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Geological structures of large landslides in Japan

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ABSTRACT

There are many large catastrophic landslides and volcanic collapses in Japan. In this paper, the large landslides (with volumes more than a million cubic metres) are categorised into three groups based on their geological structure, slope morphology, and triggering factors. The first type of landslide occurs on a cataclinal slope where the slope and bedding (or foliation) are dipping in the same direction. The landslide occurring on such a slope may be preceded by scarplets with arcuate trace convex upslope on a plan view. The second type of slide is found on a slope with bedding or foliation that dips steeply in the depth and is toppled towards the valley due to mass rock creep. This kind of rock deformation is recognised to precede many landslides in Japan with its geomorphological expressions of linear depressions and multiple ridges. The third type of landslide is found on the slope with a thick cap rock of limestone and/or greenstone underlain by a chaotic mixture of mudstone with scaly cleavage and rock blocks of sandstone and chert.

INTRODUCTION

Many large catastrophic landslides occur on bedded (sedimentary) or foliated (metamorphic) rocks as well as on volcanic deposits all over the world. These gigantic landslides are not so common in comparison with small shallow slides. But they cause severe damage, because they generally move very rapidly for a distance as long as ten kilometres and frequently block streams to make landslide dams that fail to cause a devastating flood downstream. In case of landslides triggered by volcanic activity, such as that of the 1980 St. Helens eruption (Voight et al. 1983), volcanism itself should be studied to predict the landslides, which is out of scope of this paper. For other types of large landslide triggered by earthquakes or heavy rain, geological structures and landforms are the clues to predict possible failures. Such large landslides are controlled by deeply extending characteristic geological factors, while shallow landslides are controlled mainly by superficial weathering profiles.

While investigating the geological structures of large landslides in sedimentary rocks of Japan, it was found that there are several types of geological structure in relation to slopes that are responsible for triggering large landslides with volumes more than a million cubic metres in sedimentary rocks (Chigira 1992,1993,1997,1998; Chigira and Kiho 1994). Fig. 1 and Table 1 show the distribution of large landslides in Japan. Based on these investigations, the geological structures of large landslides in Japan and their geomorphological precursors are described below.

Fig. 2 and 3 show schematically the modes of deformation of rock slopes according to the morphological relationship between bedding (or foliation) and slope. Foliated (or bedded) rock slopes deform by buckling, bending, dragging, and sliding. Previous studies on large landslides revealed that bending and sliding are the most basic causes of failure. These landslides are classified into the following three types.

LANDSLIDES ON DIP SLOPES

These types of landslide are found in many places of the world (Cruden 1976; Voight 1978; Hermanns and Strecker 1999), because this geological structure gives favourable condition to sliding if a weak zone is present in the rock succession. Such a zone may result from: 1) faulting, 2) chemical weathering (e.g. the 1984 Ontakesan Landslide in Japan; Tanaka 1985), or 3) mass rock creep. If the weak zone is related to the first two factors, the landslide might not be detected beforehand, but if it is related to the third factor, it might be predicted. The mass rock creep is not easily recognised on slopes, but some good exposures may show that it is separated into platy fragments due to shearing along the bedding (or foliation) planes and opening of joints intersecting the bedding (or foliation). Some of these landslides are reported to have been moving slowly before catastrophic rockslide or avalanche, but their geomorphic expressions are not very clear yet.

Fig. 4 and 5 are the geomorphological maps of the Nagaike scarplets in central Japan, which are inferred to be a geomorphological expression of a large landslide on a slope dipping in the direction parallel to the bedding. The scarplets are on the western edge of the low-relief surface of the Hira Mountains, which are underlain by shale and sandstone of the Permian to Jurassic Tanba Group. These strata dip due

