds to a precipitation of 22000 mm. approximately.

**7. Physical considerations on the factors connected with landslides.** From the preceding paragraphs, we can select the following factors as being the most effective in activating or initiating landslides.

(i) Destructive earthquakes,

(ii) Water, rain and melted snow.

The physical properties of the rocks composing the surface layers of the earth may also conduce to the occurrence of landslides, as is suggested by the fact that landslides frequently occur in regions of shales and andesites.

In landslide of type (iii), cited in the preceding paragraph, resistance to slip is given by

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[27] K. NAKAMURA, *Tisitugaku-Zassi*, **37** (1930), 411, (in Japanese).

$$\mu N+K,$$[28]

where $\mu$ is the coefficient of friction, $N$ the normal component of the weight of the slipping mass, $K$ the cohesion along the slip surface. No landslide can occur when the pull of gravity does not exceed the resistance by the above expression.

The distribution of stress under the action of gravity, in the surface layer of earth may not be uniform, owing to irregularities in its surface features. The mode of stress distribution determines the slip surface, or, as a two-dimensional problem, the slip line, the differential equation of which is given by

$$\frac{dy}{dx}=-\frac{2\tau}{\sigma_x-\sigma_y}\left\{1\pm\sqrt{1+\frac{(\sigma_x-\sigma_y)^2}{4\tau^2}}\right\},$$[29]

where $\sigma_x$, $\sigma_y$, $\tau$ are the stress components given as functions of the coordinates $x$ and $y$.

Since the pull causing the landslide may be gravity, the factors, enumerated above as responsible for the landslides, may act to reduce the resistance, that is, to reduce the values of $\mu$ and $K$.

We first consider the effect of earthquakes. The effect of earthquake waves on the earth's crust may consist of two components; the one in which earthquake vibration may reduce the effective value of $\mu$ along the slip surface, the other in which earthquake waves may exert stresses on the surface layer of the earth and break it. The stresses exerted by earthquake waves causing landslides may act in two different ways; one of which is due to variation in direction of the effective gravitational force by a small angle $\theta$, which is connected with the intensity of the earthquake $K$ by the relation

$$\theta=\tan^{-1}K.$$[30]

In this case, the resisting force to breaking is reduced to

$$(1-k_v)$$

times that in the case of statical state. If this reduction in resisting force were sufficient, the pull due to gravity will cause a landslide.

On the other hand, earthquake waves may as they are propagated in the earth's interior, exert stresses on the surface layer of its crust. As to deep focus earthquake, Mr. H. Kawasumi[31] calculated the stress due to earthquake waves in the neighbourhood of the origin to be of the order of $10^9$ c. g. s., which exceeds the order of magnitude of the breaking stress of the rocks composing the earth's crust, which is

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[28] A. Krey, "*Erddruck, Erdwiderstand etc.*", (Berlin 1928).

[29] C.f. Z. Anzô, *Mem. Kyûsyû Imp. Univ.*, **7** (1933), 89.

[30] N. Mononobe, "*Doboku Taisin-Gaku,*" (Tokyo 1930), etc.

[31] H. Kawasumi, *Disin*, **4** (1932), 693, (in Japanese).

assumed to be of the order of $10^7 \sim 10^8$ c.g.s. In the surface layer however the breaking stress may be smaller in order of magnitude compared with that of the interior of the earth's crust. Hence stresses of smaller magnitude are sufficient to break the surface layers.

It may be remarked that in addition to stresses due to earthquake waves, are chronic deformations of the earth's crust, as were found in association with the Kwantô and other earthquakes, and which may cause breaking of the surface layers.

Let the components of displacments of a point be $u$, $v$ and $w$ as found by precise geodetic method. Then the components of stress are given in the form

$$\widehat{xx} = \lambda\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right) + 2\mu\frac{\partial u}{\partial x}, \quad \text{etc.,}$$

$$\widehat{yz} = \mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right), \quad \text{etc.,}$$

where $\lambda$ and $\mu$ are elastic constants of the earth's crust. Of these components of displacement gradients, we have data measured at the surface for several districts, except for those of $\frac{\partial w}{\partial x}, \frac{\partial w}{\partial y}, \frac{\partial w}{\partial z}$. For values of $\frac{\partial u}{\partial x}, \frac{\partial v}{\partial x}$, etc., of the surface of the earth, we obtained magnitudes of the order of $10^{-5}$ 32) from analyses of horizontal displacements of triangulation points. Assuming the elastic constants of the surface layers to be of the order of $10^{10}$ and, substituting the above mentioned values of the displacement gradients, we have for $\widehat{xx}$ and $\widehat{yz}$, values of the order of $10^5$. Since however the surface layers of the earth will be deformed permanently, and since the horizontal displacements of the triangulation points measured contain component accumulated in the course of several tens of years, only a part of the above mentioned value may exert stress on the surface layer, although, under certain conditions, it may be enough to activate landslides.

