Crater lakes of Java: Dieng, Kelud and Ijen

Excursion Guidebook

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Manfred J. van Bergen[1], Alain Bernard[2], Sri Sumarti[3],
Terry Sriwana[3] and Kastiman Sitorus[3]

[1]Faculty of Earth Sciences, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, the Netherlands; [2]BRUEGEL (Brussels Unit for Environmental, Geochemical and Life Sciences Studies), Université Libre de Bruxelles 160/02, 50 Ave. Roosevelt, 1050 Brussels, Belgium; [3]Volcanological Survey of Indonesia, Jl. Diponegoro 57, Bandung 40122, and Jalan Cendana 15, Yogyakarta 55166, Indonesia.

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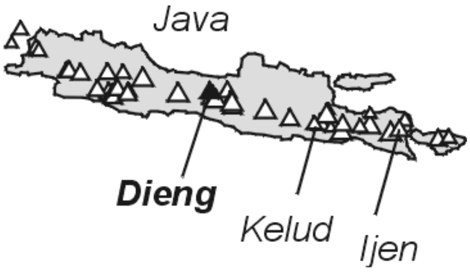
Dieng Plateau



The Dieng Volcanic Complex in Central Java is situated on a highland plateau at about 2000 m above sea level, approximately 25 km north of the city of Wonosobo. It belongs to a series of Quaternary volcanoes, which includes the historically active Sumbing and Sundoro volcanoes. The plateau is a rich agricultural area for potatoes, cabbages, tomatoes and other vegetables. There are numerous surface manifestations of hydrothermal activity, including lakes, fumaroles/solfatara and hotsprings. The area is also known for the development of geothermal resources and lethal outbursts of gas. Scattered temples are the witnesses of the ancient Hindu culture that once reigned.

Geological setting

The 14 km long and 6 km wide Dieng Plateau has a general E-W trend due to the shift of eruptive centers with the youngest activity being in the east. It is underlain by Tertiary marls, limestones, tuffaceous sandstones and volcanics. The Dieng Complex itself consists of late Quaternary to Recent volcanic cones and explosion craters, formed at the intersection of two major fault zones trending E-W and NW-SE. Three major episodes of volcanic activity have be distinguished (from Sukhyar, 1994):

(1) The oldest volcanic products have a Lower Quaternary age and form the northern and southern margins of the Dieng plateau. They include the Prahu and Tlerep stratovolcanoes and the Rogojembangan units. Subsidence of the western part of the Prau cone (+2565m) formed the plateau, which has been interpreted as a caldera or as a structural depression. The Nagasari cone is probably the western border of the plateau.

(2) During the second episode a number of stratovolcanoes emerged within the depression, producing basalts, basaltic andesites and pyroxene-andesites. Pyroclastic fall deposits, believed to have been erupted from all of these volcanoes, blanket the Dieng and Batur depressions. They are collectively referred to as Dieng tephra. Dating yielded an age of 16770 years. Bisma, situated on the southern edge, is the oldest volcano and produced basaltic lava, pyroclastic falls and flows. Sroja volcano further east has two summit craters. A parasitic eruption center on the southern slope contains an 800m wide and >150m deep crater lake (Telaga Menjer), which is used for hydroelectric power and irrigation. Pangonan and Merdada are two stratocones east of Nagasari. The latter has a crater lake, which is used for drinking water by local villagers. Pagerkandang cone is situated to the north of Merdada and is younger than the latter. Scoria falls, probably from strombolian activity, represent its latest products. Solfataras are present in the crater wall and on northern slope. They are also found within the crater of Igir Binem, the most eastern volcano of this episode. This crater, which has been partly filled by a biotite-andesite lava from the third episode, contains a colored lake (Telaga Warna). Dringo-Petarangan volcano, situated in the Batur depression

7 km east of the Dieng depression, may be similar in age as the Merdada-Pangonan cones, based on morphological appearance.

(3) The youngest magmatic activity produced viscous (olivine-) biotite andesite lavas and airfall from a cluster of nine eruption centers on the southern edge of the Dieng depression. Legetang, an isolated center 4 km to the west, also belongs to this group. The youngest lava has an age of 8540 years and is separated from the underlying Dieng tephra by a paleosoil. Magmatic air fall from the Pakuwaja eruption center, which covers the lava, is overlain by 2450 years old hydrothermal explosion deposits from Telaga Lumut (former lake in the Sikidang center). More recent hydrothermal air fall deposits were produced by explosions from the Sileri (1944) and Sinila (1979) craters.

