Geomorphology of Igneous Terrains

I. REVIEW OF IGNEOUS 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. Magma Crystallization Process

1. Hot, molten magma: ions of elements are moving freely in a fluid, unordered state, as magma cools, the ions slow and begin to form atomic bonds, arranging themselves in orderly patterns --- known as process of crystallization.

2. Rates of cooling strongly influence size of mineral crystals that develop from magma/lava.

   a. Slow Cooling - few centers of crystal growth develop, ions allowed to migrate over larger distances - results in rather large mineral crystals .

   b. Fast Cooling - many centers of crystal growth, ions readily bond together, results in smaller mineral crystals.

   c. Very rapid cooling - if magma is quenched instantly, not sufficient time for ions to bond, results in randomly distributed ions frozen - referred to as glass similar to manmade glass.

C. Naming Igneous Rocks - Based on composition and texture of igneous rock.

1. Mafic Rocks (from Mag and Fe) - generally darker colored rocks relatively high in iron, magnesium, calcium and low in silicon. Associated with high temp. end of Bowen's Reaction Series.

E.g. Gabbro = plutonic = phaneritic = mafic composition
Basalt = volcanic = aphanitic = mafic composition (Ca-rich plag., and Pyroxene).

2. Felsic (from feldspar and silica) Rocks - generally lighter in color, high in silica, Na, Potassium - consist mainly of quartz, K-feldspar, and Plagioclase

e.g. Granite = plutonic = phaneritic = felsic composition
Rhyolite = volcanic = aphanitic = felsic composition

3. Intermediate - admixtures of both felsic and mafic, dominated by amphibole, intermediate plagioclase feldspar, biotite.

e.g Diorite = plutonic = phaneritic = intermediate composition
Rhyolite = volcanic = aphanitic = intermediated comp.

4. Ultramafic = very rich in iron and mag., olivine and pyroxene, Ca-rich plagioclase

e.g. intrusive variety only = Peridotite - common in upper mantle

D. 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

b. Factors affecting viscosity

(1) temperature: the higher the temperature the lower the viscosity, i.e. the more kinetically active the magma is at atomic level, the less resistance to flow it possesses.

(a) Temp range of lavas: 1000-2700 F (540-1480 C)

i) Basaltic Lavas: 2000 F melting pt.
a) quiescent eruptions

ii) Rhyolitic Lavas: 1200 F melting pt.
a) explosive eruptions

(2) 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.

(3) 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

(4) 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)

(1) Hawaiian-type lavas- basaltic composition (60% silica), slowly flow down slopes, cooling to form basalt.

(a) Pahoehoe flows-lava flows with a smooth congealed skin, a whipped or ropy appearance.

(b) aa flows- more blocky in appearance, flows are rough jagged blocks with angular edges.

i) These are generally lower temperature lavas than Pahoehoe flows, thus tend to be cool, blocky, and thick.

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. TYPES OF VOLCANIC ERUPTIONS

A. Hawaiian Type
1. Type Area: Hawaiian Islands
2. Eruptive Style:
   a. low-viscosity, fluid lava eruptions
      (1) basaltic composition
         (a) 2000 F temp.

   b. Quiescent eruptions
   c. elongate fissure vents to domal volcanic centers

   d. large volume lava eruptions
      (1) lava curtains
      (2) lava fountains
      (3) lava rivers

   e. lava-dominant, low amounts of pyroclastics/tephra

B. Icelandic Type: Fissure Eruptions

1. Type Area: Iceland, Mid-Atlantic Ridge
2. Eruptive Style:
   a. Elongate, laterally extensive fissure eruptions
      (1) lack of central vent/volcanic cone

b. hot, fluid basaltic lavas
c. large volume eruptions
(1) fluid lava: flows laterally extending 100's of miles
(2) sheet geometry to lava flows
(3) Lava fountains/lava curtains

3. Other Localities
a. Columbia Plateau of Oregon/Washington/Idaho
(1) Columbia River Basalts
(a) >500,000 sq. km area
(b) Fissure eruptions with vents in NE Oregon
(c) cumulative thickness of >14,000 Ft

b. Snake River Plain of Idaho

c. Deccan Plateau of India

d. Parana Region of South America

C. Strombolian Type
1. Type Area: Volcano Stromboli, Sicily

2. Eruptive Style:
a. Basaltic Magmas
(1) Cooler and more viscous than Hawaiian
(2) Modest to high explosivity
(3) Pyroclastic Fragments common
(a) blocks, bombs, breadcrust

