Environmental Geology Lab 7 – Volcanic Hazards

In this laboratory period you will learn about the global distribution of volcanoes and what controls this distribution. You will also learn to appreciate the major hazards associated with volcanic eruptions and how to assess the potential volcanic hazards in a given area.

Much of the present-day volcanic activity is clearly related to plate tectonic movements and most volcanoes are located at or close to lithospheric plate boundaries (Figure 1). About 80% of the volcanoes occur above *subduction zones* at *convergent boundaries,* either as volcanic belts on continental margins or as island-arcs comprised of a chain of volcanoes formed in an oceanic setting. Along convergent boundaries plates are colliding with each other. Typical examples of continental volcanic belts are the volcanoes of the Cascade Range in the northwestern United States and of the Andes in the western South America. The Japanese and the Philippine islands are good examples of island-arc volcanic chains. The so-called Ring of Fire, defined by the volcanic chains that rim the Pacific Ocean, is actually a ring of subduction zones.

About another 15% of the world's recent volcanoes occur at *divergent boundaries* such as the Mid-Atlantic Ridge. By far the largest volume of volcanic rocks in the earth occur along the mid-oceanic ridge system, but the volcanism along this spreading center network is predominantly of the quiet, fissure eruption type rather than through volcanic vents. Along divergent plate boundaries plate move awat from each other.

Finally, a few areas of volcanic activity lie within lithospheric plates and are not related to plate boundaries. These are attributed to *hot spots* (or *mantle plumes*) -- areas below the crust that have enough heat to generate magma which eventually reaches the Earth's surface as volcanic eruptions. The Hawaiian Islands, near the center of the Pacific Plate, and Yellowstone Park, within the North American Plate, are examples of volcanism associated with hot spots.

Read the above text, study Figure 1, and answer the following questions

1. With different colored pencils mark the locations of the divergent and convergent boundaries on Figure 1 based on the discussion above,