In association with the North Idu earthquake, landslides occurred at many places, of which the Zyô landslide,33) together with several others, were found to lie on a zone of virtually active fault, that is, the zone where the earth's crust was deformed conspicuously. A landslide similar in type to the Zyô landslide occurred on the southern bank of the Omonogawa in association with the Akita earthquake of 1914,34) in

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32) C. Tsuboi, *Jap. Journ. Astr. Geophys.*, 9 (1933), 95.
N. Miyabe, *Bull. Earthq. Res. Inst.*, 11 (1933), 639.

33) *Kensin-Zihô*, 4 (1930~1931), (in Japanese).

34) A. Imamura, *Rep. Imp. Earthq. Inv. Comm.*, *loc. cit.*
Y. Aomi, *ibid.*
R. Ohasi, *ibid.*

which earthquake, the landslide slipped along the boundary surfaces of layers of different geological series. These landslides might have been activated by the triggar action of earthquake vibration, stress exerted by earthquake waves, or by the slow crustal deformation associated with earthquakes which, it is difficult to say.

We shall next deal with the effect of precipitation which, as already stated, is an important factor in the activation of landslides. There can be no doubt that penetration of water into the rock, layers causes conditions favourable to the occurrence of landslides, although its precise mechanism is as yet unknown. The following experiments may however be throw some light on the question of mechanism.

Small blocks of rock from landslides in the prefectures of Nagano and Niigata were exposed to water penetration, with the result that, as shown in Fig. 17, the hair cracks that were in the rocks prior to the experiment generally widened, while in severel cases the rock disintegrated. The widening and formation of these cracks in the rock may be the result of partial contraction in the rock mass due to complete penetration of water.

Further experiments were made with respect to the contraction of sand mass by water penetration. The water was first allowed to permeate a column of sand loosely piled in a glass cylinder of 3 cm. diameter and 30 cm. length, with a permeable membrane at the base. The cylinder into which the sand was piled was sunk into a bath of water, and the height of the penetrated water and the displacements of the surface of the sand measured with respect to various water levels. The result is shown in Fig. 18, in which the contraction of the sand column is plotted against the heights of the water that had penetrated. In Fig. 18, we notice that, within a certain range, the contraction of the sand column is approximately proportional to the height of the water in the sand.

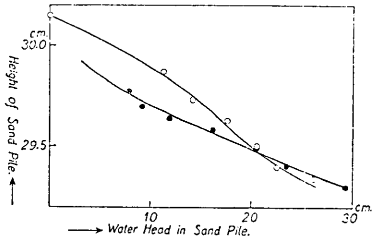

Fig. 18. Contraction of sand pile due to penetration of water.

The sand was then piled in a meter glass, to which water was added, after which the upper part of the sand mass that was found to have risen considerably had separated into a block, as shown in Fig. 19. The intermediate part between the upper and lower ends of the sand mass was filled with the air that had been forced out of the interstices in the sand mass by penetration of the water.

We shall consider two plates standing side by side in a vessel of water with a very small distance $h$ separating them. When the space

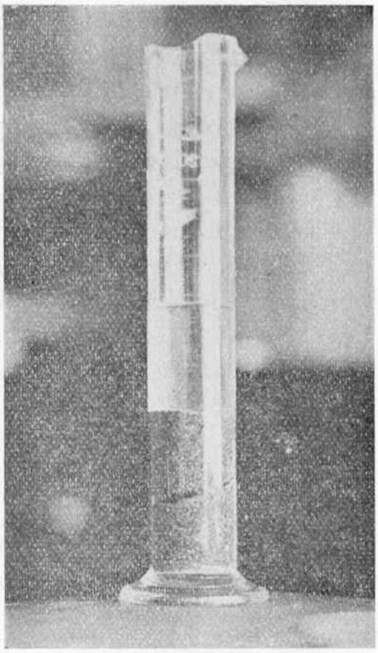

Fig. 19. Cracks in the sand piles.