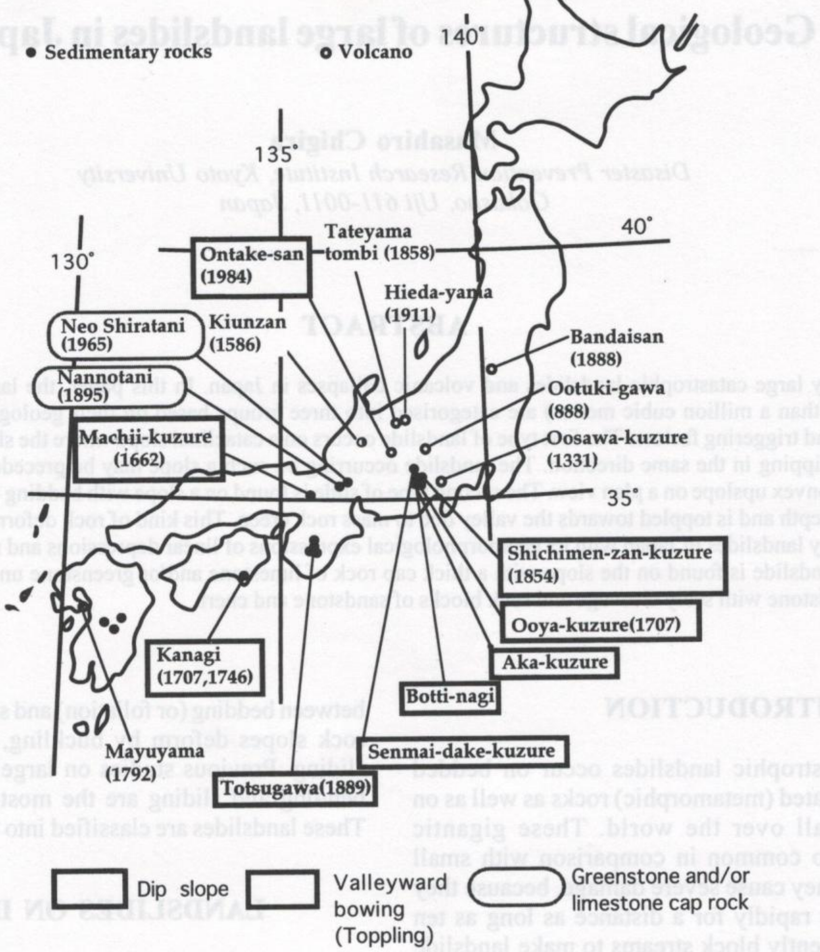

Fig. 1: Index map of large landslides in Japan

Table 1: List of landslides studied in sedimentary rocks (*Kuzure* means landslide)

Landslide	Volume (x $10^6 m^3$)	Geology	Trigger
Aka-kuzure	27	Shimanto Gr. Valleyward bending	Not known
Shichimenzan-kuzure	45	Setogawa Gr. Valleyward bending	1854 Ansei-Tokai Earthquake **
Senmaidake-kuzure	8.2	Shimanto Gr. Valleyward bending	Not known
Ooya-kuzure	120*	Setogawa Gr. Valleyward bending	1707 Hoei Earthquake **
Kanagi-kuzure	30*	Murotomisaki Hanto Gr. Valleyward bending	1707 Hoei Earthquake 1746 ?Heavy rain
Machii-kuzure	48**	Tanba Gr. Dip slope	1662 Kanbun Earthquake **
Totsugawa saigai (Many landslides)	–	Shimanto Gr. Dip slope	1889 Heavy rain
Tokuyama Shiratani	1.8**	Mino terrane, a Jurassic accretionary complex Greenstone cap rock***	1965 Heavy rain
Neo Shiratani	11**	Same as above	1965 Heavy rain

* from Machida (1984), **Ministry of construction of Japan (1997), ***Kojima et al. (1999)

