were due to the inflow of lahar or to the presence of the main course, it has been confirmed that lahar flowed from the B. Semut Lama (Old B. Semut) into the K. Kurembang, a tributary of the K. Rejali in 1911.

On the other hand, it is also likely that the B. Semut flowed into the Duren at some time in the past; the Duren is a tributary of the Mujur. As can be seen, the Semut was, in the past, subject to considerable changes in its course, but it became a notably stable under-fit river after 1940.

The B. Sat was diverted to the B. Tunggeng river after the disaster of 1909 by artificial excavation. Although other changes in river courses are not noted, works records prepared for the B. Sat Lama indicate the fixing of river courses, i.e., to the K. Mujur; on many occasions.

Changes in courses at the top of fans result in disasters whose size affects the entire area of the fans. The presence, if any, of deep valleys (fan head trench) at the top of the fans does not prevent a variation of river bed height. When the river bed rises, therefore, there is always a possible danger of changes in the river courses.

3. DISASTER STUDIES

3.1 FIELD STUDIES

Field studies were conducted based upon a study table, shown in Table-3.1; and the results of these field studies are shown in Appendix . Since accurate determination of the years in which disasters took place is not likely by means of inquiries, confirmation thereof was made using existing data. As a result, two disasters were newly added to the existing disaster area map (1/50,000). As for some disasters, several corrections were made in respect of disaster areas based upon the results of inquiries. As mentioned, determination of years through inquiries is not always accurate; however, it was learned that the data carried in the existing disaster area map was mostly correct regarding its coverage. The locations of study and a list thereof are shown in Fig.-3.1 and Table-3.2, respectively.

3.2 CONDITIONS OF DISASTERS BY PRINCIPAL RIVER

(1) B. Sat and K. Mujur

The collapse of volcanic ejecta which occcurred at the head of the B. Sat and B. Tompe in 1909 caused the lahar to overflow at the top of the B. Sat fan; further, the eruptions spread to cover the areas between the B. Sat Lama and K. Mujur and reached points as low as EL. 250 m, some even flowed down valleys of the B. Sat Lama river and went beyond the railroads before stopping. Still some ejecta flowed into the K. Lateng, belonging to the Bondoyudo river system, and attached Lumajang. The disaster brought about in this time is the greatest of those experienced at the area. The deposits from 1909, i.e., boulders, can still be recognized near the village of Kertsari even now.

Table-3.1 Questionnaire on Past Disasters No.:

Day/Month/Year		Name of surveyor	
Name of Village			
Respondent Man / Woman	Age	How long have you lived here	
Have you ever experienced a lahar	Yes No	Was your village ever hit by a lahar before you were born	I have heard it was I have heard it wasn't
Have you ever experienced a flood	Yes No	Was your village ever hit by a flood before you were born	I have heard it was I have heard it wasn't

Occurrence of lahars and floods Day/Month/Year How many years ago	Deposit	Composition	Water Height	Losses	
				House holds	Persons
	m	Clay Sand Gravel Boulders	m		
	m	Clay Sand Gravel Boulders	m		
	m	Clay Sand Gravel Boulders	m		
	m	Clay Sand Gravel Boulders	m		
	m	Clay Sand Gravel Boulders	m		

Losses in 1981 Yes No	Day/Month/Time	Depth of Deposit	m

Table-3.2 List of Study Points

Day/Month	No.	Location	Day/Month	No.	Location
7.7	1	Tunggent	14.7	1	Pandanwangi
	2	Gelapan		2	Rekesan Kidul
	3-1	Sumber Sari		3	Pandan Wangi
	3-2	Sumber Sari		4	Pandan Wangi
	4	Sumber Sari		5	Pandan Wangi
	5	Sumber Sari		6	Tempeh Kidul
	6	Wonorenggo		7	Tempeh Kidul
	7	Sumber Mujur	15.7	1	Tempeh Kidul
	8	Sumber Mujur		2	Tempeh Kidul
	9	Penanggal		3	Lempeni
10.7	1	Kerto Sari		4	Lempeni
	2	Kerto Sari		5	Kemamang, Tam Tambahrejo
	3	kerto Sari	17.7	1	Hutan Bago
	4	Kerto Sari		2	Bago Rekesan
13.7	1	Klopo Sawit - Pancut		3	Bago Rekesan
	2	Rojobalen - Klopo Sawit		4	Bago Rekesan
				5	Tengah Kali Rejali
	3	Klopo Sawit			
	4	Klopo Sawit		6	Bago Rekesan
	5	Besuk Tempeng		7	Bago Rekesan
	6	Semban			
	7	Jokarto			
	8	Jokarto			
	9	Pulo			

Day/Month	No.	Location
29.7	1-a	Panggung Lombok C. puro
	1-b	Panggung Lombok C. Puro
	1-c	Panggung Lombok C. Puro
	2	Sb. Wuluh, Candi Puro
	2	Kebondeli, Sb. Wuluh
	5	Sb. Wuluh
	6	Panggung Lombok Kidul
7.8	1	Kamar Kajang-Sb. Wuluh
	2	Kebondeli-Sb. Wuluh
	3	Kebondeli
	4	Sb. Wundkal-Sb. Wuluh
	5	Komp. Renteng-Sb. Wuluh
10.8	1	Jugo Sari
	2	Jugo Sari
	3	Jugo Sari-Jugo, Cd. puro
	4	Jugo Sari-Jugo, Cd. puro
	5	Jugo Sari-Laha Ran
	6	Jugo Sari-Laha Ran
	7	Urang-gannung
	8	Urang-gannung

Day/Month	No.	Location
11.8	1	Gondo Roso
	2	Ringin Ponh-Danu Rejo
	3	Danu Rejo
	4	Gondo Ruso
	5	Danu Rejo-Gondo Ruso
	6	Panu Rejo-Gondo Ruso
	7	Sumber Rejo, Gondo Ruso
	8	Ringin Pojor, Gondo Ruso
	9	Sudimoro-Kali Bendo
	10	Sudimoro-Kali Bendo
	11	Siluman-Bades
12.8	1-2	Tegal Banteng-Buyeng
	1-2	Tegal Rejo-Bulu Rejo
	1-3	Tegal Rejo
	2-1	Wareng-Tempur Sari
	2-2	Wareng-Tempur Sari
	3	Puro Rejo
	4	Tempur Rejo

Day/Month	No.	Location
20.8	1	Curah Kobo'an
	2	Sumber Wuluh
	3	Sumber Wuluh
	4	Curah Kobo'an
21.8	1	Suniber Vrip
	2	Kamara (Supit Urang)
27.8	1-1	Jugaton Pronojiwo
	1-2	Sidomulyo Ampelgadive
	2	Sumber Rowd
	3	
	4	Pronojiwo
15.9	1	Sumberurip
	2	Supit Urang
	3-1	Gumukmas. Supiturang
	3-2	Gumukmas. Supiturang
	4	Supiturang Pronojiwo
	5	Supiturang
	6	Kloposawit
	7-1	Selorejo Klopo Sawit
	7-2	Selorejo
	8-1	Sumberrejo Candipuro
	8-2	Sumberrejo Candipuro

Day/Month	No.	Location
15.9	9	Japit Candipuro
16.9	1	Bulak Klakah Japit
	2	Japit Candipupo
	3	Nguer Pasirian
	4	Nguer
	5	Nguer Pasirian
	6	Komplangan Pasilian
	7	Formely Kalikemeron
	8	Pasirian
17.9	1	Gaplek
	2	Karangan Yar-Japit
	3	Karangan Yar
	4	Legongjambe Selokawar
	5	Legongjambe Selokawar
	6	Selok de Bonan
	7	Lempeni
	8	Madurejo
	9	Semumu
	10	Madurejo
	11	Semumu
	12	Semumu Darungan
20.9	1	Karang Bendo
	2	Karangan Yar Jarit

Day/Month	No.	Location	Day/Month	No.	Location
20.9	3	Uranggantung Jarit	24.9	7	Bayeman Citro Trunan
	4	Bangun Sari		8	Suko Purwosono
	5	Bades Purut		9	Karang Sari Sokodono
	6-1	Bagokrajan Kidul			
	7	Bago			
	8	Gesang			
	9	Pulo			
	10-1	Suko Rejo Tempen Tengah			
	10-2	Suko Rejo Te			
	11	Tempeh Lor			
	12	Tempeh Lor			
	13-1	Besuk Tempeh			
	13-2	Besuk Tempeh			
	14	Curahjero Labruk			
23.9	1	Tulung Rejo Pasrujambe			
	2	Pasrujambe Senduro			
	3	Pasrumambe Senduro			
24.9	1	Sumber Suko			
	2	Sumber Suko Tempeh			
	3	Sumber Suko			
	4	Mojosari			
	5	Laban Labruk Lor			
	6	Purwosono			

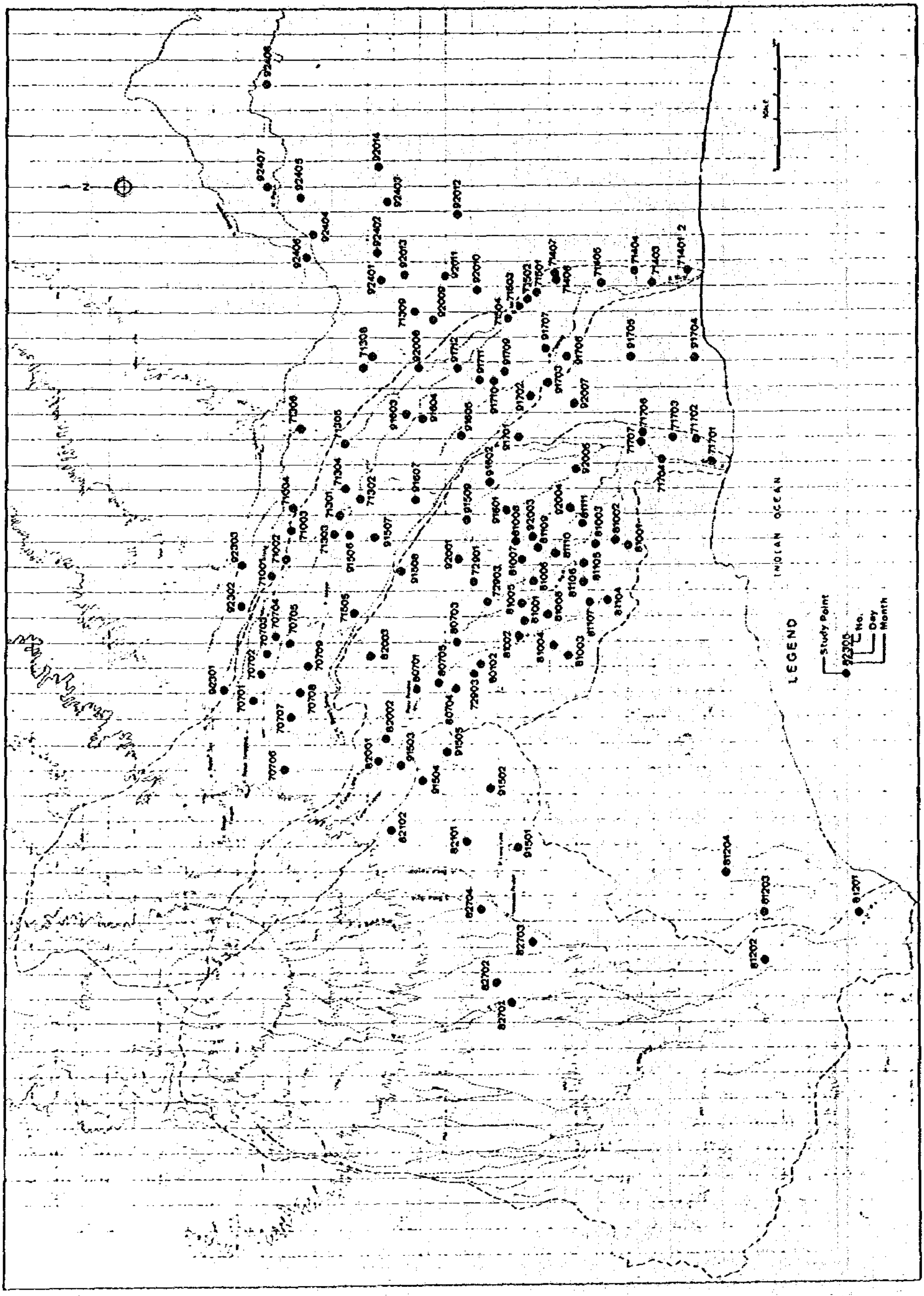


Fig.-3.1 Map of Study Points

After the disaster of 1909, the B. Sat was diverted to the B. Tunggeng. Disasters after 1909, according to available records, include that of the Bendo Dike at the fan top in 1946 and 1957 and that at the Sumber Pakel river, a tributary of the Lateng. In 1976, two floods were recorded.

On May 14, 1981, the collapse which occurred at the valley head of the B. Tunggeng caused lahar to flow down the B. Sat and B. Tunggeng. Disaster areas at this time included those along the B. Sat, B. Tunggeng and Mujur. The debris overflowed along the Tunggeng and downstream; however, the main point of overflow was seen at the top of the B. Sat fan. Part of the flooding water went beyond the embankment and flowed into the B. Sat Lama, limited in amount, and spread most in the village of Keroposawit to subside at the K. Mujur near the village of Karangculik. Water also flooded the right bank and flowed into a tributary of the K. Duren.

Other disasters include lava, or nue ardante, which reached near EL. 900 m at the K. Poh fan along the B. Tunggeng in 1895.

(2) B. Semut and K. Pancing

In the case of the B. Semut and K. Pancing, there is no known disasters after the lava overflow of 1942. Seven disasters are recorded between 1900 and 1942; and among these, disasters whose areas are known are those of 1909, 1913 and 1942, three in all. The disaster of 1913 was caused by a flowing in of debris from the B. Semut to the B. Kobo'an which brought damage to the lower reaches of the K. Rejali; from near the top of the B. Semut fan, the flow spread over the areas between the villages of Sumber Wuluh and Candi Puro and reached points near EL. 300 m.

Part of the debris which overflowed at the time can be observed along the national road connecting the two villages. The disaster of 1909 occurred in the areas between Candi Puro and Pasirian and along the K. Pancing. The B. Semut fan still consists of vast devastated land and there is the presence of deposits of lahar, suggesting frequent overflow of debris not indicated in the records. Disasters whose extent is not known can also be noted from records showing frequent changes in river courses.

No disaster is recorded for the lower reaches of the B. Semut after the lava overflow of 1942; in passing, lava, or nue ardante, flowed down along the B. Semut in 1895.

