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MASS MOVEMENT IN THE EASTERN MARGIN OF THE CENOZOIC NIIGATA SEDIMENTARY BASIN, CENTRAL JAPAN *

— ITS GEOHISTORICAL BACKGROUNDS —

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CONTENTS

ABSTRACT

The geohistorical investigation has been made on the two different kinds of large-scale mass movements in the eastern marginal region of the Niigata sedimentary basin, i.e., the Gozu debris flows and the Aburuma-gawa landslides.

The stratigraphic successions of these mass movement deposits show the following important characteristics common to the both. 1) These mass movements have occurred repeatedly at nearly the same sites since the Middle Pleistocene to the present. 2) During Middle Pleistocene and early Late Pleistocene time, the large-scale debris flows and the primary landslide occurred almost contemporaneously with the development of the mountain topography.

The origin and development of these mass movements have been strongly controlled by the crustal movements since Middle Pleistocene time. The amount of upheaval of the Gozu Mountains in this period have reached about 1,000 m in maximum height. The rapid block upheaval of the Gozu Mountains and the Uonuma Hills with an increasing elevation had brought about the fracturing and collapse associated with faulting and successive erosive rejuvenation, and finally resulted in generation of the large-scale mass movements.

The sea level lowering and periglacial process in the glacial epoch are not essential for the origin of mass movement in the region studied.

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I. INTRODUCTION

In the present paper the term "mass movement" is used according to the definition by Brunsden (1979) as follows:

"The general term mass movement is applied to those processes that involve a transfer of slope-forming materials from higher to lower ground, under the influence of gravity, without the primary assistance of a fluid transporting agent. They merge imperceptibly with processes in which transporting media, such as air, water or ice are involved and which are generally called mass transport processes. The movements may be slow or rapid, shallow or deep and include one or more of the mechanisms of creep, flow, slide or fall."

According to this definition, the phenomena which have been so far classified into landslide, landslip and debris flow are all grouped together in the mass movement.

The present mass movements are frequently causing great damages to human societies, and so they have been investigated in various disciplines including geology, geomorphology, geophysics and soil engineering. These investigations have made clear the mechanism of occurrence of mass movement. In geology, research of geologic setting and geologic structure supposed to have accelerated the occurrence of mass movements are in progress. In the course of these researches, it has been clarified that some of so-called older mass movement deposits were those which took place in different geologic ages in the mass movement deposits (Savarensky, 1936; Nakamura, 1938; Popov, 1946; Shibasaki, 1960; Záruba and Mencl, 1969), and the present mass movements coincide roughly with that of the older mass movements in the site of occurrence. With regard to landslide, in particular, the colluvial deposit of the older landslide has repeatedly migrated and supplied the materials for a yonger landslide. Therefore, the study of the older mass movements is considered to be very important, not only for an analysis of Quaternary geohistory, but also for an examination of present landslide and debris flow. On the other hand, in the Quaternary geology, they are few researches on the products of mass movement, in spite of abundant mass movement deposits in the Quaternary sequences.

The author has been interested in the above-mentioned problem, and has studied the subject mainly of the Quaternary of the eastern margin of the Niigata sdimentary basin (Takahama and Aoki, 1979; Takahama and Nozaki, 1981; Masai and Takahama, 1981; Takahama, 1982a,b; Takahama and Masai, 1983). In 1976, the author organized the Collaborative Reserch Group for the Sasagami Hills together with other members, to clarify the stratigraphy and the geological structure of the Sasagami Hills (Coll. Res. Gr. Sasagami Hills, 1980, 1982). The author's interest has been concentrated mainly to the debris flow deposits there in. The present paper is the summary of these studies.

There was so far a tendency to attach importance to the paleoclimatic condition as a cause of older mass movement. It seems, however, that an examination from the viewpoint of tectonic movement is of great importance for the study of mass movement in Japanese Islands where the crustal movement has been active since Neogene time. To solve the problems, the Gozu Mountain area and the Aburuma-gawa area around the Niigata sedimentary basin were selected, because the geologic structure and geohistory of the Quaternary in the Niigata basin have been investigated fairly in detail, the debris flow deposits are developed in the Gozu Mountain area, and the landslide deposits are widely distributed in the Aburuma-gawa area.

In this paper, the geologic setting of two areas is described first, followed by the examination of the geohistorical character of mass movements since Middle Pleistocene time, and their relation to the tectonic movement since Pliocene time in these areas.

II. PROBLEMS IN THE STUDY OF THE OLDER MASS MOVEMENTS

The existence of the older mass movements which occurred in the Pleistocene was already pointed out several tens of years ago, taking landslide as an example (Sabarensky, 1936; Nakamura, 1938; Popov, 1946; Shibasaki, 1960). Many examples are given in Appendix.

These researches indicate that most of the present active landslides in Japan are due to the remigration of colluvial deposits formed by older landslides (Nakamura, 1938; Shibasaki, 1960). In other countries, on the other hand, the remigration of older landslide deposits due to artificial causes (for example, excavation work) is a matter of immediate attention, and it is well known that older mass movements would be seldom activated under the present topographic and climatic conditions (Záruba and Mencl, 1969; Varnes, 1978). In Czechoslovakia, however, a few cases of remigrated older landslide under natural conditions have been reported (Záruba and Mencle, 1969). A repeatedly reactivated landslide was reported in USSR (Popov, 1951).

On the causes of the large-scale mass movements during Middle to Late Quaternary time, Shibasaki (1967) pointed out the importance of studying them from the viewpoint of Quaternary geohistory. Two main causes as followings have been proposed for the occurrence of mass movements.

i) The ground upheaval and growth of mountain slopes due to sea level lowering during the glacial epoch (e.g., Kobayashi, 1962; Shibasaki, 1966; Sugiyama, 1975; Aoki, 1975; Fujita, Y., 1978, 1981; Fujita, T., 1982, 1983; Takahama and Aoki, 1979; Takahama and Nozaki, 1981; Takahama, 1982a).

ii) The paleoclimatic conditions of the glacial and interglacial epochs are different from the present ones (Záruba and Mencl, 1969; Hirakawa and Ono, 1974; Aoki, 1975; Terado and Katto, 1980).

At present, much importance is given to the glacial climatic change, inclusive of sea level lowering, as a major cause of older mass movements, and especially, European researchers consider that most of the older mass movements are attributed to the paleoclimatic effects (Záruba and Mencl, 1969; Varnes, 1978).

As mentioned above, there are some differences of opinion on the occurrence of older mass movements and remigration of their products.

Only a few fragmentary descriptions have been made on the older mass movement deposits and their topography in Japan, and have many problems that have remained to be unsolved on the processes and causes of the older mass movements. Investigation of the time-space distribution and the properties of the older mass movement deposits is important. The older mass movements are examined in this paper by the following viewpoints.

i) The processes of mass movements from Middle Quaternary time to the present are clarified on the basis of the stratigraphic division of the mass movement deposits.

ii) The causes of mass movements in geologic time are comprehensively reviewed in relation to the Quaternary geohistory of the areas concerned, especially the development of mountain topography.

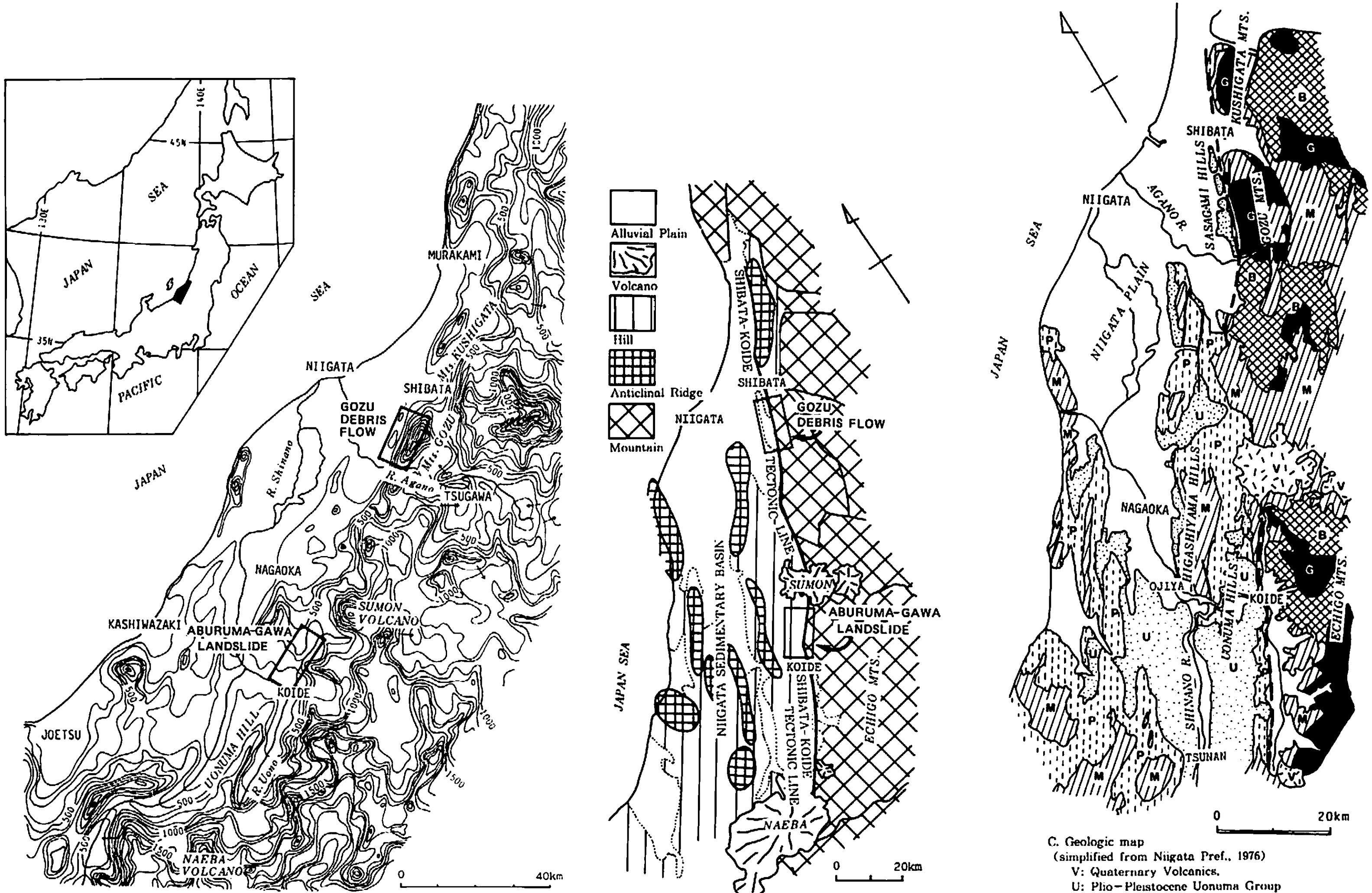
III. METHODS OF THE STUDY

The first step of the study is to recognize the older mass movement deposits in the light of the characteristic sedimentary properties of the recent ones.

Next is to establish the stratigraphic positions of the mass movement deposits, and lastly the mutual relation between the genesis of the mass movements and the crustal movements is examined.

1. Topography and Geology of the Surveyed Areas

The topography and geology of the areas around the Gozu Mountains and the drainage region of the Aburuma River which were selected as the subject of this study are briefly described here (Fig. 1).



A. Summit level map
(eliminated valleys less than 2 km wide)

B. Topographic division

C. Geologic map
(simplified from Niigata Pref., 1976)
V: Quaternary Volcanics,
U: Plio-Pleistocene Uonuma Group
P: Pliocene Haizume and Nishiyama Formations,
M: Miocene Series
B: Pre Tertiary Rocks,
G: Granitic Rocks

Fig. 1. Topography and geology of the Niigata region with the localities examined

Age		Niigata Basin (Type Sequence)		Aburuma-gawa[1] Valley	Sasagami Hills[2]
Holocene		Alluvium	Holocene Tr. dep.	Terrace Ⅳ dep.	Alluvium
Pleistocene	Late	Lower Tr. dep.		Terrace Ⅲ dep.	Nihonmatsu Tr. dep.
Pleistocene	Late	"Middle Tr. dep."		Terrace Ⅱ dep.	Anchi Tr. Ⅱ/Ⅰ dep.
Pleistocene	Middle	"Higher Tr. dep."		Terrace Ⅰ dep.	Agano-gawa Tr. Ⅱ/Ⅰ dep.
Pleistocene	Middle	Naeba volcano pyroclastics		Sumon volcano pyroclastics	
Pleistocene	Early	Uonuma G. Upper F.	Oguni F.	Uonuma G. Upper M.	Sasagami F.
Pleistocene	Early	Uonuma G. Middle F.	Tsuka-yama F.	Uonuma G. Middle M.	
Pleistocene / Pliocene	Early	Uonuma G. Lower F.	Tsuka-yama F.	Uonuma G. Lower M.	Yamadera F.
Pliocene		Uonuma G. Lowest F.	Wanazu F.	Wanazu F.	
Pliocene		Haizume F.		Haizume F.	
Pliocene		Nishiyama F.		Nishiyama F.	Dainichi F.
Miocene		Shiiya F.			
Miocene		Teradomari F.		Tsunaki F.	Haguro F.
Miocene		Nanatani F.		Nishimyo F.	Sakanaiwa F.
Miocene		Tsugawa F.		Anazawa F.	Yamanokami F.
Miocene		Kanose F.		Jonai G.	
Miocene		Mikawa F.			Arakawa F.
Basement		Pre–Neogene Rocks			Gozu Granites

1) Masai and Takahama, 1981
2) Coll. Res. Group Sasagami Hills, 1982

Fig. 2. Correlation chart of Late Cenozoic Systems of surveyed areas and the Niigata sedimentary basin. Vertical lines represent lacnae of the sediments.

The two areas examined are located on the boundary between the Niigata sedimentary basin including plains and hills in the west and mountains in the east. The geology and stratigraphy are shown in Figs. 1 – C and 2. The Upper Neogene and Quaternary sequences are widely distributed on the basin side, whereas the mountain side is composed of the pre-Neogene and Lower Neogene rocks. The boundary between two areas is a fault zone called the Shibata-Koide Tectonic Line (Yamashita, 1970) (Fig. 1 – B). The difference of gravity anomaly between the west and the east sides of the tectonic line is about 60 mgal, and the relative amount of vertical displacement since Pliocene age attains to more than 3,000 m (Maruyama *et al*., 1981).

The Gozu debris flows are distributed in the Gozu Mountains located on the east side of the northern part of the tectonic line. The Gozu Mountains, a little less than 1,000 m in height above sea level, is composed of granite and have the amount of reliefs of nearly the same order of magnitude as its elevation. The Aburuma-gawa landslides occurred in the Uonuma Hills on the west side of the southern part of this tectonic line. The hills composed of the Neogene and Quaternary Systems, have an elevation of 500 – 600 m above sea level and the amount of relief is 300 – 400 m. These differences between the two areas in physical properties of the bedrocks and topography could have produced the different types of mass movements. In both areas the mass movement deposits attain to about 20–40 km^2 in area.

2. Recognition of Mass Movement Deposits

Before describing the older mass movement deposits in the surveyed areas, it is important to distinguish the characteristic features of recent debris flow and landslide deposits. They are summarized as follows.

A. Debris flow deposits

A debris flow is a phenomenon in which the debris accumulated on the stream bed or a mountain slope comes to contain a large quantity of water and rapidly flows down in the form of mass flow (Okuda, 1981). The lithofacies of debris flow deposits were described by Imamura (1978, 1983), Okuda (1981) and Suwa and Okuda (1982). According to them, the debris flow deposits are characterized by an inclusion of numerous boulder gravels, unstratified beds with poor sorting, development of inverse grading and high-angle imbrication. Furthermore, Suwa and Okuda (1982) classified the debris flow deposits into the swollen type and flat type deposits. The swollen type deposit consists mainly of boulder gravels and is distributed in the upstream side of an alluvial fan, while the flat type deposit is smaller in gravel size and is distributed in the downstream side of an alluvial fan.

Referring to the above description, the debris flow deposits are divided in this paper into three types.

Debris flow deposit of type A (Abbreviation: A type deposit)

The A type deposit is a typical debris flow deposit, which frequently contains boulder gravels larger than 1 m across (maximum diameter 2 – 3 m) and has very low degree of sorting (Plates I – 1 , 2 , II – 1). An inverse grading and high-angle imbrication are often observed. This type corresponds to the swollen type deposit of Suwa and Okuda (1982) and to the deposit of a debris flow proper of Imamura (1983).

Debris flow deposit of type B (B type deposit)

The B type deposit has less amount of boulder gravels and better sorting than the A type deposit has (Plates I –3, II –2). This type corresponds to the flat type deposit of Suwa and Okuda (1982). This is probably a deposit derived from residual flow after the main flow released boulder gravels on the way of its downward migration.

Debris flow deposit of type C (C type deposit)

The C type deposit is massive and unstratified sand beds, sporadically containing large and small gravels (Plate III – 3). This type of deposit is generally called "dosharyu" deposit (flood deposit of sand debris) in Japan.

Now, the difference between the types B and C of debris flow deposits and the traction current deposits such as terrace gravel bed must be recognized based on the synthetic inference. For example, the terrace deposit is distinguished from the B type deposit on the basis of the following properties:

i) higher roundness of gravels, and higher degree of sorting of gravel beds
ii) more diversified gravel composition
iii) more distinctive imbrication
iv) distinct stratification and lamination in many cases

The distinction between the two deposits, however, is gradational with numerous "intermediate type deposits".

B. Landslide deposits

The term "landslide" has been used in various ways, without any unity of opinions. This is because landslides occur and move in different forms depending on the lithology of bedrock and the topographic situation of the areas concerned, and their types are complex and gradational. Uemura (1975) classified the forms of landslide movement into four basic types, i.e., creep, slide, flow and fall types.

Shibasaki (1960) designated the landslide newly occurred from the bedrock as a primary landslide, while another landslide remigrated from the older colluvial deposits as a secondary landslide. About the discrimination between a landslip and a landslide, Koide (1953, 1973) and Shibasaki (1960) have nearly the same opinion as follows. A landslip is a rapid movement of the materials constituting the surficial part of the slope, and the material is stabilized after the landslip having once occurred. While a landslide is a movement of the materials migrating from deep part of bedrock, and the material unstable to migrate, repeatedly to result in a secondary landslide.

In this paper, referring to them, a landslide is defined as follows. A landslide is migration of the bedrock derived from a deeper part. The materials were represented by those broken into blocks, and therefore, the major portion of them may still remain on the mountain slope (primary landslide). They may be removed again on various scales, thus resulting in a secondary landslide which will be repeated. The movements are mostly of the slide and creep types. They are accompanied, however, by the fall type movement in the upper slope and by the flow type movement in the lower slope.