2. Would you expect an overlap between the volcanic belts and earthquake zones? If so, why?

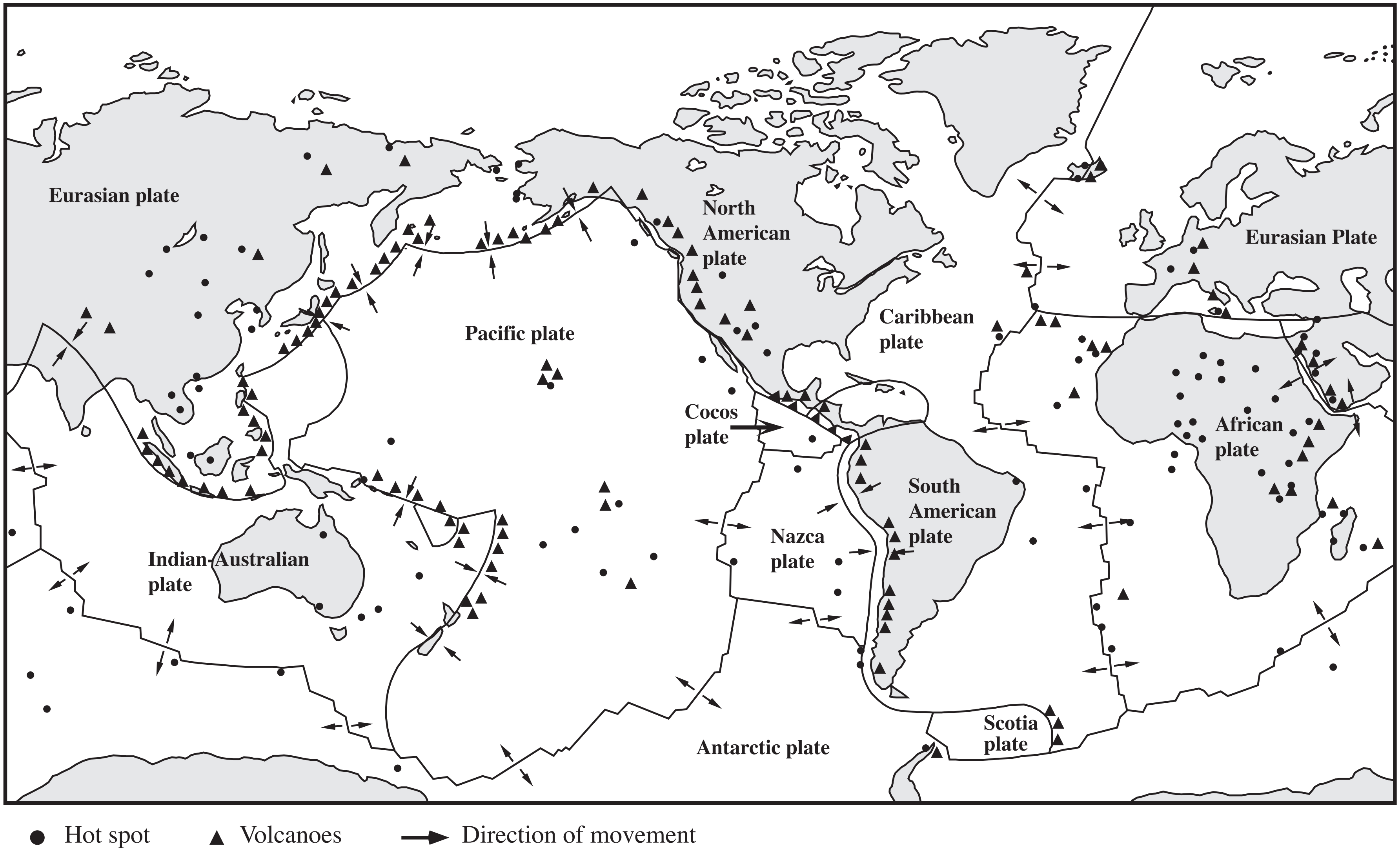

Figure 1. Location of modern volcanoes and mantle hot spots in relation to present-day plate tectonic boundaries.

Recognition of the three common volcanic igneous rocks can also be tied to the overall color of the rock (Figure 1). A gabbro magma that makes it to the surface will produce a basalt lava. Thus basalts, like gabbros, contain all dark-colored minerals. The difference between a gabbro and a basalt is in their rock textures (coarse-grained gabbros and fine-grained basalts). Likewise a 'salt and pepper' diorite magma will produce an intermediate colored lava rock; an andesite. Generally andesites have a green gray color. And a light-colored granite magma will form a light-colored rhyolite lava rock.

Whether a volcanic eruption will be passive (quiet) or become explosive depends on the *viscosity* of the magma (its resistance to flow), which increases with increasing silica content of the magma and decreases with increasing temperature. The silica content exercises a greater control on the magma viscosity than temperature. Thus, basaltic magmas, despite their generally higher temperatures, are less viscous than andesitic magmas. Rhyolitic magmas tend to be the most viscous and flow very slowly.

As a magma rises toward the surface, the load pressure (pressure due to the weight of the overlying rocks) on it decreases, and the volatile constituents (mainly water) dissolved in the magma begin to exsolve. The exsolved gas phase (mostly superheated steam) escapes relatively easily in a fluid magma, but a viscous magma tends to trap the gas and this leads to a building up of enormous pressure in the magma chamber. Eventually, the pressure becomes high enough for the magma to break through to the surface.

The gas content of the magma can be linked to the chemistry of the magma. Basaltic lavas are related to mid-ocean ridges (oceanic divergent boundaries) and hot spots are less explosive compared to those related to subduction zones. Basaltic lavas are generated by partial melting of the upper mantle. Such magmas tend to be *mafic* in chemical composition (i.e., high in iron and magnesium, but low in silica) and are less viscous and flow easily on the surface. These lavas erupt on the surface in a relatively gentle fashion and flow easily across the surface forming features such as lava fountains and lava flows that can act like rivers of lava flowing across the surface. **Basaltic lavas have a relatively low gas content.** This property seems confusing considering the vesicular texture that many basalts exhibit that can be commonly referred to as lava rock with holes in the rock formed by the exsolution of gas from the lava. The gas content is not high enough to cause an explosion of this type of lava thus explaining its relatively gentle eruptive behavior. Basaltic lava typically form broad shield volcanoes (example Big Island of Hawaii) or vast areas of basaltic lava flows referred to as flood basalts. Refer to the textbook to see a description of these types of volcanoes.

