

The Rock Cycle: the rocks are alive: if only we could “hear” them, what have they to tell us?

by

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Summary

This article attempts to elucidate what rocks are telling us, amongst which are:

(i) they are alive;

(ii) they strive for balance between opposites (polarity), an important factor in physical creation;

(iii) they strive for perfection culminating in a single DNA-like helix, i.e. intensification;

(iv) their evolution progresses towards increasing complexity and diversity, more sharing, cooperation, accomodation, and flexibility, and overcoming higher repulsion creates stronger bonds;

(v) warmth/love creates an environment for creativity.

The Rock Cycle exhibits: (a) directionality, (b) Spirit Beholding and Spirit Recollection, and (c) Heredity following the First Karmic Law.

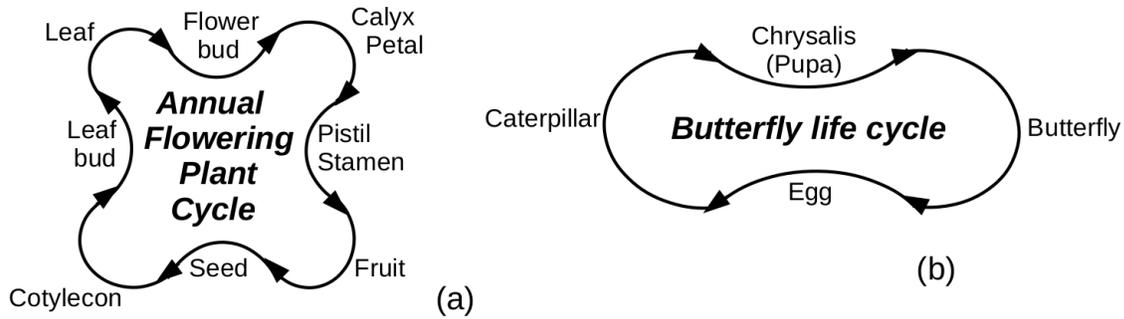
Each reader is encouraged to elucidate what the rocks are saying.

Introduction

UPPER CASE ITALICS alert the reader to topics elaborated in the last section of this article.

Previous research (Keppie, 2018) indicated the similarity between the Rock Cycle and both the Plant and Animal cycles (Fig. 1a, b, and c), and suggested that they are all alive. Whereas this is clear for the Plant and Animal cycles, rocks are commonly regarded as dead, a result of the relatively short life span of humans (≤ 120 years) compared to the millions of years for rocks to go round the Rock Cycle. As recognized by Goethe (summarized by Steiner, 1988, and Ballivet, 1995), the ideal Rock Cycle evolves through magma, igneous, sedimentary and metamorphic rocks and back to magma, although shortcuts may occur. The classification of rocks (Fig. 1c) has been extensively described (e.g. Goeke, 2002), and as this article involves the spiritual scientific aspects of rock-forming processes, the physical rocks scheme is only briefly reviewed in this article. In a spiritual scientific context, the Rock Cycle involves two processes, *SPIRIT BEHOLDING AND SPIRIT RECOLLECTION* (Steiner, 1913, 1922; Morelli, 2015).

The Rock Cycle involves 1st order alternations of contraction (crystallization of igneous rocks from magma, and recrystallization of metamorphic rocks from sedimentary and igneous rocks) and expansion (transformation of igneous minerals during physical and chemical weathering to form sedimentary rocks, and melting of rocks to form magma) = *POLARITY*. Concurrently, alternations occur in the number of mineral varieties and rock types (Fig. 1c): from a single homogeneous fluid that crystallizes to form 6 basic mineral families and ~8 common, igneous rock types, which reduces to three mineral families (quartz, clay and carbonate) and three common sedimentary rocks that grade between shale/mudstone, sandstone/conglomerate and chemical rocks, increasing to ≥ 10 mineral families and ≥ 8 common rock types in metamorphic rocks, and reducing to a single fluid upon melting (magma). 2nd order contractions and expansions (*POLARITY*) occur during the crystallization and recrystallization of individual minerals and follow a well-defined sequence: in igneous rocks the sequence is olivine, pyroxene, amphibole, biotite, K-feldspar, muscovite, quartz (Fig. 2). The sequence of recrystallization during weathering progresses in the same sequence (Fig. 2). On the other hand, recrystallization generally occurs in the reverse sequence during metamorphism and melting, i.e. *SPIRIT RECOLLECTION* (Figs. 1c and 2). During igneous crystallization and weathering, the energy derives from an internal source, whereas metamorphic recrystallization and melting require energy (heat and pressure) from an external source. This article delves more deeply into the Rock Cycle.



SEDIMENTARY (Stratified):
 Minerals: *quartz, clay, carbonate*
 Rocks: Shale, mudstone, siltstone, sandstone, conglomerate, limestone, dolostone, evaporite, coal