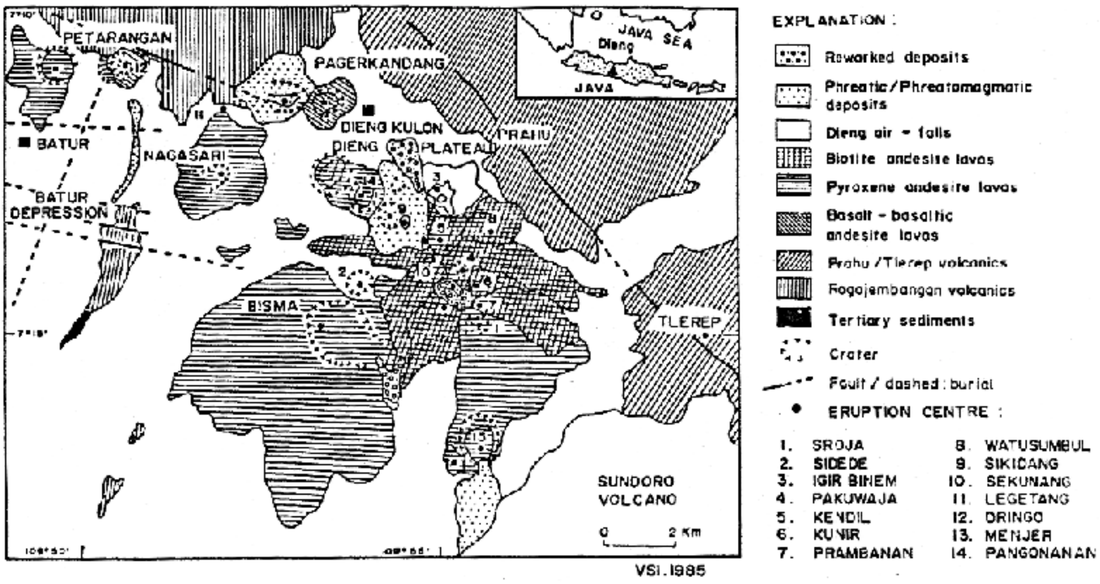


Figure 1.1 Geology of the Dieng Plateau area (from Sukhyar, 1994)

Eruptive activity

Documented eruptive activity is characterized by explosive events (VEI<3) that are phreatic in nature. Some eighteen eruptions have been recorded since the 18th century. This activity occurred at different craters: Sileri (6-7 eruptions), Pakuwaja (3), Petarangan craters (3), Sikidang (2), Sinila and Sigludug (1), Candradimuka area (1). Lahars were generated on three occasions, the most recent one accompanying the 1979 event at Sinila-Sigludug. Eight of the eruptions caused fatalities. Allard et al. (1989) suggested that explosions in the Dieng Complex can be distinguished into two types:

1. Eruptions without seismic precursors, resulting from self-sealing processes in active fumaroles/solfataras
2. Eruptions preceded by local or regional earthquakes or by fracture opening. These may occur at locations without visible geothermal surface activity. Most eruptions of this type occurred in the Batur depression (e.g., Sinila-1979; Timbang explosions in the 1940s)

The 1979 disaster

A lethal gas burst accompanying mild phreatic eruptions at Sinila and Sigludug craters in February 1979 caused the death of 149 (variously reported as 142-182) inhabitants of Kepucukan. Ejection of a dark-grey cloud from the water-filled Sinila crater started the eruption. When one hour later a second cloud escaped, a 'hot' lahar was produced.

Reports indicate that white vapor was emitted until two days after the initial eruption. The victims from Kepucukan fled towards Batur, warned by the initial earthquakes and volcanic manifestations. They were found dead on the track, seeming to be asleep in a single row as when they were walking. The casualties appeared to be asphyxiated by poisonous gas. Later reconstructions and measurements pointed to CO_2 as the most likely cause (Le Guern et al., 1982). According to Allard et al. (1989), the gas may have escaped from a newly activated fissure aligned with the Sinila-Sigludug craters. The authors suggested that the release of relatively low-temperature gas stored at shallow levels was triggered by the phreatic activity. The 1979 Dieng event has strong analogies with the lethal gas burst at Lake Nyos in 1986, which probably took place from gas-charged lake water. In both cases, CO_2-rich gas accumulated at relatively low temperatures, and was capable to flow along the surface when the blow-out occurred. A point of contrast is the close association with a high-temperature (330°C) geothermal system at Dieng. Also, local accumulation of CO_2 escaping from permeable rock/soil without 'eruptive' activity remains a matter of concern, as it has occasionally caused the death of people in the surrounding of Buntu village. The latest event occurred in 1997.

