Donald, L., Wells, Kevin, J., Coppersmith, (1994), New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, Bulletin of the Seismological Survey of America, Vol. 84, pp.974-1002.

Donald, L., Wells, Kevin, J., Coppersmith, (1994), New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, Bulletin of the Seismological Survey of America, Vol. 84, pp.974-1002.

NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part 1: Provisions (FEMA 302), (1997), Building Seismic Safety Council for the Federal Emergency Management Agency, Washington, D.C.

Douglas, J., (2001), A Comprehensive Worldwide Summary of Strong-Motion Attenuation Relationship for Peak Ground Acceleration and Spectral Ordinates (1969 to 2000), Engineering Seismology and Earthquake Engineering Report No. 01-1, Imperial Collage of Science, Technology and Medicine, Civil Engineering Department, London

8-2 Volcano

8-2-1 Target Areas

The target area for the volcanic hazard study is an area of 1,300m^2 of the Telica-El Hoyo volcanic complex.

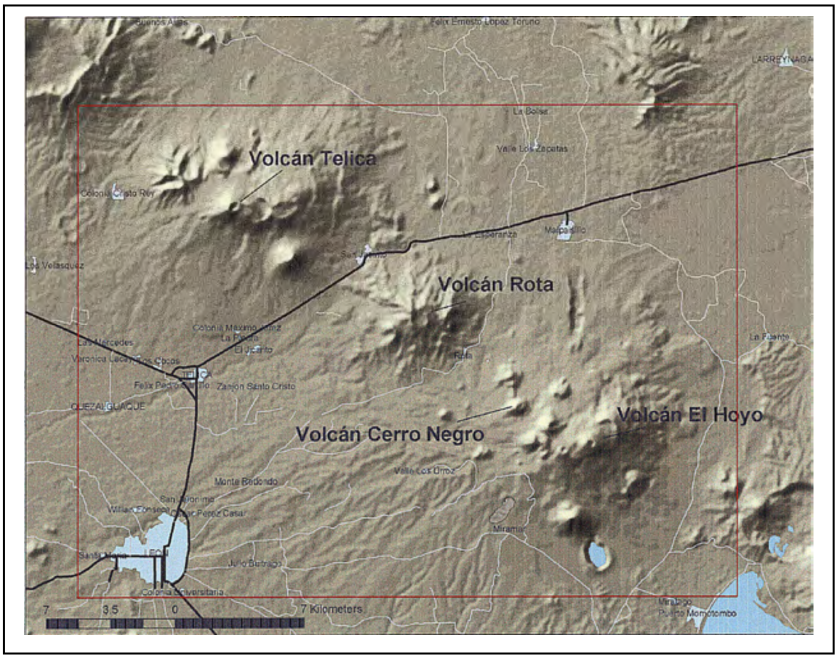


Figure 8-18 Guide Map of Volcanic Study Area

8-2-2 Target Phenomena

The target phenomena of volcanic hazard are: 1) lava flow; 2) pyroclastic flow; 3) bomb (ejecta); 4) tephra fall (ash fall); and 5) lahar.

8-2-3 Collection and Analyses of Existing Sources on Volcanic Geology

(1) Outline

Exiting research materials to examine volcanic hazards were collected from INETER, academic papers, and web sites. Fundamental reference materials that can be useful for volcanic hazard map preparation are listed as follows:

1) Martha Navarro (2002) Fichas de los Volcanes de Nicaragua, INETER

2) Martha Navarro (1994) Peligro Volcanico "Volcán Telica", INETER

3) Gardner, C. A., et al. (2004) Hazard Assessment for Volcán Telica, Nicaragua, USGS, Open File Report 2004-1046

4) Havlicek, P., et al.(2000) Estudio geológico y reconocimiento del la amenaza Geológica en el area de Leon, La Paz Centro y Malpaisillo, Nicaragua, Servicio Geológico Checo(CGU) en cooperacion con INETER

5) Brittain, E. H. et al.(1998) 1995 eruptions of Cerro Negro volcano, Nicaragua, and risk assessment for future eruptions., Geol. Sc. Am. Bull, v.110, no.10, p.1231-1241

(2) Analysis of Reference Materials

1) General

a. The stratigraphy of the stratum which constitutes a volcano object has not been established.

b. There is no data on dates. Therefore, there is no time-series data.

c. Availability of volcanic-activity data are limited in general in 1850 and afterwards.

d. There are almost no written data on each volcanic phenomenon (lithofacies, stratum).

e. There are no fundamental written data on each stratum.

f. Although there are hazard maps already available for certain volcano, INETER is not capable of processing all the procedure of preparation.