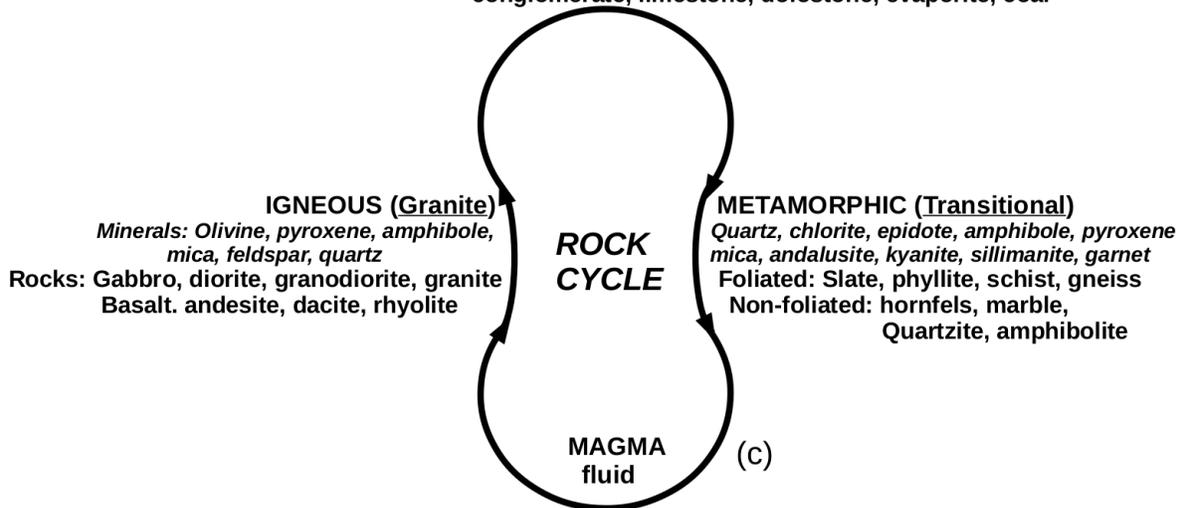
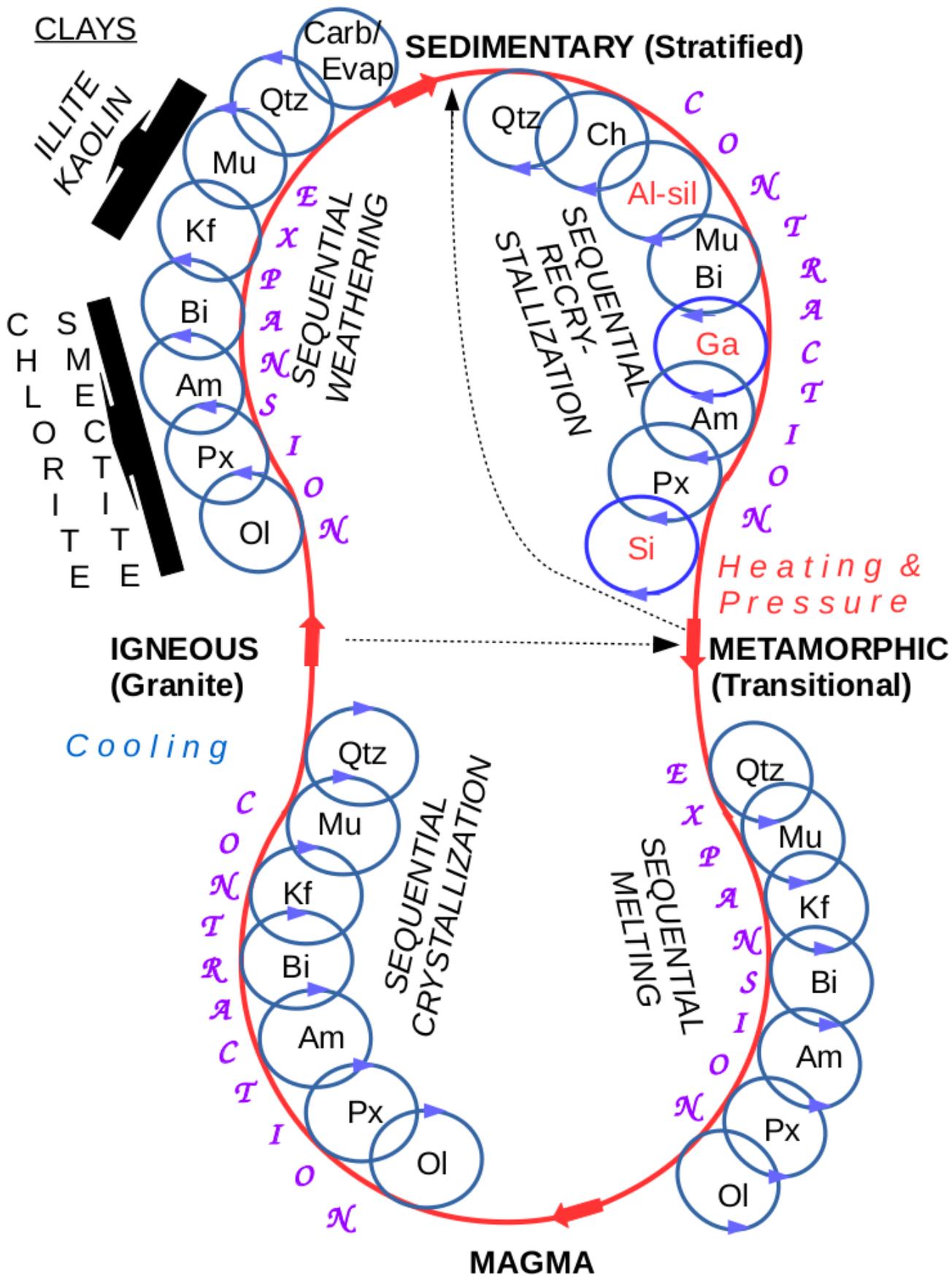


Figure 1. Comparison of examples of the life cycles of plants, animals and rocks showing 1st order alternating expansion and contraction, i.e. polarity:
 (a) annual flowering plant cycle; (b) butterfly life cycle, and (c) rock cycle showing main categories (UPPER CASE: modern terms, Underlined: Goethean terms: Steiner, 1988; Ballivet, 1995), common mineral families in *italics*, common rock types in upper and lower case

Figure 2. Rock cycle showing 1st- and 2nd-order stages with directionality (red and blue arrows) and pulsating volume changes (polarity). The 1st-order stages rotate from cooling of the magma through igneous to sedimentary (red outline), and heating/pressure from sedimentary through metamorphic to magma, and involve alternating expansion and contraction (Goethean terms are in parentheses). 2nd-order stages show sequential crystallization of different igneous mineral families from the magma, sequential weathering of different igneous mineral families to clays, sequential recrystallization to metamorphic mineral families, and sequential melting of different mineral families: individual mineral growth is illustrated as clockwise or anticlockwise blue circles either within or outside the main cycle (red) depending on whether the process involves expansion or contraction. Note the symmetry in contraction and expansion, the sequential appearance of different igneous minerals is in the same sequence during weathering (common rocks are illustrated – carbonates involve different minerals not illustrated here). Dotted lines indicate shortcuts in the cycle. Note that quartz survives throughout the 1st-order cycle. Ol = olivine, Px = pyroxene, Am = amphibole, Bi = biotite, Kf = potassium feldspar, Mu = muscovite, Qtz = quartz, Al-sil = aluminosilicate; Ga = garnet, Si = sillimanite.



