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Igneous Rocks and
Processes
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Title Slide

Formation

- Molten rock cools and solidifies

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Formation

- Molten rock cools and solidifies
  - Intrusive (plutonic)

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Magma – if cooled deep below the surface – intrusive/plutonic – large crystal size (time to grow)

Formation

- Molten rock cools and solidifies
  - Intrusive (plutonic)
  - Extrusive (volcanic)

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If extruded (pours out) – extrusive/ volcanic – smaller crystal size

Formation

- Molten rock cools and solidifies
  - Intrusive (plutonic)
  - Extrusive (volcanic)
- Interlocking crystals

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Minerals crystallise at different temperatures (see Bowen's Reaction Series later in slides) but once finally cooled will form an interlocking lattice

Classification

- Minerals
  - Size = rate of cooling

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Minerals are the main way to classify igneous rocks. Their size is an indicator of their rate of cooling (intrusive = larger, extrusive = small)

Classification

- Minerals
  - Size = rate of cooling
  - Composition = amount of silica present/ chemistry, gas in magma

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Their mineral composition defines them into categories such as mafic and felsic (see Bowen’s) and presence of gas holes indicates a gassy magma with fast cooling (extrusive)

Terminology

- Aphanitic – fine grained crystals
- Phaneritic – coarse grained crystals

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Aphanitic = rapid cooling magma, formed at or close
to the surface, individual crystals cannot be seen with the ‘naked’ eye
Phaneritic = slow cooling magma, deep within the Earth’s crust, individual crystals
can be seen without a hand lens

Terminology

- Aphanitic – fine grained crystals
- Phaneritic – coarse grained crystals
- Porphyritic – large crystals in a background of smaller crystals (groundmass)
- Glassy – very rapid cooling

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Porphyritic = magma at depth, different minerals crystallise at different temperatures. Large crystals called phenocrysts and smaller crystals called groundmass. Rock texture is called porphyritic.
Glassy = no crystals, cools too quickly for crystals to form, Obsidian is common

Terminology

- Aphanitic – fine grained crystals
- Phaneritic – coarse grained crystals
- Porphyritic – large crystals in a background of smaller crystals (groundmass)
- Glassy – very rapid cooling
- Pyroclastic – rock fragments
- Pegmatic – very coarse grained

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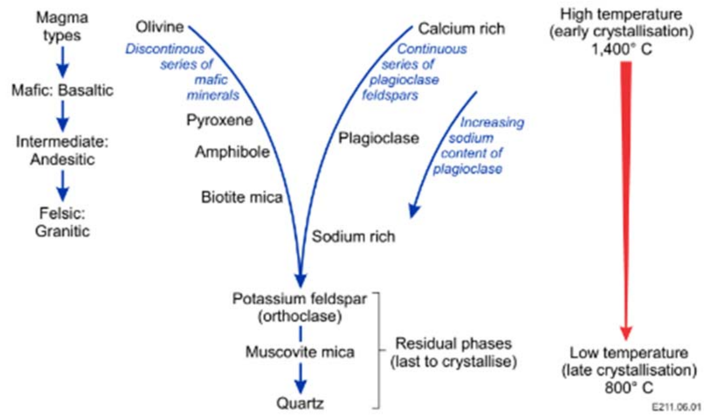
Pyroclastic = not individual crystals but fragments from violent volcanic eruptions (combined)
Pegmatic = very coarse crystals, formed in the fluid-rich late stages of magma crystallisation

Bowen's Reaction Series



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Bowen's Reaction Series, outlined in the early 1900's, assists us to understand the order of crystallisation of the common silicate minerals from a magma.

