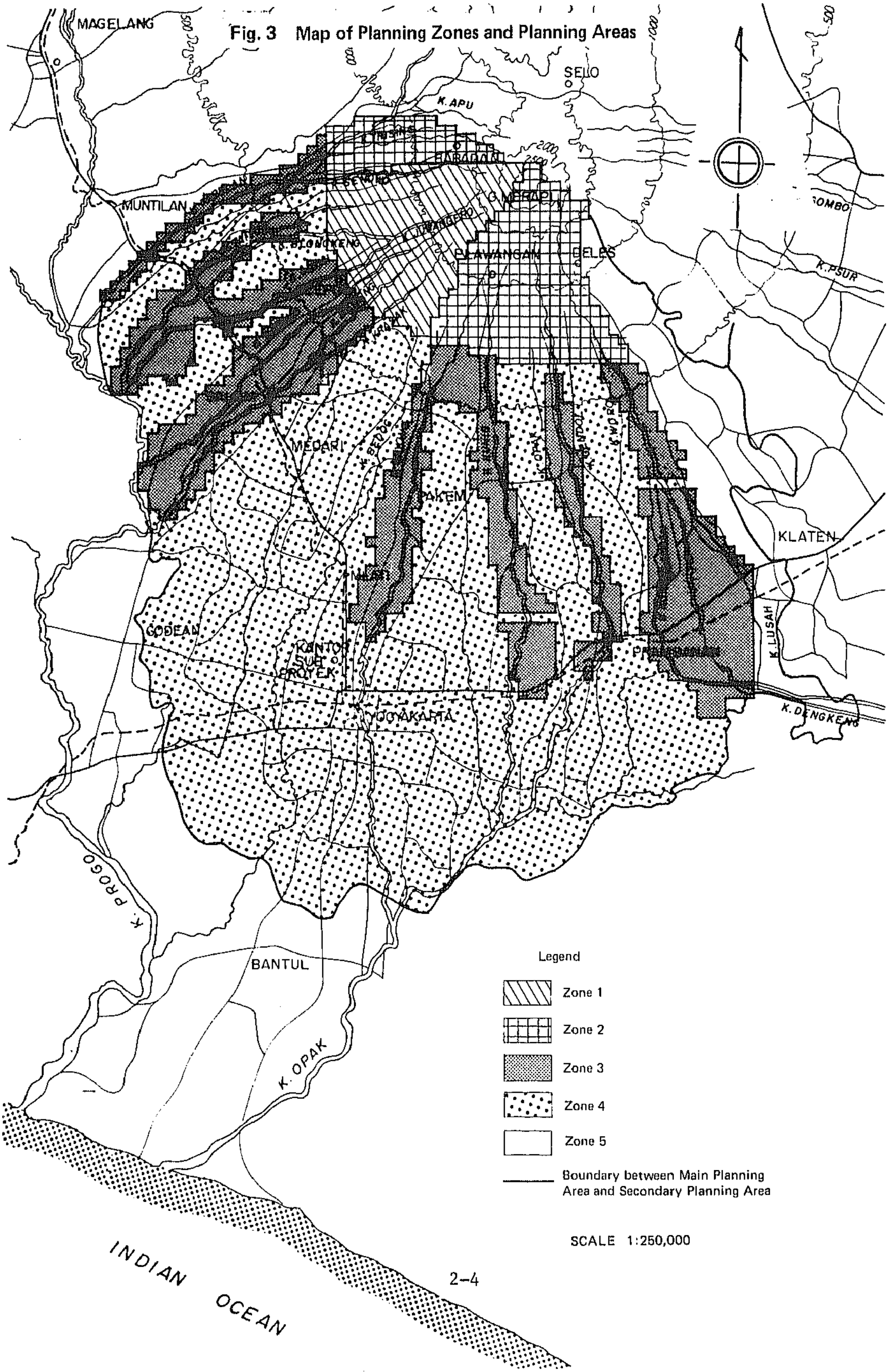
Fig. 3 Map of Planning Zones and Planning Areas



2.2 Natural Conditions

2.2.1 Topography and Geology

1) Summary of Topography

The area covered by the plan covers the west and south slopes of G. Merapi (2,968m), which is a strato-shaped active volcano. Since the volcano opens like a horseshoe towards the southwest, the major effects of volcanic destruction can be expected and have been experienced over to past 50 years mainly in that direction.

The main rivers arising from G. Merapi are:

a. K. Pabelan, K. Blongkeng, K. Putih, K. Batang, and K. Krasak, which flow down the south-southwest side into K. Progo

b. K. Boyong, K. Kuning, and K. Gendol, which flow down the south side into K. Opak, and

c. K. Woro, which flows to K. Dengkeng

Topographically, the area can be divided into the upper slope (above 2,000m), the middle slope (2,000-500m), and the lower slope (below 500m) (see Figs. 4 and 5). The characteristics of each slope is as follows.

The upper slope, which is directly influenced by volcanic activity, is formed of volcanic debris and lava. The terrain is very steep, with gradients of over 35°,

Because of continual new materials from eruptions, there is no vegetation, and fine gullies have developed on the volcanic debris on the slopes. Presently the crater opens to the southwest side, with the formation of a great, long collapse slope, and most of the volcanic debris flows into the Type-I rivers on the southwest slopes.