CLAYS

ILLITE
KAOLIN

CHLORITE
SMECTITE

SEDIMENTARY (Stratified)

SEQUENTIAL
WEATHERING

SEQUENTIAL
RECRYSTALLIZATION

Heating &
Pressure

IGNEOUS
(Granite)

Cooling

METAMORPHIC
(Transitional)

MAGMA

Carb/
Evap

Qtz

Mu

Kf

Bi

Am

Px

Ol

Qtz

Ch

Al-sil

Mu

Bi

Ga

Am

Px

Si

Qtz

Mu

Kf

Bi

Am

Px

Ol

Qtz

Mu

Kf

Bi

Am

Px

Ol

Hierarchical structure of rocks

Rocks are made up of minerals, which, in turn, are composed of crystals, molecules, and, in the Standard Model, atoms and fundamental particles (Fig. 3). Fundamental particles include fermions or matter/antimatter particles (quarks, leptons, antiquarks and antileptons), and bosons or force particles (gauge bosons and Higgs bosons) that mediate interactions among fermions and their constituents (nucleus, proton, and electron)(Briabant et al., 2012).

In the late 19th and early 20th centuries, the reality of atoms was controversial with Steiner (1890, 1919), among others, arguing that “atoms are to be regarded as ideal contents of space” and not merely motion, whereas some leading physicists regarded atoms as mathematical illusions and matter as merely energy (Newburgh et al., 2006). At the end of the 19th century, light was thought to consist of waves of electromagnetic fields, whereas matter was thought to consist of localized particles. On the other hand, Planck (1909) and Einstein (1905a and b) proposed that light was transmitted in discrete quanta of energy (light quanta), now called photons. Soon afterwards Einstein (1905a and b) and Perrin (1909) show the reality of atoms and measured their motion in liquids. De Broglie (1925) showed that all matter can exhibit wave-like behaviour (Fig. 4). Quantum mechanics gave rise to the Uncertainty Principle (Heisenberg, 1925), in which position and momentum (=mass x velocity) cannot be simultaneously known to arbitrary precision, i.e. the more precisely the position of a particle is given, the less precisely its momentum can be determined. This paradox continues today in that as many physicists think that “particles” are not things at all, but rather are either excitations in a quantum field or bundles of properties (Kuhlmann, 2013). With respect to light, this dilemma has been elegantly elaborated by Zajonc (1993). Clearly, this is beyond the scope of this article in which I will use the the Standard Model, however, I concur with Steiner (1890) when he says “If motion occurs, there must be something that moves”. The reality of atoms and their motions also applies in crystals, as stated by Downs et al. (1992) that atoms “are never at rest but are in perpetual oscillatory motion about their equilibrium positions with their mean square displacement amplitudes increasing with temperature”. Furthermore, such studies indicate that the Si and O atoms move in tandem along each SiO bond moving back and forth about their equilibrium positions: *BALANCING POLARITIES*.

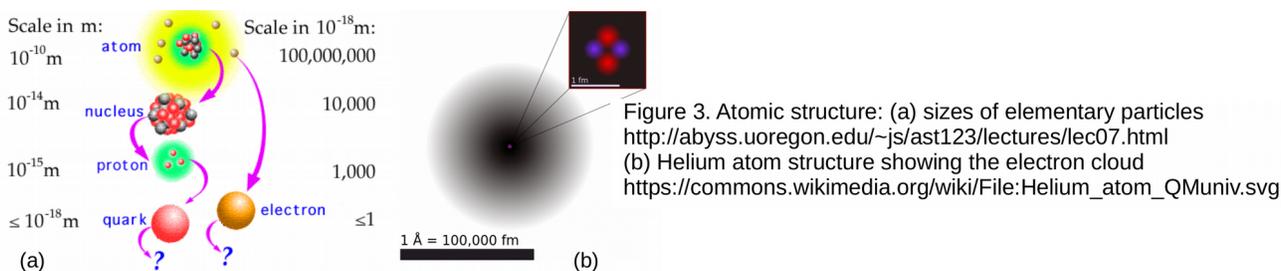


Figure 3. Atomic structure: (a) sizes of elementary particles <http://abyss.uoregon.edu/~js/ast123/lectures/lec07.html>
 (b) Helium atom structure showing the electron cloud https://commons.wikimedia.org/wiki/File:Helium_atom_QMuniv.svg

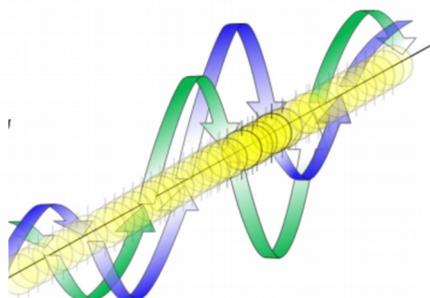


Figure 4. All particles show both wave and particle properties, i.e. wave-particle duality: real part of complex amplitude (blue), imaginary part is green. The probability (colour opacity) of finding the particle at a given point is spread out like a waveform; there is no definite position of the particle. https://commons.wikimedia.org/wiki/File:Propagation_of_a_de_broglie_wave.svg

Crystal Structure

As crystal structure provides a basic building block for crystals, a brief summary is provided here – for further information see <http://www.gly.uga.edu/railsback/FundamentalsIndex.html>, and Mattioli and Teng (2009). The discovery of X-ray diffraction by Röntgen (1895) made it possible to determine the crystal structure. The chemistry and quantity of each mineral is dependent on abundance of elements in the Earth's crust: silicate minerals are most common in the earths' crust because they are composed of Oxygen (abundance = 47%) and Silicon (28%), followed by aluminum (~8%), iron (~5%), calcium (~4%), sodium (~3%), potassium (~3%), and magnesium (~2%), totalling ~99%. The arrangement of atoms in a crystal, coordinated by larger anions like oxygen, depends on the relative sizes of the cation to the anion (R_x/R_z , radius of cation to radius of anion). X-ray diffraction determined that there are six possible geometries (Fig. 5): line, triangle, tetrahedron, octahedron, cube, irregular, i.e. cubic and hexagonal based on close packing (Mattioli and Teng, 2009). The most common silicate geometries are tetrahedra that may be: island (nesosilicates), double islands (sorosilicates), rings (cyclosilicates), single and double chains (inosilicates), sheets (phyllosilicates that may include both tetrahedra and octahedra), and frameworks (tectosilicates).

