A Summary of Geologic Information used by the Intermountain Forest Tree Nutrition Cooperative to Estimate Potassium Content of Rocks

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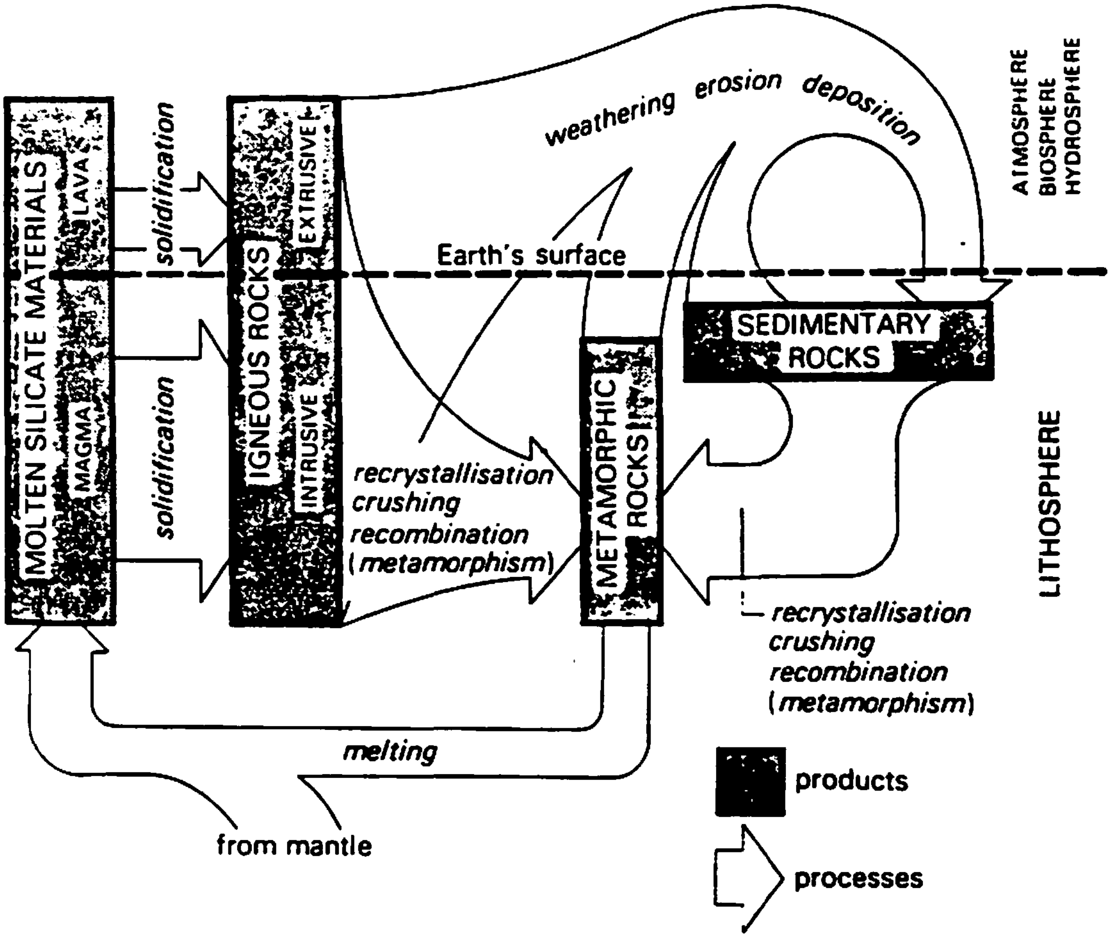
Introduction

The IFTNC currently classifies parent materials based on four rock types: Basic-Igneous (Basaltic), Acid- Igneous (Granitic), Metasedimentary, and Mixed (glacial till). In order to further clarify health-related issues and their potential association with parent materials, a more specific classification of parent materials according to content of certain critical elements, especially potassium (K) would be helpful. Such a classification system should allow us to categorize the rock types found on geologic maps and publications according to element content and contribution to soil-available nutrient supply. The purpose of this paper is to present a classification of rock types based on K content; the discussion of rock contribution to soil-available K supply will be discussed separately. The following classification system was developed based on a literature review of basic mineralogical, petrographical, geochemical and geological information.

Development of a K-based Classification

The three primary classes of rocks are igneous, sedimentary and metamorphic. These categories are interrelated as shown in Figure 1 (Gillen 1982). Within each of these categories, there are various nomenclature systems available. While standard nomenclature systems exist for both igneous and sedimentary rocks, these classifications tend to be quite arbitrary, and it is not uncommon for different geologists to classify the same rock by different names. As such, nomenclature should be our last resort when classifying rocks for K content. Instead, we should go directly to a more specific mineralogical or geochemical breakdown for a given rock at a given site, whenever this information is available.

Fig. 1


MOLTEN SILICATE MATERIALS
LAVA
MAGMA
solidification
solidification
IGNEOUS ROCKS
EXTRUSIVE
INTRUSIVE
weathering erosion deposition
Earth's surface
ATMOSPHERE
BIOSPHERE
HYDROSPHERE
SEDIMENTARY ROCKS
METAMORPHIC ROCKS
recrystallisation
crushing
recombination
(metamorphism)
recrystallisation
crushing
recombination
(metamorphism)
LITHOSPHERE
melting
from mantle
products
processes

'Petrography' or 'mineralogy' refers to the visual description of a given rock, usually from a thin section under a microscope, which breaks the rock down into volume percent of each of its mineral components. 'Geochemistry' refers to the process by which the rock is actually weighed, crushed and put through a number of analytic chemical processes, resulting in an analysis of the individual elements in an oxide form, by weight percent. Tables 1 and 2 show examples of mineralogical and geochemical descriptions, respectively (Hurlbut & Klein 1989).