D. Vulcanian Type
1. Type Area: Vulcano- volcanic island off coast of Sicily

2. Eruptive Style
a. Basaltic to Andesitic Magmas
(1) Of higher silica content compared to Strombolian
(a) > viscosity
(b) > explosivity

b. Tendency toward to congealed vent plugs/crusts
(1) Explosive plug blow-out

c. Pyroclastic Eruptions common
(1) blocks, bombs, ash, scoria, pumice

E. Plinian Type
1. Type Area: Mt. Vesuvius, mainland Italy
a. Major eruption, 79 A.D.
b. Destruction of Pompeii and Herculaneum

c. First hand account by Pliny the Elder and Pliny the Younger

2. Eruptive Style
   a. Andesitic magmas of increased silica content
   b. Very violent/explosive eruptions
      (1) Gas and tephra
         (a) Pumice and ash eruptions
      (2) Huge tephra clouds to altitudes of 200,000 Ft
   c. Post-eruption lahars and/or mudflows common

F. Pelean Type

1. Type Area: Mt. Pelee, Martinique, West Indies (Carribbean Plate)

2. Eruptive Style
   a. Explosive Eruptions
      (1) high viscosity magma
      (2) vent plugging followed by gas-charged eruption

   b. Mixtures of lava, gas and hot pyroclastic material
      (1) Nuees Ardentes: "fire clouds"
         (a) Process: hot, glowing ash clouds

            i) searing ash and gas mixtures
            ii) density clouds with D>Air, rolling mixture laterally down volcanic slopes
            iii) Gas thrust upward into eruptive column
            iv) Base Surge: Lateral blast of ash cloud

         (b) Ignimbrites: welded nuee ardent deposits
            i) glowing ash flow sheet
            ii) welded tuffs

   c. Plinian: high-cloud eruptions associated with deep gas build-up

   d. Peleean: low-cloud Nuee Ardents associated with shallow gas build-up

G. Krakatoan Type

1. Type Area: Krakatoa a volcanic island between Java and Sumatra in southeast Asia
   a. Most violent eruption in recorded history
   b. Ramifications felt world-wide in 1883 eruption

2. Eruptive Style:
   a. Caldera Collapse
      (1) Calderas- blowing apart of volcanic cone or collapse of volcanic cone into central vent
   b. Highly explosive eruption
      (1) abundance of pyroclastic material/ash
      (2) ash encircled the earth

(a) "nuclear winter" phenomena for 3 years
i) blockage of solar radiation
ii) below normal temperatures

H. Mt. St. Helens
1. Type Area: Mt. St. Helens, Washington Cascades
2. Eruptive Style:
a. Andesitic magma
(1) High viscosity, explosive eruptions

b. Magmatically induced seismic activity

c. seismically induced landslide
(1) reduction of lithostatic pressure

d. violent pyroclastic eruption

I. Solfataric Eruptions
1. gas emission only from volcanic center
2. Fumaroles: submarine gas vents

J. General Relations
1. With increasing explosivity; increasing height of eruptive column
a. Hawaiian Column Height: 2 km
b. Strombolian: 10 km
c. Subplinean: <30 km
d. Ultraplinean: < 55 km

II. 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

B. Volcano Morphology

1. Shield Volcanoes
   a. broad, shield shape, gentle slopes, low profile
   b. associated with basaltic lavas (low viscosity lavas).
   c. Hawaiian-type volcanoes

      (1) Fissure eruptions from volcanic edifice
      (2) layered basalt lava flows
      (3) little pyroclastic debris
      (4) Upwards of 30,000 Ft vertical relief from ocean floor

2. Composite Cones

   a. Composite cones or Strato Volcano- volcanoes comprised of a mixture or alternating layers of lava and pyroclastic material,

   b. Generally form large volcanoes, often associated with violent eruptions (e.g. Mt. St. Helens) and andesitic magmas (sl. more siliceous than basalt).