In this circumstances, the author gives the following two points as the criteria for identifying the landslide deposits, on the basis of the lithofacies and the surface configration of deposits. The first point is the presence of rotational slump blocks. These blocks are variable in size, ranging from very small to as large as 10−100 m across, and are irregular in shape. As a whole, the deposits present very poor sorting in lithofacies. The second point is that the rotational slump blocks can be confirmed from the surface configration immediately after the occurrence of landslide. Consequently, a landslide is distinguishable from other mass movements.

In some cases, however, a landslide grades into a landslip, or a landslide takes a debris flow style in the downstream. Therefore, it is sometimes difficult to distinguish the landslide deposits from the other mass movements deposits. Accordingly, it is required to take over-all judgement to determine the landslide deposits.

3. Recognition of Stratigrphy of Mass Movement Deposits

The division of the mass movement deposits is the same for the general stratigraphic division of Quaternary deposits.

The Gozu debris flow deposits are stratigraphically classified into, based on the following three indices.

i) The confirmation of stratigraphic relationship among the debris flow deposits themselves and of the successive ordering of debris flow deposits and terrace deposits in the Tsubeta fan and in the north bank of the Agano River.

ii) The temporal relationship inferred topographically among the depositional surface of debris flows, and the topographic relationship between the depositional surface of debris flow and the terrace surface in the Sasagami Hills and the Dainichigahara fan.

iii) To make inference of the formative age by meams of soil color range from red to brown in the surface layer of the debris flow deposits and by the degree of weathering of the gravels.

The Aburuma-gawa landslide deposits can be divided stratigraphically by the following three points.

i) The confirmation of the relation between the landslide deposits and the overlying volcanic ash beds which have definite stratigraphical position (Masai and Takahama, 1981).

ii) To notice the difference in the materials constituting the landslide deposits (AC I and AC II to be mentioned later) and also in the degree of weathering.

iii) The chronological order of the landslide forms and the topographical relationship between landslides and terraces.

Therefore, the criteria of stratigraphical division are summarized as follows.

i) The temporal relationship of topographic surface (depositional surface).

ii) The degree of weathering.

iii) The stratigraphic relationship is infered from volcanic ash layers.

iv) The stratigraphic relationship of mass movement and terrace deposits.

4. Recognition of Upheaval Movement

The criteria to comprehend the relationship between the upheaval movement of mountain region and the occurrence of mass movement have not been confirmed so far. In the present paper, the process of upheaval movement since the Pliocene in this region is attempted to reconstruct on the Gozu Mountains, referring to Collaborative Research Group for Sasagami Hills (1980, 1982) (Chapter V－2).

i) The amount of vertical displacement between the plain and the mountains since the Pliocene.

ii) The block movement of the mountains.

iii) The recognition of the transformation age of the upheaval movements.

iv) The analysis of the stepwise upheaval process of the mountains.

From these investigation, the mutual relation between the upheaval movement and the occurrence of mass movement is deduced (Chapter V－3).

IV. MASS MOVEMENTS IN THE EASTERN MARGINAL REGION OF THE NIIGATA SEDIMENTARY BASIN

In order to make comparative study on two different types of mass movements, two areas differring in the geology, the basement rocks and the type of mass movement, are chosen for study. They are the area around the Gozu Mountains and the drainage basin of the Aburuma River.

1. Gozu Debris Flow Deposits

The Gozu Mountains are situated in the eastern margin of the northern part of the Niigata Plain. From the western foot of the Gozu Mountains in the east to the Sasagami Hills in the west, debris flow deposits are confirmed at many stratigraphic horizons of the Middle Pleistocene and younger formations. The stratigraphic division of the formations and the historical development of debris flows were outlined in Takahama and Nozaki (1981). The stratigraphic division, the formative age and the successive change of volume of the Gozu debris flow deposits are described in this section.

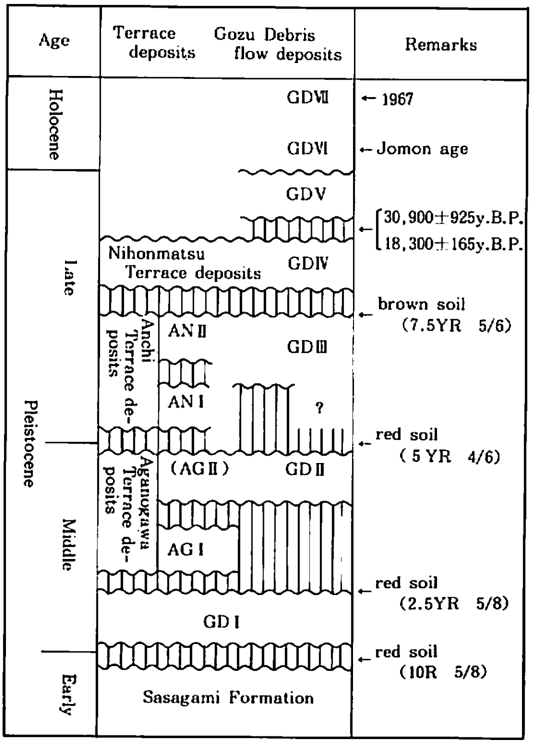


Fig. 3. Correlation of the Gozu debris flow deposits and the terrace deposits of the Sasagami Hills (Takahama and Nozaki, 1981). Vertically ruled parts represent lacunae of the sediments.

The Gozu debris flow deposits have a remarkable lateral change in lithofacies. In broader aspects, the debris flow deposit on the upstream side and the traction current deposit on the downstream side are in an interfingering relation. These are contemporaneous deposits, and the supply source of the traction current deposit is the debris flow deposit on the upstream side. In this paper, therefore, they are grouped together under the name of Gozu debris flow deposits, or GD I (Gozu gravel bed), GD II ⋯etc. The stratigraphic succession of the Cenozoic in the Sasagami Hills is shown in Fig. 2.

A. Stratigraphy of the debris flow deposits

With the indices described in III − 3, the Gozu debris flow deposits are divided into seven members, that is GD I (Gozu gravel bed), GD II (Nakayama gravel bed), GD III (Dainichigahara gravel bed), GD IV (Imaita gravel bed), GD V (Murasugi gravel bed), GD VI (Tsubeta gravel bed) and GD VII (1967 gravel bed), in ascending order (Table 1 and Fig. 3). Their distribution is shown in Figs. 4 and 5. The stratigraphic position and the topographic relation of these gravel beds in the Tsubeta fan and the Sasagami Hills are schematically illustrated in Fig. 6. The higher topographic surfaces of the older age are formed at in the Gozu Mountains and the Sasagami Hills, while the older surfaces are buried by younger deposits in the Murasugi Lowland. Each gravel bed, except GD VII, is composed of several units of debris flow deposits as will be mentioned later.

Table 1. Characteristics of Gozu debris flow deposits (Takahama and Nozaki, 1981)

Debris Flow Deposits	Type Locality	Topography	Weathering and Soil development	Thickness (estimated volume)	Remarks
1967 Graval Bed (GD VII)	Tsubeta Fan	Alluvial Fan	Not weathered	1 ~ 3 m ($2 \times 10^6 m^3$, 0.1 %)	Occurred on Aug. 28, 1967
Tsubeta Gravel Bed (GD VI)	Tsubeta Fan	Alluvial Fan	Not weathered	1 ~ 5 m ($1 \times 10^7 m^3$, 0.7 %)	Tsubeta site of Jomon age is buried in the sediments
Murasugi Gravel Bed (GD V)	Anno River	Lower stream valley fills in Gozu Mts.	With yellowish brown soil surface (10YR 5/8)	5 ~ 10 m ($4.2 \times 10^7 m^3$, 2.9 %)	Occurrence of *Pinus koraiensis* *Tsuga* cf. *diversifolia* 30,900±925y.B.P. 18,300±165y.B.P.
Imaita Gravel Bed (GD IV)	Dainichigahara Fan	Dissected, surface topography is continued to Nihonmatsu terrace surface	With brown soil surface (7.5YR 5/6)	5 ~ 10 m ($4.3 \times 10^7 m^3$, 3 %)	
Dainichigahara Gravel Bed (GD III)	Dainichigahara Fan	Dainichigahara dissected Fan, continuing to Anchi terrase surface	With brown soil surface (7.5YR 5/6) and moderately weathered gravels	10 ~ 20 m ($2 \times 10^8 m^3$, 13.5 %)	
Nakayama Gravel Bed (GD II)	Nakayama Village	Moderately dissected surface, distributed on the slope of Sasagami Hills	With yellowish red soil surface (5YR 4/6) and strongly weathered gravels	10 ~ 25 m ($3 \times 10^8 m^3$, 21 %)	The age of Sasagami Hills upheaval
Gozu Gravel Bed (GD I)	Jingamine Peak	Deeply dissected surface, distributed on the top of Sasagami Hills Covered by terrace deposits along Agano River	With red soil surface (2.5YR 5/8) and strongly weathered gravels	10 ~ 30 m ($8.5 \times 10^8 m^3$, 59 %)	

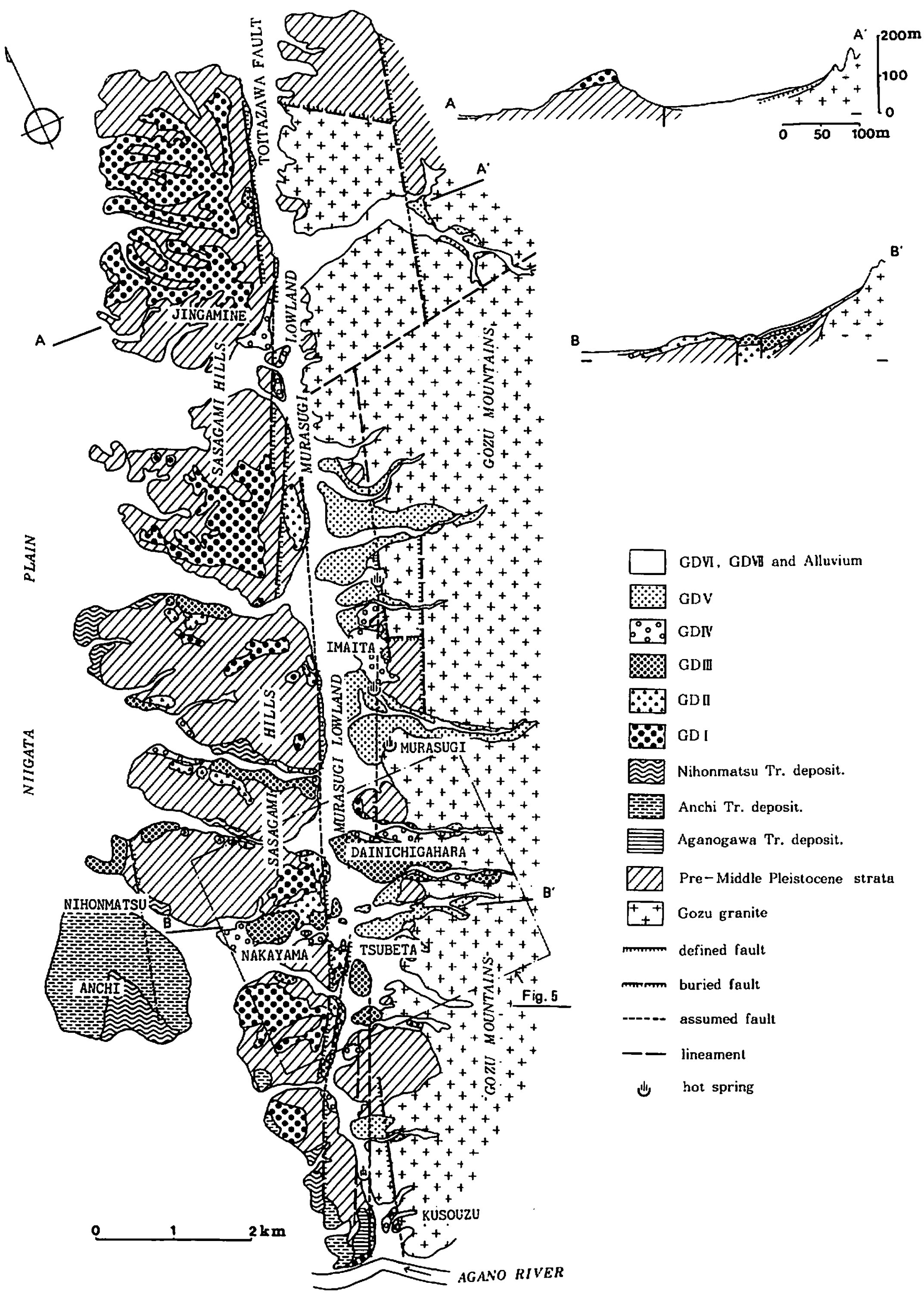


Fig. 4. Geological map and profiles of the western foot of the Gozu Mts. and Sasagami Hills (Takahama and Nozaki, 1981)

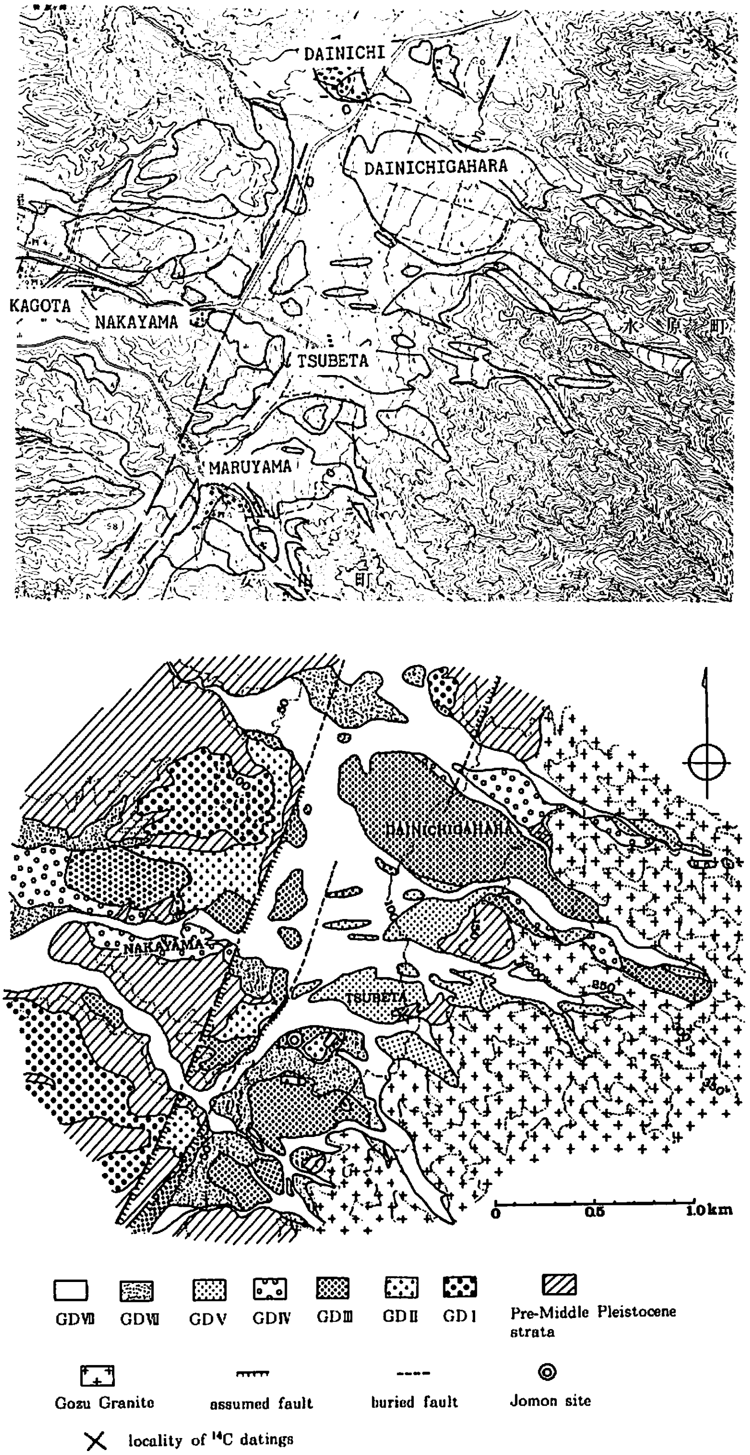


Fig. 5. Topography (above) and detailed geological map (below) of the Tsubeta and Dainichigahara fans (Takahama and Nozaki, 1981)

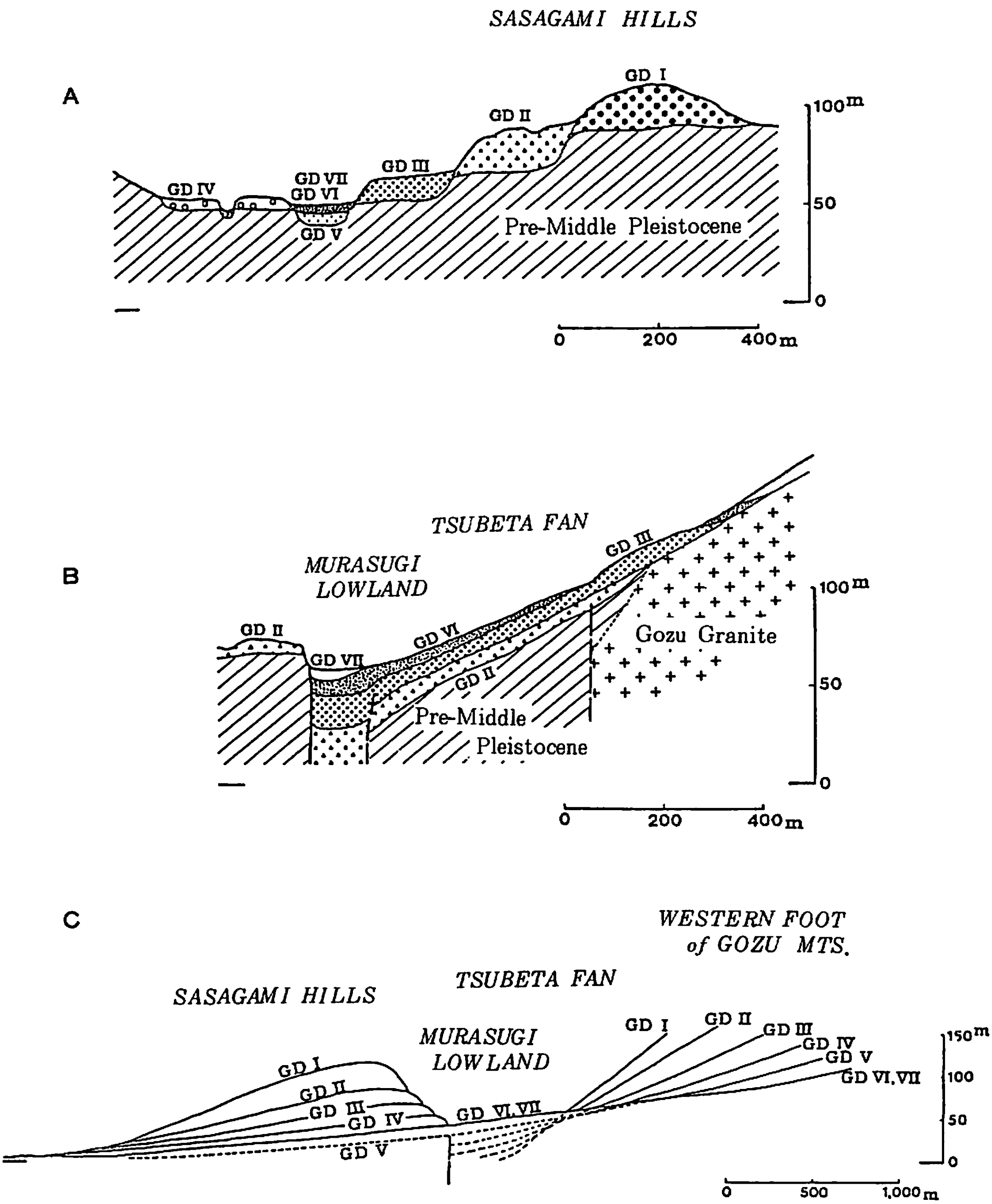


Fig. 6. Idealized cross sections of the Gozu debris flow deposits, showing the relation between topography and deposits (Takahama and Nozaki, 1981)

A: Sasagami Hills, B: Western foot of Gozu Mts.