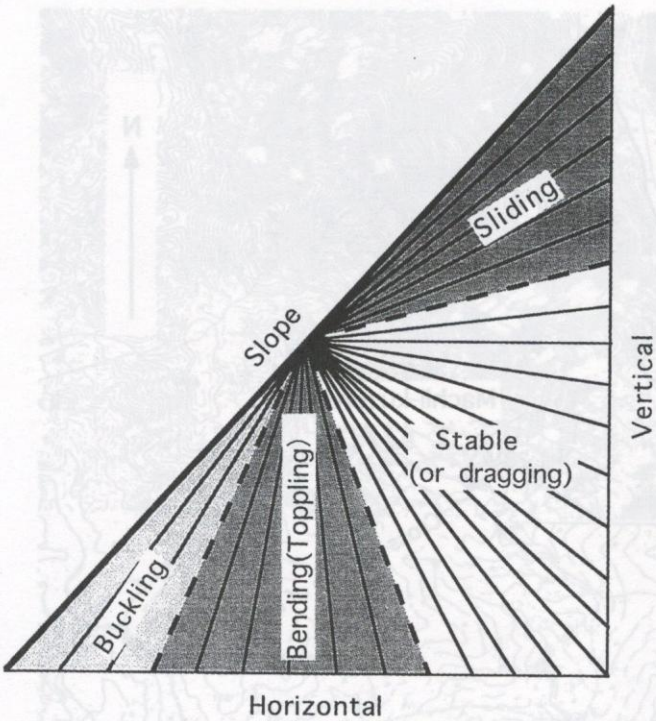

Fig. 2: Relationships between foliation and slope, and the modes of deformation of rock slopes

NW at 30° to 50° while the nearby steep slopes dip due WNW. The Nagaike scarplets (up to 20 m high) have an arcuate line convex to the east on a plan view. The scarplets cut the top of small streams flowing to the east, and form wind gaps and ponds or marshes on its west. The arcuate alignment of scarplets and the presence of wind gaps, ponds, and marshes strongly indicate that the area (400 m wide and 1 km long) bounded by the scarplets on the east have moved down by 10–100 m to the west or northwest. The landslide mass is still at the edge of a gentle surface with very steep western slope. This landform, therefore, is a precursor of a large and catastrophic landslide.

The catastrophic landslide of Machii-kuzure killed more than 250 people (Furuya et al. 1984). The landslide is 2.5 km north of the Nagaike scarplets and was triggered by an earthquake with a magnitude of 7.6 in 1662. The source area of the landslide was also on the western edge of the gentle surface of the Hira Mountains like the Nagaike scarplets. In addition, the geological structure of the Machii-kuzure is about the same as that of the Nagaike scarplets (Fig. 6). The landslide of Machii-kuzure did not leave prominent precursory landforms, but there are some linear depressions along the periphery of the landslide scar (Fig. 4). The orientation of the slope parallel to the bedding (i.e. dip slope) and the arcuate scarplets convex upslope are the geomorphological precursors of the landslide.

