Igneous Rocks

Rocks

Definition

It is a aggregate of mineral. They form major part of the earth crust.

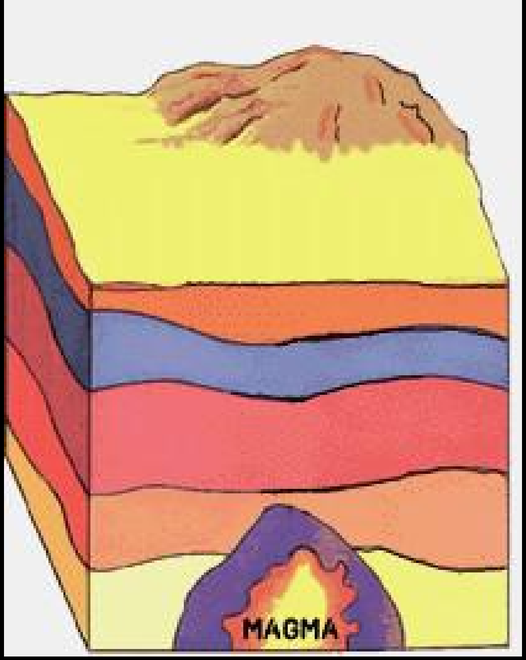
Rocks are divided in to three major groups

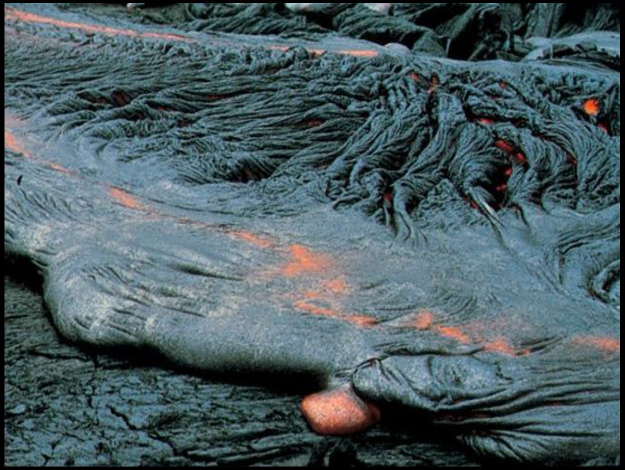
1)Igneous Rocks
2)Sedimentary Rocks
3)Metamorphic Rocks

Igneous Rocks:

Igneous rocks are formed by cooling and solidification of magma. Magma is hot, viscous, siliceous melts, containing water vapor and gases. It comes from great depth below the earth surface it is mainly composed of O, Si, Al, Fe, Na, Mg, Ca and K.

when magma comes upon the surface it is called as 'Lava'





Chemical Composition of Igneous Rocks

- **Acid Magma** : is rich in Si, Na, & K and Poor in Ca, Mg, Fe
- **Basic Magma:** is rich in Ca, Fe & Mg and Poor in Si, Na, & K

Basic Magma is divided in to three groups

1)**Ultra Basic rock:** these contains less than 45% of Si. Example Periodite

2)**Basic Rock :** These contain Si between 45 to 55 %. Example Gabbro & Basalt

3)**Intermediate Rock :** These contains Si between 55 to 65%. Example Diorite

4)**Acid Rock :** In this Si contains more than 65%. Example Granite

Peridotite

Gabbro

Basalt

Diorite

Igneous rocks can also be classified as

1)Over saturated: contains high amount of Si & abundant Qtz. & alkali Feldspars

2)Saturated: contains sufficient amount of Si & do not contains Qtz.

3)Under saturated: contains less Si & High in Alkali & aluminum Oxides.

Types of Igneous Rocks

1)Extrusive Rocks

2)Intrusive Rocks : *These are divided in to two types*

- *Plutonic Rocks*
- *Hypabyssal Rocks*

Texture of Igneous Rocks

Texture means Size, Shape and arrangement of mineral grains in a rock

In general the slower cooling or solidification of magma shows coarser grain rocks.

To study texture following four parts are important.

1)Degree of crystallization

2)Size of grains

3)Shape of crystal

4)Mutual relation between mineral grains

1) **Degree of Crystallization : It divides in two parts**

a) **Holocrystalline texture:** Rocks shows entirely crystalline texture

b) **Holohyalline texture:** Rocks shows entirely glassy texture

2) Size of grains:

a) **Phaneric : constituent minerals grains can be see by necked eyes.**

i) **Coarse grained ii) Medium grained iii) Fine grained**

ii) **Aphanitic : whose mineral grains are too small but can be see by necked eyes**

Lava

Shape of crystals:

Well developed crystals faces of grains called **Euhedral**

Partly developed crystal faces called **Subhedral**

The crystal faces are absent such grains of rock called **Unhedral**

Mutual relation of grains.

i) Equigranular texture

ii) Inequigranular texture

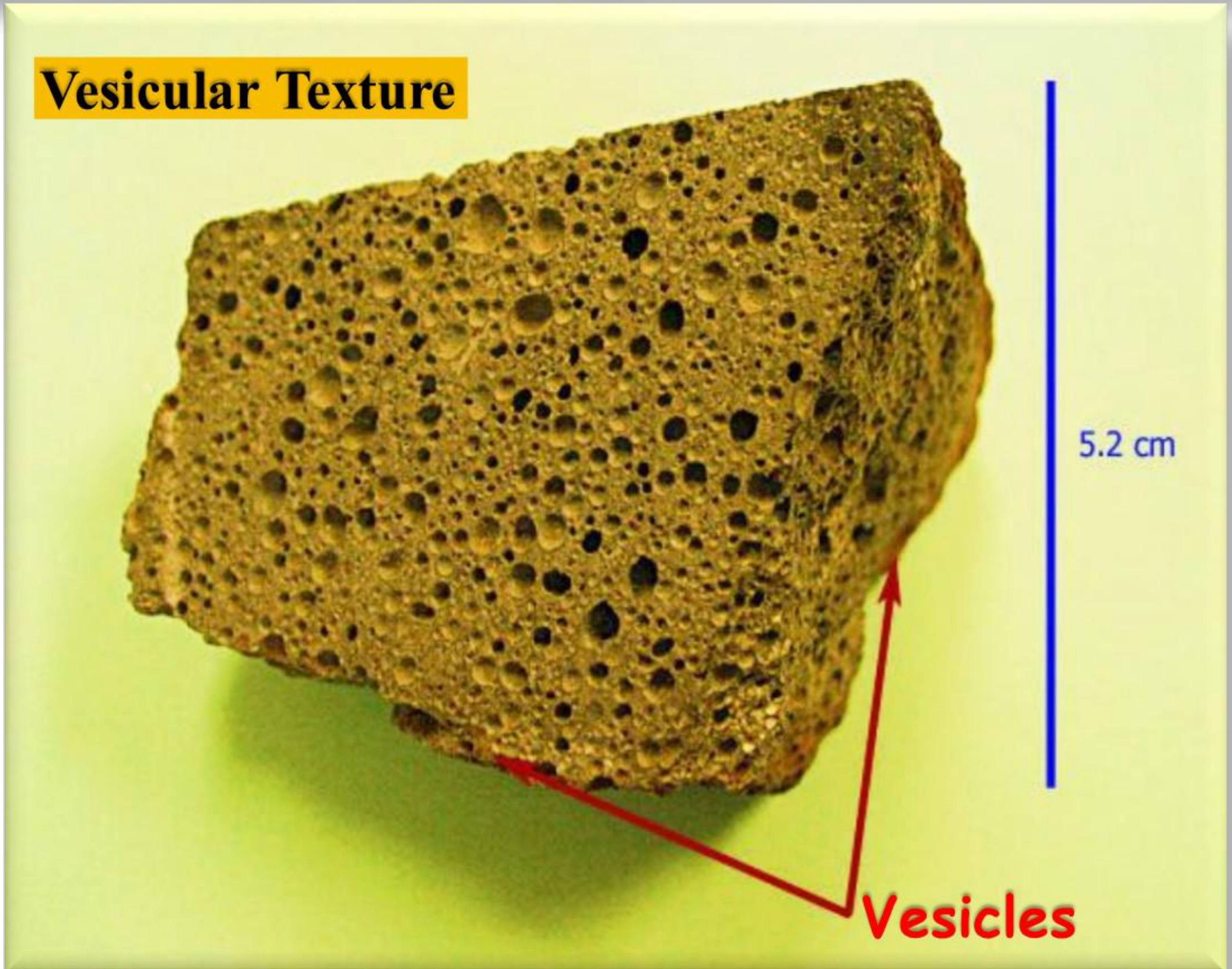
a) Porphyritic texture b) Poikilitic texture c) Ophitic texture

Porphyritic texture

Poikilitic texture

Vesicular Texture:

Volcanic rocks which have a glassy matrix often contains gas cavities called vesicles.

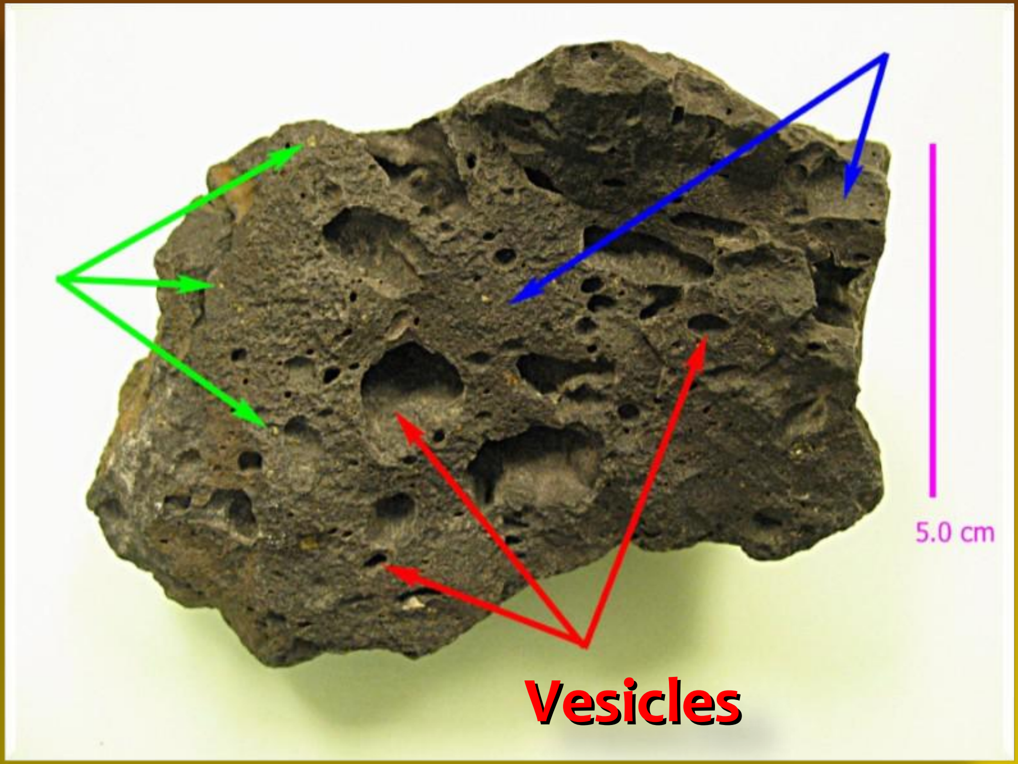


Structures of Igneous Rocks

- Flow Structure
- Reaction Rim
- Xenolith structure
- Vesicular structure
- Amygdaloidal Structure
- Pegmatite Structure

Vesicular Structure

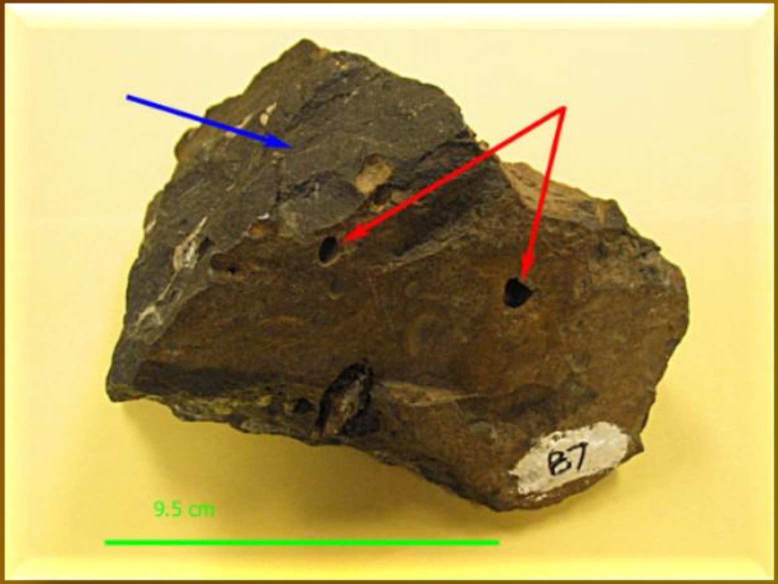
Lava contains large amount of gas & volatiles, these gases escapes in atmosphere and a way from which these gases are escaped keeps the cavities in the form of vesicles.

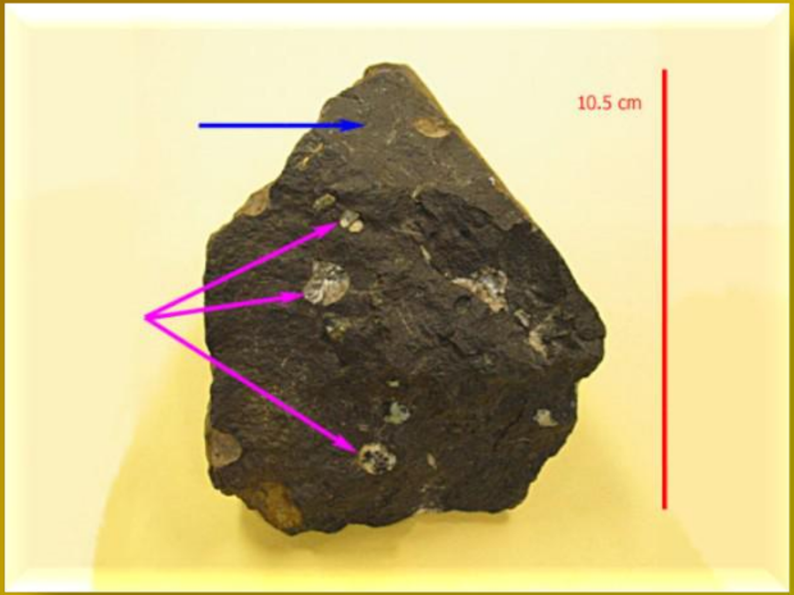


Vesicular Structure

Structures of Igneous Rocks

Amygdaloidal Structure: The vesicles of volcanic rocks may subsequently be filled by secondary minerals such as calcite and zeolites, such filled vesicles are called Amygdaloidal Structure.

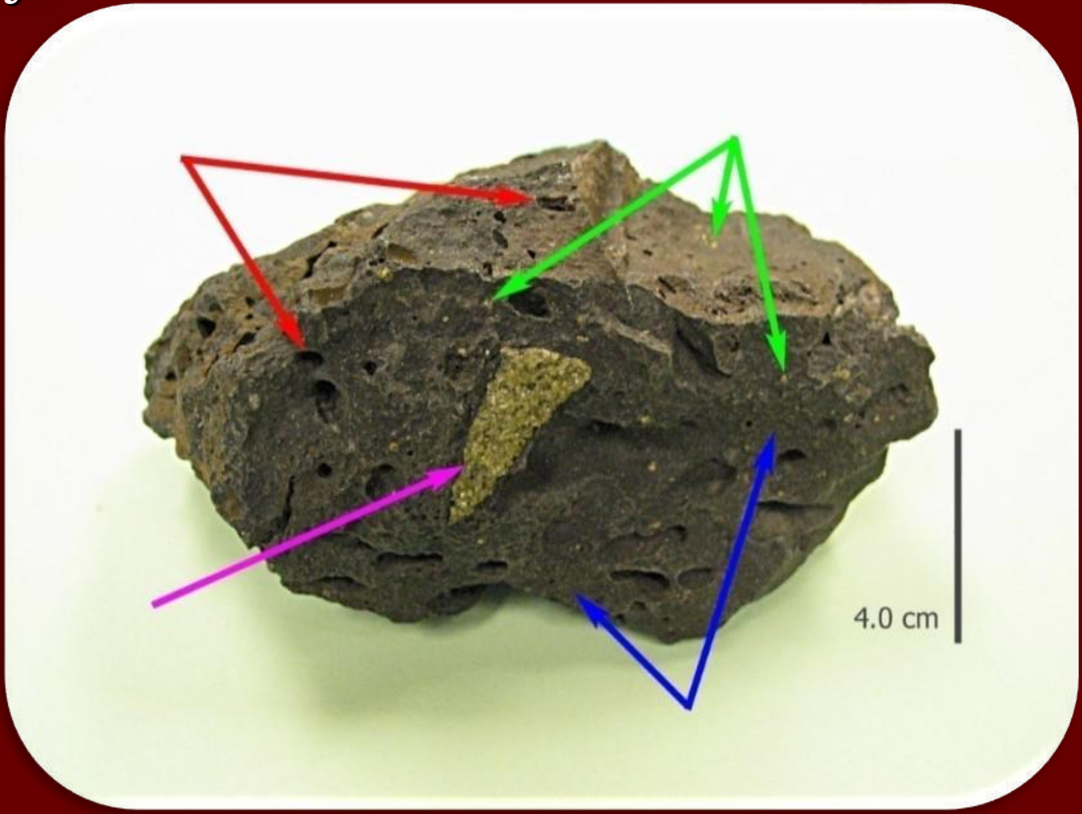




Amygdaloidal Structure

Structures of Igneous Rocks

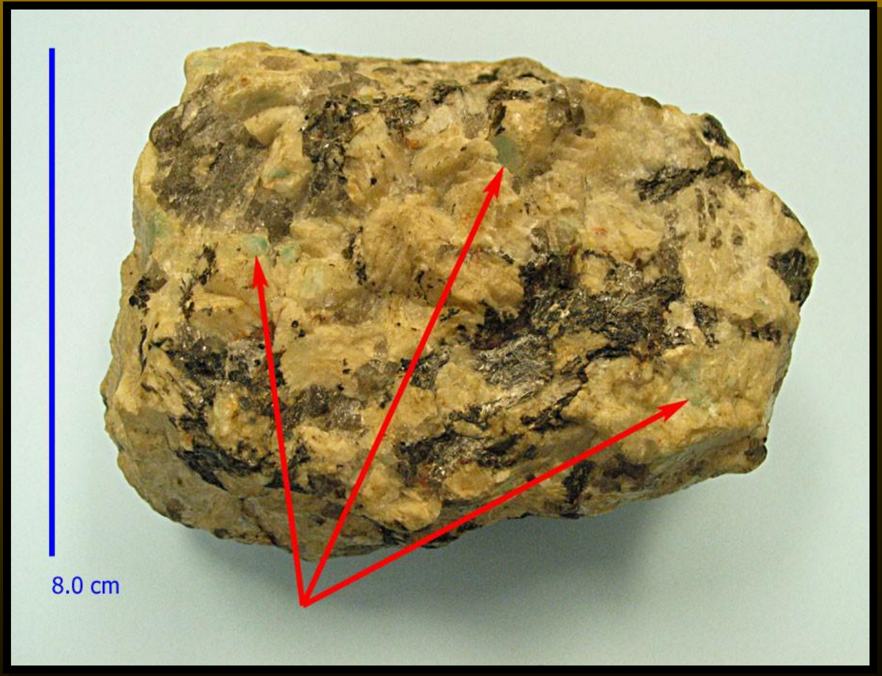
Xenolith structure: Inner rock fragments are included in to magma. When it rises up towards the surface, if they are not digested they remain entrapped within the magma and produces Heterogeneity



Xenolith Structure

Structures of Igneous Rocks

Pegmatite Structure: The constituent minerals grains exceeds several centimeters in the size, the rock is known as Pegmatite Structure.



Pegmatite Structure

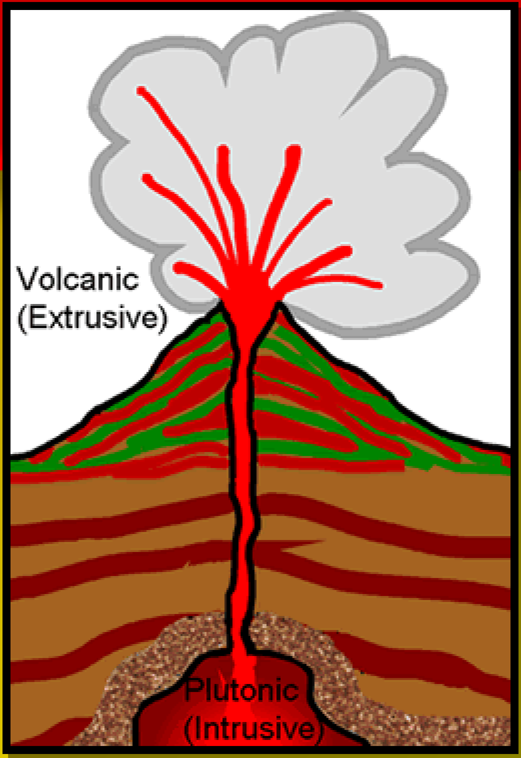
Forms of Igneous Bodies

1) **Extrusive Igneous Bodies**
2) **Intrusive Igneous Bodies.**

Extrusive Igneous Bodies : These are forms when magma reaches to earth surface and get solidification. Example Lava flow

Intrusive Igneous Bodies : These are formed by the consolidation of magma at some depth below the earth surface. Such bodies shows variations in their shape and size.

These are divided in to two parts.



I) Discordant bodies 2) Concordant bodies.

Forms of Igneous Bodies

Discordant bodies :

The discordant bodies are those which cuts through over laying strata.