2) Lava flow

There is no fundamental written source materials on each lava flow. Reference 2) and 4) can be useful reference on distribution of lava flow. Although the numbers are limited, the total rock analysis values are published for Volcan Telica and Cerro Negro.

3) Pyroclastic flow

Many reference documents suggest that there are no historical data（e.g. Gardner, C. A., et al., 2004）. The basic reference 4) shows extensive distribution of the pyroclastic flow deposit, but detailed description is not available.

4) Bomb (ejecta)

There are no reference data for the bomb (ejecta).

5) Tephra fall (ash fall)

The basic reference 5) is useful for it describes and argues fine details and physical properties of the 1995 eruption in Cerro Negro.

Referenced for the existing distribution of tephra fall on eruptions in 1968, 1992, 1995 are available; however, there is no publication on detailed eruption source materials or a descent deposit.

6) Lahar

There is no data on lahar. Near the study area, there is a case of large-scale lahar caused by Hurricane Mitch in Volcán Casita in 1998, and comprehensive papers etc. were released from USGS and others.

7) Hazard Maps

Already the hazard maps were prepared: The maps are distributed to the regional Civil

Defense offices, and city governments; however, the structure of the contents are specialized for professionals. Generally, the volcanic hazard maps are printed onto an A0 size paper.

Volcán Concepción（Themes: pyroclastic flow, pyroclastic fall, lahar, collapse of volcanic edifice)
Volcán Masaya（Themes: volcanic bomb and ash fall by month)
Central - Northern Area Hazard Map of Nicaragua (Themes: lava flow, lahar, collapse of volcanic edifice, pyroclastic fall)

(3) Analysis of Basic Reference on Hazard Mapping

In order to obtain, basic reference for the tephra fall simulation, the total amount and particle size distribution of ejecta was examined. Also, the upper layer meteorological data at the Managua airport was obtained, examined and analyzed. The items of data analysis were: 1) trends and characteristics of the whole upper layer meteorology; 2) wind direction; 3) meteorological data in the altitude of 10,000 m or lower; and 4) wind direction statistical analysis at an altitude of 5,000 meters or lower.

8-2-4 Volcanic Aerial Photograph Interpretation

Geomorphologic interpretation in the volcanic areas was conducted using the color aerial photographs taken by the Study Team. The geomorphologic interpretation has two steps of process: 1) Volcanic geomorphologic interpretation (distribution and characteristics of middle to large scale landform that include vent, lava flow, pyroclastic cone, fractured system, large scale land collapse) and 2) Fine volcanic geomorphologic interpretation (lava flow geomorphologic feature, situation of sheer in volcanic body, classification and division of downstream of lahar.

Specific interpretation items are as follows:

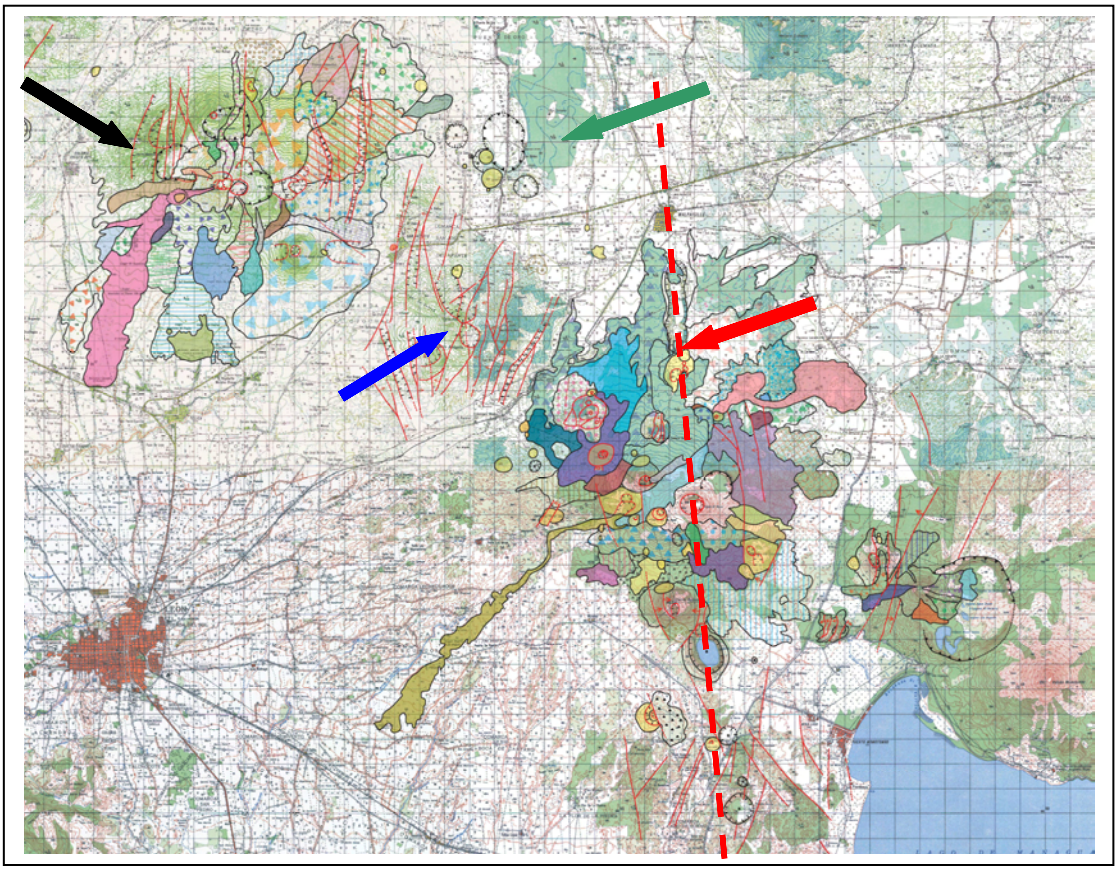
lava flow and its detailed distribution, pyroclastic cone, maar, crater, caldera, tuff ring, pyroclastic flow and its detailed distribution, lava dome, pressure dome or ridge;
land slide and its debris distribution, fan deposit area, lahar deposit area, flank erosion area and its form;
fault and its sense, estimated fault, lineation.

Figure 8-19 shows the results of the aerial photograph interpretation of the whole study area on the topographic maps of 1/50,000 scale. It is well understood from the map that the characteristic feature of the systems of fractures running from north to southward cross diagonally the northwest-southeast volcanic front. And also, it indicates that the large-scale fractured zone had been formed with the craters, maars, and so on generated in line with the Leon alignment (shown in the red arrow). It is the characteristic that basalt lavas of low viscosity blown out of the respective volcanoes of Telica and El Hoyo reached 10 km or longer downward, and at the summits of them, there are identified currently active craters besides the distribution of some calderas, which were considered to be formed during the old active stage. Moreover, such volcanoes with extensive erosion feature as Cerro De Aguero in the western part of Telica volcanic complex and Cerro Rota in the central partare considered to be a part of the pre-Telica-El Hoyo volcanic complex.

In Volcán Telica, in the northwestern side of the summit, volcanic mountains formed in the old age were located such as Cerro Los Portillos and Cerro De Agüro and others. In the southeastern side of the summit, Volcán Santa Clara is located. The Volcán Telica has divided three major geomorphologic units.

From near the summit of the Volcán Telica to south to southwestern hillside, lava flows are the major components. In the northern to eastern flank from the summit of the Volcán Telica, pyroclastic materials are recognized besides the lava flow. In Volcán El

Hoyo, it has been a distinct characteristic that there are traces of eruptions such as many cones are identified in large areas. From the summit to the northern area, there are various scales of lava flows of low viscosity. Since the condition of Cerro Negro become complex, the detailed lava flow is not included in the figure. The red arrow shows a part of Leon alignment which is a continuous tuff ring. The green arrow points to the areas of a type of geomorphologic characteristic, which was formed by flows of shield basalt. It is presumed that it was formed during a formation of the Pre El Hoyo Volcanic Complex.



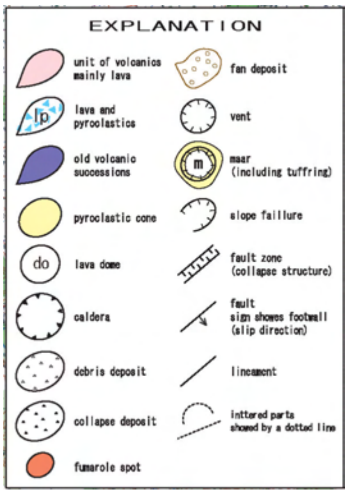


Figure 8-19 Aerial Photograph Interpretation in Telica-El Hoyo Volcanic Complex Area

8-2-5 Field Identification on Volcanic Geomorphology/Geology

Based on the results of the aerial photograph interpretation and the results from the existing reference analysis and organization, following field identification points were selected and the work was carried out.