The middle slopes are formed from volcanic debris from the new Merapi and a mountain mass formed from the old Merapi, making for a complicated topography. The debris from the new Merapi flows down the valleys of the old Merapi and at the mouth of those valleys is deposited in a fan shape. At the time of major eruptions the valleys in this area are stopped up with eruption materials (nuée ardente and lahar) and river courses shift, but as soon as the volcanic activity weakens, the deposits are quickly eroded, deep valleys are formed, and these deep valleys are radiating from the top of the mountain in spoke-like fashion. The terrain has many small protrusions, with alternation of gentle and steep slopes, the gradient diminishing gradually as one proceeds downward. Such small terrace shaped steep slopes are distributed in concentric circular fashion from the top of the mountain, as a result of the way the nuée ardente has flowed and stopped no doubt.

The lower slope begins where the deep valleys of the middle slope disappears and has few protrusions and a gentle gradient of under 3°. Since K. Progo and K. Opak have cut deep into this surface, the radial valleys from G. Merapi become shallow when they reach here, but again form deep U-shape and flow into K. Progo and K. Opak. K. Woro, however, has riverbed over 5-6 m higher than the surrounding terrain at its lower section since K. Dengkeng, into which it flows, also has a raised riverbed instead of being formed by a valley. The area through which K. Dengkeng flows is on the whole a marsh land pinned in by hills on the right bank side. The terrain of these lower slopes has been formed by deposits of volcanic debris, and in the cases of K. Boyong, K. Kuning, and K. Woro there is fan-like topography.

The lahar/banjir flooding that results from the volcanic debris and deposits of G. Merapi is a process of formation of the topography of the slopes of the mountain, and there is a close relationship the topographical features and the lahar/banjir flooding of the recent past as well as a good correspondence between the topographical conditions and the lahar/banjir flooding conditions. The main flooding points as viewed from the standpoint of the topography are (1) points of change in river gradient and points of river curves and bends and (2) areas of change in slope gradient. Furthermore, the lahar/banjir that overflows river valleys flows into medium and small river valleys that have developed in the vicinity of the old river courses and shallow valleys, and tends to flood repeatedly thereafter.

2) Geology

The geology of the slopes of G. Merapi consists of volcanic products and deposits from both old Merapi and the new Merapi on a base of Tertiary volcanic rocks and base rocks.

The geological materials can be roughly divided into the following five groups according to period of formation and form of the deposits:

(1) Recent Merapi Volcanic Products

Mainly lava, lapilli and pyroclastic material know to have been produced by eruptions since 1888 and lahar deposits dating from 1930 or later.

(2) Terrace and Other Unconsolidated Deposits

Mainly present riverbed deposits and terrace deposits distributed in river channels and downstream fan-like and alluvial deposits in the lower stream area.

(3) Young Merapi Volcanic Products

Lahar deposits and lava flow before 1930 (exact dates are not known)

(4) Old Merapi Volcanic Products

Lava flow, intrusive, and pyroclastic rocks.

(5) Base Rocks

Tertiary volcanic rocks and deposits that form the base of G. Merapi.

These groups are further clarified in Table 2, stratigraphy of G. Merapi.

3) Volcanic Activity

There have been many eruptions of G. Merapi in historic times. For instance, Sanskrit and Old Javanese legend stone inscriptions tell of the damage caused by a great flood in the year 1006, and other records state that a large eruption in 1672 claimed the lives of 3000 victims as a result of nuée ardente and lahar flow and enormous subsequent damage due to sediment discharge.

Records of the volcanic activity of G. Merapi since 1800 show alternating pattern of 1-7 years of activity and 1-6 years of inactivity. The periodicities are one eruption over 3-6 years and a major eruption every 9-16 years.

Records of lava flow in recent years show that the direction of flow has shifted as follows: NW-W-SW-N-NW-W-SW. Since the Old Merapi volcanic wall still remains in the SE direction, preventing to a certain extent the outflow of lava in that direction, the nuée ardente hazard area should continue to be in the directions of SW-W-NW.

The following are the names of the volcanic products used by the study team in the master plan study as based on the writings of R.W. Van Bemmelen and I. Suryo and on field observation of the deposits (see Fig. 6).

(1) Nuée Ardente: Avalanche Type

In periods of activity, viscous lava flows out over the edge of the crater to form a lava tongue. When the front edge collapses, red-hot lava blocks split into fragments in an avalanche of rock fragments that picks up real and quasi volcanic lapilli and breccia and kicks up clouds of smoke and dust. According to Van. Bemmelen, there is only a rock avalanche with little smoke or dust if the volume of the lava block is under $100m^3$, but if it is over $1,000m^3$, there are a lot of white hot lava fragments which give the avalanche the appearance of nuée ardente. Such a flow of white hot volcanic lapilli and breccia is known as "ladu" in Indonesia.

Normally, this avalanche type of nuée ardente only reaches 1-3km from the crater, but larger ones reach as far as 7km.

(2) Nuée Ardente: Explosion Type

At peak periods of activity and when there is a lot of gas, blocks are emitted from the eruption vent, some of them falling on the other side of the crater wall and turning into a white-hot flow of incandescent debris with the nuée ardente.

A point of different between the avalanche type of nuée ardente and this explosion type is that the latter is always accompanied by a rising cauliflower-shaped cloud of smoke.

(3) "Lahar" Mud Flow

Lahar is the Indonesian word referring to the volcanic debris flows of G. Kelud and G. Merapi.

