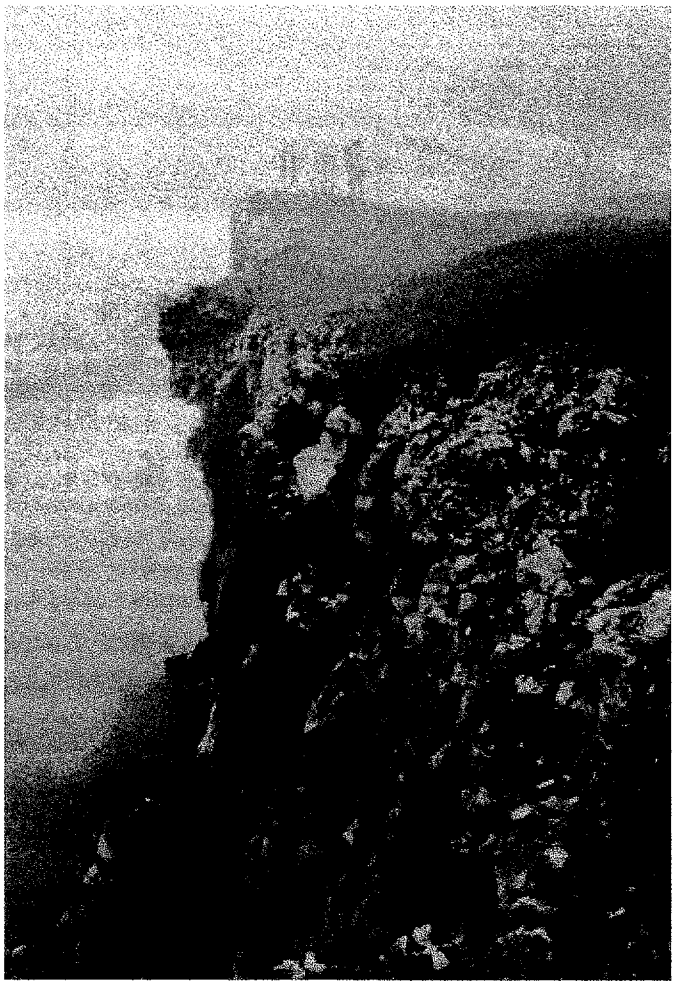
PN-ABZ-386

Natural Resource Management Project for Nicaragua

Assessment and Recommendations Regarding Geologic Hazards, Infrastructure Options, and Interpretive Resources at the Parque Nacional Volcàn Masaya in Nicaragua, Central America



Submitted to:
United States Agency for International Development, Nicaragua
Under Contract Number 524--314-C-4003-00

Submitted by:
Tropical Research and Development, Inc.
Gainesville, Florida, USA

September 1996

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PN-ABZ-386

Natural Resource Management Project for Nicaragua

ASSESSMENT AND RECOMMENDATIONS REGARDING GEOLOGIC HAZARDS, INFRASTRUCTURE OPTIONS, AND INTERPRETATIVE RESOURCES AT THE PARQUE NACIONAL VOLCAN MASAYA IN NICARAGUA, CENTRAL AMERICA

by

Deborah R. Jerez-Macpherson

Submitted to:
United States Agency for International Development, Nicaragua
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Submitted by:
Tropical Research and Development, Inc.
Gainesville, Florida, USA

November 1996

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Annex A: Glossary of Volcanic Terms Used in this Report
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EXECUTIVE SUMMARY

The information in this report addresses the concerns and information needs of the Parque Nacional Volcan Masaya (PNVM) management in the order of priority, from highest to lowest, identified in the contract scope of work and in the consultant's discussions with personnel of the PNVM and the Ministerio del Ambiente y Recursos Naturales (MARENA). The highest priority concern identified was the structural stability of the overlooks, caves, and other visitor attractions around Crater Santiago. Findings and recommendations related to that concern are addressed in Section 2.0. The second priority concern identified was a specific safety issue, namely, the effects of the volcanic gases on the health of park personnel and visitors. In the course of the site visit, however, the consultant identified a number of additional safety or security issues that should be considered and resolved by MARENA and PNVM management. Findings and recommendations related to those concerns or issues are addressed in Section 3.0. The third priority concern that the consultant was requested to assess was the adequacy and accuracy of geologic/vulcanologic exhibits and other interpretive resources at the park. Findings and recommendations related to that concern are addressed in Section 4.0 and summarized in the following paragraphs.

For public safety, the Overlook "Boca del Infierno" should be closed or public access severely restricted. The existing trail between the Overlook "Plaza de Oviedo" and Overlook "Boca del Infierno" should also be closed and pedestrian traffic routed to the paved roadway until a new trail can be constructed farther from the edge of Crater Santiago. Vehicular access as far as the Casa de los Murcielagos should be restricted to light vehicles or, preferably, closed to all vehicles and the roadway used for pedestrian traffic.

Personal protective equipment and equipment for emergency crowd control (such as whistles, bullhorns, hand lights, or colored flags) should be acquired and the park staff trained in their use. Medical monitoring of the respiratory health of the park staff should be initiated. Park staff should be informed of the health hazards of exposure to volcanic gases and should contribute to the development of plans to mitigate the adverse health effects.

The buildings, roadways, and other infrastructure at the park are seriously degraded due to lack of maintenance. A professional evaluation and plan should be developed for the immediate and long-term maintenance of the park investments. Adequate funds from the park's annual budget or generated revenues should be allocated to implement the plan. The reliability of the park's sanitary services should be improved and adequate sanitary supplies should be available for public use at all times.

The park should develop the staff and material capability to make needed modifications or improvements to the wayside and Visitors Center exhibits. Alternatively, the park should contract

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with a public or private service agency that can produce signs and/or exhibit panels that meet park specifications at a reasonable cost.

A prioritized plan for replacement or completion of the wayside and Visitors Center exhibits should be developed. The plan should include specifications, sketches, cost estimates for all elements of the work, and projected costs of long-term maintenance. In addition to providing the PNVM and MARENA management with a basis for budgeting and scheduling the work, the exhibit plan can be used to solicit appropriate international sources for funds to accomplish portions of the proposed work.

ACKNOWLEDGEMENTS

The author would like to express her appreciation to all of the people and groups who provided information, documents, and opinions that were essential to the successful completion of this report.

The author would like to thank the United States Agency for International Development (USAID) for providing support funds to carry out this work and to Mr. Gerald Bauer, in particular, for his assistance in getting things started.

A special thank you is extended to the Nicaragua Ministry of Environment and Natural Resources (MARENA) for providing support and professional collaboration, including the following individuals: Dr. Claudio Gutierrez (Minister), Lic. Nydia Cuarezma de Gutierrez (Park Director), Lic. Marvin Centeno, Lic. Maritza Rivera, Lic. Guillermo Saborio, Lic. Javier Gaitan, and the park guards, interpretative specialists and drivers.

The author would also like to extend a special thank you to Dr. Jaime Incer for information on the early history of the development of the PNVM and to representatives of the Instituto Nicaraguënse de Estudios Territoriales (INETER) who provided important information on the level of activity at Volcan Masaya: Ing. Cesar Aviles (Director, INETER), Ing. Marta Navarro (INETER), and Ing. Luis Muñoz (INETER).

The author appreciates the logistical support and coordination provided by TR&D staff members, including: Bonnie Larson, Joni Todd, Nina Horochowski, Byron Walsh, and the administrative staff.

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ACRONYMS

INE	Instituto Nicaraguense de Energia
INETER	Instituto Nicaraguense de Estudios Territoriales
IRENA	Instituto Nicaraguense de Recursos Naturales y del Ambiente (now MARENA)
MARENA	Ministerio del Ambiente y Recursos Naturales
OBE	Overlook "Balcon del Eco"
OBI	Overlook "Boca del Infierno"
OCB	Overlook "Cruz de Bobadilla"
OPO	Overlook "Plaza de Oviedo"
PNVM	Parque Nacional Volcan Masaya
TR&D	Tropical Research and Development, Inc.
USAID	United States Agency for International Development

1.0 INTRODUCTION

1.1 Purpose and Scope

This report provides a current assessment of the immediate geologic hazards at the principal sites of tourist interest around the Crater Santiago at Volcán Masaya, Nicaragua. A secondary purpose of the report is to review the existing geologic and volcanologic interpretive resources at the Parque Nacional Volcán Masaya (PNVM) and to provide recommendations on updating or enhancing the exhibits and other resources supporting that portion of the park's environmental education program. The geologic hazards assessment and other recommendations contained in this report are intended for use by the management of the PNVM to support decisions on investment priorities and operational changes that could be implemented immediately and over the next several years to ensure the safety of visitors and staff, protect existing investments, and upgrade the infrastructure and interpretive resources to better accomplish the Parque Nacional Volcán Masaya mission.

To address this need, the consultant visited Nicaragua between July 20 and 26, 1996. During that period, the consultant:

- Conducted an onsite reconnaissance of the geologic features and/or the existing infrastructure in the vicinity of the Crater Santiago, along the Camino Real del Popogatepe, and at the Visitors Center;

- Evaluated the exhibits, plaques, signage, and pamphlets interpreting the geology and volcanology of the park at the Visitors Center, in the vicinity of the Crater Santiago, along the Camino Real del Popogatepe, or distributed at the PNVM entrance;

- Made a preliminary assessment of documents and other material archived at the Ministerio del Ambiente y Recursos Naturales (MARENA) and PNVM offices to obtain information on the exhibit plans for the park and to assess the completeness of existing files of scientific literature related to the geology of Volcán Masaya;

- Met with MARENA and PNVM staff to gather information and confirm the priorities of their safety concerns and operational issues;

- Met with Instituto Nicaraguense de Estudios Territoriales (INETER) and MARENA staff to gather information on the INETER volcanic monitoring program and to identify possible areas and mechanisms for coordination of sampling and observational activities; and

- Presented a brief summary and facilitated a discussion of the preliminary findings and recommendations developed under this contract to representatives of MARENA, INETER, and the PNVM.

In addition to activities in country, the consultant spent 4 days in the United States researching currently available scientific and environmental education materials applicable to PNVM programs and obtaining specifications and descriptions of materials and techniques that could be used to improve the infrastructure and exhibits to meet the special needs or conditions within the park.

The Scope of Work (SOW) for this contract specifies that the final report will address the consultant's findings regarding the following seven specific issues or tasks:

- Assess the current geological stability, construction safety and risk potential of Overlooks 1 and 2, their respective parking areas, the Cruz de Bobadilla, and the Balcon del Eco. If necessary, recommend appropriate geologic studies needed to support a determination of the short-term (10 to 15 years) stability of the features listed previously.

- Consider specific needs identified by park representatives, review and verify the appropriateness of site designs and locations selected by PNVM management from options prepared by the TR&D landscape architect. Provide alternative recommendations and suggestions, as appropriate.

- Evaluate and compare available building materials and alternative specialized materials that could be used for construction, considering the corrosive nature of the volcanic gases and other unique conditions within the park.

- Recommend measures for worker protection against prolonged exposure to volcanic gases.

- Evaluate the potential for structural collapse and associated risks to visitor safety within the lava cave complex (Tzinanconostoc).

- Review existing interpretive materials and identify outdated information and/or important educational themes and information that could be included in wayside or museum exhibits and interpretive talks.

- Identify or update a site-specific bibliography of existing geologic/volcanologic (and other) information relevant to the PNVM.

On July 22, 1996, at the MARENA/TR&D offices, the consultant met with the Project Team to review the SOW and present a proposed outline for the final report. The Project Team affirmed

their understanding of the SOW for the contract and approved the proposed outline for the final report.

1.2 Background

Geologic hazards near active volcanoes have been the subject of folklore and study since before Pliny the Younger recorded his eye-witness account of the violent and tragic destruction of Pompeii by the 79 A.D. eruption of Mt. Vesuvius. Despite (or perhaps *because* of) the dangers, man's curiosity and awe at the powerful geologic forces working beneath the Earth's surface continue to draw tourists and scientists alike to the summit areas of volcanoes throughout the world. Few of these volcanoes compare with Volcán Masaya for accessibility to a breathtaking display of the natural forces, volcanic structures, and the erupted materials that give volcanic landscapes their unique characteristics. The PNVM was created in the late 1970s to protect this unique Nicaraguan resource and to facilitate its exploitation for tourism and environmental education.

The PNVM was developed under the auspices of the Banco Central de Nicaragua and in collaboration with the Facultad de Ecologia of the Universidad Centroamericano, the Instituto Geografico Nacional, and CATASTRO. Although the initial planning for the park recognized the inherent dangers of opening the summit area to public access, designs for infrastructure near the Crater Santiago were thought to be adequate to provide for visitor safety. The designs were completed, however, without the benefit of data from a systematic program of volcanic monitoring and geodetic measurements that could provide a baseline on the comportment of the volcano and the stability of the geologic features in the crater area.

The *Plan Maestro para el Establecimiento y Manejo del Area del Volcán Masaya como Parque Nacional*, published in 1975, called for two principal overlooks at the summit area. The larger overlook, called the "Plaza de Oviedo," was sited on the northern rim of the Crater Santiago, while a smaller overlook, called the "Boca del Infierno," was sited at the southwestern rim of the crater. Both overlooks were developed to include a paved parking area and a safety wall of rock and thick, zinc-coated iron chain set between reinforced concrete posts firmly anchored into the underlying material. At a point about midway along its length, the safety wall at each overlook incorporated a natural stone-covered tabular exhibit area to display an interpretive plaque that was to serve as a focal point of visitor interest.

The PNVM now has accumulated nearly 20 years of operational experience, including observations on visitor use patterns, results of wildlife and forest management policies, the geologic stability of the natural features, and the effects of environmental conditions on the structural integrity and aesthetic quality of infrastructure and interpretive exhibits. The greater accessibility afforded by the roads and trails has led to increased scientific study within the park by national and international researchers. The result is a better understanding of the geologic hazards and risks to visitors, staff, and the communities surrounding the PNVM.

At the 20-year mark, it is appropriate that MARENA has requested technical and financial assistance to conduct a critical review of the PNVM mission and its operational capabilities, limitations, successes, and failures. The subject of this report, an assessment of geologic hazards, interpretive resources, and options to enhance human safety and protect investments at the PNVM, is part of the larger review. The larger review is being conducted at the request of the Minister of MARENA, in collaboration with MARENA and PNVM staff, and with funding provided by the U.S. Agency for International Development (USAID) through a contract with Tropical Research and Development, Inc. (TR&D). Upon approval, a copy of this final report will be submitted by TR&D to the MARENA and PNVM management. In addition, the findings of the consultant will be incorporated, as appropriate, into a report on the overall PNVM review and recommendations by TR&D in completion of their contract with USAID.

1.3 Organization of the Report

The information in this report addresses the concerns and information needs of the PNVM management in the order of priority, from highest to lowest, identified in the contract scope of work and in the consultant's discussions with personnel of the PNVM and MARENA. The highest priority concern identified was the structural stability of the overlooks, caves, and other visitor attractions around Crater Santiago. Findings and recommendations related to that concern are addressed in Section 2.0. The second priority concern identified was a specific safety issue, namely, the effects of the volcanic gases on the health of park personnel and visitors. In the course of the site visit, however, the consultant identified a number of additional safety or security issues that should be considered and resolved by MARENA and PNVM management. Findings and recommendations related to those concerns or issues are addressed in Section 3.0. The third priority concern that the consultant was requested to assess was the adequacy and accuracy of geologic/vulcanologic exhibits and other interpretive resources at the park. Findings and recommendations related to that concern are addressed in Section 4.0 and summarized in the following paragraphs. A summary of the findings and recommendations made by the consultant is presented in Section 5.0, and a list of the references used in preparing this report is contained in Section 6.0.

The discussions of geologic processes and products in this report are intended to assist the PNVM management and future geoengineering or other consultants in understanding the volcanic issues that are relevant to the stability and safety of PNVM infrastructure. A glossary is provided in Annex A to define the technical terms used in this report.

1.4 Caveat Regarding Infrastructure Design and Construction Information in this Report

The description of the existing PNVM infrastructure contained in this report is drawn from the consultant's observations during her July 1996 visits to the park and her recollections of the designs and construction methods implemented during her work at the park between 1977 and 1982. No design plans or specifications for the major infrastructure installations were found to

exist in the archives of the TR&D, the PNVM, or MARENA. Those plans and specifications had been available in the archives of the Banco Central de Nicaragua in about 1980 but apparently were lost during or after the transfer of the PNVM program from the Banco Central to MARENA (formerly IRENA).

An additional recommendation is that an attempt be made to recover the original plans and specifications from the construction company that performed most of the work (Pedro Vargas, S.A.). Alternatively, some information on the plans and specifications may be recoverable through interviews with persons who witnessed or contributed to the construction effort. Those persons include Dr. Jaime Incer, Ing. Franco Peñalba, Ing. Pedro Cuadra, Ing. Enrique Cedeno, and Ing. Bosco Ordonez.

2.0 ASSESSMENT OF GEOLOGIC HAZARDS AND INFRASTRUCTURE OPTIONS IN THE CRATER AREA

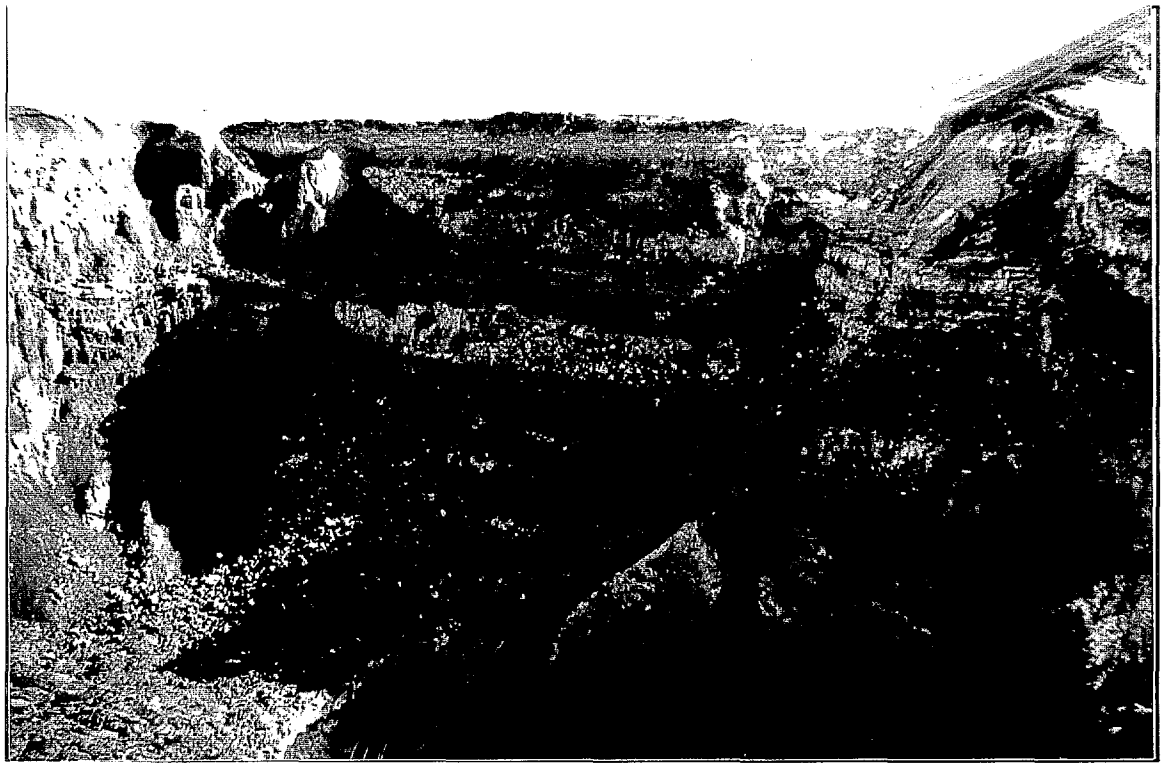
2.1 Overview of the Geologic Structures and Volcanic Materials in the Crater Area

The geologic stability of the principal tourist sites of interest around Crater Santiago is dependent on the characteristics of the underlying or surrounding volcanic materials and any dynamic processes acting on those materials. The volcanic materials found in the area are sometimes compact and coherent, as in the case of thick lava flows, or disaggregated and easily erodible, as in the case of airfall ash beds or incompletely welded pyroclastic flow breccias. The significant dynamic processes that are particular to the environment at Volcán Masaya include active faulting; fracturing that accompanied cooling of eruptives or subsequent inflation and deflation of the volcanic edifice; failures along fractures resulting in mass movements such as rockfalls and landslides; and corrosion and decomposition of materials by volcanic gases and fumaroles.

Because the characteristics and condition of the materials are critical to their stability, this section includes a description of the units exposed in the vertical walls around Crater Santiago and the potentially active geologic structures that cut those units. The description starts at the south wall of Crater Santiago and moves generally clockwise around the circumference of the crater. Many of the materials described throughout this report were assigned specific unit designations in an unpublished doctoral thesis on the Masaya caldera complex, completed by S. Williams of Dartmouth College in 1983. When possible, the text descriptions and photographs that accompany this report have referenced Williams' unit designations, to assist PNVM ecologists and environmental education professionals in using and understanding Dr. Williams' important study of the evolution of Masaya caldera. A copy of the Williams thesis was obtained from M. Navarro of INETER and now resides in the PNVM/MARENA archives.

The section of volcanic materials exposed in the south wall of Crater Santiago (Photographs 1 and 2) consists of the products of an early stage in the evolution of the present Nindiri and Masaya volcanoes. These materials include massive[1] black and red scorias from a series of cinder cones, and thin layers of lava, scoria and ash that filled a small crater that existed south of the present Crater Santiago. Together these units are designated Qv8. Later deposits consisting of thick layers of black lapilli and massive lava flows from Volcán Masaya buried these earliest products. The Qv8 deposits appear chaotic relative to the more orderly stacks of uninterrupted lava flows found elsewhere around Crater Santiago. The chaotic nature of the south wall deposits is partially due to the larger percentage of tephras (spatter from cinder cones and airfall lapilli

[1] Used in this context, massive indicates that the materials occur in thick beds with little or no internal stratification. Massive beds are usually characteristic of rapid deposition and high-energy conditions that do not permit time for natural sorting to occur.



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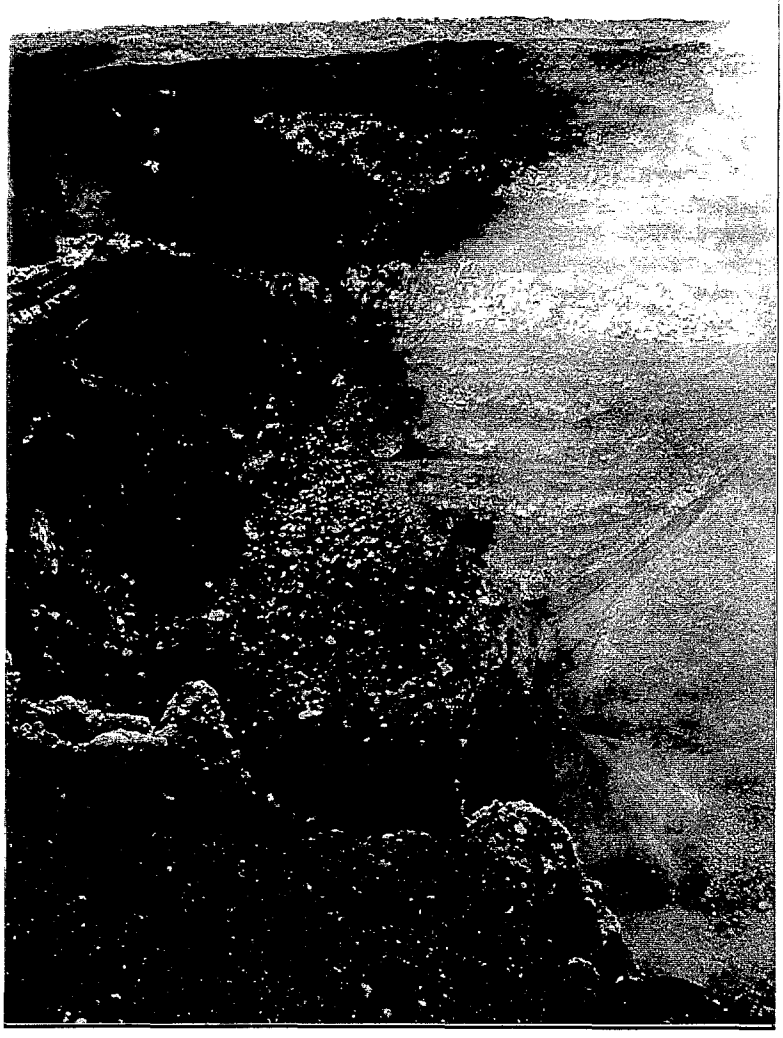
Photograph 1
Wide view of south and southeastern walls of Crater Santiago showing early cinder cone (part of unit Qv8 - see Section 2.1 of text for explanation) on left side of photograph, and thin lava flows overlying ash and massive scorias attributed to Volcan Nindiri (unit Qv20) on right side of photograph. QV20 is disrupted by faults and the lower ash and scoria beds appear to be hydrothermally altered. A small crater formed between unit Qv20 and the cinder cone of unit Qv8 . The crater filled with thin beds of ash, scoria and lavas (also designated as unit Qv8) before being buried by two thick lava flows and lapilli deposits from Volcan Masaya (unit Qv9). Much later, a lava flow (unit Ql25) from Volcan Nindiri covered the western portion of the sequence.



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Photograph 2
Southeastern wall of Crater Santiago, with detailed view of deposits designated Qv8, including red and black scoria from early cinder cone(s?) and thin layers of lava, scoria and ash that filled the small crater to the west. Note the grey and buff stratified ash that was first deposited over the wall and floor of the crater. Massive lava at the middle of the section may have issued from the cinder cone. The lava has been attributed to Masaya Volcano (as part of unit Qv9). The flow is traceable around the eastern and northern walls of Crater Santiago.

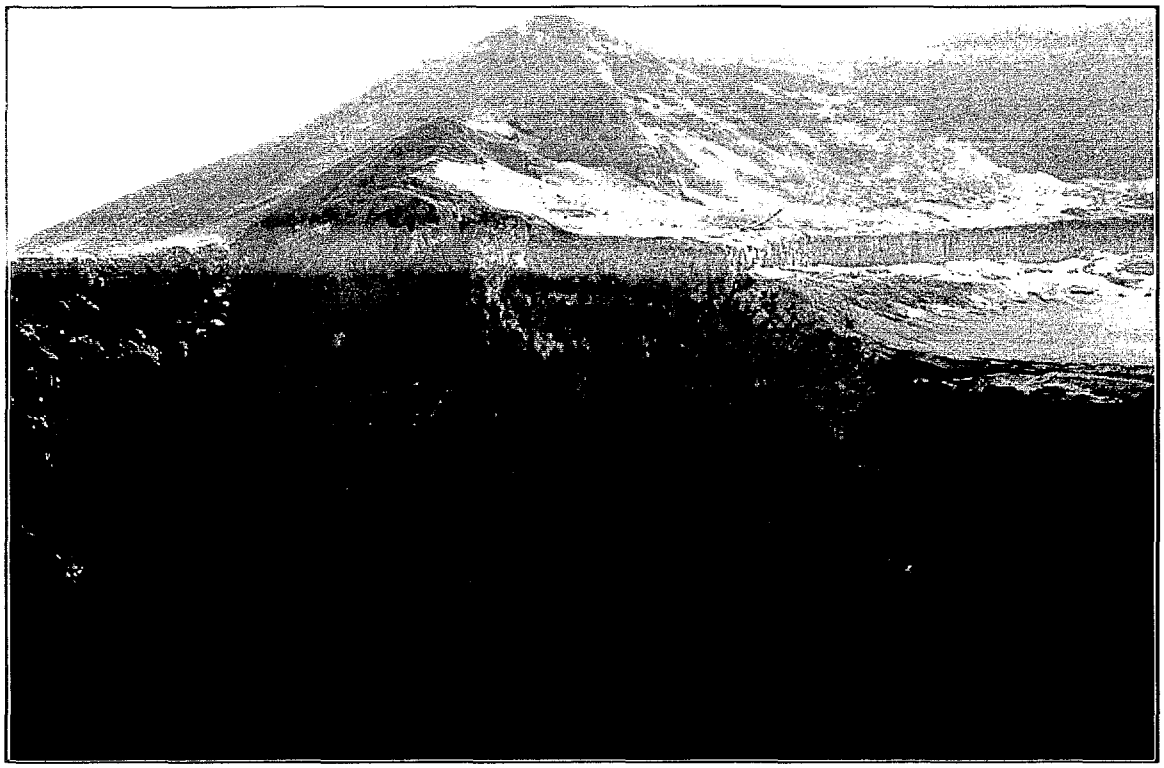
from fire fountains that accumulated downwind of the principal volcanic vents). But the appearance is made more complex as a result of numerous irregular rockfalls that have occurred from the face of the south wall and by disruption of some of the units along one or more vertical fault planes that cut diagonally across the Crater Santiago from southeast to northwest.

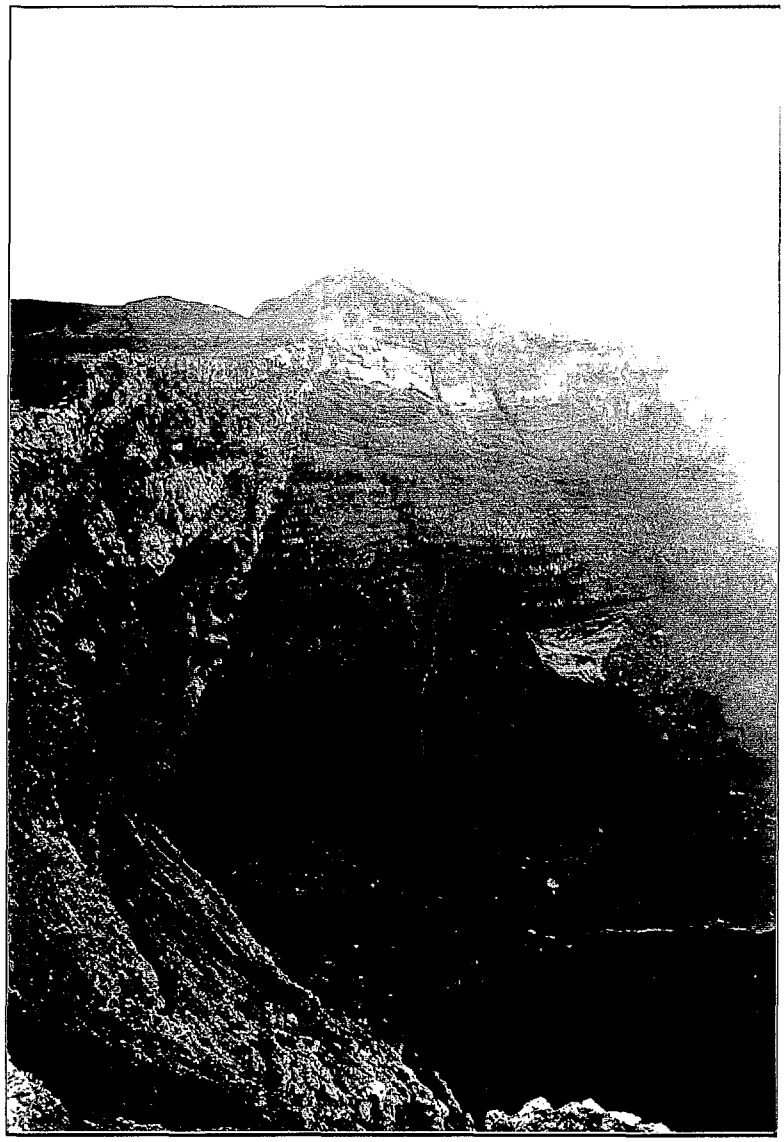
Immediately west of the units described previously, the Crater Santiago exposes a high-standing section of the rim of Volcán Nindiri (Photograph 3). At the top of the section is a thick sequence of bedded tephras. All of the tephras of the southeast rim of Nindiri that can be seen from the OBI are grey, graded beds of coarse to fine airfall ash. These units have been designated Qv23. Below the ash beds is an older sequence of tephras overlying thin red-oxidized lava and scoria layers. These, in turn, overlie a massive red scoria at the base of the wall. These older units have been designated Qv20. The east side of the Qv20 unit is multiply fractured and downfaulted, forming the west wall of a small crater that lies between the old rim of Nindiri and the scoria cones of unit Qv8.

A sequence of units similar to those just described is exposed in the northwest wall of Crater Santiago, beneath the Overlook "Cruz de Bobadilla," the highest-standing point on the crater rim (Photograph 4). At this location the stratified airfall units are cut by a series of fault or fracture lineaments that appear to define near vertical planes that dip to the northeast. The irregular bedding of the airfall units (shown as unit Qv20 on the Williams (1983) map) makes it difficult to assess whether displacement has occurred along these structural planes. Whether the lineaments represent fractures or faults, however, the planes serve as zones of weakness that undermine the structural stability of the pyroclastic tephra layers beneath the cross.

Between the two relatively high-standing sections at the northwest and southwest rim of the Crater Santiago, the western wall of Crater Santiago exposes the lava flows that filled the Crater Nindiri and produced the flat surface of the "Plaza Sapper" (Photograph 5). The flows are more massive than most of those from Volcán Masaya that are exposed in the eastern wall of Crater Santiago. The uppermost lava layer underlying the "Plaza Sapper" was produced in 1670. The lava from that eruption overflowed the northern rim of Crater Nindiri and continued down the northern flank of the volcano. Since that time the central portion of the solidified lava lake has subsided at least 20 meters below its former level.

Most of the north wall and all of the east wall of Crater Santiago expose a thick stack of lava flows with only thin layers of flow rubble and virtually no airfall tephras separating the flow units (Photograph 6). The lavas probably erupted from one of the ancient vents of Volcán Masaya to the east. A layer of black lapilli nearly 20 meters thick overlies the lava flows. Together the entire sequence is designated Qv9. The distinctive black lapilli shows little or no grading, only minor bedding structure, and contains occasional boulder-sized angular ejecta blocks of dense lava. The black lapilli layer represents the near-vent product of fire fountains that accompanied the eruption of a large volume lava flow relatively early in the evolution of Volcán Masaya. The lapilli layer thins to the north and south around the rim of Crater Santiago. On the north, near the Overlook





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Photograph 3
Southeastern rim of Crater Nindiri truncated by Crater Santiago's collapse, exposing upper section of ash (unit Qv24) overlying relatively thin lava flows (Qv20). Later massive lava flows (unit Ql27) filled Crater Nindiri and finally, in 1670, overflowed the northern rim, traveling down the flank halfway to the margin of the caldera (located just south of the Carretera Managua-Masaya).

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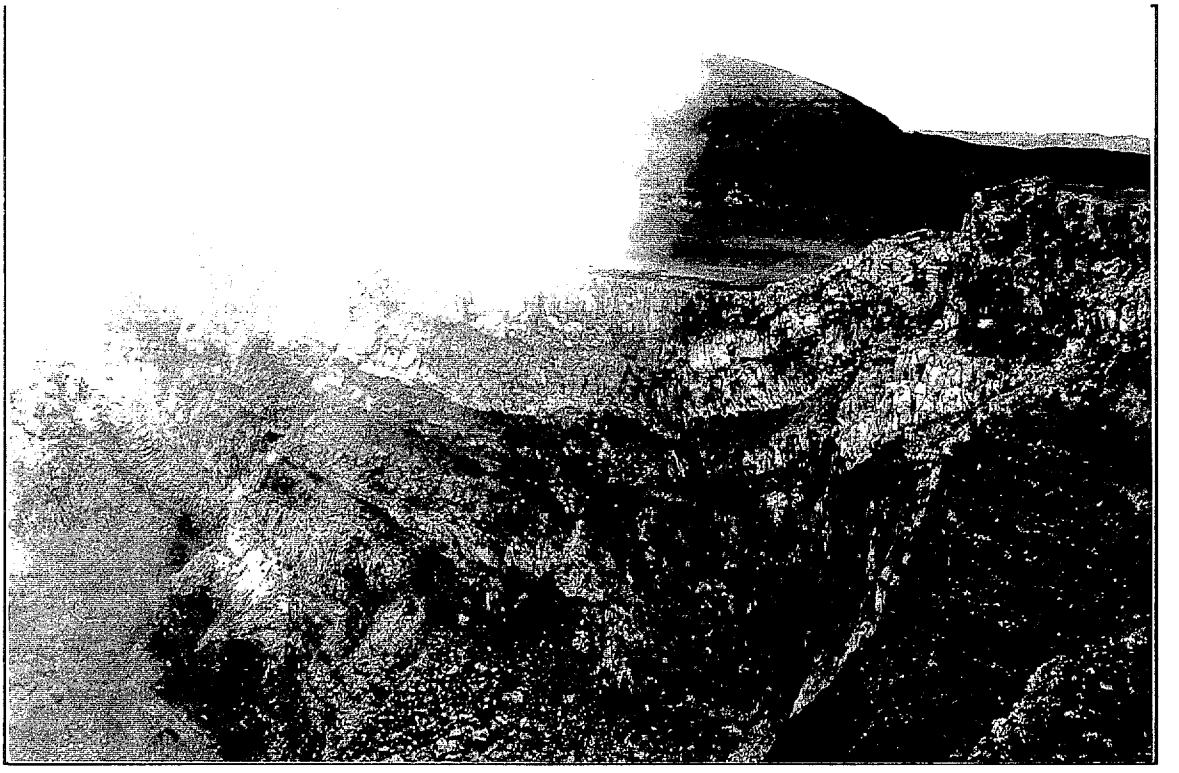
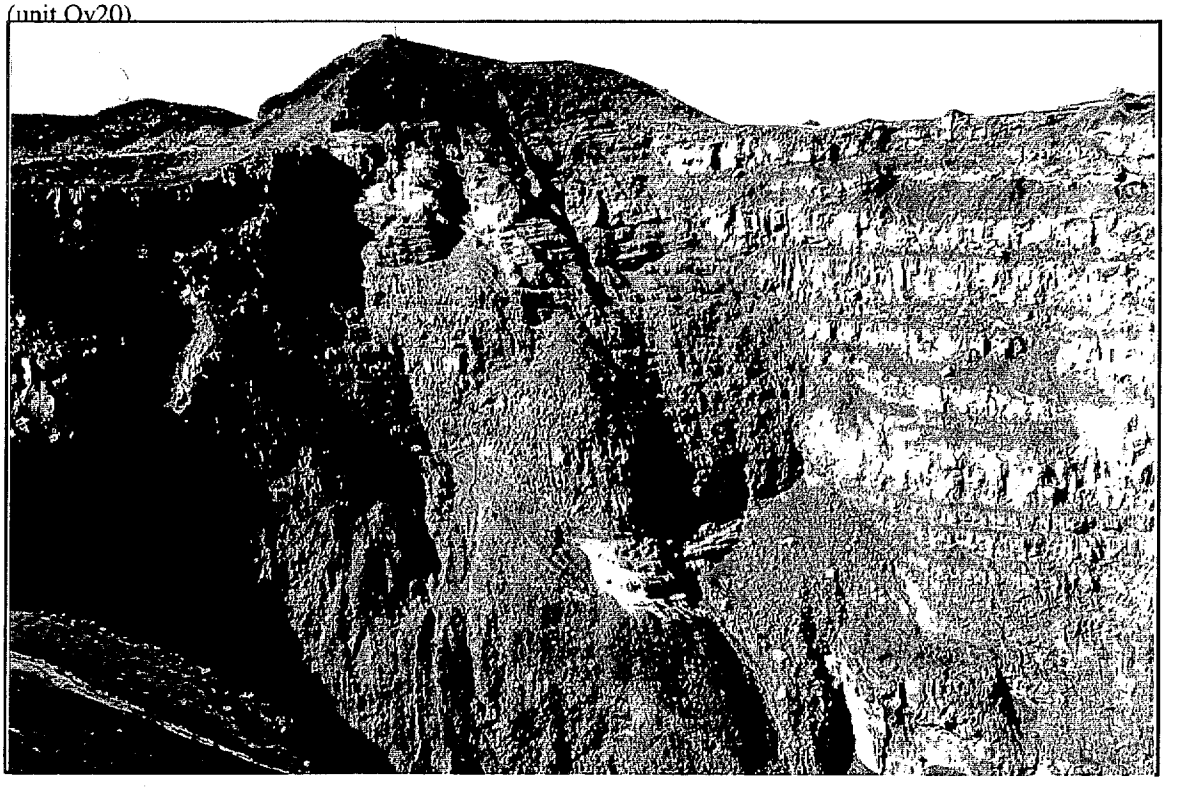
Photograph 4
Northeastern rim of Crater Nindiri, exposing a section more than 30 meter thick of alternating grey and buff bedded ash overlying thin lava flows and massive red scoria attributed to Volcan Nindiri (Qv20). Some of the ash beds appear to show cross-bedding but most appear to be stratified airfall deposits. Central buff-colored layers are due to palagonitic alteration of basaltic glass fragments in the ash. Note the apparent trace of NW-dipping faulting or fracturing that disrupts materials in crater wall. Thin, light-colored dike cuts the massive red scoria at the base of the section but may not continue into lavas.



Photograph 5 ▲

West wall of Crater Santiago, exposing lavas (unit Ql27) that filled Crater Nindiri. The central area of Crater Nindiri, known as Plaza Sapper, partially collapsed in 1852 when Santiago and San Pedro craters formed. The lower walls and floor of Crater Nindiri consist of thin lava flows and a massive red scoria (unit Qv20).



Photograph 6 ▲

Northern wall of Crater Santiago. Right side of photograph shows part of the sequence of 24 lava flows (unit Qv9) from Volcan Masaya (also see photograph 14). At least one relatively recent lava flow (unit Ql26) from Volcan Nindiri overlies the sequence of Masaya lavas just east of the old rim of Crater Nindiri (upper center of photograph).

"Plaza de Oviedo," the lapilli deposits are overlain by a single lava flow (unit Ql26) that probably issued from Crater Nindiri sometime before 1670. On the south, approaching Overlook "Boca del Infierno," the same black lapilli layer is overlain by a different lava flow, designated as Ql25. Generally, the structural stability of localities around the crater rim is dependent on the presence of a significant thickness of lava flow(s) near the surface; on the presence and thickness of any unconsolidated or poorly consolidated pyroclastic materials that overlie, separate or underlie the lava flow(s); and on the proximity of fracture or faulting zones.

2.2 Overlook "Boca del Infierno"

The Overlook "Boca del Infierno" (OBI) is located at the south rim of Crater Santiago (Photographs 7 and 8). The western part of the overlook area is immediately underlain by a lava flow (Ql25) that varies in character from massive and dense to a highly vesiculated breccia. The total thickness of the flow varies between 10 and 15 meters. It was emplaced above about 10 meters of black lapilli (uppermost unit of Qv9). In the eastern part of the overlook area the flow becomes more massive. Lava tubes are abundant in this section of the flow. The roof rock of some of the lava tubes have collapsed and the ground surface in the area is treacherous. At the edge of the lava flow just east of OBI is an area of fracturing or faulting, oriented north 30° west, that passes diagonally across the crater to disrupt the materials beneath the Overlook "Cruz de Bobadilla" (see Photographs 8 and 11).

2.2.1 Assessment of Geologic Hazards at the OBI

The southern rim of Crater Santiago has become increasingly unstable over the past 10 years, resulting in numerous small to moderate rockfalls and landslides from the crater walls and a notable enlargement in the width and depth of the intercrater. Monitoring of volcanic gases and seismicity carried out by INETER and other researchers indicates that an increased level of volcanic activity began in 1988 at Volcán Masaya. The INETER monitoring program recorded a significant increase in total gas emissions from the intercrater and an increase in cyclic fluctuations in the relative proportions of sulfur and chlorine species in the gas emissions. Seismographs at and near the PNVM recorded an increase in B-type earthquakes, high in the volcanic conduit. The seismicity was interpreted as signaling fluctuations of between 10 to 50 meters in the height of the magma column immediately beneath Crater Santiago (July 1996, personal communication, M. Navarro, INETER).

The consultant inspected the Crater Santiago area in late July 1996, nearly 13 years after her last visit to the park. Remarkable changes in the morphology of the crater area were apparent. In the early 1980s, the sides of Crater Santiago were characterized by nearly vertical walls around the entire circumference. A prominent ledge capped with massive blocks of lava projected into the crater along its southern rim. The stability of the crater walls was underscored by a pink carapace of weathered and gas-altered material that covered the walls around most of the crater, and by the lack of rockfall debris atop the surface of black pahoehoe lava (unit Ql29) that completely

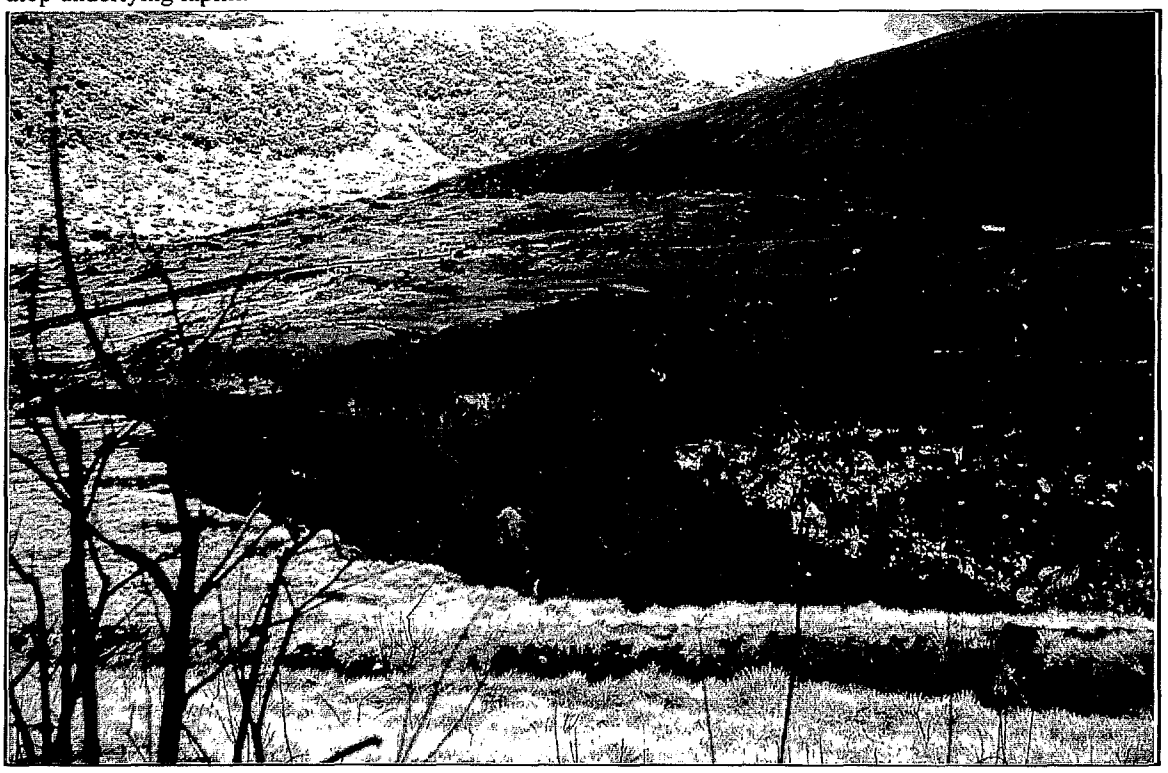
covered the floor of the crater from an eruption in 1965. The intercrater that existed in 1977 was approximately 100 meters across and 80 meters deep, and was situated just south and west of the center of the larger Crater Santiago (Photograph 9). The flank of the volcanic edifice south of Crater Santiago was a smooth, gently sloping surface covered by a smooth layer of black sand-size airfall tephra from the 1965 eruption. Sporadic small- to medium-size angular blocks of lava were deposited on top the black 1965 tephra by sporadic and short-lived explosive bursts from the volcano that occurred in the late 1970s.

Today, the intercrater is three to five times larger than its 1980 equivalent. It now extends from the center of Crater Santiago to the edge of the rockfall area at the toe of the southern crater wall (Photograph 10). The flank of the volcanic edifice south of Crater Santiago now contains numerous rills eroded into the formerly smooth surface by rainwater running off the paved parking area. The walls along approximately the southern third of the crater circumference have been affected by numerous small- to moderate-scale rockfalls, leaving a vertical scar face on the upper half of the wall that exposes fresh cuts of black, grey, and deep red lava and pyroclastic materials. The ledge that projected into the crater from the south lies in rubble on the crater floor. The pink carapace of weathered and gas-altered materials that had covered the crater walls is preserved only at the westernmost corner of the south crater wall (see Photographs 7 and 25). The larger recent rockfalls have occurred below a fractured and unstable slope at edge of the OBI parking area (Photograph 11). The crater floor below is littered with a chaotic mixture of large blocks of lava and semi-consolidated scoria interspersed with smooth, steep aprons created by a landslide of unconsolidated lapilli.

During the site inspection, the consultant also noted that the pavement in the eastern half of the parking area is interrupted by a fissure running east-west for approximately 10 meters (Photograph 12). About two to three centimeters of aperture in the fissure had been noted in March 1993, when colleagues of the consultant visited the PNVM (June 1996, personal communications, J. Alt of Epigene, Inc. and J. Johnson of J.F. Johnson and Associates). By mid-1996, surface runoff into the fissure had incised the tephra layers below the pavement and carried away the sandy materials, leaving an irregular void almost 0.5 meter across and over 1 meter deep into which several wooden posts that had lined the parking area have collapsed (Photograph 13). The fissure apparently continues 10 to 15 meters east of the paved area, where subsidence of the uppermost tephra material is occurring along a broad band. At one spot about 5 meters south of the crater rim, volcanic gas appears to emerge from small crevices within the area of subsidence. Although at first glance these appear to be new fumaroles, the crevices are cold to the touch. The gases are probably from the main intercrater plume, which has been partly sucked into the crater wall by wind currents and travels to the surface along interconnected void space created by the fissure(s). One large, superficial block located between the fissure and the edge of Crater Santiago appears to be rotated slightly, such that its surface dips slightly away from the crater. The open vertical fissure seen at the surface probably flattens northward with depth,

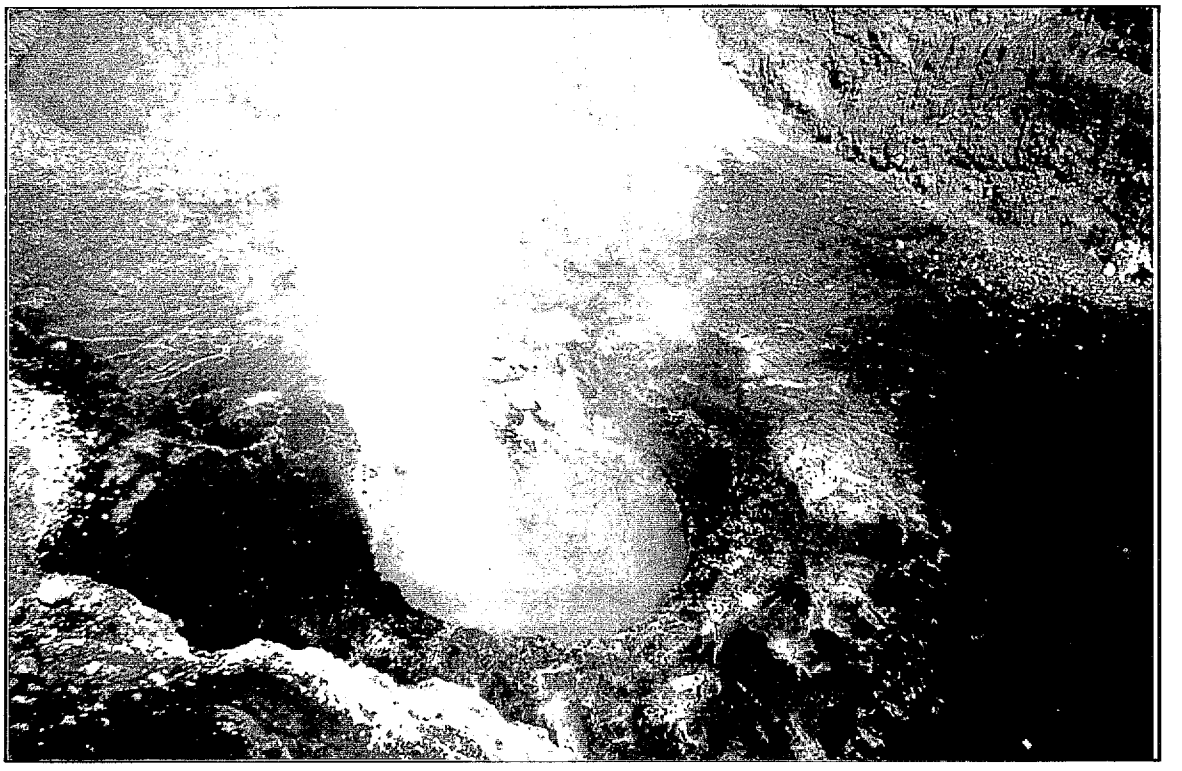
Photograph 7 ▲

Eastern side of OBI is underlain by the broad channel of an unusually fluid lava flow (unit Ql25) that covered most of the southwest quadrant of the caldera. The flow contains lava tunnels and rests on the thick bed of unconsolidated black lapilli (uppermost layer of unit Qv9) that caps the eastern side of Crater Santiago. Note distinctive red "baked" zone from heat of emplacement of lava on poorly developed soil atop underlying lapilli.



Photograph 8 ▲

Western side of the OBI is underlain by a small lens of massive lava that grades laterally into agglutinated spatter and flow rubble (unit Ql25 described above), resting on black lapilli unit (part of Qv9). Red "baked" horizon seen in Photograph 7 is visible below lava lens on left side of photograph. Beneath the black lapilli, the section consists predominantly of red scoria from cinder cones that formed above a NW-trending fissure.



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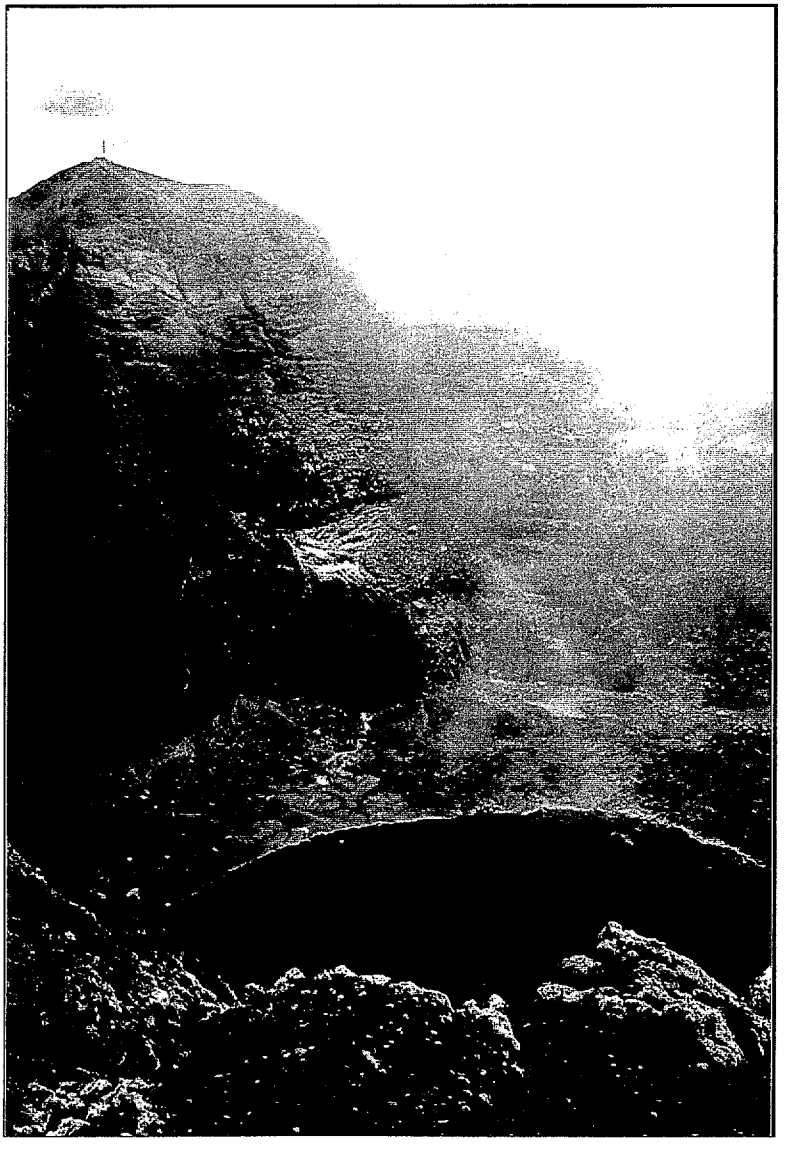
Photograph 9
Floor of Crater Santiago in 1977, showing small diameter intercrater and lack of rubble above the floor of black pahoehoe lava (unit Ql29) erupted in 1965. The intercrater at that time measured approximately 100 meters across and 80 meters deep.



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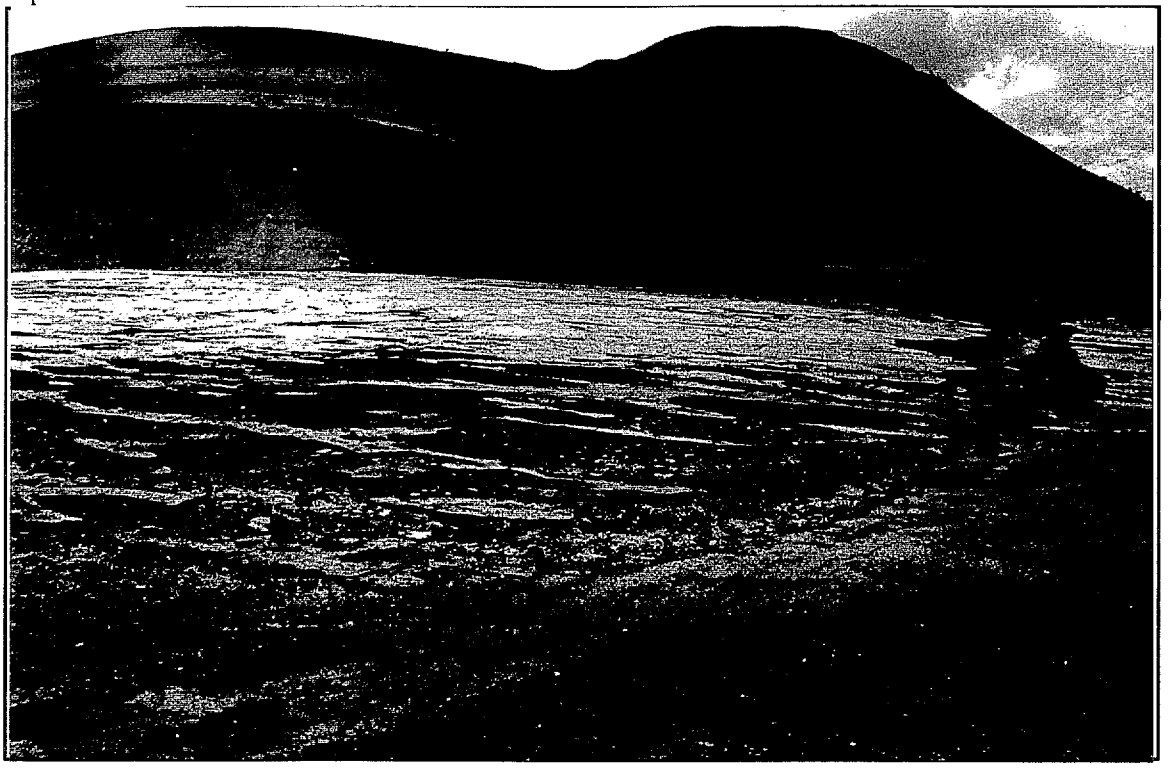
Photograph 10
Floor of Crater Santiago in 1996, showing significant widening and deepening of the intercrater. Rockfalls and landslides from the south wall of Crater Santiago disappear directly into the intercrater that now extends to the southern crater wall.

Photograph 11 ▲

Damaged OBI parking area at south rim of Crater Santiago. At least 5 meters of the overlook area has been lost into Crater Santiago since the late 1980s. At present, the area within 5 to 10 meters of the crater edge contains fissures from which volcanic gases, drawn into the fractured crater wall by air currents, are expelled.



Photograph 12 ▲

Fissure that cuts pavement at the OBI and continues eastward for at least 15 meters. Above the fissure, a linear depression dotted with small sinkholes indicates the collapse of overlying materials into underlying void.

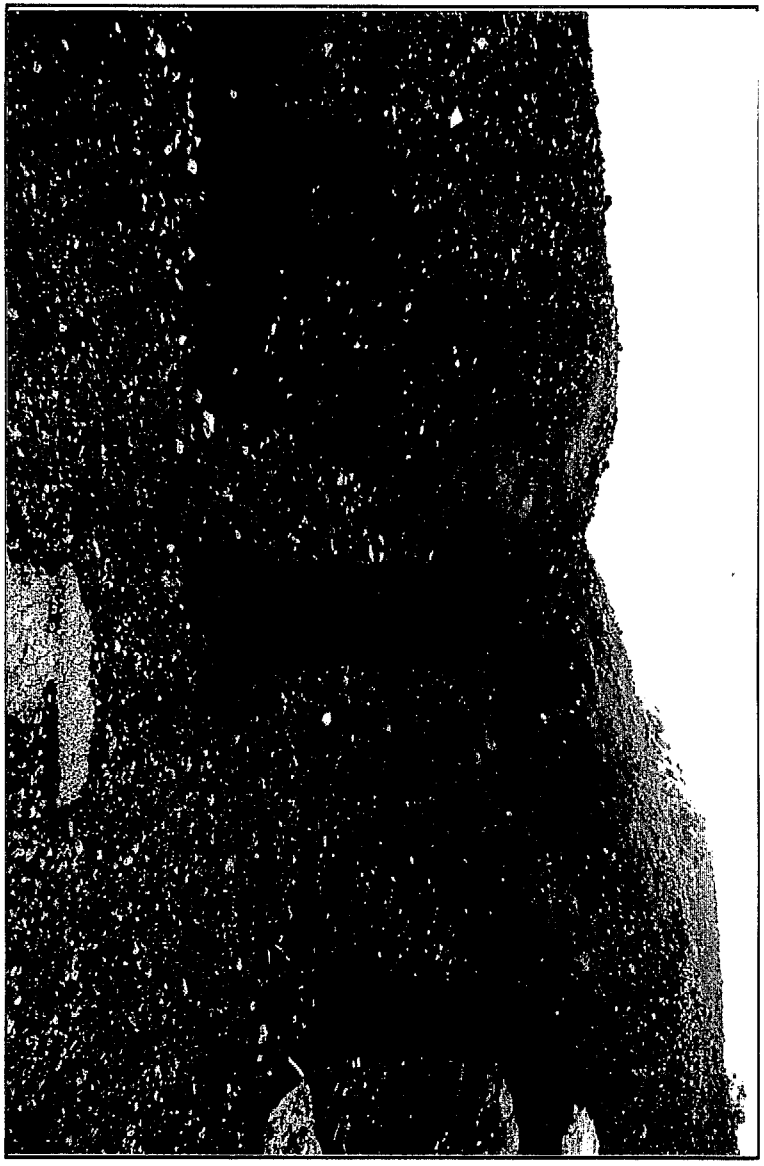
intersecting the crater wall at some distance below the rim and defining a curved failure plane along which a future rockfall could occur.

2.2.2 Infrastructure Options at the OBI

The area of the OBI will continue to be relatively unstable due to the heterogeneity of the underlying volcanic materials, the differing responses of those materials to persistent episodes of volcanic earthquakes, the proximity of a potentially active fault zone immediately east of the overlook area, and the existing system of fractures and fissures that has developed in the subsurface. The instability will be exacerbated during periods of volcanic "crisis" that are known to affect the Crater Santiago from monitoring conducted by INETER. The INETER monitoring program indicates that shallow seismicity increases during these periods, resulting in increased likelihood of rockfalls and landslides.

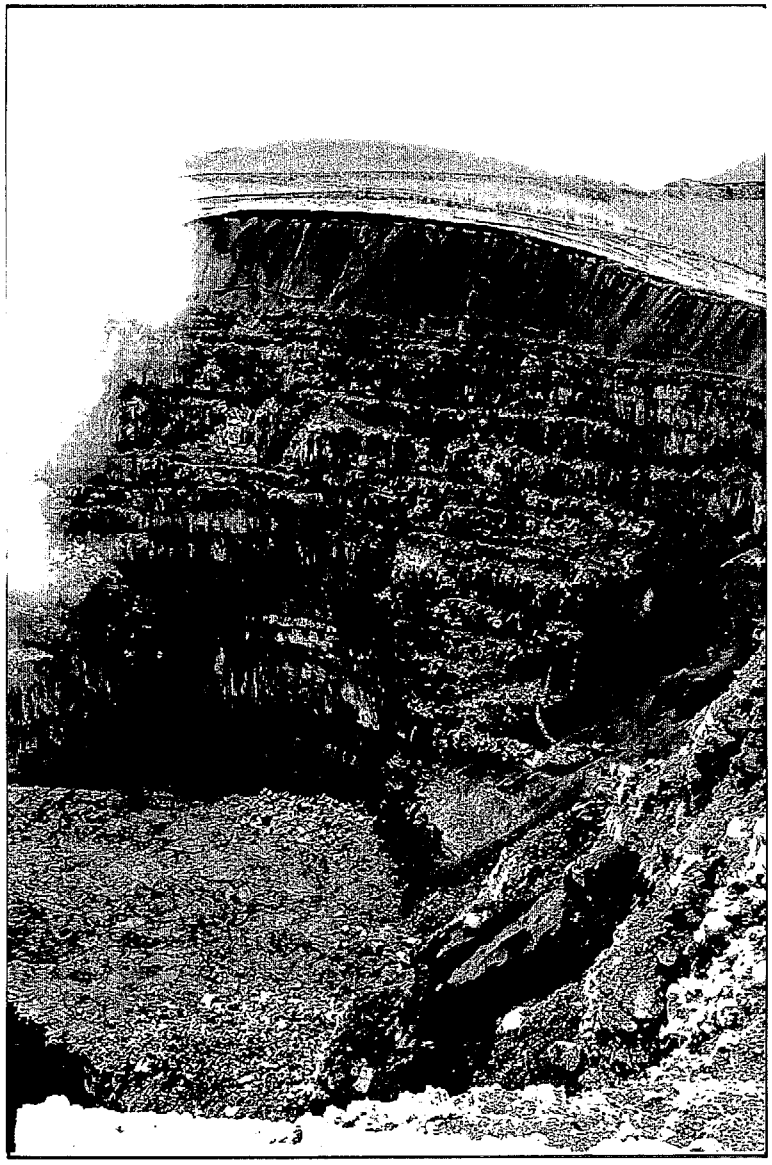
Field evidence clearly indicates that a significant portion of the OBI parking area and the area between the parking area and the crater rim is undermined by a complex set of fractures and open fissures. In the nearly 20 years between 1965 and 1983, when the consultant last inspected the crater area, only a small amount of debris falling off the crater walls had accumulated on the black crust of the 1965 lava which covered the crater floor. A much larger amount of debris, the product of minor rockfalls to large block landslides, has accumulated in the past 13 years (Photograph 14). The accumulation rate apparently increased notably in the past 8 years. Based on information pieced together from interviews, the size and number of rockfalls appears to be proportional to the intensity and persistence of shallow volcanic earthquakes (July 1996, personal communications from M. Aleman, PNVM, M. Navarro, INETER, and J. Incer, private consultant).

The consultant and TR&D management had considered the need to conduct one or more geologic/geotechnical studies (such as seismic reflection, seismic refraction, geotechnical borings, or ground penetrating radar) in parallel with the consultant's site visit. The purpose of the study would have been to better define the fissures and other failure structures in the subsurface that may have developed and that would weaken the ground beneath the parking area and the OBI. However, due to the complexity of the fractures and fissures that were apparent at the surface of that area during the consultant's field inspection, coupled with the uncertainty in the level of volcanic seismicity that is expected to continue at Masaya, it will be virtually impossible to quantitatively evaluate the stability of the overlook with respect to near term (10 to 15 year) load-



Photograph 13 ▲

Surface trace of fissure that cuts pavement of OBI parking area and continues eastward. Pieces of broken asphalt, wooden posts, and black ash underlying the paved area have disappeared into the fissure.



Photograph 14 ▲

View of the floor of Crater Santiago showing the large amount of rubble produced by rock and landslides off the southeastern crater walls.

bearing capability. Therefore, ***no further geophysical or soil engineering study is recommended for the OBI area at this time***[2]. Numerous options to mitigate the geologic hazards are proposed, but the options are *not* dependent on the results of any further geologic or geotechnical study.

Option 1:

No action alternative - Impose no restrictions on existing visitor access to the OBI; repair and use existing parking area or construct new parking south of existing paved area; use existing viewing infrastructure or provide improved viewing platform at least 10 meters away from crater edge; station park guards equipped with gas masks at the OBI during hours of public access.

Pros:

- Major attraction at the PNVM is preserved without disruption
- No decrease in general park fees derived from tourism
- Park guards are protected from effect of gases on respiratory system

Cons:

- High risk of multiple deaths and/or respiratory crises provoked by gases if existing viewing area used
  Moderate risk of multiple deaths and high risk of respiratory crises provoked by gases if new viewing area is constructed
- Construction of new (gas-resistant and higher) viewing platform at a safer distance from crater edge will be cost prohibitive and visually intrusive
- Risk of negative publicity from nonconservative response to identified dangers (even if no visitor accidents occur due to crater collapse)
- Gas masks are uncomfortable and do not protect skin and clothing of park guards from gases
- Viewing area is subjected to possible additional instability from weight and vibration of vehicular traffic

Option 2:

Restrict vehicular access to paved parking area; provide parking near the "Casa de los Murcielagos;" use existing viewing infrastructure or provide improved viewing platform away from crater edge; station park guards equipped with gas masks at the OBI during

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2 See discussion in Section 2.4.4 regarding installation of inclinometer wells in the black lapilli of unit Qv9 that underlies the trail and part of the road between the main crater overlooks

hours of public access; strictly limit length of stay (less than 4 minutes) and number of visitors (less than 5 persons) at crater rim at any one time.

Pros:

- Major attraction at the PNVM is preserved with minor disruption
- Viewing area is not subjected to possible additional instability from weight and vibration of vehicular traffic
- Park guards are protected from effect of gases on respiratory system

Cons:

- Moderate risk of multiple deaths and/or respiratory crises provoked by gases if existing viewing area used while restricting the length of stay and number of visitors at crater edge at any one time
- Moderate to low risk of multiple deaths and/or respiratory crises provoked by gases if new viewing area is constructed
- Construction of new (gas-resistant and higher) viewing platform at a safer distance from crater edge will be cost prohibitive and visually intrusive
- Risk of negative publicity from nonconservative response to identified dangers (even if no visitor accidents occur due to crater collapse)
- Possible decrease in general park fees derived from tourism due to decreased accessibility
- Gas masks are uncomfortable and do not protect skin and clothing of park guards from gases
- Incurs additional cost of constructing new parking area near "Casa de los Murcielagos"

Option 3:

Request the assistance of a military or industrial explosives expert to design and implement a series of controlled blasts to remove fractured and unstable blocks from the south wall of the Crater Santiago. Once the hanging blocks have been dislodged and fall into the crater, provide an improved viewing platform near the crater edge; station park guards equipped with gas masks at the new OBI during hours of public access.

Pros:

- Major attraction at the PNVM ***may*** be safer after some disruption
- Park guards are protected from effect of gases on respiratory system

Cons:

- Results of blasting to remove dangerous blocks are uncertain; may cause additional instability in area or obstruct the view of the molten lava or its incandescence
- Construction of new (gas-resistant and higher) viewing platform at a safer distance from crater edge will be cost prohibitive and visually intrusive
- Risk of negative publicity from nonconservative response to identified dangers (even if no visitor accidents occur due to crater collapse)
- Possible decrease in general park fees derived from tourism due to undesirable results from blasting
- Gas masks are uncomfortable and do not protect skin and clothing of park guards from gases
- High risk of negative publicity for environmental damage and uncertainty regarding safety and aesthetics of blast results

Option 4:

Restrict vehicular access to parking area at Overlook "Plaza de Oviedo;" allow controlled access to southern crater rim by pedestrians only; use existing viewing infrastructure or provide improved viewing platform near crater edge; station park guards equipped with gas masks at the OBI during visitation hours; strictly limit length of stay (less than 4 minutes) and number of visitors (less than 5 persons) at crater rim at any one time.

Pros:

- Major attraction at the PNVM is preserved for small portion of visitors able to reach the OBI on foot
- Reduced accessibility will limit the number and age range of visitors that are at risk from overlook collapse and/or respiratory crises provoked by gases
- Possible additional park fees derived from guided tours of the OBI
- Park guards are protected from effect of gases on respiratory system

Cons:

- Possible decrease in general park fees derived from tourism due to decreased accessibility
- Gas masks are uncomfortable and do not protect skin and clothing of park guards from gases

Option 5:

Restrict vehicular access to parking area at Overlook "Plaza de Oviedo;" allow visitor access to lava tunnels on foot using paved roadway; allow NO visitor access to the OBI viewing area.

Pros:

- Inaccessibility will eliminate visitor risk from overlook collapse and/or most respiratory crises provoked by gases
- Park guards will not be continuously exposed to strong gases of main plume
- No risk of negative publicity due to conservatism of actions taken for visitor and staff safety
- Potential opportunity for public education on dangers of volcanic areas

Cons:

- Probable decrease in general park fees derived from tourism due to inaccessibility of the OBI attraction
- Decreased accessibility of Lava Tunnels
- Loss of use of infrastructure invested in parking and viewing area at the OBI

Of the five options presented, the consultant recommends that PNVM move immediately to implement Option 2 and gradually transition toward implementation of Option 5. It is the opinion of this consultant that the geologic conditions of the southern side of Crater Santiago are such that instability of the infrastructure at the OBI cannot be resolved at a reasonable cost. In addition, any option that permits visitor access to the OBI incurs the need to station park guards at that site, with consequent exposure to caustic and toxic gases. Although the visitor may not suffer serious health effects from a periodic visit to the OBI, continuous exposure of the park guards to the concentration of volcanic gases at the OBI over the course of 1 to 5 years will result in serious damage to their respiratory systems.