(3) K. Rejali and B. Kobo'an

As far as disasters before 1940 are concerned, only a few disasters are recorded, including that of 1913; however, the results of inquiries and existing data strongly suggest that there were disasters also before the 1940s. Furthermore, the results of inquiries imply that the debris which overflowed before the 1940s consisted of particles not as coarse as those seen now and the size of the disasters was not extensive.

The frequency of disasters of this basin after the 1940s is significantly higher than that of areas along other rivers, and those recorded after 1946 alone amount to ten. The areas subjected to disasters after 1940 take up more than half the area of the Rejali fan; and damage is particularly frequent to fans with a steep and gentle slope and the top of lahar fans. The points where flooding starts are found between the tops of fans with a steep and gentle slope. Moreover, damage tends to extend downstream over a considerable length along the old river course.

Areas subjected to the disasters of 1976, 1978 and 1981 still lie devastated and not much restoration for land use has been done. Similarly, the top of the fans with a gentle slope along the K. Rejali, i.e., areas on the east of Gn. Jugo, still have areas for which restoration work is due.

Of factors which brought about the increase in disasters after the 1940s at the Rejali fan, the following two can be considered:

- The emergence of the river as an overfit river due to the change in the course caused by lava outflow of 1942 (increase).

- The crater may have faced the B. Kobo'an or it was directly connected to the B. Kobo'an.

From the results of field studies, it was learned that most of the lahar seen in the area was hot lahar and there was the presence of debris which was heated to a certain degree and which did not contain much moisture in the B. Kobo'an. The findings suggest that the occurence of lahar is closely connected to volcanic activity.

(4) K. Glidik

The first disaster experienced at the lower reaches of the K. Glidik is the outflow of nue ardante along the B. Supit in 1885; thereafter, no disaster has been recorded until the disaster of 1967. After 1976, disasters frequently

Table-3.3 Occurrence of Lahar Within Study Area Since 1895

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
1.	1985	Active	Flood origniated from the Laki and Tengah rivers, causing a great deal of sand inundation in the B. Sat channel.			
2.	1909	Active	The biggest flood ever known devastated 38 villages and killed 208 people. The flood originated from the B. Sat and B. Semut and devastated 1043 ha. of rice fields, 337 ha. of uplands, 227 ha. housing lands, and washed away 1449 houses and 313 cattle.	Flood devastated 5 villages and killed 1 person.		

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
3.	1913	Active		Flood from the B. Semut spread to the Rajarkuning and finally to the Kobo'an. In the east, flood flowed into the K. Pancing.		
4.	1921	Dormant				Flood from B. Cukit and B. Bang caused some damage along K. Glidik.
5.	1937	Dormant				Flood from B. Cukit and B. Bang caused some damage along K. Glidik.
6.	1946	Active	Floods spread from the B. Sat to the Sumber pakel river at Bendo and devastated some parts of Pasrujambe village.		Flood water from K. Rejali spread and devastated Sumber Wuluh and finally entered K. Siluman after devasta-	

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
6.					ting Sudinoro, Jugosari and West side of Danurejo Vil- lages.	
7.	1948	Active			Lahar hit Sumber Wuluh, east part of Kebondeli, Candipuro, Sudinoro and Danurejo vil- lages. K. Re- jali shifted to the left at EL. 250 m.	
8.	1951	Active			Flood from K. Rejali spread to Uranggantung and entered K. Silu- man.	
9.	1957	Active	Floods forced the Bendo Dike to the Sumber pakel river and destroyed some parts of Luman- jang City.			

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
10.					Flood spread along K. Rejali with a width of 100-400m; it began at Sumber Wuluh and ended at Sudinoro village.	
11.	1967	Active				Lahar destroyed river bank near bridge at Sum- berrow village.
12.	1968	Active			Flood from K. Rejali devas- tated uplands, rice fields of Sumber Wungkel village and entered K. K. Leprak at +353m elevation. At that time, 5 persons were killed, 36 houses were damaged, 15 ha. of rice fileds and 10 ha. of cassava were in- undated by sand.	

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
13.	1975 (Aug. 7)	Active			A weir was swept away, 3 ha of rice fields was covered with muddy water for 1/2 hour. 6 houses were damaged. A channel was broken, causing 75 ha of secondary crops to fail. Road connecting Jurosari-Jarit was cut off. Loss estimate was about Rp. 1.5 million.	
14.	1975 (Sept. 13)	Active			Road connecting Sumber Wuluh-Kebondeli was cut off. 100 ha of rice fields were devastated, 5 houses damaged; loss was estimated to be Rp. 20 million.	

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
15.	1976 (Oct. 13)	Active	Flood from B. Sat caused damage in Side Mulyo village, and 1 person killed.		Flood from K. Leprak damaged Kebondeli and Jugosari. 10 persons were killed. All houses in these villages were destroyed. 450 ha of rice fields were damaged.	In Prorejo 8 persons were killed and 50 houses were destroyed. Taman ayu along K. Legnkong was also damaged.
16.	(Sept.)	Active	In Gesang village, 14 persons were reported missing. 3,300 ha of rice fields were damaged. 4 intakes and the irrigation channel was also damaged over a length of 2,950 m. At Pasrujambe, 575 ha of rice fields were damaged.		Flood from K. Leprak Kebondeli, Gondoruso, and Jugosari village. 23 houses were destroyed.	

No.	Year	Volcanic Activity	Besuk Sat	Besuk Semut	Besuk Kobo'an K. Rejali	K. Glidik
17.	(May 12)	Active	Flood from B. Sat and B. Tung-geng; Along B. Sat, B. Tunggeng and K. Mujur. 242 persons were killed. Fields and facilities were extensively damaged. Lecess dike destroyed and flood spread to B. Sat lama.		Flood from Curah Lengkong; Along K. Lep-rak, 2 persons were killed and fields and many houses were destroyed.	In Purorejo, 63 houses were destroyed.
18.	1982 (Jan.)					In Purorejo village, many houses were destroyed and all rice fields became covered with sand.

took place in the Lengkong fan formed by the B. Bnag, B. Sarat and B. Kember. These disasters can be attributed to the direct connection between the crater and the B. Sarat brought about by the overflow of lava occurring after the 1960s. Owing to the frequent occurrence of lahar, the Lengkong fan is, at present, left devastated.

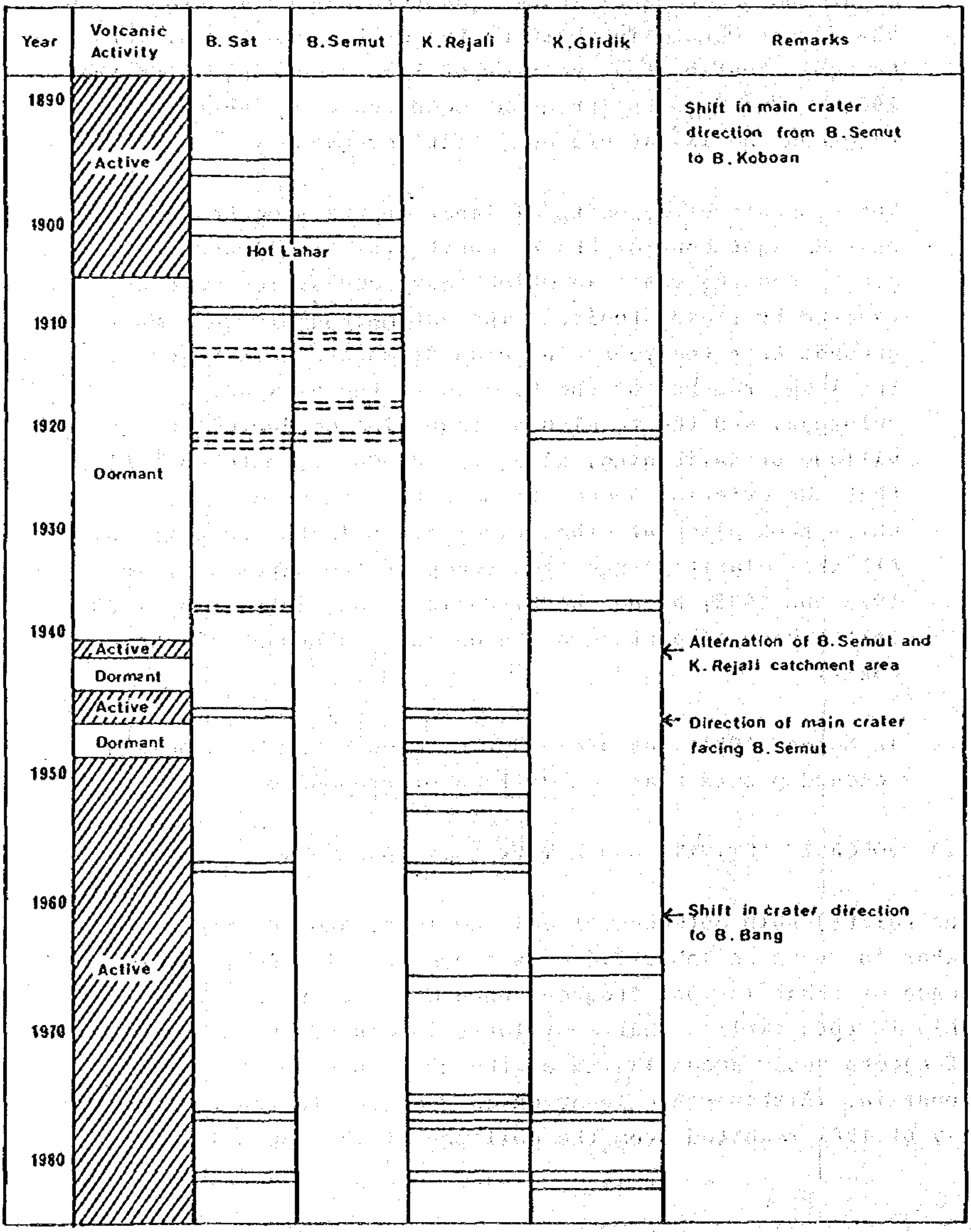
The presence of deposits of lahar or nue ardante was noted on the right bank of the B. Cukit from aerial photographs and the years in which they accumulated were estimated by field studies. The estimates were made on the grounds that the years in which disasters took place at the lower reaches of the K. Glidik, the village of Bulureyo, and the results of inquiries conducted in the village of Kalibening, along the B. Cukit, matched. Also that the existing documents show records of disasters which took place at other river areas in the same years. All this clarified the occurrence of two disasters, in 1922 and 1938, along the B. Cukit. The disaster of 1922 left a vast area of deposits on the right bank of the B. Cukit.

In March, 1981, nue ardante flowed down the B. Bang and reached points near the village of Pronojiwo.

3.3 VOLCANIC ACTIVITY AND ACTIVITY OF LAHAR

The relationship between volcanic activity and occurrence of lahar is shown in Table-3.4. As can be easily seen, the occurrence of lahar is most frequent when Mt. Semeru is active. This in turn implies that most lahar is caused by the collapse of ejecta newly accumulating at the upper part of the volcanic mountain. Although the lahar which was seen in the K. Mujur in May of 1981 resulted from the collapse of the top soil on

Table-3.4 Relationship between Volcanic Activity and Lahar



mountainsides, the area had already been covered with forests. In terms of the location of the material which collapsed, the lahar in the K. Mujur of May, 1981, differed from ordinary lahar.

Lahar occurs when the volcano is active and during such periods the frequency of occurrence of hot lahar is also high. It is also supposed that the occurrence of lahar originating in the collapse of volcanic ejecta yet to solidify is highest, followed by that caused by collapse of large-scale gullies at the valley heads. The lahar in the K. Rejali of May, 1981, is of the latter type. Lahar resulting from the collapse of mountainsides in forest belts should be quite rare, as no occurrence of landslides, except for that of May 1981, is likely on the mountainsides in the forest belts.

These factors all contribute to the frequent occurrence of lahar at valleys connected topographically to the craters.

3.4 DISASTER AREAS AND TOPOGRAPHY

The following relationships can be observed between disaster areas and topography:

(1) The nue ardante and lava flows for which records are available stop generally at ladu fans.

(2) Lahar causes damage also at ladu fans; however, its extensive damage is most likely at lahar fans.

(3) Flooding of lahar is likely to begin at the top of lahar fans.

(4) Where the deposits of previous lahar are accumulated in thick layers around the river course at fan tops, the

point of beginning of flooding may sometimes be found further downstream; conversely, where there are thick layers of deposits in the river course, such points are found further upstream.

(5) From the condition of disasters and topography of the Rejali and Semut fans, various points on a fan can be subject to disaster.

(6) In particular, areas around river courses and old river courses tend to become channels for lahar, resulting in a downstream extension of damage along the river courses and old river courses.

(7) The distribution of lahar deposits accumulated in the past is almost limited to lahar fans above EL. 150 m - 200 m.

(8) Although damage caused by large-scale lahar is likely to affect areas as far as the periphery, the materials supplied in such cases tend to consist mainly of sand and pebbels or granules.

3.5 PREPARATION OF PROBABLE FLOOD AREA MAP

As stated in Section 3.4, the unit and type of disaster of fans cleary correspond with each other. This is only natural in view of the fact that the present topography seen at the volcanic piedmont is a result of the past overflow of debris and an accumulation of deposits.

The difference in the mode of overflow of debris and the condition of deposits is closely connected to the degree of damage and the ease in restoration work; and in the light of this, flood areas were classified according to the condition of the accumulation of materials. Here, topographical classification was used as it was in principal, since the condition of such accumulation bore good correspondence to the topographical classifiction.

In establishing probable disaster areas, the following assumptions were made considering the conditions of past disasters:

(1) Within one fan unit, the degree of probability, i.e., type, frequency and scale, is identical.

(2) The rivers running through ladu fans and lahar fans with a steep slope are subject to flooding at all points along the way.

(3) With regard to fans with a gentle slope and on the periphery, no flooding occurs at points where valleys with a depth of 5 m to 10 m are formed.

(4) With further regard to fans with a gentle slope and on the periphery, areas with a limited height are excluded from flood areas.

These assumptions do not necessarily mean that the degree of probability of disaster at rivers belonging to different systems is identical; i.e., since the frequency of lahar occurrence and its type differ from one river system to another, the degree of probability at flood areas downstream thereof naturally differ depending on the river system.