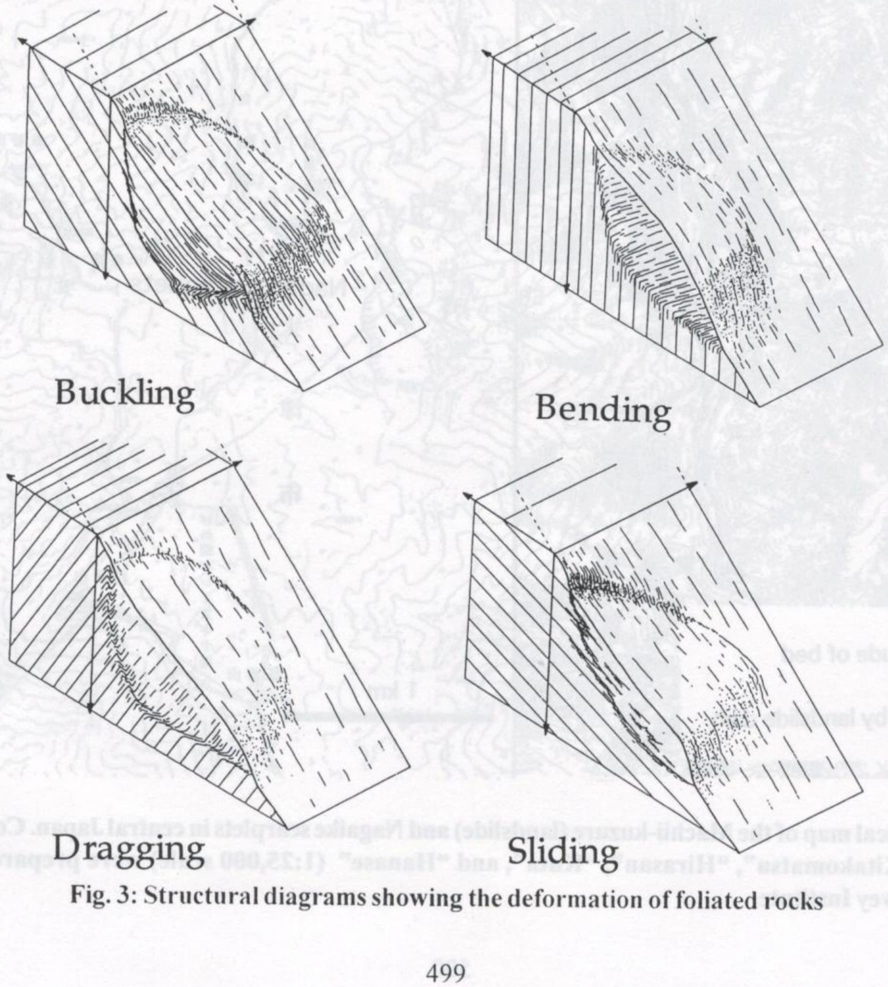

Fig. 3: Structural diagrams showing the deformation of foliated rocks

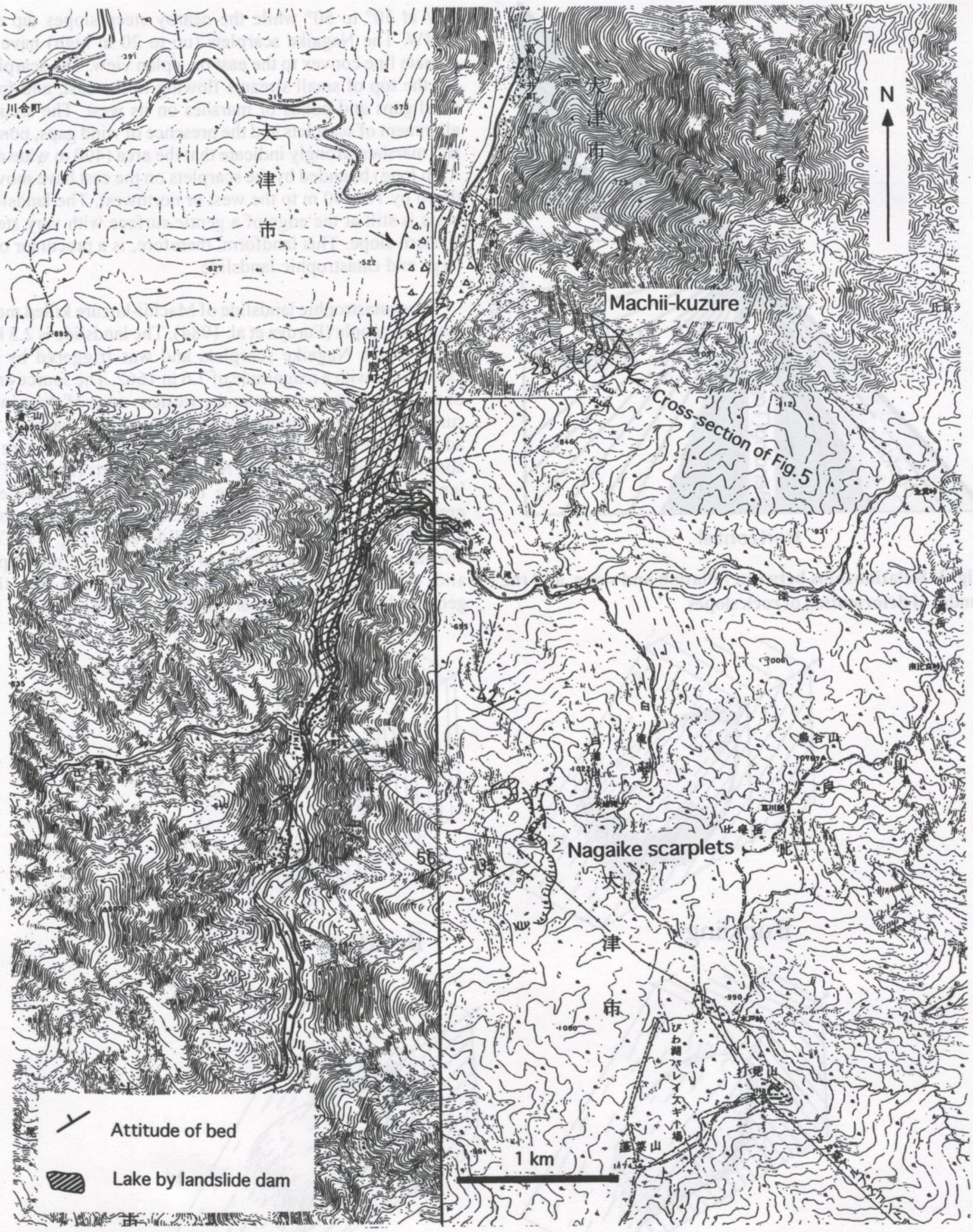

Fig. 4: Topographical map of the Machii-kuzure (landslide) and Nagaike scarplets in central Japan. Contour