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THE VOLCANOES OF INDONESIA AND NATURAL DISASTER REDUCTION (with some examples)

by
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ABSTRACT

Indonesian volcanism is related to the subduction (Benioff) zones of the Indo-Australian and the Pacific-Philippine plates at the contact with the Asian plate. Rows of volcanoes perpendicular to the plate movement point to steepening of the subduction zone with time. Strato volcanoes and also ignimbrite plateaus associated with socalled "volcano-tectonic" depressions of deep-seated faults are major features.

Fluvio-volcanic flows and slopes are common due to the humid tropical climate. Large volcanic landslides and debris flows causing rupture of crater or caldera rims and the collapse of slopes also are important volcanic geomorphological features.

The role of geomorphological survey and the use of aerospace technology in volcanic hazard zoning is emphasized.

GENERAL CHARACTERISTICS

Indonesian volcanism is related to the subduction zones of major tectonic plates and its origin and nature thus are similar to those of the Circum - Pacific volcanic belt. The Indo-Australian (Indian Ocean) plate is instrumental in Southern Indonesia (Sumatra, Java, Nusa Tenggara Islands) while the Pacific Ocean plate, inclusive the Philippine (sub) plate plays a comparable part in North eastern Indonesia. The N-S profile of Figure 1 illustrates the mechanism.

The actual intermediate (Andesito-Basaltic) volcanism (Verstappen, 1963, 1964) is not evenly distributed over the volcanic belts so formed. On Sumatra for instance only 9 active volcanoes occur that together caused 128 eruptions is historical times while on the much smaller island of Java 23 active volcanoes occur with 470 historical eruptions on record. In fact almost half (47%) of all historical eruptions has occured on Java, the most densely populated island of the country. One may say with

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justification that volcanic hazards and population density in Indonesia are incompatible.

Sumatra stretches at an angle with the direction of the plate movement and a dextral transcurrent fault, the Semangko zone hasdeveloped. This zone and the adjacent areas are the main scene of volcanic activity. Apart of strato volcanoes also ignimbrite plateaus, mostly linked to socalled "volcanotectonic" depressions, are important features. Lake Toba in northern Sumatra and Lake Ranau in the South are examples.

Java stretches perpendicularly to the plate movement and here tectonic compartmentation has occured as is evidenced by several deep-seated N-S faults (The Thousand Islands ridge of the coast of West Java; the fault cutting off the Kendeng and Rembang hills in Central Java). A broad E-W stretching depression is formed in most of the island and from it the strato volcanoes rise, with a somewhat regular spacing.

At places N-S stretching rows of volcanoes occur, the southernmost one usually being the (most) active one. This is most likely the result of a gradual steepening of the subduction zone that induces a southward displacement of the magma chambers. It may, at places also be related to the tectonic segmentation already mentioned: N-S faults occur in the top area of some strato volcanoes. It is not certain, however, that these faults reflect deep-seated segmentation faults.

The top area of the Arjuno-Welirang twin-volcano (Fig. 2, drawn from an air photo), is given as an example. Mt.Arjuno (3340 m.) forms the SSE end of an alignment of diversified volcanic features that ends in the NNW with the cone of the active Mt. Welirang (3156 m) strato volcano. In this case, no volcanic or post-volcanic activity occurs at the southern end of the fault governing the location of the volcanic features. One short parallel fault and 2 or more transverse faults can be recognized. The top area of the Arjuno strato volcano is situated on a narrow ridge separating two earlier horseshoe-shaped caldera relics. To the South of the Welirang the Old Welirang occurs and between two the main volcanoes the craters of Mt.Kembar I and II and a lava dome are dominant features. A range of other features, including smaller cones and crater pits, lava and lahar flows, etc. also can easily be traced.

