Geology 212	Petrology	Prof. Stephen A. Nelson
General Classification of Igneous Rocks		

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Classification of igneous rocks is one of the most confusing aspects of geology. This is partly due to historical reasons, partly due to the nature of magmas, and partly due to the various criteria that could potentially be used to classify rocks.

- Early in the days of geology there were few rocks described and classified. In those days each new rock described by a geologist could have shown characteristics different than the rocks that had already been described, so there was a tendency to give the new and different rock a new name. Because such factors as cooling conditions, chemical composition of the original magma, and weathering effects, there is a potential to see an infinite variety of igneous rocks, and thus a classification scheme based solely on the description of the rock would eventually lead to a plethora of rock names. Still, because of the history of the science, many of these rock names are firmly entrenched in the literature, so the student must be aware of all of these names, or at least know where to look to find out what the various rocks names mean.

- Magmas, from which all igneous rocks are derived, are complex liquid solutions. Because they are solutions, their chemical composition can vary continuously within a range of compositions. Because of the continuous variation in chemical composition there is no easy way to set limits within a classification scheme.

- There are various criteria that could be used to classify igneous rocks. Among them are:

  1. **Minerals Present in the Rock** (the ***mode***). The minerals present in a rock and their relative proportions in the rock depend largely on the chemical composition of the magma. This works well as a classification scheme if all of the minerals that could potentially crystallize from the magma have done so - usually the case for slowly cooled plutonic igneous rocks. But, volcanic rocks usually have their crystallization interrupted by eruption and rapid cooling on the surface. In such rocks, there is often glass or the minerals are too small to be readily identified. Thus a system of classification based solely on the minerals present can only be used.

     We can easily the inadequacy of a mineralogical classification based on minerals present if you look at the classification schemes for volcanic rocks given in introductory geology textbooks. For example, most such schemes show that a dacite is a rock that contains small amounts of quartz, somewhat larger amounts of sanidine or alkali feldspar, plagioclase, biotite, and hornblende, In all the years I have been looking at igneous rocks (since about the mid-cretaceous) I have yet to see a dacite that contains alkali feldspar. Does this mean that the intro geology textbooks lie? Not really, these are the minerals that should crystallize from a dacite magma, but don't because the crystallization history is interrupted by rapid cooling on the surface.

  2. **Texture of the Rock**. Rock texture depends to a large extent on cooling history of the magma. Thus rocks with the same chemical composition and same minerals

present could have widely different textures. In fact we generally use textural criteria to subdivide igneous rocks in to plutonic (usually medium to coarse grained) and volcanic (usually fine grained, glassy, or porphyritic.) varieties.

3. **Color**. Color of a rock depends on the minerals present and on their grain size. Generally, rocks that contain lots of feldspar and quartz are light colored, and rocks that contain lots of pyroxenes, olivines, and amphiboles (ferromagnesium minerals) are dark colored. But color can be misleading when applied to rocks of the same composition but different grain size. For example a granite consists of lots of quartz and feldspar and is generally light colored. But a rapidly cooled volcanic rock with the same composition as the granite could be entirely glassy and black colored (i.e. an obsidian). Still we can divide rocks in general into ***felsic rocks*** (those with lots of feldspar and quartz) and ***mafic rocks*** (those with lots of ferromagnesium minerals). But, this does not allow for a very detailed classification scheme.

4. **Chemical Composition**. Chemical composition of igneous rocks is the most distinguishing feature.

  - The composition usually reflects the composition of the magma, and thus provides information on the source of the rock.
  - The chemical composition of the magma determines the minerals that will crystallize and their proportions.
  - A set of hypothetical minerals that could crystallize from a magma with the same chemical composition as the rock (called the ***Norm***), can facilitate comparison between rocks.
  - Still, because chemical composition can vary continuously, there are few natural breaks to facilitate divisions between different rocks.
  - Chemical composition cannot be easily determined in the field, making classification based on chemistry impractical.

