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Note 04

IDENTIFYING IGNEOUS ROCKS IN THE FIELD - A BASIC INTRODUCTION



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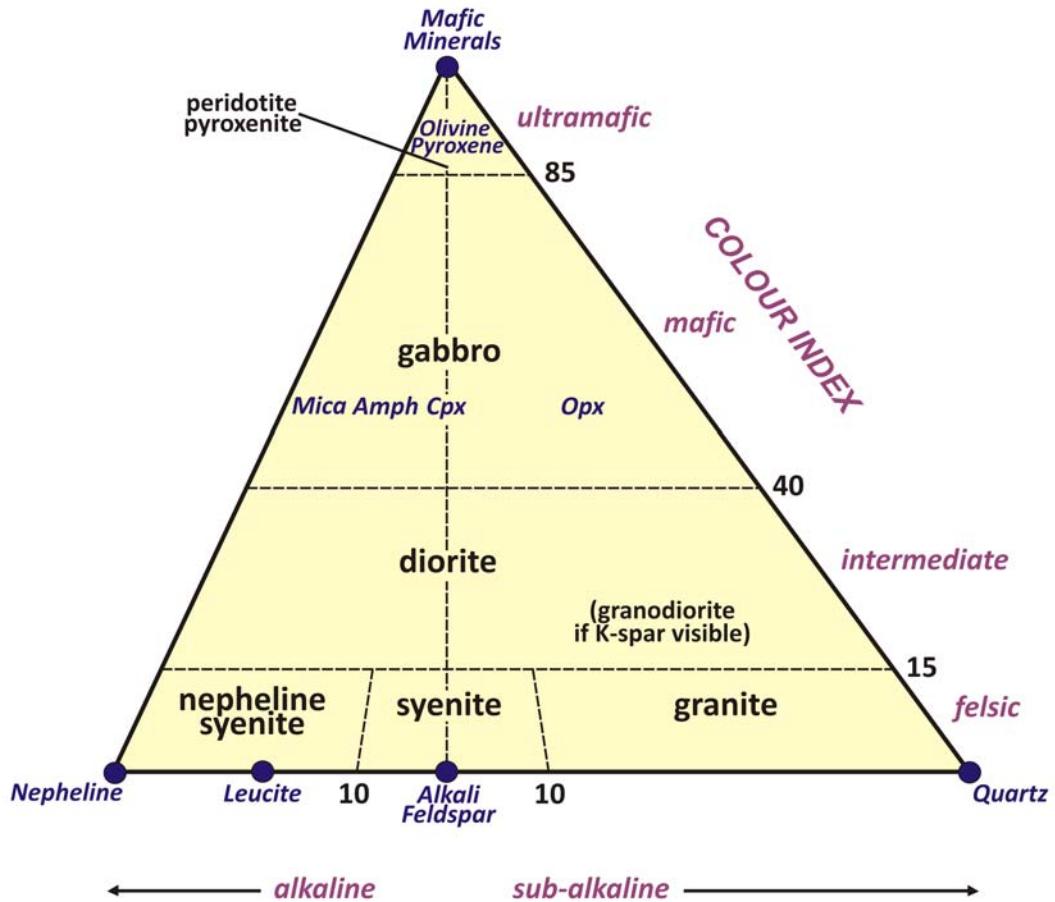
In this second file note we focus on the basics of how to classify and name igneous rocks when we are in the field and can only rely on our knowledge and hand lens. For sedimentary rocks, there are good classification diagrams readily available (e.g., Folk/Dunham/McBride/Cuffey), but for igneous rocks this is somewhat less straightforward, hence someone may find the 'beginner-level' comments and diagrams below quite handy.

• **PLUTONIC IGNEOUS ROCKS**

Plutonic (intrusive) rocks are those which crystallized below the surface of the Earth, in some cases at a significant depth, and therefore as their rates of cooling and crystallization were slow, they are comparatively coarse-grained. Because of the way they form, plutonic rocks are typically a combination of mechanically accumulated crystals (i.e., cumulate) and interstitial melt which produced a finer-grained groundmass. A basic diagram for 'roughly' classifying plutonic rocks in the field (Francis, 2001) is reproduced below and relies on the relative abundance of the principal rock-forming minerals present, as well as on gauging the overall 'colour index', which in this case corresponds to the relative proportion of mafic minerals. In other words, light-colored rocks with <15% mafic (dark) minerals are termed 'felsic', those with a proportion of 15-40% of mafic minerals are termed 'intermediate' (in composition), whereas those with >40% dark minerals are 'mafic' and 'ultramafic'. For estimating the mafic mineral content, you should use the helpful chart below, as dark minerals have a greater visual impact, leading to a potential over-estimation of the 'colour index'. Also, the accuracy of the 'colour index' estimation depends on the grain size of the rock: it can become increasingly difficult to determine in the very fine-grained rocks, therefore it is sometimes better to record an 'overall impression' of the rock's colour. With regard to this first classification diagram, note also that if quartz (or nepheline) occupy less than 10 vol.% of the rock, i.e., the rock is in the 'syenite' field, these minerals are notoriously difficult to observe.

A detailed diagram for classifying ultramafic plutonic rocks (i.e., with >85% of mafic minerals) is shown on the next page. These rocks, especially when altered can be difficult to name, in which case the term 'ultramafic rock' may at times be the best you can do. An olivine-rich rock, in which orthopyroxene and clinopyroxene cannot be distinguished is best called *peridotite*. Note that peridotites have such a low feldspar content that it is either absent or present only as a subordinate interstitial mineral.

Field classification of plutonic rocks



(After Don Francis, 2001)

