

LABS 1, 2 and 3

LABORATORY ETIQUETTE

1. Swapping between lab sections is not permitted, except for serious reasons like medical appointments and illness. Notify the TAs at least one week ahead of time if possible but no later than five working days after the missed lab.
2. Please be in the lab promptly at the beginning of the session. Announcements and explanations will occur at that time.
3. Print the lab description every lab session.
4. Before each laboratory session, read the introductory notes. The notes provide information that should be understood before the lab begins.
5. Do not remove any lab material from room 2110 HP. At the end of each lab, all materials must be returned to their correct places. Your work area must be left clean and tidy.

TEACHING ASSISTANT INFORMATION

Your TAs are:

Name: _____

Office location: _____

Telephone: _____

Email: _____

Name: _____

Office location: _____

Telephone: _____

Email: _____

Lab 1: PHYSICAL MINERALOGY

Equipment needed: Magnifying glass
Nail
Penny
Streak plate

Objective

The objective of this laboratory is to identify minerals by determining their physical properties and referring to mineral identification tables.

Introduction

A mineral is a naturally occurring inorganic solid having an orderly internal structure and characteristic chemical composition, crystal structure and physical properties. The physical properties of minerals reflect both their chemical composition and the manner in which their atoms are arranged in a geometric array called the crystal structure.

Diamond, for example, is a mineral. It is naturally formed. It is a solid. It is made of the chemical element carbon packed together in a regular geometric array. Graphite is also a mineral composed entirely of the element carbon. Graphite, however, has a different crystal structure and, as a result, exhibits different physical properties. The diamond structure consists of a three-dimensional framework of tetrahedra composed of a carbon atom surrounded by four others. The carbon atoms are held together by extremely strong covalent bonds resulting in the hardest natural substance on Earth. Graphite, on the other hand, consists of carbon atoms covalently bonded into sheets. These sheets are held together by weak van der Waals forces thus producing a very soft mineral. Coal is also composed largely of carbon, but coal is a rock. Coal contains many chemical compounds in addition to its carbon, and its composition varies from sample to sample. Nor does coal have a characteristic structure.

Physical properties of minerals

1. *Lustre*

The quality and intensity of light reflected from a mineral produce an effect known as lustre. Two minerals with almost identical colour can have quite different lustres. Lustre is either metallic or non-metallic. Metallic lustre gives the appearance of being made of metal. Non-metallic lustre is produced by reflection of light both from the surface and from within the mineral.

Terms describing lustre:

Lustre		Definition	Example
Metallic		Strong reflections produced by opaque minerals	Galena, pyrite
Non-metallic	Adamantine	Brilliant	Diamond
	Earthy or dull	Like the surface of unglazed pottery	Chlorite, hematite
	Greasy	As if the surface were covered by a film of oil	Graphite
	Pearly	Whitish iridescence like pearl	Talc
	Resinous	Like a sticky secretion	Sphalerite
	Silky	Sheen of fine fibrous aggregate similar to silk	Asbestos
	Vitreous	Bright and glassy	Quartz, feldspar

2. *Hardness*

The term “hardness” refers to the relative resistance of a mineral to scratching. Hardness is governed by the crystal structure and the strength of bonds between atoms. The stronger the bonding, the harder the mineral.

Relative hardness values can be assigned by determining the ease with which one mineral will scratch another. A scale called the Mohs’ hardness scale is divided into 10 steps, each marked by a common mineral. Mohs’ scale is not linear: the steps do not represent equal intervals of hardness. The important feature is that any mineral on the scale will scratch all minerals below it. For convenience, relative hardness is often tested by using a common object such as a penny or a steel penknife as the scratching instrument, or glass as the object to be scratched.

Mineral	Moh Hardness	Common Objects
Talc	1	
Gypsum	2	
Calcite	3	— Fingernail
Fluorite	4	— Copper coin
Apatite	5	
Orthoclase	6	— Knife blade
Quartz	7	— Window glass
Topaz	8	— Ceramic Plate
Corundum	9	
Diamond	10	

Table 1. Mohs' hardness scale

3. Colour

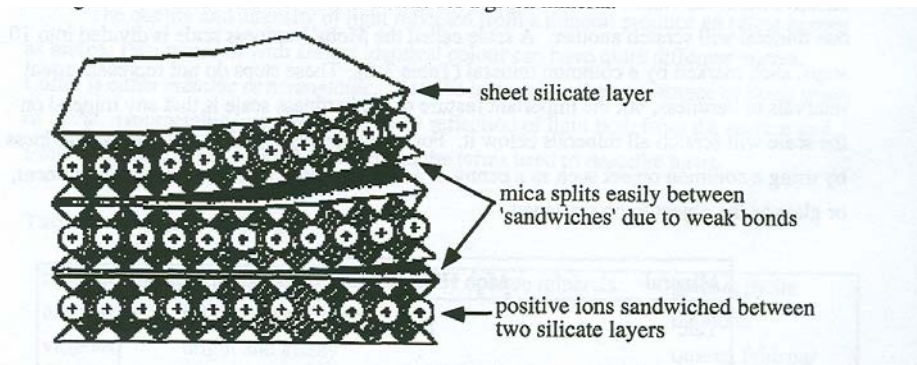
Colour may be a property of the pure substance or it may be due to impurities. As a result, while some minerals show a characteristic colour on fresh or weathered surfaces, most can be extremely variable in their colour. For example, quartz may be colourless and transparent, or because of minute chemical impurities, it may be white, pink, black, yellow or purple. Consequently, colour is not a reliable diagnostic property. It must be combined with observations of other properties to lead to a correct identification.

4. Streak

Streak is the powdered mineral produced by scratching a sharp corner across an unglazed white ceramic "streak plate". Each mineral has its own distinctive streak, relatively independent of the colour of the sample. Streak is most important in identifying opaque minerals; translucent and transparent minerals have a white or colourless streak.

5. Cleavage

Cleavage is the tendency of a mineral to break in directions controlled by its atomic structure. A mineral breaks along cleavage planes because the bonding between atoms is weaker there. Cleavage is characteristic for a given mineral. Mica, for example, splits easily into planes because the bonds between silicate layers are weak.



Simplified mica structure and its relationship to cleavage (McGeary and Plummer, 1994).

The atomic arrangement being repetitive, cleavage results in numerous parallel surfaces. Cleavage surfaces, however, are not crystal faces, but rather breakage surfaces within crystals that follow planes of weakness determined by atomic structure. Unlike crystal faces, which are found only on the surface, cleavage planes may be visible throughout the crystal.

Cleavage is described according to the number of different directions of cleavage and their relationship in space. A complete description of cleavage should include:

