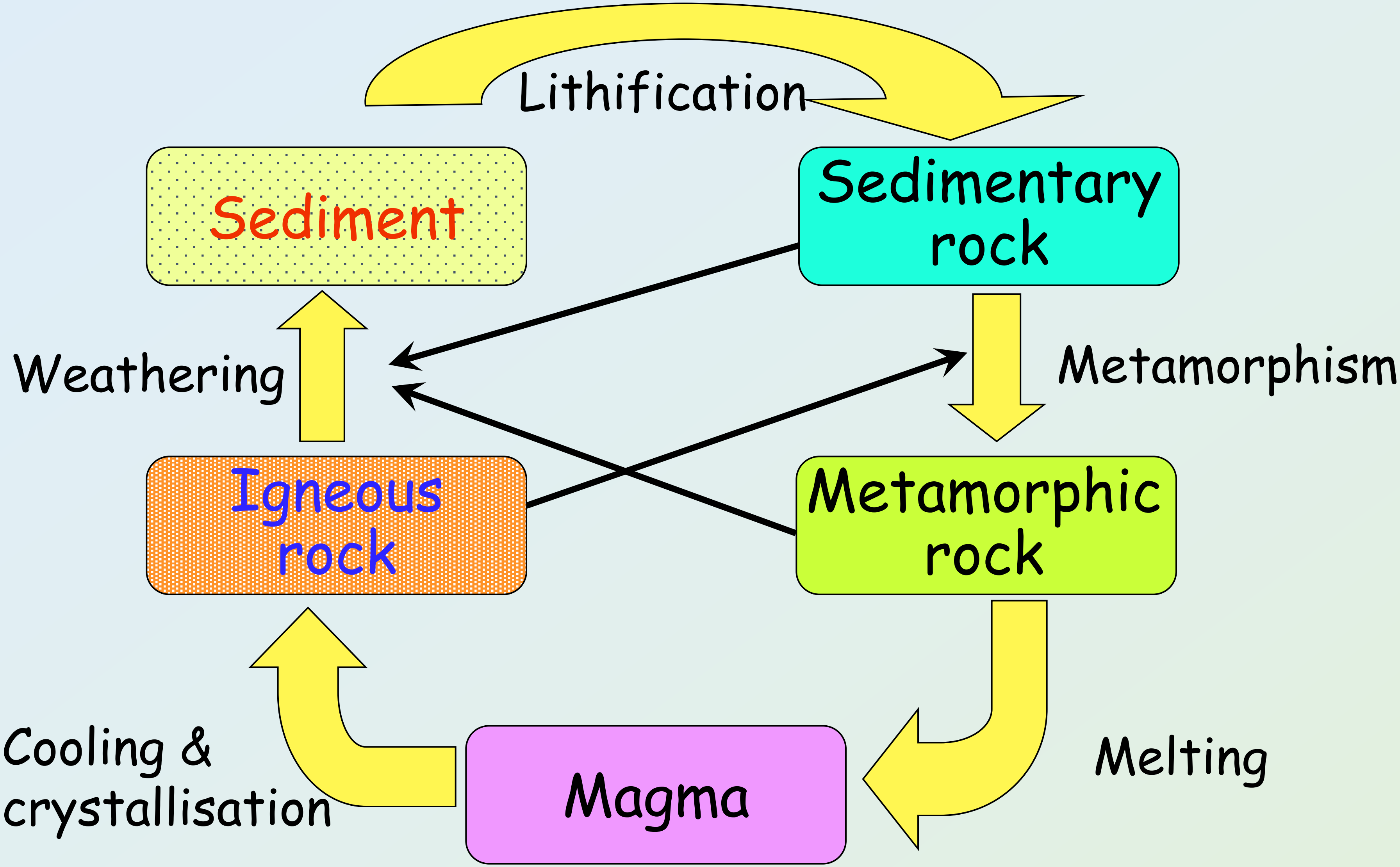
U3A Geology

Igneous rocks

The rock cycle

- All of the rock groups are related in a broad cycle
- all newly formed rocks are produced from the recycling of older rocks
- there are no longer any completely new rocks forming in the crust
- the basic rock groups may form from each other in response to changes in their physical environment
- the cycle can be repeated but not all rocks go through the entire cycle

The rock cycle



Lithification

Sediment

Sedimentary rock

Weathering

Metamorphism

Igneous rock

Metamorphic rock

Cooling & crystallisation

Magma

Melting

Introduction

- Igneous petrology → study of magma (molten rock material) and rocks that solidify from magma
- coarse-grained igneous rocks can be classified by identifying minerals present and their relative abundance
- fine-grained igneous rocks can be classified by identifying minerals and their relative abundance in thin section where possible or, from their chemical composition
- volcanic rocks are fine-grained → erupted at the Earth's surface
- intrusive igneous rocks are emplaced at various depths in the Earth's crust and are medium to coarse-grained

Igneous rock groupings

- Igneous rocks can be grouped on the basis of silica content

acidic rocks	>66% SiO_2
intermediate rocks	52-66% SiO_2
basic rocks	45-52% SiO_2
ultrabasic rocks	<45% SiO_2

- with respect to colour, igneous rocks fall into two groups:

felsic → containing mostly light coloured minerals e.g. quartz,
feldspars, feldspathoids

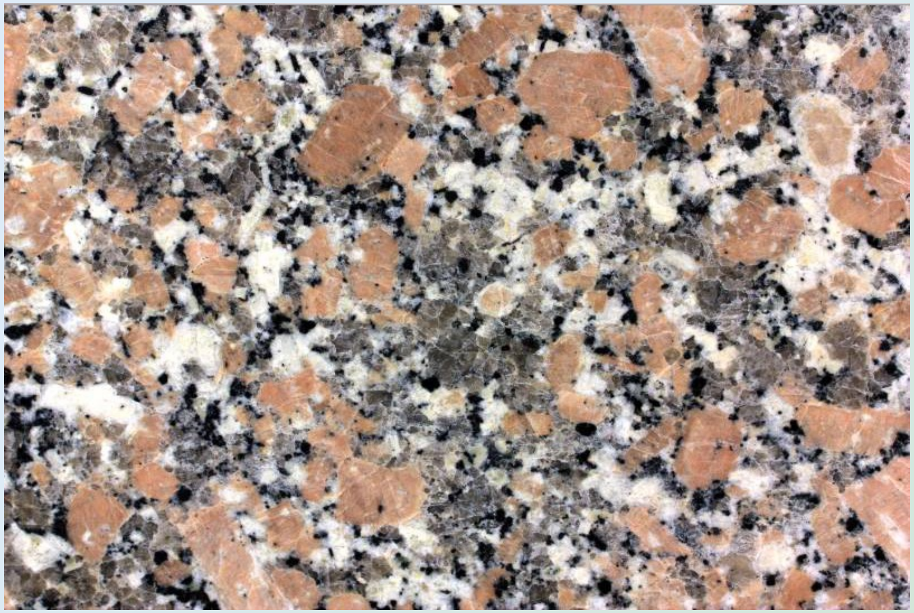
mafic → containing mostly dark coloured minerals e.g. pyroxenes,
amphiboles, olivine, biotite