Magmas beneath subduction zones are generated by melting of a variety of materials -- oceanic crust and sediments, continental crust, and upper mantle -- but all less mafic than the upper mantle. Such magmas tend to be either *intermediate* (andesite) in composition (i.e., intermediate in magnesium and iron and in silica) and, therefore, more viscous than basaltic magmas. Additionally, these lava have an intermediate gas content. Therefore, the eruptive behavior of andesite lava is variable and can be either gentle in the form of the eruption of andesite lava or violent in the form of a pyroclastic debris eruption. Andesites form composite cones, see textbook for description, that consists of layers of lava and pyroclastic debris and are the most common type of volcanoes located at continental subduction zones such as the Casades in the

Pacific Northwest.

Some volcanoes associated with subduction zones and continental hot spots can consist of rhyolitic magma that represents significant assimilation of continental material. Such magmas tend to be either *felsic* (rhyolitic) in composition (i.e., low in magnesium and iron, but high in silica) and are extremely viscous; these lavas flow very slowly. These lavas have a high gas content. Therefore, the eruptive behavior of rhyolitic lava is extremely explosive resulting in a pyroclastic debris eruption. Rhyolites form small lava domes or large caldera volcanoes, such as that below Yellowstone National Park, see textbook for description, that are broad depressed areas that overlie a large magma chamber.

QUESTIONS:

3. Compare the gas content of a basalt, andesitic, and rhyolitic lavas.

4. Compare the viscosity of a basalt, andesitic, and rhyolitic lavas.

5. Examine the three volcanic rock samples and provide a description of each rock

Rock Type	Color	Eruptive Behavior
Basalt		
Andesite		
Rhyolite		

6. Indicate the type of volcanoes associated with basalt, andesite, and rhyolite lavas.

All the hazards related to volcanism are caused directly or indirectly by the material expelledduring volcanic eruptions. Summarized below is a list of hazards associated with volcanoes:

(a) Lava flows.
(b) Pyroclastic flows.
(c) Tephra deposits
(d) Mudflows (lahars) and debris avalanches.
(e) Volanic gasses

(a) Lava flows.

Lava flows are typically associated with basaltic and andesitic lavas. Lava flows pose little hazard to life because they follow pathways dictated by topography. Because their likely downslope courses can be predicted before an actual eruption, there is usually plenty of time for evacuation. Douching with water has proven effective in checking advance of lava flows in Iceland. Construction of obstruction structures to divert the lava flow to less harmful channels have been attempted in some areas, but have not been as successful.

Figure 2 on the following pages illustrates the volcanic hazard associated with eruption of basaltic lava from the Big Island of Hawaii. This islands has been in the news as of late with a series of eruptions causing property loss and some evacuations. Answer the following questions based on an examination of Figure 2 and Table 1.

QUESTIONS:

