Benha university
Faculty of science
Geology Dept.

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Post graduated exam
Structural geology and tectonics
Igneous and Metamorphic Petrology (613G)
Time: Three Hours

Model answer of the Examination of Igneous and Metamorphic petrology (613G) for the Post graduated students (Structural geology and tectonics), Jan. 2017.

Igneous Petrology

Answer the following questions:

1- **Write short notes on the following:** (Each points 20 Marks)

a) Classification of mafic and ultramafic rocks

Gabbroic rocks (plagioclase + mafics) and ultramafic rocks (with over 90% mafics) are classified using separate diagrams (Figures). As with any classification, the IUGS subcommittee has had to find a delicate balance between the tendencies for splitting and lumping. The same is true for us. Whereas the IUGS must serve the professional community and guide terminology for professional communication, we must find a classification suitable for more common use in student petrology laboratories.

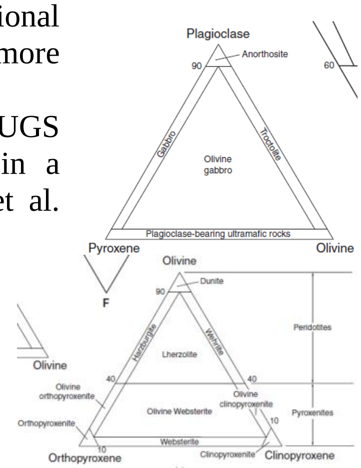
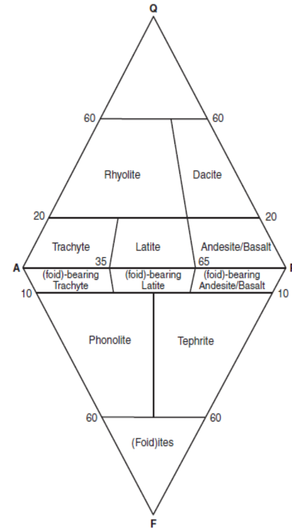


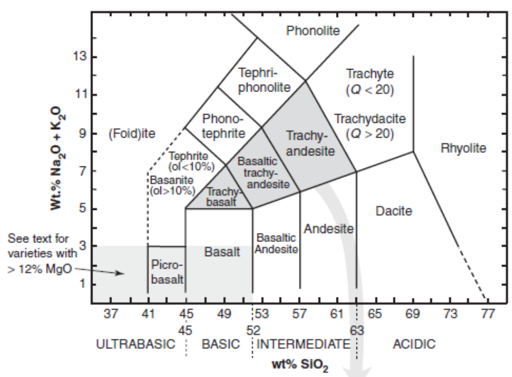
Figure 2b for gabbroic rocks is simplified from the IUGS recommendations. When one can distinguish pyroxenes in a gabbro, there is more specific terminology in Le Maitre et al. (2002) (e.g., an orthopyroxene gabbro is called a norite). Figure 2c is more faithful to the IUGS recommendations. In hand specimen work, it may be difficult to distinguish ortho from clinopyroxene in black igneous rocks. Hence the terms peridotite and pyroxenite are commonly used for ultramafics because they are independent of pyroxene type. When the distinction can be made, the more specific terms in Figure 2c are preferred. The presence of over 5% hornblende further complicates the nomenclature of both mafic and ultramafic rocks. I believe that the IUGS distinction between an olivine-pyroxene hornblendite, an olivine-hornblende pyroxenite, and a pyroxenehornblende peridotite adds more detail than necessary at this point. The student is referred to the complete IUGS classification (Le Maitre et al., 2002) for proper names if it becomes important to make more detailed distinctions in nomenclature.

b) Aphanitic rocks



Volcanic rocks for which a mineral mode can be determined are treated in the same way as plutonics in the original IUGS classification. One determines the mode, normalizes to find P, A, and Q or F, and plots the result in Figure 3, in a manner identical to that described for Figure 2. Because the mode is commonly difficult to determine accurately for volcanics,

Figure 3 is a simplification, modified from the more detailed diagram published by the IUGS (Le Maitre et al., 2002). The matrix of many volcanics is composed of minerals of extremely fine grain size and may even consist of a considerable proportion of **vitreous** (glassy) or amorphous material. Thus it is commonly impossible, even in thin section, to determine a representative mineralogical mode. If it is impossible to recognize the mineralogy of the matrix, a mode must be based on phenocrysts. The IUGS recommends that rocks identified in such a manner be called **phenotypes** and have the prefix *pheno-* inserted before the name (e.g., pheno-latite). As we shall soon see, minerals crystallize from a melt in a sequence (as indicated by, but certainly not restricted to, Bowen's Series), so the first minerals to crystallize do not necessarily represent the mineralogy of the rock as a whole. If based on phenocrysts, the position of a rock on Figure 3 will be biased toward the early-forming phases and usually erroneous for the rock as a whole.