between these two places is filled with water they will be pulled towards each other by the force of capillary attraction, which is a function of $h$, (neglecting the gravity component) of the form

$$P=-\frac{s\alpha^2}{h},$$ [35]

where $s$ is the area of the plates and $\alpha^2$ is the surface tension of the water. We shall imagine many such plates standing side by side, the distances between the plates being unequal. If water fills every space, then stress is exerted on the mass of these plates, owing to inequality in the values of $h$. that is

$$\frac{\partial P}{\partial x}=\frac{\partial P}{\partial h}\frac{\partial h}{\partial x}=+\frac{s\alpha^2}{h^2}\frac{\partial h}{\partial x}.$$

If the above expression be applicable to the case of the surface layers of the earth in estimating the stress exerted on the interior of it by penetration of water, we shall then obtain as the stress the value of $2\times10^5$ dyne/cm$^2$, or 1 kg/cm$^2$, on the assumption that $h=10^{-3}$ cm.$=10$ micron, $s=1=$unit area, $\alpha^2=80$ dyne/cm., and $\frac{\partial h}{\partial x}=1$. The value of $\frac{\partial h}{\partial x}$ may be large for smaller values of $x$. The value for the stress thus estimated is comparable with the tensile strength of clay, which if several kilograms per square centimetre[36], as given in Table V.

Table V. Tensile Strength of Clay.

| | Strength kg./cm.$^2$ |
|---|---|
| Wet clay | 0·17 |
| Dry 〃 | 4·50 |

If, in an actual case, the stress due to the force of capilarity overcomes the strength of the rocks composing the surface layers of the earth, either fresh cracks will be formed or old ones widened, in consequence of which the friction and cohesion on the slip plane will be reduced considerably. It may therefore be concluded that the cracks are developed in the rock mass composing the surface layer of the earth through complete penetration of water accompanying heavy precipitations.

As to cracks forming in the rocks, periodic variations in atmos-

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35) NEUMANN, *Theorie der Kapilarität.*

36) Cf. K. TANAHASI, *Umi to Sora*, **12** (1932), 221, (in Japanese).

pheric temperature is believed to be an important factor[37]. The periodic freezing and melting of the water contained in rocks or clays however seem to be restricted to the superficial layer, which however may not be thick enough to be comparable with that of the layer that moves at the time of landslides of type (iii).

On the other hand, it may be worthy of note that the crustal layers in the neighbourhood of faults and folds are comparatively disturbed, so that water penetration may be much easier to such regions, from which it follows that landslides are sometimes found associated with zones of faults and folds that have been much disturbed by chronic movements of the earth's crust.

The example of a landslides pointed out by Terzaghi[38] is also worthy of note. This landslide, which occurred on the bank of river, might have been caused by breakdown of underground sand layers loosened by the penetration of water.

**8. Crustal movements and landslides.** It may be suggested from what has been stated in the preceding paragraphs that the phenomenon of landslides is, among other things, intimately related to the quantity of precipitation. It may also be suggested that the part played by precipitation in causing landslides may be more pronounced in the case of earth mass or rocks that are subjected to greater prevailing chronic crustal movements than others.

Before we deal with the relation between chronic crustal movements and landslides, it should be remarked that disturbance of the earth's crust is conspicuous not only in regions of landslides, but also in Alluvial plains in regions close to epicentres of destructive earthquakes. For this reason a number of the examples cited in the present paragraph to show that chronic crustal movements seem to be related in some way to the occurrence of landslide, may serve also as data for future investigations that may be made of the relation between the two. The examples are as follows:

(i) Higasi-Kubiki Gun, Niigata prefecture, situated between two nearly parallel lines of precise levels from Naoetu to Nagaoka and from Nagaoka to Nagano, as shown in Fig. 20, is a region of frequent landslides. The vertical displacements of bench-marks along these level lines (Fig. 21) do not show conspicuous disturbance in the earth's crust which might have been associated with landslides, except the small fluctuations in the neighbourhood of Iiyama. This may of course be to due on the one hand to the widely separated bench-marks, whose changes

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[37] G. WATANABE, *Tuti-to-Midu Iinkwai Hôkoku*, No. 4 (1930), 29~43, (in Japanese).