1) Pyroclastic flow deposit

Since the occurrence possibility of and the affected area by pyroclastic flows has special importance in examining volcanic hazards, available documents were extensively examined. Because there was discrepancy in opinions in these documents whether a pyroclastic flow occurred, we decided to check the evidence of pyroclastic flow deposits in-situ.

According to the geologic survey by the Czech Republic, the non-classified pyroclastic flow deposit is to be widely distributed over the perimeter of the Telica volcanic complex. Moreover, it is illustrated that the pyroclastic flow deposit of the Volcán El Hoyo origin is widely distributed over the southern part in rgw El Hoyo volcanic complex. The following point became clear from the results of the field-identification.

The research by the Czech Republic had identified the pyroclastic flow deposit distributed over the Telica volcanic complex; however, in the locations, the Study Team only found the lava flow of the andesite or dacite not the pyroclastic flow deposit.

Although the pyroclastic flow deposit that the Czech Study Team identified at the Telica volcanic complex was questionable in its distribution location, the pyroclastic flow deposit was identified on site. The pyroclastic flow deposits identified to have origin in Volcán El Hoyo by the Czech Study Team were found to be originated in Monte Galán (cardela).

2) Lahar

The outflow situation and its quality to the lower stream of a river of a lahar were checked. Moreover, it investigated about the situation of the source of debris production in a volcano object slope face or an upper region. Since Hurricane Mitch, especially at the Telica volcanic complex, large-scale erosion has been progressing. The sediment discharge to the down-stream region caused by the erosion is a matter of concern.

and we are anxious about the sediment discharge to a down-stream region.

The following situations were checked in the field identification.

- The debris produced by erosion from the Telica volcanic complex are widely deposited on the foot of a mountain.
- The debris, which have been flowing out down-stream, are 1-2 mm or less in a mean diameter, and many make the suspended load, which consists of scoria, basalt rock fragment, etc. of the pyroclastic material origin. A selective grading analysis was conducted for confirmation of the diameters.
- The trace of the deposit, which flowed out by Hurricane Mitch, is seen along the river. The deposition thickness is about 10 cm-1.5m in general near two degrees of channel floor slopes at the foot of the mountain.

3) Lava Flow

While acquiring data mainly required for simulation, examination for confirmation on lithologic characteristics was conducted. In addition, for the reasons of hazard mapping, conditions of low-viscosity-lava flow in the southern slope of the Volcán El Hoyo and the northern part of the Volcán Rota were studied. As a result, distribution and quality of plateau basalt and shield basalt were confirmed.

4) Others

Unidentifiable matters on texture, structure, and volcanic rock distribution from aerial photograph interpretation were confirmed during the field identification.

Photo 8-1 Pyroclastic Flow Deposit

This was found in the southern area of the Volcán El Hoyo complex. It is widely distributed in the channel bed. The black deposit in the lower left is made of ash and scoria. In the center of the photo, a hammer with a length of 30 cm was placed as a reference.

The geomorphology/geology study is summarized and shown as a geology map in Figure 8-20.

