1 ***Igneous Rocks***

Earth - Chapter 4

2 **Igneous Rocks: summary in haiku form**

Olivine forms first;
quartz forms later, when it's cool.
Thanks Mister Bowen!

3

- Igneous rocks form as molten rock (magma) cools and solidifies
- General characteristics of magma:
  - Parent material of igneous rocks
  - Forms from partial melting of rocks
  - Magma at surface is called lava
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6 **Magma: Parent Material of Igneous Rock**

- The Nature of Magma
  - Consists of three components:
    - Liquid portion = melt
    - Solids, if any, are crystals of silicate minerals
    - Volatiles are dissolved gases in the melt that vaporize at surface pressure
      - Most common volatiles in magma:
        - » Water vapor (H_2O)
        - » Carbon dioxide (CO_2)
        - » Sulfur dioxide (SO_2)

7

- From Magma to Crystalline Rock
  - Crystallization is the cooling of magma which results in the systematic arrangement of ions into orderly patterns
  - Silicon and oxygen atoms link together first to form a silicon−oxygen tetrahedron (the basic building block of silicate minerals)

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- Igneous Processes
  - Magma that crystallizes at depth forms plutonic or intrusive igneous rocks
    - These rocks are observed at the surface following periods of uplifting and erosion of overlying rocks
  - The solidification of lava or volcanic debris forms volcanic or extrusive igneous rocks

9 **Extrusive Versus Intrusive Igneous Rocks**

10 **Igneous Compositions**

- Igneous rocks are composed primarily of silicate minerals
  - Dark (or ferromagnesian) silicates
    - Rich in iron and/or magnesium
      - Examples include olivine, pyroxene, amphibole, and biotite mica
  - Light (or nonferromagnesian) silicates
    - Contain more potassium, sodium, or calcium than iron and magnesium
      - Examples include quartz, muscovite mica, and feldspars
      -

11 **Igneous Compositions**

- Granitic (Felsic) Versus Basaltic (Mafic) Compositions
  - Granitic or felsic composition

- Light-colored silicates
- Composed almost entirely of quartz and potassium feldspar
- Termed felsic (*fel*dspar and *si*lica) in composition
- High silica (SiO_2) content
- Major constituent of continental crust
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12 **Igneous Compositions**

- Granitic (Felsic) Versus Basaltic (Mafic) Compositions
  - – Basaltic or mafic composition
    - Dark silicates and calcium-rich feldspar
    - Termed mafic (*ma*gnesium and *fe*rrum, for iron) in composition
    - Higher density than granitic rocks
    - Comprise the ocean floor and many volcanic islands

13

- Other Compositional Groups
  - – Andesitic or intermediate composition
    - Contain 25 percent or more dark silicate minerals (amphibole, pyroxene, and biotite mica)
    - Associated with volcanic island arcs
  - – Ultramafic composition
    - Rare composition of mostly olivine and pyroxene
    - Composed almost entirely of ferromagnesium minerals
    - Peridotite is an example
      - –Also the main constituent of the upper mantle

14 **Mineralogy of Common Igneous Rocks**

15 ***What's Wrong Here?***

16 ***What's Wrong Here?***

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- Silica content as an indicator of composition
  - – Crustal rocks exhibit a considerable range (40 percent to 70 percent)
    - The chemical makeup of an igneous rock can be inferred from the silica content
  - – Silica content influences magma behavior
    - Granitic magmas have high silica content, are viscous (thick), and erupt at a lower temperature
    - Basaltic magmas have much lower silica content, more fluidlike behavior, and erupt at a higher temperature

20 **Igneous Textures: What Can They Tell Us?**

- Texture is the overall appearance of a rock based on the size, shape, and arrangement of mineral grains
- Factors affecting crystal size:
  - – Rate of cooling
    - Slow rate = fewer but larger crystals
    - Fast rate = many small crystals
  - – Amount of silica
  - – Amount of dissolved gases
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21 **Igneous Rock Textures**