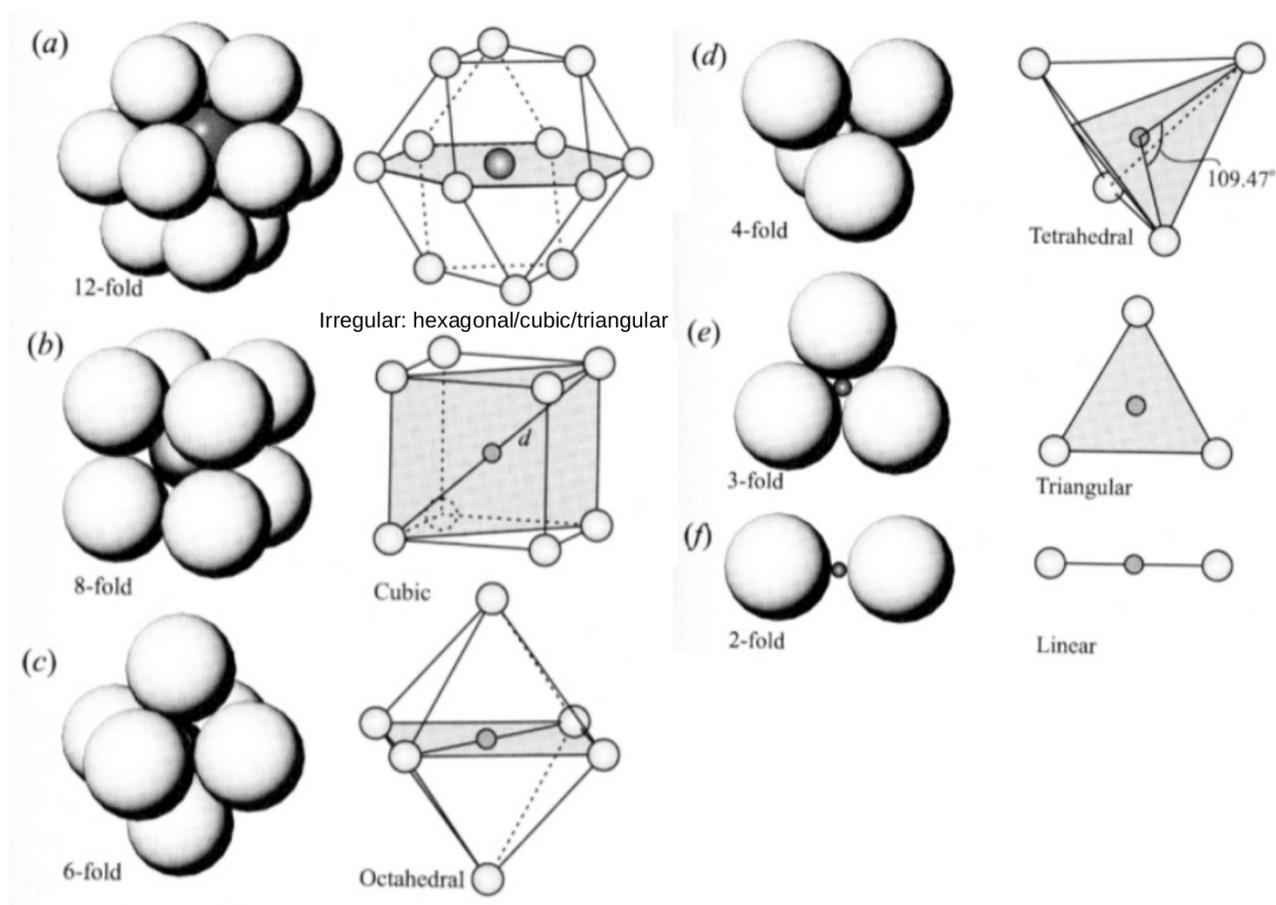


Figure 5. Six basic geometries of crystal structure depicted using packing of atoms and ball-and-stick

As silicates are the most common mineral in the earths' crust: Figure 6 shows the periodic table highlighting elements that are common in the silicates and trends in some of the physical properties, e.g. atomic radius (size), electronegativity (nucleus-electron attraction, etc.). Atomic radius is half the distance between two identical atoms touching each other (<https://sciencenotes.org/periodic-table->

trends/). The periodic table shows each element by atomic number, which increases by one with the addition of one more proton and electron: the atomic number increases from left to right in each row, and from top to bottom in each column. The electrons are attracted strongly to the positive charge in the nucleus, pulling them closer to the centre and effectively making the atom smaller with the addition of each proton. From top to bottom, the valence (charge) of the the atom remains the same, but there are more filled electron shells between the outer electrons and the positive nucleus.

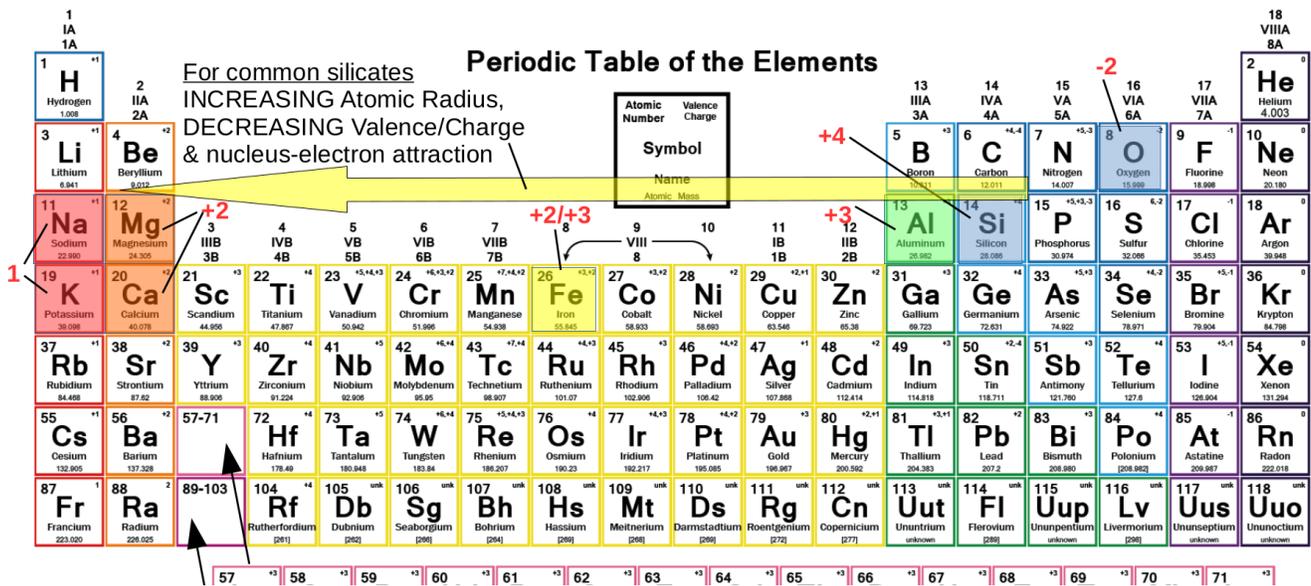
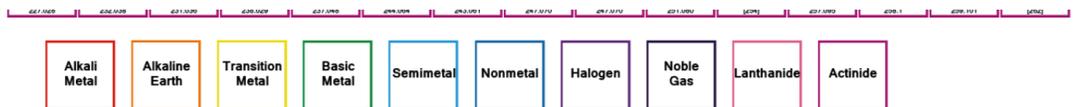