- ultramafic rocks contain no quartz, feldspars nor feldpathoids

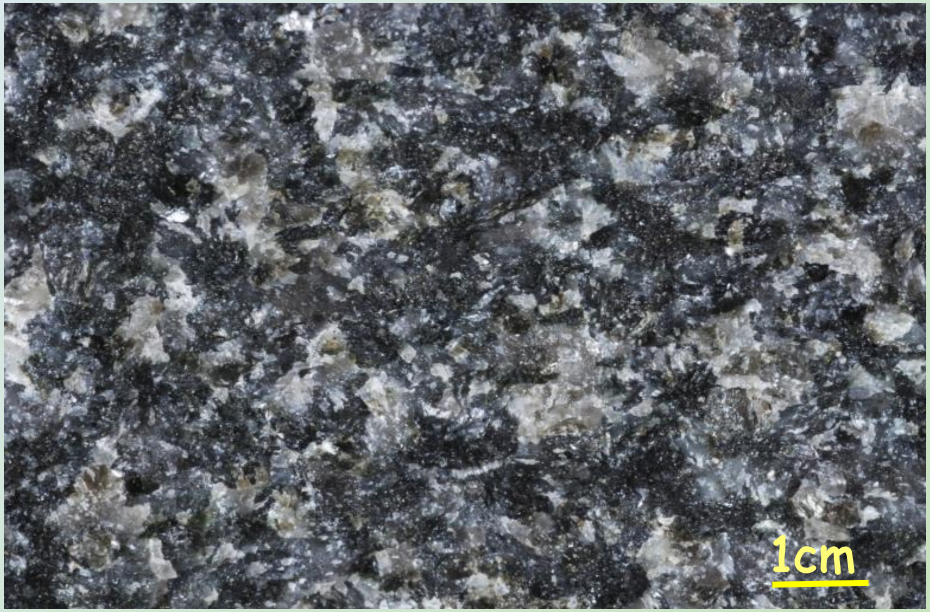
predominantly pyroxenes and olivine, <45% SiO_2

Felsic vs mafic texture

Igneous rocks can be classified as mafic or felsic depending on the predominant mineral group present in the rock



Granite - felsic



Gabbro - mafic

Classification of igneous rocks

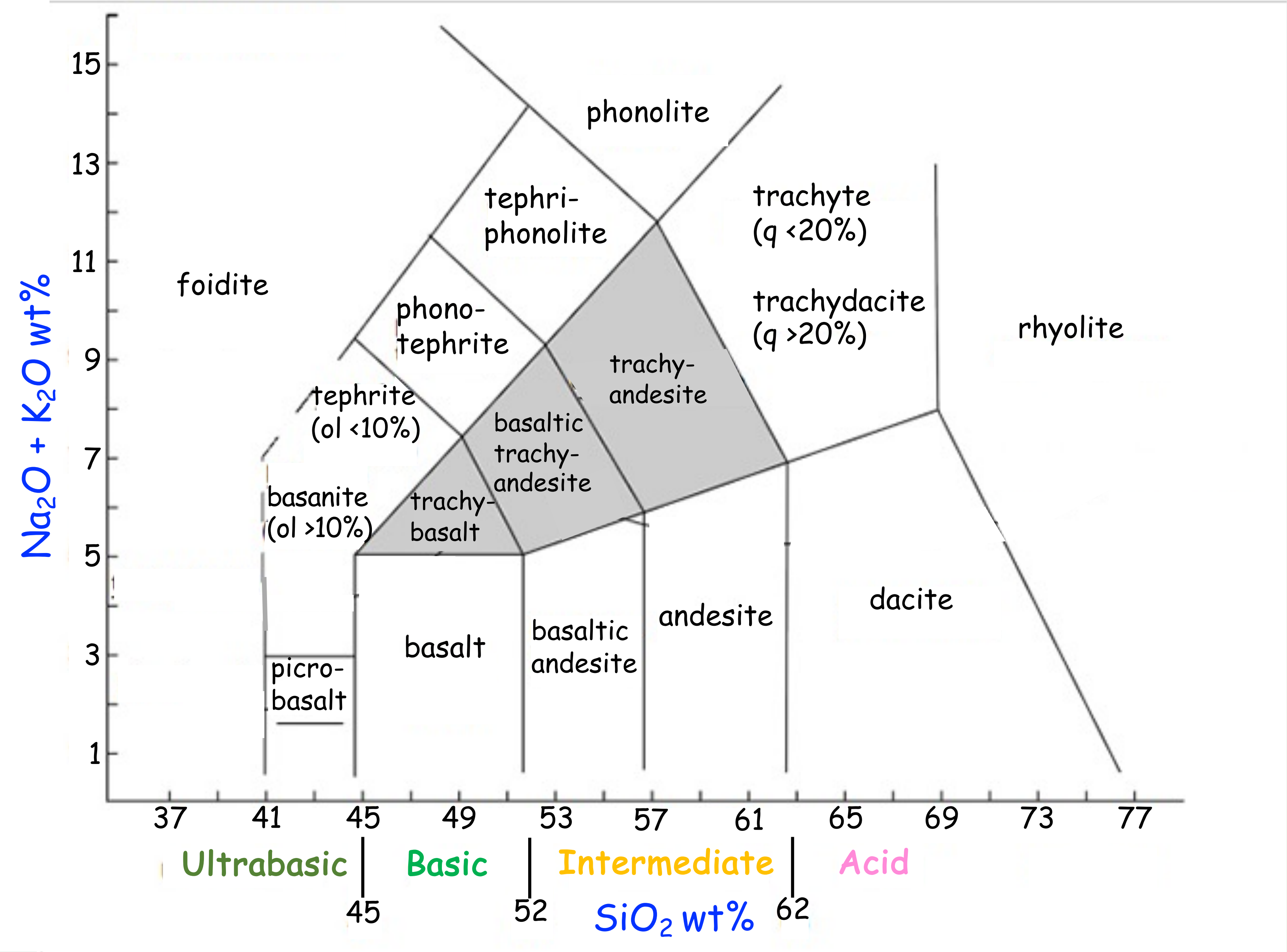
- Igneous rocks can be classified either according to the relative abundance of component minerals or, by chemical composition
- the first approach enables geologists to identify coarse-grained rocks in the field but, is not effective in classifying fine-grained rocks
- chemical classification requires analytical data and is therefore not useful in the field but is used for fine-grained and glassy rocks
- the composition of most igneous rocks can be expressed in 9 oxides: SiO_2,TiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O and K_2O