Classification of mafic and ultramafic plutonic rocks

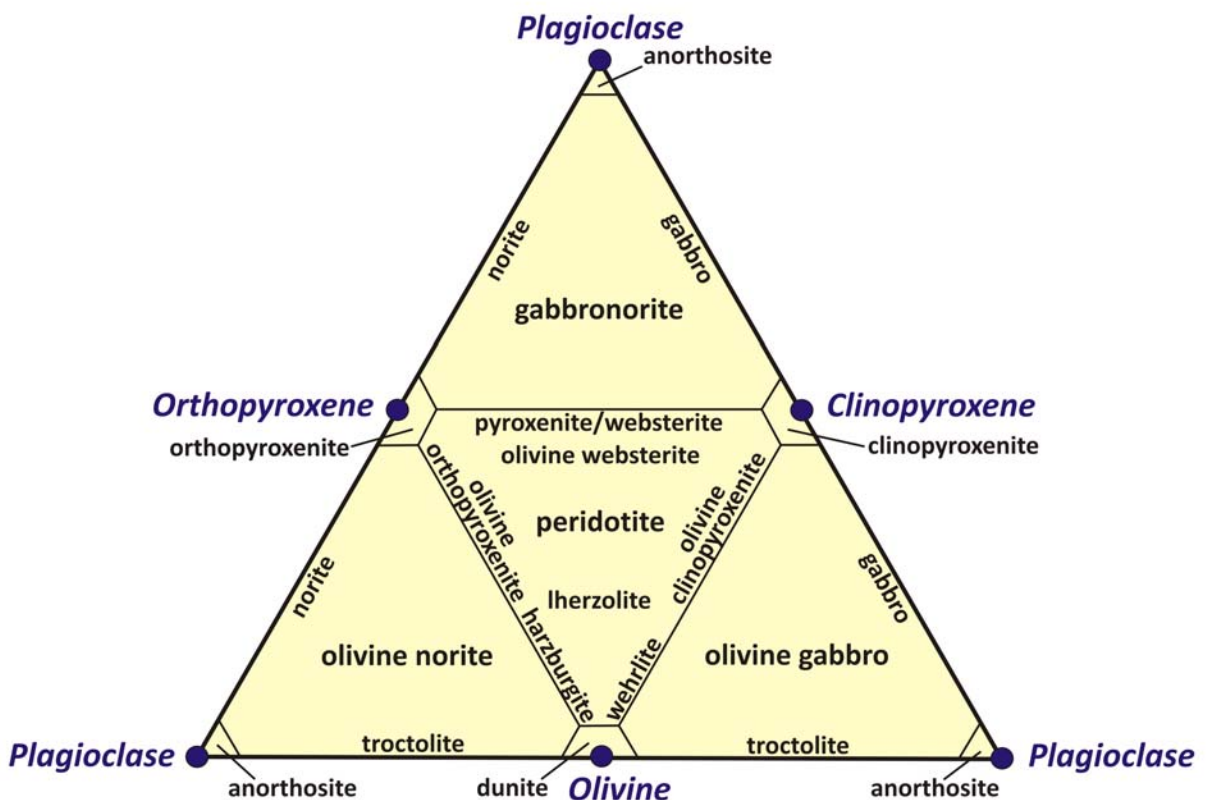
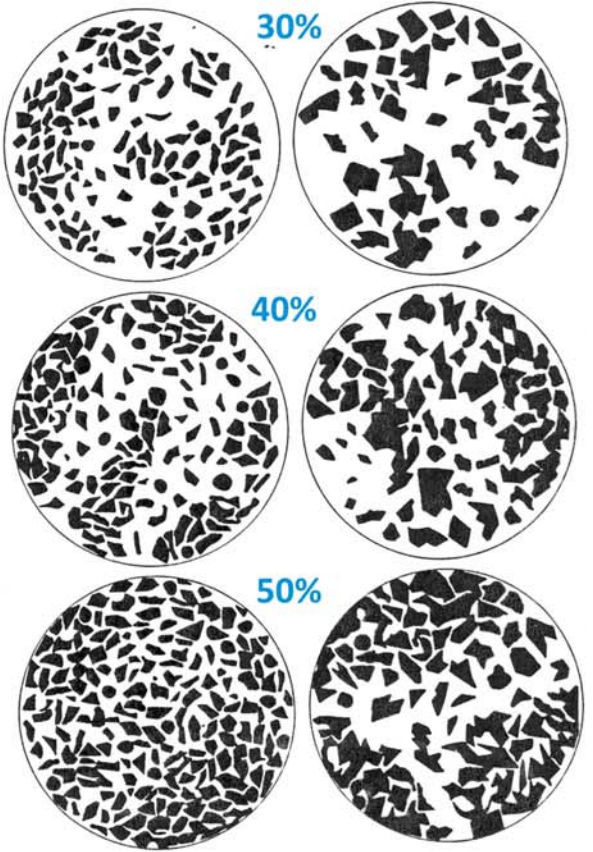
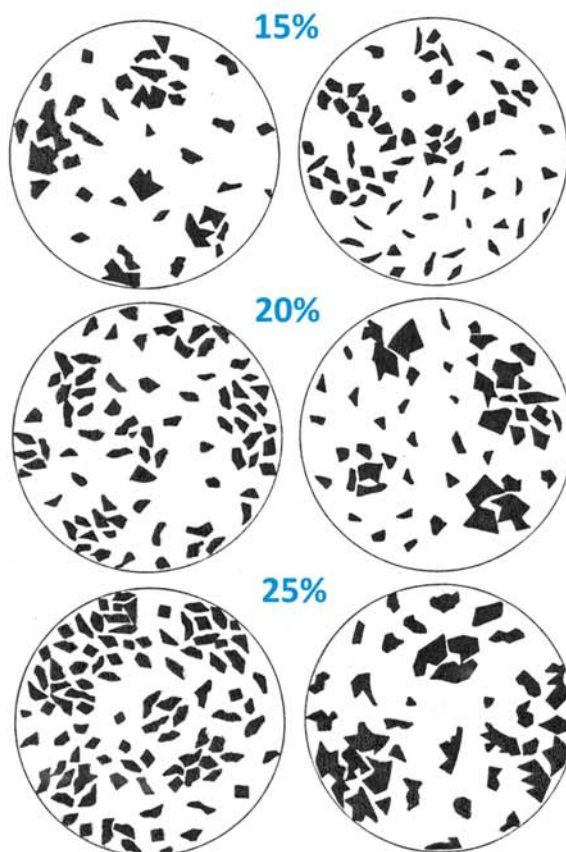
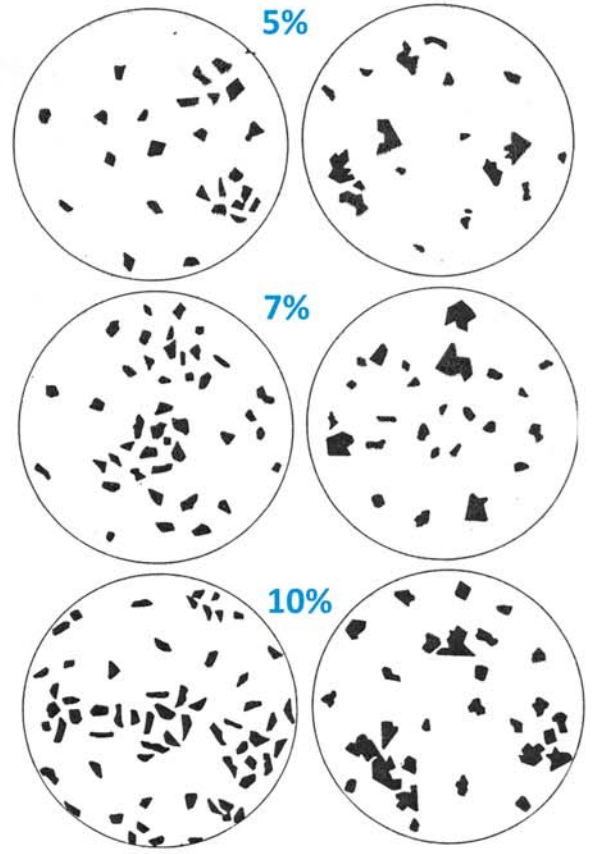
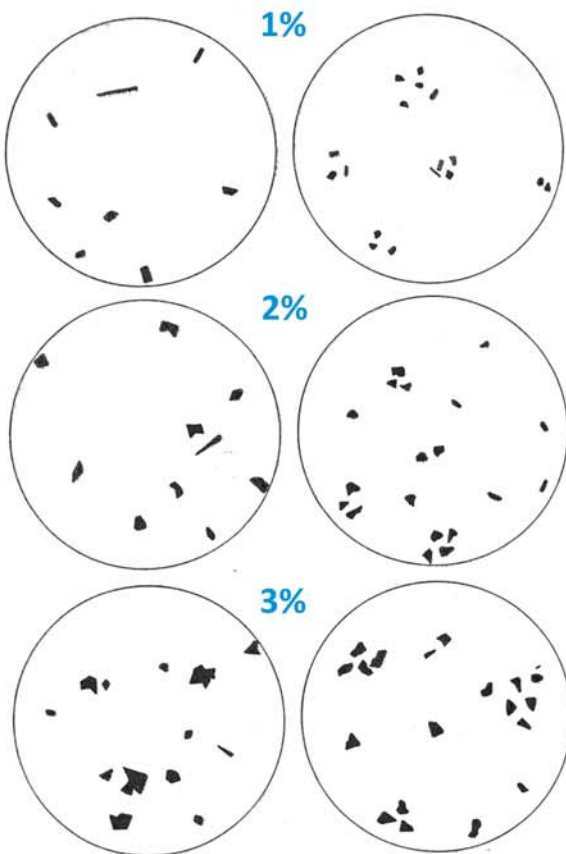