Table-3.5 shows topographical classification and types of disaster. Since the debris flow type is considered to apply to areas as far as the top of lahar fans, the areas were made to include the top of lahar fans found further downstream of ladu fans. Moreover, since the thickness of layers of lahar deposits

Table- 3.5 Relationship between Topographical Unit and Disaster Type

Disaster Types	Topographical Units	Main Sectionf of Disaster: K. Rejali	Main Sectionf of Disaster: K. Mujur
Pyroclastic Flow (Nué ardante*)	Main part of volcanic cone Ladu fan	Crater ↓ B. Kobo'an dam site	Crater ↓ Confluence with B. Tompe and B. Sat
Debris Flow (Lahar)*	Ladu fan, Upper part of lahar fan (steep slope)	B. Kobo'an dam site ↓ Kebondeli	Confluence with B. Tompe and B. Sat ↓ Confluence with B. Tunggeng and B. Sat
Mud Flow(A) (Lahar)*	Lahar fan (steep slope)	Kebondeli ↓ Gn. Jugo	Confluence with B. Tunggeng and B. Sat ↓ Confluence with B. Tunggeng K. Mujur
Mud Flow(B) (Lahar)*	Lahar fan (Gentle slope)	Gn. Jugo ↓ Bogoraksan	Confluence with B. Tunggeng K. Mujur ↓ Railway Bridge
Bed Load Flow (Banjir)*	Peripheral Area	Bogoraksan ↓ River mouth	Railway Bridge (Confluence with K. Pacing and K. Mujur) ↓ River mouth

was confirmed to differ at lahar fans with a steep slope and fans with a gentle slope by mud flow studies, two separate categories, Mud flow (A) and Mud flow (B), were made.

The determination of probable disaster areas was conducted based upon the foregoing assumptions in the following order:

1) Establishment of probable flood sections along principal rivers.

2) Establishment of Flood Limits Areas

   The boundary regarding flood periphery areas was established as follows with reference to the past disaster area.

   (i) Lateral Extension

   Topographical boundaries of mountains, hills valleys with appreciable size, other fan units, etc.

   (ii) Downstream Extension

   B. Sat fan ... with reference to the disaster area of 1909.

   (iii) Classification of sediment type in probable flood areas based upon Table-3.5.

The probable disaster area map thus prepared is shown in Fig.-3.2. The map was drawn without quantitative analysis and, therefore, further corrections based upon quantitative analysis and in terms of hydraulics may still be necessary.

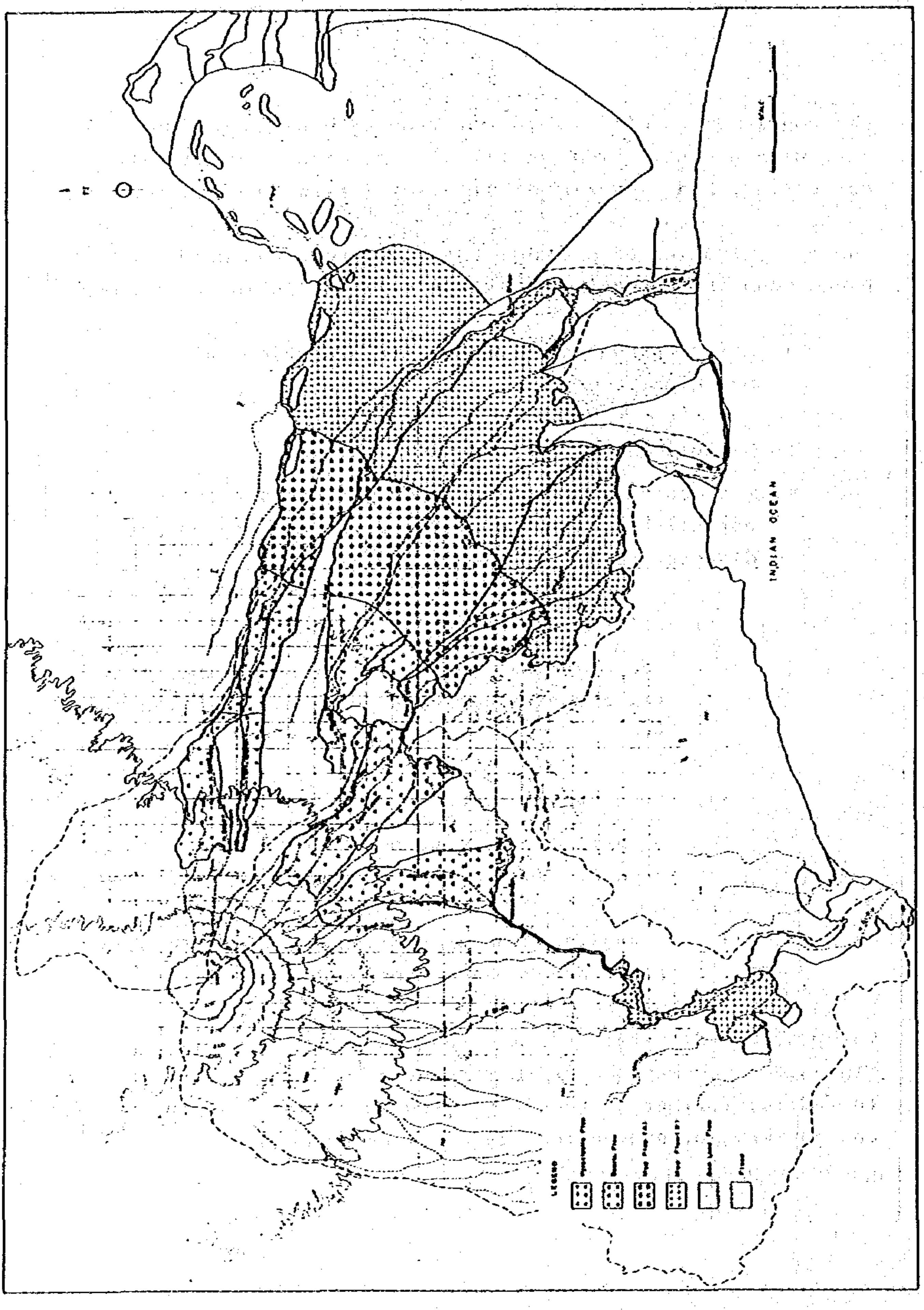


Fig.-3.2 Possible Disaster Area map

4. CONCLUSION

All the studies conducted in this report as discussed helped to clarify the outline of the topography of the study area and the existing conditions of disasters. Further, examination of the relationship between the topography and the disasters enabled preparation of probable disaster area maps.

Disasters caused by debris occur as part of the process in which formation of and change in topography takes place; therefore, comprehension of the nature of topography is an indispensable task in formulating debris control programs.

The frequency of the occurrence of disasters and the conditions thereof depend on the nature of the valleys through which earth is supplied to alluvial fans. In the light of this, the nature of valleys as a place where disasters originate was classified with reference to the frequency of past disasters. The topographical relationship between the crater and the valleys and the presence of large-scale landslide areas at the valley heads appreciably increase the chances of the occurrence of lahar disasters.

On the other hand, fans where debris tends to flood are now subject to changes in the river courses owing to considerable outflow and accumulation of debris. Changes in the river courses are likely to occur at fan tops and their effects are felt over the entire topographical unit of the fans. Each fan was divided into three units longitudinally for the purpose of this report; namely,

Lahar fan	EL. 750 - 1,500 m
Lahar fan (steep slope)	EL. 250 - 750 m

Differences in the flooding and accumulation characteristics were made clear.

Disaster investigations confirmed that the existing disaster area maps were fairly accurate; as a result, increase in the frequency of disasters inside the K. Rejali fan and the cause thereof were assumed with certain accuracy; in other words, the main cause is found to lie in the increase in the area of basin due to the outflow of lava into the B. Semut in the 1940s and the topographical relationship between the crater and the B. Kobo'an, located upstream of the K. Rejali.

Moreover, the point closest to the Leces embankment along the B. Sat was found to correspond to the top of the B. Sat fan. The knickpoint at this point helps the flowing of lahar into the K. Lateng, which is a tributary of the K. Bondoyudo. The fixing of the river course at the top of the B. Sat fan is considered to have a great deal of importance in terms of debris control for the fertile Lumajang Plains.

THE REPUBLIC OF INDONESIA

THE FEASIBILITY STUDY ON THE VOLCANIC DEBRIS CONTROL AND WATER CONSERVATION PROJECT IN THE SOUTHEASTERN SLOPE OF MT. SEMERU

SUPPORTING REPORT (5)

PART - I
VEGETATION

FEBRUARY, 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

Several types of vegetation derived from the subalpine forest are partly caused by fire, partly by volcanicity.

In the Javanese mountains forest fire is due to man in almost all cases, in a few cases possibly to fire-clouds (Nuee Ardente, ladu) or lava, as in Mt. Semeru and Merapi aeria. As far as we know, it is never due to lightning.

The more serious fires are possibly caused by the dry season which occurs regularly in the mountains of East Java, and especially affects the northern and western sides.

Every year in East Java a dry period prevails and all the mountains suffer annually from fire, from Mt. Dieng eastwards, in particular Mt. Lawu, Vilis, Kawi, Mohameru (Semeru) and Idjen, where the forest has given way to grassland.

There are only a few ligneous pioneers, Quercus sp. (Pasang), Litsen sp. (Nyampo), Varaonia sp. (Acalypha), Dodonaea sp. and others.

The foremost range among these, however, is Casuarina junghuhniana ("Cemara gunong" a kind of spruce-fir) which is the most fire resistant of them all. This dioecious tree is long-lived and many grow to a great age and majestic size. It has many seeds and geriminates easily. The tiny seedlings are often destroyed by fire or eaten by deer, but once the saplings have attained a few meters in height they are fire-resistant. Even small trees that are completely burnt will later sprout from the charred stem and larger twigs. Its root system is extensive and damaged roots will also sprout.

Casuarina junghuhniana is of course not only a pioneer in deforested grassland. It was, and still is, a characteristic pioneer on the bare soil of volcanic ash and sand, in gravelly, sandy or rocky streambeds,and on screes (as in the Mt. Semeru area). On grassland a few stunted Quercus sp. are found, otherwise pure forests of Casuarina junghuhniana are pioneering on the cone of volcanic ash and lapilli (summit C. 3,675 m) mainly along the ridges, up to C. 3,200 m.

As the fires return every year in East Java, Casuarina forests occur in extensive pure stands on all the summits (Casuarina being native eastward from Mt. Lawu onwards). This is partly due to volcanicity but largely due to man, a development which must date back to prehistoric times. If fire could be kept out of the entire region, the Casuarina forests would die out in a few centuries.

Volcanicity is another major cause of forest destruction. Lahars, hot or cold, Ladu, falling Nuee rdente, cover vegetation and many are blown down by the tremendous air-pressure. The debris found on the high ash cones prevents the growth of forest vegetation, mostly downwards to C. 3,000 m, e.g. on Mt. Semeru, where the forest is creeping upwards highest on the ridges. This is caused partly because the debris is sterile and extremely dry and further, because the seedlings are buried under the soil and ash.

According to the result of the forest survey on landslides which occurred due to heavy rain in May, 1981, around Mt. Semeru, there were still 308 trees/ha. The percentages are as follows: "Pasang" (Quercus sp.) 51,3%; "Nyampo" (Litsen sp.) 29.9% and other kinds 18.8%. Accordingly, among these young trees: "Pasang" 31.26%; "Nyampo" 24.97% and other kinds 43.77%.

Around the landslide on the slope of Mt. Leker which was formed by flank eruption, 189 trees/ha were found, among which 25.4% were "Pasang", 26.5% were "Nyampo", "Semburng" (Veraonia sp.) were 3.9%, "Tutup" (Acalypha sp.) were 7.2% and others were 37.0%. The conditions for young trees seem to be favourable enough.

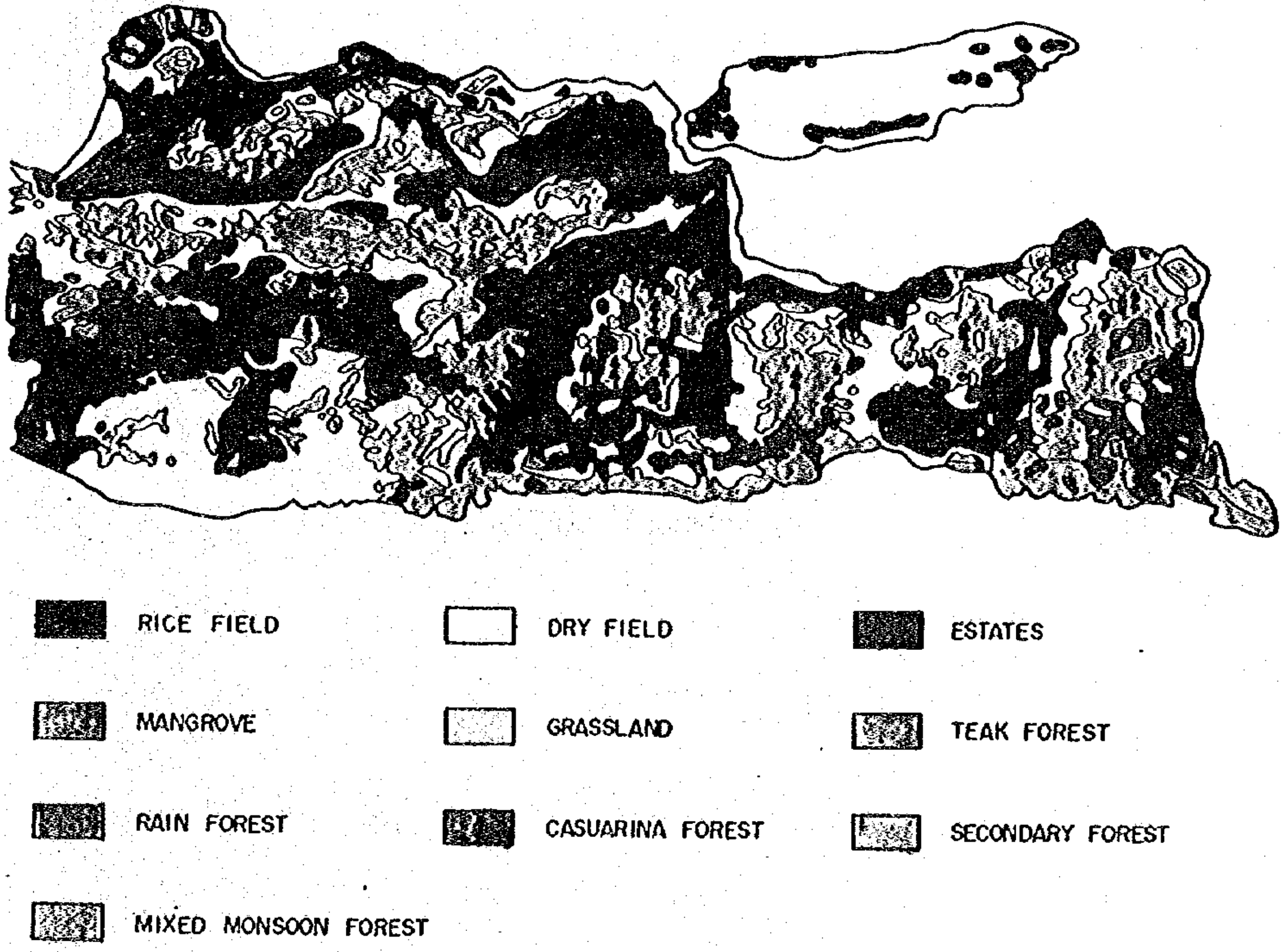


Fig.-1 Vegitation of East Jawa

THE REPUBLIC OF INDONESIA

FEASIBILITY STUDY ON VOLCANIC DEBRIS CONTROL AND WATER CONSERVATION PROJECT SOUTHEASTERN SLOPE OF MT. SEMERU

SUPPORTING REPORT (5)

PART - J
DEBRIS FLOW

FEBRUARY, 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

J. DEBRIS FLOW

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1. INTRODUCTION

1.1 OUTLINE OF DISASTERS

The study area has been suffering from the frequent disasters caused by direct pyroclastic flow and lava flow or disasters caused by volcanic mudflow. The former are referred to as "direct disaster", as they are directly connected to volcanic activity. The volume of debris accompanying these disasters is likely to be enormous (in general, in the order of 10 m to 10 m), but the size of disaster areas tend to be limited and they are most likely to occur on the upper half of the mountains. On the other hand, disasters caused by mudflow occur when volcanic debris accumulated loosely on the mountain-sides is triggered and washed away because of rainfall or other inducing factors and flows down to the piedmont. These are, therefore, called "secondary disaster", accompanied by volcanic activity. The amount of mudflow is generally around 10 m to 10 m . However, in terms of the volume of sediment being washed away, the frequency of such disasters is high (once in several years) and in many cases they cover the entire area of the piedmont, causing extensive damage to inhabitants and property.

