Paper:

Sediment Induced Disasters in the World and 1999-Debris Flow Disasters in Venezuela

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[Received January 6, 2010; accepted April 19, 2010]

Many sediment related disasters have occurred in many areas of the world. The table of sediment related disasters from 1997 to 2006 is shown. It shows strong earthquakes and super hurricanes/typhoons cause large landslides and debris flows. Climate change may trigger larger disasters more frequently in the future. Stratovolcanoes are geologically weak and cause huge landslides and debris avalanches. Active volcanoes release lava flows and pyroclastic flows, which cause serious damages. As an example of a typical sediment disaster, a disaster which occurred in Venezuela, in 1999 is briefly reported. The disaster was caused by unusual heavy rainfall. Many people were killed by many debris flows and shallow landslides. The disaster shows information on hazards such as hazard maps and rainfall is necessary and control structures may reduce damages if they had existed. Proper land-use and hazard education are needed.

Keywords: sediment hazards, list of major hazards, 1999-debris flow disasters in Venezuela

1. Introduction

Sediment-related hazards are caused by sediment movement. Many sediment related disasters have occurred in many areas of the world. The sediment related disasters happened from 1997 to 2006 is shown in **Table 1**. It shows strong earthquakes and super hurricanes/typhoons cause large landslides and debris flows. Climate change may trigger larger disasters more frequently in the future. Stratovolcanoes are geologically weak and cause huge landslides and debris avalanches. Active volcanoes release lava flows and pyroclastic flows, which cause serious damages. It is noticed that many causes of the disasters were caused by landslide. It is because the word landslide has wide meanings. Deep seated slow moving landslide, large scale quick moving landslide and sometimes even debris flow are described as landslide. The authors think that Varnes (1978)'s classification chart affects to this. His famous chart includes rock falls and earth flow as well. It is not appropriate to consider debris flows as a sort of landslide. The mechanism of debris flows has been made clear comparatively recently, within the last 40 years. Sliding and flow must be distinguished clearly.

2. Kinds and Characteristics of Sediment-Related Hazards

There are many natural phenomena that cause sediment hazards. They are rock falls, shallow landslides, deep-seated landslides, debris avalanches, debris flows and large amount of sediment discharges in river basins mainly caused by heavy rains. Lava flows, pyroclastic flows, mudflows and debris flows associated with volcanic activities can be included in sediment hazards. The bursting of natural landslide dams or glacier lakes cause sometimes sediment hazards. The natural landslide dam bursting threats these days due to climate change.

Sediment hazards occur suddenly, without much warning. As they are difficult to predict accurately, and people fall victim. Some landslides and debris flows sweep away entire villages. The debris flow disaster that happened in Venezuela in 1999 or the disasters caused by typhoon 0906 in Southern Taiwan in 2009 are typical representative examples. Below is a brief field note of the survey soon after the debris flow disaster in Venezuela in 1999 (JSCE, 2000).

3. Debris Flow Disasters in Venezuela, 1999

A catastrophic disaster happened in December, 1999. It was not clear but more than 30,000 people were killed.

Outline of Sediment-Related Hazards

(1) Conditions of Sediment-Related Hazards

A cold front which stayed for about 20 days over the Caribbean Sea caused 1,240 mm of precipitation in December, as observed at the international airport in the coastal area of Venezuela, about 20 km to the northwest of central Caracas. This compares with an average annual precipitation of 540 mm. 920 mm of the precipitation was observed December 14-16.

Table 1. A list of major sediment-related hazards from 1997 to 2006. (add some data to the table in Handbook on Sabo (2007)).