Geochemical descriptions are more indicative of the total K in a given rock than are petrographical descriptions, and though expensive, they seem to be becoming a more common practice. For our purposes, geochemical descriptions would be the preferred choice for classifying a given rock. A review of available information from a variety of sources indicates that a range of values is associated with any given rock name, as would be expected due to variability within the nomenclature systems. However, we propose a breakdown of rock types into high, medium and low- K categories according to K2O content (% by weight) as follows:

High- K Rocks: >3.50% K2O

Medium- K Rocks: 1.75-3.49% K2O

Low- K Rocks: <1.75% K2O

This classification should work as long as we have geochemical information for a given rock type. In lieu of geochemical analyses, petrographic descriptions would be the next choice for classifying rock types by K content. In order to remain comparable with geochemical descriptions, it would be desirable to convert petrographical descriptions from volume percent of various minerals to weight percent of K2O. While this will not give us as precise

Table 1

APPROXIMATE MINERAL COMPOSITIONS OF SOME PLUTONIC ROCK TYPES (IN VOLUME PERCENT)[a]

	Granite	Syenite	Grano-diorite	Quartz Diorite	Diorite	Gabbro	Olivine Diabase	Diabase	Dunite
Quartz	25		21	20	2				
Orthoclase and microperthite	40	72	15	6	3				
Oligoclase	26	12							
Andesine			46	56	64				
Labradorite						65	63	62	
Biotite	5	2	3	4	5	1		1	
Amphibole	1	7	13	8	12	3		1	
Orthopyroxene				1	3	6			2
Clinopyroxene		4		3	8	14	21	29	
Olivine						7	12	3	95
Magnetite	2	2	1	2	2	2	2	2	3
Ilmenite	1	1				2	2	2	
Apatite	Trace	Trace	Trace	Trace	Trace				
Titanite	Trace	Trace	1	Trace	Trace				
Color Index[b]	9	16	18	18	30	35	37	38	98–100

[a] After E. S. Larsen, *Handbook of Physical Constants*, 1942. The percentage values are based on grain counts of minerals in a thin section using a polarizing microscope. This is known as *modal analysis*.

[b] Color index—a number that represents the percentage, by volume, of dark-colored (i.e., mafic) minerals in a rock.

Table 2

AVERAGE CHEMICAL COMPOSITIONS OF SOME IGNEOUS ROCKS[a]

Oxide	Nepheline syenite	Syenite	Granite	Tonalite	Diorite	Gabbro	Peridotite	Dunite
SiO_2	54.83	59.41	72.08	66.15	51.86	48.36	43.54	40.16
TiO_2	0.39	0.83	0.37	0.62	1.50	1.32	0.81	0.20
Al_2O_3	22.63	17.12	13.86	15.56	16.40	16.84	3.99	0.84
Fe_2O_3	1.56	2.19	0.86	1.36	2.73	2.55	2.51	1.88
FeO	3.45	2.83	1.67	3.42	6.97	7.92	9.84	11.87
MnO	trace	0.08	0.06	0.08	0.18	0.18	0.21	0.21
MgO	trace	2.02	0.52	1.94	6.12	8.06	34.02	43.16
CaO	1.94	4.06	1.33	4.65	8.40	11.07	3.46	0.75
Na_2O	10.63	3.92	3.08	3.90	3.36	2.26	0.56	0.31
K_2O	4.16	6.53	5.46	1.42	1.33	0.56	0.25	0.14
H_2O	0.18	0.63	0.53	0.69	0.80	0.64	0.76	0.44
P_2O_5	—	0.38	0.18	0.21	0.35	0.24	0.05	0.04
Total	99.77	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[a] All analyses except the nepheline syenite from S. R. Nockolds, 1954, *Geol. Soc. Amer. Bul.*, v. 65, pp. 1007–1032.

an estimate of K2O as would a geochemical analysis, there is a procedure available for making this conversion, as shown in the appendix. Following is a brief review of minerals and mineralogy, followed by a more detailed discussion of each of the rock categories (igneous, sedimentary and metamorphic), including standard nomenclature and a proposed K-classification system.

Mineralogy

The rock-forming minerals are grouped according to structure and chemical composition (Battey 1981, Hurlbut & Klein 1977). Potassium is primarily found in three mineralogical groups. These three groups are the K-feldspar group, the feldspathoid group and the mica group. The only difference between the K-feldspar group and the feldspathoid group is that the feldspathoids are silica (quartz) deficient, and do not seem to be too common. Of main interest to us are the K-feldspar and the mica groups. The minerals pertaining to each of these groups are as follows:

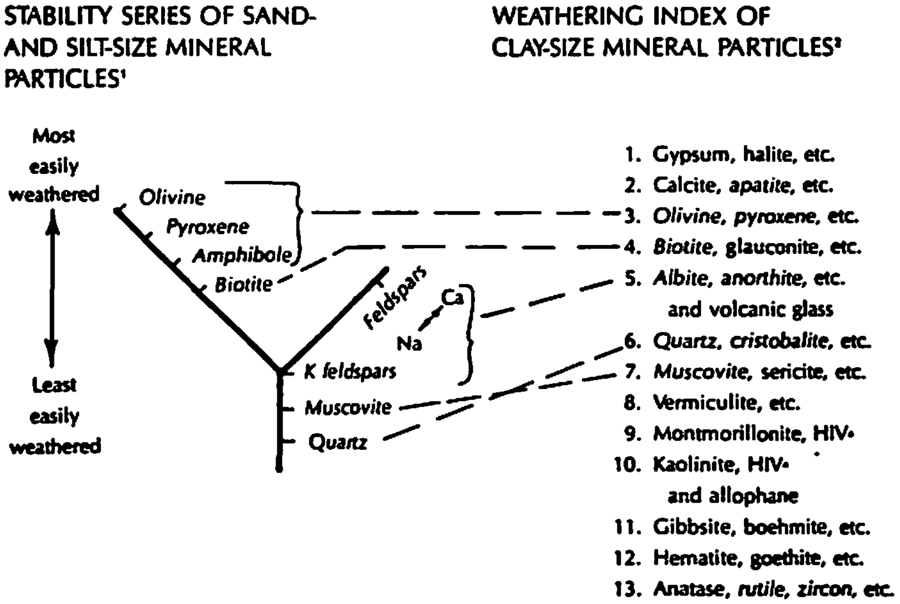
Group	Mineral	Description
K-feldspar	Sanidine	extrusive, from high temperature lava
	Orthoclase	intrusive, a medium temperature rock
	Microcline	deep-seated, slow cooling
Micas	Muscovite	common, characteristic of granites; chief constituent of mica schists. Muscovites are also the source of the clay minerals sericite and illite.
	Biotite	dark colored mineral; found in granites, diorites
Feldspathoids	Leucite	rare except in certain lavas
	Nepheline	in silica-deficient rocks

Generally, if we have any of these minerals, then we have K. For the most part, these are light-colored minerals, or felsic minerals (older terminology 'acid'). The darker, non-K minerals are termed mafic minerals (older terminology 'basic'). The exception to this color rule is biotite, which is a dark-colored K mineral. There are other K-bearing minerals, therefore if a rock name or petrographic description contains the name of an unfamiliar mineral, a mineral index showing the chemical formula should be consulted to determine whether or not K is present. For purposes of addressing weathering, a flow chart showing the 'stability indices' of various sand and silt-sized mineral particles is shown in Figure 2, along with an equivalent series for clay-sized particles (from Buol et al 1989).