Classification of volcanic and hypabyssal rocks

- Where possible, volcanic rocks are classified on the basis of their mineralogy determined from thin section examination
- hypabyssal rocks are sub-volcanic intrusive igneous rocks formed near the surface resulting in fine to medium grainsize
- there are few plutonic igneous rocks that have no volcanic equivalent e.g. anorthosite, ultramafic rocks
- the only ultramafic lava to have formed is a rare volcanic rock called komatiite
- fine-grained volcanic rocks can be classified based on their total alkali and silica contents (TAS)

Basalt in thin section (crossed polars)

TAS classification of volcanic and hypabyssal rocks



Lava flows

- Lavas have similar compositions to the parent magma, the only difference being the loss of gasses during eruption
- the nature of lavas is dependent on composition with every lava type producing its own style of flow
- because of viscosity, a proportion of gas bubbles will be remain trapped as lava flow cools
- faster cooling tops and bottoms of lava flows are typically more vesicular than the centre that cools more slowly and may lose most of the gas bubbles through compression of overlying lava

Features of mafic lava flows

- Basalt lavas are often erupted in a highly fluid mobile state and may be fast moving at speeds of 20-30km/hr
- mafic volcanic rocks occur mostly in flows of which there are two main types blocky lava and ropey lava
- slow-moving blocky lava is known as aa lava and fast-moving lava with a ropey texture is called pahoehoe lava
- pahoehoe lava can transform into aa lava with distal decrease in temperature and loss of volatiles → increase viscosity
- when basalts erupt or flow into water they form lobate shapes called pillows

Types of lava flows

Aa lava flow, Kilauea, Hawaii

Pahoehoe lava flow,
Kilhauea, Hawaii

Columnar jointing

- Forms when thick basalt lava flows (commonly ponded) cool and the basalt contracts
- cracks form → commonly produce regular, polygonal patterns