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

Again, **rocks that plot near P** in Figure 3 present a problem in the volcanic classification, just as in the plutonic one. One cannot distinguish andesite from basalt using Figure 3. The IUGS recommends a distinction based on color index or silica content (see below) and not on plagioclase composition. An andesite is defined as a plagioclase-rich rock either with a color index below 35% or with greater than 52% SiO2. Basalt has a color index greater than 35% and has less than 52% SiO2. Many andesites defined on color index or silica content have plagioclases of composition An65 or gr eater. The most reliable way to avoid the matrix problem discussed above is to analyze the volcanic rock chemically and use a classification scheme based on the analytical results (as is implicit using % SiO2 in the IUGS distinction between andesite and basalt discussed above). The IUGS has subsequently recommended a classification of volcanics based on a simple diagram comparing the total alkalis with silica, also called a "TAS" diagram (Le Bas et al., 1986). The diagram (Figure 4) requires a chemical analysis and is divided into 15 fields. To use it, we normalize a chemical analysis of a volcanic to a 100% nonvolatile basis, combine Na2O + K2O, and plot the total against SiO2. Results are generally consistent with the QAPF diagram when a good mode is available. The shaded fields in the TAS diagram can be further subdivided by considering the concentrations of Na2O and K2O indepen - dently, if desired, according to the lower box. Further refinements are presented for Mg-rich volcanics, and the IUGS (Le Maitre et al., 2002) recommends the name *picrite* for volcanics containing less than 3% alkalis and 12 to 18% MgO and *komatiite* (TiO2 < 1%) or *meimechite* (TiO2 > 1%) for volcanics with similar alkali content but richer in MgO. The term *boninite* is recommended for an andesite or basaltic andesite with more than 8% MgO and less than 0.5% TiO2. The diagrams shown in Figures 2 to

4 provide you with the names of most common igneous rocks, but a number of important rock types classified by the IUGS are not included in the figures. For instance, the classification shown does not cover any **hypabyssal** (shallow intrusive) rocks such as **diabase** (or **dolerite** in Britain), nor does it cover the less common rock types such as **carbonatites** (igneous carbonates), **lamproites/lamprophyres**, (highly alkaline, volatile rich mafic flow/dike rocks), **spilites** (sodic basalts), or **keratophyres** (sodic intermediate volcanics), etc.

Highly alkaline rocks, particularly those of continental origin, are varied, both mineralogically and chemically. The composition of highly alkaline rocks ranges to high concentrations of several elements present in only trace amounts in more common igneous rocks. The great variety results in a similarly complex nomenclature. Although these alkaline rocks comprise less than 1% of igneous rocks, fully half of the formal igneous rock names apply to them. I have tried to avoid the cumbersome detail that a comprehensive classification requires and have attempted to provide a useful compromise between completeness and practicality.

c) Textures of igneous rocks

TABLE 1 Common Igneous Textural Terms

Crystallinity	
Holocrystalline	Consisting entirely of crystals (default term, not commonly used).
Hypocrystalline	Containing both crystals and glass.
Holohyaline, vitric	Consisting entirely of glass.
Grain Size	
Aphanitic	Having minerals too fine grained to see with the naked eye.
Phaneritic	Having minerals coarse enough to see with the naked eye.
Cryptocrystalline	Having minerals too fine grained to distinguish microscopically.
Fine grained	Having an average crystal diameter less than 1 mm.
Medium grained	Having an average crystal diameter 1–5 mm.
Coarse grained	Having an average crystal diameter greater than 5 mm.
Very Coarse Grained	Having an average crystal diameter greater than 50 mm.
Pegmatitic	Being very coarse grained (historically associated with very coarse granitoid rocks: pegmatites).
Saccharoidal	Being fine- to medium-grained xenomorphic and equigranular (looking like sugar).
Aplitic	A synonym for saccharoidal, but typically restricted to leucocratic granitoid rocks.
Equigranular	Having grains that are all approximately the same size.
Inequigranular	Having grains that vary considerably in size.
Porphyritic Textures	
Porphyritic	Having approximately bimodal size distribution (usually requires a great difference).
Megaporphyritic	Having a porphyritic texture that can be seen in hand specimen (rarely used).
Microporphyritic	Having a porphyritic texture that is visible only under the microscope.
Phyric (-phyric)	An adjective (or suffix) referring to porphyritic texture.