[38] C. TERZAGHI, *Ingeniur Geologie*, S. 436, *loc. cit.*

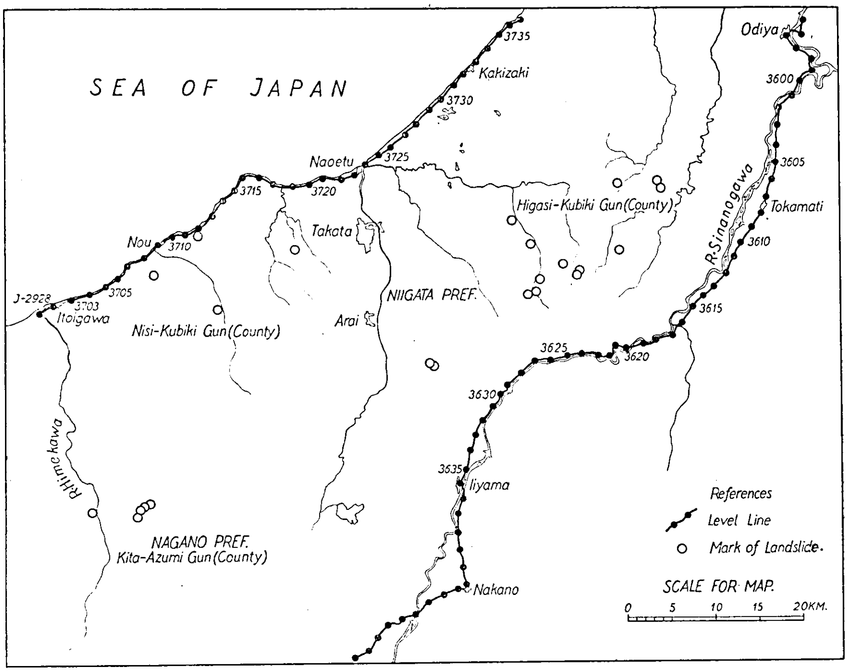

Fig. 20. Lines of levels and distribution of recent landslides in Higasi-Kubiki Gun (county), Niigata Pref.

in heights are measured, and on the other hand to the fact that the region under considerations forms part of a block different from those traversed by the level lines.

(ii) The landslide in 1922 at Teragi-mura, Hyogo prefecture, was studied in detail by Prof. M. Matuyama[39]. Recently another landslide occurred at Gamo-mura, Tottori prefecture, ten or more kilometres west of Teragi-mura landslide[40]. Topographical feature of the neighbourhood of these landslides are shown in Fig. 22. From the vertical displacements shown in Fig. 23 of bench-marks along the level lines in Fig. 22, it will be seen that the regions where the landslides occurred are situated close to the tilted blocks.

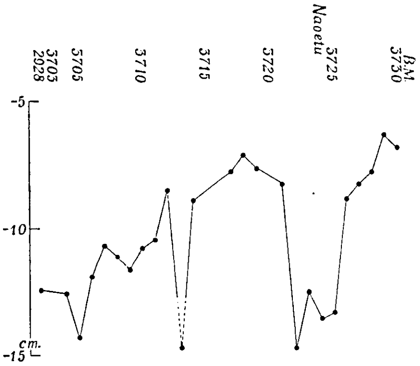

Fig. 21a. Vertical displacements of the bench-marks along the line from the Itoigawa to Kakizaki via Naoetu.

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[39] M. Matuyama, *Tikyû, loc. cit.*

[40] M. Katuya, *Sinrin-Tisui Kisyô Ihô*, No. 14 (1934), (in Japanese).

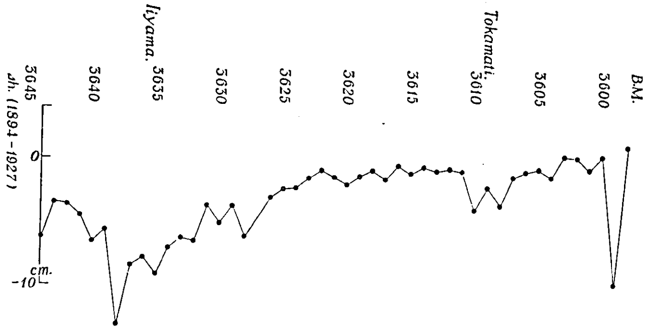

Fig. 21b. Vertical displacements of the bench-marks along the line from Nagano to Odiya via Iiyama and Tôkamati.