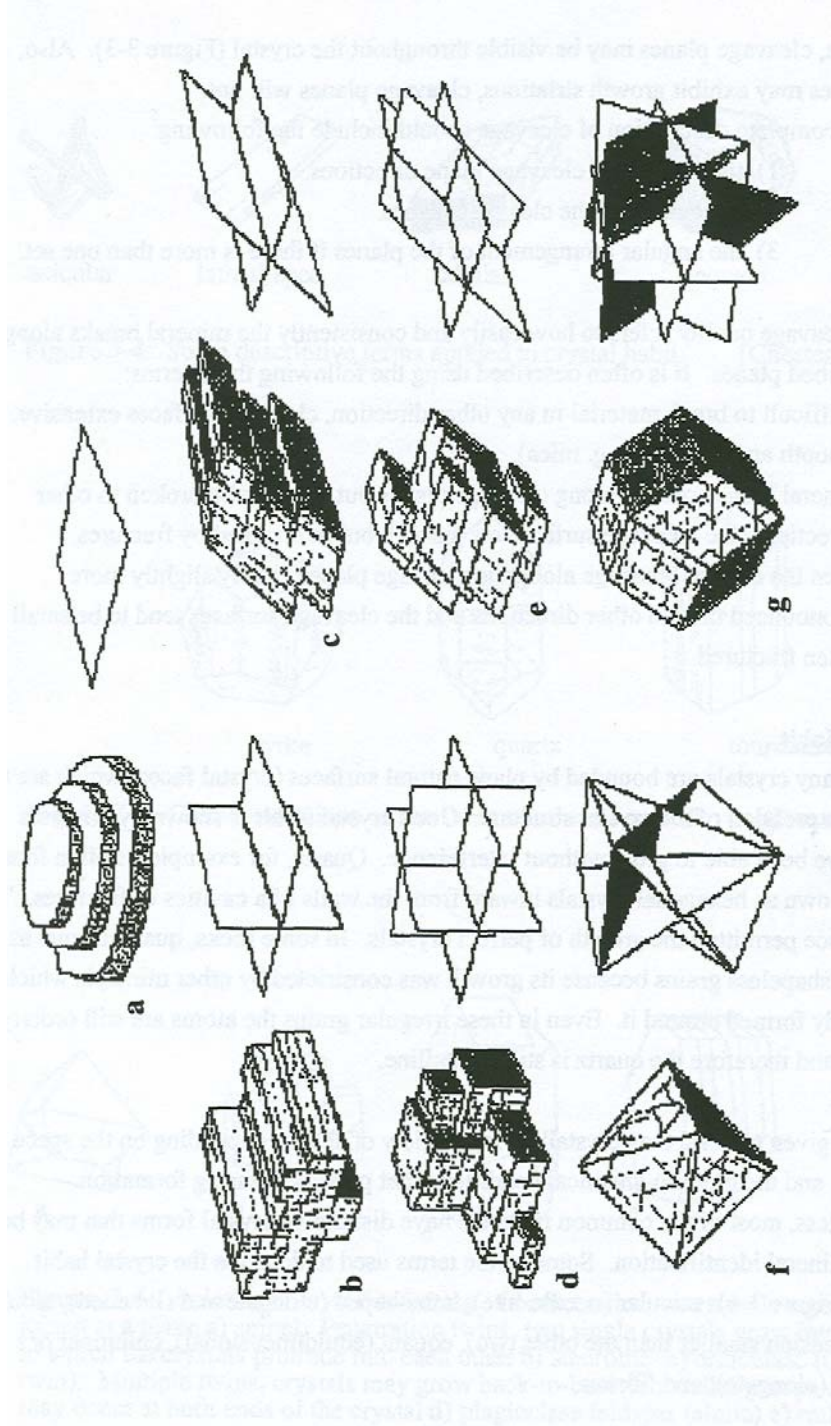
1. Cleavage quality: is cleavage observed or not?
2. The number of cleavage plane directions
3. The angular arrangement of planes if there is more than one set

6. *Fracture*

Fracture refers to surfaces created by breakage not controlled by atomic structure, and consequently is not repeated in parallel sets as is cleavage.

Terms describing fracture:

Fracture	Definition
Conchoidal	Numerous concave fracture surfaces
Even	Fracture surface, though rough, approximates a plane
Hackly	Sharp or jagged, irregular fracture surface
Splintery	Fracture surface jagged with needle-like points
Uneven	Fracture surface rough and entirely irregular



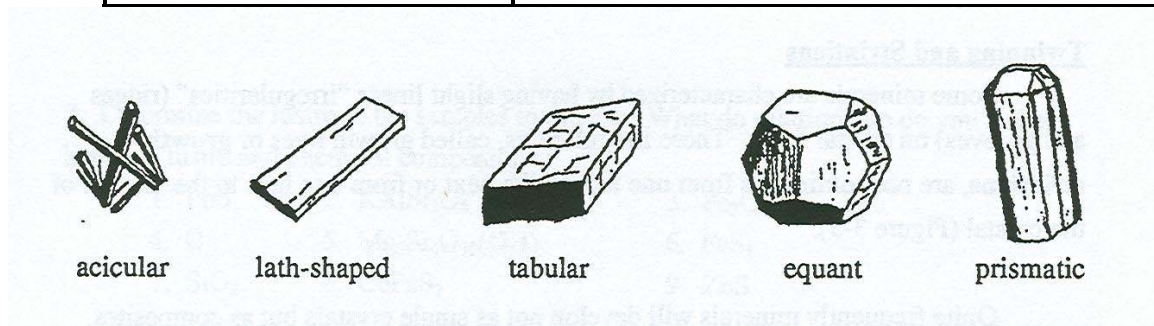
Mineral cleavage. (a) one direction of cleavage (example: mica);
 b) two directions at 90° (feldspar); c) two directions not at 90° (amphibole);
 d) three directions at 90° (halite); e) three directions not at 90° (calcite);
 f) four directions (diamond); g) six directions (sphalerite).
 (McGreary and Plummer, 1994).

7. Crystal habit

Habit is a descriptive term applied to the typical appearance of minerals which have been able to grow without interference. A given mineral may crystallize in a variety of shapes depending on the space available and the physico-chemical conditions that prevailed during formation. Quartz, for example, is often found to have grown as hexagonal crystals inward from the walls of a cavity. The ample space permitted the growth of perfect crystals. In some rocks, quartz occurs as irregular, shapeless grains because its growth was constricted by other minerals which had already formed around it.

Terms describing habit:

Habit	Definition
Acicular	Needle-like
Columnar or prismatic	Elongated
Equant	Equidimensional
Fibrous	Made of extremely slender prisms
Lath-shaped	Elongated and flattened
Tabular	One direction smaller than the two others



Descriptive terms applied to crystal habit (Chesterman, 1978).

8. Other properties

Specific gravity is the ratio of the density of the mineral to the density of water. Most of the common minerals have a specific gravity of 2.5 times that of water while a few other minerals have a distinctively higher specific gravity. Galena for instance has a very high specific gravity (7.4 – 7.6).

A few iron-bearing minerals, such as magnetite, are magnetic.

Some minerals react chemically to dilute hydrochloric acid. When HCl is applied to calcite [CaCO₃], carbon dioxide gas is released and the acid fizzes. Dolomite [CaMg(CO₃)₂], however, will only react with the acid when in the powdered form thus the mineral dolomite must be scratched to produce the fizzing reaction.

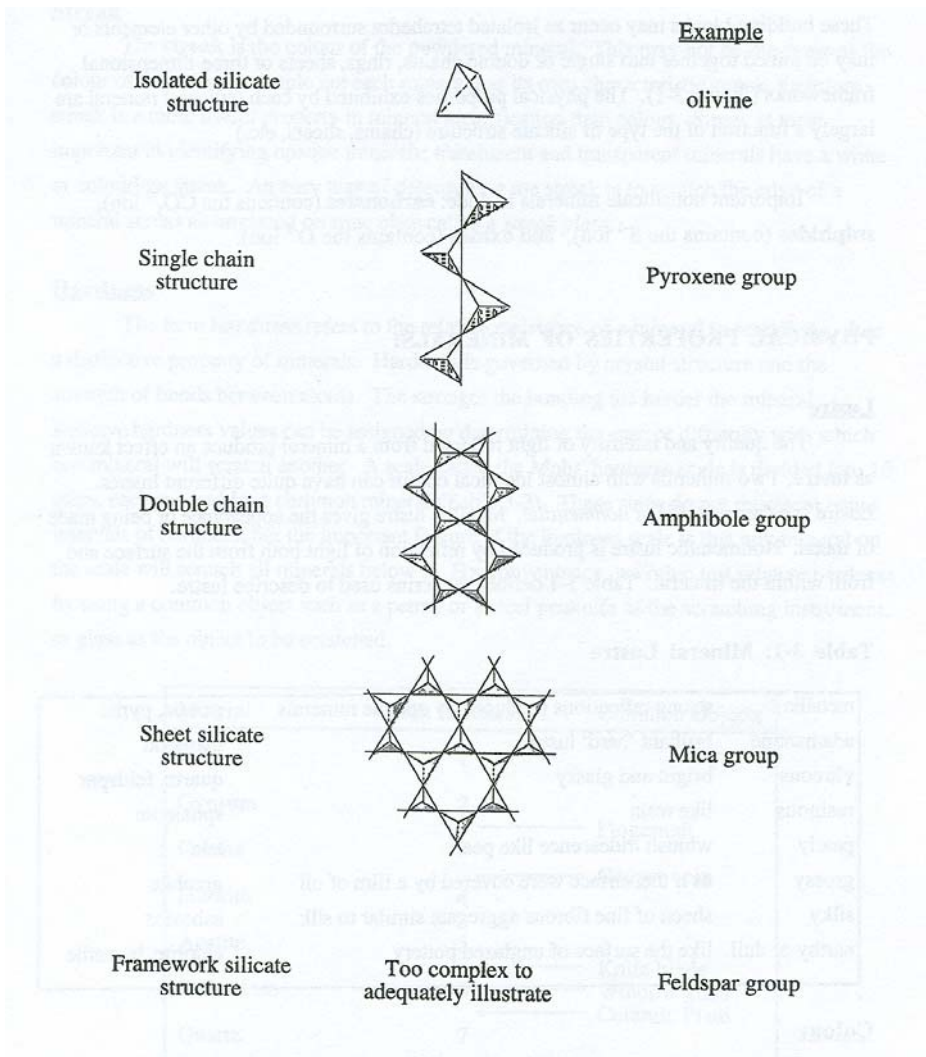
Mineral classes

Minerals exhibit wide variation in their chemical composition. Although all types of chemical bonding are represented, most common minerals may be visualized as compounds in which one or more species of positively-charged metal ions (cations) are bonded to particular, negatively-charged anions or anionic radicals. The relative sizes and electronic charges of the ions determine the chemical formula and, along with temperature and pressure, the crystals structure.