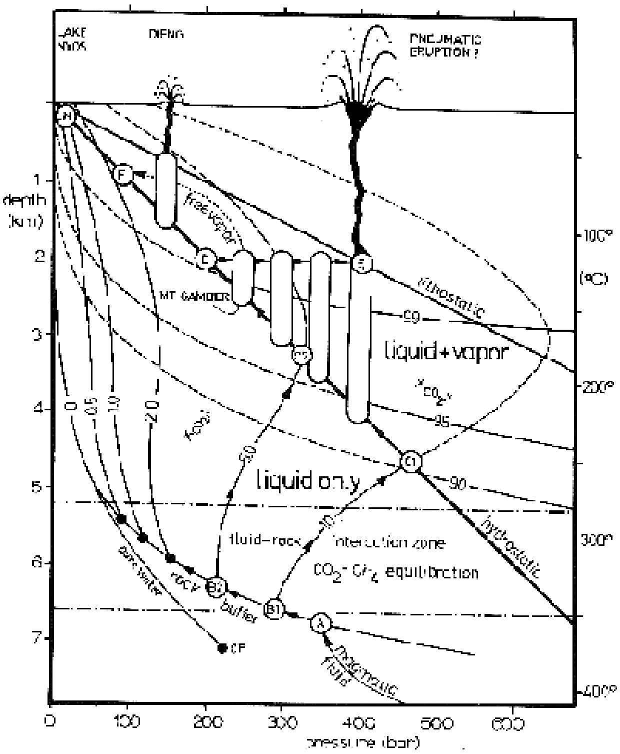


Figure 1.2 *Model for the evolution of high-CO_2 gases and 'pneumatic' eruptions (Giggenbach et al., 1991). A CO_2-bearing fluid originating from a magmatic body rises until the 'rock buffer' line is reached (A), where increasing amounts of CO_2 are removed through reaction with rocks according to CO_2+Ca-Al-silicate+feldspar= calcite+ clay. Depending on the progress of fluid-rock interaction, the fluid reaches a point where it starts to rise without further loss of CO_2 (e.g., B1). In case overall pressures are governed by the hydrostatic pressure of groundwater, the liquid will start to boil when C1 is reached, separating a CO_2-rich vapor. A slowly rising fluid mixture will move along a P-T path controlled by decreasing hydrostatic pressure, whereby the vapor becomes increasingly gas-rich. A gas pocket of steadily increasing size will form where an impermeable obstructions prevents the free escape of the fluid mixture. Once increasing pressure reaches that of the lithostatic load, the accumulated high-pressure gas maybe released through an eruption. A free vapor phase may escape by leakage from such a pocket. At shallower levels, the gas may dissolve in a water body (F) to form a gas-rich, low salinity solution, with bicarbonate as the major anion, as at Lake Nyos.*

Surface manifestations and gas emission

Surface manifestations of hydrothermal activity and degassing are widespread in the Dieng area. Surface activity in the central part near Sikidang and Sileri consists of fumaroles, acid sulfate and near-neutral sulfate-bicarbonate springs, mud pools and extensive areas of steaming ground. Soil surveys have demonstrated a large natural discharge of carbon dioxide and strongly positive mercury anomalies.

Other groups of springs are found at varying distances from the central area. To the north, the Bilingan springs occur at slightly lower altitude. They are poor in chloride but richer in sodium, calcium, magnesium, sulfate and bicarbonate. These waters probably originate from steam condensation and subsequent interaction with rocks.

The Pulosari springs are situated 3km west of Sikidang, also at slightly lower altitude. Sulfur deposits occur near vents and on the riverbank where the springs are found. Chloride concentrations are the highest closest to the central area. These waters may be a mixture of cold surface waters and hot up flowing chloride waters.

Gas emissions are frequently associated with strong hydrothermal alteration and sulfur deposits. Foggy ‘wet’ gas (up to 98% H_2O and little CO_2, SO_2) is emitted from Sikidang, Pakuwaja and Sileri craters. The hotspring and solfatara fields near Sikidang are frequently visited by tourists. ‘Dry’ gas (up to 90% CO_2) is produced by vents in the Telaga Warna crater, Telaga Lumut crater and near Buntu in the Dieng depression, and at Sigludug near Sinila in the Batur depression. Gas compositions are given in Tables 1.1 and 1.2.