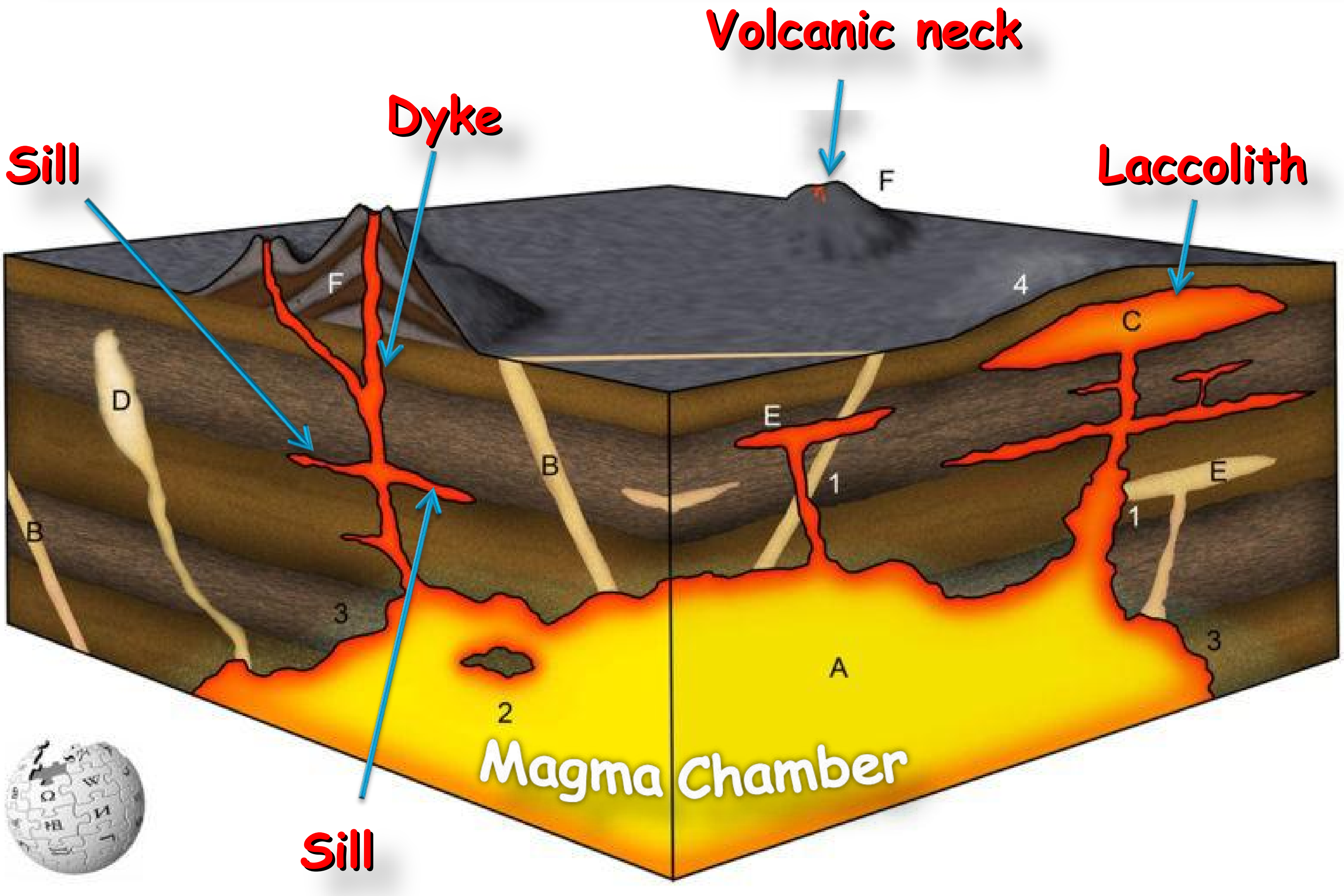
Example Batholiths, Stock and Dyke

Concordant bodies :

These bodies lies between beds.

Example- Sills, Lopolith and Laccoliths

Forms of Igneous Bodies



Volcanic necks

- Shallow intrusion formed when magma solidifies in throat of volcano

Dikes

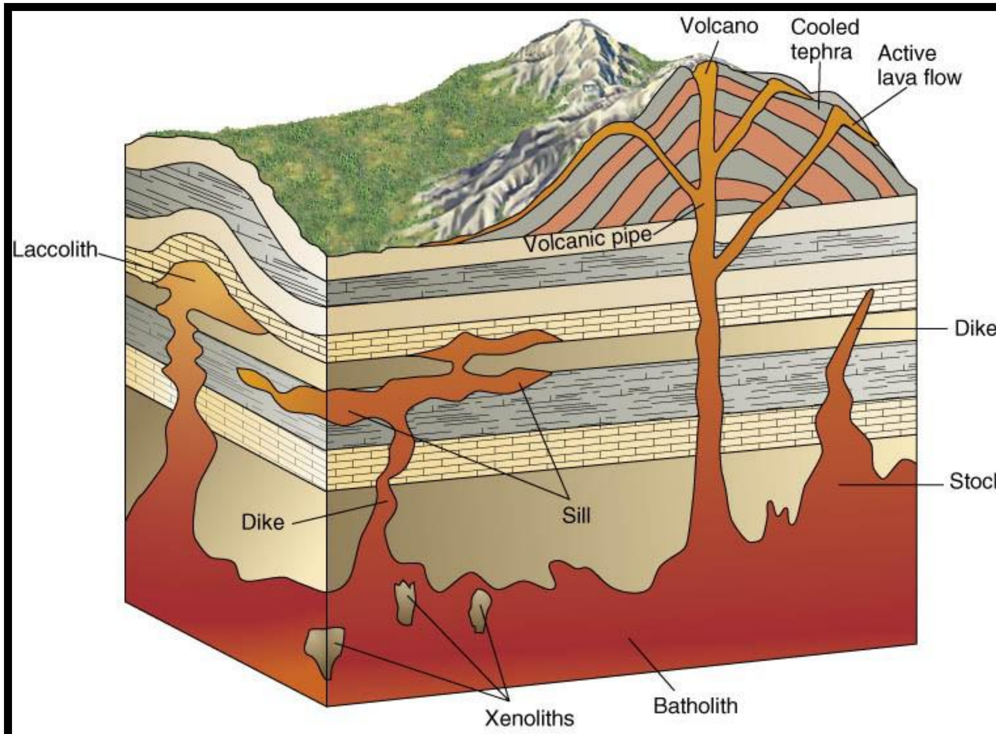
- Tabular intrusive structure that cuts across any layering in country rock

Sills

- Tabular intrusive structure that parallels layering in country rock

Plutons

- Large, blob-shaped intrusive body formed of coarse-grained igneous rock, commonly granitic
- Small plutons are called *stocks*, large plutons (>100 km^2) are called *batholiths*

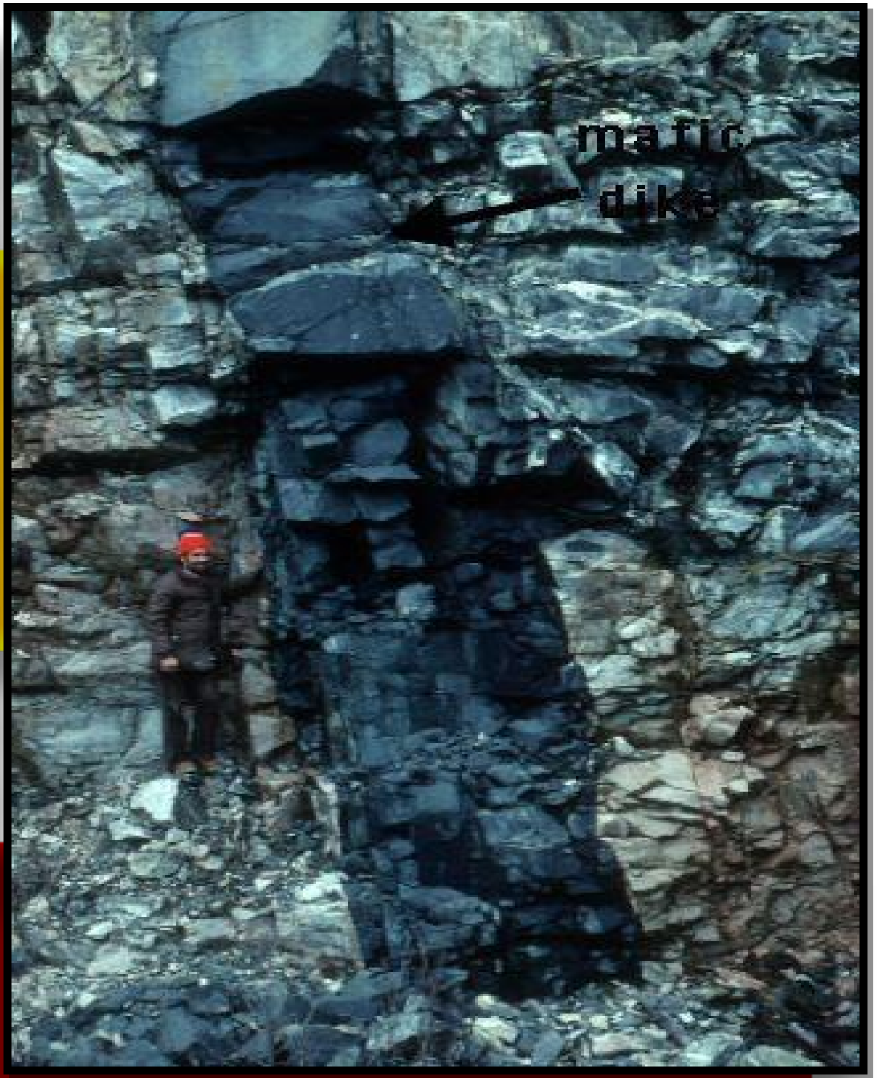


Laccoliths mushroom-shaped body of igneous rocks with a flat bottom and domed top. It is parallel to the layers

Forms of Igneous Bodies

Discordant bodies :

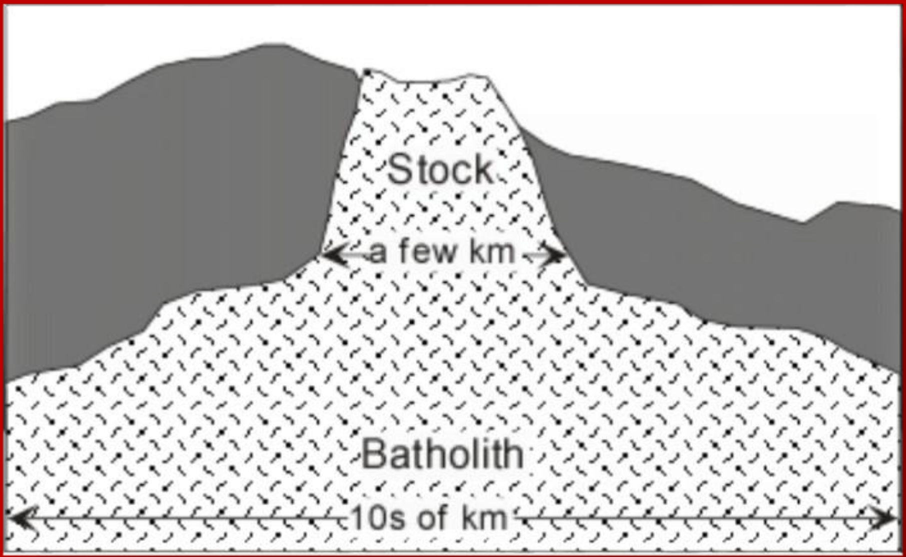
Dikes are small igneous intrusions that cut across rocks into which the magma intrudes. They are commonly sheet-like, only a few meters wide, but possibly laterally extensive. Think of magma invading a vertical or near-vertical fracture in rock. Igneous rock would fill the crack due to crystallization of magma. One would call the rock body a dike.

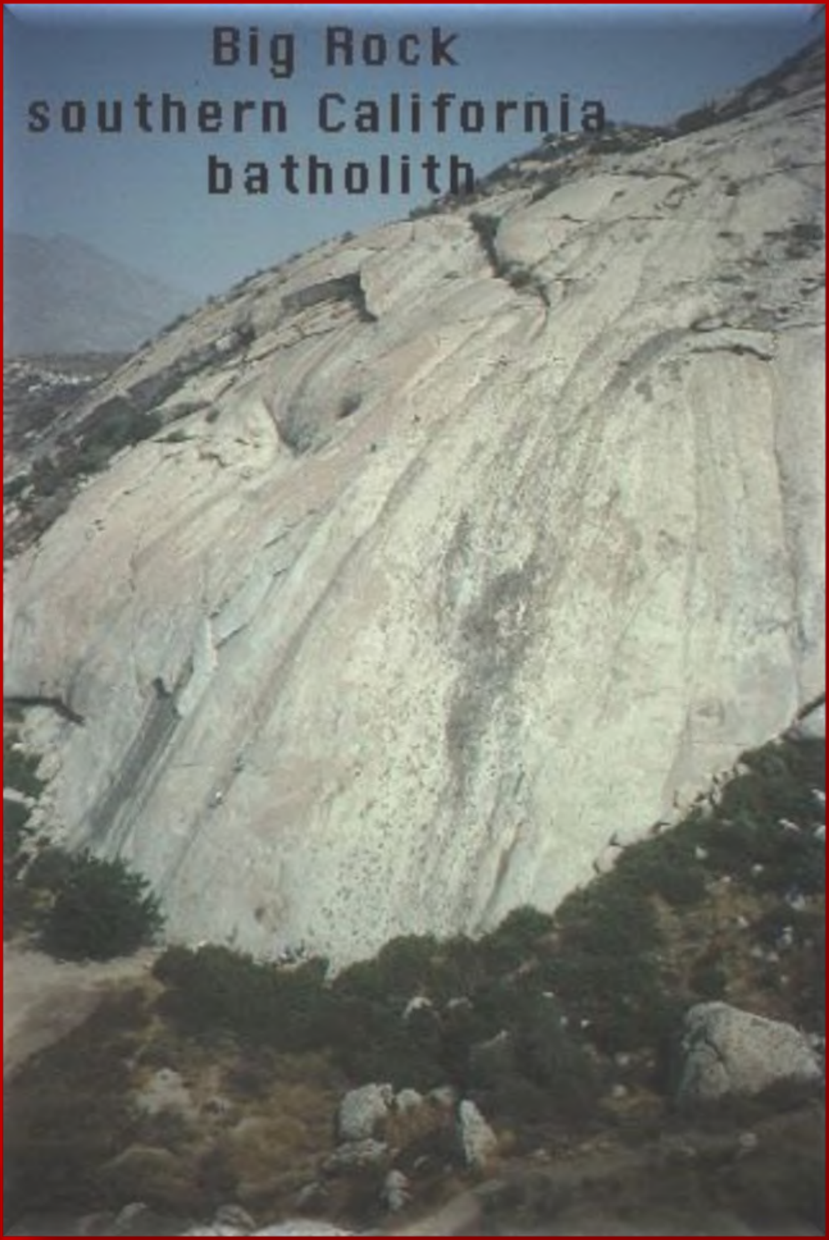


Mafic dyke

Forms of Igneous Bodies

Batholiths- are huge igneous intrusions made of many stocks. Their size is on the scale of an entire mountain range (100's of miles)





Batholiths

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End of Igneous activity

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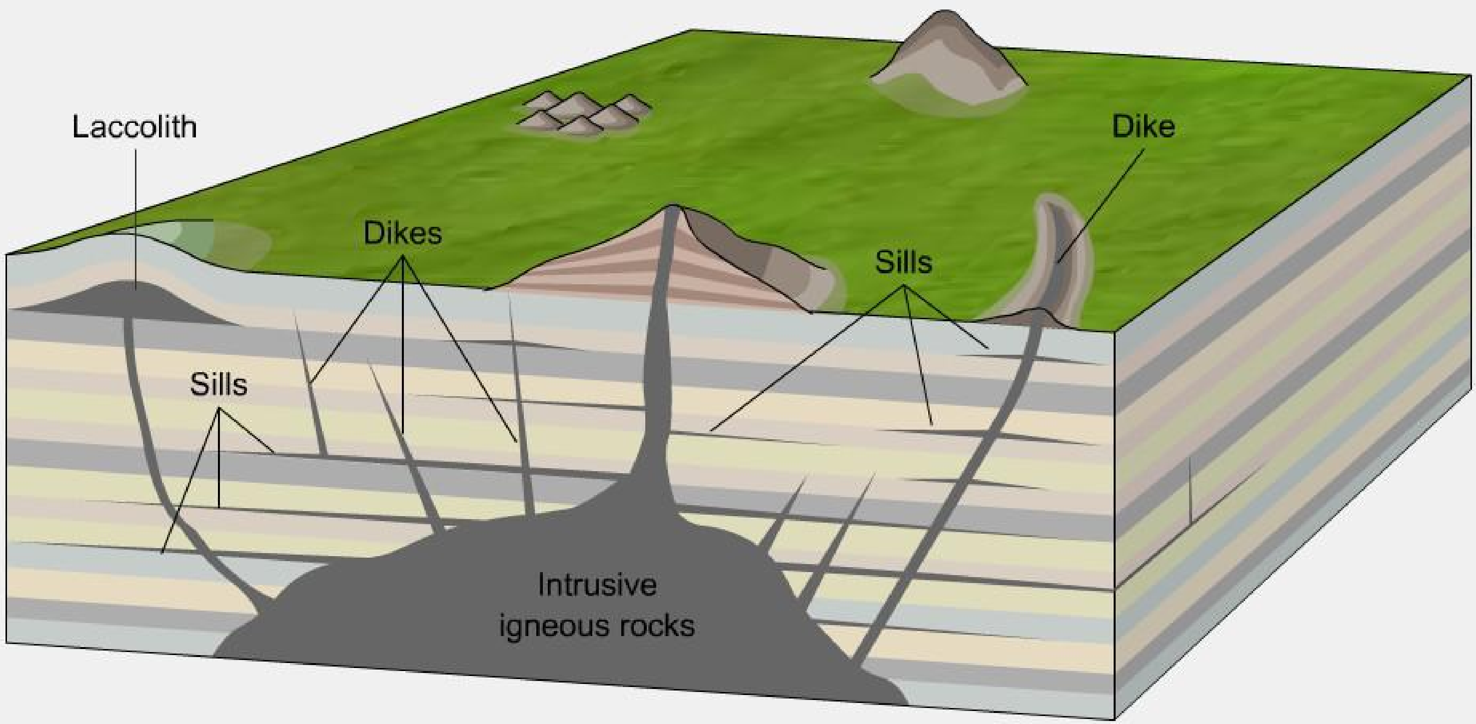

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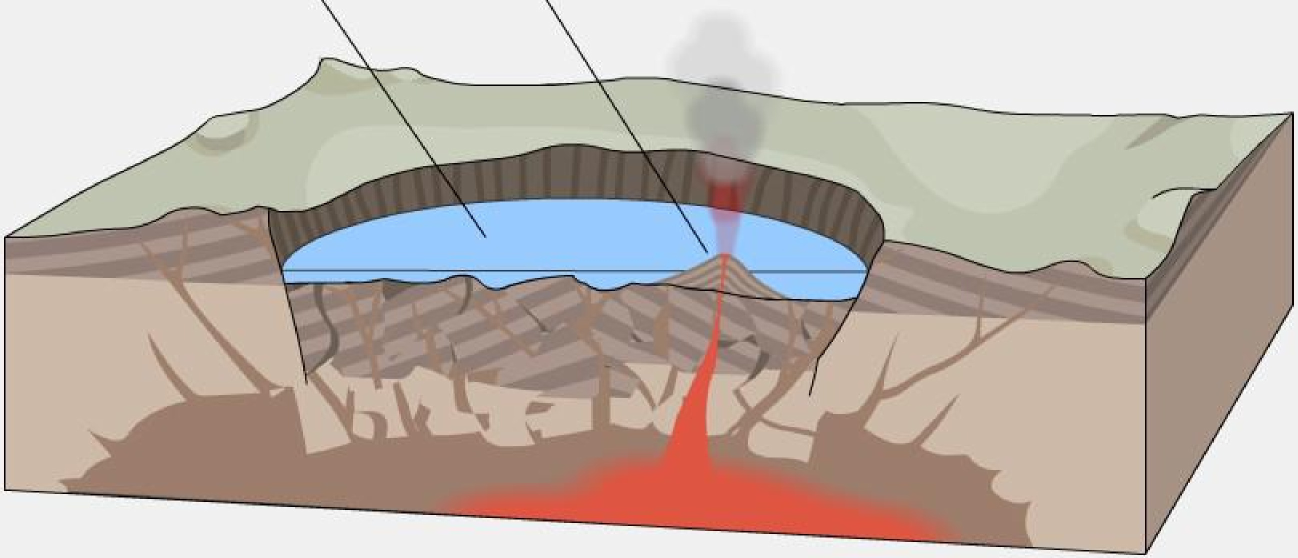


Formation of a Crater Lake--type caldera

Reset

Sills are also small igneous intrusions. They are sheets of rock that, unlike dikes, are parallel to pre-existing rocks. Think of magma invading sedimentary rocks by spreading out between rock layers. That magma would cool to form a sill.


Volcanic Eruption
Discovery
discovery.com

Classification of Igneous Rocks

“personally, I doubt that an exact petrological classification of igneous rocks can ever be attained. We may arrive at some sort of approximation to an orderly arrangement for the purposes of petrographic description and petrological discussion, which might by courtesy be called a classification…………”

H S Washington, 1922

Classification of Igneous Rocks

"A rock may be given one name on the ground of field occurrence and from hand lens examination, only to require another when it is studied in thin section, and perhaps a third when it is chemically analyzed. . . . Different schemes have different objects in view"

Classification based on Fabric

Four principal types of fabric occur in magmatic rocks: *phaneritic, aphanitic, glassy, and volcaniclastic*.

The first two refer to the dominant crystal grain size, which ranges over several orders of magnitude, from 10^{-3} to 10 m.

Phaneritic applies to rocks that have mineral grains sufficiently large to be identifiable by eye (minute accessory minerals excepted).

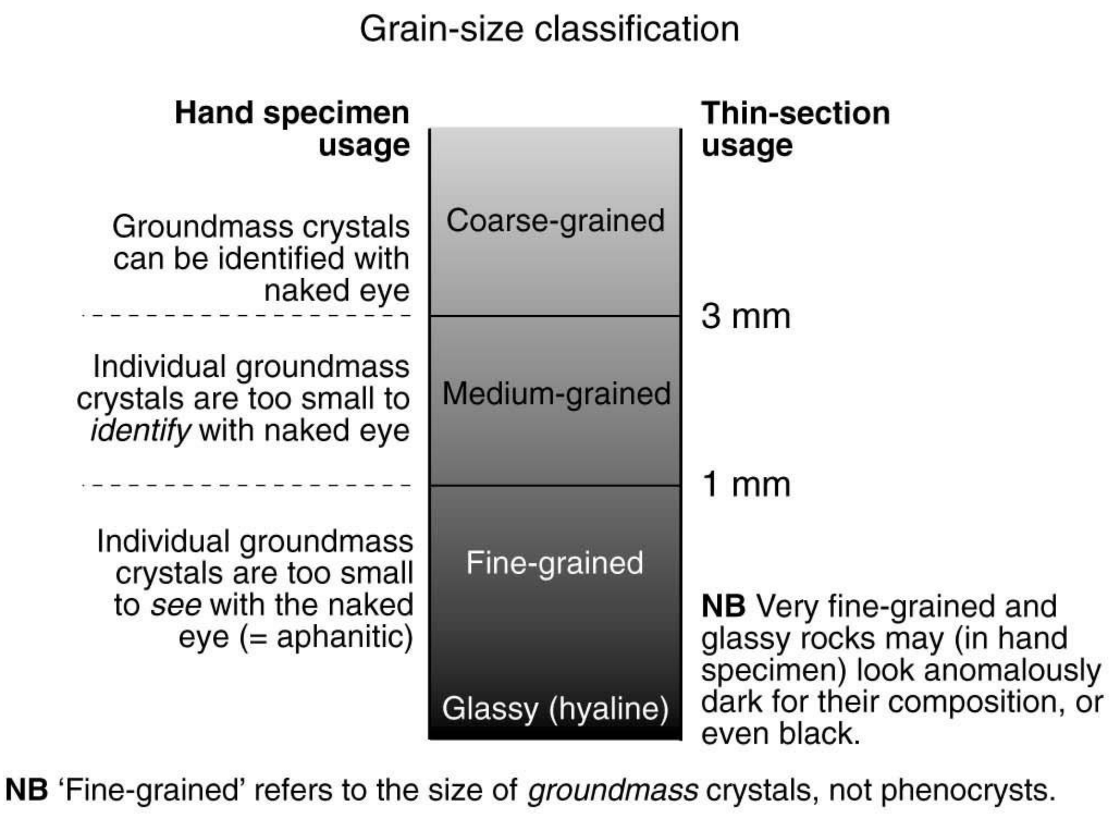
This texture is typical of rocks crystallized from slowly cooled intrusions of magma.