Figure 6. Periodic table highlighting elements that form the common rock-forming silicates and trends in atomic radius, valence/charge and nucleus-electron attraction.
<https://sciencenotes.org/printable-periodic-table/>



The silica tetrahedron has strong covalent Si-O bonds, in which (a) silica has a small atomic radius and positive charge of Si^{+4} , (b) oxygen has a large atomic radius and a negative charge of O^{-2} and occupy the four corners of the tetrahedron, with (c) the -4 imbalance being resolved by other elements, e.g. 2Fe^{+2} , 2Mg^{+2} , 2Ca^{+2} as in olivines and pyroxenes: where large single charge elements occur, such as Na^{+1} and K^{+1} , the imbalance adds a substitution of triple charge elements, Al^{+3} and Fe^{+3} for Si^{+4} as in amphibole and biotites. In silicates lacking Fe and Mg, Ca^{+2} , Na^{+1} and K^{+1} combine with Al^{+3} substitution of Si^{+4} , e.g. feldspars and muscovite. In crystals these structures are arranged in regularly-repeating unit cells that give rise to eight crystal systems: cubic, hexagonal, trigonal (hexagonal, rhombohedral), tetragonal, orthorhombic, monoclinic, triclinic (Oklahoma University, 2016). With this background, let us uncover the reasons for the observed ordered crystallization of minerals found in nature (Fig. 7).

<u>MINERAL</u>	<u>Melting Temperature (°C)</u>	<u>Bond length (Å)</u>	<u>Crystal structure</u>	<u>Crystal habit</u>	<u>Crystal system</u>	<u>Photograph</u>
Olivines	1800	1.6-2.8	Island tetrahedron	Prismatic	Orthorhombic	
Pyroxenes	1300	1 – 2.6	Single Chain	Prismatic	Orthorhombic Monoclinic	
Amphiboles	1200	2-2.1	Double Chain	Prismatic Needles	Orthorhombic Monoclinic	
Micas: Biotite Muscovite	750-950 1250-1300	1.7/2/3 1.6	Sheets	Pseudohexagonal	Monoclinic	
Plagioclase (anorthite) (albite)	1550 1100	1.6-1.8 1.5-1.8	Framework Framework	Prismatic Prismatic	Triclinic	
K-feldspar	1000	1.6-1.8	Framework	Prismatic	Monoclinic	
Quartz	700	1.6	Framework	Prismatic	Trapezohedra	
Andalusite	NA	1.9	Island tetrahedron	Dipyramid	Orthorhombic	
Kyanite	110	1.8-2	Island tetrahedron	Columnar	Triclinic	
Sillimanite	1810	1.6-3	Island tetrahedron	Prismatic Fibrous	Orthorhombic	
Garnet	1300	0.5-1.5	Single Tetrahedron Octahedron Δ-dodecahedron		Cubic	

Bond length is inversely related to bond strength by a power law
 Å = ångström, a physical unit of length

Figure 7. Properties of common mineral families

Igneous Rocks

In 1922, Bowen published a paper outlining his observations that minerals crystallize from a magma in three series: discontinuous, continuous and spinels, where crystallization occurs in a specific sequence with gradual substitution of one element for another in each mineral family (Figs. 8, 9, and 10). This sequence was derived by observing the shapes and texture of each mineral in the rocks.

1. Mineral families in the *discontinuous* reaction series are olivines, pyroxenes, amphiboles, biotites, (where some Mg replaces Fe and some Na is replaced by K), potassium feldspars, muscovites, and quartz.
2. Plagioclase feldspars form the *continuous* reaction series with Ca gradually replaced by Na (Fig. 10).
3. Spinel (oxides: chromite, magnetite etc.), zircons – as these minerals are accessories they will not be treated in this article.

Igneous rocks are classified according to their chemical/mineral composition: felsic (feldspar and quartz/silica, i.e. light coloured minerals), intermediate, mafic (magnesium or iron/ferrum: i.e. dark coloured minerals, such as olivine, pyroxene, amphibole), and ultramafic. They are also classified based on their texture/grain size: coarse- through medium- to fine-grained, and glass. This gives rise to a numerous names (Fig. 9) – for a comprehensive review see Goete (2002).