2.3 Lava Tunnels "Tzinanconostoc"

The "Tzinanconostoc" lava tunnels or lava tubes are located about 150 meters southeast of the "Casa de los Murcielagos," on the south side of Crater Santiago. The tunnels represent the subterranean channels along which molten lava continued to flow after its surface had "frozen," or solidified into a crust by loss of heat. The "Tzinanconostoc" tunnels are surprisingly large and continuous - the tunnel used for tours is up to 3 meters in height and can be traced over a distance of more than 300 meters. That tunnel is found in a superficial lava unit (Ql25) with very fluid characteristics that erupted, probably from Volcán Nindiri. Although the flow has not been dated, it is known to have erupted sometime before 1670 because it is overlain by the 1670 flow near the

western wall of the caldera. Other lava tunnels have been identified southwest of Crater Santiago and within the 1670 lava flow on the northern flank of Volcán Nindiri. Tunnels probably also exist in the subsurface beneath and just north of the paved parking area at the Overlook "Plaza de Oviedo."

2.3.1 Assessment of Geologic Hazards at the Lava Tunnels

All of the lava tunnels at the PNVM are characterized by fractures in the roof and sides of the tunnel (Photograph 15). The fractures are generally radial to the tunnel cross-section and vary in depth, from a few centimeters to those that transect the width of the rock roof or wall. As the eruption that originally created the tunnels diminished, the final pulses of lava flowed out of the tunnels to drain down slope and the frozen rock carapace of the tunnel settled against itself along these fractures. Most fractures now visible in the roof of the tunnels separate large, heavy blocks of roof rock that have settled to rest against each other for hundreds to thousands of years. The roof of the tunnel may also have smaller hanging blocks that can be shaken loose by minor seismic activity but, for the most part, the lava tunnels are a stable environment except during periods of volcanic crisis, when high levels of volcanic seismicity may destabilize the roof fractures.

2.3.2 Infrastructure Options at the Lava Tunnels

This study identifies two options for consideration by PNVM management to improve visitor safety in the lava tunnels. The consultant supports only the second option presented.

Option 1:

> Install ground support hardware currently used in commercial mine or tunnel constructions to control rock falls within the tunnel. The ground support hardware would include either rock bolts or steel sets, as appropriate for the existing ground conditions.
>
> This option is **not** considered viable for the "Tzinanconostoc" or other lava tunnels at the PNVM. All of the tunnels that the consultant has explored at the PNVM are found in superficial lava flows. Unlike constructed mines or tunnels, the fractured roof rock is not surrounded on the outside by more stable rock into which the rock bolts can be anchored. Steel sets, which consist of two large arcs of steel that are installed against the inside perimeter of the tunnel and bolted against each other to support blocks of roof or wall rock that become unstable, are visually intrusive. The steel sets would have to be installed at close intervals to support the complex fracture system in the lava tunnels. Installation of rock bolts or steel sets would be expensive, visually intrusive, and probably would provoke additional instability in the tunnels due to the drilling and fitting operations.

Photograph 15 ▲

Entrance to a small lava tunnel near the Crater Santiago rim east of the OBI. At right of photograph note the throughgoing fracture that cuts the tunnel's rock carapace. The tunnel is found in the same flow (unit Ql25) as the "Tzinanconostoc" lava tunnel.

Option 2:

The preferred option is described as follows. Access to the lava tunnels should continue to be restricted to tours conducted by park guards. Tours should be limited to groups of 10 to 15 visitors. Provide hard hats for the park guards and visitors touring the lava tunnels to decrease the risk of head injuries from walking into the irregular projections from the tunnel roofs and from minor rock falls. (Inexpensive but effective hard hats can be purchased for under US$5.00 each.) Park guards, unaccompanied by visitors, should make at least one safety inspection weekly of the lava tunnel. Using adequate lighting (such as a mine lamp, ***not*** a flashlight), the guards should inspect the roof and walls of the lava tunnels to identify any noticeable movement along large fractures, to quantify any recent rockfall from the tunnel roof and walls, and to locate any small blocks that appear ready to fall. If possible without endangering the guards, small roof blocks that appear unstable should be dislodged. Finally, tours of the lava Photo 15 tunnels should be discontinued during periods of volcanic crisis, when high levels of seismicity may provoke failures in the roof and wall blocks.

2.4 Road and Trail between Main Crater Overlooks

A paved road and a gravel-covered walking trail were installed between the two main crater overlooks, the OPO and the OBI. The road and the trail were partially or wholly constructed on the unconsolidated black lapilli (part of unit Qv9) that blankets the western flank of Volcán Masaya, between Crater Masaya and Crater Santiago (Photograph 16). Little or no maintenance has been given to the road or the trail since their installation in 1978-1979. The asphalt pavement of the road is deteriorated, especially on the steep curves southeast of Crater Santiago. Also nearly gone are the lines of reflective yellow paint marking either side of the pavement, intended to assist drivers when visibility is hampered, as it often is, by volcanic fumes, rain, or low clouds. The wooden handrail that was installed in about 1979 along portions of the pedestrian trail on the side nearest the crater has either fallen into the crater or been scavenged for firewood. Parts of the trail, particularly as it approaches the Casa de los Murcielagos, are perilously close to the edge of the crater. One small sign warning that the trail is closed to the public has been installed at the head of the trail as it leaves the OPO and another just north of the Casa de los Murcielagos (Photograph 17). However, on the several visits that the consultant made to the park in late July, the park guards made no attempt to stop groups of visitors who used the trail to transit between the OPO, the lava tunnels, and the OBI .

2.4.1 Assessment of Geologic Hazards for the Road and Trail between Main Crater Overlooks

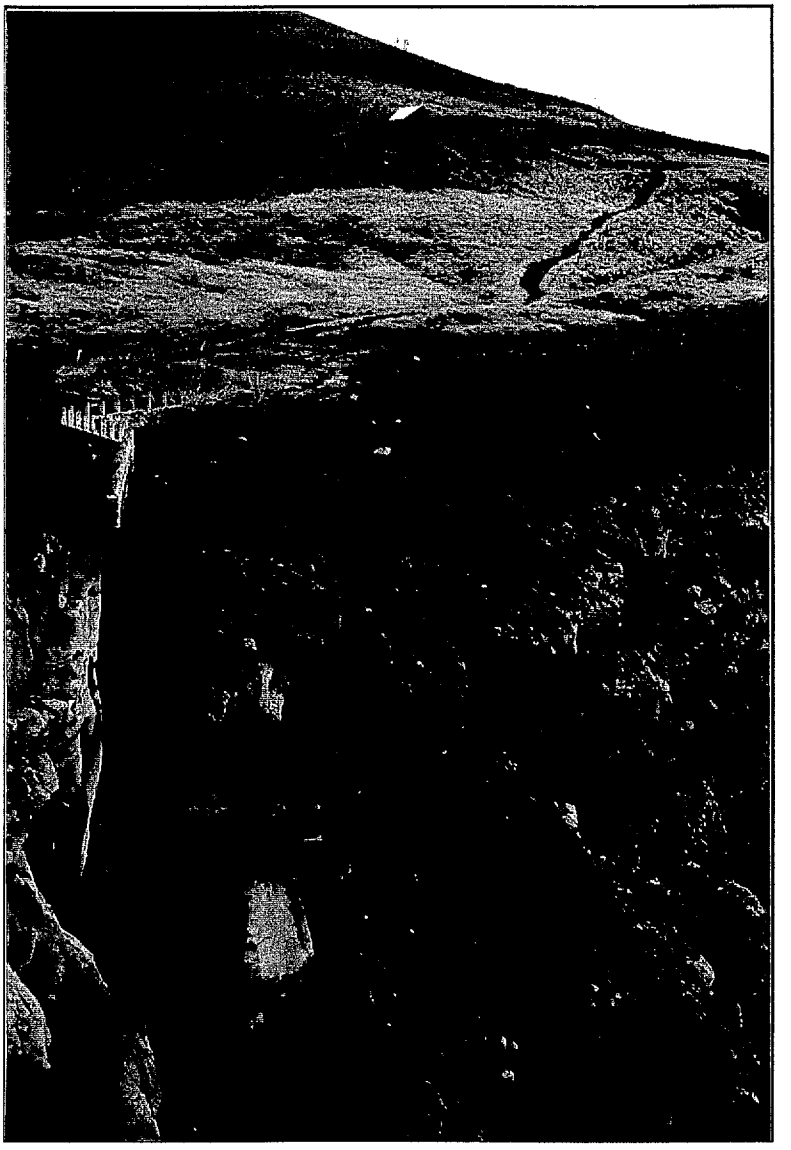
There is surprisingly little evidence that the thick black lapilli layer underlying the road and trail is eroding at a significant rate into the Crater Santiago. Only minor landslide debris derived from the lapilli unit is visible at the foot of Crater Santiago's eastern wall, despite the fact that the angle

of repose of the top several meters of the lapilli is highly unstable (see Photograph 16). Larger scale features that appear to suggest incipient slumping are the large crevices[3], up to several meters deep and tens of meters long, oriented parallel to the crater edge between the crater and the road (Photograph 18). Some of these may be active slump features, but the high rate of erosion along the crevice beds makes it difficult to evaluate their rate of growth due solely to mass movement and, therefore, assess how active the slump features may be.

If funding resources permit, a geotechnical study may be advisable to assess whether mass movement is occurring in the black lapilli unit above and below the road between the main crater overlooks. This type of study would involve installing inclinometer wells that reach the base of the black lapilli. The vertical and horizontal components that define the spatial orientation of the inclinometer or well casing would be measured initially and then monthly to establish a seasonal baseline. Thereafter, measurements would be taken quarterly to assess any measurable movement of the tiltmeter or deflection of the well casing indicating downslope creep. In some cases, rapid changes are measurable immediately prior to slope failure.

The geologic hazards that pose significant risks to visitors who use the road or trail are similar to the hazards that affect the OBI. The greatest risk to pedestrians using the trail appears to be the likelihood that a landslide may occur, especially where the trail is closest to the edge of the crater just above the Casa de los Murcielagos. Landslides and rockfalls do not appear to pose a significant danger to vehicles or persons who transit the paved roadway. However, the steep slope and the tight curves in the roadbed just above the Casa de los Murcielagos do pose a threat

[3] The arcuate shape of the features cutting the black lapilli unit suggests that these crevices are not caused by surface rupture along a fault, as proposed in a report by INETER dated July 20, 1996. The paucity of rubble on the floor of Crater Santiago derived from the black lapilli also suggests that the unit is relatively stable. Although the seismic data support the location of one or more faults in the crater area, it is not clear from the data where the surface expression of the fault might be expected. Aerial photographs (at a scale of 1:40,000) made available to the consultant did not prove useful in discriminating between a fault-rupture or gravity-movement origin of the crevices. Photographs at a larger scale may show that the arcuate segments of the various crevice features do form a convincing alignment not evident in the field, supporting an interpretation of surface rupture along a north-south fault. However, the potential for catastrophic gravity movement of the black lapilli above the east rim of Crater Santiago should be considered.



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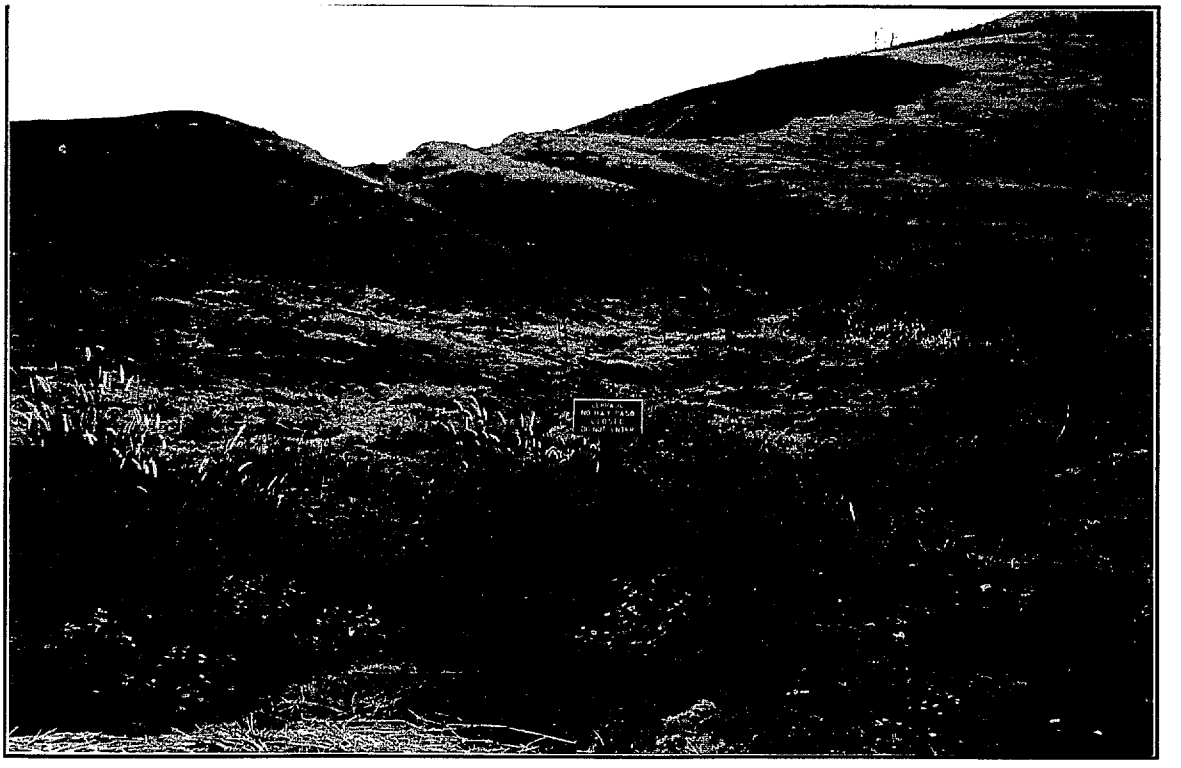
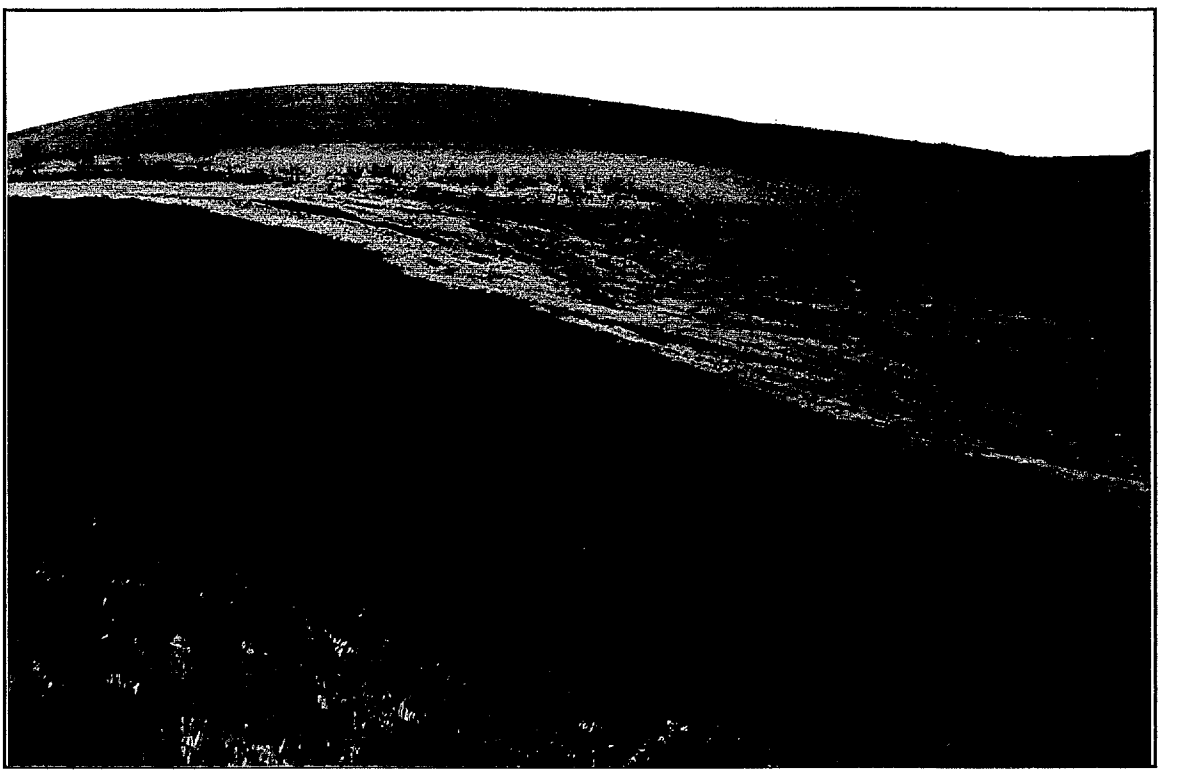
Photograph 16
The paved road (roadcut is immediately behind the small hut in the distance) and unpaved trail between the OPO and OBI are underlain by unconsolidated scoria and lapilli (part of unit Qv9) from early eruptions of Volcan Masaya. Note proximity of trail to the edge of Crater Santiago.

Photograph 17
Warning sign posted at the head of the pedestrian trail between the OBI and OPO.

▼





Photograph 18 ▲

Long arcuate crevices developed within the unconsolidated black lapilli (uppermost deposit of unit Qv9) from an early eruption of Volcan Masaya. Crevices are probably incipient slump structures, although they have also been attributed to surface rupture of a major N-S trending fault that underlies the Masaya caldera.

2.4.2 Infrastructure Options for the Road and Trail between the Main Crater Overlooks

The following options relate to the mitigation of hazards to the visitor and park guards along the trail and roadway between the two main crater overlooks. The infrastructure options that are driven by safety concerns at the OBI that may require restrictive measures affecting the trail and road are considered separately in Section 2.2.2.

Option 1:

No action alternative. Continue to allow unrestricted access of private vehicles transiting between the parking areas of the POP and the OBI. Discourage or prohibit buses from use of the roadway. Maintain signs that discourage the use of the trail by pedestrians, but do not prohibit visitors from using the trail.

Option 2:

Continue to allow unrestricted access of private vehicles to the roadway as far as the "Casa de los Murcielagos;" develop a parking area on the flat area immediately south of the existing OBI parking; prohibit buses from using the roadway past the "Plaza de Oviedo;" close the trail to pedestrian traffic, allow the trail to return to natural vegetation, and direct pedestrians to use the roadway if they wish to hike to the features on the south side of Crater Santiago; re-engineer surface drainage to mitigate further damage from erosion.

Option 3:

Close the roadway to vehicular traffic; close the trail to pedestrian traffic; allow pedestrians to use the roadway if they with to hike to the features on the south side of the Crater Santiago; reengineer surface drainage to mitigate further erosion damage.

Of the three options presented, the consultant recommends that the PNVM move immediately to implement Option 2 and gradually transition toward implementation of Option 3. ***It is worth emphasizing that Options 2 and 3 require immediate closure of the trail due to the high risk of slope failure, especially nearest the crater.*** The justification is the same as that stated in Section 2.2.2, that is, this consultant believes that the instability of the infrastructure at the OBI cannot be resolved at a reasonable cost. In addition, any option that permits visitor access to the OBI incurs the need to station park guards at that site, at significant risk to their respiratory health.

It should also be noted that Option 2 incurs the risk of pedestrians being injured or killed by passing automobiles since it proposes the incompatible pedestrian and vehicular use of the same roadway. If the management approach taken eventually prohibits visitor access to the OBI, the

incompatible use proposed in Option 2 could be restricted to a relatively small number of visitors touring the lava tunnels "Tzinanconostoc."

2.5 Overlook "Plaza de Oviedo"

The Overlook "Plaza de Oviedo" (OPO) is the first overlook encountered as the visitor approaches the summit area along the Camino Real del Popogatepe. It is located just north of Crater Santiago. The OPO consists of a large parking area, a long safety fence that borders about 100 meters of the crater edge, an unpaved graded area to the east that is used for bus parking, a primitive restroom on the hill across the roadway, and several small huts for the use of concessionaires and the park guards. Just west of the OPO is the Overlook "Cruz de Bobadilla" and just east of the OPO is the OBE and an interpretive plaque at the "Casa de los Alemanes."

With the exception of a section at the central viewpoint where a meter-high (approximately) full safety wall covered with natural lava rock was constructed, most of the safety fence along the edge of Crater Santiago consists of a half-wall (about 18 inches high) of cinder blocks faced with lava rock (Photograph 19). Sections of the wall about 2 meters in length are set between 6-foot long reinforced concrete posts that are embedded in concrete-filled holes sunk about 2 feet into the underlying materials. When the OPO and other tourist infrastructure in the crater area were constructed in 1978-1979, a thick, zinc-coated iron chain was hung between the concrete posts of the safety wall to protect the visitors while maintaining visibility across the summit area. Within several years the volcanic gases had corroded the metal chain to a brittle, rusted material that could be snapped in two with bare hands. The remnants of the chain were removed years ago and, today, the half-wall of the safety fence is the only protection along most of the length of this highly visited area.

2.5.1 Assessment of Geologic Hazards at the OPO

The geologic hazards at the OPO are related to the possibility that part of the viewing area nearest the edge may collapse into the crater. Because the western portion of the viewing area is underlain by a significant thickness of lava layers, that area is judged to have a low probability of failure of the blocks of lava beneath and behind the safety fence. Several blocks that are obviously fissured and hanging somewhat precariously can be seen between the safety fence and the edge of the crater. Those blocks were identified and avoided at the time the safety fence was installed in 1978-1979, and have yet to fall away even with the increased seismicity since 1988 (Photograph 20). A higher but still moderate probability of failure may characterize the westernmost portion of the safety fence, beginning approximately 10 meters east of the central viewpoint atop the rocks and continuing to the entrance to the Overlook "Balcon del Eco." The safety wall in this area rests directly atop a westward thinning wedge of the 1772 black lapilli. The black lapilli layer is not found beneath or on top of the surficial lava flow that supports the central viewing platform. However, the lapilli is at least 2 meters thick beneath the western end of the safety fence and the lapilli's erosion slope facing the crater has gradually migrated back to the

toe of the safety fence. At one point, the lapilli has begun to be eroded from beneath the fence, leaving it partly unsupported. One large block of the lapilli outside the safety fence is fissured and ready to fall away (see Photograph 19).

In general, the parking area and safety fence along the crater viewing area at the OPO is considered the most stable of the visitor infrastructures around Crater Santiago The major geologic hazard at the OPO is the possibility of a major seismic event or an eruption causing a catastrophic rockfall that might include or entrain a significant section of the lava units beneath the OPO viewing area.

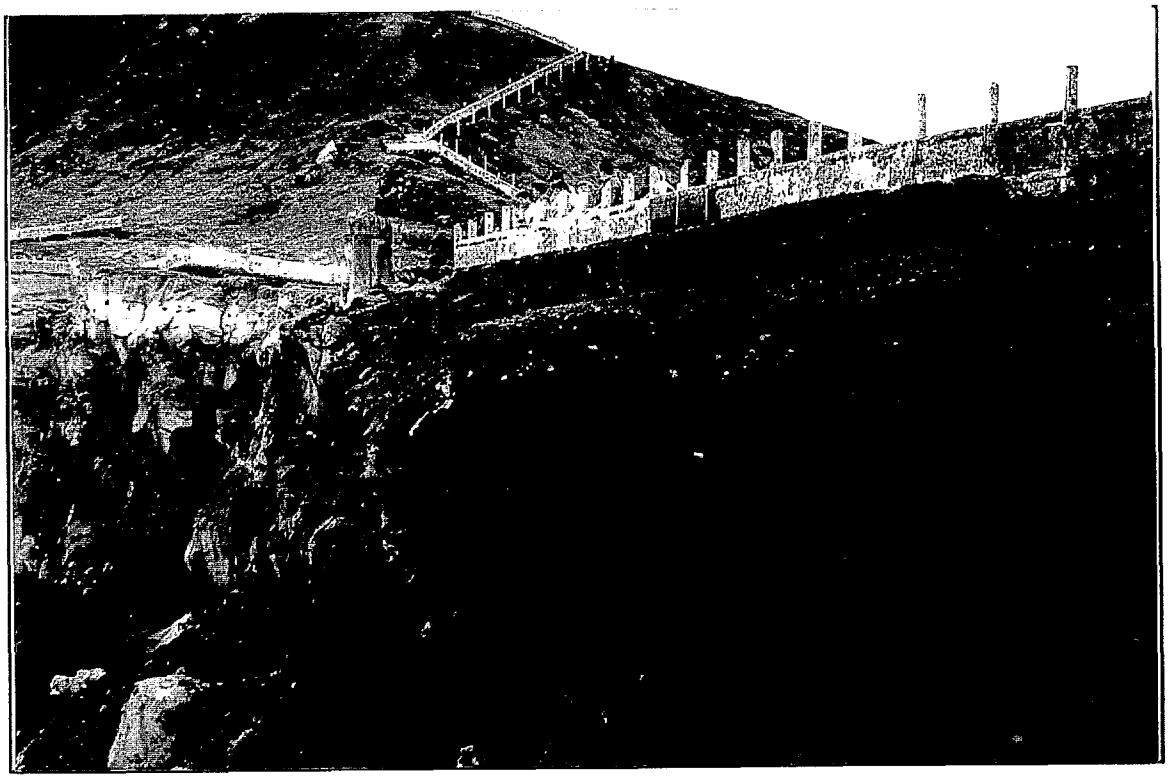
2.5.2 Infrastructure Options at the OPO

Option 1:

No action alternative - Impose no restrictions on existing visitor access to the OPO; provide minimal maintenance and use existing parking area; use existing viewing infrastructure; station park guards at the OPO during hours of public access; make no effort to equip park guards with gas masks.

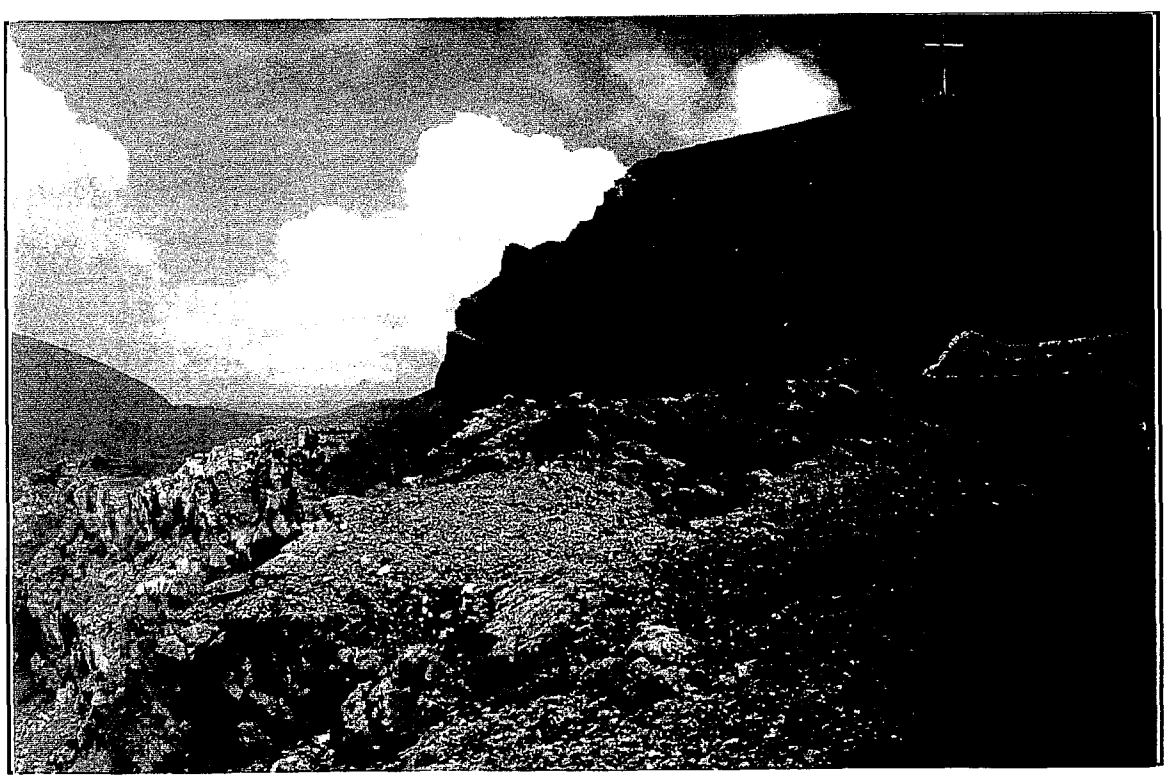
Option 2:

The preferred option is presented as follows. Construct traffic island to allow separate and distinct points of ingress and egress to OPO parking area. Provide separate parking areas for buses and private vehicles using the design prepared by the TR&D landscape architect. Pave (or use as is, if appropriate) the graded area behind the park guards' hut for additional bus parking. Raise the half-wall of the safety fence faced with natural rock to a full, 1-meter height and use measures to discourage visitors from standing atop the wall, such as facing the top with rough lava fragments or slanting the top away from the crater. (In raising the level of the wall, it will be necessary to provide adequate footing for the additional weight between the posts or risk the structural separation of the wall sections from the anchoring posts. In that case, even a minor seismic event may cause the wall segments to fall toward the parking area, possibly resulting in personal injuries, or into the crater.) Reconstruct the westernmost 10 meters of the OPO safety wall near the Overlook "Balcon del Eco" at a distance further from the crater edge, or otherwise restrict direct visitor access near that portion of the wall. If erosion continues to undermine the western section of the wall, it may be necessary to remove the undermined portions so that failure of one segment does not damage a larger portion of the wall.



Photograph 19 ▲

Safety wall at east end of the OPO, constructed on unconsolidated ash and lapilli unit that is slowly eroding into Crater Santiago. Note vertical fissure in lapilli (center of photograph) that marks the plane of failure of the slump block. Upper right of photograph shows proximity of the lapilli's erosion front tothe base of the safety wall.



Photograph 20 ▲

This large block of the lava flow (unit Ql26) by the edge of Crater Santiago at the OPO was hanging precariously when the safety wall was installed in 1977-78. The block has yet to fall, evidence of the relative stability of the northern rim of Crater Santiago compared to the high rate of rockfall and landslides on the south rim.

If additional parking must be constructed in the future, additional area should be sought near the unpaved graded area east of the OPO. The existing paved area at the northwest corner of the OPO parking area should not be extended since this area may be underlain by lava tunnels. If, in the near future, the hazards due to volcanic gases and continued instability from seismic activity worsen along the southern crater wall, the PNVM should consider locating and developing one of the lava tunnels that surely exist on the northern flank of the Volcán Nindiri for tours.

2.6 Overlook "Balcon del Eco"

The Overlook "Balcon del Eco" (OBE) is located at the edge of Crater Santiago just east of the Plaza de Oviedo. The OBE was excavated into the black lapilli (unit Qv9) that caps the eastern side of Crater Santiago. The OBE infrastructure consists of two segments of stairs and a walkway that are constructed of natural "piedra cantera" (a locally quarried, partially welded pyroclastic flow material called an "ignimbrite") and a safety wall, approximately 4 feet in height, of lava stone joined with concrete (Photograph 21). The safety wall consists of segments approximately 2 meters in length that were constructed between 6-foot reinforced concrete posts embedded in concrete, similar to those that support the safety fence at the OPO. While the safety wall on either side of the stair steps that descend to the OBE viewing area rests on top of the lapilli itself, it appears that the portion of the wall facing the crater rests directly on the underlying lava flow. The iron bars that reinforce the concrete posts in the wall facing the crater have been degraded by the volcanic gases (Photograph 22).

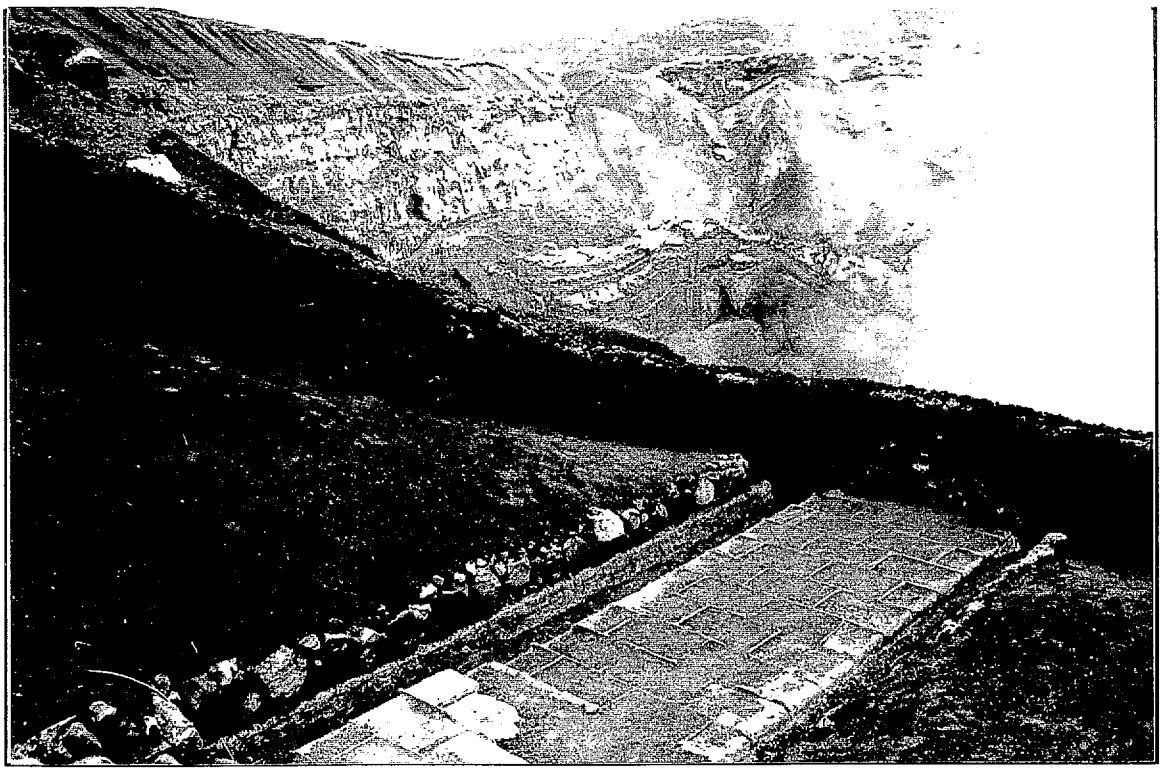
2.6.1 Assessment of Geologic Hazards at the OBE

The geologic hazards at the OBE are similar to those at the OPO. The principal viewing platform and safety wall at the OBE rests atop or is anchored into a relatively continuous and thick lava unit. The safety walls on either side of the walkway leading down to the main viewing platform are anchored into the black lapilli unit and may be less secure than the wall facing the crater. The major geologic hazard at the OBE is the possibility of a major seismic event or an eruption causing a catastrophic rockfall that might include or entrain part of the lava unit below the OBE.

2.6.2 Infrastructure Options at the OBE

Option 1:

No action alternative and preferred option. Continue to allow unrestricted access to the OBE; periodically examine the structural integrity of safety wall facing the crater;



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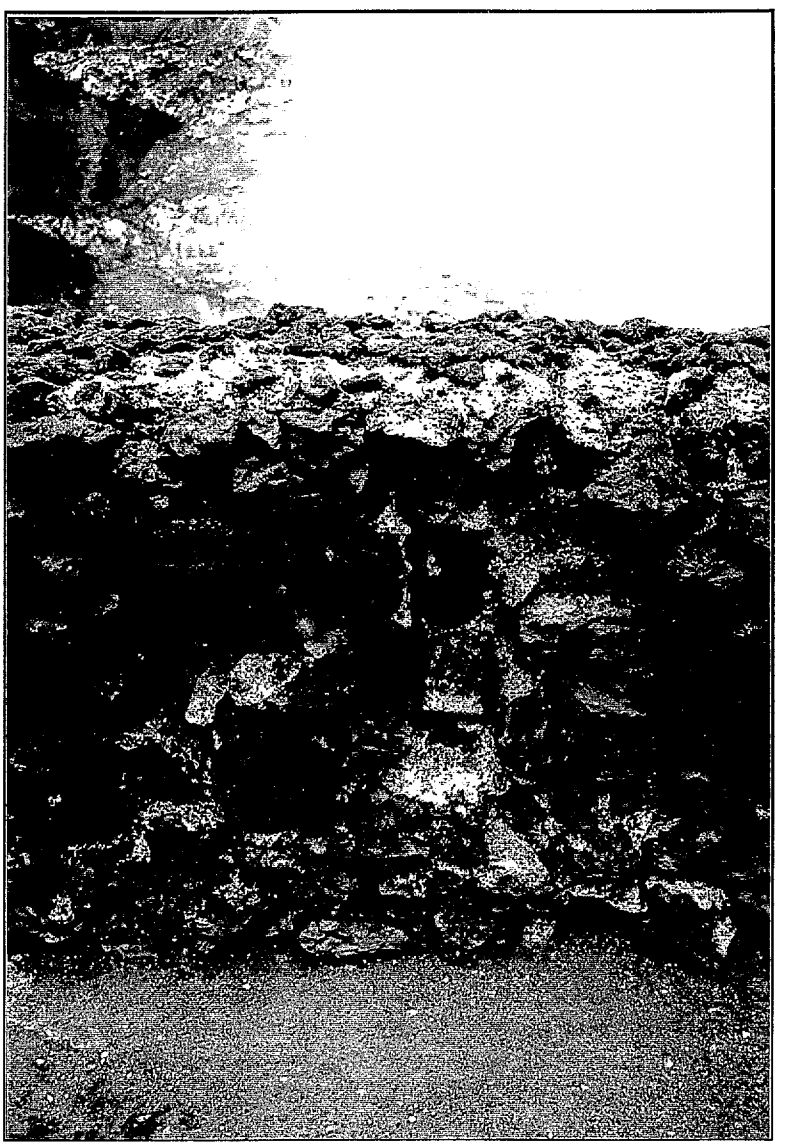
Photograph 21
OBE infrastructure, installed approximately 2 meters below the level of the paved parking area at the east end of the OPO. The OBE was constructed by excavating into the black lapilli (unit Qv9). A safety wall was installed on the front and sides of the excavated area. Where it fronts on the crater, the safety wall appears to rest on the thick lava flow (also part of unit Qv9) underlying the black lapilli.



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Photograph 22
Exposed remnant of the reinforced concrete post that anchors the safety wall fronting the crater at the OBE. Note the rusted appearance of the iron reinforcement bar embedded in the post. The safety wall remains relatively stable, due to the massive footing that rests directly on the underlying lava flow.

reinforce the structural integrity of that wall, as necessary, or replace the wall[4]; repair or replace steps that are worn and damaged by use; close public access to the OBE during periods of volcanic crises.

Pros:

- Major attraction at the PNVM is preserved
- No significant investment required at present

Cons:

- Low risk to public from potential failure of viewing platform
- Low but manageable risk to public from potential failure of safety wall facing the crater
- Some costs will be incurred for maintenance of walkway, stairs, and safety walls and periodic engineering assessment of the wall's structural integrity

Option 2:

Close the OBE to public access by constructing a barrier across the walkway and steps leading to the viewing area.

Pros:

- Eliminate risk to public from potential failure of viewing platform

Cons:

- Loss of infrastructure investment
- Potential crowd control problem with visitors who demand access to an apparent tourist viewing area

Option 3:

Close the OBE to public access; remove walkway and steps leading to the viewing area.

Pros:

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4 If the wall is replaced, all of the heavy infrastructure including the steps, walkway and safety wall facing the crater should be anchored directly into the underlying lava unit. To accomplish this, further excavation of the lapilli layer may be necessary.

- Eliminate risk to public from potential failure of viewing platform

Cons:

- Loss of infrastructure investment
- Cost of removal of infrastructure and restoration of excavated area
- Probable difficulties in restoring site to more natural conditions and ensuring public safety of resulting area

2.7 Overlook "Cruz de Bobadilla"

The Overlook "Cruz de Bobadilla" (OCB) is located above the northwest rim of the Crater Santiago, at the highest point along the crater circumference. The units upon which the infrastructure of the overlook was constructed are composed of partly welded to unconsolidated tephra deposits (Qv20) erupted from Volcán Nindiri. These units form the crater rim of Volcán Nindiri. The massive to finely bedded tephras exposed in the Crater Santiago walls are cut by a series of nearly vertical fractures or faults that are part of the system that crosses the Crater Santiago diagonally from just east of the OBI (see Photographs 4, 6 and 9).

The OCB infrastructure consists of segments of stairs constructed of "piedra cantera." A safety fence was constructed only on the side of the stairs facing the crater (see Photograph 19). The safety fence is similar to the one installed along the crater edge at the OPO. It consists of a half-wall (about 18 inches high) of cinder blocks faced with lava rock, set between 6-foot long reinforced concrete posts that are embedded in concrete-filled holes. Again, when the POP and OCB were constructed in 1978-1979, a thick, zinc-coated iron chain was positioned between the concrete posts of the safety wall to afford better protection for the visitors. The remnants of the corroded chain were removed years ago and, today, only the half-wall and concrete posts prevent something or *someone* from falling into the crater. The upper segment of stairs at the OCB and the damaged and deteriorated walkway beneath the cross are considered by the consultant to be one of the most serious safety concerns at the park. At the top of the OCB, a raised circular base constructed of concrete cylinders supports a tall (20 feet high?) wooden cross, made up of creosote-treated wooden poles anchored in earth and concrete.

2.7.1 Assessment of Geologic Hazards at the OCB

The geologic hazards at the OCB are primarily due to the precarious position of the uppermost segment of stairs at the edge of the crater, the increasing erosion of the unconsolidated materials from beneath the stairs, especially along the lowest segment, and the effect of the volcanic gases on the integrity of the building materials, especially the reinforcement bars inside the concrete posts. Furthermore, the lineament that is visible on the north flank of Volcán Nindiri appears to be a fault trace that cuts the old Crater Nindiri rim just east of the base of the cross, offsetting the

pyroclastic materials. If it is an active fault, slight movement along the fault plane may be the cause of the failure of a section of safety wall in the uppermost stairs segment (Photograph 23).

In addition to the geologic hazards, weathering of the wooden elements of the park's infrastructure may represent a significant hazard. The short wooden posts that lined the parking area at the OBI and that are now exposed by erosion show evidence of decomposition below the point where they were interred in their concrete-filled post holes. The decomposition has reduced the original 10- to 12-inch diameter of the post by almost 2 inches (Photograph 24). The much longer wooden poles of the Cruz de Bobadilla may have suffered the same fate. If so, the additional stress on the poles from the wind currents that buffet the highest points in the crater area may cause the poles to snap with little warning.

2.7.2 Infrastructure Options at the OCB

Option 1:

Replace the security fence half-wall with a full wall of cinder block faced with natural stone; repair areas undermined by erosion; do not restrict visitor access to the top of the Cruz de Bobadilla.

Pros:

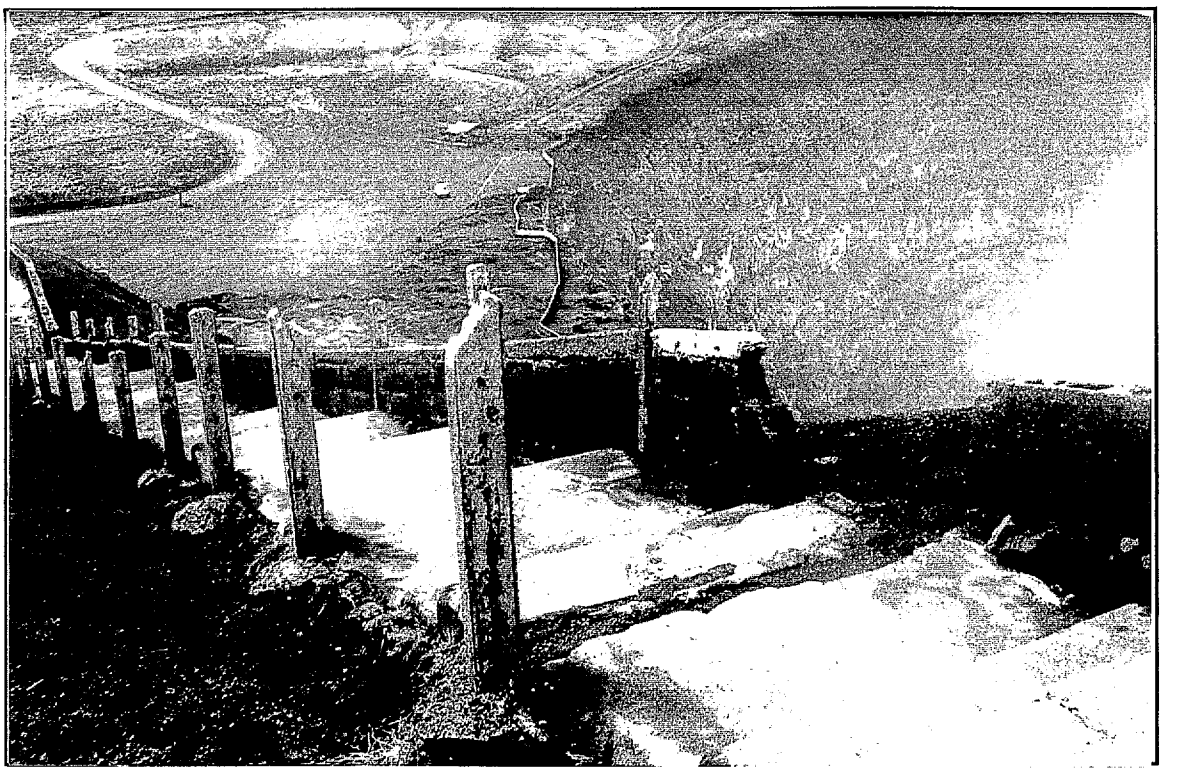
- Major attraction at the PNVM is preserved
- Visitor safety is improved by extending safety fence to full height

Cons:

- The cost of repair to the safety fence will be significant
- Continued movement of faults or settlement along fractures may continue to undermine the infrastructure of the OCB
- Erosion of the unconsolidated material beneath the stairs will be difficult to control, will require constant maintenance, and may be ineffective

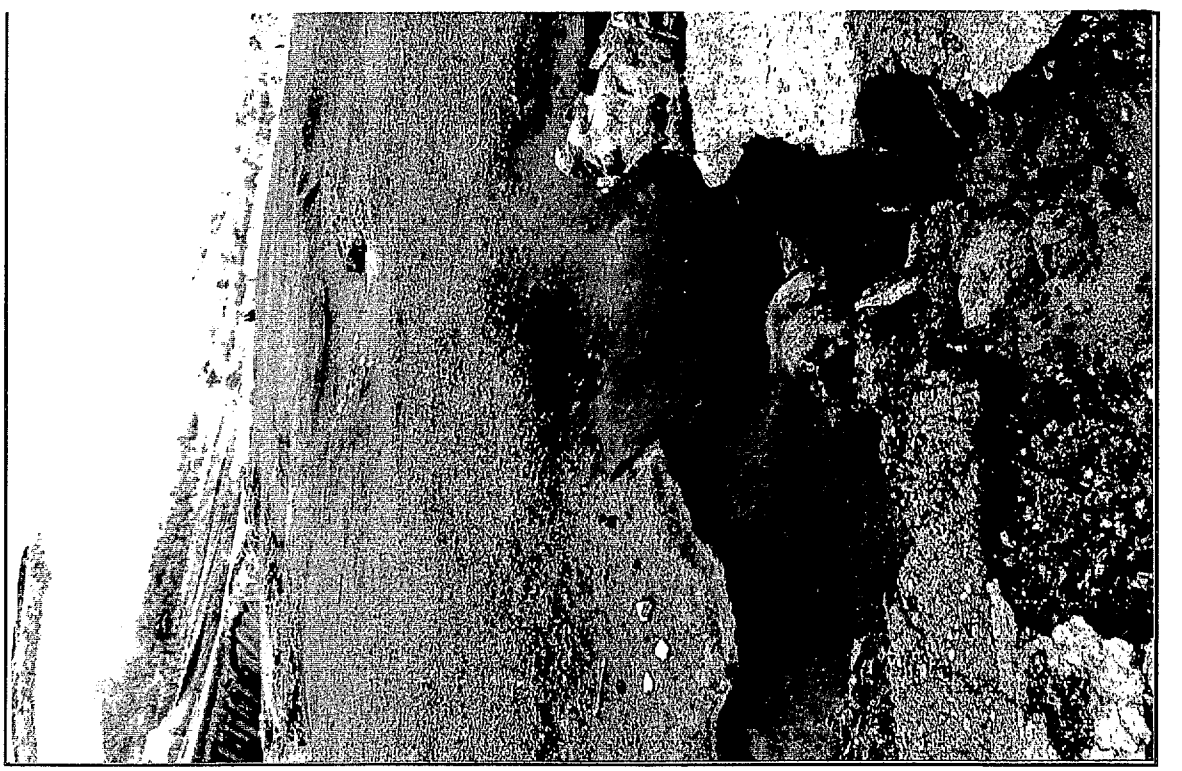
Option 2:

Recommended alternative. Terminate the stairs at the top of the second segment; replace the security fence with a full wall of cinder block faced with natural stone; repair areas undermined by erosion and re-engineer surface drainage to mitigate further erosion damage; construct a new viewing platform at the end of the second stairs segment,



Photograph 23 ▲

Damaged portion of the safety wall near the top of the OCB. Note the inadequate height of the wall at the edge of a precipetous drop into Crater Santiago. The strength of the concrete anchoring posts has been significantly degraded due to corrosion of the iron reinforcement bars by volcanic gases.



Photograph 24▲

Decomposition of part of the wooden posts embedded in concrete at the edge of the OBI parking area. The reduction of the cross-sectional areawhere the post was embedded in a concrete base raises questions about the strength of the vertical wooden poles of the Cruz de Bobadilla. This concern may provide additional impetus to restrict visitor access near the base of the cross.

including an interpretive plaque for the Cruz de Bobadilla and the view northward of the Masaya Caldera walls and secondary vents; remove the remaining stair segments to prohibit access to the base of the wooden cross structure; if possible in the future, replace the wooden cross with a cross made of synthetic resin material such as those intended for industrial use under high corrosive conditions.

Pros:

- Major attraction at the PNVM is preserved with some restrictions
- Eliminate risk to visitors from failure of the most dangerous portion of the stairs/safety fence and from failure and fall of the wooden cross
- Removal of stairs/walkway will eliminate the temptation of some visitors to scale whatever barrier and warning sign is emplaced, permitting better control of visitors who feel compelled to climb to the highest accessible point

Cons:

- Significant initial cost of removing stairs and safety wall above second segment and cost of construction of improved security fence and new viewing platform at top of second stairs segment
- Probability of a residual scar after restoration of the hill slope below the cross where the stairs and walkway were removed

3.0 SPECIFIC SAFETY ISSUES

3.1 Worker and Visitor Protection from Exposure to the Volcanic Plume

Volcán Masaya has been identified as one of the most prolific natural sources of sulfur dioxide gas in the world, producing as much as 500,000 tons per day (Stoiber and Williams, 1986). Scientific interest was focused on the environmental effects of the gases when renewed emissions from the volcano in the late 1950s and the early 1980s began to damage coffee crops, fences, telephone wires, and metal equipment at farms in the Carazo highlands and at a cement plant near Montelimar on the Pacific coast (Bolt *et al.*, 1975). At the time, however, studies were driven more by concern for the damage to crops and infrastructure leading to immediate economic losses than by concern for the impacts to human health.

3.1.1 Composition of the Volcanic Plume

The plume of gas emanating from Volcán Masaya consists primarily of water vapor, sulfur in various forms (such as S_2, SO_2, and SO_3), and chlorine as HCl. Studies at other volcanoes indicate that particles collected from the plume are more than 95 percent dilute sulfuric acid droplets. Poisonous higher sulfides of hydrogen, including an unstable oxide of sulfur and H_2S, have been found to occur at low but still elevated concentrations near volcanic vents (Blong, 1984, p. 122) . The principal gases (S_2 and SO_2) are released from the magma within the volcanic conduit and convect upward, reacting with water droplets that condense above the vent to form sulfurous acid. The sulfurous acid oxidizes in air to form sulfuric acid. The reactions occur slowly, so that the concentration of sulfuric acid in the plume increases with time and distance downwind from the volcano. Sulfur compounds dominate in the volcanic plume, but other minor components, such as hydrofluoric acid, carbonic acid and ammonia, may cause significant environmental impacts due to their toxic or corrosive characteristics.

In addition to the gas species mentioned previously, volcanic plumes generally carry some quantity of fine ash from the volcanic conduit, even when a volcano is not erupting. The quantity of ash carried in the plume is generally small as long as the volcano is degassing continuously and unable to accumulate enough internal pressure to sustain an eruption. Volcanoes that degas in violent bursts lift huge quantities of ash high into the stratosphere. Ashfall from large eruptions may continue to fall in amounts concentrated enough to cause health problems and damage to crops and machinery for many weeks after the eruption has ceased.

3.1.2 Hazards to Human Health from the Volcanic Plume

Numerous occupational health studies have been conducted on the effects of prolonged inhalation of ash from volcanic eruptions because of applicability to the conditions encountered by mine workers, sand blasters, and other industrial laborers (Bernstein, 1983). Medical conditions

suffered by those occupational workers include chronic bronchitis, pneumo(vol)coniosis, and silicosis.

Fine ash may be present in the emissions from Volcán Masaya, but the consultant found no reference that quantified how much, if any, the PNVM staff may be exposed to fine particulates from the plume. For the most serious respiratory affliction (silicosis) to develop, the victims must be consistently exposed to high concentrations (much greater than 50 micrograms per cubic meter ($\mu g/m^3$) of crystalline silica that is less than 10 microns in size [National Institute for Occupational Safety and Health (NIOSH) exposure limit, cited in Blong, R.J., 1984, p. 92]. Most of the fine particles likely to be produced by an eruption at Masaya would consist of non-crystalline basaltic glass. Although other minerals may be represented, the presence of crystalline silica (quartz, cristobalite, or tridymite) would be highly unlikely because of the overall composition of the magma. And except during and after eruptions, when an abundance of fine ash is deposited from the eruptive cloud or is reworked by wind, it is unlikely that the environment at Volcán Masaya exposes the park workers to airborne particulates in concentrations any greater than what might be expected regionally, due to prevailing agricultural and industrial activities and atmospheric conditions.

The effects of prolonged exposure to volcanic gas species, however, have not been well studied. Historic records indicate that degassing occurs at Masaya at roughly 25 year intervals in periods that last from 5 to 10 years. Measurements made during a period of active degassing in the early 1980s indicate that the *24-hour average* SO_2 level in areas downwind of the volcano is 1 part per million (ppm) or higher, significantly above the World Health Organization recommended maximum of 0.5 ppm, 24-hour mean. Instantaneous measurements of sulfate aerosol concentrations thirty kilometers downwind have reached 400 $\mu g/m^3$ (Baxter *et al.*, 1982). The same study notes that eye and skin irritations have been reported following extremely acid rain (pH 2.4-3.4) that fell through the Volcán Masaya plume. The acid rain from the Masaya plume is also suspected of reacting with zinc galvanizing on house roofs, possibly resulting in release of heavy metals into local drinking water (Baxter *et al.*, 1982).

3.1.3 Options for Protecting Workers and Visitors from Volcanic Gases

Options for protecting workers and visitors from the effects of the volcanic gases at the PNVM include provision of personal protective equipment, availability of emergency oxygen and other equipment to respond to respiratory crises, and operational plans and training to evacuate or restrict access to the summit area when dangerous conditions exist. The options are discussed in the following sections.

The PNVM management must be proactive in establishing and implementing a policy to protect park staff from the effects of exposure to the volcanic gases and acid rain. Long-time park staff already may have suffered permanent lung damage or developed respiratory or skin sensitivities

from persistent and unprotected exposures to the gases. Medical baselines should be established for individual workers, and their respiratory health should be evaluated yearly.

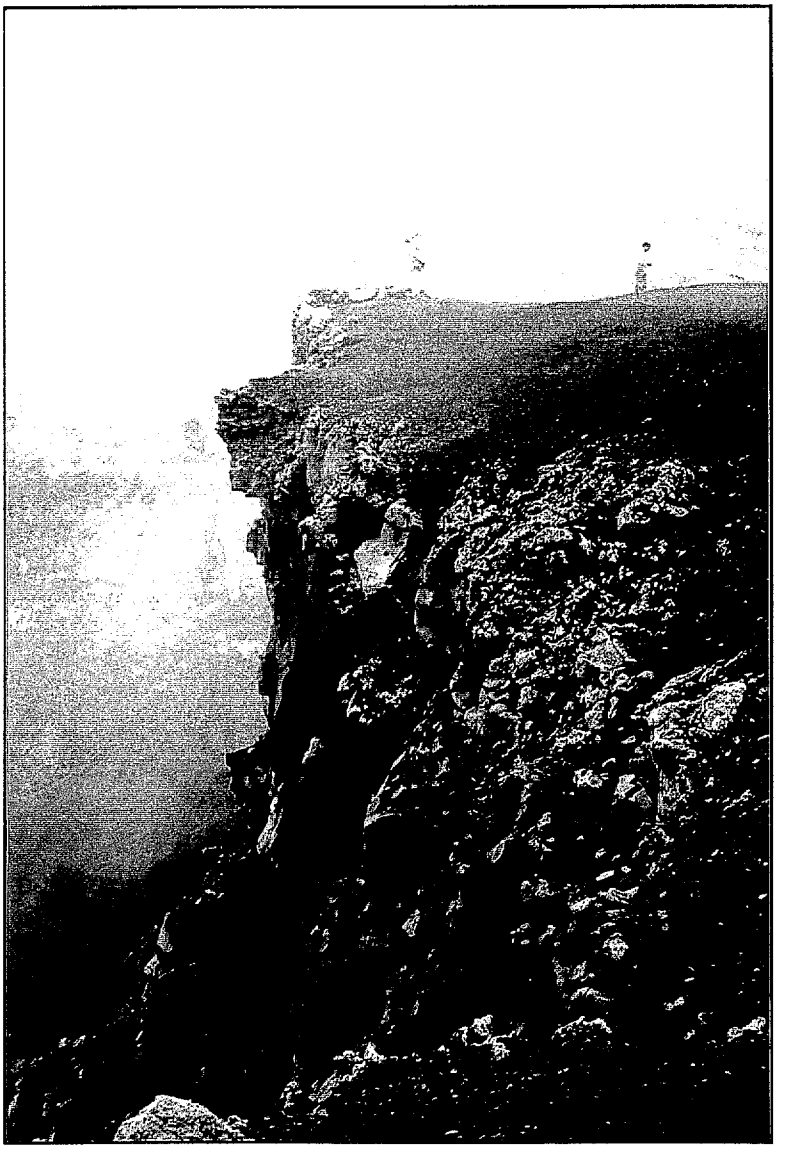
The park guards should select one of their members to work with PNVM management and an occupational health advocate to establish and implement mechanisms to safeguard employee health. Alternative approaches to visitor access or control may be required to reduce the amount of time park staff must be exposed to the concentrated levels of volcanic gas present in the crater area.

3.1.3.1 Personal Protective Equipment

Personal protection equipment that will guard against the effects of the gases from Volcán Masaya include full-coverage clothing (such as a hat, long pants, and a long-sleeved shirt that leaves as little exposed skin as possible) and gas masks with an appropriate filter cartridge for acid and toxic gases. Half-face gas masks with cartridges can be purchased for about $20.00 each. Disposable masks that filter acid mists are available for about $3.00 each. Although not intended to be reused, disposable masks can be made to last 1 or 2 weeks but are probably not a cost-effective solution for the PNVM.

Little can be done to influence the clothing that visitors choose to wear in the park and it is impractical to provide gas masks to those who visit the crater area. However, a notice describing the respiratory and acid rain hazards should be made available at the park entrance to advise visitors with special skin or respiratory sensitivities. The advisory should recommend that visitors seek shelter even in a light rain because of the probability that falling raindrops may be highly acidic and cause skin irritations or damage clothes. The acid rains also have a potential to damage the finish on automobiles. Due to the limited time most visitors stay in the crater area (probably less than 1 hour), there is little likelihood of suffering permanent respiratory damage from the volcanic gas, but highly sensitive individuals should avoid the crater area altogether.

The uniform for the park guards was selected considering the need to protect the skin from the effects of exposure to excessive amounts of acid rain and ultraviolet sunlight. The park staff should be encouraged to wear their hats at all times and to avoid rolling up their shirt sleeves. In addition, guards who are stationed in the crater area should be equipped with gas masks and be required to use them. Because the volcanic plume generally settles over the south rim of Crater Santiago (Photograph 25), gas masks should be worn nearly continuously when the guards are stationed at the OBI. The masks can be removed for short periods when winds conditions shift and the plume is not concentrated in that area. For other stationing points in the crater area, the gas masks should be kept immediately accessible. The guards should be trained and encouraged to don the masks whenever concentrated gases from the plume drift toward their stationing point.



Photograph 25 ▲

Profile of main viewing area of the OBI, showing near constant conditions of low visibility and high concentration of volcanic gases. Lava flow underlying the viewing area is unit Qv25. Light beige/pink color on surface of lava in the immediate foreground is due to alteration of the rock by long exposure to volcanic gases. Fresh grey color of some areas of the rock face indicates recent rockfall.

Appropriate gas masks should be acquired immediately. An industrial hygienist who is familiar with the quality and reliability of locally available personal protective equipment and its distribution and servicing network should recommend the type of mask that would be appropriate for the working conditions at the park. Both the PNVM management and staff should receive training from a qualified industrial health specialist on the use of personal protective equipment and the effects of prolonged exposures to acid or toxic gases and acid rain. Once the gas masks have been acquired, the employee representatives and park management should monitor whether workers have immediate access to and/or are using their personal protective equipment. Some type of incentive or recognition system may be needed to motivate the staff to use the equipment.

3.1.3.2 Emergency Medical Equipment

The consultant did not obtain statistics on medical emergencies that have occurred in the park during the past 20 years. From conversations with park staff, however, she learned that the most common serious injuries were caused by vehicular accidents. Most accidents were attributed to driver error on the winding park roads or to the poor condition of some of the cars, trucks, and buses that enter the park. Since PNVM staff generally are well equipped with hand-held radios and because emergency rescue services and medical treatment are available nearby in Masaya, it does not appear necessary to provide special equipment and training for park staff to treat trauma injuries to visitors in the park. A basic life-saving course, however, should be part of the training program for the park staff.

PNVM management should evaluate records of medical incidents in the park to determine whether respiratory crises provoked by the volcanic gas are a significant hazard to park visitors and staff. If respiratory crises are a significant hazard, an emergency medical supervisor at the local fire and rescue center should be asked to make a recommendation on the type of medical equipment that should be available, the training required to support its use, and whether the equipment should be maintained in the crater area or at the Visitors Center.

3.2 Public Access Restrictions in the Crater Area

3.2.1 Effectiveness of General Crowd Control Measures

Many of the options presented in Section 2.0 of this report combine infrastructure modifications with changes to visitor access or use patterns. The consultant observed that visitor control exercised by the park guards was inconsistent with warning signs and generally ineffective in keeping visitors away from dangerous areas. Modifying visitor behavior will be easier if PNVM staff have a basic understanding of the nature of the geologic hazards in the crater area and participate in defining the measures that are taken to mitigate the hazards. Briefings by local geologists and engineers would help develop that basic understanding.

As an example, there is currently no well defined policy or practice of restricting access to the top

of the OCB. The structural instability of the safety wall and continued erosion of the unconsolidated and fractured pyroclastic material beneath the stairs and walkways eventually will cause a failure of that infrastructure. And if the existing safety wall near the cross fails to detain a stumbling visitor, the victim likely will end his fall at the bottom of Crater Santiago. Based on an evaluation of relative priorities at the park, MARENA and PNVM management may decide to construct a new viewing platform and remove the uppermost stairs and walkway at the OCB (Option 2 in Section 2.7.2). Understanding the basis of the hazard, as well as the planned actions to address the problem, a park guard will have greater success dealing with a visitor who questions why the stairs to the cross have been closed (Option 1 of Section 2.7.2).
The PNVM management must take decisive action to restrict access to dangerous areas. A credible representative of the park's senior management should be available on days of high visitation to provide authority and to support the park guards in crowd control. Park guards and interpreters should practice role-playing in training sessions to develop skills in directing visitors away from restricted areas. Weekly staff meetings could provide opportunities for short training courses and to review "lessons learned" from handling difficult visitors or situations.

Once decisions are made to close areas to public access, permanent wooden signs with a clear, concise message should be installed as quickly as possible. Park guards must be able to respond politely and knowledgeably to questions about the restrictions, but also must be prepared to enforce the sign messages with more urgent and direct means of communication. A megaphone should be available to the senior park guard stationed at the OPO to communicate with pedestrians transiting between the OPO and the OBI. Finally, it may be necessary to escort uncooperative or highly disruptive visitors out of the park. Park staff should practice handling such an eventuality in training sessions.

3.2.2 Special Access Restriction during Volcanic Events/Crises .

The obvious signals that precede volcanic eruptions have been reasonably well established by modern scientific investigations. The more subtle volcanic signals that precede a volcanic "crisis" at Masaya and other specific volcanoes are not well known. This is because each volcano has unique characteristics that only rarely have been the focus of long periods (i.e., 10 to 50 years) of monitoring and observation.

Volcán Masaya has been relatively well studied since the mid-1970s. As a result, the personnel responsible for INETER's monitoring program are able to recognize periods during which seismic signals and/or the chemistry of the volcanic gases at Masaya are anomalous enough to warrant concern. In addition, on at least one occasion during the consultant's visit, the park guards directed visitors to leave the crater area because of dangerous atmospheric conditions, including low visibility and a concentration of the volcanic fumes in the crater area. Until a better understanding of Volcán Masaya's behavior is established, the intervals of dangerous or anomalous conditions recognized by park guards or by volcano specialists at INETER must be considered potential threats to visitor and staff safety. In the end, these "crises" may represent

only temporary hazards to safe park operations, or they may be precursors to a life-threatening eruptive event.

Reliable communication needs to be established between the directors of INETER's volcanic monitoring program and the PNVM to ensure that understandable information is shared in a timely manner between responsible staff level(s). Furthermore, the responsible staff who receive the information must be trained and empowered to respond appropriately. Senior management at INETER and the PNVM/MARENA should discuss and agree upon the most efficient channels of communication and backup measures that can be employed. Commonly, the need for communication will be initiated from INETER, since increased volcanic activity can be detected early by the seismic signals that are relayed electronically from Masaya. However, communication plans between the two agencies also should consider that anomalous conditions at Volcán Masaya may be first observed in the field and, therefore, information may need to flow from the PNVM to INETER. The basic elements of an agreement on communications between INETER and PNVM management should be formalized in a memorandum of understanding. The agreement should include provisions for emergency identification of critical personnel and authorization of access to the park by INETER volcanologists.

INETER volcanology specialists should prepare a description of the types of volcanic crises that are recognized at Masaya and their possible implications. The description and implications should be written in non-technical language for use by non-geologists. In collaboration with an experienced volcanologist and INETER management, the Director of PNVM should document and approve a set of four or five simple, clearly defined, and incremental levels of response aimed at protecting park staff and visitors when volcanic crises occur. All parties contributing to the discussion and selection of appropriate response levels should understand the implications and difficulties of each others' respective roles in protecting lives and providing public or scientific services. The four or five response levels that are adopted should range from a minimal response, such as providing verbal warnings at the park entrance of possible respiratory effects of increased gas emissions, to a maximum level of response, involving evacuation and closing of the entire park.

After appropriate levels of response have been selected, the PNVM management should develop a simple plan of action to be implemented by the critical players for each response level. Responsibilities of critical players under each response scenario should be described in the plan of action. As a general rule during public access hours at the park, one qualified person should be responsible for making decisions on implementing any response level he/she determines to be appropriate. That responsibility should be clearly delegated when the Director or Administrator of the PNVM are not onsite. In addition, the senior park guard stationed in the crater area should be delegated the authority to evacuate the crater area at any time, without prior approval of higher management. Any material resources required to mobilize a crisis response, such as color-coded hand flags or spotlights, bullhorns, radios, or special high-powered transmitting stations,

should be identified. Finally, all PNVM staff should receive thorough training to implement the response levels.

3.3 Selection of Resistant Materials for New Construction or Upgrades

Materials that are resistant to volcanic gases are the same as those recommended for industrial use under highly acid conditions. Resins, plastics, ceramics, and some anodized metals are the best examples of materials resistant to acid environments. In general, the materials that are specifically manufactured for hazardous industrial uses are expensive and/or of limited visual appeal when compared to more readily available natural products such as wood and stone.

Some of the materials used 20 years ago to construct the visitor infrastructure at the park have survived the acid environment surprisingly well. Cast aluminum signs and concrete, concrete block, and natural stone constructions have proven to be the most resistant. Reinforcement rods embedded in concrete posts and metal chain strung between the posts have fared very poorly due to the rapid oxidation of iron and other metals with exposure to acid rain and volcanic gases. Infrastructure and signs constructed of wood have been resistant to the natural environmental conditions, but have not proven resistant to pilferage by people scavenging in the park for firewood or used lumber for construction.

The large sign that was installed in 1978 at the entrance to the OPO was designed and constructed in wood using wooden "nails" and special joints to connect heavy structural elements.[5] Wooden nails were selected because iron or steel nails were expected to have a relatively short lifetime of 5 to 10 years in the crater area. In retrospect, the very rapid degradation of the thick zinc-coated iron chain that was installed in about 1978 indicates that the life expectancy of metals other than aluminum is even shorter (2 to 4 years) than had been anticipated.

Assuming that wooden signs and structures will continue to be scavenged by intruders in the park, relatively massive concrete and stone structures appear to be the most stable and resistant to the volcanic environment. The infrastructure designs should use wide bases of support that do not require (as much) iron reinforcement to provide structural stability.

Construction materials made of resins that are manufactured for use in acid environments are a reasonable alternate building material, if appropriate non-custom structural elements meeting the design requirements are available for purchase. Although the cost of importing the materials will

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5 The sign's wood surface was sealed with stain instead of paint. Routed lettering on the sign was filled with a 1/8- to 1/4-inch thick layer of latex-based paint mixed with finely ground glass to provide a reflective surface under low-light conditions. Unfortunately, the sign was scavenged and destroyed before the long-term performance of this technique for wood construction and finishing could be evaluated for the crater area. At least two years after its construction, the sign continued to be structurally sound and had high visual appeal.

be high, the resin materials are light weight, very strong, resistant to the effects of the volcanic gases and acid rain, and require less disturbance of land and landscape during installation. The last consideration may be one of the most important, since it will be difficult to camouflage the scars that will be evident when some of the park's more massive safety walls or other infrastructure must be removed or replaced.

Annex B contains information drawn from marketing literature for several types of synthetic materials that are manufactured for industrial use under acid conditions. PNVM design staff will have to evaluate the characteristics and costs of the materials to determine whether they offer an attractive alternative to locally available concrete, concrete block, and natural stone for the park's infrastructure needs.

3.4 Maintenance Program for Existing Infrastructure and Interpretive Resources

Severe financial limitations and a policy of using the available budget to maintain a high employment level in lieu of operating funds has led to a significant decline in the maintenance of buildings, roads, and other infrastructures in the park. From conversations with park personnel, the consultant found that building maintenance has been done on an ad hoc basis by the park's administrative, guard, or cleaning staff. A maintenance plan for the park was not located and apparently does not exist.

The PNVM staff does a commendable job of keeping the floors and surfaces in the Visitors Center clean, but there was no running water or working toilets[6] on the three days the consultant visited the park. A large window in the unoccupied cafeteria/conference area at the Visitors Center had fallen in several days before the consultant visited the park. Examination of the window frame revealed that the wood was soft and spongy, either from decay or termite infestation. The main park road ("Camino Real del Popogatepe") has not been patched, resurfaced, or coated with asphalt since the park was inaugurated. The extremely rapid erosion of the paved parking area at the OBI over the past 3 years is a good example of what can be expected if existing potholes in the pavement are allowed to break through the remaining basal layer of asphalt.

A civil engineer or similar professional with experience in infrastructure maintenance should assess the condition of the Visitors Center, the Camino Real del Popogatepe, and other major elements of the park's infrastructure to determine what actions and resources are needed to repair

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6 Due to the PNVM's wide international visitation, special attention is needed to ensure that the visitor's lasting impression of the park is not marred by lack of basic sanitary services. The Visitors Center should be connected to the municipal water supply if that system is available at the park entrance. The existing pump that draws from an onsite well (or is used to boost municipal water) into a holding tank at the Visitors Center should be repaired and a backup pump acquired. Toilet paper and soap dispensers in each bathroom should be adequately stocked at all times.

the existing damage and what is required on a long-term basis to ensure adequate maintenance of the investments.

3.5 Volcano Monitoring and Need for Multi-Agency Coordination

Because each volcano is unique, the information gathered as part of a volcanic monitoring program (such as seismic, gravimetric, magnetic, geodetic, and gas chemistry data) is used to establish a baseline of measurable volcanic "signals." The measurable parameters are evaluated against direct observations of eruption, deformation, increased gas emissions, or other events that occur during the succeeding hours, weeks, months, or years. Because Volcán Masaya has been monitored systematically for a relatively short time, a baseline of what constitutes "normal" comportment and what constitutes "crisis" mode is not well known.

There are three major "programs" of volcano monitoring ongoing at the park. The first is the program of informal monitoring by daily observation carried out by the PNVM staff. The second is the official program of periodic monitoring carried out by INETER personnel. The third is a program of intermittent monitoring conducted by national and international scientists, many of whom have long-running research interests in Masaya. Most of the sophisticated geophysical monitoring studies conducted at Masaya, such as gravity surveys, resistivity surveys, and precise geodetic surveys that use global positioning satellite systems, are done by scientific researchers who visit Masaya once every several years. Although these visits are infrequent, the data and interpretations made by these researchers remain a very important part of the growing body of information that elucidates the comportment of the volcano. Each of the three monitoring programs can and should play an important role in improving our understanding of Volcán Masaya.

INETER is the lead agency for Nicaragua's nationwide program of volcano monitoring. During her visit, the consultant accompanied Lic. Marvin Centeno and Lic. Martiza Rivera of MARENA to the INETER offices to meet with the Director of INETER, Ing. Cesar Avilez. The purpose of the visit was to coordinate the exchange of information regarding the current study of the geologic stability of the crater area at the PNVM. Ing. Avilez presented the key members of the INETER staff directly involved in the monitoring of Volcán Masaya (including the Director of the Department of Geophysics and Volcanology, Ing. Luis Munoz, the specialist in volcanic gases, Ing. Marta Navarro, and the lead volcanic seismologist, Ing. Cristian Lugo).