7. Is the Big Island of Hawaii is not near a plate boundary. So what explains the volcanic activity at this locale?

8. What type of volcanoe is the Big Island of Hawaii? ____________________

9. Describe two strategies for protecting an inhabited area from an advancing lava flow.

10. Circle the safest and least safe areas on Figure 2.

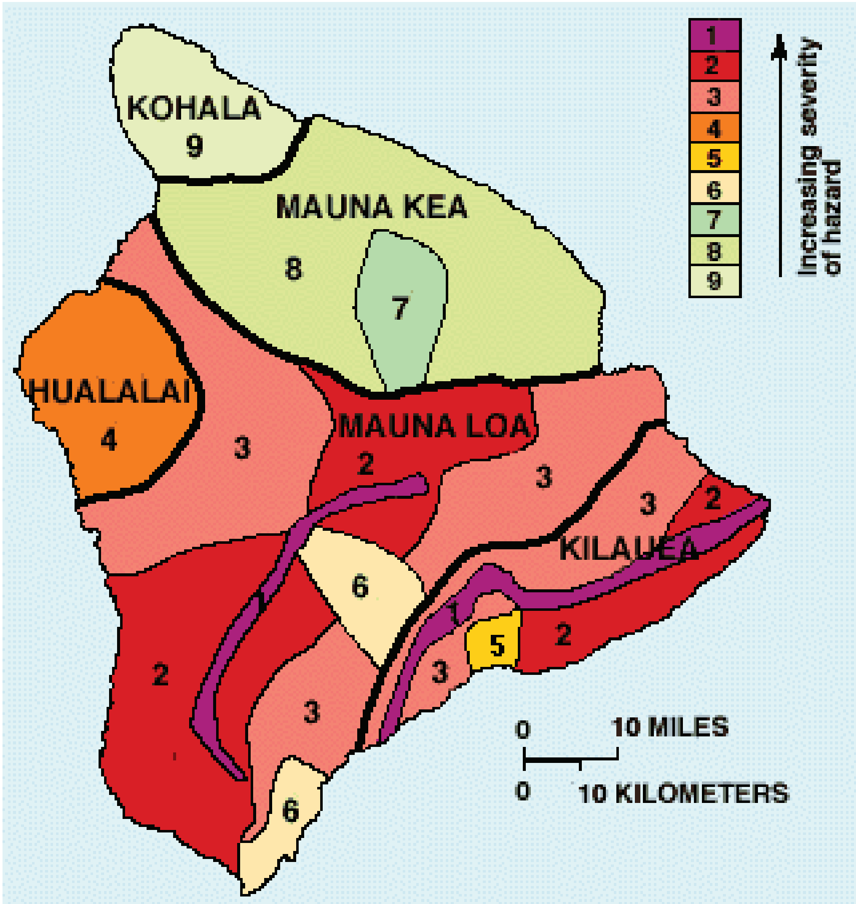

Figure 2. The Big Island of Hawaii is divided into zones according to the degree of hazard from lava flows. Zone 1 is the area of the greatest hazard, Zone 9 of the least. The names refer to districts on the island. From the U.S. Geological Survey (1987).

QUESTIONS:

11. Zones 5 and 6 are located on the volcanically active side of the island and yet have a relatively low risk from lava flows. Explain! Hint: Examine Table 1 carefully.

12. Determine the relative movement of the Big Island of Hawaii over the stationary hot spot based on the ages of lavas. Note that the older lava flows were once geographically where the active flows exist today. Draw an arrow on Figure 2 indicating this movement.

Table 1. Hazard zone for volcanic eruptions on the Big Island of Hawaii.

HAZARD ZONES FOR LAVA FLOWS

Zone	Percentage of area covered by lava since 1800	Percentage of area covered by lava in last 750 years	Explanation
1	greater than 25	greater than 65	Includes the summits and rift zones of Kilauea and Mauna Loa where vents have been repeatedly active in historic time.
2	15-25	25-75	Areas adjacent to and downslope of active rift zones.
3	1-5	15-75	Areas gradationally less hazardous than Zone 2 because of greater distance from recently active vents and/or because the topography makes it less likely that flows will cover these areas.
4	about 5	less than 15	Includes all of Hualalai, where the frequency of eruptions is lower than on Kilauea and Mauna Loa. Flows typically cover large areas.
5	none	about 50	Areas currently protected from lava flows by the topography of the volcano.
6	none	very little	Same as Zone 5.
7	none	none	20 percent of this area covered by lava in the last 10,000 yrs.
8	none	none	Only a few percent of this area covered in the past 10,000 yrs.
9	none	none	No eruption in this area for the past 60,000 yrs.

Composite cone volcanoes have a complex set of hazards, which are both directly and indirectly associated with the eruption of the volcano. Direct hazards include lava flows (described previously), pyroclastics flows, and tephra deposits. Indirect hazards are associated with mudflows (lahars) and debris avalanches.

(b) Pyroclastic flows.
When explosive eruptions occur, pyroclastic debris mix with volcanic gases, air, and water to form hot (temperatures can be over 1,000°C in the interior) gas-and-ash-charged "clouds" that, because of their density, move as a dust storm along the ground. Such flows or clouds, termed variously as *ash flows* and *nuée ardente* (the French term for "glowing cloud"), may travel downslope at velocities of more than 100 kilometers per hour and cover areas of a few hundred square kilometers near the volcano, burning or suffocating everything in their path. These clouds travel over ridges and valleys and are uninfluenced by the local topography around the volcano. Ash flows of this type were responsible for the massive loss of life related to the 1902 eruption of Mount Pelée on the Island of Martinique, West Indies, as well as for most of the fatalities ascribed to the 1980 eruption of Mount St. Helen. *Tuff* is the general name given to any rock composed mainly or exclusively of pyroclastic material. The deposits that result from hot ash flows are called *welded tuffs*, because the mineral grains are flattened and welded together by the intense heat; other tuffs are unwelded.