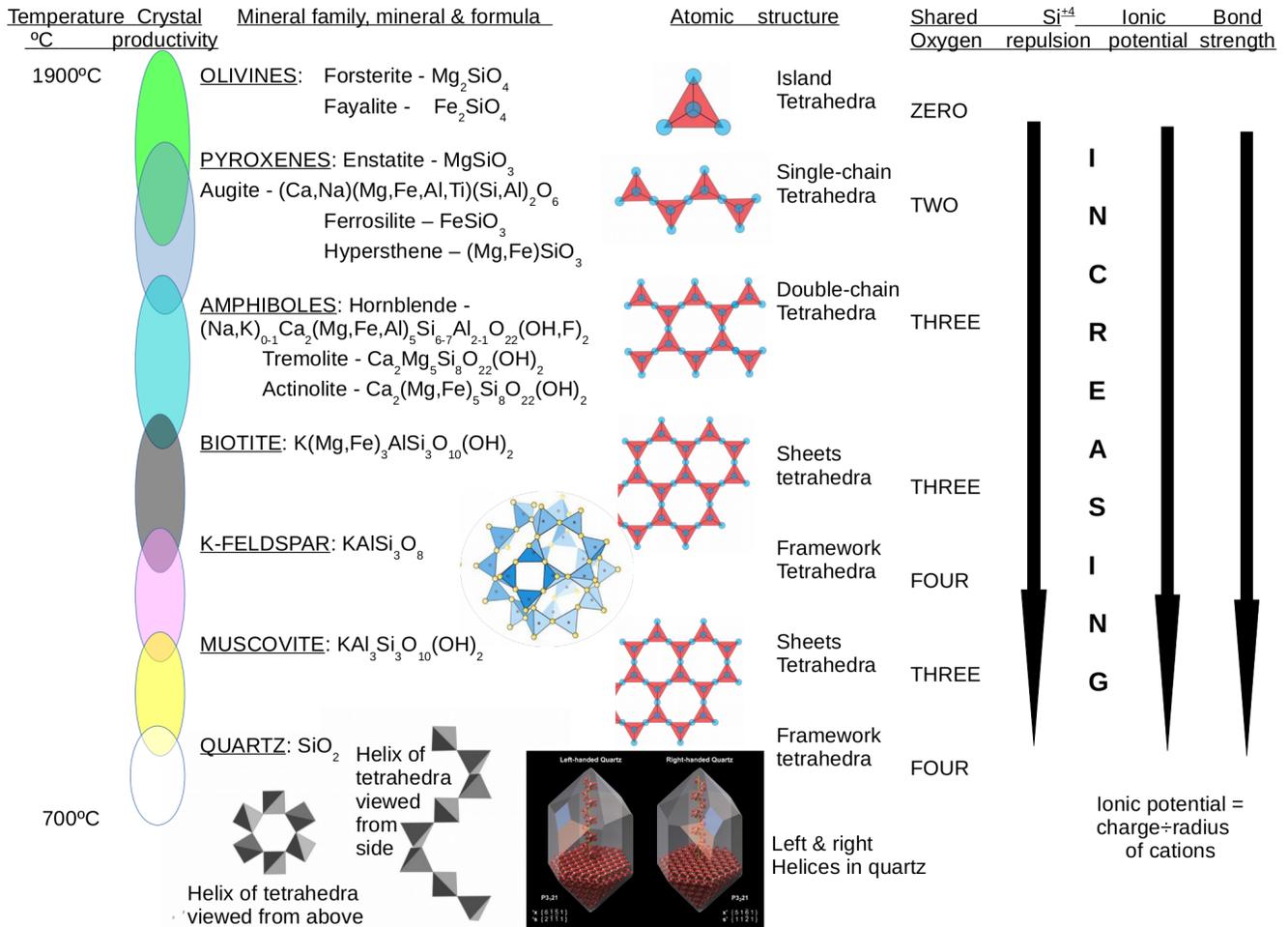


Figure 8. Attributes of Mineral families. Ellipses show pulsating crystal productivity. Triangles depict tetrahedra (c.f. Fig. 5)

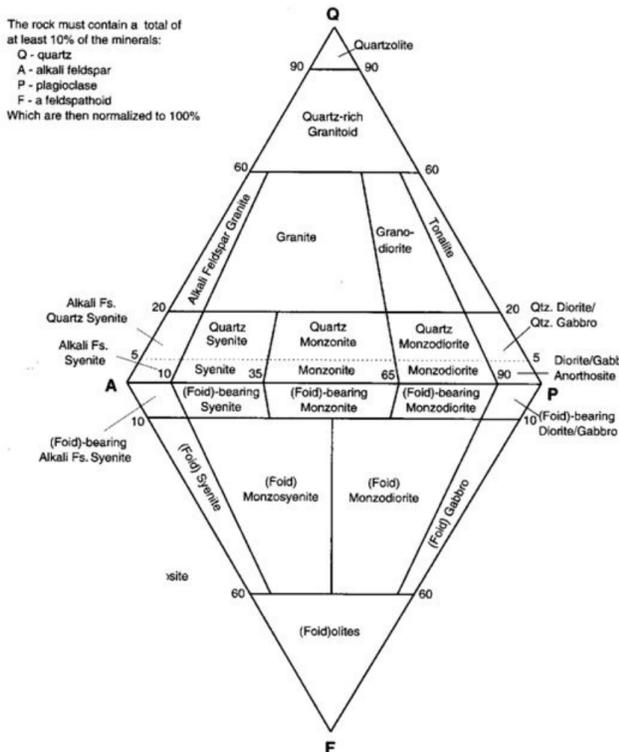


Figure 9. IUGS classification of igneous rocks.