22 **Igneous Textures: What Can They Tell Us?**

- Types of Igneous Textures
  - – Aphanitic (fine-grained) texture

        - Rapid rate of cooling
        - Microscopic crystals
    - Phaneritic (coarse-grained) texture
        - Slow cooling
        - Large, visible crystals
        -

23 **Igneous Textures: What Can They Tell Us?**

- Types of Igneous Textures
    - Porphyritic texture
        - Some minerals can grow large before others form from the magma
        - The magma can move to a different environment which causes the remaining minerals to form quickly
        - Large crystals (phenocrysts) are embedded in a matrix of smaller crystals (groundmass)

24 **Aphanitic texture**

25 **Phaneritic texture**

26 **Igneous Textures: What Can They Tell Us?**

- Types of Igneous Textures
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27 **Porphyritic texture**

28 **Porphyritic Texture**

29 **Porphyritic texture:**
"Snowflake Porphyry"
(Vancouver Island, B.C., Canada)

30 **Igneous Textures: What Can They Tell Us?**

- Types of Igneous Textures
    - Vesicular texture
        - Rocks contain voids left by gas bubbles in the lava
        - Common feature of an extrusive igneous rock
    - Glassy texture
        - Very rapid cooling
        - Ions are frozen in place before they can unite in an orderly crystalline structure
        -

31 ***Vesicular Texture***

32 **Glassy texture**

33 **Glassy texture: Obsidian**

34 ***Obsidian Arrowhead***

35 ***Obsidian Flow in Oregon***

36 **Igneous Textures: What Can They Tell Us?**

- Types of Igneous Textures
    - Pyroclastic (fragmental) texture
        - Forms from the consolidation of individual rock fragments ejected during explosive eruptions
    - Pegmatitic texture
        - Exceptionally coarse-grained
        - Form in late stages of crystallization of magmas

- Rocks with this texture are called pegmatites
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37 **Pyroclastic Texture**

38 ***Pegmatitic Texture***

39 **Pegmatitic Texture**

40 **Pegmatitic Texture**

41 **Naming Igneous Rocks**

- Igneous Rocks Classification
  - Based on texture and composition
    - Texture is influenced by cooling history
    - Mineralogy is influenced by the chemical composition of the parent magma

42 **Classification of Igneous Rock**

43 **Naming Igneous Rocks**

- Granitic (Felsic) Igneous Rocks
  - Granite
    - Coarse-grained (phaneritic)
    - One of the best known igneous rocks
    - Very abundant
    - Natural beauty, especially when polished
    - 10–20 percent quartz, roughly 50 percent potassium feldspar
    - Small amounts of dark silicates
    - Some granites have a porphyritic texture
      - Contain elongated feldspar crystals

44 **Granite Formation**

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49 **Naming Igneous Rocks**

- Granitic (Felsic) Igneous Rocks
  - Rhyolite
    - Extrusive equivalent of granite
    - Composed essentially of light-colored silicates
    - Typically buff to pink or light gray in color
    - Less common and less voluminous than granite

50 **Rhyolite**

51 **Naming Igneous Rocks**

- Granitic (Felsic) Igneous Rocks
  - Obsidian
    - Dark-colored, glassy rock
    - Forms when silica-rich lava cools quickly at Earth’s surface
    - Usually black to reddish-brown in color
    - Similar chemical composition of granite
    - Dark color is the result of small amounts of metallic ions in an otherwise clear, glassy substance

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53 **Naming Igneous Rocks**

- Granitic (Felsic) Igneous Rocks
  - Pumice

- Glassy textured rock that forms when large amounts of gas escape from the lava
- Voids are quite noticeable
- Resembles fine shards of intertwined glass
- Typically found in deposits with obsidian
- Will float when placed in water

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- Andesitic (Intermediate) Igneous Rocks
  - Andesite
    - Medium-gray, fine-grained rock
    - Volcanic origin
    - Commonly exhibits a porphyritic texture
  - Diorite
    - Intrusive equivalent of andesite
    - Coarse-grained rock
    - Looks like gray granite, but lacks visible quartz crystals
    - Can have a salt-and-pepper appearance