Dates	Countries	Hazard types	Disaster outlines: Numbers of dead and missing persons	Disaster outlines: Overall conditions
1997/3	Peru, Apurimac,	Sediment flow	35	
1997/6	Montserrat, Plymouth,	Volcanic eruption	22	Pyroclastic flows resulting from eruption
1997/7	Australia, New South Wales		19	
1997/8	Nepal	Landslide	20	
1998/1	Peru, Santa Teresa,	Landslide	15	
1998/1	Mozambique,	Landslide	87	
1998/1	Peru,	Sediment flow	31	
1998/2	Bolivia,	Landslide	40	
1998/3	Ecuador,	Landslide	17	
1998/3	Peru,	Landslide	15	
1998/4	Iran	Landslide	55	
1998/4	Tajikistan	Landslide	19	
1998/5	Italy		285	Sediment flows and flooding resulting from concentrated heavy rain
1998/5	Tajikistan	Landslide	76	
1998/6	China, Guangxi,	Landslide	63	
1998/7	Kyrgyzstan and Uzbekistan	Sediment flow	95	
1998/8	India, Pithoragarh,	Landslide	180	
1998/8	Nepal,	Landslide,	76	Flooding and landslides
1998/10	Taiwan	Landslide	27	
1998/10	Philippines, Central Philippines,		163	Landslides resulting from typhoon
1998/12	USA, Northeastern US,	Flooding and landslide	35	Flooding and landslides
1999/2	Malaysia	Landslide	17	
1999/4	Tajikistan	Landslide	9	
1999/4	Columbia	Landslide	50	
1999/5	USA, Hawaii, Oahu,	Landslide	7	
1999/5	Brazil, Salvador,	Landslide	36	
1999/7	Indonesia, East Kalimantan,	Landslide	25	
1999/8	Bangladesh,	Landslide	17	
1999/10	Nepal,	Landslide	10	
1999/9 ∼12	Columbia,	Landslide	93	Heavy rain and flooding
1999/12	Indonesia, West Sumatra,	Landslide	55	Flooding resulting from the landslide
1999/12	Venezuela	Debris flow, landslide	30,000?	
2000/1 ∼2/1	Philippines, Mindanao,	Landslide	23	Observed at 150 or more areas
2000/3	Peru, Foot of Andes,	Landslide	22	
2000/4	Ecuador, Coastal area,	Landslide	15	
2000/7	India, North of Mumbai,	Landslide	61	
2000/7	Russia, Caucasia,	Sediment flow	7	
2000/8	China, Yunnan,	Landslide	17	Flooding resulting from the landslides, the highest water level in Po river in the past 50 years
2000/10	Ecuador,	Sediment flow	10	
2000/10	Italy, northwestern Itary,	Landslide	25	
2000/10	Switzerland, southern Switzerland,	Landslide	12	Flooding resulting from the landslides, extending over an area of 1490ha
2000/10	Indonesia, Djawa Tengah,	Landslide	40	
2000/11	Indonesia, Djawa Tengah,	Landslide	52	
2001/11	India, Kerala,	Landslide	55	
2001/5	China, Sichuan,	Landslide	74	
2001/2	Indonesia, Java,	Landslide	94	
2001/7	Indonesia, Nias,	Landslide	163	
2001/7	Pakistan, northern Pakistan,	Landslide, flooding resulting from the landslides	210	Number of injured persons: 400,000
2001/5	China, Guangxi	Landslide	66	Flooding resulting from landslides, Number of injured: 9 million
2001/12	Brazil, Rio de Janeiro,	Landslide,	96	Flooding resulting from landslides
2002/1	Congo,	Volcanic eruption,	110	Number of injured: 130,000
2002/12	Indonesia, Djawa Timur,	Sediment flow	32	
2002/7	Ecuador, Mendes,	Landslide	60	
2002/12	Brazil, Angra dos Reis,	Landslide	40	
2002/9	Vietnam	Landslide	76	Flooding resulting from landslides
2003/4	Indonesia	Landslide	76	Number of injured persons: 230,000

2003/7	Nepal	Landslide	23	
2003/12	Philippines, South Leyte,	Landslide	207	
2004/4	Indonesia, Sumatra		44	
2004/3	Indonesia	Widespread devastation	32	
2005/2	Venezuela, Merida	Sediment flow	93	
2005/2	Indonesia	Landslide	143	
2005/2	Pakistan	Landslide	520	Flooding resulting from landslides
2006/1	Indonesia, Java, Central and eastern parts	Sediment flow	149	
2006/2	Philippines, Leyte	Landslide	1112	
2006/8	Nepal, Western Nepal	Sediment flow	147	Flooding resulting from the sediment flows
2006/12	Philippines, Mayon Volcano	Mud flow	1284	