C: Correlation of topographic planes between Sasagami Hills and Gozu Mountains. Schematic cross section is shown along B−B' line in Fig. 4.

GD I (Gozu gravel bed)

GD I is widely distributed at the highest level of the Sasagami Hills. In the north bank of the Agano River, GD I is unconformably overlain by the Aganogawa Terrace I deposit which is the oldest terrace deposit in this area. The unconformity with the underlying Sasagami Formation of Early Pleistocene age is confirmed at Jingamine peak in the northern part of the Sasagami Hills. The depositional surface of GD I is markedly dissected. The red soil (2.5 YR 5/8) in the surface layer is 5−6m in maximum thickness. Gravels in the upper part are also red-colored due to weathering.

The major part of GD I, distributed at the foot of the Gozu Mountains and in the north bank of the Agano River, is a bed of poorly sorted gravels with many subrounded boulders of more than 1 m in diameter. This is the A type deposit defined in the preceding section (Plates I −1, 2). All of the boulders are granite derived from the Gozu Mountains. Cobble-to pebble-size gravels derived from the Paleozoic, Mesozoic and Tertiary Systems are also contained but in a minor amount. GD I is intercalated with lenticular-or irregular-shaped thin beds of pebble-to cobble-size gravels as shown in Plate I − 1.

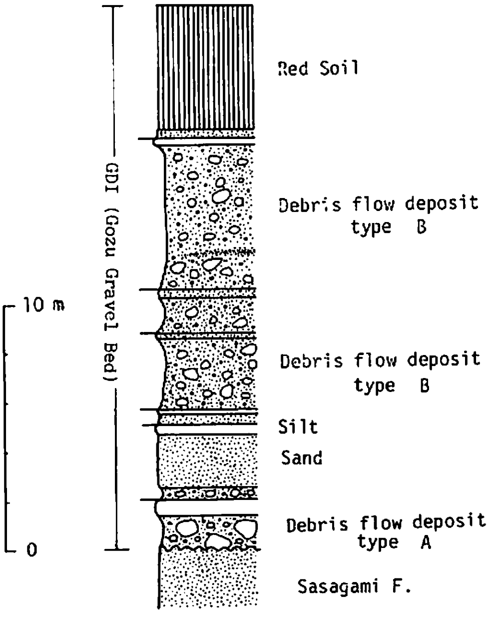


Fig. 7. Stratigraphy and litofacies of GD I at Jingamine Peak in the northern part of the Sasagami Hills. Six units of debris flow deposits can be recognized (simplified from Coll. Res. Group Sasagami Hills, 1982).

The stratigraphic type section of GD I is recognized at the north bank of the Agano River and at Jingamine in the Sasagami Hills. In the north bank of the Agano River, two or more units of debris flow deposits are observed. The intercalated thin bed of pebble-to cobble-sized gravels correspond to the B type deposit, or to the "intermediated type" deposit between the B type deposit and the traction current deposit.

On the other hand, GD I distributed in the summit area of the hills contains smaller amounts of boulder gravels than those at the foot of the mountains. In general, the size of gravels of the former is smaller than the latter, and the degree of sorting is higher in the former. In addition, the B type deposits are predominated in the former. It has numerous intercalations of traction current deposit such as laminated sand and silt layers. The columnar section at the Jingamine peak in the northern part of the hills is shown in Fig. 7. Here at least six units of debris flow deposits are distinguished. In the western margin of the hills on the west (down-stream) side of the Jingamine peak, GD I is found to grade into traction current deposits of laminated sands and well-sorted subrounded cobble-size gravel bed.

It is inferred from the present distribution pattern that GD I was widely distributed on the western foot of the mountains at the depositional stage covering the top of the Sasagami Hills (Fig. 11). Therefore, there did not exist the Sasagami Hills at that time, and the gentle fan extended there. It is estimated that the area is about $40km^2$, and the amount of sediments is about 8.5×10^8 m^3. Later the hills were formed by faulting along the eastern margin of the existing hills. GD I is considered to have been dissected markedly on the way forming the hills, resulting in the present distribution. The GD I was formed in Middle Pleistocene time, as will be mentioned later.

GD II (Nakayama gravel bed)

GD II occurs in the lowermost horizon of the debris flow deposits constituting the Tsubeta fan (Figs. 5, 10). In the Sasagami Hills, GD II is distributed in the flank of the hills. GD II in the north bank of the Agano River is unconformable with the underlying Agano-gawa Terrace I deposit and with the overlying Anchi Terrace I deposit (Fig. 10). The depositional surface of GD II is discernible in spite of advanced dissection*. The red soil (5 YR 4/6) of the GD II surface has a thickness of 3 – 4 m, and the gravels themselves are strongly weathered and partially turned to soil.

* The GD II depositional surface in the north of Nakayama reported by Takahama and Nozaki (1981) is the depositional surface of GD III which incised the GD II.

GD II in the Tsubeta fan is a type A of debris flow deposit, containing boulder gravels of 2 – 3 m in diameter. It changes to the B type deposit with intercalating laminated and irregular-bedded sand layers at Nakayama in the hills on the downstream side (Plate I – 3). By these sand layers, GD II can be divided into 3 or 4 units of debris flow deposits. GD II in the north bank of the Agano River is traction current deposits of coarse-grained, finely laminated and red-colored sands derived from granite, showing the marginal facies of debris flow deposit.

The GD II deposits is the second largest in quantity next to GD I among the Gozu debris flow deposits. It is the deposits at the stage when the Sasagami Hills began to uplift in the Middle Pleistocece.

GD III (Dainichgahara gravel bed)

GD III constitutes the Dainichigahara fan at the foot of the Gozu Mountains, and it is widely distributed along the river system which transverses the Sasagami Hills in the west. The topographic surface formed by GD III is preserved well and is easily discernible. The depositional surface of GD III corresponds to the Anchi Terrace surface in the western margin of the hills. The brown soil (7.5YR 5/6) in the surface layer is about 2 m thick.

The lateral change of lithofacies in the direction downward of the debris flow is observed most distinctively throughout all the Gozu debris flow deposits. The deposits consist mainly of boulder gravel, being intercalated with discontinuous sand and silt layers, in the apex area of the Dainichigahara fan at the foot of the Gozu Mountains on the upstream side (Plates II –1). The boulder gravel beds with the matrix composed of silt-bearing coarse sand contain numerous subrounded to subangular granite boulders (1 – 2 m in diameter), and is extremely poor in sorting on the whole. Some gravels show the high-angle imbrication. This is a typical A type deposit.

GD III in the hills is composed of the alternation of gravel and sand, accompanied by a silt layer in the middle part (Plate II – 2 and Fig. 8.). The gravel beds are relatively less in boulder contents and higher in the degree of sorting than those at the mountain foot, and are referred to as a B type deposit or the "intermediate type deposit". Sand and silt layers showing a distinct lamination are traction current deposits. At least five units of debris flow deposits are distinguishable here (Fig. 8).

GD III in the western margin of the Sasagami Hills grades into laminated sand layers containing a small amount of gravels (Plate II – 3). They are traction current deposits. The distance from the apex part of the Dainichigahara fan (Plate II –1) to the western margin of the Sasagami Hills (Plate II –3) is about 3 km.

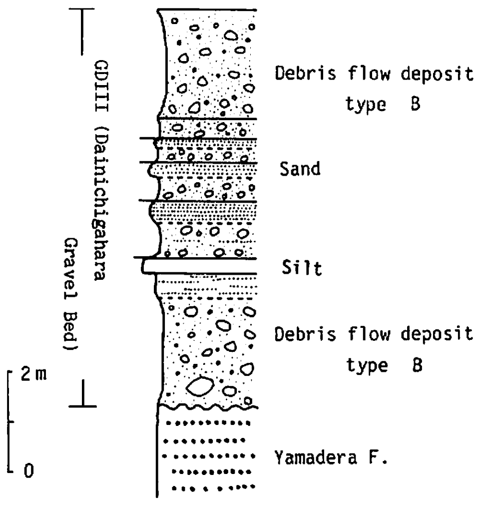


Fig. 8. Stratigraphy and litofacies of GDⅢ in the eastern part of the Sasagami Hills. Five units of debris flow deposits are discernible.

GD Ⅳ (Imaita gravel bed)

GDⅣ on the north side of the Dainichigahara fan constitutes a small fan lower than the Dainichigahara fan surface. The topographic surface is well preserved, and continues to the Nihonmatsu Terrace surface along the Tsubeta and Anno Rivers. A brown soil (7.5YR 5/6) about 1 m thick is developed in the surface layer.

GDⅣ on the north side of the Dainichigahara fan presents an A type lithofacies containing a large number of boulder gravels. In the south of Maruyama, a B type gravel bed is distributed. GDⅣ is small in scale in comparison with the other older debris flow deposits.

GDV (Murasugi gravel bed)

GDV is distributed in an area extending from the river system in the Gozu Mountains to the Murasugi lowland. It forms a fan surface at the foot of the mountains, and the surface is covered with the alluvial deposits in the Murasugi lowland. A yellowish brown soil (10YR 5/8) with a maximum thickness 1 m or so is observed in the surface layer of the gravel bed. Topographic distinction of GDV to GDⅦ is usually difficult except in the mountaineous area.

In the upstream area of the Anno River in the Gozu Mountains, the A type deposits are divided into two units by a brown silt layer.

GDⅥ (Tsubeta gravel bed)

GDⅥ, widely distributed in the Murasugi lowland, is observed well in the downstream area of the Tsubeta fan and its vicinity. It is divided into four or five units of debris flow deposit by three intercalated beds of humus soil which contains earthenwares of the Middle to Late Jomon age (Plate Ⅲ－2) in the Tsubeta fan. A layer of humus soil about 10cm thick is observed in the surface layer.

In the Tsubeta fan, the A type deposit (Plate Ⅱ－4) containing many boulder gravels rapidly grades into the C type deposit consisting mainly of massive unstratified sand (Plate Ⅲ－2) transversely to the direction of flow. The deposits are formed in late Holocene time.

GDⅦ (1967 gravel bed)

GDⅦ is a deposit that was laid down on August 28, 1967, and is distributed in the area centering on the Tsubeta fan. By the survey immediately after its occurrence, the debris flow deposit was distinguished from the so-called "dosharyu" (earth-flow) deposit distributed in the front and on the lateral sides (Chihara *et al.*, 1968) (Fig. 9). GDⅦ at Imaita comprises an A type deposit, which contains a large number of boulder gravels and reverse grading, and a C type deposit consisting mainly of massive unstratified sands with pebble-size gravels and sporadic cobble gravels lying below and on the side of the A type deposit (Plate Ⅲ－3).

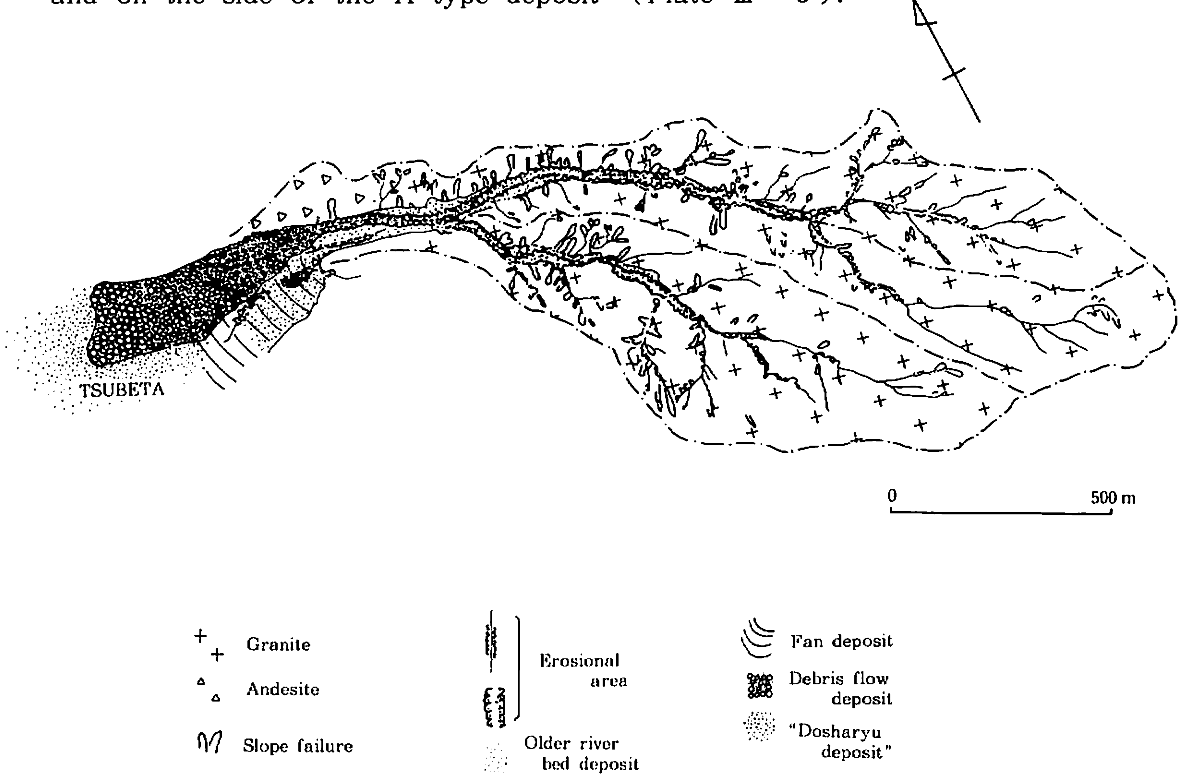


Fig. 9. Slope failure and debris flow along the Tsubeta River on Aug. 28, 1967 (Chihara *et al.*, 1968)

Characteristics of the respective debris flow deposits are shown in Table 1. Moreover, the relation between debris flow deposits and terrace deposits and soil layers is observed at the following localities (Fig. 10). The Agano-gawa Terrace I deposit is intercalated between GD I and GD II on the north bank of the Agano River. In the Tsubeta fan, the debris flow deposits are divided stratigraphically into GD II, GD III, GD IV, and GD VI in ascending order, based on intercalating thick soil layers.

B. Formative stage of debris flow deposits

The stages of formation of the debris flow deposits are determined based on the correlation of them with terraces deposits. The terrace deposits of this area are divided into the Agano-gawa I, II, Anchi I, II and Nihonmatsu beds, from older to younger (Coll. Res. Gr. Sasagami Hills, 1982). The correlation between the Gozu debris flow deposits and these terrace deposits is summarized in Fig. 3, based on the descriptions given in the preceding clause. The Agano-gawa Terraces are assigned to the Middle Pleistocene in age, the Anchi Terraces to the last interglacial epoch and the Nihonmatsu Terrace to the early last glacial epoch (Coll. Res. Gr. Sasagami Hills, 1982). According to these inferences, GD I and GD II are the debris flow deposits produced in the Middle Pleistocene, GD III in the last interglacial epoch, and GD IV in the early last glacial epoch.

It is known that the old river-bed deposit at the base of GD V was formed during the coldest period of the last glacial epoch, as judged from ^{14}C dating of the buried wood pieces (30,900 – 18,300 y.B.P.) and from the fossil plants indicating a cold climate, such as *Pinus koraiensis* and *Tsuga* cf. *diversifolia* (Table 1). Thus, GD V may have been deposited at the latest stage of last glacial epoch. GD VI was deposited during the Middle to Late Jomon age, and GD VII in 1967.

C. Historical changes of debris flows

The original distribution of GD I to GD VI at the time of their deposition is reconstructed in Fig. 11*. The figure shows that GD I was deposited widely in the area of the present Sasagami Hills. The subsequent debris flows were deposited in narrow areas, restricted at the foot of the Gozu Mountains, in relation with the uplift of the Sasagami Hills.

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* Fig. 11 shows the areas where the A type debris flow deposits have been confirmed or inferred. The figure clearly suggests that the typical debris flow deposit (A type) is distributed in a narrow area restricted to the mountain foot.

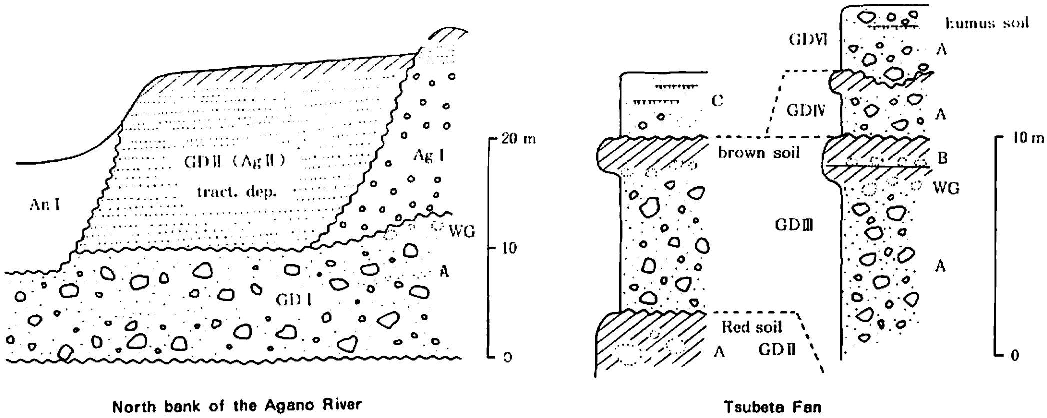

Fig. 10. Generalized section of the Gozu debris flow deposits showing stratigraphic relation.
A, B and C: Debris flow deposits of A, B and C types, respectively. GD: Gozu debris flow deposits, Ag: Aganogawa terrace deposits, An: Anchi terrace deposits, WG: Weathered gravel

The volumes of debris flow deposits were calculated from the size of the depositional area and the average thickness of deposits (Table 1), in comparison with the total sum of debris flow deposits. The comparison reveals the fact that GD I forms about 60% of the total, GD II −20%, GD III −13%, and GD IV to GD VII − 7%. Thus, the volumes of GD I and GD II of the Middle Pleistocene age and GD III of the early Late Pleistocene are much larger than those of the younger.