Igneous Rocks

Igneous rocks are classified as either volcanic or plutonic rocks. Volcanic rocks are the result of extruded lava, or lava that made it to the surface of the earth, and are faster cooling and smaller grained than their plutonic counterparts. The plutonic rocks are deep-seated or intrusive rocks, which cooled inside the earth's crust, and therefore cooled slower and have larger grain size. Mineralogically speaking, volcanic and plutonic rocks do not differ greatly from each other, they simply have different grain sizes. Therefore, a mineralogical classification of volcanic rocks will have an equivalent classification of plutonic rocks.

While several igneous rock classification systems are available, the one which seems to be most universally accepted and is commonly used on geologic maps and in the literature follows the nomenclature provided by the International Union of Geological Sciences (IUGS) Commission of Petrography. This system is represented in Figures 3a and 3b on triangles which classify the rocks according to silica (quartz) content and feldspar content, in volume



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[1] Goldich 1938. Primary minerals are italic in this figure.
[2] After Jackson 1968. *= Hydroxy-Interlayered Vermiculite.

Fig 2: A comparison between the stability series of sand- and silt-size mineral particles and the weathering index series of clay-size mineral particles. The first series consists of primary minerals arranged (*from top to bottom*) in the order of their crystallization from molten material, and also in the order of decreasing ease of weathering. The second series consists of a condensed version of the first in which the positions of muscovite and quartz have been interchanged because of the greater stability in soils of clay-size mica. At the top and in most of the lower part of this series are secondary minerals.

[1] Goldich 1938. Primary materials are underlined in this figure.
[2] After Jackson. * = Hydroxy-Interlayered Vermiculite.

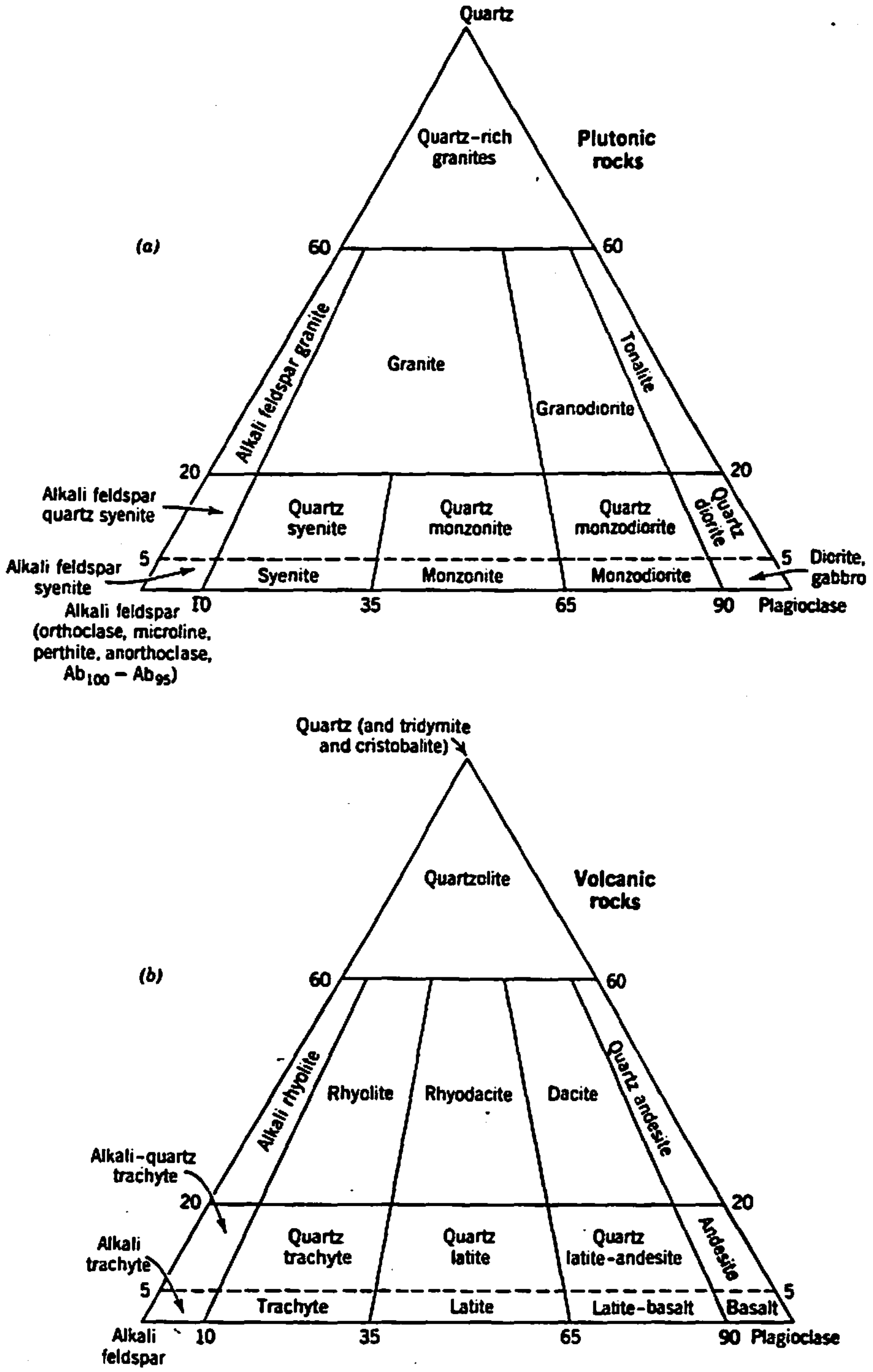

Fig 3: General classification and nomenclature of some common plutonic rock types *(a)* and some common volcanic rock types *(b)*. This classification is based on the relative percentages of quartz, alkali feldspar, and plagioclase, measured in volume percent (adapted from Subcommission on the Systematics of Igneous Rocks, *Geotimes*, 1973, v. 18, no. 10, pp. 26–30 and Hyndman, D. W., 1972, *Petrology of Igneous and Metamorphic Rocks*, McGraw-Hill Book Company, p. 35).