At that meeting, Ings. Munoz and Navarro described the current level of investigations at the PNVM, some of the monitoring data that are available to support the park's interpretive program, and three areas where coordination and support between INETER and the PNVM could be improved for the benefit of one or both agencies. The three areas are:

- INETER has extensive library resources that contain scientific publications relevant to the park's interpretive program, specifically many of the publications that document the

findings of international research that has been conducted at Volcán Masaya. Ing. Navarro provided access to three important publications that were photocopied for inclusion in the PNVM archives.

- Many of the most active international volcanologic researchers appear to coordinate their plans and field activities through INETER's Department of Geophysics and Volcanology. Nicaraguan academic researchers appear to coordinate their plans and field activities directly through the PNVM. Generally, the international researchers are allied with academic institutions that are major centers of volcanologic study, including the Open University (U.K.); Arizona State University, Dartmouth College, and Michigan Technological Institute (U.S.); and the University of Toronto (Canada). Most of the international scientists who conduct research programs in Latin America are familiar with and sympathetic to local needs for information and technology transfer. In addition, most speak passable to excellent Spanish. Better coordination and communication between MARENA/PNVM and INETER regarding scientific plans and field activities could provide excellent opportunities for the scientific community to share data and insights, and for the park to benefit through opportunities for staff training and interpretive talks at the park or in Managua.

- Volcanic monitoring equipment deployed in and around the PNVM has, in some cases, been stolen or damaged. This has resulted in delays or loss of important data, the economic burden of replacing valuable equipment, and frustration on the part of INETER's scientific staff and management. The INETER volcano monitoring program could benefit from an increased vigilance by park guards and expanded public relations efforts by the PNVM outreach staff to sensitize local populations to the park's mission of improving environmental understanding and fomenting environmental protection.

In addition to the three areas for cooperation articulated by INETER volcano monitoring personnel, a fourth should be added as follows:

- In collaboration with the INETER personnel (including field geologists) who monitor Volcán Masaya, the PNVM management should define a short (1-page) worksheet that is to be submitted to the Park Director weekly to document any significant geologic (or other) changes observed in the crater area or the park as a whole. The worksheet should be completed by a park ecologist after conferring with the park guards and interpretive specialists who may have been present in the crater area and witnessed an event. The documented events or observations should include major rockfalls or landslides, explosions in the volcanic conduit, emission of dark puffs of ash in the plume, earthquakes and where they were felt in the park, increased fumarole activity (at Comalito, the floor/walls of Crater Santiago, or elsewhere), and anomalous behavior by park wildlife (such as excitation or absence of the parakeets in Crater Santiago). The worksheet should have a small diagram of the crater area so that the location of each

event can be recorded. In addition to the weekly report, the park should begin a photo archive to capture visual evidence of changes in the morphology of the crater area and other significant events. A series of six to twelve panoramic photographs of Crater Santiago (and other areas such as Comalito where change may be occurring) should be taken at approximately 3-month intervals. INETER should be notified of the availability of the visual observation records for use as a supplement to the seismic, gas chemistry, and overall monitoring program. After an initial 6 month period during which visual observation records have been gathered by the park staff, the program should be reevaluated by PNVM management and INETER volcano monitoring personnel to determine the utility of the information obtained and/or identify any improvements required.

The potential for increased coordination and support in the aforementioned areas should be the focus of negotiations between the PNVM and INETER management. Specific accords on the subject areas and mechanisms for coordination and support should be formalized as part of the memorandum of agreement on inter-agency communication described in Section 3.2.2 of this report (or in a separate written accord between the two agencies).

4.0 ASSESSMENT OF PNVM INTERPRETIVE RESOURCES

4.1 Visitors Center

The consultant obtained from TR&D archives at MARENA a copy of a 24-page report titled "Diagnotstico y Recomendaciones para la Rehabilitacion del Centro de Interpretacion Ambiental, Parque Nacional Volcán Masaya," dated September 1992. The report was prepared by a U.S. Peace Corps interpretive specialists (possibly C. Taft) who worked at the PNVM for some period between 1983 and 1993. It briefly describes each existing exhibit at the Visitors Center and summarizes recommendations for improving the overall content and sequence of the interpretive themes presented. Since those recommendations are based on a more thorough evaluation than was intended for the present scope of work, Section 4.1 of this report is focused on providing more detailed recommendations or alternatives to those presented in the September 1992 report. For reference, the September 1992 report is reproduced in Annex C.

The layout of the Visitors Center is shown in Figure 4-1. The area designations used in Figure 4-1 are the same as those used to describe the existing exhibits in the September 1992 report, except that an additional area (Area H) has been designated. The interpretation of geology and volcanology, which accounts for about 50 percent of the exhibit area, is found principally in halls A through E.

4.1.1 Exhibit Areas

The Visitors Center exhibits areas are housed in a stylish building designed with interesting architectural detail and a natural ventilation system. Overall, the personnel, services and exhibits at the Visitors Center present a very positive image of the PNVM. The following general comments are offered, followed by more detailed observations and recommendations in subsequent sections of this report.

- The overall themes within each exhibit area should be announced in bold and imaginative titles.
- The exhibits are generally of excellent visual quality but accompanying text and titles are ineffective or lacking.
- A simple hierarchical scheme of titles is needed to offer different levels of understanding depending on visitor interest.
- Any effort to improve the Visitors Center requires the identification of a visually appealing yet durable method of presenting short passages of text or simple graphics on

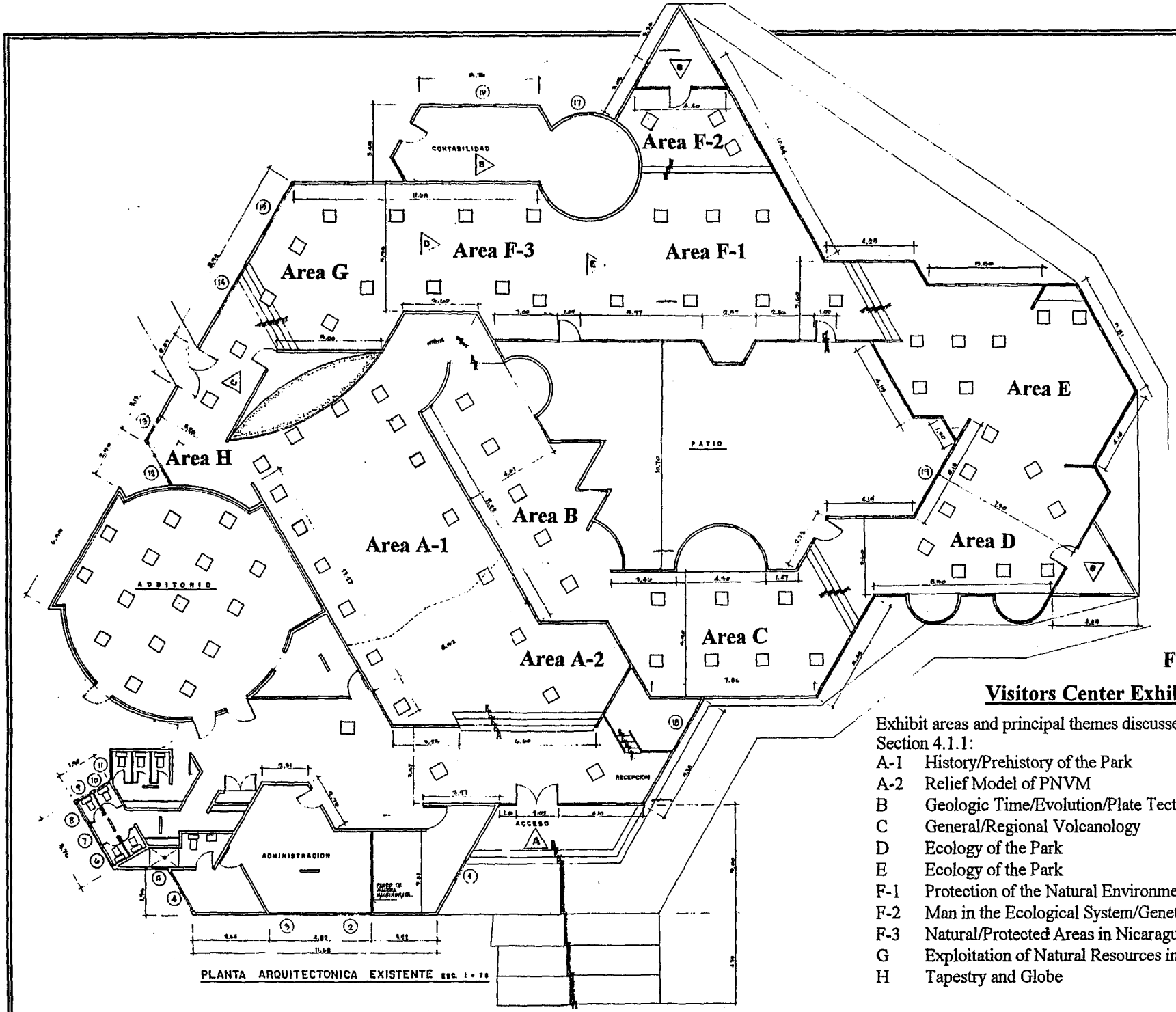

Figure 4.1

Visitors Center Exhibit Areas

Exhibit areas and principal themes discussed in Section 4.1.1:

A-1	History/Prehistory of the Park
A-2	Relief Model of PNVM
B	Geologic Time/Evolution/Plate Tectonics
C	General/Regional Volcanology
D	Ecology of the Park
E	Ecology of the Park
F-1	Protection of the Natural Environment
F-2	Man in the Ecological System/Genetic Diversity
F-3	Natural/Protected Areas in Nicaragua
G	Exploitation of Natural Resources in Nicaragua
H	Tapestry and Globe

vertical and inclined panels or other large flat surfaces (see discussion of silkscreening process in Section 4.1.1.1).

- Although the laurel wood paneling used throughout the Visitors Center has a luxurious visual appeal, the strongly contrasted grain in the wood competes for attention when juxtaposed closely with the exhibits. The bases and background panels for the exhibits generally should be **matte surfaces** in **muted color tones**.

- The building has many interesting semi-circular and triangular alcoves. These areas are often used to recess exhibits, leaving a front surface that is flush with the walls on either side of the alcoves. The exhibits should project into the room to impose a non-linear path through the exhibits and to break up the rectangular volume of the room. The alcoves should generally be left open for occasional seating or decorative plants or photographs.

- Where possible, dioramas should be constructed with free-standing cases that do not rely on the integrity of the ceiling panels to protect them from animals and insects. In addition to affording better protection and ease of inspection of the dioramas, the free-standing cases will provide added mobility for updating/rearranging exhibits and will reserve the alcoves for decorative use or seating.

Sections 4.1.1.1 through 4.1.1.5 provide detailed recommendations on Exhibit Halls A, B, C, D and E where most of the geologic/vulcanologic exhibits are found. A summary of the recommendations is contained in Table 4-1. A few additional recommendations for specific exhibits in other areas of the Visitors Center are contained in Sections 4.1.1.6 through 4.1.1.8.

4.1.1.1 Exhibit Hall A

Exhibit Hall A is entitled, "La Historia del Volcán Masaya." The hall has been divided into two areas (Figure 4-1). From the entrance of the Visitors Center looking toward the large mural at the end of the hall, Area A-1 is the main body of the hall, encompassing all of the exhibits on the left (north) wall, the large mural, and most of the exhibits on the right (south) wall, with the exception of those in Area A-2. Area A-2 is the small alcove directly behind the reception/sales area on the right (south) of the main hall.

Area A-1 contains an eclectic mixture of exhibits representing man's historic and prehistoric relationship with Volcán Masaya. When Exhibit Hall A was designed, it was intended to be a showcase for a series of eight paintings and the large mural commissioned by the Banco Central in about 1977 that were to be executed by Sr. Rodrigo Peñalba, an accomplished Nicaraguan painter. Only four of the paintings were finished before Sr. Peñalba's death in about 1979, and Table 4-1

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

Current Sequence Designation and Exhibit Title			Consultant Recommendations		
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
A2	Parque Nacional Volcan Masaya	retain as A2 (see Appendix C)	retitle and refocus text	"Masaya Caldera: Microcosm of our Natural Heritage" "La Caldera de Masaya: un Microcosmo de Nuestro Património Naturál"	A(1)
A1	Sala A - Historia del Volcan Masaya (panel de introduccion)	retain as A1 (see detailed discussion in Appendix C)	retitle and relocate	"The Record of Man at Volcan Masaya" "El Record del Hombre en el Volcán Masaya"	A(2)
A3	Arqueologia Precolombina	relocate as A3-1&2 (2 vitrinas nuevas), A12, A13 (see Appendix C)	retitle and redesign display (see discussion in Section 4.1.1.1); location dependent on use of oblique panels in Exhibit Hall A-1.	"Myths and Legends: Precolombian Inhabitants and the Smoking Mountain" "Mitos y Leyendas: Los Indígenas Precolombinos y la Montaña que Arde"	A(3)
A4	Escenas Historicas del Volcan Masaya	retain as A4 (see Appendix C)	delete title	(redundant with A1; individual exhibit elements throughout hall are titled)	N/A
A4(1)	Sacerdotista Aborigen (Pre-1500)	relocate with A1 (see Appendix C)	relocate	"Aboriginal Shaman" "Sacerdotísta Aborígen"	A(4)
A4(2)	El Bautizo del Volcan (1529)	resequence within A4-A13 (see Appendix C)	retitle and relocate	"Exorcism of Volcan Masaya in 1529" "Exorcismo del Volcán Masaya en 1529"	A(5)

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Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
A4(3)	La Exploracion de Oviedo (1529)	resequence within A4-A13 (see Appendix C)	retitle and relocate	"The Explorations of Oviedo (1529)" "Las Exploraciónes de Oviedo (1529)"	A(6)
A5(3)	Iconografia del Volcan Masaya (Vista del Masaya en el Siglo XVI - dibujo de Oviedo, 1529)	resequence within A4-A13 (see Appendix C)	produce in silkscreen ; location dependent on use of oblique panels in Exhibit Hall A-1	"A Renaissance Naturalist at Volcan Masaya" "Un Naturalísta del Siglo XV y su Visita al Volcán"	A(7)
A4(4) missing	La Bajada de Fray Blas de Castillo	recover and resequence within A4-A13 (see Appendix C)	recover painting; provide appropriate title and location in historical sequence	"The Search for Gold at Volcan Masaya" "La Búsqueda de Oro en el Volcan"	A(8)
A6	La Gran Erupcion de 1772	retain as A14 (see Appendix C)	retitle	"The Salvation of Pueblo Nindiri in 1772" "La Salvación del Pueblo Nindiriño en 1772"	A(9)
A4(5) - propuesto	Redescubrimiento del Volcan	none	delete	delete	N/A
A4(6) - propuesto	El Nacimiento del Crater Santiago	none	delete	delete	N/A

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

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			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
A4(7) - propuesto	La Odisea de los Ingenieros Alemanes	none	obtain photograph or other illustration to create exhibit; provide title and appropriate location in historical sequence	"An Attempt to Harness the Volcanic Plume" "Un Atentado de Embudar los Gases del Volcán"	A(10)
A5(1)	Iconografia del Volcan Masaya (Los Crateres en el Siglo XX - fotografia tomado por Dr. Bruno Mierifch)	resequence within A4-A13 (see Appendix C)	obtain information about Dr. Mierifch to provide context for picture; provide title and appropriate location in historical sequence	Depends on historical context of photo. Suggest something like "A 1920 Vacation at Volcan Masaya"	A(11)
A7	El Entorno Socio-economico del Volcan Masaya	eliminate	eliminate	eliminate	N/A

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

Current Sequence Designation and Exhibit Title		Consultant Recommendations			
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
B - un-numbered	Sala B - Geologia General (panel de introduccion)	consider new title and retain as B1 (see Appendix C)	retitle; relocate if necessary to provide better visibility	"Volcanoes: A Scientific Perspective " "Volcanes: Una Perspectiva Científica"	B(1)
C3	Larreynaga y su Hipotesis sobre los Volcanes	resequence as B5 (see Appendix C)	retitle; develop text to focus on early scientific rationization of volcanism; relocate to wall near entrance of Exhibit Hall B	"Volcanoes and 18th Century Scientific Thought" "Los Volcanes y el Pensamiento Científico del Siglo XVII"	B(2)
A5(2)	Iconografia del Volcan Masaya (Dibujo y Primer Mapa de la Caldera por Von Seebach, 1865)	resequence within A4-A13 (see Appendix C)	retitle; develop text to focus on 1800s scientific rationization of volcanism; re-produce graphics in silkscreen; relocate to wall near entrance of Exhibit Hall	"A 19th Century Geologist at Volcan Masaya" "Un Geólogo del Siglo XIX en el Volcán Masaya"	B(3)
B2	Los Volcanes de la Tierra	retain as B3 (see Appendix C)	retitle;provide appropriate text (see discussion in Section 4.1.1.2); use rotating globe to locate major volcanic features of the Earth	"Where do Volcanoes Form?" "Donde Forman los Volcanes?"	B(4)
B1	La Escala Geologica	retain as B2 (see Appendix C)	retitle; provide appropriate text; provide fossils, artifacts or photographs on all or glass cases to illustrate ; protect wall painting with handrail	"The Evolution of our Planet" "La Evolución de nuestra Planeta"	B(5)

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E					
Current Sequence Designation and Exhibit Title		Consultant Recommendations			
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Título Actual	1992 Report Recomendaciones	Overall Changes	Título Recomendado	sequence w/in hall
B3	El Movimiento de las Placas en America Central	retain as B4 (see Appendix C)	retitle; redesign to focus on cross-section of lithosphere; backlight and animate, if possible (see discussion in Section 4.1.1.2); may need to relocate	"Collision of Tectonic Plates" "Choque de las Placas Terrestres"	B(6)
C - un-numbered	Sala C - Vulcanologia General Regional (panel de introduccion)	retitle and retain as C1 (see Appendix C)	retitle	"Volcanoes: Volcanic Features and Eruptions" "Volcanes: Rasgos Volcanicas y Erupciones"	C(1)
C4(2)	Los Diferentes Tipos de Volcanes	retain as C4 (see Appendix C)	Combine C4(1) and C4(2) under a single title and interpret their cause-and-effect relationship; relocate at entrance to Exhibit Hall C	"Volcano Types and their Eruptive Styles" "Tipos de Volcanes y sus Estilos Eruptívos"	C(2a)
C4(1)	Los Diferentes Tipos de Erupciones Volcanicas	retain as C3 (see Appendix C)	Combine C4(1) and C4(2) under a single title and interpret their cause-and-effect relationship; relocate at entrance to Exhibit Hall C	"Volcano Types and their Eruptive Styles" "Tipos de Volcanes y sus Estilos Eruptívos"	C(2b)

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			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Título Actual	1992 Report Recomendaciones	Overall Changes	Título Recomendado	sequence w/in hall
B4	Estructura Interna de un Volcan	relocate (together with C3) as new B5 (see Appendix C)	retitle; improve text and label features; apply matte varnish to reduce glare; combine with existing elements D4(1) and (2) and relocate to the entrance of Exhibit Hall C, possibly including the end of Hall B at the entrance to Hall C.	"The Magmatic Plumbing System" "Un Sistema Terrestre de Flujo Magmática"	C(2c) or use to support D(5)
C5	La Cordillera Volcanica del Pacifico de Nicaragua	resequence as C6 (see Appendix C)	retitle; improve the text and its presentation	"The Nicaraguan Link in the Pacific Chain of Fire" "La (link) Nicaragüense en la Cadena de Fuego del Pacífico"	C(3)
C1	La Historia de los Volcanes en las Capas de Suelo de Managua	resequence as C8 (see Appendix C)	retitle; develop text and provide photographs of types of eruptions that would have produced the soil layers; text should describe how scientists determine date of tephra deposition and length of depositional hiatuses; relocate	"Soil Layers: Clues to an Explosive History" "Los Suelos: Evidencia de una Historia Explosíva"	C(4)
E1	El Tunel de Lava	resequence as D9 (see Appendix C)	retitle; develop text to describe the relation between lava tunnels and eruption type and volcanic cone shape; relocate at end of Hall C or within Hall D	"Molten Rivers Beneath the Surface" "Los Rios Incandescentes Subterráneos"	C(5) or D(3a)

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

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			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
D	La Naturaleza del Volcan Masaya/El Volcan Masaya y su Ambiente	retitle and retain as D1 (see Appendix C)	retitle; refocus hall on the geologic history of Volcan Masaya and its existing natural environment	"Eruption, Devastation and Rebirth of the Volcano" "Erupción, Distrucción y Renacimiento del Volcán"	D(1)
D1	Historia Geologica de la Caldera de Masaya	retain as D2 (see Appendix C)	retitle; develop text with photographs of plinian, strombolian and fissure eruptions that occurred throughout Volcan Masaya's history; may need to relocate	"The Catastrophic Origin of Masaya Caldera" "El Origen Cataclísmico de la Caldera de Masaya"	D(2)
D7	Otros Rasgos del Paisaje Volcanico	resequence as D3 (see Appendix C)	eliminate this as a separate exhibit; consolidate the identification of volcanic features within the caldera with the history of the Masaya Caldera (recommended Exhibit D2; existing Exhibit D1)	"Volcanic Features within the Masaya Caldera" "Rasgos Volcánicas dentro de la Caldera de Masaya"	D(3)
C2	Los Materiales que Salen del Volcan	resequence as C5 (see Appendix C)	retitle; provide brief text to explain vesicles, phenocrysts, textural differences; obtain specimens of plant casts in volcanic ash from Tiquantepe; may need to relocate	"Eruptive Art: Sculptures in Ash and Stone" "El Árte Eruptívo: Escultúras en Ceniza y Piedra"	D(4)

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E					
Current Sequence Designation and Exhibit Title		Consultant Recommendations			
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Título Actual	1992 Report Recomendaciones	Overall Changes	Título Recomendado	sequence w/in hall
D4	La Fumarola de Santiago & Danos	retain as D4 (see Appendix C)	retitle; describe chemical composition and volcanic contributions to evolution of Earth's atmosphere and global climate changes; may need to relocate	"The Smoking Mountain: Composition of the Volcanic Plume" "La Montaña que Arde: Composición de los Gases Volcánicos"	D(5)
C6	Los Volcanes y el Homre	resequence as C7 (see Appendix C)	Treat under one super-title but break into 2 sub-titles; incorporate volcanic gas hazard from exhibits D4; may need to relocate	"Volcanoes and Man: An Uneasy Alliance" "Volcanic Blessings" "Volcanic Hazards" "Los Volcanes y El Hombre: Una Alianza Frágil" "Beneficios Volcánicos" "Peligros Volcánicos"	D(6)
D5	Juego para ninos en el mirador	relocate at outside patio	not evaluated	(management decision)	N/A

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

Current Sequence Designation and Exhibit Title		Consultant Recommendations			
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
E4	La Sucesion Vegetal en Accion	retain as D11 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(1)[1]
E2 - propuesta	(Diorama con Ficus encima de la lava)	combine with E3 (see Appendix C)	not evaluated but appears to be related to recolonization of lavas. Concur with 1992 recommendation.	(predominantly ecological theme)	E(1a)[1]
E8	Las Flores y sus Visitantes	resequence as D12 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(2)[1]
E9	El Sacuanjoche	resequence as D13 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(3)[1]
E3	Los Tuneles de Lava	combine with proposed E2 and retain as D10 (see Appendix C)	not evaluated; should deal with plants (helechos) and animals (bats, coral snakes, others?) that preferencially live in the lava tunnels	"Lava Tunnels: A Unique Habitat"	E(4)[1]
D2a	Adaptaciones de los Animales	resequence as D7 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(5)[1]

[1] Designation represents "best guess" of logical sequence for remaining ecological exhibits.

Table 4-1. Summary of Sequence Designations, Current Titles, and Consultant Recommendations for Exhibits at the PNVM Visitors Center Halls A through E

Current Sequence Designation and Exhibit Title		Consultant Recommendations			
			THIS REPORT RECOMMENDATIONS		
Elemento Actual (1992 Rept)	Titulo Actual	1992 Report Recomendaciones	Overall Changes	Titulo Recomendado	sequence w/in hall
D6	Los Chocoyos del Crater	resequence as D8 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(6)[2]
D2	La Vida Diurna del Parque	resequence as D5 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(7)[1]
D3	La Vida Nocturna del Parque	resequence as D6 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(8)[1]
E5 - propuesta	Busto de Ramirez Goyena; primer botanico nicaraguense	consider contracting for bust (see Appendix C)	not evaluated	(predominantly ecological theme)	N/A
E6	Alteracion del Ambiente por el Hombre	resequence as D15 (see Appendix C)	not evalutaed	(predominantly ecological theme)	E(9)[1]
E7	Proteccion del Parque Nacional	resequence as D16 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(10)[1]
E3a	El Paisaje del Parque	resequence as D14 (see Appendix C)	not evaluated	(predominantly ecological theme)	E(11)[1]

[2] Designation represents "best guess" of logical sequence for remaining ecological exhibits.

only three are on exhibit in Area A-1. The mural was executed by Sr. Peñalba's son, Ing. Franco Peñalba, also an accomplished artist and photographer.

To supplement the finished paintings, exhibits were prepared using enlargements of historic illustrations of Volcán Masaya, including a 1529 line drawing by Oviedo, an 1865 line drawing and map by von Seebach, and a photograph by Dr. Bruno Mierifch from about 1920. The black and white enlargements were Xeroxed onto 11- by 17-inch transparent acetate sheets that have become warped over time.

Area A-2 contains a relief map of the larger volcanic structure, Masaya caldera, within which the park is located. Two of the three wall areas surrounding the relief map are used for text and diagrams that present the categories of protected areas in Nicaragua as well as the types of management areas within the park.

Recommendations

Area A-1 should be rededicated to a single theme, namely, the highlights of man's historic and prehistoric interactions with Volcán Masaya. A suggested new title for the main portion of the hall is *"The Record of Man at Volcán Masaya."* The title should be installed in large attractive letters on a full-length panel that projects from the left wall of the room at the top of the three steps.

There should be a reasonable chronological progression, from oldest (prehistoric) to the most recent (early 1900s), accommodating the constraint that the position of the mural (1772 lava flow) is fixed at the end of the hall. As suggested in the 1992 report, the panel identified as A7 ("El Entorno Socio-economico del Volcán Masaya") should not be a part of Area A-1.

The prehistory presentation titled "Arqueologia Precolombina" is not well focused and fails to take full advantage of the aboriginal petroglyphs found on the walls of the Masaya caldera. The petroglyphs should be used as a means of tying man's early interactions with the volcano to a description of the local pre-Colombian Indian populations, their beliefs, and the remnants of their cultural heritage. The exhibit should be given a more provocative title such as *"Myths and Legends: Precolombian Inhabitants and the Smoking Mountain."* Full-size petroglyphs could be readily "carved" (with paint) onto a dark grey texturized "caldera" wall that would serve as a backdrop for the pre-Colombian artifacts. The backdrop would end where a full-length panel is installed at an oblique angle to the wall to display Peñalba's "Sacerdotista Aborigen" painting (wall panel is discussed in the next paragraph). The prehistory exhibit needs more factual information, if it is available, about how the local Indians (or similar tribes in other Central American countries) perceived the natural environment (specifically volcanic phenomena). If enough information is available, a follow-on exhibit should be developed for Area F or G to depict the pre-Colombian culture and indigenous beliefs about nature and natural forces.

The three Peñalba paintings currently are hung against the left (north) wall of Area A-1. Natural light from the high window above the mural strikes the paintings from one side. Because of the glossy varnish on the paintings, the approaching visitor sees only a bright glare until he stands directly in front of each work. At that point, the high angle of the incident light (from above and to one side) makes the colors in the painting appear dull. Ideally, the paintings should be mounted on individual wall-high panels that protrude at an oblique angle from a side wall of Area A-1. Viewed from the entrance looking toward the mural, the panels would be slanted toward the back of the hall. All three paintings should not be on one side of the room. The panel arrangement, in addition to solving the lighting problem, would serve to break the monotony created by the length of the parallel unbroken walls surfaces on either sides of Area A-1.

The missing Peñalba painting (Fray Blas de Castillo descending into the crater) referred to under the heading A4 of the 1992 report depicts a fascinating element of the history of Volcán Masaya. The work should be recovered if possible. Records at the Banco Central should indicate who took possession of the paintings when the Peñalba contract was closed. If the painting cannot be recovered, MARENA eventually may decide to commission another painting or drawing to illustrate the worldly preoccupations and misconceptions that characterized Blas de Castillo and other early explorers in the New World.

An effort also should be made to obtain drawings, early photographs, or otherwise illustrate the German engineers' attempt to "harness" Volcán Masaya to produce sulfur. The written narrative of this venture leaves the reader incredulous as to man's fearlessness (and foolishness) when trying to manipulate the forces of nature. Although difficult to imagine, similar attempts at exploiting a volcanic plume may have been made at volcanoes elsewhere in the world. An appeal to the U.S. Library of Congress or a major university (Princeton, Oxford, etc.) may turn up an appropriate illustration. Alternatively, the Peñalba family may have some initial sketches made by Don Rodrigo in preparation for the painting that had been commissioned by the Banco Central.

The wall panels to be installed in Exhibit Hall A will establish a zig-zag path toward the back of the room. The last logical station will be to move from the mural of the 1772 lava flow to a final exhibit on the right wall. This last exhibit should be the German engineers attempt to industrialize the gases of the volcanic plume or the 1920s photograph, if an interesting historic context can be established for it. The map and drawing by von Seebach and supporting text (all part of current Exhibit A5) should be moved to a new exhibit in Hall B (new B3 in Table 4-1).

The photocopied transparencies should be replaced. Large museums use a technique of silkscreening onto matte-finish Formica sheets to produce two-tone illustrations or text for exhibits. The technique is relatively simple and inexpensive and the result is visually appealing yet sturdy and enduring. The graphic arts department at one of the local universities may be able to assist in training a few members of the MARENA/PNVM permanent staff and providing the basic equipment needed to use this technique.

In addition to its use inside the Visitors Center, the silkscreening technique may be useful for wayside exhibits. Existing wayside exhibits are restricted to simple text messages routed into wooden or plastic signs. Silkscreening may provide the ability to print labeled panorama scenes, a narrative, or line drawings on the surface of a wooden sign. A thick coat of polyurethane varnish could be used to seal the print. All of the materials need to be tested for resistance to volcanic gases and other environmental conditions within the park.

Area A-2 should use the relief model of the caldera to orient the visitor to the major features of interpretive interest within the park. The A-2 alcove area should be physically separated (with plants or a wall panel) from the exhibits of area A-1, and should have its own title such as *"The Caldera of Masaya: Microcosm of Our Natural Heritage."* The discussion of protected areas and management zones should be reserved for an exhibit in Area F. The relief model should be repainted in fresher and more natural colors. Key features should be attractively numbered.

The wall on the left behind the relief model should contain a brief narrative in large letters. The narrative should describe the large caldera that formed in a cataclysmic eruption about 6,600 years ago and the resurgent volcanoes, Masaya and Nindiri, and the lava flows that cover the caldera floor, all of which have formed since that cataclysmic eruption. The panel should also note that the area was designated a national park to protect its as a unique and important part of Nicaragua's natural heritage. In addition to the title and text, the walls behind the model should display enlargements of color photographs of the chocoyos in flight, orchids in bloom, the incandescent lava lake, and other outstanding features of the park.

4.1.1.2 Exhibit Hall B

This area of the Visitors Center makes a transition between historical views of Volcán Masaya and a scientific view of volcanic phenomena. The transition should be facilitated by the addition and/or rearrangement of at least two elements. The first element is a visible and appealing title (Exhibit element B1) at the doorway to Exhibit Hall B to entice the visitor to proceed and to foreshadow the change in perspective from historic to scientific. A candidate title is *"Volcanoes: Windows to the Earth's Interior."* An alternate title is *"The Restless Earth Beneath Us: A Scientific Perspective."*

Moving past the new title (element B1) into Exhibit Hall B, the visitor should encounter a transition exhibit on early examples of scientific thought about volcanic phenomena -- the oil painting of Larreynaga's hypothesis (current Exhibit B4) with interpretive text, followed immediately by von Seebach's map and field sketch of the volcano based on turn-of-the-century European scientific understanding. These themes can be developed in two wall panels against the left wall stepping down into Exhibit Hall B.

A significant problem in Exhibit Hall B is that the hall is dedicated to dynamic processes, yet most of the exhibits appear dull and static, either anchored to a wall or lodged within an alcove. The exception is the wall mural which portrays motion in the fluid white ribbon serving as a painted background for the progressive "snapshots" of the Earth evolving through time. The other elements in Exhibit Hall B require major revisions/improvements.

From the new exhibit (Larreynaga and von Seebach) that follow element B1, a natural thought progression would lead to the wall mural. Unfortunately, the wall mural requires an uninterrupted presentation that moves the visitor non-stop to the opposite end of the room. To provide a more gradual path through the room and to add a dynamic element, the free-standing globe (currently housed in Exhibit Hall G) should be used to depict the theme "Los Volcanes de la Tierra" (wall panel Exhibit B3).

The title of the exhibit should be made more dynamic, for example, *Where do Volcanoes From*? or *Lines of Fire and Brimstone that Divide the Earth.* The globe should rotate slowly on its axis by installing a small motor in its wooden base. The ocean floors should be painted in shades of blue and purple to depict their bathymetry, and the location of spreading ridges and isolated hot spots should be identified with fluorescent orange/red paint. The 300 plus active volcanoes of the world can be depicted on the globe by the location of fluorescent orange/red dots. If resources and space permit, the dots can be numbered to correspond to a list of volcano names displayed on the wall. However, the primary focus of the accompanying text should be to indicate that volcanoes are generally found at active boundaries between the Earth's lithospheric plates (that is, where there is relative motion such as divergence or convergence between oceanic/oceanic or oceanic/continental plates -- one element of plate tectonics). The globe should be installed in front of the first half-circular alcove along the left wall of Exhibit Hall B (where Exhibit B4, titled *El Movimiento de las Placas en America Central* is installed). If the globe is installed at floor-level, a half-circular waist-high railing should encircle the portion of the globe that extends into the room. A recommended alternative is to construct a 16- to 18-inch high wooden base, several feet wider than the diameter of the globe, protruding into Exhibit Hall B from the alcove and wall and upon which the globe can be mounted. The top of the base could be slanted at low angle away from the globe to provide area for the accompanying text. Installing the globe on a base will allow the globe to be viewed from about 270 degrees.

At this point, the visitor will be confronted by the beginning of the wall panel (existing element B2). The artwork of the wall mural is of excellent quality and should be preserved. The exhibit, however, needs to be augmented by text and (as recommended in the 1992 consultant Report) with fossils and other illustrative specimens, artifacts, or photographs. Care should be taken in selecting the appropriate specimens. The trilobite fossil mentioned in the 1992 consultant Report would be inappropriate because no Paleozoic rocks (rocks older than about 400 million years) containing identifiable fossils are known to exist in the continental basement areas of northern Nicaragua.

The relief model titled *El Moviemiento de las Placas en America Central* should be modified to emphasize the cross-section through the lithosphere and mantle and de-emphasize the surface relief, which is redundant with the larger relief model in Exhibit Hall C. The geologic cross-section should be corrected to show a more narrowly focused band of magma migration (responsible for the single line of volcanoes along the western margin of the Nicaraguan Depression). The vertical scale, indicating the relative depth of the subduction zone and the thickness of the lithospheric slab should be reviewed. The cross-section should also be painted in more vibrant colors on a translucent plexiglass panel that is back lighted and, if possible, given a sense of motion by the use of a small rotating wheel with geometric lines projected with a low-wattage (cool) incandescent or a fluorescent bulb. Appropriate text should accompany the exhibit. Finally, the exhibit should be given a better title, such as *Tectonic Plates Collide beneath Central America.*

4.1.1.3 Exhibit Hall C

Exhibit Hall C and D require careful rethinking and offer the greatest challenges in terms of space and other limitations. Ideally, Area C should be used to present generic information on volcanic processes using examples found in the park. Unfortunately, the large relief model of the volcanoes of western Nicaragua fills most of the room. Exhibit Hall D and E do not appear to have an appropriate space to house the relief model without imposing untenable constraints on those areas.

The best solution appears to be to refocus Exhibit Hall C on the types of volcanoes and eruptive styles. Some of the exhibits housed in Hall C must be relocated into Halls D and E. Table 4-1 indicates a "best guess" as to how the exhibits need to be redistributed. The actual layout of the exhibits requires information on the dimensions of exhibit areas, sizes of proposed and existing exhibits, and budget that was not available to the consultant when writing this report.

The relief model should be moved away from the back wall of Hall C. A lightweight structure hanging from the ceiling is required to mount text. The overhead text panels should terminate about 3 feet above the surface of the model and be slanted toward its center to facilitate viewing by visitors standing around the model.

A new exhibit combining elements of several existing exhibits should be installed on the walls at either side of the entrance to Hall C. The new exhibit must rely on colorful graphics, photographs, and text to describe the basic types of volcanic edifices and the kinds of eruptions they produce. Key concepts such as stratovolcano, shield volcano, cinder cone, and plinian, strombolian, and fissure eruptions should be explained. The cut-away model of the stratovolcano currently located in Hall C should form part of this exhibit if space permits. Some use of space at the end of Hall B may be required to provide adequate area for this exhibit.

The text and photographs above the large relief model should pick up the key words and provide

examples. To do this, features other than the 17 active stratovolcanoes of the Nicaraguan volcanic chain must be identified.

The semi-circular alcove of Hall C would be ideal to house a series of 3 or 4 vertical panels describing the local soil column and its record of explosive eruptions that affected the region between Managua and Masaya. The information for these panels can be obtained in the 1983 dissertation by D. Bice (see reference list).

The wall above the steps at the end of Area C may be appropriate for a panel exhibit, depending on space and visibility considerations once the large relief model is relocated. If space and visibility permit, the area can be used for an exhibit on lava tunnels and their impact on the shape of the volcanic edifice. If the space and visibility is constrained, the left side of that wall from the steps toward the entrance to Exhibit Hall D should be used for the title of the next exhibit area.

4.1.1.4 Exhibit Hall D

The validity of the recommendations provided for this area are contingent on a realistic assessment of available space and budget. Several of the existing exhibits in this area are unfocused and use space inefficiently. Removing and rearranging the exhibits, however, will require financial resources that may not be currently available. The following suggestions include a major revision to Areas D and E as well as options for minor changes and rearrangements.

Between Exhibit Halls C and D, an interpretive transition is made between volcanic processes with regional examples toward site-specific interpretation of the features within the park. The initial exhibit should describe what is known about the volcanic history of the Masaya Caldera. The 1983 S.N. Williams thesis contains the information required for this exhibit (see reference list). A major focus of the exhibit should be the unusual and explosive nature of the eruption that created the caldera and how recently that eruption occurred. An additional point of interest is the very high rate of eruption that apparently has characterized Volcán Masaya since the 6,600 year-old plinian event that created the caldera. The high eruption rate has produced lavas that cover the entire caldera floor (and outside areas) to a depth of at least 200 meters.

The geologic evolution of the Masaya Caldera should segue to several exhibits of volcanic features and phenomena that can be seen within the park. These exhibits, described in Table 4-1, include a description of lava tubes, gases, and lithic products of volcanism. The final exhibit within Area D should offer a transition to ecological themes by describing the tense coexistence between man and volcano. This exhibit should describe the benefits man derives from volcanic activity (rich soils, mineralization, building materials, the aesthetic qualities of the landscape, areas for national parks) as well as the hazards of living near volcanoes (the many types of volcanic hazards that pose a threat to man's life and livelihood).

4.1.1.5 Exhibit Hall E

Any rearrangement of exhibits in Hall E is dependent on the space required to develop the geologic themes of eruption and devastation at the Masaya Caldera in Hall D. Table 4-1 (column 6) presents a possible sequence for the exhibits supporting the recolonization of the devastated area and a description of the existing ecosystems within the caldera. The exhibits and text requirements to fully develop the themes within Exhibit Hall E should be left to an ecologist or similar specialist.

4.1.1.6 Exhibit Hall F

No significant evaluation or recommendations are made for this area which is primarily focused on ecologic themes. As a minor comment, however, the relief model of a volcano that is meant to illustrate the results of proper and improper watershed management practices purports to show several large water reservoirs behind dams on the slopes of the volcano. Considering the high frequency of large ash eruptions at Nicaraguan volcanoes, planning to obtain this particular "benefit" by good watershed management is probably not prudent. The relief model exhibit, like many others in the Visitors Center, also needs to be accompanied by appropriate text.

4.1.1.7 Exhibit Hall G

No evaluation or recommendations are made for this area that focuses primarily on interpreting ecologic themes.

4.1.1.8 Exhibit Hall H

The recommendation for this area is to remove the globe and use it in Area B to replace the existing exhibit B2 ("Los Volcanes de la Tierra") to introduce plate tectonics and the localization of most volcanoes at inter-plate margins (see discussion in Section 4.1.1.2).

4.1.2 Audiovisual Resources

A narrated slide show, approximately 40-minutes in length, is the standard presentation used for school groups who visit the park. The show was developed by Dr. Jaime Incer, the noted Nicaraguan geographer and ecologist, and covers a broad range of information, both specific to the park and generic to Nicaragua as a whole. A single version of the narrative, presumably aimed at junior high or early high-school level, is used for all school groups.

Recommendations

Currently the PNVM does not have the needed audiovisual resources (one oversize or multiple normal-size television monitors and a video cassette recorder, or VCR) to present video programs. The PNVM should attempt to acquire the necessary equipment to take advantage of the many short video programs in Spanish that are commercially available. Several videos pertinent to the geology or volcanology of the park are listed in Annex F. At a minimum, at least two large television monitors (with viewing screens greater than 26-inch diagonal) or an oversize (projection) monitor and a VCR would be required. The slide presentation could be moved to a video cassette format to eliminate the mechanical difficulties that invariably accompany synchronized multi-media programs involving recorded narration and slide changes.

4.1.3 Educational Materials for School Groups

The school groups that visit the park range from about third grade to senior high school level. The park staff includes several teachers (on the payroll of the Ministerio de Educacion, MED) who specialize in environmental education. These teachers escort the school groups, in tours of about 60 students each, through the Visitors Center and to the crater area.

The PNVM/MED teachers have developed a curriculum for environmental education that is approved by MED for use at specific grade levels. The educational materials used in the park consist exclusively of the those available at the Visitors Center: the narrated slide show and the exhibits.

Recommendations

Options for supplementing the materials used by school groups include virtually any mechanism that requires or encourages a student to interact with what is being presented. PNVM/MED interpretive specialists should consider purchasing or designing several colorful worksheets, specific to early elementary, middle school, and senior high school levels. The worksheets should pose questions, require the student to solve a riddle or puzzle based on the information presented, or otherwise entice the student to participate in the learning experience at the park. Worksheets of this type may be commercially available through national park systems in the U.S. or in Latin America.

The Internet Home Pages for volcanology (see Annex F) contain ideas for environmental education for all age groups. Unfortunately, most Net sites are in English. The PNVM/MARENA management should identify one or more bilingual staff members to investigate what is available and appropriate for use at the park. One of the exercises proposed on one web site provides free software that creates a three-dimensional image of a volcano, then allows the user to select from a series of options describing the demographics and surrounding land use patterns as well as the type and severity of a theoretical eruption. The model then simulates the

effect of the eruption on the surrounding land areas. The overall exercise is aimed at senior high school level and, while visually exciting, requires the students to formulate and test short-term plans (i.e. evacuation routes) and long-term plans (land use zoning and restrictions) that could mitigate the hazards posed by the volcano.

4.2 Wayside Exhibits

4.2.1 Crater Overlooks

The wayside exhibits originally installed in the crater area consisted of cast aluminum plaques at the main viewing areas of the OPO, the OBE, and the OCB. The plaques contained a short narrative in Spanish and English of the points of interest and some basic statistics (such as width and depth of the crater and depth to the magma). The three plaques that were installed in about 1977 were stolen between 1979 and 1980 and never replaced.

Recommendations

New plaques should be installed as soon as possible at the OPO and near the foot of the stairs leading to the OCB (until a decision is made about the future configuration of the OCB infrastructure). Cast aluminum is the most likely candidate material for the interpretive plaques based on local availability, durability, relatively low cost, and reasonable resistance to the volcanic gases. The plaques should be cemented (not screwed) onto existing or new bases constructed of concrete block lined with natural stone.

The topographic specialist at MARENA should use recent aerial photographs to actualize the statistics of size, depth, and maximum rim elevations for each of the major craters and the Santiago intercrater.

Plans for future wayside exhibits in the crater area should include two additional plaques to describe the sequence of development of the features in the crater area and the relationship of the larger caldera and nearby volcanic vents to the geologic history of Masaya. Both of these themes will require a more elaborate presentation, possibly using panoramic line drawings on a larger surface. The wayside exhibits could be routed into large wooden panels and painted or burnished for contrast. Alternatively, the displays could use the silkscreening technique described in Section 4.1.1.1 after the materials (paint, sealant, and base of wood or Formica mounted on wood) have been field tested in the volcanic gases of the crater area.

4.2.2 Lava Tunnels "Tzinanconostoc"

A park guard (A. Aleman) accompanied a group of TR&D staff and consultants to the Tzinanconostoc lava tunnel on July 21 and provided an excellent account of the development and current use of the trail to and through the tunnel near the Casa de los Murcielagos. The tunnel

examined by the group is the largest and most accessible of those explored by the consultant within the park.

The lava tunnels offer a the opportunity to present a variety of environmental education themes that can be incorporated into the personal interpretation offered by the park guards or interpretive specialists. The themes that are appropriate for the tours include a discussion of the volcanic processes that formed the tunnels and the flora and fauna that exploit this unique ecological habitat. Annex D contains a brief non-technical discussion of the volcanic processes at the Masaya caldera complex, with one section focused on the significance of the lava tunnels to understanding volcanic processes and the morphology of volcanic edifice. The information contained in Annex D is provided to assist the PNVM interpretive staff in updating the interpretive presentation currently used for the park's lava tunnel tour.

4.2.3 Fumaroles at Cerro "El Comalito"

The nature trail at Cerro el Comalito was closed to the public when the consultant visited the park and appeared to have been closed for several years. A rustic path that loops around the fumarole area is a self-guided tour, with numbered markers deployed along the trail that corresponded to an information pamphlet. Some of the markers were hidden by vegetation that has overgrown the trail. In addition, the diagram at the entrance to the trail is somewhat misleading compared to the actual layout of the trail.

The fumarole area is dispersed across a hilly area of elongate lapilli mounds that accumulated above a fissure vent on the north flank of Volcán Masaya. During an inspection of the park on July 21, the TR&D consultant for landscape architecture (J. Todd) expressed concern about the fragile and potentially hazardous nature of the area and suggested that an elevated wooden walkway and platform be used to provide public access to the active fumaroles, while protecting the natural resource. This approach is used with success in several active mud pool areas at Yellowstone National Park. The simple walkways at Yellowstone are approximately 12 to 14 inches above the ground surface, high enough to make the step down to ground level awkward but low enough that no serious injury would occur if a visitor were to fall from the elevated path. Generally, only the main viewing areas at Yellowstone are constructed with a handrail to minimize the height and visual impact of the overall installation. However, unless the PNVM management is able to resolve the problem of scavenging in the park, the investment required for the walkway and viewing platform would be at risk.

The nature trail purports to require 40 minutes to complete. If the PNVM management considers reopening the nature trail for use by school group who might lunch at the picnic tables beside the entrance, the restrooms should be repaired. A lunch stop and hike along the trail would require about 1.5 hours, long enough that sanitary services should be available nearby to discourage indiscriminate use of the bushes alongside the trail.

Although probably low on the list of priorities at the park, the PNVM interpretive program eventually should consider developing a basic interpretive message that can be presented on 10 to 12 signs or plaques along the trail. The use of numbered markers and an accompanying pamphlet could then be reserved for more specialized interpretation keyed to age-specific interests of school groups.

4.2.4 Lava Flow of 1772

The original wayside exhibit of this feature along the Camino Real del Popogatepe consisted of a small wooden sign that announced the "Colada de Lava de 1772." Due to the restricted width of the road, no further interpretive sign or plaque was considered for this location. The same consideration still applies. It is recommended that this feature be noted on the diagram and in the text of the park pamphlet. Visitors should not be encouraged to park their vehicles along the road to explore the flow surface or nearby spatter cone.

4.3 Informational Archives

4.3.1 Geologic/Vulcanologic Literature

Due to time constraints during her July visit, the consultant was unable to review the set of geologic and vulcanologic publications available in the PNVM and MARENA archives. However, Annex E contains an updated list of scientific publications relevant to the geology and volcanology of the park. The PNVM staff should compare the list in Annex E with the publications available in their archives.

4.3.2 Environmental Education Materials

Although outside the scope of work for this report, Annex F contains a short list of environmental education materials that were obtained by the consultant and delivered to MARENA/PNVM personnel in July or that can be obtained readily by PNVM management from commercial or other sources.

4.3.3 Infrastructure and Interpretive Plans and Designs

A limited number of interpretive plans and designs were available in the TR&D archives at MARENA. None of the original plans or specifications for the buildings or other infrastructure installed at the park between 1977 and 1983 were found in the PNVM, MARENA, or TR&D archives. See the recommendation in Section 1.4 of this report.

5.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

For public safety, the Overlook "Boca del Infierno" should be closed or public access severely restricted. The existing trail between the Overlook "Plaza de Oviedo" and Overlook "Boca del Infierno" should also be closed and pedestrian traffic routed to the paved roadway until a new trail can be constructed farther from the edge of Crater Santiago. Vehicular access as far as the Casa de los Murcielagos should be restricted to light vehicles or, preferably, closed to all vehicles and the roadway used for pedestrian traffic.

Personal protective equipment and equipment for emergency crowd control (such as whistles, bullhorns, hand lights or colored flags) should be acquired and the park staff trained in their use. Medical monitoring of the respiratory health of the park staff should be initiated. park staff should be informed of the health hazards of exposure to volcanic gases and should contribute to developing plans to mitigate the adverse health effects.

The buildings, roadways, and other infrastructure at the park are seriously degraded due to lack of maintenance. A professional evaluation and plan should be developed for the immediate and long-term maintenance of the park investments. Adequate funds from the park's annual budget or generated revenues should be allocated to implement the plan. The reliability of the park's sanitary services should be improved and adequate sanitary supplies should be available for public use at all times.

The park should develop the staff and material capability to make needed modifications or improvements to the wayside and Visitors Center exhibits. Alternatively, the park should contract with a public or private service agency that can produce signs and/or exhibit panels that meet park specifications at a reasonable cost.

A prioritized plan for replacement or completion of the wayside and Visitors Center exhibits should be developed. The plan should include specifications, sketches, cost estimates for all elements of the work, and projected costs of long-term maintenance. In addition to providing the PNVM and MARENA management with a basis for budgeting and scheduling the work, the exhibit plan can be used to solicit appropriate international sources for funds to accomplish portions of the proposed work.

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agglutinate - A welded pyroclastic deposit characterized by vitric material cementing the fragments, the presence of scoria, and the absence of a tuff matrix. (AGI, 1972)

ash - Fine pyroclastic material (under 4.0 mm diameter; under 0.25 mm for fine ash). The term usually refers to the unconsolidated material but is sometimes also used for its consolidated counterpart, or tuff. (AGI, 1972)

basalt - A dark- to medium-dark-colored, commonly extrusive, mafic igneous rock composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained groundmass. (AGI, 1972)

base surge - A ring-shaped cloud of gas and suspended solid debris that moves radially outward at high velocity as a density flow from the base of a vertical explosion column accompanying a volcanic eruption or crater formation by an explosion or hypervelocity impact. (AGI, 1972) A type of pyroclastic deposit that is composed of solidified scoria and ash derived from a magma explosively erupted from a volcanic vent after interacting with shallow groundwater or surface water. The eruption column of a base surge generally is not energetic enough to entrain large quantities of dense lithic fragments ripped from the sides of the volcanic conduit. The basal layer of the eruptives contains large blocks of dense ejecta in a fines-depleted matrix, overlain by cross-bedded scoria and ash layers containing fewer lithic clasts than comparable hot surge deposits. The early scoria and ash beds often have pisolitic structure indicating agglomeration of ash particles by abundant water droplets in the eruptive column. Base surges are generally restricted to within 10 km of their source vent. (Tilling (ed) 1989, p. 11-12)

caldera - A large, basin-shaped volcanic depression, more less circular in form, the diameter of which is many times greater than that of the included vent or vents, no matter what the steepness of the walls or form of the floor. (Williams, 1941 in AGI, 1972)

cinder cone - A conical hill formed by the accumulation of cinders and other scoriaceous ejecta, normally of basaltic or andesitic composition. The steepness of the slopes may differ widely depending on the coarseness of the ejecta, the height of eruption, wind velocity, and other factors. (AGI, 1972)

crater - A basinlike, rimmed structure that is usually at the summit of a volcanic cone; its floor is approximately the diameter of the vent. It may be formed by an explosive eruption or by the gradual accumulation of pyroclastic material into a surrounding rim. (AGI, 1972)

earthquake, "A-type" - A release of seismic energy generated by (1) the movement of magma and associated crack formation or (2) volcanic explosions. The earthquakes are typically shallow, of small to moderate magnitude (M is less than or equal to 5), and seldom cause damage far from the source volcano. (Tilling (ed) 1989, p. 54)

earthquake, "B-type" - A release of seismic energy at depths of 1 kilometer or less. Like A-type earthquakes, B-type events are thought to be caused by rock fracture, but the seismic signal has a lower frequency probably due to passage through heterogeneous layers of ash and lava (Tilling (ed) 1989, p. 54)

effusion rate - The rate at which magma is delivered to the surface, indicative of the productivity of the source zone and the characteristics of the path to the surface. Lava flows from Volcan Masaya are estimated to have had high effusion rates that contributed to the high fluidity and long flow lengths. The high effusion rate at Masaya may be due to the thin, non-continental character of the underlying crust and the proximity of the Cofradia fault that penetrates deep into the crust and probably served as a major conduit for the upward migration of magma (from S. Williams, 1983).

ejecta, volcanic - Accidental lithic fragments that are plucked from the sides of the volcanic conduit by the force of rapidly rising magma deep below the surface or by the lower (gas-thrust) part of an eruption column near the surface. While still airborne, the fragments are referred to as ballistic projectiles. (Tilling (ed) 1989, p. 17, modified)

eruption cloud - A gaseous cloud of volcanic ash and other pyroclastic fragments that forms by volcanic explosion; the ash may fall from it by air-fall deposition. (AGI, 1972)

eruption column - The initial form that an eruption cloud takes at the time of explosion; the lower portion of an eruption cloud. (AGI, 1972)

fault - A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale. (AGI, 1972)

fissure - A surface of fracture or a crack in rock along which there is a distinct separation. (AGI, 1972)

fissure eruption - An eruption that takes place from an elongate fissure, rather than from a central vent. It is generally basaltic. (AGI, 1972)

flow, lava - A lateral, surficial outpouring of molten lava from a vent or a fissure; also, the solidified body of rock that is so formed. (AGI, 1972)

flow, pyroclastic - Dense, convecting mixtures of hot (300 to 800 degrees C) rock fragments and gases that hug the ground and move rapidly away from an erupting volcano at velocities ranging from 10 to several hundred meters per second, burying and burning most everything in its path. The flow can be relatively small, affecting only one sector of the volcano's flanks, or it can be very large, moving radially away from the volcano in all directions. A large pyroclastic flow is among the most hazardous of volcanic events recognized by man. (Tilling (ed) 1989, p. 11)

fracture - A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fracture includes cracks, joints, and faults. (AGI, 1972)

hazard, volcanic - The probability of a given area being affected by potentially destructive volcanic processes or products within a given period of time. In contrast, volcanic *risk* includes a consideration of the *value* of what is in an area affected by destructive volcanic or geologic process as well as the *vulnerability* or proportion of the value likely to be lost if the area is affected by a specific *hazard*. Potential volcanic hazards include lava flows, pyroclastic density currents (lateral blasts, surges or flows), structural collapse by faulting or debris avalanches, debris flows (lahars), tephra fall, gases, earthquakes, tsunamis, and atmospheric shock waves. (Tilling (ed) 1989)

ignimbrite - The rock formed by the deposition and consolidation of ash flows and nuees ardentes. The term originally implied dense welding but there is no longer such a restriction, so that the term is only partially synonymous with welded tuff, and may include the nonwelded *sillar* as well. (AGI, 1972)

lapilli - Pyroclastics that may be either essential (formed from the erupting magma), accessory (such as made of crystals that have settled in the magma), or accidental (plucked from the wall rock) in origin, of a size range that is generally defined as 1 to 64 mm in diameter The fragments may be either solidified or still viscous when they land (though some classifications restrict the term to the former). (AGI, 1972)

lava - A general term for a molten extrusive; also, for the rock that is solidified from it. (AGI, 1972)

lineament - Arranged in a line or lines, as a linear group of vents. It is a one-dimensional arrangement, in contract to the two-dimensional planar arrangement. (AGI, 1972, modified)

magma - Naturally occurring mobile rock material, generated within the Earth and capable of

intrusion and extrusion. It may or may not contain suspended solids (such as crystals and rock fragments) and/or gas phases. (AGI, 1972)

parasitic cone - Said of a volcanic cone, crater, or lava flow that occurs on the side of a larger cone; it is a subsidiary formation. (AGI, 1972)

pyroclastic - Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; also pertaining to rock texture of explosive origin. It is not synonymous with the adjective "volcanic." (AGI, 1972)

scoria - Vesicular, cindery, crust on the surface of andesitic or basaltic lava, the vesicular nature of which is due to the escape of volcanic gases before solidification; it is usually heavier, darker, and more crystalline than pumice. (AGI, 1972)

seismic event - An earthquake or a somewhat similar transient Earth motion caused by an explosion. (AGI, 1972)

surge, pyroclastic- Turbulent mixtures of volcanic ash, scoria, and gases that flow down the flanks of an erupting volcano above the ground surface at high velocities. A surge can be either hot or cold. Hot pyroclastic surges may form (1) by separation of more mobile gases and fine ash that move ahead of a slower and denser pyroclastic flow, forming a basal ash layer that may be preserved beneath the overriding pyroclastic flow deposits, (2) by the collapse of an eruption column that may or may not also be spawning pyroclastic flows, or (3) by separation of less dense gas and ash that rises above a denser pyroclastic flow, forming an ash layer on top of the underlying pyroclastic flow deposits. Hot pyroclastic surges are more mobile than pyroclastic flows, can climb topographic barriers, and can affect areas many tens of kilometers from their source vent. Cold pyroclastic surges, or base surges, originate from hydrovolcanic explosions in which shallow groundwater or surface water interacts with magma. Base surges are generally restricted to within 10 km of their source vent. (Tilling (ed) 1989, p. 11-12)

tephra - A general term for fragments of rock and lava that are ejected into the atmosphere during a volcanic eruption and fall back to the Earth's surface. The fragments range in size from ash (<2 mm) to lapilli (2-64 mm) to blocks and bombs (>64 mm) that may reach several meters in diameter. Densities vary from viscular pumice and scoria to dense crystals and lithic fragments). Materials may be juvenile (formed of magma involved in the eruption) or accidental (derived from pre-existing rocks). (Tilling (ed), 1989, p. 17)

tremor, volcanic - Is the distinctive, essentially continuous seismic disturbance recorded at active

volcanoes. Volcanic tremor is different from the discrete earthquake events (A-type, B-type, long-period, or explosion earthquakes). At least three types of volcanic tremor are distinguished: harmonic, spasmodic, and banded. (Tilling (ed) 1989, p. 55)

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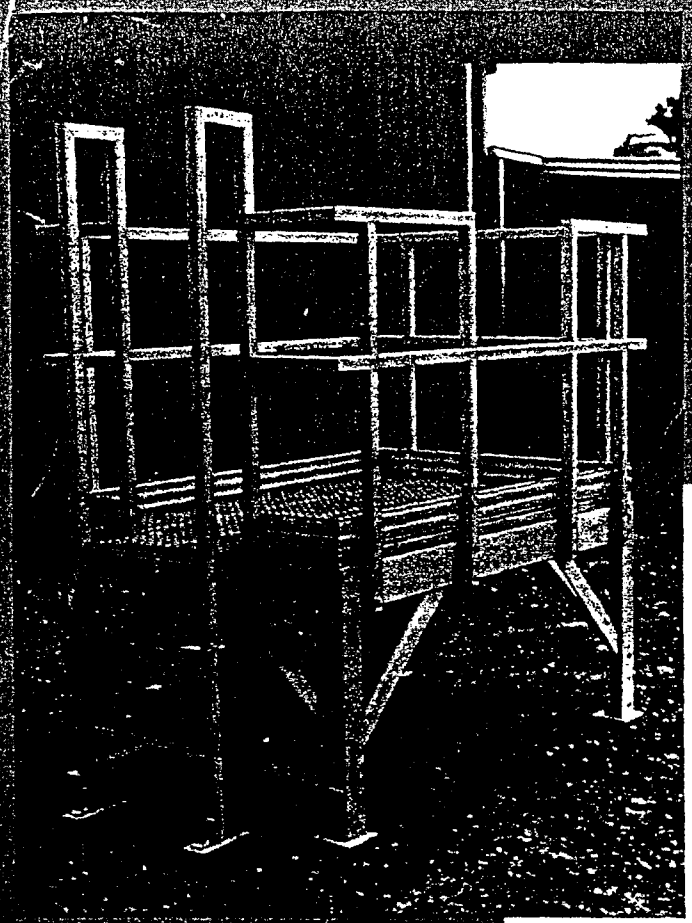
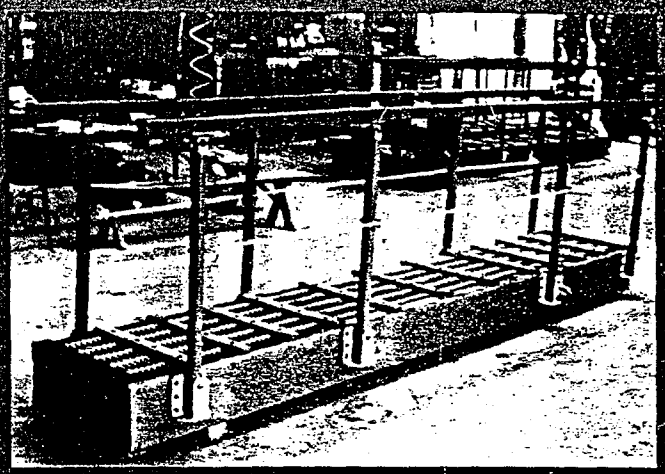
Selected Examples from Manufacturers' Marketing Literature





STRUCTURAL FABRICATION

Seasafe offers you high-strength, light-weight, maintenance-free products which solve the problems of conventional materials in industry today.

A wide variety of FRP structural shapes enable construction of standard platforms, walkways, ladders, stair stringers, and handrails as well as custom fabrications for all industries.

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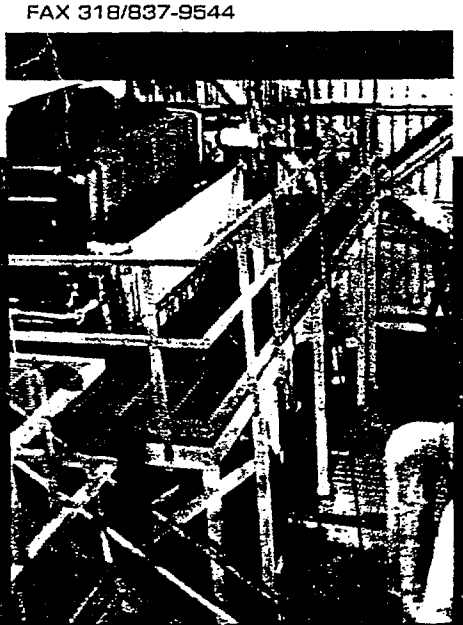
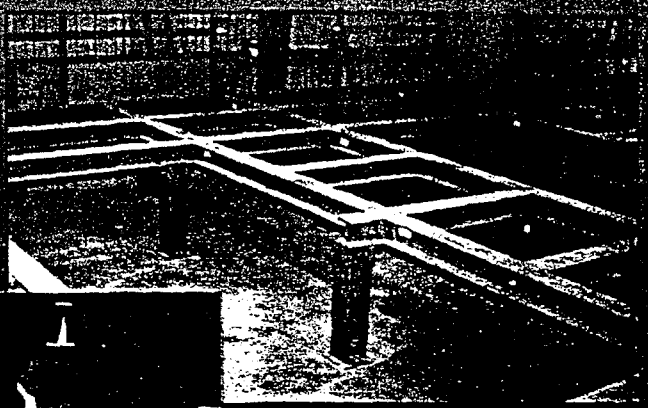




FEATURES

- Corrosion Resistant
- High Strength/Light Weight
- Maintenance-Free
- Non-Conductive
- Fire Retardant
- Ultra-Violet Protection
- Low-Thermal Conductivity
- Choice of Resins
- Structural Shapes to 12"

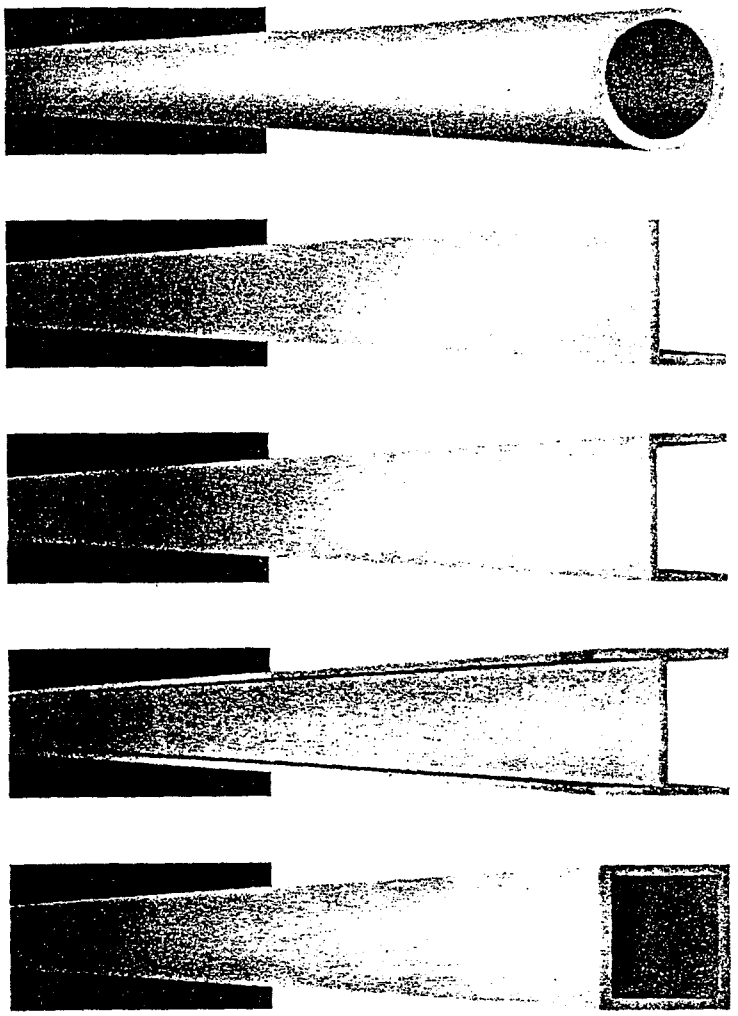
APPLICATIONS

CHEMICAL
- Pulp & Paper
- Recreational
- Military

OIL & GAS
- Brewing
- Food Processing
- Mining

MARINE
- Water & Waste Water
- Plating
- Power

PULTEX® FIBERGLASS STRUCTURAL SHAPES



PULTEX® standard shapes and custom composite shapes, manufactured by Creative Pultrusion, Inc., can be produced in a wide variety of resin systems best suited for your application. Three standard resin systems have been developed that generally cover most applications and remain readily available.

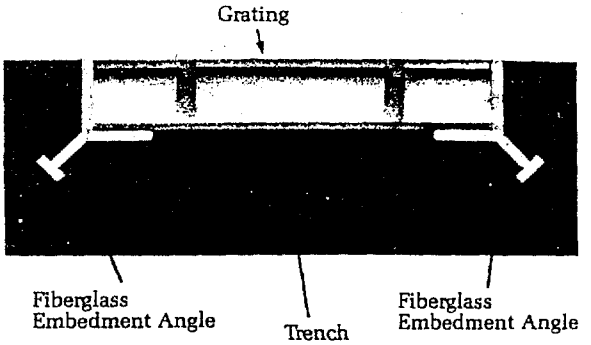
Stocked-item structural shapes are standard in the following systems:

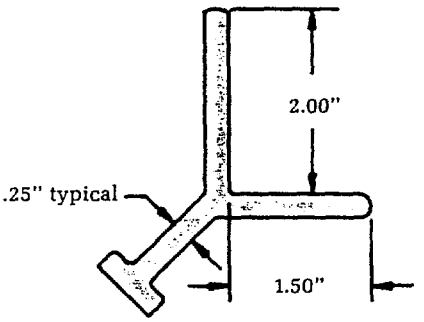
Series 1500-Isophthalic Polyester
- Olive Green

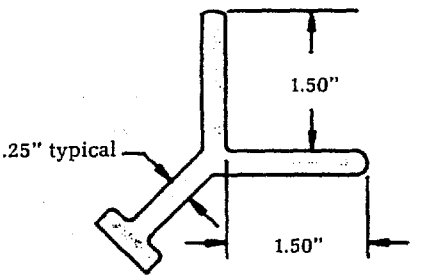
Series 1525-Iso Polyester Class 1 FR
- Light Grey

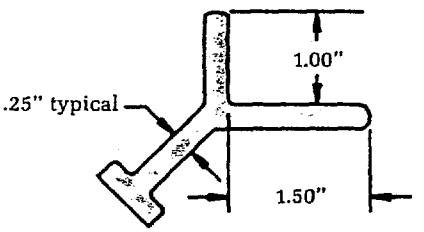
Series 1625-Vinylester Class 1 FR
- Beige

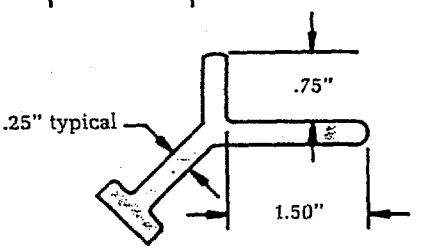
CURB ANGLE

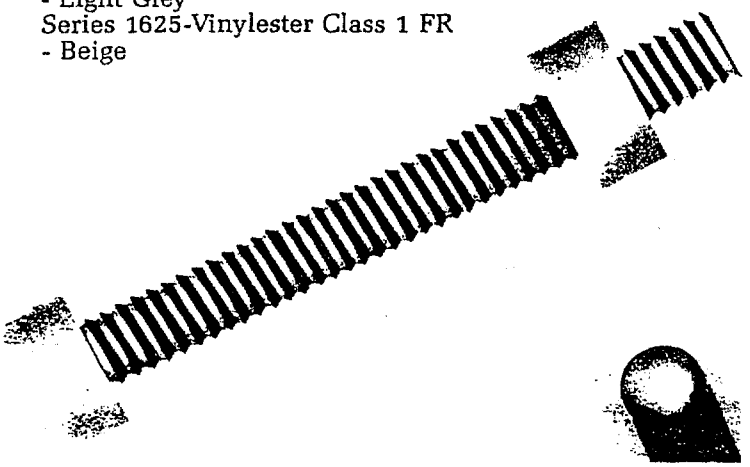












SUPERSTUD™ AND NUTS

SUPERSTUD™ all-thread rod is a proprietary combination of fiberglass and Class 1 flame retardant vinylester resin designed and manufactured by Creative Pultrusion specifically for mechanical fastener applications where corrosion resistance, non-conductivity and non-magnetic characteristics are a must.

SUPERSTUD™ and compatible fiberglass nuts are stocked in the diameters listed below and are grey in color. The standard length is 48" and 96". Other lengths can be produced upon request. SUPERSTUD™ is the ideal fastener for PULTEX structural shapes.

3/8", 1/2", 5/8", 3/4", 7/8", 1"

All Superstud and Supernut products are grey in color.

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SAFE-T-GRATE CHEMICAL COMPATIBILITY GUIDE

The information shown/presented in this corrosion guide are based on full immersion laboratory tests and data generated from resin manufacturer's data.

It should be noted that in some of the environments listed, splashes and spill situations may result in a more corrosive situation than indicated due to the evaporation of water. Regular wash down is recommended in these situations.

All data tabled represents the best available information and is believed to be correct. The data should not be construed as a warranty of performance for that product as presented in these tables. User tests should be performed to determine suitability of service if there is any doubt or concern.

Such variables as concentration, temperature, time and combined chemical effects of mixtures of chemicals make it impossible to specify the exact suitability of SAFE-T-GRATE in all environments. Seasafe will be happy to supply grating samples for testing.

These recommendations should only be used as a guide and Seasafe does not take responsibility for design or suitability of materials for service intended. In no event shall Seasafe be liable for any consequential or special damages for any defective material or workmanship including without limitation, labor charge, other expense of damage to properties resulting from loss of materials or profits or increased expenses of operation.