All of the lahar of G. Merapi arises from rainfall. If there is an outflow of highly dense volcanic blocks and volcanic ash in a saturated state as a result of rainfall during an eruption or immediately after when the deposited volcanic products are still hot, this is known as hot lahar, and if the volcanic products have already cooled, it is known as cold lahar. Some of the characteristics of lahar are collective carriage, admixture of a large number of large to gigantic stones, thick deposits without strata structure, and straight forward movement.

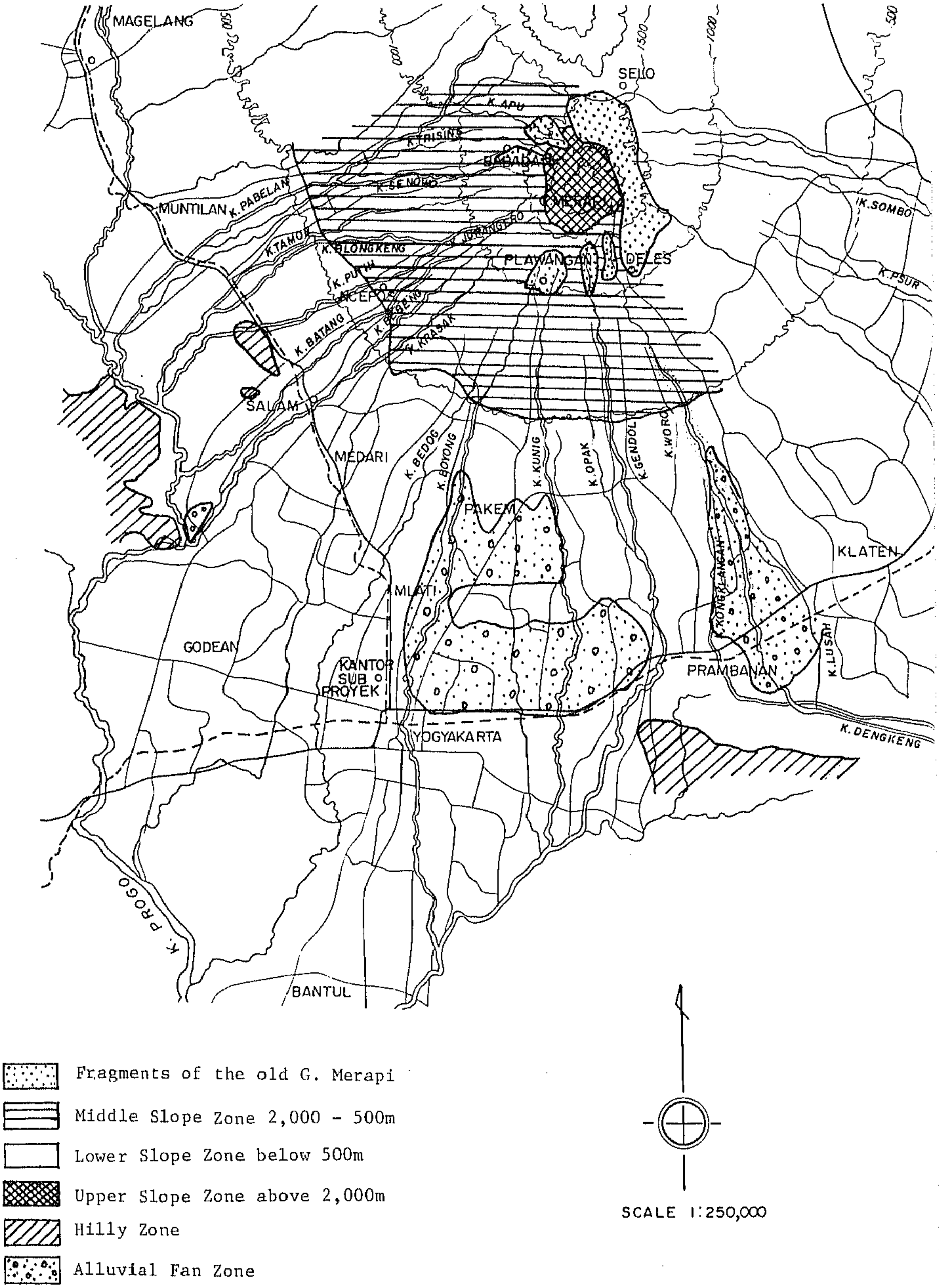
(4) "Banjir" Flood

This is Indonesian term "Banjir" means flood. The flood is mostly water and flows downwards or tractive force. The deposits consist mainly of small to medium sized gravel and sand, and the layers are thin and clearly defined. Such flows have agreat deal of destructive force, and they cause considerable damage to farmland, etc., when they give rise to flooding over wide areas.