At the time of the depositional volumes are compared, it must be examined whether accumulation of the Gozu debris flows were "periodically" or were "concentrated" at some definite stages. If the debris flows were produced "periodically", the above mentioned comparison of their volumes would mean only that the volumes are proportional to the length of time. The stratigraphic successions of GD I, GD II and GD III have the following four characteristics.

i) The Agano-gawa Terrace I gravel bed is intercalated between GD I and GD II in the north bank of the Agano River (Fig. 10). As those two deposits are clearly distinguished geologically, therefore, the long time interval is estimated between the two deposits.

ii) The succession of GD II through GD IV is confirmed in the Tsubeta fan (Fig. 10). Weathered gravels and buried old red or brown soils are found in the upper part of GD II and GD III. These facts show the existence of long time intervals between two successive debris flow deposits.

iii) GD I, GD II and GD III distributed in the Sasagami Hills are clearly different in altitude of distribution and in topographic relief each other (Table 1). These facts also support that there were long breaks of deposition.

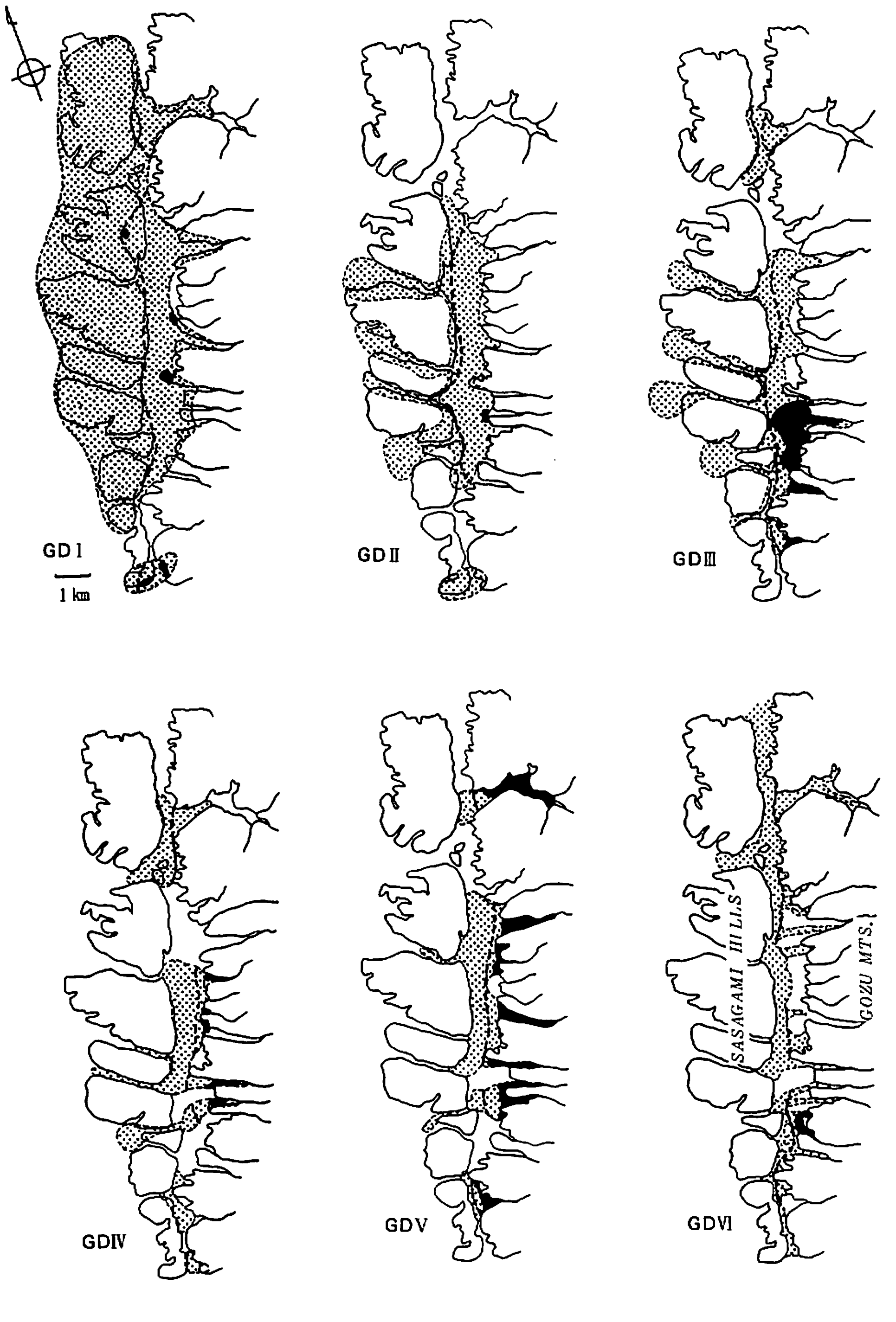

Fig. 11. Reconstructed distribution area of the Gozu debris flow deposits (Takahama and Nozaki, 1981). The area is the same as that shown in Fig. 4. Black indicates the confirmed area of debris flow deposits of A type. Eastern side of the broken line shows the inferred area of distribution of A type. A type is limited to the eastern foot-hill in distribution.

iv) Several flow units of debris flow deposits are recognized respectively in GD I , GD II and GD III .

From collective features of those debris flows, it is reasonable to assume that they were formed in a relatively short time followed by a long interval.

2. Aburuma-gawa Landslide Deposits

The landslides developed on the west side of the Aburuma River in the eastern margin of the northern Uonuma Hills have been outlined by the author (Takahama, 1981). Stratigraphy and lithofacies of the Aburuma-gawa landslide deposits, and their formative stages are described here. The geology and the topography of the drainage region of the Aburuma River are given in Figs. 12, 13 and 15, and the stratigraphy in Fig. 2.

AC I is a mass movement deposits, but it could not be identified as a distinctive landslide deposit. However, "Aburuma-gawa landslide deposits" is used here in a broader sense inclusive of AC I for the convenience.

A. Stratigraphy of the landslide deposits

With the criteria mentioned in III − 3 , the mass movement deposits can be classified into four groups, namely, AC I , AC II AC III and AC IV , from older to younger (Fig. 14, Table 2). Their distributions are illustrated in Fig. 15.

ACI

AC I is distributed mainly in the summit area of the Uonuma Hills. It covers unconformably the Lower Pleistocene Uonuma Group. The depositional surface is deeply dissected. The deposits are covered with the "Red volcanic ash beds" and " Brown volcanic ash bed" (Fig. 16).

The sources of AC I are the gravels of the Uonuma Groups and andesites of the Pliocene and Middle Pleistocene Series of the hills. Andesite angular clasts reach a maximum diameter of 3 − 4 m. The matrix is composed of tuffaceous red soil and silt-bearing sand, and is very poorly sorted (Plate IV − 1). Irregular lamination showing subaqueous depositional enviroment and lenticular carbonaceous layers are observed in part, but no distinct stratification and sorting are recognized. The maximum thickness of AC I is more than 50 m. In the surface layer, both gravels and matrices are red-colored due to intence weathering. From these occurrences, AC I is considered to be a landslide deposit which remigrated under water for a short distance, or a deposit of an intermediate type between a water-soaked landslide deposit and a debris flow deposit. The AC I was formed at the formative stage of the Uonuma Hills in Middle Pleistocene time as will be mentioned later.

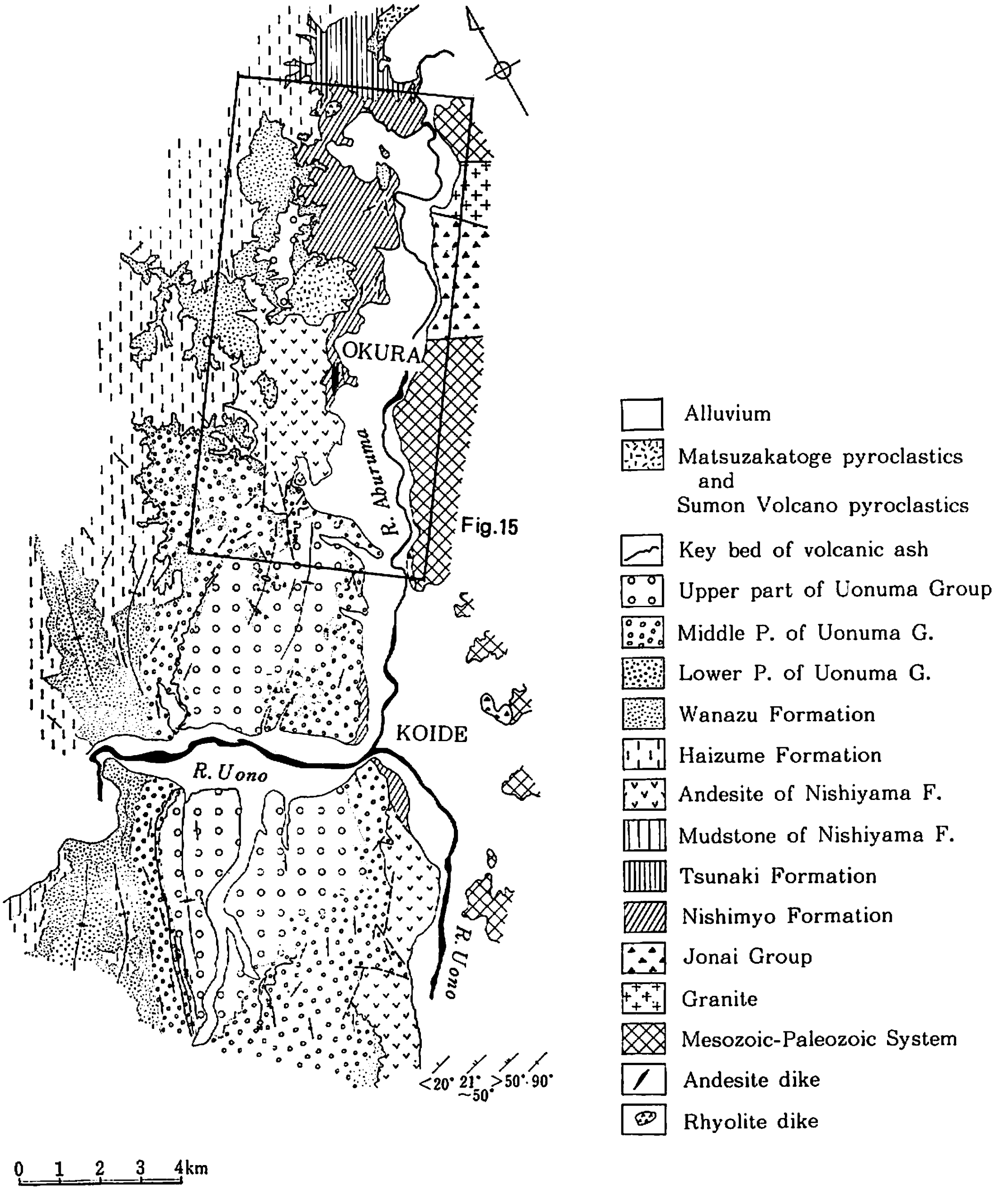

Fig. 12. Basement geoloy of the Aburuma-gawa Valley, northern part of the Uonuma Hills (Masai and Takahama, 1981)

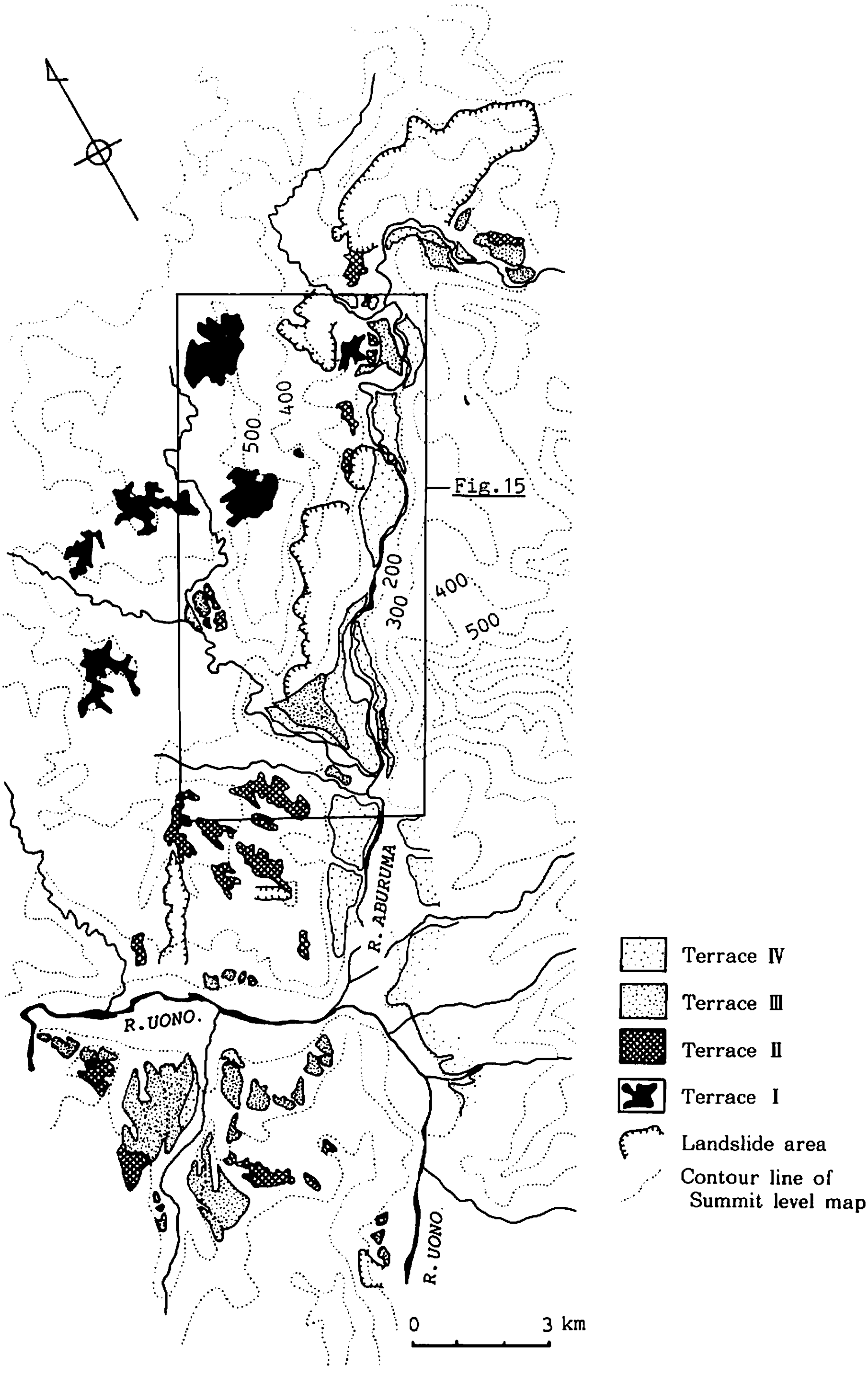

Fig. 13. Distribution of river terraces in the northern part of the Uonuma Hills (Masai and Takahama, 1981)

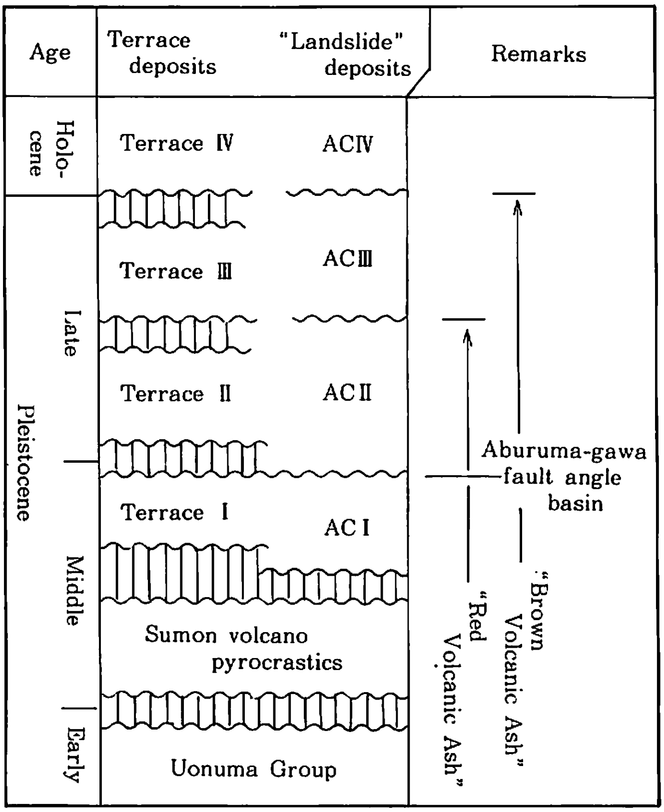

Fig. 14. Correlation table of the Aburuma-gawa landslide deposits and the terrace deposits of the Aburuma-gawa Valley (Takahama, 1981). Vertically ruled parts represent lacunae of the sediments.