(c) Tephra deposits.
Tephra refers to pyroclastic debris which is blasted into the atmosphere during eruptions. The tephra ejected from explosive volcanoes ranges from fine-grained dust (<0.25 mm in size) and *ash* (0.25 to 4 mm in size) to large size fragments known as *lapilli* (4 to 32 mm in size) and *bombs* (>32 mm in size). Most of the tephra falls back close to the volcano on its leeward side and accumulates as *ash-fall* deposits, which may be several tens of feet in thickness. A large volume of ash-fall in areas proximal to the volcanic eruption may cause roof collapse and disruption of normal life for days. When violent eruptions discharge tephra high into the air, ash may fall on areas hundreds of miles downwind, requiring a massive clean-up operation. Fine dust may even circle the planet and remain for years in the atmosphere (as was the case with the 1815 Tambora eruption in Indonesia) resulting in global cooling that explains the year without a summer during which snow was recorded during June in the northeastern United States and Europe.

Volcanic ash can cause a number of problems with transporation, infrastructure, and health. Encounter with a plume of volcanic ash in the atmosphere can pose serious problems for an aircraft. Not only does damage to the windshield considerably reduce visibility, but the ash may melt and coat jet turbine blades, often causing the engine to stall. So far air-borne volcanic ash plumes have not caused an airplane crash, but near-crash situations have been encountered in a number of cases, the most recent ones being caused by ash plumes from Readout, Alaska (1989), and Mount Pinatubo, Philippines (1991). Additionally, ash can clog the air filters of vehciles and is extremely abrasive to engine components. In terms of infrastructure, ash can cause short circuiting disrupting electrical distribution and also can contaminate water supplies. Finally, inhalation of ash can result in silicosis, a condition commonly referred to as black lung disease, which can result in death.

(d) Mudflows (lahars) and debris avalanches.
The term "Lahar" was first used in Indonesia to describe fast-moving mudflows that caused thousands of deaths. Lahars may be hot or cold and are generated when pyroclastic ejecta around a volcano is mobilized because of mixing with water. The water may be supplied by heavy rain

(as in the case of the 1991 Mount Pinatubo eruption) caused by the condensation of the large volumes of water expelled during a volcanic eruption, or by the rapid melting of massive glacial ice or snow on a volcanic peak due to the heat released during an eruption (as in the case of the 1985 Nevado del Ruiz eruption). As this water moves downslope, it initially incorporates large amounts of volcanic ash and soil, and then, eventually, large boulders and trees. Most mudflows follow the established drainage network in the area and are confined to river valleys. Depending on the topography and the geometry of the drainage system surrounding the volcano, lahar mudflows can reach distances of several tens of kilometers beyond the actual volcano, choking the drainage system on their way and increasing the risk of floods in the area. A lahar may rush down the slopes without much warning, because the volcano itself may not be very active when such a flow is generated.

QUESTIONS:

13. What characteristics of pyroclastic flows make them so hazardous to life?

14. What economic, climatic, and health problems may result from volcanic ash (tephra)?

15. How does the movement across the earth's surface of a pyroclastic flow differ from that of a lahar?

16. Name the factors which may increase the velocity of a lahar.

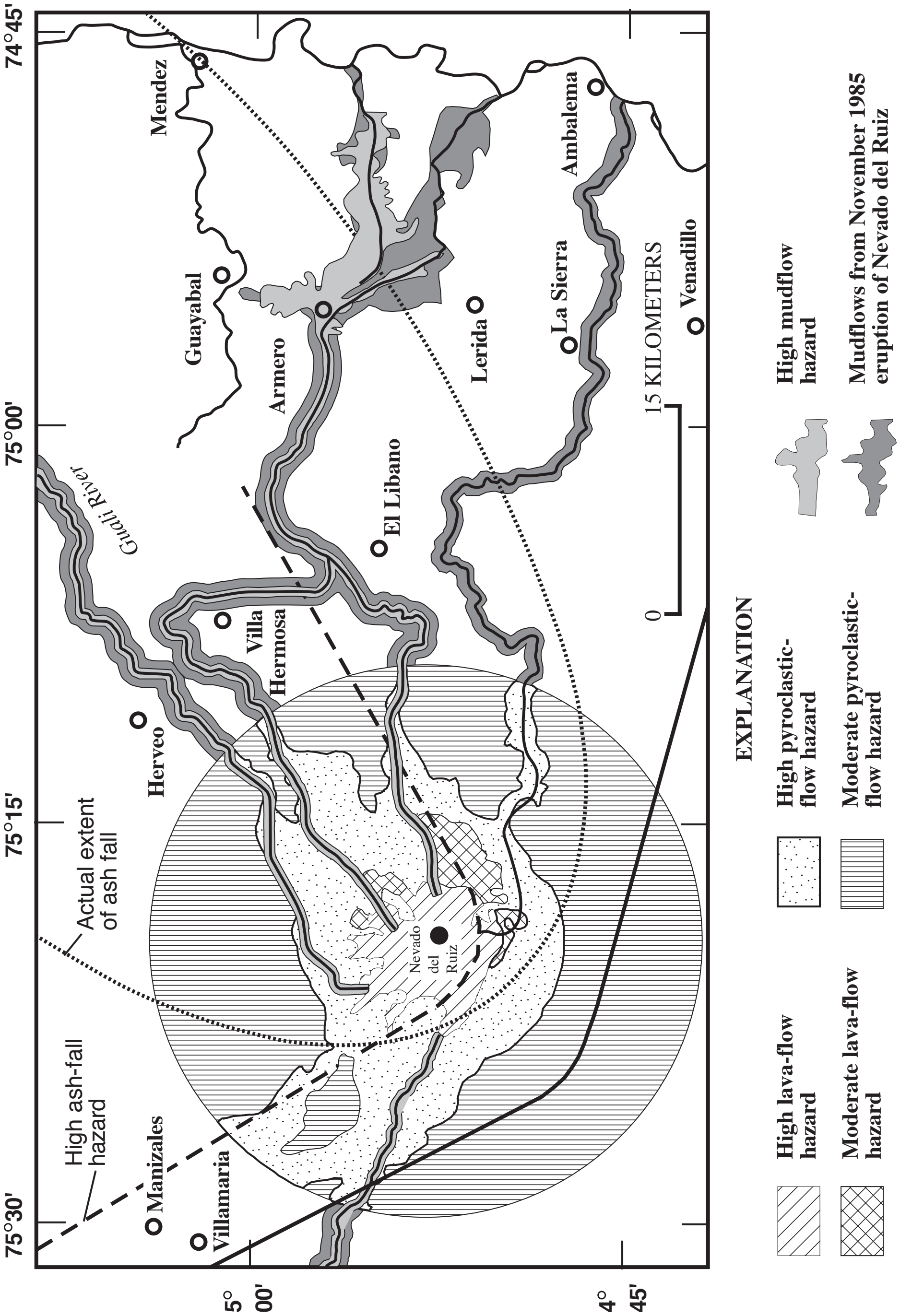

Figure 3. Hazard zone map of the area around Navado del Ruiz volcano, Columbia, prepared by INGEOMINAS (Columbian Institute of Geology and Mines) and circulated 1 month prior to the November 13, 1985 eruption of the volcano.

Given adequate information, the likely nature and aerial extent of risk to be anticipated in the case of renewed activity in a known volcano can be described with the help of a *hazard zone map* (see Figure 3). Such a map is constructed largely on the basis of past history (explosiveness, and distribution of lava flows, pyroclastics, mudflows, and ash) and present topography. Although a hazard map offers no guarantees about the consequences of a future volcanic eruption, it certainly is worth the effort for the guidance it can provide. For example, the map shown in Figure 3 was completed 1 month prior to the catastrophic eruption of November 13, 1985, and had accurately anticipated the nature and aerial extent of potential volcanic hazards, but the usefulness of the hazard map was negated by inadequate preparation for a catastrophic eruption and ineffective emergency management during the disaster. The town of Armero had been overrun by destructive mudflows triggered by eruptions in 1595 and 1845, but its vulnerability had apparently been forgotten during the ensuing 140-year period of inactivity causing a massive loss of life.

QUESTIONS:

17. Describe the location of lava flow, pyroclastic flow, and lahar hazards relative to the volcanic summit. Are these hazards confined to drainage valley or do they move out in all directions. Also indicate how far these hazards can move away from the volcanic summit.