percent (from Hurlbut & Klein 1977). The feldspar may be of the K/Na variety (alkali) or the Na/Ca variety (plagioclasic). The base of the triangle shows the alkali (potentially high-K) rocks on the left, and the plagioclasic (definitely low-K) rocks on the right. The top of the triangle indicates high quartz percentage (definitely low-K), while the base indicates rocks lower in quartz (possibly higher-K). Hence, there is a gradual transition from potentially high- to definitely low- K rocks as we go across the triangle from left to right, and as we increase in quartz going from bottom to top. It should be noted that the placement of lines on this diagram is arbitrary, and that a great deal of variation occurs within and among these groups.

Again, for our purposes a geochemical description of the specific rock under scrutiny would be preferred. In lieu of that, a great number of publications are available which list average geochemical breakdowns for various igneous rock types (Dutro et al 1989, Hyndman 1972, Nockolds & Allen 1954). Using these figures in combination with the IUGS nomenclature system, a breakdown of igneous rocks into three K categories would be as follows:

Igneous Rock K-Groups

K-Group	Plutonic	Volcanic
High (Felsic, Acid)	Nepheline syenite	Phonolite
	Alkali granites, syenites	Alkali rhyolites, trachytes
	Granite	Rhyolite
	Quartz syenite	Quartz trachyte
	Syenite	Trachyte
	Monzonite	Latite
Medium (Intermed.)	Some lower-K granites	Rhyodacite
	Quartz monzonite	Quartz latite
	Granodiorite	Dacite
	Quartz diorites	Latite-andesites
	Monzodiorite, diorite	Latite-basalt

Low (Mafic, Basic)	Tonalite Low-K quartz diorites Gabbro, Anorthosite Peridotite, Pyroxenite	Quartz andesite Andesite Basalt

Modifiers may be used with any of these terms, and the modifiers will give more information based on mineralogy and/or texture. This is particularly important if we have no other geochemical/mineralogical information to work with, because addition of a modifier may allow us to better categorize a particular rock.

Sedimentary Rocks

Sedimentary rocks are the result of weathering of igneous, metamorphic and other sedimentary rocks (Blatt 1982, Pettijohn et al 1987, Hatch & Rastall 1971). They tend to be classified based on particle size and composition rather than mineralogical components, for several reasons. Since sedimentary rocks are the result of weathering of other rocks, the mineralogical components tend to be fairly regionalized according to the source rock type and degree and type of weathering. Mineralogical components of sedimentary rocks are often quite difficult to identify in the field, especially the potentially K-bearing clay minerals. A fairly standard breakdown of sedimentary rocks according to particle size is as follows:

Category	Rock Types
detrital rocks	mudstones, sandstones, other mixed types (conglomerates, breccias, volcanic detritus, tuffs, agglomerates)
carbonate rocks	limestones, dolomites
chemical precipitates	ironstones, evaporates, cherts, phosphates

For our purposes, sedimentary rocks of detrital origin will be of the most interest, both because these rocks comprise 80-90% of all sedimentary rocks, and because K minerals will primarily be found in this group. Volcanic tuffs may contain some K as well; the carbonate and chemical precipitates will generally not contain K minerals except as impurities. Within the detrital rock category, mudstones are most prevalent (65%), followed by sandstones (25%), and others (10%).

A review of available geochemical information on average sandstones and mudstones indicate that sandstones generally fall into the lower end of our medium-K category (Ave. K2O 2.1), while average mudstones fall into the higher end of our medium- K categories (Ave. K2O 3.2-3.3). However, as previously mentioned, the mineralogy of sedimentary rocks can be highly variable based on regional occurrences. For example, certain feldspathic sandstones can have K2O percentages as high as 4.30-4.80 (Pettijohn et al 1987), while certain quartz-rich mudstones can have K2O percentages as low as 0.69 (Crook 1974). Therefore, the detailed descriptions given on our geologic maps may be preferable for classifying sedimentary rock as high, medium or low K. In reading descriptions from geological maps, it would be a good idea to consult a dictionary of geologic terms, because there seems to be a great deal of variation in sedimentary terminology among the different authorities.

Generally speaking, sedimentary rocks will probably contain less K than our high-K group (i.e. the felsic (acid) igneous rocks) due to the mobility and instability of K minerals under weathering. Source materials are of primary interest to us when interpreting the K status of any sedimentary rock. For example, a granitoid source rock will more likely contain the K-feldspars, while a granodiorite or gabbro source rock will more likely result in plagioclase feldspars (Blatt 1982). We do know that K-feldspars, particularly microcline, are generally more abundant than the plagioclasic feldspars (Pettijohn et al 1972, Hatch & Rastall 1971). This is largely because plagioclases tend to break down more quickly than orthoclases. We also know that the K-feldspars weather to illite and sericite clays (alterations of muscovite); the plagioclase feldspars to montmorillonite (Blatt 1982). Both illite and montmorillonite weather to kaolinite, a K-poor clay. Other K-bearing clay minerals include phlogopite and biotite. Current climatic conditions (cool and temperate) favor the stability of the clay minerals. An interesting note regarding clays and geologic time: Illite forms about 25% of modern clay minerals, increasing to about 80% in the Paleozoic era. This is thought to be the result of diagenesis, or the conversion of alternating montmorillonite/illite clay sheets to pure illite under increasing pressure and temperature. We might take this one step further to infer that our pre-Mesozoic (including Precambrian) clays might also be higher in illite than our "newer" clays.