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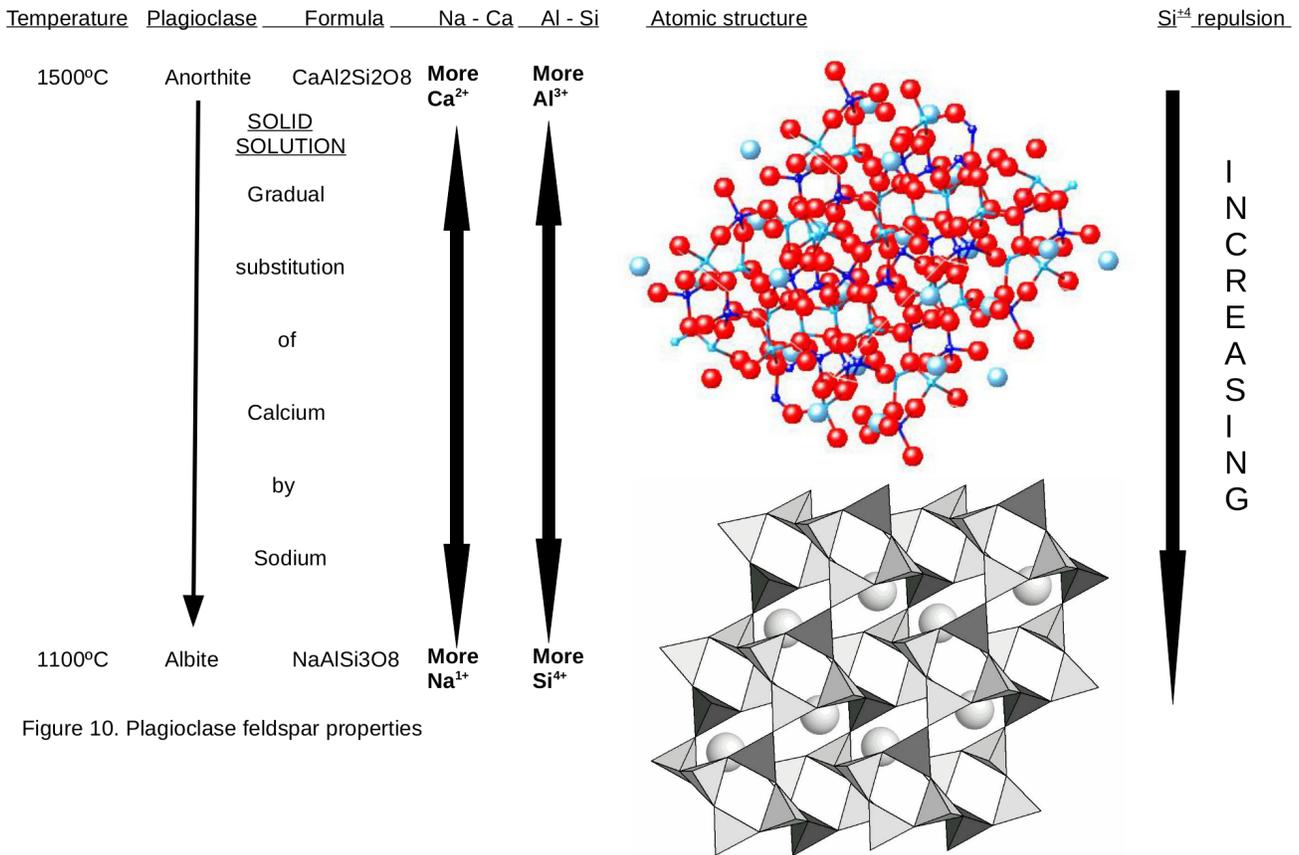


Figure 10. Plagioclase feldspar properties

Wyllie (1963) and Morse (2011) have shown that during cooling of the magma, crystal productivity is initially rapid slowing down with time, however, this is modified by the gradual replacement of one element for another – depicted as circles in Figure 2 and as ellipses in Figure 8 for the discontinuous mineral series. An examination of figure 8 shows the following trends in the discontinuous reaction series as the crystallization temperature decreases:

- (i) pulsating production of crystals of each mineral family: *BALANCING POLARITIES*;
- (ii) increasing sharing of oxygen atoms between tetrahedra ± octahedra ranging from zero (olivine islands) through one (pyroxene single chains), two (amphibole double chains), three (mica – biotite & muscovite - sheets), to four (potassium feldspar and quartz frameworks): *INCREASING SHARING AND COOPERATION WITH EVOLUTION*;
- (iii) increasing size (atomic number) of the elements that make up the crystals: *INCREASING COMPLEXITY*;
- (iv) decreasing charge from Fe⁺² through Mg⁺², Ca⁺², Na⁺¹ to K⁺¹ accompanied by substitution of Al⁺³ for Si⁺⁴: *INCREASING DIVERSITY AND ACCOMMODATION*;
- (iv) increasing repulsion, ionic potential, and bond strength between silica, Si⁴⁺: *OVERCOMING INCREASING RESISTANCE TO SHARING AND COOPERATION BUILDS STRONGER RELATIONSHIPS*;
- (v) SiO₂ shows the following attributes as temperature decreases: (a) SiO₂ crystals increase in density, (b) vibrations of the atoms in the crystal lattice decrease, and (c) a transformation occurs from cubic crystallobite sheets through hexagonal β-quartz sheets at ca. 1050°C to trigonal α-quartz frameworks at 570°C, the latter developing both right- and left-handed, 3-fold and 6-fold helices that show elastic properties (Heaney, 1994; Levien et al., 1980). As α-quartz is the last mineral to crystallize, it adjusts its' shape to fill the remaining spaces: *EVOLUTION APPROACHING DNA*

DOUBLE HELIX IN HUMANS & ACCOMMODATION TO OTHERS, STRONGEST BONDS FORMED WHEN STRONGEST RESISTANCE IS OVERCOME.

An examination of figure 10 shows the following trends in the continuous reaction series as the crystallization temperature decreases - this only involves plagioclase:

- (i) the gradual replacement of calcium (Ca^{2+}) by sodium (Na^{1+}), the disparity in the charge being balanced by an increasing replacement of alumina (Al^{3+}) by silica (Si^{4+}). Ca^{+2} is the most abundant +2 cation of sufficiently low ionic potential that it can be tolerated in a structure with so much Si^{+4} : *INCREASING DIVERSITY, WHILE MAINTAINING BALANCE*;
- (ii) increasing repulsion between Si^{4+} : *OVERCOMING INCREASING RESISTANCE TO SHARING AND COOPERATION BUILDS STRONGER RELATIONSHIPS*;
- (iii) the framework structure of plagioclase allows it to be elastic: *FLEXIBILITY AND ACCOMMODATION*.

Weathering and Sedimentary rocks

It is a wonderful revelation that the susceptibility to weathering and recrystallization occurs in the same sequence as that observed in igneous rocks (Fig. 11): *HEREDITY PARALLELS THE FIRST KARMIC LAW* (Steiner, 1906). This is due to the fact that early formed minerals have the weakest bonds, and the lowest Gibbs energy. A negative Gibbs number indicates a favourable reaction as the mineral “wants” to move towards a lower state (i.e. near surface temperatures and pressures) with its’ value giving the energy released from the reaction (Fig. 12). Chlorite and clays are the weathered products having a structure that includes sheets of both tetrahedra and octahedra (Fig. 12). Quartz (α -quartz) is the most stable mineral and although it is separated from the igneous and metamorphic rocks by physical forces forming sand grains, it survives chemical weathering.

Thus, there are three main mineral families, quartz, clay and carbonate, which result in three end-member sediments: sand, mud, and carbonate, which grade between one another (Fig. 13). Upon compaction, these become the following rock types: sandstone, mudstone/shale and carbonate, which also grade between one another. There is one relatively less abundant sedimentary rock group (biological), within which occur coal and chert.