interval is 10 m. Maps of "Kitakomatsu", "Hirasan", "Kuta", and "Hanase" (1:25,000 scale) were prepared by the Japan Geographical Survey Institute.

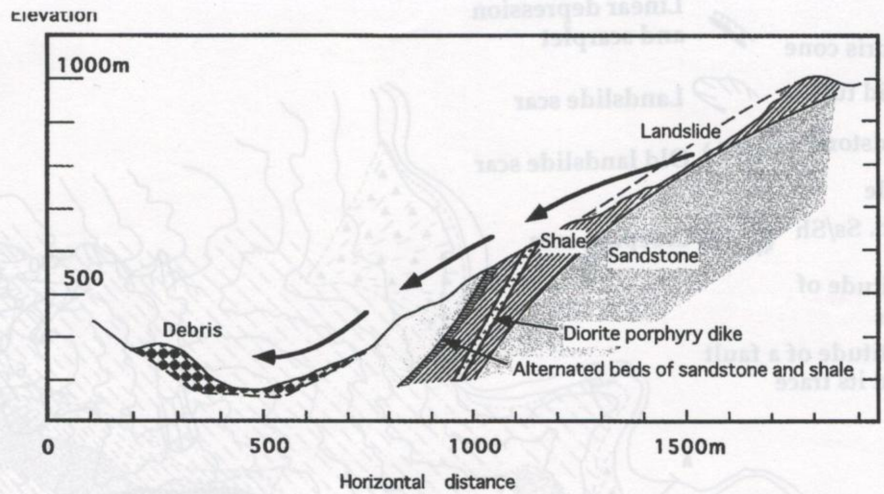

Fig. 5: Geological cross-section of the Machii-kuzure (which occurred in 1662)