TABLE 1 (Continued)	
Textures of Mafic Igneous Rocks	
Ophitic	Having large pyroxene grains enclosing small, random plagioclase laths (Figure 8).
Subophitic	Having plagioclase laths that are larger and only partially enclosed by the pyroxene.
Nesophitic	Having a plagioclase that is larger, with interstitial pyroxenes.
Intergranular	Having small, discrete grains of pyroxene, olivine, etc., filling the interstices in a random network of larger plagioclase laths (Figure 15).
Intersertal	Having glass, cryptocrystalline material, or alteration products occupying the spaces between plagioclase laths.
Hyalo-ophitic	Having an intersertal texture in which a larger amount of glass is present than pyroxene.
Hyalopilitic	Having a large amount of glass, with plagioclase occurring only as tiny, random microlites.
Diktytaxitic	The texture of certain volcanics in which bounding crystals protrude into abundant angular interstitial gas cavities.
Cumulate	Displaying interstitial growth of a mineral between earlier ones that are all in contact and give the distinct impression that they accumulated at the bottom of a magma chamber (Figure 14).
Orthocumulate	Having cumulate texture, with other minerals occupying the interstitial areas (Figure 14b).
Adcumulate	Having cumulate texture in which the early cumulate minerals grow to fill the pore space (Figure 14c).
Mesocumulate	Having a texture that is intermediate between ortho- and adcumulate.
Replacement Textures	
Pseudomorph	A replacement texture in which one or more minerals replace another, retaining the form of the original mineral.
Symplectite	A replacement texture in which a mineral is replaced by an intergrowth of one or more minerals.
Specific Mineral Replacements	
Uralitization	Replacement of pyroxene by amphibole (Figure 21a).
Saussuritization	Replacement of plagioclase by epidote.
Biotitization	Replacement of pyroxene or amphibole by biotite.
Chloritization	Replacement of any mafic mineral by chlorite (Figure 20b).
Seritization	Replacement of feldspar or feldspathoids by fine white micas.
Miscellaneous Terms	
Interstitial	Having one mineral filling the interstices between earlier crystallized grains (Figure 7).
Crystallites	Minute, inchoate crystals in the earliest stages of formation. They are isotropic and cannot be identified under the microscope.
Microlites	Tiny needle- or lath-like crystals of which at least some properties are microscopically determinable.
Felty	Consisting of random microlites (Figure 13b).
Pilotaxitic	A synonym for felty.
Trachytic	Consisting of (feldspar) microlites aligned due to flow (Figure 12a).
Embayed	Having embayments due to reaction with the melt (resorption) (Figure 2).
Skeletal	Having crystals that grew as, or have been corroded to, a skeletal framework with a high proportion of internal voids (Figure 4).
Sieve	Crystals filled with channelways (appearing as holes) due to resorption (Figure 11a).
Epitactic	Oriented nucleation of one mineral on another of a different kind.
Rapakivi	Overgrowths of plagioclase on alkali feldspar.
Vesicular	Containing gas bubbles.
Scoriaceous	Highly vesicular.
Pumiceous	Having a frothy vesicular structure characteristic of pumice.
Miarolitic	Having gas cavities into which euhedral minerals protrude. Applies to certain plutonic rocks.
Pipe vesicles	Tubelike elongate vesicles that result from rising gases.
Vesicular pipes	Cylindrical bodies that are highly charged with vesicles.

Metamorphic Petrology

1- Write short notes about the following: (Each points 20 Marks)

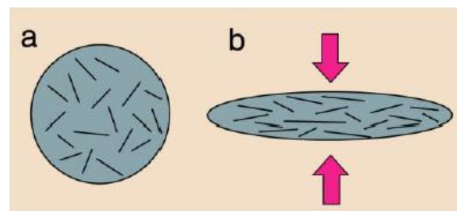
(a) Contact metamorphism of argillaceous rocks

Argillaceous rocks which have undergone metamorphism are referred to as Pelites
• Low Grade – Spotted Rock
• Medium Grade – Chiastolite Rock
• High Grade – Hornfels

Argillaceous rocks undergo most change as they are composed of chemically complex clay minerals such as kaolinite, illite, smectite, bentonite and montmorillianite.
Increased temperature to 300 – 400 degrees centigrade.
Partial recrystallization occurs