Mudstones include rocks of silt and clay composition, and may be categorized in order of increasing clay and decreasing silt content: siltstone (>2/3 silt), mudstone (1/3-2/3 clay), and claystone (>2/3 clay) (Blatt 1982). Illite, sericite, phlogopite, and biotite are K-bearing clay minerals which we would look for in classifying a mudstone. Silt-sized particles may also include K-bearing micas or feldspars. As far as placing a mudstone in a high-, medium- or low- K category, the modifiers listed in the field description will often help (for example, 'carbonaceous' would indicate low K). If the rock is known to exist from the Cambrian or preCambrian eras, we could classify it as medium-K. Given the general prevalence of K-feldspars which weather to illite, and the geochemical averages for mudstones which are in the medium category, in the absence of any identifiers, a mudstone would be classified as a medium-K rock.

Sandstones consist of grains, with or without a matrix or cement holding them together (Jenks 1996, pers. comm.). The grains may consist of rock fragments (lithic grains), quartz grains, and/or feldspar grains; some geologists include feldspar grains with the lithic grains. The grains may be loose, or may be held together by either a matrix (detrital material), a cement (chemical precipitate), or both. The three potential K sources include the detrital materials in the matrix (specifically clay minerals and feldspar or lithic particles), lithic grains, and feldspar grains. Lithic grains are often composed of micas, so they have a fair chance of containing K. Feldspar grains cannot be differentiated into potassic and plagioclasic types outside of a laboratory (Tucker 1982, Pettijohn 1972, Hatch & Rastall 1971). In the absence of a geochemical or petrographical description, we can look for several things. As previously mentioned, if we know a source rock, this would help us out. Any information about the quartz percentage would also help; a high quartz percentage would indicate a low-K rock. A low quartz percentage would indicate greater clay, feldspar and/or lithic percentages and would thus be a potentially higher-K rock. Modifiers such as micaceous, arkosic or feldspathic would be indicators of a lower quartz percentage and therefore a potentially higher-K sandstone. Given the broad geochemical average for sandstones and the knowledge that some sandstones in the Inland northwest are of the micaceous variety, we could cautiously place sandstones in the medium-K category, in lieu of other geochemical or mineralogical information.

Other sedimentary rocks in the detrital category include various mixes of weathered rocks (larger than sand-sized particles) from a variety of sources. They are classified based on origin, uniformity, texture, depositional mechanism, and presence or absence of a matrix. These detrital mixes consist of large clasts with or without a muddy or sandy matrix. The clasts may be of pebble size or larger, and they are often described as conglomerate if rounded, or breccia if angular. Other terms used in this category include agglomerates, tuffs and tills. If a volcanic source is known, then some information may be given as to whether the detrital material is of rhyolitic (higher K) or andesitic/basaltic (lower K) composition. If we know that a depositional rock group is primarily of intraformational (local) origin, then we could probably make a K-classification call based on the surrounding rock type. However, our experience indicates that within many depositional rock types (such as alluvial or glacial deposits), there can be a great deal of variability even within a small unit area. Therefore, if we have a geologic map unit indicating one of these detrital types and no detailed description, we really have no way of classifying these rocks.

Sedimentary Rock K-Groups

K-Group	Rock Type	Requisites and specific rock types
Sedimentary Med.	Mudstones	graywackes; K-clays (illite, sericite, phlogopite, biotite) predominant, or era Paleozoic and earlier, OR no other information available
	Clayey Sandstones	arkose, graywacke; modifiers micaceous, arkosic, feldspathic, lithic
	Volcanic	Rhyolitic detritus, tuffs
Sedimentary Low	Mudstones	graywackes, subgraywackes; K-clays not predominant; modifiers carbonaceous, siliceous
	Sandstones	arenite, quartzarenite; modifier quartz; anything with the prefix sub- (this indicates a high quartz percentage); OR no other information available

Volcanic	Andesitic detritus, tuffs
Carbonate rocks	limestone, dolomite
Chemical precipitates	Ironstones, evaporates, chert
Undefined detritus	Conglomerates, breccias, agglomerates, tuffs, tills

Metamorphic Rocks

Metamorphic rocks consist of igneous, sedimentary and other metamorphic rocks which have been transformed under high heat and pressure conditions to another rock type. 'Regional' metamorphism refers to large scale metamorphism, while 'contact' or 'local' metamorphism refers generally to metamorphism on a local scale, usually by contact with magma or lava from a local intrusion. The 'grade' of metamorphism is also often referred to; the higher the degree of pressure and temperature change, the higher the 'grade' of metamorphism. High grade metamorphic rocks have undergone high temperature and pressure changes, and low grade metamorphic rocks have undergone low temperature and pressure changes. During metamorphism, certain groups of minerals tend to occur repeatedly, and are known as 'mineral assemblages.' Metamorphic rocks are classified into groups known as 'facies' according to the development of these mineral assemblages. The key minerals of a facies are known as the 'index minerals.' Though a rock undergoing metamorphosis may progress through the various facies, the same elements that we started with will generally still be there following metamorphism. However, there is a process known as 'metasomatism' by which new replacement products known as 'skarns' may be produced during metamorphosis. Metasomatism occurs due to chemical reactions involving interstitial pore liquids or gases contained in the rock or introduced from outside the rock body. Metasomatism is often associated with faults and mineral ridge areas, and the replacement products may or may not contain K.

Textural terms used in conjunction with metamorphic rocks include hornfels, slate, phyllite, schist, and gneiss, which represent metamorphosed rocks of increasing grain size and layering from fine through coarse. The terms 'metacryst' and 'porphyroblast' refer to large crystals formed in metamorphic rocks by recrystallization. The term 'fabric' refers to the alignment of the grains in a rock. 'Schist' and 'gneiss' are fabric terms referring to how closely spaced the 'bands' or layers in a rock are, which in turn relate to the amount of mica or other platy minerals present. While not a rule, it is generally found that the schists (platy, narrower bands) are mica-rich and contain <20% feldspars, while gneisses (wider bands) contain >20% feldspar. If a metamorphic rock is known to have a sedimentary protolith, then the prefix 'para-' is used. If an igneous rock was the source, then 'ortho-' is used. So a gneiss of sedimentary origin is a paragneiss, and one of igneous origin would be an orthogneiss.