Minerals are classified according to their predominant anionic species.

Class	Examples
Carbonates	Calcite [CaCO_3]
Oxides and hydroxides	Hematite [Fe_2O_3]
Halides	Halite [NaCl], fluorite [CaF_2]
Native elements	Graphite [C], Diamond [C]
Phosphates	Apatite $\text{Ca}_5\text{F}(\text{PO}_4)_3$
Silicates	Albite [$\text{Na,Al Si}_3\text{O}_8$]
Sulphates	Gypsum [$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$]
Sulphides	Pyrite [FeS_2]

The most abundant minerals in the Earth's crust and mantle, the rock-forming minerals, are members of the silicate group (conventionally including quartz [SiO_2] which could alternatively be grouped with the oxides). The silicate minerals are characterized by building blocks of silicon and oxygen, called silica tetrahedral. Each tetrahedron consists of four oxygen atoms packed around a single silicon atom. These building blocks may occur as isolated tetrahedra surrounded by other elements or may be joined together into single or double chains, rings, sheets or three-dimensional frameworks. The physical properties exhibited by each silicate mineral are largely a function of their structure.



Common silicate structures
(modified from McGreary and Plummer, 1994).

Date: _____

Student name: _____

Student ID: _____

PHYSICAL MINERALOGY

Assignment

1. Visit the various stations featuring the physical properties used to identify minerals.
2. Identify a series of minerals by observing their properties and using the mineral identification flowcharts and the tables in Appendix A. Fill in the charts.

Identification procedure

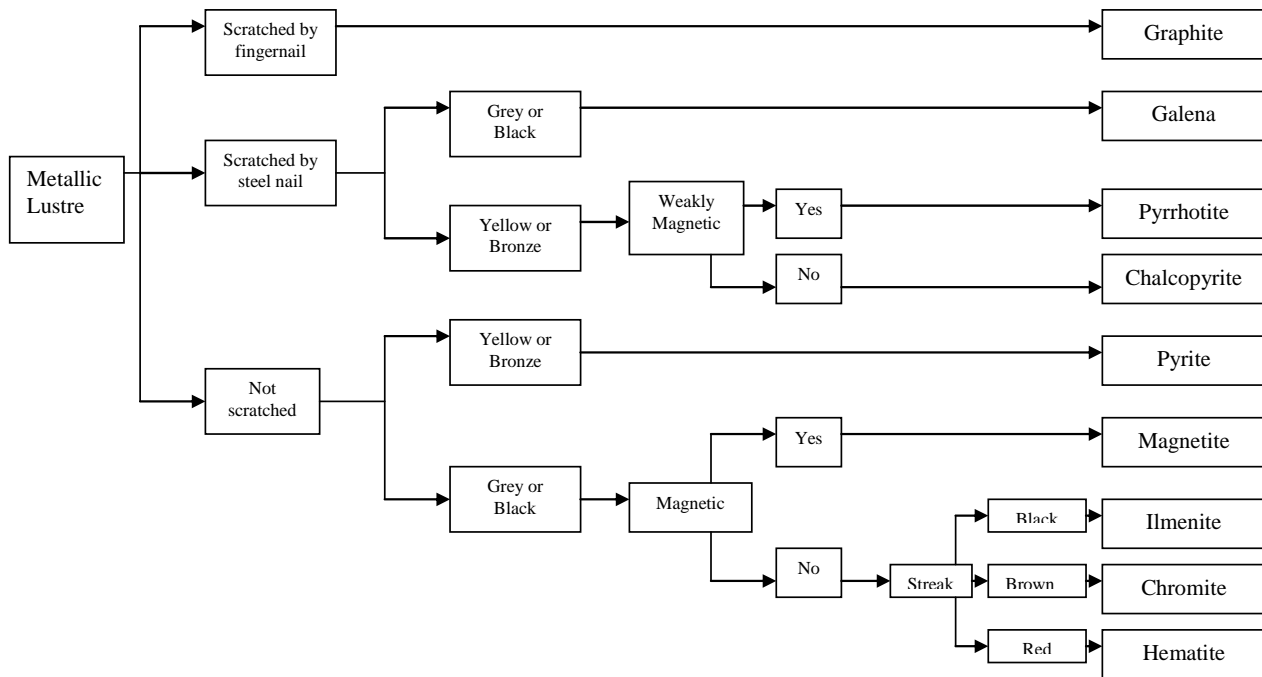
In the identification flowcharts and tables, minerals are first listed on the basis of lustre, then according to hardness, followed by other properties.

1. Is lustre metallic or non-metallic?
2. What is the hardness of the mineral?
3. Note colour, streak, cleavage, habit and any other physical properties.