Figure 1.3 Simplified map of the Dieng Plateau

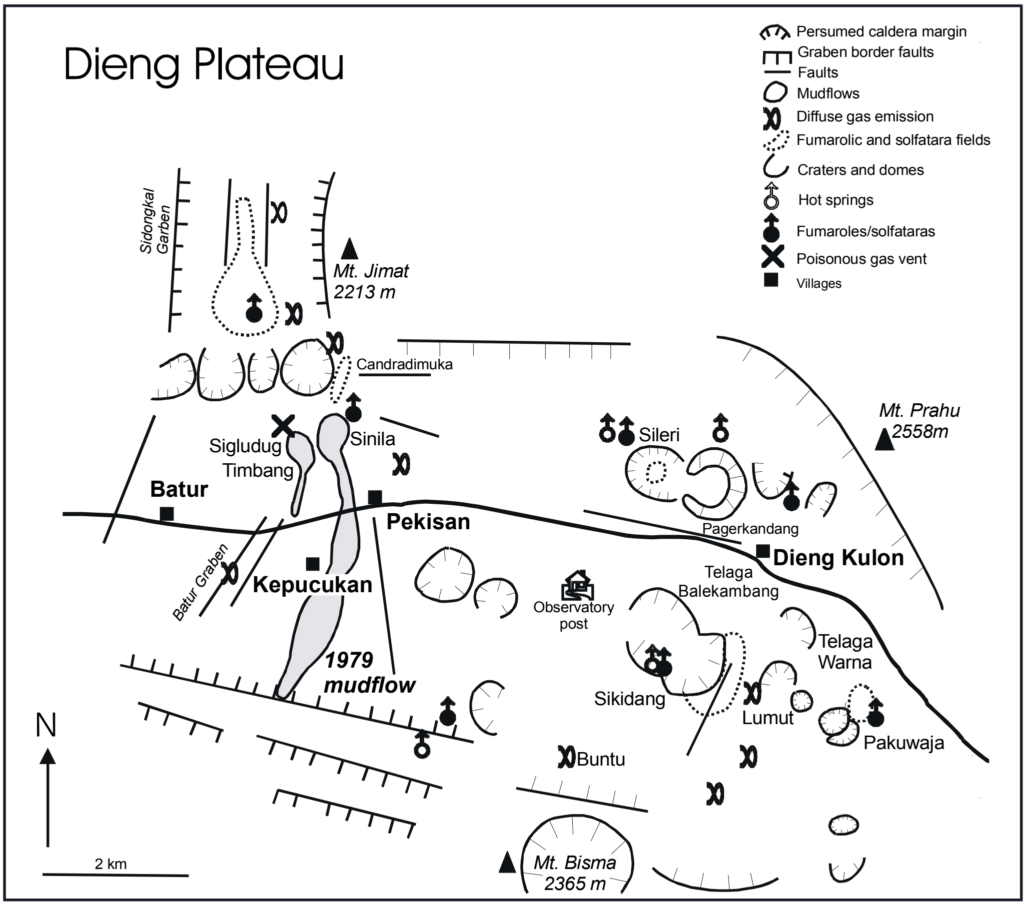


Table 1.1. Gas compositions Dieng Complex

(1994 Data from the CCVG-IAVCEI Newsletter, December, 1995; comparison of results from different laboratories: KS=Kusatsu Shirane, LH=Lower Hutt, PL=Palermo, PP=Petropavlovsk, TM=Tempe, TS=Tsukuba, YY=Yogyakarta)

(a) On total discharge basis (mmol/mol)

	Temp (°C)	H_2O	CO_2	SO_2	H_2S	S_t	n	HCl	HF	NH_3	H_2
Dieng-Sikidang, 25 July 1994											
KS	94	983	9.8	0.04	6.79	6.83	-1.9	-	-	-	0.021
LH	-	988	6.1	-	5.53	5.53	-2.0	0.009	-	0.0006	0.035
PL	95	985	6.2	0.08	7.71	8.82	-1.7	0.023	0.040	-	0.021
PP	95	987	6.2	-	6.90	6.90	-2.0	<0.010	0.0004	-	0.027
TM	94	962	25.1	-	-	12.00	-	-	-	-	0.137
TS	94	986	7.1	0.48	5.95	6.43	-1.6	0.056	-	<0.0002	0.053
YY	94	981	11.3	7.10	0.50	7.60	3.6	0.003	-	-	0.030
Dieng-Pakuwaja, 11 Sept. 1993											
KS*	91	916	77.6	<0.05	1.20	1.20	-2.0	-	-	-	0.078