In Indonesia, these volcanic mudflow are commonly called "lahar". Lahar, in brief, is a downflow of volcanic debris, such as ash with water, and it is similar to such phenomena as debris flow or mudflow as they are known in Japan. The term "banjir" is used to refer to flood, although it is generally used to refer to flood as a synonym of lahar. It sometimes contains a great amount of materials and in such cases the distinction between lahar and bonjir is not clear.

In contrast to the Japanese practice of using such terms as floods, debris flow and mudflow which are distinguished in relation to their mechanism of transport, it appears that the terms lahar and banjir are used as a matter of custom.

1.2 PURPOSE AND OUTLINE OF STUDIES

Comprehension of such conditions as erosion, transport and accumulation of debris within a given basin is a prerequisite to any formulation of sediment control planning.

Assumption of the size of disasters or floods and the condition of accumulation to be to scrutinized in connection with such plains is possible only when there is an appreciable understanding of the study area, which in turn enables the formulation of effective countermeasures regarding the characteristics of sediment movement.

In the light of this, it is considered that comprehension of the condition of the nature and transport volume of sediment discharge in areas which suffered disasters in the past provides a standard in respect to measures against disaster. The present study undertakes to investigate relatively recent disasters, for which better understanding is more likely, based upon the foregoing considerations.

The study was, therefore, advanced with regard mainly to the lahar of May 14, 1981, which is the most recent disaster in the river basin under discussion.

Traces of debris movement caused by lahar and the extent of floods were clearly recognized, even at the time of the field investigation (July, 1982), and comprehension of the condition of debris accumulation was further facilitated by the availability of aerial photographs, taken after the disaster in July, 1981. In passing, the lahar resulted in 365 deaths, including those reported missing, 1,002 lost houses and public facilities and damage to a vast area of cultivated land.

The rain, which later caused the lahar started around 2 o'clock in the afternoon and stopped around 7 o'clock in the evening on May 14th. The maximum hourly rainfall is reported to have been 60 mm/hr (17:00 - 18:00). The total rainfall reached as much as 164 mm.

Lahar occurred at two locations, i.e., at the lower reaches of the K. Mujur and the K. Rejali. The occurrences of Lahar reported for the K. Mujur, occurred around 18:20 and 19:30.

2. STUDY ON DEPOSITS

2.1 METHOD OF STUDY

The study was conducted through the interpretation of aerial photographs and field investigation.

The distribution, morphology, structure, composition, longitudinal/lateral cross sections of valley and thickness of the lahar deposits were observed or measured in the area of the study.

(1) Interpretation of Aerial Photographs

The location and distribution of the deposits and the morphology of the lahar deposits were scrutinized by means of aerial photographs. In addition, a preliminary study was conducted on the study areas.

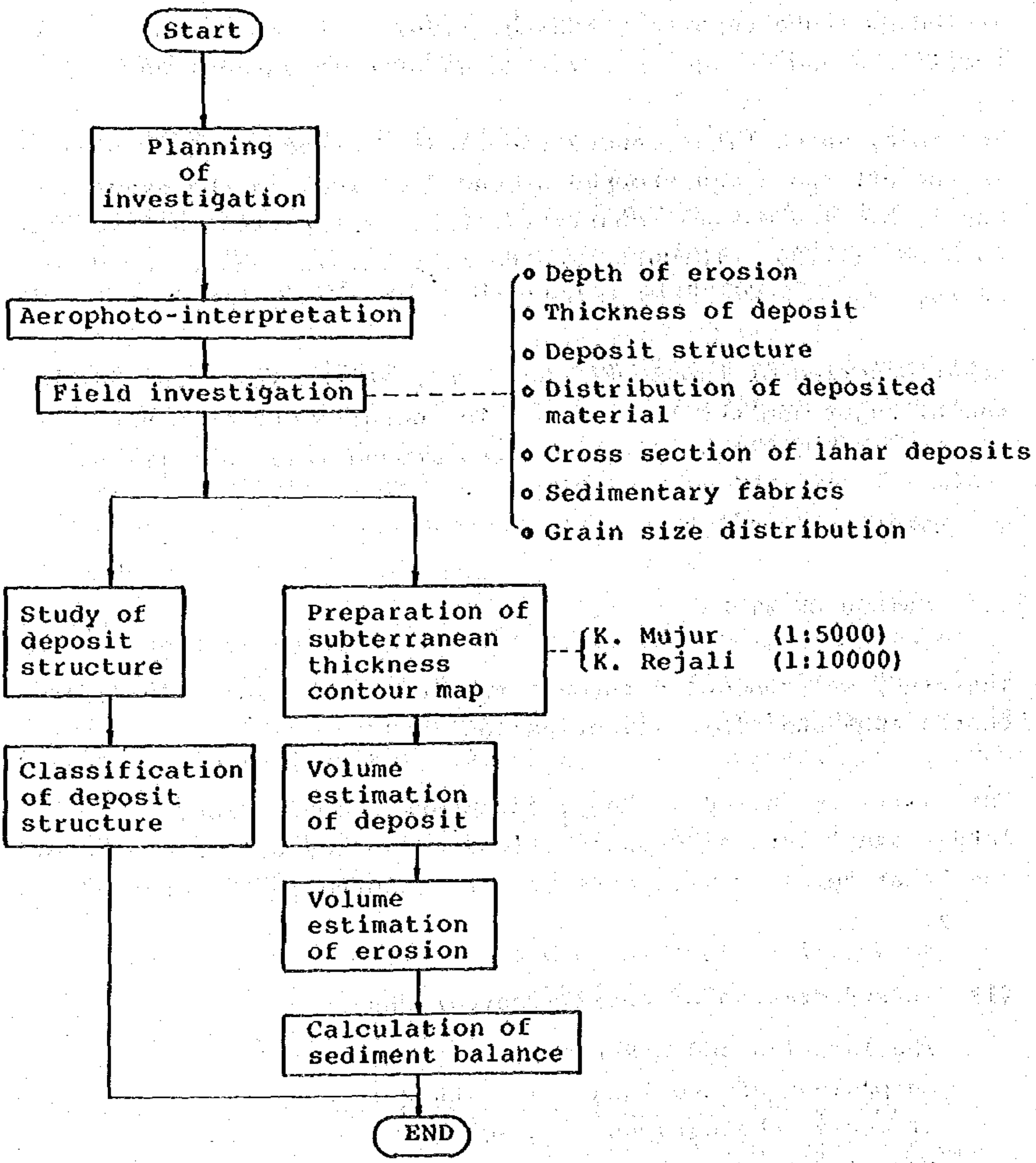


Fig.-2.1 Flow Chart for the Study

(2) Field Investigation

The study of the deposits was carried out with reference to the outcrops along the principal river course and rills or trenches formed in the deposits. The thickness, composition, structure, cross sections, etc., of the deposits were examined; where direct measuring of particle diameter thickness of the deposits proved considerably difficult by means of tapelines, eye measurements were taken.

(3) Classification of Deposits

The deposits were duly classified based upon the investigation results. Classification standards were established after examining the thickness, structure, composition, cross sections and flooding mode of the deposits.

2.2 RESULTS OF STUDY

(1) K. Rejali Basin

1) Outline

A conceptual map is shown in Fig.-2.2. The upper reaches of the river consist of two torrents, i.e., B. Kobo'an and Curah Lengkong, whose sources lie on the volcanic slopes above the forest belt. The two torrents converge near EL. 720 m and flow downstream through a valley at the east end of Mt. Kukusan which is composed of Tertiary rocks, and form a vast fan extending from near EL. 500m to the Indonesian Ocean. In the fan, many small streams run twisted together and the formation of a few small-scale fans can be recognized. The main river course is found along the mountains in the west and is referred to as, from the top of the fan, K. Leprak, K. Regoyo and K. Rejali.

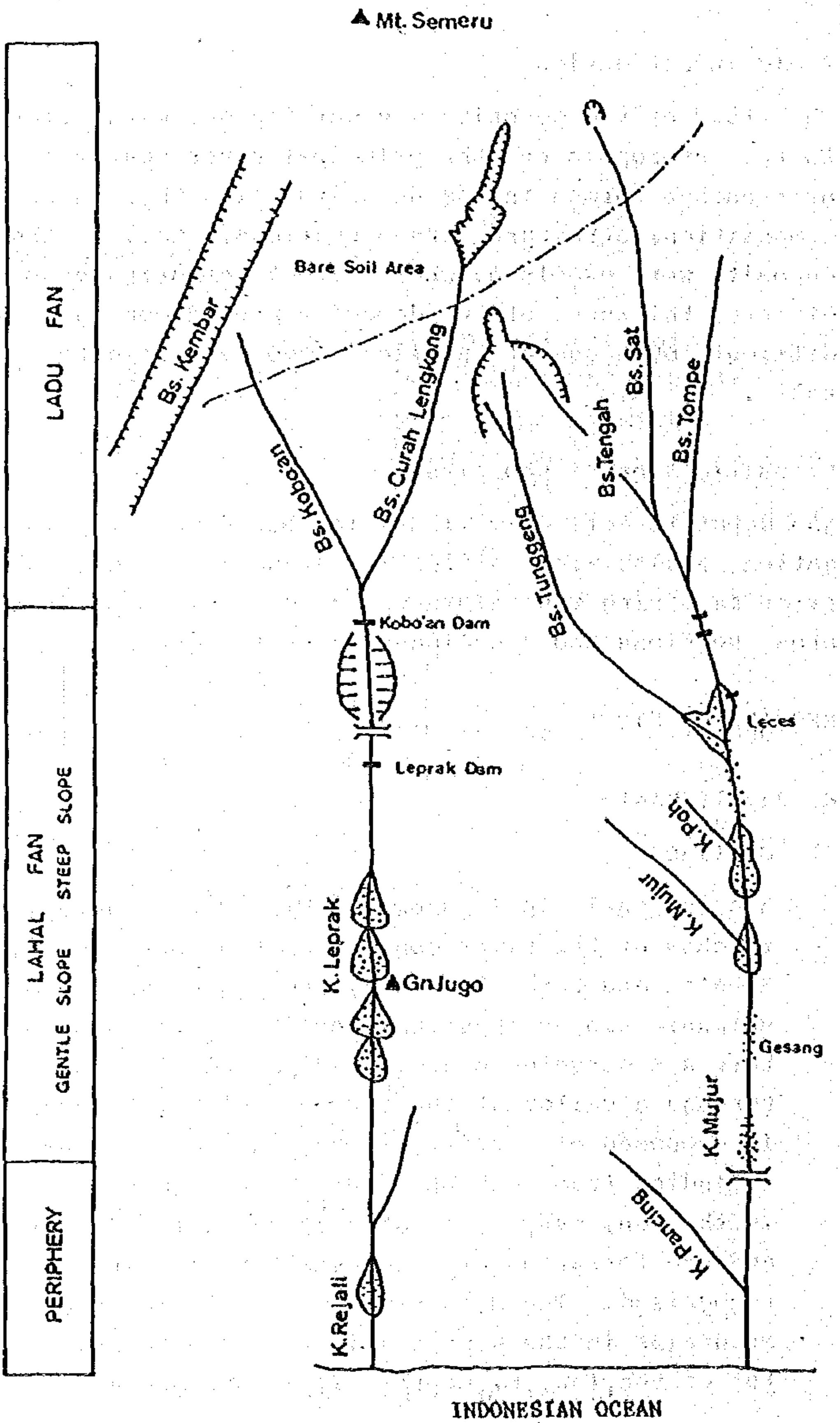


Fig.-2.2 Simplified Diagram of River Systems of Investigation Area

The basin under discussion is classified into the main part of the cone (EL. 1,500 m up), ladu fan (EL. 1,500 - 800 m) and lahar fan (EL. 800 m down).

The lahar of May, 1981 occurred on the slope of the B. Curah Lengkong source (referred to as Curah Lengkong hereafter) and the upper reaches of the B. Kobo'an and flowed down the B. Kobo'an valley before flooding at the K. Leprak fan (see Fig.-2.3). The lahar formed several types of lahar topography and some of debris brought by the lahar is found in areas as far as the Indonesian Ocean.

2) Curah Lengkong

A large-scale landslide area is seen in areas between the source head of the Curah Lengkong and the summit, i.e., bare slopes at EL. 2,000 m - 3,300 m. According to the staff working at the office in Semeru, the landslide areas were first discovered after the lahar of May, 1981, and interpretation of photographs and eye observation also indicate that the landslide is a recent occurrence. All this suggests that the lahar originated in this landslide area and flowed downstream. (See Fig.-2.3)

The landslide is considered to have been caused by the failure of some of the rocks which are part of the

---

* There is no description of the lahar which occurred at the upper reaches of the B. Kobo'an in the past disaster map (1/50,000) prepared by the Project Semeru. The occurrence was confirmed, however, through inquiries made of the residents and added accordingly.

cone proper and ejects which had accumulated thereon. From the aerial photographs, the average depth of degradation and ratio of remaining earth of the landslide area are estimated to be approximately 77,500 m , 10 m to 15 m, and 1/3, respectively.