→ This should lead to a positive identification

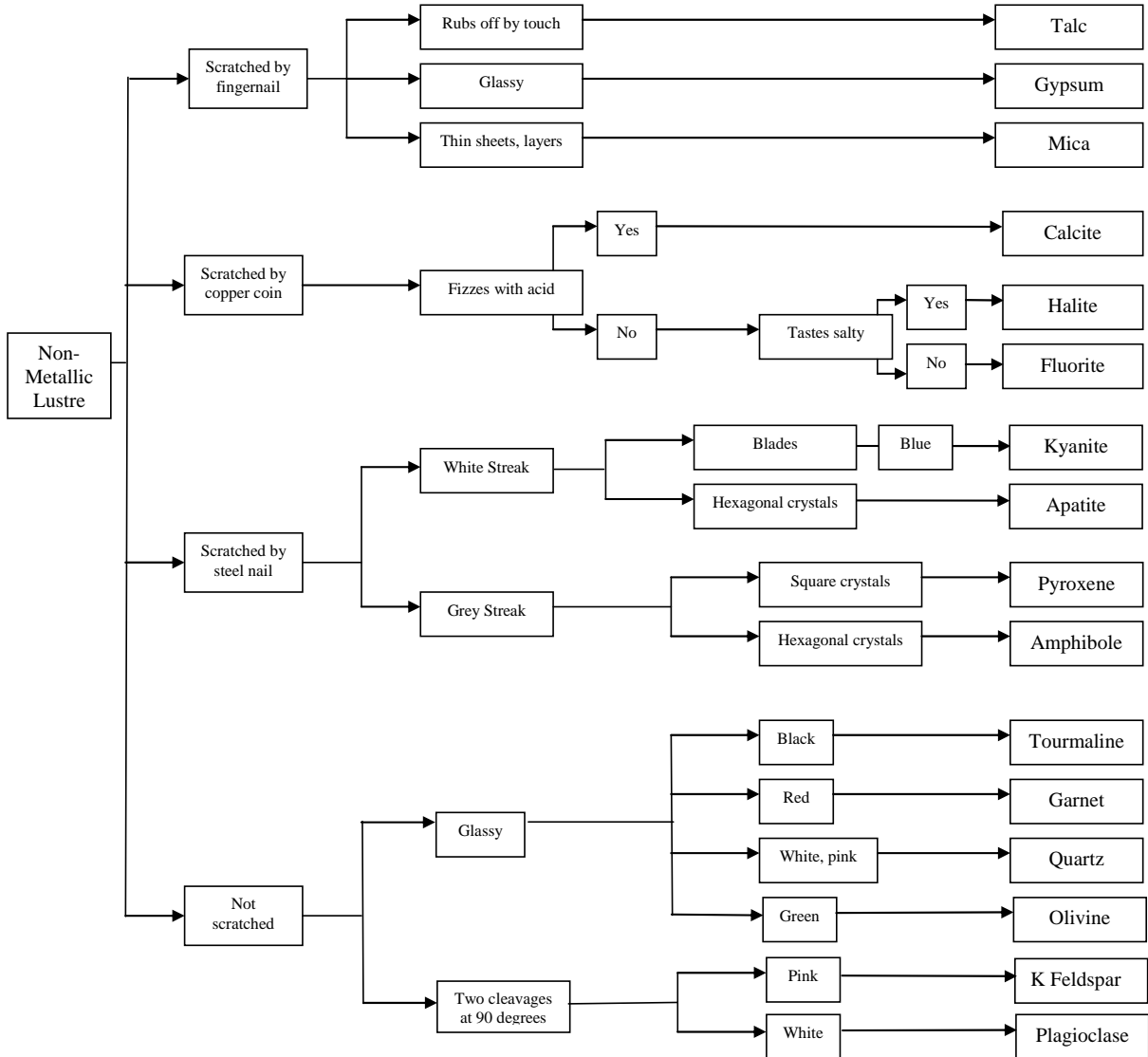
Mineral identification flowchart

Minerals with metallic lustre



Mineral identification flowchart

Minerals with non-metallic lustre



SPEC. NO.	LUSTRE	HARDNESS	COLOUR	STREAK	CLEAVAGE FRACTURE	HABIT	OTHER PROPERTIES	NAME AND CLASS

SPEC. NO.	LUSTRE	HARDNESS	COLOUR	STREAK	CLEAVAGE FRACTURE	HABIT	OTHER PROPERTIES	NAME AND CLASS

SPEC. NO.	LUSTRE	HARDNESS	COLOUR	STREAK	CLEAVAGE FRACTURE	HABIT	OTHER PROPERTIES	NAME AND CLASS

SPEC. NO.	LUSTRE	HARDNESS	COLOUR	STREAK	CLEAVAGE FRACTURE	HABIT	OTHER PROPERTIES	NAME AND CLASS

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LAB 2: IGNEOUS ROCKS

Objective

Identification and classification of common igneous rocks.

Introduction

Rocks that crystallized from a magma at high temperatures (typically 700-1200°C) are termed igneous.

Magma originates in the deep crust or mantle of the Earth. When it rises but remains trapped below the Earth's surface, it cools slowly allowing the growth of large, phaneritic crystals (visible to the unaided eye). The resulting medium- to coarse-grained rocks, with crystal size generally within the range 1-10 mm, are termed intrusive or plutonic. Magma which reaches the surface normally cools rapidly and solidifies too rapidly for large crystals to grow. The solidified products are termed extrusive or volcanic rocks, which typically are fine-grained (grain size <1 mm), aphanitic (crystals invisible to the unaided eye), or glassy (non-crystalline). Open spaces are rare in igneous rocks, except in vesicular lavas.

Igneous rocks vary systematically in chemical (and hence, mineral) composition according to: (1) the source within the Earth from which the melt was derived; and (2) the conditions of melting and crystallization. Because physico-chemical laws limit the number of independent variables, only a few minerals crystallize in abundance. Generally only these abundant essential minerals need to be recognized for the identification of igneous rocks.

Classification of igneous rocks

When magma of a given composition solidifies, the mineral assemblage that forms is the same for intrusive and extrusive igneous rocks. The differences are textural. Once the texture of an igneous rock has been determined, the specimen is named according to its mineral assemblage.

Texture

Texture relates to the size, shape and arrangement of the mineral grains. One of the most important textural features is grain size. The grain size terminology used in igneous rock classification is:

Texture		Average grain size [mm]	Examples
Non-crystalline	No grains formed		
Crystalline	Fine-grained	< 1	Basalt, Rhyolite
	Medium-grained	1 – 5	Diabase
	Coarse-grained	> 5	Granite, Gabbro

Lava may sometimes cool and solidify so rapidly that its atoms do not have time to organize themselves into minerals. Glass, a mineraloid, forms instead. Extrusive igneous rocks that are largely or wholly glass are called obsidian. Such rock display a distinctive fracture pattern, on a broken surface, that consists of a series of smooth, curved surfaces. This is termed conchoidal fracture and is typical of all samples of volcanic glass. If the glass is frothy in appearance due to abundant fine gas bubbles it is referred to as pumice. Pumice is very light (it may even float on water) and feels abrasive to the touch.

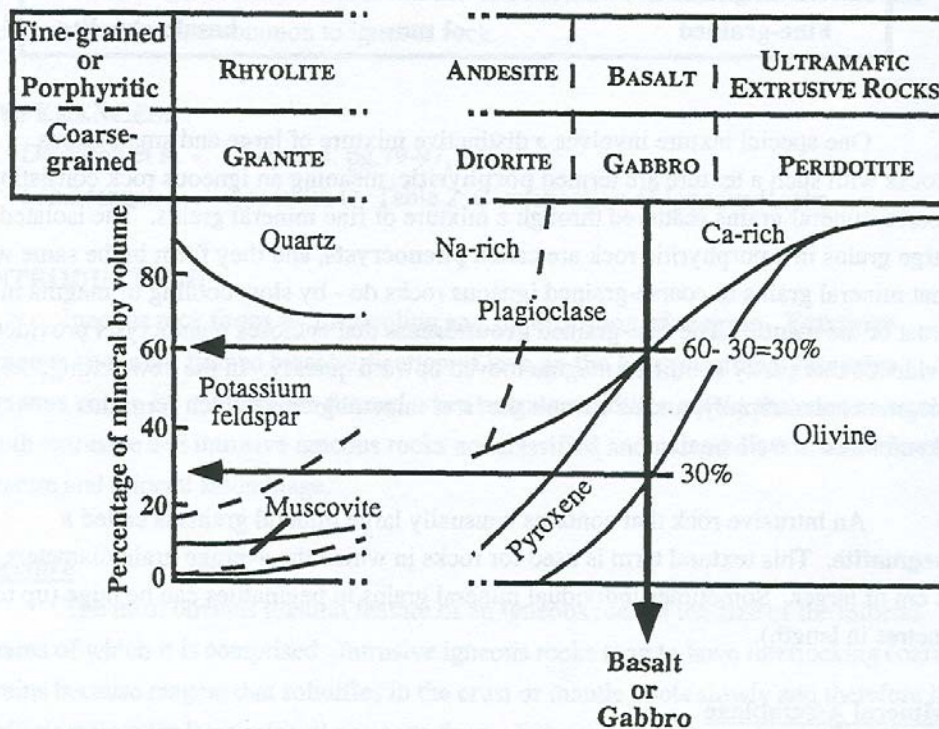
One special texture involves a distinctive mixture of large and small grains. Rocks with such a texture are called porphyritic. This term refers to igneous rocks consisting of coarse mineral grains scattered through a mixture of fine mineral grains. The isolated large grains in a porphyritic rock are called phenocrysts, and they form in the same way that mineral grains in coarse-grained igneous rocks do – by slow cooling of magma in the crust or the mantle. The fine-grained groundmass that encloses phenocrysts provides evidence that partly solidified magma moved upward quickly. In the new setting, the magma cooled rapidly and, as a result, the later mineral grains which form the groundmass are small.

An intrusive rock that contains unusually large mineral grains is called a pegmatite. This textural term is used for rocks in which the average grain diameters are 2 cm or larger.

Pyroclastic rocks, tuff for example, are formed by the accumulation of tephra (particles thrown out of a volcanic vent) and possess a clastic texture similar to that of clastic sedimentary rocks. Consequently they are in the special category of volcanoclastics.

Mineral assemblages

All common igneous rocks are composed of one or more of these six minerals or mineral groups: quartz, feldspar (both K-feldspar and plagioclase), mica (both biotite and muscovite), amphibole, pyroxene and olivine. The vertical axis in the classification table records the volumetric mineral percentages. When the percentage of each mineral in a rock specimen has been estimated, the correct rock name is determined by drawing a vertical line with the appropriate proportions of minerals. For example, suppose you have a rock specimen that is 30% olivine, 30% pyroxene and 40% plagioclase. To name this specimen, you estimate the point on where the curve separating olivine from pyroxene cuts a horizontal line drawn through 30%. Draw a vertical line through this point. You will see that this vertical line cuts the curve between pyroxene and plagioclase at a point close to 60%. Olivine (30%) plus pyroxene (30%) equal 60%. Plagioclase accounts for the remaining percentage. If the rock specimen is coarse-grained it is a gabbro; if it is fine-grained, it is a basalt.