Aphanitic rocks have mineral grains too small to be identifiable by eye and require a microscope or some other laboratory device for accurate identification.

Classification of Igneous Rocks

Classification based on fabric:

- Aphanitic- crystals too small to see by eye
- Phaneritic- can see the constituent minerals
  - Fine grained- < 1 mm diameter
  - Medium grained- 1-3 mm diameter
  - Coarse grained- 3-50 mm diameter
  - Very coarse grained- > 50 mm diameter
- Porphyritic- bimodal grain size distribution
- Glassy- no crystals formed



Classification based on Fabric

Aphanitic texture is most common in rapidly solidified extruded magma but can also be found in marginal parts of magma intrusions emplaced in the cool shallow crust.

Some magmatic rocks contain essentially two grain-size populations and few of intermediate size; such texture is said to be **porphyritic.**

The larger grains are **phenocrysts,** and the smaller constitute the **groundmass, or matrix.**

Porphyritic aphanitic rocks are far more common than porphyritic phaneritic rocks.

Glassy, or vitric, rocks contain variable proportions of glass, in contrast to **holocrystalline rocks** made entirely of crystals.

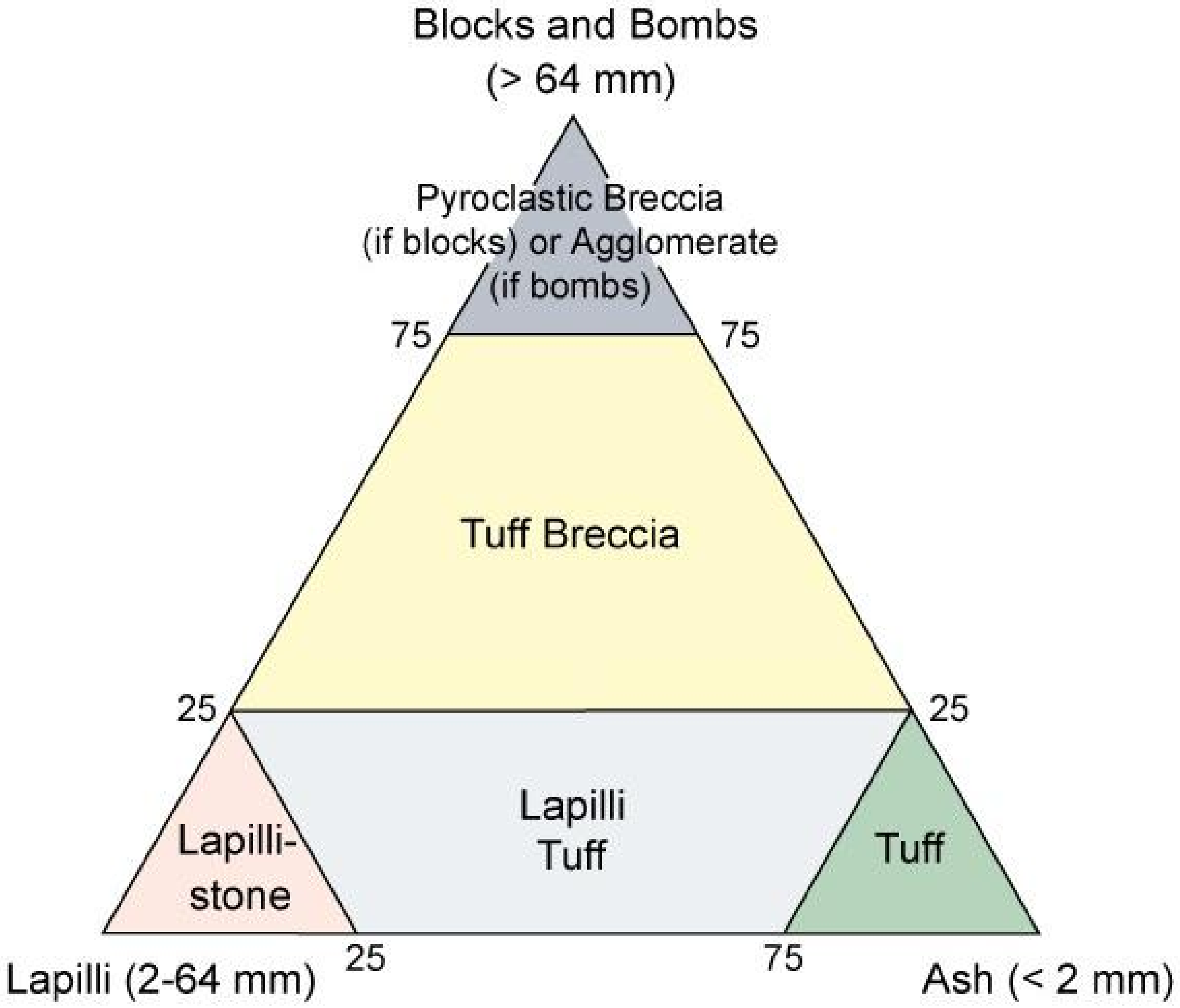
A **vitrophyre** is a porphyritic rock that contains scattered phenocrysts in a glassy matrix.

Classification based on Fabric

The fabric of **volcaniclastic** rocks is produced by any fragmenting process that creates broken pieces of volcanic rock and/or mineral grains.

Classification of volcaniclasts parallels that of sedimentary clasts according to their particle size, as follows:

	< 2 mm	*2–64 mm*	*> 64 mm*
volcaniclasts	**ash**	**lapilli**	**block, bomb**
sedimentary clasts	clay, silt, sand	granule, pebble	cobble, boulder



Classification of the pyroclastic rocks. After Fisher (1966) Earth Sci. Rev., **1**, 287-298.

Classification based on Field Relations

The location where magma was emplaced provides a basis for rock classification.

Some petrologists recognize three categories for rocks solidified from magmas emplaced onto the surface of the Earth (**volcanic** or **extrusive**), into the shallow crust (**intrusive hypabyssal**), and into the deep crust (**intrusive plutonic**).

The first and the last categories are readily distinguished on the basis of their field relations but less directly on the basis of their grain size, **degree of crystallinity** (proportion of crystals to glass), and mineralogical composition.

Classification based on Field Relations

Magmas emplaced onto the surface of the Earth as coherent lava flows or as fragmental deposits form **extrusive,** or **volcanic rocks.**

These rocks are typically aphanitic and glassy. Many are porphyritic.

Some have fragmental (volcaniclastic) fabric.

Intrusive, or plutonic, rocks form where magma was intruded into preexisting rock beneath the surface of the Earth as **intrusions, or plutons.**

Plutonic rocks are typically phaneritic. Monomineralic rocks composed only of plagioclase, or olivine, or pyroxene are well known but rare.

Classification based on Field Relations

Characteristics of intermediate-depth **hypabyssal** rocks are not clearly distinct from those of volcanic and plutonic rocks.

Many occur in shallow crustal dikes, sills, and plugs that represent feeding conduits for surface extrusions of magma.

But dikes and sills are also intruded deep in the crust. Hypabyssal rocks can have fabric similar to that of plutonic and volcanic rocks.

Because of these ambiguities, many petrologists tend to categorize magmatic rocks in the field simply as plutonic or volcanic.

Classification based on Mineralogical and Modal compositions

These different compositional aspects are related but may lead to confusion at times.

Quartz, plagioclase, alkali feldspar, muscovite, biotite, hornblende, pyroxene and olivine.

Felsic: Feldspar and Silica, Mafic: Magnesium and Ferric iron.

Felsic is also used for rocks composed of feldspathoids.

Smoky quartz and darker plagioclase are felsic.

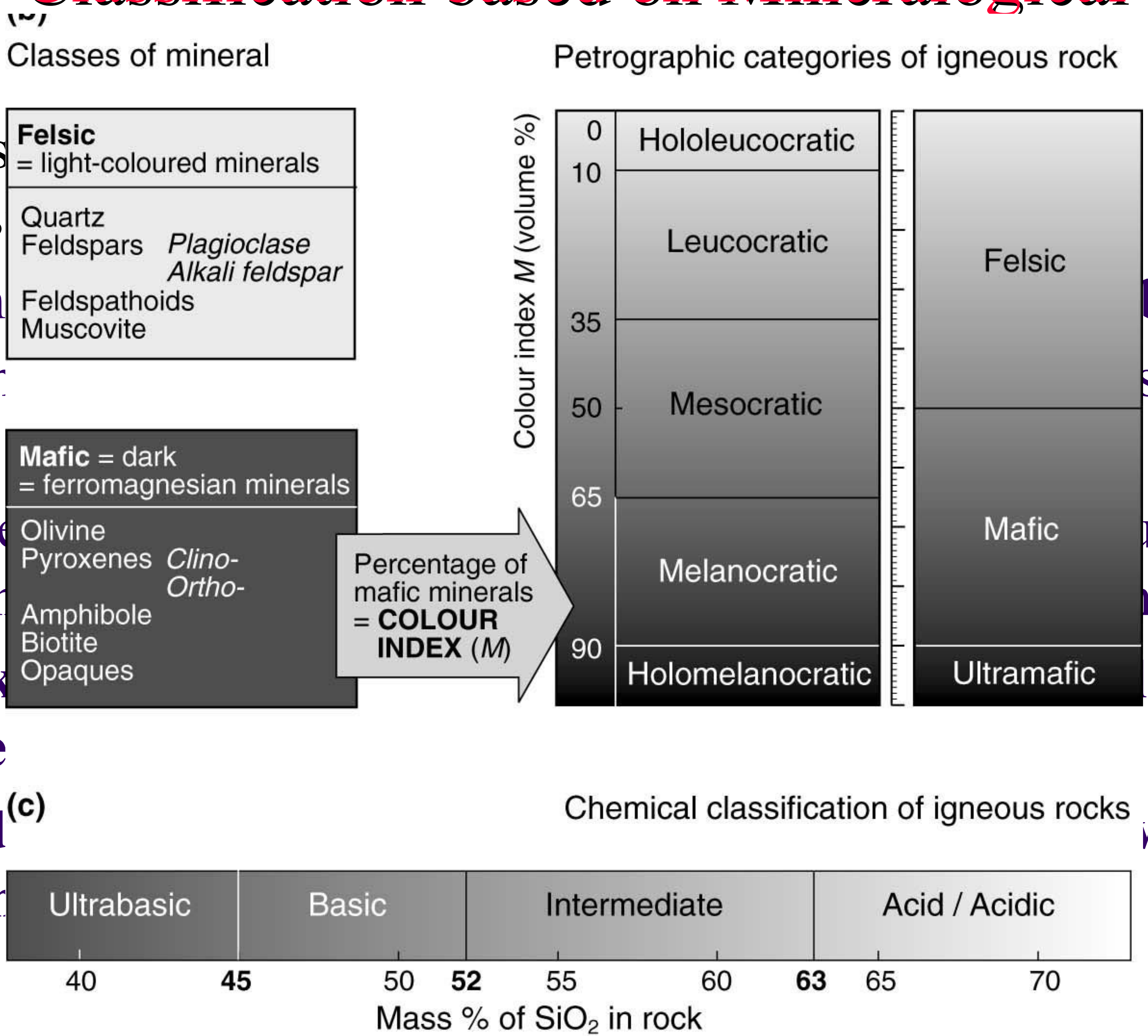
Apatite, zircon, titanite, epidote, chlorite are accessory.

Ultramafic rocks are especially rich in Mg and Fe and generally have little or no feldspar, eg is peridotite.

Silicic rocks contain large concentrations of silica, rhyolite.

Classification based on Mineralogical

Color is … indicator of
compos…
Eg. Wh… bout An_{50}, it
is comr… s also quite
dark.
Most ge… use roots of
felsic ar… n.
A rock … d thus be
conside…
Instead … idely used
which r…



Classification based on Mineralogical and Modal compositions

If one attempts to devise a practical classification of igneous rocks, many problems arise that can be averted if one separates the volcanic from the plutonic rocks.

These 2 groups of rocks generally cool, and congeal, at different rates; and this cooling tends to occur in different physical and often chemical environments.

Plutonic rocks are generally medium- to coarse-grained whereas many volcanic rocks are partially, or wholly, glassy and/or fragmental, and the phenocrysts/megacrysts they contain are often not a clear guide to the overall composition of the rock.

It thus seems rational to use modal criteria to classify plutonic rocks that contain easily, recognizable minerals, and chemical criteria to classify volcanic rocks.

Classification based on Mineralogical and Modal compositions

In 1973, International Union of Geological Sciences subcommission on the systematics of igneous rocks (IUGS) introduced a new modal classification of the plutonic rocks.

The classification uses

1. **Q = Quartz or high temperature polymorphs**
2. **A = Alkali feldspars (orthoclase, Albite (An_{00-05})**
3. **P = Plagioclase (An_{05-100})**
4. **F = Feldspathoids and**
5. **M= Mafic and related minerals (micas, amphiboles, pyroxenes, olivines), opaque minerals (Fe-Ti oxides), accessory minerals and primary carbonates.**

Classification of Igneous Rocks

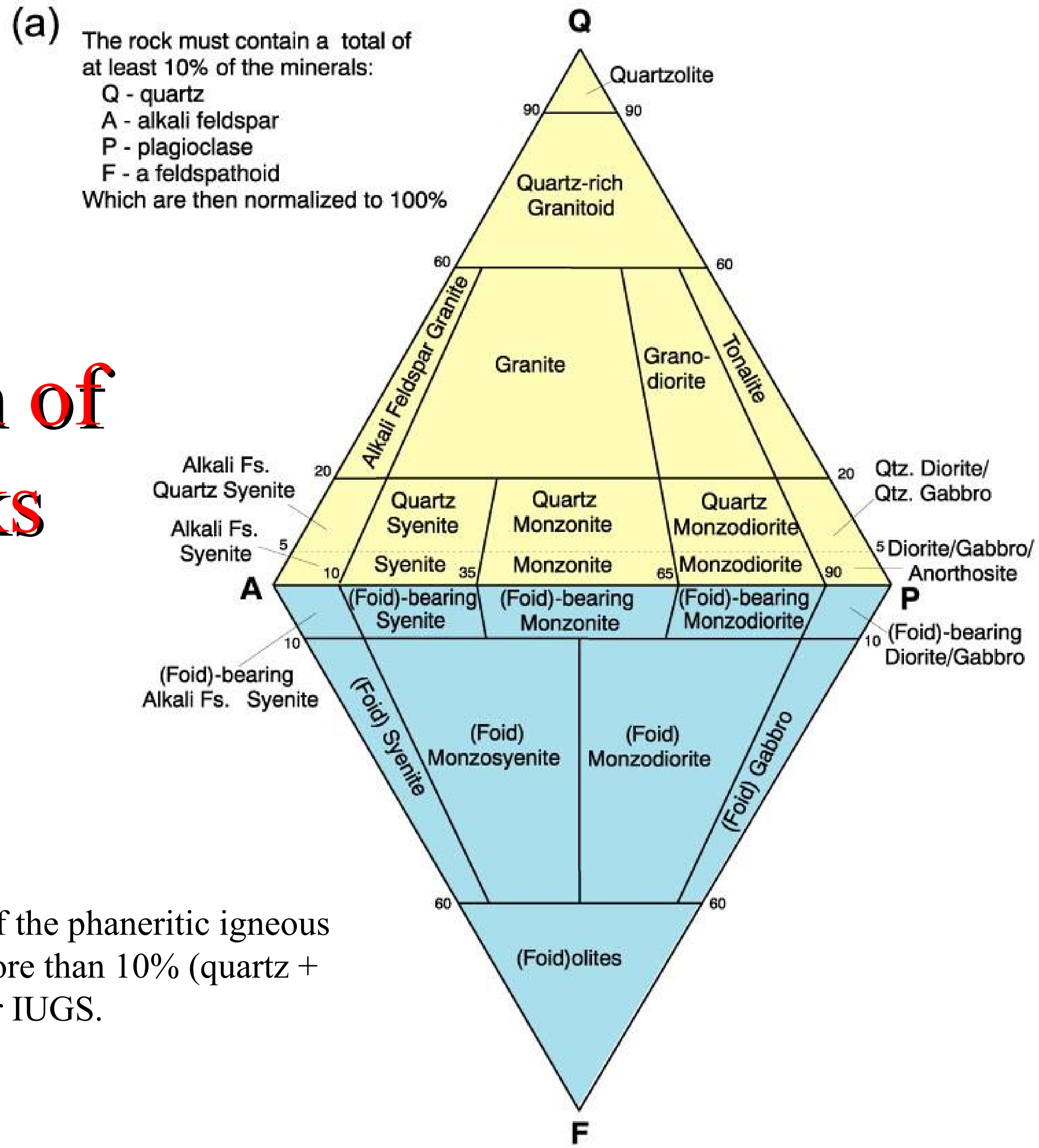


Figure 2.2a. A classification of the phaneritic igneous rocks: Phaneritic rocks with more than 10% (quartz + feldspar + feldspathoids). After IUGS.

Classification of Igneous Rocks

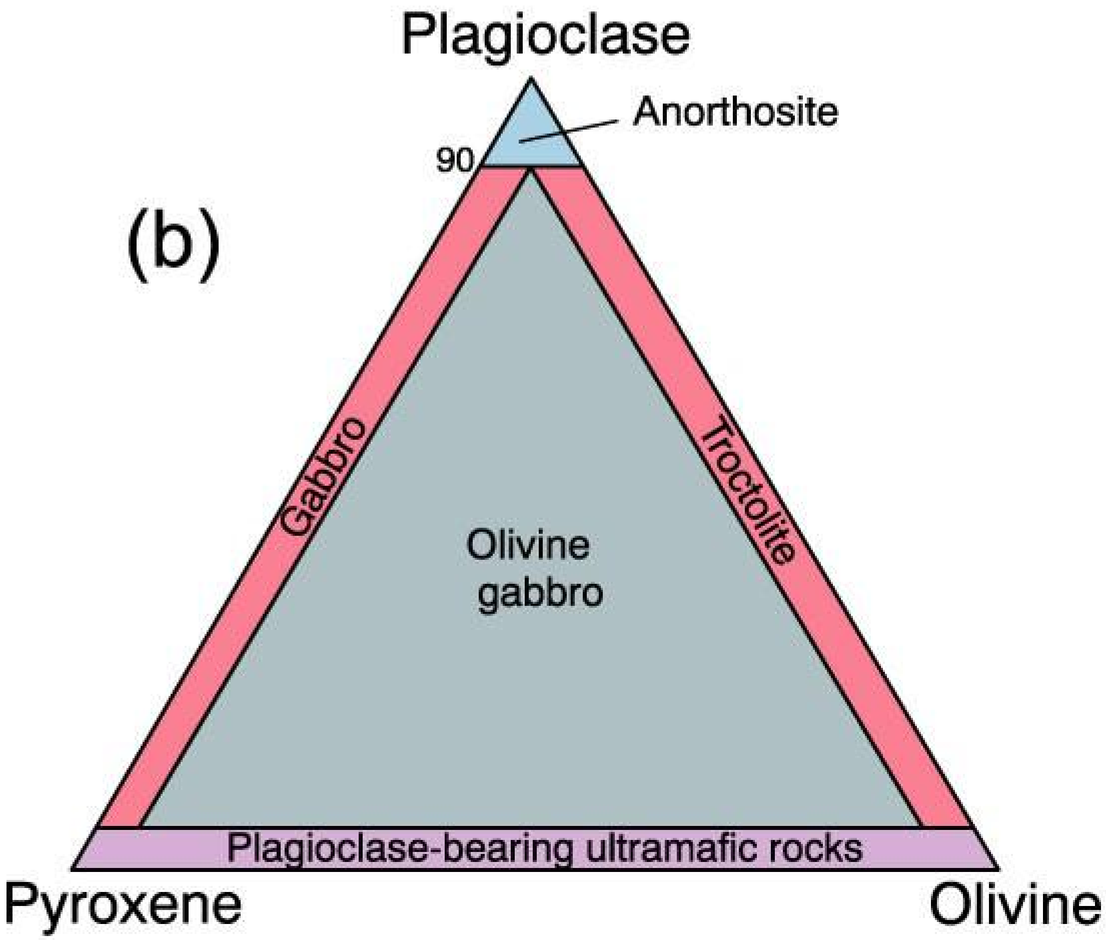


Figure 2.2b. A classification of the phaneritic igneous rocks: Gabbroic rocks. After IUGS.

Classification of Igneous Rocks

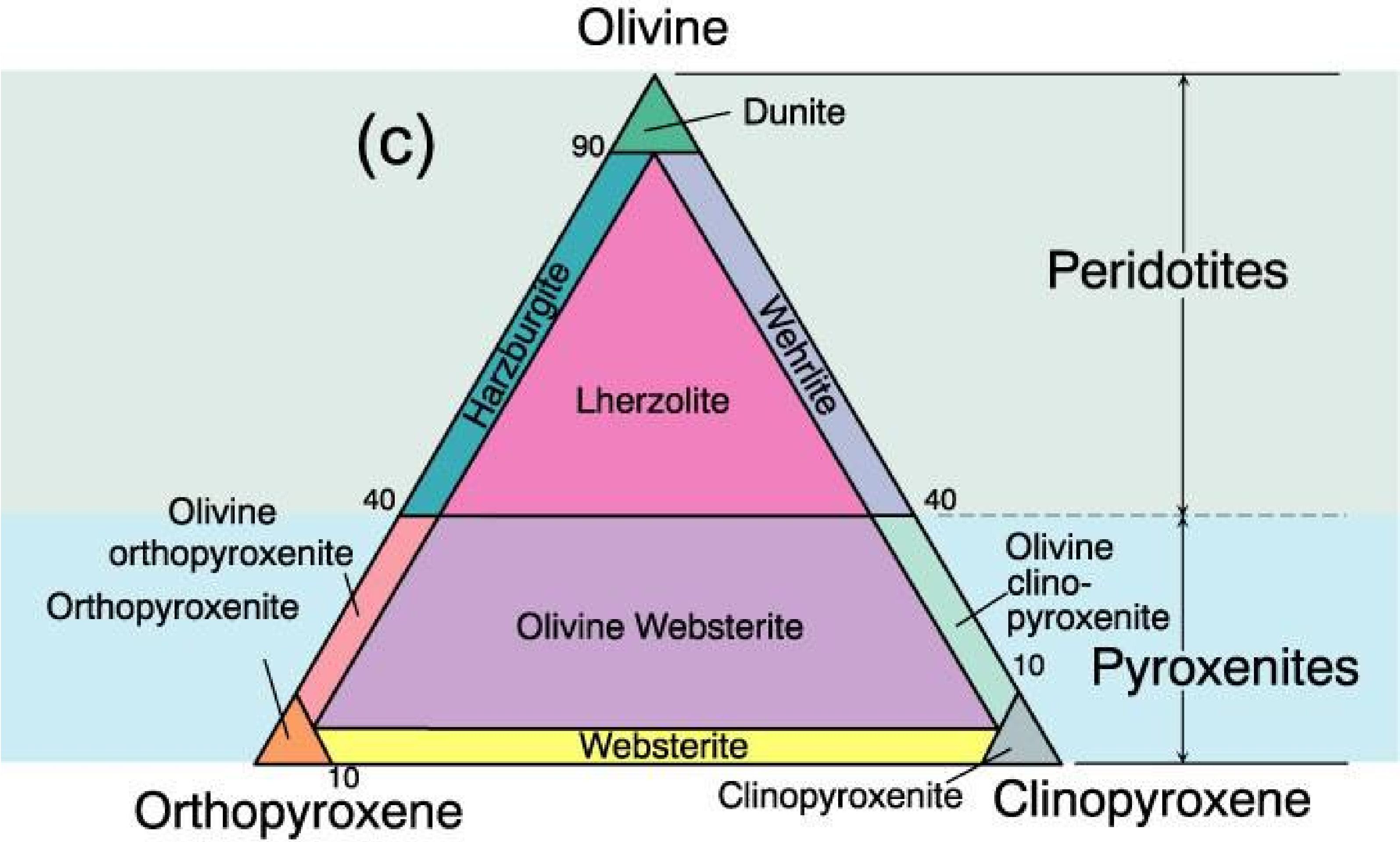


Figure 2.2c. A classification of the phaneritic igneous rocks: Ultramafic rocks. After IUGS.