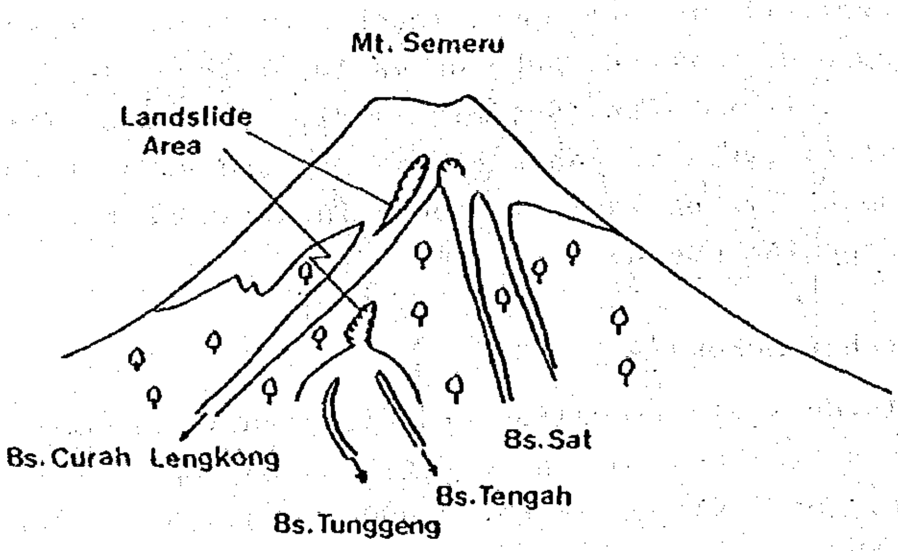
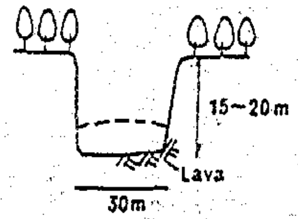
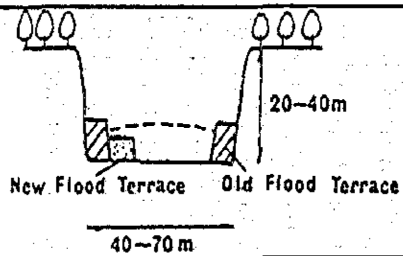
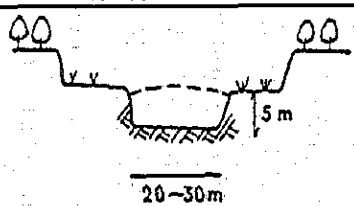


Fig.-2.3 Sketch of Landslide Areas on the Eastern Slope of Mt. Semeru

The debris flowed down inside the valleys cutting into the mountainsides downstream of EL. 2,000 m. At EL. 1,000 - 800 m, in particular, it flowed down leaving terraces with a height difference of 1.5 m to 3 m on one or both sides of their channel. The terraces mainly consist of sand and gravel including some big boulders, however, their matrix is of slit and fine sand, and many boulders are found inside the terraces and on the surface (about 2 m). The outcrops of such terraces consist of several layers, distinguishable by the particle diameter and color of the

Table-2.1 Outline of Lahar Deposits (Curah Lengkong)

Eleva-tion	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment	
3300			Bare slope extending to summit.		Large-scale landslide at EL. 2000m - 3300m (77,500m^2). Depth of landslide is assumed Approx. 1/3 of debris caused by landslide remains.	PI
2000	5.2	10.9	Mountainsides. Forest belt. Valleys are U-shaped.		Erosion of river bed and valley wall is considered to have predominated. Landslide on valley wall seen at several locations (bending points of channels, etc.)	PI
1000	2.3	5.0	Ladu fan. Forest belt. Traces of lava flow deposits seen on left bank.		Presence of lahar terraces, 1.5m - 3m in relative height and 10m - 20m in width; Large boulders (ϕ 1m - 2m) seen at several locations. Valley bed and old terraces considered to have been eroded.	
800	1.4	3.3	Ladu fan. Channels are enclosed by lava and form gorges. Joins Bs. Kobo'an at EL. 720m.		Large boulders (ϕ 2m) seen at several locations; however, deposits of lahar are minimum. Lahar flows down without causing erosion or deposition.	
720						

the matrix within the layers. The boulders, however, are found without consistent order within each layer. The surface of the terraces is flat and their longitudinal cross section is nearly parallel with the slope of the valley bed. However, the lateral cross section is considered to have had an undulating line during the flowing down of lahar.

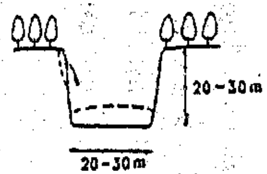
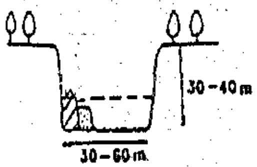
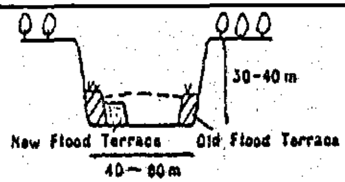
3) B. Kobo'an

No landslide areas are recognized at the source head of the B. Kobo'an. This is partly due to the densely occurring gullies in the area, which makes detection of landslide difficult.

Aerial photographs and the results of field investigations indicate erosion of valley beds in the valley area downstream of EL. 2,000 m. Various locations with outcrops of lava are observed as gorges and waterfalls. From these observations, the lahar of the B. Kobo'an is assumed to have been the result of valley deposits found at EL. 2,000 m - 1,000 m and which were washed away downstream.

Inside the valleys found at EL. 1,000 m - 720 m, lahar deposits are seen terraced at many locations. In general, the terraces are 1 m to 3 m in height. The height of the terrace scarp at the upper reaches is greater than at the lower reaches. In the vicinity of EL. 750 m, they are as low as 1 m in height. These terraces are mainly composed of sand, pebbles and cobbles, and their spaces are filled with silt and sand. Although a structure of several layers can be recognized on the cross section, the boulders are irregularly distributed within each layer.

Table-2.2 Outline of Lahar Deposits (Bs. Kobo'an)

Elevation	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment	
3500			Volcanic bare slope with many rills.		No presence of landslide area (not observed due to presence of densely formed gullies)	PI
2000	5.3	10.7	Mountainsides. Forest belt. Lava and ladu seen in the form of a tongue on slopes; outcrops of lava seen also inside channels.		River bed erosion seen, approx. 1m in depth. Landslide areas on valley walls seen at several locations. Formation of flood terraces with a relative height of 1m - 2m.	
1000	2.3	5.0	Ladu fan. Forest belt. Accumulation of ladu and lava flow deposits.		Lahar considered to have flowed down eroding river bed and old terrace. Landslide areas on valley walls seen at several locations. Formation of flood terraces with a relative height of 1m - 3m.	PI OB
800	2.3	3.3	Same as above. Curah Lengkong flows in at EL. 720m.		Lahar considered to have flowed down eroding river bed and old terraces. Formation of flood terraces with a relative height of 1m - 2m.	PI OB
720	0.7	3.3	Upper basin of Kobo'an dam. River forming pockets of sediments.		Presence of flood terraces with a relative height of 1m - 4m.	
680	0.7	3.3	Natural sand pockets formed upstream side of valleys (Kukusan mountains) and gorges.		Formation of terraces. Small-scale sliding seen on left banks.	
640			Forms valleys and gorges. Landslide area in the past seen at several locations.		River bed and valley walls relatively stable; lahar considered to have flowed down without causing erosion or deposition.	

Further, the deposits contain many large boulders with a diameter of 1 m to 2 m.

4) Near Kobo'an Dam

There are terraces composed of lahar material in a section of deposits (EL. 680 - 720 m) of the Kobo'an dam. The relative height of the terraces is 4 m - 5 m near the area directly upstream of the dam and about 1 m at a point 0.8 km upstream of the dam. The deposits are mainly of sand and gravel and contain a considerable number of large boulders (1 m to 3 m). Although a structure consisting of several layers is recognized in the deposits, the boulders within each of these layers are irregularly distributed.

The center of lahar flow tends to be closer to the left bank at the upper stream of the dam. The cross section of the deposits is considered to rise at the center of flow (see Fig.-2.4). In addition, the flow is considered to run in a straight line, as suggested by its downstream course.

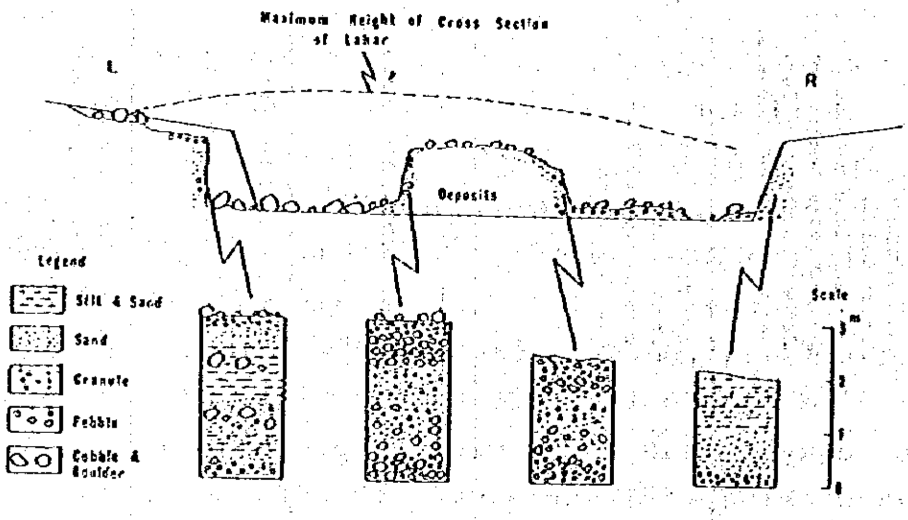


Fig.- 2.4 Sketch of Lahar Diposits (1981)
in the Koboan Dam

5) K. Leprak Fan

Inside the Leprak fan, four flooding locations can be confirmed. Two of them are found upstream of Gn. Jugo and the other two, downstream thereof.

At the point where the river widens near its mouth, there is an area with conspicuous deposits.

The characteristics of these areas of flooding and deposits are shown in Table-2.4 (the areas of deposits are numbered from the upper stream down). These conditions of flooding/deposits can be summarized as follows:

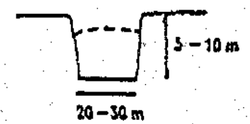
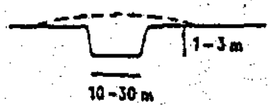
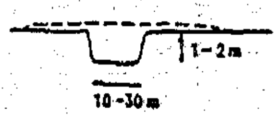
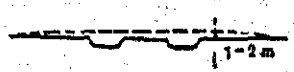
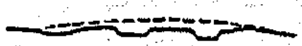
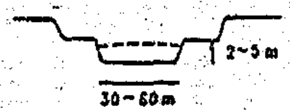
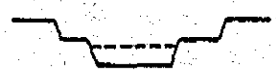
a) The areas of flooding/deposits numbered 1 and 2 are situated at the top of the K. Rejali fan (steep-slope fan). At the top to the center of the fan, channels run with a depth of 3 m to 10 m, and no flooding occurs.

b) The areas of flooding/deposits numbered 3 and 4 lie at the top to the center of the K. Rejali fan (gentle-slope). At the center to end of the fan, it flows into the dissected channels.

c) In the flooding area numbered 5 the river course cuts into the fan surface over a depth of 2 m to 10 m (dissected valley), so that the deposits remain at the valley bottom. The movement and accumulation of debris at these flooding areas can be characterized as follows.

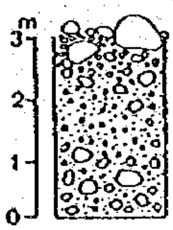
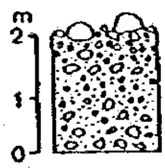
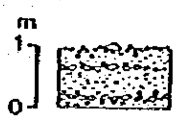
a. Debris disperses near points where the flooding starts, however, it later flows into small- and medium-sized streams. The main flow of lahar moves downstream along the dent, such as channels.

Table-2.3 Outline of Lahar Deposits (K. Rejali Fan)

Elevation	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment	
500	1.7	3.0	Top of Lahar Fan (steep-slope). River cuts into fan surface with a depth of 5 m - 10m and forms present channel.		Lahar flows down without flooding over river course. Little deposit inside river course. Lahar considered to have flowed down eroding river bed and valley walls.	PI OB
410	1.9	2.4	Center of Lahar Fan (steep-slope)		First flood area; maximum deposit thickness of 2m (along river course).	PI OB
330	1.9	2.1	Lower part of Lahar Fan (steep-slope). (Downstream of I.P.) Upper basin of Gn. Jugo.		Second flood area; maximum deposit thickness of 2m (along river course).	PI OB
260	2.0	2.0	Lower part of Lahar Fan (gentle-slope).		Third flood area; maximum deposit thickness of 1.5m. Flooded at bending point of channel over both right and left banks. Formation of new channel.	PI OB
190	2.8	*1.0	Lower half of Lahar Fan (gentle-slope).		Fourth flood area (point of shift in slope).	PI OB
140	5.1	*0.9	Dissected valley.		Flood is small-scale. Deposition at bending points, etc. seen; mixing of boulders decreases.	PI OB
60	2.8	*1.2	Dissected valley		Deposits, mainly inside river course; maximum deposit thickness is 1.7m. A few large boulders within deposits; deposits are mainly of sand and gravel.	PI OB
0						

*Bending of river courses is taken into consideration.