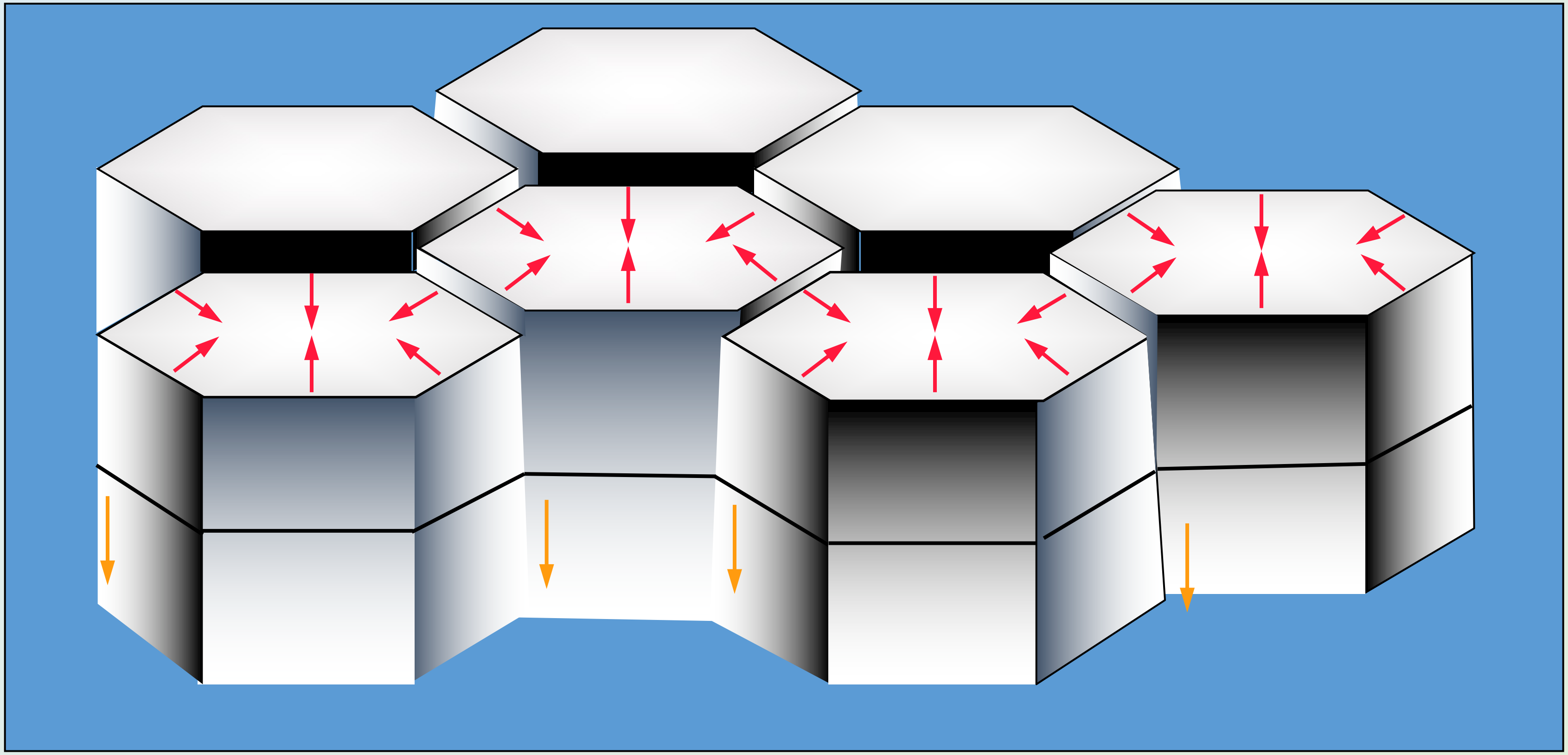
  → columnar jointing

Columnar jointing Hofsos, Iceland

X-section through columnar jointing Hosfos

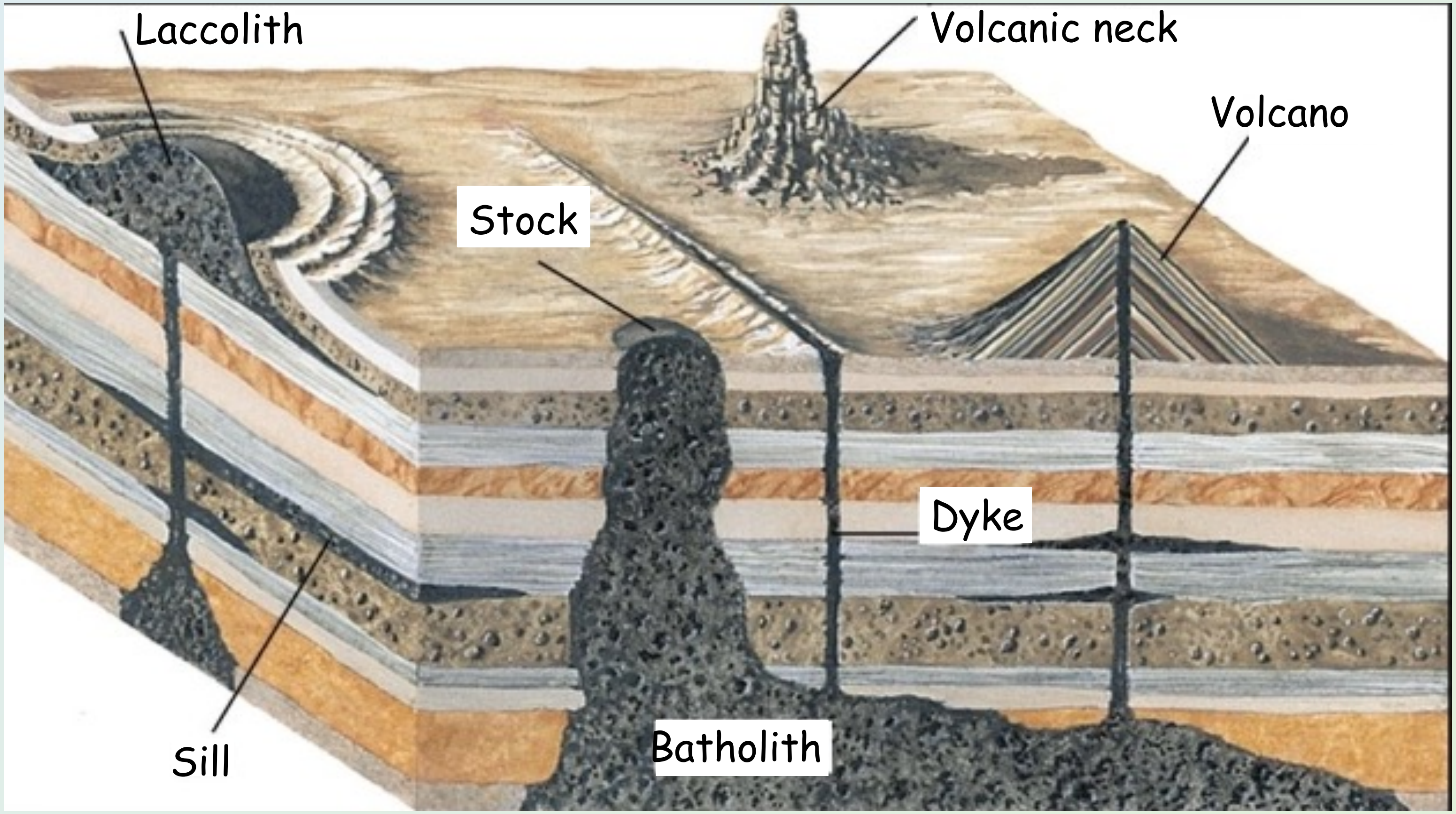
Columnar jointing

The rock contracts as it cools with the cracks beginning at the surface and progressing deeper into the flow.



Structures in hypabyssal rocks

Hypabyssal rocks are sub-volcanic rocks that crystallise at shallow depths in crust forming structures that include lava domes, volcanic necks, laccoliths, dykes and sills



Lava domes

- Lava domes occur in both hypabyssal and volcanic environments
- form from highly viscous lava → form small bulging, steep-sided dome shaped bodies → can be several hundred metres high
- if silica content is high (highly viscous magmas) and gas content low, eruptions are quiet without explosion
- surface of dome may be composed of fragmental lava erupted on surface
- below surface is composed of magma that solidified at shallow depth and was pushed into shape by magma intruding from below

Lava dome

Rhyolite lava dome in crater of Cháiten volcano, Chile

Volcanic necks

- Some volcanoes erupt easily eroded fragmental rocks
- as a volcanic edifice erodes, rocks in the vent of the volcano are more resistant to erosion
- an irregular cylinder shaped spire forms called a volcanic neck

Volcanic neck,
El Capitan, Arizona

Dykes

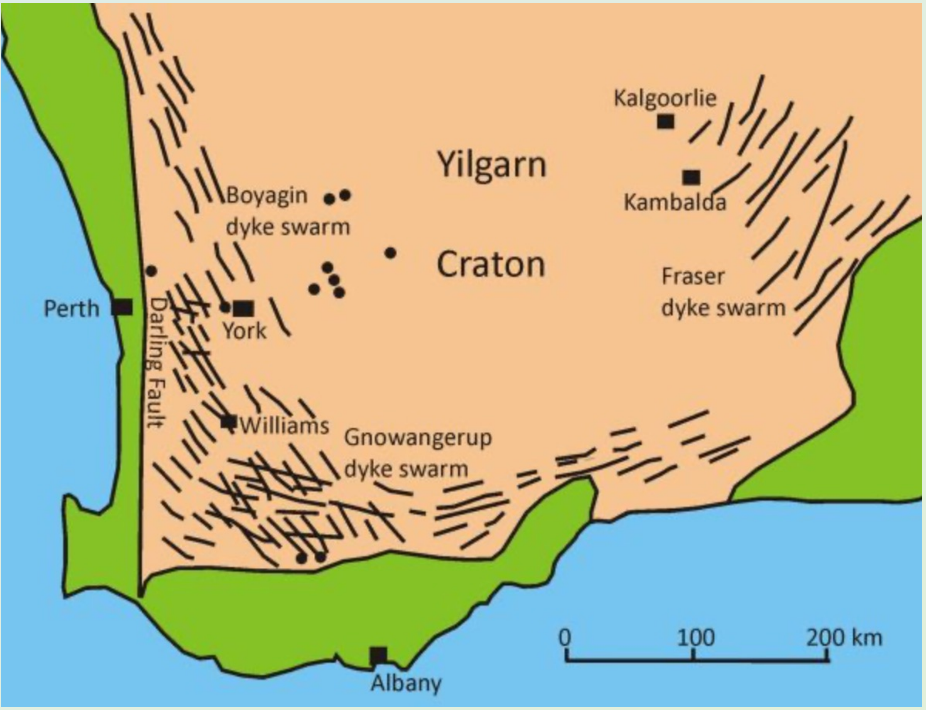
- **Dykes** → Sub-vertical to vertical tabular bodies of igneous rock that form in subterranean tension fractures
- can range from cm to km in width although most hypabyssal dykes tend to be in the order of metres in width
- some volcanic necks have associated dykes radiating outwards that may extend for more than 10km e.g. Shiprock, New Mexico
- when crust fractures in a tectonic environment, intrusion of magma into faults produces dyke swarms
- a dyke swarm consists of many dykes with similar orientation and chemistry