Among the major volcanic landforms of Indonesia cones of strato volcanoes, calderas, and "volcano-tectonic" depressions with related ignimbrite/welded tuff plateaus rank high. Since, however, magnitude and frequency of volcanic eruptions are inversely correlated, the emphasis of volcanic disaster reductiones is on the average-intensity eruptions of some strato volcanoes and on the activity at smaller eruption point, including also gas emanations, that put large populations at risk.

The humid tropical climate of Indonesia has an important effect on the development of volcanic slopes. The upper slopes of strato volcanoes are usually dominated by the gravity force on the volcanic debris and slope angle thus approximates the maximal angle of repose. Below this zone of "dry" transportation and often separated from it by a fairly distinct knick point the middle slopes stretch. These have been formed primarily by rain-fed lahars and this "wet" transportation has led to gradients in the order of 8-12. This phenomenon is least developed in the drier areas of SE Indonesia. The lower, very gentle, slopes of the volcanos are of fluvial origin.

Summit or Somma calderas are common features and have been formed during Plinian eruptions of the past. If no shift in eruption centre occurred a nested crater may result but much more common is the collapse of part of the caldera/crater rim and the corresponding slope sector leading to the formation on of a horseshoe-shaped caldera. Also the large radial tectonic collapse barrancos known from several of the stratovolcanoes (Slamet) and calderas (Tengger) are noteworthy. Among the slope processes land slips affecting lava layers with the underlying ash deposits acting as sliding plane, rank high. Huge volcanic landslides resulting in labyrinths of hills and hummocks on the affected collapsed slopes also are on recora.

Large calderas resulting from major collapse following a paraxysmal Plinian eruption are common. In historical times the formation of the Tambora caldera on the island of Sumbawa (1815) destroyed an about 4000 m high strato volcano. 10,000 people died in the process while another 82,000 died the following months from starvation and disease even on the adjacent island of Lombok. The ill-famed Krakatoa eruption (1883) in Strait Sunda was of considerably smaller magnitude but killed nevertheless about 30,000 people mainly by tsunami waves. Most existing calderas protect the population around them from new volcanic activity indise. At places, however settlements occur on the caldera bottom.

The ignimbritic eruptions that centered in the socalled "volcano-tectonic" depressions and along the collapse zone of Strait Sunda are pre-historic. Fission track (Nishimura and Stauffer, 1981) and K-Ar dating (Debaveye et al, 1986) of Toba ashes deposited in Malaysia give a age of 75,000 B.P. and 30,000 B.P. for the youngest eruptions. Contrary to earlier views (v.Bemmelen, 1949) it is now generally agreed that the tectonic depression predates the eruptions although its subsequent development may be influenced by the eruptions activity. Verstappen (1961, 1973) observed two levels of warped lake terraces, related to these eruptions, in the eastern part of the Toba graben, The maximum uplift, to the South of the village of Prapat, is 150 and 350 m respectively. The average uplift rate there is thus about 5 mm/yr. The phenomenon is probably intermittent, however, and when unexplained changes of the lake level occur one should therefore be on the alert. Differential changes notably in the Sibulangit-Samosir area would point to renewed (volcano) tectonic activity. Subsidence near the outfall of the lake would result in an all-over fall of the lake level except near Porsea since the bench mark there would go down. The lake level lowering recorded in the 19 eighties do not seem to fit this picture and has been attributed to hydrological and some other causes.

VOLCANIC GEOMORPHOLOGICAL SURVEY AND AEROSPACE TECHNOLOGY

It is obvious that geomorphological survey is an essential prerequisite for studies on volcanic geomorphology and for subsequent volcanic hazard zoning and assessment of volcanic hazards (Verstappen, 1988, 1992). The sequence of volcanic deposition as well as the denudational history of the volcanoes have to be considered in this context. Aerial photographs are a usefull tool as is evident from the example of Figure 2.