Table-2.4 Outline of Lahar Deposits on K. Rejali Fan

Item	No. 1 and No. 2 Flood Areas El. 500 - 600 m	No. 3 and No. 4 Flood Areas El. 260 - 140 m	No. 5 Deposit Area El. 140 - 0 m
Characteristics of deposit area Maximum deposit thickness Maximum deposit width	Deposited thickly within a limited area 3 m Approx. 300 m	Deposited thickly over a wide area 1.5 m Apprx. 500 m	Deposited mainly within river course 1 m Approx. 500 m
Maximum grain size Typical maximum grain size	5 m 2 - 3 m	3 m 1.5 - 2 m	0.5 m 0.5 m
Main composition	Silt, sand and gravel	Silt, sand and boulders	Sand and gravel
Deposit structure	Layered structure with several layers Boulders are arranged irregularly within a single layer	Same as 1 & 2 Same as 1 & 2	Layered structure with several layers Presence of laminas
Deposit surface Lateral cross section Longitudinal cross section	Nearly silt Large boulders seen at several locations Nearly parallel to general surface Parallel to river bed slope	Same as 1 & 2 Same as 1 & 2 Same as 1 & 2	Nearly flat Parallel to general surface Same as 1 & 2
Plane formation	Tongue-shaped accumulation seen at some locations	Same as 1 & 2	Absent in general
Flood beginning point	Bending points of river course Points of low river embankment (Fan center - Fan end)	Bending points of river course Points of shift in slope Points of low river embankment (Fan apex - Fan end)	Widening points of river
Topographical classification of flood area	Lahar fan (steep-slope fan)	Lahar fan (gentle-slope fan)	Valley bottom plane
Cross section of deposits			

b. The materials of lahar which have flooded accumulate thickly near points where the flooding started, and the accumulation tends to become thinner from the main flow toward the sides. Such tendency is appreciably conspicuous.

(2) K. Mujur Basin

1) Outline

As illustrated on the conceptual map of the basin (Fig.-2.2), the upper reaches of the K. Mujur comprise torrents such as the B. Tunggeng, B. Sat, B. Tompe and B. Tengah. Among them, the source of the lahar under discussion is found within the mountainside (forest belt) near EL. 2,000 m with regard to the B. Tunggeng and on the bare slope directly under the summit with regard to the B. Sat (see Fig.-2.3). The B. Tengah, which is a tributary of the B. Sat, shares its source with the B. Tunggeng and joins the main B. Sat near EL. 900 m. Both the B. Sat and B. Tunggeng converge near EL. 450 to form the K. Tunggeng, which later joins the K. Mujur near EL. 450 m before flowing into the Indonesian Ocean.

The basin is classified into the main part of the cone (EL. 1,500 m up), ladu fan (EL. 1,500 - 750 m) and lahar fan (EL. 750 m down).

The lahar of May, 1981, resulted from landslides on the mountainsides at the head of the B. Tunggeng which eroded the slopes and rivers downstream thereof and developed into lahar while flowing down. Some of the debris flowed downstream along the B. Tengah and B. Sat and joined the debris flowing down both these rivers near the top of the fan at EL. 600 m to 500 m. Still more of the debris destroyed the Leces conditions of flooding/deposits can be summarized as follows:

a) The areas of flooding/deposits numbered 1 and 2 are situated at the top of the K. Rejali fan (steep-slope fan). At the top to the center of the fan, channels run with a depth of 3 m to 10 m, and no flooding occurs.

b) The areas of flooding/deposits numbered 3 and 4 lie at the top to the center of the K. Rejali fan (gentle-slope). At the center to end of the fan, it flows into the dissected channels.

c) In the flooding area numbered 5 the river course cuts into the fan surface over a depth of 2 m to 10 m (dissected valley), so that the deposits remain at the valley bottom. The movement and accumulation of debris at these flooding areas can be characterized as follows.

   a. Debris disperses near points where the flooding starts, however, it later flows into small- and medium-sized streams. The main flow of lahar moves downstream along the dent, such as channels.

   b. The materials of lahar which have flooded accumulate thickly near points where the flooding started, and the accumulation tends to become thinner from the main flow toward the sides. Such tendency is appreciably conspicuous.

embankment before flowing out of the river mounth. In the course of its flow, the debris spread and formed a certain type of topography at several locations near EL. 650 m to 250 m.

The condition of the accumulated debris according to each basin is described below.

2) B. Tunggeng

The landslide area in the mountainside (EL. 2,000 m - 1,820 m) was the source of the lahar and the flow moved downstream collecting unstable materials along the way.

The landslide area is found inside the forest belt and its depth is 1 m to 4 m. Outcrops of lava are found on some of the slide surfaces longitudinally. These lava rocks are cut near EL. 1,850 m. A deep gully, 75 m in width and 15 m in depth, is formed. Forest lands existing before the degradation still remain in some parts of the degraded area and within such soil the roots of trees and grass remain in large numbers. The soil is composed of silt and does not contain boulders (refer to Studies on River Courses).

A sketch of the landslide areas is shown in Fig.-2.5.

The debris from the landslide flowed down eroding the surface layers and valley beds and banks of the gully walls at EL. 1,820 m - 1,350 m. The area subjected to erosion extends over a length of about 1.7 km and a maximum width of 0.9 km, and the soil in the surface layers was eroded with a depth of 0.5 m on the slopes.

The lahar flooded valleys and flowed downstream at the valley areas below EL. 1,350 m. This is because the area of the cross section of rivers at the valley area was not adequate to let the whole volume of the lahar pass (see Table-2.5).

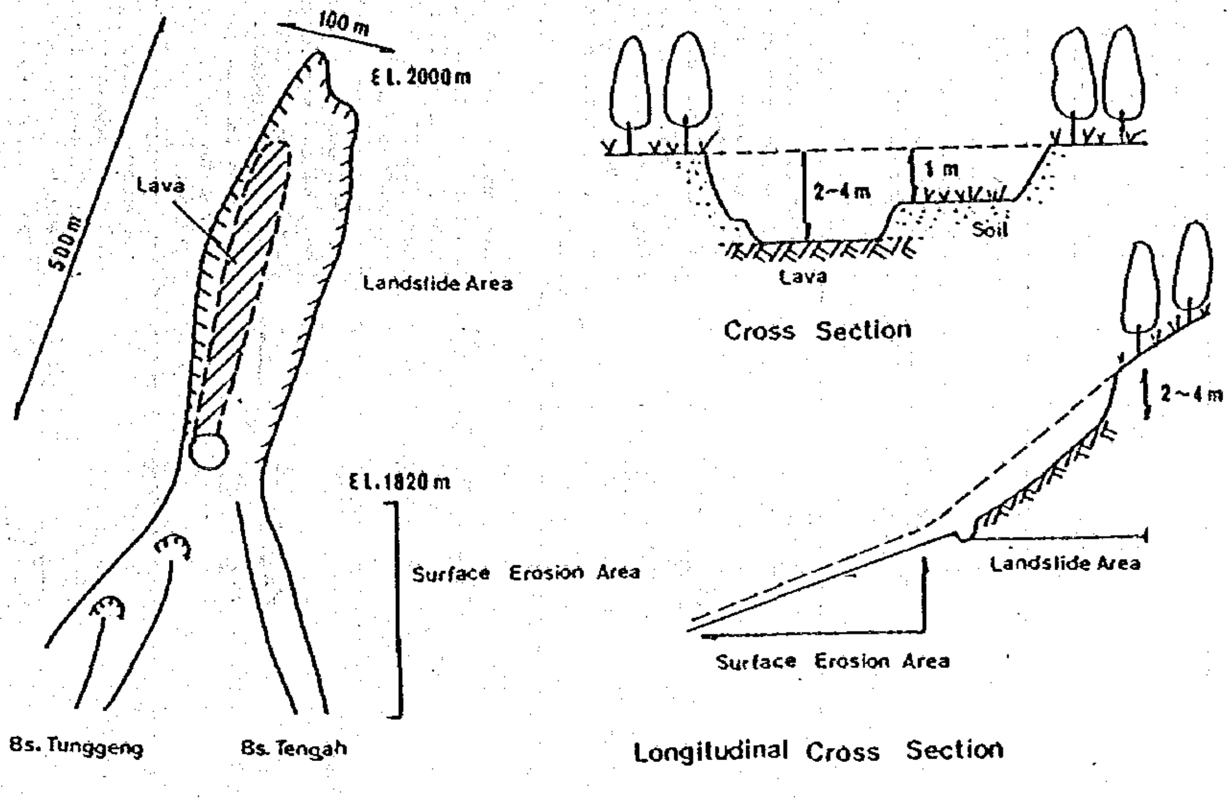
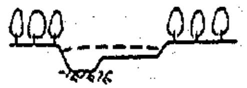
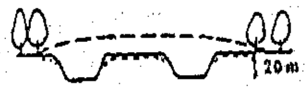
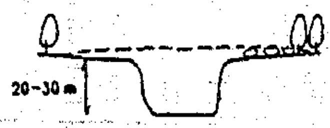
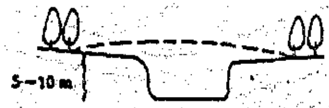
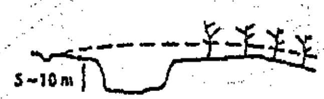


Fig.- 2.5 Sketch of Landslide Areas at the Valley Head of Bs. Tunggeng River

Table-2.5 Outline of Lahar Deposits (Bs. Tunggeng)

Elevation	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment	
2000			Upper part of mountainside Forest belt		Degradation is 500m in length, 100m in width and 2m - 4m in average depth. Outcrops of lava exist on part of sliding surface.	PI OB
1820	1.7	15.4	Upper part of mountainside Forest belt Valley head of main torrent		Surface layer is eroded by lahar from landslide area (depth of erosion is 0.3m - 0.5m) (part of sediment flows down into Bs. Sat River) Valley bed and walls also subject to erosion	PI OB
1350	2.6	7.7	Ladu fan Forest belt Valleys are U-shaped.		Lahar flows down eroding valley bed, walls, shoulder and slope surface layer; thickness of accumulation is 0.3m - 0.5m; few deposit flood terraces seen on valley bed. Many taluses extending from valley walls are seen. Large boulders (φ1m - 2m) seen at several locations on the volcanic slope.	PI OB
1000		Ladu fan			Lahar flows down eroding valley bed, walls, shoulders and slope surface layer; although deposition is 0.3m - 0.5 m. Large boulders (φ1m - 2m) seen on volcanic slope.	
750	1.3	4.3	Lahar fan (steep-slope)		Lahar flows down eroding valley bed, walls, shoulders and slope surface layer; thickness of depositing tendency predominates, the area is considered to have been a transport section in general.	PI OB
650	4.0	2.8	Same as above		Depositing tendency predominates. Lahar floods over left bank of channel, destroys forest and flows into the Bs. Sat river. Slope surface layer is subject to erosion.	
450						

From near EL. 750 m, the accumulative tendency predominated and downstream of near EL. 650 m the lahar flooded over the left bank and destroyed part of the forest, flowing into the B. Sat nearby.

The deposits found on the slopes between EL. 1,350 m and EL. 750 m consist mainly of silt and sand and contains only a limited number of boulders. The deposits form a single layer and no laminas are seen within the layer. The thickness of the layer is about 0.3 m to 0.5 m.

Although the longitudinal/lateral cross sections of the deposits are similar with the section of the such volcanic slopes, the traces of the downflow suggest that it was swelled on the center of the flow.

Boulders are found here and there over the entire area (1 m to 2 m) and, in areas above EL. 750 m, there are several locations where 10 to 30 large boulders are densely accumulated (no imbrication is seen).

3) B. Sat

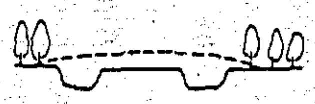
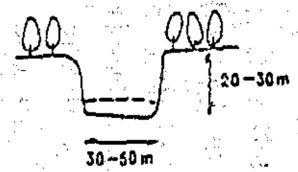
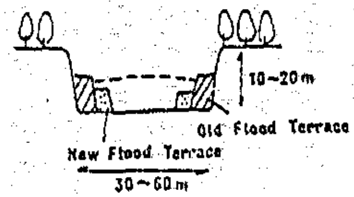
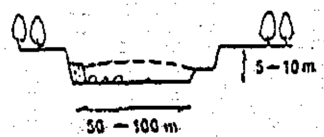
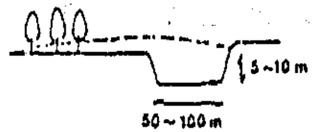
Some of the materials (EL. 1,820 m to 1,350 m) from the lower slope of the landslide area at the source head of the B. Tunggeng flowed into the B. Sat through the B. Tengah (EL. 1,350 m to 910 m). The deposits of earth/sand seen inside the valley (EL. 910 m to 750 m) of the B. Sat form terraces on one or both sides of the channel. These terraces have a relative height of about 3 m and the cross sections of the deposits possess a structure consisting of three layers. The thickness of each layer is about 1 m and boulders are arranged irregularly inside thereof.

Furthremore, the layers consist mainly of silt, sand and boulders and some large boulders 1 m to 2 m in diameter are also seen. The longitudinal cross section of the deposits has a slope somewhat gentler than that of the river course and the lateral cross section shows a difference in height between the left and right terrace surfaces. It is therefore considered that the cross section used to possess a rise in the direction of the center of flow. The surfaces of the terraces are flattened. On the other hand, a new series of terraces with a relative height of 1 m to 1.5 m along the main course of the B. Sat near EL. 1,000 to 900 m is seen independent of the lahar from the B. Tengah. This suggests inflow of lahar from the main course of the B. Sat.

Aspects of erosion in the bare soil slopes near EL. 3,200 m of the source head of the main course of the B. Sat, as well as traces of flow of earth/sand at the downstream valley area, can be recognized through interpretation of photographs. The earth/sand deposits seen along the downstream channels are assumed to contain earth/sand from the source head of the B. Sat.

The lahar deposits become more conspicuous from EL. 650 m - 450 m down, and part of the debris is known to have flooded over the right bank, destroyed the forest and flowed into the B. Tunggeng basin. The section is considered to correspond nearly to the center of the area of small-scale fans, which take up the upper half of the steep-slope lahar fan.

Table-2.6 Outline of Lahar Deposits (Bs. Sat)

Elevation	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment	
1820 1350	1.7	15.4	Mountainside Valley head of Bs. Tengah (tributary of Bs. Sat)		Sediment flowing out from landslide at upper reaches (source head of Bs. Tunggeng river) erode slope surface layer.	PI OB
910	3.1	8.1	Mountainside to Ladu fan Forest belt outcrop of lava at part of valley bed		Lahar flows down within valleys; it is considered to have flowed down eroding valley bed and walls. No presence of deposit flood terraces within valley bed.	PI
750	2.5	3.7	Ladu fan Forest belt Presence of old lahar terraces within valley bottom Main Bs. Sat at EL. 910m		Lahar flowed down eroding old flood terraces and valley bed. Formation of new flood terraces 2m - 3m in relative height is seen. Many large boulders (φ2m - 3m) contained in deposits. Flood terraces consist of 3 layers. Lahar deposits spread widely at confluence with Bs. Tompe river.	PI- OB
650	1.8	3.2	Ladu fan to Lahar fan Presence of sabo dams (3)		Mainly considered to be a transport section. Flood terraces 1m - 1.5m in relative height are seen at several locations.	PI OB
450	3.8	3.0	Lahar fan		Deposition tendency predominates; lahar floods over right bank of the channel and part of lahar destroys forest and flows into the Bs. Tunggeng. Lahar mainly erodes slope surface layer.	PI OB

4) Junction between B. Tunggeng and B. Sat to K. Mujur River Mouth

The area between the junction of the B. Sat and B. Tunggeng (EL. 450 m) and that between the B. Tunggeng and K. Mujur (el. 290 m) corresponds in terms of topographical classification, to the lower half of the steep-slope lahar fan.