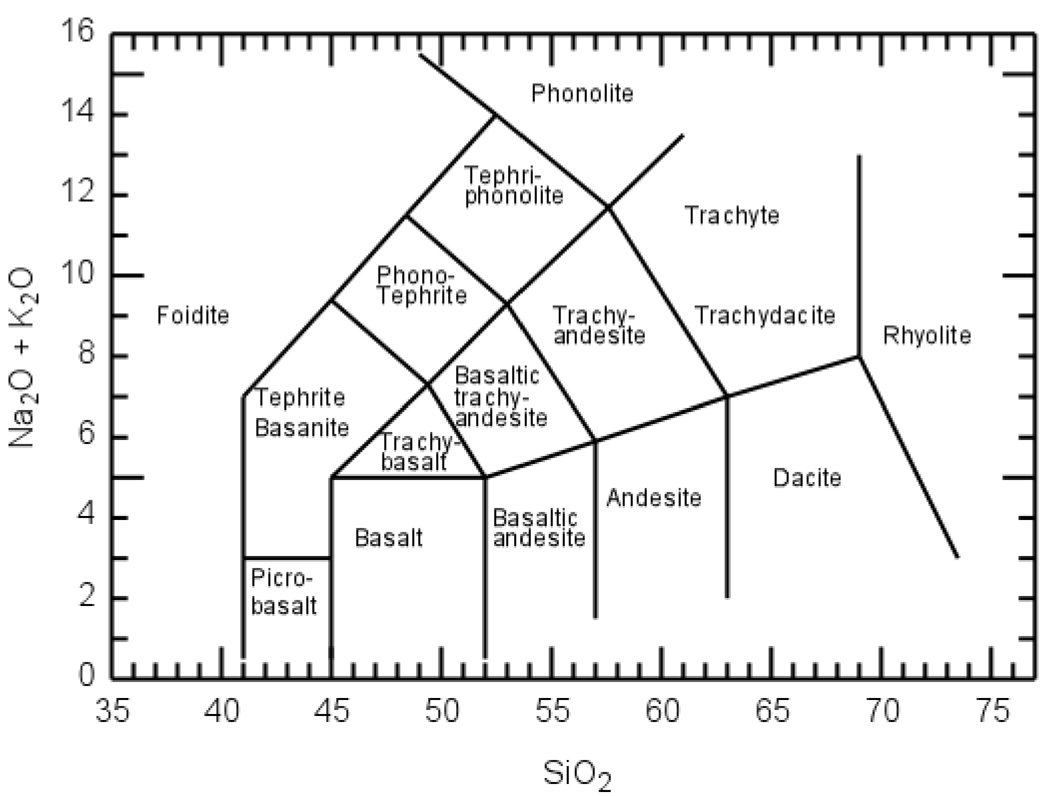
Because of the limitations of the various criteria that can used to classify igneous rocks, geologists use an approach based on the information obtainable at various stages of examining the rocks.

1. In the field, a simple field based classification must be used. This is usually based on mineralogical content and texture. For plutonic rocks, the IUGS system of classification can be used. For volcanic rocks, the following table can be used.

Simple Field Classification of Volcanic Rocks (For use in Geology 212)		
Rock Name	Essential Minerals*	Other Minerals (may or may not be present)
Basalt	Olivine	Cpx, Opx, Plag.
Basanite	Olivine + Feldspathoid (Nepheline/ Leucite)	Cpx, Plag.
Andesite	No olivine, abundant Plagioclase	Cpx, Opx, Hornblende
Trachyte	Sanidine + Plagioclase	Na-Cpx, Hornblende, Biotite
Dacite	Plagioclase + Hornblende	Cpx, Opx, Biotite
Rhyolite	Quartz	Sanidine, Biotite, Plag., Hornblende, Cpx, Opx
* The amount of glass in the groundmass increases, in general, from the top to the bottom of the chart.		

2. Once the rocks are brought back to the laboratory and thin sections can be made, these are examined, mineralogical content can be more precisely determined, and refinements in the mineralogical and textural classification can be made.

3. Chemical analyses can be obtained, and a chemical classification, such as the LeBas et al., IUGS chemical classification of volcanic rocks (based on total alkalies [$Na_2O + K_2O$] vs. SiO_2 diagram shown below)



Note that at each stage of the process, the classification may change, but it is important to keep in mind that each stage has limitations, and that classification at each stage is for the purposes of describing the rock, not only for the individual investigator, but anyone else. Thus, the classification scheme should be employed in a consistent manner so that later investigators can understand what you are talking about at each stage of the process.