Volcanic neck and associated dyke, Shiprock, New Mexico

Dykes

Mafic dyke intruding granite,

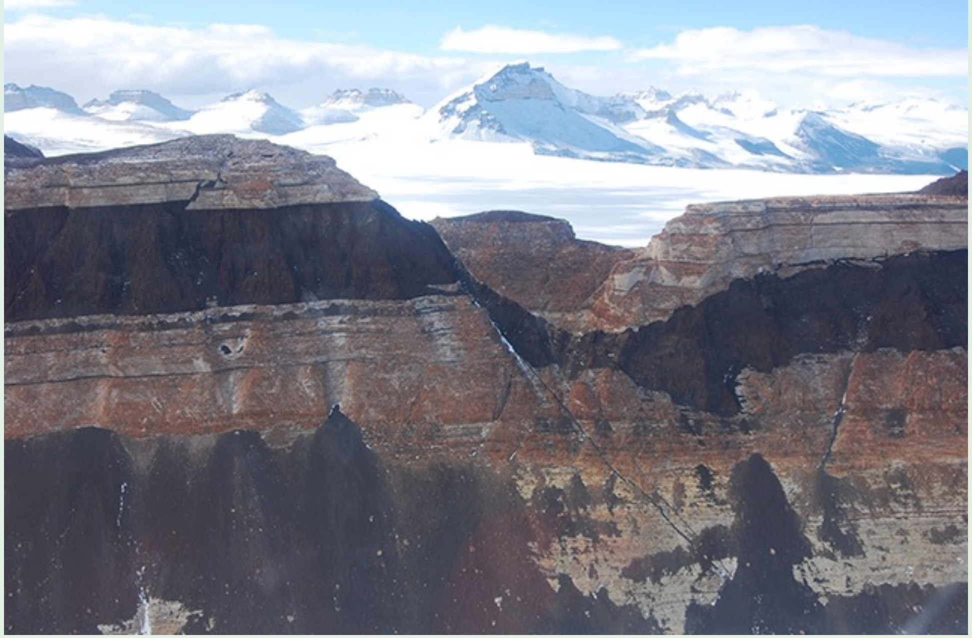
Finlayson Point, Victoria, Canada



Dyke swarms in the Yilgarn, WA

Sills

- Sills → horizontal or low angle concordant flat sheet intrusions of highly fluid basaltic magma
- only form at relatively shallow depths (few Km) → at greater depths pressure of overlying rocks prevents opening of spaces for magma
- more common in near surface bedded sequences particularly sedimentary sequences commonly parallel to bedding
- may also form as offshoots of dykes



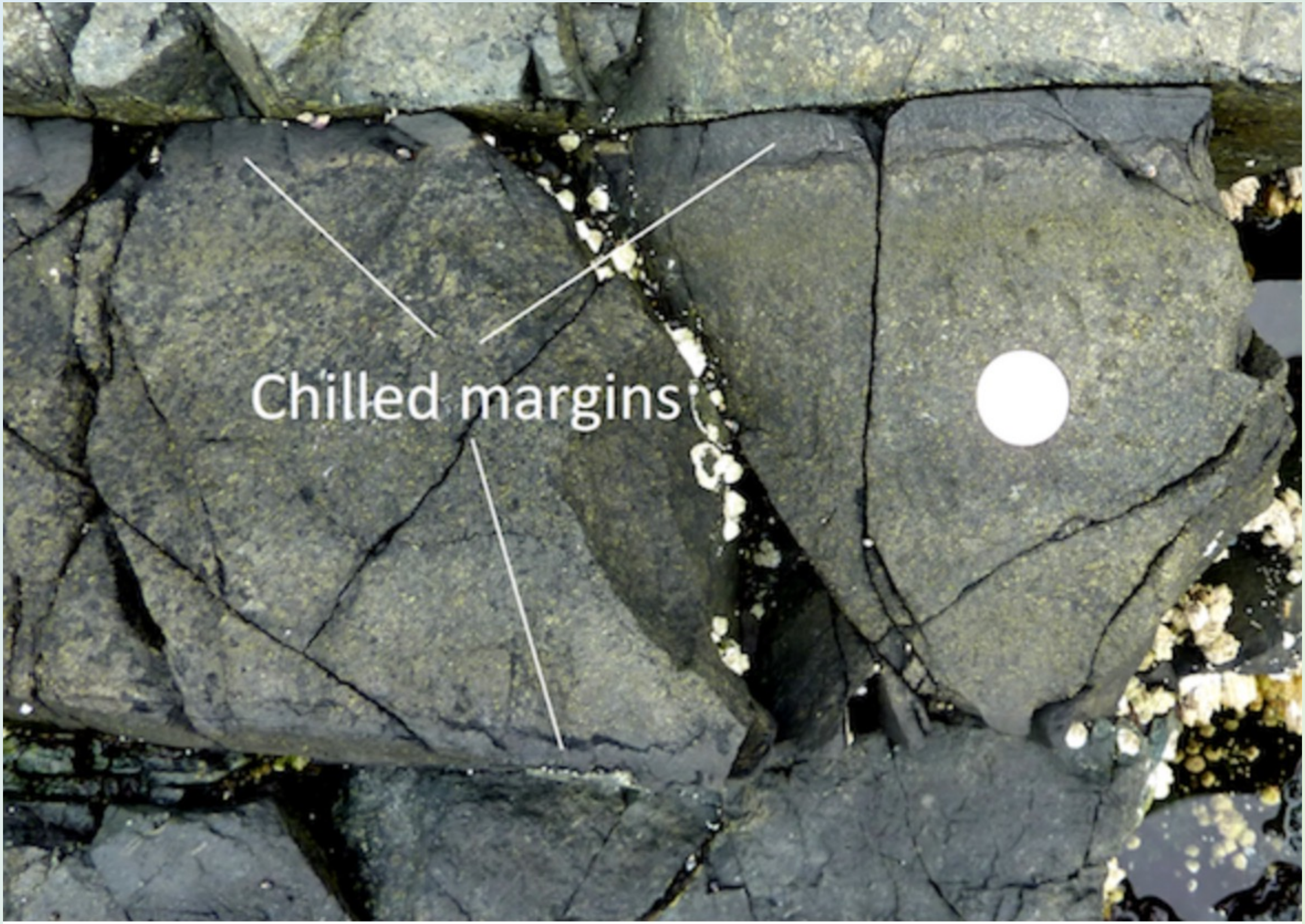
Jurassic dolerite sill,

Beacon Valley, Antarctica

Chilled margins

- Chilled margins → common distinctive features of hypabyssal sills and dykes
- when magmas are emplaced at shallow depths in the crust, the enclosing rocks are at a much lower temperature than the magma
- magma on the edge of dyke or sill may chill rapidly → fine-grained
- fine-grained margins of dyke or sill insulates the interior → cools more slowly → coarser grained

Chill margin



Pyroclastic deposits

- Pyroclastic deposits are composed of volcanic ash and rock fragments ejected from a volcano during an eruption
- fragments larger than 64mm are referred to as bombs → lumps of magma that were plastic or partly plastic when erupted
- erupted materials between 4 and 64mm are called lapilli
- accretionary lapilli are spheroidal, concentrically layered pellets formed by accretion of ash and dust by moisture in eruption clouds
- ash is incoherent ejecta less than 4mm in diameter and may be vitric, crystal or lithic ash

Volcanic bomb

Volcanic bomb Kilhauea, Hawaii, 1983

Pumice and scoria

Pumice and scoria → ejecta of melt with porosity of 50-80%

Pumice Tenerife,
Canary Islands

Scoria,
Anakies, Vic.