Lahar flowed over the rivers along all these sections, but the accumulation of sediment is appreciably thicker near EL. 340 m, i.e., the junction of K. Poh. The channel near the point zigzags and the embankments are low, making the area prone to flooding.

The deposits are mainly of sand, small and medium-sized boulders. Large boulders (1 m to 2 m) are seen in great numbers on the deposits. This accumulation of large boulders is concentrated in the form of a tongue at several locations. However, no imbrication of such boulders is recognized. The surface of the deposits is flat and the longitudinal cross section is nearly parallel to the general topographical surface. The lateral cross section possesses a slight rise near the center of flow.

Although the presence of deposits similar to those seen in the upper reaches of the river is recognized in the lower reaches at EL. 290 m, the scale of flooding and accumulation tends to become limited.

These flood starting points are seen at areas with low embankments, with narrow cross sections of the river and with bending points of the river, while the points of termination and the periphery of the floods are seen along streams and at areas with irregular topography. Once in a while, part of the flood flows into streams and displays tendencies to repeat small-scale flooding and depositing.

At present, the area of floods becomes smaller downstream of Gesang (EL 150m) and flood material mainly accumulates within the river course. Accumulations of sediment are mostly seen on slip-off slopes and near sections where the river course widens. The distribution of large boulders is conspicuous, as at the upper reaches of the river. However, the frequency of lahar deposits containing a lot of big boulders compared with that at the upper reaches is less.

At areas downstream of the Mujur bridge (EL. 80 m), the lahar flowed down without flooding due to the dissection of the volcanic periphery surface by the river course over a length of 5 m or more, making the topography less prone to floods.

The deposits in the river course are mainly of sand, small and medium-sized boulders and the surface of the deposits is flat. Layered structure and the presence of laminas can be clearly recognized. The presence of large boulders is not noted except in deposits downstream of the Mujur bridge.

The manner in which debris was transported inside the K. Rejali and K. Mujur basins can be summarized as shown in Table-2.8.

Table-2.7 Outline of Lahar Deposits (Bs. Tunggeng)

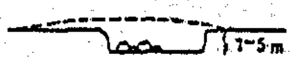
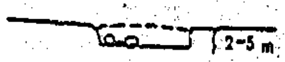
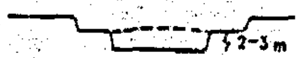
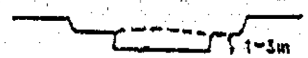
Elevation	Length km	Slope deg.	Topography	Flow (---approx. cross section)	Condition of Produced & Deposited Sediment
450	4.7	1.9	Lahar fan (steep-slope)		Depositing tendency predominates. In particular, flood deposits are conspicuous at EL. 350m - 290m, i.e., near point where K. Poh joins the course. Deposits contain large boulders (⌀1m - 3m) and large boulders are accumulated in dense clusters to a degree that they do not pile up. Part of valley bed is eroded at section between EL. 450m and EL. 380m.
290	2.9	1.4	Lahar fan (steep-slope - gentle-slope)		Flooding is not violent compared to upstream areas. Flood material contains only a few large boulders. Deposits within river course contain many large boulders.
150	5.2	0.8	Lahar fan (gentle-slope)		Flooding outside the river course is limited. Deposits mainly found within the river course.
80	3.4	0.7	Channel dissects general surface over a depth of 5m - 10m		Deposits found mainly within river course. Deposits, in general, do not contain large boulders and are composed of sand, granules and pebbles.
40	5.5	0.4	Same as above		Deposits found mainly within river course, (flooding seen near river mouth) Deposits are mainly of sand, granules and pebbles. No large boulders are seen.
0					

Table-2.8 Outline of Transport of Lahar

	K. Rejalf Basin	K. Mujur Basin
Condition at source	Landslide at volcanic bare slopes at source head of Curah Lengkong river (EL. 2000 - 3000 m).	Landslide inside forest belt at source head of Bs. Tunggeng (EL. 1820 - 2000 m).
Area where sediment produced	Lahar flowed down eroding river bed within valleys.	Lahar flowed down eroding slope surface layer, valley walls and bed within the section between EL. 1820m and EL. 1300m.
Area of sediment transport	Lahar flowed down forming flood terraces within valleys. Partial deposition near Kobo'an dam (EL. 680m). Deposits contain many large boulders 1m or more in diameter, a rise in the center or flow is seen and flow tends to be straight (maximum deposit height is approx. 4m).	Lahar flowed down forming flood terraces within valleys. Lahar flooded over the river course at the section between EL. 650m and 450m and destroyed part of forest belt.
Fan	Flood areas are seen at four locations within the fan (EL. 500 - 400m). Deposits contain many large boulders 1m - 2m in diameter. Deposits tend to accumulate thickly (max. 1.5m and over) within a limited area at upstream areas (EL. 260m up) and thinly in a wide area at down-stream areas.	Large-scale floods and deposits are seen near EL. 300 - 400m. Concentration of large boulders 1m - 2m in diameter seen. However, no conspicuous rise in the end portion or imbrication of boulders.
The beginning point of flood	Bending points of river course. Points where cross section of river course narrows. Near points of shift in slope.	Same as left. Near confluence of river courses.

2.3 CLASSIFICATION OF DEPOSITS

Formulation of plans for sabo necessitates the evaluation of the mechanism of transport of sediment, in addition to determining the volume of outflow of sediment at a given point.

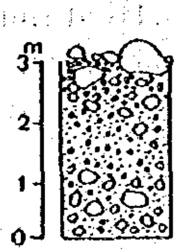
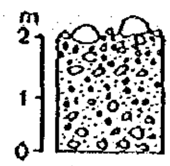
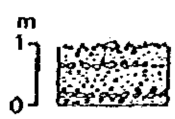
The mechanism of transport is dependent on the topographical conditions of the location, runoff volume at the time, composition of the bed load and other various conditions, and tends to be highly complex. The difference in the mode significantly affects the way in which disasters occur and, in turn, has a considerable bearing on the establishment of measures, selection of works method and various other conditions in sabo planning.

Since actual timing of the movement of sediment is not possible, the deposits are classified based upon the mode of accumulation which has been observed around the out crops. In other words, the deposits brought about as a result of the lahar of May, 1981, were classified into the following three types with respect to the thickness, structure, composition and cross sectional configuration of the deposits. Each mode of accumulation was given the following names for the purpose of the study, with reference to the condition and area of accumulation, from the upper reaches to the lower reaches of the river, i.e. topographical classification standards (ladu and lahar fans):

1) Debris flow deposit
2) Mudflow deposit
3) Bed load flow deposit

These standards of classification are as indicated in Table-2.9.

Table-2.9 Classification Standards for Lahar

		Debris Flow Deposit	Mud Flow Deposit	Bed Load Flow Deposit
Max. deposit thickness		3 m and over	1 - 3 m	Less than 1 m
Composition	Distribution of stones	Wide distribution of areas with a great deal of gravel 0.1 - 1 m in dia.	Wide distribution of areas with a great deal of gravel 0.1 - 1 m in dia.	Gravel particles about 0.1 m in dia.
	Matrix.	Silt Fine sand (muddy)	Silt Fine sand	Fine sand Course sand
	Max.	2 - 3 m and over	2 - 3 m and over	Less than 0.5 m
	Roundness	Sub angular	Sub angular Sub rounded	Rounded
Deposit structure	Layered structure	Present	Present	Present
	Single-layer structure	Thickness about 1m. Gravel arranged irregularly.	Thickness is less than 1 m. Gravel particles arranged irregularly.	Presence of laminas.
	Imbrication	Absent	Present in some	Present
	Sorting	Poorly sorted.	Poorly - moderately sorted.	Moderately sorted.
Deposit formation	Cross section	Rise toward center of flow is seen.	Slight rise toward center of flow is seen. Flood area is flat.	Nearly horizontal.
	Longitudinal section	Slope is gentler than that of river course.	Almost parallel to river course cross section, somewhat gentler.	Almost parallel to river course cross section.
	Horizontal section	Accumulation at bending points of river course and where it widens.	Tongue-shaped deposit units are sometimes seen.	Nearly horizontal.
	Flood beginning point	Flooding at points where river course cross section is narrow; deposition at points where river widens (confluence, upstream of dam); terraced, inside valleys.	Flooding at bending points of river course and at points where river course cross section is narrow; same is true for deposition.	No flooding except local flooding at bending points, etc., of river course.
Slope of deposit		3 and greater.	3 - 1.5	Less than 1.5
Deposit surface		Gravel particles 0.3 - 3 m in dia. seen at several locations. No concentration or rise of boulders toward the tip is seen.	Boulders 0.3 - 3 m in dia. are seen at several locations; many large boulders are seen in clusters locally; no imbrication of boulders is seen.	Not particularly noticeable.
Ideal outcrops of lahar deposits.				

The area of distribution of mudflow deposits corresponds to the transit area between the debris flow deposit and the bed load flow deposit area. Inside this area, the formation of deposits is highly complex. The bed load flow deposit area enables the use of clear-cut classification standards and facilitated judgement of the deposits, focusing on the distribution of deposits in this area with regard to the frequency of occurrence of bed load flow deposits and non-bed load flow deposits allowing classification of the area into the following the types:

a. Mudflow Zone-A

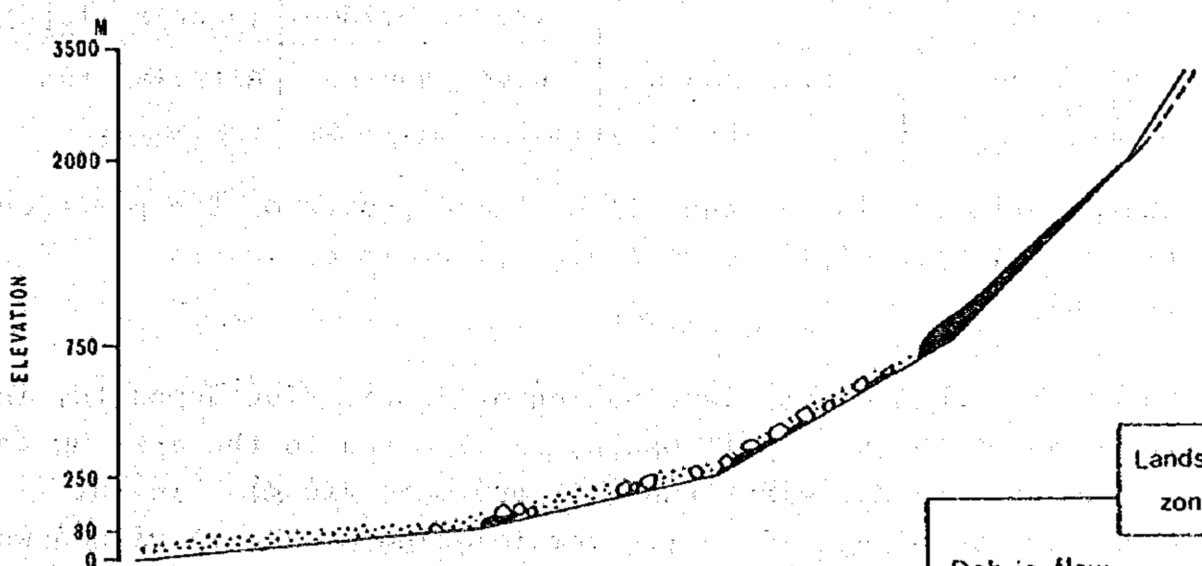
This zone has a distribution of debris and mudflow deposits more conspicuous than that of bed load flow deposits. The maximum thickness of deposits is, in many cases, 1.5 m or more.

b. Mudflow Zone-B

This zone has a distribution of bed load flow deposits which predominates over that of debris deposits. The maxiumum thickness of deposits is less than 1.5 m, in general.

The longitudinal distribution of these deposits can be typically illustrated as in Fig.-2.6, and the distribution of deposits within the study area is as shown in Table-2.10. It is noted that the areas of distribution of these classified deposits correspond well to the topographically classified fan divisions.

In passing, it should also be noted that although the deposits tentatively named "debris flow deposits" in this section contain many large boulders and have traces indicating flow in a straight line and lateral cross sections with a rise, no



Classification of Deposits	Bed load flow deposits zone	Mud flow zone-B	Mud flow zone-A	Debris flow deposits zone; Landslide zone
		Mud flow deposits zone		
Remarks	All parts are bed load flow deposits.	Some parts are of mud flow deposits. Some parts are of bed load flow deposits	Most parts are of mud flow deposits.	
Topography	Peliphery	Lahar fan (Gentle slope)	Lahar fan (Steep slope)	Ladu fan

Fig.-2 .6 Zone Classification by Sediment Type

Table-2.10 Distribution of Lahar Deposits

Classification of Deposits	K. Rejali Basin	K. Mujur Basin	Mainly Land Form Unit
Debris flow deposit	K. Leprak Fan El. 410 m up	Bs. Sat El. 750 m up Bs. Tunggeng El. 750 m up	Ladu fan
Mud flow A deposit	El. 260 m up (Gn. Jugo)	El. 290 m up (conf. of K. Tunggeng and K. Mujur)	Lahar fan (steep-slope)
Mud flow B deposit	El. 60 m up	E. 80 m (Mujur bridge)	Lahar fan (gentle-slope)
Bed load flow deposit	River mouth	River mouth	Alluvial fan

characteristic rise at the tip of the deposits or the presence of accumulation of large boulders or debris banks was recognized.

Moreover, the area of distribution of debris flow deposits, in the case of the K. Rejali basin, was limited to the area up to the top of the K. Leprak fan (EL. 500 m to 410 m). In this area, no conspicuous deposits remain owing to the flowing down of lahar along and within the channel, which dissects the fan surface over a depth of 5 m to 10 m. There is, however, an accumulation of the deposits brought by the lahar of 1976 over an extensive area of the left bank, and since the deposits correspond to the debris flow deposits as classified in this section, the area was dealt with as an area of distribution of debris flow deposits.

2.4 CHARACTERISTICS OF FLOODS

Phenomena such as floods and the accumulation of debris are part of the process through which the topography of a piedmont is formed while causing a change in the topography of the deposit area. Understanding, therefore, of the phenomena will prove effective in learning the tendencies of floods and accumulation likely to occur in the near future and will accordingly provide important basic data for the determination of flood areas and the establishment of location plans regarding sediment control facilities.