General Chemical Classifications

SiO_2 (Silica) Content

> 66 wt. % - Acid

52-66 wt% - Intermediate

45-52 wt% - Basic

< 45 wt % - Ultrabasic

This terminology is based on the onetime idea that rocks with a high % SiO_2 were precipitated from waters with a high concentration of hyrdosilicic acid H_4SiO_4. Although we now know this is not true, the acid/base terminology is well entrenched in the literature.

Silica Saturation

If a magma is oversaturated with respect to Silica then a silica mineral, such as quartz, cristobalite, tridymite, or coesite, should precipitate from the magma, and be present in the rock. On the other hand, if a magma is undersaturated with respect to silica, then a silica mineral should not precipitate from the magma, and thus should not be present in the rock. The silica saturation concept can thus be used to divide rocks in silica undersaturated, silica saturated, and silica oversaturated rocks. The first and last of these terms are most easily seen.

- Silica Undersaturated Rocks - In these rocks we should find minerals that, in general, do not occur with quartz. Such minerals are:

Nepheline- $NaAlSiO_4$	Leucite - $KAlSi_2O_6$
Forsteritic Olivine - Mg_2SiO_4	Sodalite - $3NaAlSiO_4 \cdot NaCl$
Nosean - $6NaAlSiO_4 \cdot Na_2SO_4$	Haüyne - $6NaAlSiO_4 \cdot (Na_2,Ca)SO_4$
Perovskite - $CaTiO_3$	Melanite - $Ca_2Fe^{+3}Si_3O_{12}$
Melilite - $(Ca,Na)_2(Mg,Fe^{+2},Al,Si)_3O_7$	

Thus, if we find any of these minerals in a rock, with an exception that we'll see in a moment, then we can expect the rock to be silica undersaturated.

If we calculate a CIPW Norm (we'll see how to do this in lab) the normative minerals that occur in silica undersaturated rocks are nepheline and/or leucite.

- Silica Oversaturated Rocks. These rocks can be identified as possibly any rock that does **not** contain one of the minerals in the above list.

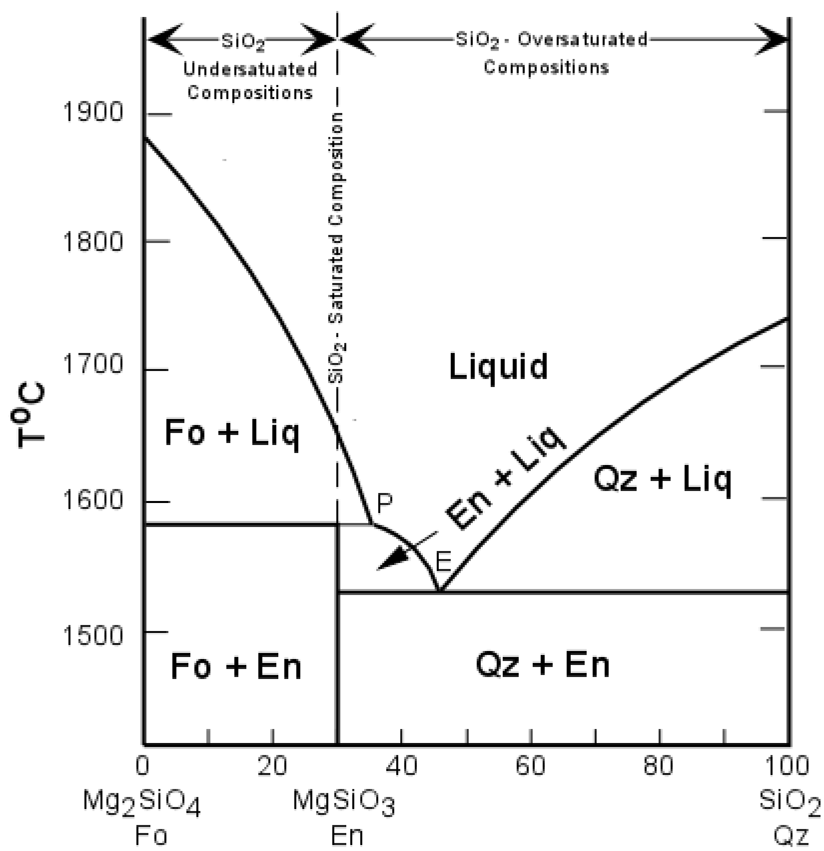
  If we calculate a CIPW Norm, silica oversaturated rocks will contain normative quartz.