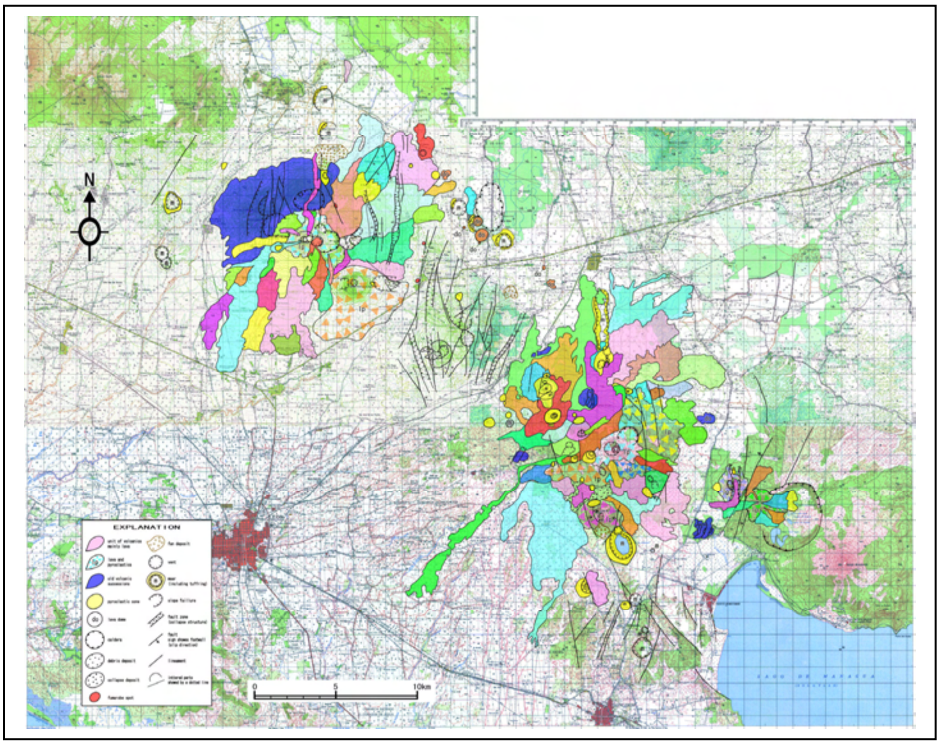


Figure 8-20 Geological Map of Telica – El Hoyo Volcanic Complex Area

8-2-6 Volcanic Hazard Simulation

(1) Specifications of Existing Simulation

The software for volcano simulation used in INETER is as follows:

- Lava flow, Pyroclastic flow: "Flow3D" model developed by the University of Buffalo;
- Ash fall: Volcanic bomb; model developed by UNAM;
- Lahar:: "LAHARZ" model developed by USGS.

The platform of the above software is UNIX, while the hardware and software resources in INETER are different from the platform. Therefore, INETER has not yet achieved self-sufficiency in management of all the process of work required for hazard mapping. Therefore, in the Study, the concepts of the simulation are not referred.

(2) Theoretical Foundation for Numerical Analysis

In order to conduct simulation on volcanic phenomena, following theoretical papers were referred.

1) Lava Flow

K. Ishihara, et al (1990) Numerical Simulation of Lava Flows on Some Volcanoes in Japan, J. H. Fink(Ed), Lava Flows and Domes, Springer－Verlag

The Bingham fluid flowing model describes lava flow in this paper.

2) Pyroclastic Flow

Energy cone model

Sheridan, M. F. (1979) Emplacement of pyroclastic flows: A review, Geol. Sc. Am. Special Paper 180, p.125-136

3) Bomb (ejecta)

M. Iguchi and K. Kamo(1984)On the range of block and lapilli ejected by the volcanic explosions, Annuals of Disaster Prevention Research Institute, Kyoto Univ., 27 B-1, p.15-27 (in Japanese)

Paper on the ballistic dispersal calculation with wind effect

4) Tephra fall (ash fall)

T. Suzuki (1983)A Theoretical Model for Dispersion of Tephra ,in D., Shimozuru and Yokoyam, I., ed. Arc Volcanism: Physics and tectonics: Tokyo, Terra Scientific Publishing Company,

5) Lahar

Software of the empirical model and digital cartographic technique, LAHARZ, described by Schilling, S.P. (1998) is used.

Schilling, S.P.(1998) LAHARZ: GIS programs for automated mapping of lahar-inundation hazard zones. U.S. Geological Survey Open-File Report 98-638, p.80.

Iverson, R. M., et al (1998) Objective delineation of lahar-inundation hazard zones. Geol. Soc. Am. Bull. v.110, no.8, p.972-984

(3) Development of Simulation Models

1) Lava Flow

Simulation is performed based on the open source program provided by Isihara and et al. (1990).

a. Physical properties of lava-flow assumes typical basalt based on the existing source material and field identification.
b. An effusive rate assumes a 100-200m3/s based on figures from cases of data from Kilauea volcano and others.
c. The maximum scale and distribution of a lava flow (total run-off) is adopted from the representative sample lava flows from Volcán Telica and Volcán El Hoyo each (See Figure 8-21). This representative lava flow performs the calibration on lava flow.
d. Eruption of lava is assumed from the possible vent distribution areas estimated by the results of aerial photograph interpretation and field identification.
e. The dimension of a calculation mesh is set to be 100m in consideration of the accuracy of existing 1 / 50,000 topographic maps.