Table 2. Characteristics of the Aburuma-gawa landslide deposits (simplified from Takahama, 1981)

Landslide Deposits	Materials	Covering Volcanic Ash	Weathring	Topography	Remarks
ACIV	Acidic tuff Andesite	Lacking	Not weathered		Secondary landslide dep. originated from ACII & ACIII
ACIII	Acidic tuff Andesite	"Brown Volcanic Ash"	Weakly weathered	"Tongue form" distributed in lower part on the slope	Secondary landslide dep. originated from ACII
ACII	Acidic tuff Andesite	"Brown Volcanic Ash" and upper part of "Red Volcanic Ash"	Strongly weathered	Moderately dissected, distributed in middle part on the slope	Primary landslide dep., partly covering gravels of Terrace II huge blocks (max.500m in diam.)
AC I	Gravels of the Uonuma G. and Andesite	"Brown Volcanic Ash" and "Red Volcanic Ash" (total thick.6−7m)	Strongly weathered	Deeply dissected, distributed on the hill-tops	Mass movement deposits

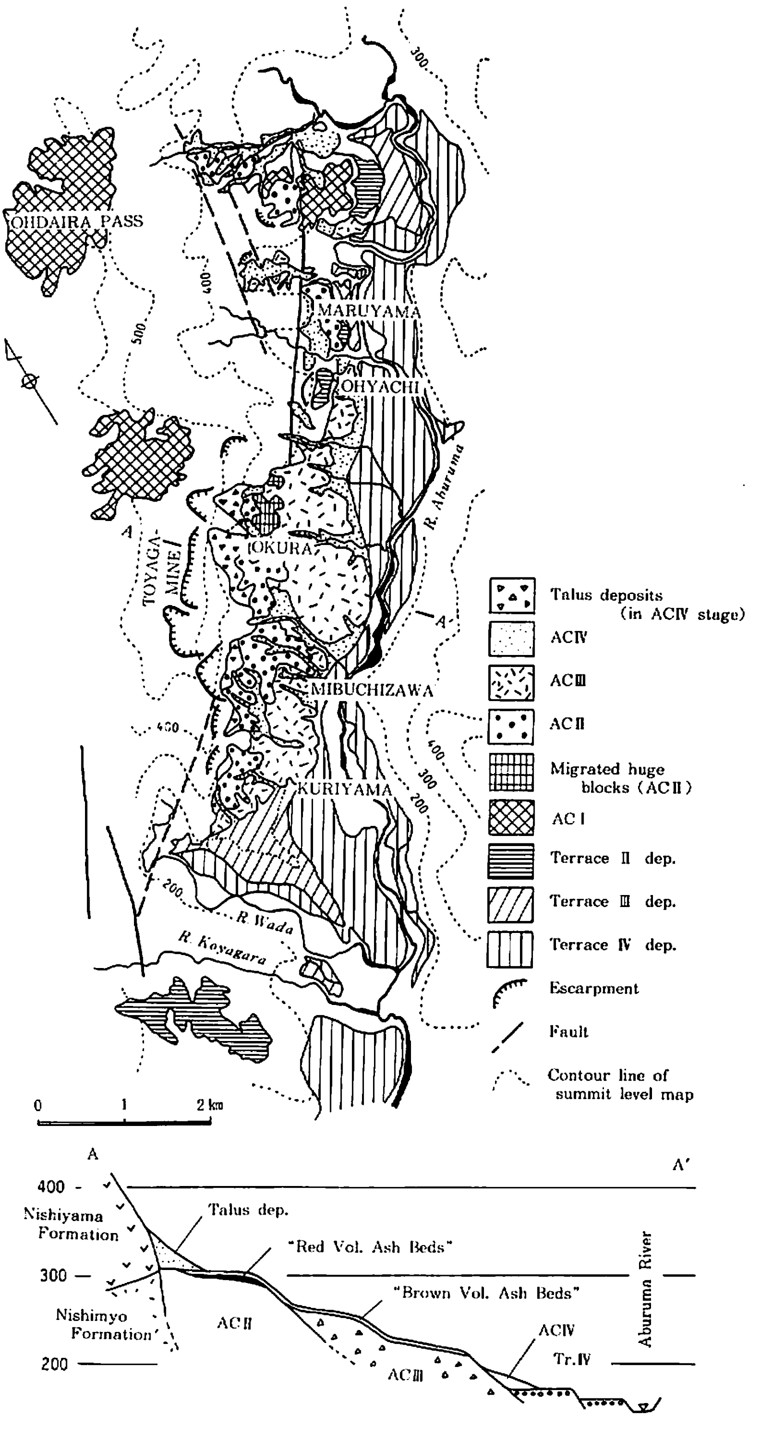

Fig. 15. Surface geology of the west side of the Aburuma River, showing terrace and landslide deposits (above), and the idealized cross section (below) AC I, II, III and IV correspond to the mass movement deposits A, B, C and D of Takahama (1981), respectively.

ACII

ACII is distributed on the middle slope of the west side of the Aburuma River. At Maruyama it covers the Terrace II gravel bed. The surface layer of ACII is weathered into red-color, and is locally covered with the "upper Red volcanic ash" and "Brown volcanic ash" beds (Fig. 16).

ACII is composed of a poorly sorted colluvial deposits derived from the acidic tuff of the Miocene Nishimyo Formation and the andesite of the Pliocene Nishiyama Formation and the Middle Pleistocene Matsuzaka-toge pyroclastics. The lithofacies of ACII varies from place to place. At Okura it abounds in andesite breccias, and matrix is filled with fragments of the tuff of the Nishimyo Formation. It includes also huge migrated blocks of about 500 m diameter. At Mibuchi-zawa, it consists of colluvial deposits composed mainly of strongly weathered andesite and tuff (Plate IV − 2), and at the north of Okura it is composed of breccias and fragments of tuff.

ACII is a deposit of the primary landslide which occurred in the Nishimyo Formation and the overlying pyroclastics which are distributed in the slope of west side of the Aburuma River. It is distributed at the foot of the fault cliff along the Aburuma River in early Late Pleistocene time, and is considered to have been formed at the same stage of the faulting.

ACIII

ACIII, topographically cutting into ACII surface, is distributed in the lower part of the slope. It has an extensive distribution at Okura. The depositional configuration of ACIII shows a gentle "wavy" landform which is characteristically observed in the lower part of the landslide site. ACIII is locally

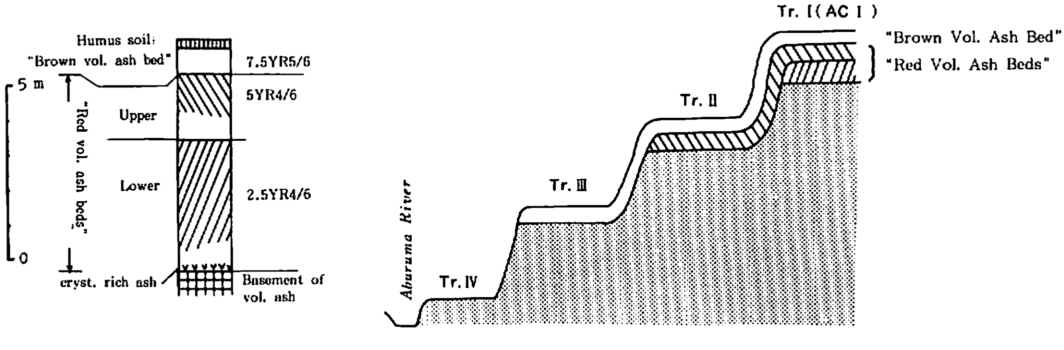

Fig. 16. Relation between volcanic ash beds and terraces along the Aburuma-gawa Valley.

Columnar section shows the typical succession of the volcanic ash beds in the Aburuma-gawa Valley at the southern foot of Sumon Volcano. Profile is schematically shown in the west side of the Aburuma River (modified from Masai and Takahama, 1981).

covered with the "Brown volcanic ash bed" and the humus soil. It is not covered, however, with the "Red volcanic ash bed". The landform made by ACIII is cut topographically by the Terrace IV surface.

At Okura the colluvial deposits contain abundantly andesite breccias, or are composed of blocks and fragments of tuff derived from the Nishimyo Formation. At the south of Okura, a colluvial deposit derived from the Nishimyo Formation is overlain by a colluvial deposit which abounds in andesite breccias (Plate IV − 3). A colluvial deposit derived from the Nishimyo Formation is observed in Oyachi, and a colluvial deposit composed of andesite breccias with matrix of weathered acidic tuff fragments is found in Mibuchi-zawa.

The major part of ACIII is a secondary landslide deposit reworked from ACII. At Oyachi and other localities, however, a primary landslide deposit formed by directly cutting into the bedrock is also observed. ACIII is the Upper Pleistocene, as will be mentioned later.

ACIV

ACIV, topographically cutting into ACII and ACIII, is distributed in a small area along a tributary on the west side of the Aburuma River. No volcanic ash layer is found above ACIV, and the "depositional surface" of ACIV grades into the Terrace IV surface.

ACIV is a secondary landslide deposit from ACII and ACIII. The colluvial deposit derived from the tuff of the Nishimyo Formation shows advanced fragmentation, and many parts are muddy, irregularly mixed with andesite breccias. ACIV is formed in the Holocene, as will be mentioned later.

B. Formative stage of landslide deposits

The formative stages of mass movement deposits in the drainage region of the Aburuma River are determined in the following, based on the correlation with the terraces.

The terraces in this area are divided into groups of I to IV from higher to lower levels; the ages of Terrace I, II, III and IV groups are the Middle Pleistocene, the last interglacial epoch, the last glacial epoch, and the Holocene, respectively (Masai and Takahama, 1981). The stratigraphic relations between these terraces and the volcanic ash layers are shown in Fig. 16. The figure indicates that the "Red volcanic ash bed" and "Brown volcanic ash bed" cover the topographic surfaces older than the Terrace II and older than the Terrace III, respectively. The relationships between the Aburuma-gawa landslide deposits and the terrace deposits is summarized as follows.

AC I is the same deposit as "Terrace I group deposit" of Masai and

Takahama (1981)*. ACII is supposed to have been deposited at about the same time as the formation of Terrace II, because it locally overlies the Terrace II gravel bed and is covered by "upper part of Red volcanic ash bed". ACIII was deposited probably around the formative stage of Terrace III, since it is covered by the "Brown volcanic ash bed" and is topographically cut by Terrace IV group. ACIV is not covered with volcanic ash layer, and its "depositional surface" corresponds to the Terrace IV surface, so it must have been deposited during the formative stage Terrace IV.

Accordingly, in relation to the terrace-forming stages, the age of formative these landslide deposits are assigned as follows: AC I in Middle Pleistocene time, ACII in the last interglacial epoch, ACIII in the last glacial epoch, and ACIV in Holocene time (Fig. 14).

C. Historical changes of landslides

From the above descriptions, two time sequences of large-scale mass movements are distinguished in the west side of the Aburuma River; one is the time of AC I deposition, and the other is that of ACII, ACIII and ACIV deposition.

AC I is considered to be a product of a gigantic mass movement which occurred in the summit area of the Uonuma Hills during the Middle Pleistocene, because of its extensive distribution area estimated at about 10km^2 and its great thickness reaching more than 50 m in maximum. In the distribution area of AC I, active landslides are seldom observed at present.

ACII is a deposit of a large scale primary landslide which occurred in association with the formation of the slope in the west side of the Aburuma-River (fault scarp of the Aburuma-gawa fault angle basin to be described later) in early Late Pleistocene time. The main deposit of ACIII is a remigrated, secondary landslide deposit from ACII, although a small scaled primary landslide deposit is also contained. ACIV is mostly a secondary landslide deposit of a small scale, and still being active.

3. Characteristics Common to the Tow Areas

The characteristics of history of mass movements common to both the Gozu area and the Aburuma-gawa area are described below.

* "Terrace I group deposit" in Masai and Takahama (1981) is identical with AC I of this paper. Identification of deposits was difficult at that time because of the advanced dissection of the topographic surface, which caused confusion in distinguishing terrace deposits from mass movement deposits.

Middle Pleistocene

GD I and GD II in the Gozu area and AC I in the Aburuma-gawa area are the deposits of the mass movements that occurred in Middle Pleistocene time. These deposits have common features in that they are distributed in the summit areas of the Sasagami Hills and the Uonuma Hills respectively, that their depositional surface are deeply dissected, and that their surface layers are red-colored due to intense weathering. A more important common characteristic is that the both mass movement deposits are very voluminous in comparison with the deposits of younger ages.

Early Late Pleistocene

GDIII in the Gozu area and AC II in the Aburuma-gawa area are deposits of the mass movements which occurred in this stage. Their distributions show that GD III was formed after the appearance of the Sasagami Hills and AC II after the formation of the slope of the Uonuma Hills in the west side of the Aburuma River. The depositional configuration is preserved and the weathering of the deposits is of medium degree. The volume of the deposits is large next to that in Middle Pleistocene time in the both areas. AC II in the Aburuma-gawa area is a primary landslide deposit.

Late Late Pleistocene

GDIV and GD V in the Gozu area and ACIII in the Aburuma-gawa area are deposits of the mass movements in this stage. The depositional configuration is preserved well and the degree of weathering is low. The volume of the Gozu debris flows deposits is smaller than that in the previous stage. The Aburuma-gawa landslides are mostly secondary landslides derived from AC II.

Holocene to Present

The mass movement deposits of this stage are GDVI and GDVII in the Gozu area and ACIV in the Aburuma-gawa area. The volume of these mass movement deposits is smaller than that of older ones. ACIV is a secondary landslide derived from AC II and AC III.

Although they are of different types, one being debris flow and the other landslide, the mass movements in the two areas have common characteristics as follows.

i) They occurred repeatedly at nearly the same sites and almost contenporaneously with the topographic development of the both areas.

ii) Their volumes were larger in Middle Pleistocene and early Late Pleistocene times than in the later stages.

V. ORIGIN OF MASS MOVEMENTS IN THE EASTERN MARGINAL REGION OF THE NIIGATA SEDIMENTARY BASIN

As mentioned in the preceding chapter, large-scale mass movements were generated repeatedly in the studied area since the Middle Pleistocene. As it is generally believed that mass movement takes a major part of denudation in the mountains (Penck, 1924), it is an important problem to clarify the origin of mass movement in relation to topographical developmental process.

In this chapter, the formation of mountains topography is considered from a viewpoint of the geohistorical development of the Niigata sedimentary basin and its eastern marginal region since Pliocene time. Firstly, the land-forming process in the whole studied area, and secondly the upheaving process of the mountains will be discussed by taking the Gozu Mountains as an example.

1. Topographical Development of the Mountains

The author (Takahama, 1982a) divided the land-forming process since the Pliocene in the studied area into the following three stages, I to III (Table 3, Fig. 17).

A. Land-forming stage I — Initiation of the major tophography —

This is the stage when the eastern mountaineous region began to emerge and the boundary zone, the Shibata-Koide Tectonic Zone, demarcating the eastern mountaineous region from the western sedimentary region developed (Fig. 17A). This stage corresponds to the Pliocene -Early Pleistocene.

For considering a topographic development of this stage, local unconformities recognized in the eastern marginal region are important. They comprise the Dainichi unconformity in the Sasagami Hills at the base of the Nishiyama Formation (Fujita, 1979, 1982; Maiya *et al.*, 1980; Coll. Res. Gr. Sasagami Hills, 1980; Maruyama *et al.*, 1981), the Yamadera unconformity in the Hills at the base of the Uonuma Group, (Masai and Takahama, 1981; Coll. Res. Gr. Sasagami Hills, 1982) and the Sasagami unconformity at the upper part of the Uonuma Group (Saito, 1980; Masai and Takahama, 1981; Coll. Res. Gr. Sasagami Hills, 1982). All these are accompanied with a high-angle abutting and locally overlapping unconformities. The abutting surfaces are considered to be paleo-slopes formed by faulting of the Shibata-Koide Tectonic Zone (Coll. Res. Gr. Sasagami Hills, 1980, 1982; Fujita, 1981; Takahama, 1982a). This fact shows that intermittent upheaval with faulting took place in the eastern mountains at least three times from the Pliocene to Early Pleistocene time.

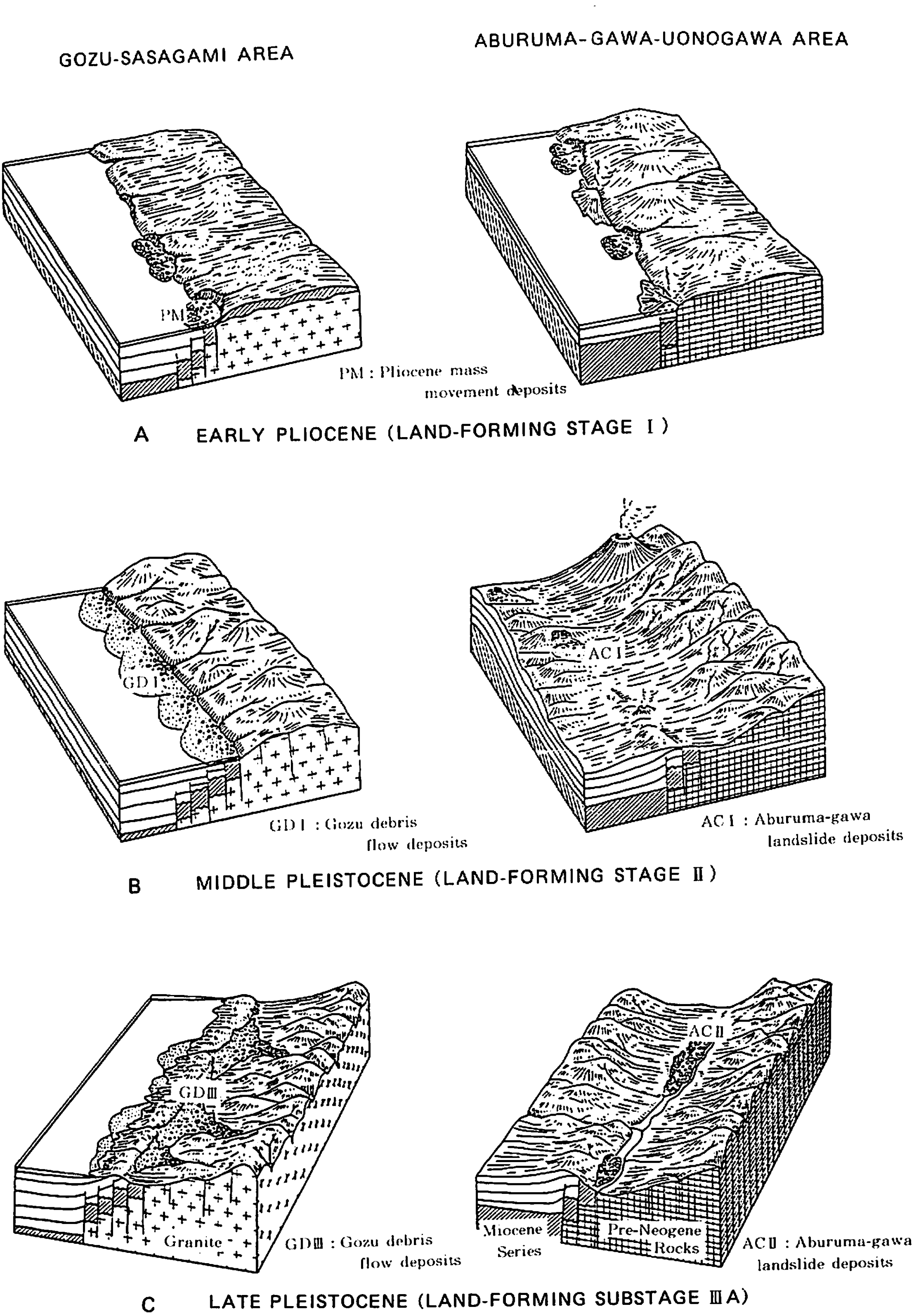

Fig. 17. Schematic block diagrams of paleo-topography of the eastern marginal region of the Niigata sedimentary basin