Table 2 Stratigraphy of G. Merapi

Group Name	Formation Name		Geological Component
Recent Merapi Volcanic Products	Recent pyroclastic materials		Volcanic ash, lapilli, block, volcanic bomb.
	Lahar deposit of 1969	L_3	Volcanic ash, sand, block, etc.
	Lahar deposit of 1961 ∿ 1962	L_2	"
	Lahar deposit of 1930	L_1	"
	Dome and lava flow		Andesitic lava flow, flow ages are identified
Unconsolidated deposits	Alluvial deposit	Al	Sand, gravel, clay
	Terrace deposit		Gravel, sand, etc.
	Alluvial fan deposit	Fl	"
Young Merapi volcanic products	Fan like deposit	Fu	Gravel, sand, etc.
	Pyroclastic deposit	YMp	Volcanic breccia, ash, etc.
	Lavas	YMl	Hypersthene-augite andesitic lava
Old Merapi volcanic products	Loam	L_o	Pumice bearing loam
	Pyroclastics	OM_p	Volcanic breccia, tuff breccia, tuff etc.
	Lavas	OMl	Olivine brearing hypersthene augite basalt and andesite
Base Rocks	Bemmelen formation	Tb	Andesitic lava and breccia
	Semilir formation	Ts	Tuff breccia, tuff, clay stone

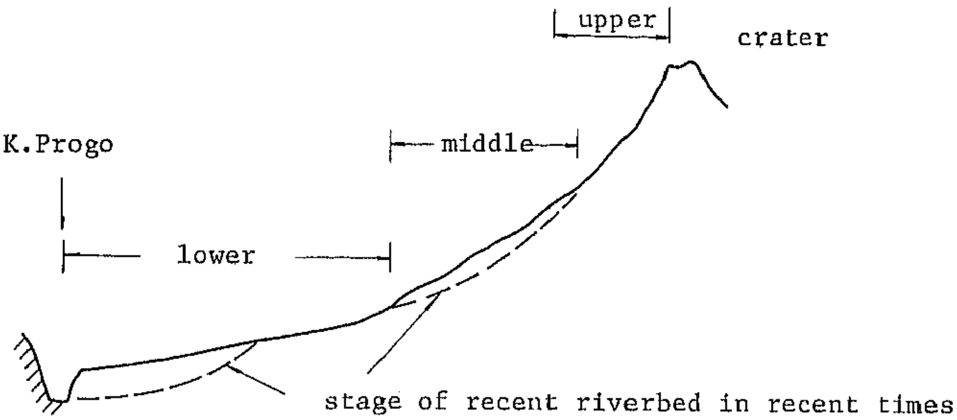
Fig. 4 Map of Main Morphological Area



(Note: Main cities along the national road are shown in capital letters)