Lapilli

Lapilli tuff,
Tenerife

Accretionary lapilli

Tuff and ignimbrite

- **Tuff** → rock composed of volcanic ash erupted by a volcano, deposited and lithified into solid rock
- **Ignimbrite** → hard welded tuff
- form from thick deposits of hot pyroclastic flows that compress and weld under hot ash
- ignimbrites are a poorly sorted mixture of volcanic ash, pumice and lithic fragments

Tuff and ignimbrite

Pumiceous tuff with rock fragments,

Santorini

Ignimbrite with pumice,

Grand Canaria, Canary Islands

Enclaves

- Igneous intrusions commonly include exotic blocks of rock that range in size from cm to km
- these blocks are referred to as enclaves
- enclaves composed of fragments of country rocks that break off and fall into the magma are called xenoliths
- other enclaves may be refractory remnants of the partially melted protolith, these enclaves are called autoliths
- enclaves may also form through mixing or mingling of two or more magmas of different compositions

Enclaves

Enclaves of various sizes
in monzogranite, Elba, Italy

Mafic autolith in granite

Magma mingling and mixing

- Magmas of different composition commonly interact in magma chambers
- in most cases the process results in the complete mixing of the starting magma
- complete mixing of starting magmas give a hybrid geochemical signature and petrographic clues e.g. reverse zoning of phenocrysts
- in some cases, magma mingling/mixing is incomplete, resulting in the formation of magmatic enclaves

Enclaves from magma mingling

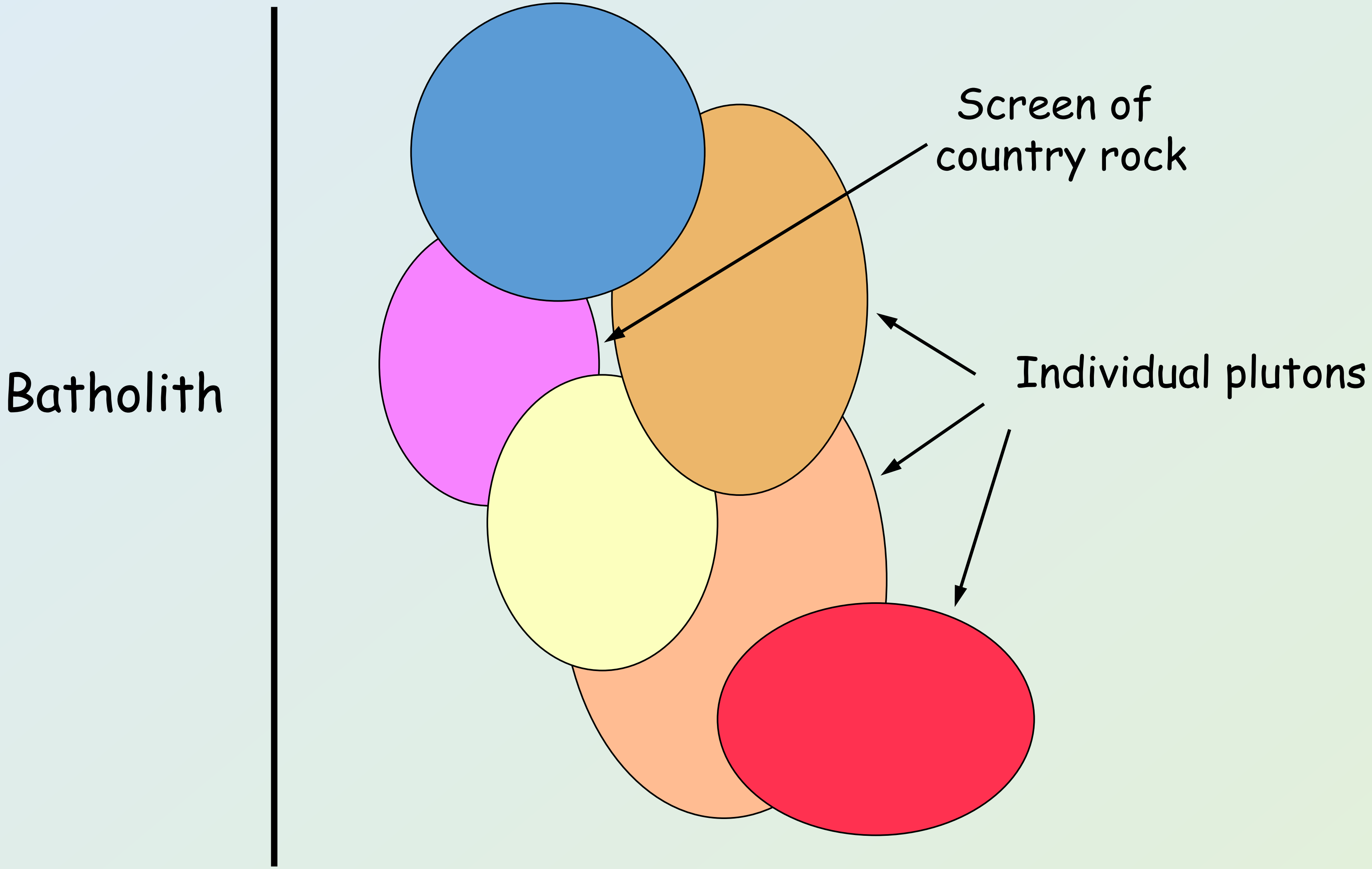
Basalt enclaves surrounded by dacite erupted in 1915 Lassen volcano, California, USA