Table 3. Late Cenozoic tectonics and development of geomorphology in the eastern marginal region of the Niigata sedimentary basin (simplified from Takahama, 1982)

		Gozu-Sasagami area: Tectonic movements	Gozu-Sasagami area: Geomorphology, Niigata Basin	Gozu-Sasagami area: Geomorphology, Eastern Mts.	Gozu-Sasagami area: Mass movement deposits	Aburuma-gawa Valley: Tectonic movements	Aburuma-gawa Valley: Geomorphology, Niigata Basin	Aburuma-gawa Valley: Geomorphology, Eastern Mts.	Aburuma-gawa Valley: Mass movement deposits	Land-forming stage
Holocene			↑ *Murasugi lowland* / *Sasagami Hills* ; ↑ *Dainichigahara and Tsubeta fans*	↑ *Gozu Mts.*	GDⅦ GDⅥ		↑ *Uonuma Hills*	↑ *Aburuma River* / *Aburuma-gawa fault angle basin* ; ↑ *Echigo Mts.*	ACⅣ	Stage Ⅲ: Ⅲc
Pleistocene	Late				GDⅤ				ACⅢ	Stage Ⅲ: Ⅲb
		Tiling of Dainichigahara Fan surface			GDⅣ	Deformation of Tr. Ⅱ surface (140m)				
		Movement of Toitazawa fault (50−100m+)			GDⅢ	Movement of Eastern marginal fault of Uonuma Hills (150−200m)			ACⅡ	Stage Ⅲ: Ⅲa
	Middle	Uplift of Sasagami Hills			GDⅡ	(formation of Aburuma-gawa fault angle basin)			ACⅠ	Stage Ⅱ
			Paleo-debris flow fan		GDⅠ	Volcanic activity of Sumon		*Sumon Volcano*		
		Block uplift of Gozu Mts.	Emergence			Emergence and uplift of Uonuma sed. basin	Emergence			Stage Ⅰ
	Early		Lagoon-sea		Mass movement deposits	Folding of Niigata basin Block uplift of Echigo Mts.	Lagoon			
		Fault movement and abut -overlap unconf.	Erosion			Overlap unconf.	Erosion			
Pliocene			Sea	*Gozu Hills*	Mass movement deposits		Sea-Lagoon			
		Fault movement and abut -overlap uncanf.	Erosion			Abut overlap unconf.	Erosion			
			Sea		Mass movement deposits	Fault movement and eruption of andesite Unconf.	Sea			
		Fault movement and abut.-overlap unconf.	Erosion				Erosion			

In a later part of this stage, the southern part of the eastern mountains is considered to have had a larger relative relief than the northern part, judging from the huge accumulation of gravel beds in the Uonuma Group in the southern part of the basin side where the sediments have been supplied from the eastern mountains.

B. Land-forming stage II —Development of the mountain topography—

This is the stage when the mountains and hills as seen today made their appearance, and the mass movements mentioned in Chapter IV occurred frequently (Fig. 17B). This stage corresponds to Middle Pleistocene time.

The tectonic movement in this stage was characterized by the rapid block upheaval of the eastern mountains (e.g., the Gozu Mountains) and, also by beginning of the uplifting and emergence of the Uonuma and Sasagami Hills near the boundary zone. In this period, the activity of crustal movement which made the present topography was calminated. The strata in the Niigata Oil Field were folded and the anticlinal hills, namely Higashiyama, Nishiyama and Central Oil Zone (Chuo-yutai), made their appearance. The Quaternary volcanoes along the Shibata-Koide Tectonic Zone, i.e., the Sumon, Masugata, Iiji and Naeba Volcanoes (Shimazu *et al*.,1983), became active.

In the meantime, the Gozu Mountains increased remarkably in their elevation due to a rapid block movement. The mass movement of GD I and GD II in the Gozu area and AC I in the Aburuma-gawa area were generated. The uplifting of the Sasagami Hills took place in a later half of this stage after the generation of GD I .

C. Land-forming stage III — Establishment of the present topography —

This stage can be divided into three substages; IIIA, IIIB and IIIC.

Substage IIIA

This substage corresponds to the final interglacial epoch. A remarkable topographic feature of this r :ion is the presence of small-scale and linear depression, i.e., the Mu asugi Lowland (Coll. Res. Gr. Sasagami Hills, 1980, 1982), the Hayade-gawa Lowland (Takahama *et al*., 1980) and the Aburuma River (Takahama and Masai, 1983), from north to south (Fig. 17C). Each of them is located on the east side of the Sasagami, the Atago and the Uonuma Hills, respectively, alined along the boundary between the Niigata sedimentary basin and the eastern mountains.

At the boundary between the lowland and hills, high-angle faults of 100—200m throw are recognized; for example, the Toitazawa fault (Coll. Res. Gr.

Sasagami Hills, 1982), the Muramatsu fault (Takahama *et al.*, 1980) and the fault along the west side of the Aburuma River (Takahama and Masai, 1983). These faults were formed by relative subsidence of the lowland on the east with the uplifting of hilly area on the west.

Therefore, these depressions are considered to be fault-angle basin or grabens which were formed along the boundary zone of blocks, that is, along the Shibata-Koide Tectonic Zone. The amount of the upheaval of the Gozu Mountains was much larger than that of the Sasagami Hills since Middle Pleistocene time as shown in the difference of topographic reliefs. The uplifting of the hills was secondary phenomenon accompanied with by the upheaval of the mountains (see V-2). GDⅢ in the Gozu area and ACⅡ in the Aburuma-gawa area generated in this period.

Substage ⅢB

This substage roughly corresponds to the final glacial epoch. By the glacial regression, coastal plains and hills were subjected to active down-cutting of the river bed. In this substage inland hills also suffered deep erosion in many places.

In the Dainichigahara fan at the foot of the Gozu Mountains, the average gradient of the GDⅢ depositional surface is as high as 112/1,000, which may indicate tilting in the Late Pleistocene epoch. In the west side of the Aburuma River, it is found that the flexuring of Terrace Ⅱ surface caused by the upheaval attains to 140 m in difference of elevation (Shirai, 1967; Takahama and Masai, 1983).

In this period, GDⅣ and GDⅤ were formed in the Gozu area and ACⅢ in the Aburuma-gawa area.

Substage ⅢC

This substage is equivalent to the Holocene. This is the final stage of the formation of the present topography. In the coastal plains and hills, the valley formed during the substage ⅢB came to be aggraded due to the Holocene transgression. In the studied region, however, the down-cutting of river-bed was going on continuously from the preceding stage. GDⅥ, GDⅦ and ACⅣ have been generated in this substage.

In conclusion, the mass movements in the studied area since the Middle Pleistocene depend upon the formative process of mountains, controlled by the sequence of the tectonic movements since Pliocene time. In order to analyse quantitatively this causal relationship, the upheaval movement of mountains must be considered.

2. Upheaval Process of the Mountains

In order to confirm the upheaval of mountains as the generative cause of mass movement, the author tried to reconstruct the upheaving process of the Gozu Mountains since Pliocene time, referring to Collaborative Research Group for the Sasagami Hills (1980, 1982).

A. Vertical displacement of the mountains relative tc the plain (Figs. 18, 19, Table 1)

Fig. 18 shows a generalized cross section through the Niigata sedimentary basin to the Gozu Mountains. The geological profile is based on the date of oil exploration boring (Ikebe, 1982) and gravity anomaly (Maruyama *et al.*,1981).

At present, the Miocene beds are sporadically distributed on the granitic basement rocks of the Gozu Mountains (Figs. 18, 19). The geologic succession of the Sasagami Hills shows a conformable Miocene marine sequence of the Yamanokami, Sakanaiwa and Haguro Formations in asceding order, until the Gozu Mountains emerged in the formative stage of the unconformity at the base of the Pliocene Dainichi Formation (Table 1). This means that in the Miocene period an extensive area of deposition existed in the Gozu Mountains, and the thick Miocene sequence was accumulated over the granite body.

The Miocene around these areas is at least 300m thick or more, according to the profiles of Ikebe (1982). The Miocene Series in the Mountains area probably attained to 300 m thick at that time. Accordingly, the original surface when the Gozu Mountains emerged in Early Pliocene time, can be restored at 300 m higher than the present summit level (about 1,000 m above sea level) of the mountains (Fig. 18).

The base of the Pliocene Dainichi Formation in the Sasagami Hills is 20 – 30 m above sea level. At Shichikoku in the Niigata Plain, only 2 km west of this Hills, the oil boring (Shichikoku SK – 1) revealed that the base of the Pliocene series is at about 2,000 m depth from the surface. Becuase the base is inferred to be originally horizontal, the vertical displacement since the formative stage of the Dainichi unconformity is estimated at about 2,000 m. Furthermore, the displacement between the Sasagami Hills and the Gozu Mountains is about 1,300 m, and the total value of 3,300 m can be regarded as the upheaval of the Gozu Mountains relative to the Niigata Plain since Pliocene time to the present.

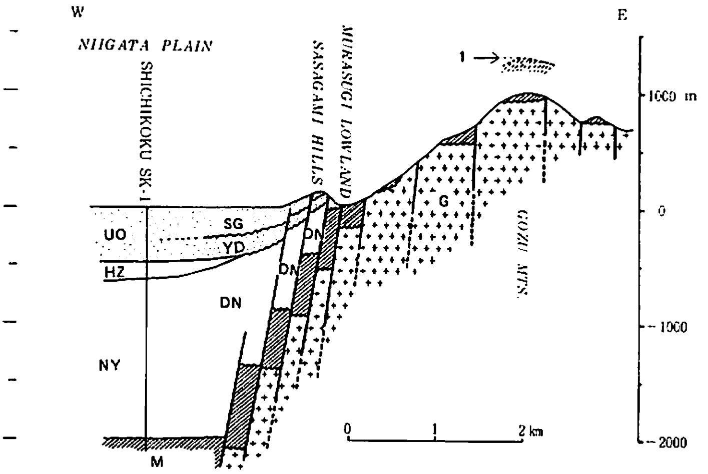

Fig. 18. Schematic cross section, showing the vertical displacement between the Gozu Mts. and the Niigata basin (modified from Coll. Res. Group Sasagami Hills, 1980).

UO: Uonuma Group, SG: Sasagami Formation, YD: Yamadera Formation,
HZ: Haizumi Formation, NY: Nishiyama Formation, DN: Dainichi Formation,
M : Miocene Series, G: Gozu Granite,
1 : Emerged plane at beginning of Dainichi stage

B. Block movement of the mountains (Fig. 19)

The conglomerate of the Miocene Yamanokami Formation is sporadically distributed at various levels, namely at the summit, on the flank and at the foot of the Gozu Mountains (Fig. 19). The difference of these elevations reaches about 1,000 m in maximum.

The granite body of the Gozu Mountains is broken into many blocks by numerous faults. The different levels of the distribution of the Yamanokami Formation can be explained by stepwise differential block movement. Most of the fault in the Gozu Mountains are accompanied with an unconsolidated fracture zone and or clay.

This fact sugests that the block movement continued up to a very young geologic age.

Many flat-topped crests of small scale are distributed on the western slope of the Gozu Mountains (Fig. 19). The level of their distribution is various, as in the case of the Yamanokami Formation.

These crests represent the erosional landform after greater part of the Miocene Series overlying the Gozu granite was eroded away.

Consequently, the block movement repreasented by different distribution of the Yamanokami Formation, with a maximum of 1,000 m difference in elevation, belonged to a younger event (since Middle Plestocene time) which was a continuation of the upheaving since Pliocene time.

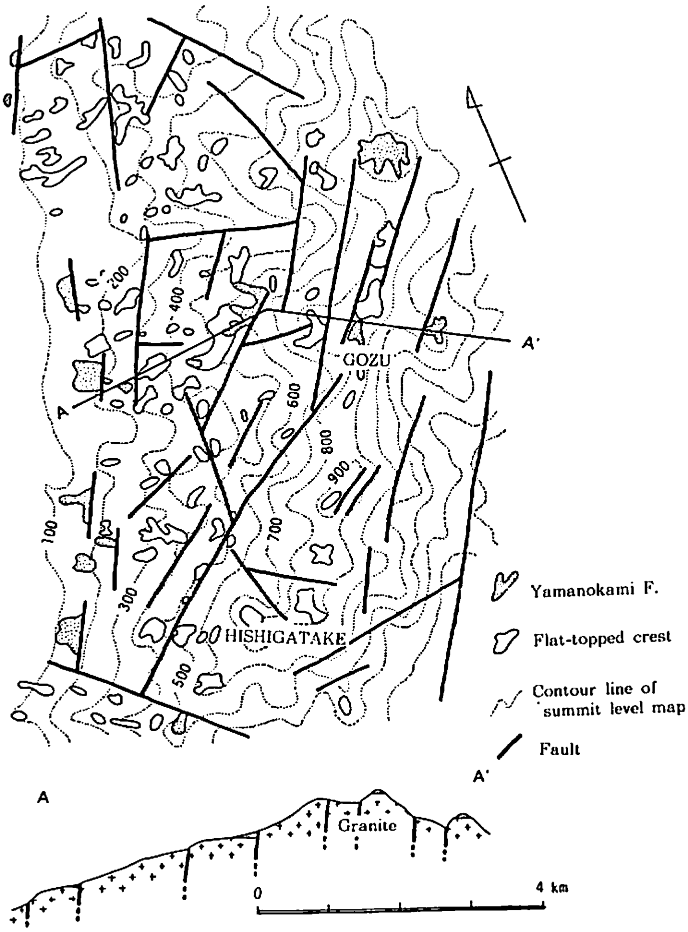

Fig. 19. Fault system (above) and cross section (below) in the Gozu Mts., showing the block upheaval (unpublished data from Coll. Res. Group Sasagami Hills).

C. Transformation of the upheaval movements (Fig. 20)

Throughout the geological history of the Gozu Mountains and the Sasagami Hills from the Pliocene to the Recent, the greatest change in the upheaving movement is noticed in the Middle Pleistocene period (Fig. 20, Table 3). The first characteristic of this period is the emergence of the Sasagami Hills after the Sasagami Formation was deposited. The second is the abrupt change in the composition of gravels supplied from the Gozu Mountains to the Sasagami Hills. The gravels in the Sasagami and Yamadera Formations of the Early Pleistocene are composed mostly of the Paleozoic and Mesozoic rocks, similar to those of the Miocene Yamanokami Formation. However, the gravel beds of the Middle Pleistocene are characterized by a large amount of debris flow deposits composed mostly of granite. This compositional change suggests that the

		Paleo-topography of Gozu Mts.		Estimation of vertical displacement
Holo. / Late (Pleistocene)	Post Gozu stage	Debris flow deposits Tilting of fan surface Movement of Toitazawa fault Appearance of Sasagami Hills	Present Gozu Mts.	Present height of Gozu Mts.
Middle (Pleistocene)	Gozu stage	Large quant. of debris flow dep. ……intense erosion of Gozu granite Formation of many flat-topped crest (Erosion surface) lower than 500 m	Relief of Gozu Mts. about half of the present	(1,000 m)
0.4 Ma	Gozu unconformity stage			Rapid block uplift
Early (Pleistocene)	Sasagami stage	Large quant. of gravels, derived from Yamanokami Formation on Gozu Mts. Formation of flat-topped crest of top of Gozu Mts. Mass movement deposits at the base	Planation Low-relief mountains	
	Sasagami unconformity stage			Erosion at unconf. 80m+
	Yamadera stage	Pebble, sand and mud (Transgression) Mass movement deposits at the base	Low-relief hills	(2,300 m)
	Yamadera unconformity stage			Erosion at unconf. 400m+
Pliocene	Dainichi stage	Muddy sediments Transgression Mass movement deposits at the base	"Peneplain"	"Buried steep slope" 500-1000m at basement (inferred from Oil boring and Bouguer anomaly)
4.4 Ma	Dainichi unconformity stage		Emergence	Erosion at unconf. 600m+

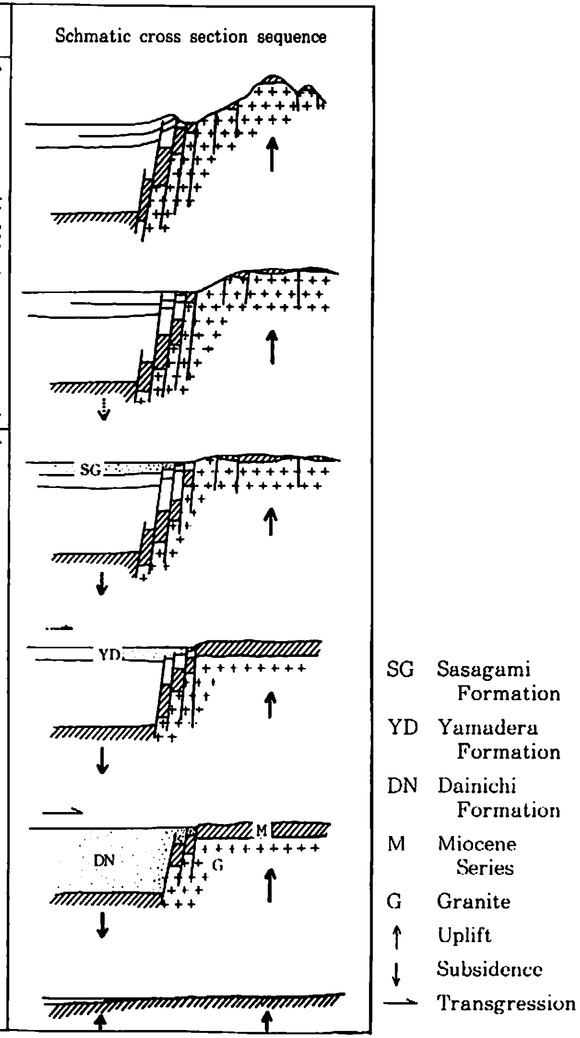

Fig. 20. Summary of vertical displacements in and around the Gozu Mts. and the Niigata basin

Yamanokami Formation covering the granite was eroded away for the most part by the time of the Sasagami stage (depositional stage of the Sasagami Formation), and also that the granite body of the Gozu Mountains came to have a steep and high topography enough for supplying great quantities of debris flows after the Gozu unconformity stage of the Middle Pleistocene (Fig. 20).