The heavy rain caused a number of debris flows and shallow landslides. The most heavily damaged areas observed were in the coastal area in state of Vargas and along the bypass highway running between Caracas and Maiquetia International Airport (**Fig. 1**). This is in accordance with rainfall distributions.

(2) Past Hazards

The major hazards that hit the coastal area in the northern part of the state of Vargas in the past include those in 1948 and 1951. Huge amounts of sediment and debris drowned domestic animals in Maiquetia, Macuto, Catia de la Mar, and Puerto Viejo on July 28, 1948. The coastal area was discolored with several thousand tons of sediment. There were 1,500 victims (about 300 families) in total on February 16-17, 1951, mainly in Maiquetia, Macuto, and La Guaira. The roads running between Vargas and Caracas were paralyzed. The port of La Guaira port closed. The roads in the coastal areas lost many bridges.

(3) Outline of Hazard-Hit Area

The sediment-related hazards were caused by debris flows and shallow landslides. A number of houses clung to the mountain slopes in Caracas and along the highway running between Caracas and Maiquetia Airport. It is considered that the disasters were aggravated by inadequate land utilization control, housing structures, and drainage structures. The major hazards were caused by debris flows along the 13 mountain rivers in the coastal area. The geologies in the disaster-hit coastal area in the state of Vargas are characterized by pegmatite in the mountain-top areas, granite-gneiss at an altitude of 1,500 to 1,000 m, limestone at an altitude of 1,000 to 500 m, and serpentine at altitudes below 500 m. Limestone and serpentine are well weathered, and granite-gneiss is extensively cracked.

(4) Sediment Production and Flow Conditions

Of the debris flows evolving in the central portion of state of Vargas, the extensive deposits were observed downstream of the 13 mountain rivers (**Fig. 1**). **Fig. 2** shows an amount of deposited sediment in each mountain river. The basins are very large, 41.5 km^2 at the largest around the Camuri Grande River and 1.3 km^2 at the smallest around the Carioca River. These compare with up to around 1 km^2 and 0.1 km^2 or less in many cases in Japan.

These rivers are steep, with an inclination of 5 to 11% (3 to 6°). They run from water sources at altitudes above 2,000 m (2,750 m at the highest) to the coastal alluvial fan areas (altitude: 0 m).

The geology is characterized by psammitic schists on the downstream side and gneiss on the upstream side. There are a number of faults running east-west. The psammitic schists, extensively cracked and well weathered, tend to collapse the mountain slopes.

In the basins of the 13 mountain rivers, a number of mountain slopes collapsed, producing large amounts of sediment. In the San Julian River (**Fig. 3**), for example, sediment deposited on the riverbed in the central part of the river can conceivably erode to produce a large amount of sediment. The slopes collapsed to show a number of planar slips and long, thin, valley-like collapses. The average collapse depth was relatively shallow, around 1.0 m. Many of the rivers carried large amounts of sediment, advancing the coastal lines towards the sea by 50 to 100 m.

(5) San Julian River Basin

San Julian River basin is picked out as a representative.

1) Geography and Geology

The river originates on Pico Oriental (altitude: 2,700 m) in the Costa Mountains and forms an inversed triangular basin 21.92 km^2 in area, 9 km in length, and about 4 km in width at the widest point (**Fig. 4**). The valleys are U-shaped and 100 m wide or more, because the slopes have mild inclinations (15 to 20°) at an altitude of 300 m or lower. At higher altitudes, the valley slopes running along the river are steep, having an inclination of 45° or more. These slopes have a specific height of 320 to 360 m. The valleys along the river are V-shaped.