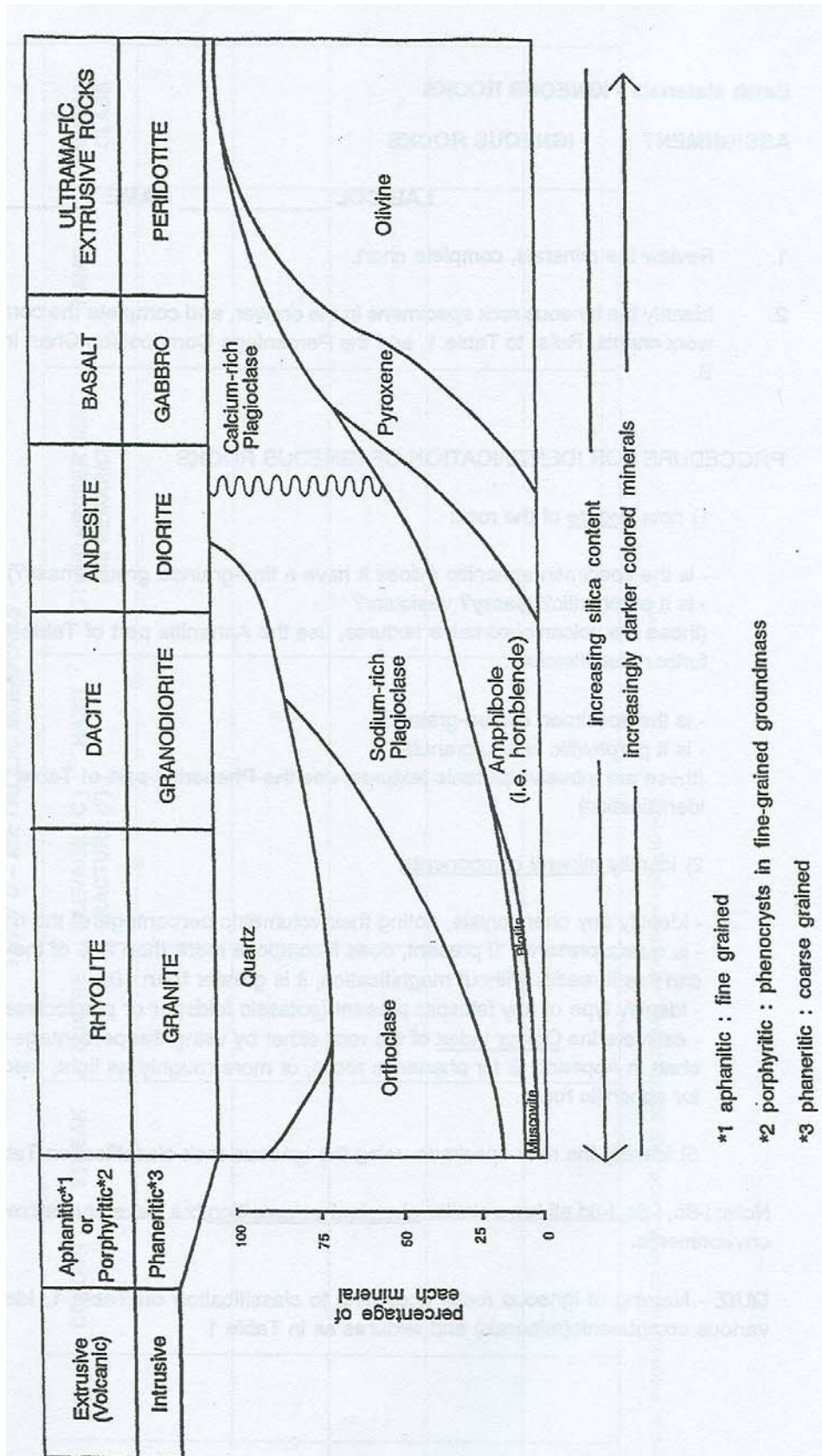


Table 1a. Classification of igneous rocks

Mafic and ultramafic

Felsic Intermediate

Rock Colour		Light	Medium	Dark
A P H A N I T I C	typical phenocrysts in parentheses below rock name	RHYOLITE (quartz, K-feldspar)	DACITE (plagioclase, biotite)	
	> 10%* QUARTZ	TRACHYTE (K-feldspar)	ANDESITE (plagioclase, hornblende, pyroxene)	BASALT (olivine, plagioclase, pyroxene)
P H A N E R I T I C	< 10%* QUARTZ			KOMATIITE ultramafic extrusive
	Typical Colour Index	0 - 40		40 - 90
	ESSENTIAL MINERALS	POTASSIC FELDSPAR	PLAGIOCLASE FELDSPAR	PLAGIOCLASE+ PYROXENE
	Common Varietal Minerals	Plagioclase Hornblende Biotite- Muscovite	K-Feldspar Hornblende Biotite	Olivine Hornblende
	> 10% QUARTZ	GRANITE	GRANODIORITE	
< 10% QUARTZ	SYENITE	DIORITE ANORTHOSITE (>90% Plagioclase)	GABBRO (Diabase is a fine-grained variety)	PYROXENITE (Pyroxene) PERIDOTITE (Pyroxene+Olivine) DUNITE (Olivine)

* not detectable in aphanitic rocks.

Table 1b. Classification of igneous rocks

Variety of igneous rocks

Felsic rocks

A felsic rock is an igneous rock which is rich in silica and has a relatively high content of potassium and sodium. Feldspar and quartz are the most abundant minerals in felsic rocks. Coarse-grained felsic rocks include granite and granodiorite. Many granites and granodiorites contain scattered grains of amphibole and mica (biotite and/or muscovite).

A fine-grained porphyritic rock with phenocrysts of quartz is either a rhyolite or a dacite. They are chemically and mineralogically equivalent to granite and granodiorite. The difference between rhyolites and dacites rests, as it does with granites and granodiorites, on the composition of the feldspars. In rhyolites, potassium feldspar is more abundant than plagioclase; in dacite, the reverse is true. It is rarely possible to identify very fine-grained feldspars without using a petrological microscope, so dacites are often difficult to distinguish from rhyolites.

Intermediate igneous rocks

Intermediate igneous rocks lack the excess silica found in felsic rocks. The chief mineral in intermediate rock, such as diorite, is plagioclase. Quartz and mica are usually absent, but either or both amphibole and pyroxene are invariably present. A porphyritic igneous rock similar in appearance to a dacite but lacking quartz phenocrysts is an andesite. Named for the Andes, the major mountain belt of western South America, andesite is equivalent in composition to a diorite.

Mafic and ultramafic igneous rocks

Diorite grades into gabbro in which the dark-coloured minerals, pyroxene and olivine, may exceed 50%. This is an example of a mafic rock. A mafic rock is a silica-deficient igneous rock with a higher content of magnesium, iron and calcium. Minerals which contain iron and magnesium are dark in colour and are referred to as ferromagnesian minerals.

The dominant rock of the oceanic crust is basalt, a fine-grained, sometimes porphyritic, igneous rock. Compositionally equivalent to gabbro, basalt is the most abundant type of extrusive igneous rock. Phenocrysts, when present, can be either plagioclase, pyroxene or olivine. The medium-grained equivalent of gabbro or basalt is diabase. Diabase is a rock found commonly in dykes and sills.

Rocks composed entirely of ferromagnesian minerals are referred to as ultramafic. A common example of an intrusive (coarse-grained) ultramafic rock is peridotite, which contains more than 40% olivine. Fine-grained ultramafic rocks do exist but they are very rare.

Date: _____

Student name: _____

Student ID: _____

IGNEOUS ROCKS

Assignment

Identify the igneous rock specimens. Fill in the charts.

Reference material

Tables 1a and 1b: Classification of igneous rocks
Appendix B: Percentage composition chart

Procedure for igneous rock identification

1. Note the texture of the rock

- Does the specimen have a fine-grained groundmass (aphanitic texture) or is it coarse-grained (phaneritic texture)?

2. Identify mineral components

- Identify any phenocrysts, noting their volumetric percentage
- Is quartz present? If present, does it compose more than 10% of the rock? (If you can see it without magnification, it is greater than 10%)
- Identify any type of feldspar present (potassic feldspar or plagioclase)
- Estimate the colour index of the rock either by using the "Percentage composition chart" for phaneritic rocks, or more roughly as "light", "medium" or "dark" for aphanitic rocks.

3. Identify the rock specimen using Tables 1a and 1b.

IGNEOUS ROCKS

SPEC. NO.	TEXTURE	COLOUR INDEX	ESSENTIAL MINERALS %	VARIETAL MINERALS %	ROCK NAME

IGNEOUS ROCKS

SPEC. NO.	TEXTURE	COLOUR INDEX	ESSENTIAL MINERALS %	VARIETAL MINERALS %	ROCK NAME

IGNEOUS ROCKS

SPEC. NO.	TEXTURE	COLOUR INDEX	ESSENTIAL MINERALS %	VARIETAL MINERALS %	ROCK NAME

LAB 3a: SEDIMENTARY ROCKS

Objective

Identification and classification of both detrital and chemical sedimentary rocks.