Consequently, the vertical displacement between the Niigata Plain and the Gozu Mountains attained to about 3,300 m since Pliocene time. The displacement of 1,000 m had occurred since Middle Pleistocene time, and the remaining 2,300 m had displaced from the Pliocene Dainichi unconformity stage to the Early Pleistocene Sasagami stage.

D. Stepwise upheaval of the mountains (Figs. 20, 21)

The upheaval process of the Gozu Mountains since Pliocene time is schematically shown in Fig. 21. The base of the Pliocene Nishiyama Formation in the Niigata region is dated to be 4,4 Ma (Petroleum Mining Association, 1982), and the Dainichi unconformity is correlated to the base

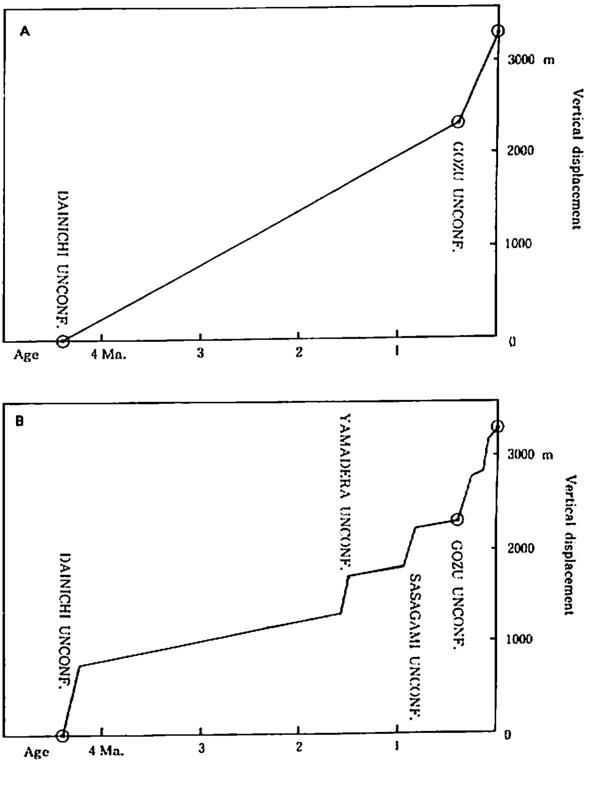

Fig. 21. Alternatives to explain for the relative movements between Gozu Mts. and Niigata basin since Pliocene time. A is simply based on total sum, while B is in reference with calibration at each stage.

of the Nishiyama Formation. The "Higher terrace" of the Uonuma Hills is considered to have been formed about 0.3 Ma (Hayatsu and Arai, 1981). The emergence of the Sasagami Hills and formation of the Gozu unconformity were a little older, and was at about 0.4 Ma.

Fig. 20 was compiled from paleotopography of the Gozu Mountains based on the amount of denudation at the unconformity in the Sasagami Hills and on the lithofacies of the Plio-Pleistocene series distributed in the Hills.

In the Sasagami Hills, the abutting unconformity is recognized at three different horizons, namely, the Dainichi, Yamadera and Sasagami unconformities, associated with the mass movement deposits of the Pliocene-Early Pleistocene age as will be mentioned in Ⅵ－2. The stage of three unconformities indicate the times when the upheaval movement was active and the denudation was progressive. These facts suggest the intermittent upheaval of the Sasagami Hills and the Gozu Mountains. In Fig. 21 A the total amount of displacement since the Dainichi unconformity stage to the Sasagami stage is expressed by the average values, because of difficulties in estimation of displacement and in the age determination of each unconformity.

The period since the Middle Pleistocene may have been as active as the unconformity stage when the stepwise upheavals proceeded by Early Pleistocene time. Moreover, at least two or three "sub-active periods" may be recognized, during the land-forming stages Ⅱ and Ⅲ. Fig. 21B is schematically shown on the basis of the above discussion. The figure indicates that the upheaval was more active in the period since the Middle Pleistocene that in the previous period.

3. Relation between Topographic Developement and Mass Movement

The Gozu Mountains and the Uonuma Hills were both formed by the active block upheaval since the Middle Pleistocene. The Gozu debris flow and the Aburuma-gawa landslide occurred just at that time. It follows that the generation of mass movement was related closely to the block upheaval of mountains.

The relationships between the land-forming process and the occurrence of mass movement is summarized as follows (Table 3).

Firstly, in the Gozu area, GD I, the first and largest debris flow deposits, show the beginning of a rapid denudation of the Gozu granite. Its formative stage coincides with Middle Pleistocene, at the time block upheaval of the Gozu Mountains began to be active. As a result of active uplifting, an increment of elevation, relief and gradient of the mountains, and also of the fracturing of bedrocks were bronght about. The unstable mountain slopes caused the frequent debris flow of large volume. The occurrence of GD II of large volume also indicates the active block upheaval of the mountains in this period under the similar conditions to GD I . But, the deposits are distributed restrictedly in the lowland between the Gozu Mountains and the Sasagami Hills and in the mid-flank area of the Hills, and absent on the top of the Hills. Therefore, the formative stage of GD II corresponds to the early stage of the upheaval of the Sasagami Hills caused by the uplifting of the mountains.

In the Aburuma-gawa area, the generation of the mass movement deposit AC I shows that the topographic relief was originated after the emergence of the Uonuma Hills, and was contemporaneous with that of GD I . This means that the generation of these mass movements were caused by the upheaval movement of the mountaineous regions, corresponding to the land-forming stage II in Middle Pleistocene time.

Secondaly, GD III in the Gozu area occurred during the active period of the Toita-zawa fault in the eastern margin of the Sasagami Hills. The hills were uplifted mainly at that time. AC II (the primary landslide deposit) in the west side of the Aburuma River was caused by the faulting of the Uonuma Hills, which produced the Aburuma-gawa fault angle basin, as mentioned in V−1. This faulting fractured the bedrock and formed the unstable steep slope of the west side of the river, and resulted in the primary landslide. It occurred in the soft tuff bed of the Miocene in a lower part of the slope, followed by the landslide of the andesite at the upper part of it*.

Thirdly, GDIV−GDVII (small-scale debris flow) in the Gozu area and ACIII−ACIV (small-scale and secondary landslides) in the Aburuma-gawa area occurred at the time of gentle upheaval, which was characterized by the tilting of the Dainichigahara fan surface (GD III depositional surface) in the Gozu area and by the flexuring of the Terrace II surface in the Aburuma-gawa area. GDIV, GDV and ACIII correspond to the land-forming substage IIIB in later Late Pleistocene time, and GDVI, GDVII and ACIV to the substage IIIC in the Holocene.

It is concluded that the generation of mass movements in the studied area is closely related to the land-forming process, namely the crustal movement, which proceeded step by step.

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* Where the soft rocks such as the Tertiary mudstone and tuff are overlain by the hard and cracky volcanic ejecta, a landslide may occur near the boundary. This type of landslides called "cap rock slide" in Japan, and is often observed in Northeast Japan and Nagasaki Prefecture.

VI. DISCUSSIONS

Many and complex factors contribute to generate mass movement, such as a formation of unstable slope, production of mobile materials, "trigger" to induce mass movement, etc. In preceding chapters, the author clarified that the topographic development of mountains by tectonic movements is an important factor in the generation of mass movements. However, as the effect of glacial eustasy and paleoclimate have been also discussed as causative phenomena, it is necessary to examine his consideration to take those views into consideration.

1. Geohistorical Factors Inducing Mass Movement

Many researchers have attached importance to the following geohistorical factors as causes of older mass movement (e.g., Hirakawa and Ono, 1974; Sugiyama, 1975; Aoki, 1975). Those are, i) change of mountain slope from stable to unstable by deep erosion of river-bed due to sea level lowering in the glacial epoch, ii) production and transportation of debris due to the periglacial process in the glacial epoch, and also of the weathered materials in the interglacial epoch.

The heavy precipitation is important as trigger to the present mass movement in Japan, and it must have been also important in the geologic past. It is, however, difficult to evaluate it to compare with the phenomena of a long geologic time interval as discussed here. It is usually mentioned that the earthquakes also act as an important trigger of mass movement, but they can be treated as a part of block movement of the mountaineous regions discussed here.

A. Effects of sea level lowering by glacial eustasy

Popov (1946) emphasized that one of the important factors causing older mass movement depends on the difference of "base level" height of past. In the coldest stage of the last glacial epoch (about 20,000 y.B.P.), the sea level was lower than the present by 140 m (Minato, 1966) or 85 m (CLIMAP Project Members, 1976). The sea level fall affected also the rivers on land and active down-cutting of river-beds proceeded to form unstable slopes. This is considered to have played an important role in bringing about mass movements in the mountains (Sugiyama, 1975; Isozaki, 1983).

In the mountains and hills of the Niigata region, there are many places where a large amount of down-cutting in this epoch is recorded. It has been generally considered that it was largely due to the sea level lowering (Isozaki, 1977). Takahama (1982b) considered that this explanation is doubtful as far as the studied region is concerned, and that the deep erosion of this region may be caused by upheaval movement at that time. He investigated further the subject as described below, taking the example of the Uonuma Hills where many river terraces are developed and the process of topographic evolution can be easily discerned.

The maximum elevation of the Lower Pleistocene Uonuma Group in the Uonuma Hills is about 1,000 m above sea level. This fact indicates that the Uonuma Hills have undergone a large-scale upheaval after their emergence in the Middle Pleistocene.

In the hills on the right side of the Shinano River, nine steps of terraces are developed as shown in Fig. 22. The highest Taniage Terrace was formed at about 0.3 Ma (Hayatsu and Arai, 1981), the Maibara Terrace II of middle level in roughly the last interglacial epoch (Niigata Volcanic Ash Research Group 1981) and the Shomen Terrace of lower level about 20,000 y.B.P. which corresponds to "Würm" Maximum, the lowest sea level time (Hayatsu and Arai, 1981). All terraces shown in Fig. 22 are erosional terraces with gravel beds of less than 10m in thickness (Shinano River Terrace Research Group, 1969).

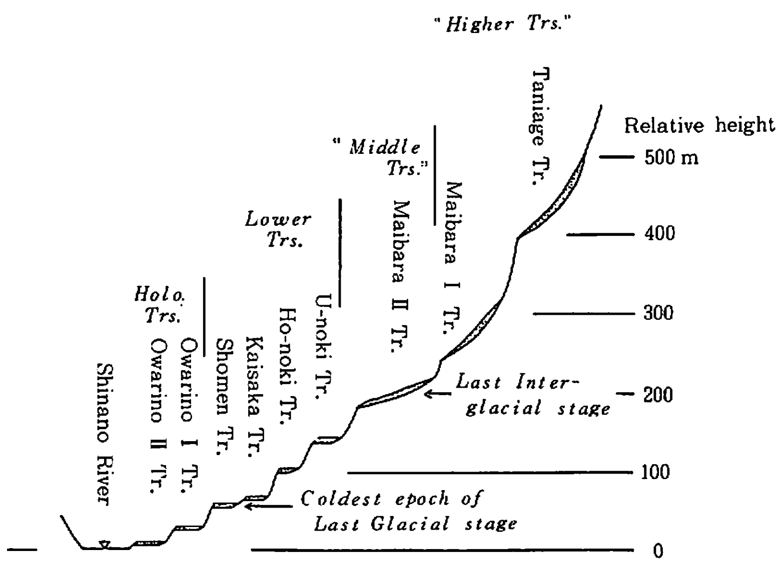

Fig. 22. Schematic profile of river terraces on the right side of the Shinano River in the Tsunan area, showing the one-side erosion of the river-bed was progressing intermittently (data from Shinano River Terrace Res. Group, 1968).

Thus, the down-cutting of the Shinano River in the Uonuma Hills was progressing, though intermittently, throughout the whole period from the Middle Pleistocene to the present. The amount of down-cutting is recorded as large as 400-500 m after the formation of the Taniage Terrace of the Middle Pleistocene and, notably, about 200 m after the formation of the Maibara Terrace II of the last interglacial epoch. Moreover, the amount of down-cutting has reached about 60 m in the Holocene transgression epoch, after the formation of the Shomen Terrace.

Such down-cutting of the river bed throughout the glacial age can not be explained satisfactorily by the glacial eustasy. It is, therefore, reasonable to regard that the intense down-cutting of the Shinano River was basically controlled by the uplifting of the Uonuma Hills in the terrace-forming stage. Actually, even in the downstream area around Ojiya City are found the active folding and tilting of alluvial plane from the terrace-forming stage to the present (Otuka, 1942; Ota and Suzuki, 1979; Iikawa, 1982).

The present author (Takahama, 1982) found an older "knick point" in the river profile near Ojiya City by reconstructing the old river-bed gradient of the Shinano River at about 20,000 y.B.P. (Fig. 23). The existence of the knick point is considered to be a boundary point between the downstream area where the down-cutting is controlled by sea level fall of glacial epoch and the upstream area (Uonuma Hill side) where it is primarily regulated by the uplifting.

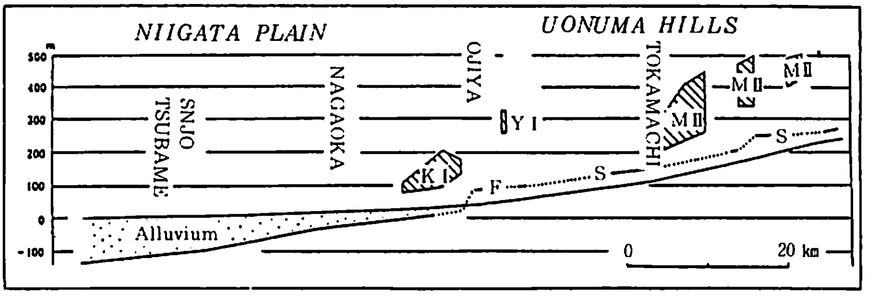

Fig. 23. "Longitudinal profile of river-bed" of the middle and lower reaches of the Shinano River, shows the discontinuity of old river-bed gradient to the present one near Ojiya City (simplified from Takahama, 1982).

K I, Y I and M II represent the level of the river terrace surfaces at the time of the last Interglacial stage, while S and F are the river terrace surfaces formed in the coldest epoch of the last Glacial stage. Base line is buried beneath the river-bed in the Alluvium at the last Glacial stage.

It is concluded that down-cutting of the river-bed which was directly caused by the sea level fall at about 20,000 y.B.P., was restricted only to the Niigata Plain, whereas in the studied area the sea level fall had given no fundamental influence but secondary one on the topographic evolution and also on the generation of mass movement. No debris flow at this period is recognized in the Gozu area as shown in Fig. 3.

Furthermore, little is known about the influence of older glaciation during the Middle Pleistocene period in Japan. Besides, the lowering of sea level in that period was supposedly smaller than that in the last glacial epoch (Fairbridge, 1971).

B. Paleo-climatical effects

Periglacical process

The periglacial process, e.g., freezing, thawing, solifluction, etc., plays an important role in producing and transporting the debris in the high latitudes or mountaineous region. Sakai (1981) pointed out that the periglacial process of the last glacial epoch in Central Japan are recognized only in the areas higher than 1,000m above sea level.

However, the studied area is located in lower latitude (37°—38°N) and hence at a smaller elevation (less than 1,000m), and no evidence of prominant periglacial phenomera is found even in the coldest stage of the last glacial epoch. Therefore, the periglacial process played an insignificant role in the generation of mass movement in the studied area.

Weathering process

The weathering due to a temperate climate of the interglacial epoch is well-known to be an important factor in the production of materials migrated by mass movement (Aoki, 1975; Terado and Katto, 1980; T. Fujita, 1983). Besides, it is well-known that the tectonic fracturing and hydrothermal alteration also play an important roles for the origination of debris flow materials. In the case of landslide, the primary landslide deposits supply the materials to the secondary landslide.

The old red soil distributed in the studied area suggests that the strong weatherring occurred during the last interglacial epoch and Middle Pleistocene time. The granite body of the Gozu Mountains is also strongly weathered over a wide area. It is especially intensive along numerous faults and fracture zones within the body, reaching to a depth of 100m or more in some part. This weathering of the granite body is too deep to have resulted only from a temperate climate. It is, therefore, attributed mainly to fracturing due to repeated activities of the Shibata-Koide Tectonic Zone. Besides, the hydrothermal alteration is sometimes recognized along this zone.

In the Aburuma-gawa area, the primary landslide, AC II, was generated evidently in the deep part of the bedrock, several tens of meters underground, as suggested by a huge slide blocks included in it (max. 500 m in diameter). It is difficult to explain the cause of such a deep-seated landslide only by weathering on ground surface.

In conclusion, the fall of sea level and periglacial process were less effective than other causes of older mass movements in the reported region. The weathering is an important factor in producing the mass movement materials, and the deep weathering is closely related to the fracturing caused by block movement. Also, voluminous mass movement is derived from various elevation levels accompanying the development of topographic relief. Accordingly, the development of older mass movement depended upon deep weathering and formation of high mountain slope, and all of them were generated by rapid upheaval of the earth crust in the reported region.

2. Generality of Origin of Mass Movement

The generality found in the relationship between mass movement and crustal movement in the present field will be examined to pursue after the case studies of still older time and also of the mass movement of other regions.

A. Mass Movements occurred before the Middle Pleistocene

As mentioned before, there are found three unconformities within the Pliocene to Lower Pleistocene in the studied area (Table 3, Fig. 20). In the Sasagami Hills, mass movement deposits are recognized at the bases of the Dainichi, Yamadera and Sasagami Formations in ascending order (Coll. Res. Gr. Sasagami Hills, 1980, 1982). Mass movement deposits in the Dainichi Formation consist mainly of non-stratified and ill-sorting blocks of the Miocene mudstones. This deposits abut on the Miocene Series with high-angle unconformity of 50m. Mass movement deposits in the Yamadera Formation are talus deposits composed of mudstone and sandstone blocks (max. several meters in diameter) derived from the Dainichi Formation. They also abut on the Dainichi Formation. In the Sasagami Formation the mass movement deposits, including blocks of several meters in diameter, abut on the Yamadera Formation. Moreover, some landslide deposits are locally recognized at the base of this formation.

These older mass movements were usually accompanied with the formation of high-angle unconformities. In addition, the surfaces of those unconformities are coincident to old fault scarps which were formed by the upheaval of the mountain side block. According to Fujita (1979, 1982), the successive tectonic process as upheaval-collapse-appearance of sedimentary basin occurred repeatedly in six or seven times since the Pliocene in the Japanese Islands. He suggested that these tectonic disturbance − Island Arc Disturbance − had contributed to the generation of mass movement.