Chart for estimating the mafic mineral content of a rock (after Svecova, 1954)



Many ultramafic rocks are cumulates and in the larger scale display the presence of multiple layers differing in mineral composition, with the bottom of a cumulate layer displaying a sharp boundary, and the top – a gradational one. Another characteristic feature is also the presence of oikocrysts, i.e., larger crystals that grew from the interstitial melt and poikilitically encompassed earlier-formed chadocrysts of another mineral, e.g., pyroxene oikocrysts encompassing olivine crystals. As the oikocrysts are effectively single crystals, in hand specimen their cleavage surfaces produce characteristic flashes of reflected light. Note that mafic minerals weather very easily, hence always look at a fresh rock surface. Olivine may commonly be serpentinized and black in color, unless subsequent oxidation took place and turned it to a reddish brown. (Thus, ultramafic rocks weathering brown are most commonly peridotite).

Mafic ('gabbroic') rocks normally contain between 15-60% feldspar, with the notable exception of *anorthosite*, the bulk of which is composed of dark calcic plagioclase. High-level porphyritic mafic dykes can be difficult to distinguish from mafic volcanics, but the presence of chilled margins against both the top and bottom contacts with their host, as well as the general lack of vesicles are quite characteristic. Such fine- and medium-grained mafic plutonic rocks are commonly referred to as *dolerite* (or *diabase*). A strict distinction between gabbro and diorite can only be made based on the composition of the plagioclase present, but using just field observations an abundance of pyroxenes hints at a gabbro, whereas common biotite and amphibole are more typical of diorite.

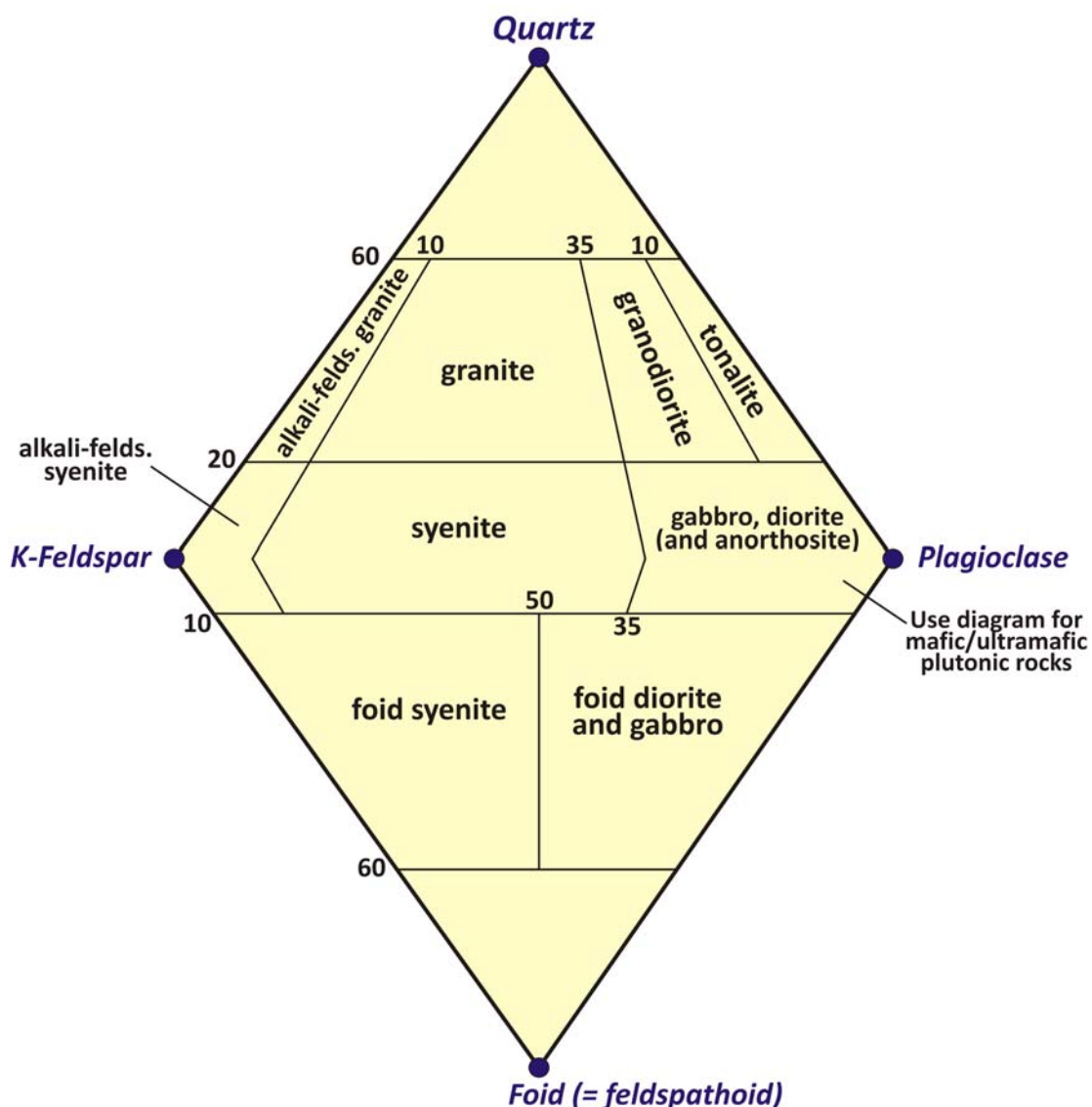
Felsic and intermediate plutonic rocks can be classified using the rhomb-shaped, simplified IUGS diagram below, with the name of the rock being preceded by the predominant mafic silicate, e.g., 'hornblende granodiorite'. Here, note that granodiorite typically has more mafic minerals than granite, something not reflected in the diagram. On the other hand, granitic rocks on the left (i.e., alkaline series) side of the diagram tend to have little mafic minerals, which though commonly display characteristic green or dark-blue colors (rather than the usual black). Rocks near the silica saturation boundary may contain only small amounts of either quartz or feldspathoid (e.g., nepheline), which therefore can be difficult to observe.