The river runs at an essentially constant bed inclination of 7% (4°) over its 4,000 m length from the coast. The inclination then increases exponentially upstream . In the zone in which altitudes are from 300 to 700 m, the river has strong erosion effects, and the rocks are also geologically crushed by the faults, with the result that short, steep side streams are formed dendritically.

The geologies are characterized by deposits in the alluvial fan, green schist, psammitic schist, and gneiss

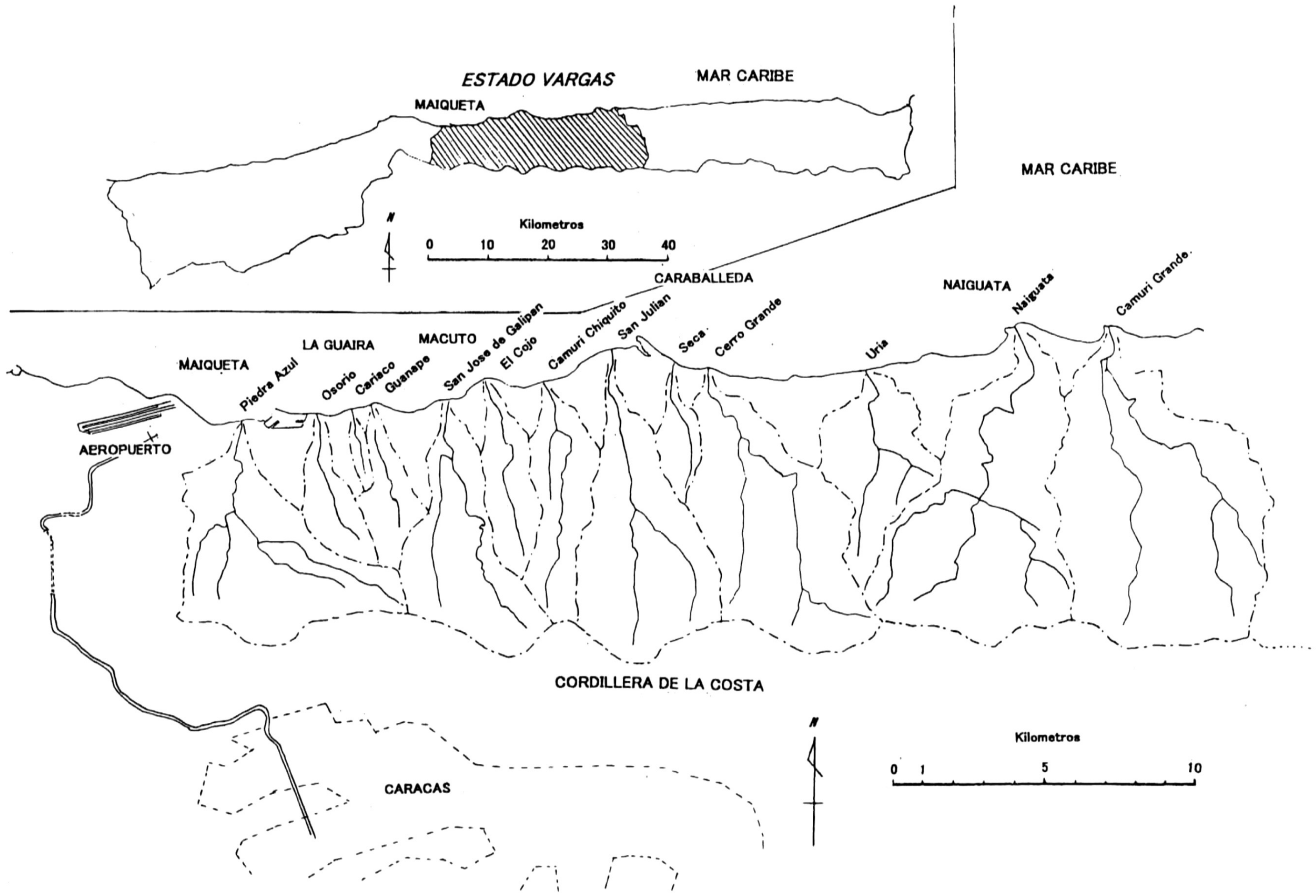

Fig. 1. 13 Mountain rivers which massively carried sediment.