- Silica Saturated Rocks. These are rocks that contain just enough silica that quartz does not appear, and just enough silica that one of the silica undersaturated minerals does not appear. In the CIPW norm, these rocks contain olivine, or hypersthene + olivine, but no quartz, no nepheline, and no leucite.

To get an idea about what silica saturation means, let's look at a simple silicate system - the system Mg_2SiO_4 - SiO_2

Note how compositions between Fo and En will end their crystallization with only Fo olivine and enstatite. These are SiO_2-undersaturated. compositions. All compositions between En and SiO_2 will end their crystallization with quartz and enstatite. These are SiO_2 - oversaturated compositions.

Note also that this can cause some confusion in volcanic rocks that do not complete their crystallization due to rapid cooling on the surface. Let's imagine first a composition in the silica-undersaturated field. Cooling to anywhere on the liquidus will result in the crystallization of Fo-rich olivine. If this liquid containing olivine is erupted and the rest of the liquid quenches to a glass, then this will produce a rock with phenocrysts of olivine in a glassy groundmass.



Applying the criteria above for identifying silica undersaturated rocks would tell us that this is a silica-undersaturated rock, which we know to be correct. Next, let's look at a silica oversaturated composition, such as one just to the left of the point labeled 'P' in the diagram. If this liquid is cooled to the liquidus and olivine is allowed to crystallize, and is then quenched on the surface, it will contain phenocrysts of Fo-rich olivine in a glassy groundmass. Applying the criteria above would suggest that this rock is also silica undersaturated, but we know it is not. This illustrates one of the difficulties of applying any criteria of classification to volcanic rocks where incomplete crystallization/reaction has not allowed all minerals to form.

Alumina (Al_2O_3) Saturation

After silica, alumina is the second most abundant oxide constituent in igneous rocks. Feldspars are, in general, the most abundant minerals that occur in igneous rocks. Thus, the concept of alumina saturation is based on whether or not there is an excess or lack of Al to make up the feldspars. Note that Al_2O_3 occurs in feldspars in a ratio of 1 Al to 1 Na, 1K, or 1 Ca:

$KAlSi_3O_8$ -- **1/2**K_2O **:** **1/2**Al_2O_3

$NaAlSi_3O_8$ -- **1/2**Na_2O **:** **1/2**Al_2O_3

$CaAl_2Si_2O_8$ -- **1**CaO **:** **1**Al_2O_3

Three possible conditions exist.

1. If there is an excess of Alumina over that required to form feldspars, we say that the rock is ***peraluminous***. This condition is expressed chemically on a molecular basis as:

   $Al_2O_3 > (CaO + Na_2O + K_2O)$

   In peraluminous. rocks we expect to find an Al_2O_3-rich mineral present as a modal mineral - such as muscovite [$KAl_3Si_3O_{10}(OH)_2$], corundum [Al_2O_3], topaz [$Al_2SiO_4(OH,F)_2$], or an Al_2SiO_5- mineral like kyanite, andalusite, or sillimanite.

   Peraluminous rocks will have corundum [Al_2O_3] in the CIPW norm and no diopside in the norm.

2. ***Metaluminous*** rocks are those for which the molecular percentages are as follows:

   $Al_2O_3 < (CaO + Na_2O + K_2O)$ and $Al_2O_3 > (Na_2O + K_2O)$

   These are the more common types of igneous rocks. They are characterized by lack of an Al_2O_3-rich mineral and lack of sodic pyroxenes and amphiboles in the mode.