Unfortunately, none of these textural terms implies the presence of any characteristic minerals. If a rock is described simply as a 'gneiss' or a 'schist,' we have no way of classifying that for K content; in other words some descriptor of origin or mineral constituents is needed. If low-grade metamorphism occurred and the protolith is still identifiable, then we may classify a metamorphic rock according to its sedimentary, felsic igneous or mafic igneous parent rock. Unfortunately, more often than not the protolith is not identifiable, particularly if a rock has been highly metamorphosed. Therefore, we will more often have to depend on the geologic map description. Standard metamorphic nomenclature includes to a list of mineral constituents (the mineral assemblage) placed in front of the rock name. In order to be included in this mineral assemblage, a mineral must comprise more than 5% by volume of the rock. The minerals are then listed in front of the rock name, in order of decreasing content. For example, a K-bearing schist might be a 'biotite-garnet-staurilite schist (biotite is the primary constituent)', while a lower-K schist might be a 'quartz-mica-garnet schist (quartz is the primary constituent, followed by mica).' Due to the wide variety of potential mineral assemblages, only a few more common metamorphic rocks will be listed in the summary of K-classification by rock type.

Summary of K-groupings:

HIGH-K ROCKS: K2O > 3.50 % BY WEIGHT
LIKELY TO INCLUDE THE FOLLOWING ROCK TYPES:

Acid Igneous Rocks

Plutonic	Volcanic
Nepheline syenite	Phonolite
Alkali granites, syenites	Alkali rhyolites, trachytes
Granite	Rhyolite
Quartz syenite	Quartz trachyte
Syenite	Trachyte
Monzonite	Latite

MEDIUM-K ROCKS: K2O 1.76-3.50 % BY WEIGHT
LIKELY TO INCLUDE THE FOLLOWING ROCK TYPES:

Intermediate Igneous Rocks

Plutonic	Volcanic
Some lower-K granites	Rhyodacite
Quartz monzonite	Quartz latite
Granodiorite	Dacite
Quartz diorites	Latite-andesites
Monzodiorite, diorite	Latite-basalt

Medium-K Sedimentary Rocks

Rock Type	Requisites and specific rock types
Mudstones	Graywackes; K-clays (illite, sericite, phlogopite, biotite) predominant, or era Paleozoic and earlier, OR no other information available
Clayey Sandstones	Arkose, graywackes; modifiers micaceous, arkosic, feldspathic, lithic
Volcanic	Rhyolitic detritus & tuffs

Medium-K Metamorphic Rocks (partial list)

Rock Type	Requisites and specific rock types
Meta-mudstones	Argillite, slate, siltite
Metamorphics	Schists, phyllites, gneisses, etc., WITH modifiers indicating the presence of high-K minerals: biotite, muscovite, phlogopite, K-feldspars)

LOW-K ROCKS: K20 < = 1.75 % BY WEIGHT

LIKELY TO INCLUDE THE FOLLOWING ROCK TYPES:

Basic Igneous Rocks

Plutonic	Volcanic
Tonalite	Quartz andesite
Low-K quartz diorites	Andesite
Gabbro, Anorthosite	Basalt
Peridotite, Pyroxenite	

Low-K Sedimentary Rocks

Rock Type	Requisites and specific rock types
Mudstones	Graywackes, subgraywackes; K-clays not predominant, modifiers carbonaceous, siliceous
Sandstones	Arenite, quartzarenite; modifier quartz; anything with the prefix sub- (this indicates a high quartz percentage); OR no other information available
Undefined detritus	Conglomerates, breccias, agglomerates, tuffs, tills
Volcanic	Andesitic detritus & tuffs
Carbonate rocks	Limestone, dolomite
Chemical precipitates	Ironstones, evaporates, chert

Low-K Metamorphic Rocks (partial list)

Rock Type	Requisites and specific rock types
Meta-sandstones	Quartzites
Metamorphics	Schists, phyllites, gneisses, etc., WITH modifiers indicating the presence of low-K minerals: hornblende, chlorite, albite, epidote)
Hornblendite	
Actinolite	
Amphibolite	
Eclogite	
Greenschist	
Greenstone	

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Appendix: Calculation from Modes

Three methods for calculation of weight percent K2O from mineralogical analyses are given here. Method 1 is quicker, Method 2 is more correct. Results are comparable.

Method 1a: Direct conversion of mineral percentages to weight percentages using gravimetric factors (Dutro et al 1983)

This method entails the use of gravimetric conversion factors which are based on molecular equivalents of K2O in specific minerals. A list of gravimetric conversion factors for potassium-bearing minerals are given in Table A-1 (from Dutro et al 1983). This is the most straightforward method, and simply involves dividing the reported percentage of each constituent by its gravimetric factor in order to obtain the equivalent amount of K2O. An example follows:

Example 1a: From Table 1 on page 4, we have an approximate mineral composition for granite. Within the list of constituent minerals, we know that potassium occurs in orthoclase and biotite. We would convert to K2O as follows:

Mineral	Description	Gravimetric factor	% K2O
Orthoclase	40%	5.91	6.77
Biotite	5%	8.93	0.56
Non-K minerals	55%	0.00	0.00
		TOTAL K2O	**7.33%**

Method 1b: Conversion of mineral percentages to weight percentages using a breakdown of mineral constituents into individual oxide components (Holmes 1921).

This method consists of first assigning values to the individual components of the mineral constituents in a given rock, followed by the multiplication of that value by the reported total amount of that mineral in the rock (Homes 1921). Table A-2 (Grout 1932) lists the compositions of various rock minerals. NOTE: The values in Table A-2 are also based on either molecular weights or chemical analyses of the minerals. The equivalent gravimetric factor (such as that listed above) may be obtained by dividing 100 by the mineral % from Table A-2. (For example, Orthoclase: 100/16.9 = 5.917, Biotite: 100/11.2 = 8.93, etc.)

Example 1b: Using the same granite listed above and the values from table A-2, the following conversion would occur:

Mineral	Description	%K2O in mineral (Table A-2)	%K2O in rock
Orthoclase	40%	16.9	6.76
Biotite	5%	11.2	0.56
Non-K minerals	55%	00.0	0.00
		TOTAL K2O	**7.32%**

Method 2: Conversion of mineral percentages to weight percentages using specific gravity of the minerals (Holmes 1921), followed by use of method 1a or 1b above.
NOTE: This is the more correct method!