B. Mass movement in other regions

It seems to be that there are several studies to support the conclusion of the present paper. But also, it should be mentioned that a detailed examination of older mass movement deposits has not yet sufficiently done.

In the Kushigata Mountains of Niigata Prefecture, near Gozu, Nishida *et al*., (1968) already pointed out the existence of ancient debris flow deposits. Tanaka (1982MS) confirmed three horizons of large-scale debris flow deposits since the Middle Pleistocene. In the Sekita area at the upper course of the Shinano River, Takano (1983) reported that large-scale debris flows were generated since the Middle Pleistocene based on the topographic investigation. It is of the same opinion that the debris flow generated closely related with the upheaval of the mountains.

In the Rokko Mountains, north of Kobe City, it has been known that the debris flow deposits were reworked several times since the Middle Pleistocene. Some debris flow deposits are involved in the Middle Pleistocene Series, and the Upper Pleistocene and Holocene Series consist of fan deposits contained numerous boulders of mass movement deposits (Hujita and Kasama, 1971; Hujita, 1982). The Rokko Mountains consist of the strongly fractured and weathered granite, and are characterized by continuous elevation with active faulting (Hujita, 1976). Shibasaki (1956) and Isozaki (1977) designated the presence of active tectonic zones in the Kinki and Hokuriku districts, because of the distribution of the successive landslide in those areas.

As shown in Appendix, in many places of Japan there are mass movements since the Middle Pleistocene. Almost all mountains in the Japanese Island have upheaved largly in Quaternary epoch, particularly since Middle Pleistocene time, and reached the present elevation (Quaternary Tectonic Movement Group, 1973; Hujita, 1976, 1982; Fujita, 1982). It is, therefore, concluded that the generation of mass movement has been dominated by the crustal movement in the younger tectonic belt such as the Japanese Islands.

Ⅶ. CONCLUSION

There are found two different kinds of large-scale mass movement that have been active since the Middle Pleistocene to the present in the eastern margin of the Niigata sedimentary basin. One is the Gozu debris flows in the Gozu Mountains, and the other is the Aburuma-gawa landslides in the Uonuma Hills.

In this paper, the mass movement deposits and their generation was examined from a geohistorical viewpoint. The result are summarized as follows.

(1) Several mass movement deposits can be discriminated in the Quaternary strata by critical examination of the sedimentary lithofacies, stratigraphy and topography. The Gozu debris flow deposits can be divided into seven gravel beds, GD Ⅰ to GDⅦ from older to younger. The Aburuma-gawa landslide deposits are divided into four beds, AC Ⅰ to ACⅣ. The deposits GD Ⅰ, GD Ⅱ and AC Ⅰ were formed in the Middle Pleistocene, GDⅢ, GDⅣ, GD Ⅴ and AC Ⅱ and ACⅢ in the Late Pleistocene, and the rest in the Holocene.

(2) The mass movements of the two areas have occurred repeatedly since the Middle Pleistocene to the present at nearly the same sites in each of there areas. It is noteworthy that in the Aburuma-gawa area, the primary landslide generated in the bedrock during an early Late Pleistocene has repeatedly remigrated as secondary landslide up to the present.

(3) Although the two different kinds of mass movements took palce in different area, the geological time of their occurrence was almost contemporaneous. In Middle Pleistocene and early Late Pleistocene time, the large-scale debris flow and the primary landslide took place, and from a later Late Pleistocene to the present the small-scale debris flows and the secondary landslides occurred.

(4) The development of the mass movements were strongly controlled by the land-forming process. The Gozu Mountains and the Uonuma Hills have been formed by the active block upheaval movement since the Middle Pleistocene to the present. The amount of upheaval of the Gozu Mountains attained to a maximum of about 1,000m in this period. The active block upheaval brought about the unstable mountaineous slopes, resulting in the generation and development of mass movements.

In the reported region, another land-forming factors, such as the sea level lowering and the periglacial process during the glacial epoch, are not essential for the mass movements.

(5) The strong control of crustal movements on the generation of mass movements is not limited to the studied areas, nor to a later harf of the Quaternary. The similar phenomena are found in the pre-Middle Pleistocene strata of this region and in the Quaternary deposits in many other areas in Japan. Therefore, it can be said that it is not possible without understanding the geohistory of tectonism since Pliocene to realize the origin and formation of the mass movement deposits in such tectonically active region as the Japanese Islands.

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APPENDIX

List of Older Mass Movement

Middle Pleistocene

Nagano Pref.

Nashinoki gravel bed (Matsumoto basin)	Fujita, Y., 1978, *Ann. Red. Jibansaigai-Ken, Niigata Univ.*, 4, 35-46.
Narao landslide	Saito, Y. *et al.*, 1978, *Jour. Japan Landslide Soc.*, 15, 1-10.
Older debris flow deposit (Ina Valley)	Matshushima, N., 1980, *Geol. Shimo-Ina*, 5.

Niigata Pref.	
Kushigata debris flow deposit	Tanaka, T., 1982MS, Master Thesis Niigata Univ.
Sekita debris flow	Takano, T., 1983, Rep. 37th Ann. Meeting Assoc. Geol. Coll. Japan, 31-36.
Sarukura landslide	Nozaki, T., 1983, ibid., 19-24.
Older landslide (Yoneyama Mts.)	*ibid.*
Kibu landslide	Takahama, N., 1980, *Rep. Res. Inst. Hazards in snowy Areas, Niigata Univ.*, 2, 51-61.
Nagisawa mass movement	Aoki, S. *et al.*, 1979, Rep. Grant-in-Aid for Cooperative Res.by Minist. Educ. Japan.
Kamatsuka-Dangosashi debris flow	Takano, M., *et al.*, 1983, Rep. 37th Ann. Meetings Assoc. Geol. Coll. Japan, 1-6.
Gifu Pref.	
Sakuragaoka gravel bed	Kajita, S., & Ishihara, T., 1977, *Mem. Geol. Soc. Japan*, 14, 93-102.
Nara Pref.	
Older talus deposit (Suzuka Mts.)	Kawabe, T., 1981, *Jour. Geol. Soc. Japan*, 87, 457-473.
Mie Pref.	
Older debris flow deposit (Kumanoura)	Tamura, T. *et al.*, 1975, *Quat. Res. Japan*, 14, 107-114.
Hyogo Pref.	
Older talus deposit (Rokko Mts.)	Rokko Coll. Res. Group, 1984, Rep. Grant-in-Aid for Sci. Res. by Minist. Educ. Japan.
Older debris flow deposit (Rokko Mts.)	Hujita, K., 1982, *Nihon no Sanchi-keiseiron*, Kaibundo.
Nagasaki pref.	
Hokusho landslide	Hatano, S. *et al.*, 1974, Rep. Nat. Res. Cent. for Disster Prevention, 32, 7-23.

Early Late Pleistocene

Akita Pref.	
Narusegawa landslid	Nozaki, T., 1983, above mentioned
Nagano Pref.	
Obasute debris flow	Saito, Y., 1982, *Jour. Japan Landslide Soc.*, 19, 1-5.
Niigata Pref.	
Kamatsuka-Dangosashi landslide	Takano, M. *et al.*, 1983' above mentioned
Landslide deposit of Yasuda Formation	Uda, T. *et al.*, 1982, Abst. 89th Ann. Meetings Geol. Soc. Japan, 531.
Mizo'o-Monoide landslide	Aoki, S. & Takahama, N., 1976, *Ann. Rep. Jibansaigai-Ken Niigata Univ.*, 2, 11-18.
Sekita dedris flow	Takano, T., 1983, above mentioned
Kushigata debris flow deposit	Tanaka, T., 1982MS., above mentioned
Ushigakubi landslide	Isozaki, Y., 1983, *Rep.* 37th Ann. Meetings Assoc. Geol. Coll. Japan, 7-12
Kiriyama landslide	*ibid.*
Wanazu landslide	*ibid.*
Yamamotoyama landslide	*ibid.*
Ishikawa Pref.	
Yoshiura landslide	Isozaki, Y., 1983, above mentioned
Kitanabune landslide	*ibid.*

Tokushima Pref.	
Large-scale mass movement (Yoshino-gawa Valley)	Terado, T. *et al.*, 1980, *Geology and Paleontology of shimanto Belt*, Rinya-Kosaikai., 17-26.
Nagasaki Pref.	
Hokusho landslide	Hatano, S. *et al.*, 1974, above mentioned

Later Late Pleistocene to Holocene (Radiocarbon data)

Akita Pref.	
Yachi landslide 7,310±130, 1,970±130, 20,790±940y. B. P.	Ohnishi, Y. & Terakawa, T., 1983, Rep. 37th Ann. Meetings Assoc. Geol. Coll. Japan, 37-40
Kiridome landslide 20,790±940y. B. P.	*ibid.*
Fukushima Pref.	
Landslide of Hidaka dam 23,290±1,020, 12,150±1,200, 8,430±200, 8,890±260y. B. P.	Ohnishi, Y. & Terakawa, T., 1983, above mentioned
Numano-Taira landslide 10,640±300, 8,890±260 8,670±160y. B. P.	*ibid.*
Nagano Pref.	
Obasute debris flow 13,550±460, 3,250±260y. B. P.	Saito, Y., 1982, above mentioned
Narao landslide 8,350±200, 6,410±170 , 5,760±180y. B. P.	Ohnishi, Y. & Terakawa, T., 1983, above mentioned
Cha'usuyama landslide 22,940±790, 19,460±880, 3,060±320y. B. P.	*ibid.*
Kuranami landslide 6,140, 5,260±150, 5,010y. B. P.	*ibid.*
Nishigawara landslide 22,510±1,230y. B. P.	*ibid.*
Niigata Pref.	
Hirota landslide 10,970±220y. B. P.	Ohnishi, Y., & Terakawa, T., 1983, above mentioned
Itayama landslide 9,330±270y. B. P.	*ibid.*
Nikami landslide 8,130y. B. P.	*ibid.*
Nakamaruke landslide 25,500±2,450y. B. P.	*ibid.*
Osaka Pref.	
Kamenose landslide 37,800, 26,320±1,860y. B. P.	Kasama, R. *et al.*, 1976, Rep. *Kamenose Landslide,* 4. Minist. Const. Japan.
Myojinyama landslide 17,900±220, 17,300±260y. B. P.	Fujita, T., 1983. *Mobile Belt in Asia,* 343-362. Kaibundo.
Kochi Pref.	
Kuromaru landslide 9,340±170y. B. P.	Okamura, N. *et al.*, 1976, *Jour. Japan Landslide Soc.* 19, 1-5.
Shimojizoji landslide 33,240±3,950y. B. P.	*ibid.*

Tokushima Pref.	
Taira landslide. 37,800y. B. P.	Fujita, T. 1983, above mentioned
Morito'o landslide 15,400±400y. B. P.	Hayashi. T. & Yamaguchi, S., 1971, *Jour. Japan Landslide Soc.*, 7, 1-6.
Kuki landslide 27,700±5,000y. B. P.	Nakagawa, C. & Kanamaru, H., 1975. *ibid.*, 12. 25-33.
Hyogo Pref.	
Okutango landslide 33,000y. B. P.	Shibasaki, T., 1967, *Chikyu Kagaku*, 85-86, 19-24.

Older mass movement in the Other Countries

U.S.S.R.	
Volga River landslide Ancient landslide	Popov, I.V., 1951, *Inzhenernaya geologia*
Lenin Hills landslide Glacial epoch	Churinov, 1957, *Voplosy gidrogeol. i inzhenernoi geol.*, 15, 62-78.
Angara River landslide Middle Pleistocene	Palshin, G. B., 1963, *Bratskoe vodokhranilishche,* 13-152.
Czechoslovakia	
Handlova landslide Older landslide	Záruba, Q. & Mencl, V., 1969, *Landslides and Their Control,* Elsevir.
Miksova landslide Interglacial epoch	*ibid.*
Motal landslide Pleistocene	*ibid.*
Lucina River landslide Late Pleistocene	*ibid.*
Turnov landslide Late Pleistocene	*ibid.*
Landslide of Ceske Stredohri Mts. Pleistocene	*ibid.*
Landslide of Carpatia Pleistocene	*ibid.*
Switzerland	
Flims landslide R/W Interglacial epoch	Záruba, Q. & Mencl, V., 1969, above mentioned
Austria	
Landslide of Glarner Alps Interglacial epoch	Záruba, Q. & Mencl, V., 1969, above mentioned
Landslide of Lunersee Pleistocene	Mignon, K., 1962, *Vorarlberg. Jb. Geol. B. A.*, 105, 49-64.
Italy	
Landslide of Crati basin Fossill landslide	Nossin,J.J., 1972, *Geol. en Mijnbouw*, 51, 591-607.
Iran	
Saidmarreh landslid Pre-historic landslide	cited Bolt, H.H.S., 1975, *Geological Hazards*, Springer-Verlag.
Canada	
Downy slide End of last Glacial epoch	Piteau, D.R. *et al.*, 1979, *Rockslides and Avalanches*, 1, 365-392.
U.S.A	
Blackhawk landslide 18,000y. B. P.	Stout, M.L., 1975, *Geol. Soc. Am. Spec. Paper,* 108.

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EXPLANATION OF PLATES

Plate I.

1 : GD I —Debris flow deposits of type A (upper and lower parts) and type B (middle part) in the north bank of the Agano River

2 : GD I —Strongly weathered debris flow deposit of type A at Kusouzu

3 : GD II —Debris flow deposits of type B with intercalations of sand layers

Plate II.

1 : GD III —Debris flow deposit of type A showing the high-angle imbrication at the Dainichigahara Fan

2 : GD III —Alternation of debris flow deposits of type B and fine tractive sediments in the eastern part of the Sasagami Hills (see Fig. 8)

3 : GD III —Tractive sand layers in the western part of the Sasagami Hills

4 : GD VI —Debris flow deposit of type A (above the humus soil), and GD III of type A or B (lower part).

Plate III.

1 : Gozu debris flow deposits intercalated with the buried soil beds at the Tsubeta Fan, upper, middle and lower gravel beds are correlated with GD VI, GD IV and GD III, respectively (see Fig. 10)

2 : GD VI —Debris flow deposits of type B (upper part) and type C (lower part) intercalated with humus soil layers bearing the Jomon earthenware

3 : GD VII —Debris flow deposits of type A (upper part) and type C (lower part) showing the inverse grading at Imaita

Plate IV.

1 : AC I —Mass movement deposit derived from gravel beds of the Lower Pleistocene Uonuma Group

2 : AC II —Landslide deposit composed of fragments of acidic tuff and wedge-shaped colluvial deposit of andesite

3 : AC III —Landslide deposit composed of weathered acidic tuff debris covered with colluvial deposit including andesite breccias at the south of Okura

Plate Ⅰ (N. Takahama)

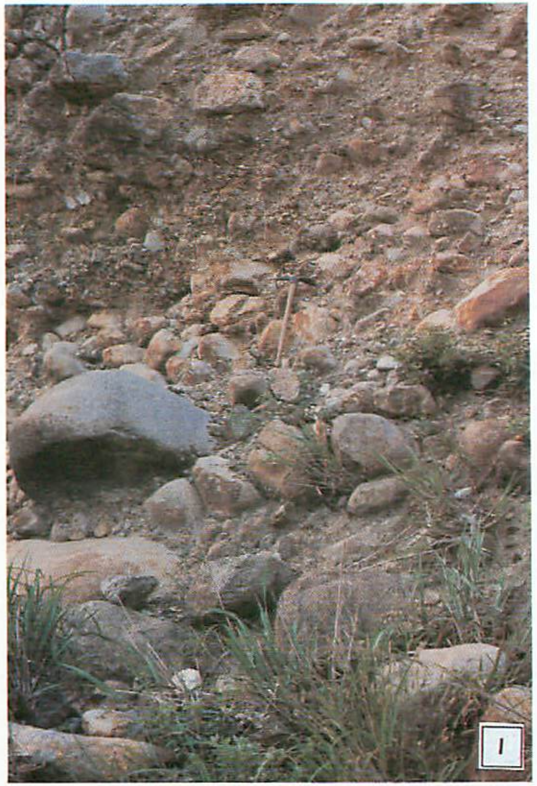

Plate Ⅱ (N. Takahama)

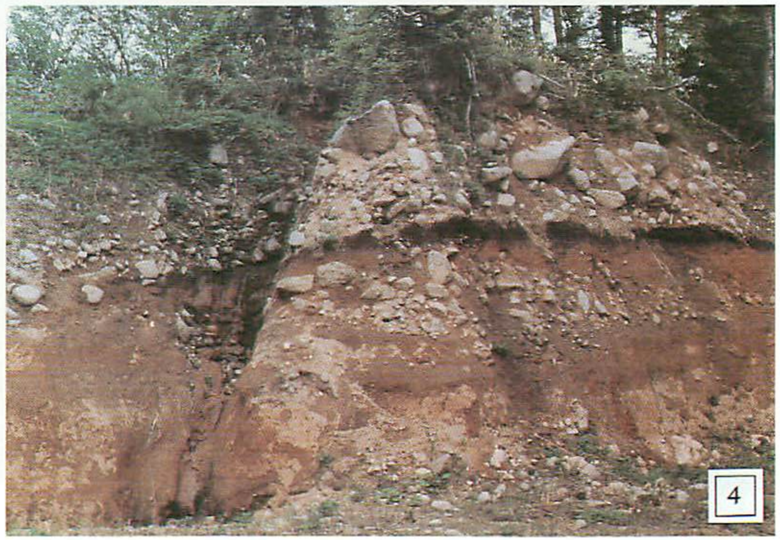

Plate Ⅲ

(N. Takahama)

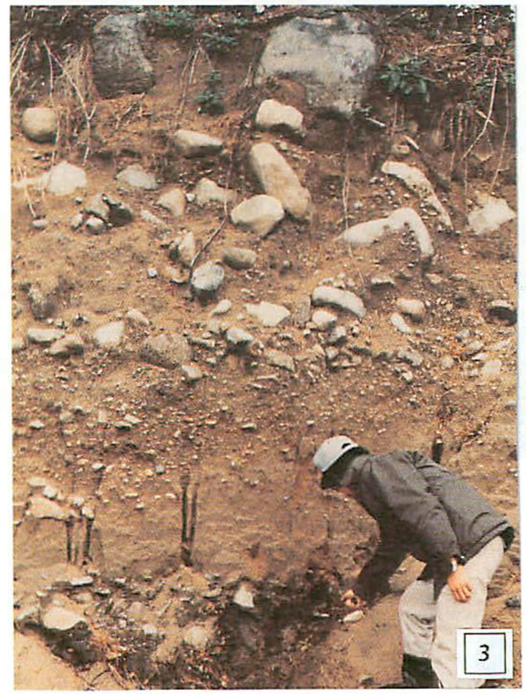

Plate Ⅳ (N. Takahama)