Volcanic Hazards - Overview

I. REVIEW OF VOLCANIC PROCESSES

A. Basic Terminology

1. Igneous Rocks- a rock (or agglomeration of one or more minerals) that results from the cooling of magma, or molten rock. As the magma cools, minerals crystallize from the molten rock.

2. Magma - molten or hot liquid rock, originates beneath the earth's surface (up to 120 miles beneath), composed of elements found in silicate minerals, water vapor, and gases.

3. Lava - magma that is extruded onto the earth's surface via volcanic eruptions (hot magma is confined at depth beneath surface, relatively lighter than confining rock, rises upward, may eventually erupt onto earth surface).

4. Extrusive Igneous Rocks or Volcanic Ig. Rocks - rocks which solidify from lava (or were extruded onto earth's surface)

5. Intrusive Igneous Rocks or Plutonic Ig. Rocks - rocks which solidify from magma beneath the earth's surface.

B. Volcanism

1. Volcanism- process by which magma, gas, and water are released from the interior of the earth. Volcanic processes and eruptions often result in the spewing and build up of volcanic material about a volcanic center, constructing a volcanic edifice commonly referred to as a volcano.

a. Status of Volcanic History

(1) Active: volcano observed in eruption during historic time

(2) Dormant: volcano with no historic record however show evidence of geologically recent activity

(a) volcanic deposits

(b) hydrothermal activity

(3) Extinct: no historic record and no evidence of geologically recent activity

2. Nature of Volcanic Activity

a. Style of volcanism; i.e. Explosive vs. Quiescent is determined by the composition of the magma, its temperature, and amount of dissolved gases contained within. All of which influence the magmas viscosity, or resistance to flow.

(1) > viscosity, > violent nature of the eruption

(2) < viscosity, < explosive nature of the eruption

(3) chemical composition: the SiO_2 or silica content of the magma also influences the viscosity.

(a) Rhyolitic/Granitic magma = 70% silica
   i) Very "sticky" explosive eruptions

(b) Andesitic/intermediate magma = 60% silica,

(c) basaltic magma = 50% silica.
   i) In general > silica content, > viscosity of magma, believed to result from tendency of complex silica anions to form long chains of molecules before crystallization begins. Thus granitic magmas are more viscous than basaltic magmas.

(4) Gas content:
   (a) dissolved gasses tend to < viscosity of magma,
   (b) gasses also exert pressure on magma resulting in explosive eruption of magma from vent

      i) "Degassing" as magma rises towards surface, confining pressure decreases, and temperature slightly decrease resulting in expansion of gasses and POW!
         a) Product: frothy gaseous lava
         b) pumice and glass shards

      ii) Fluid basaltic lavas easily allow gases to escape, often resulting in lava fountains such as in Hawaii, generally quiescent eruptions

(5) Phreatic State:
   (a) external occurrences of groundwater, surface water, snow and ice
      i) can create large steam explosions and increase explosivity of eruption

3. Products of Volcanic Eruptions
   a. Lava Flows- lava may be produced from any composition magma, but in general flowing or molten lava is commonly associated with low silica, basaltic composition magmas (e.g. Hawaii)
   b. Escaping Gases from Lava-

      (1) Magmas hold dissolved gases within them, as these magmas are extruded as lava, gases begin to escape.

         (a) Gases estimated to compose 1-5% of total wt. of lava,
            i) most of which is water vapor (70%),
            ii) Lesser amounts of carbon dioxide (15%),
            iii) Sulfur oxide and nitrogen oxides (<5%), also hydrogen, chlorine, and argon.

c. Pyroclastic Materials - fragments of pulverized rock and lava ejected from a volcano. These ejecta range in size from very fine dust or ash to sand sized volcanic ash, to house-sized volcanic bombs and blocks.

(a) Pyroclastic eruptions are commonly associated with highly viscous rhyolitic-magmas with high-pressure buildup of gases
(b) May also be associated with basaltic magmas
(c) Tephra- airborne volcanic material of any size

(1) fine ash- result of gas-filled frothy magma, gases expand and blast semi-cohesive lava into tiny pieces to form ash.
(a) Tuff- deposits of ash
i) welded tuffs- glass shards in ash heat-fuse after deposition.