Which minerals would you expect in a mafic igneous rock?
Dominant minerals = pyroxene, calcium-rich plagioclase feldspar
Accessory minerals = amphibole, olivine
Extrusive rock = basalt
Intrusive rock = gabbro

Which minerals would you expect in an intermediate igneous rock?
Dominant minerals = amphibole, sodium & calcium-rick plagioclase feldspar
Accessory minerals = pyroxene, biotite
Extrusive rock = andesite
Intrusive rock = diorite

Which minerals would you expect in a felsic igneous rock?
Dominant minerals = quartz, orthoclase (potassium) feldspar, sodium-rich plagioclase feldspar

Accessory minerals = muscovite, biotite, amphibole
Extrusive rock = rhyolite
Intrusive rock = granite

Common Igneous Rocks

	Mafic	Intermediate	Felsic
Aphanitic	Basalt	Andesite	Rhyolite
Phaneritic	Gabbro	Diorite	Granite
Dominant Minerals	Pyroxene Calcium-rich plagioclase feldspar	Amphibole Sodium & calcium-rich plagioclase feldspar	Quartz Orthoclase feldspar Sodium-rich plagioclase feldspar
Accessory minerals	Amphibole Olivine	Pyroxene Biotite	Muscovite Biotite Amphibole

Other igneous rocks to know

- Komatiite
- Pumice
- Tuff
- Obsidian

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Komatiite = ultramafic, extrusive igneous rock, very rare, many ~2.7bya+ associated to deposits like Kambalda nickel
Pumice = glassy texture with lots of holes/ voids as gases escape (vesicular texture)
Tuff = small ash particles from a volcanic eruption cemented together
Obsidian = felsic magma, quenched, dark because of metal ions, conchoidal fracture

Earth resources

- Intrusive ore deposits – formed during the cooling of magma

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Earth resources

- Intrusive ore deposits – formed during the cooling of magma
- Exhalative ore deposits – formed from volcanic materials which are extruded or 'exhaled' onto the Earth's surface through hydrothermal vents

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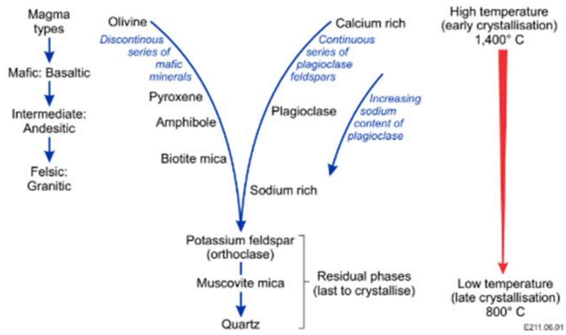
Sulfide ores formed by these processes account for ~60% of world nickel supply, 98% of platinum group metals and large quantities of copper, cobalt and vanadium

Fractional crystallisation

- As magma cools, some minerals form crystals before others



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This concept helps us to understand both gravitational settling and differentiation

Differentiation – Pegmatite deposits

- As magma crystallises out minerals like pyroxene and calcium rich plagioclase, it becomes progressively more felsic
- Late stage magmas can be fluid rich and contain rare elements like lithium, tin and tantalum
- E.g. Greenbushes tin-tantalum-lithium deposit

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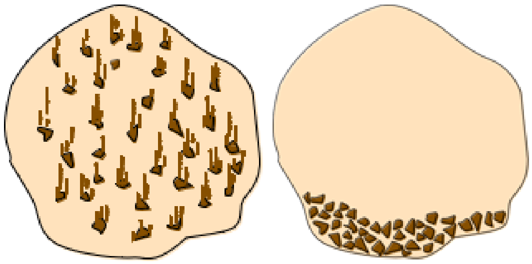
Magma becomes increasingly more felsic as it crystallises out
lower solubility minerals. Residual magmas are rich in water, low-melting silicates and elements like lithium, beryllium, tantalum, tungsten and uranium.
Most exhibit some mineral zoning. Depths from 1.5 to 11km.
e.g. Greenbuses tin-tantalum-lithium deposit, south-east of Bunbury, unit is 7km long and 1km wide, crystallised from extremely fractionated magma.