From sediments to sedimentary rocks

There are two mechanisms by which sedimentary rocks form:

1. Weathering of a host rock, erosion and transport of this weathered material by rain, ice or wind, then deposition.
→ After lithification, this leads to the formation of detrital sedimentary rocks.

Sediment remains sediment without lithification. This means that a rock does not form until individual particles are consolidated together. An important lithification process, cementation occurs at any time following deposition, at or near the Earth's surface or within hundreds of metres of burial. The two most common cement mineralogies are silica (quartz) and calcite. Cement typically represents less than 5% of the total volume of a rock; it is often not easy to see. However, mineralogical differences and how these respond to HCl (hypochloric acid) make it very easy to tell whether a rock is cemented by calcite or quartz. There are other cement types: dolomite, phosphate and Fe-oxide.

2. Precipitation at the site of deposition.
→ This leads to the formation of chemical sedimentary rocks.

Definitions

Framework: sediment particles that comprise the majority of the rock, and create a supporting structure.

Matrix: sediments that fit between and/or bind (but not cement) the framework grains together. They are usually not as abundant as the framework particles.

Cement: "glue" that holds the sediments together.

Sedimentary rock classification

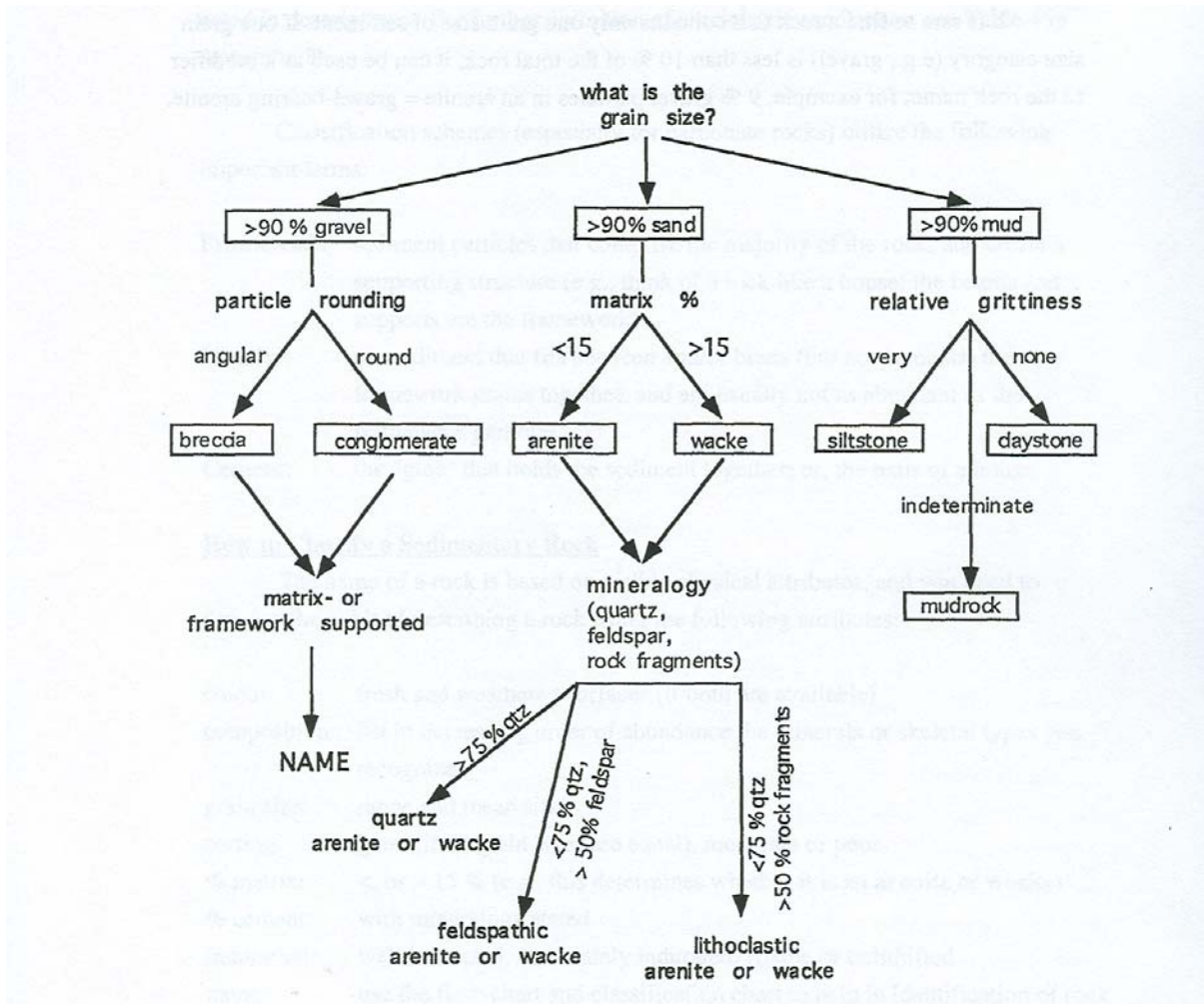
The sedimentary rock classification scheme uses the following features:

- grain size
- composition of sediments (mineralogy and/or skeletal material)
- textural attributes: sorting, framework, matrix

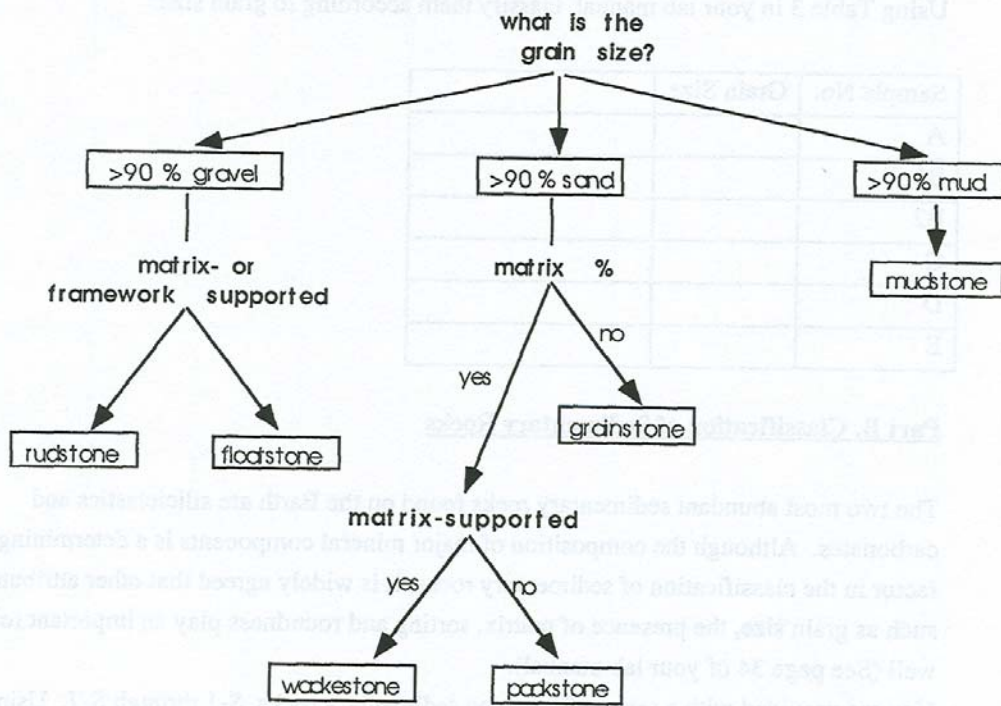
Colour, roundness of fragments and sedimentary structures should also be noted in description.

Grain size* (log scale)	Sediment	Detrital sedimentary rocks	Chemical sedimentary rocks with clastic texture	
			Framework-supported	Matrix-supported
Boulders — 256 mm	Gravel	<u>Conglomerate</u> <u>Breccia</u> (framework- or matrix-supported for both)	<u>Rudstone</u>	<u>Floatstone</u>
Cobbles — 64 mm				
Pebbles — 2 mm — 1 mm				
Very coarse sand — 500 µm	Sand	<u>Sandstone</u> <u>Arenite</u> (<15% matrix) <u>Wacke</u> (>15% matrix)	<u>Grainstone</u> (no matrix) <u>Packstone</u> (matrix present)	<u>Wackestone</u>
Coarse sand — 250 µm				
Medium sand — 125 µm				
Fine sand — 62 µm				
Very fine sand				
Silt — 4 µm	Mud	<u>Mudrock</u> (if fissile = <u>Shale</u>)		<u>Mudstone</u>
Clay				

Table 1. Classification of sediments and sedimentary rocks with clastic texture



Flowchart for the identification of detrital sedimentary rocks



* all terms can be modified with the predominant type of carbonate particle: e.g., if skeletal material = fossiliferous

Flowchart for the identification of chemical sedimentary rocks with clastic texture

Date: _____

Student name: _____

Student ID: _____

SEDIMENTARY ROCKS

Assignment

Identify the sedimentary rock specimens. Fill in the charts.