Fig. 5 Idealized Profile of the River and Slope

K. Krasak Profile



K. Woro Profile

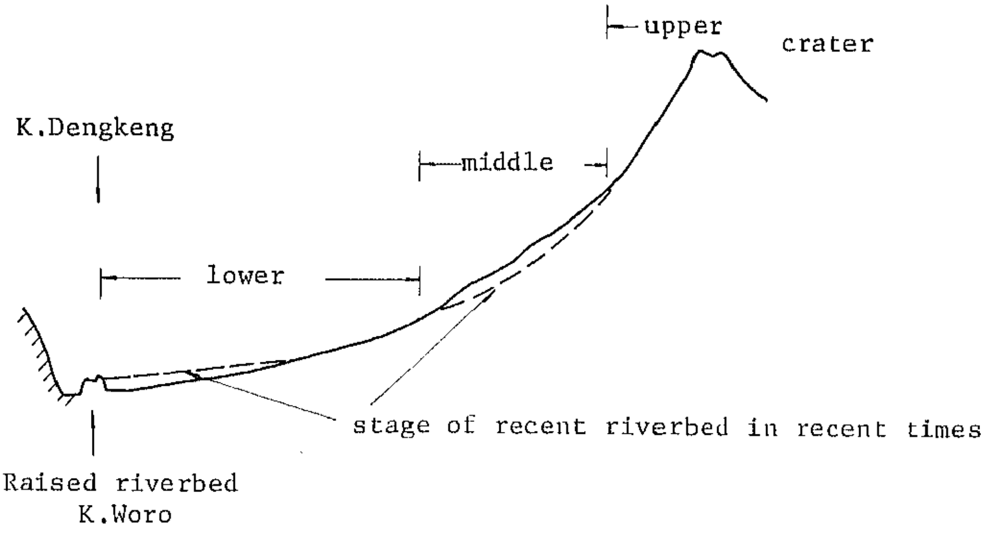
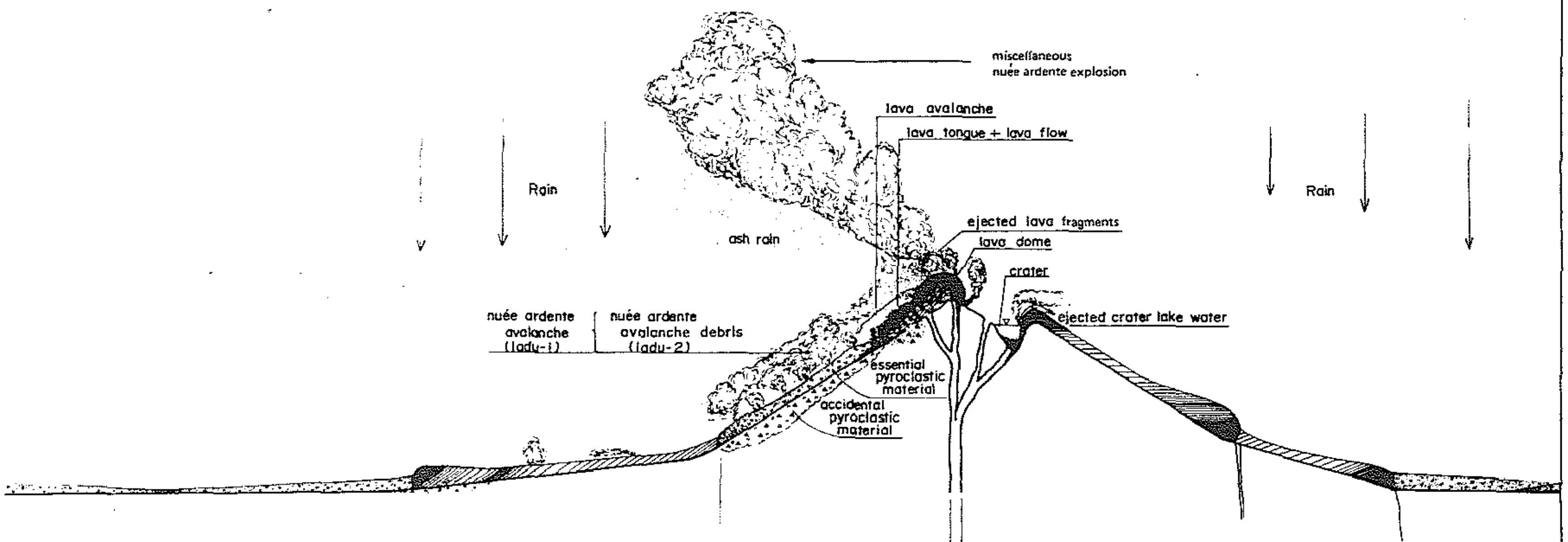
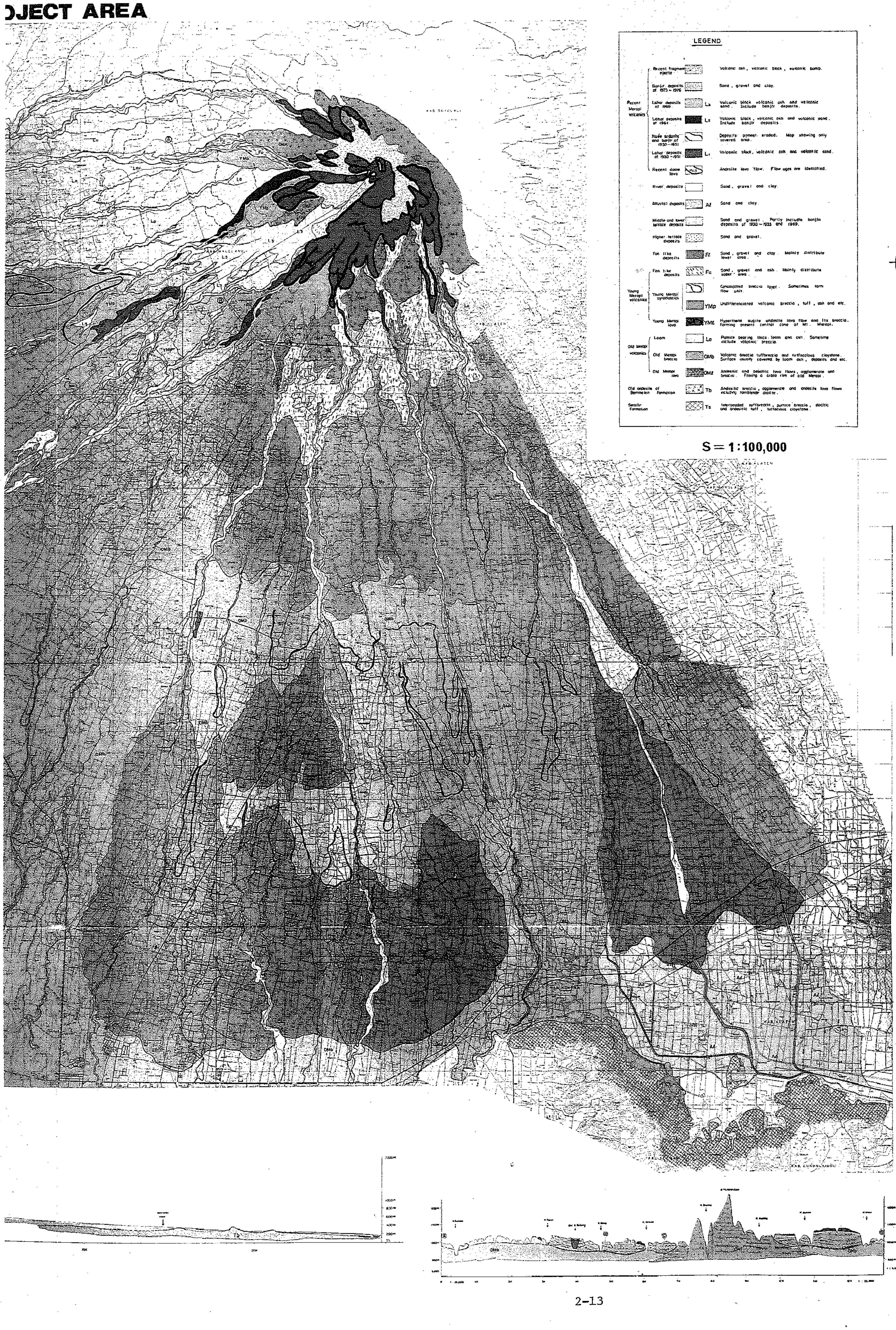