Also data from satellites or manned orbiters and in the humid tropics notably radar imagery are important. Figure 3 gives a geomorphological interpretation of a Space Shuttle SIR-A radar image of part of the east coast of Sumbawa. The spatial situation and temporal relations of diversified volcanic landforms are indicated, emphasizing Holocene volcanism. Erosional as well as depositional and structural features are distinguished. Older volcanics are mapped as a separate unit. The map also gives a first view on the volcanic and fluviovolcanic processes that played part in the landscape genesis.

The products of a volcanic complex are usually of rather similar lithology even if they derive from different eruption points and periods. Establishing a lithostratigraphic sequence thus is difficult. The lack of marker horizons that could serve to establish chronological relations is a further complication. For these reasons it is essential to consider the geomorphologic situation and establish a morpho-stratigraphic sequence. When mapping the volcanic deposition emphasis should be on the genesis and causative processes of the products. The analysis of the volcanic denudation should aim at establishing the danudational chronology of the volcanic complex. An important element is the pre-existing relief since it governs to a large extent the distributional pattern of volcanic deposition and denudation. The chronological classification has a spatial (morpho arrangement) and a temporal (chronology) element. Both should be incorporated in the volcano-stratigraphic units that are defined primaliry on the basis of landform analysis. Situmorang (1986) has elaborated on this concept for Indonesia. He also developed a rating system, rooted in this approach, as to arrive at a better hazard zoning through quantification of the factors affecting the volcanic hazards.

GEOMORPHOLOGY AND VOLCANIC HAZARD MITIGATION IN INDONESIA

Volcanic hazard zoning is strongly related to geomorphologic mapping of active volcanoes and their surroundings. A dilemma always is how to incorporate the diversified hazard types in a limited number of hazard classes. The alternate solution, to make separate zoning maps for every hazard type lacks comprehensiveness and is not practised in Indonesia. Monitoring volcanic activity is largely outside the realm of geomorphology but a part in hazard reduction through structural means (check dams, sediment traps, etc) may be played by assessing the processes operating and the landforms involved.

One may, for instance, question on geomorphological grounds whether the checkdams and other structures erected in some lahar-prone ravines on the West slopes of the Merapi volcano, Central Java, are appropriate. They lead to a gradual rise of the beds of these ravines thus increasing the hazard for the nearby villages. Using a pyroclastic convexity higher up-slope for spreading out the Merapi products there and thus reducing the chances of them reacing the densely populated lower areas may be an alternate solution (Verstappen, 1988). It would require the step-by-step reduction of the incisions existing in the convexity.

The volcanic hazard zoning system applied in Indonesia is, generally speaking, well adapted to the strato volcanoes and the eruption types occurring. It comprises three multi-hazard classes:

The forbidden zone where nobody is supposed to live, is close to the eruption point and subjected to pyroclastic flows/nuees ardentes, primary lahars and tephra.

The first hazard zone where no settlements should be founded, are parts destroyed by previous eruptions; possibly subjected to pyroclastic flows while paroxisms may lead to bomb outfall.

The second hazard zone includes strips in or near valleys and ravines radiating from the top areas. The main hazard here is formed by lahar flows but also lava flows may occur. Because this zone stretches far downslope into often densely populated areas of high vulnerability the quantified risk in this zone of lowest degree of hazard is considerable at many volcanoes.

Assumptions made in the classification are (i) the eruptions occurs at the main active crater or craters of earlier activity, (ii) explosive eruptions are directed vertically upward, (iii) no collapse phenomena or caldera formation are included. Evidently a change in the morphological situation or a shift in activity centre requirst adaptation of the zoning.

An example is the shift in activity of the Merapi volcano, Java (Directorate, 1977) from the southern to the western side of the top area early this century: The lahars of the southern slopes are now inactive but still figure in the same category on the hazard zoning map as the active ones on the western slopes! The fact that they are more sandy and differ essentially from the coarse-textured lahars in the west also is not indicated. The western slopes of the Old Merapi have collapsed as a result of a pre-historic paroxysmal eruption and the subsequent pyroclastic flows and lahars originating from the New Merapi thus were directed to the West. (Berthommier, P.,1990). The southern slopes have been covered by ashes and thick fluvio-volcanic deposits some centuries ago when the Hindu-Javanese temples located there were buried. The collapse of eruption, previously thought to have caused the collapse of the Old Merapi (v. Bemmelen, 1949), occured between these two major eruption (period)s. The inherent geomorphological characteristics of the Merapi resulting from its eruption history affect the distribution of present volcanic hazards in the area.