Granitic rocks, which form a large group of common felsic plutonic rocks can also be subdivided into four broad genetic groups, based on their mineralogy – see table below.

Whereas deep-seated felsic plutonic rocks are typically coarse-grained and equigranular, shallow level felsic dykes are porphyritic, with quartz and/or feldspar phenocrysts in a very fine-grained felsic matrix – these are commonly termed ‘*quartz-feldspar porphyry dykes*’ (QFP). Specific examples of felsic plutonic rocks also include very coarse-grained *pegmatites* and fine-grained *aplites*, the latter characterized by a ‘sugary’ texture and usually being of a paler color than their host (i.e., whitish or pinkish).

To finish, one shall mention the existence of other, less common types of plutonic igneous rocks, such as *carbonatites* (intrusive dykes and plugs with >50% carbonate minerals), *lamprophyres* (medium-grained, dark, porphyritic rocks with phenocrysts of biotite and/or amphibole in a groundmass of feldspars and/or feldspathoids), and *kimberlites* (fragmental rocks, possessing a characteristic variety of polymictic xenolithic inclusions, such as olivine, pyroxene, red garnet, spinel, and phlogopite megacrysts, typically contained in a dark green matrix).

Field classification of granitic (plutonic) rocks



Some field characteristics of the four major ‘alphabet’ types* of granitoids:

	I-type	S-type	A-type	M-type
Rock type	tonalite to granite	granodiorite to granite	granite	tonalite (rare !)
Mafic minerals	amphibole (hornblende) biotite	muscovite biotite (sometimes two-mica granites)	Na-amphibole Na-pyroxene green biotite	hornblende biotite clinopyroxene
Accessory minerals	titanite allanite	garnet cordierite topaz corundum (Al-rich minerals) tourmaline monazite	fluorite pyrochlore tourmaline	
Oxides	magnetite	ilmenite	magnetite	magnetite
Feldspars	K-spar and plagioclase (subsolvus)	K-spar and plagioclase (subsolvus)	perthite (hypersolvus)	plagioclase and very little alkali feldspar
Restite/enclaves	amphibolite diorite gabbro	biotite-cordierite sillimanite-garnet gneiss (common xenoliths and schlieren of metapelites)	few	hornblende-rich
Genesis	melting of mafic igneous rocks (large input of mantle / lower crust derived magma)	partial melting of metasedimentary rocks (large component of continental crust) followed by fractional crystallization	direct, high-T partial melting of dry source rocks (granulitic lower crust) with halogen volatile flux	fractional crystallization from high-T basaltic magmas or partial melting of subducted oceanic crust)
Mineralization	porphyry Cu-Mo-Au	aplite-pegmatite-greisen, polymetallic Sn-W-U-Mo-Cu and Be-B-Li-P	Sn-W-U-Mo and rare-metal (Nb-Ta) greisens + Zr, Hf, REE	

* see comment next page

Additional comments:

- (1) A medium-grained crystalline rock has an average grain size of 1-5 mm. A coarse-grained rock has an average grain size of > 5mm, and nearly all crystal boundaries can be distinguished with the naked eye.
- (2) Prefixes *leuco-*, *meso-*, and *mela-* (e.g., leucocratic/mesocratic/melanocratic) designate varieties of a rock type (e.g., granite), with mafic mineral contents below average, average, and above average for the rock type in question.
- (3) When working on drill core, be aware of the scale – you could be looking at a very large xenolith/enclave. First look at the broader picture !

* In the opinion of eminent granite specialist, Prof. D.Barrie Clarke, the ‘alphabet’ classification of granites is actually inconsistent and mixes classification criteria: not all the letters have the same connotation at the initial level of classification; post-magmatic processes can cause the crossing of these classification boundaries; the Earth’s crust is too heterogenous to be exclusively “I” or “S”; and the nature & composition of the granite source is the parameter we know least about, therefore it is the one least suitable for classification purposes [cf. D.B. Clarke “Granitoid Rocks”, Chapman & Hall 1992, p.14; see also “A geochemical classification for granitic rocks” by Frost et al., *Journal of Petrology* v.42, n.11, p.2033-2048, 2001]. Instead, Prof. Clarke recommends to use Barbarin’s ‘geochemical’ classification, which relates granite composition to plate tectonic environment (*Lithos* 46, p.605-626, 1999), summarized below in the key figures from this paper:

- MPG** – Muscovite-rich peraluminous leucogranites & two-mica granites (abundant, large flakes of primary zoned muscovite ± tourmaline, garnet, monazite, etc.);
- CPG** – Cordierite-bearing peraluminous granites and granodiorites (cordierite, biotite ± sillimanite, andalusite, minor muscovite ± tourmaline, garnet, monazite, etc.);
- ACG** – Amphibole-bearing calc-alkaline (low K high Ca) granodiorites and tonalites (abundant calcic amphibole and titanite ± pyroxene);
- KCG** – K-rich calc-alkaline (high K low Ca) granites and granodiorites (rare amphibole, no pyroxene, some titanite);
- RTG** – Mid-ocean Ridge tholeiitic plagiogranites / trondhjemites / tonalites / gabbros (amphibole-rich and pyroxene-bearing);
- PAG** – Peralkaline and alkaline (perthitic alkali feldspar) granites to syenites (these host sodic amphiboles and pyroxenes).

