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ERUPTIVE HISTORY OF THE DIENG MOUNTAINS REGION, CENTRAL JAVA, AND
POTENTIAL HAZARDS FROM FUTURE ERUPTIONS

By

C. Dan Miller, R. Sukhyar¹, Santoso¹, and S. Hamidi¹

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¹Volcanological Survey of Indonesia, Bandung, Indonesia

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ABSTRACT

The Dieng Mountains region consists of a complex of late Quaternary to recent volcanic stratocones, parasitic vents, and explosion craters. Six age groups of volcanic centers, eruptive products, and explosion craters are recognized in the region based on their morphology, degree of dissection, stratigraphic relationships, and degree of weathering. These features range in age from tens of thousands of years to events that have occurred this century. No magmatic eruptions have occurred in the Dieng Mountains region for at least several thousand years; volcanic activity during this time interval has consisted of phreatic eruptions and non-explosive hydrothermal activity. If future volcanic events are similar to those of the last few thousand years, they will consist of phreatic eruptions, associated small hot mudflows, emission of suffocating gases, and hydrothermal activity. Future phreatic eruptions may follow, or accompany, periods of increased earthquake activity; the epicenters for the seismicity may suggest where eruptive activity will occur. Under such circumstances, the populace within several kilometers of a potential eruption site should be warned of a possible eruption, given instructions about what to do in the event of an eruption, or temporarily evacuated to a safer location.

INTRODUCTION

This report presents the results of a reconnaissance investigation of the character, relative age, and distribution of products from eruptions in the Dieng Mountains region, central Java.

This work is part of a long-range study of volcanic hazards at volcanoes in Indonesia sponsored by the Government of Indonesia and the U.S. Department of State, Agency for International Development, under PASA IC/INDO--0266-1-79. We wish to extend our thanks to all the geologists of the Volcanological Survey of Indonesia (VSI) with whom we conferred, for their friendly cooperation and advice. We especially wish to thank K. Kusumadinata and A. C. Effendi for helpful advice during our studies. We were accompanied in the field during various parts of our fieldwork by O. Kaswanda, L. Djoharman, S. Soejanto, S. Bronto, M. Z. Syarifuddin, and Mas Ace.

The primary objectives of our work in the Dieng Mountains were to:

1. Determine the stratigraphic relationships of eruptive products, their sequence, and the nature and scale of prehistoric eruptions in the Dieng Mountains during the past few thousand years;
2. Determine the extent and thickness of the products of recent phreatic explosions (particularly from the 1944 eruption of Silari);
3. Determine the distribution of areas of current hydrothermal activity including active hot springs, solfataras, fumaroles, and mofettes;
4. Plot known areas of past and present gas emission (mofettes), gas movement, and accumulation; and
5. Interpret the significance of these data in terms of potential hazards from future eruptions in the area.

The Dieng Mountains are located in central Java about 75 km northwest of Yogyakarta (fig. 1). They consist of volcanic peaks rising to 2200-2565 m that form part of the mountainous "backbone" of Java. These peaks enclose an upland area that ranges between 1600 and 2100 m in altitude and which has moderate topographic relief. Principal surface drainage from this upland area is to the southwest. Rainfall for the Dieng Mountains region is reported to be between 3000 and 4000 mm per year. Despite the relatively high altitude and high rainfall, this region supports a large rural population.

The Dieng Mountains region consists of a complex of late Quaternary to recent volcanic stratocones, parasitic vents, and explosion craters; many of these have been hydrothermally active during this century. This complex is thought to have originated at the junction of two major fracture zones that are represented by major topographic lineaments (Muffler, 1970). The first zone is west trending and extends from the Dieng Mountains 50 km westerly to Mount Slamet. The second zone is represented by a row of young cones, including Mounts Sundoro and Sumbing, that extend southeast of the Dieng Mountains for 35 km. According to Umgrove (1930) and Van Padang (1936), the Dieng Mountains consist of a complex of separate extrusions ranging from basalt, erupted early in the sequence, through successively younger eruptions of olivine andesite, augite-hypersthene andesite, hornblende andesite, and biotite andesite. More recently, the youngest lava cones, flows, and domes of the eastern Dieng Mountains have been classified as biotite-bearing rhyodacites to quartz latites (Gunawan, 1968). Several early workers described the physiography, structural characteristics and petrology of the region in detail (Umgrove, 1930; Van Padang, 1936; Van Bemmelen, 1937). They also produced early maps of the region at various scales and described historic eruptive activity. These accounts, and many others published in several different languages, have been summarized in excellent detail and critically reviewed by Gunawan (1968). Gunawan also completed extensive field investigations of the region and presented a summary of the geology, structure, and eruptive history of the Dieng Mountains. The reader is also referred to Gunawan (1968) for detailed accounts of historic events in the