Gravitational settling

- Early formed, heavier minerals sink to the base of the magma chamber
- E.g. chromium at Coobina, near Newman



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Fractional crystallisation – heavier minerals sink. Form a cumulate layer. E.g. if chromium is present it tends to crystallise out early as chromite and then accumulates at the base of the intrusion
Chromite deposits at Coobina, near Newman – layered mafic-ultramafic igneous intrusions.
Also ilmenite and magnetite.

Immiscible liquid separation

- Like oil and water, some minerals don't readily mix
- Heavy sulfur-rich liquid (high in Ni & Cu) separates from silicate-rich liquid and sinks. E.g. Kambalda

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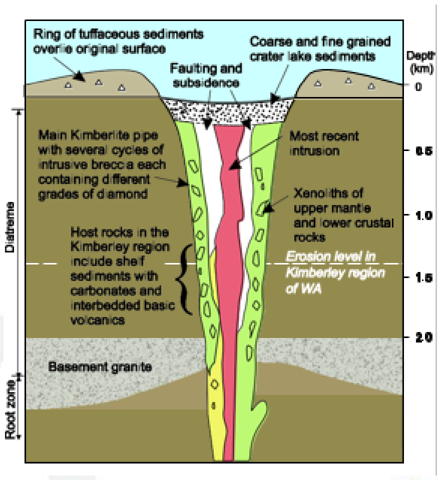
As magma cools it can physically separate into silicate-rich and sulfur-rich liquid
Don't mix well and can be discrete drops within each other
or separate out completely. The sulfur-rich liquid is heavier so tends to sink.
Nickel (pentlandite) and copper (chalcopyrite) bearing minerals can crystallise out in the sulfur-rich liquid
Many are very old – Archean
e.g. Kambalda nickel deposits hosted in komatiitic volcanic flows and sills

Lamproite/Kimberlite Pipes

- Diamond-bearing igneous rocks (fine-grained ultramafic)
- ‘Punch up’ from depth of ~600km
- Usually vertical, pipe-like bodies
- Rise rapidly and cool rapidly



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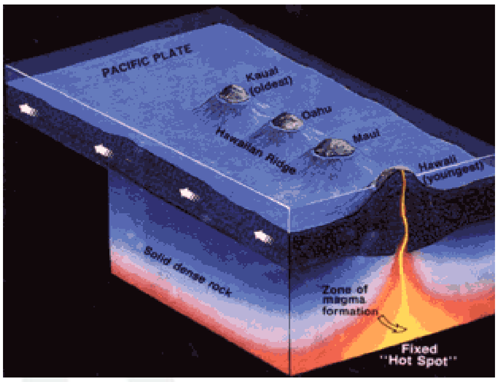
Lamproite = diamond bearing igneous rock found in Proterozoic mobile belts adjacent to cratons (Argyle and Ellendale pipes in WA)
Kimberlites = diamond bearing igneous rock found in highly stable Archean cratons (Premier Mine, Africa)
Fine grained ultramafic rocks, generated at mantle depths of ~600km. Mix of gas, liquid and crystals which moves upwards at great speeds.
Punches a circular hole through the crust collecting fragments (xenoliths) of wall rock on the way up.
Diamonds may occur in these rocks – rare as formed at pressures and temperatures greater than those found in the Earth’s crust.
Pressure = ~50,000 times atmospheric pressure Temperature = ~1500 degrees Celsius
Need to move to the surface rapidly to be preserved (can be greater than 50km/hr)

Mantle hot spots

- Hot spots are thought to be abnormally hot sections of the mantle
- The material is thought to originate at the core-mantle boundary



(USGS 1999, public domain)

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Possible source of materials such as nickel?