Reference material

Classification of sediments and sedimentary rocks with clastic texture

Flowchart for the identification of detrital sedimentary rocks

Flowchart for the identification of chemical sedimentary rocks with clastic texture

Procedure for sedimentary rock identification

Identify the following physical attributes:

- Predominant grain size:
 - Gravel
 - Coarse-grained (c.g.) sand
 - Medium-grained (m.g.) sand
 - Fine-grained (f.g.) sand
 - Silt
 - Clay
- Sorting: Good (all grains equal size) / moderate / poor

- Framework composition:

For detrital sedimentary rocks, list in order of decreasing abundance: quartz (Q), feldspar (F), lithoclasts (L);

For chemical sedimentary rocks, list in order of decreasing abundance: lithoclasts (L), bioclasts (B) and oolites (O).

- % Matrix: Estimate the amount, if any, of material that binds the framework grains. Is it greater or less than 15%?
- % Cement: Estimate the amount and state composition (quartz, carbonate, iron oxides, etc.). In most cases, you will need magnification for this.
- Induration: How tough is the rock? Can you rub fragments off with your fingers? Terms are: very well indurated / well indurated / moderately indurated / poorly indurated / friable / unlithified.
- Colour: Describe colour of both the fresh surface (F.S.) and the weathered surface (W.S.).

Follow the flowchart to the correct name.

Note: it is rare to find a rock that contains only one grain size of sediment. If one grain size category (e.g. gravel) is less than 10% of the total rock, it can be used as a modifier to the rock name. For example, 9% gravel particles in an arenite is called a “gravel-bearing arenite”.

SEDIMENTARY ROCKS

SEDIMENTARY ROCKS							
SPEC. NO.							
PREDOMINANT GRAIN SIZE							
SORTING							
FRAMEWORK COMPOSITION							
MATRIX > 15% <							
CEMENT							
MINERAL							
FORMULA							
TEXTURE							
INDURATION							
COLOUR (F.S. / W.S.)							
NAME OF ROCK							

SEDIMENTARY ROCKS

SEDIMENTARY ROCKS							
SPEC. NO.							
PREDOMINANT GRAIN SIZE							
SORTING							
FRAMEWORK COMPOSITION							
MATRIX > 15% <							
CEMENT							
MINERAL							
FORMULA							
TEXTURE							
INDURATION							
COLOUR (F.S. / W.S.)							
NAME OF ROCK							

SEDIMENTARY ROCKS

SEDIMENTARY ROCKS							
SPEC. NO.							
PREDOMINANT GRAIN SIZE							
SORTING							
FRAMEWORK COMPOSITION							
MATRIX > 15% <							
CEMENT							
MINERAL							
FORMULA							
TEXTURE							
INDURATION							
COLOUR (F.S. / W.S.)							
NAME OF ROCK							

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Lab 3b: METAMORPHIC ROCKS

Objective

Identification and classification of metamorphic rocks.

Introduction

The word metamorphic comes from two roots, “meta” (meaning “change”) and “morph” (meaning “shape”). Metamorphic rocks are the result of the change of pre-existing rocks by mainly pressure and temperature. When rocks or unconsolidated sediments are subjected to changes in temperature and/or pressure, the minerals in the original rock recrystallize and new minerals are formed. The main process that facilitates the growth of new minerals is called diffusion and this occurs in the solid state. Metamorphism is thus the alteration of one rock to another in response to temperature (T), pressure (P) or reaction with fluids.

The types of minerals formed during metamorphism depend on the chemical composition of the original rock and the P-T conditions. The precursor to a metamorphic rock is known as the protolith. The assemblage of minerals within a metamorphic rock can be used to evaluate the pressure-temperature conditions that have affected the protolith. The intensity or degree of metamorphism is known as the metamorphic grade. One such example is given by a layer of mud deposited in an ocean. As the mud becomes buried, mud-size particles become cemented forming a mudstone. As the rock is subjected to higher pressure, the mudstone is converted into a slate. As pressure and temperature increases, the slate is converted into a schist in which completely new minerals are formed and are all oriented parallel to one another. At higher metamorphic grades, the schist is converted into a gneiss in which many new minerals are formed. As metamorphic grade increases, the gneiss begins to melt, and the mixed rock is called a migmatite. At higher temperatures, the rock ultimately melts and forms a magma.

Type of metamorphism

We can recognize five types of metamorphism.

Scale	Type of metamorphism	Metamorphic agents	Change in chemical composition
Regional	Regional Sedimentary rocks only: Burial	Heat and P	No
Local	Contact	Heat	
	Dynamic	P	
	Impact	P	
	Hydrothermal	Fluids	Yes

During regional metamorphism, large tracts of the crust have been affected. Regional metamorphism generally results from mountain-building processes which are caused by collision between tectonic plates. Such collisions give rise to considerable deformation which normally leads to crustal thickening. Overthickened crust acts as an insulating layer and can trap heat rising up from the mantle, resulting in higher than normal temperatures. Examples include large parts of the Canadian Shield, and some of the younger fold-mountain belts such as the Appalachians and the Canadian Cordillera. Almost all of the rocks in the Gatineau Hills have been formed by regional metamorphic activity.

Contact metamorphism is caused by an increase in temperature without accompanying high pressure, and it normally occurs around hot, igneous bodies as they are intruded into the crust. Because this type of metamorphism does not involve great changes in pressure, the new minerals are not oriented along a preferred direction. A massive rock commonly found at the contact of igneous intrusions is called a hornfels.

In dynamic metamorphism, rocks are produced by mechanical processes such as crushing and grinding, within and adjacent to faults, shear zones and fractures. During dynamic metamorphism, the brittle minerals are broken, flattened or strung out.

Impact metamorphism is due to the rare occurrence of space bodies striking the Earth.

In hydrothermal metamorphism, the chemical composition of the protolith is altered because of the addition or replacement of minerals due to the action of ion-rich fluids.