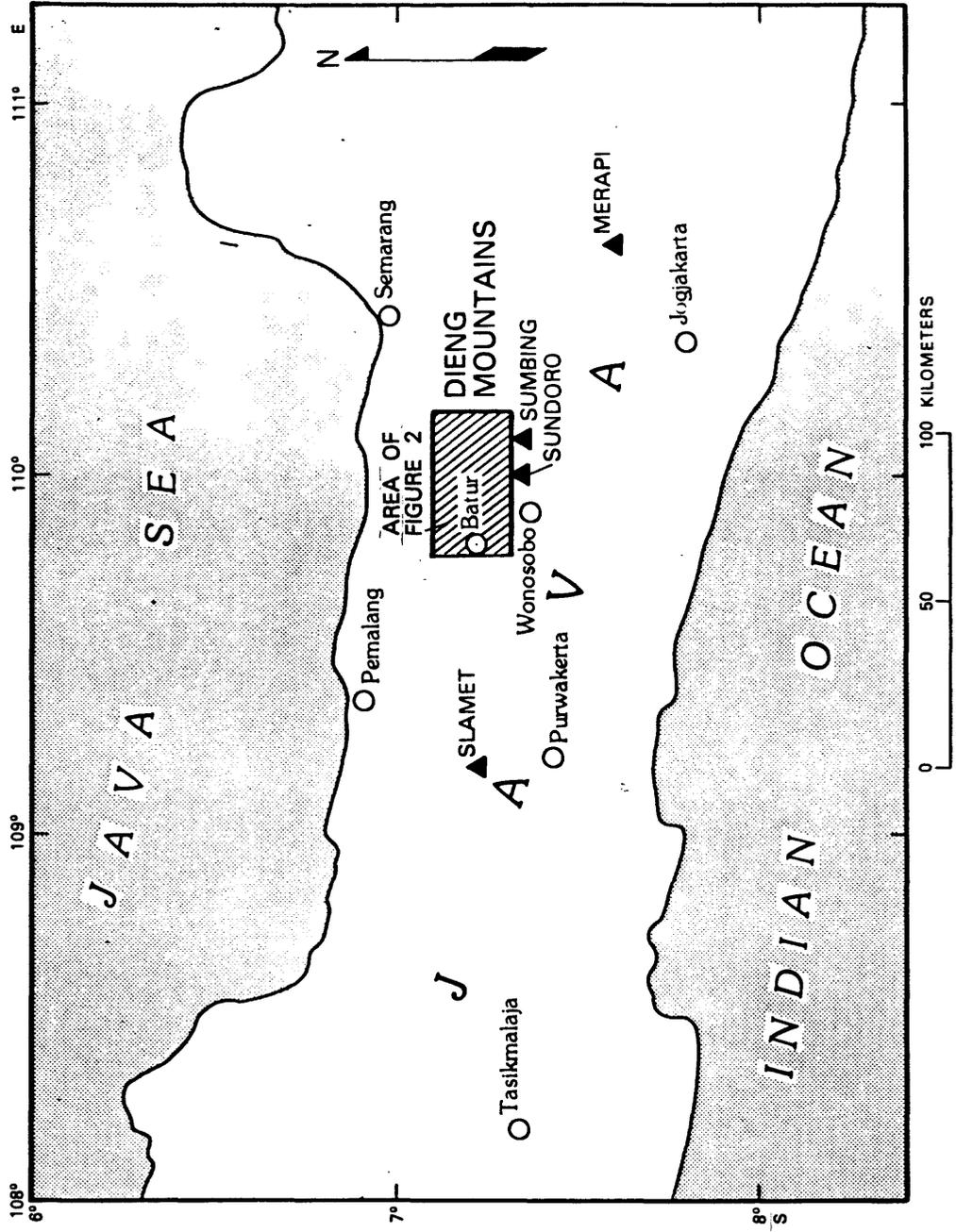


Figure 1.--Index map of Dieng Mountains area and central Java. Volcanoes and towns shown by triangles and circles, respectively.

region and for physical descriptions and dimensions of the major volcanic cones, flows, explosion vents and hydrothermal features. The 1979 phreatic eruptions of Sinila and Sigluduk (fig. 2) and emission of poisonous gas at Timbang craters (fig. 2) are described by Zen and Alzwar (1980). This report extends previous knowledge in the Dieng Mountains region by describing the character and origin of the Dieng tephra sequence and more recent phreatic eruptions, and by providing relative-age data for eruptive vents and deposits.

FIELD METHODS

Superposition of deposits and crosscutting relationships between volcanic features were the primary evidence used in the field to determine the relative ages of volcanic features. In addition, comparing the degree of preservation or dissection of volcanic cones and vents--their morphologic "freshness"--were helpful in estimating the relative ages of volcanic features in the Dieng Mountains. Field evaluation of volcanic features was greatly facilitated by the availability of aerial photographs at a scale of 1:35,000 and topographic maps at a scale of 1:50,000.

Another useful tool for determining the approximate relative ages of deposits in the Dieng Mountains is degree of weathering and amount of soil-profile development at the surface of deposits. The thickness, degree of oxidation, and clay content of a soil profile on a volcanic deposit are parameters that increase with time. The degree to which silicate mineral grains and volcanic clasts in deposits exposed at the surface are altered to clay minerals is a function of time. Fresh siliceous magmatic deposits contain no clay materials when first erupted, but silicate minerals and rocks can become altered to clays by their interaction with organic acids and water in the soil profile. Soil profiles and their color, clay content, and other characteristics are described herein for many deposits in the Dieng Mountains.

An estimate of the rate of soil-profile development for the Dieng Mountains might be forthcoming from a radiocarbon-age determination on charcoal collected from a tephra deposit within the Dieng tephra sequence and submitted to the U.S. Geological Survey radiocarbon laboratories.

The number and physical characteristics of deposits from prehistoric eruptions were investigated in order to infer the nature and frequency of past eruptive events. This information, along with the extent of deposits from eruptions, forms the basis for assessment of the probable nature, frequency, and distribution of future eruptions and their associated hazards.

A major problem, which hampered stratigraphic studies of the uppermost volcanic deposits in the Dieng Mountains, is the degree to which these deposits have been terraced and modified by local farmers. In almost all areas of the Dieng Mountains, the land has been reworked into terraces. Construction of these terraces has totally mixed the upper 2-3 m of surface