(2) Pumice- sand to gravel sized fragments of cooled lava with many air voids.

(3) Lapilli- walnut sized pyroclastic ejecta.

(4) Cinders- pea-sized basaltic particles

(5) Blocks and bombs- pyroclastic fragments larger than lapilli, blocks = comprised of ejected hardened lava, bombs=ejected as molten lava. Bombs are semi-molten when ejected and attain a stream line shape as result of aerial shear forces exerted on it as follows its trajectory through the atmosphere.

(6) Composition of Pyroclastic Material
(a) Crystals- single mineral crystals of varying size
(b) Lithic Fragments: volcanic rock fragments
(c) Vitric Fragments: glassy shards from rapid cooling of magma

I. VOLCANOGENIC LANDFORMS
A. Volcanic Edifices
1. Volcanoes-mountainous accumulations of volcanic material

2. Anatomy of Volcano
a. Crater- steep-walled depression at summit of volcano, < 1 km in diameter
b. Calderas - large craters > 1 km.
c. Magma Chamber - magma center located beneath volcano, source of magma/lava.
d. Central vent or pipe- conduit leading from magma chamber to crater or opening of volcano
e. Flank Eruption- eruption of volcanic materials from side of volcano, not through central vent.

f. parasitic cone- smaller secondary volcanic buildup on side of volcano, via flank eruptions

II. Cascade Volcanic Hazards Overview - Mt. Rainier Case Study

A. Tectonic Setting of Cascade Volcanic Arc

1. Convergent tectonic margin with the Juan de Fuca Plate subducting eastward beneath North America.

2. Long history of oblique convergence, tectonic accretion, arc volcanism, dextral shear, and clockwise rotation (Wells and others, 1984).

3. Long-term rates of plate convergence average 3.5 to 4.0 cm/yr

4. Cascades are associated with intermediate to mafic volcanism dating from late Eocene (40-35 Ma) to present.

5. Arc volcanism has been narrowing and migrating eastward over time, with the geometry of High Cascade volcanoes controlled by the present-day subduction-zone configuration

B. High Cascade Volcanoes
1. 4 m.y. old and younger, many deposits < 2.0 m.y.
2. Significant volumes of eruptive deposits < 10,000 years old
3. Most of high Cascaded volcanoes = glaciated in last 20,000 yrs
a. present-day glaciers

C. Hazardous Volcanic Phenomena and Processes
1. Tephra (eruptive hazard)

a. impact area - widespread greater Pacific NW
b. process
(1) plumes of hot gas and volcanic particles
(2) buoyant clouds
(3) wind-driven dispersion
(a) particle size < with distance > from volcano
(b) deposit thickness < with > distance from volcano
c. hazard
(1) large fragments may cause death or injury
(2) source of forest fires up to 10 km from vent
(3) social / economic disruption
(a) damage to machinery
(b) crop damage
(c) roof-collaps damage
(d) disruption of transportation
(4) respiratory problems

2. Ballistic Projectiles (eruptive hazard)

a. impact area - immediate volcano vicinity
b. process
    (1) large scale ballistic blocks and bombs
    (2) distance up to 5 km
    (3) sizes up to 1 m in diameter
c. hazard
    (1) fires
    (2) death / injury by impact

3. Pyroclastic Flows (eruptive hazard)
    a. impact area - immediate volcano vicinity
    b. process
        (1) pyroclastic flow: mixture of hot gases and volcanic rock particles, denser than air ("sinker")
            (a) dense, particle rich, gas poor
        (2) pyroclastic flow: mixture of gases and rock particles
            (a) gas rich, less dense than flow
        (3) pyroclastic flow driven by valley topography and gravity
        (4) high speeds - up to 10 m/sec
        (5) temp > 300 C
        (6) variation: pyroclastic flow melts snow and ice during transport, transforms into lahar or debris flow
    c. hazard
        (1) burial / death - high temp. sizzling
        (2) death by impact
        (3) destruction of trees and property

4. Lava Flows (eruptive hazard)
    a. impact area - immediate volcano vicinity
    b. process
        (1) streams of molten rock following topography / slope
        (2) relatively slow moving, especially when associated with andesitic lavas
        (3) may induce rapid snow melt / flooding
    c. hazard
        (1) low hazard to humans
            (a) slow moving
            (b) not far reaching