CHEMICAL ENVIRONMENT	ISO		VINYLESTER	
	Max. Wt. %	Max. Oper. Temp. °F	Max. Wt. %	Max. Oper. Temp. °F
Acetic Acid	10	190	10	210
Acetic Acid	50	125	50	180
Acetone	N/R	N/R	100	75
Aluminum Chloride	SAT	170	SAT	200
Aluminum Hydroxide	SAT	160	SAT	170
Aluminum Nitrate	SAT	150	SAT	170
Aluminum Sulfate	SAT	180	SAT	200
Ammonium Chloride	SAT	170	SAT	190
Ammonium Hydroxide	1	100	10	150
Ammonium Hydroxide	28	N/R	28	100
Ammonium Carbonate	N/R	N/R	SAT	150
Ammonium Bicarbonate	15	125	SAT	130
Ammonium Nitrate	SAT	160	SAT	190
Ammonium Persulfate	SAT	N/R	SAT	150
Ammonium Sulfate	SAT	170	SAT	200
Amyl Alcohol	ALL	N/R	ALL	90
Amyl Alcohol Vapor	—	140	—	120
Benzene	N/R	N/R	100	140
Benzene Sulfonic Acid	25	110	SAT	200
Benzoic Acid	SAT	150	SAT	200
Benzoyl Alcohol	100	N/R	100	N/R
Borax	SAT	170	SAT	200
Calcium Carbonate	SAT	170	SAT	200
Calcium Chloride	SAT	170	SAT	200
Calcium Hydroxide	25	70	25	165
Calcium Nitrate	SAT	180	SAT	200
Calcium Sulfate	SAT	180	SAT	200
Carbon Disulfide	N/R	N/R	N/R	N/R
Carbonic Acid	SAT	130	SAT	180
Carbon Dioxide Gas	—	200	—	200
Carbon Monoxide Gas	—	200	—	200
Carton Tetrachloride	N/R	N/R	100	75
Chlorine, Dry Gas	—	140	—	170
Chlorine, Wet Gas	—	N/R	—	180
Chlorine Water	SAT	80	SAT	180
Chromic Acid	5	70	10	120
Citric Acid	SAT	170	SAT	200
Copper Chloride	SAT	170	SAT	200
Copper Cyanide	SAT	170	SAT	200

CHEMICAL ENVIRONMENT	ISO		VINYLESTER	
	Max. Wt. %	Max. Oper. Temp. °F	Max. Wt. %	Max. Oper. Temp. °F
Copper Nitrate	SAT	170	SAT	200
Crude Oil, Sour	100	170	100	200
Cyclohexane	N/R	N/R	N/R	N/R
Cyclohexane, Vapor	ALL	100	ALL	130
Diesel Fuel	100	160	100	180
Diethyl Ether	N/R	N/R	N/R	N/R
Dimethyl Phthalate	N/R	N/R	N/R	N/R
Ethanol	50	75	50	90
Ethyl Acetate	N/R	N/R	N/R	N/R
Ethylene Chloride	N/R	N/R	N/R	N/R
Ethylene Glycol	100	90	100	200
Fatty Acids	SAT	180	SAT	200
Ferric Chloride	SAT	170	SAT	200
Ferric Nitrate	SAT	170	SAT	200
Ferric Sulfate	SAT	170	SAT	200
Ferrous Chloride	SAT	170	SAT	200
Fluoboric Acid	N/R	N/R	SAT	165
Fluosilicic Acid	N/R	N/R	SAT	70
Formaldehyde	50	75	50	100
Formic Acid	N/R	N/R	50	100
Gasoline	100	80	100	150
Glucose	100	170	100	200
Glycerine	100	150	100	200
Heptane	100	110	100	120
Hexane	100	90	100	130
Hydrobromic Acid	50	120	50	120
Hydrochloric Acid	10	150	10	200
Hydrochloric Acid	20	140	20	190
Hydrochloric Acid	37	75	37	95
Hydrofluoric Acid	N/R	N/R	15	80
Hydrogen Bromide, Dry	100	190	100	200
Hydrogen Bromide, Wet	100	75	100	130
Hydrogen Chloride	—	120	—	200
Hydrogen Peroxide	5	100	30	100
Hydrogen Sulfide, Dry	100	170	100	210
Hydrogen Sulfide, Wet	100	170	100	210
Hypochlorous Acid	20	80	20	150
Isopropyl Alcohol	N/R	N/R	15	80
Kerosene	100	140	100	180

— No Information Available N/R Not Recommended SAT Saturated Solution FUM Fumes

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CHEMICAL ENVIRONMENT	ISO		VINYLESTER	
	Max. Wt. %	Max. Oper. Temp. °F	Max. Wt. %	Max. Oper. Temp. °F
Lactic Acid	SAT	170	SAT	200
Lead Acetate	SAT	170	SAT	200
Lead Chloride	SAT	140	SAT	200
Lead Nitrate	SAT	—	SAT	200
Linseed Oil	100	150	100	190
Lithium Chloride	SAT	150	SAT	190
Magnesium Carbonate	SAT	140	SAT	170
Magnesium Chloride	SAT	170	SAT	200
Magnesium Hydroxide	SAT	150	SAT	190
Magnesium Nitrate	SAT	140	SAT	180
Magnesium Sulfate	SAT	170	SAT	190
Mercuric Chloride	SAT	150	SAT	190
Mercurous Chloride	SAT	140	SAT	180
Methyl Ethyl Ketone	N/R	N/R	N/R	N/R
Mineral Oils	100	170	100	200
Monochlorobenzene	N/R	N/R	N/R	N/R
Naptha	100	140	100	170
Nickel Chloride	SAT	170	SAT	200
Nickel Nitrate	SAT	170	SAT	200
Nickel Sulfate	SAT	170	SAT	200
Nitric Acid	5	140	5	150
Nitric Acid	20	70	20	100
Oleic Acid	100	170	100	190
Oxalic Acid	ALL	75	ALL	120
Paper Mill Liquors	—	100	—	120
Perchlorethylene	100	N/R	100	N/R
Perchloric Acid	N/R	N/R	10	150
Perchloric Acid	N/R	N/R	30	80
Phosphoric Acid	10	160	10	200
Phosphoric Acid	100	120	100	200
Potassium Aluminum Sulfate	SAT	170	SAT	200
Potassium Bicarbonate	50	80	50	140
Potassium Carbonate	10	N/R	10	120
Potassium Chloride	SAT	170	SAT	200
Potassium Dichromate	SAT	170	SAT	200
Potassium Hydroxide	N/R	N/R	25	150
Potassium Nitrate	SAT	170	SAT	200
Potassium Permangante	100	80	100	210
Potassium Sulfate	SAT	170	SAT	200

CHEMICAL ENVIRONMENT	ISO		VINYLESTER	
	Max. Wt. %	Max. Oper. Temp. °F	Max. Wt. %	Max. Oper. Temp. °F
Propylene Glycol	ALL	170	ALL	200
Phthalic Acid	—	—	SAT	200
Sodium Acetate	SAT	160	SAT	200
Sodium Benzoate	SAT	170	SAT	200
Sodium Bicarbonate	SAT	160	SAT	175
Sodium Bisulfate	ALL	170	ALL	200
Sodium Bromide	ALL	170	ALL	200
Sodium Carbonate	10	80	35	160
Sodium Chloride	SAT	170	SAT	200
Sodium Cyanide	SAT	170	SAT	200
Sodium Hydroxide	N/R	N/R	50	150
Sodium Hydroxide	N/R	N/R	25	80
Sodium Hypochlorite	N/R	N/R	10	150
Sodium Monophosphate	SAT	170	SAT	200
Sodium Nitrate	SAT	170	SAT	200
Sodium Sulfate	SAT	170	SAT	200
Sodium Thiosulfate	ALL	100	ALL	120
Stannic Chloride	SAT	160	SAT	190
Styrene	N/R	N/R	N/R	N/R
Sulfated Detergent	0/50	170	0/50	200
Sulfur Dioxide	100	80	100	200
Sulfur Trioxide	100	80	100	200
Sulfuric Acid	93	N/R	93	N/R
Sulfuric Acid	50	N/R	50	180
Sulfuric Acid	25	75	25	190
Sulfurous Acid	SAT	80	N/R	N/R
Tartaric Acid	SAT	170	SAT	200
Tetrachloroethylene	N/R	N/R	FUM	75
Toluene	N/R	N/R	N/R	N/R
Trisodium Phosphate	N/R	N/R	SAT	175
Urea	SAT	130	SAT	140
Vinegar	100	170	100	200
Water, Distilled	100	170	100	190
Water, Tap	100	170	100	190
Water, Sea	SAT	170	SAT	190
Xylene	N/R	N/R	N/R	N/R
Zinc Chloride	SAT	170	SAT	200
Zinc Nitrate	SAT	170	SAT	200
Zinc Sulfate	SAT	170	SAT	200

— No Information Available N/R Not Recommended SAT Saturated Solution FUM Fumes

Annex C **Diagnostico y Recomendaciones para la Rehabilitacion del Centro de Interpretacion Ambiental, Parque Nacional Volcán Masaya**

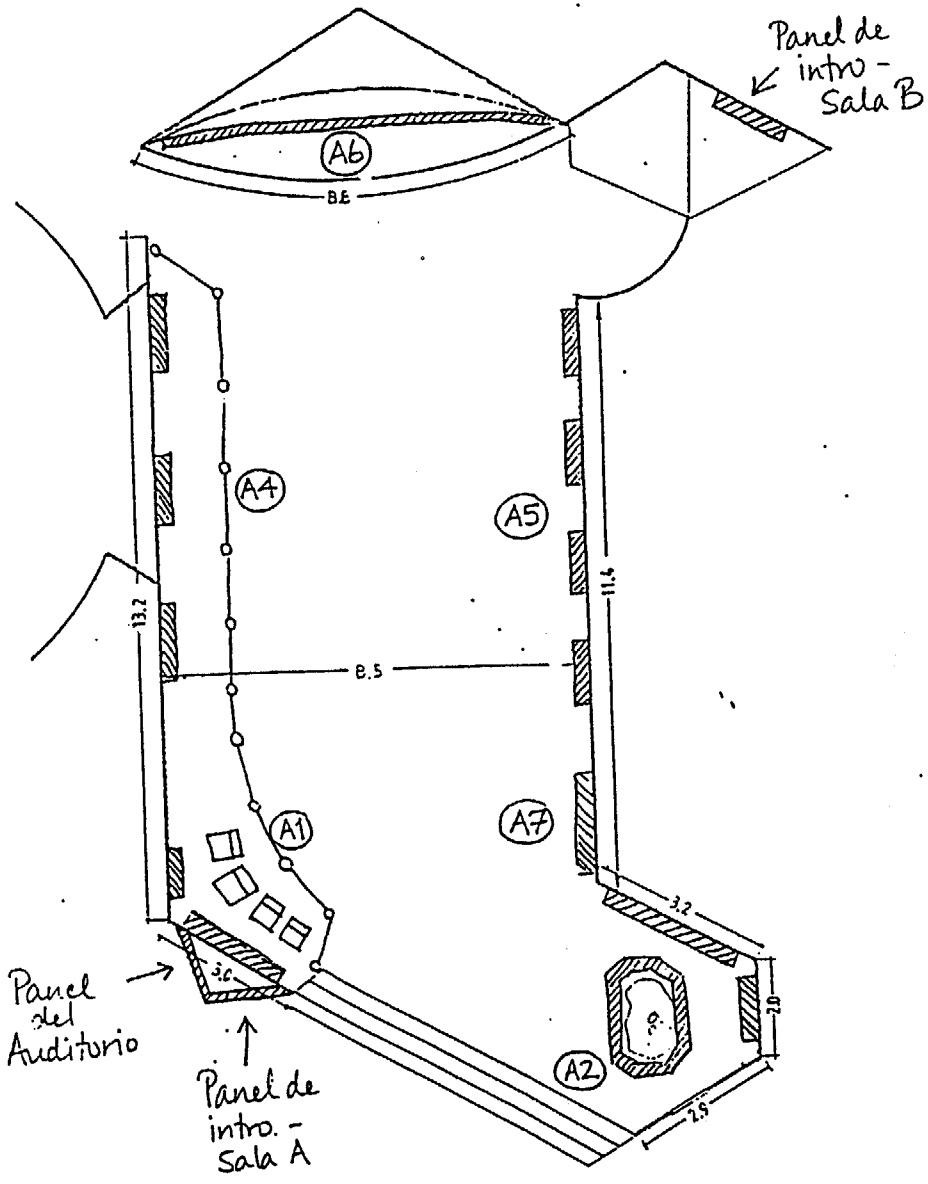
Report (in Spanish) dated September 1992 by Environmental Education Consultant

DIAGNOSTICO Y RECOMENDACIONES PARA LA REHABILITACIÓN DEL
CENTRO DE INTERPRETACIÓN AMBIENTAL - PARQUE NACIONAL VOLCÁN MASAYA

Hojas de Trabajo
Septiembre 1992

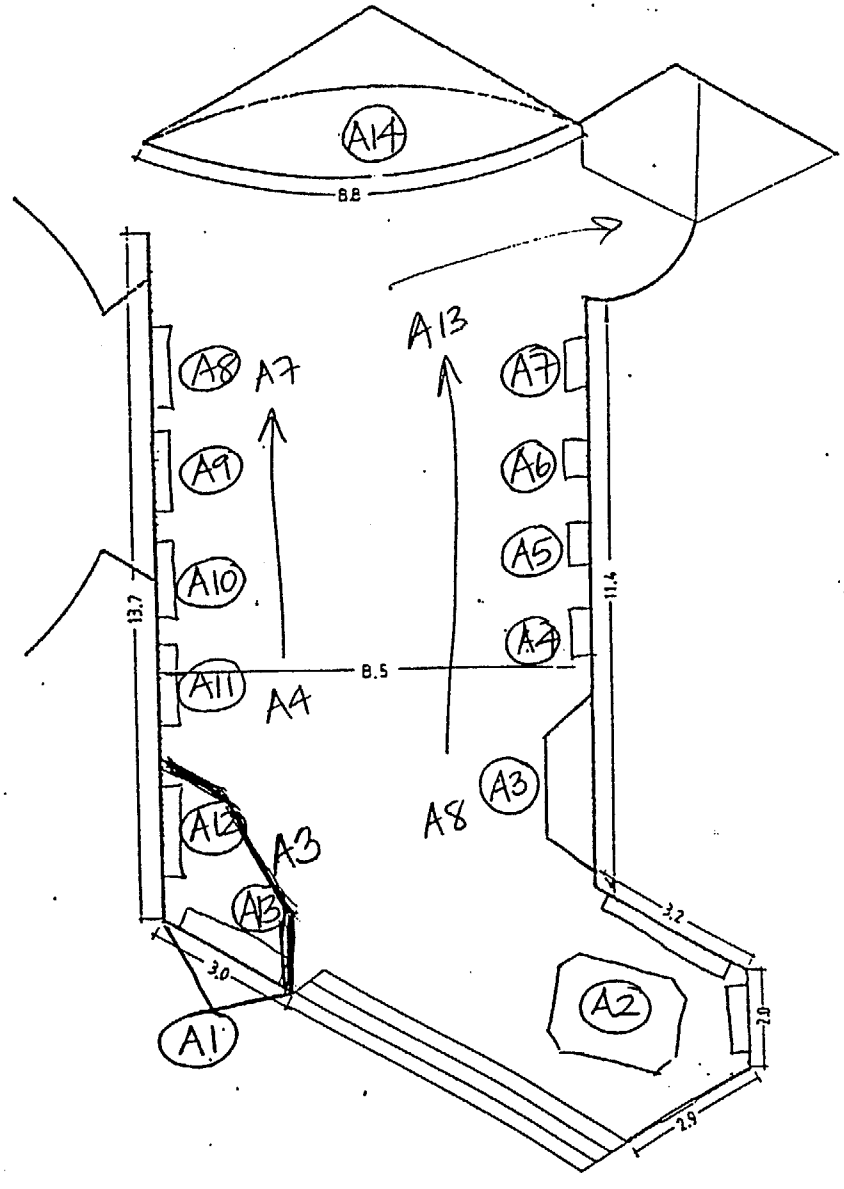
ELEMENTOS ACTUALES	RECOMENDACIONES
SALA A. [illegible] - Sala A - *La Historia del Volcán Masaya.* -a la par tiene un panel para anunciar las presentaciones en el Auditorio. Título debe reflejar más lo que tiene la sala.	Secuencia recomendada para la sala: A1. [Panel de introducción] "El Parque Nacional Volcán Masaya y su Historia" A2. [Maqueta de la caldera de VM]; [2 paneles] Qué es un parque nacional, importancia del VM en el contexto nacional, historia del VM como área protegida, etc.; [escudo nacional]. A3. [Vitrina] Arqueología precolombina. A4 al A13. Historia del Volcán Masaya. A14. [Gran mural] La erupción de 1772. <u>Nuevo No. A1:</u> Título cambio: El Parque Nacional Volcán Masaya y su Historia.
NO. A2. *"Parque Nacional Volcán Masaya"* -orientación al PNVM -maqueta del caldera; panel sobre PNVM con datos y mapa; panel sobre el manejo y la zonificación del parque. Maqueta carece rotulación y escala. Es muy alto para niños. Mapa es redundante, no apoya. Los datos no son interesantes. Panel sobre PNVM falta historia del Parque. Panel sobre el manejo y la zonificación del PNVM es muy técnico.	<u>Nuevo No. A2:</u> –Maqueta - pintarla más natural, poner escala, no rotularla pero señalar algunos rasgos sobresalientes para orientara los visitantes. Orientar la maqueta para que concuerda con la posición de los rasgos reales. Instalar gradas para niños. –Usar los dos paneles para presentar: que es un PN, importancia del VM en el contexto nac. y la historia del VM como área protegida (primer proyecto así, posición estratégica, es y ha sido en el área más densamente poblado entonces y ahora...). Incorporar fotos del PNVM hoy y actividades de la gente. Eliminar el mapa del PNVM (se debe ofrecer al público en un folleto). Usar el mapa de A7 con textos más interesantes. Eliminar la información sobre manejo y zonificación. –Instalar el escudo de Nicaragua en el lugar de la ventanilla triangular.
NO. A1. *"Arqueología Precolombina"* -Arqueología precolombina; arte rupestre inscrito en los farallones de la laguna. -2 paneles con repros de arte, textos; pedestales con artefactos. Los materiales no están protegidos. Repro. del arte en película positiva muy frágil, debe presentar más ejemplos. Falta información sobre los indígenas.	<u>Nuevo No. A3:</u> Diseñar una vitrina para alojar todos los elementos. Ubicarla en la posición indicada en el plano adjunto. Escribir textos más interpretativos y usar dibujos o mejores descripciones, p.e. abrir una urna, ubicar esqueleto dentro y explicar uso. Usar la información sobre étnias ocupantes del sitio (desde A7). Usar más repros de petroglifos o tal vez fotos. Rehacer los repros como fotostatos.

NO. A4. *"Escenas Históricas del Volcán Masaya"* -sacerdotista aborigen; el bautismo del volcán (1529, Fraile Bobadilla); exploración de Oviedo (1529). La bajada de Fray Blas de Castillo existe pero no lo tiene en el Centro. -3 óleos de Rodrigo Peñalba, falta uno. No se preparó: el redescubrimiento del volcán; el nacimiento del cráter Santiago; la visita de Karl Sapper; la odisea de los ingenieros alemanes. Marcos de madera muy rústico. Falta protección, la baranda existente es muy inestable.	<u>Nuevos Nos. A4 al A13 (con viejo A5):</u> Conseguir el óleo que falta. Usando materiales de A5 junto con los óleos de A4 y otros materiales anteriormente no presentados, diseñar una serie de paneles sobre la historia del VM, para posiciones A4 al A13. Rehacer los marcos y rediseñar el montaje para que el agua que filtra desde el techo no los dañe. Construir una baranda fija para protegerlos.
NO. A5. *"Iconografía del Volcán Masaya"* -antiguos dibujos, mapa, foto de VM. -4 paneles con repros de arte o fotos en película positiva. Falta material--podría presentar más. Repros de arte muy frágil.	<u>Nuevos Nos. A4 al A13 (con viejo A4):</u> Introducir mas elementos. Determinar la secuencia con los óleos de A7. Se puede usar el espacio de A1 para presentar más iconografía. Considerar el uso de algunos objetos o libros viejos en mini-vitrinas a la para de los paneles. Rehacer los repros como fotostatos. Construir una baranda fija para protegerlos.
NO. A6. *"La Gran Erupción de 1772"* -Gran mural con masatera grande o jardincito debajo. Jardincito en frente deteriorado, escoria no tiene ningún diseño. El texto podría ser ubicado mejor. A veces la gente sin guía va a la salida en vez de entrar a las exhibiciones.	<u>Nuevo No. A14:</u> Poner la leyenda en un pedestal pequeño en medio y debajo del mural. Componer el jardincito allí--preparar un diseño. A la derecha de la entrada a las demás exhibiciones, poner rótulo "Entrada a las exhibiciones"; a la izquierda de la salida hacia el restaurante, poner rótulo "Salida al restaurante".
NO. A7. *"El Entorno Socio-económico del Volcán Masaya"* -Los pueblos indígenas y el volcán; las étnias indígenas en la época precolombina; un Parque Nacional en la zona más poblada de Nicaragua; perspectivas para el año 2000. -panel con mapas y textos Contenido fuera de secuencia.	Eliminar este panel. El contenido de "los pueblos indígenas" pasa a A1. Corregir el mapa poniendo los Nandaimes con los Dirianes. El contenido del "parque nacional en la zona más poblada y perspectivas" pasa a A2.



SALA A

ACTUAL



SALA A

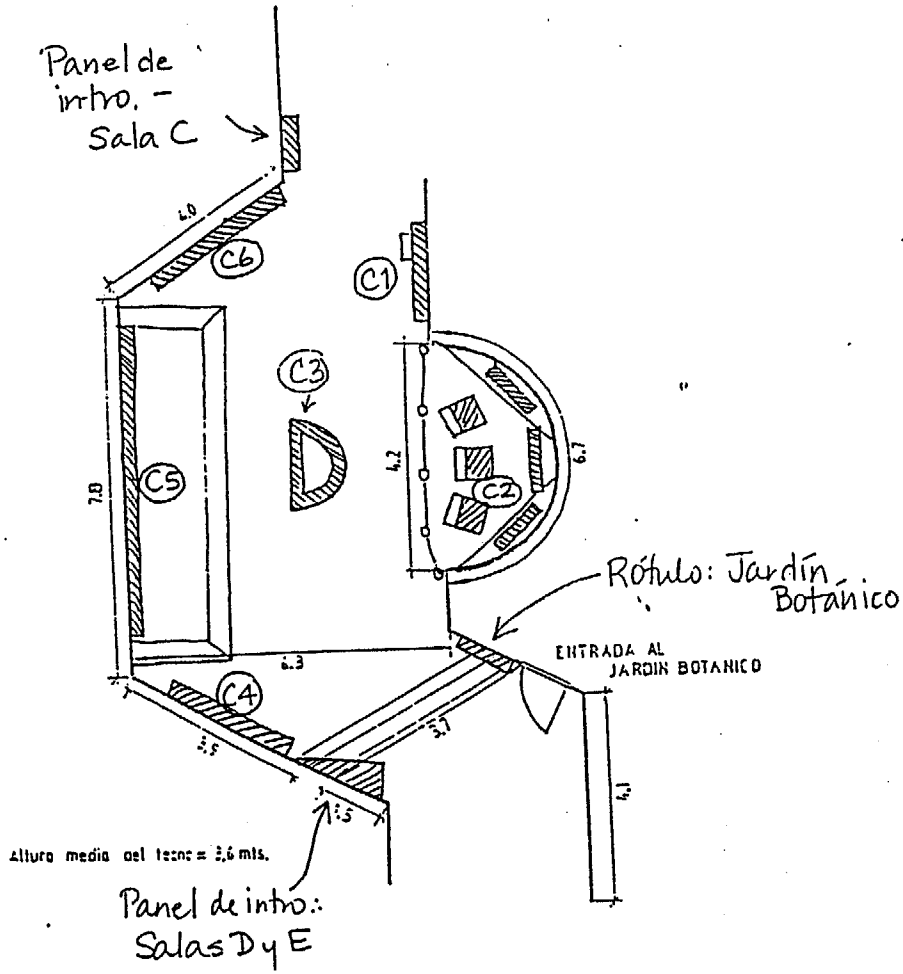
PROPUESTA

ELEMENTOS ACTUALES	RECOMENDACIONES
SALA B. -Panel de introducción: "*Sala B - Geología General*".	Nuevo No. B1: Poner un título mas interpretativo???
NO. B1. "*La Escala Geológica*" -mural grande que explica varios temas complejos: la escala geológica; formación de la Tierra; composición de la Tierra; la corteza dinámica (movimiento de placas); teoría de la deriva continental; formación del istmo de Centroamérica. Algunos dicen que tiene información y datos en exceso pero los maestros que lo utilizan dice que es el único recurso que tienen para explicar este proceso, lo explican con mucha paciencia y cuando llegan al final del mural, se sientan que han hecho un gran recorrido--les gusta mucho. Cuidado que la secuencia de evolución de la tierra y de vida no sugieren conceptos equivocados. Está manchado por murciélagos.	Nuevo No. B2: Considerar como mejorar algunos elementos o la presentación. Redactar los textos para disminuirlos y evitar duplicación. Considerar el uso de elementos tri-dimensional para enseñar la evolución de vida en una banda separada a un nivel que el público puede tocar (por ejemplo, podría montar un panel vitrina inclinada para exhibir evidencias de evolución biológica y geológica--alga primitiva, fósil artrópodo como trilobite, registro fósil in situ, esqueleto de reptil,...). ¿No
NO. B2. "*Los Volcanes de la Tierra*" -placas tectónicas; volcanismo; anillo del fuego del Pacífico -maqueta iluminado desde atrás, que enseña las placas y los volcanes del mundo. Panel inclinado abajo tiene ilustraciones y textos. Mapa incompleto, falta volcanes mencionados en los textos. Ilustraciones y textos muy pequeños.	Nuevo No. B3: Enseñar el relieve del fondo del mar. Eliminar las ilustraciones pequeñas de las placas de la tierra y el anillo de fuego. Ampliar más la ilustración grande del corte de la tierra. Instalarla más alto y inclinado. Usar textos más interpretativos..."Cómo y por qué nacen los volcanes juntos?" Bajar el título principal. [Para el futuro, contemplar un diseño nuevo, tal vez usar globo grande que ya tienen.]
NO. B3. "*El Movimiento de las Placas en América Central.*" -fenómeno de vulcanismo en A.C.; subducción de la placa Cocos debajo la placa Caribe -maqueta de una sección de Nicaragua en la región de Volcán Masaya. Tiene dos ilustraciones y textos para explicar el fenómeno. Está muy oscuro debajo, no se ve bien la parte de la placa que está subduciendo. Difícil ver los ilustraciones y textos. Dibujos no ayuden entender el fenómeno. Muy alto para niños--no pueden ver la superficie.	Nuevo No. B4: Renovar la maqueta: Investigar posibilidad iluminar la placa Cocos desde atrás. Hacer trincha más profunda y volcanes más altos. Redactar la información y ilustraciones. Ampliar las ilustraciones y usar todo el espacio de la pared atrás. Bajar el título principal. Poner leyendas como "corte", "movimiento tectónico en las Américas"... Es oportunidad de hablar de fenómeno de temblores y terremotos en A.C.

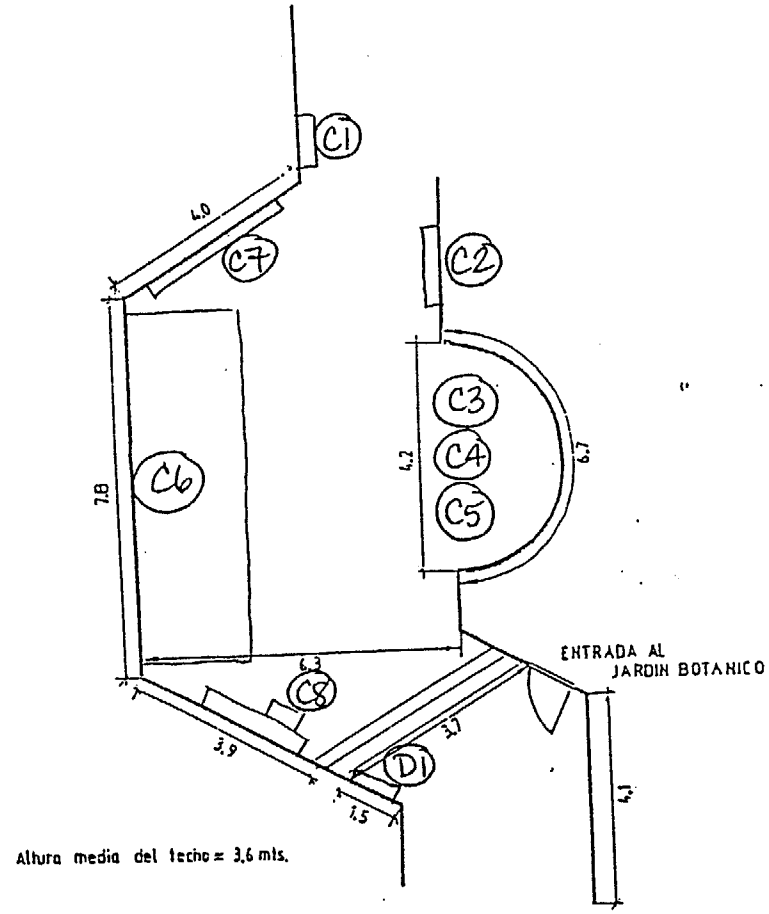
NO. B4. *"Larreynaga y su hipótesis sobre volcanes."* -Óleo representando Larreynaga y su hipótesis con un texto biográfico. Falta el concepto que el mar refracta los rayos del sol y funde las rocas. La Sala B falta información sobre lo que es un volcán y su constitución. Mejor poner Larreynaga en Sala C y ubicar aquí la maqueta de la estructura interna de un volcán.	Nuevo No. B5: *"Estructura Interna de un Volcán"* Poner la maqueta C3 aquí y poner el óleo de Larreynaga en Sala C. [C3 es la maqueta de un volcán, se puede montar un espejo en la pared del nicho para que se ven sin rodear la maqueta. Instalar rótulos. Incluir información sobre lo que es un volcán y su constitución.]

ELEMENTOS ACTUALES	RECOMENDACIONES
SALA C. -Panel de introducción - "Sala C - *Vulcanología General Regional*"	Reevaluar secuencia de las exhibiciones, se sugiere: 2. Hipótesis de Larreynaga y conocimiento científico actual del volcán. 3. Tipos de volcanes. 4. Tipos de erupciones. 5. Materiales volcánicos. 6. La cordillera volcánica del Pacífico de Nicaragua. 7. Los volcanes y el hombre. a. Los volcanes vistos por los primeros hombres (concepción mágica). b. Los terremotos: Castigos o fenómenos naturales? c. Buscando explicaciones: investigación científica, sismografía. 8. Historia de los volcanes y suelos de Managua. <u>Nuevo No. C1:</u> Cambiar título de sala "Vulcanología General y Regional". <u>Nuevo No. C2:</u> "Hipótesis Larreynaga y conocimiento científico actual del volcán"
NO. C1. "*La Historia de los Volcanes en las Capas de Suelo de Managua*" -formación de suelos por volcanismo; origen y composición -panel con columna de las capas de suelos de Managua atrás de vidrio, textos y ilustraciones Deteriorado los rótulos. Muy cargado de texto. Foto y mapa muy pequeños.	<u>Nuevo No. C8:</u> "Historia de los Volcanes y Suelos de Managua" Redacción rigurosa, usar más subtitulación. Pintar los números y bandas en el vidrio. Usar bandas de color para unir las capas con su textos interpretativos. Cambiar su ubicación para que sea el último en la secuencia, poniéndolo en el viejo lugar de C4. Su nuevo número seria C7.
NO. C2. "*Los Materiales que Salen del Volcán*" -tipos de lava y materiales arrojados No instalaron los rótulos. Necesita más variedad de muestras y más información interpretativa. Iluminación mala. Baranda inestable.	<u>Nuevo No. C5:</u> Rediseñar. En este nicho se puede exhibir tipos de volcanes, tipos de erupciones y materiales volcánicos. Instalar luces direccionales (spots).
NO. C3. "*Estructura Interna de un Volcán*" -morfología de volcán -maqueta de un volcán cortado en sección No instalaron los rótulos. Falta domo protectivo pero parece que la maqueta no ha sufrido daños a pesar de todo. Debe estar ubicado en Sala B.	Ubicarlo en Sala B en el viejo lugar de "Larreynaga". Instalar rótulos. Poner espejo atrás en la pared del nicho. Protección?

NO. C4. "*Los Diferentes Tipos de Erupciones Volcánicas*" -tipos de volcanes y erupciones -panel con 5 panelitos de los tipos de erupciones, abajo cada uno hay fotos, ilustraciones y textos de tipos de volcanes Muy cargado. Varios elementos han caído.	<u>Nuevos Nos. C3 y C4:</u> Rediseñar. Ubicar "tipos de erupciones" en el viejo sitio de C2 combinado con materiales volcánicos y tipos de volcanes.
NO. C5. "*La Cordillera Volcánica del Pacífico de Nicaragua*" -volcanes de Nicaragua; cordillera -maqueta de área, 1:50,000 Falta rotulación y interpretación. Falta fotos de varios volcanes. Sufre daños por no tener baranda que prohíbe que niños suben la maqueta.	<u>Nuevo No. C6:</u> Preparar rótulos. Pintarlo naturalmente enseñando zonas urbanas, algodonales, etc. Destacar Cerro Negro. Preparar caja con iluminación atrás y foto-positivas en colores de todos los volcanes o estructuras parecidas. Posiblemente puede exhibir una muestra de un material característico arrojado por cada volcán en cajitas de plexiglas en una banda debajo cada foto o en la base de la maqueta--la cara inclinada al público.
NO. C6. "*Los Volcanes y el Hombre*" -peligros y beneficios de volcanes para el Hombre -panel construido y colgado No lo prepararon.	<u>Nuevo No. C7:</u> Terminar diseño y textos. Ubicarlo en el viejo lugar de C6 que ahora tiene un panel vacío. Contenido: Los volcanes y el hombre (beneficios y peligros de volcanes) a. Beneficios: suelos fértiles, minerales, etc. b. Erupciones y terremotos, castigos o fenómenos naturales? c. Buscando explicaciones: investigación científica, sismografía.



SALA C
ACTUAL



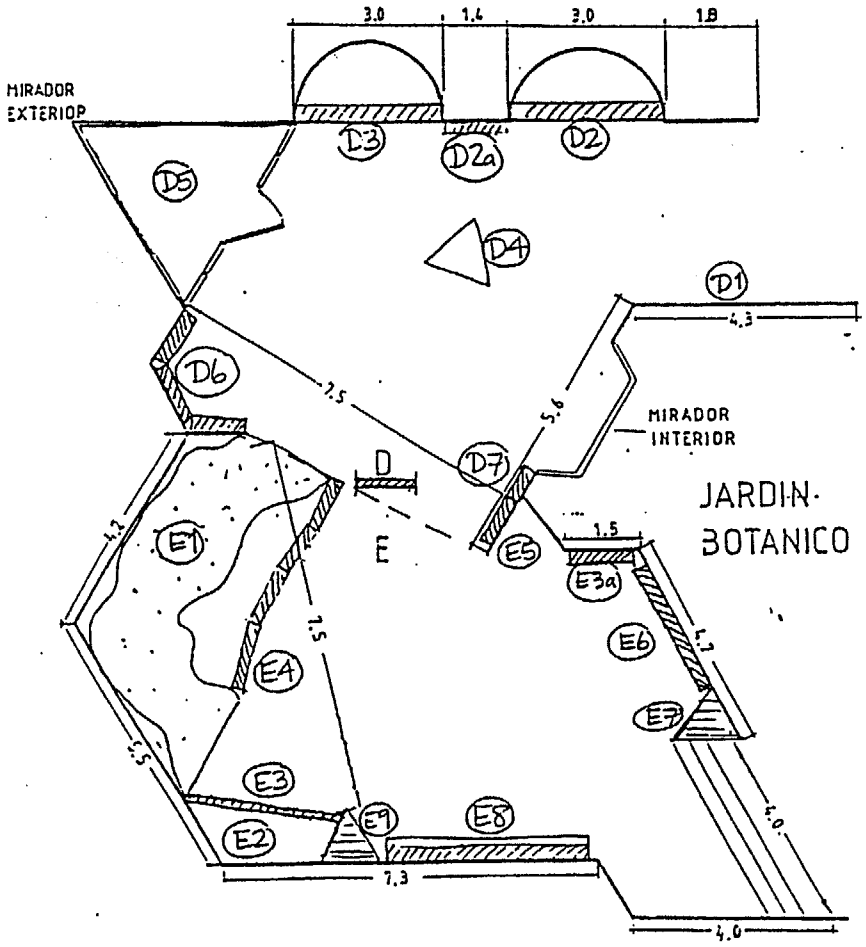
SALA C
PROPUESTA

ELEMENTOS ACTUALES	RECOMENDACIONES
SALAS D Y E. -Panel de introducción: "*La Naturaleza del Volcán Masaya*" Secuencia temática actual: Fauna Fumarolas de Santiago y daños Chocoyos Otros rasgos del paisaje volcánico Túneles de lava Flora: sucesión, estacionalidad, y relaciones Alteración del ambiente por el hombre y alternativas de protección Secuencia algo mezclado.	Secuencia propuesta: 2. Geomorfología del VM 3. Otros rasgos del paisaje volcanico 4. La actividad volcánica: fumarolas y efectos 5. Animales diurnos 6. Animales nocturnos 7. Adaptaciones de animales 8. Los chocoyos 9. Los túneles de lava 10. [Animales?? Especies en peligro?? Coyote??] 11. Sucesión vegetal 12. Las flores y sus visitantes 13. Sacuanjoche 14. Bosque tropical seco–estacionalidad 15. Alteración del ambiente por el hombre y alternativas de protección 16. Incendios <u>Nuevo No. D1:</u> Cambiar a: "El Volcán Masaya y su Ambiente"
NO. D1. "*Historia geológica de la caldera de Masaya*" -origen de VM No se preparó.	<u>Nuevo No. D2:</u> Diseñar, preparar.
NO. D2. "*La Vida Diurna del Parque*" -animales diurnos; adaptaciones (colores, sonidos) -diorama con plantas y animales disecados, mural en la pared atrás. Baja calidad. Falta rótulos interpretativos. Deterioro por filtración de agua del techo. Murales de fondo muy dañados. Es muy popular con estudiantes y quieren mas ejemplos de animales (disecados).	<u>Nuevo No. D5:</u> Componer el techo del nicho para que no filtre el agua. Mejorar presentación. Bajar título principal. Contemplar pintar la pared del fondo si pueden componer el techo. Más animales??? Perfiles para identificar animales?
NO. D2a. "*Adaptaciones de los Animales*" -adaptaciones depredador-presa -panel-muralito en color Información aglomerada. Uno (o más?) rotulitos caídos. Montado un poco alto?	<u>Nuevo No. D7:</u> Retocar y hacer de nuevo los rotulitos. Montar un poco mas bajito.

NO. D3. *"La Vida Nocturna del Parque"* -animales nocturnos; adaptaciones (olores, sonidos) -diorama con plantas y animales disecados, mural en la pared atrás. Baja calidad. Falta rótulos interpretativos. Deterioro por filtración de agua del techo. Murales de fondo muy dañados. Es muy popular con estudiantes y quieren mas ejemplos de animales (disecados).	Nuevo No. D6: Componer el techo del nicho para que no filtre el agua. Mejorar presentación. Bajar título principal. Contemplar pintar la pared del fondo si pueden componer el techo. Más animales??? Perfiles para identificar animales?
NO. D4. *"La Fumarola de Santiago" y "Daños"* -de-gasificación, gases; actividad y daños -3 paneles en forma de pirámide, un lado con mural de la fumarola, otros lados con fotos y textos Fotos caídas.	Nuevo No. D4: Fumarola debe ser más cargado, más como "coliflor". Reponer fotos caídas. Poner fotos de vegetación afectada pòr los gases. Mejorar mapa.
NO. D5. *Juego para niños en el mirador.* -relaciones tróficas No se preparó.	Recomiendo que no se pone exhibiciones fuera, el clima es altamente dañino.
NO. D6. *"Los Chocoyos del Cráter"* -chocoyos del cráter; comportamiento; dieta; adaptaciones -panel tríptico con ilustraciones pintadas en color. Rótulos encima de las ilustraciones poco estético? No tiene mucha información básica de chocoyos y no presenta nombre científico (Aratinga holochlora). No es seguro que solo ponen un huevo por año. Las plantas faltan nombres vulgares y científicos.	Nuevo No. D8: Averiguar información de la biología de los chocoyos (un huevo/año?). Retocar y rehacer rótulos. Poner nombres científicos en las ilustraciones.
NO. D7. *"Otros Rasgos del Paisaje Volcánico"* -estructuras adventicias -panel con una mini-maqueta de la caldera, fotos de las estructuras Fotos de mala calidad.	Nuevo No. D3: Buscar mejores fotos. Reponer fotos. Componer maqueta--hacerla mas grande, mas detallada Incluir "El Arenoso". Instalarla a la par de la exhibición sobre la geomorfología del VM. ——— En el lugar de este panel, preparar otro sobre la ecología del área (red trófica).
NO. E1. *"El Túnel de Lava"* -origen; morfología; habitantes -re-creación de un túnel de lava. -panel de introducción (free-standing). -tiene 3 nichos por dentro del túnel para tres exhibiciones No se instaló las exhibiciones en los nichos del túnel.	Nuevo No. D9: Determinar y diseñar el contenido de los 3 nichos: 1. Túneles de lava y flora (Ficus)--origen, morfología 2. Fauna--Murciélagos 3. Arqueología: evidencias Instalar alambre y spots en los 3 nichos. Preparar paneles de vidrio o plexi para los nichos.

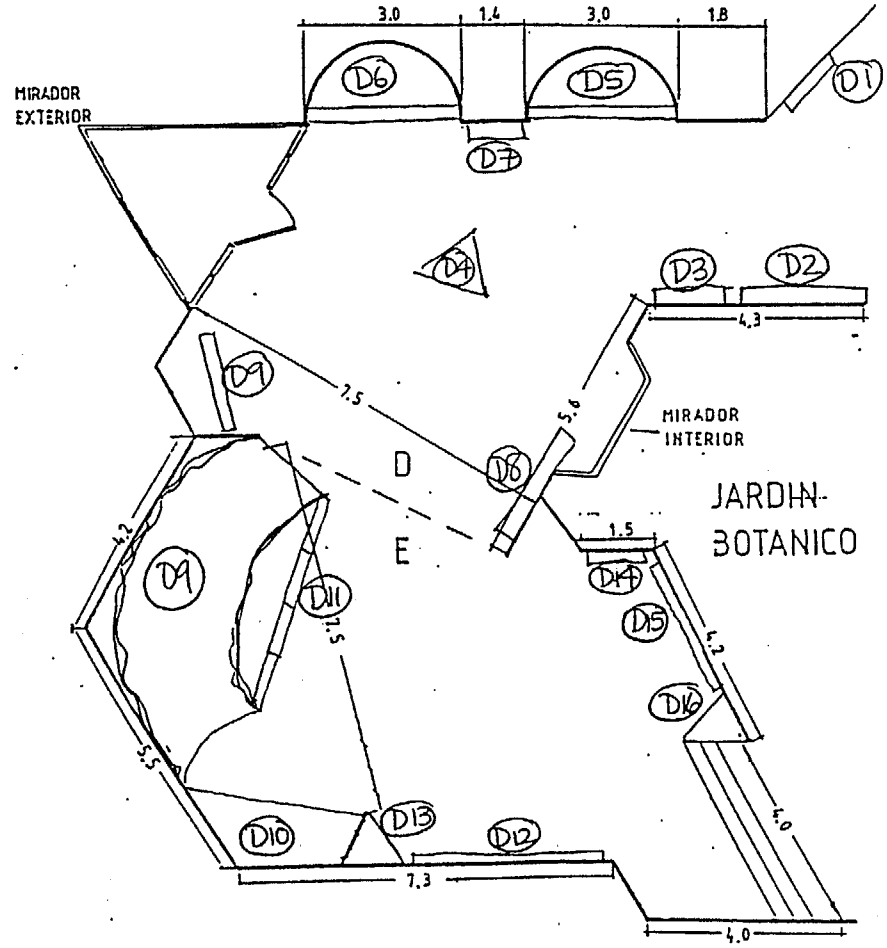
NO. E2. [iba a ser una diorama con Ficus encima de la lava] NO. E3. *"Los Túneles de Lava"* -origen; morfología; habitantes -área para diorama cerrado con plywood encima, fotos de los túneles presentado temporalmente. Diorama que no se instaló por problemas de filtración de agua.	Nuevo No. D10: Eliminar las fotos de túneles aquí, la información pasa a nicho numero uno en el túnel. Quitar los paneles de plywood y abrir el diorama. Componer techo del nicho. Determinar y diseñar el contenido del diorama [Animales?? Especies en peligro?? Coyote??].
NO. E3a. *"El Paisaje del Parque - Verano - Invierno"* -bosque seco; estacionalidad; ambientes Solo tiene rótulos informativos, no interpretativos.	Nuevo No. D14: Retocar. Redactar y rehacer los rótulos.
NO. E4. *"La Sucesión Vegetal en Acción"* -sucesión en suelo volcánico -4 paneles con ilustraciones pintadas No integra el fenómeno volcánico con la formación del suelo. No se terminó el panel de la etapa última. Los rótulos están montados muy alto.	Nuevo No. D11: En el primer panel se puede alterar la ilustración para que incluya el fenómeno volcánico con la formación del suelo (pintar un volcán en el fondo a la izquierda). Poner los nombres vulgares y científicos de las plantas. Terminar el último panel. Bajar los rótulos.
NO. E5. No se instaló - busto de Ramírez Goyena, primer botánico nicaragüense.	Opción: Conseguir y instalar busto de Ramírez Goyena??
NO. E6. *"Alteración del Ambiente por el Hombre"* -incendios; deforestación, erosión, extracción, agricultura; ganadería; destrucción de hábitats; contaminación; caza -panel con fotos y subtítulos. Diseño no apoya mucho. Elementos no concuerdan.	Nuevo No. D15: Rediseñar y preparar. Usar más imágenes y menos texto. Se separa en las siguientes secciones: - uso de los recursos del volcán - alteraciones que se producen y problemas de conservación - alternativas de protección Preguntar: "Como puede ayudar usted a proteger el PNVM?" y anexar un libro de registro para que los visitantes escriben sus comentarios (ayudará a la evaluación de la exhibición también).
NO. E7. *"Protección del Parque Nacional"* -normas de seguridad y protección -película positiva iluminada desde atrás por una caja de luces Baja calidad, la positiva está deteriorada. No es interpretativo, muy frío.	Nuevo No. D16: Preparar algo nuevo porque la información del reglamento del parque se debe presentar por otro medio (folleto). Recomiendo un panel sobre incendios (mayor peligro al parque, como comienzan, como se puede evitarlos, que hacer si Ud. encuentra uno...) con foto diapositiva iluminada desde atrás. Diseñar, preparar, etc.
NO. E8. *"Las Flores y sus Visitantes"* Falta información sobre especies en simbiosis.	Nuevo No. D12: Retocar. Rehacer rótulos.

NO. E9. "*La Sacuanjoche*" Se preparó pero no se instaló una exhibición sobre el sacuanjoche, su polinización y dispersión de semillas. Fue una película positiva iluminada desde atrás. Se perdió la caja de luces y la ilustración.	Nuevo No. D13: Preparar ilustración de la sacuanjoche, hacer diapositiva. Construir caja de luces. Instalarla.



SALAS D y E

ACTUAL



SALAS D y E

PROPUESTA

SALAS F Y G
ALTERNATIVA NO. 1 – REPARACIÓN DE LA EXHIBICIÓN ACTUAL

ELEMENTOS ACTUALES	RECOMENDACIONES
NO. 1. *"El medio-ambiente nicaragüense - El reto de proteger y producir"* -Título de la exhibición, introducción; créditos. -Panel ilustrado. Algunos se quejan de que hay un soldado armado, una señora que no descansa (canasta en la cabeza), y un campesino que parece que está "picado".	Retocar, eliminar los elementos no deseados.
NO. 2 (F1). *"Los beneficios de las áreas silvestres"* -Introducción. -Panel (free-standing) con símbolo precolombino y texto. Se fija poco en este panel.	Retocar.
NO. 3 (F2). *"Qué son las áreas silvestres?"* -Características. -Colección de fotos y titulación. Mensaje no está claro. No plantea nada específico. Fotos caídas. Reacción de visitante es–"que bonito es Nicaragua". Leyendas no son sobresalientes comparado con las fotos.	Rediseñar para que se nota más el mensaje.
NO. 4 (F6). *"Más beneficios de las áreas silvestres"* -Inspiración artística; apreciación estética; logros de ciencia; educación y recreo al aire libre; beneficios ambientales; confraternidad con la fauna; fuentes de farmacéuticos industriales y tradicionales. -Vitrina con cuatro lados y caja encima. No se terminó algunas secciones (educación y recreo al aire libre, beneficios ambientales, fuentes de farmacéuticos). Se han perdido muchos rótulos y ilustraciones. Muy cargado. Las cosas bidimensionales no se ve bien en la vitrina. La caja de plexi encima está desarmándose. Muy alto para niños.	Conseguir los elementos que falta. Buscar más elementos tridimensionales para complementar los otros. Montarlos, inclinando los elementos bidimensionales para que no son difíciles para ver.

NO. 5 (F4a). *"Interdependencia de la vida"* -Usando el ejemplo del jícaro (usos tradicionales y modernos por el hombre; el murciélago polinizador; el caballo dispersador). -Panel con ilustraciones y fotos. No se puso el título del panel. Lo han interpretado como "producción". El papel de algunos textos y dibujos se ha amarilleado. Mucho texto.	Preparar estencil del título y chuponearlo. Redactar textos. Preparar de nuevo los dibujos y textos y montarlos.
NO. 6 (F4b). *"Somos parte de un sistema natural. La diversidad de animales nos indica la sanidad del ambiente."* -Humanos y animales tiene las mismas necesidades básicas. -Ilustración romántica pintada. Falta leyenda abajo. Falta idea de "educación" como necesidad básica, según los maestros.	Retocar. Poner leyenda.
NO. 7 (F5). *"Beneficios de diversidad genética"* -concepto diversidad genética; orígenes silvestres de animales domesticados; etc. -panel con diagramas en color Está manchado y los colores están desapareciendo. Reacción del público muy positivo pero dicen que falta enseñar las razas del Hombre como ejemplo de diversidad.	Limpiar y retocar el panel. Incluir razas humanas??? Hacer los textos y dibujos de nuevo y preparar fotostatos (colorear y fotografiarlos después).
NO. 8 (F3a). *"Las plantas comestibles - Desarrollo de una dieta diversa"* -diversidad de plantas; orígenes silvestres de plantas domesticadas -panel con diagramas en color y B/N Les gusta la información pero por su posición o falta de luz, no reciben mucha atención. El guía genera mucho interés.	Limpiar. Retocar panel.
NO. 9 (F3b). *"Los Trópicos - Clave de la producción agrícola"* -importancia de preservar diversidad -panel con diagramas en color y B/N Les gusta la información pero por su posición o falta de luz, no reciben mucha atención. El guía genera mucho interés.	Limpiar. Retocar panel.

NO. 10 (F3c). *"La productividad de un bosque - por cuanto tiempo?"* -comparación de productividad de un bosque permanente y manejado con otro talado -panel con ilustración en color Se entienden fácilmente.	Limpiar. Retocar panel.
NO. 11 (F7). *"Nuestro Patrimonio Cultural"* -riqueza arqueológica y herencia étnica de Nicaragua. -panel con colección de fotos, caras de nicaragüenses, mapa arqueológico. No se preparó.	Buscar las fotos que había--se perdieron??? Preparar los elementos del panel.
NO. 12 (F8a). *"La Tortuga Verde (Chelonia mydas)"* -biología, distribución, comportamiento -panel pequeño con tortuga recortada en plywood, fotos, ilustraciones Fotos muy pequeños. Falta elementos.	Ampliar fotos. Retocar. Conseguir elementos que falta.
NO. 13 (F8b). *"Los Indios Miskitos"* -cultura, distribución, economía de subsistencia -panel pequeño Fotos muy pequeños. Falta elementos.	Ampliar fotos. Retocar. Conseguir elementos que falta.
NO. 14 (F8c). *"La pesca tortuguera en el Caribe occidental"* -comparación de pesca tortuguera artesanal con la de comercial; consecuencias de explotación no-sostenible. -vitrina con ilustraciones, fotos, objetos. Difícil ver en la vitrina, especialmente para niños. Colores de rótulos de algunos elementos han desaparecido. Necesita más artículos tridimensionales.	Ampliar fotos. Retocar. Conseguir elementos que falta. Instalar grada para niños.
NO. 15 (G1). *"Desequilibrio"* -introducción a la sección de problemas ambientales -panel (free standing) con símbolo precolombino y texto Sin guía, el público no se nota.	Retocar.
NO. 16 (G9). *"Cómo estará nuestro futuro si seguimos así?"* -rango y frecuencia de problemas ambientales -colección de artículos reales de periódicos de Nicaragua montado en 18 paneles pequeños. No se terminó.	Componer orden de los paneles. Montar artículos de periódicos. Se puede poner al día cada de vez en cuando. Una alternativa sería montar una colección de fotos sobre los recursos naturales protegidas en el Sistema de Áreas Silvestres de Nicaragua. Véase al Nuevo No. 28.

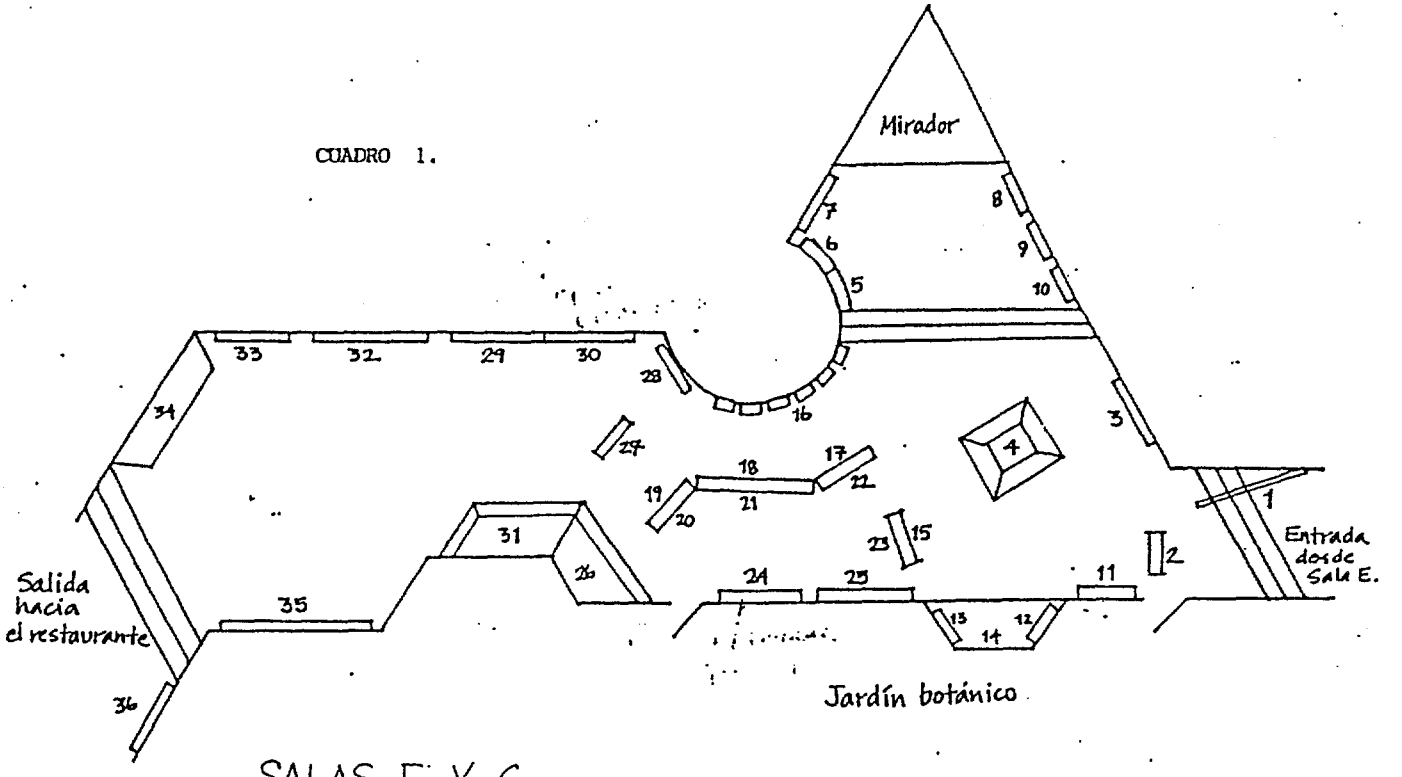
NO. 17 (G3). *"La comunidad de bosque tropical lluvioso - complejo incomparable"* -comunidad; diversidad; niveles del Bosque Tropical Lluvioso (emergente, bóveda, sotobosque, suelo) -Panel (free-standing), dos secciones con ilustraciones en color Muy efectivo según los maestros.	Retocar.
NO. 18 (G4). *Beneficios del bosque y efectos de la deforestación.* -previene erosión; hojarasca--abono; penetración del agua al suelo; productos de leña, alimentos, medicinas, madera, forraje, sombra; problemas del fuego; protección de cuenca -Formato muñequitos (cartoon). Muy efectivo según los maestros.	Retocar. Hacer dibujos de nuevo (proceso fotostato).
NO. 19 (G5). *"Un bosque o un desierto?"* -expansión de la frontera agrícola y consecuencias -Formato muñequitos (cartoon). Muy efectivo según los maestros.	Retocar. Actualizar. Hacer dibujos de nuevo (proceso fotostato).
NO. 20 (G6a). *"La pesca nicaragüense"* -variedad de peces y crustáceos comerciales dependientes de manglares -Panel (free-standing), ilustración pintada Muy efectivo según los maestros.	Retocar.
NO. 21 (G6b). *"El manglar - semillero de vida"* -sistemas estuarios y manglares; su importancia; causas de su destrucción y consecuencias -Panel (free-standing), sección grande con ilustración (perfil) pintada, fotos, etc. Muy efectivo. Ilustraciones pequeñas caídas.	Retocar. Reponer ilustraciones.
NO. 22 (G6c). *"Amenazas a los manglares"* -destrucción de manglares - problema complejo -panel (free-standing), dibujos B/N Es muy cargado pero esto no ha sido problemático. Falta color.	Retocar. Reponer ilustraciones (proceso fotostato--coloreado).
NO. 23 (G2). *"El pasado olvidado"* -causas de deterioro a yacimientos arqueológicos; "información" perdida. -panel (free-standing), al otro lado de No. 15. No se preparó.	Preparar el panel según diseño anteriormente planificado.

NO. 24 (G7a). *"El Jaguar (Felis onca)"* -ejemplo de especie en peligro de extinción; su biología; comportamiento; relación con el hombre; causas de su desaparencia -panel con jaguar tamaño natural recortado en plywood, con otras ilustraciones en B/N y textos La parte abajo muy cargado de textos. Falta color.	Redactar textos. Reponer ilustraciones (proceso fotostato--coloreado).
NO. 25 (G7b). *"Las especies desapareciendo--por qué?"* -juego para niños -factores que provocan la extinción de animales Muy efectivo--a la gente le gusta. Falta un mecanismo para abrir y cerrar las tapas.	Retocar. Reponer leyendas. Diseñar mecanismo para abrir/cerrar las tapas o usar truco de rótulito: "Abre" con flechas.
NO. 26 (G8). *"La importancia del buen manejo del territorio"* -"Un territorio mal manejado" -maqueta que enseña territorio deteriorado por practicas agrícolas no adecuadas. La maqueta está muy sucio. La maqueta está demasiado alto para verla. Las leyendas no son efectivos, muy largas. Falta rotulación en la maqueta para destacar las características importantes.	Renovar la maqueta completamente. Bajar toda la estructura. Cambiar las leyendas por rotulitos más cortitos instalados encima de la maqueta. Tal vez combinarlas con fotos. Diseñar y preparar vitrina para la maqueta.
NO. 27 (H1). *"Qué estamos haciendo sobre la situación?"* -Panel de introducción a la tercera sección sobre soluciones a los problemas ambientales. -panel (free-standing) con símbolo precolombino y texto	Retocar.
NO. 28 (H2). *"Los bosques tropicales"* -los bosques de Nicaragua; comparación de tipos de bosques; recurso forestal Los elementos se perdieron. No se montó.	Eliminar este tema. El Nuevo No. 28 sería (viejo 32) "Sistema Nacional de Áreas Silvestres".
NO. 29 (H3a). *"Chacocente"* -refugio de vida silvestre; sitio de anidación de tortugas marinas; 4 especies de tortugas marinas -panel grande, ilustración pintada Mapa no ilustra bien el área, falta color, es muy pequeña y montado demasiado alto.	Eliminar el mapa. Retocar.

NO. 30 (H3b). *"Ciclo de vida de la tortuga marina"* -anidación; sobrevivencia; depredación natural y la del hombre; colaboración pública para protegerlas -panel grande, ilustración pintada Muy efectivo según los maestros.	Retocar.
NO. 31 (H7). *"Un territorio bien manejado"* -buenas prácticas en cuencas para evitar problemas ambientales -maqueta, otro lado de No. 26. La maqueta está muy sucio. La maqueta está demasiado alto para verla. Las leyendas no son efectivos, muy largas. Falta rotulación en la maqueta para destacar las características importantes.	Nuevo No. 35. Renovar la maqueta completamente. Bajar toda la estructura. Cambiar las leyendas por rotulitos más cortitos instalados encima de la maqueta. Tal vez combinarlas con fotos. Diseñar y preparar vitrina para la maqueta.
NO. 32 (H5). *"Sistema Nacional de Áreas Silvestres"* -áreas silvestres protegidas, manejados, propuestos; regiones ecológicas -mapa tri-dimensional No se ve bien los limites de áreas actualmente protegidas. No esta actualizado. Algunos dicen que la presentación de las regiones ecológicas no es interesante pero los maestros las utilizan para interpretar los climas en diferentes zonas de Nicaragua.	Nuevo No. 28. Conservar o no los colores de las regiones ecológicas? Actualizarlo (limites) y eliminar áreas no protegidas legalmente. Preparar el relieve del mapa para que sea mas natural, no como gradas.
NO. 33 (H4). *"Rehabilitación Ambiental"* -áreas protegidas de los Maríbios; planes de manejo, Proy. Héroes y Mártires de Veracruz; participación popular. No se preparó.	Eliminar este tema. Construir un panel nuevo (dos lados, áuto-sostenida) para exhibir No. 32–*Reserva Marina Cayos Miskitos* y No. 33–*SI-A-PAZ.* Determinar elementos, diseñar, preparar.
NO. 34 (H6). *"Parque Nacional Archipiélago Zapatera"* -ambiente, fauna, arqueología -caja inclinada con fotos y textos Solo tiene fotos, algo aburrido. No está montado correctamente.	Hacer panel nuevo para el nuevo lugar. Determinar elementos, diseñar, preparar. Tratar de conseguir una de los estatuas u otro elemento parecido. El viejo sitio sería No. 31–*"BOSAWAS"*. Determinar elementos, diseñar, preparar.

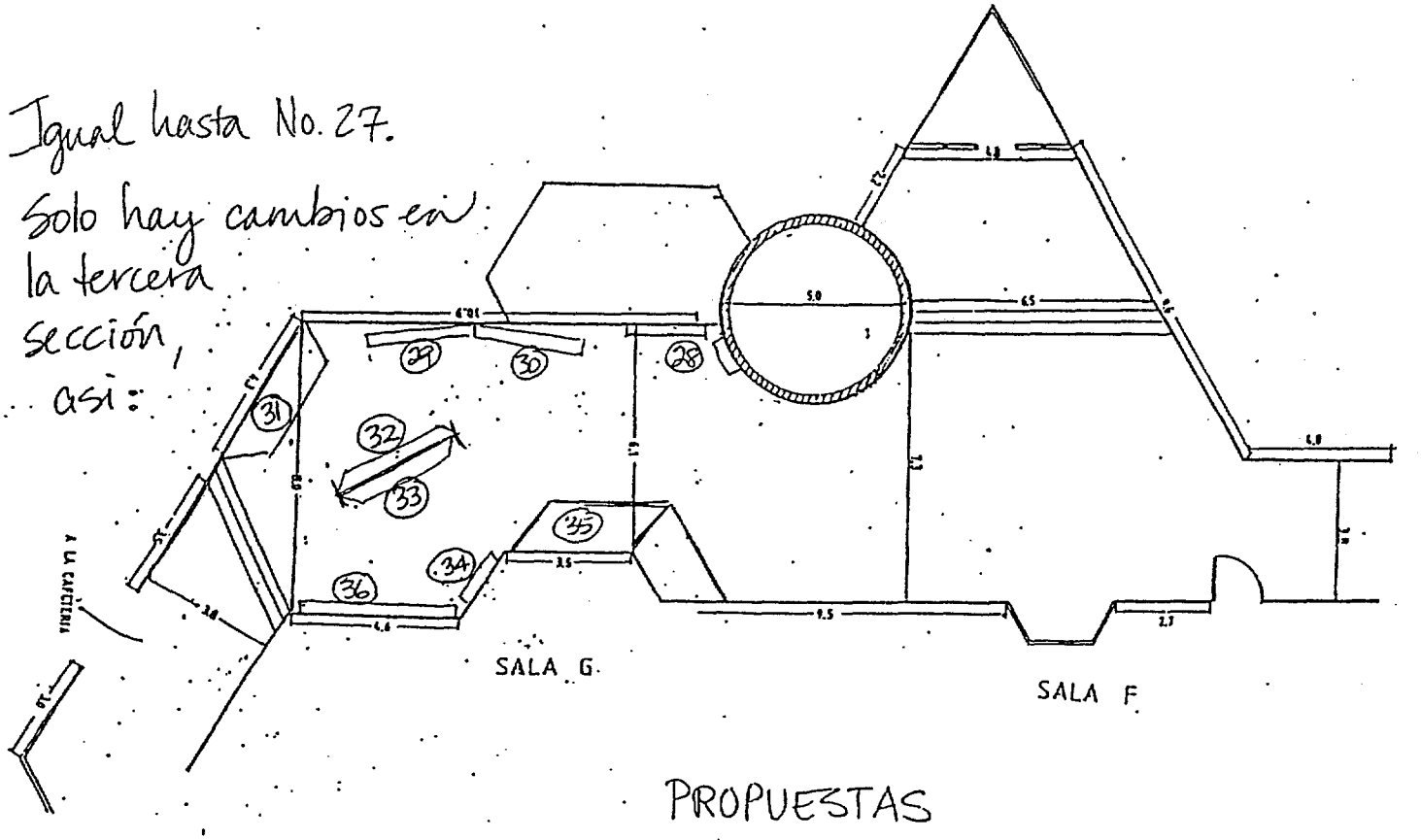
NO. 35 (H11). *"El futuro - naturaleza y desarrollo integrado"* -futuro potencial en armonía con la naturaleza, ejemplos de buenas prácticas ambientales -mural idealizado Muy popular con el público. El elemento más fotografiado. Leyenda algo largo.	Nuevo No. 36. Considerar que hacer con la leyenda. Limpiar, retocar. Preparar leyenda nueva (y perfil?).

CUADRO 1.



SALAS F Y G
ACTUALES

Igual hasta No. 27.
Solo hay cambios en la tercera sección, asi:



PROPUESTAS

PARQUE NACIONAL VOLCAN MASAYA
CENTRO DE INTERPRETACION AMBIENTAL

LISTA DE EXHIBICIONES

___A1. Sala A. Historia del Volcán Masaya
___A2.(A2) Parque Nacional Volcán Masaya
___A3.(A1) Arqueología Precolombina
___A4.(A4) Escenas Históricas del Volcán Masaya
___A14.(A6) La Gran Erupción de 1772
___B1. Sala B - Geología General
___B2.(B1) La Escala Geológica
___B3.(B2) Los Volcanes de la Tierra
___B4.(B3) El Movimiento de las Placas en América Central
___B5.(C3) Estructura Interna de un Volcán
___C1. Sala C - Vulcanología General Regional
___C2.(B4) Larreynaga y su Hipótesis sobre los Volcanes
___C3. Los Diferentes Tipos de Volcanes
___C4.(C6) Los Diferentes Tipos de Erupciones Volcánicas
___C5.(C2) Los Materiales que Salen del Volcán
___C6.(C5) La Cordillera Volcánica del Pacífico de Nicaragua
___C7.(C6) Los Volcanes y el Hombre
___C8.(C1) La Historia de los Volcanes en las Capas de Suelo de Managua
___D1. La Naturaleza del Volcán Masaya/El Volcán Masaya y su Ambiente
___D2.(D1) Historia Geológica de la Caldera de Masaya
___D3.(D7) Otros Rasgos del Paisaje Volcánico
___D4.(D4) La Fumarola de Santiago & Daños
___D5.(D2) La Vida Diurna del Parque
___D6.(D3) La Vida Nocturna del Parque
___D7.(D2a) Adaptaciones de los Animales
___D8.(D6) Los Chocoyos del Cráter
___D9.(E3) Los Túneles de Lava
___D10. ????????
___D11.(E4) La Sucesión Vegetal en Acción
___D12.(E8) Las Flores y sus Visitantes
___D13.(E9) El Sacuanjoche
___D14.(E3a) El Paisaje del Parque
___D15.(E6) Alteración del Ambiente por el Hombre
___D16.(E7) Protección del Parque Nacional

LISTA DE EXHIBICIONES, p.2

___NO.1. El Medio ambiente Nicaragüense - el Reto de Proteger y Producir
___NO.2. Los Beneficios de las Areas Silvestres
___NO.3. Qué son las áreas silvestres? Pueden tener
___NO.4. Más Beneficios de las Areas Silvestres
___NO.5. Interdependencia de la Vida
___NO.6. Somos Parte de un Sistema Natural
___NO.7. La Importancia de los Recursos Genéticos
___NO.8. Las Plantas Comestibles - Desarrollo de una Dieta Diversa
___NO.9. Los Trópicos - Clave de la Producción Agrícola
___NO.10. La Productividad de un Bosque - por cuánto tiempo?
___NO.11. Nuestro Patrimonio Cultural
___NO.12. La Tortuga Verde (Chelonia mydas)
___NO.13. Los Indios Miskitos
___NO.14. La Pesca Tortuguera en el Caribe Occidental
___NO.15. Desequilibrio
___NO.16. Cómo estará Nuestro Futuro si Seguimos así?
___NO.17. La Comunidad de Bosque Tropical Lluvioso - Complejo Incomparable
___NO.18. Causas de Deforestación
___NO.19. ¿El Bosque o Un Desierto? (Tasas de deforestación en Nicaragua)
___NO.20. La Pesca Nicaragüense
___NO.21. El Manglar -- Semillero de Vida
___NO.22. Amenazas a los Manglares
___NO.23. El Pasado Olvidado
___NO.24. El Jaguar (Felis onca)
___NO.25. Causas de extinción de animales--juego para niños
___NO.26. La Importancia del Buen Manejo del Territorio
___NO.27. Qué estamos haciendo sobre la situación?
___NO.28. Sistema Nacional de Areas Silvestres
___NO.29. Chacocente
___NO.30. Ciclo de Vida de la Tortuga Marina
___NO.31. Bosawás
___NO.32. Reserva Marina Cayos Miskitos
___NO.33. SI-A-PAZ
___NO.34. Parque Nacional Archipiélago Zapatera
___NO.35. Un Territorio Bien Manejado
___NO.36. El Futuro - Naturaleza y Desarrollo Integrado

Supplemental Information for Use in the PNVM Interpretive Program

Significance of Lava Tunnels

A great deal is known about lava tunnels from studies of prehistoric and active eruptions at Hawaii Volcanoes National Park. There, scientists have determined that lava tunnels influence the overall shape of a volcano and provide insights about the origin of the magma and/or its path as it ascends to the Earth's surface.

Lava tunnels (or lava tubes, as they are sometimes called) develop only in relatively fluid flows of basaltic composition that are erupted at an unusually high temperature or at an unusually low viscosity, or both. The higher temperature or lower viscosity may be due to subsurface structural controls that allow the magma to rise more rapidly than normal to the surface, or to the unusual chemical composition that gives the magma a higher melting temperature and greater heat capacity than found in other eruptions.

Both favorable structural controls and unusual chemical composition may be responsible for the frequent occurrence of lava tunnels at Volcán Masaya.

Many of the lavas erupted from the Masaya caldera complex have unusually fluid characteristics. Three characteristic of highly fluid lavas can be observed in or near the park: (1) Ropy surface texture (called "pahoehoe"). The flow at the base of the stairs to the OCB is a good illustration of pahoehoe lava. (2) Lack of flow rubble on the surface or beneath the flow (made of pieces of "clinker" or "aa" lava that has a spiny, vesiculated texture). The best examples are the flow mentioned in (1), above, and the lavas in the walls of the caldera near the Laguna de Masaya, where a number of flow units are superimposed with no intervening rubble or ash layers. (3) Unusually long flow lengths compared to flow thicknesses. The best example is a flow that erupted on the northwestern margin of the caldera about 6,600 years ago and flowed north almost eight kilometers to the Aeropuerto Augusto Sandino (Williams, 1983).

Lava tunnels contribute to the extreme length of some flows by conserving the heat of lava as it moves away from the volcanic vent. Without loss of heat, the flow continues for some distance away from the volcanic summit and the lava does contribute to building a high cone above the volcano. This, in turn, results in the low profile (or "shield" shape) of some volcanoes. For that reason, Hawaiian volcanoes have been called "shield volcanoes."

Eruptive Style and Possible Causes

Several famous volcanologists who visited Volcán Masaya in the 1950s and 1960s observed the shield-like shape and the fluid characteristics of Masaya lavas and erroneously believed that Volcán Masaya produced only "passive" or "effusive" eruptions of low explosivity, such as those seen in Hawaii (McBirney and Williams, 1956). Recent studies have concluded just the opposite. Within the past 30,000 years, Masaya has erupted at least three times with incredible explosivity, each time producing voluminous and widespread deposits of ash that literally have buried the

surrounding countryside and blanketed areas as far away as Managua with a half-meter thick layer of ash or lapilli (Bice, 1982; Williams, 1983).

Volcanologists now believe that the unusual eruptive history of Volcán Masaya is due to several important causes. First, the caldera is located above a very large and active fault, known as the Falle de Cofradia. Together with a similarly large and active fault that parallels the alignment of volcanic vents near the Carretera Sur, passes beneath the western edge of Managua, and continues under the Chiltepe Peninsula and Lake Managua, the Cofradia fault marks the location of an important change in the relative motions of the oceanic and continental plates beneath Nicaragua (Stoiber and Williams, 1986). Somewhere deep below the cities of Managua and Masaya, the sharp bend in the oceanic plate that plunges beneath northern Central America at an angle of about 60 degrees begins to flatten. The change in angle of subduction causes large-scale faults to form to relieve pressure.

Scientists know that when the subduction rate speeds up, these deep faults become stressed and break apart producing large earthquakes. Some scientists now believe that, in breaking apart, the faults may also provide a fast path to the surface for magmas that form at the base of the continental crust (Williams, 1983). Generally, basaltic magmas are so fluid that they slowly lose most of their dissolved gases as they rise to the Earth's surface. However, the basalts that rapidly rise along very deep faults such as the Cofradia are able to retain enough gas in the magma that when it reaches the surface the rapid release of the gas can propel a very explosive eruption. In addition, the Cofradia fault taps enormous quantities of groundwater where is cuts through the subsurface between Lakes Managua and Nicaragua. If enough groundwater is available to interact with the rapidly rising magma, the resulting eruption can be catastrophic. Such was the eruption of Volcán Masaya about 6,600 years ago that blew more than 10 cubic kilometers of ash over 50 kilometers into the stratosphere and caused the collapse of the Masaya caldera (Bice, 1982; Williams, 1983).