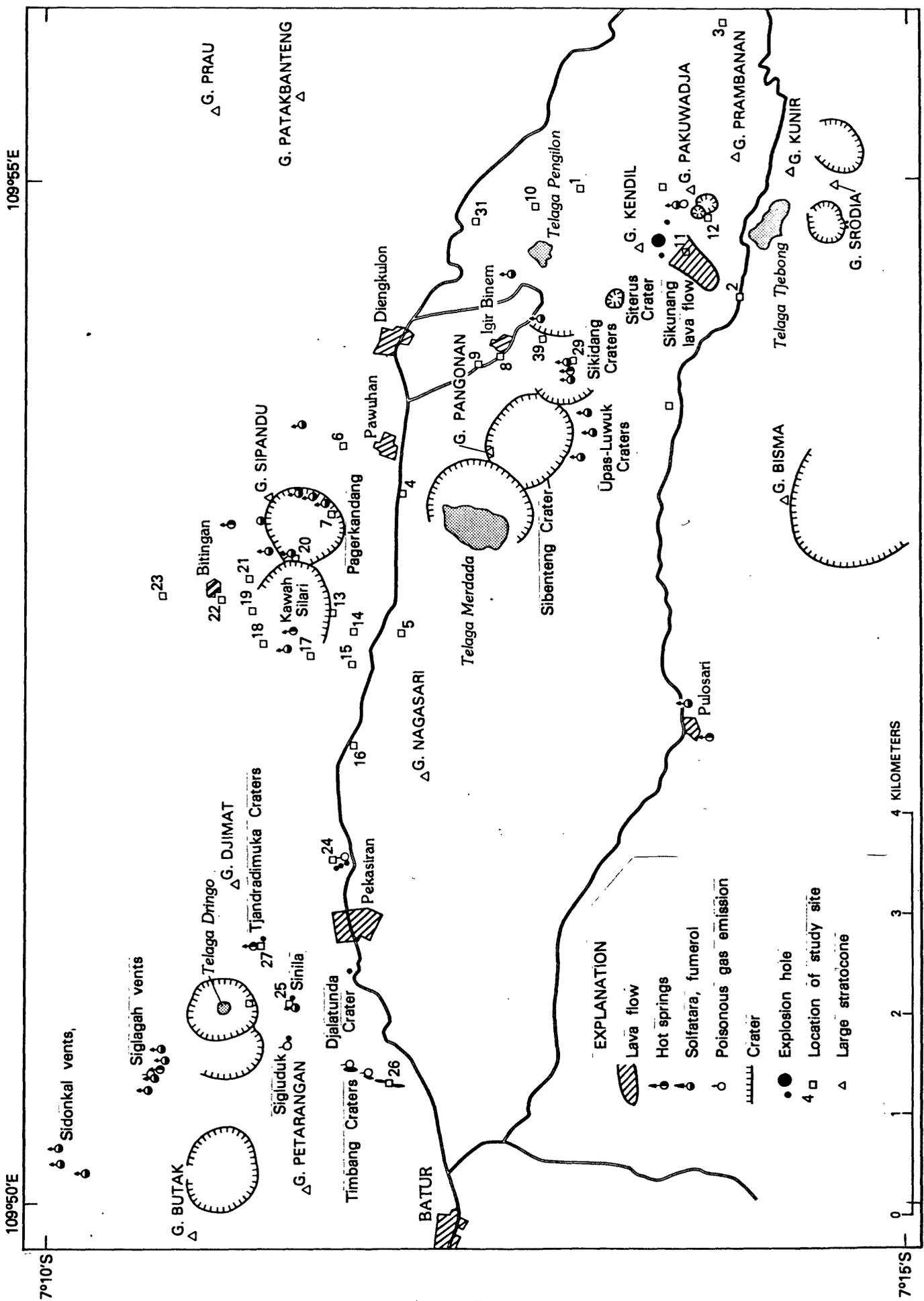


Figure 2.--Location of volcanoes and hydrothermal features, and study sites in the Dieng area, Java, Indonesia.

deposits, thus destroying the stratigraphic relations and natural soil profile. Even in flat or gently sloping areas, repeated tilling of the ground has thoroughly mixed at least the upper meter of the deposits. These activities make stratigraphic and soil-profile studies of recent eruptive deposits and events in the Dieng area difficult.

ERUPTIVE ACTIVITY

Volcanic centers, eruptive products, and explosion craters in the Dieng Mountains can be divided into six groups according to relative age, based on their morphology, degree of dissection, stratigraphic relationships, and degree of weathering. These groups of features, listed below (see fig. 2 for locations), are described from oldest to youngest in the text.

- I. Djimat, Prau, and Tlerep (not shown on fig. 2) volcanic complexes (oldest)
- II. Bisma, Srodia, and Nagasari volcanic centers
- III. Volcanic cones and explosion craters of intermediate age
- IV. Dieng tephra sequence
- V. Lava cone, lava flow, and dome sequence in the eastern Dieng Mountains
- VI. Postlava complex phreatic eruption and explosion craters (youngest)

Djimat, Prau, and Tlerep Volcanic Complexes

These volcanic centers are old, deeply dissected volcanoes; little or none of the original volcano morphology (craters and young deposits) remains, suggesting that these volcanoes have long been extinct. Gunawan (1968) summarized different explanations of origin of a steep scarp-like slope on the southwest sides of Prau and Tlerep. He concluded that the scarp is the result of tectonic events that occurred after the formation of Prau, and produced a large graben-like feature trending northwest. These old volcanoes were not studied as part of this investigation; they were discussed in detail, however, by Gunawan (1968).

Bisma, Srodia, and Nagasari Volcanic Centers

Based on their morphology, this group of stratovolcanoes is younger than the stratocones described above, and they are thought to postdate formation of the graben at the southwest side of Prau (Gunawan, 1968). An age younger than that of the Djimat, Prau, and Tlerep complex is suggested because the Bisma, Srodia, and Nagasari stratovolcanoes possess more youthful and less dissected slopes, and some crater morphology remains on Bisma and Srodia volcanoes. These volcanic centers, not studied in this reconnaissance investigation, also were described by Gunawan (1968).

The Volcanic Cones and Explosion Craters of Intermediate Age

This group of six volcanic cones and (or) groups of explosion craters is distributed over a wide area in the Dieng Mountains. These eruption centers still have relatively fresh morphology and well-defined craters and are all broadly similar in age. Volcanic products derived from these eruption centers overlie the older volcanic cones described above. This group of vents (see fig. 2 for locations) is listed below from generally west to east; actual age relationships between all individual vents are not known, but stratigraphic and morphologic evidence suggests that the Dringo crater complex is one of the youngest in this group of vents. They include:

- A. Butak-Petarangan stratovolcano.
- B. Dringo stratovolcano.
- C. Pagerkandang stratovolcano.
- D. Pangonan-Merdada stratovolcano.
- E. Igir Binem pyroclastic cone.
- F. Siterus crater.

These centers were active over a relatively long period of time and produced a thick, widespread blanket of phreatic, phreatomagmatic, and magmatic air-fall deposits that covers all older vents and volcanic landforms in the Dieng Mountains region. This air-fall sequence is referred to informally in this report as the "Dieng tephra sequence" and is described in more detail below.

