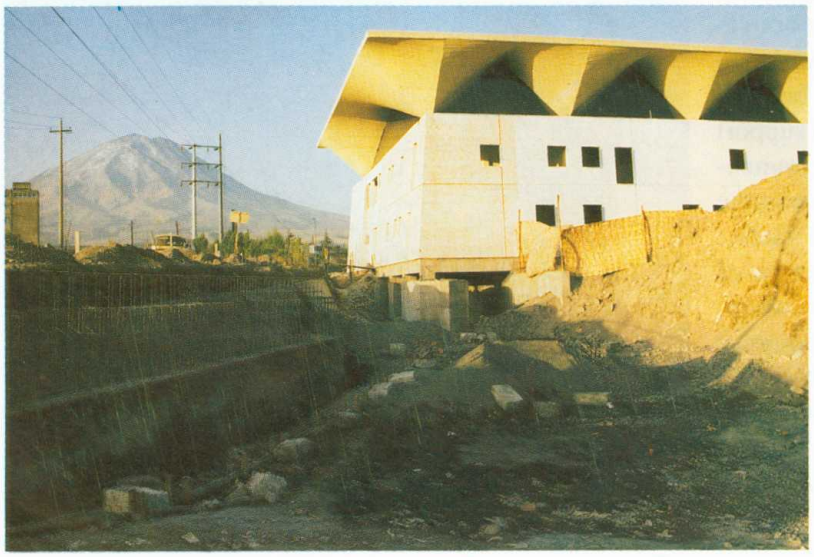
vectors as flies, mosquitoes and other insects.

On the gully hazard map shown here, it can be seen that the risk is high in areas where the gullies cross built-up areas. That effect is most evident in the Chillo gully. The risk is generally medium or low in built-up areas where the gully beds have not been encroached upon and in areas not yet occupied by man.

This is an unfortunate example of how human activity can have adverse impact on the environment, aggravating the effects of natural disasters.



AREQUIPA GROUND TERMINAL. THE COLUMNS OF ITS LATERAL FACADE ARE FIXED IN CONCRETE IN THE MIDST OF THE GULLY.

EL MISTI VOLCANO HAZARD

Arequipa is one of the Latin American cities growing at the base of an active volcano. In the process, it is drawing increasingly closer to the base of the cone, posing a serious threat to the people who live within range of an eruption or other extreme phenomenon.

The El Misti volcano, 5,822 metres above sea level, with its shapely cone, is the tutelary mountain of the White City, as Arequipa is also known; indeed, ashlar - or white volcanic tuff - is the most commonly used building material in the area. El Misti belongs to the volcanic chain of southern Peru and northern Chile, which is characterized by long periods of inactivity, lasting 500 to 1,000 years or more, followed by extremely violent eruptions.

The Spanish chroniclers recount how, in the early fifteenth century, during the reign of the Inca Yupanqui, when Arequipa was called Yarapampa, the populated centre was destroyed by the eruption of El Misti. "It threw up great bursts of flame which could be seen from the coast, with a terrible amount of noise and a powerful stench of sulphur, accompanied by earthquakes, an abundance of falling rocks and ashflow, as well as by extraordinary thunderclaps over a period of five days. Not one person or building was saved. The only survivors were the Indians who lived in the place called San Lázaro in the late sixteenth century, because they had gone to Cuzco to perform forced labour (mita del Inca)".

Minor eruptions of El Misti took place in May 1677, July 1784 and between July and October 1787.

Variable levels of fumarolic activity - mostly out of sight of the city -are still a feature of El Misti. The threat posed by the El Misti volcano to Arequipa was investigated by the Geology and Geophysics Department of the National University of San Agustíne, with the collaboration of professors and graduates and international advice provided by Dr. Minard Hall, an American vulcanologist based in Ecuador.