Classification of Igneous Rocks

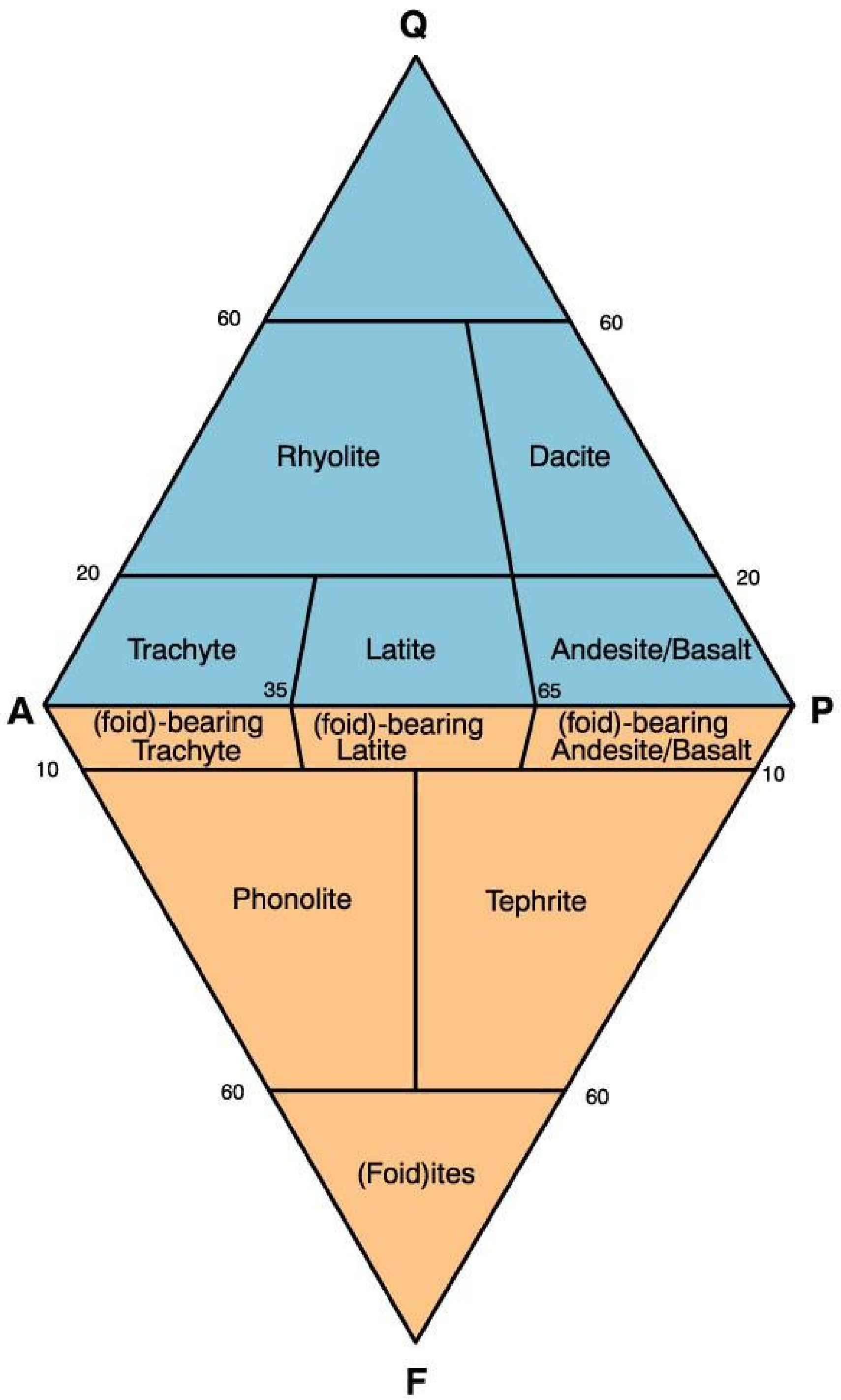


Figure 2.3. A classification and nomenclature of volcanic rocks. After IUGS.

Does an Igneous rock analysis represent magma composition?

In the quest to discover the origins of magmas and the conditions under which they form, extensive use is made of major element, trace element and isotopic analyses of volcanic rocks.

The key assumption in doing so is that such analyses accurately represent the chemical compositions of the magmas from which the volcanic rocks crystallized.

How widely can this assumption be justified, and what factors limit its application?

1. Degassing and volatile release

Magma confined at depth in the Earth contains gases dissolved in the melt.

As load pressure is relieved during ascent toward the surface, this gas content will progressively come out of solution to form separate bubbles of gas (often apparent as vesicles in erupted lavas), which may escape from the magma into the atmosphere.

Such 'degassing' is common in all magmas held in shallow magma chambers or erupted on the surface.

It follows that the volatile content measured in a fresh volcanic rock sample will generally be less than the true content originally dissolved in the melt at depth.

1. Degassing and volatile release

How can we determine the true pre - eruption ‘ magmatic ’ volatile contents of erupted volcanic rocks?

One approach is to analyse the volatile content of minute glass inclusions (generally referred to loosely – even though no longer molten – as ‘ melt inclusions ’ because they represent trapped melt) within individual phenocrysts.

The tensile strength of the surrounding crystal effectively ‘armours’ the melt inclusion against rupture and gas escape as the host magma ascends towards the surface; micro - analysis of the ‘ trapped ’ volatile content of these glass inclusions provides the best available measure of that of the undegassed melt.

2. Hydrothermal alteration and low grade metamorphism

Anhydrous minerals formed at melt temperatures such as olivine and plagioclase, if exposed to hydrous fluids at lower temperatures during cooling, are prone to react and recrystallize into hydrous secondary minerals such as smectite, serpentine, chlorite and epidote.

The analysis of a volcanic rock that has undergone such alteration or low-grade metamorphic reactions will therefore show elevated contents of H_2O and other volatile species, introduced by these post-magmatic reactions, that bear no relation to the original volatile content of the magma.

It is much harder to correct for any changes in the contents of relatively soluble non-volatile elements such as Na_2O, K_2O and CaO that may also have accompanied these reactions.

For this reason geochemical work needs to be based on unaltered samples that show negligible amounts of such post - magmatic minerals under the microscope.

3. Crystal accumulation

In deep-seated magma chambers where the cooling rate is slow, crystals may sink or float in the melt according to their density and crystal size, and may then form deposits in which one mineral (or more than one) is selectively concentrated at particular horizons.

Alternatively, one type of crystal may nucleate more efficiently on the chamber floor and walls than other minerals and thereby become selectively concentrated there.

The possibility of such selective accumulation processes, operating on various scales, means that the composition of a plutonic rock hand–specimen will not accurately record the melt composition from which it crystallized.

3. Crystal accumulation

Moreover, accumulations of early crystals will generally have higher Mg/Fe (in the case of ferromagnesian minerals) or higher Ca/Na (in plagioclase) than the melt from which they separated.

Though crystal accumulation processes exhibit their most dramatic effects in large layered intrusions, they are also known to occur in minor intrusions and even in thick lava flows.

Whereas in volcanic rocks the minerals that form can be seen as dictated by magma chemistry, in plutonic rocks where crystal sorting may have occurred the converse applies: the whole-rock chemical composition is in part a consequence of the minerals present and the proportions in which they happen to be combined.

4. Xenocrysts and Xenoliths

Many igneous rocks contain foreign material in the form of xenoliths, torn from conduit walls during magma ascent, or present in a disaggregated state as individual xenocrysts.

A bulk chemical analysis of the host rock will not faithfully represent the composition of the host magma if such exotic matter has not been carefully picked out during sample preparation.

Even when obvious foreign bodies have been removed, the analysis may be distorted by chemical exchange between magma and xenoliths, especially in the case of slowly cooled plutonic host rocks.

Table 8-3. Chemical analyses of some representative igneous rocks

	Peridotite	Basalt	Andesite	Rhyolite	Phonolite
SiO_2	42.26	49.20	57.94	72.82	56.19
TiO_2	0.63	1.84	0.87	0.28	0.62
Al_2O_3	4.23	15.74	17.02	13.27	19.04
Fe_2O_3	3.61	3.79	3.27	1.48	2.79
FeO	6.58	7.13	4.04	1.11	2.03
MnO	0.41	0.20	0.14	0.06	0.17
MgO	31.24	6.73	3.33	0.39	1.07
CaO	5.05	9.47	6.79	1.14	2.72
Na_2O	0.49	2.91	3.48	3.55	7.79
K_2O	0.34	1.10	1.62	4.30	5.24
H_2O^+	3.91	0.95	0.83	1.10	1.57
Total	98.75	99.06	99.3	99.50	99.23

Classification based on whole rock chemical composition

In order to discuss problems relating to the nature, origin and evolution of magmas, to compare igneous rock series and to interpret chemical analysis themselves, it is desirable to have chemical classification of igneous rocks.

Obviously, these tell nothing of rock textures and only hint at mineral content.

Thus they ignore the cooling and crystallization history, for magmas of generally similar (not identical) chemical composition may yield rocks of many different textures and markedly different mineral content like obsidian, rhyolite and granite.

Classification based on whole rock chemical composition

Because the mode is commonly difficult to determine for the volcanics, since the matrix of many volcanics is composed of minerals of extremely fine grain size and may even consist of a considerable proportion of glassy or amorphous material.

The most reliable way to avoid the matrix problem is to analyze the volcanic rock chemically and use a classification scheme based on the analytical results.

The IUGS recommended a classification of volcanics based on a simple diagram comparing total alkalis with silica, also called as TAS diagram.

Classification based on whole rock chemical composition

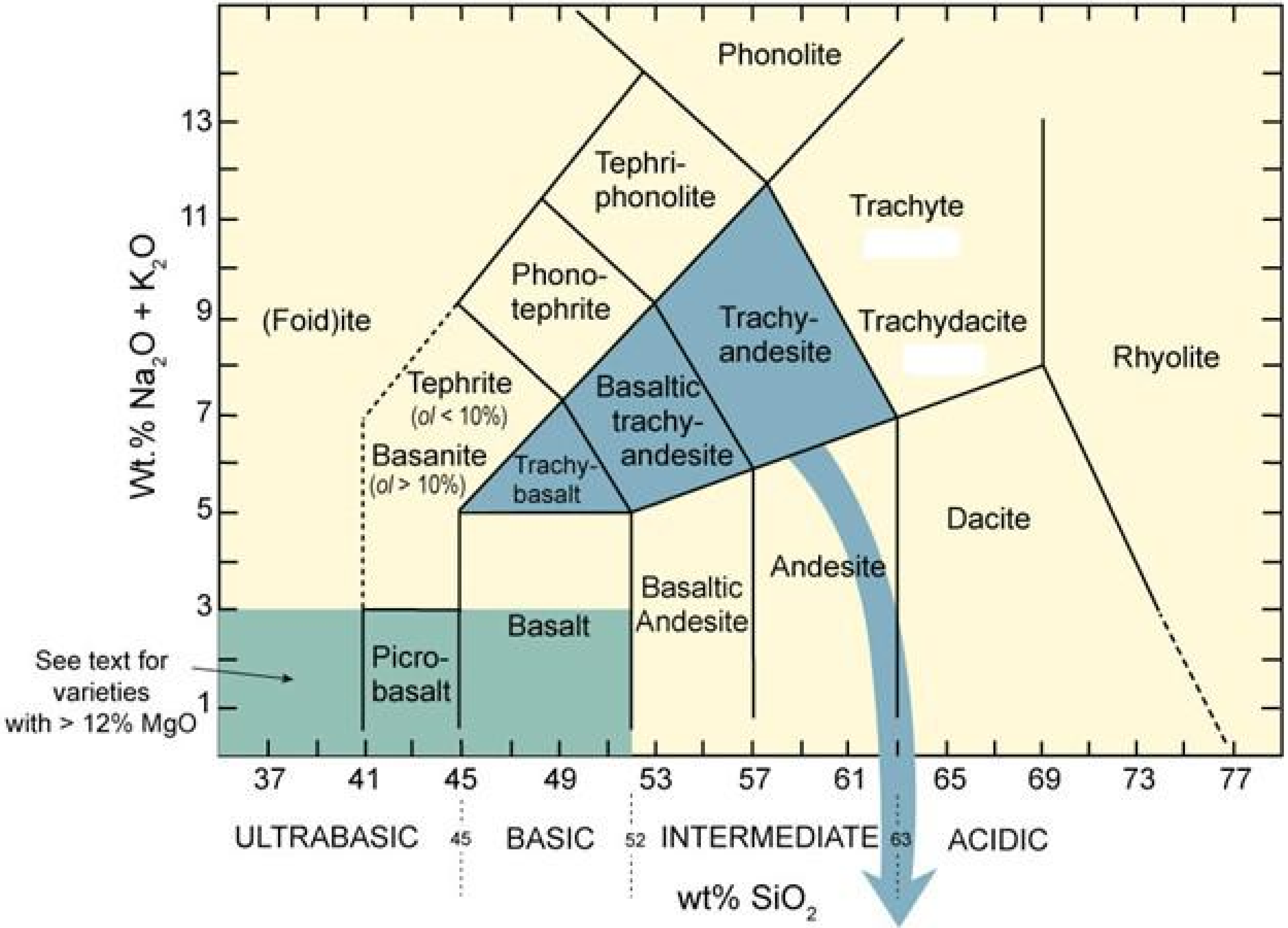
The use of silica in the classification of igneous rocks is particularly appropriate because it is the dominant oxide in the common magmatic rocks of Earth, and the silica content of the melt exerts considerable control over the physical nature and structure of the melt.

It is also important to take Na_2O and K_2O into account as these oxides, together with silica, essentially determine the silica saturation of the common magmatic rocks.

This is because the SiO_2, Na_2O and K_2O contents of a rock usually determine the quantity and type of felsic minerals that form.

Alumina, CaO and MgO, are generally the next most important oxides in determining the gross chemical and modal character of the common magmatic rocks.

A chemical classification of volcanics based on total alkalis vs. silica. After Le Maitre (2002) .



Further subdivisions of shaded fields	Trachybasalt	Basaltic Trachyandesite	Trachyandesite
$Na_2O - 2.0 \geq K_2O$	Hawaiite	Mugearite	Benmoreite
$Na_2O - 2.0 < K_2O$	Potassic Trachybasalt	Shoshonite	Latite

Classification based on whole rock chemical composition- Silica saturation (Quasi-chemical)

Shand in 1950, divided igneous rocks into undersaturated, saturated and oversaturated rocks.

Consider a simple hypothetical magma consisting only of O, Si, Al, and Na.

If there is an excess of molar SiO_2 relative to that needed to make albite from Na_2O, that is, $SiO_2/Na_2O > 6$, then the magma can crystallize quartz in addition to albite.

(In a natural magma, the albite would be in solid solution in plagioclase and/or alkali feldspar.)

This magma and the corresponding rock are silica-oversaturated.

Classification based on whole rock chemical composition- Silica saturation

If the magma contains SiO_2 and Na_2O in the exact ratio of 6, then these two constituents can only combine into albite; the magma and rock are silica-saturated.

If the molar ratio SiO_2/Na_2O < 6 but 2 in the magma, then there is insufficient SiO_2 to combine with all of the Na_2O into albite and some nepheline is created instead; the magma and rock are silica-undersaturated.

If the molar ratio SiO_2/Na_2O < 2 in the magma, then there is insufficient SiO_2 to combine with the Na_2O to create any albite at all and only nepheline can be produced; the magma and rock still qualify as silica-undersaturated.

Classification based on whole rock chemical composition- Alumina saturation

Al_2O_3 is the second most abundant constituent in most magmatic rocks and provides another means of classification, especially for felsic rocks, such as granitic ones.

The concept of alumina saturation is based on whether or not there is an excess or lack of Al to make up the feldspars.

The **alumina saturation index is defined as the** ***molecular ratio*** $Al_2O_3/(K_2O + Na_2O + CaO)$.

In alumina-oversaturated, or **peraluminous** rocks**,** $\mathbf{Al_2O_3 > CaO+Na_2O+K_2O}$**.**

In peraluminous rocks, we expect to find an Al2O3 rich mineral to be present as modal mineral, Muscovite, Corundum, Topaz, Andalusite

Classification based on whole rock chemical composition- Alumina saturation

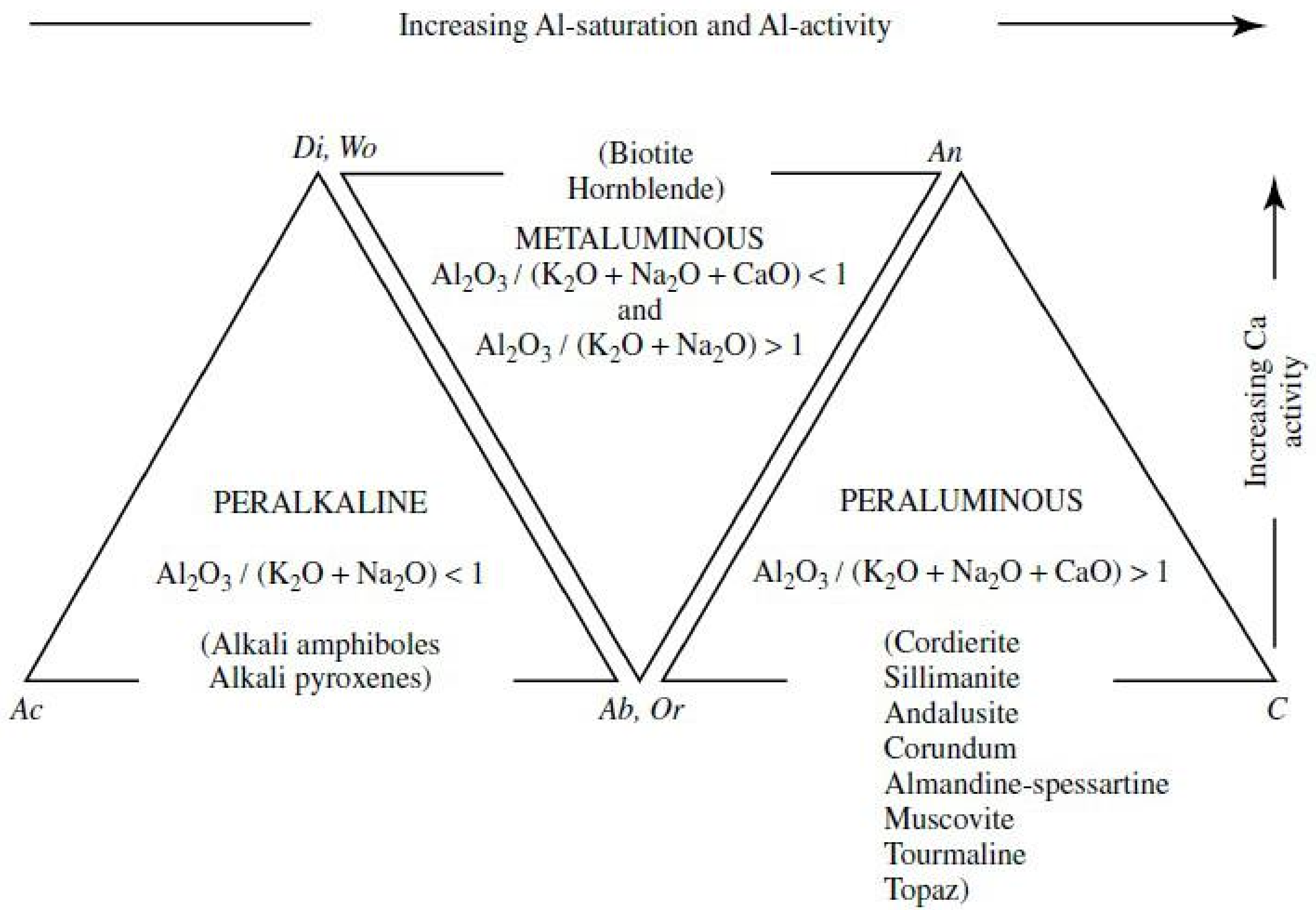
In alumina-undersaturated, or **metaluminous** rocks, $\mathbf{CaO+Na_2O+K_2O > Al_2O_3 > Na_2O+K_2O}$.

These are more common types of igneous rocks. They are characterized by lack of an Al_2O_3-rich mineral.

In **peralkaline** rocks, they are oversaturated with alkalis, and thus undersaturated with respect to Al_2O_3. $\mathbf{Al_2O_3 < Na_2O+K_2O+CaO}$**.**

They have Na-rich minerals like aegirine, riebeckite in the mode.

Classification based on whole rock chemical composition- Alumina saturation

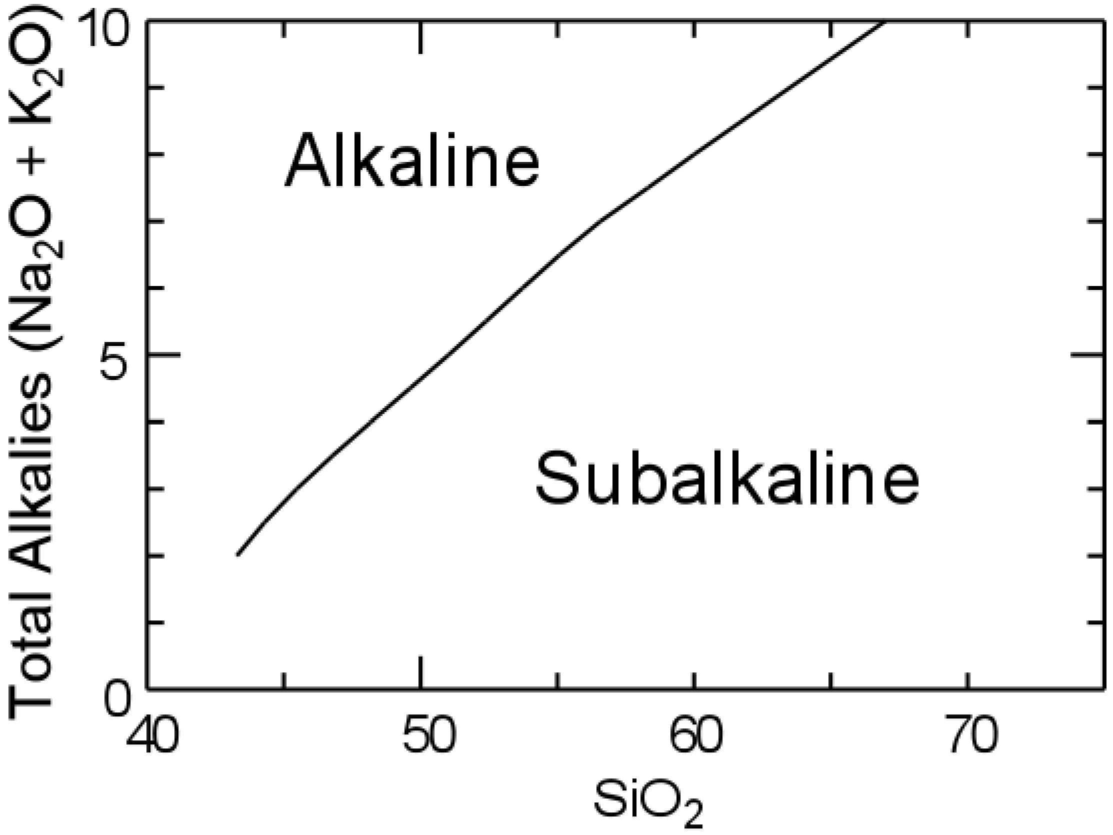


Classification of felsic rocks on the basis of degree of aluminum saturation. Ratios are molar. Apices of triangles are normative minerals. Diagnostic real minerals are listed in parentheses (muscovite, cordierite, etc.) for each of the three saturation categories.