Exhalative ore deposits

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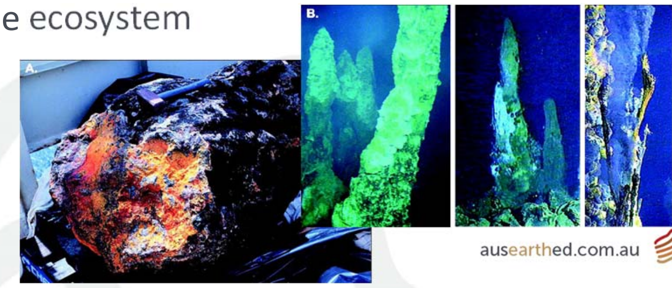
Hydrothermal vents = fissures or openings in the Earth’s crust.
Geothermally heated water is released on the Earth’s surface
Common in places where the crust is moving apart e.g. divergent boundaries, hotspots and ocean arcs (Mid-Atlantic Ridge)

Black smokers

- Hot vents spewing clouds of black sulfur-bearing compounds
- Rich in copper, iron, zinc, etc.
- Supports a unique ecosystem



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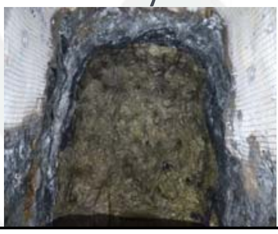
Black smokers exist under the ocean and emit black clouds of materials. Usually at a depth of ~2,100 m
Very hot and emit high levels of sulfur-bearing compounds. Precipitates are rich in copper, iron, zinc etc
Support a unique ecosystem – base = chemosynthetic bacteria – support tubeworms, clams, worms, eels etc

Volcanogenic Massive Sulfide (VMS) Deposit

Or volcanic hosted massive sulfide (VHMS)

- Hot, saline, metal-rich fluids are exhaled from hydrothermal seafloor vents or fumaroles
- Zinc, copper, lead, silver, gold, etc.
- E.g. The DeGrussa copper-gold deposit, 150 km NE of Meekarhara, hosted in what may have been a back arc basin

Image courtesy of Sandfire Resources NL



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VMS deposits are also formed in extensional environments – both oceanic seafloor spreading and arc
May also contain cobalt, manganese, selenium, cadmium, bismuth and mercury

Hot spring deposits

- Hydrothermal solutions reach the surface
- Superheated water overflows and precipitates out very fine silica (sinter)
- May contain lead, zinc, mercury, etc.

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Recently formed sinter deposits at Hell’s Gate, New Zealand

Volcanic fumarole deposits

- Hot volcanic gases condense and precipitate out hematite, sulfur and gypsum minerals
- Bacteria may also precipitate sulfur

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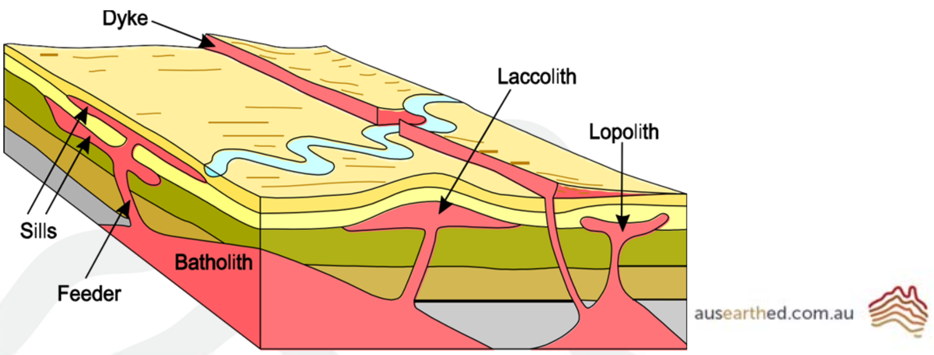
Bacteria can produce hydrogen sulfite gas and oxidising sulfur
Photos all from White Island, New Zealand

Igneous intrusions

- Massive or tabular
- Discordant or concordant



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•USGS, 1999, “Hotspots”: Mantle thermal plumes, accessed 15 May 2012 from http://pubs.usgs.gov/gip/dynamic/hotspots.html

Unless otherwise stated all information and graphics are from:

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