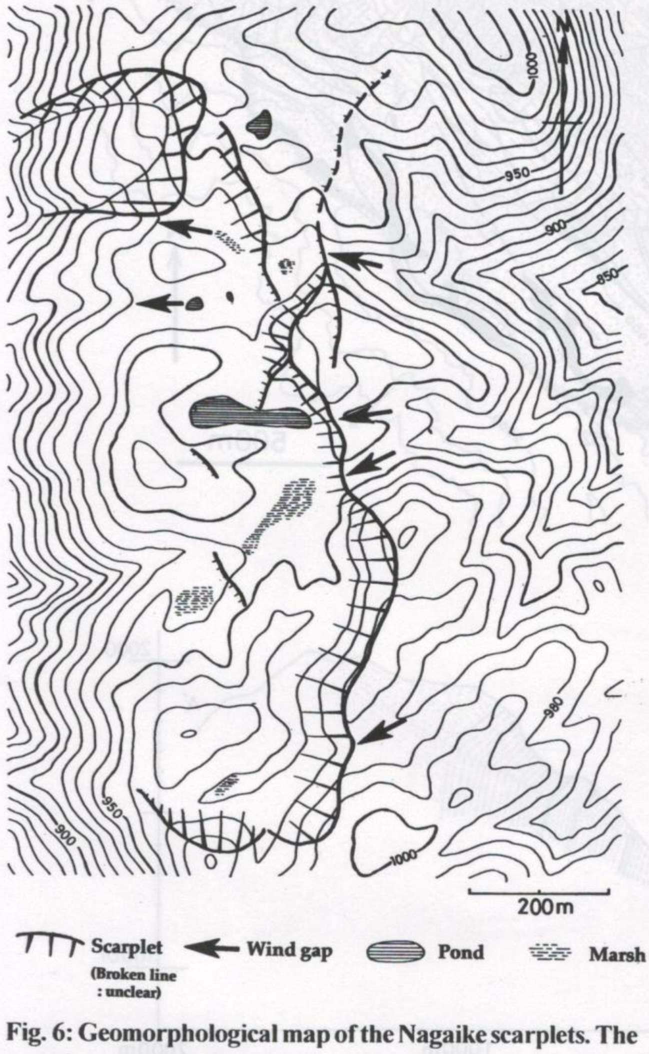

Fig. 6: Geomorphological map of the Nagaike scarplets. The scarplets, showing the descent of the west side, are arranged on an arcuate line convex towards the east. Note that the heads of streams are terminated as wind gaps along the scarplets.

The Ontakesan Landslide occurred on a dip slope in 1984. It is 34 million cubic metres in volume and was triggered by an earthquake (Tanaka 1985). Its slip surface was confined within a weathered pumice bed and liquefaction was probably the main mechanism of failure of this catastrophic landslide (Sassa 1985). There were no perceivable precursory movements in this case.

LANDSLIDES DUE TO MASS ROCK CREEP

Many landslides are preceded by toppling (i.e. valley-ward bending of the steeply dipping foliation) due to mass rock creep. Some of the examples are the Aka-kuzure, Shichimenzan-kuzure, and Senmaidake-kuzure (Chigira 1992; Chigira and Kiho 1994), and Ooya-kuzure and Kanagi-kuzure (Chigira 2000).

The details of the Aka-kuzure are shown in Fig. 7. The bedding plane at the depth below the creeping area dips steeply into the mountain, but it is bent downslope at the surface. The depth of bending is more than a hundred metres. The deeper intact strata in the landslide area consist mainly of steeply dipping shale or slate, with or without sandstone. But they are bent (toppled) downslope at the surface due to mass rock creep, and make linear depressions and multiple ridges at the upper part of the slope. The linear depressions (which are from a few metres to several tens of meters deep) and the intervening multiple ridges are the expressions of mass rock creep. At least some of the depressions near the landslide scar of Aka-kuzure were formed by normal faulting due to extension associated with the downslope bending of the strata (Plate 1). The creep zone is about 500 m deep. With the propagation of mass rock creep, the strata are sheared along their bedding planes and separated into platy fragments. Landslide scars are frequently located at the periphery of a creeping area where the rock mass is eroded at the toe by a stream.