Since that eruption, much smaller volumes of magma have continued to rise along the Falle de Cofradia. While the ascent of the magma may still be more rapid and the erupted lava hotter than at other Central American volcanoes, the eruptions have become less explosive. The new cones (Nindiri and Masaya) that have grown on the floor of the old caldera were produced by many relatively thin lava flows, some with lava tunnels. The resulting shield-like shape of the two volcanoes hides the fact that Volcán Masaya produced one of the most explosive eruptions that has occurred anywhere in the world during the past 10,000 years.

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Annex E Geologic and Volcanologic Publications Relevant to the Interpretive Program of Parque Nacional Volcán Masaya

Annex E

The following is a list of geological or other scientific publications of relevance to the interpretive program at the Parque Nacional Volcán Masaya. The publications are organized into three groups according to the technical complexity of the subject matter: (1) Technical or social issues presented for the scientist and non-scientist; (2) Technical issues specific to Masaya presented for the scientific specialist; and (3) General geology/volcanology issues relevant to Volcán Masaya and its geologic setting presented for the scientific specialist.

(1) Technical or social issues presented for the scientist and non-scientist

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Annex F

The following is a list of environmental education materials relevant to the Interpretive Program at the Parque Nacional Volcán Masaya. All of the materials were obtained from Internet Web sites related to public education on issues of volcano hazards. Copies of material that were downloaded from the Web sites are also appended. These materials are included because they contain up-to-date descriptive text and graphics about volcanic processes aimed at a lay audience. The included materials contain information that can be extracted, summarized, or used verbatim in preparing text to accompany several of the Visitors Center exhibits. Enlargements of graphics are included with some attachments.

Several of the attachments listed are for use in obtaining further information or products. Other attachments are intended to provide information that will support preparation of text for exhibits in the Visitors Center. An annotation of the intended use of each attachment of Annex F is also provided. If the attachment is intended to support an existing or previously proposed future exhibit in the Visitors Center, the exhibit is identified in accordance with the designation scheme used under the "Recomendaciones" column of the 1992 Consultant Report (Annex C of this report). If an exhibit is newly recommended in the current report, the exhibit is designated as "New" and its general position in the sequence of exhibits is indicated by "to follow" the recommended exhibit designation in the 1992 Consultant Report.

"Related Information Provided by Other Organizations" from the Michigan Technological Institute homepage (Attachment #1)
List of volcanology-related sites on the Internet for use in obtaining additional information.

Selected information from the Michigan Technological Institute Volcanology web site. The material listed below are elements found under the menu item titled "Volcanic Hazards":

1. **Volcanic Gases** (Attachment #2)
   Portions of this information may be appropriate as text to accompany Exhibit C5 and/or an expanded volcanic hazards component related to Exhibit C7.

2. **Tephra** (Attachment #3)
   Portions of this information may be appropriate as text to accompany Exhibit C5 and/or an expanded volcanic hazards component related to Exhibit C7.

3. **Volcanic Earthquakes** (Attachment #4)
   Portions of this information may be appropriate as text to accompany Exhibit C5 and/or an expanded volcanic hazards component related to Exhibit C7.

Selected information from the VolcanoWorld web site supported by the National Aeronautical and Space Administration (NASA) program for public use of earth and space science data over the Internet. The material listed below are elements found under the menu item titled "Volcanoes: The Inside Story":

1. **Lava Types and Viscosity** (Attachment #5)
   Portions of this information may be appropriate as text to accompany Exhibit C5.

2. **Volcano Types: Strato or Composite, Cinder Cones, Shield, and Caldera** (Attachment #6)
   Portions of this information may be appropriate as text to accompany a revised version of Exhibit C4 and/or Exhibit B5.

3. **Sizes of Eruptions: Disregard at your own peril** (Attachment #7)
   This material includes an interesting graphic titled "How Large is Large" that could be modified to include the 6,600 B.P. Plinian eruption of Masaya and several smaller historic eruptions of Cerro Negro, Las Pilas, and others. The graphic and portions of the information may be appropriate to support an exhibit on types of volcanic eruptions and volcanic explosivity (New, to follow Exhibit C3 and C4).

4. **Looking Inside the Earth** (Attachment #8)
   Portions of this information may be appropriate as text to accompany Exhibit B4.

5. **Location of Volcanoes** (Attachment #9)
   Portions of this information may be appropriate as text to accompany Exhibit B3 and/or B4.

6. **Plate Tectonics and Heat Flow** (Attachment #10)
   Portions of this information may be appropriate as text to accompany Exhibit B3 and/or B4.

7. **Volcanoes and Climate** (Attachment #11)
   Portions of this information may be appropriate as text to accompany an expanded long-term volcanic impacts component to follow Exhibit C7.

8. **Volcano Monitoring** (Attachment #12)
   Portions of this information may be appropriate as text to accompany a new exhibit on how scientists study volcanoes (New, to follow Exhibit C7).

9. **Volcanic Hazards** (Attachment #13)
   Portions of this information may be appropriate as text to accompany an expanded volcanic hazards component related to Exhibit C7.

10. **Dealing with Volcanic Hazards** (Attachment #14)
    Portions of this information may be appropriate as text to accompany an expanded volcanic hazards component related to Exhibit C7.

11. **Risk Analysis** (Attachment #15)
    Portions of this information may be appropriate as text to accompany an expanded volcanic hazards component related to Exhibit C7.

Selected information from the United States Geological Survey (USGS)/Cascades Volcano Observatory (CVO) web site. The material listed below are elements found under the menu item titled "Index and Information -- Volcanic Features and Phenomena":

1. **Index and Information -- Volcanic Features and Phenomena** (Attachment #16)
   Menu of information elements available under this menu for use in obtaining additional information.

2. **Description: Lava Tubes** (Attachment #17)
   Portions of this information may be appropriate as text to accompany the revised Exhibit C3 and C4 on effusive lava eruptions.

3. **Description: Lava, Lava Flows, Pahoehoe, Aa** (Attachment #18)
   Portions of this information may be appropriate as text to accompany revised Exhibit C3 and C4 on effusive lava eruptions and/or Exhibit C5 on volcanic products.

4. **Hazards: Pyroclastic Flows** (Attachment #19)
   Portions of this information may be appropriate as text to accompany revised Exhibit C3 and C4 on explosive ash eruptions and/or the expanded volcanic hazards component of Exhibit C7.

5. **Hazards: Pyroclastic Surges** (Attachment #20)
   Portions of this information may be appropriate as text to accompany revised Exhibit C3 and C4 on explosive ash eruptions and/or the expanded volcanic hazards component of Exhibit C7.

Slide sets of volcanoes and volcanic processes available for purchase. From EOS Volcanology Education Outreach web site. (Attachment #21)
The slides are available for a nominal price through the American Geophysical Union in Washington, D.C. and could be used to produce a narrated slide show on volcanic features or volcanic hazards.

Set #1: Surface and atmospheric effects of the 1991 eruption of Mt. Pinatubo
Set #2: Volcano Topography
Set #3: Volcanoes and volcanic hazards
Set #4: Peter Francis Slide Sets Parts I, II, III, and IV.By Peter Francis illustrating his 1993 book titled "Volcanoes: A Planetary Perspective" (Oxford University Press, Oxford, UK)
- Part I: Volcanoes
- Part II: Lavas and Related Features
- Part III: Pyroclastic Eruptions and Products
- Part IV: Hydrovolcanic Eruptions

Study of Recent Tsunamis Sheds Light on Earthquakes. By Sataki, Kenji, from EOS, v. 75, n. 1, January 4, 1994. (Attachment #22)
Portions of this information may be appropriate as text to accompany the expanded volcanic hazards component of Exhibit C7.

GPS Monitoring Data for Active Volcanoes Available on Internet. By Dixon, T.H. et al, from EOS, v. 76, p. 2. (Attachment #23)
Portions of this information may be appropriate as text to accompany a new exhibit on how scientists study volcanoes (New, to follow Exhibit C7).

Do you want to become a volcanologist? By Rowland, S. From VolcanoWorld. (Attachment #24)
Portions of this information may be appropriate as text to accompany a new exhibit on how scientists study volcanoes (specifically, what type of scientist studies volcanoes) (New, to follow Exhibit C7).

Volcanoes and Global Climate Change. Anonymous from NASA Facts, EOS Volcanology homepage. (Attachment #25)
Portions of this information may be appropriate as text to accompany an expanded long-term volcanic impacts component to follow Exhibit C7.

Volcanic Gases Provide Clues to How Volcanoes Work (Attachment #26). Anonymous from USGS/Hawaiian Volcano Observatory homepage.
Portions of this information may be appropriate as text to support an exhibit on types of volcanic eruptions and volcanic explosivity (New, to follow Exhibit C3 and C4).

Volcanology-Related Thought Problems and Laboratory Exercises for School Groups.
Various Internet Web sites as indicated at upper right of attached pages.
(Attachment #27)

Annex F- Attachment #1

Related Information Provided by Other Organizations

NASA

NASA Earth Observing System Project Science Office

- Mission to Planet Earth *and GIF image of the* EOS Mission Profile
- *EOS Instruments:* | AIRS | ASTER | Landsat 7 | MISR | MODIS | TES | others |
- Science Strategy for EOS: Chapter 8: Volcanoes, Dust Storms, and Climate Change

EOSDIS Core System Information for Scientists

- NASA Facts: Volcanoes and Global Climate Change

ESA

European Space Agency (ESA) *and* European Space Research Institute User Services

VOLCANO NEWS REPORTS

- Bulletin of the Global Volcanism Network (Smithsonian)
- Volcano Listserve Proceedings

GENERAL VOLCANO INFORMATION

Michigan Tech. University: Information on Volcanoes

VolcanoWorld

- The Electronic Volcano (Information on Active Volcanoes) -- Dartmouth Univ.

USGS VOLCANO OBSERVATORIES / U.S. VOLCANOES

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AVO: Alaska Volcano Observatory

CVO: Cascades Volcano Observatory

- French Volcano Observatories (Martinique, Guadeloupe, Réunion, Comores)
- HVO: Hawaiian Volcano Observatory Volcano Watch weekly newsletter
- Long Valley Caldera (USGS Monitoring)
- Mauna Loa Decade Volcano
- Mount St. Helens: Images/Stories/Curriculum

University of Washington Volcano Systems Center (UW + USGS)

OTHER OBSERVATORIES & VOLCANO MONITORING INSTITUTES

- Geological Survey of Japan, Hokkaido Branch
- Hakone Volcano Research Center (VRC) [Asama, Kirishima, Izu-Oshima Volcano Observatories]
    - Unzen - Decade Volcano
- INGEOMINAS Volcano Observatories in Colombia at Manizales, Pasto, and Popayán
- Fernandina, Galapagos: Reports on the volcanic activity
- Mount Erebus Volcanic Observatory

NVI: Nordic Volcanological Institute *and a* list of Volcano Observatories world-wide

- Stromboli Project (University of Udine, Italy)
- Wairakei Research Center Taupo Observatory

VOLCANO RESEARCH / INFORMATION

Ascension Island Geology

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- Batur Volcano, Bali, Indonesia
- Boris Behncke's Volcano Home Page (Stromboli and other volcanoes) or the mirror site at Michigan Tech. Univ.
- Canadian Meteorological Centre [soon to be designated a Volcanic Ash Advisory Centre (VAAC)] and links to VAAC Montreal (...version in Francais)
- Compiled Volcanology Data Set CD-ROMs (Remote Sensing of Kilauea, Mauna Loa, and Kamchatka)
- Center for the Study of Active Volcanoes, Univ. Hawaii at Hilo
- Daniel J. Johnson's Volcanic Activity Web site
- GEOMAR Research Center for Marine Geosciences of Christian Albrechts University, Kiel, Germany
- Global Positioning System Time Series and more GPS Information
- Global Volcanic and Environmental Systems Simulation (GVES): Vesuvius
- IAVCEI: International Association of Volcanology and Chemistry of the Earth's Interior
  - January 1997 IAVCEI Meeting in Puerto Vallarta, Mexico
- Istituto Internazionale di Vulcanologia - C.N.R. - Catania, Italy
- Jonathan Dehn's Computer Modeling of the Volcanic System
- Rincon de la Vieja Volcano, NW Costa Rica
- Ruapehu Erupts!
- Ruapehu Eruption Alert Bulletins (Inst. Geological & Nuclear Sci. Ltd, New Zealand)
- Stromboli on-line
- Under the Volcano by Peter Tyson (from MIT's Jan. 96 Technology Review magazine)
- University of Naples, Department of Geophysics and Volcanology
- University of Pisa, Italy - Volcanic Simulation Group
- U.K. Volcanologists Group
- Vesuvio Decade Volcano, Italy

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- Volcaniclastic Information Center (UCSB)
- Volcano Mercenaries of America
- Volcano Topography and Volcanic Hazards (Goddard Geodynamics Branch)

RADAR IMAGING AND TOPOGRAPHY

- SIR-C/XSAR Radar Images of Earth (several volcano images)

NASA/JPL Imaging Radar and SRL Volcano Exhibit

- Alaska Synthetic Aperture Radar Facility
- Digital Elevation Data Catalog

VOLCANO HAZARDS AND EMERGENCIES

NGDC Natural Hazards

- Emergency Preparedness Information eXchange (EPIX)
- Emergency Information System International
- Natural Disaster Reference Database

VOLCANO-CLIMATE INTERACTIONS

- NOAA / CMDL Aerosol Group
- Global Change Master Directory
- Global Change Research Information Office
  - A Report: Forum on Global Change Modelling

GEOTHERMAL ENERGY

- Geothermal Energy Information (Center for Renewable Energy and Sustainable Technology)
- Geothermal Energy Information (International Geothermal Association)

MISC. RELATED SITES

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- Public Use of Remote Sensing Data (NASA Cooperative Agreement Notice): VolcanoWorld (bringing volcano remote sensing data to classrooms, National Parks, and Monuments), and Virtually Hawaii (includes a virtual field trip to Kilauea)

- Univ. of Hawaii - School of Oceanography and Earth Science and Technology

- Hawaii Space Grant Consortium

- Michigan Technological Univ. - Dept. of Geological Engineering, Geology & Geophysics

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Return to EOS Volcanology Home Page

This page is maintained by Joy Crisp (joy@glassy.jpl.nasa.gov)

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Volcanic Gases

An erupting volcano will release gases, tephra, and heat into the atmosphere. The largest portion of gases released into the atmosphere is water vapor. Other gases include carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrochloric acid (HCl), hydrogen fluoride (HF), hydrogen sulfide (H_2S), carbon monoxide (CO), hydrogen gas (H_2), NH_3, methane (CH_4), and SiF_4. Some of these gases are transported away from the eruption on ash particles while others form salts and aerosols. Volcanic gases are also produced when water is heated by magma. Gases also escape from pyroclastic flows, lahars, and lava flows, and may also be produced from burning vegetation.

Acid rain can be produced when high concentrations of these gases are leached out of the atmosphere. When Katmai erupted in 1912, acid rain damaged clothes that were drying outside on a line 2000 km away from the erupting volcano in Vancouver, British Columbia (Bryant, 1991). High concentrations of CaF_2 can burn vegetation and other material on contact. Fluoride and chloride can contaminate water. Livestock have died from drinking such contaminated water. Fluoride and chloride can also be irritating to the skin and eyes of animals, and can damage clothes and machinery. Carbon monoxide and carbon dioxide are usually produced in small amounts. However, large amounts of these gases will sometimes build up in low lying areas and can asphyxiate livestock and harm vegetation (Bryant, 1991 and Scott, 1989).

Recently, a new volcanic hazard involving tropical lakes in volcanic regions was discovered. Carbon dioxide built up at the bottom of tropical Lake Nyos was released from the bottom of the lake when the lake overturned. Fifteen hundred people were killed and 10,000 people burned in this disaster (Bryant, 1991).

Harmful concentrations of volcanic gases usually do not extend further than 10 km from the volcano (Scott, 1989). Remote sensing instruments have been used to track volcanic gases such as SO_2. To find out more information about remote sensing and volcanic clouds click here. Other instruments have also been used to monitor volcanoes. These instruments measure amounts and types of volcanic gases. Currently much research is being done on how volcanic gases may contribute to changes in climate.

Text by C.M. Riley, Photo courtesy of the U.S. Geological Survey at CVO

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Tephra

When a volcano erupts it will sometimes eject material such as rock fragments into the atmosphere. This material is known as *tephra*. The largest pieces of tephra (greater than 64 mm) are called *blocks* and *bombs*. Blocks and bombs are normally shot ballistically from the volcano (refer to the gas thrust zone described in the direct blast section). Because these fragments are so large they fall out near their source. Blocks and bombs as large as 8-30 tons have fallen as far away as 1 km from their source (Bryant, 1991). Small blocks and bombs have been known to travel as far away as 20-80 km (Scott, 1989)! Some of these blocks and bombs can have velocities of 75-200 m/s (Bryant, 1991). Smaller ejecta such as *lapilli* (2-64 mm) and *ash* (<2 mm) which are convected upward by the heat of the eruption will fall out farther from the volcano. Most particles greater than a millimeter in size will fall out within 30 minutes of the time they are erupted (W.I. Rose personal communication). The smallest particles which are less then .01 mm can stay in the atmosphere for two or three years after a volcanic eruption. Sometimes these particles produce fantastic sunsets such as was seen after the eruptions of Krakatau in 1883 and Pinatubo in 1991. Some scientists believe that these particles may contribute to global warming.

The size of particles that fall out is largest near the volcano and gets progressively smaller further from the volcano. The thickness of material usually decreases the further away from the volcano. Occasionally, as occurred in Ritzville, Washington when Mount St. Helens erupted in 1980, secondary thickening will occur. Secondary thickening means that ash deposits are thicker in a particular area than in surrounding areas. This results when ash particles and water form clumps which produce larger particles that have higher terminal velocities and so fall out of the ash cloud. When these particles hit the ground they break apart and produce a thicker deposit of ash than in surrounding areas.

The distance that ejecta travels away from a volcano depends on the height of the eruption column, temperature of the air, wind direction and wind speed. An erupting column that reaches into the stratosphere will be sheared by strong winds in this region and cause the eruption cloud to spread out over a larger area. The temperature of the air during an eruption will increase due to the hot material ejected into the atmosphere. This produces a bouyant force that carries tephra higher into the atmosphere which allows it to be deposited over a larger area. Wind direction and wind speed are very important in determining where and how large an area will be covered by ash. Ash erupting from Mount St. Helens on May 18, 1980 covered the town of Yakima, which is approximately 80 miles to the east of the volcano, with 10 mm of ash (Foxworthy and Hill, 1982). This caused the sky to become as dark as night during the middle of the day. The town of Vancouver, approxiamately 50 miles south of the volcano, had no ash deposited from the eruption because the wind direction was blowing away from it toward the northeast.

So how far away can ash be deposited? The eruption of Krakatau deposited ash over an area of 800,000 square kilometers. People 70-80 km away from the volcano had their clothes burnt by ash (Bryant, 1991). Fallout from the eruption of Tambora in 1815, which is the largest eruption in recent history, was deposited as far away as 1300 km (Francis, 1993)! More than 10 cm of ash fell in India 3000 km away from the Toba Caldera when it erupted 75,000 years ago.

Tephra produces a wide range of hazards. When the ejected material is in the atmosphere it is electrically charged and often produces lightning. Several people have been killed by lightning from volcanic eruption clouds. Large ejecta shot ballistically from the volcano are also a hazard to those

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unfortunate enough to be near the volcano. Other hazards are produced when the ash is deposited on the ground. Ash can disrupt electricity, television, radio, and telephone communication lines, bury roads and other manmade structures, damage machinery, start fires, and clog drainage and sewage systems. Ash can produce poor visibility and cause respiratory problems. Often people living in areas affected by volcanic ash will wear masks with filters or wet cloth over their nose and mouth to protect themselves from breathing in volcanic ash and fumes. If ash builds up on the tops of roofs, it will often cause collapse. This is especially common on flat topped buildings. Most deaths resulting from the eruption of Mount Pinatubo in 1991 were due to collapsing roofs (Wolfe, 1992).

Ash is also a great hazard to airplanes. Ash from the 1982 eruption of Galunggung Volcano in West Java, Indonesia caused engines in two jet airplanes to fail. Both aircraft dropped 25,000 feet before they could get their engines to start again. Ash end St. Elmo's fire entered the cabin and caused damage to the aircraft. Greater than sixty airplanes have been damaged by ash from various volcanic eruptions. Damage can include pitting of wind sheilds which causes them to look foggy. The fuselage, wings, engines, and light covers can also be damaged by ash and are very expensive for the airlines to repair. Volcanic eruption clouds cause rerouting, cancellation, and delays in flights which is also expensive for the airlines. The accumulation of ash can also load down a plane which may cause the plane to rest on its tail. Ash on runways is another problem because anytime a plane lands or takes off the ash is resuspended. Special techniques have been developed to remove ash from aircraft and runways (Casadevall, 1993). Currently much research is being done in using satellites to track volcanic clouds. For more information about tracking ash clouds using remote sensing devices click here.

Tephra can also destroy vegetation which can result in famine. Famines are the largest indirect hazard produced by volcanic eruptions. In 1815, after the eruption of Tambora which ejected 151 cubic kilometers of ash into the atmosphere, 80,000 people died due to famine (Bryant, 1991 and Francis, 1993).

Residents in areas that may be affected by volcanic ash during an eruption, need to be prepared. They should stock up on water and food supplies, stay indoors to avoid having clothing burnt or skin irritated by acids carried by volcanic ash, avoid going outside without a wet cloth or some sort of filter over their mouth and nose, stay in areas that are unlikely to receive large amounts of tephra or large sized tephra, avoid staying in buildings that are flat-roofed, and be prepared to be without telephones, electricity, and radio communication. Residents should also be prepared to do a lot of cleanup, and when doing this be careful not to resuspend the ash.

Tephra produces many hazards but is also very beneficial. Its greatest benefit is that it produces fertile soil for crops. This is the biggest reason why so many people live on or near active volcanoes.

Text by C.M. Riley, Sunset and huts with ash photos by M.T. Dolan, Palm trees with ash by W.I. Rose

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Volcanic Earthquakes

Earthquakes related to volcanic activity may produce hazards which include ground cracks, ground deformation, and damage to manmade structures. There are two general categories of earthquakes that can occur at a volcano: volcano-tectonic earthquakes and long period earthquakes.

Earthquakes produced by stress changes in solid rock due to the injection or withdrawal of *magma* (molton rock) are called *volcano-tectonic earthquakes* (Chouet, 1993). These earthquakes can cause land to subside and can produce large ground cracks. These earthquakes can occur as rock is moving to fill in spaces where magma is no longer present. Volcano-tectonic earthquakes don't indicate that the volcano will be erupting but can occur at anytime.

The second category of volcanic earthquakes are *long period earthquakes* which are produced by the injection of magma into surrounding rock. These earthquakes are a result of pressure changes during the unsteady transport of the magma. When magma injection is sustained a lot of earthquakes are produced (Chouet, 1993). This type of activity indicates that a volcano is about to erupt. Scientists use seismographs to record the signal from these earthquakes. This signal is known as *volcanic tremor*.

People living near an erupting volcano are very aware of volcanic earthquakes. Their houses will shake and windows rattle from the numerous earthquakes that occur each day before and during a volcanic eruption. Residents in Pompeii felt earthquakes daily before Vesuvius erupted in A.D. 79 but continued to go about their daily routines (Francis, 1993). When Mount Pinatubo in the Philipines erupted in 1991, nerves were rattled as much as windows by volcanic earthquakes.

Earthquakes exhibiting volcanic tremor warn of an impending eruption so that people can be evacuated to areas of safety. The volcanic tremor signal has been used successfully to predict the 1980 eruptions Mount St. Helens and the 1991 eruption of Pinatubo. Volcano-tectonic earthquakes can cause damage to manmade structures and landsliding. To prevent damage from being done, structures should be built according to earthquake standards, building foundations should be constructed on firm ground and not unconsolidated material which may amplify earthquake intensity, and buildings should be constructed on stable slopes in areas of low hazard potential.

Text by C.M. Riley, Photo by M.T. Dolan

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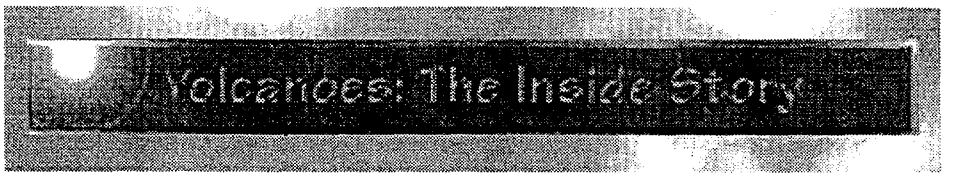
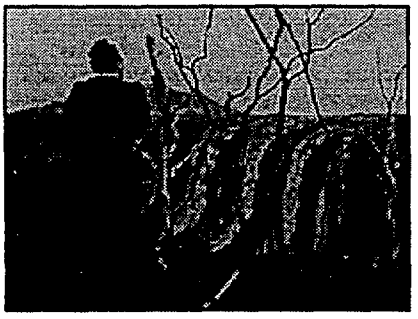
Annex F- Attachment #5

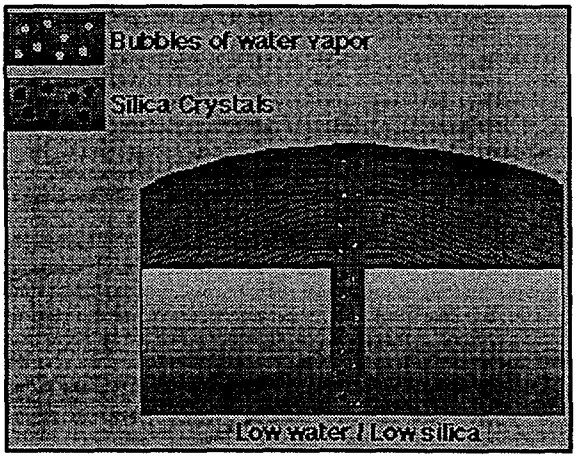


Lava Types and Viscosity

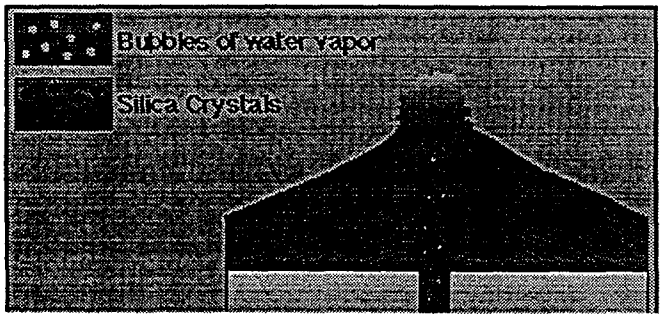


Volcanoes come in many shapes and sizes. Volcanic eruptions may be quiet outflows of lava so peaceful that one can stand close enough to toss in pebbles (or leis; see figure), or so explosively violent as to blow mountains apart and blast everything within a hundred miles to smithereens (not recommended for close observation). Both the shapes of volcanoes and the violence of volcanic eruptions depend on the same rather mundane thing: the physical properties of erupting lavas.

The two most important properties of lavas are 1) its viscosity, and 2) the amount of gases dissolved in the liquid rock. Let's look at each of these separately.



Viscosity is a term that describes the fluidity or "runniness" of the lava. Some lavas are very "runny," not quite like water, but more like warm honey or hot wax. When these lavas erupt, they flow for large distances before cooling enough to turn solid. You can imagine what kind of volcanic mountain you could make with runny lavas by thinking about (or carefully doing) pouring hot wax on a large sheet of paper. The wax spreads out into a large, flat layer. Let it cool and harden and then pour another layer. The second "flow" of wax will partly pond on the first and partly run off onto the paper to form another flat layer. If you keep pouring more and more "flows," you will get a large, but almost flat pile of wax. So lots of small eruptions of runny lavas form large, almost flat mountains like shield volcanoes. Eruptions of huge amounts of really runny lavas form **flood basalt** type volcanoes.



Other lavas are very "pasty" like soft clay, and hardly flow at all. Imagine piling lumps of soft ice cream on a big, flat dish - you end up with a tall, narrow pile. Likewise, pasty lavas form tall, steep-sided mountains like strato volcanoes.

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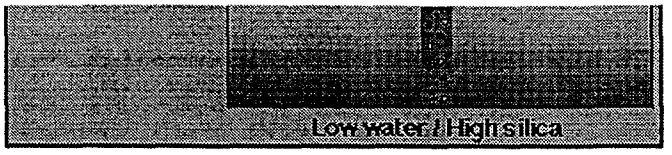

Viscosity in lavas depends on several factors. One of the most important is composition, especially the amount of silica (SiO_2 or quartz) melted in the lava. Silica molecules have the tendency to stick together to form long chains. These long chains literally get tangled together and make it difficult for molecules in the melt to slide past each other. This slowing of movement at the molecular level makes the whole lava less fluid. A small difference in silica content can make a huge difference in viscosity: lavas with about 70% silica (called rhyolites) are about 10 billion times stiffer than lavas with about 50% silica (called basalts).

The other important property of lavas governing the type of eruption is the amount of gases dissolved in the lava. The most important gases in lavas are water and carbon dioxide. (Although water is a liquid at room temperature, it is definitely a gas at typical lava temperatures of 900 C [1600 F] to 1200 C [2200 F].) Very little gas can be dissolved in lava at the low pressures (around one atmosphere) found at the surface of the Earth. We say the solubility of gases in liquids is low at low pressures. On the other hand, deep in the Earth where lavas are formed the pressures are high (thousands to millions of atmospheres), and significant amounts of gas can be dissolved in the lavas (up to several per cent by weight). We say the solubility of gas in liquids is high at high pressures. If we dissolve lots of gas in a lava at high pressure and high solubility and then lower the pressure to get low solubility, the gas will "undisolve" (or "exsolve") from the liquid to form bubbles.

So what happens to the gases in lava when it rises from the deep interior of the Earth to the volcano on the surface? Let's consider a couple of everyday examples. Look a clear plastic bottle of soda pop that hasn't been opened or recently shaken. Most soda pop contains a few per cent by weight of dissolved carbon dioxide. If you look carefully at the liquid, you can't see any gas inside (remember, it is dissolved) except perhaps a few small bubbles and a tiny air pocket at the top. If you carefully open the bottle, you see many small bubbles quickly form and rise to the top and escape. If enough bubbles form, they take part of the liquid with them as a foam that flows out of the top. If you shake the bottle vigorously just before opening it, you trigger the formation of so many bubbles so quickly that the soda pop bursts explosively from the top, and you and everyone around you is sprayed with fine droplets of liquid. On the other hand, if you leave the bottle of soda pop open for long, virtually all of the dissolved gas escapes, and no amount of shaking can cause the remaining liquid to spray out. It can only be poured out.

This shows the effect of dissolved gases. What about viscosity?

Think about blowing bubbles through a straw in a glass of liquid. If the liquid is water (low viscosity), the bubbles you form escape easily. If you blow slowly (representing small amounts of escaping gas), the water is little disturbed. Even if you blow vigorously (representing large amounts of escaping gas), the water froths and bounces around a lot, but very little gets out of the glass. If you try the same thing with an ice cream soda or malt (representing high viscosity), bubbles escape only with difficulty. Even small bubbles bursting from a malt can get blebs of ice cream on your clothes. Blowing vigorously can launch the entire malt across the room!

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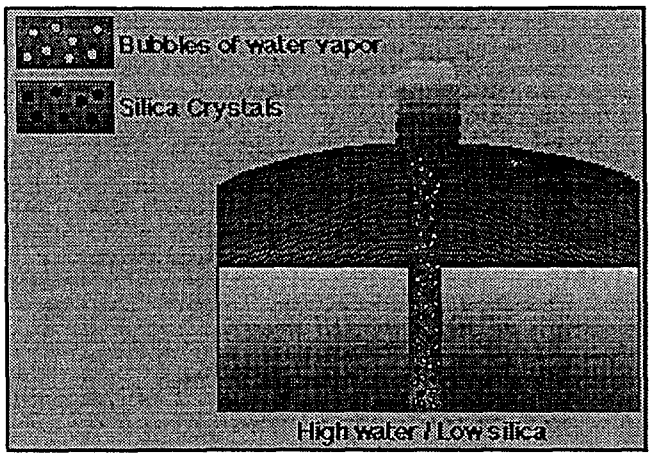
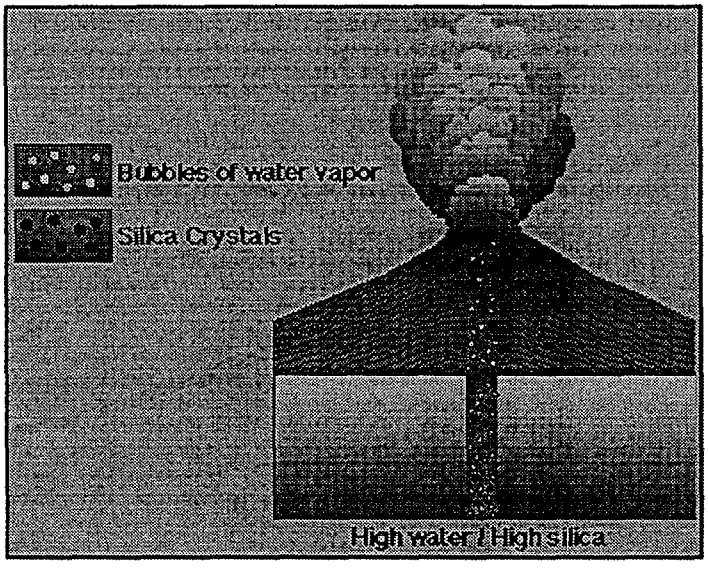


Lavas show the same types of behavior. If an erupting lava has low viscosity and little or no dissolved gases, it simply flows out of the central vent and spreads far over the surface (see low water/low silica figure). If it has high viscosity and no dissolved gases, the lava oozes slowly out to form a bulbous dome which mostly just sits there (see low water/highsilica figure). In either case, you could stand nearby in relative safety. If the erupting lava has lots of dissolved gases, the gases come out of solution and form bubbles as the lava approaches the surface. If the viscosity of the lava is low, the lava bubbles and froths a lot right at the surface, tossing out tiny cinders and larger "bombs" of lava that quickly cool and fall back to the ground. This type of eruption (see figure to left) produces a spectacular "fire fountain" right over the vent, usually resulting in a **cinder cone**. Any remaining lava quietly flows away.



However, the last combination, lots of dissolved gases and high viscosity, is deadly (see figure to left). As the lava oozes to the surface, the gases quickly form bubbles that turns the lava into a red-hot froth that explodes out of the ground as a searing, greyish cloud of superheated steam and tiny particles called ash. The ash forms when the walls of the gas bubbles burst into tiny fragments. This type of lava causes explosive eruptions at volcanoes like **Vesuvius** and Mount St. Helens, and drives the cataclysms that produce the **"giant" caldera.**

Back to The Inside Story

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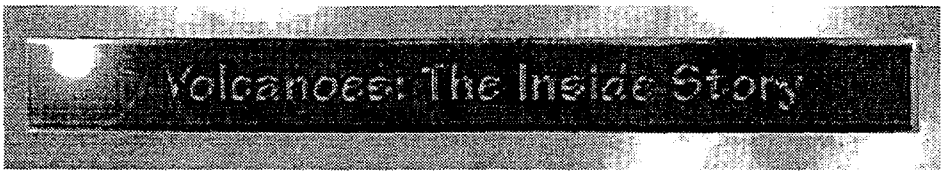
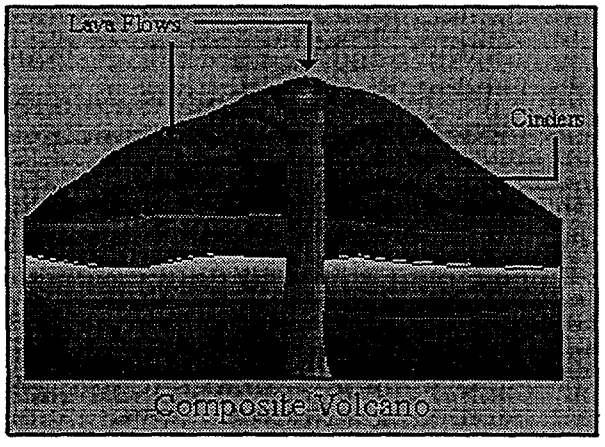
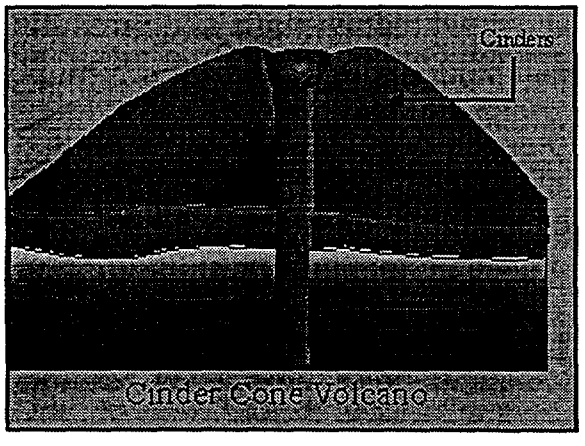


Volcano Types: Strato or Composite, Cinder Cones, Shield, and Caldera

Most people have never seen a real volcano, but have learned about them through movies or books. So when we think of a volcano, we usually conjure up the Hollywood version: a huge, menacing conical mountain that explodes and spews out masses of lava down on rampaging dinosaurs, screaming cave people or fleeing mobs of betogaed Romans - depending on your favorite volcano disaster movie. While those types of volcanoes do indeed exist, they represent only one "species" in a veritable zoo of volcano shapes and sizes. Some types of volcanoes are easily recognizable and some are not.



The "Hollywood" types are easily recognized. Many are located in populated areas and have well-known names: Vesuvius, Krakatoa, Fujiyama, and Mount St. Helens. These volcanoes are typically tens of miles across and ten thousand or more feet in height. As illustrated in the figure, they have moderately steep sides and sometimes have small craters in their summits. Volcanologists call these "strato-" or composite volcanoes because they consist of layers of solid lava flows mixed with layers of sand- or gravel-like volcanic rock called cinders or volcanic ash.



Another easily recognized type of volcano is the "cinder cone." As you might expect from the name, these volcanoes consist almost entirely of loose, grainy cinders and almost no lava. They are small volcanoes, usually only about a mile across and up to about a thousand feet high. They have very steep sides and usually have a small crater on top.

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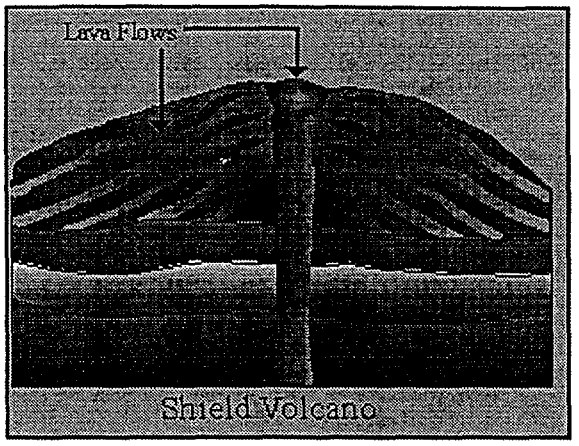
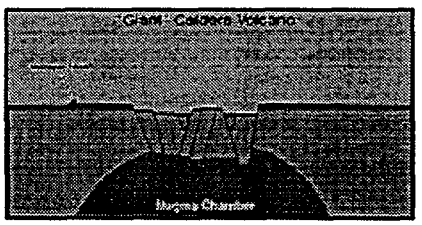
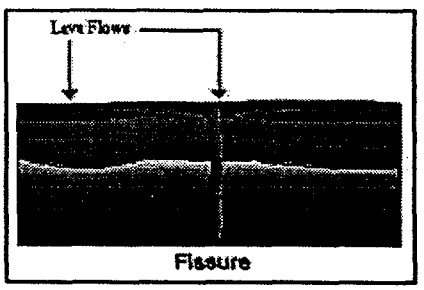


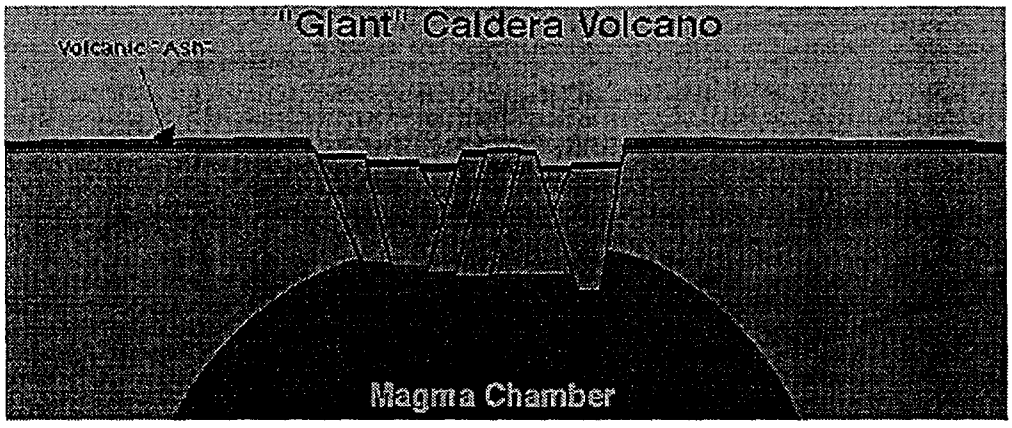
A third easily recognized volcano may be familiar to you from news reports from Hawaii: the "shield" volcano. This type of volcano can be very large: hundreds of miles across and many tens of thousands of feet high. The individual islands of the state of Hawaii are simply large shield volcanoes. Mauna Loa, a shield volcano on the "big" island of Hawaii, is the largest single mountain in the world, rising over 30,000 feet above the ocean floor and reaching almost 100 miles across at its base. Shield volcanoes have low slopes and consist almost entirely of frozen lavas. They almost always have large craters at their summits.

Two important types of volcanoes are difficult to recognize as such, especially when they are very large. The first of these is the "giant caldera" (see below, left). Calderas, which are simply circular depressions, are found on the summits of many volcanoes. "Giant" calderas are the largest of these: huge craters up to many tens of miles across. Giant Calderas form by collapse (See animation) in gigantic eruptions that spew volcanic rocks out to hundreds or even a thousand miles in all directions. Sometimes the calderas are so filled with lavas and volcanic ash that there is no recognizable depression at all. These can only be found by carefully locating the big fractures or "faults" in the ground that mark the edges of the caldera. One such caldera nearly fills Yellowstone National Park. In other cases, the edges of the caldera remain as large cliffs or ridges surrounding the central depression. However the depression is so large that a person standing in the middle could hardly see the edges and would only recognize them as such if they were pointed out. These giant calderas can best be seen in images taken from space, like the one of the Valles Caldera in New Mexico(below, right).



The second type of volcano difficult to recognize either from the ground or from space is the "fissure eruption" type. In this kind there is no central crater at all. Instead, giant cracks open in the ground and pour out vast quantities of lava that spread far and wide to form huge pools that can cover almost everything around. When these pools of lava cool and solidify, the surface remains mostly flat. Since the source cracks are usually also buried, there is often nothing "volcano-like" to see - only a flat plain. The fissure eruption shown below at right was at Los Pilas volcano in Nicaragua in 1952.





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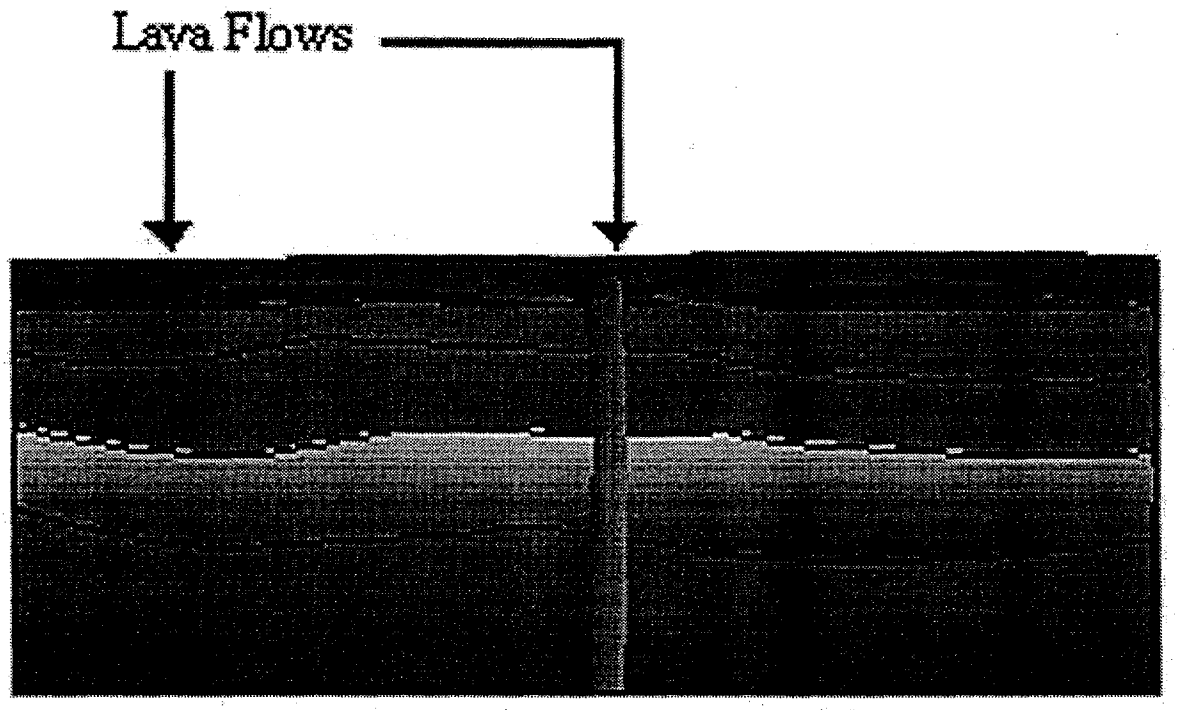

Fissure

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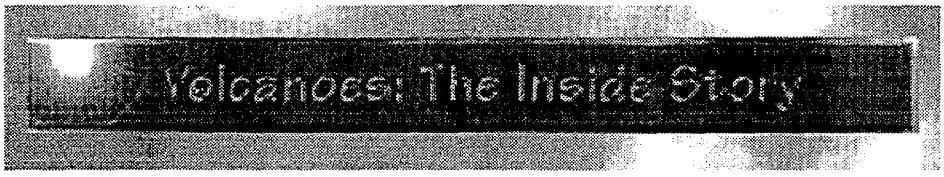
Annex F- Attachment #7



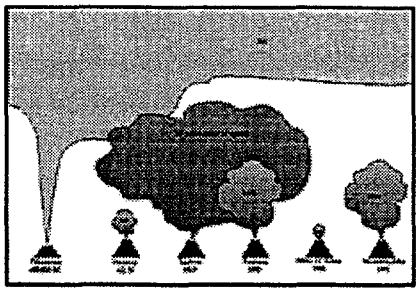
Sizes of Eruptions: Disregard at your own peril

Volcanic eruptions come in all sizes: small, meduim, large, extra large, giant economy size, and super-giant-mega-huge-knock-your-socks-off-more-than-you-could-possibly-imagine size. Giant eruptions can literally affect the whole world. On the other hand, small eruptions may affect only a single hillside or single valley. Let's look at the characteristics and effects of volcanic eruptions of different sizes, starting small and working our way up.

How close?
A small volcanic eruption may consist of single small burst of steam and volcanic ash, as the initial eruption of Mount St. Helens (image?), or a single lava flow, like those which make the local evening news in Hawaii. By exercising some caution, many small eruptions can be viewed from a reasonable distance. What is reasonable? It all depends on the type of eruption. Explosive eruptions (high-water, high-silica), even small ones, are best seen from a distance of miles. On theother hand, effusive eruptions (low-water, low-silica) can be viewed from quite close if you position yourself properly. Large flows of very fluid lavas can attain speeds of 50 to 60 mph, so you would not want to try standing in front of such a flow! With care and proper clothing, however, these flows can be observed and even sampled from the side at a distance of a few feet.

C.R. Chapman tells of two volcanologists walking beside a lava flow during a long hike to the source vent. They grew hungry and decided to cook a frozen pizza they had been carrying on the solid, but hot crust forming at the edge of the flow. Unfortunately for their stomachs, while the pizza was cooking, the "oven" of unstable rock crust broke free and drifted into the flow, carrying their pizza out of reach. They went on, hunger unsatisfied, because wading in liquid rock is not recommended procedure.

Some flows are very slow, and even the fastest flows eventually cool, slow, and stop. "Slow" here means human walking speed or less. You can observe slow flows from any vantage point - front, side, even on top (in some cases). G.A. McDonald tells of a volcanologist who had observed a slow-moving "blocky" flow through a long, hot morning in Hawaii. By noon, the flow had appeared to stop, and the volcanologist decided to have lunch on the top of the flow. After sitting and eating for awhile, the volcanologist noticed that the surrounding scenery was still moving! The flow he was sitting on was still creeping along and was not "dead" after all.



How Large is Large?
There is no accepted scale for measuring the sizes of volcanic eruptions like the Richter Scale for earthquakes. One useful comparison is the volume of new volcanic rock blasted out by the eruption. The volumes of new volcanic rock are shown here in two ways: by the figure at left graphically comparing ejected volumes, and in the table below. The designations used here of "small," "large," "major," and "great" eruptions are simply descriptive, and are used only to draw attention to the great range in the sizes of volcanic eruptions.

Volcanic Eruption Volumes
Volume New Lava Erupted

Volcano	Year	Cubic Miles	Cubic Kilometers
	"Large" Eruptions		
Kilauea, Hawaii	1983	0.02	0.1
Mauna Loa, Hawaii	1976	0.09	0.375
"	1984	0.05	0.22
Mt. Pelee, Martinique	1902	0.1	0.5
Mount St. Helens	1980	0.2	0.7
Askja, Iceland	1875	0.5	2
Vesuvius, Italy	79	0.7	3
	"Major" eruptions		
Pinatubo, Philippines	1991	2.4	10
Krakatoa, Indonesia	1883	4.3	18
Ilopango, El Salvador	300	10	40
Santorini, Greece	1450 B.C.	14	60
Mazama, Oregon	4000 B.C.	18	75
Tambora, Indonesia	1815	36	150
	"Great" Eruptions		
Valles, New Mexico	1.4 Million B.C.	72	300
Long Valley, Calif.	740,000 B.C.	120	500
Yellowstone, Wyoming:			
Lava Creek Ash	600,000 B.C.	240	1000
Mesa Falls	1.2 Million B.C.	67	280
Huckleberry	2.0 Million B.C.	600	2500
Columbia, Washington	15 Million B.C.	24,000	100,000

* Volumes are approximate. 1 mi3 = 4.168 km3
Sources: R.L. Smith (1979) GSA Special Paper 180, p. 5-27; R.B. Smith and L.W

Press, F. and R. Siever (1974) Earth, W.H. Freemam & Co.

Small eruptions The volume of volcanic material tossed out in the bursts or flows of small eruptions is relatively small: a few football stadiums full (equal to a few million cubic feet or a few ten thousandths of a cubic mile). No worries, mate! After all, the inhabitants of the island of Stromboli in Italy simply ignore the virtually constant thumps of red-hot lava "bombs" being tossed out of the vent of their resident volcano. Of course, just how big or important a particular eruption appears depends largely on how close you were at the time. Even a small steam explosion seems huge if you happen to be standing right next to the vent when it "blows." And a single lava flow seems catastophic if it happens to go right through your bedroom! Small eruptions may also be of concern if they are harbingers of bigger things to come - a large eruption.

Large volcanic eruptions often make national and even international headlines, so you have probably

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heard of some of these: El Chichon, Mount Redoubt (which nearly nailed a passing jetliner!), and Mount St. Helens. Large eruptions affect areas around them up to tens of miles away and eject typically a few tenths of a cubic mile of volcanic rock and lava (figure). Depending on the local population distribution, large eruptions can be very destructive of life and property. Potential hazards in these eruptions include huge blasts of super heated steam and pulverized rock, rock avalanches, massive clouds of volcanic ash, asphixiating gases, and, in the case of volcanoes with snow-caps or glaciers on them, giant mudslides. The eruption of **Vesuvius** in 79 AD buried the towns of Pompeii and Herculaneum in Italy and killed thousands of people by falling ash and poisonous gases. The main blast of steam and rock from the 1902 eruption of Mount Pelee on the Caribbean island of Martinique destroyed St. Pierre in less than two minutes, killing all but two of the city's 30,000 inhabitants. Ironically, warnings about the dangers of an imminent eruption were down-played by public officials anxious to keep the voting populace in town for an upcoming election. Unfortunately, the volcano exploded 3 days before the scheduled election, annihilating both electors and potential electees. Mudslides triggered by a 1985 eruption of Nevado del Ruiz in Columbia swept through a small town and killed 25,000 people. In contrast, only 57 people were killed in the 1980 Mount St. Helens eruption, largely because of the remote location and the effectiveness of public warnings.

As important as large eruptions appear locally, they are still relatively small compared to our next larger size class: major eruptions.

Major volcanic eruptions, including Mount Pinatubo in the Philippines in 1991 and Krakatoa in Indonesia in1883 (Hollywood even made a movie about that one!), are tens to hundreds of times larger than the eruption of Mount St. Helens. These eruptions are often **caldera**-type eruptions. They eject many cubic miles of material (see size comparison figure above) and affect areas around them up to hundreds of miles away. Everything about major eruptions must be written in superlatives. Major eruptions are incredibly destructive: the very islands, several miles across in each case, on which Krakatoa, Tambora (Indonesia, 1815), and Santorini (Greece, about 1500 BC) had stood simply disappeared into the sea during the eruptions. Tambora spread thick layers of ash and floating islands of pumice across 2000 miles of Indonesia. Superheated steam and ash from Krakatoa's main blast killed and burned people 30 to 40 miles away on the Sumatra coast. Krakatoa also spawned tidal waves over 100 feet high that swept the coasts of Java and Sumatra, claiming most of the 37,000 lives lost in that eruption. The destruction is so great and widespread in large and especially major eruptions that **eyewitnesses** often describe the eruptions and their aftermath as "the end of the world."

Major eruptions are incredibly loud: noises from the eruption of Tambora in Indonesia in 1815 were mistaken for nearby canon fire in European settlements 200 and 750 miles away from the volcano itself. In each community, nervous military leaders sent out ships and soldiers to investigate what were thought were attacks on nearby outposts! If the main eruption of Mount St. Helens had made as much sheer noise as Tambora, it would have been heard all over the United States.

Major eruptions can affect weather around the world. Clouds of ash and sulfur-rich particles thrown into the stratosphere by large volcanic blasts reflect part of the sunlight reaching the Earth, causing cooling of the atmosphere. The larger the blast, the greater the effect. A global cooling of about 1.5 deg. F (detected by modern sensors) continued for about two years after the Mount Pinatubo eruption. Cooling was so severe following the Tambora eruption that 1816 was called "the year without a summer" or "Eighteen hundred and froze to death." Cold temperatures and killing frosts in Europe and New England in America caused extensive crop failures and resulted in famine in post-Napoleonic France. Many farmers in New England left for the frontier in New York in search of better weather, swelling the American "Move West."

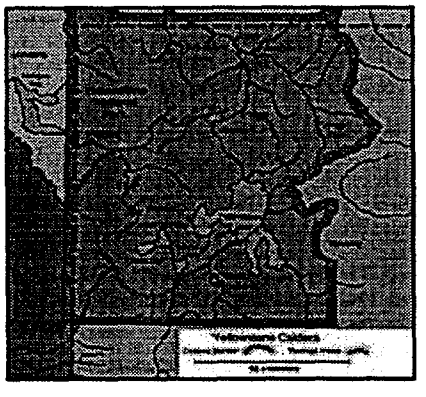
Major eruptions have even been responsible at times for literally changing the course of history. The Mataram empire in Java was apparently destroyed by a major eruption of Merapi in 1006 AD. The course

of Mayan civilization was changed when a major eruption of Ilopango in El Salvador destroyed the highland Mayas around 300 AD. Subsequent shifts in population, trade routes and resultant economic power gave a great boost to the development of the "Classic Maya" civilization. And the eruption of Santorini in the middle of Bronze age Europe apparently caused the destruction of the advanced Minoan civilization on Crete and the surrounding Islands and allowed the expansion of the early Greeks. Ash clouds and tidal waves from Santorini may also have reached Egypt about the time the Hebrews were leaving the country and given rise to the stories of the biblical plagues in Egypt.

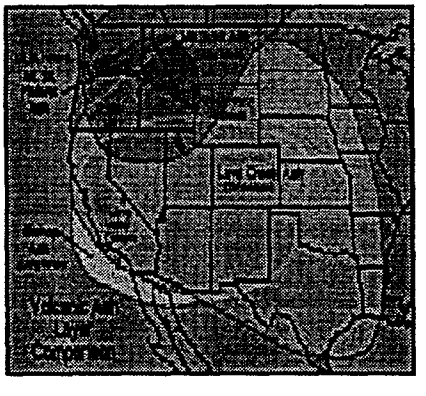
Lest we become complacent thinking that major eruptions only occur in other parts of the world, just remember that the blast that destroyed Mount Mazama to form the placid-appearing Crater Lake in Oregon occurred only about 7000 years ago. Almost any of the Cascade volcanoes could do a repeat performance at any time.

"Great" Eruptions As large and devastating as major eruptions are, they are not the largest volcanic eruptions known. None of these largest, or "great," eruptions have occurred in historic times (thank goodness!). We have only gigantic deposits of volcanic rock as eloquent evidence of their reality.

Great eruptions emerge from two types of volcanoes: **fissure eruption** and **giant caldera**. In both types, the volume of volcanic rock deposited on the surface of the Earth during a single great eruption can be many hundreds of cubic miles - hundreds of times larger than the major eruptions mankind has direct experience with.



Giant caldera eruptions explode with violence, noise, and destruction that defies description - try to imagine an eruption ten thousand times larger than Mount St. Helens! Several giant caldera eruptions are known to thave occurred in the United States. The Valles caldera in New Mexico expelled about 100 cubic miles of ash that still covers much of the middle of the state. The Long Valley caldera in southwestern Nevada ejected over 150 cubic miles of ash that now makes up thick layers of rock in mountains all over the West. But the largest of these eruptions known in the United States came from a fairly recently recognized giant caldera right in the middle of Yellowstone National Park. This caldera, some 30 by 50 miles in size, covers about half of the park, as seen in the map at left.



The Yellowstone Caldera is much larger than the crater on Mount St. Helens. The explosive ask deposit from Yellowstone is also much larger that the deposit from Mount St. Helens, as shown at left. The Yellowstone eruption blasted out a phenominal 300 cubic miles of ash in a thick blanket that extended from California to the Mississippi River. All life within hundreds of miles must have been extinguished in less than an hour.

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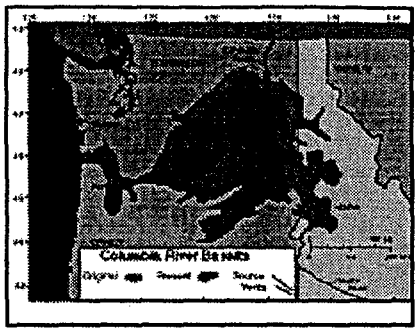

In giant fissure eruptions, sometimes called "flood basalt" eruptions, the Earth simply cracks open and disgorges vast amounts of fluid basalt. These giant outflows are not explosive, but they may continue for weeks without a break, inexorably burying vast areas under a sea of liquid rock. Flood basalt eruptions also come in swarms: as soon as one finishes, another begins. Multiple outflows from the same set of cracks continue for thousands of years, creating enormous barren plains of rock. The largest flood basalt deposit in the United States is the Columbia River Basalt group which covers the eastern third of the state of Washington, a quarter of Oregon, and part of Idaho. One individual layer of basalt - a single eruption - covers 15,000 square miles to depths of 100 feet or more - a total volume of about 600 cubic miles. The entire Columbia River group covers 50,000 square miles to depths of a mile or more, with a total volume of 25,000 cubic miles! All of this stuff came out of a group of cracks, each 30-50 yards wide and tens of miles long, in western Idaho. Flood basalt volcanoes are the largest known deposits of volcanic material.

Given what we know about what a major eruption can do the the world's environment, we can only guess at the conditions great eruptions create. However, we do know that many of the world's great flood basalt eruptions correspond in time with some of the great periods of extinction of life in the Earth's past - indicating extremely challenging climatic conditions for extended periods of time. Fortunately, the larger an eruption is, the less frequently it occurs: many small eruptions occur around the world every year, large eruptions occur every year or so, major eruptions occur on scales of decades to centuries, while great eruptions.... Well, the Columbia basalts, the world's youngest major flood basalt deposit, are about 15 million years old. The Long Valley and Valles Calderas blew up, respectively, about 11 million and 700 thousand years ago. The Yellowstone caldera erupted about 600 thousand years ago. Certainly no great eruptions have occurred during recorded history. It would seem that humanity is unlikely to experience a great eruption anytime soon. On the other hand, the Yellowstone blast is only the latest in a string of eruptions in that area that occur every 600 thousand years or so. And its about that time again....

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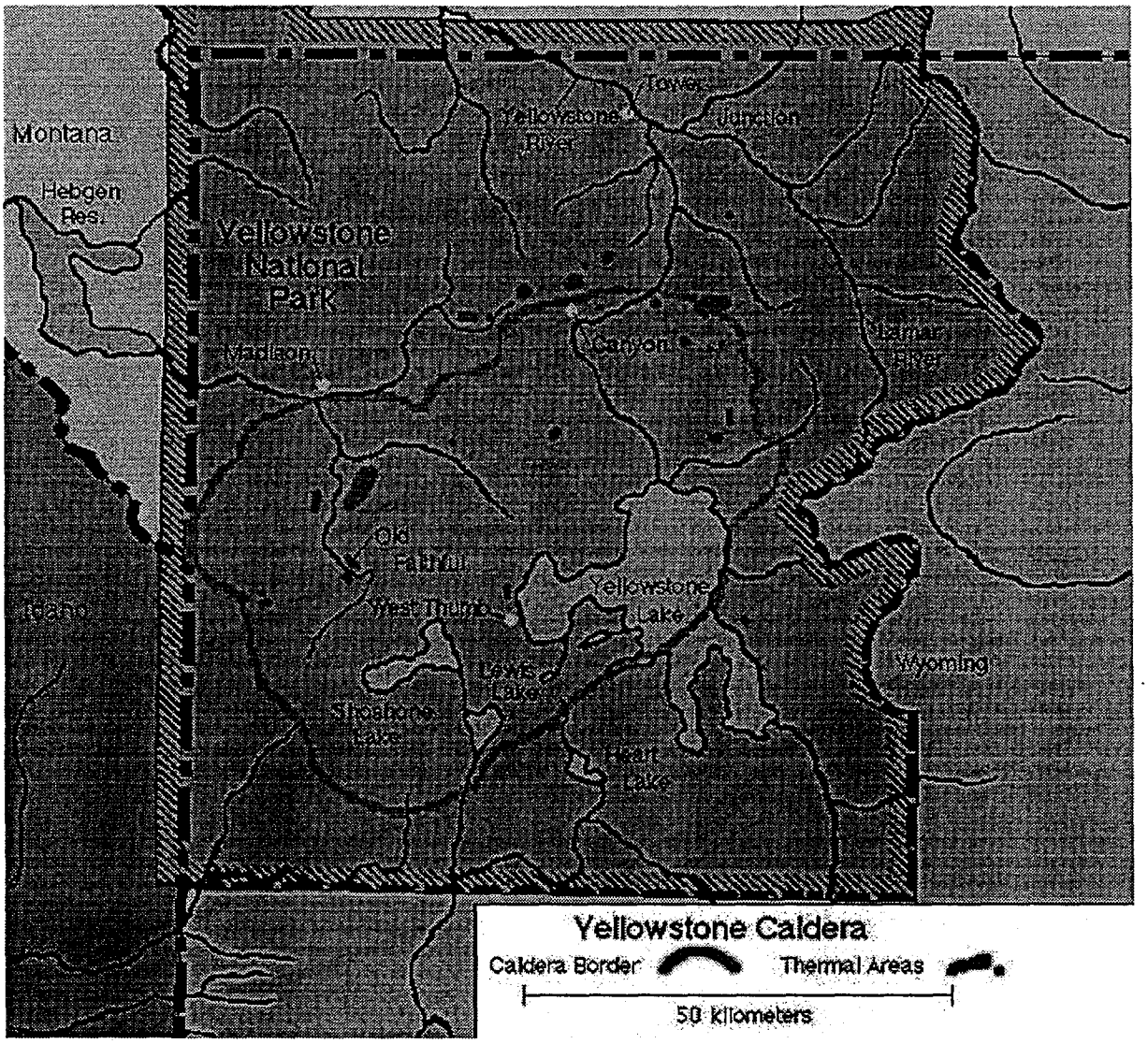
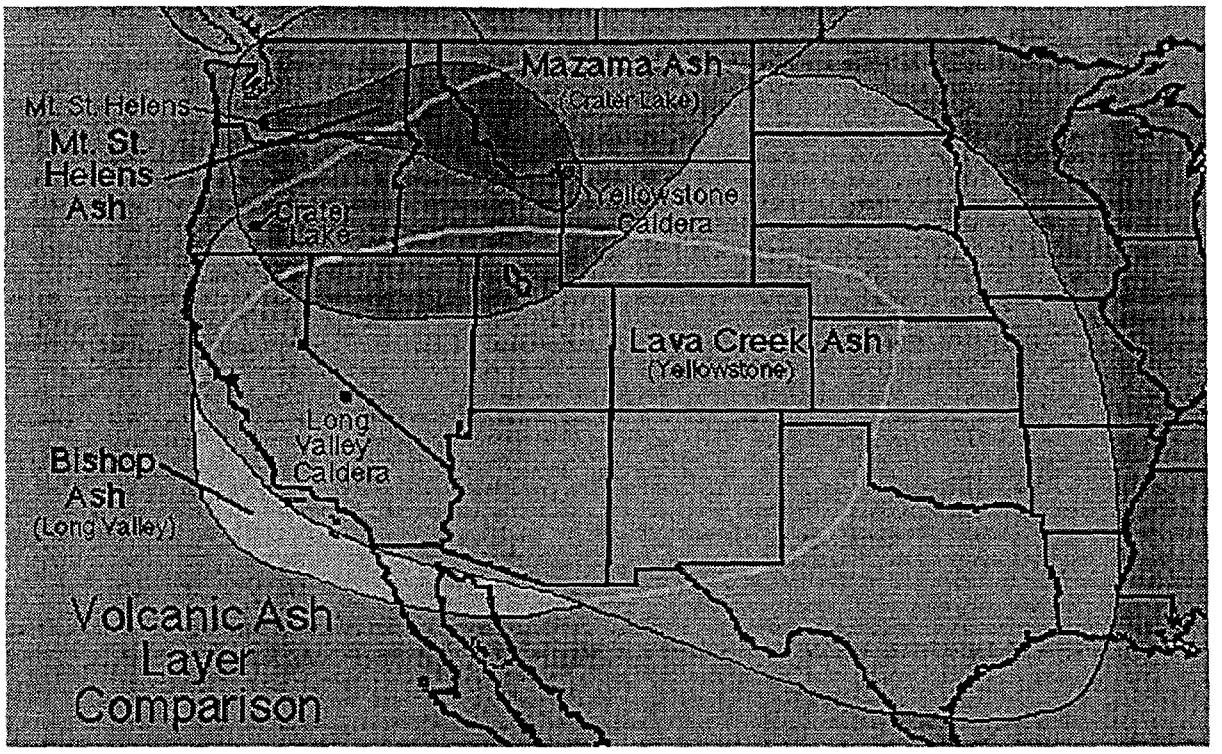

Montana
Hebgen Res.
Yellowstone National Park
Yellowstone River
Tower Junction
Madison
Canyon
Yellowstone Lake
Old Faithful
West Thumb
Lake Lake
Shoshone Lake
Heart Lake
Idaho
Wyoming
Yellowstone Caldera
Caldera Border
Thermal Areas
50 kilometers

157


Mazama Ash
(Crater Lake)
Mt. St. Helens
Mt. St. Helens Ash
Crater Lake
Yellowstone Caldera
Lava Creek Ash
(Yellowstone)
Long Valley Caldera
Bishop Ash
(Long Valley)
Volcanic Ash Layer Comparison

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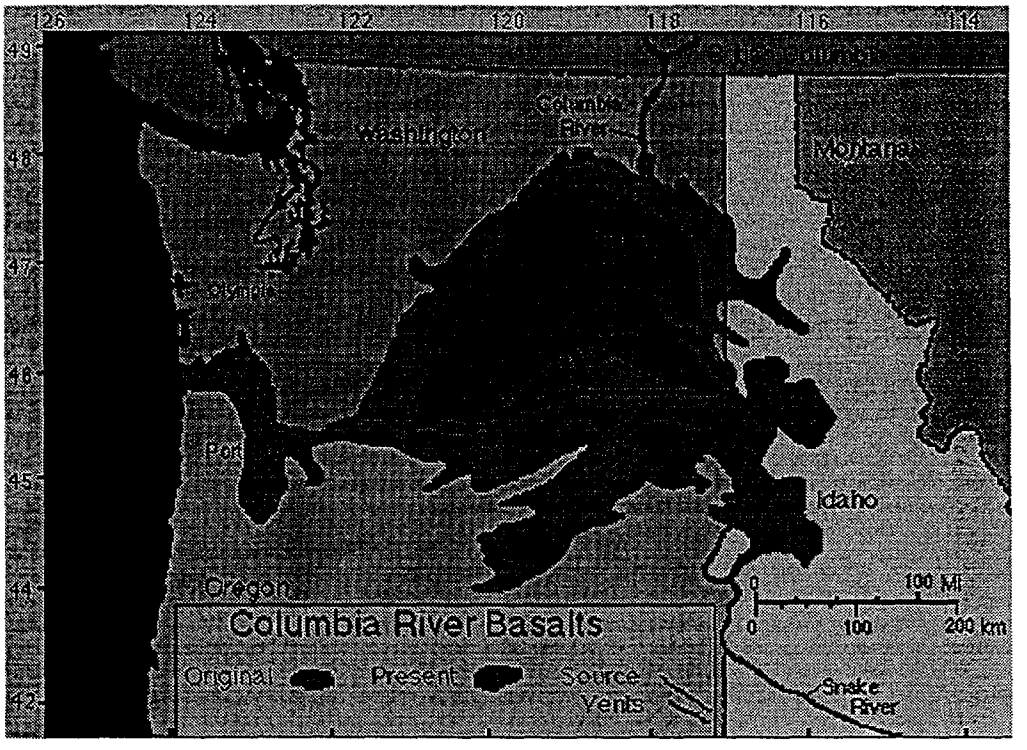
126
124
122
120
118
116
114
49
48
47
46
45
44
43
Columbia River
Washington
Montana
Olympic
Portland
Idaho
Oregon
Columbia River Basalts
Original
Present
Source Vents
0
100 MI
0
100
200 km
Snake River

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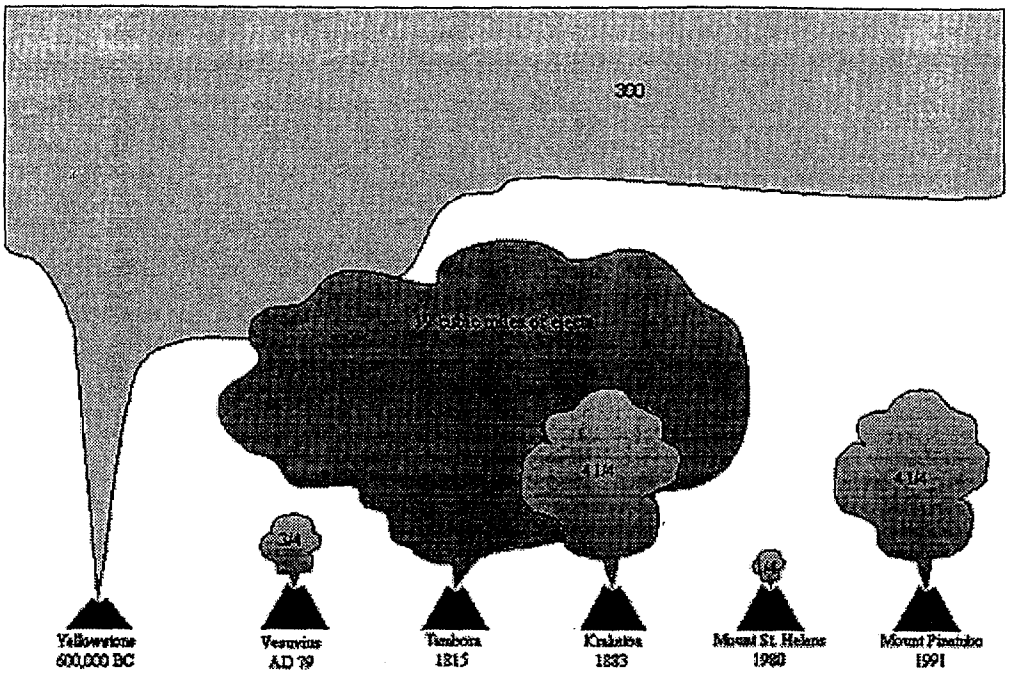
300
114
Yellowstone
600,000 BC
Vesuvius
AD 79
Tambora
1815
Krakatoa
1883
Mount St. Helens
1980
Mount Pinatubo
1991

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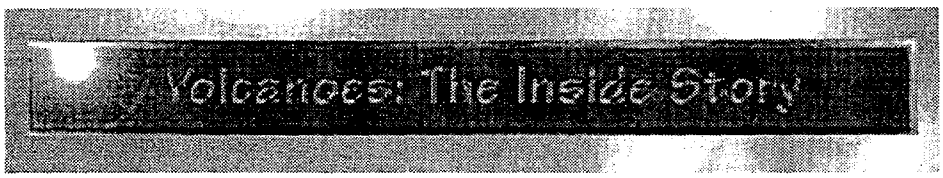
Annex F- Attachment #8

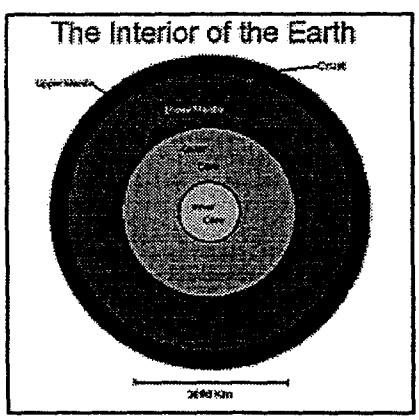
Scenarios | Problem Solving



Looking Inside the Earth

The interior of the Earth more than just a few miles beneath our feet is far more difficult to reach than the surface of Pluto or even a nearby star! The deepest mines in the world are only three to four kilometers deep. The deepest well ever drilled only penetrates 12 kilometers into the interior. Since it is 6371 kilometers to the center of the Earth, comparatively speaking, we have not even been able to get through the skin of the apple. Why haven't we gone any deeper? Even at a depth of 12 kilometers, the high pressures and temperatures of the surrounding rocks cause the metal of even the strongest drills to quickly weaken and deform. At depths of 100 kilometers, rocks flow like butter, and any hole we could form would quickly close upon us.