5. Volcanic Gases (eruptive or non-eruptive hazard)
    a. impact area - immediate volcano vicinity
    b. process
        (1) gas types
            (a) water vapor
            (b) carbon dioxide
            (c) sulfur compounds
        (2) wind controlled distribution
        (3) limited distribution to vent region
    c. hazard - limited unless you're a volcanologist in the vent

6. Lateral Blases (eruptive hazard)
   a. impact area - immediate volcano vicinity
   b. process
      (1) example Mt. St. Helens eruption in 1980
      (2) depressurization and blast of volcanic flank
         (a) bulging in combination with slope failure / release
      (3) induces slope failure and debris avalanche
   c. hazard
      (1) limited to immediate volcanic zone
      (2) may be monitored via geodesy / flank bulge studies

7. Debris Avalanches and Lahars (eruptive or non-eruptive hazard)
   a. impact area - broad region in valleys surrounding volcano
      (1) may extend up to 10's of km from volcano
   b. process
      (1) debris avalanche - rapidly moving landslide
         (a) velocity: 10-100 mi/hr
      (2) lahar
         (a) slurry of water and sediment (>60% of sediment by volume)
            i) velocity 10's of miles / hr
         (b) cohesive lahars - higher clay content
         (c) noncohesive lahars - dominated by granular material
      (3) causes
         (a) spawned by slope failure, volcanic bulging and oversteepening of slopes
         (b) oversteepening of slopes via mass wasting and glacial erosion
         (c) positive feedback from seismic events
         (d) intense rainstorms / slope failure
      (4) factors conducive to non-magmatic debris avalanche
         (a) volumes of weak hydrothermally altered rock
         (b) substantial topographic relief and slope
         (c) active hydrothermal system
   c. hazards
      (1) dangerous because they may be nonmagmatic / spontaneous
      (2) valley dams of side tributaries + catastrophic flooding / backflooding
      (3) lahars and avalanches are the greatest hazard to communities down-valley from large Cascade volcanoes

8. Glacial Outburst Floods (eruptive or non-eruptive hazard)
   a. impact area - broad region in valleys surrounding volcano
   b. process
      (1) sudden release of large volumes of water from glaciers residing on volcanoes
      (2) outburst floods = high discharge events
      (3) floods are highly erosive, commonly transform to debris flow / lahard down valley

(4) exacerbated by high temperatures and heavy rainfall

c. hazard

(1) flood hazard in down-valley community

(2) lahar hazard in down-valley community

III. Volcanic Hazard Mitigation

A. Risk analysis and Land Use Planning

1. restricted land use and zoning

2. public warning systems

a. e.g. lahar monitoring systems for town of Puyallup, WA on flank of Mt. Rainier

3. evacuation and emergency response planning

B. Volcanic Monitoring

1. gas emissions

2. seismic activity

3. precipitation patterns

4. river discharge

C. Hazard Mapping

1. topography and valley configurations

2. mapping of volcanic deposits

3. process modelling

a. flood models

b. lahar models

4. hazard zonation (hazards generally decrease away from volcanic center)

a. lahar hazard zone

b. pyroclastic flow zones

c. tephra fall zones

d. blast zones

PROPERTIES OF MAGMAS:

1. ERUPTION TEMPERATURES

ryholite	700-900 degrees C
dacite	800-1100 "
andesite	950-1200 "
basalt	1000-1200 "

2, Viscosity is important - affects form and mobility of erupted lavas & rate of vesiculation (influence on explosive fragmentation and erupt.)

FACTORS CONTROLLING VISCOSITY

pressure - higher pressures, at T = const., basaltic magma less viscous

temperature - viscosity increases significantly with cooling (in part related to crystallization)

volatile content - viscosity is lowered with increasing water content

chemical content - magma composed of network formers and nonnetwork formers. Silica content decreases viscosity due to Si-O bonds being strongest anion and cation bond in magma. This bond controls stength and shear resistance