Summarizing it can be said that the volcanic hazard zoning methodology applied in Indonesia is deeply rooted in the geomorphology (Neumann v.Padang, 1951; Kusumadinata, 1979) and is well adapted to the strato volcanoes occuring. The classification is less suitable, however, to eruption types such as gas emanations found e.g. in part of the Dieng Plateau in Central Java. One may also argue that, since emergency scenarios inevitably vary with the intensity and type of land utilization the compilation of vulnerability maps of the endangered areas merits consideration in the context of disaster reduction policy.

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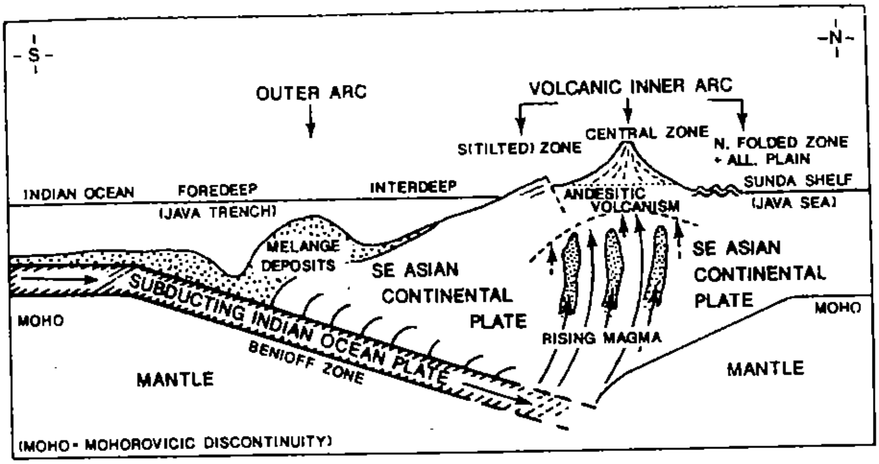

Figure 1.