Protoliths

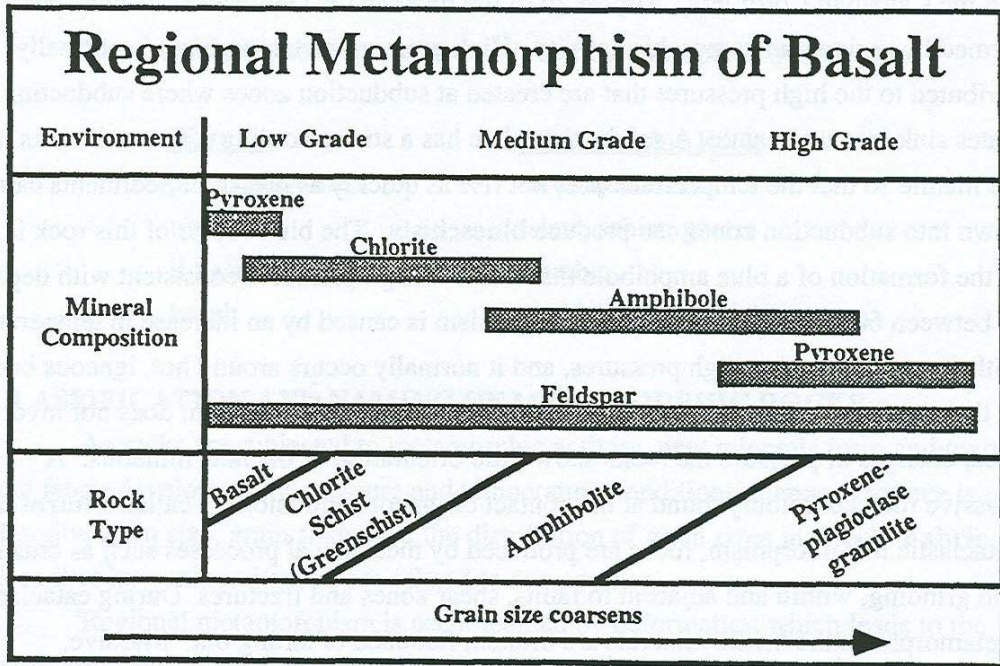
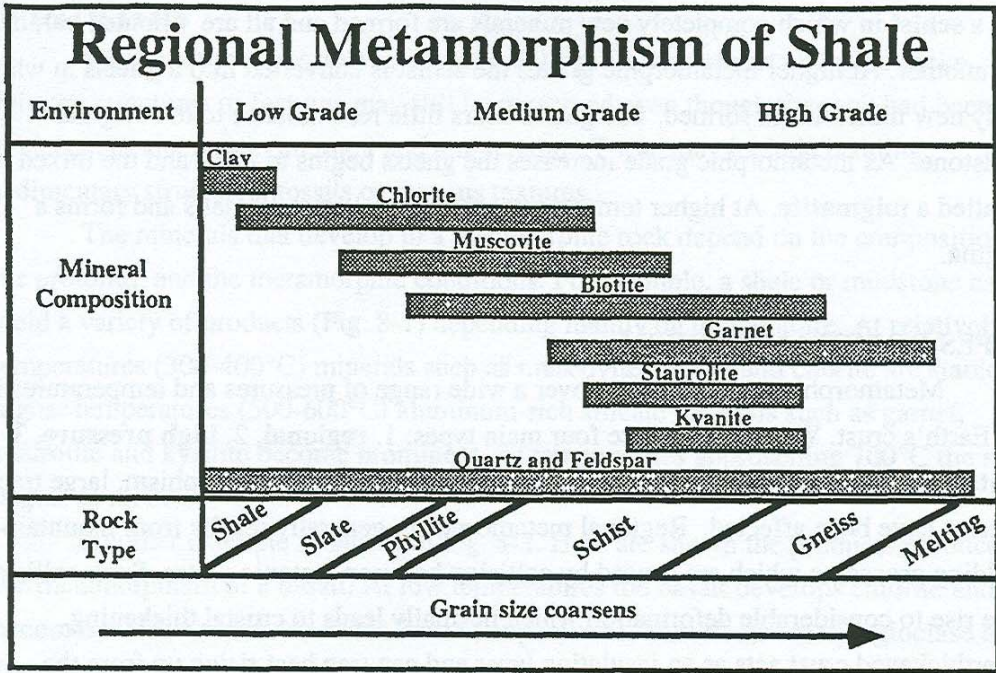
It is sometimes possible to determine the protoliths of metamorphic rocks. Primary structures or features may still be preserved even though the rock has been subjected to changes in pressure and temperature. These may include bedding, sedimentary structures, fossils or igneous textures.

The minerals that develop in a metamorphic rock depend on the composition of the protolith, and the metamorphic conditions. For example, a shale or mudstone can yield a variety of products depending mainly on temperature. At relatively low temperatures (300 – 400°C), minerals such as muscovite, biotite and chlorite are stable. At higher temperatures (500 – 600°C), aluminium-rich silicate minerals such as garnet, staurolite and kyanite become prominent. At temperatures approaching 700°C, the rocks begin to melt.

Another example is the metamorphism of basalt. At low temperatures, basalt develops chlorite and become a chlorite schist. At moderate temperatures, hornblende and plagioclase are formed, and the metamorphic rock is known as an amphibolite. At high temperatures, the metamorphic mineral assemblage consists of pyroxene and plagioclase, and the rock is known as a granulite.

Given below are some protoliths and their metamorphic equivalents:

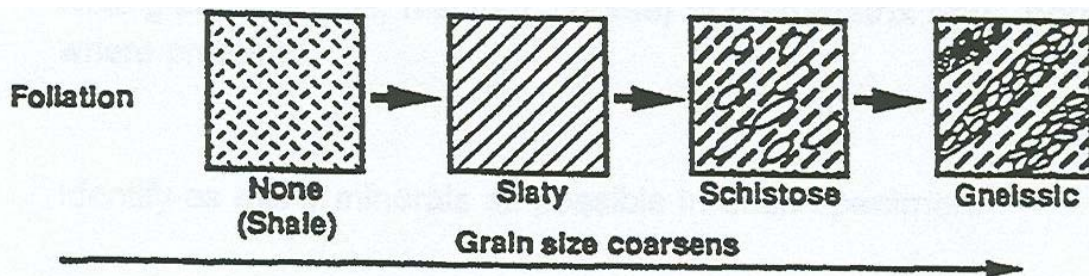
Protolith	Metamorphic rock
Pure sandstone	Orthoquartzite
Mudrock	Slate, schist, gneiss
Limestone	Marble
Basalt	Amphibolite, eclogite



Classification and naming of metamorphic rocks

As rocks are subjected to metamorphic activity and the pressure and temperature conditions change, new minerals form and new texture and fabric develop. Texture is used to describe grain size, grain shape and the distribution of grain sizes in a rock. Fabric describes how mineral grains are related to one another.

Regional metamorphism is accompanied by deformation which leads to the preferred orientation of minerals. Tabular or “platy” minerals such as mica can become oriented in a planar arrangement with their flat faces parallel to one another. This texture, known as foliation (foliation is derived from the Latin word meaning “leaf”), resembles a stack of sheets. In some rocks, for example slate, the foliation is so closely spaced that the rock tends to break into very flat, parallel sheets which is known as cleavage or schistosity. Prismatic (“pencil-like”) crystals such as pyroxene and amphibole can be oriented with their long axes parallel to form a lineation. Certain minerals in metamorphic rocks, such as garnet, are substantially larger than others, and these are referred to as porphyroblasts.



Minerals can also segregate into thin lenses to produce foliations or, with extreme deformation, they can form into relatively continuous layers or gneissic structures. A gneiss is a banded or lineated metamorphic rocks typically consisting of alternating bands of platy or linear minerals with quartz and feldspar. Such segregations form lighter and darker layers. The individual grains in the lighter parts of these lenses or layers may be more or less randomly oriented and equidimensional. In rocks such as marble or quartzite, which are made up of only one mineral, no mineral segregations occur and the rock is massive.

Table 1. Identification of common metamorphic rocks

Structure	Grain Size	Essential Minerals	Name
slaty cleavage with or without lineation	aphanitic	not identifiable	slate
cleavage with or without lineation	aphanitic, but micas large enough to give sheen	micas and/or chlorite	phyllite
schistosity with or without lineation, foliation	fine- or medium-grained	micas and/or chlorite, plagioclase (may contain porphyroblasts of garnet, etc.)	schist
layered or lenticular	medium-grained	feldspar, quartz	gneiss
massive	aphanitic or very fine-grained	not identifiable	hornfels
massive	medium- to coarse-grained	feldspar, mica, alumino-silicates	granofels
massive or foliated	fine- to coarse-grained	calcite and/or dolomite	marble
massive	fine- to coarse-grained	quartz	quartzite

Date: _____

Student name: _____

Student ID: _____

METAMORPHIC ROCKS

Assignment

1. Examine the minerals plagioclase, biotite, pyroxene, magnetite, amphibole, quartz, garnet, chlorite, graphite, molybdenite, staurolite and kyanite.
2. Identify the metamorphic rock specimens. Fill in the charts.

Reference material

Table 1. Identification of common metamorphic rocks

Procedure for identification

1. Determine the type of preferred orientation of minerals, if any, and enter under "Structure".
2. Note the grain size (fine, medium, coarse) of both matrix and porphyroblasts, where present.
3. Identify as many minerals as possible.
4. Using Table 1, assign each specimen a name. When naming a metamorphic rock, list the visible mineral components starting with the least common mineral (e.g. garnet muscovite schist).
5. Suggest the type of rock from which it may have been derived (protolith).

METAMORPHIC ROCKS						
ROCKS WITH ORIENTED FABRIC						
SPEC. NO.	STRUCTURE	GRAIN SIZE* (fine, medium, coarse)	PRINCIPAL MINERALS* > 5%	OTHER MINERALS < 5 %	ROCK NAME	PROTOLITH

* Distinguish prophyroblasts and matrix where appropriate.

METAMORPHIC ROCKS						
ROCKS WITH ORIENTED FABRIC						
SPEC. NO.	STRUCTURE	GRAIN SIZE* (fine, medium, coarse)	PRINCIPAL MINERALS* > 5%	OTHER MINERALS < 5 %	ROCK NAME	PROTOLITH

* Distinguish prophyroblasts and matrix where appropriate.

METAMORPHIC ROCKS

MASSIVE ROCKS

SPEC. NO.	MINERAL COMPOSITION	GRAIN SIZE (fine, medium, coarse)	ROCK NAME	PROTOLITH