MINERALS	MPG	CPG	KCG	ACG	RTG	PAG
Biotite	x	x x x	x x x	x x	x	x x
Muscovite	x x x	x	x	o	o	x
Cordierite	o	x x	o	o	o	o
Sill.-And.	o	x	o	o	o	o
Amphibole	o	o	x	x x x	x x x	alk. amph.
Pyroxene	o	o	o	x x	x x	alk. pyr.
Apatite	x x x	x x x	x x	x x	x x	x x
Zircon	x	x x	x x x	x x x	x x x	x x x
Monazite	x	x	o	o	o	o
Garnet	x x	x	o	o	o	x
Tourmaline	x x x	x x	o	o	o	o
Allanite	o	x	x x	x x	x	x x
Titanite	o	o	x x	x x x	x	x
Ilmenite	x	x	x	x	x	x x
Magnetite	o	o	x	x x	x x	x x
Plag.-An%	0 - 20	15 - 40	15 - 30	20 - 50	20 - 50	0 - 10

(o : absent; x : rare; xx : common; xxx : abundant)

Fig. 1. Principal mineral assemblages (A), field and petrographical (B), major elements and isotopes (C) features of the main types of granitoid. (M.E.: microgranular enclaves).

PETROGRAPHY	MPG	CPG	KCG	ACG	RTG	PAG
Petrographic types	Leucogranites (Granites)	(Leucogranites) Granites Granodiorites (Qz diorites)	(Leucogranites) Granites Granodiorites Qz diorites	(Granites) Granodiorites Tonalites Gabbros	Plagiogranites Trondjemites Tonalites Gabbros	Alk. granites Alk. syenites Syenites Granites (Gabbros) (Anorthosites)
Associated rocks						
Metamorphic	o	Migmatites Anatexites	o	o	o	o
Volcanic	o	o	Acid lavas ("Tuffs") Qz diorites Gabbros (Appinites)	Andesites & Dacites Gabbros (in large amounts)	Olivine-bearing Tholeites Gabbros (in large amounts)	Alkaline lavas Gabbros (in large amounts)
Mafic	o	Qz diorites (Vaugnerites)				
Enclaves						
Xenoliths	x	o - x	x	x	x	x
Restites	x	x x x	x	o	o	o
Felsic M. E.	x	o - x	x	x	x	x
Mafic M. E.	o	x	x x	x x x	x x x	x
(o : absent; x : rare; xx : common; xxx : abundant)						
Differentiation processes	fractional crystallization	fractional crystallization or restite unmixing	fractional crystallization and magma mixing	strong fractional crystallization and magma mixing	extreme fractional crystallization	extreme fractional crystallization and subsidiolus interactions

CHEMISTRY	MPG	CPG	KCG	ACG	RTG	PAG
Alumina Index	A ≥ CNK		CNK > A > NK			A ≤ NK
A / KCN (molar)	≥ 1		< 1			alkaline
Al ₂ O ₃	x x x	x x x	x x	x x	x x	x
CaO	x	x	x x	x x x	x x	x
Na ₂ O	x x	x x	x x	x x	x x x	x x x
K ₂ O	x x	x x x	x x x	x x	x	x x x
FeOt+MgO+MnO	x	x x	x x	x x x	x x	x x
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	x	x	x x	x x x	x x x	x x
FeOt/(FeOt+MgO)	< 0.8	< 0.8	0.8 - 1.0	< 0.8	> 0.8	> 0.8
⁸⁷ Sr / ⁸⁶ Sr	.706 to .760	> .708	.706 to .712	.706 to .708	≤ .704	.704 to .712
ε _{Nd}	- 4 to -17	- 6 to - 9	- 4 to - 9		-	-
δ ¹⁸ O (‰)	+ 10 to +14	+ 10 to + 13	+ 5 to + 10		-	-
δ ³⁴ S (‰)	- 12 to + 2		+ 5 to + 20		-	-

(x : low; xx : medium; xxx : high)

GRANITOID TYPES WITH DISTINCTIVE MINERALS

MPG (muscovite ± bt)	CPG (bt-rich ± cordierite)	KCG (K-fd mc ± Ca-amp)	ACG + ATG (Ca-amp ± Ca-px)	RTG (amp + px)	PAG (Na-amp ± Na-px)
CRUSTAL AND MANTLE CONTRIBUTIONS					
CRUSTAL CONTRIBUTION			MANTLE CONTRIBUTION		

Fig. 2. Schematic diagram showing the various granitoid types, their AFM mineral assemblages, and the proportions of mantle and crustal components in each of them. (bt: biotite; K-fd mc: K-feldspath megacryst; amp: amphibole; px: pyroxene).

• VOLCANIC IGNEOUS ROCKS

Volcanic (extrusive) rocks are those which crystallized at or near the surface of the Earth, and owing to their fast cooling rate are relatively fine-grained and have compositions approximating those of the melts from which they formed. The texture of volcanic rocks can be quite varied and reflects the crystal content of the melt upon eruption and its subsequent cooling rate, which depends on the position of the rock within the unit, as well as on the environment (i.e., sub-aerial versus submarine, the latter causing a much faster cooling). As a shallow emplacement of the magma involves a marked decrease of the confining pressure, magma degassing takes place leading to the formation of gas vesicles within the lava flows. These vesicles are initially empty (gas-filled), but can subsequently be filled with minerals such as calcite or zeolites and are then referred to as 'amygdules' (filled vesicles). Note that mafic magmas are hotter and have less volatiles, and therefore have a much lower viscosity than felsic magmas, which quickly 'freeze' (solidify) upon degassing. Consequently, it is much easier for mafic magmas to ascend to shallower crustal levels and extrude on the surface of the Earth, and so mafic-intermediate volcanic rocks are much more common than their felsic counterparts. As mafic (basaltic) lavas are typically very fluid, the eruption style and the textures they form upon cooling are also very distinct.