Fig. 6 Schematic of Volcanic States

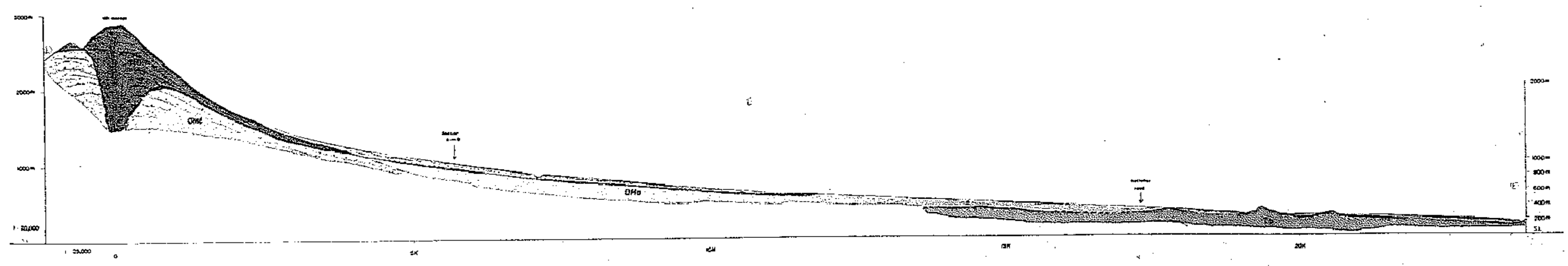


VOLCANIC STATE	Banjir (Kozuiryu · Dosharyu)	Rain Lahar (Dosharyu · Dosekiryu)	Nuee Ardente Avalanche (Kasairyu or Pyroclastic flow)	Eruption Lahar: Primary Lahar (Kazandeiryu, Dosekiryu)	Secondary Lahar (Dosekiryu, Deiryu)	Banjir (Dosharyu)
Weather Condition	Wet	Wet	Dry	Dry + Crater Water	Wet	
Type of Transportation	Individual Objects Flow (including bed load and suspended load)	Massive Flow	Debris Flow or Pyro-Volcanic Flow	Hot Lahar Flow	Secondary Lahar flow	

OJECT AREA


LEGEND
Recent Merapi volcanics
Recent fragment ejecta — Volcanic ash, volcanic block, volcanic bomb.
Banjir deposits of 1975 – 1976 — Sand, gravel and clay.
Lahar deposits of 1969 — L3 — Volcanic block volcanic ash and volcanic sand. Include banjir deposits.
Lahar deposits of 1961 — L2 — Volcanic block, volcanic ash and volcanic sand. Include banjir deposits.
Nuée ardante and banjir of 1930 – 1931 — Deposits almost eroded. Map showing only covered area.
Lahar deposits of 1930 – 1931 — L1 — Volcanic block, volcanic ash and volcanic sand.
Recent dome lava — Andesite lava flow. Flow ages are identified.
River deposits — Sand, gravel and clay.
Alluvial deposits — Al — Sand and clay.
Middle and lower terrace deposits — Sand and gravel. Partly include banjir deposits of 1930 – 1933 and 1969.
Higher terrace deposits — Sand and gravel.
Fan like deposits — Fl — Sand, gravel and clay. Mainly distribute lower area.
Young Merapi volcanics
Fan like deposits — Fu — Sand, gravel and ash. Mainly distribute upper area.
Young Merapi pyroclastics — Consolidated breccia layer. Sometimes form flow unit.
YMp — Undifferenciated volcanic breccia, tuff, ash and etc.
Young Merapi lava — YMl — Hypersthene augite andesite lava flow and its breccia. Forming present central cone of Mt. Merapi.
Old Merapi volcanics
Loam — Lo — Pumice bearing thick loam and ash. Sometime include volcanic breccia.
Old Merapi breccia — OMb — Volcanic breccia tuffbreccia and tuffaceous claystone. Surface usually covered by loam ash, deposits and etc.
Old Merapi lava — OMl — Andesitic and basaltic lava flows, agglomerate and breccia. Frming a crate rim of old Merapi.
Old andesite of Bemmelen Formation — Tb — Andesitic breccia, agglomerate and andesite lava flows including homblende diorite.
Semilir Formation — Ts — Interbedded tuffbreccia, pumice breccia, dacitic and andesitic tuff, tuffaceous claystone.
S = 1:100,000

GEOLOGICAL MAP OF MAIN PROJECT AREA



2.2.2 Climate and Hydrology

1) Climate

The area has a typical tropical climate, with a temperature of about 24-25°C year-around, with very little variation. The rainy season extends from the middle of October to the middle of May, and the dry season over the rest of the year.

In the rainy season the prevailing winds are from the west, and in the dry season they are from the southeast. The wind velocity, however, is only about 2-3m/s. The humidity is about 75% in the dry season and 85% in the rainy season. The mean daily evaporation is about 5mm, and the sun shines approximately 60% of the time over the whole year.