This method involves the conversion of mineral percentages in volume percent to weight percent estimates using specific gravities of the various minerals. Specific gravities are listed in most mineral indices (see Hurlbut & Klein 1989 or 1977). A weighted average is then compiled for the individual minerals, followed by use of either method 1a or 1b above. A number of 'trial runs' using this method indicated that there is minor variation from the use of straight volume percent values (Methods 1a and 1b above). This method is more involved than the first two because in order to derive weighted averages of the minerals, it is necessary to know all the mineral components of the rock. Following is an example using the same granite from Table 1, page 4:

Example 2:

Granite from Table 1		Conversion to Weight %			Method 1b		Method 1a	
Mineral	Vol.%	Sp.Grav.	Wt.	Wt%	Mineral comp.		Gravimetric	
Quartz	25	2.65	0.66	24				
Orthoclase	40	2.57	1.03	38	16.9	6.42	5.91	6.43
Oligoclase	26	2.65	0.69	26				
Biotite	5	3.00	0.15	6	11.2	0.67	8.93	0.67
Amphibole	1	3.10	0.03	1				
Magnetite	2	4.30	0.09	3				
Ilmenite	1	4.70	0.05	2				
TOTAL	100		2.70	100	**K_2O:**	**7.09%**		**7.10%**

Table A-1

AGI DATA SHEET 60.5

Constituent reported	Formula or atomic weight	Weight of one equivalent	Constituent sought	Gravimetric factor
Ga	69.72	23.24	Ga_2O_3	1.3442
Ga_2O_3	187.44	31.24	Ga	.7439
Ge	72.60	18.15	GeO_2	1.4408
GeO_2	104.60	26.15	Ge	.6941
H	1.0080	1.0080	H_2O	8.9365
H_2O	18.016	9.008	H	.11190
			O	.8881
			OH	1.8881
H_2S	34.082	17.041	S	.940
Hf	178.50	44.63	HfO_2	1.17
HfO_2	210.50	52.63	Hf	.848
Hg	200.61	(1 +) 200.61	HgCl	1.1767
			Hg_2O	1.0399
			Hg_2S	1.0799
		(2 +) 100.31	$HgCl_2$	1.3535
			HgO	1.0798
			HgS	1.1599
I	126.91	126.91	O (equivalence)	.06340
In	114.82	38.27	In_2O_3	1.2090
K	39.100	39.100	KCl (sylvite)	1.9068
			K_2CO_3	1.7674
			$KHCO_3$	2.5606
			K_2O	1.2046
KCl (sylvite)	74.557	74.557	K	.52443
			Cl	.47557
			K_2O	.63173
KNO_3 (niter)	101.11	101.11	K	.38671
			K_2O	.46583
			NO_3	.61327
K_2O	94.20	47.10	K	.83015
			KCl	1.5830
			$KAlSi_3O_8$ (orthoclase, microcline)	5.910
			$KAl_3Si_3O_{10}(OH)_2$ (muscovite)	8.457
			$KMg_3AlSi_3O_{10}(OH)_2$ (phlogopite)	8.860
			$KAlSi_2O_6$ (leucite)	4.634
			biotite (3)	8.93
La	138.92	46.31	La_2O_3	1.1728
La_2O_3	325.84	54.31	La	.8527
Li	6.940	6.940	Li_2O	2.153
Li_2O	29.88	14.94	Li	.4645
			$LiAlSi_2O_6$ (spodumene)	12.456
Mg	24.32	12.16	$MgCl_2$	3.916
			$MgCO_3$	3.467
			$Mg(HCO_3)_2$	6.018
			MgO	1.6579
$MgCl_2$	95.23	47.62	Mg	.25538
			Cl	.7446
$MgCO_3$ (magnesite)	84.33	42.17	Mg	.2884
			MgO	.4781
$Mg(HCO_3)_2$	146.36	73.18	Mg	.16662
			HCO_3	.8338

TABLE A-2 COMPOSITION OF ROCK MINERALS

(Modified from Hance)