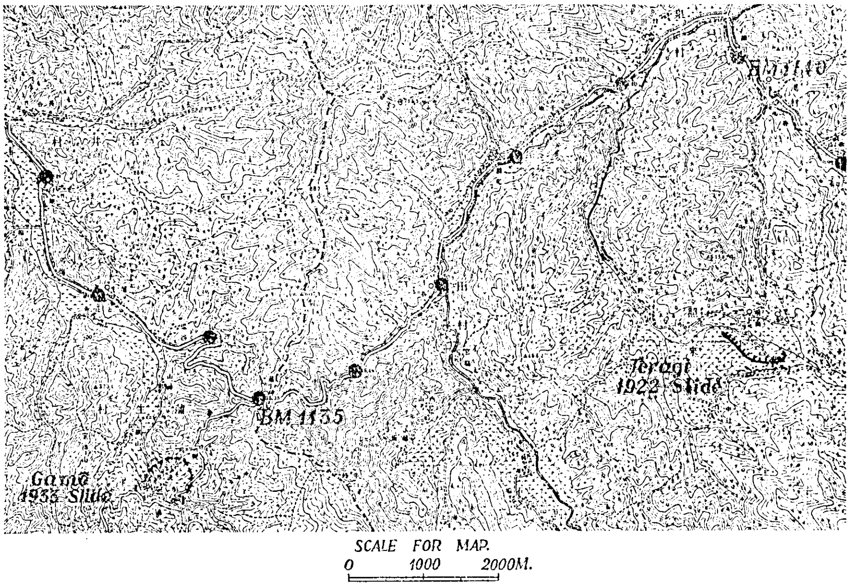

Fig. 22. Map showing the distribution of bench-marks in the neighbourhood of Teragi-mura and Gamô-mura landslides.

(iii) At the neck of the Noto peninsula is a mountain range extending NE-SW. Landslides have occurred on the northern and southern slopes of this mountain range, the localities of which are shown in Fig. 24, together with the topographical features. Of these landslides, those that occurred in 1904 and 1932 were studied by several authors[41]. On the other hand, the vertical displacements of bench-marks along the level lines that cross this mountain range have been measured a number of times as shown in Fig. 25. Of these curves representing the recent vertical displacements (Fig. 25), the one that

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41) J. OHIKATA, *loc. cit.*; H. HONDA, *Kensin-Zihô*, 4 (1930~1931), 403.

represents the recent vertical earth movements during the time interval, 1927~1933, shows that the earth's crust upwarped during that period. The mode of deformation of the earth's crust in these regions is similar to that believed to have occurred in association with the 1904 landslide[42].

As already stated landslide occur when the values of $K$ and $\mu$ are reduced considerably by earthquakes and by the penetration of the water into the layers of the earth. Crustal deformations may of course contribute in some measure to increase the pull by one of the components of the gravitational force, which however may not be sensibly large. The crustal disturbance just mentioned may also assist in causing the water to penetrate into the surface layers of the earth and the rocks.

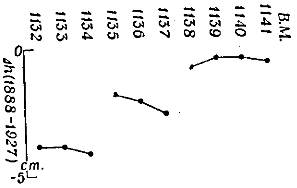

Fig. 23. Vertical displacements of the bench-marks in the neighbourhood of the Gamô-mura and the Teragi-mura landslides.