(b) On dry basis (mmol/mol)

	x_g	CO_2	S_t	HCl	HF	NH_3	He	H_2	Ar	O_2	N_2	CH_4	CO
Dieng, Sinila, 70° C													
KS	500	994	0.4	-	-	-	0.0020	0.18	-	0.12	5.4	9.9	-
LH	524	981	<0.5	-	-	0.02	0.0049	0.19	0.017	<0.01	6.9	12.4	<0.0008
PL	-	970	0.2	-	-	-	0.0028	0.17	-	-	25.0	11.5	0.0025
TM	493	985	-	-	-	-	0.0020	0.12	-	-	4.8	10.8	-
TS	524	983	<0.5	0.7	-	0.004	0.0042	0.20	0.019	0.12	6.0	11.1	-
YY	680	974	8.2	6.9	-	-	-	0.29	-	-	8.4	1.8	-
KS*	84	924	14.0	-	-	-	0.032	0.09	0.285	4.90	40.5	18.1	-
Dieng, Telaga Warna, 19° C													
KS	-	926	52	-	-	-	0.0029	0.26	-	0.15	9.1	12.8	-
LH	-	911	59	-	-	0.02	0.0070	<0.01	0.038	<0.01	11.8	18.4	<0.0010
PL	-	930	-	-	-	-	0.0030	0.20	-	-	14.8	16.9	0.0008
YY	-	920	33	13.6	-	-	-	-	-	-	11.7	2.1	-
Dieng, Sikidang													
FR	-	815	184	-	-	-	-	0.14	-	0.0?	0.3	0.009	0.00001
KS	17	584	408	-	-	-	0.0039	1.25	-	0.16	7.4	0.17	-
LH	12	515	469	0.8	-	0.05	0.0148	2.97	0.043	<0.01	11.3	0.26	<0.0002
PL	15	406	578	1.5	2.6	-	0.0041	1.38	-	-	14.5	0.12	0.0054
PP	13	496	552	<0.8	0.03	-	-	2.16	0.144	0.8	21.6	0.04	<0.0008
TM	38	653	313	19.8	-	-	0.003	3.55	0.380	-	9.6	0.83	-
TS	14	516	469	4.1	-	<0.01	0.0226	3.87	0.036	-	13.1	0.47	-
YY	19	596	400	0.2	-	-	-	1.58	-	-	4.2	0.018	-

Table 1.2 Gas compositions (total discharge, mol%)

VSI data, 1999

	Sigludug	Timbang	Buntu
Temp (°C)	air temp.	62	air temp.
H_2	-	-	0.007
O_2+Ar	2.47	1.99	5.02
N_2	12.13	14.63	65.69
CH_4	0.95	0.37	-
CO_2	81.79	80.13	2.98
SO_2	0.04	-	3.5
H_2S	0.08	-	2.05
HCl	2.53	2.88	12.06
H_2O	-	-	9.61

Crater lakes

In terms of chemical composition, Telaga Warna is the most interesting crater lake in the Dieng area. The original shape of the crater has been modified by a lava flow. The water occupies <1km^2. Gas bubbles can be seen rising to the lake surface, and the air has a sulfurous odor. Its colorful appearance ('warna' stands for 'color(s)' in Indonesian) makes the lake an interesting tourist attraction. The water has a pH of about 3, which may fluctuate depending on seasonal variations. Sulfate and chloride contents are moderately high (Table 1.3). Strong emissions of CO_2-rich gas on-shore have occasionally killed animals, so that a path on the north side used to be closed to avoid risks for local villagers. The emissions show considerable fluctuations in strength. The Sinila crater lake is near neutral (pH=~6.5) and has lower sulfate and chloride contents (Table 1.3).