      (1) Composite cones produce:
         (a) nuee ardents - glowing clouds of hot volcanic ash.
            i) hot ash flows
            ii) gas-driven

         (b) lahars - debris flows formed of water saturated volcanic debris.
            i) cold-state debris flows

3. Plug Domes

   a. Steep-faced dome composed of obsidian and pumice
   b. very viscous magma, extremely plastic and sticky
      (1) rhyolitic-dacitic compositions

4. Cinder Cones
   a. Cinder cones- composed of ejected lava fragments or pyroclastic material
      (1) Avg. diameter: < 1.5 km
      (2) Volume: 10^4-10^7 cu. m.

   b. Steeper sides to volcano than shield type
      (1) Accumulated pyroclastic debris at angle of repose (30-35 degrees)

   c. Cones occur singly or in clusters
      (1) Cone fields

5. Spatter Cones
    a. Parasitic cones and vent eruptions
    b. Ejected lava
        (1) bombs and spatter

6. Table Mountains
    a. Flat-topped volcanic cones with steep sides
    b. Sub-glacial volcanism/melt-water quenching
        (1) pillow-lavas
        (2) glassy accumulations

7. Calderas
    a. Extremely large craters > several km in diameter
        (1) e.g. Crater Lake in Oregon
            (a) Remanent caldera of Mt. Mazama
                i) Explosion dated at 6000-7000 yrs ago
                ii) "Mazama Ash" deposit throughout western interior

    b. Causes
        (1) Explosion of summit area
        (2) volcanic collapse
            (a) stoping of magma chamber
            (b) collapse under weight of overburden

8. Maar- Phreatomagmatic crater with steep to vertical inner slopes surrounded by tuff ring
    a. explosive craters formed by interaction of magma and water saturated depression (sub-aqueous lake eruptions)

        (1) characterized by volcanic breccia in central vent with collapsed margins

9. Landform Evolution of Volcanoes
    a. < in relief of constructional landform
    b. > drainage density
    c. > soil development on slopes
    d. > weathered sediment apron surrounding core

III. LAVA FLOW MORPHOLOGY
    A. Hawaiian Types- low-viscosity basaltic lava flows
        1. Aa- blocky, rough lava flows
            a. higher viscosity than Pahoehoe
            b. crumbly flow advance, crusting process

        2. Pahoehoe- ropy, smooth lava flows
            a. lower viscosity than Aa
            b. fluid lava flows

B. Pressure Ridges- crenulated flow lines on lava flow, perpendicular to direction of flow

C. Lava Tubes- solidified exterior/crust forming
   1. continued molten flow through tube

D. Flow Processes
   1. Lobate flow form
   2. lava streams
   3. levees
   4. Water Cooled lava
      a. Chilled glassy rinds
      b. Pillow lavas

E. Differential Erosion and Lava Flows
   1. With erosion process over time
      a. Lava flows commonly form resistant cap rocks and serve as ridge formers

IV. INTRUSIVE IGNEOUS LANDFORMS

A. Intrusive Activity and Phenomenon (Plutons: Cooled from below)

   1. Intrusive- refers to injection and cooling of magma beneath the earth's surface

      a. Dikes - planar bodies of igneous intrusive rock that resulted from the injection of magma across strata or layers of rock, i.e. discordant sheet-like intrusive bodies.

         (1) Feeder Dikes: dikes may represent feeder fissures supplying magma to form surface volcanic lava flows

         (2) Radial Dike Swarms: series of dikes radiating outward from volcanic center

         (3) Ring Dikes: concentric sets of ring-shaped dikes
            (a) Dikes may dip inward toward central feeder point

         (4) Differential Erosion: dikes commonly form resistant, tabular bodies that stand high in relief on landscape

      b. Volcanic Necks - column-shaped landforms comprised of congealed magma

         (1) solidified plumbing conduit of volcanic center

            (a) differential erosion leaves neck standing high in relief

               i) e.g. Shiprock New Mexico, volcanic neck with ring dike complex

c. Sills - planar bodies of igneous intrusive rock that resulted from the injection of magma parallel to strata or layers of rock, i.e. concordant sheet-like intrusive bodies.

(1) May stand high in relief; resistant to erosion
(a) Mesas- flat-topped mountains
(b) Cuestas
(c) Hogbacks

d. Laccoliths - inverted lense-shaped igneous intrusive bodies (convex side up), analogous to a sill, but much larger and result in upwarping pre-existing strata or rock layers (e.g. Black Hills of South Dakota).

(1) Intrusive process results in doming of surrounding rock strata

(a) Cuesta-hogback relations surrounding central laccolithic intrusion

e. Batholiths- large intrusive bodies of igneous rock that are > 100 sq. km. in diameter, in reality magma chambers that have cooled and solidified beneath the earth's surface (e.g. Sierra Nevada Mountains of California, Idaho Batholith)

(1) Commonly form granitic cores of mountain ranges
(a) stand high in relief
(b) commonly form exfoliation domes

f. Stocks- massive igneous rock intrusions < 100 sq. km. in diameter