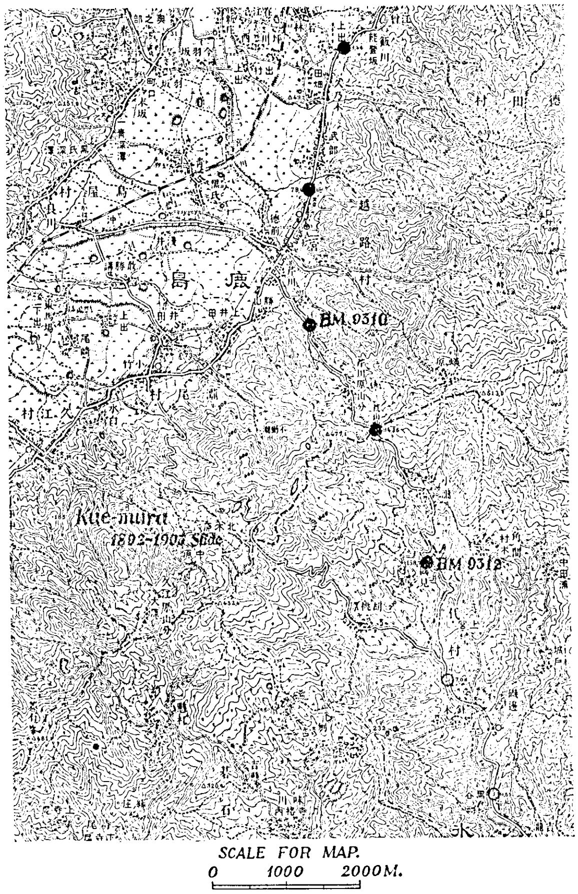

Fig. 24. Map showing the distribution of bench-marks in the neighbourhood of the boundary of prefectures of Toyama and Isikawa.

**9. Mud flows.** The reader's attention may now be drawn to the phenomena of mud flows. As already stated, several landslides, have been accompanied by either mud flows or rock flows. These flows sometimes sweep away farms and houses and do much damage.

The flows are generally initiated at the rear of landslides of type (iii). The velocity of the flow varies within wide

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[42] J. OHIKATA, *loc. cit.*

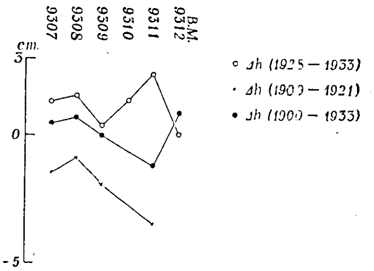

Fig. 25. Vertical displacements of the bench-marks situated in the neighbourhood of the boundary of the prefectures of Toyama and Isikawa.

ranges. Frequently it is as much as ten or more metres per second, while, in some cases, it is so small that we cannot notice the movements at a glance. A flow of considerable mass of earth or rocks moving with considerable velocity is sometimes called "Yama-tunami" (mountain-tunami). Several of the Alpine landslides[43], the landslides associated with the Kwantô eartnquake[44] and the North Idu earthquake[45], and the Hieda-yama landslide[46] (a map of the neighbourhood of the Hieda-yama landslide is shown in Fig. 26 reproduced from Yokoyama's paper), are what may be called "Yama-tunami", while the mud flow associated with the Tyausuyama landslide is a typical example of the mud flow that moves very slowly.

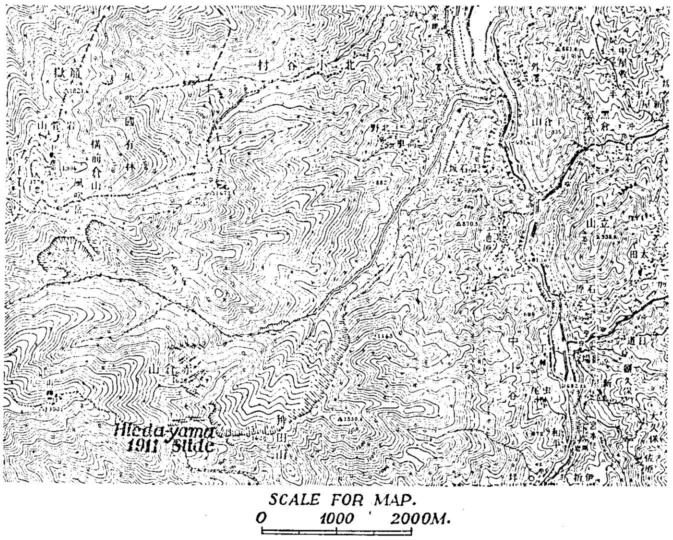

Fig. 26. The map in the neighbourhood of the Hieda-yama landslide.

When, however, the velocity of flow is considerable, the mode of flow seems to differ somewhat from that of a viscous liquid, the analogy

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43) The cases are shown in A. HEIM's book, *loc. cit.*

44) The Nebukawa landslide reported by T. MATUZAWA, *loc. cit.*

45) The Kadiyama landslide etc. reported in *Kensin-Zihô*, *loc. cit.*

46) Report by M. YOKOYAMA, *loc. cit.*

being applicable to mud flows with small velocity.