(in this order) from the coast. The demarcations, however, are not clear, and they seem to be denatured more strongly as they go toward the crests. The faults run largely east-west, and fault slopes are inclined at 40 to 70° towards the north. Green schist prevails at an altitude of 300 m or less, causing slope collapses with flat, elliptic slips. At altitudes of 300 to 700 m, psammitic schist prevails, causing slope collapses with dendritic slips that have irregular surfaces.

2) Damage

The houses, apartment buildings etc. in the alluvial fan were damaged by the debris flows. According to the Venezuelan government, completely destroyed, half destroyed, and partially destroyed houses 202, 806 and 1,551 respectively. The sediment-flooded area extended about 0.6 km^2 with the amount of sediment estimated at 1,627,000 m^3.

3) Flooding and Deposition of Sediment

Deposition of the debris flow fronts were found at altitudes of 20, 40, 60 and 110 m, indicating that the flow hit the area in 4 waves (**Fig. 5**). The inclination was 3.3° (1/16.5) at these spots. The debris flow fronts at altitudes of 110, 50, 40 and 20 m ran towards the left coast side in the alluvial fan, towards the alluvial fan center, towards the left coast side from the fan center, and in the direction of river flow, which may suggest that the spots at which the flows stopped moved from the downstream side due to the sediment deposits.

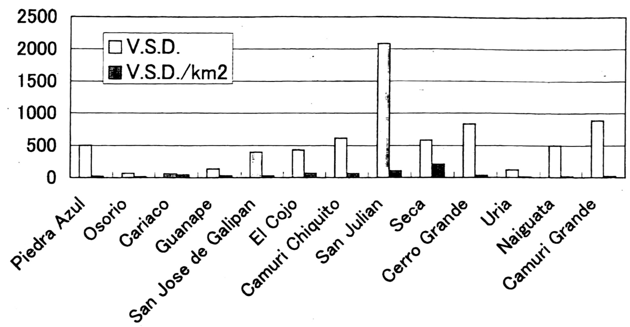

Fig. 2. Amounts of deposited sediment. (V.S.D: Amount of sediment deposited (1000 m^3), V.S.D./km^2: Specific amount of deposited sediment (1000 m^3/km^2))

At an altitude of 10 m and less, the deposits are characterized by sand, containing a number large rocks.