The description of volcanic rocks in the field should always start by establishing the broader volcanic context we are looking at, as well as where the rock sample in question is located within this specific cooling unit. Possibly the first question to answer (as per the generalized descriptive classification diagram that follows) is whether we are looking at *fragmental volcanics*, i.e., the products of explosive volcanic activity or 'quieter' *massive lava flows*. The latter display specific styles, reflecting the lava composition and the cooling environment. (Note that faster cooling results in a smaller grain size of the rock, which upon extremely fast quenching can form glass). For example, *pillow-lavas* are the product of submarine eruptions of basaltic lavas, which got rapidly quenched in cold water and formed flow units with characteristic 'pillow' shapes. The broad size of these pillows increases towards the vent from which they erupted, and when looking at an entire flow unit (not at a single pillow, which may have been overturned), their shape clearly indicates the upward side of the flow: the top of the pillows is nicely rounded, whereas its bottom is deformed, because of sagging down into a topographic low, where it develops a narrower 'toe'. Pillow-lavas are generally not rich in vesicles, because the confining water pressure holds the gases in the lava. Young pillow lava

flows, which have not subsequently recrystallized commonly have a red/orange outer margin, due to the weathering of volcanic glass present on their outer margin. Older pillow lava flows can be extremely tectonized and their primary mineralogy has commonly been replaced by greenschist facies metamorphic minerals.

In contrast to the latter, sub-aerial basaltic lava flows look different: depending on the viscosity of the lava, they can either have a '*ropy*' top (pahoehoe) or a *breccia top* (AA). The outer surface of '*ropy*' top lava flows generally cooled quickly to produce volcanic glass, but their interior is holocrystalline. The distribution of the grain size within the rock and the character of the vesicles can tell us which part of the unit represents the top, interior, and bottom of a particular flow (which commonly was covered by a succession of subsequent lava flows). The base of the flow can display 'pipe'-like gas vesicles, which managed to nucleate and partly rise upwards, but soon solidified, due to faster cooling of the rock near the bottom of the flow. The interior of the lava flow is generally massive (lacks vesicles), as upon eruption it was still liquid and the volatiles escaped upwards. Conversely, the upper part of a lava flow contains larger, coarser vesicles, which formed by coalescence of a number of vesicles, but these markedly decrease in size towards the top of the flow, becoming very fine, as the faster cooling of the top of the flow hampered their development.

In the case of more viscous basaltic lavas, their tops tend to solidify more rapidly, while their interior is still molten and is still flowing, which causes widespread brecciation of the solidified flow top, typical of *breccia top* (AA) lava flows. Here, the interior of the flow is massive, but its top is composed of a layer of a very coarse monomictic breccia (i.e., all the fragments are the same volcanic rock), which forms a very irregular, rough surface, that would be very difficult to cross barefoot ('Aa !' - I guess this is the experience that led to the naming of the flow style...). These commonly form sequences of flows, the tops of which are highlighted by breccia, and bottoms – by chilled margins. As is common for sub-aerial flows, the top of the flow typically weathers red, due to oxidation of Fe-rich minerals exposed to the atmospheric conditions, whereas the interior remains black or grey. Thus, a succession of alternating red and grey/black volcanic strata is quite characteristic of multiple sub-aerial lava flows. Occasionally, it is also possible to observe in the field a transition from pillow lavas to layered volcanics with red weathering horizons – these indicate a transition from submarine to sub-aerial volcanism.

In contrast to mafic melts, which typically form lava flows, the more felsic melts are more silica- and volatile-rich, therefore more viscous, and the bulk of them are involved in explosive volcanism, producing fragmental volcanic rocks. Rapidly cooled felsic lavas can produce *obsidian* – a black volcanic glass, which is translucent in thin shards. (Obsidian is so dark, despite its felsic composition, because it is glass – a quenched liquid. Note that large chunks of dark glass are nearly always rhyolite, and the outside of basaltic volcanics is only rimmed by a thin layer of glass). Another feature typical of felsic volcanics are *spherulites* – spheroidal aggregates of radiating quartz and/or feldspar, which occasionally line up to form flow banding. Here note, that the only lavas to exhibit flow banding are felsic, e.g., ‘banded rhyolites’, and this banding is typically preserved even upon the recrystallization of the rock. (Mafic/intermediate lavas lack flow banding).

Felsic volcanics, such as shallow-level felsic dykes and sills are commonly porphyritic, and contain euhedral phenocrysts of quartz and/or feldspar in a fine-grained felsic matrix (these are termed ‘QFP dykes’, i.e., quartz-feldspar porphyry rhyolite dykes, but the proper naming would be ‘quartz-feldspar-phyric rhyolite’). Note that amphibole is commonly a phenocryst phase in mafic dykes, but is rare in mafic volcanic rocks (Francis, 2001). High-level dykes and sills are typically fine-grained and can be distinguished from the massive portions of thick flows by their symmetric quenched margins, as opposed to the thick upper quench and thin lower quench zones of flows (Francis, 2001).

The classification of fragmental volcanic rocks is based on their grain size, matrix-versus clast-support, sorting, presence of layering or grading, monomictic versus polymictic character, evidence of aerial/water/hot/cold emplacement, etc. First of all, fragmental volcanic rocks are divided into coarse-grained (i.e., with fragments >64 mm) and fine-grained (<64 mm), i.e., tuffs - see simplified classification diagram below. Tuffs frequently exhibit layering and those deposited in water have a very fine lamination. Tuffs are composed of either *ash* (fragments <2 mm) or *lapilli* (fragments >2 mm), which consist of either crystals (*crystal tuff*), glass (*vitric tuff*), or fragments of volcanic rock (*lithic tuff*). Some *ignimbrites* are also fine-grained (<64 mm) – these welded tuffs have been deposited by ash flows that were so hot that the pumice/glass fragments behaved in a plastic fashion and after emplacement literally welded together, producing a hard and very compact rock, in which vertical flattening of the fragments (due to the overburden pressure) produced characteristic ‘*fiamme*’. Occasionally, alteration rims can be observed around the larger rock