3. ***Peralkaline*** rocks are those that are oversaturated with alkalies ($Na_2O + K_2O$), and thus undersaturated with respect to Al_2O_3. On a molecular basis, these rocks show:

   $Al_2O_3 < (Na_2O + K_2O)$

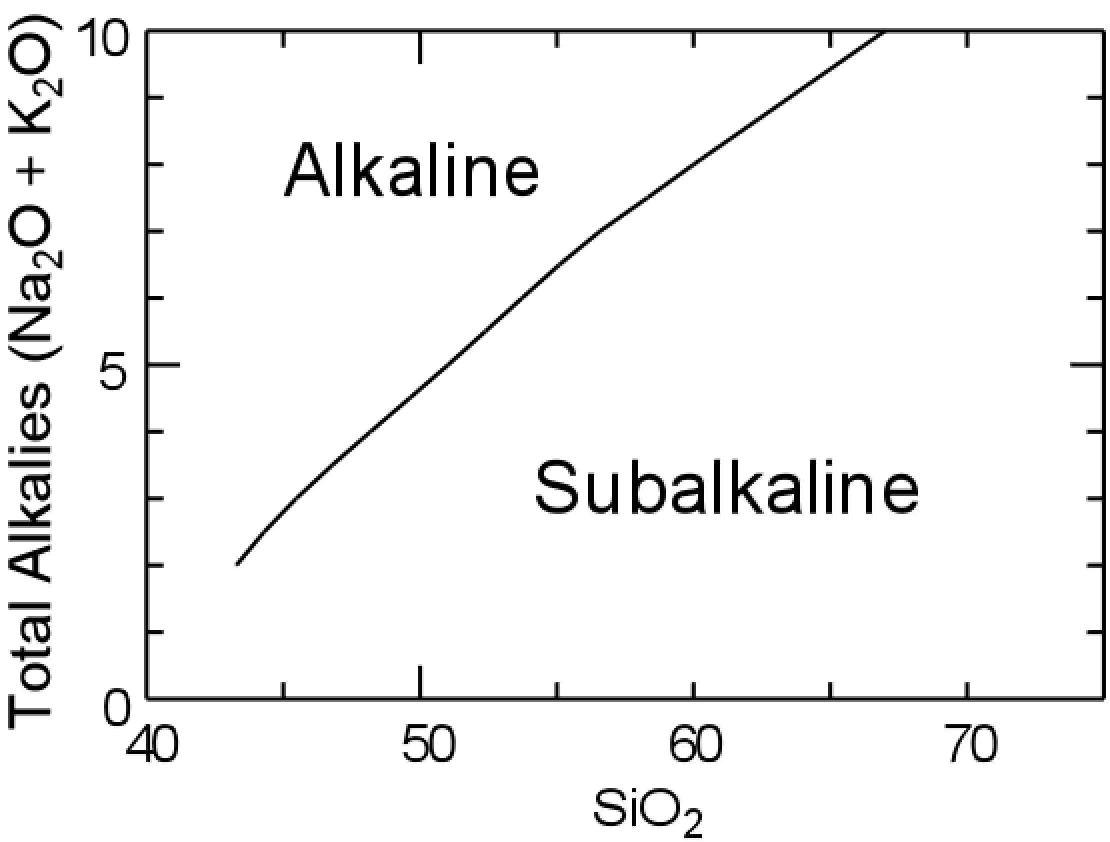
   Peralkaline rocks are distinguished by the presence of Na-rich minerals like aegerine

[$NaFe^{+3}Si_2O_6$], riebeckite [$Na_2Fe_3{}^{+2}Fe_2{}^{+3}Si_8O_{22}(OH)_2$], arfvedsonite [$Na_3Fe_4{}^{+2}(Al,Fe^{+3})Si_8O_{22}(OH)_2$], or aenigmatite [$Na_2Fe_5{}^{+2}TiO_2Si_6O_{18}$] in the mode.

In the CIPW norm, acmite [$NaFe^{+3}Si_2O_6$] and/or sodium metasilicate Na_2SiO_3 will occur as normative minerals.

Alkaline/Subalkaline Rocks

One last general classification scheme divides rocks that alkaline from those that are subalkaline. Note that this criteria is based solely on an alkali vs. silica diagram, as shown below. Alkaline rocks should not be confused with peralkaline rocks as discussed above. While most peralkaline rocks are also alkaline, alkaline rocks are not necessarily peralkaline. On the other hand, very alkaline rocks, that is those that plot well above the dividing line in the figure below, are also usually silica undersaturated.



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