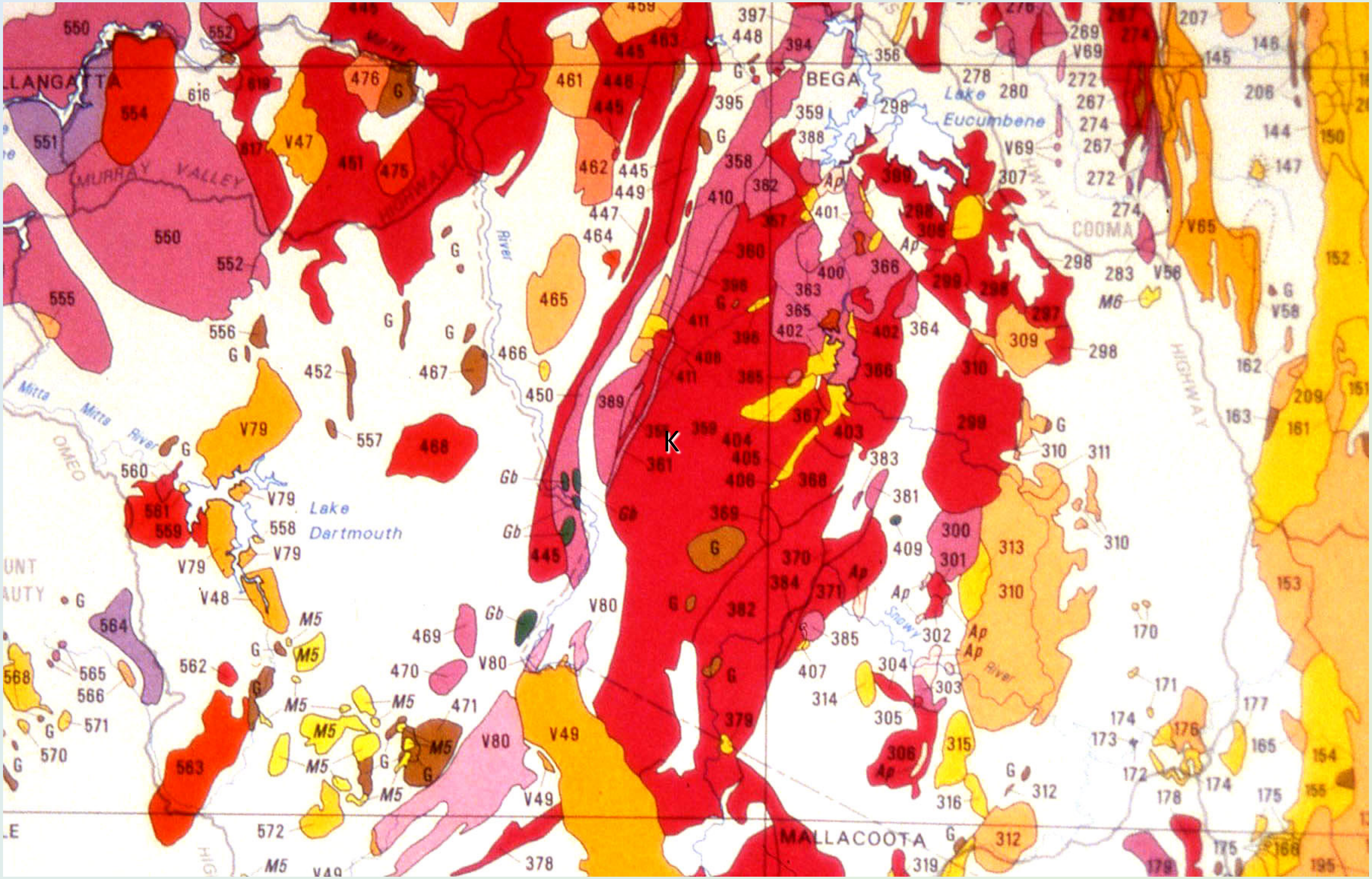
Irregular mafic enclaves in granodiorite, Sudtirol, Italy

Structure in plutonic rocks

- Plutonic rocks occur in irregular, elliptical shaped bodies known as plutons that are intruded at depth within the crust
- batholiths are composite bodies composed of multiple individual plutons
- the term batholith is usually applied to granitic rocks
- large plutons composed of mafic rocks are more commonly referred to simply as intrusions
- plutons emplaced at shallow depths may preserve chill margins, while those emplaced deeper may not

Structure of a Batholith





Geological map showing distribution of granite plutons, SE NSW

Ultramafic igneous rocks

- Ultramafic rocks have low silica contents (<45% SiO_2), elevated Mg and Fe (generally >18% MgO) and low K
- generally composed of >90% of mafic minerals, dominantly olivine and pyroxenes
- differ from ultrabasic rocks → ultrabasic rocks not necessarily enriched in Fe and Mg
- intrusive ultramafic rocks commonly found in large layered intrusions e.g. Bushveld complex, Sth Africa; Skaergard, Greenland
- surface exposure of ultramafic rocks occur in ophiolite complexes → deep mantle derived rocks obducted onto continental crust

Volcanic ultramafic rocks

- Volcanic ultramafic rocks are rare outside of the Archaean where komatiites occur in the greenstone belt in the Yilgarn, WA
- komatiites are fine-grained, volcanic rocks with a high Mg concentration >18wt% MgO → no longer form on Earth
- ultramafic rocks such as kimberlites, lamproites and lamprophyres reach the surface, although no modern eruptions observed
- ultramafic inclusions transported from the mantle to the surface by magma include dunite, peridotite and pyroxenite

