Reactivity vs Solubility

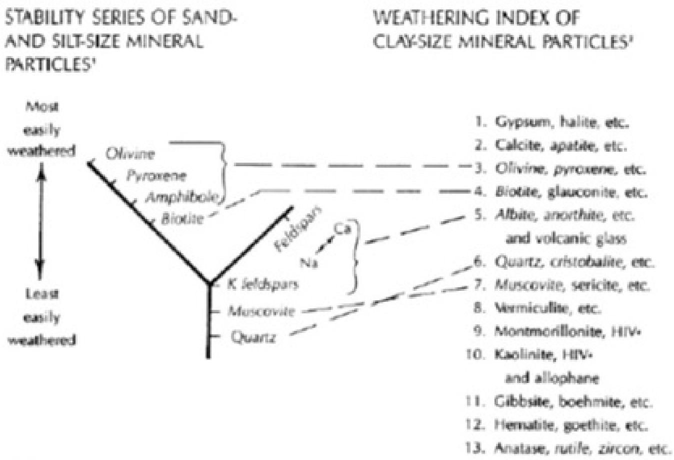
Historical Overview

"Weathering is the chemical and physical alteration of rocks and minerals at or near the surface of the earth because they are not in equilibrium with temperature, pressure and moisture conditions of their environment" (Birkeland 1974; Kittirk 1986; Marshall 1977). This results in the disintegration of the rocks and decomposition and/or modification of both primary and secondary minerals to more stable forms in their environment. "Primary minerals are those formed at high temperatures and/or pressure in igneous and metamorphic rocks whereas secondary minerals are those formed at low temperatures and pressures prevailing at or near the earth's surface in sedimentary rocks and in soils" [Jackson 1964a S.W. Buol, F.D. Hole, R.J. McCracken, Soil Genesis and Classification, Third Edition, 1989]. This explanation of mineral weathering is purely based on chemical processes influenced predominantly by the atmosphere and hydrosphere.

Soil minerals were arranged in an order of stability or weather ability. In 1938 Goldich proposed the "stability series" to describe the weather ability of common soil primary minerals. The "stability series" is roughly the inverse of Bowen's "Reaction Series", which describes the order in which minerals form in a cooling melt (molten rock derived from the Earth's crust and mantle). The least stable minerals are those that crystallize from the melt at the highest temperatures. Bowen concluded that greater instability was related to their greater disequilibrium with the environment (i.e. soil environments).

The second factor identified in Goldich's stability series was the Si:O ratio. Olivine has the lowest, while quartz containing the highest Si:O ratio at 0.5. Also, there is a reduction in hydrolysable bases, (Ca, Na, Mg, K) from least to most stable minerals.

Stability Series (pg.106, Soil Genesis and Classification, Third Edition*)*



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

Fig. 4.3. 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.

Geologists classify primary igneous rocks on rock chemistry and one of the more common classifications employed is the concentration of silica (SiO2).

Igneous Rock Classifications
(pg. 137 Principles of Mineralogy, Second Edition)

Highly Reactive — Non-reactive

	Ultramafic	Mafic	Intermediate	Felsic
Weight % SiO_2	45	52	66	

In addition, those rocks with total alkalies, Na2O and K2O which are high relative to silica content are described as alkaline. The term mafic (combination of magnesium and ferrum) includes minerals rich in iron and magnesium. The most reactive rocks (most easily weathered) are classified as **alkaline ultramafic rocks**. Alkaline ultramafic rocks are chiefly comprised of olivine, pyroxene, amphibole, biotite and iron minerals. High levels of base cations and low silica content characterize them. In the weathering process this group of rocks weather to very important secondary clay minerals (vermiculite, illite, montromillinite) and in the process give up calcium, magnesium, sodium, potassium and other metal cations.

Weathering historically has been classified either as physical or chemical. Physical weathering is the disintegration of rocks without any chemical or mineralogical changes. This can be caused by temperature fluctuations, freezing and thawing and root pressure. These physical processes have little direct effect on soil formation but indirectly make rock more susceptible to chemical weathering. Chemical weathering is a change in the chemical and/or mineralogical composition of rocks, minerals and soils. The chemical weathering reactions include oxidation, oxidation-reduction, reduction, hydrolysis, hydration, solution and chelation. In a soil profile all of these reactions are occurring simultaneously.

Igneous rocks and many metamorphic rocks contain iron and other transition metals in a reduced or semi reduced state. Common mafic minerals contain a great amount of reduced metals and when exposed to the oxygen bearing atmosphere generally will result in oxidation. Sedimentary rocks and soils have undergone at least one sedimentary cycle, resulting in most of the iron and transition metals occurring in a higher oxidation state.

Nutrient Availability – The Solubility Interpretation

Plant nutrient availability relies on a solubility analysis of potential inputs and soil conditions. This neither describes the availability of plant nutrients in the fertilizer or in the soils. Soluble fertilizers are in the highest state of oxidation and when applied to soils immediately want to reduce to stable secondary soil minerals. It is widely recognized that plant available nutrients applied as soluble fertilizer account for 50 to 70% for nitrogen, 10 to 15% for phosphorous and 20 to 25% potassium. This is further acerbated by soil acidification caused primarily through the long-term application of acidifying fertilizers that has increased soil oxidation processes. As soils age the essential clay components begin to transition to amorphous Mn and Fe hydroxides, the most aggressive elements at scavenging mobile elements.

Ironically, it is the acidifying nature of chemical fertilizers that results in accelerating this problem resulting in larger fertilizer applications to achieve the same yields further degrading an impacted soil.