18. Name the towns in Figure 11 that have a high risk and essentially no risk from volcanic hazards.

(e) Volcanic gasses

Particularly dangerous are the pyroclastic ejecta produced by explosive volcanism, because such material, when mixed with water or volcanic gases, can move very rapidly down the flanks of a volcano. Volcanic gases are composed predominantly of water vapor and carbon dioxide, but may also contain significant concentrations of gases such as carbon monoxide, sulfur dioxide (which may combine with water to form sulfuric acid) and hydrochloric acid, which are toxic. Votalite acids such as hydrochloric acid can form an acid haze known as laze. Sulfur compounds form volcanic smog known as vog. Small amounts of carbon dioxide in the volcanic gas is not toxic, but large amounts of it may prove fatal. For example, the death toll of more than 1,700 resulting from the 1986 eruption in Cameroon is believed to have been caused by a plume of cool carbon dioxide gas emitted from the bottom of Lake Nyos, a crater lake within the volcanic cone.

QUESTION:

19. Describe the hazards associated with the release of volcanic gasses. Specifically disucss the gasses that pose a threat and describe this threat.

Large caldera volcanoes, such as that below Yellowstone National Park, can erupt massive amounts of ash; 1000's times greater than eruptions from composite cones. These eruptions are referred to as Supervolcanoes that have the potential to cause massive lose of life. In the western United States there are three potential volcanoes that have erupted in the last several million years as shown in Figure 4. Within the zone of ash falls deaths can be caused by inhalation of ash or collapse of roofs and structures as described above in the Tephra section. Even outside the zone of ash fall the massive amounts of ash and gasses, such as sulfur dioxide, can trigger an episode of global cooling potentially causing crop failures and mass starvation. The last supervolcanic eruption was in Indonesia approximately 75,000 years ago and nearly wiped out the human species. Fortunely, supervolcanic eruptions are rare; although, Yellowstone is showing signs of impeding activity but at the present it is difficult to determine precisely when a major eruption will occur.

QUESTIONS:

20. What part of Texas would be directly affected by the ash fall from a Yellowstone supervolcanic eruption.

21. Describe how Laredo would be impacted by a Yellowstone supervolcanic eruption. Describe both the direct and indirect impacts of such an event.

Figure 4. Extent of damaging ash fall deposits from past Supervolcanic eruptions from the Long Valley and Yellowstone Calderas.

DETERMING VOLCANIC RISK

Questions relevant to the prediction and assessment of potential volcanic hazards include:

(a) Whether a particular area is prone to volcanic activity;

(b) If so, what is the likelihood (or risk) of a volcanic eruption in the area in the near future;

(c) What type of volcanism should be anticipated; and

From data collected from hundreds of volcanoes around the world and our understanding of the plate-tectonic framework of the earth's dynamism, volcanologists are able to answer some of these questions with reasonable confidence and make educated guesses about others.

(a) Recognition of volcanic belts.

All volcanic activities are related to convergent and divergent plate boundaries and mantle hot spots. Thus, belts with a past volcanic history are the most likely places for future volcanism, even if volcanoes in such a belt appear to be *dormant* or even *extinct* at present. Inactive volcanoes in a volcanic belt should be considered "potentially active" rather than extinct. The probability of volcanism intraplate regions is negligible in areas without any evidence of past volcanic activity and extremely low in areas without volcanic activity during the last several thousand years.

b. Risk of a volcanic eruption in a given area.

Within a belt of past volcanic activity, recurrence of volcanism in an older volcano is more likely than the initiation of a new volcano. Shield and composite volcanoes and calderas of the Yellowstone type commonly erupt more than once from the same vent or, on the case of Yellowstone-type calderas, may develop overlapping or nested eruptive centers. Shield volcanoes erupt frequently and almost continuously. Composite cones have major eruptions on the order of once a century such as Mt. St. Helens, which has erupted in 1844, 1857, and 1980-86. Supervolcanoes erupt on the order of 100,000's of years.

QUESTIONS:

22. What is the probability (very high, high, or practically none of a volcanic eruption in the near future at the following localities)? What is the basis of your assessment considering proximity to plate boundaries or hot spots.

Locality	***Probability of volcanism***	***Basis of Assessment***
South Texas		
Hawaiian Islands		
Japan		
Iceland		

23. Comment on the explosivity of volcanism in the Hawaiian Islands verus Japan. Fully justify your answer.

24 State your home town and evaluate, with justification, the likelihood of a major volcanic eruption in that area. Provide the basis for your assessment.

25. What is the underlying plate tectonic cause for the volcanic activity in the Cascade Range of the Pacific Northwes United States? The same cause is also at work for the volcanoes in Mexico. Explain.