Table 1.3 Crater lake compositions (ppm)

VSI data, 1999 and Bernard (unpublished)

	T. Warna	T. Warna	T. Warna	K. Sinila	K. Sinila	Sikidang1	Sikidang2
Date	Jul-94	Jul-99	Oct-99	Jul-99	Oct-99	Jul-94	Jul-94
Temp. (°C)	21.5	18	22	20	22	89	57
pH	2.6	3.3	2.8	6.5	6.7	2.4	2.1
Na	4	1.9	2.0	2.4	1.9	92.0	36.0
K	n.d.	0.3	0.3	0.4	0.4	20.0	4.0
Ca	8	6.0	7.8	7.7	5.5	136.0	95.0
Mg	3	2.7	3.0	5.7	5.1	74.0	30.0
NH_3	n.d.	2.0	2.0	3.2	1.7	n.d.	n.d.
HCO_3	n.d.	n.d.	n.d.	66	51	n.d.	n.d.
SO_4	215	134	240	29	24	1738	2057.0
Cl	11	86	97	56	97	12	11.0
B	0.02	0.7	3.8	0.0	4.5	20.0	0.3
SiO_2	13	15.3	17.9	15.3	16.5	135.0	180.0
H_2S	n.d.	1.6	0.3	0.4	0.8	n.d.	n.d.

Geothermal potential

The Dieng field is considered to have a heat flow from the surface thermal features in excess of 50 MW, making it one of the few fields in this category in Indonesia. Geothermal energy is being developed for electricity in the central and eastern parts of the complex. Data obtained from deep wells drilled in the Dieng field show variable temperatures (Tmax=369°C), with higher values occurring to the north. High temperatures at depth are consistent with above-boiling-point temperatures of thermal features. The presence of dacitic rocks at Pakuwadja suggests that there may exist a silicic magmatic heat source under the caldera. Temperature and pressure profiles in the wells are indicative of a liquid-dominated field with boiling conditions apparent at many locations. Estimates point to approximately 180 MW capacity for electricity generation.

Hindu temples

Indian culture and Hinduism had obtained firm footing in Java by about A.D 400. The Arjuna, a group of Shiva temples, is located in the east-central part of the Dieng Complex. These Hindu temples, built in the 8th and 9th centuries, are the oldest in Java. The name "Dieng" comes from "Di Hyang" which means Abode of the Gods. The plateau was once the site of over 400 temples. The five groups of temples are all dedicated to Shiva. The style of architecture is Dravidian and South Indian. Studies have suggested that the Dieng Art shows most agreement with South Indian Art, specifically from the square plan, symmetry, roof stages and stresses on horizontal lines.

Field stops

Stop 1 - Gardu Tieng viewpoint
View of Sumbing and Sundoro volcanoes and Pakuwaja cone in the Dieng area.

Stop 2 – Telaga Balekambang
Walk along the dry lake to see Hindu temples and the Pandansari location where several activity events occurred in the 1990s.

Stop 3 – Sikidang
Watch the active area of fumaroles and mud pools; geothermal installations.

Stop 4 – Telaga Warna
Observe the colored acid crater lake and nearby location of CO_2 gas discharge. Possibility for taking water samples.

Stop 5 – Sinila-Sigludug
Visit the area of the 1979 disaster, caused by emission of CO_2-rich gas. Observe the Sinila crater and CO_2 gas discharge location at Sigludug.

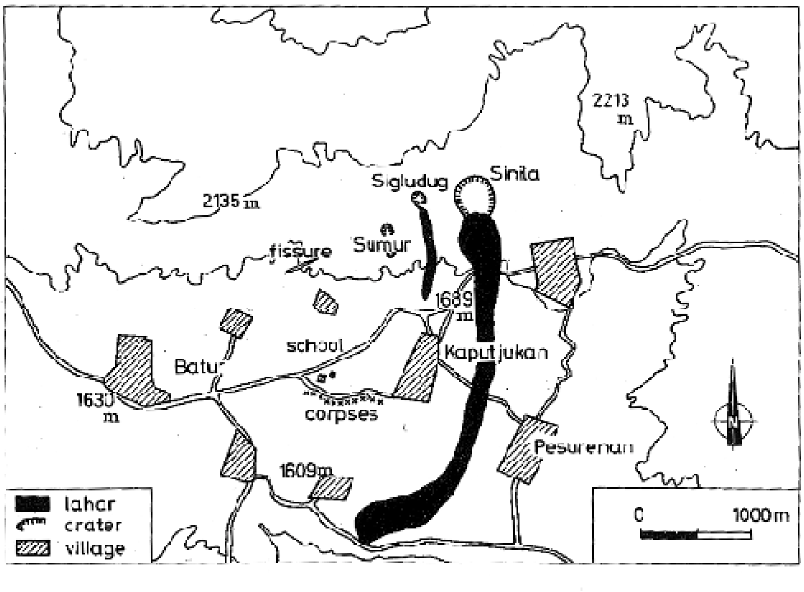


Figure 1.4
Map of the 1979 disaster area

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