With the exception of Siterus Crater, all the volcanic vents listed above consist of a constructional volcanic cone or cones modified by one or more explosion craters. Siterus Crater is an explosion vent within lavas from the Pangonan cone. Most of the craters have relatively well preserved rims, and steep inner walls. Some of the crater walls are breached in one or more places, while other craters contain lakes. With the exception of Dringo, all the volcanoes in this intermediate age group are mantled by the Dieng tephra sequence. The Dringo explosion craters appear to postdate most if not all of the Dieng tephra sequence.

The Dieng Tephra Sequence

The Dieng tephra sequence consists of a widespread blanket of tephra deposits which covers the Dieng Mountains region. The deposit mantles all older deposits and extends from east of Diengkulon (village) to more than 10 km west of Batur (fig. 1). Over this entire region, the sequence is several tens of meters thick or more and smooths out the preexisting topography making a gentle rolling landscape.

The tephra sequence consists of interbedded lapilli- and ash-fall beds each of which varies in thickness from a few centimeters to about 1.5 m. Based on their texture and composition, individual air-fall beds can be identified as either phreatic, phreatomagmatic, or magmatic in origin. Within the tephra sequence, there are numerous buried soil profiles, suggesting that long periods without eruptions occurred during the time interval represented by this sequence.

At any single locality in the Dieng Mountains, the air-fall deposits probably came from several to many different vents in the region. This is suggested by lateral increases both in grain size and thickness toward different directions within successive beds.

Figure 3 shows the upper 3 m of a stratigraphic exposure north of Pawuhan Village (see fig. 2 for location) that is representative of the Dieng tephra sequence. The section includes deposits from phreatic, phreatomagmatic, and magmatic eruptions.

Phreatic air-fall deposits in this sequence typically are:

1. Poorly sorted mixtures of angular lithic fragments and contain an abundant sand- to clay-size matrix.
2. A mixture of old lithic rock types and contain no juvenile component.
3. Characterized by lithic fragments that are extensively hydrothermally altered, clay-rich, and have a mottled gray, white, or yellowish color.

Phreatomagmatic deposits within the Dieng tephra sequence may be characterized by:

1. Relatively well sorted mixtures of nonvesicular lithic components that contain a significant vesicular, bread-crusteD, or prismatically jointed juvenile component.
2. Small percentages of hydrothermally altered and clay-rich material.
3. Reverse and (or) normal grading and friable openwork textures.

Magmatic tephra deposits within the Dieng tephra sequence show the following typical features:

1. Relatively good sorting and either reverse or normal grading.
2. Predominance of vesicular, bread-crusteD, or prismatically jointed juvenile magmatic components, perhaps with a subordinate component of lithic fragments.
3. No primary clay-rich or altered components and a friable openwork texture.

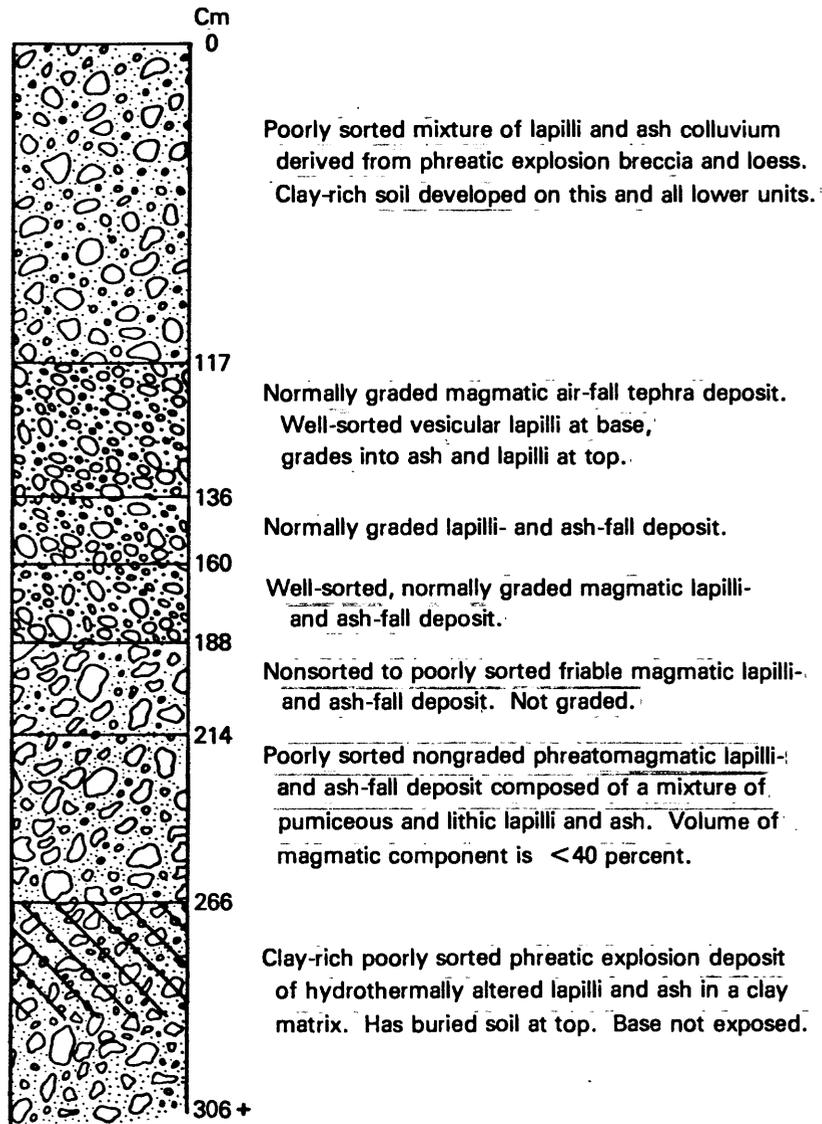


Figure 3.--Representative stratigraphic section showing upper 3 m of the Dieng tephra sequence exposed north of Pawuhan Kulon (location 6, fig. 2).

The upper 1-1.5 m of the Dieng tephra sequence consists of a well-sorted massive silt deposit. The deposit is loose and friable, and is interpreted as loess.

The upper part of the Dieng tephra sequence is deeply weathered and shows a well-developed soil profile. The soil development includes a mature A/B/C profile, and strong oxidation extends to a depth of about 3 m (fig. 4). The B-horizon contains clay that formed in place; that, and the depth of oxidation, suggest that the soil required at least several to many thousands of years to form. An age of at least several thousand years is reinforced by the fact that the deposits of the Dieng tephra sequence are deeply weathered and most lithic rock fragments, magmatic fragments, and minerals are altered extensively or completely to clay minerals.