2) Rainfall

The annual rainfall is 1,500-4,500mm, increasing with elevation, and about 80% of it occurs in the rainy season. There is a lot of rain in the afternoon: 60% of the total occurring between 2:00 and 6:00PM. Furthermore, the range of the rainfall is relatively small: a survey of the middle section of K. Dengkeng showed that the rainfall of a single day extends over an area of 50-100km^2 at most, with the highest frequency in the range 30-50km^2. The amount of rainfall tends to decline as the range increases: the average being only about 60% of the maximum at a single point when the range is about 100km^2 and only about 50% when the range is 700km^2. Although there is some regional variation in daily amount of rainfall according to elevation annual rainfall increase with the increase of altitude. It is about 200mm/day with a probability of 1/100. As for the rainfall intensity of heavy rainfalls (over 100mm a day), approximately 46% of the daily rainfall occurs during a single hour (see Figs. 7∿9 and Tables 3 and 4).

3) River Discharge

Although there are no records of river discharge over a long period, the daily average at Duwet on K. Progo (catchment area of 1,763km^2) for the period 1969-1976 was 13m^3/s (0.74 m^3/s/100km^2) at 355th discharge, 32m^3/s (1.8m^3/s/100km^2) at 275th discharge, 68m^3/s (3.4m^3/s/100km^2) at 185th discharge, and 115m^3/s (6.5m^3/s/100km^2) at 95th discharge.

As for flood sicharge at the Blawang Weir on K. Opak (catchment area of 390km^2) and at the Krasak Weir on K. Krasak (catchment area of 31.3km^2), it is 1,100m^3/s (2.8m^3/s/km^2) in the first case and 580m^3/s (18.5m^3/s/km^2) in the second case with an probability of 1/100.

The calculation of flood discharge of K. Krasak and the other tributaries on the basis of the rational formula and of K. Progo and K. Opak on the basis of the storage function method. These results show that past maximum flood water flows have been close to those calculated with a probability of 1/100.

Since the rainfall range in this area is very small, the average amount of rainfall in the catchment area is much less. As a result, the specific discharge declines rapidly going downstream (see Fig. 10).

Table 3 Frequency Analysis of Daily Rainfall

Unit: mm/day

Return Period	Temanggung	Srumbung	Kaliurang	Yokyakarta
2-year	105	113	145	115
5	130	164	175	135
10	150	173	190	150
50	190	209	230	175
100	200	228	245	185

Table 4 Probable Daily Rainfall vs Area

Unit: mm/day

Return Period	0.0 sq.km. (Point Rainfall)	79 sq.km	314 sq.km	707 sq.km	2297 sq.km	4383 sq.km
2-year	113	77	54	47	46	43
10	164	102	82	77	76	72
30	195	120	101	95	87	89
50	209	124	109	103	102	97
100	228	133	120	114	113	108
150	238	138	126	121	191	114
200	247	142	130	125	124	119

Note: (1) Point Rainfall is based on Srumbung Station.
(2) Data utilized is 26 years during 1951 to 1976.
(3) Frequency analysis method is Gumbel Method.