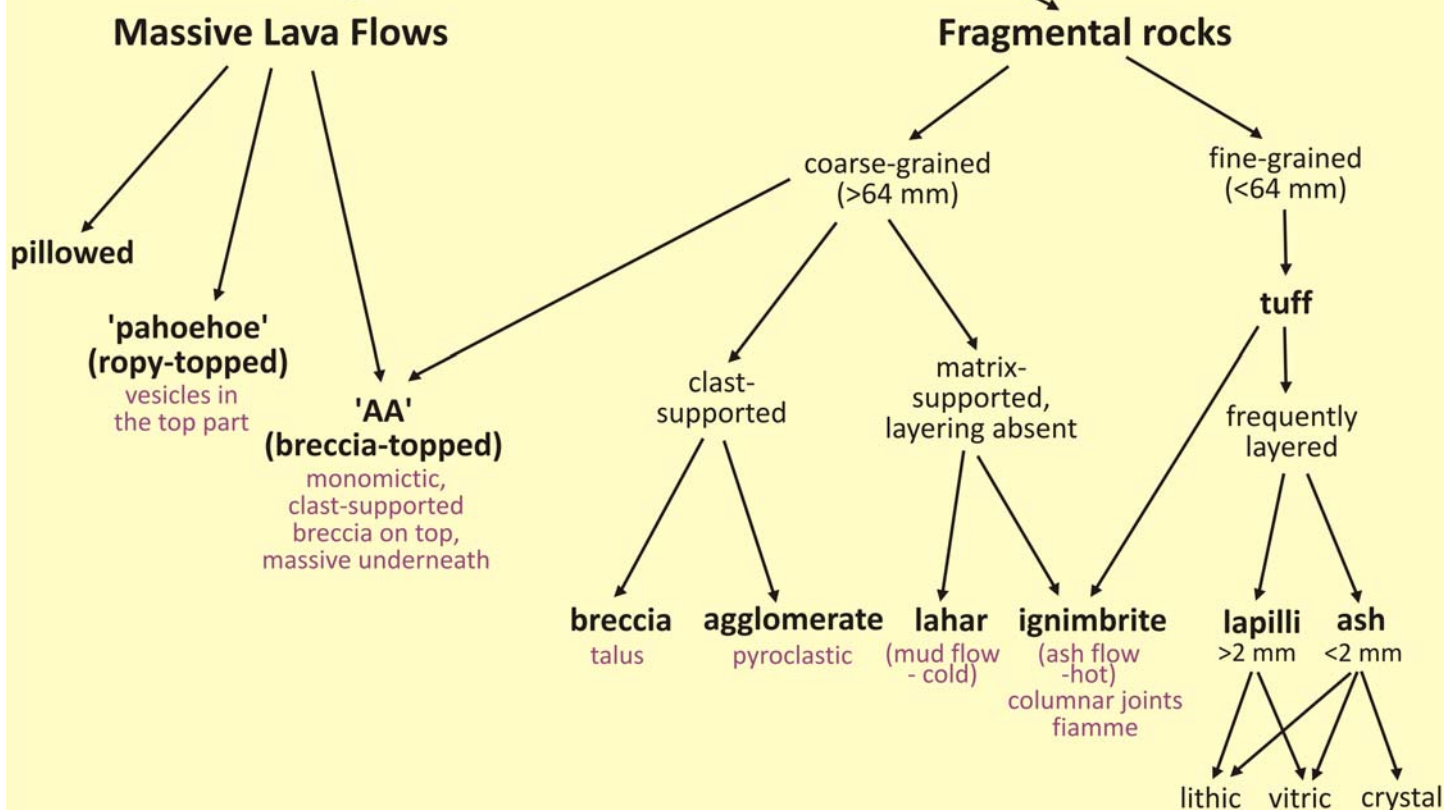
fragments. Ignimbrites may possess columnar joints but never have any layering, and their distal examples can be quite fine-grained. Note, however, that many *ash flow tuffs* are not welded and can only be recognized based on their lack of layering and/or poor sorting. *Air-fall tuffs* are deposited cold and may or may not be layered, whereas *water-lain tuffs* are typically well-layered and exhibit the best sorting (Francis, 2001).

Coarse-grained fragmental volcanic rocks (>64 mm) that are matrix-supported and lack layering include ignimbrites, as well as *lahars* (mud flows) which formed in a 'cold' environment and do not show any signs of heat/welding. Clast-supported coarse-grained fragmental rocks are subdivided into *agglomerates*, which have a pyroclastic nature, and *talus breccias*, which gravitationally accumulated at the base of a volcanic vent. Monomictic, clast-supported breccias occur also in the top part of AA-type lava flows.

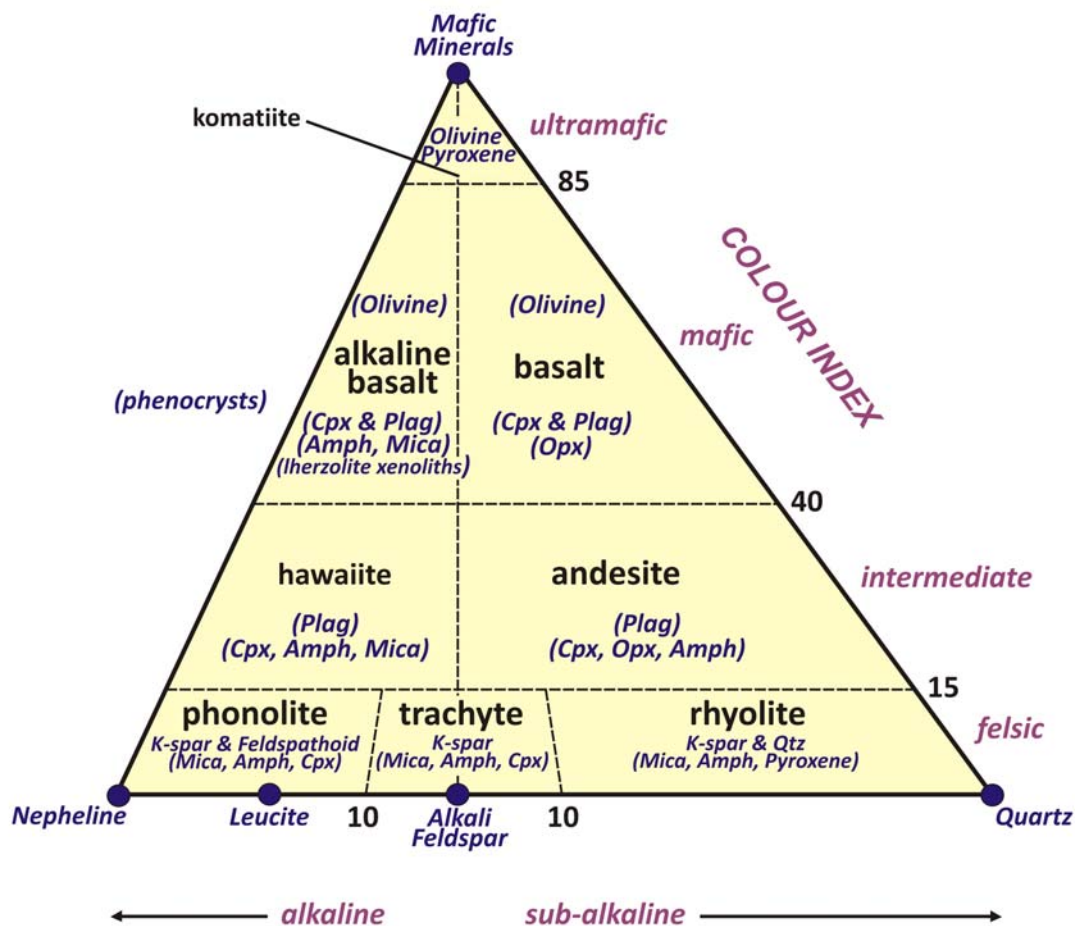
Once the nature of the volcanic unit examined and the location of the specific rock sample within the architecture of the cooling unit have been established, one can proceed to assign a preliminary name to the volcanic rock. This will have to be a tentative identification, as the classification of volcanic rocks is based on their chemical composition, and can be very difficult when they are altered, so at times using the general terms 'mafic volcanic'/'felsic volcanic' is all you can do. Francis (2001) proposed a simple field classification of volcanic rocks that is based on their colour index and the mineralogy of the phenocrysts observed in the rock (see below). Note that the colour index refers here to the colour of a crystalline rock (not glass), and that ultramafic volcanics, such as komatiite constitute an exception to this general trend: because of an abundance of Mg and paucity of Fe, they actually have a pale greenish colour. (The other characteristic feature of komatiite is its *spinifex* texture, best developed in the upper chilled margin of the lava flows, and consisting of a very platy/elongated habit of the quench-textured olivine crystals, which form needles that can be felt if you lick the rock. Komatiites are rare, essentially restricted to Archean greenstone belts, and commonly weather to a brown colour because of the abundance of olivine. They could be confused with andesite).