The Agricultural Lime Index – Does it Really Determine the Effectiveness of Lime Sources?

Research conducted in the late sixties and seventies on the sorptive capacities of limestone in scrubbers showed that stones with similar chemistries didn't always produce similar results. According to Shaffer, similar stones can differ by more than a thousand percent in the amount of sulfur dioxide they can absorb.

To study the composition of limestone in detail, Shaffer employed an empirical "relative-reactivity test," which places careful controls on the chemical processes that take place during wet-scrubbing. "In this test," Shaffer explains, "limestone is the only variable, allowing us to see how certain properties increase or decrease its reactivity." Shaffer's data show that a complex of chemical and physical factors can affect a limestone's scrubbing capacity. Physical properties, including porosity and hardness or "grindability," significantly affects reactivity. Limestone must be crushed to a specified texture for use in a particular scrubber; stones that are too hard scrub less efficiently and cost more to grind.

Chemical properties such as the amount of magnesium contained in a limestone also affect its reactivity. Limestones that contain up to 5 percent magnesium work well, but if magnesium is present as dolomite, reactivity can be hurt.

Though nonreactive, under the analytical Ag Index test, dolomite would have the highest acid neutralizing value. Under reactivity tests, though, dolomite would be unable to perform this function. Relying on analysis alone does not determine the effectiveness of any mineral input; rock genesis, crystal structure and catalytic trace elements does.

Reactivity – A New Standard for Evaluating Mineral Input Effectiveness

Boreal's use of the term **"reactivity"** entails mineral dissolution and assimilation rates based on specific mineral deposits and the soil environment in which it is put into. The unique characteristics of a particular rock formation and dissolution rates within a soil profile is understood by:

1. **Mineral Genesis** – understanding the genesis of rock formations and the mineral constituents of the rocks have a direct bearing on weathering rates.
2. **Mineralogy and Crystal Habit** – crystal structure, hardness, cleavage, fracturing diagnostics, gravity, trace catalytic elements all effect reactivity and dissolution rates, (e.g. dolomite limestone are harder, heavier, have warped cleavage and are not as reactive as limestone).
3. **Microbial Influences on Dissolution** - micro organisms directly or indirectly will cause mineral assimilation or weathering orders of magnitude higher than model mineral analogy. An understanding of microbial weathering influences and mineral characteristics which aid in microbe colonization will help to predict mineral dissolution once in the soil system.

The Supremacy of Boreal Agromineral (BAM) – The Ultramafic Rock of Choice

Ultramafic rocks are referred to as alkalic or alkaline. Though they are rare, representing only 0.1% of all igneous rocks, they account for almost one third of all rock names; numbering more than 250. This is a testament to their mineralogical complexity and geological fascination. Their amazing diversity of chemical composition has resulted in challenging present theories on the genesis of igneous rocks. Understandably the definition of alkalic rock is open to criticism and confusion.

In brief the general characteristics common to all alkalic rocks and the overwhelming evidence of their role in developing the most vibrant landscapes on Earth are:

1. They usually occur on stable platforms behind active tectonic plates. Geologists believe it is one of the mechanisms that result in their highly explosive volcanism. It is no coincidence that great civilizations fed by immensely fertile soils flourished in the shadows of these sleeping giants. Some examples are:

    a. Researchers suggest that the vast savannas of Africa are supported by the active alkalic/carbonatite volcanic ash blowing in from the African rift valley. In fact the rich Nile flood plains, that supported ancient Egypt, was likely composed of complex alkalic rock flour sourced from the same active African rift valley.
    b. The overwhelming opinion of the Mt. Saint Helen eruption was it would take several hundred years to return to its former biological splendor. To everyone's astonishment life returned in short order and scientists are rewriting the rules of nature. Unfortunately this is lost on agriculture and the same deterministic assumptions prevail.
    c. Recently Boreal was asked to evaluate the geological circumstances that created the soil environment that grew the world renowned plum tomatoes of the San Marzano region in Italy. This investigation resulted in discovering that this world-renowned growing region is underlain by limestones influenced by adjacent basaltic to cabonatitic alkalic rocks. The geological settings of the great agricultural districts, (i.e. wines, cheeses, tomatoes), grasslands, migratory routes of land animals, birds and marine mammals contain the same geological similarities; carbonate terrain influenced by complex alkalic rocks through volcanism and weathering.

2. Their explosive genesis is due to their disproportionate concentrations of volatiles (CO_2, H_2O, etc.). It is believed that these stable rock platforms behind active plate boundaries would act like a cap allowing the build-up of volatiles inevitably leading to highly destructive eruptions.
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   a. Ca plays a critical role in the metabolism of all nucleated cells. The complex communication of the soil system is absolutely dependent on calcium. Without Ca soils cease to communicate.
   b. Calcium ions play a prominent role in the synthesis of mica type clays. Second to photosynthesis is the exchange reaction occurring in our soils. The ability of soils to efficiently transfer information, nutrients and recycle them is reliant on the health of soil clays, where calcium plays a critical role.
   c. Active calcium carbonate is the one chemical constituent generally associated with food quality. Calcium is sited over every other mineral deficiency.

4. Disproportionate levels of lithophile elements, (those with a strong affinity for oxygen with a greater free energy of oxidation). Alkalic rocks are by far the most reactive, as well as the hydrolysable bases present. Lithophile elements accelerate mineral weathering.
5. All alkalic rocks have high levels of rare earths. When Boreal began studying alkalic rocks and the catalytic effect of rare earths on plants we found the Chinese have been using rare earths in fertilizers. Their results showed stronger plants, disease suppression and increased seed production.