Results of radiocarbon determinations from a charcoal sample collected from a magmatic lapilli-fall deposit about 3 m below the top of the Dieng tephra sequence (locality 31, fig. 2) will establish an age for the last magmatic eruption in that sequence. This radiocarbon date will also provide a maximum time interval for development of the 3-m-thick soil profile.

Lava Cone, Lava Flow, and Dome Sequence, Eastern Dieng Mountains

The eastern part of the Dieng Mountains region is dominated by a complex of young silicic lava domes and blocky flows erupted from at least five vents; individual flows are as long as about 3.5 km. These domes and flows lie stratigraphically on top of the Dieng tephra sequence and are composed primarily of andesite, rhyodacite, and quartz latite. The physical and petrologic characteristics of these volcanoes are summarized by Gunawan (1968). Based on morphology, crosscutting relationships, and photogeologic studies, the sequence of eruptions is as follows:

(See fig. 2 for volcano locations)

1. Prambanan flows (oldest)
2. Pakuwadja dome and flows
3. Kunir dome and flows
4. Kendil dome and flows
5. Sikunang lava flows (youngest)

These eruptive centers appear to have produced only viscous blocky lavas; no pyroclastic deposits or other evidence of explosive volcanism were identified.

The upper surface of these lavas is not covered by the Dieng tephra sequence. Instead, their surfaces are overlain by 1-1.5 m of massive, well-sorted silt, interpreted as windblown loess. Within the loess are several minor phreatic air-fall deposits.

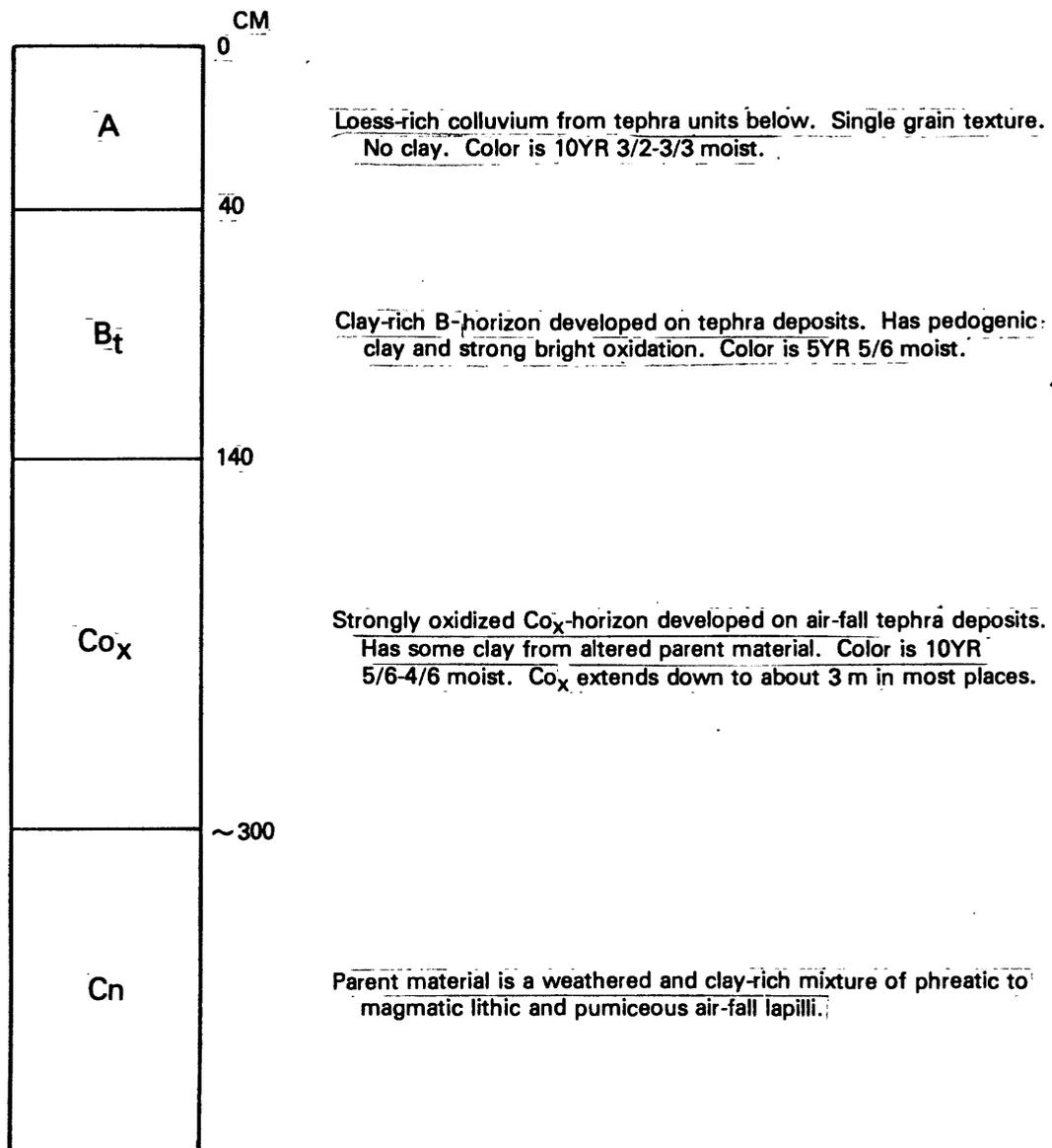


Figure 4.--Representative soil profile developed on the Dieng tephra sequence (locations 4 and 5, fig. 2).

Soil-profile development and weathering characteristics suggest that this complex of lavas erupted shortly after deposition of the Dieng tephra sequence, and that the lavas are at least several thousand years old. The soil profile consists of a mature A/B/C profile with clay formation in the B-horizon (fig. 5). Well-developed oxidation extends down to 3 m in most places. The degree of soil development is comparable to that on the Dieng tephra sequence.

Lava blocks within the soil profile on these flows have been extensively weathered and altered to clay minerals. This degree of decomposition typically requires many thousands of years and, therefore, reinforces the age suggested by the degree of soil development.

