The “DNA” of the Earth

Minerals and Rocks - A Quick Primer

- **Rock** – aggregates of mineral grains
  - Cemented together – *sedimentary rocks* (recycled rock fragments and skeletal material glued together)
  - Fused through heat and mineral growth (*igneous rocks* – cooled from molten rock; *metamorphic rocks* – rock altered by heat and pressure)
- **Mineral** – an inorganic, crystalline solid with a defined chemical composition
  - Chemical composition – can be fixed or defined as a specific range of compositions
- Minerals are made up of atoms of element(s) bonded together
Sedimentary Rocks and Composition

- Classification:
  - Clastic rocks – cemented rocks made up of weathered rock and mineral fragments – subdivided on basis of grain size of particles – shales, sandstones, conglomerates
  - Biochemical rocks – accumulations of skeletal particles or precipitants mediated by organisms – many limestones, “coals”
  - Chemical rocks – precipitate inorganically – oolitic limestones, rock salt, rock gypsum, banded iron formation
Quartz sand rimmed with quartz cement

Sedimentary rocks – undergo lithification – the process by which sediment is turned to rock.

Lithification – Cementation and Compaction

**Clastic Sedimentary Rocks**

<table>
<thead>
<tr>
<th>Grain size</th>
<th>Sediment name</th>
<th>Rock name</th>
<th>Common minerals – dominantly silicates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger than 2 mm</td>
<td>Gravel (pebbles, cobbles, boulders)</td>
<td>Brecia</td>
<td>Clay minerals, quartz, feldspars</td>
</tr>
<tr>
<td>1 to 2 mm</td>
<td>Sand</td>
<td>Brecia</td>
<td>Si, Al, O</td>
</tr>
<tr>
<td>0.1 to 0.01 mm</td>
<td>Mud</td>
<td>Mudstone</td>
<td>+/- Ca, K, Na, Mg, Fe</td>
</tr>
</tbody>
</table>

Si, O
Sedimentary rocks – undergo lithification – the process by which sediment is turned to rock.
Lithification – Cementation and Compaction

Limestone and Dolostone – chemical or biochemical
Fossiliferous limestones, oolitic limestones, chalk

Chert – silica – can be biochemical (accumulation of sponge spicules or diatoms) or chemical (some hot spring mineralization)

Rock Salt and Rock Gypsum – precipitate from evaporation of seawater

Coal – not a rock – but usually by tradition called a rock – accumulation of degraded organic matter

Even Smaller Number of Basic Elements!

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Igneous Rocks and Composition

- Igneous rocks – very rational classification – based on magma composition and grain size
- Magma composition - %silica, Fe and Mg content
  - More Fe-Mg – darker colored rocks
  - More silica – lighter colored rocks
- Grain size – implies cooling rate
  - Finer grained – more rapid cooling (usually volcanic)
  - Coarser grained – slower cooling (usually plutonic)
Metamorphic Rocks and Composition

• Metamorphic rocks – lots of classification schemes
• Basic classification – foliated vs. non-foliated
  • Does the rock split into layers or not
  • Then further subdivided on basis of chemistry (mineralogy)

Low-grade dolomitic Marble – preserves 2.3 billion year old structure created by bacteria called a stromatolite

Marbles start out as either limestones or dolomites

Ca, Mg!

Non-foliated Metamorphic Rock = Marble
Protolith = shales – started as clay-rich rocks. Now higher temperature clays and micas.

Foliated Metamorphic Rock = slate

~5,200 formally named mineral species
Most are quite rare – only a few dozen are common = Rock-Forming Minerals
Another ~100 minerals are economically important = Ore Minerals

Weathered, detrital Zircon (ZrSiO₄) – has enough U (1000's ppm) and Th (100's ppm) to age date!
Deoxyribonucleic acid (DNA)

Made up of C, H, N, P, O

Which combine to form the building blocks:

- Phosphates
- Sugars (deoxyribose)
- Nitrogenous bases (Adenine, Thymine, Guanine, Cytosine)

Many minerals form from ionic bonding of an anion and cation.

Anions are often more complicated polyatomic species like carbonate, phosphate or sulfate. Cations are usually metals.
Mineral “DNA” - Classification

• “All the so-called elements of matter are found in the mineral kingdom, either in a pure or combined state; and it is the object of chemical analysis to ascertain the proportions of each in the constitution of the several minerals.”

James Dwight Dana
Manual of Mineralogy
1865 Edition

Early Classification of minerals - based in part on chemical composition! We still use Dana’s classification today!

Rock-forming minerals: Silicates

• Silicate minerals have Silicon and Oxygen as part of their chemical composition
• Silicates include two of the most common minerals in the Earth’s crust – Feldspar and Quartz

Quartz
K-Feldspar
Rock-forming Minerals: Non-silicates

- Often classified based on their chemical composition – especially the dominant anion present in the structure
- Many have important industrial applications or are ore minerals
  - Carbonates (CO$_3^{2-}$) - Calcite, Dolomite
  - Phosphates (PO$_4^{3-}$) - apatite
  - Oxides (O$^2-$) – hematite, magnetite, corundum
  - Chlorides (Cl$^-$_) – halite
  - Sulfides (S$^2-$) – pyrite, galena
  - Sulfates (SO$_4^{2-}$) – gypsum
  - Native Elements – pure elemental materials – Au, Ag, Cu, S, etc.
Mineral “DNA”

- A finite number of elements make up the bulk of the Earth
- So how did they end up here on Earth???

Nucleosynthesis – the formation of new atoms from subatomic particles – develops the 94 naturally occurring elements described on Earth!

Nucleosynthesis

- Stellar Nucleosynthesis – elements formed during the birth and normal activity of stars
- Explosive Nucleosynthesis – formed during supernovae (Some artificial – supercollider experiments)
- Majority formed during Big Bang

Fusion reactions in the early sun create light elements (Up to Iron)
Supernovae – spread out matter into region forming nebulas. Gravity pulls material into a protostar at center.

Nebula begins to rotate due to balance between gravitational attraction and inertia.

Accretion of larger and larger particles over time, including initial Planetesimals.

Stabilization of Early Planets – Orbits and Shape. Some Planetesimals captured as moons.

Accretionary Model – contraction of material to form proto-star and eventually even the Solar system.

H and He
Silicates + light Metals (Ca, Al, Si, ...)
Ice (H, He ±O, C, N...)

Terrestrial Planets

Gas and Ice Planets

Notice the Compositional Differences across the Solar System.
Planetary Differentiation – explanation for distribution of elements in the Earth’s interior

Impact of the Atmosphere

Hematite stable at earth surface

Oxidizing Atmosphere

Reducing Atmosphere

Minerals like pyrite (and other sulfides) and siderite stable at earth surface
The chemistry of the Earth is the result of:

- The material in the nebula that the early solar system formed from
- Compositional Differentiation in the early solar system
- Planetary Differentiation in the early Earth – developed layered Earth (Core-Mantle-Crust)

Key Points

- **Rock** – an aggregate of minerals
  - Composition – based on minerals present
  - Sedimentary rocks
  - Igneous rocks
  - Metamorphic rocks
- **Mineral** – an inorganic, crystalline solid with a *defined chemical composition*
  - Composition – due to environment mineral formed in and available elements
  - Minerals are made up of atoms bonded together