To investigate the mode of mud flows in greater detail, an experiment was made with dry sand. The velocities of the sand flow on slopes of various inclinations are shown in Fig. 27.[47]

This figure seems to suggest that the dissipation of energy as the sand flows along the slope may be due mainly to friction of the boundary surface. According to our experiments, equivalent viscosity does not seem to sensibly reduce the velocity. This may be due mainly to thinness of the layer of flowing sand.

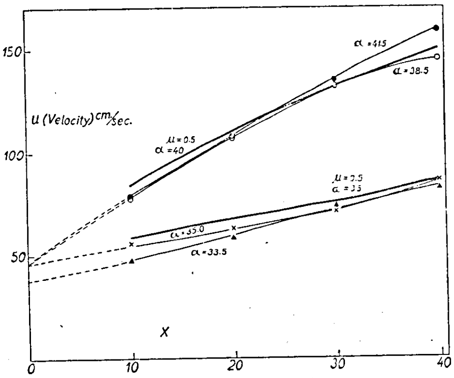

Fig. 27. Relation between the terminal velocity of sand flow and the distance which has been flown by sand.
(The thick lines shows the theoretical relation represented by $u=\sqrt{2g(\cos\alpha-\mu\sin\alpha)x}$.)

In such cases therefore we can calculate the velocity, as did Heim, by a simple formula

$$\frac{du}{dt}=g\,(\sin\alpha-\mu\cos\alpha),$$

where $\alpha$ is the inclination of the slope and $\mu$ the coefficient of friction. The calculates values of $u$ on the assumption, that $\mu=0\cdot5$ and $u_0=45$ cm./sec., agree very well with those observed, as shown in Fig. 27.

Further experiments were carried out with respect to the flow of sand along a slope, using two slopes of different inclinations, namely, a steep slope followed by a gentler one. In this case, the distances traversed by the sand over the gentler slope was measured relative to various combinations of inclinations of the two slopes.

In Fig. 28, the values of $x_1/x_0$, that is, the ratios of the distances traversed by the sand over the gentler slope to these over the steeper are plotted against inclinations of the gentler slope, from which we see that the ratios become larger as the inclinations of the gentler slope increase, that is, the greater the inclination the larger the rate of increase, and that the ratios suddenly increase when the inclimation of the steeper slope exceeds 35°.

Of the receipts just mentioned, the former may be due mainly to frictional resistance of the gentler slope, while the latter may be the

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47) The detail of the results of the experiments will be reported in due course.

48) A. Heim, *Bergsturze und Menschenleben*, *loc. cit.*

result of differences is terminal velocity at the end of the steeper slope, which varies with $\alpha$ as shown in Fig. 27.

Taking several actual cases, the values of $\frac{x_1}{x_0}$ are calculated and plotted in Fig. 28 with asterisks, from which it will be seen that it is possible to apply the result of the experiments of sand flows the study of a number of actual cases, especially when the velocity of flow is great. The deviation of the actual values of $x_1/x_0$ may be considered as due to the following causes:

(i) The frictional resistance at the bottom of the flow may be reduced considerably if the flowing earth mass contains water.

(ii) In the flow of a water-bearing earth masses, the dissipation of energy in the course of its flow may also be reduced.

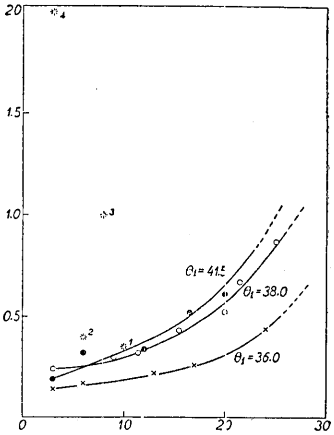

Fig. 28. Relation between $x_1/x_0$ and $\theta_2$.

The values of $x_1/x_0$ for actual cases of

1. Val Bedretto landslide 1898 (48).
2. Schächental landslide 1887 (43).
3. Aegerti landslide 1897 (45).
4. Elm landslide 1881 (41).

are plotted by *.

(iii) In certain cases the inertia mass of the flowing earth may play an important rôle, when the value of $x_1$ will be larger than these estimated by considering the dissipation due to frictional resistance only.

**10. Summary and conclusion.** In the present paper, the writer described the modes of a number of landslides and discussed the relationship between several probable factors and landslides. The most important factors are

(i) Stresses exerted by earthquakes on the layers of the earth, the effect of the vibration reducing the effective value of friction along the slip surface.