Yet we have learned a good deal about the Earth's interior using indirect means. Earthquakes and nuclear explosions generate sound (seismic) waves that travel through the entire volume of the Earth. By measuring the intensity and timing of seismic waves at many locations on the surface of the Earth, we are able to determine the density of materials at different levels in the interior. (The technique is a very sophisticated version of tapping on a barrel or wall to see if there is something inside.) By measuring the properties of different materials under high pressure in the laboratory, we can make good estimates of what different parts of the Earth's interior are made of.



From all these measurements, we find the Earth's interior is layered something like the inside of a peach. The "pit" at the center of the Earth is called the "core". It is made mostly of iron, some nickel, and about 10 to 15% of a less dense material, probably silicon, oxygen, or sulfur. Like a peach pit, the core itself is made of two concentric pieces, a solid inner core and a liquid outer core.

The large zone corresponding to the flesh of the peach is called the "mantle". It is made mostly of rocky minerals with names like olivine, pyroxene, quartz, and periclase (any good book on geology or mineralogy will tell you everything you ever wanted to know about these minerals, and then some). Almost all rocks are made of silicon and oxygen mixed with other elements such as calcium, aluminum, and iron. Mantle rocks contain particularly large amounts of iron and magnesium. The mantle is also divided into two parts, both solid: the lower mantle and the upper mantle. This division in the mantle, based on seismic data, may be due to small differences in the amounts of iron and magnesium, or may be due to differences in how close the atoms are to each other. (As an analog, think of a piece of Styrofoam. If you crush it, the particles inside are closer together because you have closed the tiny open spaces inside, but it is still made of Styrofoam.)

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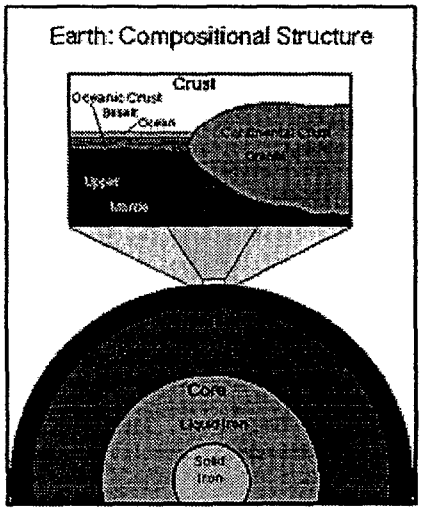
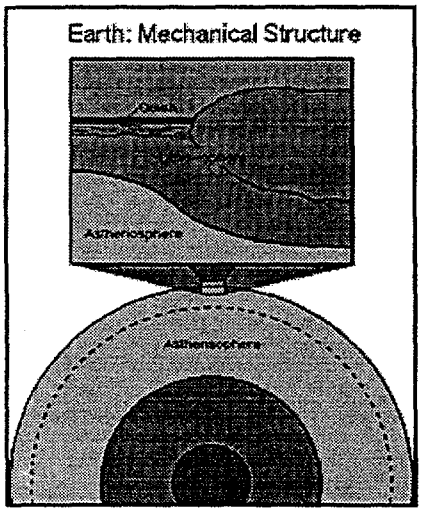


The "skin" of the Earth, called the "crust", is very thin like the skin of a peach. So thin, in fact, that we have to magnify a small piece of our sketch of the Earth to see any detail at all. There are two types of crust: oceanic and continental. As you might suspect from the names, oceanic crust is found mostly under the oceans, and continental crust is found on the continents. Oceanic crust is made mostly of a rock called **basalt**. It contains almost as much iron and magnesium as the mantle rocks. Oceanic crust also contains thin layers of **limestone**, **serpentine**, and **clay**. Limestone is made of calcium and carbon dioxide. Serpentine and clay are rocks like basalt that contain parts of water molecules. An important fact about these rocks is that when they are heated, the carbon dioxide and water "boil" out as gases.

Continental crust is made mostly of **granite**, a rock that contains smaller amounts of iron and larger amounts of **quartz**. As you may know from just looking around, continental crust also contains some limestone, sandstone, basalt - a little bit of just about everything. An important fact about continental crust is that it is less dense than basalt or mantle rocks. Thus it "floats" on the mantle rocks like a piece of wood in water. In fact, you and I live on dry land because the continents "float" much higher in the mantle "ocean" than oceanic crust does (like balsa floats higher than pine).

The terms core, mantle, and crust refer to parts of the Earth that differ in "composition". The Earth's interior is also divided up according to "mechanical" behavior. Specifically, parts of the Earth bend and flow when pressure is applied, and other parts fracture and break. This way of looking at the Earth helps us understand where earthquakes, volcanoes, and mountain ranges are found.



The part of the Earth where rocks fracture and break (we say the rocks are brittle) is called the "Lithosphere" (literally, the "sphere of rock"). The lithosphere covers the entire surface of the Earth down to about 100 kilometers under the oceans and down to about 200 kilometers under the continents. The term "lithosphere" is often used interchangeably with the term "crust," but they are **not** the same. The lithosphere includes the Earth's crust and parts of the upper mantle (See above figure). All faults (like the San Andreas fault in California) and earthquakes occur in the lithosphere, because earthquakes result from sudden breaks or shifts in rock. This can only happen where the rocks are brittle.

The rest of the Earth's interior below the lithosphere is called the "asthenosphere" (literally "sphere without strength"). Rocks at great depths in the Earth slowly bend and flow (we say the rocks are ductile or plastic). Generally, the rocks in the lithosphere have the same composition as the rocks in the asthenosphere. So why do they behave differently in different places? The explanation might be called the "Hot Wax Syndrome." If you take a piece of cold wax (like a piece of candle) and squeeze it between your fingers, it will crack and crumble. If you heat wax until it melts, it will flow like water. However, if you heat a piece of wax **almost** to melting and squeeze the piece between your fingers (careful not to burn yourself!), it will deform and flow like putty. Experiments have shown that almost all solids - wax, metal, rock, glass - act the same way: they are

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brittle at low pressures and temperatures significantly below their melting points, but soft and ductile at high pressures or temperatures near their melting points. So what has this to do with the Earth's interior?

We have learned through measurements of seismic waves and the flow of heat through the surface of the Earth that the interior of the Earth is hot. Estimates of the temperatures in the deep interior of the Earth range from about 4000 deg. C to about 7000 deg. C, about as hot as the surface of the Sun! (The rocks and iron in the deep interior at these temperatures remain as solids and liquids instead of gases because of the very high pressures down there.) Yet the surface that you and I stand on is cool and solid.

Near the surface of the Earth, both temperatures and pressures are low, so rocks behave like cold wax: they crack and crumble. As we delve into the Earth's depths, temperatures and pressures rise quickly. At only a depth of 50 kilometers (about 30 miles), temperatures are already near 1000 deg.F (500 deg.C) and pressures are near 200,000 psi (pounds per square inch). For comparison, a typical pressure in automobile and bicycle tires is around 35 psi. Putting 200,000 psi inside a tire will blow it to (very tiny) smithereens! Putting 200,000 psi on the outside of a rock heated to near 1000 deg.F will cause it to flow like the hot, but unmelted, wax. So the heat and pressure inside the Earth cause rocks at depth to be soft, "without strength," forming the asthenosphere.

Table: The Earth's Interior Divisions

Layer Name	Outer Radius, km	Approximate Temperature	Composition
Inner Core	1229	7000 deg. C (max.)	Solid Iron
Outer Core	3484	5000 deg. C	Liquid Iron
Lower Mantle	5700	2000 deg. C	Iron-rich Rock
Upper Mantle	6360	500 deg. C	Iron-rich Rock
Crust	6371	0 deg. C	Basalt, granite

For more information about the interior of the Earth, you may want to look at "The Earth" in the Solar System Gallery at http://www.c3.lanl.gov:80/~cjhamil/SolarSystem/earthint.html

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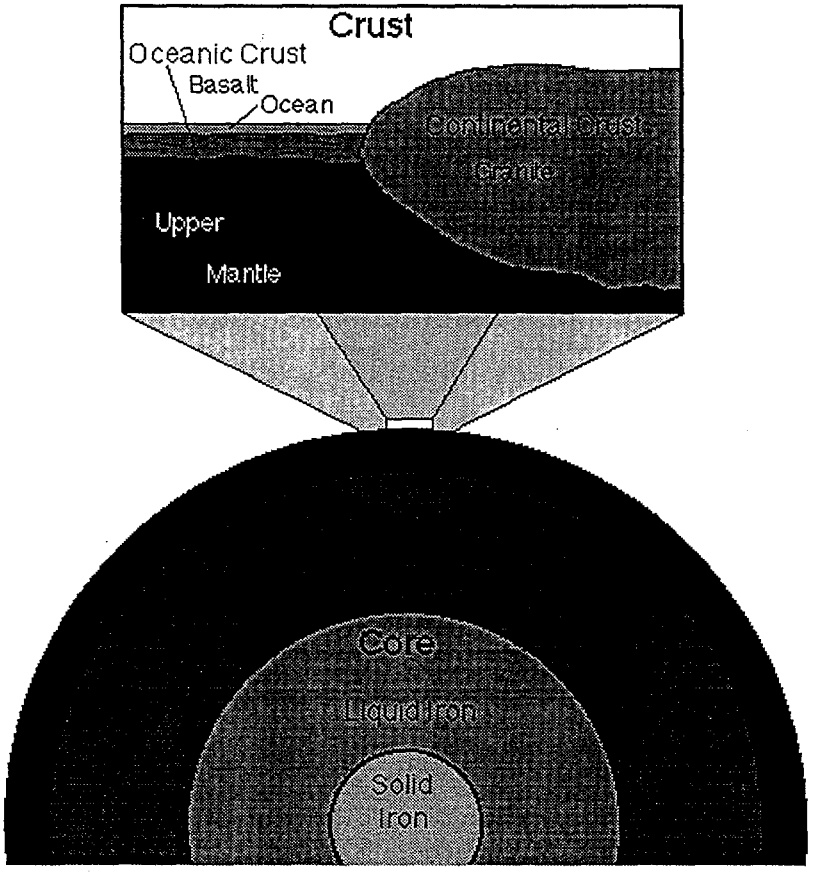
Earth: Compositional Structure



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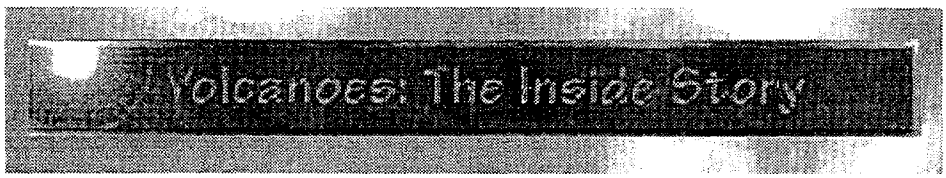
Annex F- Attachment #9

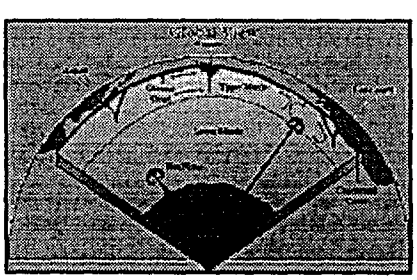


Location of Volcanoes

Imagine taking a world map, closing your eyes, and putting your finger down on the map anywhere at random. If you could be instantly transported to that spot on the Earth marked by your finger and looked around, do you think you would be able to see a volcano? Or even more exciting, would you see an erupting volcano? Probably not, because most volcanoes, especially active ones, occur in only a few well-defined narrow bands across the face of the Earth - something like wild animals confined to reservations. Actually, at most locations on the Earth you would only see a lot of sea water (but that's another story!). But even if you picked a place on land, in most cases there would be no volcano nearby. That is probably just as well, because volcanoes, like wild animals, can be very dangerous and unpredictable neighbors. Sometimes volcanic eruptions are quiet outpourings of lava or playful displays of fire fountains that can safely be viewed from a **reasonable distance**. Other eruptions are so destructive that everything within a thousand miles is annihilated within minutes to hours.

Why do volcanoes occur mostly in these narrow bands? Why not everywhere, such as in your backyard? Why are some explosive and some not? For that matter, why do volcanoes occur at all? Reasonable understanding of the answers to these questions has only been attained during the last hundred years or so.

An important clue to understanding volcanoes is the location of the volcanic bands. Many of the world's active volcanoes are located around the edges of the Pacific ocean: the west coast of the Americas, the east coast of Siberia, Japan, the Philippines, Indonesia, and in island chains from New Guinea to New Zealand - the so-called "Ring of Fire." Recently active volcanoes are also found in Iceland, the Kenya Rift Valley in eastern Africa, Italy, and Hawaii. Looking at the locations of these volcanoes through the glasses of **plate tectonics**, we notice that most volcanoes occur near the edges of the large "plates" that comprise the solid surface of the Earth. Looking even more closely, we notice that the dangerous explosive volcanoes such as Mount St. Helens and Mount Pinatubo that make the evening news are located where plates are crunching together. The quieter, "effusive" volcanoes like Iceland and Hawaii are found mostly where plates are coming apart or in the middle of a plate.



Let's carefully examine the edges of colliding plates to see why volcanoes might be found there. Remember that the plates move because heat flowing up from the Earth's core causes mantle rock to slowly flow in giant convection currents. The rigid plates are carried about, crunching into each other. Plate edges may be either **oceanic crust** or **continental crust**. So when plates collide, we have only three possibilities: oceanic-oceanic, oceanic-continental, or continental-continental collisions.

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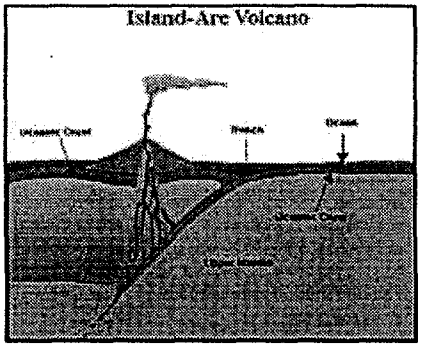
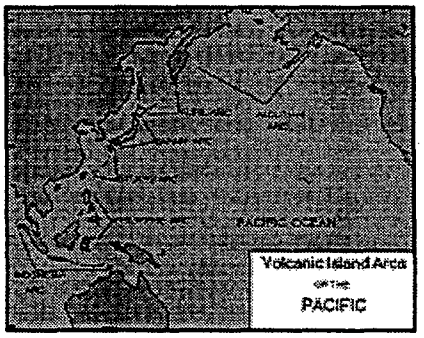
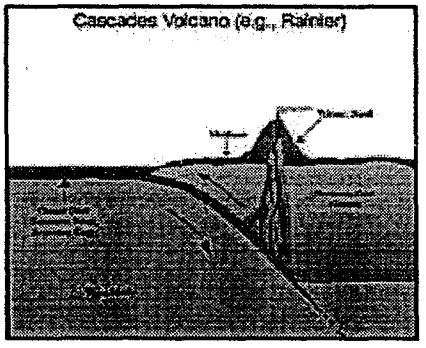


In oceanic-oceanic collisions, one of the edges is forced down into the **upper mantle**. Oceanic crust is able to sink into the mantle because its main component, cold **basalt**, is about the same density as the mantle rocks. The edge that goes down is called the "descending slab." Although the descending slab is mostly basalt, it also contains layers of **clay, limestone**, and **serpentine** that formed on the ocean floor. The clay and serpentine contain water. Limestone is made of minerals combined with carbon dioxide (CO2). As the slab containing all these different kinds of rocks descends into the mantle, it heats up. The heat causes the rocks containing the water and CO2 to decompose, releasing these gases. Dry basalt will not melt at mantle temperatures, but when it comes in contact with the water and CO2 its melting point is lowered. (The effect is just like using salt or anti-freeze to lower the melting point of water ice to clear roads in winter or keep your car radiator from freezing in cold weather.) Consequently, some of the basalt melts and absorbs the water and CO2. The liquid basalt is less dense than the surrounding solid rocks, so buoyancy forces cause the liquid rock to rise through the overlying mantle and oceanic crust to form a volcano on the ocean floor. As the lavas pile up, they form groups of volcanic islands like Japan and Indonesia.



The most likely intersection of a flat descending slab with the curved surface of the Earth is a long, gentle curve or arc. Since the volcanic islands tend to form a few hundred miles "downslab" from the collision site (marked by a deep trench on the ocean floor), they usually form an arc-shaped group. The arc-shape is easy to see in many examples: the islands of Japan, the Aleutian Arc extending from the SW coast of Alaska almost to Siberia, and the Timor-Java-Sumatra chain in Indonesia. Consequently these types of volcanoes are called "island-arc volcanoes." What kind of eruptions do we get with island arc volcanoes? Remember the lava forms because it contains lots of dissolved water and CO2. Thus when the lava reaches the surface, the gases are released, making for very explosive eruptions. Some of the most violent historical eruptions are of the island arc type: Tambora (1815), Krakatoa (1883), and Mount Pinatubo (1992).



Now let's look at oceanic-continental collisions. In these cases, the oceanic crust always forms a descending slab beneath the continent because the **granite** in the continental crust is too light to sink into the mantle. In the descending oceanic slab, the same conditions for melting occur as before except this time, as the liquid rock ascends through the continental crust, some of the granite is melted and mixed with the liquid lava. Granite contains lots of **silica**, so the lava becomes very **viscous**. So when these lavas reach the surface, the resulting eruptions tend to be even more explosive than the island arc eruptions. The Cascade volcanoes in the American northwest are the best studied examples of this type. Examples include **Mount Rainier** and **Mount St. Helens**. A 3-D map showing the Cascades and the prominent volcanoes can be seen by clicking here

The third type of plate collision is continental-continental. The rocks on both sides of this type of collision are too light to sink into the mantle, so the edges simply crumble and fold into giant mountain ranges. The best example is the Himalayan Mountains in central Asia, which are the result of India crashing into Asia.

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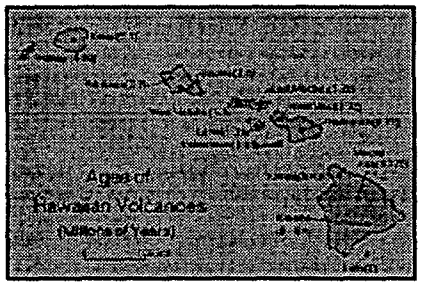
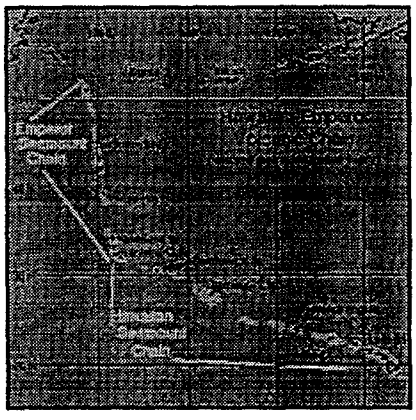
Very few rocks in these collisions are forced to great depths, so little melting occurs, and few volcanoes form. (Just in case you are wondering, there are only a few volcanoes in the Himalayas.)

So much for plate collisions. What about plate separations? In these cases, no rocks are forced down to where they can melt, so no volcanoes form, right? Wrong! Nature does it again! Where plates are separating, something must flow in to fill the gap or else we would have giant, open cracks extending hundreds of kilometers into the Earth's interior (talk about your ultimate sky-diving experience!). The stuff that flows in is hot, soft rock from the upper mantle. This rock is originally under great pressure, but as it rises into the gap between plates, the pressure drops faster than the rock can cool. A small amount of the rock of basaltic composition melts and flows to the surface through cracks. There is little or no dissolved gas in this lava, so the eruptions are not explosive. The amounts of lava erupting at any given time are small, but the eruptions are continuous and occur along all the oceanic ridges, so this type of volcano is the most common in the world. Iceland and the Kenya rift are among the very few places in the world where this type of volcanism occurs on land.

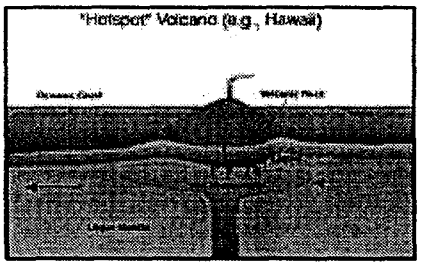
The lavas in plate collisions are formed from cold basaltic rocks being carried down to great depths where they are heated at high pressure. Even then, melting only occurs because the dissolved water and CO2 carried down with the basalt lowers its melting temperature. The lava in plate separations are formed by carrying already hot rock up to low pressures near the surface. This type of melting is called "depressurization melting," and works for nearly all solids. This type of melting is not observed in everyday life because the pressure changes necessary are very large.





We have now accounted for most of the volcanoes in the world, but there are still a few not associated with plate boundaries. These oddballs include some of the most continuously active volcanoes in the world, like Kilauea in Hawaii and La Fournaise on Reunion Island in the Indian Ocean. The lavas in these volcanoes are basaltic and contain little dissolved gas. This type of volcano is usually found at one end of a long chain of extinct volcanoes. For example, the active volcanoes in Hawaii - Mauna Loa, Kilauea, and the Loihi Seamount volcano off the SE side of the big island of Hawaii - form a small cluster of active volcanoes at one end of a kinked chain of hundreds of extinct volcanoes nearly three thousand miles long. Curiously, the ages of the volcanoes in these chains increase systematically along the chain from one end to the other. In the Hawaiian chain, the ages change from zero at the active volcanoes on Hawaii to several million years on Niihau, the westernmost of the major Hawaiian islands, to over 100 million years old at the far end of the chain. At the "old" end of such chains, one often finds a huge **flood basalt** type volcano. These gigantic formations include the largest deposits of volcanic rock in the World. One of these deposits, the Columbia Flood Basalts, covers over one third of the state of Washington. A chain of dead volcanoes leads eastward from the Columbia Basalts to the "live" one now located at **Yellowstone**. Volcanic chains and flood basalt deposits are scattered randomly in time and place around the world. They range in size from single volcanoes to giant groups of volcanoes and flood deposits half the size of the United States.

The long chains of extinct volcanoes with a "live" one at one end motivated the idea of "hotspot" volcanism: a small, fixed source of lavas from deep in the mantle that continuously "burns through" the overlying lithospheric plate as it passes over. In this model, the island chains would be something like a string of burn spots left in a thin piece of wood by passing it over a fixed torch. What could cause a hotspot? Can the hotspot idea account for the observed volcanoes?



We currently think that hot spots are caused by **plumes** that rise from the lower mantle. Remember that not all of the Earth's **internal heat** is transported by mantle convection, but that part is transported by plumes of very hot rock. Experimental and computer models suggest that when a plume reaches the lithosphere, the plume flattens out against the bottom of the lithosphere, heats it, and causes it to bulge and fracture. Decompression melting converts some of the plume material to lava that then rises through cracks to the surface to form a huge flood basalt volcano. Later, as the plate continued to move over the hot spot, the "head" of the plume would shear off, leaving the narrower hot "tail." Lava rising up the tail and through the plate over a long period of time would leave a trail of **shield volcanoes** leading away from the huge flood basalt deposit. Since the lavas come from the mantle, the plumes would be basaltic in composition and low in dissolved gases. Plumes come in all different sizes and can occur anywhere.

All of this should sound familiar. Virtually all of these model predictions match features seen in hotspot volcanism, which is why the plume model is the leading hypothesis for hotspot volcanoes.

An interesting consequence of hotspot volcanism is that a hotspot volcano can occur anywhere, even in your own back yard! In fact, a volcano did occur recently in one farmer's back yard: in 1943, Dionisio Pulido found a crack in his cornfield spewing out red hot rocks and lava. Within a year, the crack grew to a volcano - Paricutin - that covered his field, his farm and his local village - everything within five miles. Paricutin is still active today in southwestern Mexico. Of course, a glance at the map will show that Paricutin is in a zone of many active volcanoes caused by plate subduction under Mexico, so its location was not exactly a complete surprise. On the other hand, it is estimated that hotspot volcanism will affect every part of the Earth's surface on an average of every 500 million to 800 million years. So even if you live in Lafayette, Indiana, you might wake up some morning to find a brand new hotspot volcano in your own back yard!

(Now all you have to do is figure out the probability of that actually happening in your lifetime!)

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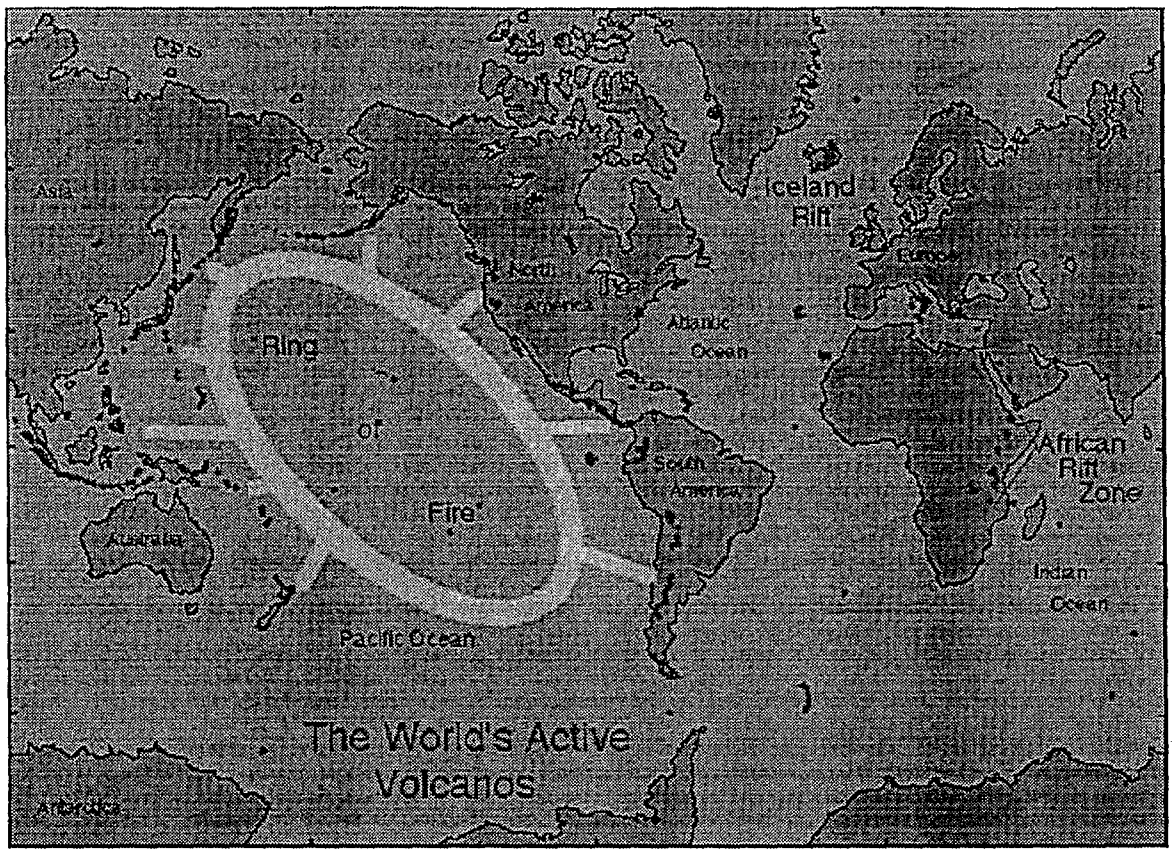
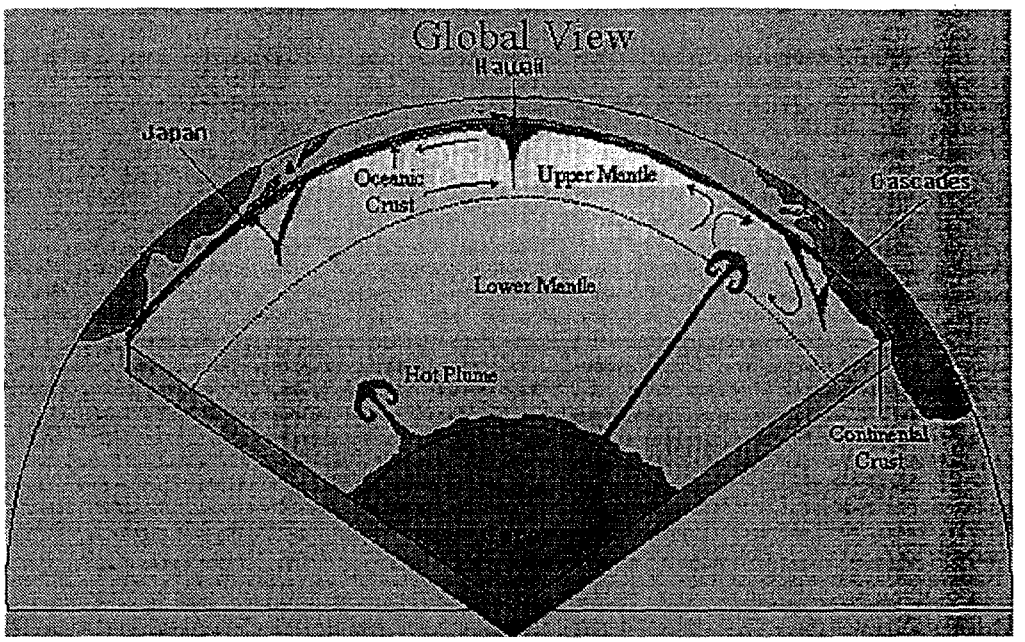

Asia
Iceland
Rift
Europe
North
America
Atlantic
Ocean
Ring
of
Fire
South
America
African
Rift
Zone
Australia
Indian
Ocean
Pacific Ocean
The World's Active
Volcanos
Antarctica


Global View
Hawaii
Japan
Oceanic Crust
Upper Mantle
Cascades
Lower Mantle
Hot Plume
Continental Crust

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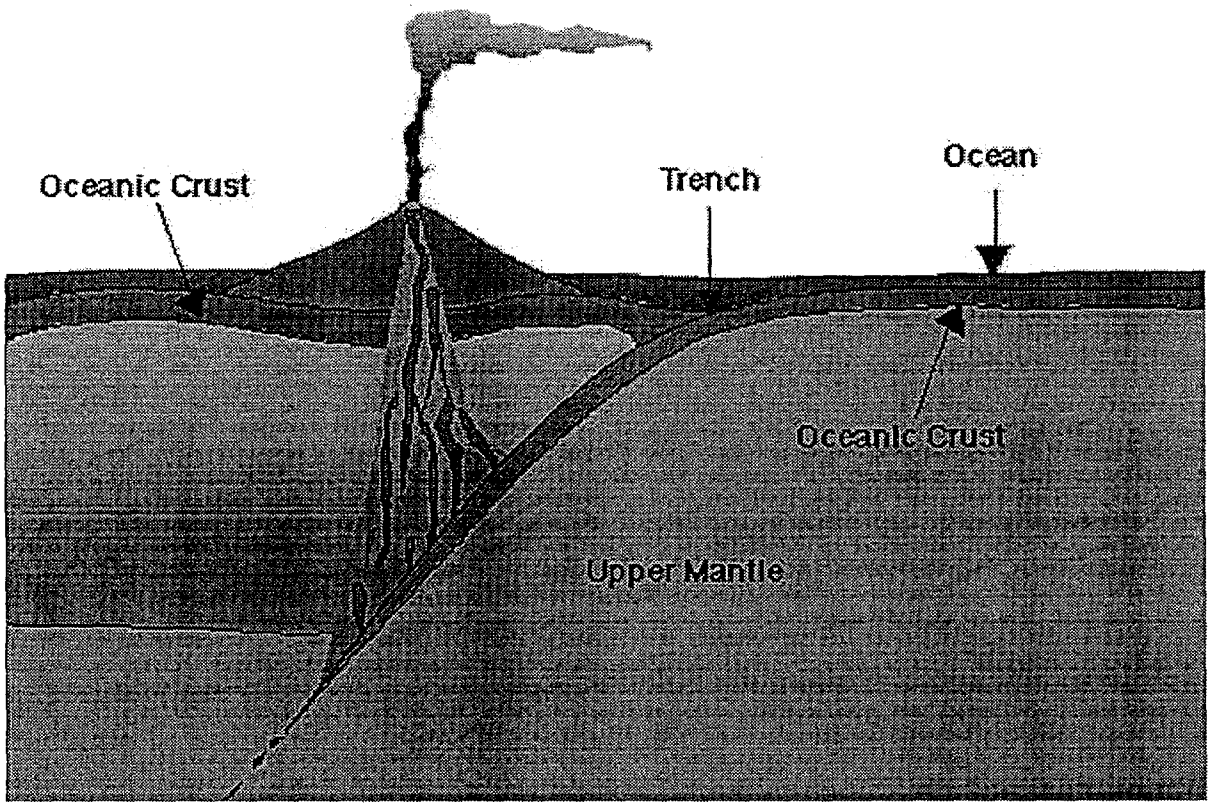
Island-Arc Volcano



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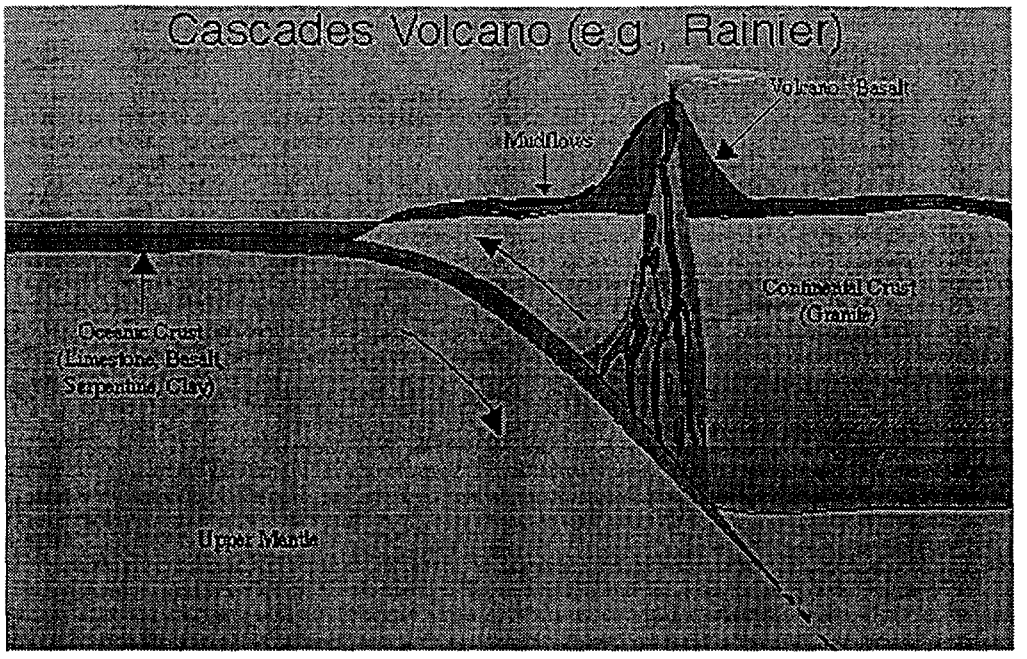
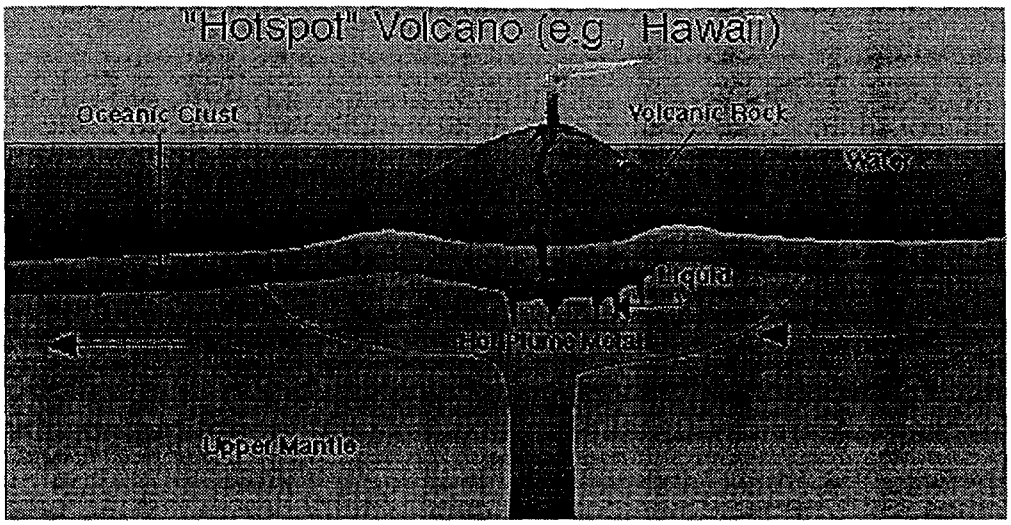

Cascades Volcano (e.g., Rainier)
Volcano: Basalt
Mudflows
Continental Crust
(Granite)
Oceanic Crust
(Limestone, Basalt,
Serpentine, Clay)
Upper Mantle


"Hotspot" Volcano (e.g., Hawaii)
Oceanic Crust
Volcanic Rock
Water
Magma
Hot Plume Rock
Upper Mantle

Scenarios | Problem Solving

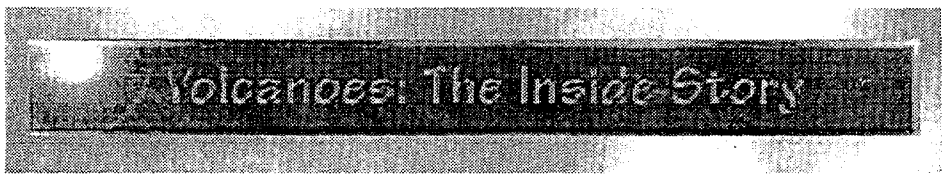
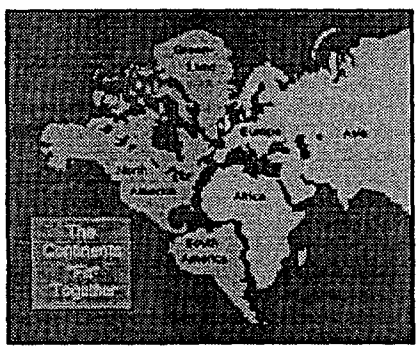
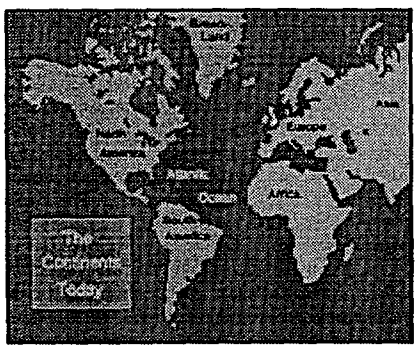


Plate Tectonics and Heat Flow





Almost since the creation of the first accurate maps of the eastern coasts of the Americas and the western coasts of Europe and Africa, it has been noticed that the two coastlines almost "fit" together. In the 1960's it was recognized that in fact the whole **lithosphere** of the Earth was like a giant puzzle, consisting of small and large pieces - called "plates" - joined at the edges by huge cracks, faults, and deep trenches. A really incredible thing about the individual plates is that they are moving in different directions across the surface of the Earth. The movement of the plates is very slow, only a few centimeters a year (about the speed at which your fingernails grow), but the consequences are enormous for all of us clinging to the surface of the Earth. Think for a moment. If huge chunks of the Earth's surface are moving in different directions, they must be ripping apart in some places and crunching together in others.

At first, the evidence for the movement of the plates was circumstantial: the "fits" of continental coastlines, similar groups of rock and fossils in mountains facing each other across the Atlantic in South America and Africa, fossils of tropical plants and animals in what are now polar climates, and magnetic "stripes" of increasing age across the ocean floors between the continents. However, since 1976 the motion between the Pacific and North American plates has been measured directly by bouncing lasers off of LAGEOS (Laser Geodynamics Satellite) - a sort of two-foot diameter orbiting cannonball with hundreds of small mirrors ground into its surface.

Characteristic geologic features are found at the edges of plates. Where the plates are separating on ocean floors, we find the oceanic ridges: a continuous ridge snaking about the Earth that has a small canyon along its crest. The sides of the small canyon are huge faults or cracks. Small amounts of **basaltic** lava are continuously erupting along these and other cracks in the canyon floor to fill in the gaps made by the separating plates. Where plates are separating on land we find long canyons with faulted sides called "rifts." Examples are the Kenya rift in Africa and the Rio Grande Rift in New Mexico. Where the plates are colliding, we have either huge mountain ranges such as the Himalayas in India (on land) or incredibly deep trenches (in the ocean) such as the Kermadek Trench near New Zealand. Mountain ranges like the Rockies and Appilachians were formed by continental crashes in the past. **Volcanoes** commonly occur along colliding plate boundaries. The volcanoes around the edges of the Pacific Ocean, evidence of "continental crunch" around the entire Pacific plate, are called the **Ring of Fire**.

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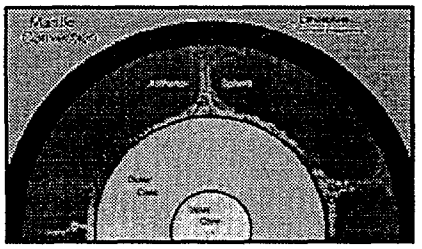
In some places, like Southern California, the plates are neither colliding nor separating, but are just sliding past each other. In these cases we just get a great, big crack or fault (like the San Andreas in California). Unfortunately, the sliding is not smooth, but sticky and jerky. To the minuscule beings living on the "rubbing shoulders" of the gargantuan Pacific and North American plates, these tiny stops and starts are huge earthquakes that cause no end of problems.

What causes the plates to move? It turns out to be a consequence of the **high temperatures** inside the Earth. Common experience tells us that heat flows from hot to cold, so the heat in the Earth's deep interior must be flowing somehow to the surface. Hot lavas and gases coming out of **volcanoes** are direct evidence for heat flowing out of the Earth . Another indicator of heat flow is the increase in temperature with depth inside deep mines. These measurements of heat flow, however, are all made near the surface. The processes by which heat moves in the Earth's deep interior are investigated by computer simulations which can be compared with seismic and heat flow data which show temperature variations in the Earth's interior.



Based on both the measurements and simulations, we find that the hottest part of the Earth's interior is the iron **core**. Part of the heat down there is actually left over from the fiery formation of the Earth, part is from latent heat released by the freezing of liquid iron in the outer core onto the solid inner core, and part is (possibly) from the slow decay of naturally radioactive elements like uranium and potassium mixed in the core. The core heats the bottom of the rocky **mantle**. The hottest rocks near the bottom of the mantle become slightly less dense than the somewhat cooler rocks above them, so buoyancy forces try to push the hottest rocks upward. Although the rocks in the mantle are solid, the pressures and heat are so great that the rock can deform slowly, like hot wax. So the hot rock creeps upward through the cooler rocks. As the hot rock rises, cooler rock flows downward to take its place next to the core, where it is heated and becomes buoyant enough to rise again later. The rising hot rock comes in contact with cold rocks near the surface of the Earth where it gives off its heat, cools, and sinks again. Most of the rock in the mantle moves in this broad cyclic flow, indicated by the arrows in the figure. This zone where rocks are soft enough to flow is called the **asthenosphere**.

(This means of heat transport - the cyclical movement of hot and cold material - is called "convection." You can see an example of this in your kitchen by heating a pan of water to what is called a "rolling boil:" hot water from the bottom of the pan rises up the sides, flows to the center, and sinks to the bottom again.)

Occasionally, however, masses of hotter-than-normal rock rise independently of the broad flow, like bubbles through a flowing stream. These masses of very hot rock form "**plumes:**" rising columns with rounded tops.

Rocks near the surface of the Earth are so cold and at such low pressures that they cannot flow like mantle rock. So how does heat get through this rigid layer (called the **Lithosphere**) to the surface? One way is by "conduction" which describes heat flow in an iron pan held over a fire. The part of the pan over the flame gets hot first, followed by the handle which is not over the flame. The heat in the handle came from the pan, but there was no movement of hot material from one part of the pan to another as in convection (the metal in the pan and handle certainly didn't flow!). The heat, which is vibrations of atoms in the solid pan, moves by fast moving (hot) atoms bouncing off of slow moving (cool) atoms, causing the slow atoms to move faster (heat up). So at the top of the asthenosphere, the hot rock flows along the bottom of the lithosphere, transferring its heat to the cold rocks by conduction. The heat then flows through to the surface, again by conduction.

A second way of getting heat through the lithosphere is more exciting: melt some of the mantle rock and let it flow through cracks in the lithosphere to the surface! Sound familiar? Flows of liquid rock (lava) onto the Earth's surface are usually called **volcanoes**!

How does all this relate to the motions of the plates on the earth's surface? The movement of heat by convection in the asthenosphere causes the rocks of the mantle to slowly move in huge streams. The solid (but brittle) rocks of the lithosphere are resting directly on top of the solid (but soft) rocks of the asthenosphere. As the rocks of the asthenosphere move in different directions, they carry parts of the lithosphere along. The lithospheric rocks can't stretch, so they break into pieces - forming the plates. Interestingly, once the plates form, they begin to act somewhat independently of the convection flow because their cold edges tend to sink into the mantle wherever they happen to be. The detailed relation between of the motions of the plates and the underlying convective motions are still being studied.

This whole group of observations and ideas describing the motions of the plates and their associated geologic features is called "Plate Tectonics." You should see by now where the "plate" part comes from. "Tectonics" derives from the Greek word for "builder," and is used in geology to describe structures like folds, faults, and mountains. Since one of the important results of plate collisions is rock fracture and mountain building, the use of this word should also be clear. Plate Tectonics is the current "paradigm" or unifying philosophy for understanding most of the geologic features on the surface of the Earth. Its development in the 1960's and 1970's represented an enormous leap forward in understanding how the Earth works.

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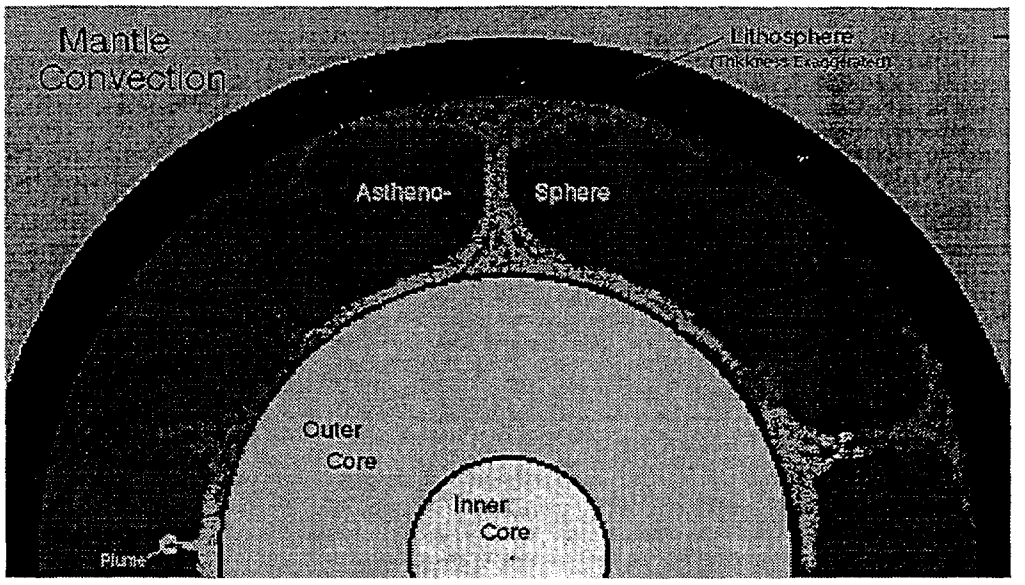

Mantle
Convection
Lithosphere
Asthenosphere
Outer
Core
Inner
Core
Plume

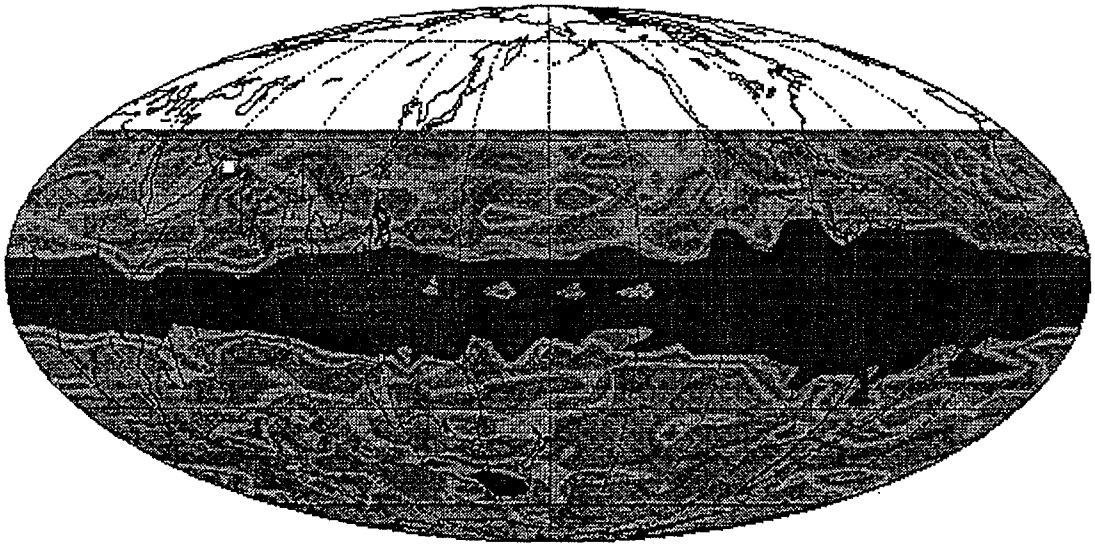
Annex F- Attachment #11

Volcanoes: The Inside Story

Volcanoes and Climate

Volcanic eruptions can alter the climate of the Earth for both short and long periods of time. For example, average global temperatures dropped about a degree Fahrenheit for about two years after the eruption of Mount Pinatubo in 1991, and very cold temperatures caused crop failures and famine in North America and Europe in the two years following the eruption of **Tambora** in 1815. It is also believed that the balance of the Earth's mild climate over periods of millions of years and longer is maintained by ongoing volcanism. Volcanoes affect the climate through the gases and dust particles thrown into the atmosphere during eruptions. The effect of the volcanic gases and dust may be warming or cooling of the earth's surface, depending on how sunlight interacts with the volcanic material.

Volcanic dust blasted into the atmosphere causes temporary cooling. The amount of cooling depends on the amount of dust put into the air, and the duration of the cooling depends on the size of the dust particles. Particles the size of sand grains and larger fall out of the air in a matter of a few minutes and stay close to the volcano. These particles have little effect on the climate. Tiny dust-size ash particles thrown into the lower atmosphere will float around for hours or a few days, causing darkness and cooling directly beneath the ash cloud, but these particles are quickly washed out of the air by the abundant water and rain present in the lower atmosphere. However, dust tossed into the dry upper atmosphere, or stratosphere, can remain for weeks to months before they finally settle. These particles block sunlight and cause some cooling over large areas of the Earth.



Volcanoes that release large amounts of sulfur compounds like sulfur oxide or sulfur dioxide affect the climate more strongly than those that eject just dust. The sulfur compounds are gases that rise easily into the stratosphere. Once there, they combine with the (limited) water available to form a haze of tiny droplets of sulfuric acid. These tiny droplets are very light in color, so they reflect a lot of sunlight for their size. Although the droplets eventually grow large enough to fall to the Earth, the stratosphere is so dry that this

takes a long time, months to years. Consequently, reflective hazes of sulfur droplets can cause significant cooling of the Earth for up to a few years after a major sulfur-bearing eruption. Sulfur hazes are believed to have been the primary cause of the global cooling that occurred after the Pinatubo and Tambora eruptions. The sulfur cloud produced by Pinatubo was tracked by satellite for many months. The image shows the cloud about three months after the eruption. It is already a continuous band of haze circling the entire globe. You can learn more about the cooling effects of sulfur hazes by clicking here

Volcanoes also release large amounts of water and carbon dioxide. When these two compounds are in the form of gases in the atmosphere, they absorb heat radiation (infrared) emitted by the ground and hold it in the atmosphere. This causes the air below to get warmer. So you might think that a major eruption would cause a temporary warming of the atmosphere rather than a cooling. However, there are very large amounts of water and carbon dioxide in the atmosphere already, and even a large eruption doesn't change the global amounts very much. In addition, the water generally condenses out of the atmosphere as rain in a few hours to a few days, and the carbon dioxide quickly dissolves in the ocean or is absorbed by plants. Consequently, the sulfur compounds have a greater short-term effect, and cooling dominates. However, over long periods of time (thousands or millions of years), multiple eruptions of giant volcanoes, such as the **flood basalt** volcanoes, can raise the carbon dioxide levels enough to cause significant global warming.

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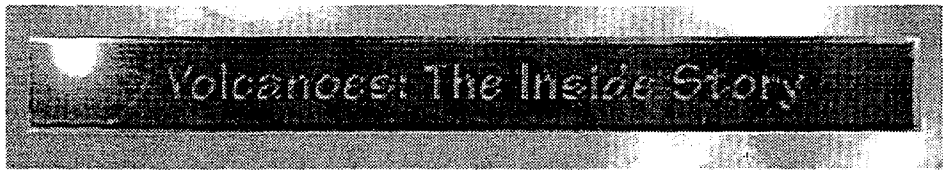
Annex F- Attachment #12

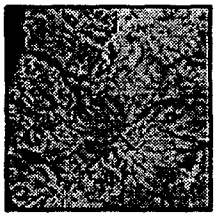


Volcano Monitoring

In any sporting event, a good player tries to figure out what his opponent is going to do next by carefully examining his past record and by keeping a close watch on him during the game. Likewise, if we want to know what a volcano is going to do, we need to study its past activity and keep a close watch on any current eruptions. This is what volcano monitoring is all about. In order to "keep an eye" on our volcanic neighbors, permanent volcano observatories are maintained around the world in areas of high volcanic activity, including Hawaii, Alaska, the Cascades, and central Italy.

Let's look at some of the important techniques of volcano watching and what we can learn by using them.

Geologic Structure. First we look at the structure and location of a volcano to see what type it is. This is important because the main types of volcanoes (Cascade, Island Arc, and Hot Spot) have characteristic types of eruptions: some explosive, some effusive, and some both. We look at the size of the volcano and its neighbors. We look for thick ice packs or glaciers on its sides or summit to see if mudflows are possible. We look at how heavily eroded it is to see if it is still active and whether there are sections likely to break off.



As an example, here is a SIR-C radar image of Mount Pinatubo in the Philippines showing the central cone and summit crater, rough ash flows (red) high on the volcano's sides, and smooth (dark) mudflows extending down the surrounding drainage valleys. This is an island arc volcano, which has many similarities to Cascade-type volcanoes like Mount Rainier and Mount Hood.

Past Eruptive History. Now we look at volcanic deposits around the volcano: what kinds of deposits (lava flows, mudslides, ash flows), how large they are and how far they extend from the volcano, and when they occurred. This will tell us if the volcano is active or not. We look for patterns of activity. Does the volcano erupt or produce mudflows at regular intervals? Does it have a consistent sequence of events, say a number of effusive eruptions followed by an explosive one, or several small eruptions followed by a large one? Combining the sizes and ages of different types of deposits will help us evaluate the risk of a particular volcanic hazard at a particular volcano.

A simple example of eruptive histories of the Cascade volcanoes is given in the diagram in this article at the Cascades Volcano Observatory.

Past history can only help us so far, however, because experience with many volcanoes has shown that no two eruptions of a single volcano are exactly alike, and no two volcanoes produce exactly the same sequence of eruptions. Each volcano is unique, and predictions concerning the next eruption of any given volcano always have an element of uncertainty. This is why any volcano showing current signs of activity needs to be monitored in "real time."

Seismic Activity. The first evidence of an impending eruption is usually a series of seismic events or earthquakes. This is because for an eruption to occur, lava must rise from its formation zone deep

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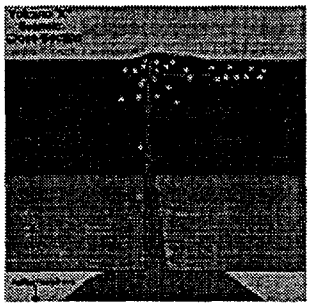
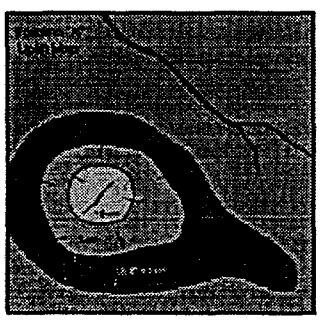
underground to near the surface. The lava must literally push overlying rocks aside to rise through them. The rocks are brittle and break as they are bent and twisted, releasing seismic energy that we record as earthquakes. By placing a number of seismic recorders around a volcano, the movement of the new mass of rising lava can be followed. Usually, the recorders are linked to a volcano observatory by radio so that people don't have to be present on the active volcano. By tracking lava movement, the place where the eruption is likely to occur can be identified.



Here is a short animation (Mpeg or Quicktime) simulating the occurrence of earthquakes during the formation of Volcano "X." At great depths, in the asthenosphere, huge globules (called diapirs) of magma rise through the soft rock without causing any earthquakes. As the globule reaches the bottom of the lithosphere, it flattens out and pushes upward against the rigid barrier, fracturing the brittle rock. The magma can then continue to ascend by forcing a crack through the lithosphere to the surface. Many small to medium earthquakes occur around the crack tip and in the adjacent rock. As the magma rises, the earthquake activity follows it. Near the surface, the magma may sometimes force its way through pre-existing weaknesses between rock layers. Earthquakes will occur wherever the rock is deformed enough to break. Clusters of small earthquakes called swarms also occur when magma flows quickly through narrow sections of magma-filled cracks. Both types of quakes are used to follow magma movement underground. Eventually, the tip of the rising crack reaches the surface, and a new volcano is born.

Uplift or Inflation. As a mass of new lava rises to the surface, it pushes the old rock aside and upward making a bulge or uplift on the surface. The process is often called inflation, because the expansion of a volcano due to the lava pushing up inside is similar to inflating a balloon by blowing new air into it. The inflation of a volcano is measured in several ways: by tilt meters that measure the angle of the ground surface, by laser ranging using mirrors placed on the mountain, and by precision surveys using aerial photographs.



Here is an animation (Mpeg or Quicktime) illustrating the inflation of the ground caused by the formation of Volcano "X." There is no bulge when the magma is still very deep. The bulge begins and grows as the magma rises, reaching a maximum when the magma is near the surface. The bulge deforms the near surface rock and small cracks often form in and around it. The eruption begins when the main magma-filled cracks reaches the surface. As the magma flows out onto the surface as lava, the bulge will decrease somewhat, like a deflating balloon.

Measurement of the volume of a bulge is very important because it gives an indication of how large the later eruption will be. This is because the volume of the bulge on the surface is roughly equal to the volume of the new magma underground. For example, about one square mile of the north side of Mount St. Helens bulged outward about 450 feet before the May 18 eruption. Thus the volume of the bulge was about one square mile times about a tenth of a mile, or about a tenth of a cubic mile. By comparison, the volume of new lava expelled during the eruption was later estimated to be a few tenths of a cubic mile.

Let's estimate the volume of the new magma under the bulge of Volcano X. We will work with the maximum bulge shown in frame 4 of the animation. One way to measure the volume is to think of the bulge as a layer cake: the bottom layer is one centimeter (cm) thick, the next layer - given as 5 cm tall - is

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5-1 = 4 cm thick, and the top layer - listed as 10 cm tall - is 10-5 = 5 cm thick. The volume of each layer may be found by measuring its area and multiplying by its thickness. The volume of the bulge is then found by adding the volumes of all three layers together. To illustrate a point, let's make a quick estimate, rather than an exact measurement of the volume. The bulge is nearly circular, except for the "tail" to the lower right, so we can get our rough estimate by approximating the outline of each layer as a circle. If we assume the diameter of the 1 cm contour is about 10 kilometers across, then the area of 1 cm layer is about 3.15x52 = 79 square kilometers (km2), the area of the 4 cm thick layer (about 7 km in diameter) is about 38 km2, and the top 5 cm thick layer (about 3.5 km in diameter) is about 10 km2. Multiplying each layer by its thickness and adding together (remembering that 1 km = 100,000 cm) gives a volume of about 0.0028 cubi c kilometers (km3). Remember, this is only an estimate because we approximated each layer as a simple circle.

A more exact volume can be found if you have access to an image analysis program like NIH Image. [Directions for NIH Image: use File/Open to pull frame 4 into NIH Image. Use the measure tool (see measuring activity) to measure the vertical diameter of the 1 cm contour and Set Scale assuming this diameter is 10 km. Select Area under Analyze/Options Select Options/Density Slice and use the tool to narrow the red selection bar that appears on the LUT. Move the narrow selection bar up and down the LUT u ntil one of the colored contours of the bulge is changed to red. This area is now "selected." Select Analyze/Measure. Repeat for each colored contour. Finally, select Analyze/Show Results to see your three measured areas.] Rather than treating the bu lge like a layer cake, this approach measures the area of each thickness directly, so the volume of the bulge is obtained by multiplying each measured area by its total thickness and adding. Using NIH Image, we obtained 64.2 km2 for the 1 cm area, 27.9 k m2 for the 5 cm area, and 8.41 km2 for the 10 cm area. Multiplying together and adding the volumes gives 0.00288 km3. This more accurate value is slightly larger than the estimate we first made, largely because we included the "tail" on the bulge. Howe ver, our first estimate was close enough for many purposes, and shows that even without sophisticated image processing programs, useful measurements can be made by careful approximations.

Now that we have measured the volume of the bulge of Volcano X, let's consider what we have. By either technique, we obtain a rounded volume of 0.003 km3. Comparing this amount with the observed volumes of different sizes of eruptions in the table of Eruption Sizes shows that even if all of the new magma erupts onto the surface, this will still only be a small eruption. If the volume had turned out to be 10 or 100 km3, then the expected eruption would be much larger and destructive.

"Typical" Events. This category includes a number of different types of observations, including avalanches and landslides triggered by inflation, releases of volcanic gas and steam, changes in the temperature or mineral content of springs on or near the volcano, and the formation of new fractures or faults. New cracks and faults form where the rocks are pushed out of shape so much that they break. Faults typically form around the edges of a large bulge and indicate the area over which rock failure might occur during the coming eruption.

For example, large fractures formed around the edges of the bulge on Mount St. Helens. Virtually all of the heavily fractured zone broke and fell off of the mountain during the May 18 eruption.

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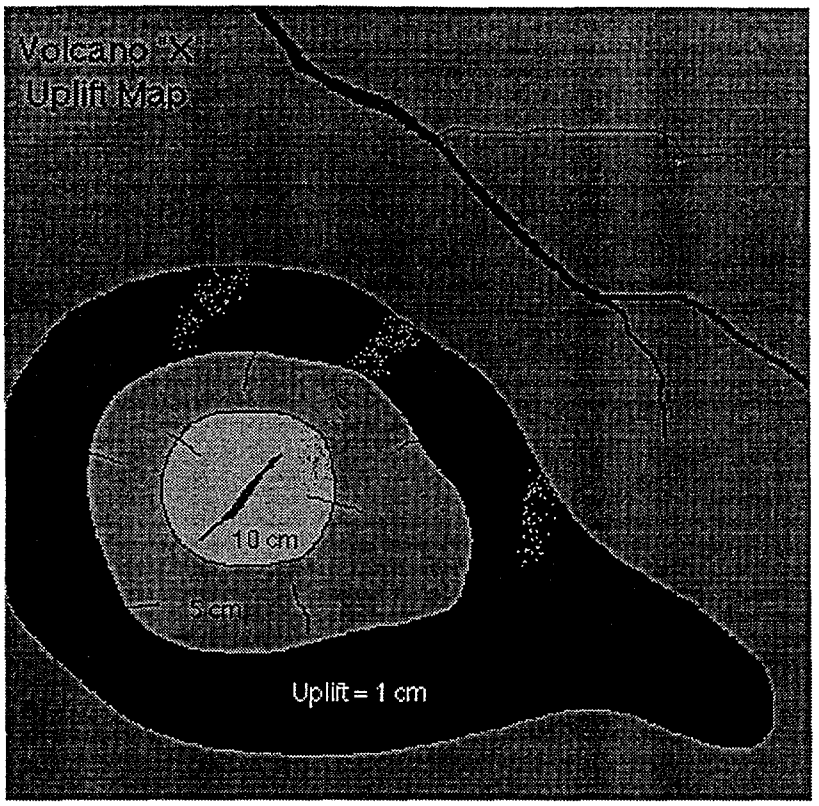
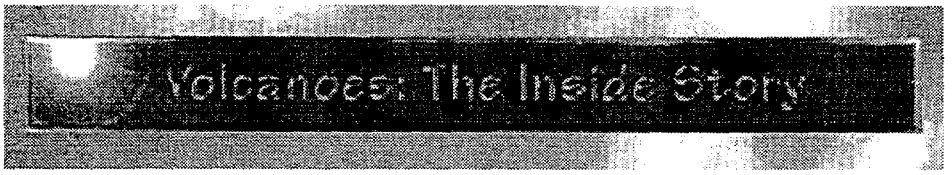

Volcano "X"
Uplift Map
10 cm
5 cm
Uplift = 1 cm

Annex F- Attachment #13

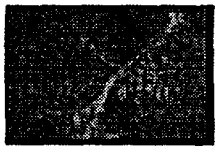
Scenarios | Problem Solving



Volcanic Hazards

Active volcanoes pose many hazards to life and property. Some, like huge lava flows and explosive blasts associated with volcanic eruptions, are spectacular headline-grabbers recognized by everyone. Other hazards, like glowing avalanches and ash falls, are much less flamboyant and little known by the general public, but can be just as deadly. A few hazards, such as rockslides and mudflows, can occur even in the absence of an eruption. Short descriptions of many volcanic hazards are given here. If you wish more information on volcanic hazards, click here.

Lava Flows are sheets and tongues of liquid rock expelled from the crown or flank of an **effusively** erupting volcano. They are probably the best known volcanic hazard. They are usually depicted in books and movies as roaring down the erupting volcano's steep slopes to inundate houses, cars, trees and expendable movie extras. Lava flows can indeed travel very fast, up to 50-60 mph, but some lava flows move very slowly, at human walking speeds or less. The speed of a flow depends on the viscosity of the lava, and how steep the slope the flow is moving down. The destructive power of lava flows lies in the high temperature of the rock, which can set structures aflame, and the size and mass of the flow, which can engulf or crush even large buildings. The destructive capabilities of a flow depend on its size, of course. Lava flows small enough for a person to step across cause little damage. On the other hand, lava flows like the **Columbia River Basalts** are large enough to literally cover entire states, totally destroying everything in their path.



The **Explosive Blast** is the "Feature Presentation" of a (surprise!) explosively erupting volcano. It is an outburst of fragments of rock and lava driven by expanding gases, which were dissolved in the erupting lava at great depths. These blasts may throw great blocks of rock many miles. More destructive is the superheated blast cloud itself, which expands out from the volcano at hundreds of miles per hour, enveloping and searing anything in its path. The destructive power of the blasts lies in the high velocity winds - exceeding wind speeds in hurricanes - within the cloud and the very high temperatures of the gas. The blasts are capable of destroying all life within many miles of the volcano within minutes. The main blast at Mount St. Helens destroyed over 230 square miles of forest in a few seconds. The destroyed area is seen to the upper right of the remains of the mountain in this Shuttle image (STS 47-73-056)

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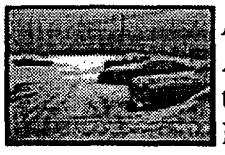
Ash Flows are dense masses of gas and tiny fragments of lava that flow down the sides of volcanoes at great speeds. Much less well known (and understood) than lava flows or explosive blasts, ash flows are sort of a combination between a blast cloud and a lava flow. They form when gas-saturated lavas come near the surface of the Earth where the pressure in the lava becomes low enough to let the dissolved gas form bubbles. If the bubbles form fast enough, the lava breaks into tiny fragments of liquid rock (called ash) that are carried out of the surface vent with the gas. If the ratio of the amount of gas to fragments is large (lots of gas), the ash is carried by the gas into blast clouds that can reach the upper atmosphere. If the ratio of gas to ash is small (lots of fragments), the ash can drag the gas downward into red-hot flows. These red-hot flows are partially controlled by gravity, and since the gas makes the friction between the ash particles very small, they can flow very far (up to hundreds of miles), very fast (over a hundred mph). The relatively small red-hot ash flows that have been seen by geologists are called "glowing avalanches" because of their similarities to snow avalanches.

Ash flows finally stop because the gas finally escapes from between the particles. Glowing avalanches usually leave thin deposits of loose fragments like sand mixed with gravel. The ash fragments are hot, however, and deposits of ash have been found which are so thick that the hot particles actually fused together to form solid masses of rock after they stopped flowing. Geologists have never actually watched the formation of such a deposit, but the amount of ash in these deposits is so large that it requires ash flows hundreds of times larger than the glowing avalanches that have been seen. The destructive power in ash flows is both the high flow speed and the high temperatures of the gas and rock. Even relatively small ash flows can be incredibly destructive: a glowing avalanche destroyed the town of St. Pierre in less than 30 seconds. The force of the flow left walls standing, but ripped off roofs and killed over 30,000 people in the town by burning and asphyxiation. Ash flows occur in explosive eruptions, and are a significant problem with eruptions in Japan and the American Cascades.

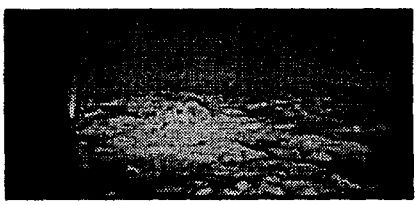


Ash Falls are less devastating than ash flows, but can be very disruptive to modern life. Ash falls are the blanketing deposits dropped downwind by the clouds of ash thrown into the atmosphere by explosive volcanoes. These deposits may be a thin dusting or a thick layer of grit. They appear grayish to whitish and look like fallen snow, but, unlike snow, ash deposits do not melt, and must be removed physically. The ash is heavy and can collapse roofs, break branches, and coat the leaves of plants. Unless the plants are cleaned (manually or by rain), they can die. This is a significant problem for farmers' crops. The ash is particularly hard on machines: some ash particles are so small they pass through engine air filters and ruin the engine. This image shows the ash layer on cars near Mount Pinatubo.

Rock/Debris avalanches are masses of cold, dry rock broken free from the sides of a volcano. They are driven downslope by gravity and destroy simply by burial and the force of their motion. A good example of a rock avalanche triggered by an eruption is the mass of rock that broke off of the north face of **Mount St. Helens** and buried the valleys to the north. However, an eruption is not needed to trigger a rock avalanche. Simple undermining of a mass of rock by slow erosion can start a rock avalanche, as can an earthquake unrelated to an eruption. Of course, such rock avalanches can occur on any steep mountain slope, but volcanoes are particularly prone to rock avalanches because: 1) their sides consist of outward-sloping

layers of solid and fragmental rock (it is easier to slide down a sloping table top than across the ends of a bunch of stacked tables), and 2) volcanic rock is easily altered by water into slippery clay which promotes failure and sliding.

Mudflows are masses of fluid mud moving downhill under the influence of gravity. Mudflows commonly start with melting of ice or snow high on a volcano's side. The melted water mixes with the (usually) abundant loose soil and ash to form a muddy liquid about as runny as wet cement. The mud follows stream and river valleys down and away form the volcano to become a fast-moving (40-50 mph) wall of mud that will carry away anything in its path. These two images show a house in the Philippines seen from about the same spot before and after a mudflow from Pinatubo. Only the pointed roof is visible in the second image. Mudflows at Mount St. Helens carried huge trucks and machinery many miles and tore bridges and houses from their foundations. They can be seen along river valleys in the Shuttle image above. A mudflow roared down a river valley on the side of Nevado del Ruiz in Columbia in 1985 and swept through a town of 25,000 people, killing nearly everyone and leaving nothing standing.



Mudflows are a particular problem on high volcanoes that have glaciers on them, such as volcanoes in the Andes Mountains in South America and the Cascades in the western United States. Mount Rainier's "cap" and drapings of ice are clearly visible in this image of its west side. Here are some of the volumes of ice found in glaciers on selected Cascade volcanoes:

Volcano	Volume of Glacier Ice
Rainier	155.8 billion cubic feet
Hood	12.2 "
Three Sisters	5.6 "
Shasta	4.7 "
St. Helens -now	1.5 "
-pre 1980	5.0 "

Compiled from S.L. Harris (1988) Fire Mountains of the West

As you might expect, the larger the amount of ice available to melt, the larger the potential mudflows. About 3.5 billion cubic feet of ice melted during the 1980 Mount St. Helens eruption. Mudflows from that eruption flowed many tens of miles down local river drainages. Mudflows around Mount Rainier, with its much larger mass of glaciers, are an ongoing problem. Some Rainier mudflows are known to have traveled 50 to 100 miles away from the mountain. Mudflows are a significant danger during eruptions, when the heat from the inside of the mountain or from falling hot ash is capable of melting large amounts of water. However, mudflows can also occur when there is no eruption. An earthquake may shake off a mass of ice that melts due to friction as it rolls down the mountain, mixing with loose material to make a mudflow. A heavy snow fall or rapid spring melt may trigger a burst of ice or water from a glacier that may form a mudflow.

Glacial Outbursts, as the name suggests, are masses of water or ice suddenly released from a glacier. Outbursts may be caused by rapid melting, an earthquake, or heat from lava moving inside a volcano. Glacial outbursts are mostly water, but they can turn into mudflows if they flow over ground with abundant

soil or gravel. Glacial outbursts and mudflows can occur on any mountain with glaciers or heavy snow pack, but since many volcanoes grow to altitudes at which glaciers form, outbursts and mudflows are frequently significant volcano-related hazards as well.