Regarding volcanic glass, even rhyolite glass appears black, so thin shards of the glass need to be examined against bright light: rhyolite glass is colorless and basaltic glass is brown. Also, if you are looking at a large chunk of glass it has to be rhyolite or phonolite, as it is difficult to quench silica-poor mafic magmas.

Volcanic Rocks



Field classification of volcanic rocks



The distinction of andesite from hawaiite is commonly problematic, hence the association of the 'intermediate-coloured rock' with other rocks is used: hawaiite is associated with silica-undersaturated rocks, as in fractionation trends the vertical divide line between alkaline (silica-undersaturated) and sub-alkaline rock fields cannot be crossed. In turn, alkaline basalts are typically darker in colour than associated sub-alkaline basalts, but can only be confirmed in the field if they contain spinel lherzolite xenoliths, i.e., olivine-rich enclaves (Francis, 2001). Note that nepheline phenocrysts are rarely observed in volcanics, so felsic volcanic types are tentatively assigned based on the igneous province and association with other rocks.

For the identification of the phenocryst mineralogy, the reader is referred to 'File note 03' but a general statement can be made that elongated mafic minerals possessing cleavage are most likely amphiboles, as clinopyroxenes in lavas tend to be equant and orthopyroxenes are very rare (only in boninites). On the other hand, dark micas are much softer. Mafic volcanics have abundant olivine phenocrysts (if only olivine is observed, the rock is basalt), as well as some clinopyroxenes and typically not too much plagioclase. On the other hand, andesites and hawaiites, which typically (but not always!) have a lighter-coloured matrix, are characterized by a dominance of plagioclase among the phenocrysts. (Here, a note of caution – andesites sometimes resemble greywackes!...) The presence of amphibole in a volcanic rock indicates a buildup of water, which can only take place in more felsic varieties of andesitic rocks. The presence of quartz phenocrysts is in turn typical of rhyolite.

The hardness of the volcanic rock matrix provides another useful identification feature: as a general rule, on scratching with a knife rhyolite is markedly harder than basalt (which can be scratched). Rhyolite also has a more conchoidal fracture than andesite, whose fracture is still more conchoidal than that of basalt. Last of all, remember that weathered felsic rocks are light-coloured as compared to mafic/intermediate rocks (e.g., rhyolite weathers 'white').

For a 'definitive' reference on volcanic rocks, their classification and textures, the reader is referred to the excellent "Volcanic textures – a guide to the interpretation of textures in volcanic rocks" by J. McPhie, M. Doyle, and R. Allen (CODES University of Tasmania, 1993). In this book, the authors propose a descriptive terminology for volcanic rocks which is summarized below:

- For **MASSIVE VOLCANICS** (i.e., coherent lavas and intrusions), the naming sequence shall be:

(1) **Alteration** (e.g., pervasively chloritised / weakly silicified / patchily sericitized, etc.

(2) **Texture** (porphyritic – e.g., highly olivine-phyric / moderately amphibole-phyric / poorly quartz-phyric, etc., OR aphanitic (= uniformly microcrystalline) / aphyric (= no phenocrysts present) / glassy / vesicular / spherulitic, etc.

(3) **Lithofacies** (massive or flow banded / pillow-shaped / concentrically jointed, etc.)

(4) **Rock composition** – based on the phenocryst assemblage and for aphanitic rocks - on their colour (rhyolite/dacite/andesite/basalt, etc.).

e.g., sericitic, highly quartz-phyric, coarse, flow-banded rhyolite

moderately vesicular, poorly olivine-phyric, fine, columnar-jointed basalt

- For **FRAGMENTAL VOLCANICS** (i.e., volcaniclastics) the naming sequence shall be:

(1) **Alteration** (e.g., pervasively chloritised / weakly silicified / patchily sericitized, etc.

(2) **Lithofacies** (massive = non-bedded & non-graded OR stratified = bedded, e.g., laminated/thinly bedded/very thickly bedded, etc. OR normal-graded/reverse-graded AND clast-supported/matrix-supported/poorly sorted/well sorted, etc. AND/OR platy jointed/columnar jointed/blocky jointed, etc.

(3) **Components** (crystal-rich/lithic-rich/lapilli-rich/vitriclast-bearing/fiamme-bearing/shard-rich/pumiceous/scoriaceous/siliceous/carbonate-cemented, etc.

(4) **Grain size** – mud/mudstone (<0.06 mm) OR sand/sandstone (0.06-2 mm) OR gravel / conglomerate OR breccia.

e.g., chloritic-pyritic, very thickly bedded, volcanic lithic breccia

thinly interbedded, shard-rich mudstone

(after McPhie et al., 1993)



Picture on left – agglomerate unit from Serbia's Timok zone (MM).

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