(ii) The water that has penetrated into the layers of the earth, exerts local stress within the mass of earth or rocks to widen the cracks or form new ones, in consequence of which the effective values of $\mu$ and $k$ are reduced considerably.

(iii) The relation between chronic crustal deformation and landslides is not yet understood.

In the last paragraph, the modes of mud flows are described in comparison with experimental sand flows.

To avoid dangers from landslides, the next best way to avoiding

Fig. 12. Mud flow of the Tyausuyama landslide.

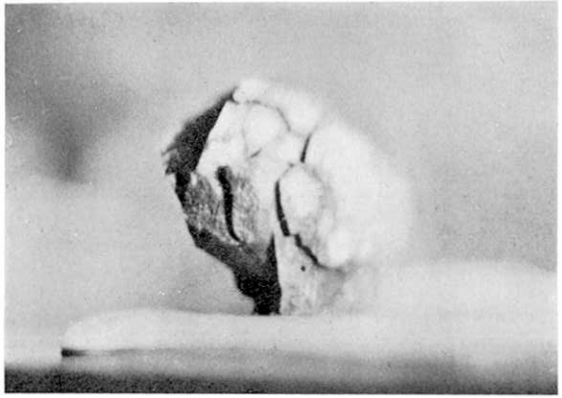

Fig. 17. Cracks in the rock produced by the water penetrated.

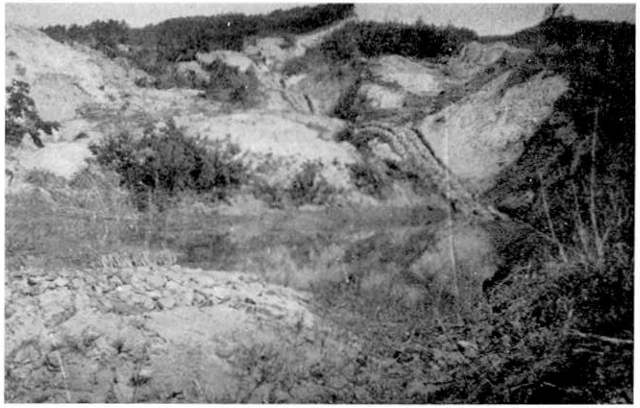

Fig. 29. The deformation of the surface layer of the earth in the Tyausuyama landslide.

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Fig. 16. Precipitations at Nagano, Takata and Niigata and occurrences of landslides

The numbers against the marks of landslides designate these in the first column of Table I.

them is to prevent friction and cohesion of the surface layers of the earth from being reduced. Retaining walls, drains for surface water run off, and such present day engineering operations are in effective in supporting the sliding earth mass or in preventing landslides. Retaining walls rigid enough to support a sliding earth mass are very difficult to construct, not only because of its enormous cost, but also because of technical difficulties. Most drams for surface water run off are almost useless for preventing the occurrence of or progress in movements of landslides, as they are destroyed by the movement of the sliding earth mass, an example of which is the Tyausuyama landslide, shown in Fig. 29.

In conclusion, the writer wishes to express his sincere thanks to Professor Torahiko Terada for his kind advices and suggestions.

## 7. 山崩れの研究

地震研究所 宮部直巳

山崩れに關する從來の文獻や，二三の觀察の結果からみると，從來別種に取扱はれてきた，所謂地辷りと山津浪とは全然別な現象でなくて，地辷りが高い處に生じた場合，押出された岩塊又は土塊が，比較的急な斜面を流れ下る時に山津浪といふ現象が見られる樣に考へられる.

山崩れは結局，山腹の樣な斜面の地下に於ける歪力分布の狀態から期待される辷り面に沿うての摩擦や凝集力と歪力との平衡が何かの原因で破られた場合に生ずるのであるから，雨水や雪融水が地下に透入した場合や，地震動が作用した場合や，或は又緩慢な地殼の變動がある場合に，摩擦や凝集力の減少，歪力の增加が如何に行はれるかを知れば，從來認められてゐる事實を說明する幾分の助けにはなる. 本文ではそれ等の點については少し許り考へてみた.

又. 山津浪や泥流などの場合に，實用的には，それ等の流れが如何なる範圍まで影響を及ぼすかといふことが問題になるわけであるが，この場合簡單な砂流の實驗から得た結果が，實際の場合にも延用出來るやうな場合もあるやうに思はれる.