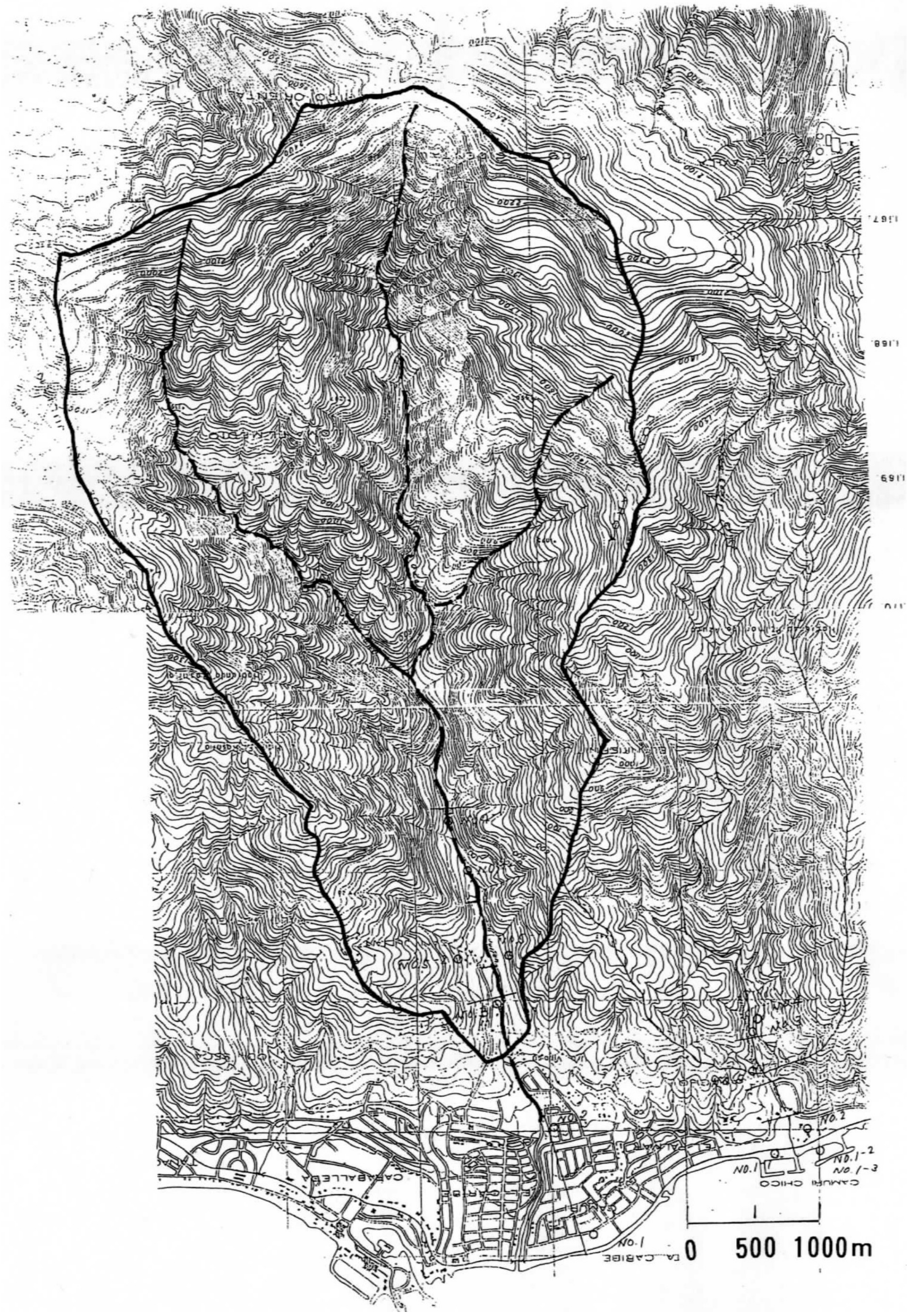

Fig. 3. Topographic map of the San Julian River Basin.

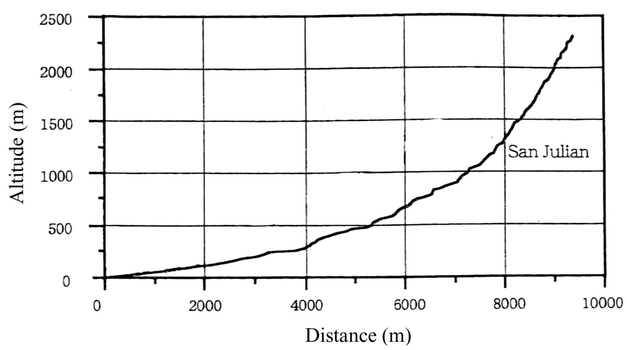

Fig. 4. Longitudinal sectional view of San Julian river.

It is of note that large rocks are found at an altitude of 20 m or more. At an altitude of 125 m or less, the deposits were re-eroded in some spots by subsequent flows. The deposits were as deep as 10 m along the river and 4 m outside of the area.