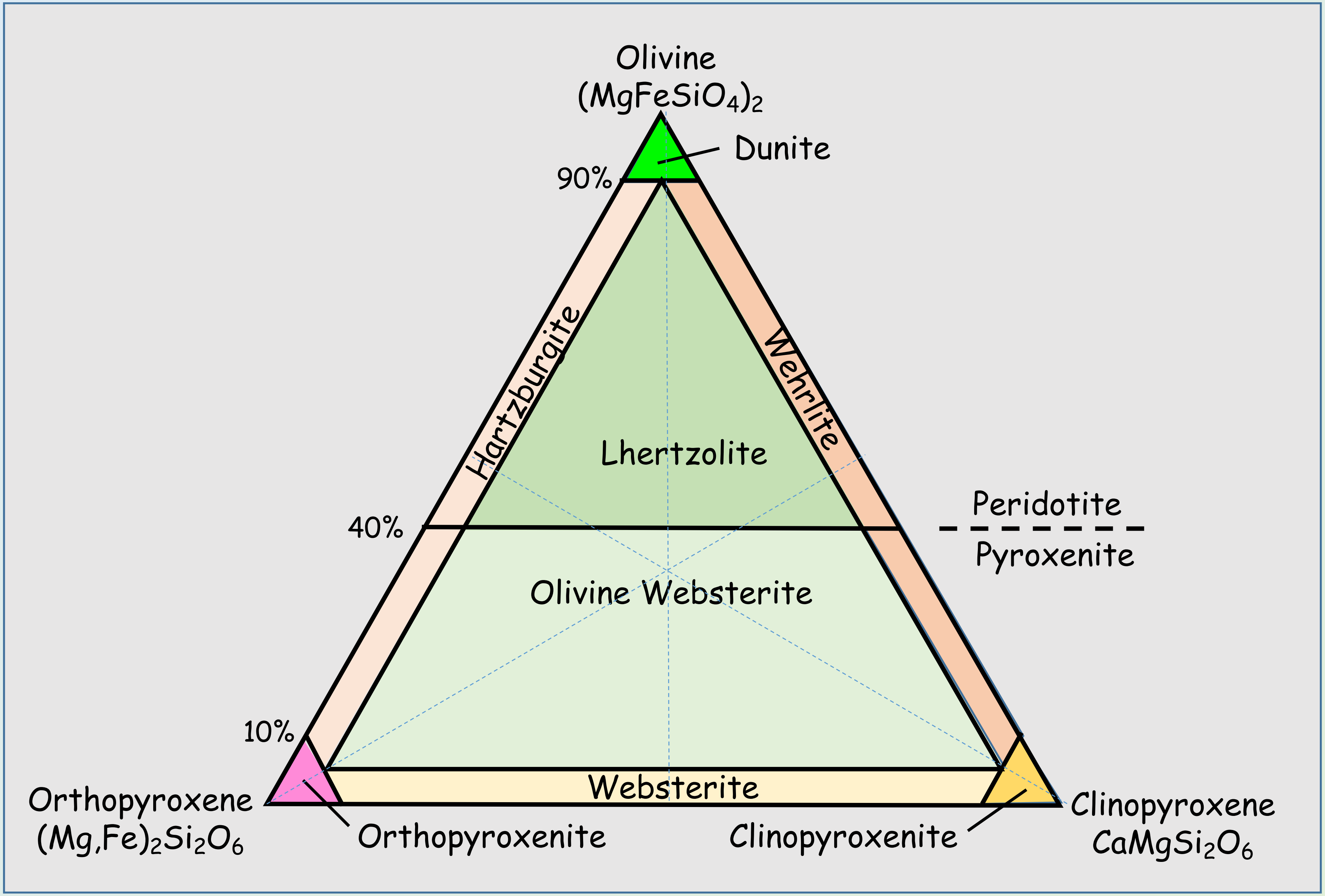
Komatiites

- Komatiites – mantle-derived ultramafic volcanic rocks composed essentially of olivine and pyroxene
- depleted in Si, Al and felsic elements, extremely Mg enriched
- Komatiite lavas are restricted to Archaean age (2.5 – 3.8billion years)
- for komatiites to form requires a very high degree of partial melting in the mantle (50-60%) c.f. 20% that occurs today
- two possible scenarios for how they formed:

  (a) Temperature of mantle was 500°C hotter than today

  (b) The mantle had a higher content of water and volatiles that would lower the melting temperature

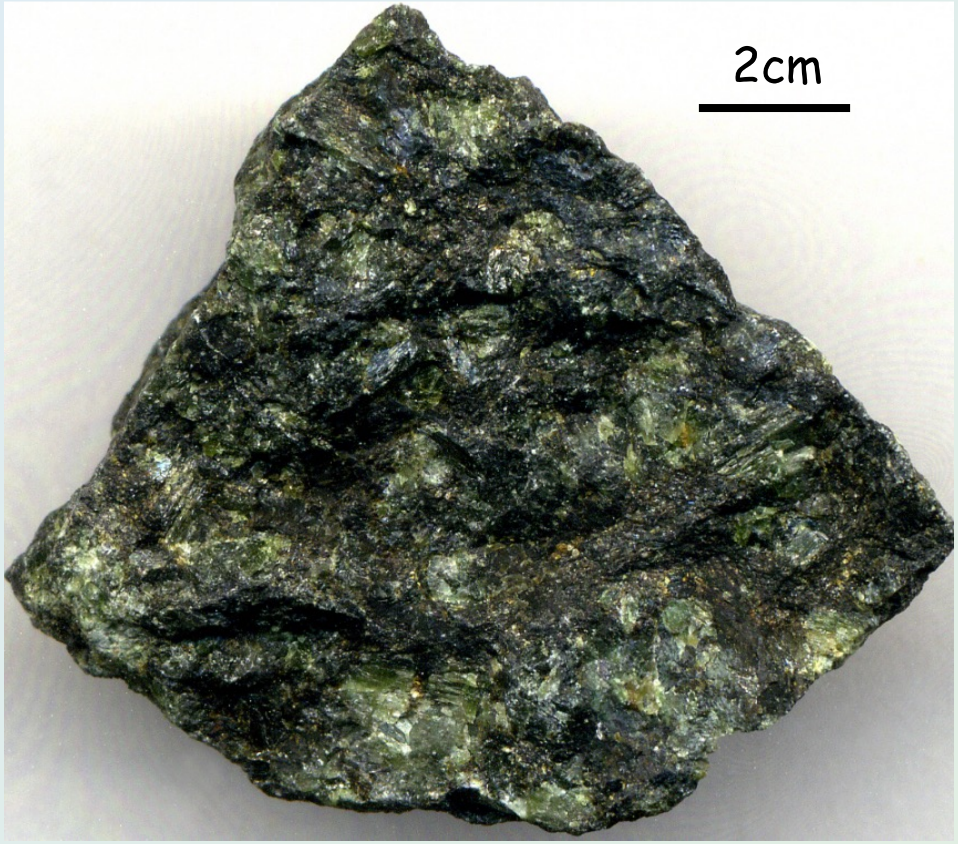
Classification of ultramafic rocks



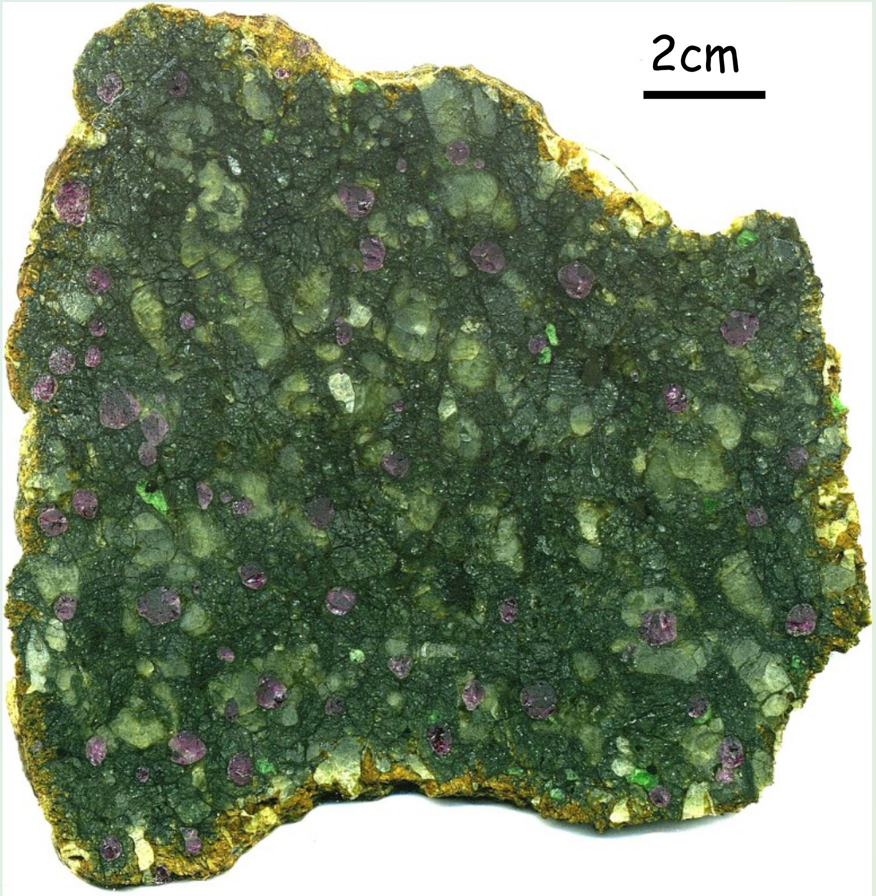
Ultramafic mantle xenoliths

Two xenoliths from the mantle. Orthopyroxenite (brown), lherzolite (green)

Ultramafic rock types



Pyroxenite from the Stillwater Complex, Montana, USA



Garnet lherzolite from South Africa