Earthquakes around volcanoes are caused by movement of lava inside the volcano. The lava literally pushes rocks aside as it moves underground. The rocks are brittle and break as they are moved, releasing seismic energy that we record as earthquakes. Most of the earthquakes are small to medium in size. They often occur in large groups in short periods of time called swarms. The swarms can keep the ground continuously shaking for long periods of time. Some earthquakes can be large, such as the 5.1-magnitude earthquake that started the May 18 eruption of Mount St. Helens which was the result of the north half of the mountain breaking free.

Tidal Waves are giant water waves that form when volcanoes erupt in or near large bodies of water. Waves can be caused by large earthquakes associated with the volcano, by movement of seafloor rocks during caldera eruptions, by giant rock avalanches, or by boiling or expulsion of water out of a hot, collapsed crater.

Poison gases are released in and around volcanoes before, during, and for many years after volcanic eruptions. The most abundant gases released by volcanoes are just water vapor and carbon dioxide, which are not directly poisonous. However, many of the less abundant volcanic gases are definitely not recommended for breathing, such as (in order of decreasing abundance): sulfur dioxide (SO_2) and sulfur trioxide (SO_3) - which are nasty enough by themselves, but also combine with the abundant water to form sulfuric acid - hydrochloric acid (HCl), carbon monoxide (CO), hydrofluoric acid (HF), boric acid (H_3BO_3), etc. These gases are released by eruptions, but also percolate up from underground masses of lava to the surface. Where the gases vent through dry rocks, fumaroles form. Where the gases vent into the lakes that often form in volcanic craters, poisonous lakes develop. One lake in Indonesia has been converted to a huge basin of concentrated sulfuric acid. Lake Nylos, a lake in a volcanic crater in Cameroon, Africa, became saturated with carbon dioxide. In 1986, a disturbance in the lake caused about a cubic kilometer of heavy CO_2 gas to bubble to the surface and flow down a nearby valley like the CO_2 mist used on monster movie sets. The gas settled over a village in a low-lying spot for a short time before dispersing, asphyxiating over 1700 villagers and all their animals.

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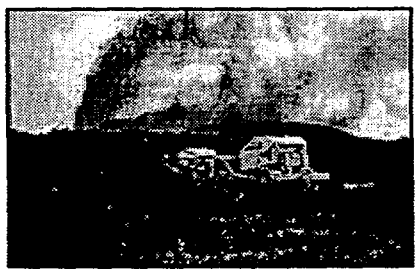
Annex F- Attachment #14

Volcanoes: The Inside Story

Dealing with Volcanic Hazards



What do you do when the volcano in your own back yard erupts? Call your family volcanologist? ("Sandbag the river bank and call me in the morning....") What if it is your responsibility to make an evaluation or to take action? First, you must gather information to determine the current situation (seismic activity, active eruption, etc.) and evaluate the potential type and magnitude of hazards associated with the current situation. Then you must choose a response to the threat. Options include (but are not restricted to):

1. Ignore. The situation may warrant no further concern.

2. Wait and watch (Literally). The situation may only need careful continuous monitoring without movement restrictions of the people.

3. Put monitoring system in place. The technology exists to put sensors in place that will detect a variety of changes in a volcano like inflation or seismic activity. A system of motion sensors high in a valley prone to mudslides can give some early warning to communities farther down the valley. (The warning time depends on the sensor's distance upstream and the speed - typically 40 to 50 mph - of the mudflow.) Many volcanoes already have some monitoring systems, but most do not.

4. Restrict access to an area. Rather than evacuate, you may choose to allow only certain types of people into the danger area, such as businessmen or employees of companies operating in the area, owners of private homes in the area, police or forest rangers, or geologists monitoring the volcano. A question here is whom to restrict and why.

5. Evacuation of an area around the volcano. The size and location of the evacuation area depends on the projected size and type of eruption. You may only need to evacuate particular valleys (as in the case of local lava flows or mudslides), or you may need to evacuate all around the volcano for many miles. Some eruptions may throw ash high enough to affect passing aircraft, in which case you may want to restrict movement in a large airspace around the volcano.

6. Brace for the "End of the World." An eruption may be so large that there are no practical responses.

7. Something else? The possibilities are limited only by your creativity.

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Remember that any action taken will have consequences. Some, like #2 and #3 cost money for equipment and/or people - money that will have to come out of somebody's pocket. Any kind of access restriction or evacuation will cost money, disrupt lives, and take time. Businesses in a restricted area like hotels or grocery stores will lose money due to loss of customers, others like lumber companies and mines will lose access to their means of production. You will have to balance the potential risk to public safety against the needs and interests of private individuals. In our society, individuals can often exert a lot of pressure on decision makers to choose courses of action that may not be in the public interest (remember **St. Pierre**). As an evaluator or decision maker, you need to be as honest and accurate in your judgments as possible, because if you are wrong, you will either cause needless disruption or economic hardship for people, or you will allow lives to be lost that could have been saved.

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Annex F- Attachment #15

Risk Analysis

This rather thorny term, "risk analysis," camouflages a seemingly esoteric subject that hits virtually every American right where it hurts most -- in the pocketbook! Risk analysis is the study of the chance of a damaging or life-threatening event happening in your life this very day. Fire! Flood! Theft! Earthquakes! Car accidents! Rabid T-Rex attacks! What are **your** chances today?

The basic ideas of risk analysis are quite simple, but the application can be quite complicated depending on the risk evaluated. But don't let that stop you! Insurance agents know all about risk analysis (that is how they decide how much you will pay for insurance), and they are just normal people like you. To give you an idea of what's involved, let's look at a simple example: auto insurance premiums. The total cost an insurance company has to cover each year for a particular type of accident is:

Total Cost = (Cost of each accident) x (# Accidents per year)

where the number of accidents per year refers to the group insured by the company. The actual number of accidents within a given group of people will, of course, change somewhat from year to year. So to get a good estimate of the average yearly cost, an insurance company will simply count the number of accidents for the group over an interval of several years and then divide the total number of accidents by the number of years. The resulting number per year is called the probability of occurrence for the particular accident. To break even, the insurance company must collect the Total Cost from the group. So your annual premium, or the cost per person in the group to cover that particular accident, is:

Premium = (Cost of each accident) x (# Accidents per year)
(# of people in group)

You premiums will actually be slightly larger (a few %) so that the company can make a small profit.

We have considered only the cost of a single type of accident, but everyone knows that there are many different kinds of accidents -- from small fender-benders costing a few hundred dollars to fix to large car-totaling crashes costing tens of thousands of dollars to fix. So a more realistic way of thinking of your premiums is to think of the total cost of accidents as a sum like: (the cost of small accidents times the number of small accidents) + (cost of large accidents times the number of large accidents) and so on. When you take a "deductible," you are saying that you will pay for any accidents you have costing less than a certain amount. Since you pay for one type of accident, the total cost to the insurance company is less, so the premium you pay them is less.

You should also realize that different kinds of accidents have different probabilities of occurrence. For instance, experience shows that small wrecks occur more often than large ones, so the probability of a large wreck is smaller than the probability of a small wreck. The number of accidents also depends on the type of people in a group. In general, high school students have more accidents per person than their parents, so the students' premiums are larger than their parents'.

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Just for comparison, here are the chances of a few types of interesting events occurring in your life this year:

Event	Chance this Year
Car Stolen	1 in 100
House catch fire	1 in 200
Die from Heart Disease	1 in 280
Die of Cancer	1 in 500
Die in Car wreck	1 in 6,000
Die by Homicide	1 in 10,000
Die of AIDS	1 in 11,000
Die of Tuberculosis	1 in 200,000
Win a state lottery	1 in 1 million
Killed by lightning	1 in 1.4 million
Killed by flood or tornado	1 in 2 million
Killed in Hurricane	1 in 6 million
Die in commercial plane crash	1 in 1 million to 10 million (Depends on airline)

Note that these numbers are national averages - they will be somewhat different depending on where you live, how old you are, whether or not you smoke or exercise, whether you like to golf during thunderstorms, and which airline you choose. On the other hand, there are some useful comparisons. For example, you are about 1,000 times more likely to be killed on the way to the airport than to die during the airplane flight. You are about 10,000 times more likely to die from any cause or to have your car stolen than to win a lottery.

Now let's apply risk analysis to natural hazards. How do you estimate the annual probability of occurrence of a particular type of natural disaster -- especially of disasters that don't happen every day? In just the same way as above: count the number of the type of event over an interval of time and divide the sum by the number of years in the interval. For example, based on geologic evidence, the 14 Cascade volcanoes have erupted 50 times in the last 4000 years. So the probability of eruption for any given volcano in the Cascades in any given year is 50/(14)(4000), or about 1 in a thousand (10^{-3}) per year. This translates into about 1 or 2 eruptions among the 14 Cascade volcanoes each century.

All of these 50 eruptions were relatively small ones -- even the 1980 eruption of Mount St. Helens! However, there is geologic evidence of eruptions over 100x larger than Mount St. Helens in the Cascades. How often do these very large eruptions occur? The data are:

Volcano	Age, yrs	Magma Volume	Caldera Size
Crater Lake, Or (Mount Mazama)	6900	~40 mi^3	5 x 6 mi
Newberry, Or	~350,000	>5-10 mi^3	4 x 5 mi
"	<500,000	>>10 mi^3	"
Long Valley, Ca	700,000	~140 mi^3	15 x 20 mi

Four eruptions in about a million years. This implies a probability of eruption of about 1 in 250,000 per year. Now, how accurate is this estimate? We must be careful because the so-called "statistics of small numbers" can be very misleading. In statistics, we are looking for typical events, not unique ones. If we looked at only the last 10,000 years, we would find only one event: the Mazama eruption. If we assumed the Mazama eruption to be typical, a simple calculation gives an annual probability of eruption of 1 in 10,000 ("Aaaaaaahhh! We're all gonna' die!"). But what if the Mazama eruption was unique? A one-shot deal? Then there would be no giant eruptions in the future, and the actual probability of eruption would be zero ("No worries, Mate!"). Which is right? Unfortunately there is no way to tell whether a single event is unique or not. The best that we can do to find out is to try to find other similar events.

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We obtained our list of four events by expanding the time period of our search to over 200 times as long as the period considered for the smaller eruptions. Four is still not a large number for statistical analysis, but it is better than one. Not only that, but one of the eruptions, Long Valley, is not even in the Cascades, only nearby. It may or may not be affected by the conditions driving large eruptions in the Cascades. Let's look at what we have. On the one hand, there have been more than one Mazama-scale eruption in the Cascades. Thus Mazama is not unique and the probability of eruption is greater than zero. On the other hand, the 1 in 10,000 probability we calculated considering Mazama as typical would predict about 100 Mazama-scale eruptions less than a million years old in the Cascades. There are actually only (at most) four. Consequently, in the absence of additional data, we can accept the 1 in 250,000 eruption probability as approximately correct, but we must also recognize the uncertainty in that number and the need to gather additional data if possible.

One more point: if we compare the probability of small Cascade eruptions with the probability of large eruptions, we find that small eruptions are much more likely than large ones. This result is consistent with much experience in dealing with many natural phenomena (earthquakes, hurricanes, tornadoes, floods, etc.): large events are much less probable than small events of the same kind. This is because the extreme conditions required to bring about extreme events are unusual in themselves and usually require enormous concentrations of energy that are difficult to achieve.

Annex F- Attachment #16

USGS/Cascades Volcano Observatory
Vancouver, Washington

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- Volcano Types

URL for CVO HomePage is: <http://vulcan.wr.usgs.gov/home.html>
URL for this page is: <http://vulcan.wr.usgs.gov/Glossary/framework.html>
If you have questions or comments please contact: <webmaster@pwavan.wr.usgs.gov>

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URL for CVO HomePage is: <http://vulcan.wr.usgs.gov/home.html>
URL for this page is: <http://vulcan.wr.usgs.gov/Glossary/LavaFlows/description_lava_tubes.html>
If you have questions or comments please contact: <webmaster@pwavan.wr.usgs.gov>

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Annex F- Attachment #17

USGS/Cascades Volcano Observatory
Vancouver, Washington

DESCRIPTION: Lava Tubes

From: R.I.Tilling, C.Heliker, and T.L.Wright, 1987, Eruptions of Hawaiian Volcanoes: Past, Present, and Future: U.S.Department of the Interior, U.S.Geological Survey Publication, p.30.

... During long-lived eruptions, **lava flows** tend to become "channeled" into a few main streams. Overflows of lava from these streams solidify quickly and plaster on to the channel walls, building natural *levees* or *ramparts* that allow the level of the lava to be raised. Lava streams that flow steadily in a confined channel for many hours to days may develop a solid crust or roof and thus change gradually into streams within **lava tubes**. Because the walls and roofs of such tubes are good thermal insulators, lava flowing through them can remain hot and fluid much longer than surface flows. Tube-fed lava can be transported for great distances from the eruption sites. For example, during the 1969-74 **Mauna Ulu** eruptions at **Kilauea**, lava flows traveled underground through a lava-tube system for more than 7 miles long to enter the ocean on five occasions.

From: M.P.Doukas, 1990, Road Guide to Volcanic Deposits of Mount St. Helens and Vicinity, Washington: U.S.Geological Survey Bulletin 1859, p.12.

... **Ape Cave** is one of numerous **lava tubes** formed in the Cave Basalt. The basalt consists of **pahoehoe flows** that originated on the southwest flank of Mount St. Helens and flowed down the surface of older pyroclastic-flow deposits. Charcoal samples from two localities under the lava tubes yielded Carbon-14 ages of 1,860+/-250 and 1,925+/-95 years (Greeley and Hyde, 1972).

From: P.T.Pringle, 1993, Roadside Geology of Mount St. Helens National Volcanic Monument and Vicinity: Washington Department of natural Resources Division of Geology and Earth Resources Information Circular 88, p.64.

Ape Cave lava tube ... is the longest lava tube (12,810 ft or 3.9 km) in the conterminous United States (similar tubes are found in Oregon, California, and Idaho) and one of the longest in the world. The cave was constructed by a **pahoehoe flow** that crusted over; soon after, the molten lava on the inside drained away, leaving the outer crust in place. Lava stalactites and stalagmites and flow marks can be seen on the walls and floor of the cave. Lava stalactites, conical or cylindrical deposits of lava that hang from the ceiling of a tube, are formed by dripping; stalagmites are similar in shape and are formed on the floor of the tube by the accumulation of drips from the ceiling. ...

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Annex F- Attachment #18

USGS/Cascades Volcano Observatory
Vancouver, Washington

DESCRIPTION:
Lava, Lava Flows, Pahoehoe, Aa

From: B.Myers and S.R.Brantley, 1995, Volcano Hazards Fact Sheet: Hazardous Phenomena at Volcanoes, USGS Open-File Report 95-231.

Lava Flows: Molten rock (magma) that pours or oozes onto the Earth's surface is called **lava**. The higher a lava's silica content, the more viscous it becomes. For example, low- silica basalt lava can form fast-moving (10-30 miles per hour), narrow lava streams or spread out in broad sheets up to several miles wide. Between 1983 and 1993, **basalt lava flows** erupted at Kilauea Volcano in Hawaii destroyed nearly 200 houses and severed the coast highway along the volcano's south flank.

In contrast, higher-silica **andesite and dacite lava flows** tend to be thick, move slowly, and travel short distances from a vent. Dacite and rhyolite lava flows often form mound-shaped features called domes.

From: B.L.Foxworthy and M.Hill, 1982, Volcanic Eruption of 1980 at Mount St. Helens: The First 100 Days, USGS Professional Paper 1249, p.122

Lava: General term for **magma** (molten rock) that has been erupted onto the surface of the Earth.

Lava flow: An outpouring of lava onto the land surface from a vent or fissure. Also, a solidified tonguelike or sheetlike body formed by outpouring lava.

From: R.I.Tilling, C.Heliker, and T.L.Wright, 1987, Eruptions of Hawaiian Volcanoes: Past, Present, and Future, p.7, p.37.

Scientists use the term **lava** for molten rock (and contained gases) that breaks through the Earth's surface, and the term **magma** for molten rock underground. ...

Lava flows form more that 99 percent of the above-sea parts of Hawaiian volcanoes. **Pahoehoe** (pronounced "pah-hoy-hoy") and **aa** (pronounced "ah-ah") are the two main types of Hawaiian lava flows, and these two Hawaiian names, introduced into the scientific literature in the late 19th century, are now used by volcanologists worldwide to describe similar lava-flow types. **Pahoehoe** is lava that in solidified form is characterized by a smooth, billowy, or ropy surface, while **aa** is lava

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that has a rough, jagged, spiny, and generally clinkery surface. ...

From: R.P. Hoblitt, C.D. Miller, and W.E. Scott, 1987, Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest, USGS Open-File Report 87-297

Lava flows: Lava flows are streams of molten rock that erupt relatively nonexplosively from a volcano and move downslope. The distance traveled by a lava flow depends on such variables as the effusion rate, fluidity of the lava, volume erupted, steepness of the slope, channel geometry, and obstructions in the flows path. Basalt flows are characterized by relatively low viscosity and may reach more than 50 km from their sources; in fact, one Icelandic basalt flow reached 150 km (Williams and McBirney, 1979). Andesite flows have higher viscosity and few extend more than 15 km; however, one andesite flow of Pleistocene age in the Cascades is 80 km long (Warren, 1941). Because of their high viscosity, dacite and rhyolite lava extrusions typically form short, thick flows or **domes.**

Lava flows cause extensive damage or total destruction by burning, crushing, or burying everything in their paths. They seldom threaten human life, however, because of their typically slow rate of movement, which may be a few meters to a few hundred meters per hour. In addition, their paths of movement generally can be predicted. However, lava flows that move onto snow or ice can cause destructive **lahars** and floods, and those that move into forests can start fires. The flanks of moving lava flows typically are unstable and collapse repeatedly, occasionally producing small explosive blasts or small **pyroclastic flows**.

Lava flows have been erupted at many vents in the Cascade Range during Holocene time; their compositions range from basalt to rhyolite. The longest known basalt, andesite, and rhyolite lava flows erupted at Cascade volcanic centers during Holocene time are, respectively, the 45-km-long Giant Crater basalt flow at **Medicine Lake volcano** the 12-km-long Schriebers Meadow andesite flow at **Mount Baker**, and the 2-km-long Rock Mesa rhyolite flow at **Three Sisters**. Lava flows of varied composition are likely to erupt again in the Cascade Range and will endanger all non-moveable objects in their paths.

From: T.L.Wright and T.C.Pierson, 1992, Living With Volcanoes, The U.S. Geological survey's Volcano Hazards Program, USGS Circular 1973, p.37

Lava flows: Streams of molten rock that either effuse quietly from a vent or are fed by lava fountains. Fluid basalt flows can move at velocities from 15 to as high as 50 kilometers per hour on steep slopes and travel up to tens of kilometers from their source. Viscous andesite flows move only a few kilometers per hour and rarely extend more than 8 kilometers from their vent. Lava flows destroy everything in their path, but most move slowly enough that people can escape. **Lava domes:** Lava (usually dacite or rhyolite) that is too sticky to flow far from its vent forms steep-sided mounds called **lava domes.**

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Annex F- Attachment #19

USGS/Cascades Volcano Observatory
Vancouver, Washington

HAZARDS: Pyroclastic Flows

From: USGS Open-File Report 87-297
Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest, by R.P. Hoblitt, C.D. Miller, and W.E. Scott

Pyroclastic flows are high-density mixtures of hot, dry rock fragments and hot gases that move away from their source vents at high speeds. They may result from the explosive eruption of molten or solid rock fragments, or both, or from the collapse of vertical eruption columns of ash and larger rock fragments. Pyroclastic flows may also result from a laterally directed explosion, or the fall of hot rock debris from a dome or thick lava flow.

Rock fragments in pyroclastic flows range widely in grain size and consist of dense rock, pumice, or both. Individual pyroclastic flows, worldwide, range in length from less than one to more than 200 km, cover areas from less than one to more than 20,000 km2, and have volumes from less than 0.001 to more than 1000 km3 (Crandell and others, 1984). Pumiceous pyroclastic flows with volumes of 1-10 km3 can reach distances of several tens of kilometers from a vent and travel downslope at speeds of 50 to more than 150 km/hr (Crandell and Mullineaux, 1978), their velocity depending largely on their volume and on the steepness of slopes over which they travel. Pyroclastic flows and their deposits commonly contain rock debris and gases with temperatures of several hundred degrees Celsius (Banks and Hoblitt, 1981; Blong, 1984, p. 36).

Most pyroclastic flows consist of two parts: a basal flow of coarse fragments that moves along the ground, and a turbulent cloud of finer particles (ash cloud) that rises above the basal flow (Crandell and Mullineaux, 1978). Ash may fall from the cloud over a wide area downwind from the basal flow.

Pyroclastic flows generally follow valleys or other depressions, but can have enough momentum to overtop hills or ridges in their paths. The larger the mass of a flow and the faster it travels, the higher it will rise onto obstacles in its path. Some pumiceous pyroclastic flows erupted during the climactic eruptions of Mount Mazama (Crater Lake) about 6850 years ago moved 231 m upslope to cross a divide 17 km from the volcano (Crandell and others, 1984) and ultimately reached a downvalley distance of 60 km from the vent (Williams, 1942; Bacon, 1983).

Pyroclastic flows are extremely hazardous because of their high speeds and temperatures. Objects and structures in their paths are generally destroyed or swept away by the impact of debris or by accompanying hurricane-force winds (Blong, 1984). Wood and other combustible materials are commonly burned by the basal flow; people and animals may also be burned or killed beyond the margins of a pyroclastic flow by inhalation of hot ash and gases.

Pyroclastic flows have been erupted repeatedly at many volcanic centers in the Cascade Range during Holocene time. Moreover, large silicic magma chambers may exist at several volcanic centers in the Cascade Range that have had explosive eruptions of large volume (101 - 102 km3). Such eruptions can

produce pyroclastic flows which could travel more than 50 km from a vent and could be extremely destructive over wide areas. Because pyroclastic flows move at such high speeds, escape from their paths is unlikely once they start to move; areas subject to pyroclastic flows must be evacuated before flows are formed.

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Annex F- Attachment #20

USGS/Cascades Volcano Observatory
Vancouver, Washington

HAZARDS: Pyroclastic Surges

From: USGS Open-File Report 87-297
Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest, by R.P. Hoblitt, C.D. Miller, and W.E. Scott

Pyroclastic surges are turbulent, low-density clouds of rock debris and air or other gases that move over the ground surface at high speeds. They typically hug the ground and depending on their density and speed, may or may not be controlled by the underlying topography. Pyroclastic surges are of two types: "hot" pyroclastic surges that consist of "dry" clouds of rock debris and gases that have temperatures appreciably above 100 degrees C, and "cold" pyroclastic surges, also called base surges, that consist of rock debris and steam or water at or below a temperature of 100 degrees C (Crandell and others, 1984).

Both hot and cold pyroclastic surges damage or destroy structures and vegetation by impact of rock fragments moving at high speeds and may bury the ground surface with a layer of ash and coarser debris tens of centimeters or more thick (Crandell and others, 1984). Because of their high temperatures, hot pyroclastic surges may start fires and kill or burn people and animals. Both types of surges can extend as far as 10 km from their source vents and devastate life and property within their paths. During an eruption of Mont Pelee on Martinique in 1902, a cloud of hot ash and gases swept into the town of St. Pierre at an estimated speed of 160 km/hr or more (Macdonald, 1972). About 30,000 people died within minutes, most from inhalation of hot ash and gases. Pyroclastic surges have occurred at volcanoes in the Cascade Range in the past and can be expected to occur again. Future cold surges (base surges) are most likely to occur where magma can contact water at volcanic vents near lakes, those that have crater lakes, and at vents in areas with a shallow water table.

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Annex F- Attachment #21

EOS Volcanology Educational Outreach

Links to Other Volcano K-12 Educational Sites: Lessons and Activities

Educational and Outreach Panel for the EOS Science Executive Council

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Educational Outreach Slide Sets:

- #1: Surface and atmospheric effects of the 1991 eruption of Mt. Pinatubo
- #2: Volcano Topography
- #3: Volcanoes and Volcanic Hazards
- #4: Peter Francis Slide Set: Volcanoes, Lavas and Related Features, Pyroclastic Eruptions and Products, and Hydrovolcanic Eruptions

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This page is maintained by Joy Crisp (joy@glassy.jpl.nasa.gov)

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A slide set compiled by Peter Francis from the book:

Volcanoes: A Planetary Perspective

(1993) Peter Francis, Oxford University Press, Oxford, UK, 443 pp.

This selection of slides was compiled in reponse to requests for illustrative material arising from my Oxford University Press book. I hope it will be of some help in teaching volcanology. Inevitably, it was difficult to choose 40 slides to cover the whole field of volcanology, and there are many subjects not covered at all. In making the selection, I chose slides that were:

1. Reasonably good pictures in themselves.
2. Good illustrations of some volcano or point of volcanology.
3. Not already too widely familiar.
4. Suitable for use in class teaching.
5. Covering a wide range of subjects.

I have indicated in parentheses the relevant parts of the book text in which the material is described (e.g., Section 7.4) and also the same or similar figures (e.g., *Fig. 9.17*). In some cases, these are not identical, because I have replaced original black and white prints with color slides.

I hope that you find the slide set useful, and would of course welcome any comments you may have on the slides themselves or the explanatory captions. Please write to me at: Peter Francis, Earth Sciences, Open University, Milton Keynes MK7 6AA, England, or send email to: P.W.Francis@open.ac.uk

35 mm Color Slide Set Available for Purchase from Peter Francis: Ordering Information

Note: The copyright for these slides remains vested with Peter Francis, not Oxford University Press.

- Part I: Volcanoes (10 slides shown below)
- Part II: Lavas and Related Features (7 slides)
- Part III: Pyroclastic Eruptions and Products (13 slides)
- Part IV: Hydrovolcanic Eruptions (10 slides)

Part I: Volcanoes

SLIDE #1 (133K): Mauna Loa, Hawaii, photographed from Kilauea caldera

This 4169 m high basaltic shield volcano is the Earth's largest volcanic construct, rising some 9000 m above the Pacific ocean floor. It has a volume of about 40,000 cubic kilometers, the result of the accumulation of innumerable flows of low-viscosity basalt lava. Only about 17% of this volume is above sea-level. Submarine eruptions probably commenced 1-2 million years ago, and eruptions above sea level about 400,000 years ago. The extremely gentle slopes seen in the photograph result from the fact that Mauna Loa is an elongate volcano, extended along south-west and east rifts, from which most lavas are erupted. The profile across the rift zones (towards the camera) is somewhat steeper, but still does not exceed 10 degrees in the middle slopes. At the summit of Mauna Loa is the 2.6 x 4.5 km Mokuaweoweo caldera. Mauna Loa last erupted in 1984. *(Fig. 2.26; 6.4; 6.5; 14.27(c)).*

SLIDE #2 (140K): Nevado Ojos del Salado, Chile / Argentina frontier

At 6885 m, this is the world's highest active volcano, although the edifice itself is not large -- its basement is at about 4500 m, roughly the level of the camera. Nevado Ojos del Salado is a compound or multiple volcano, consisting of a massif covering some 70 square kilometers formed of at least a dozen andesitic and dacitic cones intermingled with lava domes and craters. The volcano has never been studied in detail. It has not erupted in historic times, though it exhibits continuing fumarolic acitivity. White material in gullies is snow; the greyer material is pumice from a large but undated plinian eruption. *(Fig. 2.4).*

SLIDE #3 (135K): San Pedro, North Chile

This 6150 m high andesite-dacite composite volcano is an exceptionally well-exposed example of numerous similar volcanic constructs around the circum-Pacific "Ring of Fire." It is a large volcano, rising from a base at just over 3000 m. It consists of two essentially different units. At left, the reddish brown, snow-covered peak forms part of the "Old Cone," constructed mostly of basaltic andesite lavas, thin flows of which can be seen near the summit. At some unknown time, this cone failed, producing a massive dé•bris avalanche deposit, not seen in the photo. Subsequently, a large dome of hornblende dacite lavas accumulated, forming the greyish massif on the right side. This dome became very steep, and many flow fronts of the lavas failed, yielding the visible scars, and forming an apron of hot avalanche debris, the upper parts of which are visible (pink toned) immediately below the lava scarps. Fumarolic activity continues to the present day on the summit of the dome. The foreground and middle distance is mantled with a plinian pumice fall deposit, creating a very smooth surface. *(Fig. 12.4-12.6).*

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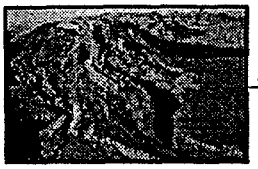


SLIDE #4 (149K): Láscar, Chile

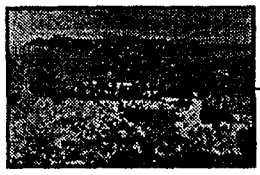
Volcan Láscar 5,641 m, is the most active volcano in the central Andes. Since 1988 a silicic lava dome has been growing in the summit crater, and there have been several recent eruptions, notably on April 19 and 20, 1993, when pyroclastic flows were erupted on both southern and northern flanks, and ash fell out as far distant as Buenos Aires, Argentina. The volcano consists of elongate series of six overlapping craters, trending roughly northeast, with the active, fuming crater located near the center of this cluster. It is about 800 m in diameter and 300 m deep. Grey pumice deposits from the 1993 eruption are visible in this photo, and the margins of some pyroclastic flows can be seen at right center. Most impressive, however, are the older, massive andesitic lava flows, exhibiting flow margins tens of meters high, well developed flow levé•es and transverse ogive ridges. (Section 7.4, *Fig. 9.17; 9.18*).

SLIDE #5 (88K): Agua, Guatemala

Seen in profile at sunset, this photo illustrates the classical symmetrical cone that defines the 'ideal' volcano. Such cones result from the interplay of eruption and erosional processes, and rely on eruption of small lavas and tephra from a single summit crater and rapid radial transport of talus to maintain their radial symmetry. Agua is 3752 m high, with a summit crater 200 m in diameter. Its symmetrical profile is echoed by the two volcanoes in the background, Fuego (left; 3700 m) and Acatenango (right; 3960 m). (Section 16.2).

SLIDE #6 (130K): Mt. Pelée, Martinique, Caribbean

This notorious volcano looms above the town of St. Pierre (middle distance) exactly as it did prior to its catastrophic eruption of May 8, 1902, when the town was destroyed and more than 20,000 inhabitants were killed. In French, the word *pelé•* means bald. This implies that when Mt. Pelée;e acquired its name, its summit was an unvegetated dacitic lava dome, just as it is today. The visible lava dome was constructed during the volcano's most recent eruptive episode (1929-1930) but a closely similar edifice was built during the 1902 eruption, to be later destroyed. St. Pierre was destroyed by *nuée•es ardentes* (glowing avalanches) which detached from the growing lava dome and crashed under gravity down the flanks of the volcano. For the most part, these avalanches were topographically controlled by preexisting valleys, such as that of the Rivière Blanche (extreme left) but some were big enough to engulf St. Pierre on their margins. *(Fig. 4.18).*

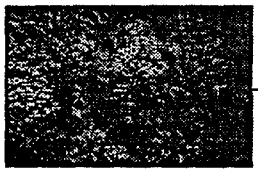


SLIDE #7 (147K): Vulcano, Vulcanello and Lipari (Mediterranean)

Vulcano, eponym of all volcanoes, has been intermittently active throughout historical times, and took its name from the Roman god of fire, Vulcan. Active fumaroles and deposits of yellow sulphur on the rim of the crater formed during the 1888 eruption provide a foreground for a tourist resort and harbor. They illustrate the risk developers are prepared to take in areas of *obvious* volcanic risk. In the middle distance is the small cone and lava shield of Vulcanello. This was originally a separate island, and the Vulcano-Vulcanello pair said to be the "Scylla and Charybdis" of Homer. Vulcanello was united to Vulcano by an eruption in the 16th century. In the background is the island of Lipari, also volcanic, but with no historic activity. *(Fig. 6.12).*

SLIDE #8 (125K): Wizard Island and Crater Lake, Oregon, USA

Crater Lake's serenity belies a violent origin. Its blue waters fill a caldera nine kilometers in diameter, whose floor is 600 meters below the lake level, while the encompassing walls rise steeply 600 meters above it. Howel Williams, a distinguished American volcanologist of Welsh extraction, concluded in a classic study that the present caldera occupies the site of an older volcanic cone, about 3600 meters high, called Mt. Mazama. 6,800 years ago, a huge plinian eruption destroyed the original volcano, formed the present caldera and showered tephra as far as Alberta in Canada. After the plinian phase, a series of ignimbrites was erupted, filling the valleys radiating from the old cone. Wizard Island, a small volcanic cone constructed after the eruption, now occupies one corner of the lake. *(Fig. 10.11; 14.4).*



SLIDE #9 (201K): Cerro Galan caldera, northwest Argentina

Landsat Thematic Mapper false color composite image. An elliptical structure 35 x 25 km in diameter, Cerro Galan is the world's best exposed example of a resurgent caldera. It was formed about 2.2 million years ago by the eruption of the Cerro Galan ignimbrite, which has a minimum volume of 1 million cubic kilometers. Unwelded ignimbrites are exposed on western and eastern flanks of the caldera as deeply gullied, yellow and grey weathering units; welded ignimbrites form the resurgent center of the caldera (dark greys and browns). The west rim of the caldera reaches 5200 m; its floor is at 4500 m and the summit of the resurgent center at 6000 m. An older andesite volcano (Cerro Colorado) is visible in the bottom left hand corner, mantled by ignimbrites. The caldera was occupied by a lake after it formation. Laguna Diamante (blue, south west corner of caldera) is a salty relic of a much larger body of water. *(Fig. 14.13).*

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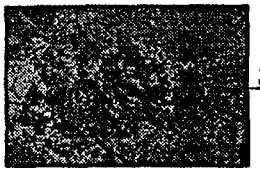

SLIDE #10 (199K): Cerro Panizos, southwest Bolivia

First recognized as an unusual volcanic construct on spacecraft images, Cerro Panizos straddles the frontier between Bolivia and Argentina. Preliminary age dates indicate that Panizos is largely Late Miocene in age with no Holocene activity. Panizos is a roughly circular feature about 40 km in diameter with an average elevation of about 4700 m. It is a radially symmetrical shield of ignimbrites more than 300 m thick with a central complex of dacitic coulé•es and lava domes reaching up to 5,400 m in elevation. Three ignimbrites closely spaced in time have a total volume exceeding 500 km3 . The later flows and domes were erupted in the ignimbrite vent area. Because the whole structure has radial dips of about 3 degrees from the center of the complex, Panizos was initially though to be an ignimbrite shield which had undergone little syn- or post eruptive collapse. However, later work showed the rocks in the center of the shield had subsided (down-sagged), with local inward dips of up to 6 degrees, and that the ignimbrite center had several vents. Panizos may be either a collapse caldera, filled by late-stage ignimbrites and post caldera collapse lavas, or a nested caldera. (Section 14.3.1).

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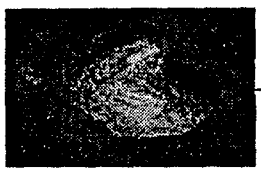
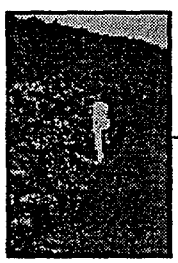
Part II: Lavas and Related Features



SLIDE #11 (168K): Kupaianaha lava pond, Hawaii, July 1988

Lakes or ponds of basaltic lava which may persist for months or years are intriguing aspects of basaltic volcanism. Persistent lava lakes may be established within a preexisting crater if sustained by convective circulation with a deeper reservoir. This situation persisted within the Halemaumau crater during much of the 19th century. The 100 m diameter Kupaianaha lava pond, seen here, represents a different situation, where lava supplied at a steady rate of about 5 cubic meters per second from the nearby Pu'u O'o vent ponded on an area of flat topography, to form a constantly replenished 'holding tank,' which was constantly drained by a series of lava tubes which debouched on the Pacific coast 12 km distant. Only a small amount of gas can be seen; most was vented from Pu'u O'o. The shifting patches of chilled, plastic crust and glowing incandescent lava provide instructive analogs of lithospheric plate motions. *(Fig. 6.9).*



SLIDE #12 (194K): A'a and pahoehoe flows, Hawaii

Chemically similar basaltic lavas may exhibit grossly different surface characteristics under different physical conditions, notably rate of flow. Pahoehoe flows (left) have grey glassy, shiny surfaces which are generally smooth when fresh, and form curious plastic patterns of ropes and whorls with dimensions of a few centimeters to a few meters. Individual flow lobes are rarely more than a meter thick, and are typically 10-20 cm. They form at low rates of flow. At higher rates of flow, internal shearing shreds the lava, and highly irregular, angular scoriaceous fragments result forming a'a flows (reddish colored, right side). Individual fragments may range up to a meter or more in size, though those seen here are 10-20 cm in diameter. Both lavas seen here were erupted within a short time of each other during the 1969-74 eruption of Mauna Ulu, Hawaii. *(Fig. 7.9).*

SLIDE #13 (174K): Lava tree mold, Hawaii

Many of the lavas erupted from Hawaiian volcanoes flowed into dense rain forest consisting mostly of *ohia* trees. After rapidly engulfing the trunk of this tree, pahoehoe lava set it on fire, incinerating the wood, while itself chilling solid around the outside. Soon after, the bulk of the flow drained away again, leaving a tall pipe-like 'chimney' of chilled basalt 1.5 m high marking the site where the tree once grew. An imprint

of the pattern of the bark can often be seen on the inner wall of the mold. 'Lava tree forests' are known in many other parts of the world. *(Fig. 7.18).*

SLIDE #14 (146K): Trachytic lava flow field, El Teide, Tenerife

A 'lava flow' is not necessarily a single entity. The term *flow field* describes the tangle of flows from a single eruptive episode, as seen here beneath the steep summit of 3700 m high El Teide volcano. A flow that cools rapidly relative to its flow rate will sprout many offshoots. As a result, long durations of flow at slow effusion rates generate flow fields that have large width to length ratios, composed of many branches; at higher flow rates, flows move rapidly from their sources to form relatively long, simple flows, such as that extending to the lower right corner of the photo. These flows also exhibit well developed levées, and have coarse aa surface textures. *(Fig.7.7).*

SLIDE #15 (165K): Advancing aa flow, Mt. Etna

Although fast flowing in their upper reaches, the distal snouts of aa flows often advance slowly, like shuffling slag heaps. This 1971 Etna lava illustrates the height of the flow front (5-7 meters) and its coarse rubbly surface, with blocks over a meter in diameter. These conceal and insulate the hot core of the flow, which can just be glimpsed glowing red-hot in one or two places, for example in the crevice between the lady in a red poncho and her companion in a brown jacket. When photographed, the flow was creeping forward at a few meters an hour. Flows from this eruption ruined the skiing on Etna, which had previously boasted many smooth ash-covered slopes (left and foreground). Some black mud flows triggered by the eruption can be seen in the middle distance at left of the flow. *(Fig. 6.18, 7.10).*

SLIDE #16 (120K): Chao lava coulée, north Chile

Coulées are a cross between lava domes and lava flows: they are thick extrusions erupted on slopes steep enough for shear stresses to exceed the yield strength, thus permitting the flow to ooze down slope. One of the world's best known examples of a coulée, and the largest of its type in the world, is the Chao dacite occupying the saddle between Paniri and Léon volcanoes. 39Ar-40Ar ages indicate it is less than 100,000 years old. It is a 14.5 km long coulée, with flow fronts 350-400 m high and has a total erupted volume of about 26 km3. A characteristic feature of this body are the prominent 30 m high flow ridges or ogives on its surface, resulting from folding during emplacement of surface layers with different mechanical properties due to differential cooling of the lava. Eruption of the huge coulée appears to have occurred in three main stages. Chao is so young that its internal structure is not exposed, but in older, dissected examples, coulées display *ramp structure*, formed as successive increments of lava are extruded from the vent and squeeze earlier erupted increments outwards. Most of the outward movement of the flow is

accommodated in a thin zone of shearing at the base. *(Fig. 7.25).*

SLIDE #17 (151K): Showa Sin-Zan plug dome, Japan

Upheaved plug domes are masses of rock that are pushed bodily upwards like pistons. "Showa Sin-Zan " or "New Roof Mountain" grew during the height of the Second World War, so there were no official records of its growth, but the astute village postmaster, Masao Mimatsu, kept a unique pictorial record of its progress by drawing a series of profiles on the paper covering of his window. From January 1944 until November 1944 the uplifted area rose steadily, but no new rock was visible -- the uplifted material was all crater lake sediments, baked hard by the heat of the lava beneath, carried upwards as smoothly as if on an elevator. In November of 1944, a plug of lava eventually punched its way through the elevated dome, rising until it was about 100 m above the top of the dome, and nearly 300 m above ground level. It is this extrusive crown which dominates the photo. *(Fig. 7.28).*

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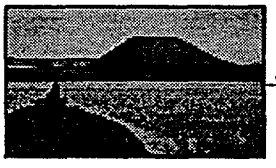
Part III: Pyroclastic Eruptions and Products

SLIDE #18 (111K): Strombolian eruption, Pacaya, Guatemala

Strombolian explosions are short blasts, separated by periods of less than a tenth of a second to several hours. Each burp probably represents the bursting of a rising bubble of gas within the magma column as it approaches the surface. The fragmented clasts propelled upwards are probably globs of the magma which formed the skin of the exploding bubble. Strombolian eruptions involve release of much larger proportions of gas to magma than other types of activity; in some cases, the magmatic material may not escape from the vent at all, and is recycled. They are usually photographed at night and are most familiar as time-exposures in which individual glowing clasts trace elegant incandescent parabolas. This daytime 1/60-second shot captures the first instants of an explosion, in which the ejected material still forms a discrete slug. Large blocks can be silhouetted against the sky on the right, and some blocks are visibly glowing against the dark central part of the column. Pacaya has been intermittently active throughout recorded history. *(Fig. 6.10).*



SLIDE #19 (131K): La Poruña monogenetic scoria cone, north Chile

A monogenetic volcano is the product of a single eruptive episode lasting a few hours, or a few years. Basaltic scoria cones are good examples of monogenetic volcanoes and are found in thousands all around the world. They all have the same distinctive morphology. They are rarely more than two or three hundred meters high, and are often asymmetrical; either elongated along a fissure, or else higher on the side that was downwind at the time of eruption. A distinctive feature is their simple geometric profile, defined by the angle of rest for loose scoria: *all* young scoria cones have side slopes close to 33 degrees. Their craters are large in relation to the size of the edifice as a whole (compare Agua in Slide 5--Part I). Naturally, their crisp profiles soften with age, but the ratio of crater width to basal width changes remarkably little. Thus, scoria cones remain easily recognizable, even after millennia of weathering. La Poruña in the Atacama desert of Chile is 300 m high and appears pristine, but because of the hyperarid environment it may be several thousand years old. A train on the Antofagasta-La Paz railroad (in the shadow near the cone) provides scale. *(Figs. 7.8; 16.1).*

SLIDE #20 (162K): Strombolian scoria fall deposit, Bandera, New Mexico

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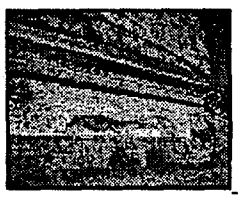
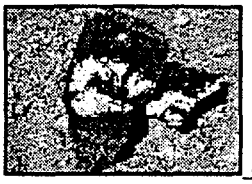
Basaltic *scoria* is the typical product of strombolian activity. Cindery in appearance, scoria fragments have a light, frothy texture. Individual clasts are sharp-edged and angular. Normally, basaltic scoria is a greyish-black colour, but when fresh it may be stunningly iridescent, shining in peacock blue colours. Because the lava is easily fragmented by escaping gas, only a small proportion of the finest grained material is produced, so a typical scoria deposit is not dusty. Most fragments here near the Bandera cone in New Mexico are 1-3 cm in diameter. About 0.01 cubic kilometers of magma was erupted, and the eruption column probably did not reach more than a few hundred meters above the vent. Thus the deposit thins rapidly away from the vent. Because basaltic scoria is used extensively for road making, scoria cones are often quarried, displaying their internal structures, as here at Bandera. Within the cone itself, there is often well-developed layering, resulting from separate explosive pulses, but here, a little way downwind, the deposit forms a very even blanket. Note how the loose material piles up at the bottom of the quarry face, forming slopes with the same angle of rest as those of the main cone. (Section 9.4).


SLIDE #21 (179K): Plinian pumice fall deposit, Arequipa, Peru

Superficially similar to the scoria fall deposit in Slide 20, this 2 m thick plinian deposit also consists of well sorted clasts 1-3 cm in diameter. These are of rhyodacitic composition. Unlike the scoria fall deposit which is of limited areal extent, this plinian deposit mantles an area of many hundreds of square kilometers and was erupted from a much higher eruption column, possibly reaching an altitude of 30 km. The pumice layer shows slight evidence of internal layering or shower bedding. It is overlain by several other fall units of different composition, which were apparently erupted without a major erosional interval. It is not known when the plinian deposit was erupted. *(Fig. 9.22).*

SLIDE #22 (192K): Breadcrust block, Socompa, north Chile

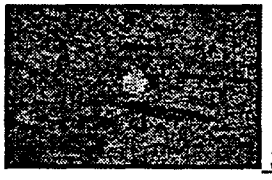
Bread-crust blocks are rounded or angular lumps with a smooth, glassy crust broken by deep cracks and fissures, exposing the frothy, vesicular core of the bomb, and reminiscent of a well-baked, crusty loaf of bread. Bread-crust blocks are formed when lumps of viscous, gas-rich lava are ejected from the vent: the outer crust chills quickly to form the glassy crust, but the interior remains hot, and continues to vesiculate, frothing up the interior. As in a decently baked loaf, the internal expansion causes the brittle outer crust to crack. This block was found in the Socompa debris avalanche deposit. It shows that hot magma was present within the volcano when the catastrophic flank failure took place, since the vesiculated brittle block would have broken up during transport. Similar blocks are often found as ejected bombs in vulcanian pyroclastic deposits. *(Fig. 9.20).*


SLIDE #23 (198K): Mixed pumice clast, Láscar, north Chile

Some explosive eruptions may be triggered by the introduction of fresh, hot basaltic magma into a preexisting magma chamber. There is subtle evidence for magma mixing in many eruptions, but it is rarely as black-and-white as in this clast from an undated pyroclastic flow from Láscar. The darker component is andesitic; the lighter dacitic. In this example, identical isotopic characteristics of the two components suggest that they fractionated from the same source. (Section 14.4). Lascar is also featured in Slide #4--Part I.

SLIDE #24 (157K): Major ignimbrites, Rio Loa, North Chile

Individual ignimbrites may have volumes in excess of 1,000 cubic kilometers and travel for distances in excess of 100 km from their source. They form important parts of the landscape in many parts of the world, and are particularly well exposed over huge areas of the Central Andes. Two massive ignimbrites, each tens of meters thick, separated by a terrace, can be seen in this view of the canyon of the Rio Loa. As the photo suggests, they can be readily traced for tens of kilometers along the canyon. The pinkish weathering dacitic ignimbrites are an unwelded variety known by the Peruvian term *sillar*, the original pumices have undergone vapor phase alteration forming a light, strong homogenous rock much used for building stone. The lowermost unit is the 8.1 Ma old Sifon ignimbrite, which travelled at least 150 km from its source caldera, Pastos Grandes in Bolivia. (Chapter 10).


SLIDE #25 (225K): Fiamme in welded ignimbrite, Aso, Japan

The most densely welded ignimbrites are glassy rocks hard to distinguish from lavas. More commonly, it is only the pumice clasts that are conspicuously glassy: they are squashed into black, glassy flattened pancakes. These, seen in cross section, resemble candle flames, and are known by their Italian name of *fiamme*. Similar textures can be seen on a microscopic scale, with tiny glass shards flattened and molded over one another. Extreme degrees of flattening can be produced by squashing of shards at the base of thick ignimbrites, whereas higher up, where pressure is less, the flattening is proportionally less. Before ignimbrites were properly understood, eutaxitic texture was the main diagnostic criterion used to identify them. Most ignimbrites, however, look more like Slide 26 than 25. Eutaxitic texture is still a valuable criterion for identifying ancient ignimbrites. *(Fig. 10.32).*

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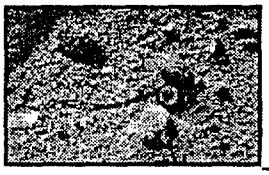
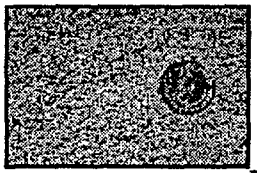

SLIDE #26 (226K): Unwelded ignimbrite, Cerro Galan, Argentina

This slide illustrates the texture of a typical large volume ignimbrite. It consists of fist-sized dacitic pumice clasts and small sparse lithics in a crumbly, finer grained matrix. Such rocks are very rapidly eroded, and are thus not well preserved or exposed in temperate regions. This example is from the 4.6 million year old Real Grande ignimbrite which has a volume of the order of 500 cubic kilometers. Landsat image of Cerro Galan volcano is shown in Slide 9--Part I. *(Figure 10.22).*

SLIDE #27 (176K): Compositional zonation in ignimbrite, Crater Lake, Oregon

The ignimbrite erupted during the formation of Crater Lake caldera 6,800 years ago (Slide 8--Part I) shows magnificent compositional zonation. The lowermost (pale) component exposed here is rhyodacitic in composition (70-72% SiO2); the uppermost (dark) component is andesitic (56-62% SiO2). Tapping of a compositionally zoned magma chamber with more evolved dacitic magma at the top yielded zoned deposits, showing mirror-image relationships: the first-erupted rhyodacites are at the bottom. There are no obvious breaks in the sequence: the mechanisms of transport and emplacement of ignimbrites that can yield these relationships remain poorly understood. Note the splendid pillars, evidence of rapid erosion. *(Fig. 10.11).*


SLIDE #28 (220K): Homogeneous ignimbrite, Cerro Galan, Argentina

Not all ignimbrites possess easily recognizable pumice and lithic clasts, nor do they show compositional zonation. The 2.2 million year old Cerro Galan dacitic ignimbrite is an excellent example of a very large ignimbrite (at least 1,000 cubic kilometers) which is remarkably homogeneous throughout, and is also pumice and lithic poor. This slide shows a typical close-up view, in which the abundance of crystals is evident. Black biotite is conspicuous, but quartz and plagioclase are also evident. Fragmentation of fragile dacite pumice and crystal concentration probably took place during emplacement. Landsat image of Cerro Galan volcano is shown in Slide 9--Part I. (Chapter 10 and Section 14.2.2; *Fig. 14.17*).

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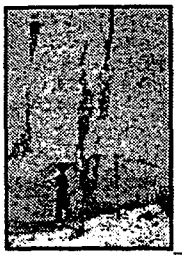
SLIDE #29 (184K): Fluidization pipes in ignimbrite, Cerro Galan, Argentina

Convincing evidence for the important role of gas fluidization in the mobility of ignimbrites is provided by segregation structures which form as escaping gases cause clasts of different sizes and densities to jostle apart from one another, to provide direct routes for the gas through the body of the material. These lithic-filled pipes rise many meters through the 4.6 million year old Real Grande ignimbrite. The largest clasts within the pipes reach 20 cm in diameter, most of the finer material in the pipes has been blown away or *elutriated.* Landsat image of Cerro Galan volcano is shown in Slide 9--Part I. *(Fig.10.8).*

SLIDE #30 (169K): Mudflow, Chigliapichina volcano, north Chile

Mud flows are amongst the most dangerous of volcanic phenomena. They took the lives of 25,000 inhabitants of the town of Armero, Colombia, during the 1985 eruption of Nevado del Ruiz. Some mud flows are caused by the breaching of crater lakes (Kelut 1966); others by melting of snow and ice by an eruption (Nevado del Ruiz 1985) and still others by rain falling on fresh, unconsolidated ash (Pinatubo 1991). This miniature Chilean example illustrates many of the main features. It formed after a rare rainstorm in 1969. Broad levées 30 cm high and a sinuous central channel are well displayed. After emplacement, the mud set hard. *(Fig. 13.18).*

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Return to Part II: Lavas and Related Features

Continue to Part IV: Hydrovolcanic Eruptions

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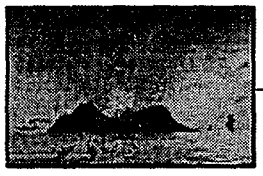
Part IV: Hydrovolcanic Eruptions

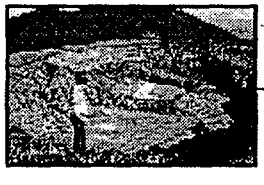


SLIDE #31 (119K): The 1831 eruption of Graham island, Mediterranean

This rare gouache painting illustrates the eruption which formed Graham island 50 km north of Pantelleria in 1831. Submarine eruptions generally commence with an exposive hydrovolcanic phase of activity, termed *surtseyan* after the eruption off Iceland in 1963. Strombolian activity is indicated in this painting, suggesting that the vent had become insulated from sea water. Because of its strategic importance, the new island was immediately claimed by Britain, Spain and Italy and many names were proposed -- Graham Island, Ferdinanda, Hotham, Corrao, Sciacca, Giulia and Nerita. Sadly the island rapidly succumbed to erosion by waves. By the end of October 1831, it had almost gone. By early in 1832 it had disappeared altogether. This caused Charles Lyell to comment in his great geology textbook: "as the island was visible for only about three months, this is an instance of wanton multiplicity of synonyms which has scarcely ever been outdone, even in the annals of zoology and biology." *(Fig. 6.14).*

SLIDE #32 (159K): Diamond Head Crater, Honolulu, Hawaii

Diamond Head is a fine example of a *tuff ring*, formed by hydrovolcanic explosive activity about 40,000 years ago. It is about 1 km in diameter and its rim is mostly about 100 m high. On its southwestern extremity, however (away from the camera) it reaches 232 m. This marked asymmetry was the result of northeast trade winds blowing during the eruption, as they do for much of the year at the present day. The crater currently houses the Honolulu headquarters of the FAA (Federal Aviation Administration). *(Fig. 16.5).*



SLIDE #33 (172K): Acid crater lake, Poas, Costa Rica

Poas has contained a hot, acid crater lake for much of its recent history. The lake water typically has a temperature of 40-50 degrees C, and a pH approaching 1. It is quite shallow, and sometimes disappears to reveal a witches' cauldron of bubbling mud and molten sulphur. Minor eruptions through the lake are quite common, showering the surrounding forest with acid rain. An extensive and extremely complex hydrothermal system is present -- most of the pale colored rocks in the crater wall are extensively altered. Because the lake water buffers the temperature of the system, fumarolic sulphur deposits accumulate, rather than being sublimated as they would in dry conditions *(Fig. 6.15, 6.16).*

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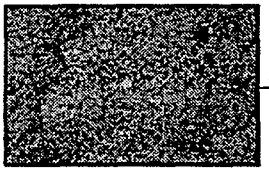
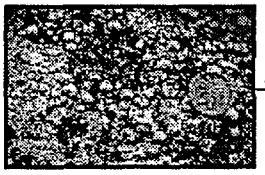


SLIDE #34 (228K): Surtseyan tuff, Tenerife, Canary Islands

The hydrovolcanic eruptions that result from the interactions between basaltic magmas and water produce pyroclastic rocks with distinctive characteristics seen in this photograph showing a close-up of rocks exposed in the walls of a typical tuff ring on the island of Tenerife. Fuel-coolant like explosive fragmentation of the magma produces a high proportion of very fine grained, glassy material, which rapidly alters in the warm, wet environment to form the yellowish palagonitic tuff making up the most of the matrix of the rock. Ill-defined layers of angular fragments of fresh grey basalt lava are also present. Each layer was probably the product of an individual explosive blast. (Section 9.9.1).



SLIDE #35 (207K): 400 million year old accretionary lapilli, England

Accretionary lapilli, also termed *pisolites*, are small spheres of extremely fine ash, which may reach more than centimeter in diameter. They are commonly found in tephra deposits formed by eruptions where water has been involved -- hydrovolcanic or phreatomagmatic eruptions. Often, they consist of an outermost shell of harder ash surrounding a more friable core; sometimes they have a concentric, onion-like structure. Although it is clear that accretionary lapilli are associated with 'wet' eruptions, it is not clear exactly how they form. It used to be thought that they resulted from raindrops flushing through dense tephra clouds, fine ash accreting around rain drops. While this is one possible mechanism, it is clear that there are others, since lapilli are found in a range of deposits, not only air-falls. They are common, for example in base surge and other pyroclastic flow deposits. These examples are in the 400 million year old (Ordovician) Borrowdale Volcanic Series of the English Lake district, and illustrate how well subtle volcanic features can be preserved in ancient rocks. *(Fig. 9.31).*

SLIDE #36 (110K): Mount St. Helens, USA June 1980

This aerial view of Mount St. Helens immediately after its eruption of May 18, 1980 illustrates the great horseshoe shaped amphitheatre that resulted from the massive avalanche of the north flank that initiated the eruption. Originally, the cone was 2949 m high; after the eruption the highest point on the rim of the amphitheatre was 2560 m, while its floor was at 1800 m. Most of the missing material ended up in the 2.8 cubic kilometer debris avalanche deposit which entered the valley of the Toutle river, but some was reamed away by the violent plinian eruption that ensued. Since 1980, an extrusive dacite lava dome grew within the amphitheatre, but was inactive at the time of writing. (Section 4.4 and *Fig. 4.27*).

SLIDE #37 (181K): Mount St. Helens blast zone

Millions of trees, many of them full-grown Douglas firs, were flattened by blast over an area of nearly 600 square kilometers. Most were simply uprooted and stripped as bare as telegraph poles. Some, partially sheltered behind ridges, were snapped like match sticks. Initially, the blast had a velocity of 90 - 100 meters per second. It probably accelerated to supersonic velocities (greater than 300 meters per second) as it expanded in the vent area. Since it was travelling so much faster than the avalanche, the blast overtook the avalanche before the latter had travelled more than a kilometer or two. Since wind speeds of as little as 20 meters per second (80 kilometers per hour) can blow trees down, it is scarcely surprising that the blast levelled the forest so comprehensively. Note how the trees in the photo are pointing radially away from the volcano. They were all stripped of their foliage, so that only bare trunks remain. Note also how little volcanic material was deposited. The blast was a rapidly moving, low density cloud of dust and gas, from which denser material sedimented to form a deposit a few centimeters thick; at the margin of the blast zone, it density became low enough that it lofted away from the ground. (Section 4.4.2).

SLIDE #38 (190K): Socompa volcanic debris avalanche, north Chile

This Landsat Thematic Mapper image displays the world's best exposed example of a large volcanic debris avalanche deposit. About 7,200 years ago the jolt of an earthquake on one of the faults triggered failure of Socompa's western flank, triggering an avalanche which carved out a 70 degree wedge, 12 km across, from the original 6300 m high volcano, whose present summit is seen in blue (snow in false color) at bottom right. The volume of displaced material was ten times greater than Mount St. Helens and formed a deposit which now covers about 500 square kilometers of the Atacama desert. A small proportion of the 20 cubic kilometers of material in the moving avalanche 'froze' in place to form a primary avalanche deposit (red tones; left center) and a great marginal levée (grey tones; top left margin). Most of the material came to rest transiently behind the levées, and then moved off down the northeastward facing slope, in a direction almost at right angles to the *primary* avalanche to form a *secondary* avalanche. Material which arrived at the snout of the avalanche (grey, top center) had travelled at least 40 km. (Section 13.1.1. and *Fig. 13.5*).

SLIDE #39 (172K): Margin of Socompa debris avalanche

This oblique aerial view of the southwestern margin of the avalanche deposit conveys an impression of its scale. The field of view extends about 15 km into the distance. Here the avalanche laps up on some hills of crystalline Palaeozoic basement rocks. The marginal levée is about 40 m high and several hundred meters wide in places. In the left foreground, the scarp left by the break away of the secondary avalanche can be

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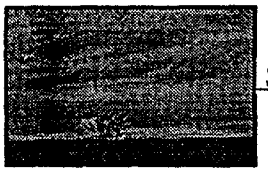
seen; fortuitously, the Antofagasta-Salta railroad follows this scarp for several kilometers. *(Fig. 13.10).*



SLIDE #40 (128K): Sunset, Chelsea, London, November 26, 1883

Brilliantly colored sunsets and prolonged twilights were noted all over the world after the August 1883 eruption of Krakatau, Indonesia, as the result of the global spread of aerosols from the eruption throughout the stratosphere. These displays were recognised as distinct from the familiar red sunsets seen though London's smoke-laden atmosphere and were the subject of considerable contemporary discussion. Artist William Ascroft drew a series of explicit renderings of Krakatau sunsets as he saw them from the banks of the Thames on November 26, months after the eruption. This slide is one of several paintings made while the sun set. Although the sunset effects were obvious, the effects on global temperature were more subtle, perhaps about 1 degree C in the northern hemisphere. Similar effects were seen worldwide after the June 1991 eruption of Mt. Pinatubo, Philippines.

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This page is maintained by Joy Crisp (joy@glassy.jpl.nasa.gov)

Annex F- Attachment #22

Study of Recent Tsunamis Sheds Light on Earthquakes

Eos Vol. 75, No. 1, January 4, 1994, p. 3. *© 1994 American Geophysical Union*Permission is hereby granted to journalists to use this material so long as credit is given, and to teachers to use this material in classrooms.

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In the space of one year, three major destructive tsunamis, or seismic sea waves, devastated coastal regions of Nicaragua (September 2, 1992), Flores Island, Indonesia (December 12, 1992), and Hokkaido, Japan (July 12, 1993). The maximum run-up heights of each of these tsunamis were more than 10 m, and a total of about 1500 people were killed. Field surveys were made for these tsunamis and reported in *Eos* [Satake et al., 1993; Yeh et al., 1993; Hokkaido Tsunami Survey Team, 1993]. The survey teams, typically consisting of scientists and engineers from various fields, documented the behavior of the tsunamis in detail. Tsunami survey data are used for various types of research, ranging from coastal behavior of tsunamis to past and future earthquakes.

Most tsunamis are caused by shallow submarine earthquakes. Indeed, all three tsunamis mentioned above were caused by magnitude 7-8 earthquakes. Fault motion causes ocean bottom deformation, which generates tsunamis; this tsunami generation and propagation can be simulated on computers. The synthetic tsunamis from seismologically estimated fault parameters usually reproduce the observed tsunami waveforms [Satake, 1992].

The Nicaraguan earthquake, however, caused much larger tsunamis than are to be expected from seismological analysis. Several similar earthquakes have occurred in the world and have been called "tsunami" earthquakes [Kanamori and Kikuchi, 1993], but why these tsunamis are unusually large is not known. Seismic wave analysis of the Nicaragua event shows that the fault motion continued for an unusually long time. Furthermore, comparison of the tsunami field data with computations from various fault models shows that the Nicaragua fault motion occurred in the top 10 km of oceanic crust, which means the earthquake was much shallower than typical subduction-zone earthquakes. We now believe that unusually large tsunamis are due to slow fault motion within subducted sediments.

Tsunami waveforms are particularly useful in the study of old earthquakes for which little good-quality seismic data exists; such data have been available only since the 1960s, whereas tsunami waveforms have been recorded since the mid-19th century. It is important to study old earthquakes because the typical recurrence time of a large subduction-zone earthquake is 100 years. Tsunami analysis of the 1957 Aleutian earthquake-which was believed to be the third largest of the century-showed that it was actually much smaller. The earthquake has been downgraded to seventh in the rankings.

Geologists use even older tsunami data. Recently, a tsunami deposit was found that provided evidence for an earthquake occurring in the Seattle area about 1000 years ago [Atwater and Moore, 1992]. The recurrence of large earthquakes in the Pacific northwest, along the Cascadia Subduction Zone, has been estimated from tsunami deposits as well as from other paleoseismological data. Abnormal sediments in Texas and Mexico have been interpreted to be tsunami deposits, apparently from a gigantic meteorite impact near Yucatan at the Cretaceous/Tertiary boundary [Bourgeois et al., 1988], when a mass extinction took place. Study of deposits from recent tsunami events will provide an important calibration to quantify such geological studies.

Coastal behavior of tsunamis needs to be examined in more detail. For example, the field survey of the Hokkaido tsunami revealed that the maximum run-up height was 30 m in a small valley on Okushiri Island, but 20 m or less a short distance away; the run-up height varies significantly with local topography. Three-dimensional run-up

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Annex F- Attachment #23

The following article was published in the January 3, 1995 issue of EOS: Transactions of the American Geophysical Union (volume 76, page 2)

GPS Monitoring Data for Active Volcanoes Available on Internet

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Frank Webb, Jet Propulsion Laboratory

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Ross Stein and Grant Marshall, US Geological Survey

Large changes in surface strain near active volcanoes may accompany, and in many cases precede, major volcanic eruptions by days, weeks or even months. Recent results at Long Valley Caldera in California indicate that surface strain changes may even precede changes in the rate of seismicity by several months (Langbein et al., 1993). These observations suggest that geodesy is a critical component of any monitoring program designed to assess hazard and perhaps predict eruptions at Long Valley and other active volcanoes.

The Global Positioning System (GPS) has been used to make high precision geodetic measurements on some active volcanoes over the past few years (e.g., Dixon et al., 1993). These measurements typically involve observations at yearly intervals, which means that strain signals varying rapidly in time could be missed. Recent advances make it feasible to monitor active volcanoes continuously with remotely operated GPS receivers. A research project funded by NASA and the USGS has monitored activity in Long Valley Caldera since January, 1993 with a permanent GPS station at the USGS two color laser facility "CASA" (named for nearby Casa Diablo hot springs) near the top of the resurgent dome. Results from the first year of observations were recently summarized by Webb et al. (1994). Following a three month period in early 1993 when the antenna was covered by snow, the system has performed very well, and has provided a nearly continuous record of three dimensional surface strain. Uplift has continued through late-1994 at a rate very similar to that of the previous three years, as indicated by leveling (Yamashita et al., 1992), two color laser (Langbein et al., 1993) and previous yearly GPS data (Dixon et al., 1993). A second GPS site ("KRAKATAU") about 10 km north of CASA was installed at the end of September 1994.

Some of the challenges we encountered in this project reflect conditions that are typical of many volcanoes, including:

* harsh environmental conditions. The range of temperatures has exceeded 55°C, and the antenna at CASA has been covered by up to 2 meters of snow;

* limited facilities available to support a permanent receiver. While our first site at CASA had the advantage of facilities associated with the USGS two color laser site, notably power, we needed to install a dedicated telephone line. The remote KRAKATAU site needed its own power, provided by solar panels and a bank of batteries, as well as its own communications, since nearby telephone lines did not exist. A high speed radio link to the CASA facility provides the necessary connection.

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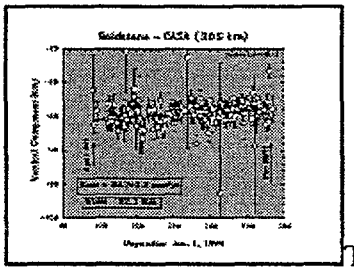
The ultimate goal is to obtain high accuracy results in a timely manner, and make them readily available to a large user community with a broad range of interests and backgrounds. For volcanologists who may not be well versed in GPS technology or may not have facilities to rapidly process large amounts of GPS data, obtaining the GPS results may prove diffcult.

To address this last problem we recently initiated a system that makes the results of a "quick look" analysis from the two permanent GPS sites in Long Valley available to anyone with access to Internet. The system works like this: Raw data from CASA are sent automatically every 24 hours via high speed modem and telephone line to the International GPS Service for Geodynamics (IGS) Central Bureau at the Jet Propulsion Laboratory (JPL), much like other permanent GPS tracking sites around the world (Zumberge et al., 1994). Data from the remote KRAKATAU site are transmitted via radio link to CASA for incorporation into the data stream. Additional data from the southern California Permanent GPS Geodetic Array (PGGA; Bock, 1991) and from the northern California Bay Area Regional Deformation network (BARD; Romanowicz et al., 1994) are also available. The raw data from Long Valley and the other global and regional sites are then transmitted from the IGS Central Bureau, PGGA or BARD to the University of Miami via Internet, and are analyzed within 24 hours with automated routines. Raw data are archived at JPL, Scripps Institution of Oceanography, Goddard Space Flight Center, the University of Miami and elsewhere. The analyzed data for CASA, KRAKATAU and selected other sites reside on the public access directory of the University of Miami's Geodesy Lab computer, and are available on Internet via anonymous ftp (**ftp corsica.rsmas.miami.edu**, or use our IP address, **ftp 129.171.100.35**). The "README.1" file in the public directory (pub) gives a brief summary of the analytical techniques and available files.



The data for CASA begin April 1, 1994. The data for KRAKATAU begin October 14, 1994. Figure 1 is a plot of data from one of these files (GOLDCASA.NEV), and shows the vertical component of the baseline vector between CASA and GOLDSTONE, a station in the Mojave Desert about 300 km south-southwest of CASA. Over this eight-month period, average uplift of CASA relative to GOLDSTONE, presumably reflecting motion at CASA, occurred at a rate of 30.7±5.5 mm/yr. For comparison, uplift in the period 1979-1980 reached ~100-200 mm/yr (Hill et al., 1985), while average uplift at CASA for the period 1989-1992 recorded by three GPS experiments spanning three and a half years was 27.5±4.7 mm/yr (Dixon et al., 1993). Thus we have succeeded in detecting an uplift signal with a precision comparable to that achieved by the earlier intermittent experiments, but over a much shorter time.

The first 12 days of data from the remote KRAKATAU site were available at the time of writing, and preliminary results indicate that this station is performing well. For example, on the 7.7 km CASA-KRAKATAU baseline, the wrms scatter of the north, east and vertical components is 1.5, 3 and 6 mm respectively. We observed north-south lengthening of this baseline (25±6 mm/yr) reflecting the fact that these two sites span the deforming, expanding resurgent dome (Langbein et al., 1993). This rate agrees with the 2 colr laser rate within errors.

In principle, any volcano could be monitored in this way as long as data are available for transmission via Internet. Data transmission within 24 hours of collection is best, since these data can be included in our near real time analysis, and since the results have direct relevance to hazard assessment. However, it is also possible to analyze a second data stream that lags real time by several weeks or more in order to

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incorporate remote stations lacking automated communications.

We think this is an exciting development in the history of volcano studies, and look forward to expanding and further testing the system on additional targets. Hazardous volcanoes in Mexico, Costa Rica, Columbia and Peru may be added to this monitoring system within the next one to two years depending on receiver availability.

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Figure Caption: Time evolution of the vertical component of the baseline vector between CASA (Long Valley) and Goldstone (Mojave Desert). Error bars represent ± one standard error. Weighted root mean square scatter (wrms) of the daily position estimates about the best fit line (11 mm) is a measure of data precision.

Back to RSMAS Geodesy Lab, University of Miami GPS Volcano Monitoring Page

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Tim Dixon's web pages are served via ftp on corsica.rsmas.miami.edu (129.171.100.35), a Sparc 10.

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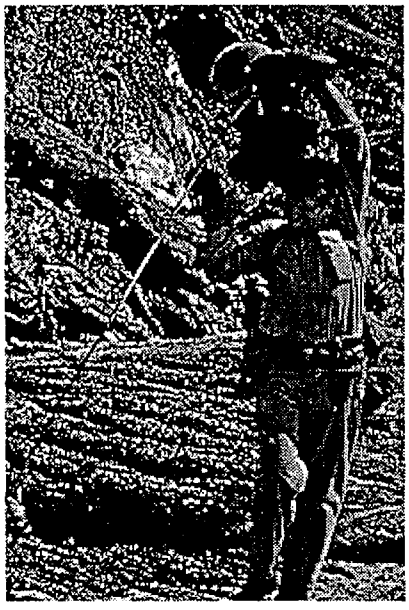
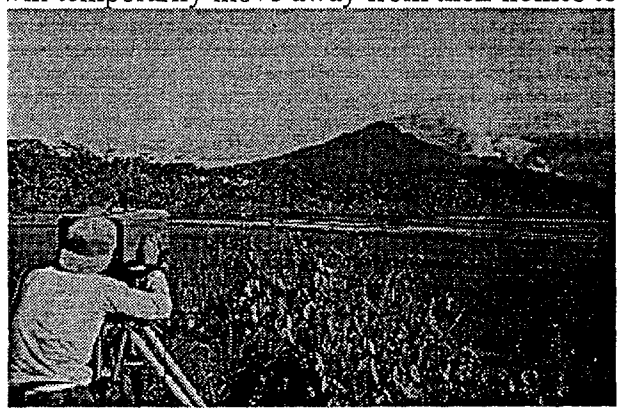
Annex F- Attachment #24

Do you want to become a volcanologist?



Many volcanologists believe they have the best jobs in the world. They have the exciting chance to study active volcanoes in beautiful and often exotic places. The volcanologist's work advances science, but also has direct importance to the lives of people who live near volcanoes. If a volcanologist says a volcano is not going to erupt, but it does, many people may die in the eruption. But if the volcanologist warns that it will erupt, many people will temporarily move away from their homes to safety.



Volcanoes are complicated phenomena that can't be understood without knowledge of the structure and chemistry of the Earth and its rocks, and the interaction of volcanic materials with air and water. To really understand volcanoes it is necessary to study a number of sciences, but the most important is geology - the study of the Earth's rocks.

To be prepared to study geology at a university or college, students must take math and science classes when they are in high school and even in junior high school. It seems unfair, but it is true, that how much you learn when you are in grade school and high school usually determines what you will be able to do during the rest of your life. If you want to become a volcanologist you must concentrate on your classes, even if other kids seem to spend all their time with sports or dating or other pastimes. Don't be a nerd; enjoy life, but also be serious about your studies!

Here is a list of the types of courses to take in high school so that you will have the option to study volcanoes later in college if you want to. Take biology, chemistry, physics, and Earth science if available. Take algebra, trigonometry, and pre-calculus. And learn Basic or some other computer language so you can use a computer without being frightened by it.

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Where should you go to college? Very, very few colleges offer even one course in volcanology, but the basic information you need is taught in geology courses at many universities. Major in geology, taking courses in geomorphology, geophysics, geochemistry, petrology, structural geology, sedimentary geology, and remote sensing. If you go to a college in the American West, or in Hawaii or Alaska, you will probably see a lot of volcanoes and volcanic rocks during geology field trips.

If you want to be a volcanologist you can't stop with just a bachelor of science degree in geology. With a B.S. your career choices are pretty much limited to being an assistant or technician. This might get you a chance to map volcanoes or analyze rock chemistry under somebody else's direction, but your salary will be low and you will not have the chance to decide for yourself what volcano problems to study. You have to go back to school to get a doctor of philosophy (Ph.D.) degree in geology. This will probably take four to five years of additional study and research after you have completed a B.S.