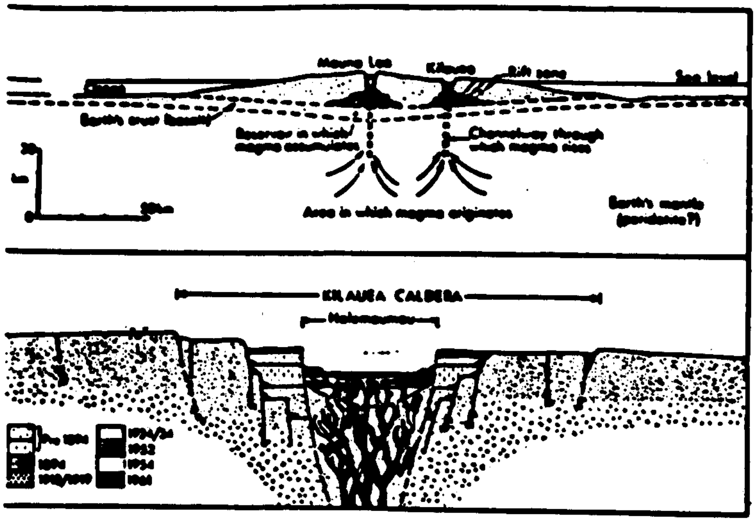
crystal content - suspended crystal increase bulk viscosity

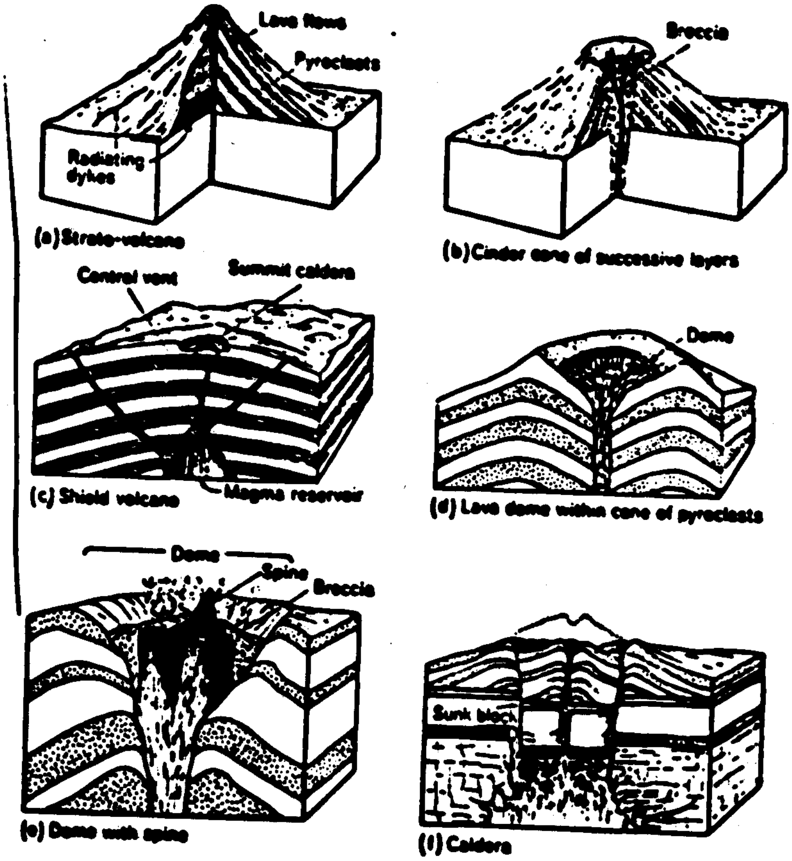
bubble content - effect highly variable

TABLE 2-2

CLASSIFICATION OF VOLCANOES (MODIFIED FROM RITTMANN, 1962)

QUALITY OF MAGMA	SMALL ← QUANTITY OF MAGMA → GREAT					TYPE OF ACTIVITY
FLUID VERY HOT, BASIC	LAVA FLOWS		SHIELD VOLCANOES	BASALTIC PLAINS	LAVA FLOODS	EFFUSIVE
INCREASING GAS CONTENT AND SILICA ↓	TEPHRA-AND-SPATTER CONES	COMPOSITE CONES	STRATOVOLCANOES		STRATO-VOLCANIC CHAIN	↓
	TEPHRA CONES					
	ENDOGENOUS DOMES; PLUG DOMES	DOMES WITH THICK FLOWS	NONE KNOWN			MIXED
VISCOUS, "COOL," ACIDIC	MAARS	TUFF CONES				↓
VERY VISCOUS, ABUNDANT CRYSTALS	DIATREMES	EXPLOSION CALDERA	VOLCANO-TECTONIC SINKS		IGNIMBRITE SHEETS	EXPLOSIVE
	← SINGLE VENT →				FISSURE VENT	