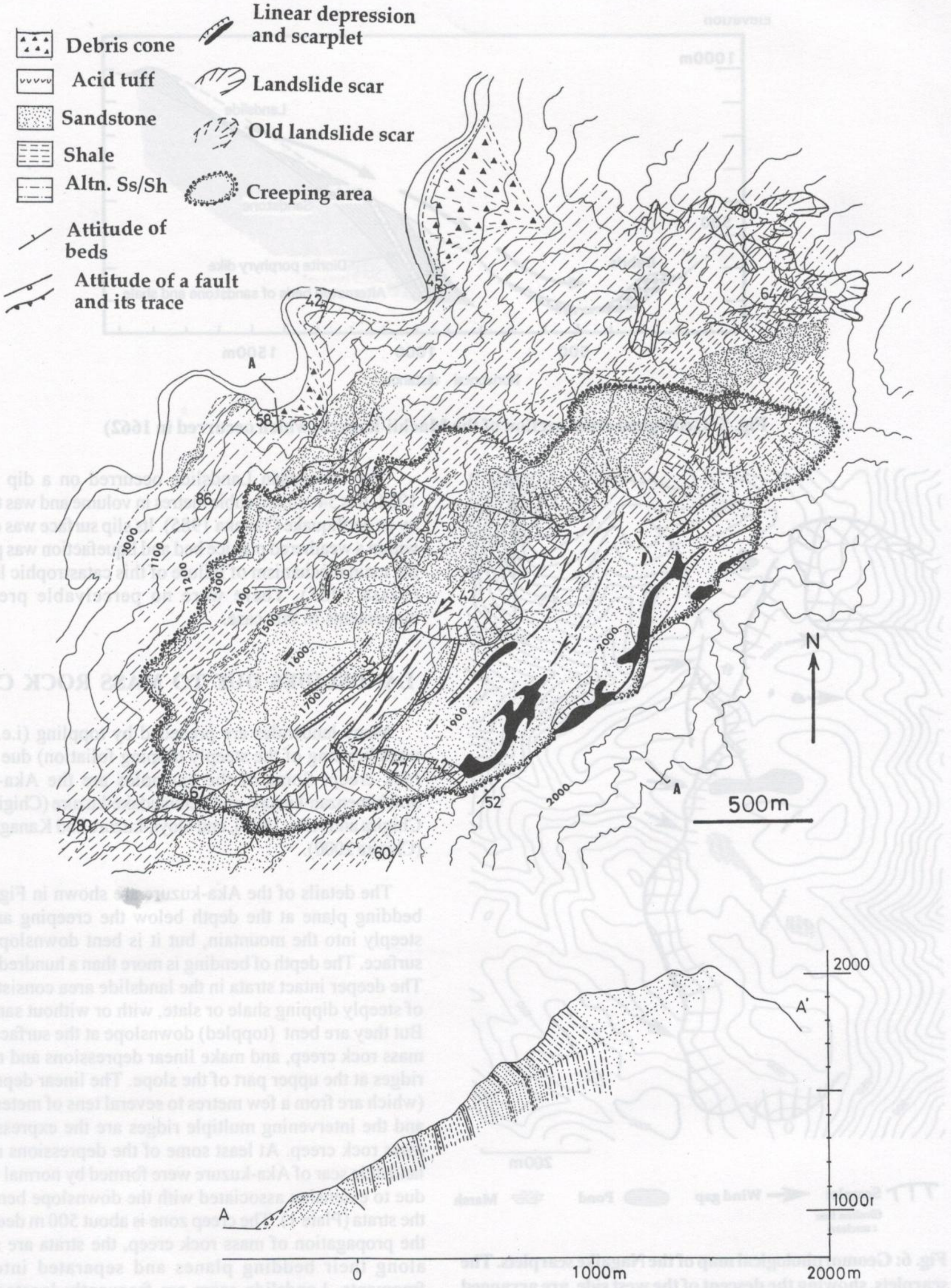

Fig. 7: Geological map and cross-section of the Aka-kuzure (modified from Chigira and Kiho 1994). An arrow indicates the location of Plate 1.