Postlava-Complex Phreatic Eruption and Explosion Craters

Since the eruption of lava domes and flows in eastern Dieng Mountains, no deposits of magmatic eruptions, explosive or otherwise, have been identified in the Dieng region. Numerous historic and prehistoric phreatic or hydrothermal explosive eruptions have occurred, however, from vents widely spaced over the Dieng Mountains region (fig. 2). The eruptions have occurred on, and adjacent to, older volcanic centers and along tectonic lineaments and regional fracture systems in the area. Some of the eruptions have produced single, steep-walled, circular craters (e.g. Djalatunda and Sigluduk) while others have produced a series of connected or elongated craters or fissures (e.g., Djimat craters and Timbang craters).

On the basis of morphology, soil-profile development, and historic accounts for recent events, some of these volcanic vents may be as old as many hundreds (possibly thousands) of years, yet eruptions have occurred as recently as 1979 (table 1). Volcanic vents are listed in table 1 according to the estimated order of eruption from oldest to youngest. Details about the nature of eruptions, their products and precursors if any, and their effects on the surrounding region are summarized briefly in table 1, and discussed in more detail by Gunawan (1968).

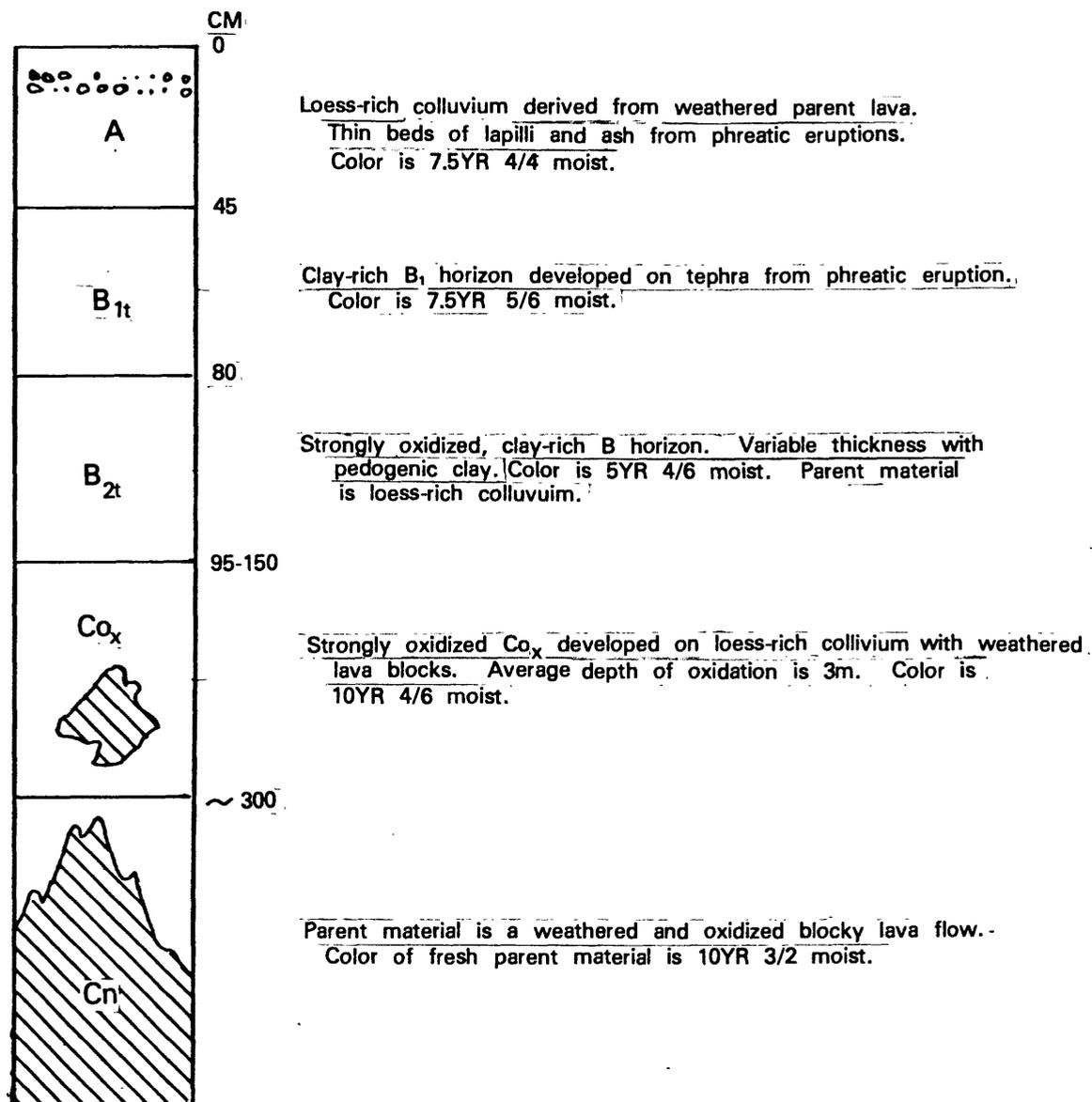


Figure 5.--Representative soil profile developed on top of the Sikunang blocky lava flow (location 2, fig. 2).

Table 1.--Phreatic eruptions in the Dieng Mountains region
 [Data on historic eruptions from Gunawan (1968) and Zen and Alzwar (1980)]