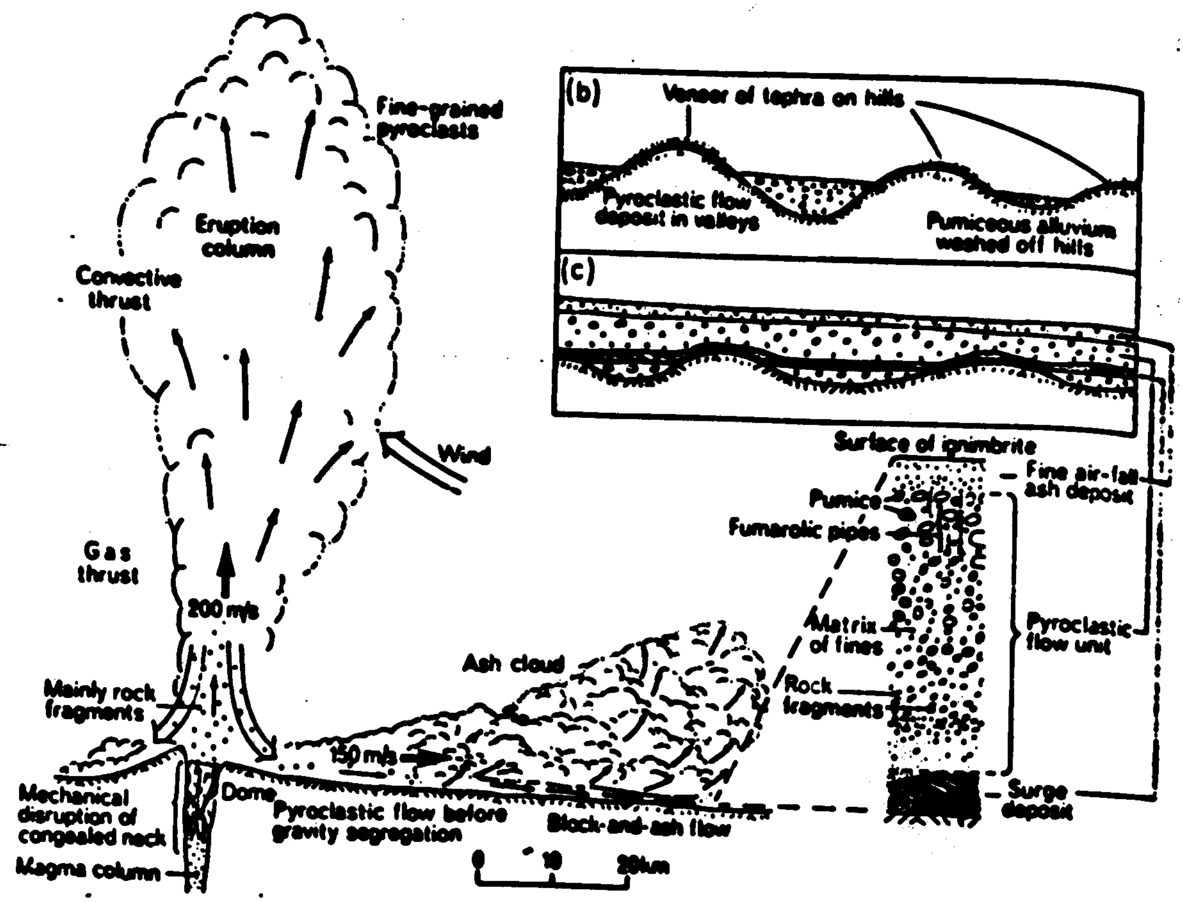


Fig. 5.8 (a) A representation of the probable mechanism of eruption and emplacement processes which produce ignimbrites. (b) Pyroclastic flow deposits of an indented relief. (c) Formation of plateau ignimbrites.

FIGURE 11–13
Mount St. Augustine, Alaska, a typical composite cone. (Photo by M. E. Yount, U.S. Geological Survey)

Hazardous Geologic Events at Mount Hood