4) Erosion of and Deposition on Upstream River Beds

At altitudes of 120 to 300 m, the sediment deposits, which were formed not many years ago although it is not clear when, were eroded. At an altitude of 300 m

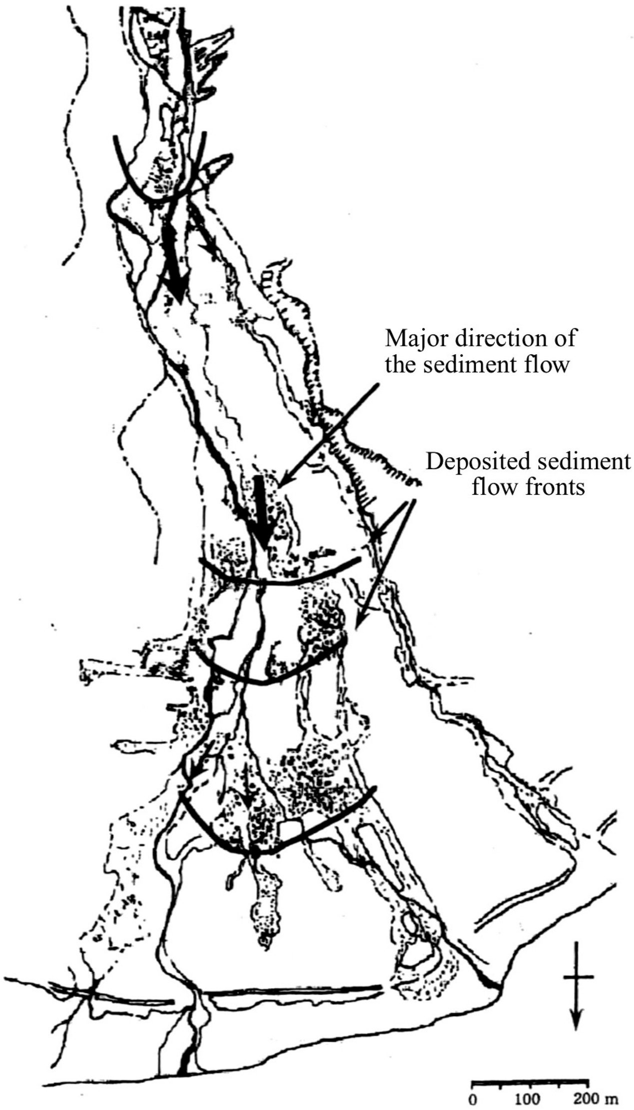

Fig. 5. Deposited sediment flow fronts.

or more, the deposits on the beds were eroded.

5) Sediment Balances

A JICA report (2000) estimates that the sediment that was produced totaled 1,627,000 m^3 and was deposited in the alluvial fan, of which 767,000 m^3 was caused by slope collapses, 347,000 m^3 by erosion in the upper reach and 513,000 m^3 by erosion in the middle reach of the river.

6) Hearing Survey Results

According to the hearing survey, the residents noticed the debris flows at 1am, 7am and 11am on December 16.

7) Estimated Peak Flow Rate

The JICA investigation team estimated a peak flow rate of 942 m^3/sec, based on the observed flood marks of the floods.

(6) Lessons from the Disaster

The disaster gave some useful lessons.

1) Similar debris flow and landslides occur as happened before though the frequency is low. They should learn what happened in the area from history and topography.
2) People have to select where they build houses considering the danger of sediment hazards. Strict regulation on proper land use is sometimes necessary.
3) This disaster was caused by unusual heavy rainfall. Meteorological information has to be informed properly. Warning should be issued from governments with good timing. People have to be educated to understand the information.

4. Countermeasures

Countermeasures to prevent or to mitigate sediment related hazards are classified into structural and nonstructural measures. Structural measures include erosion and sediment check dams (or Sabo dams), dikes, and channels. Nonstructural measures include appropriate land use and evacuation warning systems. Hazard maps are necessary to provide essential preparation for both structural and nonstructural measures.

The 1999 disaster in Venezuela shows information on hazards such as hazard maps and rainfall is necessary and control structures may reduce damages if they had existed. Sediment disaster prone areas are many and widely distributed. Structural measures are often not taken from cost-benefit view point. Proper land-use and hazard education are needed. It is difficult to find the proper land use has been taken. It is necessary to take information on former disasters and convey them to next generation.

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Academic Societies & Scientific Organizations:
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