All the existing information on El Misti was reviewed. The ravines and watercourses which descend from the volcano to the city were the subject of geological reconstructions. Different stratigraphic columns were erected and their thicknesses and characteristics were determined by means of petrographic laboratory studies and the interpretation of geochemical data archives. The volcanic hazard was delineated in accordance with the findings of the studies and based on graphic scale plans of the area. Stereograms were prepared indicating the direction of winds at heights of 6,000 and 9,000 metres above sea-level.

The findings of the studies can be summed up as follows. **Lava flows**, because of their great viscosity, which is a common characteristic of the Andean volcanoes, have low velocity and a short range. **Phyroclastic flows** are high-temperature dry masses, dense at the bottom with turbulent ash clouds at the top. They are produced by the collapse of the vertical eruption column or by a lateral explosion, and constitute the most potentially dangerous phenomenon in proximity to the El Misti volcano. They can cause death by asphyxiation, fire, burial or impact. Although the studies must be verified, the preliminary findings suggest that the collapse of the column would cause pyroclastic flows to spread 21 kilometres on the southern side of the volcano, towards the city, and 16.5 kilometres on the northern side, in cases of high-energy flows; and 15 kilometres and 12 kilometres, respectively, in case of medium-energy flows. This poses a threat primarily to the north-eastern side of the city, including the ravines of San Lázaro and Agua Salada, which originate from the lowest part of the volcano's rim. Studies of the stratigraphic columns alongside San Lázaro in fact show that past events were responsible for the deposit of pyroclastic ma-

THE EL MISTI VOLCANO DURING RECENT FUMAROLIC ACTIVITY. INSERT THE CRATER OF THE VOLCANO. (PHOTOGRAPHS COURTESY OF DR. ALBERTO PARODI.)

terials in zones which are currently inhabited, such as Chilina, Independencia and Selva Alegre.

When these flows mix with water, they form mud flows or lahars which can descend through the ravines originating at the volcano and cover great distances. However, the threat of lahars is not great because the volume of snow on the volcanic peak is small during most of the year due to the aridity of the surrounding area.

A **debris avalanche** or a landslide composed of volcanic material is produced by a weakening of the volcanic structure or by eruptive explosion, seismic vibration or erosion of the base. The instability of the volcanic structure may have serious consequences for the city, considering that its water supply comes almost exclusively from the Chili river, which encircles the volcano. In addition, the Charcani hydroelectric plant, which provides electrical power to the city and southern Peru, is located on the Chili river at the base fo the volcano.

Pyroclastic falls comprising primarily ashes and fragments of pumice depend on the volume of emission and its characteristics, as well as on wind direction and velocity. Stereograms from the 1980s and data on winds at 9,000 and 6,000 metres above sea-level have been used to estimate the zones which would be affected by the fall of ashes in each season of the year.

Generally speaking, each volcanic eruption is different in terms of the characteristics and volume of the discharge of material, so that the findings are merely points of reference to make it possible to plan within given constraints. None the less, the city clearly cannot continue to expand towards the slopes of the volcano or to increase its population on the north-eastern side. Additionally, the gullies must be kept clear, especially the San Lázaro gully, so as not to block the path of the material which an eruption of El Misti could generate.

MICROZONATION OF AREQUIPA AND LAND-USE PLAN FOR DISASTER MITIGATION

The microzonation plan of Arequipa was obtained by collating the maps and harmonizing the results of the studies concerning expected seismic intensities, flood hazard from gullies and the El Misti volcanic hazard. This is a valuable document for the land-use plan, which will enable the city to expand towards the safest sectors, regarding both buildings and vital public services such as water, drainage, energy, transport and communications. Building costs can also be significantly reduced, since the high supporting capacity of the soil permits cost-saving on foundations. Moreover, by eliminating an increase in the seismic coefficient due to the soil factor, savings can also be achieved in the structure of buildings.

The city of Arequipa and its expansion zones have been divided into four sectors under the microzonation plan. High-hazard sector I is threatened by volcanic activity in the north-eastern triangle of the city, as well as by some of the watercourses descending from the volcano and their flood zones. Also included in this sector is a small area in the southern part of the city where high seismic intensity, liquefaction and land subsidence are expected.