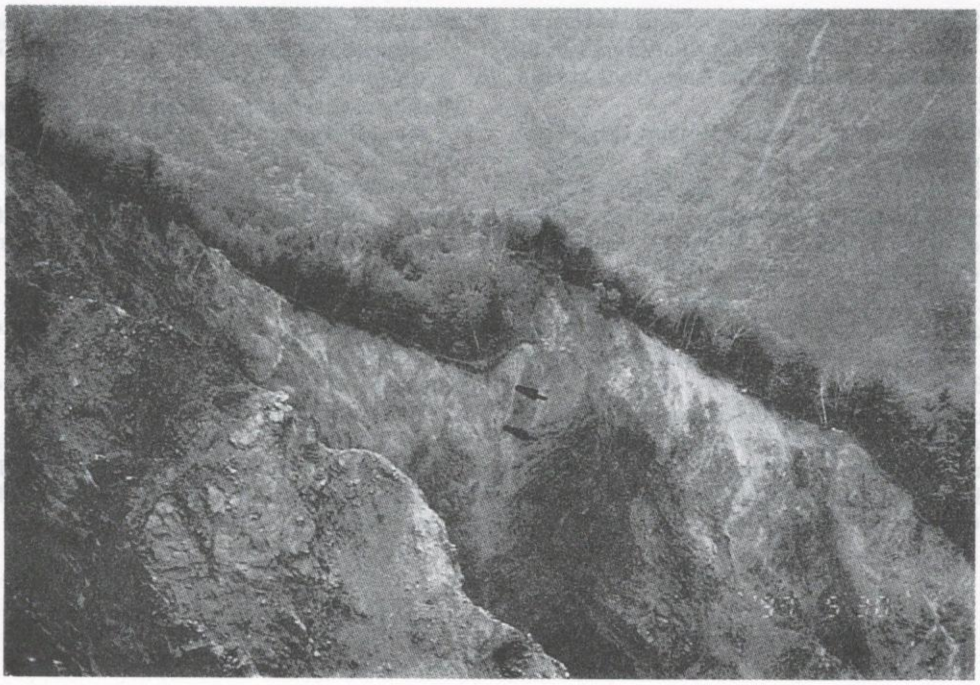

Plate 1: Cross-section of a linear depression and an uphill-facing scarp observed at the landslide of the Aka-kuzure. An arrow shows a normal fault, which dips to the right parallel to the bedding plane. The location of the photograph is shown in Fig. 7.

Such rockslides or avalanches might be predicted by the following geological and geomorphological characteristics: 1) steeply dipping regional bedding, 2) presence of linear depressions and multiple ridges, and 3) toe erosion by river.

LANDSLIDE ON MELANGE WITH A CAP ROCK

The third type of catastrophic large landslides in Japan occur on a slope with a thick cap rock of limestone and/or greenstone underlain by a chaotic mixture of mudstone with scaly cleavage and rock blocks of sandstone and chert (Kojima et al. 1999). This type of geological structure is present at many locations in the accretionary complexes of Japan. Hence, such landslides are also presumed to have occurred widely. A typical landslide of this type is the Neo-Shiratani Landslide with a volume of about 1 million cubic meters. It was triggered by a heavy rainfall in 1965.

CONCLUSIONS

In Japan, large catastrophic landslides generally occur on bedded (sedimentary) or foliated (metamorphic) rocks as well as on areas occupied by volcanic rocks. They can be broadly grouped into the following three types: 1) landslides occurring on dip slopes, 2) landslides triggered by toppling due to mass rock creep, and 3) landslides found on melange with a cap rock of limestone and/or greenstone. The first type of landslide may be preceded by arcuate scarplets; the second type of slide is preceded by linear depressions and ridges; whereas in the third type of landslide, the cap rock is underlain by a chaotic mixture of mudstone and blocks of hard rock.

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