Actinolite: 3.1—$(OH)_2Ca(Mg, Fe)_5(Si_4O_{11})_2$: CaO—13.0; MgO—15.0; FeO—12; SiO_2—58.0; H_2O—2.0.
Aegirite (acmite): 3.55—$NaFeSi_2O_6$: Na_2O—13.4; Fe_2O_3—34.5; SiO_2—52.1.
Albite: 2.63—$NaAlSi_3O_8$: Na_2O—11.8; Al_2O_3—19.4; SiO_2—68.8.
Almandite (garnet): 4.05—$Fe_3Al_2Si_3O_{12}$: FeO—43.2; Al_2O_3—20.5; SiO_2—36.3.
Alunite: 2.66—$KAl_3O_6H_6S_2O_8$: K_2O—11.4; Al_2O_3—37.0; SO_3—38.6; H_2O—13.0.
Analcite: 2.25—$NaAlSi_2O_6H_2O$: Na_2O—14.0; Al_2O_3—23.2; SiO_2—54.6; H_2O—8.2.
Andalusite: 3.18—Al_2SiO_5: Al_2O_3—62.9; SiO_2—37.1.
Andesine: 2.68—Ab_3An_2: Na_2O—6.9; CaO—8.3; Al_2O_3—26.6; SiO_2—58.2.
Andradite (garnet): 3.85—$Ca_3Fe_2Si_3O_{12}$: CaO—33.0; Fe_2O_3—31.5; SiO_2—35.5.
Anhydrite: 2.94—$CaSO_4$: CaO—41.2; SO_3—58.8.
Anorthite: 2.75—$CaAl_2Si_2O_8$: CaO—20.1; Al_2O_3—36.7; SiO_2—43.2.
Apatite: 3.20—$Ca_4(Ca, F)P_3O_{12}$: CaO—55.5; P_2O_5—42.3; F—3.8.
Augite: 3.31—complex: CaO—20.9; MgO—12.6; FeO—6.9; Fe_2O_3—4.6; Al_2O_3—7.4; SiO_2—47.6.
Barite: 4.45—$BaSO_4$: BaO—65.7; SO_3—34.3.
Bauxite: 2.48—$Al_2O_3{\cdot}2H_2O$: Al_2O_3—73.9; H_2O—26.1.
Biotite: 2.95—complex: K_2O—11.2; (Mg, Fe)O—19.2; Al_2O_3—24.4; SiO_2—43.1; H_2O—2.1.
Calcite: 2.72—$CaCO_3$: CaO—56; CO_2—44.
Chalcedony: 2.61—SiO_2; SiO_2—100.
Chlorite (penninite): 2.72—complex: MgO—19.5; FeO—23.2; Al_2O_3—16.5; SiO_2—29.2; H_2O—11.6.
Cordierite: 2.63—$H_2(Mg, Fe)_4Al_8Si_{10}O_{37}$: SiO_2—49.4; Al_2O_3—33.6; FeO—5.3; MgO—10.2; H_2O—1.5.
Corundum: 4.0—Al_2O_3: Al_2O_3—100.
Diopside: 3.33—$CaMgSi_2O_6$: CaO—25.8; MgO—18.6; SiO_2—55.6.
Dolomite: 2.84—$CaMgC_2O_6$: CaO—30.4; MgO—21.7; CO_2—47.9.
Enstatite: 3.17—$MgSiO_3$: MgO—40; SiO_2—60.
Epidote (pistacite): 3.38—$Ca_2(Al, Fe)_3HSi_3O_{13}$: CaO—23.5; Al_2O_3—24.1; Fe_2O_3—12.6; SiO_2—37.9; H_2O—1.9.
Fayalite (olivine): 4.14—Fe_2SiO_4: FeO—70.6; SiO_2—29.4.
Fluorite: 3.13—CaF_2: Ca—51.1; F—48.9.
Forsterite (olivine): 3.25—Mg_2SiO_4: MgO—57.1; SiO_2—42.9.
Gibbsite: 2.36—$Al(OH)_3$: Al_2O —65.4; H_2O—34.6.
Grossularite (garnet): 3.57—$Ca_3Al_2Si_3O_{12}$: CaO—37.3; Al_2O_3—22.7; SiO_2—40.0.
Gypsum: 2.32—$CaSO_4.2H_2O$: CaO—32.6; SO_3—46.6; H_2O—20.9.
Hedenbergite: 3.6—$CaFeSi_2O_6$: CaO—22.2; FeO—29.4; SiO_2—48.4.
Hematite: 5.1—Fe_2O_3: Fe—69.9; O—30.1.
Hornblende: 3.24—complex: CaO—5.8; MgO—8.3; FeO—22.1; Fe_2O_3—16.3; Al_2O_3—10.5; SiO_2—37.0.
Hypersthene: 3.45—$(Mg, Fe)SiO_3$: MgO—17.3; FeO—30.9; SiO_2—51.8.
Kaolinite: 2.62—$Al_2Si_2O_7.2H_2O$: Al_2O_3—39.5; SiO_2—46.5; H_2O—14.0.
Labradorite: 2.71—Ab_2An_3: Na_2O—4.6; CaO—12.3; Al_2O_3—30,0; SiO_2—53.1.
Leucite: 2.48—$KAlSi_2O_6$: K_2O—21.5; Al_2O_3—23.3; SiO_2—55.2.
Limonite: 3.8—$2Fe_2O_3.3H_2O$: Fe—59.8; O—25.7; H_2O—14.5.
Magnesite: 3.04—$MgCO_3$: MgO—47.6; CO_2—52.4.
Magnetite: 5.13—Fe_3O_4: FeO—31.0; Fe_2O_3—69.0 (or Fe—72.4; O—27.6).
Melilite: 3.0—$Na_2(Ca, Mg)_{11}$ $(Al, Fe)_4(SiO_4)_9$: Na_2O—4.3; CaO—31.3; MgO—8.4; Fe_2O_3—11.2; Al_2O_3—7.1; SiO_2—37.7.
Muscovite: 2.87—$(OH)_2KAl_3Si_3O_{10}$: K_2O—11.8; Al_2O_3—38.5; SiO_2—45.2; H_2O—4.5.
Nephelite: 2.6—$K_2Na_6Al_8Si_9O_{34}$: K_2O—7.7; Na_2O—15.1; Al_2O_3—33.2; SiO_2—44.0.
Oligoclase: 2.66—Ab_3An_1: Na_2O—8.8; CaO—5.2; Al_2O_3—23.9; SiO_2—62.1.
Opal: 2.1—$SiO_2.xH_2O$: SiO_2—85 to 97; H_2O—3 to 12.
Orthoclase: 2.56—$KAlSi_3O_8$: K_2O—16.9; Al_2O_3—18.4; SiO_2—64.7.
Pyrite: 5.03—FeS_2: Fe—46.6; S—53.4.
Pyrrhotite: 4.59—$Fe_{11}S_{12}$: Fe—61.5; S—38.5.
Quartz: 2.66—SiO_2: SiO_2—100.
Rutile (etc.): 4.2—TiO_2: TiO_2—100.
Serpentine: 2.56—$H_4Mg_3Si_2O_9$: MgO—43.0; SiO_2—44.1; H_2O—12.9.
Siderite: 3.86—$FeCO_3$: FeO—62.1; CO_2—37.9.

Sodalite: 2.3—$Na_4Al_3Cl(SiO_4)_3$: Na_2O—25.6; Cl—7.3; Al_2O_3—31.6; SiO_2—37.2.
Staurolite: 3.70—$HFeAl_5Si_2O_{13}$: FeO—15.8; Al_2O_3—55.9; SiO_2—26.3; H_2O—2.0.
Talc: 2.73—$(OH)_2Mg_3Si_4O_{10}$: MgO—31.7; SiO_2—63.5; H_2O—4.8.
Titanite: 3.52—$CaTiSiO_5$: CaO—28.6; TiO_2—40.8; SiO_2—31.7.
Tourmaline: 3.1—$R_9Al_3B_2(OH)_2Si_4O_{19}$: SiO_2—35 ±; B_2O_3—10 ±; Al_2O_3—30 to 43; (FeO.MgO)—15 ±; Misc.—5 ±.
Wollastonite: 2.85—$CaSiO_3$: CaO—48.3; SiO_2—51.7.
Zircon: 4.69—$ZrSiO_4$: ZrO_2—67.2; SiO_2—32.8.
Zoisite: 3.31—$HCa_2Al_3Si_3O_{13}$: CaO—24.6; Al_2O_3—33.7; SiO_2—39.7; H_2O—2.0.