56 **Andesite**

57 **Diorite**

58

- Basaltic (Mafic) Igneous Rocks
  - Basalt
    - Very dark green to black, fined-grained rock
    - Composed mostly of pyroxene and calcium-rich plagioclase feldspar
    - When porphyritic, contains small, light-colored feldspar phenocrysts
    - Most common extrusive igneous rock
    - Upper layers of oceanic crust are composed of basalt

59 **Basalt**

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- Basaltic (Mafic) Igneous Rocks
  - Gabbro
    - Intrusive equivalent of basalt
    - Very dark green to black, fine-grained rock
    - Composed mostly of pyroxene and calcium-rich plagioclase feldspar
    - Uncommon on the continental crust, but makes up a significant portion of the oceanic crust

62 **Gabbro**

63

- Pyroclastic Rocks
  - Composed of fragments ejected during a volcanic eruption

64

- Pyroclastic Rocks
  - Tuff
    - Common pyroclastic rock
    - Composed of ash-sized fragments cemented together
  - Welded tuff
    - Ash particles are hot enough to fuse together
    - Can contain walnut-sized pieces of pumice and other rock fragments
    - Covers vast portion of previous volcanically active areas of the western United States

65 **Welded Tuff**

66 ***A Welded Tuff Deposit***

67 ***Welded Tuff Deposits, plus…***

68

- Pyroclastic Rocks
  - Volcanic breccia
    - Composed of particles larger than ash
  - Names do not imply mineral composition and are identified with a modifier
    - Example: rhyolitic tuff

69 ***Figure 4.11***

70 ***Figure 4.12***

71 **Origin of Magma**

- Earth's crust and mantle are primarily composed of solid rock
- Magma is generated in the uppermost mantle
  - Greatest amounts are produced at divergent plate boundaries
  - Lesser amounts are produced at subduction zones
  - Can also be generated when crustal rocks are heated

72

- Generating magma from solid rock
  - Geothermal gradient: temperatures in the upper crust increase about 25° C per kilometer
  - Rocks in the lower crust and upper mantle are near their melting points
    - Tectonic processes trigger melting by reducing the melting point

73 **Geothermal Gradient**

74 **Origin of Magma**

- Generating Magma from Solid Rock
  - Decompression melting
    - Melting occurs at higher temperatures with increasing depth
    - Reducing pressure lowers the melting temperature
    - Solid, hot mantle rocks will ascend to regions of lower pressure, inducing melting

75 **Decompression Melting**

76

- Generating Magma from Solid Rock
  - Addition of water
    - Occurs mainly at subduction zones
    - As an oceanic plate sinks, heat and pressure drive water from the crust and overlying sediments
    - Fluids migrate into the overlying wedge of mantle
    - The addition of water lowers the melting temperature of the mantle rocks to trigger partial melting

77 **Introduction of Water Triggers Partial Melting**

78

- Generating Magma from Solid Rock
  - Temperature increase: melting crustal rocks
    - Heat from nearby magma sources can melt the surrounding crustal rocks
    - Can also form melt from heat generated during continental collisions

79

- Generating Magma from Solid Rock
  - In summary, there are thee ways to create magma
    - Decrease in pressure
    - Introduction of water
    - Heating crustal rocks above their melting temperature

80 **How Magmas Evolve**

- A single volcano may extrude lavas that vary in composition

- Bowen's reaction series
    - Minerals crystallize in a systematic fashion based on their melting points
    - As minerals crystallize, the composition of the liquid portion of the magma continually changes
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81 **Bowen's Reaction Series**

82

- Magmatic Differentiation and Crystal Settling
  - Crystal settling
    - Earlier-formed minerals are denser than the liquid portion of the magma and sink to the base of the magma chamber
  - When the remaining magma solidifies, the mineralogy will be different from the parent magma
  - Magmatic differentiation
    - The formation of one or more secondary magmas from a single parent magma