Site of eruption (see fig. 2)	Year of eruption	Details of eruption and deposit
Pakuwadja		
Southeast summit crater.	Prehistoric-----	Phreatic eruption of hydrothermally altered material. Deposit more than 1.5 m thick on crater rim. Strong oxidation at top.
Northwest summit crater.	Prehistoric-----	Phreatic eruption of fresh "muddy" explosion debris. Deposit more than 90 cm thick on crater rim. Weak A/C soil profile with moderate oxidation to 60-cm depth.
Small crater on northeast flank.	Prehistoric-----	Phreatic eruption produced base-surge deposits more than 1.5 m thick on crater rim. Has weak A/C soil profile with strong oxidation to 20-cm depth. Deposit is indurated, impermeable.
Kendil		
Large east crater.	Prehistoric-----	Phreatic eruption of hydrothermally altered material. Deposit is more than 3 m thick on the crater rim. Weak A/C soil profile with weak oxidation to 40-cm depth.
Small west crater.	Prehistoric-----	Phreatic eruption built ejecta cone south of vent. Deposit thickness and soil development are unknown.
Djalatunda crater.	Prehistoric-----	Phreatic eruption. Deposit is more than 2 m thick on rim of crater. Data not collected on soil-profile development, so age relative to other craters unknown.
Upas-Luwuk explosion craters, south and east sides of Sibenteng crater.	Prehistoric-----	Phreatic eruptions of unknown age and character. Craters described by Gunawan (1968).
Djimat explosion crater and Tjandradimuka vents.	1786 and possibly older prehistoric eruptions.	Phreatic eruptions from several vents. Formation of fissures and emission of sulfurous vapors. 1786 eruption preceded by 4 months of felt earthquake activity. Several people killed by eruption and 38 people killed by landslide (Gunawan, 1968).
Timbang crater complex.	1928-----	Phreatic eruptions of fresh blocks and clay matrix from three vents. Deposit more than 35 cm thick at the site of the former village of Timbang. Eruption preceded by 10 days of felt earthquakes. Eruption produced small mudflows and poisonous gases. One person killed by falling blocks.

Table 1.--Phreatic eruptions in the Dieng Mountains region--Continued

Site of eruption (see fig. 2)	Year of eruption	Details of eruption and deposit
Timbang crater complex-- Continued	1939-----	Phreatic eruptions produced a series of 15 craters or fissures. Deposit of fresh lithic blocks and clay matrix is more than 35 cm thick at the site of the former village of Timbang. The eruptions were preceded and accompanied by earthquakes. Eruption destroyed Timbang village and killed 10 people. Small mudflows were reported.
Silari crater-----	1944-----	Phreatic eruption of hydrothermally altered material. Thickness and distribution of material shown on figure 6. Deposit more than 2 m thick on west rim of crater. Large blocks fell as far as 1.5 km from the crater. Eruption preceded by development of fissures in crater, but no felt earthquakes. Several villages were destroyed or damaged and 114 people and many animals died.
Tjandradimuka-----	1945-----	Small phreatic eruption reported. Eruption was preceded by increased hot spring temperatures, but no felt earthquakes were reported.
Silari crater-----	1964-----	Small phreatic eruption of mud and ash. Ash fell as far as 1 km from vent. No reported felt earthquakes or injuries.
Sinila and Sigluduk craters.	1979-----	Phreatic eruptions of hydrothermally altered material. The deposit is nearly 0.5 m thick 200 m south of rim of Sinila crater. Blocks fell nearly 1 km from Sinila crater. Eruption was preceded by microseismic activity for 5 days, and felt earthquakes for several hours. Eruption produced mudflows, and poisonous gases were emitted from several vents in the area. One hundred forty-eight people were killed by poisonous gases downslope from the vent.

HYDROTHERMAL ACTIVITY--ACTIVE FUMAROLES, SOLFATARAS, HOT SPRINGS, AND MOFETTES

Hydrothermal activity is widespread in the Dieng Mountains region at the present time. The activity consists of active fumaroles, solfataras, hot springs, and mofettes (areas which release large quantities of CO and CO₂ gases) that are distributed over an area approximately 11x4 km between Batur village and Pakuwadja volcano (see fig. 2). Most of the hydrothermally active localities are associated with explosion craters, tectonic lineaments, or fracture zones in the Dieng region. These features are thought to be the surface manifestations of a large geothermal reservoir below the region (Muffler, 1970). Table 2 lists areas of current hydrothermal activity in the Dieng region and describes the major type or types of activity at each location. The reader is referred to Gunawan (1968) and Zen and Alzar (1980) for more details on hydrothermal activities in the region.

SUMMARY OF ERUPTIVE ACTIVITY IN THE DIENG MOUNTAINS AND DISCUSSION OF FUTURE VOLCANIC HAZARDS

The last explosive magmatic eruptions in the Dieng Mountains occurred during deposition of the Dieng tephra sequence. The sequence is tens of meters thick and consists of andesitic air-fall tephras from phreatic, phreatomagmatic, and magmatic eruptions from many widely spaced vents in the region. These eruptions occurred intermittently, and numerous buried soils in the sequence mark time intervals without major explosive eruptions. Soil-profile development and weathering at the surface of the Dieng tephra sequence suggest that the last of these eruptions occurred many thousands of years ago.

Following deposition of the Dieng tephra sequence, a complex of silicic lava cones, lava flows, and domes erupted nonexplosively in the eastern Dieng area. These thick, viscous, blocky lavas were extruded from at least five different vent areas, and individual lava flows are as long as about 3.5 km. Soil-profile development and weathering on these lavas suggest that they were erupted very soon after the Dieng tephra sequence, and that they are also several thousand to many thousands of years old.

During a period lasting thousands of years since the eastern Dieng lavas erupted, no magmatic eruptions, explosive or otherwise, are known to have occurred in the Dieng Mountains region. Volcanic activity during this time interval has apparently consisted of phreatic eruptions and nonexplosive hydrothermal activity. These hydrothermal events appear to be related to the presence of a large hydrothermal system under the Dieng Mountains and to be concentrated along major tectonic lineaments in the region.

Table 2.--Hydrothermally active areas in the Dieng Mountains
 (after Gunawan, 1968)

Location of activity (see fig. 2)	Type(s) of activity
Sikidang-----	Fumaroles, solfataras, and hot springs.
Silari-----	Do.
Tjandradimuka-----	Do.
Timbang-----	Mofettes.
Djimat-----	Do.
Sinila-----	Fumaroles and mofettes.
Sigluduk-----	Mofettes.
Iger Binem-----	Solfataras and hot springs.
Pakuwadja	
North crater-----	Solfataras.
North flank-----	Do.
Sidongkal-----	Fumaroles.
Bitingan-----	Fumaroles and hot springs.
Pagerkandang complex-----	Fumaroles and solfataras.
Siglagah-----	Do.
Pangonan-Merdada-----	Fumaroles, solfataras, hot springs and mofettes.
Siterus crater-----	Fumaroles, solfataras, and hot springs.
Pulosari-----	Solfataras and hot springs.