Fig. 7 Distribution of Monthly Rainfall

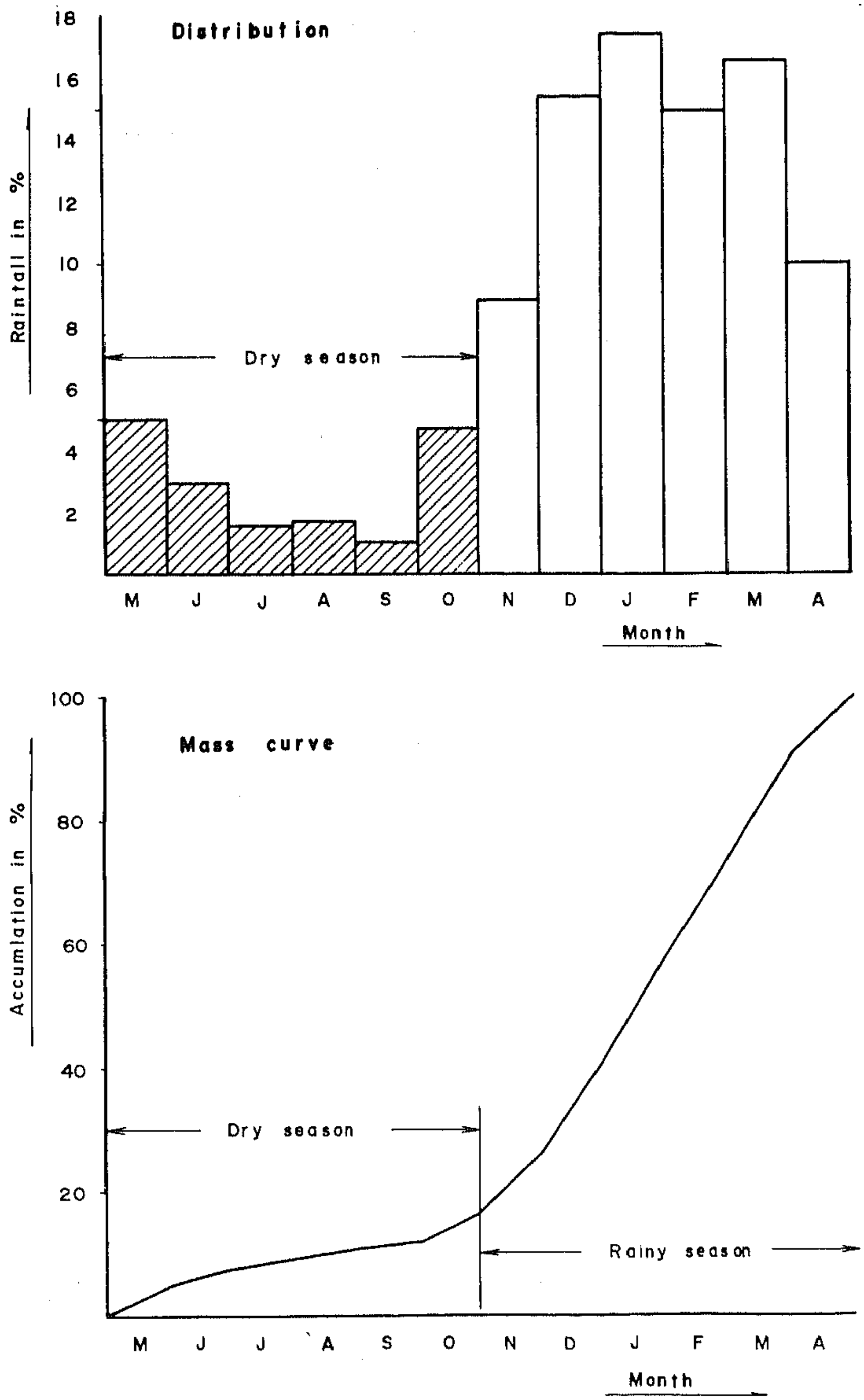


Fig. 8 Annual Rainfall vs. Altitude

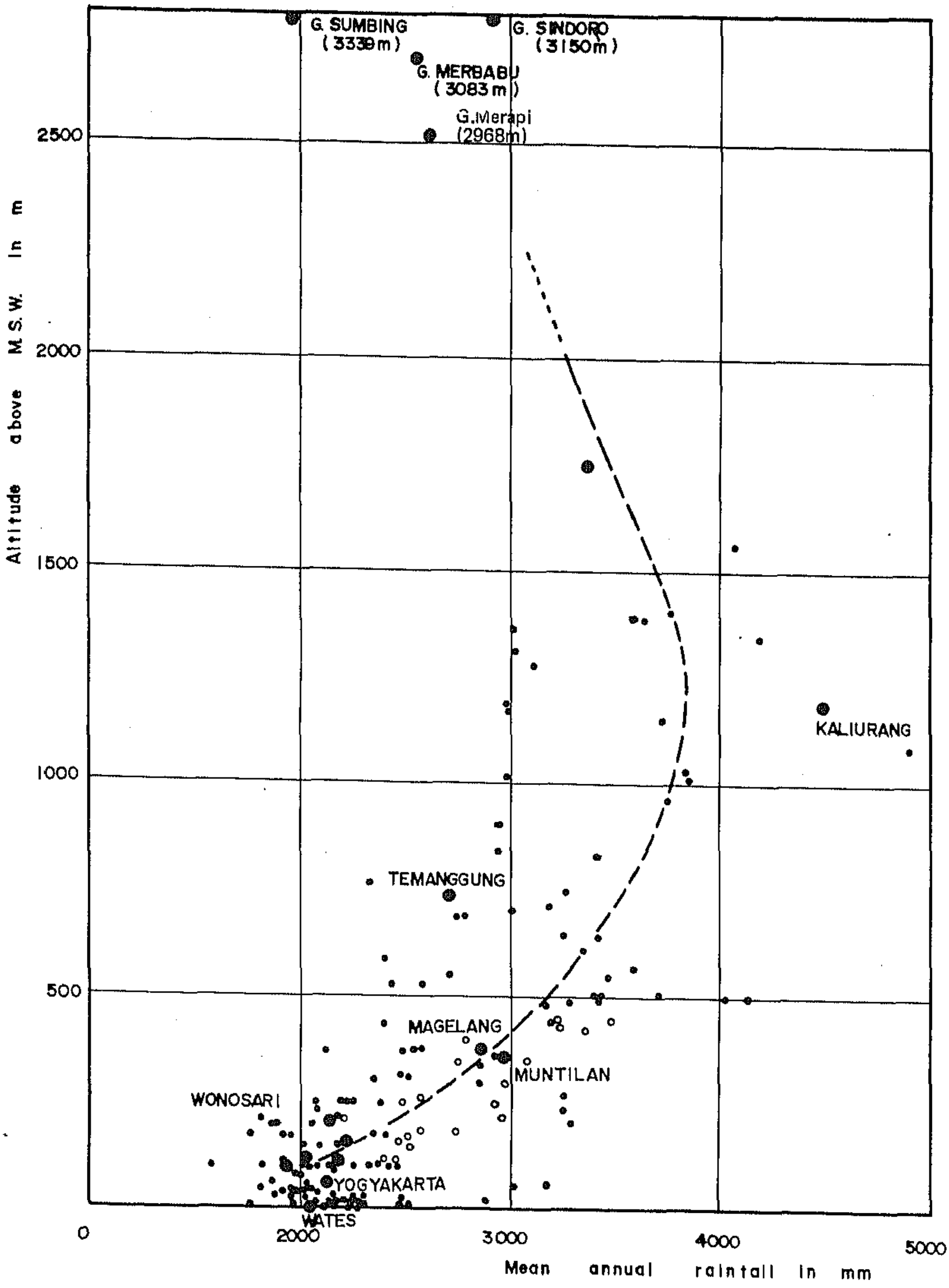


Fig. 9 Isohyetal Map of Annual Rainfall