In the light of this, a summary is given below of the characteristics of floods and accumulation of deposits as observed in the course of the studies so far carried out in connection with the lahar of May, 1981.

<u>Characteristic features observed at flood beginning points</u>

- Bending portion of river course
- Near point of shift in slope of river course
- Point of low embankment/escarpment
- Portion with narrow cross section of river course

<u>Characteristic features observed at flood areas</u>

- The flooding lahar at first spreads in the form of a fan whose center is the river course. It later flows into the downstream channels, small and medium-sized streams and old river courses.
- The mainflow of lahar is most likely to move downstream along the channels and lowland.
- Lahar which flows into the downstream channels, small and medium-sized streams for a second time repeats flooding several times as it flows downstream along the courses.
- These flood areas tend to have their boundary at points where rising topography or streams are found.

- Accumulation of deposits caused by flooding is most conspicuous near the beginning point of the flood and inside the channel along the course of flow at the center of flow, or around its periphery.
- The distribution of accumulation of flood deposits is thick at areas near the beginning point of the flood and along the center of flow; it tends to be thin at areas around the periphery.

2.5 ESTIMATED THICKNESS OF LAHAR DEPOSITS

Maps were prepared to illustrate the probable extent of flooding of lahar deposits based upon the results of various studies conducted in connection with the lahar of May, 1981.

Examination carried out as discussed in the foregoing sections proved that floods and deposits on the fans are seen mainly along the principal river courses, and the extent of floods and the distribution of deposit thicknesses remain within certain limits.

Notwithstanding these findings, local and temporary accumulation of debris causes the height of the river bed at the beginning points of floods to change and, accordingly, the extent of floods and the accumulation of deposits tend to shift in fans which are under development with the active flowout of lahar materials, such as the area under study. In this respect, the extent of floods and the distribution of deposits thicknesses caused by lahar are considered to be found on the circumferences of concentric circles within a single fan, as in the case of the arrangement of contour lines of the fan surface, irrespective of the location of the flood beginning point.

The maps prepared to illustrate the probable extent of flooding of deposits are based upon such assumptions. That is, the farthest downstream end of each isopleth for lahar deposits thicknesses was extended along the contour lines to obtain the extent of probable deposit thicknesses with reference to the existing distribution maps of deposits structure and deposits thicknesses. (See Fig.-2.7)

3. STUDY ON SEDIMENT VOLUME BY LAHAR

3.1 METHOD OF STUDY

The change in the volume of sediment caused by a single disaster can be learned by studying the difference in the topography before and after the disaster. Such data can be obtained through a comparison of the results of the topographical surveys of the area in these two periods.

With regards to the basin under discussion, however, data indicating the topographical conditions of the area before the disaster is significantly inadequate and the comparison between the topographical conditions before and after the disaster proved difficult. In view of this, during the course of the study, emphasis was placed on the comprehension of the volume of accumulated sediment, which can be examined after the disaster. In other words, the volume of the accumulated sediment was calculated by directly measuring the deposit thickness during field investigations after the extent of the deposit distribution was studied on the aerial photograph reading. In addition, the volume of erosion was also studied through observation of the area, questionnaires and interviews with local residents.

(1) Calculation of Volume of Sediment

(i) Measuring of the Distribution and Area of the Deposits

The distribution of the deposits was read from aerial photographs and transcribed into topographical maps drawn on a scale of 1/10,000. The area thereof was measured by means of a planimeter.

(ii) Measuring of the Thickness of Deposits

The thickness of the deposits was measured by means of a tapeline or by eye using the deposits cross sections of outcrops, rills and excavated trenches.

(iii) Preparation of Isometric Curve of Lahar Deposits

Based upon the above data, isometric maps for the distribution thicknesses were drawn over maps on a scale of 1/10,000. The intervals between the isometric curves are 0.5 m and those between the auxilliary curves are 0.25 m.

(iv) Calculation of the Volume of Deposits

(a) Volume of deposits (V_d m)

The volume of the deposits was calculated by the following formula based upon an isometric map of deposits:

$$V_d = A_h \times (h_a + h_b)/2$$

Where,

A_d: Area (m^2) enclosed by the isometric lines h_a and h_d.

h_a and h_b: Isometric lines (m)

(b) Volume of deposits in the river course

The thickness of deposits inside the river course was obtained through observations and inquiries made during the field investigations and calculated by the following formula:

$$V_c = A_c \times D_c$$

Where,

A_c: Area of river course (m^2)
D_c: Average accumulation depth (m)

The terrace deposits existing in the river course were calculated in the same manner.

(c) The total volume of accumulated earth (V_t) can be obtained by the following formula:

$$V_t = V_d + V_c$$

(2) Calculation of Volume of Eroded Slopes

As formerly mentioned, the volume of eroded slopes can be understood from the difference in the topography of the area before and after a certain disaster. The former topographical conditions can be understood mostly in terms of estimation made in this study. Here, the volume of earth was calculated as follows with regard to three items, for which certain reliability can be expected. The items include i) volume of landslide areas, ii) volume of surface erosion and iii) volume of erosion of the scarp shoulder.

(i) Volume of Landslide Areas

The volume of landslide areas was calculated by multiplying the average depth (D) and the area which was estimated from aerial photographs (S) and transcribed on the map.

$$V = S \times D - Vr$$

Here, Vr represents the volume of the remaining volume, which was obtained by the following formula:

$$Vr = Sr \times Dr \text{ or } Vr = Ve \times Re$$

where,

Sr: Area of remaining debris
Dr: Average depth of remaining debris
Re: Ratio of remaining debris

Both the average depth of landslide areas and the ratio of remaining debris were estimated in respect of the results of field investigations and interpretation of photographs. In the course of the work, the zone of erosion was divided into several units, as necessary, and the above formula was applied.

(ii) Volume of Surface Erosion

Traces of erosion of ground surface can be recognized, together with earth deposits, in areas through which lahar flowed. The depth of such erosion is generally determined with reference to the eroding force of lahar and the resisting force of the soil in the area. During the field investigations, it was observed that the depth of erosion of the slopes was nearly identical to or less than the thickness of the surface layer. Generally speaking, the thickness of the surface layer appears to be about 50 cm. In the light of this, the volume of surface erosion (Ve) was calculated in the following formula based upon the suppositions indicated there below:

$$Ve = Ae \times De$$

Where,

(Ae is the area of the respective deposits thickness in terms of its distribution.)

a) Dd 50 cm, De = 50 cm
b) 50 cm Dd 25 cm, De = 37.5 cm ... = (50 + 25)/2
c) 25 cm Dd, De = 0 cm

Further, cases in which channels are newly formed in the ground surface due to surface erosion are also seen. These cases can be easily confirmed through interpretation of photographs, field investigations and inquiries. For such areas the volume of eroded earth can be obtained through application of the following formula:

$$Vg = Ag \times Dg$$

Where,

Ag: Area of channel newly formed
Dg: Average depth of erosion of channel

(iii) Volume of Erosion of Scarp Shoulder

Erosion of valley banks, especially valley scarp shoulders, is conspicuous along the B. Tunggeng through which lahar flowed down flooding the valley (see diagram below). The volume of erosion for these valley scarp shoulders was calculated by the following formula:

$$Vh = (L_a \times L_b)/2 \times L_c$$

Where,

L_a and L_b: Width and height of valley shoulders subjected to erosion (triangular cross section was assumed)

L_c: Length of section subjected to erosion

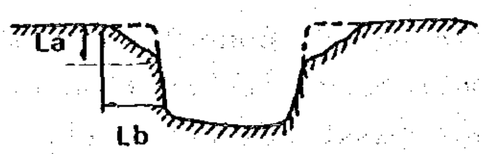


Fig.-3.1 Erosion of Valley Scarp Shoulders

3.2 RESULTS OF STUDIES

The results of studies conducted in connection with the volume supplied by lahar and accumulated volume are shown in Tables-3.1, 3.2, 3.3 and 3.4. These results can be summarized as given in Table-3.5.

Table-3.1 Volume of Sediment Products from Landslide

Location	Partial Area (x 1000 m)	Mean Depth (m)	Partial Volume (x 1000 m)	Total Volume (x 1000 m)	Remain Volume	Discharge Volume (x 1000 m)
Curah Lengkong (Head part)	35	15	525	950	(x 1/3) 317	633
	19.5	10	195			
	12.5	10	125			
	10.5	10	105			
	77.5					
B. Tunggeng (Head part)	40	1	40	85	0	85
	15	3	45			

Table-3.2 Volume of Sediment Products from shoulders of Gulley

Location	El. (m)	Length (km)	La (m)	Lb (m)	Lc (km)	Volume (x 1000 m)
B. Tunggeng	2000					
	1820	1.7	15	5	3.4	127.5
	1350	2.6	15	5	5.2	195.0
	1000	3.3	10	3	6.6	99.0
	750	1.3	5	1	2.6	6.5
	650	4.0	5	1	8.0	20.0
	450					
B. Sat	1820	1.7	10	5	3.4	85.0
	1350					

Table-3.3 Volume of Lahar Deposit in K. Rejali Basin

	Flood Deposit				Deposit in Channel				Total Volume x 1000m³
	Depth cm	Area x 1000m²	Vol. x1000m³	Vol. x1000m³	Depth m	Area x 1000m²	Vol. x1000m³	Vol. x1000m³	
Curah Lengkong El. 820 - 1000m					2.0	20.5	41.0	41.0	
B . Kobo'an El. 820 - 1000m					2.0	15.5	31.0	31.0	
B . Kobo'an El. 720 - 820m					2.0	12.0	24.0	24.0	
B . Kobo'an Dam - Curah Lengkong El. 680 - 720m					4.0	9.5	38.0		
					3.0	13.7	41.1		
					2.0	15.1	30.2	131.7	
					1.0	22.4	22.4		
					T	(60.7)			
El. 640 - 680m					4.0	13	52.0		
					2.0	15	30.0	87.0	
					1.0	5	5		
					T	(33)			
K. Leprak Fan No. 1 Flood Area El. 330 - 410m	200 - 250	5	11.3						
	150 - 200	8	14.0						
	100 - 150	26	32.5	200.4				77.0	277.4
	50 - 100	79	59.2						
	25 - 50	188	70.5		1.4	55	77		
	0 - 25	103	12.9						
	T	(409)							
No. 2 Flood Area El. 260 - 330m	100 - 150	6	7.5						
	50 - 100	115	86.2						
	25 - 50	194	72.8	178.4				98.4	276.8
	0 - 25	95	11.9		1.2	82	98.4		
	T	(410)							
No. 3 Flood Area El. 190 - 260m	100 - 150	2	2.5						
	50 - 100	180	135.0	320.3				136.5	456.8
	25 - 50	383	143.6						
	0 - 25	313	39.2		0.7	182	136.5		
	T	(878)							
No. 4 Flood Area El. 140 - 190m	50 - 100	40	30.0						
	25 - 50	105	39.4	98.5				135.5	234.0
	0 - 25	233	29.1		0.5	271	135.5		
	T	(378)							
	50 - 100	21	15.7					101.0	188.0
	25 - 50	149	55.9	87.0					
	0 - 25	123	15.4		0.5	202	101.0		
	T	(293)							
No. 5 Flood Area El. 0 - 60m	150 - 200	12	21.0						
	100 - 150	22	27.5						
	50 - 100	184	138.0	245.4				248	493.4
	25 - 50	28	10.5		0.5	496	248		
	0 - 25	387	48.4						
	T	(633)							

Table-3.4 Volume of Lahar Deposits in K. Mujur Basin

	Flood Deposit				Deposits in Channel			
	Contour cm	Area x 1000m²	Vol. x 1000m³	Vol. x 1000m³	Depth m	Area x 1000m²	Vol. x1000m³	Vol. x 1000m³
B., Tunggeng El. 1350 - 1820m	20	720	144	144				
El. 1000 - 1350m	25 - 50	70	26.3	49.9				
	0 - 25	189	23.6					
	T	(259)						
El. 750 - 1000m	50 - 100	43	32.2	135.1				
	25 - 50	107	40.1					
	0 - 25	502	62.7					
	T	(542)						
El. 650 - 750m	50 - 100	12	9.0	49.9				
	25 - 50	78	29.3					
	0 - 25	92	11.5					
	T	(182)						
El. 450 - 650 m	50 - 100	122	91.5	238.9	1.0	115	115.0	115.0
	25 - 50	237	88.9					
	0 - 25	468	58.5					
	T	(827)						
Bs. Sat	20	460	92.0	92.0				
El. 750 - 910m					2.5	20	50.0	50.0
El. 650 - 750m					1.5	6	9.0	9.0
El. 450 - 650m	100 - 150	4	5.0	226.5	1.0	383	383.0	383.0
	50 - 100	165	123.7					
	25 - 50	202	75.8					
	0 - 25	176	22.0					
	T	(547)						
B. Tunggeng to K. Mujur El. 290 - 450m	50 - 100	141	105.8	422.4	1.0	250	250.0	250.0
	25 - 50	582	218.2					
	0 - 25	787	98.4					
	T	(1510)						
Gesang El. 150 - 290m	50 - 100	3	2.2	169.5	0.7	301	301.0	301.0
	25 - 50	205	76.9					
	0 - 25	723	90.4					
	T	(931)						
Mujur Bridge El. 80 - 150m	50 - 100	17	12.7	58.9	0.6	165	99.0	99.0
	25 - 50	73	27.4					
	0 - 25	150	18.8					
	T	(240)						
K. Pancing conf. El. 40 - 80m	50 - 100	10	7.5	35.5	0.8	112	86.9	86.6
	25 - 50	40	15.0					
	0 - 25	104	13.0					
	T	(154)						
El. 0 - 40m	50 - 100	5	3.8	77.8	0.5	457	228.5	228.5
	25 - 50	82	30.8					
	0 - 25	346	43.2					
	T	(433)						

Table 3.5 Debris Products and Deposition (x 1000m^3)

River	K. Rejali Basin		K. Mujur Basin		Remarks
	Curah Lengkong	B. Kobo'an	B. Tunggeng	B. Sat	
Volume produced from Landslides	633.0	0	85.2	0	y: Inflow volume from B. Sat source area.
Volume produced in upper and middle stream area	X	X	1081.1 +X	475.6 +X	X - X : Another type product volume.
Volume deposited in upper and middle stream area	41	273.7	732.7	760.5	
Volume produced in fan area	927.7		456.4		
Volume deposited in fan area	1926.4		1732.2		
Volume flushed out to sea	(X + X - 680.7)		(Y + X + X - 1127.3)		