New minerals occur as oval spots 2 – 5mm in diameter. Cordierite or iron oxides
Spots show sieve or poikiloblastic texture Spots have overgrown and included grains of the original argillaceous rock
Relic structures such as bedding/lamination and fossils may be evident
• Increase in temperature to 400 – 500 degrees centigrade, results in coarser grained rock
• Extensive recrystallization occurs
• Needles of chiastolite develop and show porphyroblastic texture. Up to 2cm long, 3mm in diameter, square cross section often with iron inclusions. Groundmass is mainly micas
• Needles show random orientation, having crystallised in the absence of pressure
• No relic structures are evident
• Increase in temperature 500–600 degrees centigrade, results in grain size >2mm
• Hornfels shows hornfelsic texture-a tough, fibrous and splintery-looking rock with a crystalline texture
• Andalusite often occurs as porphyroblasts
• No evidence of any relic structures

(b) Deviatoric Stress
Only when the pressure is unequal in various directions will a rock be deformed. Unequal pressure is usually called deviatoric stress (whereas lithostatic pressure is uniform stress).



Stress is an applied force acting on a rock (over a particular cross-sectional area)
Strain is the response of the rock to an applied stress (= yielding or deformation)
Deviatoric stress can be maintained only if application keeps pace with the tendency of the rock to yield
This occur most often in orogenic belts, extending rifts, or in shear zones. (i.e. generally at or near plate boundaries)
Deviatoric stress affects the textures and structures, but not the equilibrium mineral assemblage
• We can envision deviatoric stress as being resolvable into three mutually perpendicular stress (s) components:

s_1 is the maximum principal stress
s_2 is an intermediate principal stress
s_3 is the minimum principal stress
• In hydrostatic situations all three are equal
• Foliation is a common result, which allows us to estimate the orientation of s_1
• $s_1 > s_2 = s_3$ □ foliation and no lineation
• $s_1 = s_2 > s_3$ □ lineation and no foliation
• $s_1 > s_2 > s_3$ □ both foliation and lineation

(c) Foliated and non-foliated metamorphic rocks

1. FOLIATED ROCKS
In general, foliations in non-high-strain rocks are caused by orogeny and regional metamorphism, and the type of foliation varies with metamorphic grade. In order of increasing grade, they are: *Cleavage*. Traditionally: the property of a rock to split along a regular set of subparallel, closely spaced planes.
A more general concept adopted by some geologists is to consider cleavage to be any type of foliation in which the aligned platy phyllosilicates are too fine grained to see individually with the unaided eye.
Schistosity. A preferred orientation of inequaint mineral grains or grain aggregates produced by metamorphic processes.
Aligned minerals are coarse grained enough to see with the unaided eye. The orientation is generally planar, but linear orientations are not excluded.

Gneissose structure. Either a poorly developed schistosity or segregation into layers by metamorphic processes. Gneissose rocks are generally coarse grained.

The rock names that follow from these textures are given below. Again, these names are listed in a sequence that generally corresponds with increasing grade:

Slate. A compact, very fine-grained, metamorphic rock with a well-developed cleavage. Freshly cleaved surfaces are dull. Slates look like shales, but have a more ceramic ring when struck with a hammer.

Phyllite. A rock with a schistosity in which very fine phyllosilicates (sericite/phengite and/or chlorite), although rarely coarse enough to see unaided, impart a silky sheen to the foliation surface. Phyllites with both a foliation and lineation (typically crenulated fold axes) are very common.

Schist. A metamorphic rock exhibiting a schistosity. By this definition, schist is a broad term, and slates and phyllites are also types of schists. The more specific terms, however, are preferable. In common usage, schists are restricted to those metamorphic rocks in which the foliated minerals are coarse enough to see easily in hand specimen.

Gneiss. A metamorphic rock displaying gneissose structure. Gneisses are typically layered (also called banded), generally with alternating felsic and darker mineral layers.

Gneisses may also be lineated, but must also show segregations of felsic-mineral-rich and dark-mineral-rich concentrations.

Gneissic layers or concentrations need not be laterally continuous.

2. NON-FOLIATED ROCKS

This category is simpler than the previous one.

Again, this discussion and classification applies only to rocks that are not produced by high-strain metamorphism.

A comprehensive term for any isotropic rock (a rock with no preferred orientation) is a granofels. Granofels(ic) texture is then a texture characterized by a lack of preferred orientation.

An outdated alternative is *granulite*, but this term is now used to denote very high-grade rocks (whether foliated or not) and is not endorsed here as a synonym for granofels.

A hornfels is a type of granofels that is typically very fine grained and compact, and it occurs in contact aureoles.