Classification based on whole rock chemical composition

Here, classification divides the rocks into alkaline and subalkaline. It is based solely on alkali vs silica diagram.

Very alkaline rocks, are also silica undersaturated.



Granite

The term **"Granite"** is derived from latin word ***"Granum"*** meaning "grain" because of its granular nature.

Mineralogically:

- ✓**Essential minerals** - Quartz , Feldspar
- ✓**Accessory minerals** – Biotite, muscovite , amphibole.
- ✓Other accessories are **zircon, apatite, ilmenite, magnetite, sphene, pyrite** etc.

Texturally:

Medium to coarse grained crystalline rock generally exhibiting **Hypidiomorphic texture** and **Intergrowth textures** (perthite, Antiperthite, Myrmekite, Graphic, Granophyric, rapakivi).

Chemically : SiO_2 - > 65 %, (other oxides vary)

Classification of Granitoids:

- ✓**Mineralogical classifications** (IUGS classification)
- ✓**Chemical classification** (alumina saturation, S-I-A-M classification etc.)
- ✓**Tectonic classification** (Based on plate tectonic setting)

Q-A-P classification of Granitoids (a part of QAPF classification)

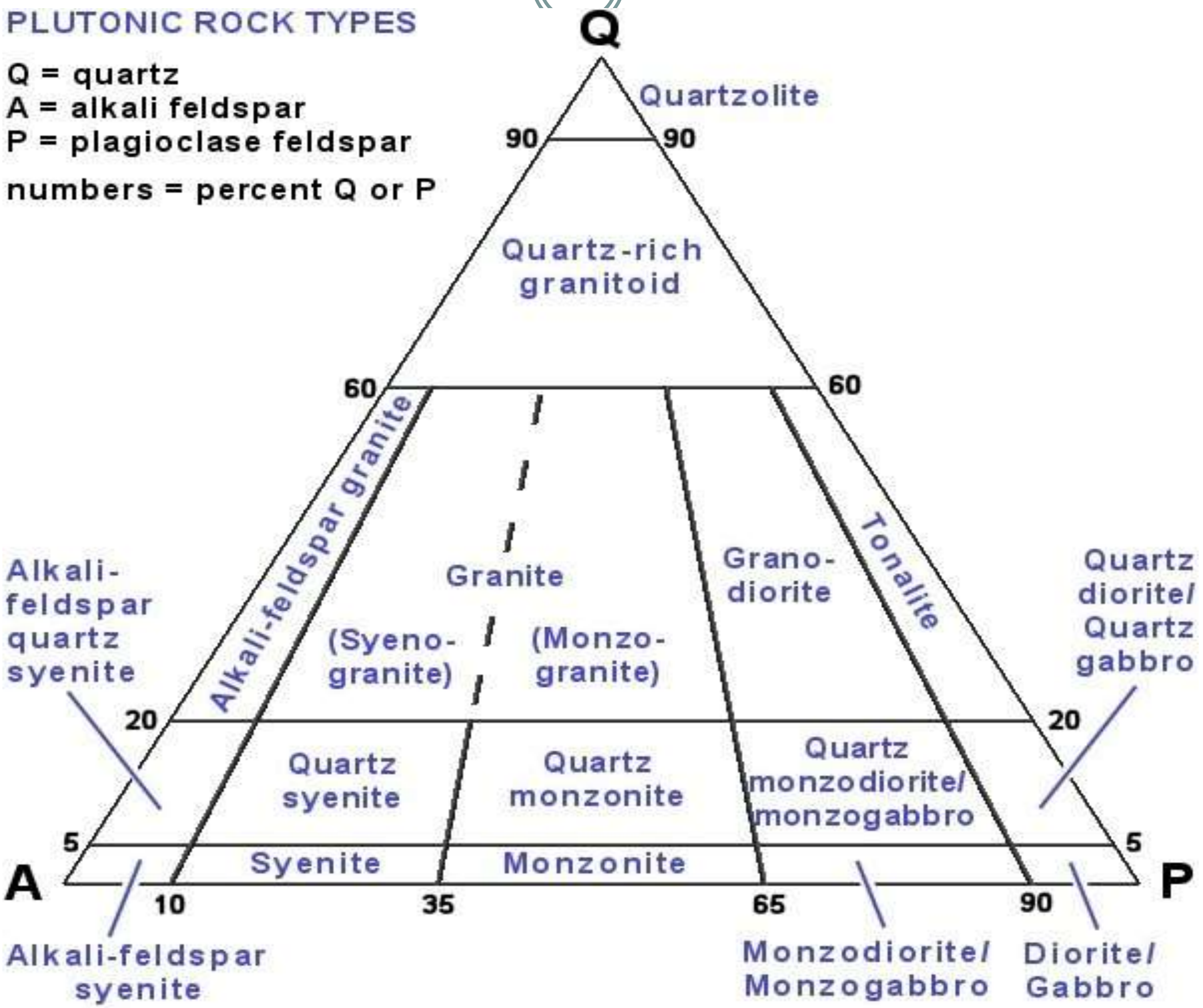


Fig.1. After IUGS (1973)

Granite classification based on alumina Saturation (by Shand):

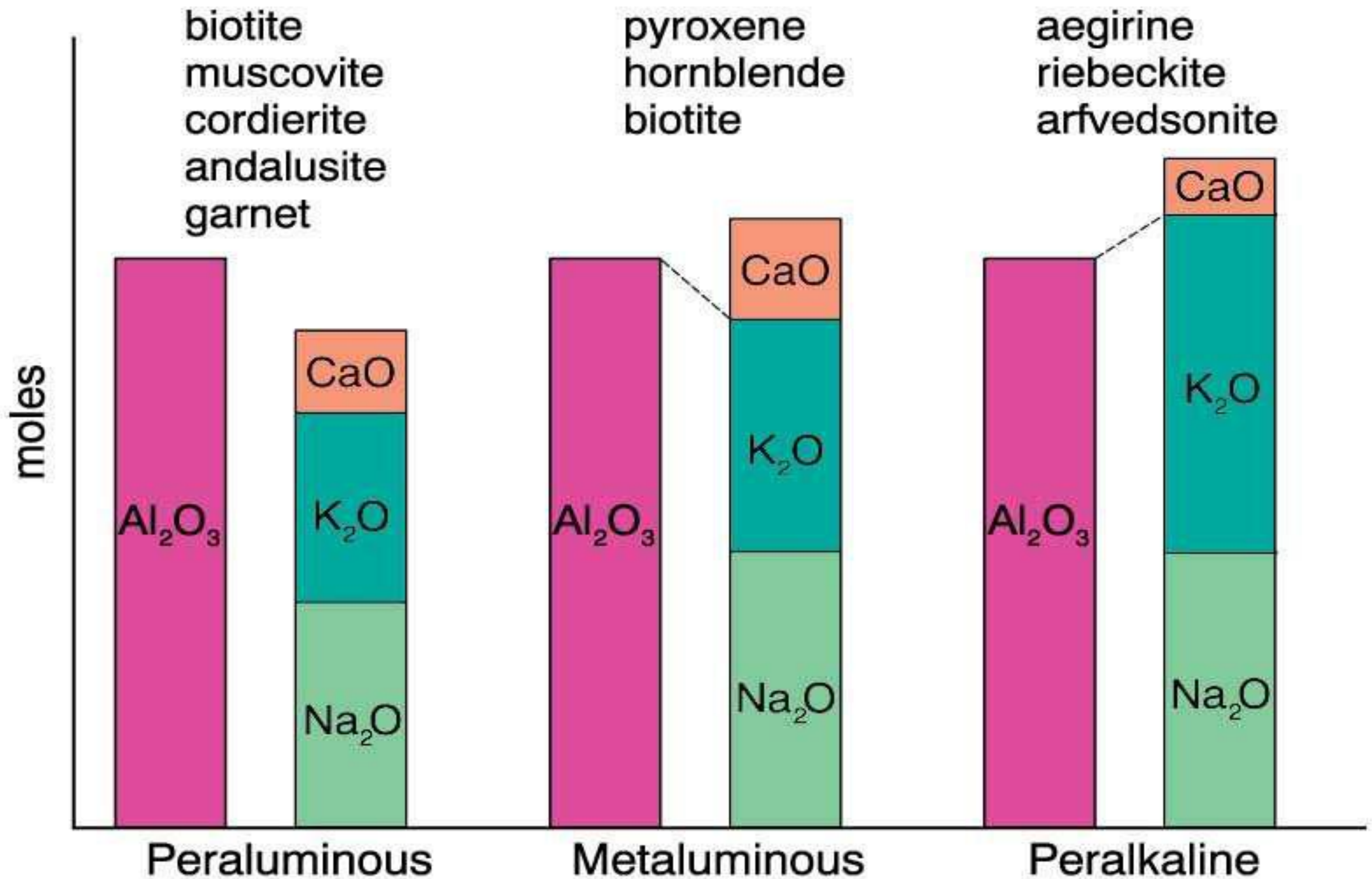


Fig 2. Alumina saturation classes based on the *molar* proportions of $Al_2O_3/(CaO+Na_2O+K_2O)$ ("A/CNK") after Shand (1927).

Alphabetic (S-I-A-M) Classification of Granitoids:

By Chappell and White (1974)

- ✓**S-type Granitoid (**sedimentary protolith)
- ✓**I-type Granitoid**(igneous protolith)
- ✓**M-type Granitoid** (direct mantle source)

By Loiselle and Wones (1979)

- ✓**A-type Granitoid** (anorogenic type)

S-Type Granitoids:

- ✓Derived due to partial melting of sedimentary and metasedimentary rock.
- ✓S-type are more common in collision zones.
- ✓These are peraluminous granites [i.e. they have molecular Al_2O_3 > (Na_2O + K_2O+CaO)].
- ✓S-type granites are charecterised by presence of muscovite, biotite and marginally higher SiO_2 contents.

- ✓ e.g. Himalayan Granites

I-Type Granitoids:

- ✓Derived due to partial melting of **igneous proloith.**

- ✓Deep seated igneous or metaigneous rocks of lower continental crust subjected to partial melting due upwelling of mantle material to higher levels.
- ✓Generally metaluminous granites, expressed mineralogically by the absence of peraluminous minerals like muscovite. But there are exceptions.
- ✓I-type granites are charecterised by presence of hornblende / alkali amphiboles biotite.

M-Type Granitoids:

✓Derived due to fractional crystallisation of basaltic magma.

✓Relatively Plagioclase rich**(plagiogranite of ophiolite).**

✓Associated with Gabbros and Tonalites.

✓Characteristics of Subduction zone.

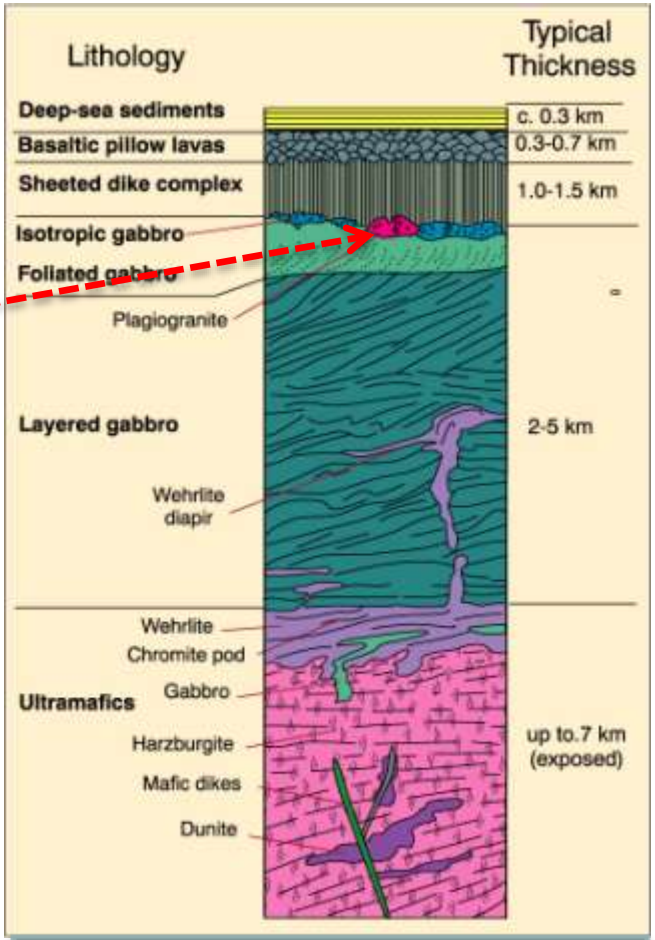


Fig.3. Ophiolite Sequence

A-Type Granitoids:

A-type granites are emplaced in either within plate anorogenic settings or in the final stages of an orogenic event.

Characterised by:

✓High SiO_2 **(~73.81%)**
✓High F contents **(6000 to 8000 ppm)**
✓Presence of **fluorite** is an important characteristic of A-type granites.

S-I-A- M Classification of Granitoids:

Type	SiO_2	K_2O/Na_2O	Ca, Sr	A/(C+N+K)*	Fe^{3+}/Fe^{2+}	Cr, Ni	$\delta^{18}O$	$^{87}Sr/^{86}Sr$	Misc	Petrogenesis
M	46-70%	low	high	low	low	low	< 9‰	< 0.705	Low Rb, Th, U Low LIL and HFS	Subduction zone or ocean-intraplate Mantle-derived
I	53-76%	low	high in mafic rocks	low: metal-uminous to peraluminous	moderate	low	< 9‰	< 0.705	high LIL/HFS med. Rb, Th, U hornblende magnetite	Subduction zone Infracrustal Mafic to intermed. igneous source
S	65-74%	high	low	high peraluminous	low	high	> 9‰	> 0.707	variable LIL/HFS high Rb, Th, U biotite, cordierite Als, Grt, Ilmenite	Subduction zone Supracrustal sedimentary source
A	high → 77%	Na_2O high	low	var peralkaline	var	low	var	var	low LIL/HFS high Fe/Mg high Ga/Al High REE, Zr High F, Cl	Anorogenic Stable craton Rift zone

* *molar* $Al_2O_3/(CaO+Na_2O+K_2O)$

Data from White and Chappell (1983), Clarke (1992), Whalen (1985)

Classification of Granitoid Rrocks based on Tectonic Setting:

OROGENIC:

✓Mountain building resulting from compressive stresses associated with subduction.

e.g. Continental collision granites- Himalayas.

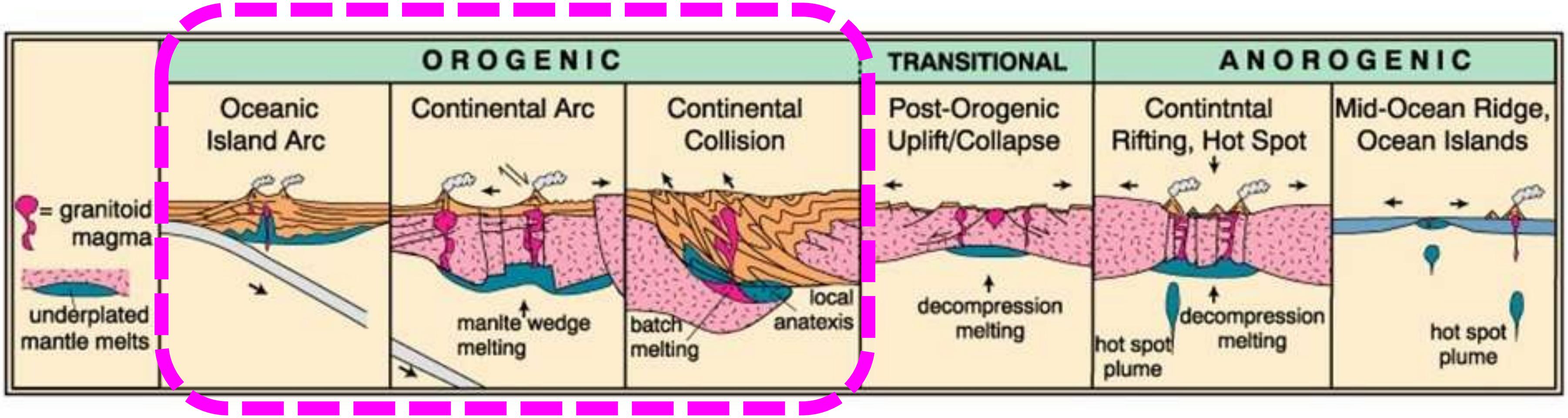


Fig.4. A Classification of Granitoid Rocks Based on Tectonic Setting. After Pitcher (1983) in K. J. Hsü (ed.), *Mountain Building Processes*, Academic Press, London; Pitcher (1993), *The Nature and Origin of Granite*, Blackie, London; and Barbarin (1990) *Geol. Journal*, 25, 227-238. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Classification of Granitoid Rrocks based on Tectonic Setting:

ANOROGENIC:

✓Magmatism within plate or at a spreading plate margin.

✓Here magmatism occurs in settings that are not genetically related with compressive orogeny.

e.g. Yellowstone-snake river plain in USA

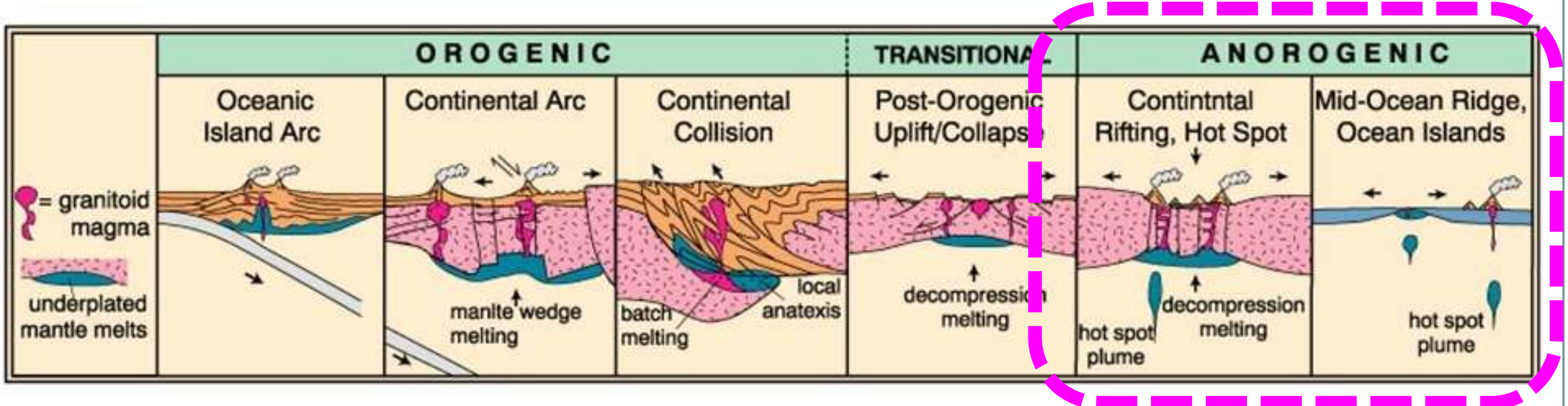


Fig.5. A Classification of Granitoid Rocks Based on Tectonic Setting. After Pitcher (1983) in K. J. Hsü (ed.), *Mountain Building Processes*, Academic Press, London; Pitcher (1993), *The Nature and Origin of Granite*, Blackie, London; and Barbarin (1990) *Geol. Journal*, 25, 227-238. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Classification of Granitoid Rrocks based on Tectonic Setting:

TRANSITIONAL /POST-OROGENIC :

✓Magmatism takes place after the main orogenic event. (because it needs a precursor orogeny two diverse groups exist whether they are orogenic or anorogenic).

e.g. Late Caledonian plutons of Britain

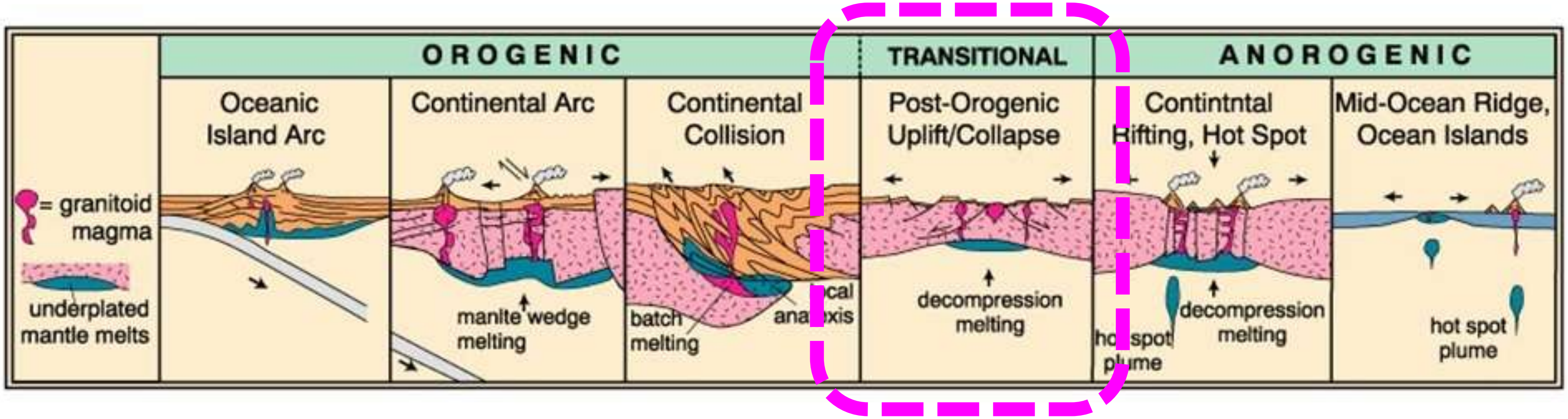


Fig.6. A Classification of Granitoid Rocks Based on Tectonic Setting. After Pitcher (1983) in K. J. Hsü (ed.), *Mountain Building Processes*, Academic Press, London; Pitcher (1993), *The Nature and Origin of Granite*, Blackie, London; and Barbarin (1990) *Geol. Journal*, 25, 227-238. Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Geochemical (trace element) Discrimination Plots of Granitoids:

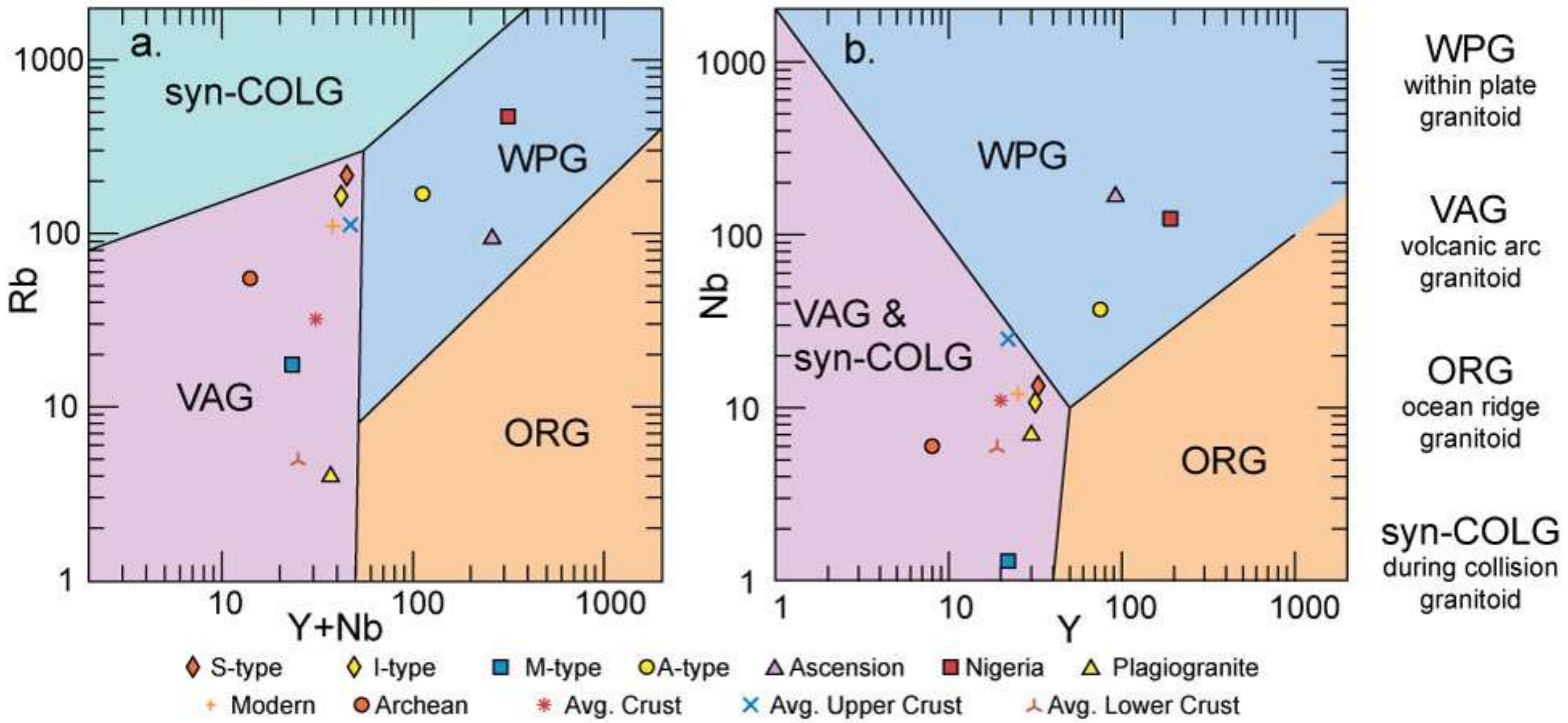


Fig. 7. Tectonic discrimination plots of Rb–(Nb+Y) and Nb–Y (Pearce et al.1984). Fields for syn-collision (COLG), volcanic arc (VAG), within plate (WPG) and ocean ridge (ORG) granites.

Petrogenesis:

- ✓ Magmatic Origin
- ✓ Metasomatic Transformation (Granitisation)

❖ **Bowen's** studies showed that a basaltic magma can give rise to acid magma (granitic) due to differentiation.

❖ Extensive field studies , in high grade terranes, showed that extensive metasomatic transformation was capable of bringing about compositional changes insitu of a variety of pre-existing rocks to create granites **(H.H.Read).**

- ✓Most granitoids of significant volume occur in areas where the **continental crust** has been **thickened** by orogeny, either continental arc subduction or collision.

- ✓Because the crust is solid in its normal state, some **thermal disturbance** is required to form granitoids.

- ✓Most workers are of the opinion that the majority of granitoids are derived by **crustal anatexis**, but that the **mantle may also be involved**. The mantle contribution may range from that of a **source of heat** for crustal anatexis, or it may be the **source of material as well.**

Many workers believed there are more than one origin for granites & the term **‘GRANITES & GRANITES’** was coined.

Future Work:

✓ Study about Granite Geochemistry with special reference to Warangal and Nalgonda District.

✓ Interpretation of the available data.

✓ Uranium Mineralization in Granite of the same area.


THANK YOU

SEMINAR ON

LAMPROPHYRE

CONTENTS

INTRODUCTION

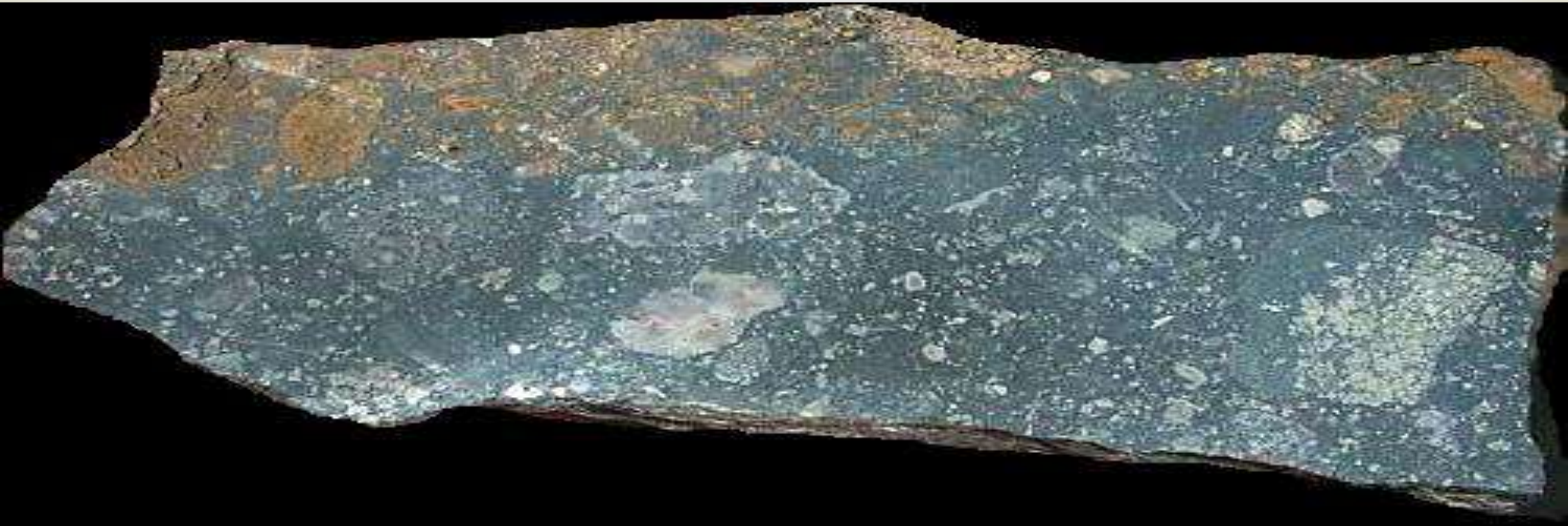
- Lamprophyres derived from Greek word lampros meaning ‘bright’ and phyro meaning ‘to mix’.
- Lamprophyres are melanocratic ,porphyritic ,hypabyssal rocks.
- Lamprophyres are generically referred to ultramafic, mafic,(or)intermediate rocks.
- That intrude the basement at shallow-crustal levels and form dikes(or)sills.
- It has a panidiomorphic granular texture.

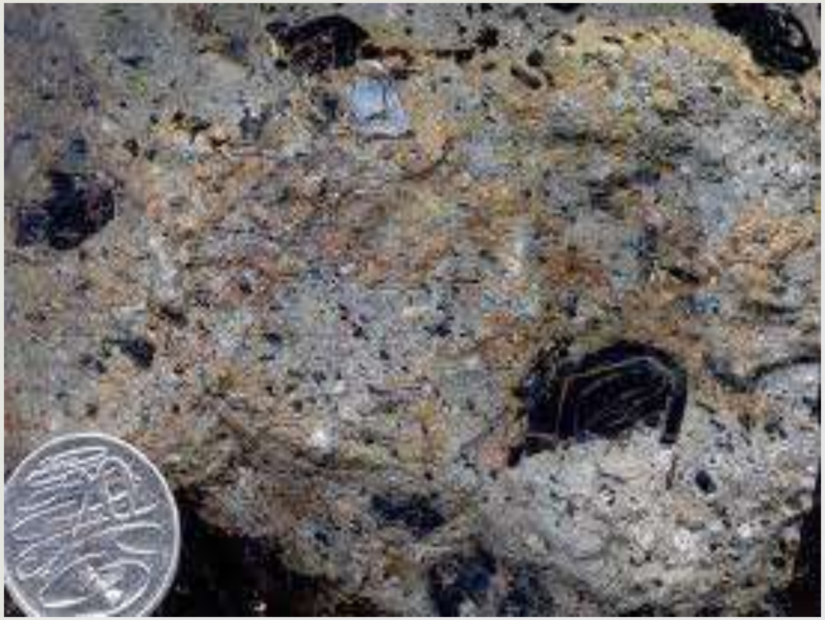
MINERALOGY

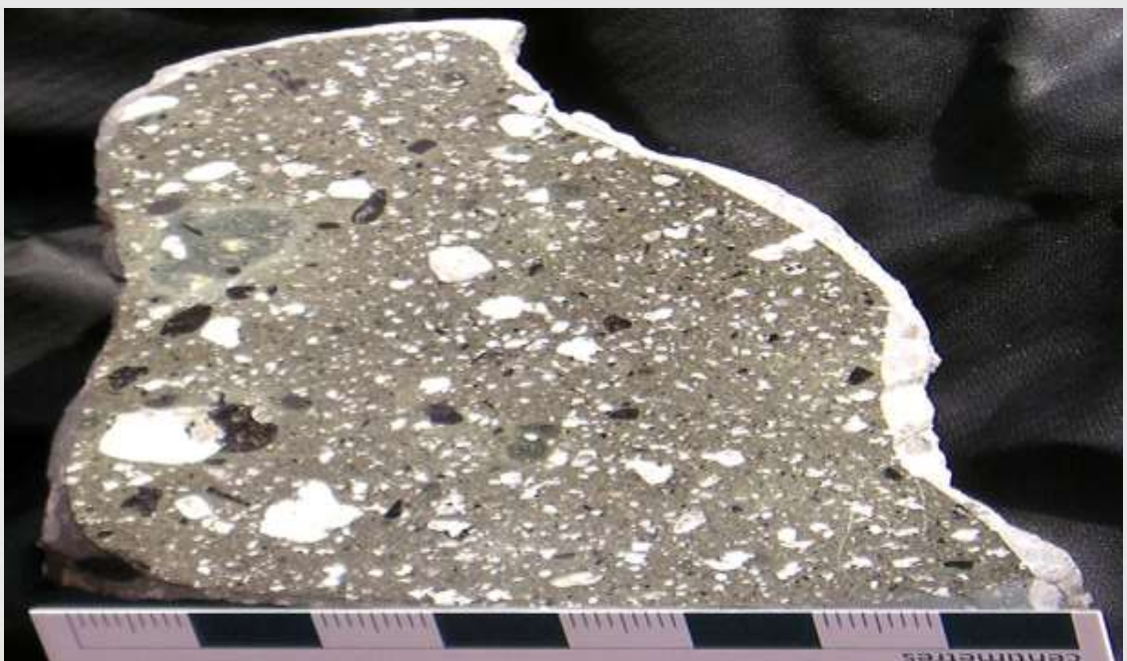
- The lamprophyres commonly consists of alkali rich calc-alkali to ultramafic minerals.
- The essential mineral composition of lamprophyre are Biotite, Amphibole,Pyroxene, plus feldspar and feldspathoids.
- The accessory minerals compositions of lamprophyre are Sulphides, zeolites, flourite, iron, titanium, oxides and apatite to quartz(or)olivine.

Petrology

Mitchell has suggested that rocks belonging to the lamprophyre facies are characterized by the presence of phenocrysts of mica (or)amphibole together with lesser clinopyroxene melitlite set in a groundmass which may consist of plagioclase, alkali feldspar feldspathoids carbonate monticellite. Any dark intrusive rock in which dark minerals occur both as phenocrysts and as groundmass.






centimetres

CLASSIFICATION

Lamprophyre are classified into three types;

1.Calc-alkaline lamprophyres

2. Alkaline lamprophyres

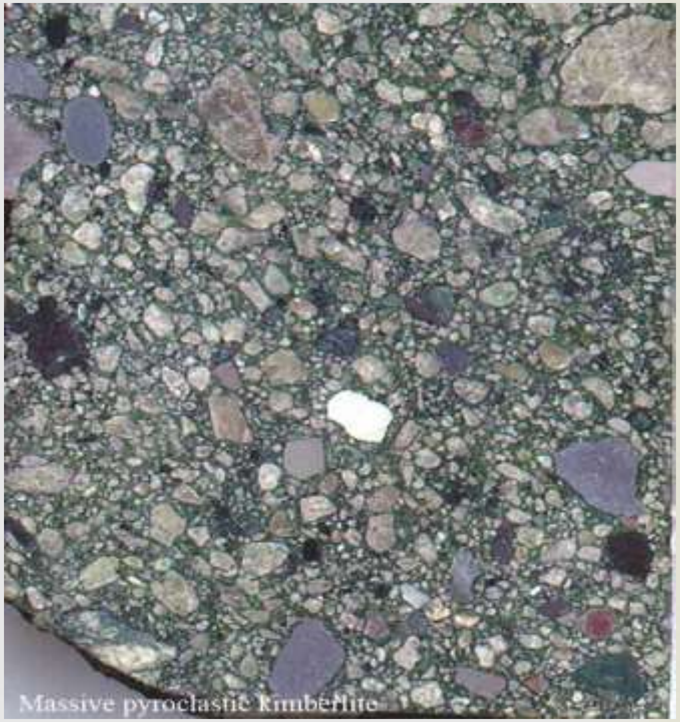
3. Melilitic lamprophyres

The lamprophyres that belong to these groups, and the mineral characteristics of each, as recommended by the IUGS, are given in the following table.

Light colored constituents		Predominant mafic minerals			
feldspar	foid	Biotite, diopsidic augite,(± olivine)	Hornblende, diopsidic augite, (± olivine)	Na-Ti-amphiboles, Ti-augite, olivine, biotite	**Melilite, biotite ±Ti-augite ± olivine ± calcite**
or > pl pl > or or > pl pl > or - -	- - feld > foid feld > foid glass or foid -	Minette kersantite	Vogesite spessartite	Sannaite Camptonite Monchiquite	**Polzenite alnoite**
Lamprophyre branch:		**Calc-alkaline**		**Alkaline**	**Melilitic**

CALC-ALKALINE LAMPROPHYRES

- The calc-alkaline lamprophyres are the common lamprophyres and often described as ordinary lamprophyres.



- This four lamprophyres are most readily classified using modal data:

Vogesites:

From Vosges in Northern France. A vogesite is a porphyritic alkaline igneous rock dominated by essential amphibole, usually hornblende, and potassic feldspar, often with augite and plagioclase present as accessories within the groundmass.

Minettes:

From an old term used by miners in the Vosges, are alkali-feldspar. A minette is a porphyritic alkaline igneous rock dominated by essential biotite and potassic feldspar, often with augite and plagioclase present as accessories within the groundmass.

Spessartites:

From Spessart mountains in Germany. A spessartite is a porphyritic alkaline igneous rock dominated by essential amphibole, usually hornblende, and plagioclase feldspar, often with augite present as an accessory. Plagioclase occurs in the groundmass and potassic feldspar is absent or present in low abundance.

Kersantites: From Kersanton, a village in France, are Plagioclase, Honrblende, Augite lamprophyres.

ALKALINE &MELILITIC LAMPROPHYRES

- The alkaline and melilitic lamprophyres will be considered together.
- Because both groups contain alkaline rocks and are usually associated with alkaline complexes and the rocks of the carbonatite-nepheline-ijolite association.
- The common alkaline lamprophyres are comptonites, sannaites, and monchiquites and they are chemically akin to alkaline Basalt, Basanites and Nephelinites.

Comptonite:

From Campton in the New Hampshire (USA). A camptonite is a porphyritic alkaline igneous rock dominated by essential plagioclase and brown amphibole, usually hornblende, often with titanaugite. Plagioclase occurs in the groundmass.

Sannaites:

From Sannavand, Fen complex, Sweden.

Sannaites are broadly to Comptonites, except that they contain alkali feldspar in place of plagioclase.

Monchiquites:

From Sierra de Monchique in Southern Portugal. A monchiquite is a porphyritic alkaline igneous rock dominated by essential olivine, titanaugite and brown hornblende.

Alnoite;

From Alno island, Sweden. A alnoite is a porphyritic alkaline igneous rock dominated by essential olivine, biotite and pyroxene, in a groundmass containing melilite. It can contain monticellite.

Polenzite:

From Polzen area of the Bohemian massif, Czechoslovakia. Is a melilitic lamprophyre that usually contain between 10-30% of feldspathoids (Nepheline and Hauyne) and it normally contains the same minerals as occur in alnöite.

ORIGIN

The essential components in lamprophyre genesis are;

- High depth of melting
- Which yields more mafic magmas
- Low degrees of partial melting
- which yields magmas rich in the alkalis (particularly potassium)

Cont. d

- Lithophile element (K, Ba, Cs, Rb) enrichment, high Ni and Cr,

- High potassium and sodium concentrations (silica undersaturation is common) some form of volatile enrichment

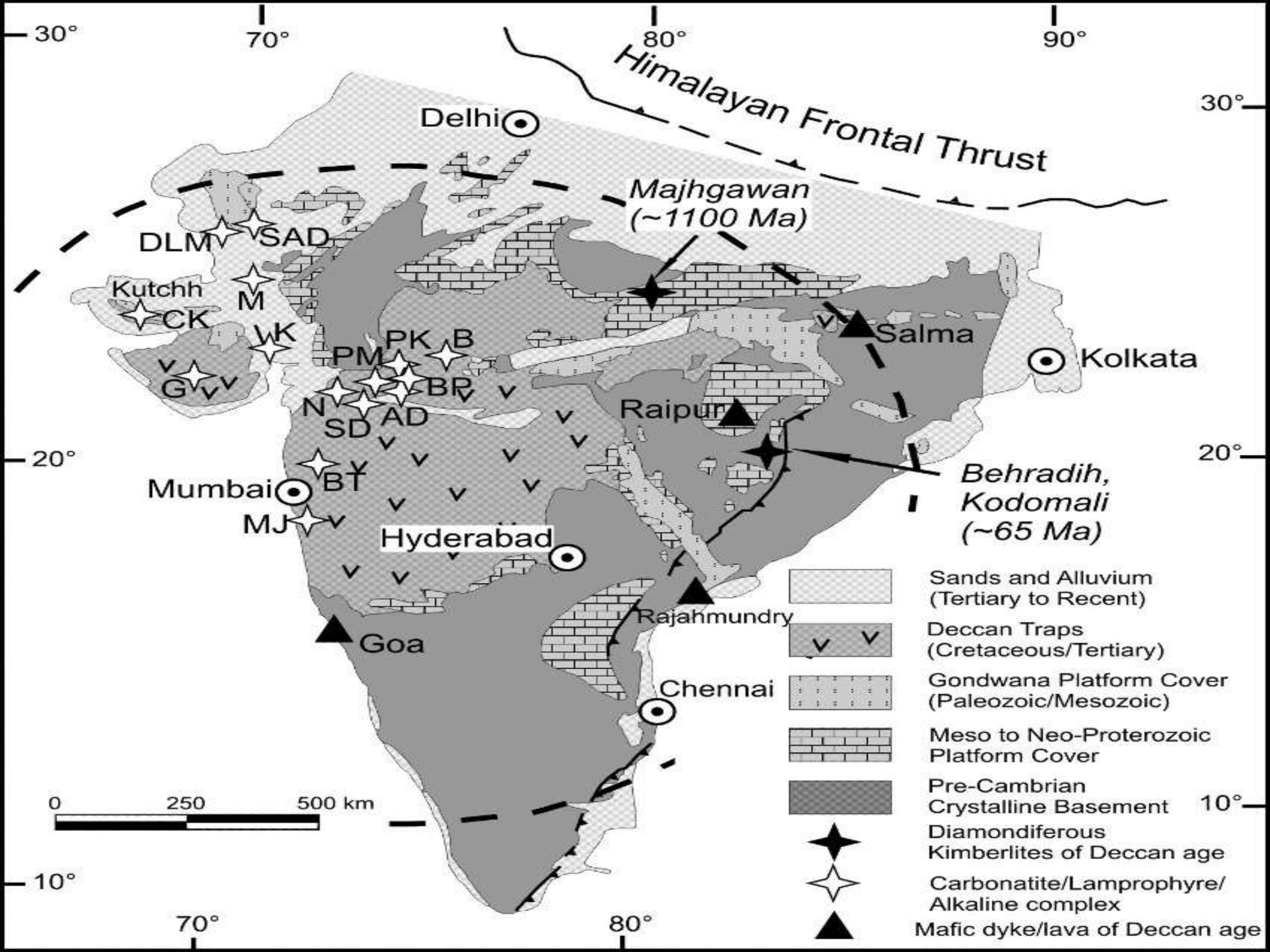
- To provide the biotite (phlogopite) and amphibole (pargasite) mineralogy lack of fractional crystallisation

DISTRIBUTION

- Lamprophyres are usually associated with voluminous granodiorite intrusive episodes. They occur as marginal facies to some granites, though usually as dikes and sills marginal to and crosscutting the granites and diorites. In other districts where granites are abundant no rocks of this class are known. It is rare to find only one member of the group present, but minettes, vogesites, kersantites, etc., all appear and there are usually transitional forms.
- Lamprophyres are also known to be spatially and temporally associated with gold mineralisation. The more reasonable explanation for the correlation is that lamprophyres, representing "wet" melts of the asthenosphere and mantle, correlate with a period of high fluid flow from the mantle through the crust, during subduction-related metamorphism, which drives gold mineralisation.