If future volcanic events are similar to those during the past few thousand years, they will consist of phreatic eruptions, associated relatively small hot mudflows, and various types and scales of hydrothermal activity. All sites of past phreatic eruptions and past or present hydrothermal activity in the Dieng Mountains region (tables 1, 2) should be considered to be possible locations of future phreatic eruptions. In addition, all tectonically active areas and fractures or lineaments in the Dieng Mountains may be the sites of future phreatic eruptions.

Although magmatic eruptions are possible in the area, they are less likely in the near future than phreatic ones, based on the most recent volcanic events. Magmatic eruptions, however, probably would require movement of new magma up from depth and thus probably would be accompanied by increased seismicity and possibly other warning signs, such as deformation, development of new thermal anomalies, or a marked increase in fumarole or hot spring discharge or temperatures.

In the past, some phreatic eruptions have been preceded by microseismic or felt earthquake activity, increased solfataric or fumarolic activity, increased discharge and (or) temperature of hot springs, or the formation of new or larger craters or fissures. These events should be carefully watched for in the future, and the occurrence of one or more of them should suggest the possibility of an imminent eruption nearby.

Based on past activity, future phreatic eruptions may occur with or without felt seismic warnings. Some eruptions have apparently occurred without felt earthquakes or after only a few hours of felt earthquake activity. Because the location and occurrence of phreatic explosions appears to be controlled partly by tectonic features, future earthquakes and other tectonic events should immediately alert the populace and authorities to the possibility of imminent phreatic eruptions.

Monitoring and location of hypocenters for microseismic activity in the Dieng Mountains by the Volcanological Survey of Indonesia might provide a warning of impending eruptions hours and possibly even days before the actual event. Such eruptions may be expected in the general vicinity of the earthquake epicenters and the populace could thus be warned and (or) evacuated.

Future eruptions can be expected to vary greatly in size, and include small relatively harmless events, destructive ones like the 1944 eruption of Silari, and perhaps even larger ones. The 1944 Silari eruption covered at least several square kilometers with hot mud and bombs (fig. 6). Bombs large enough to penetrate the roofs of houses, and to be fatal to humans and livestock, fell up to 1.5 km from the vent. Extensive damage to crops occurred in areas subject to fall of ash and debris from the eruption. Most future eruptions may also be accompanied by emission of large quantities of CO₂, CO,

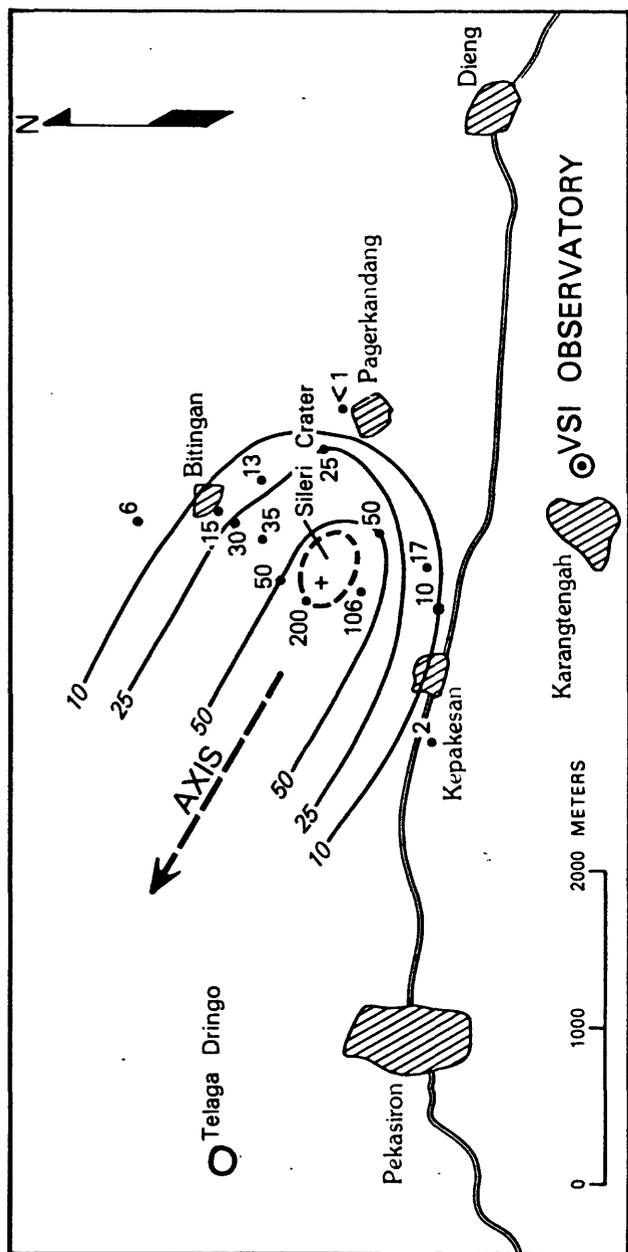


Figure 6.--Thickness (in centimeters), partial extent, and axis of phreatic explosion deposit erupted at Silari Crater in 1944. Numbers represent thickness of deposit in centimeters at sample points.

and other gases as occurred in 1979 during and after the Sinila and Sigluduk eruptions. Such gases may be emitted from craters, cracks, and fissures over a wide area in the vicinity of an erupting vent.

Carbon dioxide and carbon monoxide gases are heavier than air and thus flow near the ground into topographically low areas, and they collect in closed depressions. Therefore, areas subject to the greatest hazard from "poisonous" gases will be downwind and (or) downslope from, and in depressions near, active craters, vents, fissures, or hydrothermal features.

If microseismic or larger earthquakes are detected at the Dieng observatory seismograph, a portable seismic array should be installed promptly if possible and an attempt should be made to locate hypocenters for the events. The epicenters for the seismic activity may suggest where eruptive activity might occur. Under such circumstances, the populace within several kilometers of the potential eruption site should be warned of a possible eruption, given instructions about what to do in the event of an eruption, or temporarily evacuated to a safer location. Evacuation routes utilizing high ground, in order to avoid topographically low areas in which gas might be trapped, should be determined in advance for those populated areas near possible eruption sites to minimize exposure of the populace to poisonous gases and hot mudflows.

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