83 **Crystal Settling**

84 **How Magmas Evolve**

- Assimilation and Magma Mixing
  - Assimilation
    - As magma migrates through the crust, it may incorporate some of the surrounding rock
  - Magma mixing
    - During the ascent of two chemically different magma bodies, the more buoyant mass may overtake the slower-rising body

85 **Assimilation and Magma Mixing**

86 **Partial Melting and Magma Composition**

- Incomplete of rocks is known as partial melting
  - This process produces most magmas
  - During partial melting, the melt is enriched in ions from minerals with the lowest melting temperature
    - Partial melting of ultramafic rocks yields mafic magmas
    - Partial melting of mafic rocks yields intermediate magmas
    - Partial melting of intermediate rocks yields felsic magmas
    -
    -
    -

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- Formation of Basaltic Magmas
  - Most magma that erupts is basaltic (mafic) magma
  - Most originate from partial melting of mantle rocks at oceanic ridges
    - These melts are called primary or primitive magmas

89

- Formation of Andesitic and Granitic Magmas
  - Andesitic magma
    - Magmatic differentiation of mantle-derived basaltic magma
    - Can also form when basaltic magmas assimilate crustal rocks
  - Granitic magmas
    - Most form when basaltic magma ponds beneath the continental crust
      - Melted crustal rocks alter the magma composition
    - Can form from magmatic differentiation of andesitic magma

90 **Formation of Granitic Magma**

91 **Intrusive Igneous Activity**

- Most magma is emplaced at depth in Earth
- Nature of Intrusive Bodies
  - A pluton is cooled, emplaced magma into preexisting rocks
  - Classification of plutons
    - Plutons are classified by their orientation to the surrounding rock

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92

- Nature of Intrusive Bodies
  - Classification of plutons
    - Tabular—table-like
      - Discordant—cut across existing structures
      - Concordant—are parallel to features like sedimentary strata
    - Massive—Irregularly shaped

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93 **Intrusive Igneous Structures**

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- Tabular Intrusive Bodies: Dikes and Sills
  - Dike—a tabular, discordant pluton
    - Serves as tabular conduits to transport magma
    - Parallel groups are called dike swarms
  - Sill—a tabular, concordant pluton
    - Tend to accumulate magma and increase in thickness
    - Closely resembles buried lava flows
    - May exhibit columnar jointing
      - Occurs when igneous rocks cool and develop shrinkage fractures that produce elongated, pillar-like columns with 6 sides
-
-

95 **Exposed Sill**

96 **Igneous structures**

97 **Dikes near Ojos Negros, B.C.**

98 **Basalt Dikes in the Grand Canyon**

99 **Sills in Salt River Canyon, Arizona**

100

- Massive Intrusive Bodies: Batholiths, Stocks, and Laccoliths
  - Batholith
    - Largest intrusive body
    - Surface exposure of 100+ square kilometers (smaller bodies are termed stocks)
    - While expansive, most are less than 10 km thick

101 **Columnar Jointing**

102 **Columnar Jointing in the Grand Canyon**

103 **Calavera Hill (Carlsbad, CA)**

104 **Columnar Jointing**

105

- Massive Intrusive Bodies: Batholiths, Stocks, and Laccoliths
  - Emplacement of batholiths
    - Magma at depth is much less dense than the surrounding rock
    - In the mantle, the more buoyant magma pushes aside the host rock and rises in Earth

through a process called shouldering

106

107

- Massive Intrusive Bodies: Batholiths, Stocks, and Laccoliths
  - Emplacement of batholiths
    - Nearer to Earth's surface, the rocks are cooler and brittle
    - Upward movement is accomplished by stoping, where the overlying blocks of country rock sink through the magma
      - Xenoliths are suspended blocks of country rocks found in plutons

108 **Xenoliths**

109

- Massive Intrusive Bodies: Batholiths, Stocks, and Laccoliths
  - Laccoliths
    - Forcibly injected between sedimentary strata
    - Causes the overlying strata to arch upward

110 **End of Chapter**