The good thing about getting a Ph.D. is that you will be working with a group of other students and professors who are as excited about volcanoes as you are. After about a year of classes you will probably become involved in volcano research, and at the end of your graduate student days you will know more about one volcano or some volcanic process than anyone else in the world! You will write scientific papers and present talks to other volcanologists at scientific meetings. And you will start to look for a job.

Many volcanologists in the US work for the U.S. Geological Survey, the government agency responsible for studying the nation's geology and finding ways to utilize geologic resources, and ways to mitigate potential geologic hazards. The USGS operates three volcano observatories. The oldest is in Hawaii, on the rim of the Kilauea volcano. Volcanologists there predict, monitor, and closely study the eruptions of Kilauea and the nearby Mauna Loa volcanoes. Another volcano observatory is at Vancouver, Washington, where Mt. St. Helens and other Cascade volcanoes are monitored. The third observatory is in Alaska, where geologists from the USGS and the University of Alaska work together to monitor the 100 active Alaskan volcanoes.

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In addition to working with the USGS, some volcanologists work in state geologic surveys, especially in states like California, Oregon, and Washington, where volcanoes are plentiful. But probably the largest number of volcanologists teach in university geology departments. Besides teaching occasional volcanology courses, most volcanologists teach other traditional courses such as petrology, geochemistry, and geophysics. University faculty have to be on campus most of the year, and thus they tend to do volcanic fieldwork during summer vacations.

We've tried to explain various aspects of learning to be a volcanologist, but you may have some other questions. If so, go to the Ask a Volcanologist part of VolcanoWorld and send us your questions!

For more information about what it like to work on volcanoes see:

- Scott Rowland's Working On Hawaiian Volcanoes

Photo credits (from top to bottom):
1. Volcanologist collecting a lava sample. Photo by **R. Tilling**, U.S. Geological Survey, 1974.
2. Volcanologist using electronic distance measurements (EDM) to monitor an active volcano in Indonesia. Photo by **J. Dvorak**, U.S. Geological Survey, 1982.
3. Seismologist using a portable seismometer to assist volcanologists in their study of lava tubes. Photo by **C. Thornber**, U.S. Geological Survey, 1994.
4. Volcanologists measure ground deformation on the south flank of Kilauea volcano, Hawaii. Photo by **S. Mattox**.
5. Volcanologist collects a gas sample, Kilauea volcano, Hawaii. Photo by **S. Mattox**.

To Ask a Volcanologist To VolcanoWorld

Annex F- Attachment #25

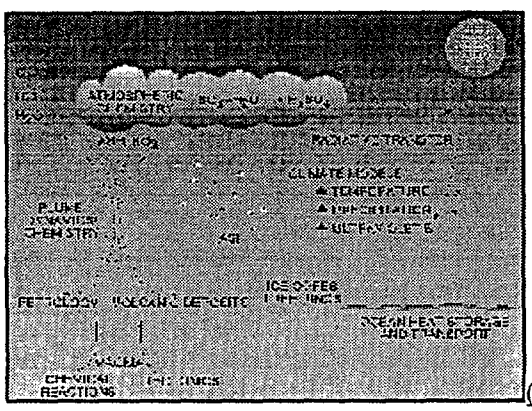
NASA Facts

Volcanoes and Global Climate Change

Volcanoes and Global Cooling

Volcanic eruptions are thought to be responsible for the global cooling that has been observed for a few years after a major eruption. The amount and global extent of the cooling depend on the force of the eruption and, possibly, its latitude. When large masses of gases from the eruption reach the stratosphere, they can produce a large, widespread cooling effect. As a prime example, the effects of Mount Pinatubo, which erupted in June 1991, may have lasted a few years, serving to offset temporarily the predicted greenhouse effect.

Figure 1 shows that as volcanoes erupt, they blast huge clouds into the atmosphere. These clouds are made up of particles and gases, including sulfur dioxide. Millions of tons of sulfur dioxide gas can reach the stratosphere from a major volcano. There, the sulfur dioxide converts to tiny persistent sulfuric acid (sulfate) particles, referred to as aerosols. These sulfate particles reflect energy coming from the sun, thereby preventing the sun's rays from heating the Earth.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Caption: (Figure 1. Volcanism studies are an important aspect of climate research [see glossary at the end of this article])

Global cooling often has been linked with major volcanic eruptions. The year 1816 often has been referred to as "the year without a summer." It was a time of significant weather-related disruptions in New England and in Western Europe with killing summer frosts in the United States and Canada. These strange phenomena were attributed to a major eruption of the Tambora volcano in 1815 in Indonesia. The volcano threw sulfur dioxide gas into the stratosphere, and the aerosol layer that formed led to brilliant sunsets seen around the world for several years.

However, there is some confusion about the historical evidence that global cooling may be caused by volcanic emissions. Two recent volcanic eruptions have provided contradictory evidence on this point. Mount Agung in 1963 apparently caused a considerable decrease in temperatures around much of the world, whereas El Chichn in 1982 seemed to have little effect, perhaps because of its different location or because of the El Nino that occurred the same year (see **NASA Facts--El Nino**). El Nino is a Pacific Ocean phenomenon, but it causes worldwide weather variations that may have acted to cancel out the effect of the El Chichn eruption.

Volcanoes and Ozone Depletion

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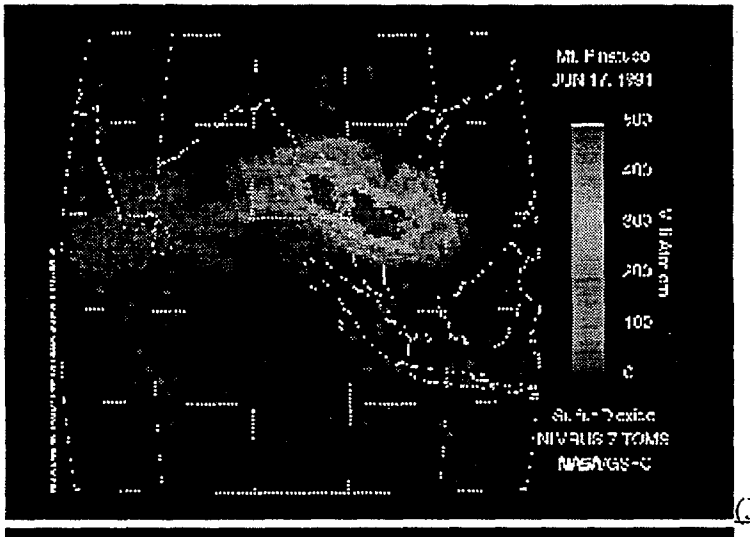
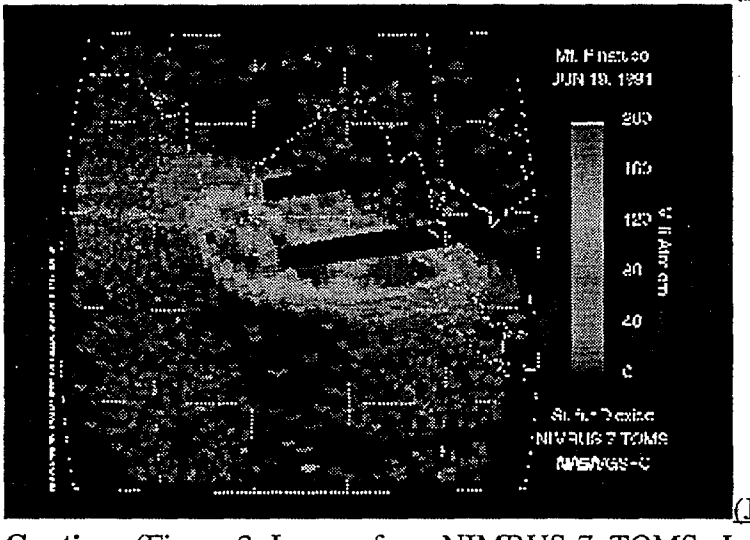
Another possible effect of a volcanic eruption is the destruction of stratospheric ozone. Researchers now are suggesting that ice particles containing sulfuric acid from volcanic emissions may contribute to ozone loss. When chlorine compounds resulting from the breakup of chlorofluorocarbons (CFCs) in the stratosphere are present, the sulfate particles may serve to convert them into more active forms that may cause more rapid ozone depletion (see **NASA Facts--Ozone**).



(June 17, 1991)



(June 19, 1991)

Caption: (Figure 2. Images from NIMBUS-7: TOMS--June 17 and 19, 1991, showing the spread of sulfur dioxide from the Mt. Pinatubo eruption. The "gray scale" indicates the thickness the sulfur dioxide cloud layer would have had if it were observed at standard surface conditions of temperature and pressure).

Monitoring the Effects of Volcanoes

Even if one can get to a volcano, it's practically impossible to measure its gas output because one can't synoptically see the whole cloud. Even aircraft can't do it because they're too low and it's too dangerous. Space observations from NASA's Total Ozone Mapping Spectrometer (TOMS) instrument have contributed significantly to our knowledge of the total amount of sulfur dioxide emitted into the atmosphere in the course of major volcanic eruptions. Figure 2 shows TOMS images of the sulfur dioxide spreading across the Pacific region following the eruption of Mount Pinatubo. Several weeks later the sulfur dioxide had spread around the world as observed by the Microwave Limb Sounder (MLS) instrument on NASA's Upper Atmosphere Research Satellite (UARS) (see Figure 3).

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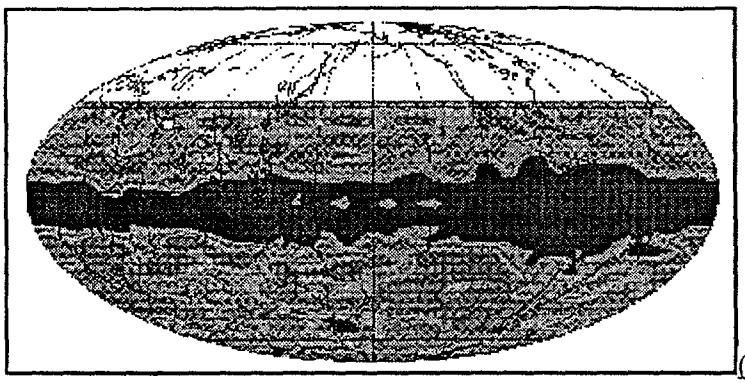

(Figure 3.)

Caption: (Figure 3. Images from UARS satellite--sulfur dioxide cloud from Mt. Pinatubo on September 23, 1991, after dispersal around the world).

In addition to detecting the sulfur dioxide from Mount Pinatubo, TOMS has made similar observations of more than 100 volcanic events including a major eruption from the Cerro Hudson volcano in Chile in 1991. A TOMS instrument was launched on the Russian Meteor-3 spacecraft in 1991; it is also scheduled to fly on a special-purpose NASA satellite, an Earth Probe, in 1994, and on the Japanese Advanced Earth Observing System (ADEOS) mission in 1996. Current plans are for TOMS to monitor volcanic eruptions well into the next century.

Data from the Stratospheric Aerosol and Gas Experiment (SAGE II) instrument on NASA's Earth Radiation Budget Satellite (ERBS) have shown that during the first five months after the Mount Pinatubo eruption, the optical depth of the stratospheric aerosol increased up to 100 times in certain locations. Optical depth is a general measure of the capacity of a region of the atmosphere to prevent the passage of visible light through it. Greater optical depth means greater blockage of the light. In this case, the increased optical depth means that considerably less of the sun's energy can get through the cloud to warm the Earth's surface.

Observations of the effects of Mt. Pinatubo aerosols on global climate have been used to validate scientist's understanding of climate change and our ability to predict future climate. Researchers at NASA's Goddard Institute for Space Studies in New York City have applied their general circulation model of Earth's climate to the problem. They have reported success in correctly predicting the effects of the sulfate aerosols from Mount Pinatubo's eruption on lowering global temperatures.

The following related information can be found in the EOS Reference Handbook:

- Mission Elements - Total Ozone Mapping Spectrometer (TOMS)
- Microwave Limb Sounder (MLS)
- Mission Elements - Advanced Earth Observing System (ADEOS)

NASA Missions to Study Volcanoes

Some of NASA's past and present missions that contribute to the study of volcanoes are listed in the accompanying table. Included in the table is the Earth Observing System (EOS), the key element of NASA's Mission to Planet Earth. The first launch in the series of EOS satellites is scheduled to take place in 1998.

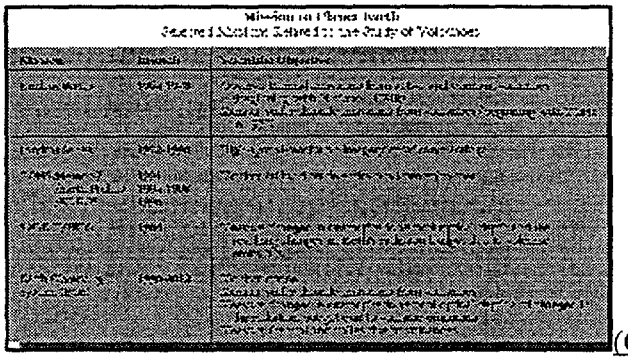
The High Resolution Infrared Radiometer (HRIR), first flown on NASA's Nimbus-1 satellite in 1964, has been used to observe both active and dormant volcanoes. On Nimbus-2, HRIR recorded energy changes

from the volcanic activity on Surstey, Iceland in 1966. The Multispectral Scanner (MSS) and Thematic Mapper (TM) instruments on the Landsat satellite have provided a long series of images of volcanic activity, e.g., venting, volcanic ash falls, and lava flows.

The EOS program will incorporate a series of satellites that will carry advanced instruments to provide a highly-accurate, self-consistent, and long-term data base of many aspects of Earth's atmosphere, land, and ocean characteristics. The information gained from this major effort to study Earth phenomena will expand our knowledge of the interactions of volcanoes with Earth's climate.

Glossary of Chemistry

- ☐ Cl2 chlorine
- ☐ HCl hydrogen chloride
- ☐ H2O water
- ☐ O3 ozone
- ☐ H2SO4 sulfuric acid
- ☐ SO2 sulfur dioxide



(Click here for full image)

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Annex F- Attachment #26

Volcano Watch--August 25, 1996

Volcanic Gases Provide Clues to How Volcanoes Work

In a double handful of molten magma (weighing about a pound), there is less than a tenth of an ounce, by weight, of dissolved gas--roughly the same weight as a pinch of table salt. Yet this tiny amount of gas can drive spectacular lava fountains hundreds of feet into the air. The fountaining occurs because dissolved volcanic gases expand when pressure on the magma is released. Anyone who has shaken a bottle of soda and opened it quickly has gotten the full value of this basic principle of physics.

The Volcano Watch column for this week will be on volcanic gases. What gases come out of volcanoes like Kilauea and Mauna Loa, where the gases come out from, and what happens to them afterwards.

Gases are trapped (dissolved) in magma at depth, where pressures within the Earth's crust are very great--many thousands of pounds per square inch. As the magma rises to the surface and is erupted, the pressure decreases, and some of the gas is released. The main gases dissolved in magma are water vapor, carbon dioxide, and sulfur gases, with lesser amounts of hydrogen, hydrochloric acid, and hydrofluoric acid. In our pinch-of-salt-to-a-double-handful-of-magma illustration earlier, most of the "pinch" is water vapor, followed by lesser amounts of carbon dioxide and sulfur gases with a few "grains" of hydrogen and the other acid gases. At HVO, we study gases emitted from Kilauea and Mauna Loa in order to assess the state of eruptive activity, and to help improve our understanding of how volcanoes work.

At the summit of Kilauea, most of the gas released--aside from water vapor--is carbon dioxide (CO_2), the same gas found dissolved in soda (and beer). Kilauea emits about 1,300,000 tons of carbon dioxide each year, an amount that seems large, but is actually about 1/17,000 th of the man-made CO_2 generated each year, and contributes very little to the greenhouse effect.

Sulfur dioxide (SO_2) and lesser amounts of hydrogen sulfide (H_2S) are the most abundant sulfur gases emitted in volcanically active areas that are very hot, or where molten magma is close to the surface. These areas include the summit of Kilauea, the eruptive sites on and near Pu'u 'O'o, and the lava-tube system going down to where lava enters the ocean. In geothermal areas, such as Pohoiki, however, hydrogen sulfide is essentially the only sulfur gas emitted. Hydrogen sulfide, sometimes called "sewer gas", is a toxic gas that irritates the eyes, nose, and throat and has a rotten egg odor. It is an insidious poison, because although our noses can initially detect H_2S at very low concentrations, under prolonged exposure to higher levels of the gas, our sense of smell may become fatigued. Because of this fatigue, we may no longer be able to detect H_2S but could still suffer from its effects. Furthermore, our ability to distinguish between moderate and very high concentrations of H_2S is limited. Sulfur dioxide, in contrast, is the biting, choking gas that you smell right after you've lit a kitchen match, or the sharp odor you sense at the Halema'uma'u overlook. Sulfur dioxide is also toxic but is typically so irritating to the nose that it provides its own warning when concentrations reach toxic levels.

An interesting chemical relationship exists between the sulfur dioxide and the hydrogen sulfide released by the volcano. These two gases react quickly (within minutes) with each other to produce sulfur particles and

water vapor. Both of the products of this reaction are odorless and are less toxic than either H_2S or SO_2. Most of the hydrogen sulfide released in eruptive areas on Kilauea is consumed and is converted to sulfur particles by this process, because there is much more sulfur dioxide than hydrogen sulfide coming out of the volcano. This is why you seldom smell hydrogen sulfide at the summit caldera or along the eruptive east rift. The volcano has its own hydrogen sulfide abatement system! Geothermal areas, by contrast, have no large quantities of SO_2 available for reaction, so any H_2S released is removed by reaction with oxygen in the air to form sulfur dioxide, a process that takes a day or more.

Scientists at HVO measure the amount of sulfur dioxide released from Kilauea using a correlation spectrometer (COSPEC). The COSPEC is mounted in a vehicle that is driven beneath the volcanic gas plume. The COSPEC "looks" up through the plume and measures the SO_2 as it is blown across the road and away from the volcanic vent. By recording how much sulfur dioxide the COSPEC sees and by knowing the speed of the wind blowing the gas plume, we compute the amount of SO_2 emitted from the volcano. Before the current east rift eruption began 10 years ago, Kilauea released about 150 tons of SO_2 each day, nearly all of which was emitted from the summit caldera. Sulfur dioxide emissions were as high as 30,000 tons per day during the high fountaining episodes at Pu'u 'O'o. These episodes occurred every three to four weeks from 1983 to 1986 and typically lasted 24 hours or less. Starting from 1986 when the Kupaianaha lava pond formed, Kilauea released as much as 1,800 tons of SO_2 each day, between 150 and 300 tons of which were from the summit and the balance from the east rift eruptive sites. This sulfur dioxide emission rate has continued at roughly the same or a slightly lower level ever since. During eruptive pauses emission rates are much lower. By comparison, Pinatubo Volcano in the Philippines released 19,000,000 tons of SO_2 during its catastrophic eruption on June 15, 1991.

Sulfur dioxide is released at the summit, at Pu'u 'O'o, at the 51-53 vents, and at the skylights along the tube system. The sulfur dioxide reacts chemically with oxygen, dust particles, sunlight, and water in the air to form a mixture of sulfate-aerosols (tiny particles and droplets), sulfuric acid, and other oxidized sulfur species known as "vog." What happens to the vog is determined primarily by wind direction and intensity. When moderate to strong northeasterly trade winds blow, the vog is typically carried to the southwest towards South Point, where the wind patterns wrap around the island, sending the vog up the Kona coast. During Kona winds, or in the absence of strong trade wind conditions, however, vog stays on the east side of the island, affecting people, animals and plants, sometimes from Ka Lae to Hilo.

Gas release of another form occurs where lava enters the ocean. Again, a chemical reaction occurs, this time between molten lava and sea water. The reaction is vigorous because of the intense heat, generating a large, white plume cloud containing a mixture of hydrochloric acid and sea water, commonly called laze. During along-shore or on-shore winds, this laze plume can drop rainwater on people along the coast. This rain is often more acidic than lemon juice, with a pH of 1.5 to 2.5, but is more corrosive than lemon juice to skin and clothing. Hydrochloric acid is toxic and causes irritation to the throat, lungs, eyes, and nose. Visitors should heed park warning signs and avoid standing directly in or under the coastal-entry plume.

U.S. Geological Survey
Hawaiian Volcano Observatory
P.O. Box 51, Hawaii Volcanoes National Park, HI 96718
Phone (808) 967-7328 FAX (808) 967-8890

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Annex F- Attachment #27

Evacuating a Volcano: A Simulation

Goal: To explore hazards associated with cataclysmic natural events, and human responses to them.

Objectives: Students will

1. Work cooperatively in small groups to solve a problem
2. Consider ways of minimizing risk and threats to human safety
3. Identify behaviors appropriate in an emergency situation
4. Plan an orderly, step-by-step process in a limited amount of time
5. Evaluate their own group decision-making processes.

Concept: Cataclysmic events create threats to individual safety that must be analyzed and managed logically, methodically, and cooperatively.

Summary: Students imagine themselves staying for the weekend in a summer cabin near Mount St. Helens (or other volcanic site,) and having to quickly evacuate the area. Working in groups of three to six, they decide on the location of their cabin in relation to the mountain, and plan an evacuation procedure on a 30-minute timeline. Groups attempt to solve this problem cooperatively. Students then evaluate their groups' success, analyzing and discussing processes used to establish priorities, make plans and decisions, manage time and achieve consensus.

Content Areas: Social studies, language arts, science, group-process skills*

Materials Needed:

Handout:

1. Anywhere Recreation Area Map
2. Evacuation Scenario
3. film (optional) "This Place in Time: The Mount St. Helens Story"
4. butcher paper
5. marking pens

Instructional Strategies:

1. Clustering/Mindmapping Techniques
2. The Magic of Metaphor (especially p. 3, "Guided Fantasy.")

*Group's task may be simplified for younger students; for older students, it may be preceded or accompanied by specific instruction in such group-process skills as consensus-building, decision-making, conflict resolution, etc.

Instructional Sequence:

1. Divide students into groups of three to six members each. Provide each group with one copy of

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Anywhere Recreation Area Map. Group is to begin by deciding upon the location of their summer cabin, listing at least three reasons for their choice. Emphasize that they must all agree on the location and the criteria for choosing it. Once they have decided, they should draw their cabin on the map.

2. Ask students to imagine themselves in the **Evacuation Scenario**. Read it aloud to the class. (For dramatic effect, you may want to show the film or video version of "This Place in Time: The Mount St. Helens Story")

3. Explain that it is now 7:30 a.m., and the groups have only 30 minutes in which to plan their evacuation. They must decide upon a plan that uses the resources they have available, and gets them out of the area in the least possible time. Emphasize that every member of the group must agree to the plan. Their resources include:

   a. an all-terrain two-person vehicle
   b. a battery-operated am/fm radio
   c. three days' worth of food
   d. three fishing poles and a hunting knife
   e. three knapsacks
   f. a camp lantern
   g. map of **Anywhere Recreation Area**
   h. a deck of cards.

4. It will be helpful to provide the groups with instruction in the following problem-solving process:

   a. Brainstorm members' thoughts and ideas about the evacuation, and list them on sheets of butcher paper.
   b. Decide on the three best ideas and discuss negative and positive aspects of each.
   c. Choose the best idea or combine ideas to arrive at the best option.
   d. Brainstorm ways to carry out the plan.
   e. Choose the best strategies, and assign roles and responsibilities.
   f. Write up a plan of action, consisting of steps on a timeline.

   (When students have agreed upon and completed the plan of action, they may consider themselves "evacuated." Have each group record the time it took them to complete the task.)

5. After thirty minutes, find out which groups made it out in time and which did not. Record their times on the blackboard. Allow time for each group to share its plan. Encourage comments on the plans from other students.

6. Have students discuss in their groups the following questions:

   a. What were your thoughts and feelings about this activity?
   b. What did you find difficult about it?
   c. How does this simulation compare to a real-life situation?
   d. How did your group resolve conflict?
   e. What kinds of behaviors are important in an emergency situation?
   f. What issues prevented or threatened to prevent your group's getting out in the time allowed?
   g. Choose one of these issues and brainstorm possible alternate solutions.

7. Conduct a whole-class discussion. Provide opportunity for students to see how those in other groups made decisions, resolved conflicts, etc.

8. Provide closure. Explain that volcanic activity can be seen as destructive when you think about its impact on the landscape, bridges, homes, highways, wildlife and people. However, as they continue this unit their study will focus on another side of volcanic eruptions: volcanic forces as part of a natural earth-building process.

Extension:

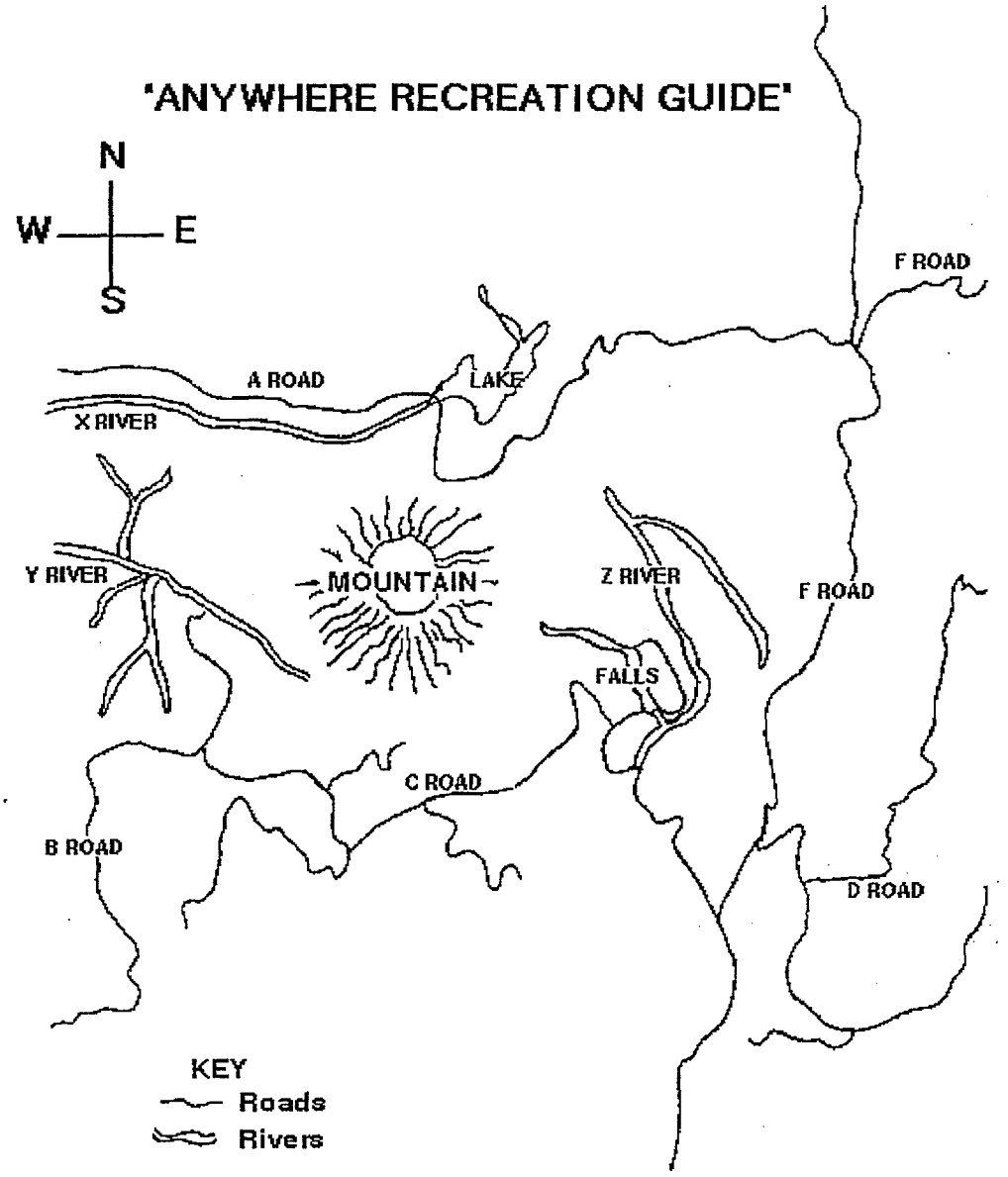
1. Provide original groups with butcher paper and colored marking pens. As a lead-in to further work with this unit, direct them to brainstorm what they already know about volcanoes and volcanic eruptions. If they are unsure of their information, or as they have questions, have them circle those items in their brainstorming list. After ten minutes or so, have groups share with the class their questions and needs for additional information about the topic.

2. Post a composite list of questions in the classroom, so that you can refer back to them as the unit progresses. Unanswered questions can also be the starting points for students' final independent projects.

Return to:

Living Laboratory Curriculum **Living Lab Curriculum**

Mount St. Helens **Mount St. Helens**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C ROAD
B ROAD
D ROAD
KEY
Roads
Rivers

Evacuation Scenario

It is a beautiful weekend in late Spring, and you have permission to spend it in a cabin owned by your friend Pat's parents, located near (Mount St. Helens or other volcanic site.) Until they return to pick you up on Sunday evening, you are "on your own" in the wilderness. You and your friends have spent your first day fishing and swimming in a nearby river, scouting the trails for a hike you plan to take tomorrow, eating, laughing, and generally having a wonderful time. By evening you are all exhausted, ready for dinner and an early bedtime. But one member of the group, Rudy, can't sleep. His restless movements around the cabin keep disturbing your dreams, and the others are complaining that he's keeping them awake, too. By dawn, your sleepless friend is up, crashing around the kitchen, fixing breakfast. Groaning and grumpy, everyone is awake by 6:30 a.m. It is May 18, 1980.

While the group eats, Rudy tells you all about the dreams that kept waking and upsetting him last night. He dreamed of a series of earthquakes and violent volcanic eruptions. At first, you tease him about his fears. You've all lived in the shadow of this familiar mountain most of your lives. True, over the last year it has been showing increasing, mild activity; however, scientists have maintained that there is no present danger.

But Rudy insists that he has a "premonition," that the dreams were so vivid he believes they're a warning. He wants to pack up the gear, and leave the area. His words are having an effect on the rest of you, who begin to look anxiously out the windows.

Just then, Pat bursts through the cabin door. He'd gone to get a clear view of the mountain from a spot about 40 feet in front of the cabin, and now he urges the rest of you to come out and look. Something new is happening. Instead of the usual light-colored puff of steam, there is a huge, dark-gray cloud hanging over the peak. And then, there is a slight tremor at your feet. And then, a stronger shaking that knocks a can of soup off a kitchen shelf, and causes several empty Styrofoam cups to roll off the table onto the floor.

Realizing that you should:

1. stay together
2. decide on the best route out of the area
3. avoid panic.

You gather around the kitchen table to plan your evacuation.

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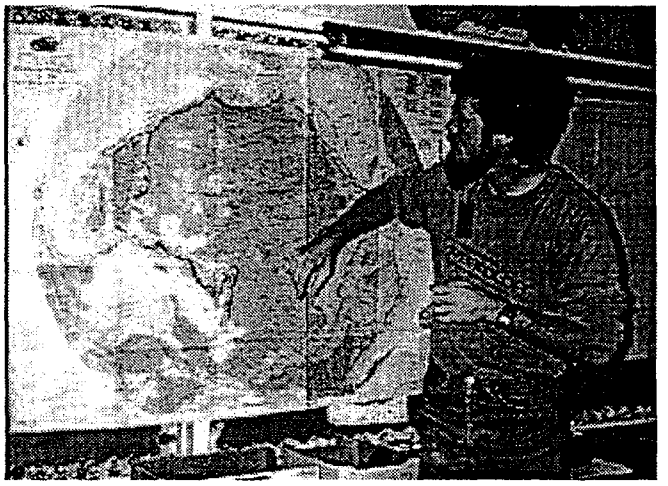
Volcano Lesson Plans



One goal of VolcanoWorld is to provide students and teachers with lessons about volcanoes. Even if you are not a formal student or teacher you might find something interesting. Here's a few lessons and activities to get you started. Keep an eye on this page. We'll be adding many more lessons as fast as we can.

1. A Teacher's Guide to the Geology of Hawaii Volcanoes National Park
2. UKESCC
3. **Earth Science Lessons for grades 5-8**
   - Hyperstudio lessons
   - Online lessons
4. Mount St. Helens Lessons for grades 5-12
5. On-Line Lesson: VOLCANOES by Lois Carter

To VolcanoWorld

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On-Line Lesson

VOLCANOES

Lois Carter, 5th Grade Teacher, Brookneal Elementary School, Brookneal, VA

Objective

1. Students will locate an active volcano around the world.
2. Students will ask a volcanologist from Hawaii or North Dakota a challenging question.

Background

Before this lesson the class:

1. Read and discussed the chapter in their science text on volcanoes.
2. Researched types of volcanoes and made a chart with data including type, size, shape, and an example.
3. Divided into cooperative groups observed how a volcano erupts by making a working model.
4. Viewed videos on Mount Saint Helens and Kilauea.
5. Examined samples of pumice, basalt, and obsidian.
6. Examined articles and pictures of volcanic eruptions in magazines and newspapers.
7. Brainstormed questions to ask a volcanologist and chose a question.
8. Teacher's Note: It would be helpful if you prepared a handout of the questions below for the students to use during the activity.

Activity

The student will locate Volcano World on Netscape and do the following:

1. Click on Current and Recent Eruptions and select an active volcano. Take notes on its current volcanic activity and other significant information.

   QUESTIONS
   1. What is the name of the volcano?
   2. What is the location of the volcano?
   3. What type of volcano is it?
   4. Date and description of any current or recent eruptions.
   5. Give other interesting facts about the volcano.

2. Click on Ask a Volcanologist. Click on Previous Questions. If your question has been asked, read and take notes on the answer. If not, type in your question. Return at a later time to see the volcanologist's reply to your question.

Earth Science HyperStudio Stacks

Following are hypherstudio stacks that Scott Johnson, a elementary school teacher in Licoln Elementary in Grand Forks, has developed. These lessons are geared toward and tested by 5-8 grade students.

Here is a philosophical discussion of how one teacher - Scott Johnson, a member of the VolcanoWorld development team - plans to use VolcanoWorld in his 5/6th grade classroom. Specific lesson plans like those listed below could be components of Scott's general plan. Let us know how you might use VW in your classroom.

The stacks are compressed. You will need to grab (by clicking your mouse on the file) the HyperStudio Player before downloading the stacks.

HyperStudio Player requires you to set the monitor of your Mac to 256 colors before you use it. You can do so by picking 256 in your [Control Panels] [Monitors].

The CopyMaster in each chapter has questions and answers that can be used by teachers. Please read the README file in the CopyMaster before using the stacks.

- ☐ HyperStudio_3.0_Player.sea.hqx: HyperStudio Player for Macintosh required to use the stacks.
- ☐ Plate Tectonics
  - ☐ Chapter 1 Copymaster A: Tests, Reviews and Answer Keys.
  - ☐ Chapter 1 Copymaster B : Content Center, Hands-On Center, Tests, Reviews, Vocabulary Sheets, Answer Keys, Chapter Schedule, Goals, materials, and objectives for each lesson.
  - ☐ The_Earth's_Layers: Teaches the students about the different layers of the Earth and how they work together.
  - ☐ Pangea_to_the_Present: A history of plate movements from 250 million years to the present.
  - ☐ How_Plates_Move: Teaches the processes involved in plate movement.
- ☐ Earthquakes and Volcanoes
  - ☐ Chapter 2 Copymasters
  - ☐ The Rolling Earth
  - ☐ Volcanoes
  - ☐ Volcanic Terms
- ☐ Cones, Eruptions, and Pyroclasts

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- ☐ Chapter 3 Copymaster
- ☐ Hot spot volcanoes
- ☐ Lava flows and pyroclasts
- ☐ Volcanic Cones and Eruptions

☐ Rocks and Minerals
- ☐ Chapter 4 Copymaster
- ☐ Rocks
- ☐ Minerals
- ☐ Igneous Rocks
- ☐ Sedimentary Rocks
- ☐ Metamorphic Rocks
- ☐ Rocks and Mineral Slideshow

☐ Prehistoric Earth
- ☐ Chapter 5 Copymaster
- ☐ Prehistoric Earth

To VolcanoWorld

How I Will Use VolcanoWorld in the Classroom

Scott Johnson
5/6th grade teacher
Lincoln Elementary, 400 Pakenham
Grand Forks, N.D. 58201

This Intermediate/Middle School Earth Science Curriculum will utilize three centers for instruction. The three centers will enhance student learning by teaching concepts and processes hands-on as the students gain an understanding of one of the most powerful forces on Earth-Volcanism.

The students will daily read, discuss, experiment, utilize CD ROM technology, and access SENDIT/INTERNET information to gain a better understanding of the Earths dynamic systems. [SENDIT is a statewide, local version of Internet that our schools in North Dakota are connected to.]

The students will work in pairs in the Computer Center bringing up information of daily volcanic activity that will be supplied through SEND-IT/INTERNET from VolcanoWorld. This information will have been screened and rewritten by VolcanoWorld personnel for the use of 5th - 8th graders. The students will use this information in our Adopt-A-Volcano program. This program will enable the students to become real scientists by analyzing current information of volcanic and seismic activity, and by encouraging students to make predictions of further activity.

The students will be actively involved in the learning of concepts and processor of our dynamic Earth by taking Interactive Field Trips into Mt. St. Helens National Monument and Hawaii Volcanoes National Park all through the use of Internet resources and ultimately CD ROMs to be produced by VolcanoWorld.

The students will use Content Cards in the Content Center. These cards will be read and the information discussed in groups. Quizzes and tests will be supplied for student assessment and evaluation.

The students will perform daily experiments utilizing the scientific method in the Hands-On Experimental Center. The students will work in small groups collecting data and discussing concepts learned at this center.

The students will gain knowledge and a good understanding of volcanoes and volcanic processes by working in these three centers, each center enhancing the information gained at the others.

Scott Johnson is a member of the VolcanoWorld Development Team.

To VolcanoWorld **To Volcano Lesson Plans**

Earth Science Lessons

Following are Earth Science lessons Scott Johnson, a elementary school teacher in Licoln Elementary in Grand Forks, has developed. These lessons are geared toward and tested by 5-8 grade students.

Here is a philosophical discussion of how one teacher - Scott Johnson, a member of the VolcanoWorld development team - plans to use VolcanoWorld in his 5/6th grade classroom. Specific lesson plans like those listed below could be components of Scott's general plan. Let us know how you might use VW in your classroom.

The CopyMaster in each chapter has questions and answers that can be used by teachers. Please read the README file in the CopyMaster before using the lessons.

- Chapter 1: Plate Tectonics
  - The Earth's Layers, Lesson #1: Teaches the students about the different layers of the Earth and how they work together.
    - Content Center Lesson 1: The Earth's layers.
    - Goals, Objectives and Materials For Lesson #1, The Earth's Layers.
    - Hands-on Center Lesson 1: Earth's Layers
    - Discussion Questions Lesson 1 Answers.
    - Discussion Answers for Lesson 1, The Earth's Layers, and Lesson 2, Pangaea to the Present.
  - Pangea to the Present, Lesson #2: A history of plate movements from 250 million years to the present.
    - Content Center Lesson 2: Pangaea To The Present.
    - Goals, Objectives and Materials For Lesson #2, Pangaea to the Present.
    - Hands-on Center Lesson 2: Pangaea to the Present.
    - Discussion Questions Lesson 2 Answers.
  - How Plates Move, Lesson #3: Teaches the processes involved in plate movement.
    - Content Center Lesson 3: Plate Movements.
    - Goals, Objectives and Materials For Lesson #3, How the Earth's Plates Move.
    - Hands-on Center Lesson 3: How Plates Move.
    - Discussion Questions Lesson 3 Answers.
  - Chapter #1 Copymaster: Tests, Reviews, Vocabulary Sheets, Answer Keys, Chapter Schedule, Goals, materials, and objectives for lesson 1, 2, and 3.
    - Read Me First!
    - Review Questions Chapter 1 The Earth: A Dynamic Planet

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- Test Questions Chapter 1 The Earth: A Dynamic Planet.
- Student Copy Vocabulary Words Chapter 1, The Earth: A Dyanamic Planet
- BaseballGame
- Content Center Lesson 1: The Earth's layers.
- Content Center Lesson 2: Pangaea To The Present.
- Content Center Lesson 3: Plate Movements.
- Goals, Objectives and Materials For Lesson #1, The Earth's Layers.
- Goals, Objectives and Materials For Lesson #2, Pangaea to the Present.
- Goals, Objectives and Materials For Lesson #3, How the Earth's Plates Move.
- Hands-on Center Lesson 1: Earth's Layers
- Hands-on Center Lesson 2: Pangaea to the Present.
- Hands-on Center Lesson 3: How Plates Move.
- Teachers Copy Vocabulary Words Chapter 1, The Earth: A Dyanamic Planet.
- Discussion Questions Lesson 1 Answers.
- Discussion Questions Lesson 2 Answers.
- Discussion Questions Lesson 3 Answers.
- Discussion Answers for Lesson 1, The Earth's Layers, and Lesson 2, Pangaea to the Present.
- Review 1 Answers for Chapter 1, The Earth: A Dynamic Planet.
- Test 1 Answers for Chapter 1, The Earth: A Dynamic Planet.

☐ Chapter 1 Online test, you can take the chapter 1 test here and get it graded.

☐ Chapter 2: Earthquakes and Volcanoes

☐ The Rolling Earth, Lesson #4

- Content Center Lesson 4 Earthquakes-The Rolling Earth.
- Goals, Objectives and Materials For Lesson #4, "Earthquakes-The Rolling Earth"
- Hands-On Center Lesson 4, Earthquakes-The Rolling Earth.

☐ Volcanoes, Lesson #5

- Content Center Lesson #5 Volcanoes.
- Goals, Objectives and Materials For Lesson #5, "Volcanoes"
- Hands-On Center Lesson 5, Volcanoes.

☐ Volcanic Terms, Lesson #6

- Goals, Objectives and Materials For Lesson #6, "Volcanic Terms"
- Hands-on Center Lesson 6, Volcanic Terms.

☐ Chapter #2 Copymaster: Tests, Reviews, Vocabulary Sheets, Answer Keys, Chapter Schedule, Goals, materials, and objectives for lesson 4, 5, and 6.

- Chapter Review Chapter 2, Earthquakes and Volcanoes
- Test Chapter 2 Earthquakes and Volcanoes.
- Student Copy Vocabulary Chapter 2, Earthquakes and Volcanoes.
- BaseballGame
- Content Center Lesson 4 Earthquakes-The Rolling Earth.
- Content Center Lesson #5 Volcanoes.
- Goals, Objectives and Materials For Lesson #4, "Earthquakes-The Rolling Earth"
- Goals, Objectives and Materials For Lesson #5, "Volcanoes"
- Goals, Objectives and Materials For Lesson #6, "Volcanic Terms"
- Hands-On Center Lesson 4, Earthquakes-The Rolling Earth.
- Hands-On Center Lesson 5, Volcanoes.
- Hands-on Center Lesson 6, Volcanic Terms.
- Answer Discussion Questions Lesson 4 "Earthquakes-The Rolling Earth
- Teacher Copy Vocabulary Chapter2, Earthquakes and Volcanoes.

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- Chapter Review Answers Chapter 2, Earthquakes and Volcanoes
- Test Answers Chapter 2, Earthquakes and Volcanoes

☐ Chapter 2 Online test, you can take the chapter 2 test here and get it graded.

☐ Chapter 3: Cones, Eruptions, and Pyroclasts

☐ Lava flows and pyroclasts, Lesson #7.
- Content Center Lesson 7 Volcanoes.
- Goals, Objectives and Materials For Lesson #7, "Lava Flows and Pyroclasts"
- Hands-on Center Lesson 7, Lava Flows and Pyroclasts.

☐ Volcanic Cones and Eruptions, Lesson #8.
- Goals, Objectives and Materials For Lesson #8, "Volcanic Cones and Eruptions"
- Hands-on Center Lesson 8, Volcanic Cones and Eruptions.

☐ Hot spot volcanoes, Lesson #9.
- Content Center Lesson 9 Hot Spots-Hawaii and Yellowstone.
- Goals, Objectives and MaterialsFor Lesson #9, "Hot Spot Volcanoes-Hawaii and Yellowstone"
- Hands-on Center Lesson 9, Hot Spots: Hawaii and Yellowstone.

☐ Chapter #3 Copymaster: Tests, Reviews, Vocabulary Sheets, Answer Keys, Chapter Schedule, Goals, materials, and objectives for lesson 7, 8, and 9.
- Chapter 3 Review Questions Cones, Eruptions, and Pyroclasts
- Chapter 3 Test Questions Cones, Eruptions, and Pyroclasts
- Student Vocabulary Chapter 3
- BaseballGame
- Content Center Lesson 7 Volcanoes.
- Content Center Lesson 9 Hot Spots-Hawaii and Yellowstone.
- Goals, Objectives and Materials For Lesson #7, "Lava Flows and Pyroclasts"
- Goals, Objectives and Materials For Lesson #8, "Volcanic Cones and Eruptions"
- Goals, Objectives and MaterialsFor Lesson #9, "Hot Spot Volcanoes-Hawaii and Yellowstone"
- Hands-on Center Lesson 7, Lava Flows and Pyroclasts.
- Hands-on Center Lesson 8, Volcanic Cones and Eruptions.
- Hands-on Center Lesson 9, Hot Spots: Hawaii and Yellowstone.
- Discussion Questions Answers Lessons 7, 8, and 9.
- Teacher Vocabulary Chapter 3
- Chapter 3 Review Answers Cones, Eruptions, and Pyroclasts
- Chapter 3 Test Answers Cones, Eruptions, and Pyroclasts

☐ Chapter 3 Online test, you can take the chapter 3 test here and get it graded.

☐ Chapter 4: Rocks and Minerals

☐ Rocks, Lesson#10.
- Read Me FIRST!, Lesson plan for Rocks and Minerals lessons.
- Chart.

☐ Minerals, Lesson#11.

☐ Sedimentary Rocks, Lesson#12.

☐ Metamorphic Rocks, Lesson#13.

☐ Rocks & Minerals Slide Show.

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To VolcanoWorld

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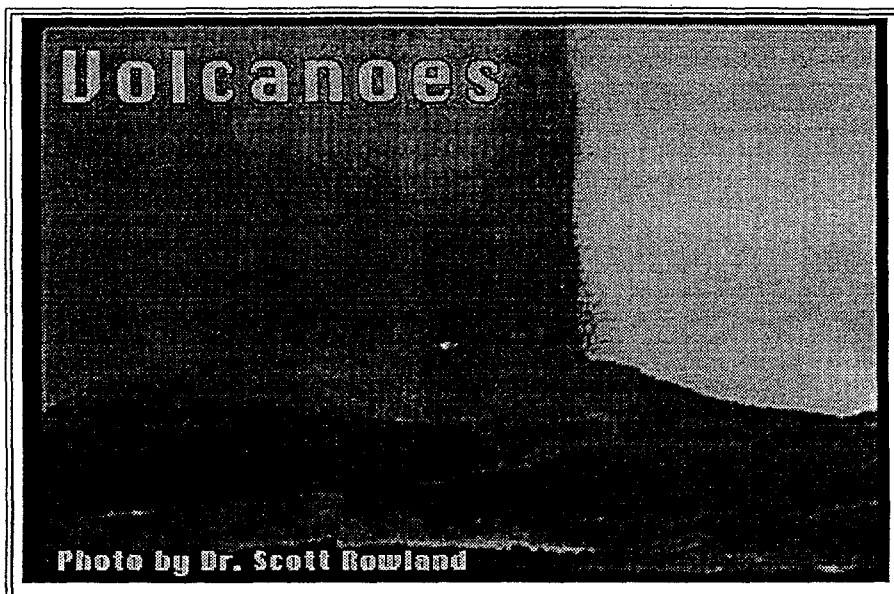


Welcome to the lesson "Volcanoes". You need to click on the buttons and icons to move through the pages of the lesson. If at any point in this lesson you would like to return to the beginning just click on the "Earth" icon. If at any point you would like to go directly to the questions just click on the "Questions" button.This will allow you to move through the lesson at your own pace.

Click on the "Next" icon to begin your study of volcanoes!!!

Questions Next To VolcanoWorld

Volcanic activity is the most powerful force in nature. Some volcanic eruptions are much more powerful than the largest nuclear explosion. Volcanoes have killed thousands of people and have created some of the most frightening events in human history.

Volcanoes have been the basis for myths and legends the world over.

Volcanoes are also responsible for much of the land we live on, 90% of all the continents and ocean basins are the product of volcanism. The air we breathe, and the water we drink have been produced by millions of years of eruptions of steam and other gases.

The volcanic mountain to your left is Mount Adams which is located in the Cascade Range of Washington.

Click on the "Next" button to see the island that gave volcanoes their name!!

Back Beginning Questions Next To VolcanoWorld

Many volcanoes erupt in very consistant patterns, while other volcanoes have no eruption pattern at all. This makes forecasting eruptions difficult.

What makes predicting eruptions even more difficult is the fact that many volcanoes start with one type of eruption pattern and then change eruption patterns as they grow older.

Some of the most powerful eruptions in recorded time have come from volcanoes that have been dormant for hundreds and even thousands of years.

Here we have geologists studying a tilt meter. A tilt meter is used to measure the growth of the lavadome in the foreground. The tiltmeter will show a different angle as the dome grows. With careful study the geologists can tell if magma is on the rise and that an eruption may occur in the near future.

Click on the "Questions" or "Next" button to review the lessons main points.

Back Beginning Questions Next To VolcanoWorld

Hands-on Center

(Volcanoes)
Lesson #5

Erupting Volcano

Materials:

1. 3 small plastic bottles of seltzer of soda
2. 1 small bottle of food coloring

The teacher should conduct the following experiment. Wearing safety goggles and old clothing is advised. The experiment could ruin clothing and hurt unprotected eyes. Follow the steps below having the students write down what they observe and hear.

1. Show the students the bottle before it is opened explaining that the gases dissolved in the liquid are under much more pressure than gases outside the bottle. As the bottle is opened the gas (Carbon Dioxide) will be visible as it escapes creating bubbles and a hissing sound.

2. add 3 drops of red food coloring

1. put the plastic cap back on the bottle
2. shake the bottle profusely hold the bottle over a sink or drain- tell the students that the liquid inside the bottle represents magma, which is molten rock and gas inside the Earth.

3. turn the cap slowly allowing the "lava" to erupt-tell the students that as magma escapes to the surface it is then called lava.

The teacher should explain that the liquid has dissolved gases in it (Carbon Dioxide), just as magma has many dissolved gases in it.

When the bottle is not open the students will not be able to see the gas because the liquid has the gas disolved in it. Because of the higher pressure in the bottle you can not see the gas bubbles. When the bottle is opened the students will see the gas escape. The liquid will erupt out with the gas because it is under more pressure than the outside environment. When magma rises in the conduit the pressure falls as it nears the surface of the Earth. The lava will escape violently as the pressure drops for the same reasons that the soda water escaped with the carbon dioxide gas. When a volcano erupts the lava may be very frothy from the escaping gases. This is true especially if the magma has a high gas content. The most violent eruptions are due to a great build up of pressure from magma that has a high gas content. Magmas with little dissolved gas usually do not erupt violently.

Lava Dome Building

Materials:

1. Toothpaste in a tube
2. Cardboard
3. scissors

Cut a hole in the cardboard so that the neck of the opened toothpaste tube fits into the hole. Squeeze the tube lightly so that a little toothpste comes out then stop. Explain that the toothpaste is very thick and pasty like dactitic lava is. This is the same lava that has built the lava dome in the crater in Mt. St. Helens. Squeeze the tube again and stop, explaining that the dome was built very slowly with these same starting and stopping motions. The dome grew for seven years and has basically halted its growth as of 8/20/95.

The dome that is in the crater in Mt. St. helens today is not the only dome that has occupied this space. Another dome grew during the first month after the original eruption but blew up in June of 1980.

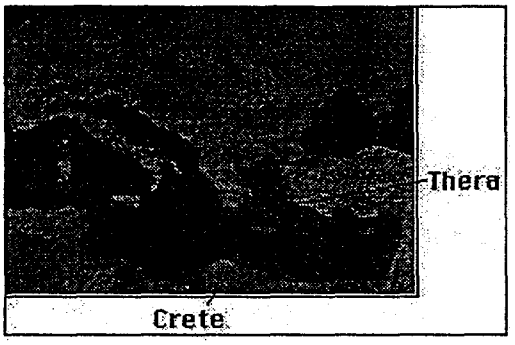
Continue the same pattern of squeezing and stopping until the students understand the concept of dome growth.

Other Lessons To VolcanoWorld

Content Center

(Lesson #5)
Volcanoes
"The Lost Continent of Atlantis"

Have you ever heard of the lost continent of Atlantis? Where was the lost continent of Atlantis? Historians have speculated that it was in the middle of the Atlantic Ocean, off of the coasts of both Spain and France, and also in the western Mediterranean Sea. We do not know for sure where it was, but in 1956 a Greek seismologist by the name of Angelos Galanopoulos suggested that the great continent was located in the eastern Mediterranean Sea. More specifically south of Greece on the island of Santorini, which was called Thera in 1470 B.C. He believed a great volcanic eruption was the end to this wonderful civilization.



Plato, a great Greek poet and historian, was fascinated with an ancient Egyptian story of a fantastic civilization which was lost during a terrible catastrophe.
Plato called this civilization Atlantis. He depicted Atlantis as the greatest civilization of its time. The people were famous for their beauty and their culture. Plato wrote about this beautiful place one thousand years after it was destroyed. His writings were based on ancient Egyptian writings and his translation of the language was questionable.

Plato made a mistake in his math!!! He claimed the lost continent to be about ten times the size that it actually was. He also put the time of the calamity to be about 9000 years before the rise of the great Athenian empire, which was about 10 times earlier than it could have really occurred. Historians now believe that Atlantis was destroyed about 900 years before Athens. A factor of ten was the problem with Plato's accounts, ten times too large and ten times too early.

What happened to wipe this superior civilization off the face of the Earth? A great volcanic eruption was the cause. A volcano named Santorini exploded with such fury that it not only blew most of the island into the heavens but also caused a huge tsunami that wiped out many of the neighboring civilizations.

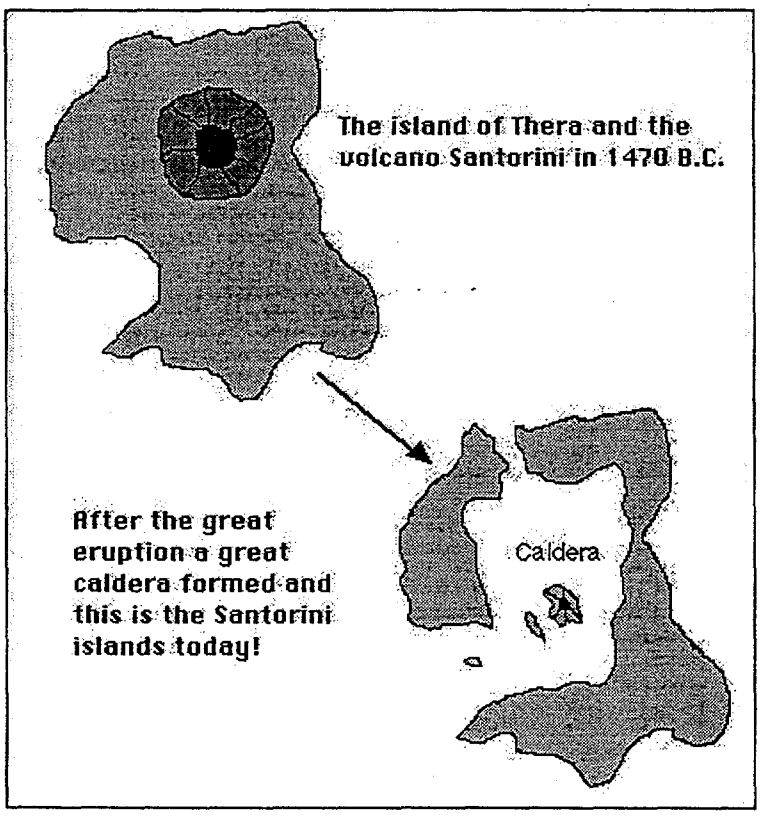
When Santorini erupted, much of the volcanic cone exploded into the atmosphere and over 32 square miles of the island was destroyed. What happened next was the formation of a caldera. A ***caldera*** is a bowl shaped depression caused by the magma chamber under the volcano emptying during an eruption and the volcano falling into the magma chamber because of its own weight. When the caldera formed, a series of tsunamis produced by the crashing of the top of the volcano wiped out many cities and towns in the eastern Mediterranean. This tsunami was reported to have reached the height of over 300 feet. The explosion was heard as far away as Sweden, and the earthquakes produced knocked down walls in Crete over 100 miles away!! Historians believe these giant sea waves were what caused the mysterious end of the great Minoan civilization in the Mediterranean.
Archaeologists have recovered artifacts from the island lately that show a great ancient civilization was present on Thera about 3500 years ago. The artifacts have come from the sunken part of the island far under the surface of the sea. This evidence helps us to believe that Santorini may be the "Lost Continent of Atlantis"!!!!

Questions

1. What caused great civilizations in the Mediterranean to disappear about 1400 B.C.?

2. What is a caldera?

3. What caused the production of a huge tsunami over 300 feet tall?



Other Lessons To VolcanoWorld

Hands-On Center

(Volcanic Terms-Lesson #6)

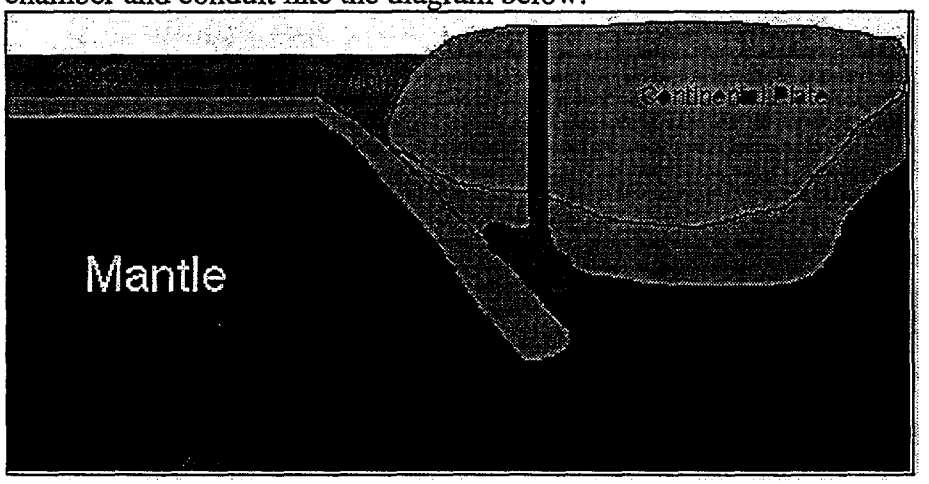
A Model of a Strato Volcano

Materials:

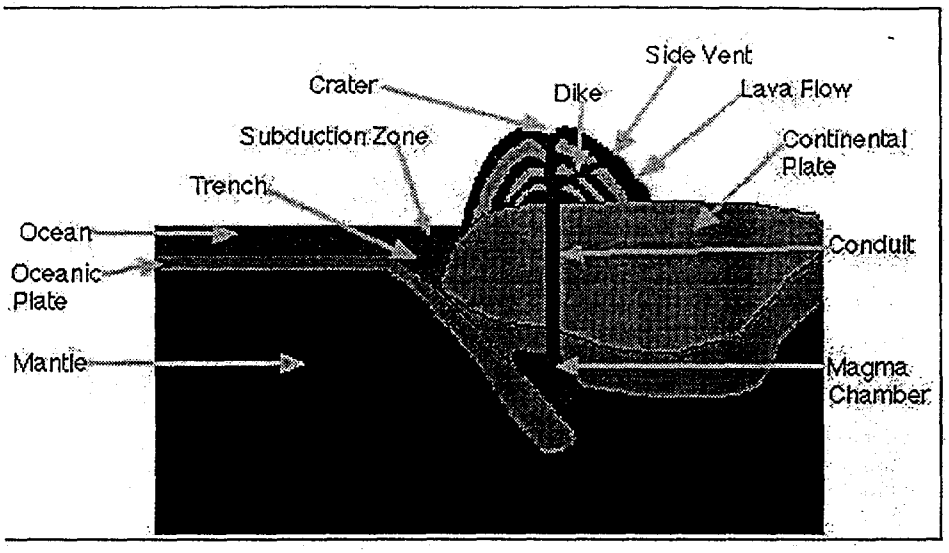
1. Five colors of modeling clay or playdough-Red, Brown, Gray, Black, Blue
2. Thumb Tacks
3. 10 X 12 sheets of tag board
4. Felt tip pen for labeling
5. Thick Thread

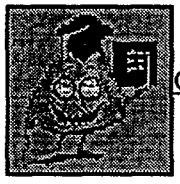
There will be no Content Lesson today because the Hands-On lesson will take at least a half-hour. The students will build a volcano model on tag board. The students will add lava and ash layers one by one simulating the process that builds a real strato volcano cone.

The students will start by building the upper layer of the mantle and lower crust with a magma chamber and conduit like the diagram below.



The students will then start to build the strato volcano model by rolling "snakes" that will represent the alternating layers of hardened lava (Black clay)and ash (Gray clay). They will need to add an extension to the conduit (Red clay) with each set of layers added. As they build the volcano higher have the students add a fissure (Red clay) and a lava flow (Red clay) down the flank of the cone.
When the students are finished making the model have them label it by writing the following terms on the tag board and connecting the terms to the model with pins. (See Diagram below)




Other Lessons

To VolcanoWorld

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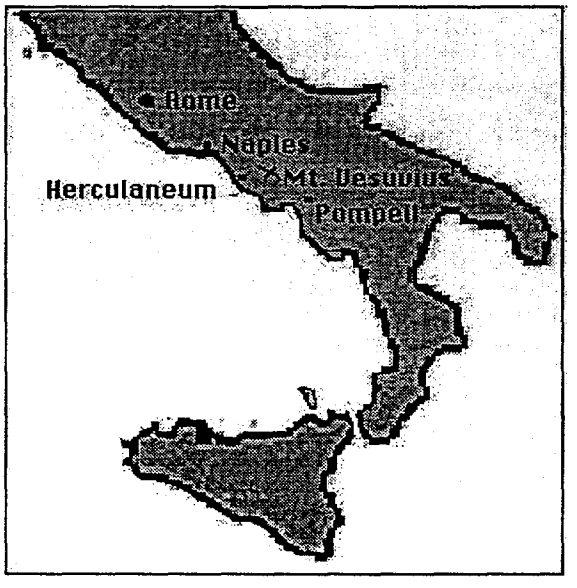
Content Center
Lesson #5 "Volcanoes"
Vesuvius "The Day it Rained Fire"

Pompeii and Herculaneum were bustling Roman cities in 79 A.D. Mt. Vesuvius hadn't erupted in over eight hundred years and the mountain was green with fig and olive trees. Farmers cultivated the sides of the cone. The people were used to earthquakes and didn't pay much attention to the numerous quakes that had been rattling their bowls and plates prior to the eruption. What they didn't know would kill thousands of people that beautiful August day in 79 A.D. Vesuvius was awakening from its long slumber.

Vesuvius awakened with a huge eruption of ash and pumice raining down on the city of Pompeii. Pompeii lay to the south of the volcano and that day the wind was from the north pushing the cloud toward the city. Pompeii was buried in up to 20 feet of pumice and ash. Many animals and people were suffocated and buried alive. Many people though, did survive the initial eruption. Some decided to flee but many stayed.



The city of Herculaneum lays to the west of the volcano and much closer to Vesuvius than Pompeii. Herculaneum was a beautiful beachside resort city in 79 A.D. Herculaneum was barely touched by the first eruption. In fact, about only one inch of ash and pumice fell on the city during the first eruption.
The next eruption was the deadly one. This eruption blanketed the whole surrounding area with very hot,

turbulent, twirling gases and ash. This glowing cloud was very heavy and hugged the ground as it flowed down the side of Vesuvius. The temperatures of this pyroclastic flow were probably around 700 degrees F. and at a speed of over 70 miles per hour animals and people could not out run it. With temperatures this high everything in its path is killed instantly.

Herculaneum didn't get lucky this time. It was buried in an extremely hot flood of volcanic mud. This steam filled volcanic mud buried the city with a layer over 50 feet high. Pompeii suffered through this eruption also. Over 20,000 citizens died in the pyroclastic flows only hours after the initial eruption.

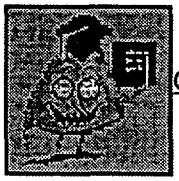
A man by the name of Pliny the Younger wrote an account of this eruption as he viewed Vesuvius from Naples to the northwest of the volcanic mountain. His account was probably the first one ever written. His uncle, Pliny the Elder, died in the second eruption that day. Pliny the Elder was a commander of a fleet of Roman battleships. He was also a naturalist, a person who studies natures spectacles and writes about them. He was viewing the eruption when he was probably over come by hot gases.

Today Vesuvius is the most visited volcano in the world. The mountain that hadn't erupted in about eight hundred years has erupted many times since. In 1631, Vesuvius belched out another pyroclastic flow, which has been the worst eruption since 79 A.D. Many tourists pay to make the very difficult climb to the crater to view the steaming lava inside the volcano. They flock to the excavated ruins of Pompeii and Herculaneum to view the plaster casts of bodies as they lay when they died almost two thousand years ago during the day that rained fire.

Discussion Questions

1. What caused the death of so many people during the second eruption of Vesuvius?

2. What is a pyroclastic flow?


Other Lessons

To VolcanoWorld

ANNEX G

INDEX AND DATES OF PHOTOGRAPHS INCLUDED IN THE REPORT

#, page	Date	Caption	Roll	Negative
1, p.7	7/96	Wide view of south and southeastern walls of Crater Santiago showing early cinder cone (part of unit Qv8 - see Section 2.1 of text for explanation) on left side of photograph, and thin lava flows overlying ash and massive scorias attributed to Volcan Nindiri (unit Qv20) on right side of photograph. QV20 is disrupted by faults and the lower ash and scoria beds appear to be hydrothermally altered. A small crater formed between unit Qv20 and the cinder cone of unit Qv8 . The crater filled with thin beds of ash, scoria and lavas (also designated as unit Qv8) before being buried by two thick lava flows and lapilli deposits from Volcan Masaya (unit Qv9). Much later, a lava flow (unit Ql25) from Volcan Nindiri covered the western portion of the sequence.	R3	N7
2, p.7	3/93 J. Alt	Southeastern wall of Crater Santiago, with detailed view of deposits designated Qv8, including red and black scoria from early cinder cone(s?) and thin layers of lava, scoria and ash that filled the small crater to the west. Note the grey and buff stratified ash that was first deposited over the wall and floor of the crater. Massive lava at the middle of the section may have issued from the cinder cone. The lava has been attributed to Masaya Volcano (as part of unit Qv9). The flow is traceable around the eastern and northern walls of Crater Santiago.	R4	N35A/36 or N24A/25 or N19A/20
3, p.9	3/93 J. Johnson	Southeastern rim of Crater Nindiri truncated by Crater Santiago's collapse, exposing upper section of ash (unit Qv24) overlying relatively thin lava flows (Qv20). Later massive lava flows (unit Ql27) filled Crater Nindiri and finally, in 1670, overflowed the northern rim, traveling down the flank halfway to the margin of the caldera (located just south of the Carretera Managua-Masaya).	R4	N20A/21 or N23A/24
4, p.9	7/96	Northeastern rim of Crater Nindiri, exposing a section more than 30 meter thick of alternating grey and buff bedded ash overlying thin lava flows and massive red scoria attributed to Volcan Nindiri (Qv20). Some of the ash beds appear to show cross-bedding but most appear to be stratified airfall deposits. Central buff-colored layers are due to palagonitic alteration of basaltic glass fragments in the ash. Note the apparent trace of NW-dipping faulting or fracturing that disrupts materials in crater wall. Thin, light-colored dike cuts the massive red scoria at the base of the section but may not continue into lavas.	R2	N9
5, p.10	7/96	West wall of Crater Santiago, exposing lavas (unit Ql27) that filled Crater Nindiri. The central area of Crater Nindiri, known as Plaza Sapper, partially collapsed in 1852 when Santiago and San Pedro craters formed. The lower walls and floor of Crater Nindiri consist of thin lava flows and a massive red scoria (unit Qv20).	R3	N9
6, p.10	3/93 J. Johnson	Northern wall of Crater Santiago. Right side of photograph shows part of the sequence of 24 lava flows (unit Qv9) from Volcan Masaya (also see photograph 14). At least one relatively recent lava flow (unit Ql26) from Volcan Nindiri overlies the sequence of Masaya lavas just east of the old rim of Crater Nindiri (upper center of photograph).	R4	N29 or N30 or N33

#, page	Date	Caption	Roll	Negative
7, p.13	7/96	Eastern side of OBI is underlain by the broad channel of an unusually fluid lava flow (unit Ql25) that covered most of the southwest quadrant of the caldera. The flow contains lava tunnels and rests on the thick bed of unconsolidated black lapilli (uppermost layer of unit Qv9) that caps the eastern side of Crater Santiago. Note distinctive red "baked" zone from heat of emplacement of lava on poorly developed soil atop underlying lapilli.	R1	N19
8, p.13	7/96	Western side of the OBI is underlain by a small lens of massive lava that grades laterally into agglutinated spatter and flow rubble (unit Ql25 described above), resting on black lapilli unit (part of Qv9). Red "baked" horizon seen in Photograph 7 is visible below lava lens on left side of photograph. Beneath the black lapilli, the section consists predominantly of red scoria from cinder cones that formed above a NW-trending fissure.	R1	N20
9, p.14	2/77 J. Johnson	Floor of Crater Santiago in 1977, showing small diameter intercrater and lack of rubble above the floor of black pahoehoe lava (unit Ql29) erupted in 1965. The intercrater at that time measured approximately 100 meters across and 80 meters deep.	R4	N22A/23 or N21A/22
10, p.14	7/96	Floor of Crater Santiago in 1996, showing significant widening and deepening of the intercrater. Rockfalls and landslides from the south wall of Crater Santiago disappear directly into the intercrater that now extends to the southern crater wall.	R2	N10
11, p.15	7/96	Damaged OBI parking area at south rim of Crater Santiago. At least 5 meters of the overlook area has been lost into Crater Santiago since the late 1980s. At present, the area within 5 to 10 meters of the crater edge contains fissures from which volcanic gases, drawn into the fractured crater wall by air currents, are expelled.	R2	N21
12, p.15	7/96	Fissure that cuts pavement at the OBI and continues eastward for at least 15 meters. Above the fissure, a linear depression dotted with small sinkholes indicates the collapse of overlying materials into underlying void.	R2	N19
13, p.17	7/96	Surface trace of fissure that cuts pavement of OBI parking area and continues eastward. Pieces of broken asphalt, wooden posts, and black ash underlying the paved area have disappeared into the fissure.	R2	N23
14, p.17	7/96	View of the floor of Crater Santiago showing the large amount of rubble produced by rock and landslides off the southeastern crater walls.	R2	N4
15, p.23	7/96	Entrance to a small lava tunnel near the Crater Santiago rim east of the OBI. At right of photograph note the throughgoing fracture that cuts the tunnel's rock carapace. The tunnel is found in the same flow (Ql25) as the "Tzinanconostoc" lava tunnel.	R1	N16
16, p.26	7/96	The paved road (roadcut is immediately behind the small hut in the distance) and unpaved trail between the OPO and OBI are underlain by unconsolidated scoria and lapilli (part of unit Qv9) from early eruptions of Volcan Masaya. Note proximity of trail to the edge of Crater Santiago.	R1	N3
17, p.26	7/96	Warning sign posted at the head of the pedestrian trail between the OBI and OPO.	R2	N34
18, p.27	7/96	Long arcuate crevices developed within the unconsolidated black lapilli (uppermost deposit of unit Qv9) from an early eruption of Volcan Masaya. Crevices are probably incipient slump structures, although they have also been attributed to surface rupture of a major N-S trending fault that underlies the Masaya caldera.	R2	N33

#, page	Date	Caption	Roll	Negative
19, p.31	7/96	Safety wall at east end of the OPO, constructed on unconsolidated ash and lapilli unit that is slowly eroding into Crater Santiago. Note vertical fissure in lapilli (center of photograph) that marks the plane of failure of the slump block. Upper right of photograph shows proximity of the lapilli's erosion front to the base of the safety wall.	R1	N4
20, p.31	7/96	This large block of the lava flow (unit Ql26) by the edge of Crater Santiago at the OPO was hanging precariously when the safety wall was installed in 1977-78. The block has yet to fall, evidence of the relative stability of the northern rim of Crater Santiago compared to the high rate of rockfall and landslides on the south rim.	R3	N22
21, p.33	7/96	OBE infrastructure, installed approximately 2 meters below the level of the paved parking area at the east end of the OPO. The OBE was constructed by excavating into the black lapilli (unit Qv9). A safety wall was installed on the front and sides of the excavated area. Where it fronts on the crater, the safety wall appears to rest on the thick lava flow (also part of unit Qv9) underlying the black lapilli.	R3	N3
22, p.33	7/96	Exposed remnant of the reinforced concrete post that anchors the safety wall fronting the crater at the OBE. Note the rusted appearance of the iron reinforcement bar embedded in the post. The safety wall remains relatively stable, due to the massive footing that rests directly on the underlying lava flow.	R3	N6
23, p.38	7/96	Damaged portion of the safety wall near the top of the OCB. Note the inadequate height of the wall at the edge of a precipetous drop into Crater Santiago. The strength of the concrete anchoring posts has been significantly degraded due to corrosion of the iron reinforcement bars by volcanic gases.	R3	N24A
24, p.38	7/96	Decomposition of part of the wooden posts embedded in concrete at the edge of the OBI parking area. The reduction of the cross-sectional areawhere the post was embedded in a concrete base raises questions about the strength of the vertical wooden poles of the Cruz de Bobadilla. This concern may provide additional impetus to restrict visitor access near the base of the cross.	R2	N12
25, p.42.	7/96	Profile of main viewing area of the OBI, showing near constant conditions of low visibility and high concentration of volcanic gases. Lava flow iunderlying the viewing area is unit Qv25. Light beige/pink color on surface of lava in the immediate foreground is due to alteration of the rock by long exposure to volcanic gases. Fresh grey color of some areas of the rock face indicates recent rockfall.	R1	N22

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