INDIAN OCCURRENCE

- In INDIA lamprophyres are mostly from the gondwana basins. Although they have been reported from some younger alkaline complexes also.
- From raniganj coal field minette and kersantite are the most frequently reported types
- Calc-alkali lamprophyres are reported from mundwana complex of RAJASTHAN
- Amba-dongar carbonatite complex of GUJARAT is intruded by camptonite and kersantite



30°
70°
80°
90°
30°
20°
20°
10°
10°
70°
80°
Himalayan Frontal Thrust
Delhi
Majhgawan
(~1100 Ma)
DLM
SAD
Kutchh
M
CK
VK
PK
B
PM
G
BR
N
AD
SD
Salma
Kolkata
Raipur
Behradih,
Kodomali
(~65 Ma)
BT
Mumbai
MJ
Hyderabad
Rajahmundry
Goa
Chennai
0
250
500 km
Sands and Alluvium
(Tertiary to Recent)
Deccan Traps
(Cretaceous/Tertiary)
Gondwana Platform Cover
(Paleozoic/Mesozoic)
Meso to Neo-Proterozoic
Platform Cover
Pre-Cambrian
Crystalline Basement
Diamondiferous
Kimberlites of Deccan age
Carbonatite/Lamprophyre/
Alkaline complex
Mafic dyke/lava of Deccan age

ECONOMIC IMPORTANCE

The economic importance of ultrapotassic rocks is wide and varied. Kimberlites, lamproites and perhaps even lamprophyres are known to contain diamond. These rocks are all produced at depths in excess of 120 km and thus can bring diamond to the surface as xenocrysts

Ultrapotassic granites are a known host for much granite-hosted gold mineralisation. Significant porphyry-style mineralisation is won from highly potassic to ultrapotassic granites. Ultrapotassic A-type intracontinental granites may be associated with fluorite and columbite – tantalite mineralization.

CONCLUSION

- Lamprophyres are melanocratic ,porphyritic, hypabyssal rocks.
- The lamprophyres commonly consists of alkali rich calc-alkali to ultramafic minerals.
- In INDIA lamprophyres are mostly from the gondwana basins. Although they have been reported from some younger alkaline complexes also.
- The economic importance of ultrapotassic rocks is wide and varied.

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SEMINAR ON
PEGMATITES AND ASSOCIATED MINERAL
DEPOSITS

CONTENTS

INTRODUCTION TO PEGMATITES

Pegmatites are coarse-grained igneous or metamorphic rocks showing intergrowth texture of grain size usually larger than 2.5cm

Pegmatites are hypabyssal igneous rocks equivalent to plutonic granite. Most pegmatites are composed of feldspar, quartz and mica.

CONTINUED…

Crystal size is the most striking feature of pegmatites, with crystals usually over 5 cm in size. Individual crystals over 10 meters across have been found, and the world's largest crystal was found within a pegmatite.

Jahns (1955) defined pegmatite as “holocrystalline rocks that are at least in part very coarse-grained, whose major constituents include minerals typically found in ordinary rocks and in which extreme textural variation, especially grain size, are characteristic.”

TYPES OF PEGMATITES

- METAMORPHIC PEGMATITES
- MAFIC PEGMATITES
- SYENITE PEGMATITES
- GRANITIC PEGMATITES

METAMORPHIC PEGMATITES are formed when the more mobile quartzofeldspathic constituents of a rock are concentrated in dilation opening during metamorphic differentiation. They are mineralogically simple, unzoned, virtually newer of ecnomic interest.

MAFIC PEGMATITES:

They are clots or lenses of olivine, pyroxenes and plagioclase in peridotites, gabbros and other mafic rocks. They seldom contain valuable minerals except in exceptional such as in Merensky reef of Bushveld igneous complex.

ZONED SYENITE PEGMATITE:

They are found in the Bancroft, Ontario (Canada) have yielded uranium ores but most syenite pegmatites elsewhere are not economically noteworthy.

GRANITIC PEGMATITES:

It consist of quartz, perthite and albite with subordinate to accessory muscovite, biotite or both. They are enriched with minerals of LIL (large ion lithophile)elements like lithium, potassium, sodium, rubidium and beryllium.

TEMPERATURE OF ORIGIN

- Geothermometric studies indicate that pegmatites form over a wide range of temperatures. Fluid inclusion studies indicate temperatures ranging from 700°-250°C

CHARACTERISTICS:

- Although pegmatites can be found in almost any shape. Most commonly they occur as dikes or lensoidal bodies.
- The great majority of pegmatites develop in deep seated high-pressure environments. They are rare in unmetamorphosed sediments or shallow intrusive, lavas or tuff
- Most pegmatites are small, but dimensions can vary from few meters to hundreds of meters in the longest dimension and from 1cm to as much as 200 meters in width

CLASSIFICATION OF PEGMATITES

- **HOMOGENEOUS PEGMATITES**

Majority of pegmatites are mineralogically simple,unzoned and consist mostly of coarse grained quartz and feldspar with subordinate mica, and are uniform in both composition and texture. Some of the homogeneous pegmatites are economically important source of lithium, feldspar and quartz.

E.g.: Kings mountain district, North Carolina, USA , Manona-Kitole, Zaire

- **HETEROGENEOUS PEGMATITES**

Heterogeneous pegmatites result from igneous processes rather than recrystallisation or palingenesis associated with metamorphism. They are thought to have formed as a result of one period of crystallization, after injection of a water rich siliceous late-stage melt, during which the first formed minerals react with a progressively changing residual magmatic fluid from the outer to the inner zones with time. These are economically important.

ZONING IN PEGMATITES

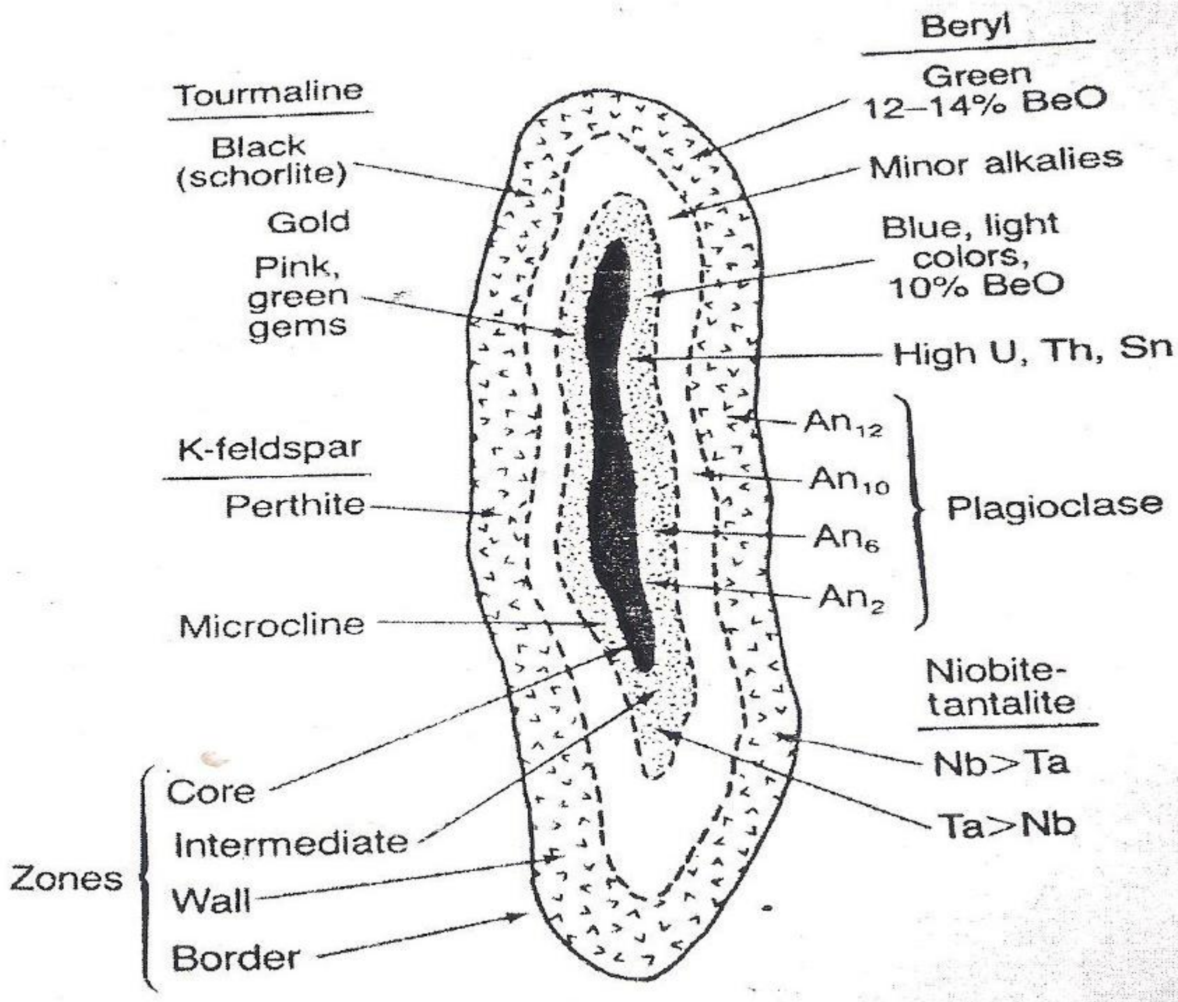


Figure 11-50. Cryptic zoning from wall zone to core in individual pegmatite mineral species (*Composited from* Cameron et al., 1949.)

- **BORDER ZONE :**

  This zone is thin, averaging a few centimeters in most pegmatites. Although in some deposits it cannot be recognized, it is likely to be the most continuous of the zones. The most common minerals are fine grained feldspars, quartz and muscovite. Accessory minerals include garnet, tourmaline, beryl etc.

- **WALL ZONE :**

  It is well developed in many and absent in others. In general the wall and border zones contain same minerals, though the proportions may differ but the wall zone is more coarsely textured and thicker than the border zone. The essential minerals present are plagioclase, perthite, quartz and muscovite but appreciable amount of beryl, tourmaline, garnet, apatite may be present.

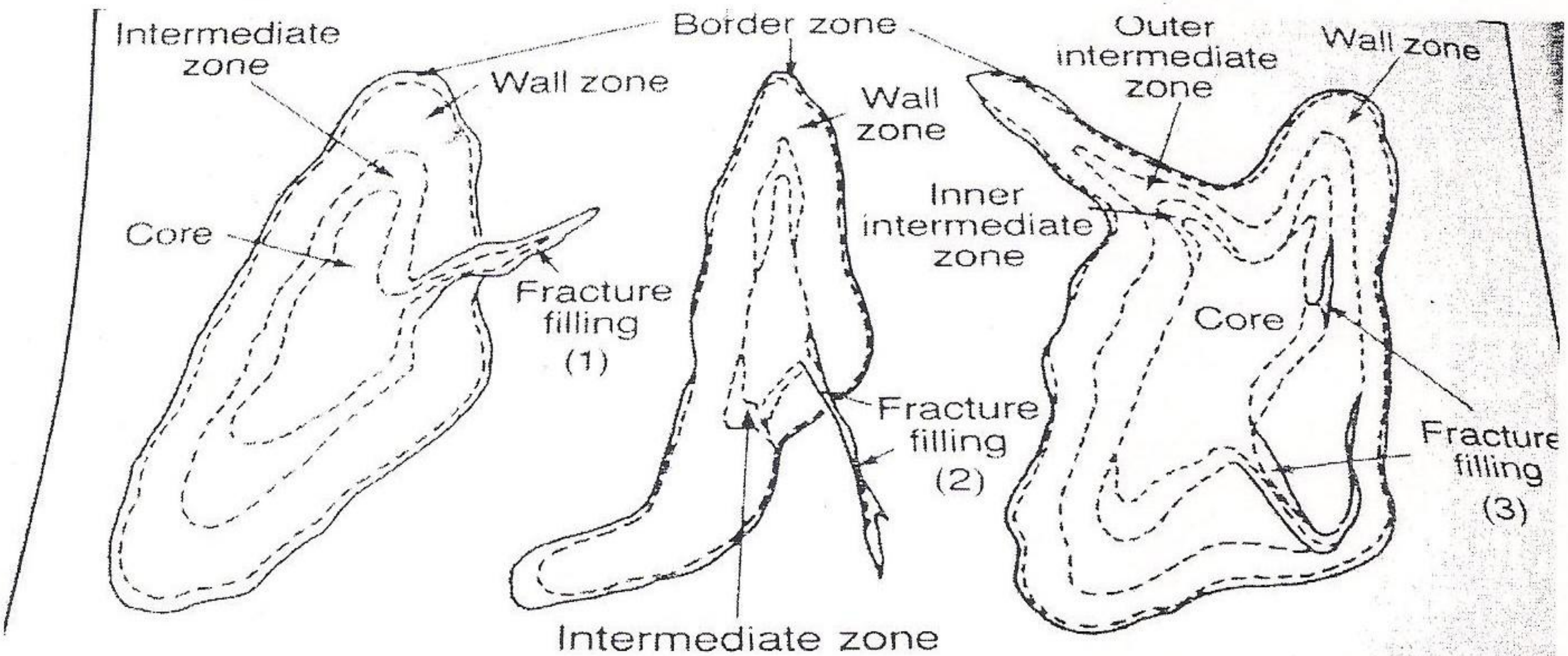
- **INTERMEDIATE ZONE :**

  This is an important zone as it may contain variety of mineable minerals. Cameron (1949) recognized intermediate zone. Most complex granitic pegmatites consist of as many 5 or 6 intermediate zones.

- **CORE ZONE**

  The core zone in pegmatites is commonly a solid mass of barren white quartz, coarse grained quartz with feldspar or quartz with large euhedral crystals of tourmaline or spodumene.

FRACTURE FILLINGS IN PEGMATITE



(1) Thick fracture filling that extends from inner zones of pegmatite acros wall and border zones into country rock.

(2) Thin fracture fillings that were developed during formation of discontinuous intermediate zone and podlike core of pegmatite.

(3) Fracture fillings in large, irregular pegmatite body.

PEGMATITE AND ASSOCIATED ORE MINERALS

- Pegmatites have their primary value for its mica content. But they also contain lithium, beryllium, niobium, rubidium cesium, tantalum etc.

- Lesser sources of uranium,thorium,rare earth elements, molybdenum, tin ,tungsten and

- Major sources of muscovite mica,perthite-quartz for glass making, high-purity silica, and variety of gem stones and salable minerals including emeralds, beryls, topaz, tourmalines and many more.

Blue quartz Bearing Pegmatite

Aquamarine Pegmatite

Garnet Pegmatite

Lepidolite (Mica) Pegmatite

Lithium-Pegmatite

Muscovite-Pegmatite

Pegmatite Bearing Beryl

Tourmaline Pegmatite

INDIAN OCCURRENCES

Pegmatites occurs in some places in India namely,

1.In Rajasthan mica pegmatite belt (Jaipur, Ajmer-Merwara)

2.In Nellore mica belt covering Gadur, Rapur, kavali taluks of Andhra Pradesh

3.In the Bihar mica belt from Kodarma, Chatkari, Dhab, Gawan, Tisri etc.

CONCLUSION

- **Pegmatites** are coarse-grained igneous or metamorphic rocks showing intergrowth texture of grain size usually larger than 2.5cm.

- They are hypabyssal igneous rocks equivalent to plutonic granite. Most pegmatites are composed of feldspar, quartz and mica.

- Crystal size is the most striking feature of pegmatites, with crystals usually over 5 cm in size. Individual crystals over 10 meters across have been found, and the world's largest crystal was found within a pegmatite.

- Geothermometric studies indicate that pegmatites form over a wide range of temperatures. Fluid inclusion studies indicate temperatures ranging from 700°C-250°C

- The different types of pegmatites are
  1) Metamorphic pegmatites
  2) Syenite pegmatite
  3) Mafic pegmatites
  4) Granitic pegmatites

- Pegmatites are classified into two, they are
  1) Homogeneous pegmatites (unzoned)
  2) Heterogeneous pegmatites (zoned)

- Different zones in them are border zone, wall zone, intermediate zone and the core zone.

- They yield lithium, beryllium, niobium, rubidium, cesium, tantalum, uranium, thorium, rare earth elements, molybdenum, tin ,tungsten, muscovite mica, perthite-quartz and variety of gem stones and salable minerals including emeralds, beryl, topaz, tourmalines and many more.

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Evolution of Magma

Stuffing's

- Introduction (magma)
- Types of magma
- Origin
- Bowens Reaction Series
- Pressure, Temperature
- Density, composition
- Melt structure, properties & Polymerization
- Partial melting
- Geochemical implication
- Evolution, Migration
- Cooling, Volcanism
- Wrapping up
- References

Magma

- **Magma** (from Greek μάγμα "mixture") is a mixture of molten or semi-molten rock, volatiles and solids that is found beneath the surface of the Earth, and is expected to exist on other terrestrial planets.
- Besides molten rock, magma may also contain suspended crystals, dissolved gas and sometimes gas bubbles.
- It often collects in magma chambers that may feed a volcano or turn into a pluton.

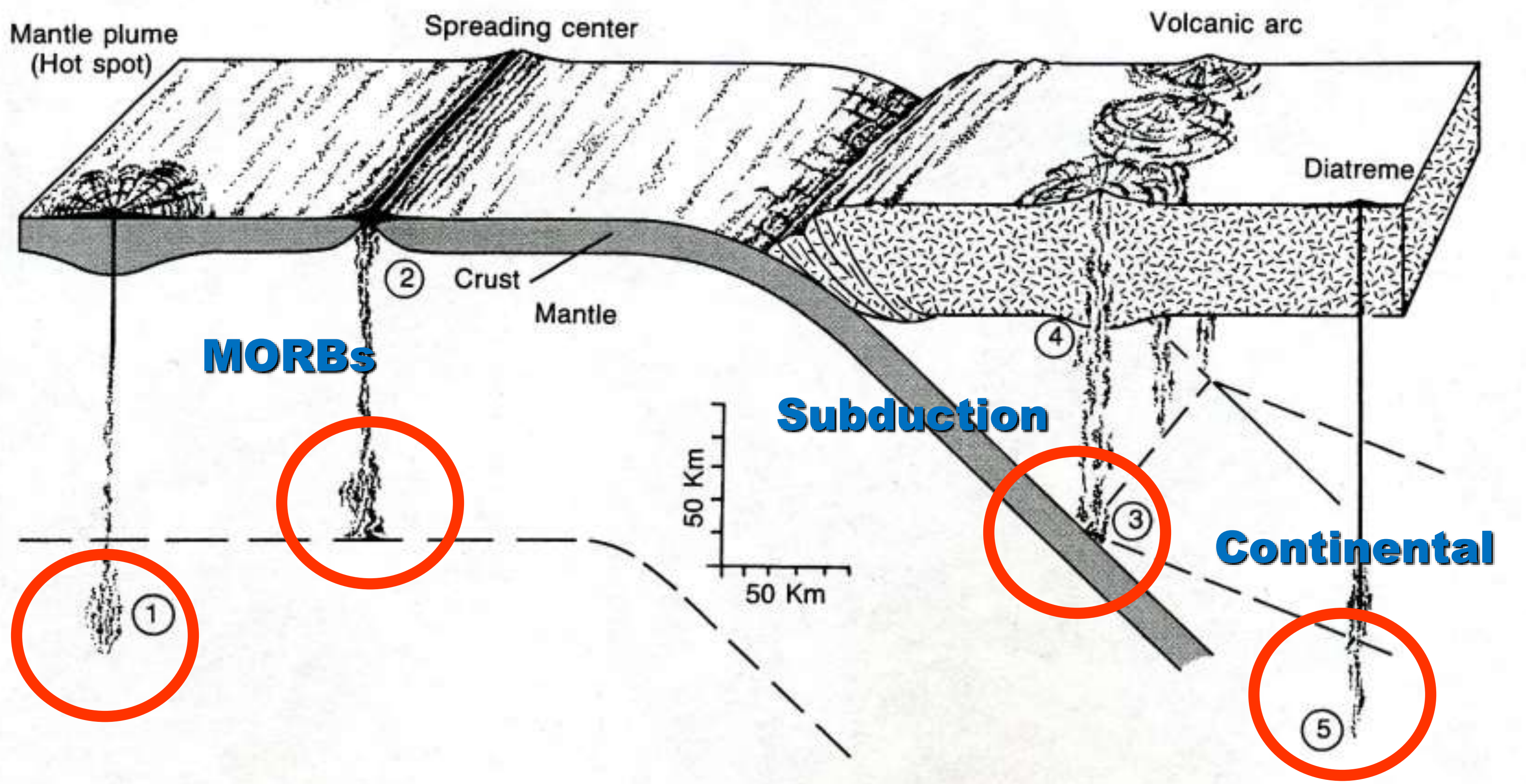
Magma

- Magma is a complex high-temperature fluid substance. Temperatures of most magmas are in the range 700 °C to 1300 °C (or 1300 °F to 2400 °F), but very rare carbonatite melts may be as cool as 600 °C, and komatiite melts may have been as hot as 1600 °C. Most are silicate mixtures
- It is capable of intrusion into adjacent rocks, extrusion onto the surface as lava, and explosive ejection as tephra to form pyroclastic rock
- Most magmas (crystal) that is found beneath the earth surface and it is generated in the upper parts of mantle (Asthenospehere) and lower crust

Types of Magmas

- **Primitive magma**: They are unmodified magmas that form through anataxis (melting of mantle rocks that have not been changed in composition since they formed.
- **Primary magma**: This magma are any chemically unchanged melt derived from any kind of preexisting rocks. All primitive magma is primary but most primary magma that yields modern rocks is not primitive.
- **Parental magma:** The magma that have given rise to another magma.
- **Derivative magma:** Derivative magmas are the magma which derived directly from a preexisting magma.