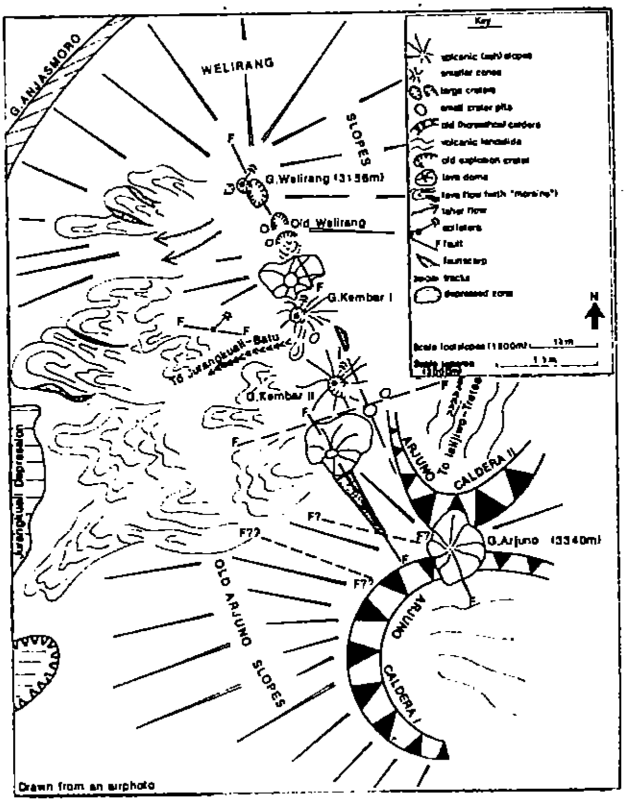

Figure 2. – The volcanic arjuno-welirang faultzone

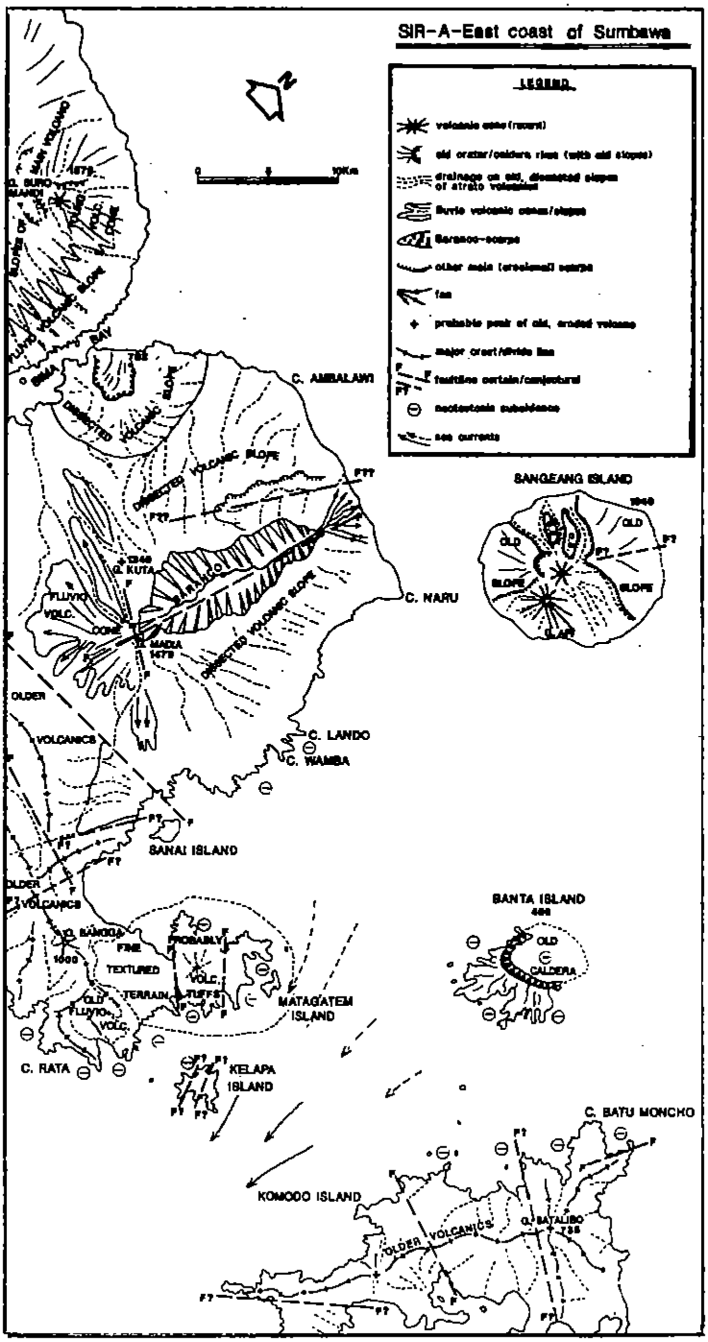
SIR-A-East coast of Sumbawa
SANGEANG ISLAND
C. AMBALAWI
C. NARU
C. LANDO
C. WAMBA
SANAI ISLAND
SANTA ISLAND
CALDERA
MATAGATEM ISLAND
KELAPA ISLAND
C. RATA
C. BATU MONCHO
KOMODO ISLAND
OLDER VOLCANICS
DISSECTED VOLCANIC SLOPE
FLUVIO VOLC. CONE
FINE TEXTURED TERRAIN
G. KUTA
G. SANGGA
G. BATALIBO

Figure 3.

Figure 4.