Site and Source for Magma Generation

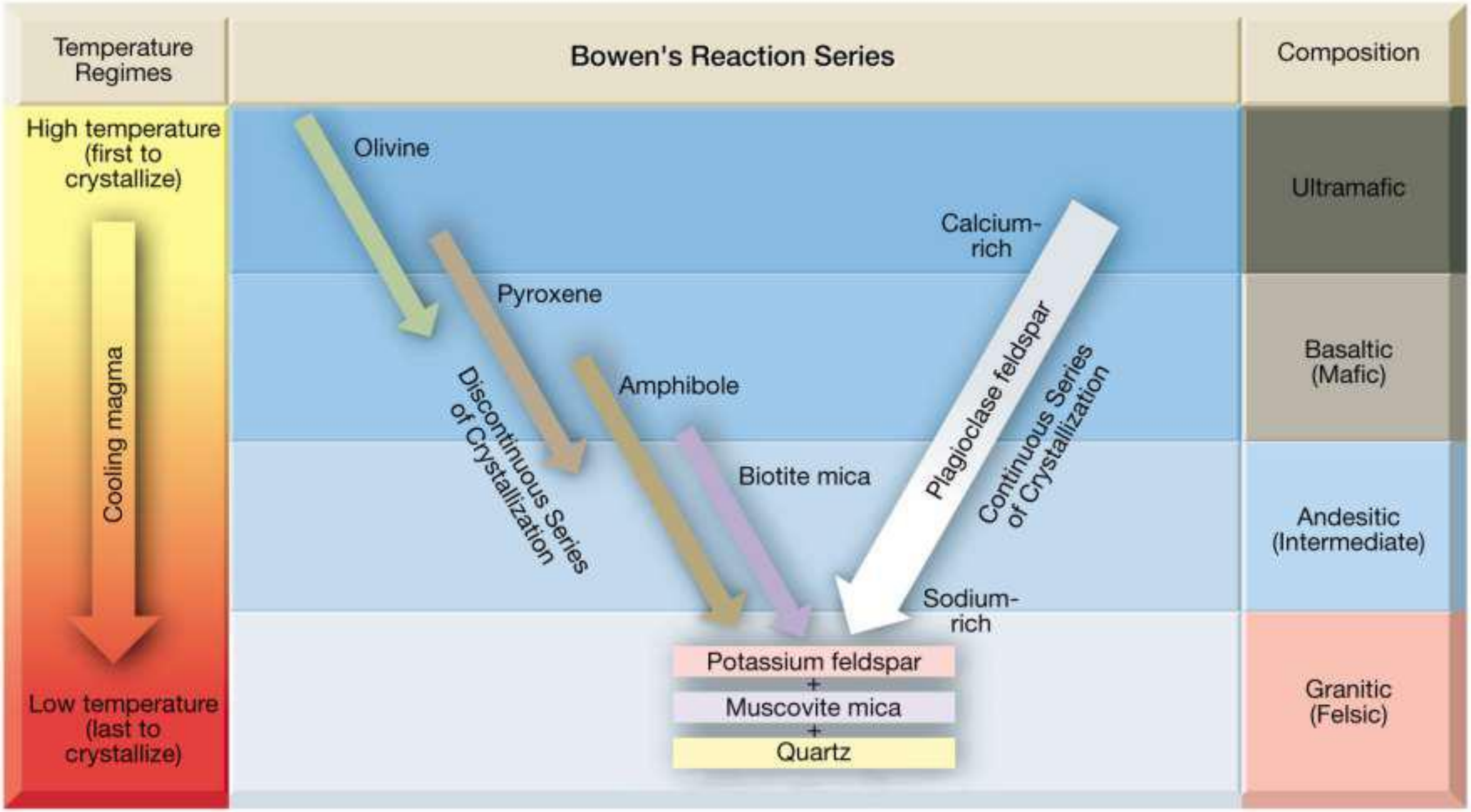


Origin

- Magma moving upward, or sideways, within the Earth, will take in rock along the edges of magma chambers, even in huge pieces, and the aped material will be melted into the magma, changing its composition somewhat.
- If an intermediate composition magma moves upward into continental crust, which is a hodgepodge of all types of rocks, **assimilation** of country rock will result in a diluting of iron and magnesium content (the aped material doesn't have as much iron and magnesium, usually). So, the magma may become felsic in composition after the assimilation.
- **Mixing of magma** Two magmas, perhaps of differing composition, can mix together if they come into contact, and the resulting magma is a kind of combination, most likely different from either of the original magmas.
- In the case of olivine, which starts crystallizing first, at high temperatures, iron and magnesium, along with silica, are taken out of the magma, depleting it of these substances

- As other minerals grow, they will likewise remove certain chemical elements from the magma. So, the overall composition of the magma changes, as crystallization happens.
- Norman Bowen did laboratory experiments to determine the order of crystallization of minerals growing in a magma as it cools, and made a chart showing the order.
- This is called **Bowen's Reaction Series**, and is important to understanding how magmas evolve? Why is it important?
- Because early formed igneous rock might contain one set of minerals, but a later forming igneous rock, forming from the same magma, but changed, will have a different mineralogy.
- For such things as ore deposits like gold and silver, understanding how minerals crystallize helps you map out where you think deposits are located within mountain ranges.

Bowen's Reaction Series

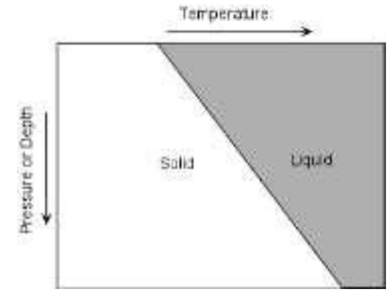


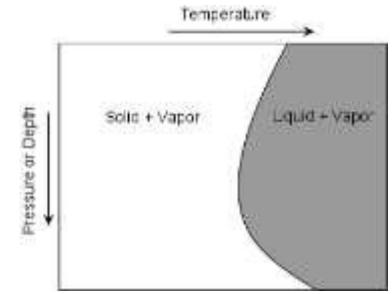
• There are two general cases for a pure dry (no H2O / CO2) mineral the melting temperature increase with increasing pressure

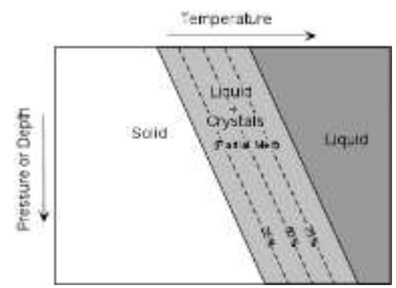
• For a mineral with H_2O / CO_2 present the melting temperature first decrease with increasing pressure.

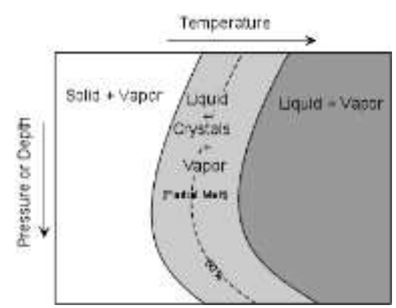
•Melting of dry rock is similar to melting of dry minerals . Melting temperature increase with increasing pressure except there is a range of temperature over which there exist a partial melt. The degree of partial melt can change or range from 0 – 100 %.

•Melting of rocks consisting water or CO2 is similar to melting of wet minerals . Melting temperature initially decrease with increasing pressure except there is a range of temperature over which there exist a partial melt .





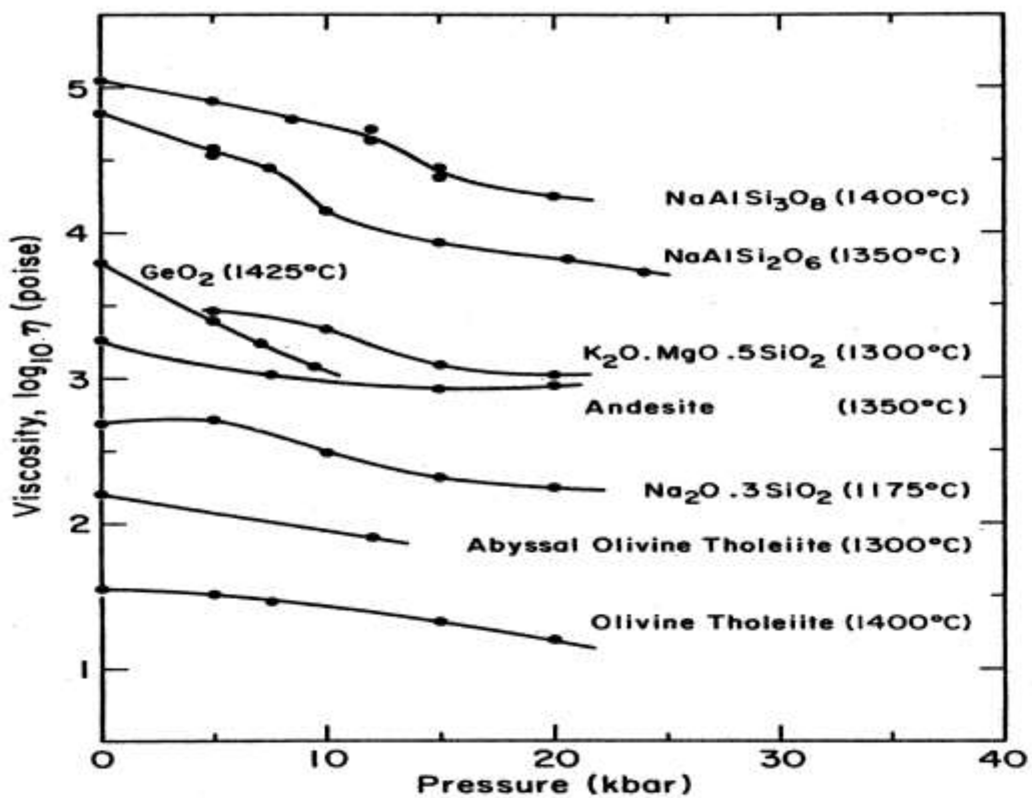




Temperature, Pressure

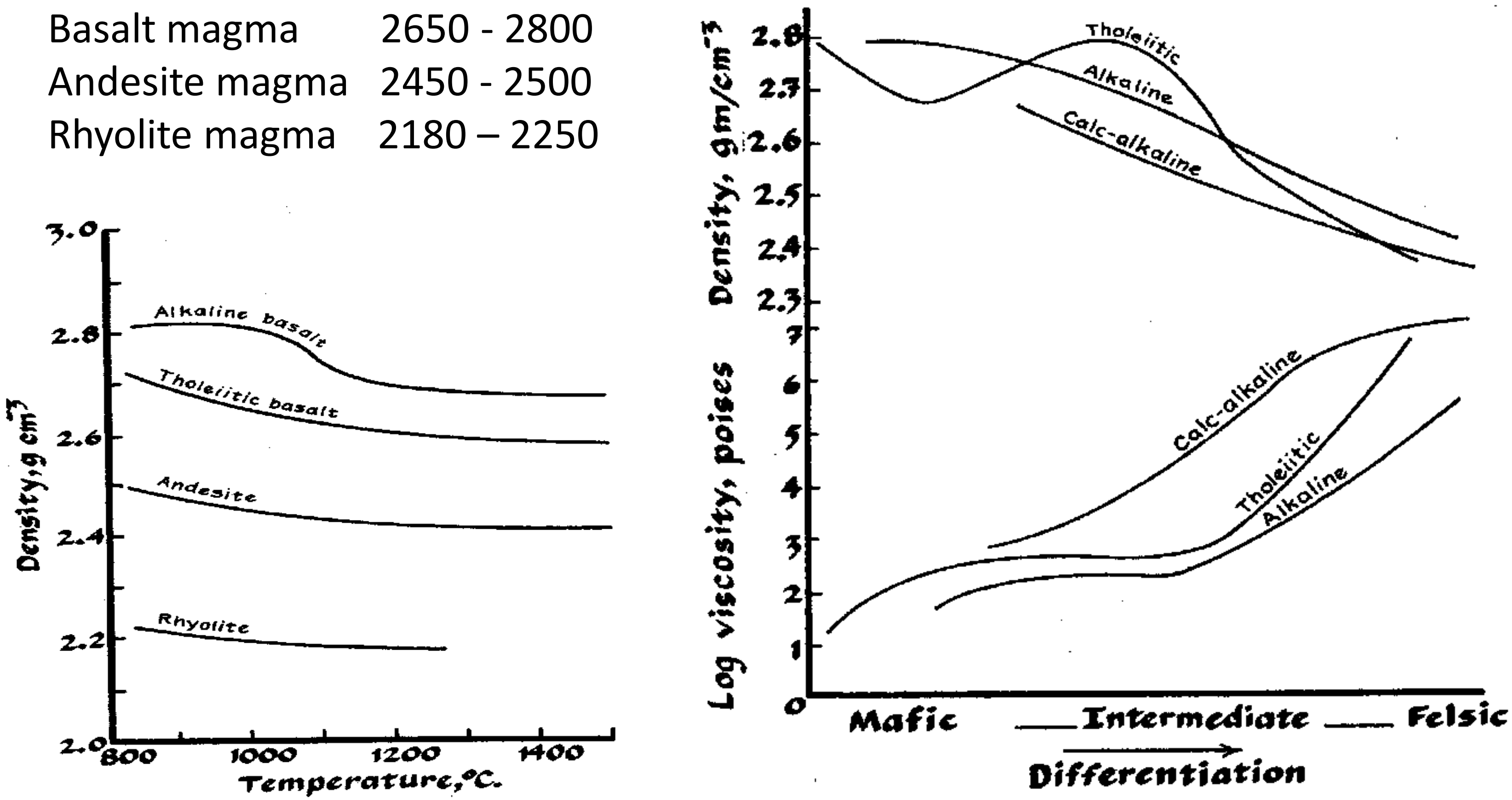
- Within the solid earth, the temperature of a rock is controlled by the geothermal gradient and the radioactive decay within the rock.
- The geothermal gradient averages about 25 °C/km with a wide range from a low of 5–10 °C/km within oceanic trenches and subduction zones to 30–80 °C/km under mid-ocean ridges and volcanic arc environments
- As magma buoyantly rises it will cross the solidus-liquidus and its temperature will reduce by adiabatic cooling. At this point it will liquefy and if erupted onto the surface will form lava.
- On the other hand increased load pressure causes melting temp of rocks by a process known as decompression melting
- Temp of dry magma higher in compare to wet magmas

- **Pressure** is play also an important role in part of viscosity. When pressure increase viscosity is low and vice versa



Density

Type	Density [kg/m³]
Basalt magma	2650 - 2800
Andesite magma	2450 - 2500
Rhyolite magma	2180 – 2250



(a) (b)

Figure shows the density of liquid with the composition of common igneous rock over a broad range of temperature note that the decrease of density due to thermal expansion so much less then that of changing composition

Composition

- It is usually very difficult to change the bulk composition of a large mass of rock, so composition is the basic control on whether a rock will melt at any given temperature and pressure.
- The presence of volatile phases in a rock under pressure can stabilize a melt fraction.
- The presence of even 0.8% water may reduce the temperature of melting by as much as 100 °C. Conversely, the loss of water and volatiles from a magma may cause it to essentially freeze or solidify.
- Magma also contains gases, which expand as the magma rises.
- Magma that is high in silica resists flowing, so expanding gases are trapped in it.
- Pressure builds up until the gases blast out in a violent, dangerous explosion.

Magma on the basis of silica %

- **Acidic or Felsic (rhyolitic) magma**
  - SiO_2 >70%
  - Fe-Mg: ~ 2%
  - Temp: < 900°C
- **Intermediate (andesitic) magma**
  - SiO_2 ~ 60%
  - Fe-Mg: ~ 3%
  - Temperature: ~1000°C
- **Basic or Mafic (basaltic) magma**
  - SiO_2 < 50%
  - FeO and MgO typically < 10 wt%
  - Temperature: up to ~1300°C
- **Ultramafic (picritic) magma**
  - SiO_2 < 45%
  - Fe-Mg >8% up to 32%MgO
  - Temperature: up to 1500°C
  - Viscosity: Very Low

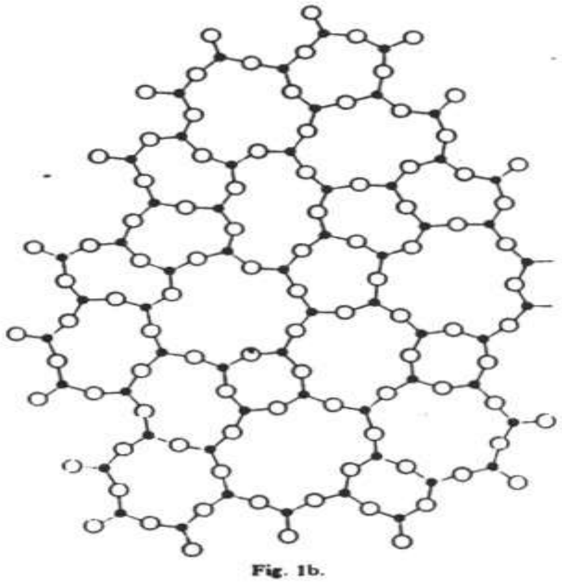
Melt structure and Properties

- Silicate melts are composed mainly of silicon, oxygen, aluminium, alkalis (sodium, potassium, calcium), magnesium and iron.
- The physical behaviours of melts depend upon their atomic structures as well as upon temperature and pressure and composition.
- More silica-rich melts are typically more polymerized, with more linkage of silica tetrahedra, and so are more viscous.
- Viscosity is a key melt property in understanding the behaviour of magmas, Dissolution of water drastically reduces melt viscosity. Higher-temperature melts are less viscous.
- Low viscosity leads to gentler, less explosive eruptions.

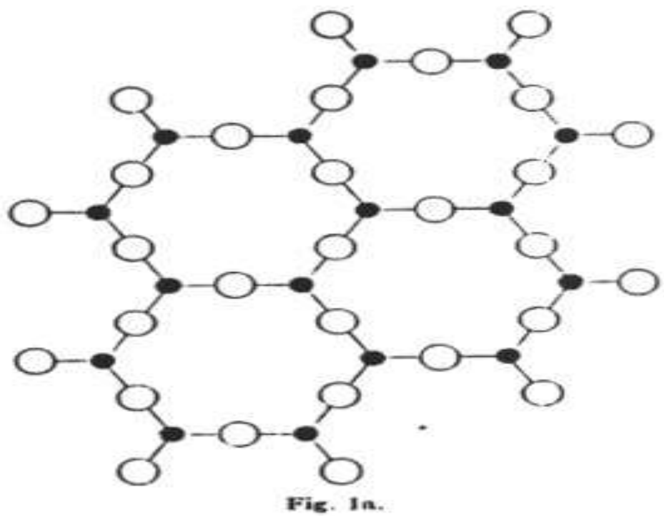
Polymerization of magma

- Excepting the carbonatites all magmas are silicates. Their physical properties like viscosity and density are related to the internal arrangement of atoms and molecules in the magma
- The fundamental structural unit of all silicate minerals and any magma is the $[SiO_4]^{4-}$ tetrahedron . A small Si^{+}ion at its centre is covalently bonded to four O^{2-} ions at its apices.
- In most silicate minerals $[SiO_4]^{-}$ tetrahedral units share some of the apical O^{2-} ions which are called "bridging " oxygen .The no shared O^{2-} ions , called "nonbridging " oxygen are bonded to other cations (e.g. Mg Fe , Na , Ca) present in the mineral structure .
- Si and other fourfold coordinated cations (mainly Al) that form the backbone of the tetrahedral framework are called "network formers".

- During melting of a silicate mineral or rock , the covalent bonds betweens Si4+ and apical oxygen's are generally too strong to break
- But the bonds between non bridging oxygen's and network modifiers dip break , enabling these other cations to move around within the framework of polymerized [SiO_4] chains in a molten silicate.
- So polymerization means the networked nature of a silicate magma. Degree of polymerization depends on the SiO_2 content of the magma more siliceous magmas are more polymerized , and thereby more viscous , than mafic magmas.



fully polymerized melt



fully polymerized crystal

Partial melting

- Melting of solid rocks to form magma is controlled by three physical parameters: its **temperature, pressure, and composition**.
- When rocks melt they do so incrementally and gradually; most rocks are made of several minerals, all of which have different melting points, and the physical/chemical relationships controlling melting are complex.
- As a rock melts, its volume changes. When enough rock is melted, the small globules of melt (generally occurring in between mineral grains) link up and soften the rock.

Geochemical implications of Partial melting

- The degree of partial melting is critical for determining what type of magma is produced.
- The degree of partial melting required to form a melt can be estimated by considering the relative enrichment of incompatible elements versus compatible elements. Incompatible elements commonly include potassium, barium, caesium, rubidium.
- Rock types produced by small degrees of partial melting in the Earth's mantle are typically alkaline (Ca, Na), potassic (K) and/or peralkaline (high aluminium to silica ratio).
- Under pressure within the earth, as little as a fraction of a percent partial melting may be sufficient to cause melt to be squeezed from its source.

- Typically, primitive melts of this composition form lamprophyre, lamproite, kimberlite and sometimes nepheline-bearing mafic rocks such as alkali basalts and essexite gabbros or even carbonatite.
- Pegmatite may be produced by low degrees of partial melting of the crust. Some granite-composition magmas are eutectic (or cotectic) melts, and they may be produced by low to high degrees of partial melting of the crust, as well as by fractional crystallization.
- At high degrees of partial melting of the crust, granitoids such as tonalite, granodiorite and monzonite can be produced, but other mechanisms are typically important in producing them.

Evolution

Primary melts

- Primary melts have not undergone any differentiation and represent the starting composition of a magma.
- In nature it is rare to find primary melts.
- The leucosomes of migmatites are examples of primary melts.
- Primary melts derived from the mantle are especially important, and are known as *primitive melts* or primitive magmas.
- By finding the primitive magma composition of a magma series it is possible to model the composition of the mantle from which a melt was formed, which is important in understanding evolution of the mantle.

Parental melts

- Where it is impossible to find the primitive or primary magma composition, it is often useful to attempt to identify a parental melt.
- A parental melt is a magma composition from which the observed range of magma chemistries has been derived by the processes of igneous differentiation, it need not be a primitive melt.
- A composition from which they could reasonably be produced by **fractional crystallization** is termed a *parental melt*.
- Fractional crystallization models would be produced to test the hypothesis that they share a common parental melt.
- At high degrees of partial melting of the mantle, komatiite and picrite are produced.

Types of FX

- gravity settling
- filter pressing
- convective fractionation
- congelation crystallization
- flow differentiation

Ways to produce variation

- different source rocks
- partial melt fractionation
- fractional crystallization
- assimilation
- diffusion/volatile transfer
- magma mixing
- post-solidification alteration

Migration

- Magma develops within the mantle or crust when the temperature-pressure conditions favour the molten state.
- Magma rises toward the Earth's surface when it is less dense than the surrounding rock and when a structural zone allows movement.
- Magma can remain in a chamber until it cools and crystallizes forming igneous rock, it erupts as a volcano, or moves into another magma chamber.

Cooling of magmas

- There are two known processes by which magma ceases to exist: by **volcanic eruption**, or by **crystallization** within the crust or mantle to form a pluton.
- In both cases the bulk of the magma eventually cools and forms igneous rocks.
- When magma cools it begins to form solid mineral phases.
- Magma that cools slowly within a magma chamber usually ends up forming bodies of plutonic rocks such as gabbro, diorite and granite, depending upon the composition of the magma.
- Alternatively, if the magma is erupted it forms volcanic rocks such as **basalt**, **andesite** and **rhyolite** (the extrusive equivalents of **gabbro**, **diorite** and **granite**, respectively).

Volcanism

- During a volcanic eruption the magma that leaves the underground is called lava. Lava cools and solidifies relatively quickly compared to underground bodies of magma.
- This fast cooling does not allow crystals to grow large, and a part of the melt does not crystallize at all, becoming glass. Rocks largely composed of volcanic glass include obsidian, scoria and pumice.
- Before and during volcanic eruptions, volatiles such as CO_2 and H_2O partially leave the melt through a process known as exsolution.
- Magma with low water content becomes increasingly viscous. If massive exsolution occurs when magma heads upwards during a volcanic eruption, the resulting eruption is usually explosive

Wrapping up

- Magma form during partial melting either in mantle or in the lower part of the crust on the way toward the surface .
- Magma is commonly assembled is large pools of molten rocks , which are called Magma chambers . Magma may subsequently rise to the surface during volcanic eruptions resulting in formation of extrusive rocks.
- When magmas crystallize at depth, intrusive rocks are formed . Magma that crystallize in fracture resulting the formation of dykes and sills.
- Magma are complexes chemical system that melt crystallize over temperature intervals of several tens of degree centigrade

- Below mid – oceanic ridge , basaltic magmas is formed during partial melting of the underlying asthenosphere which i.e. of ultramafic composition .
- In association with subduction forces different types of magma are formed . Andesitic magma forms during partial melting of the subducted oceanic crust . Basaltic magmas forms during partial melting of the mantle wedge above the subducted slab.
- In addition granitic magma may form during continental crystal above the subduction zone. When minerals are crystallizing from magma, the chemical composition of the magma changes the magma differentiates.
- Other mechanisms that are responsible for alteration of magma composition are contamination and magma mixing.

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