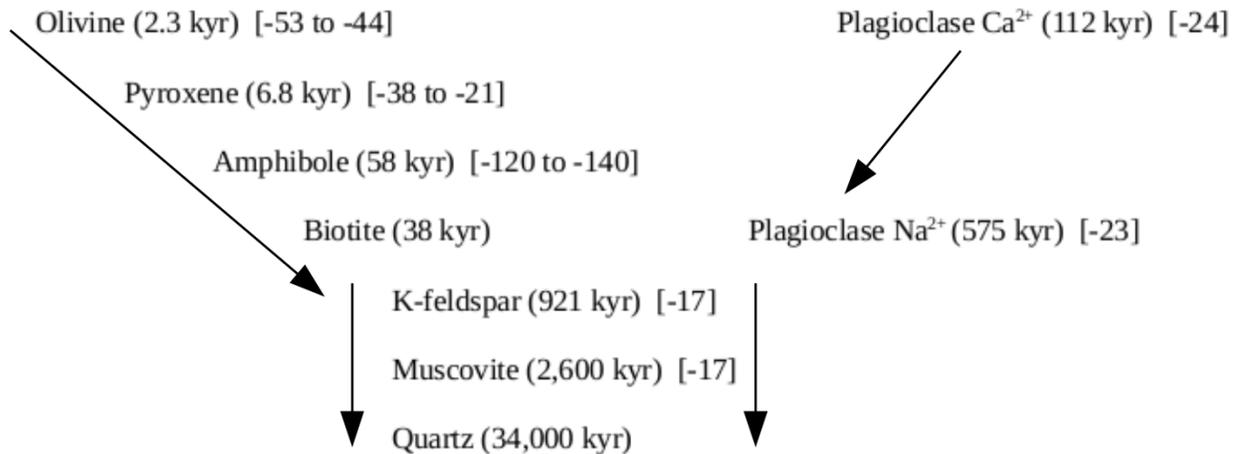


Figure 11. Susceptibility to weathering of the different mineral families varies with Gibbs energy. () parentheses are the lifetimes in thousands of years. [] Change of Gibbs energy in kcal/mol: negative indicates spontaneous reaction. Both increase from top to bottom,

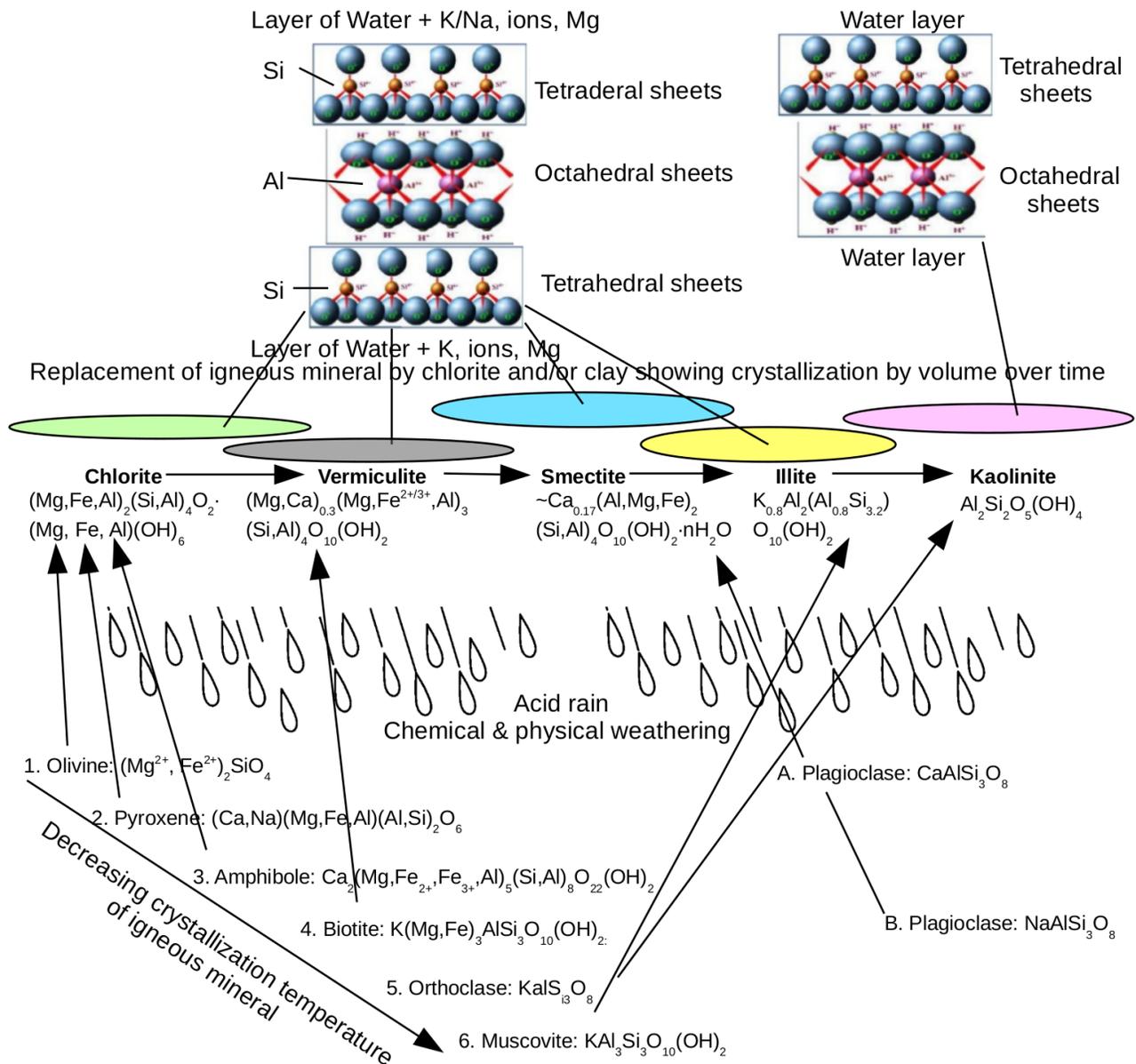


Figure 12. Sequential recrystallization of igneous minerals into chlorite & clay parallels the decreasing temperatures of initial igneous crystallization (1->8). Chlorite & clays form tetrahedral & octahedral sheets during weathering near the earth's surface. Ellipses depict pulsating growth.

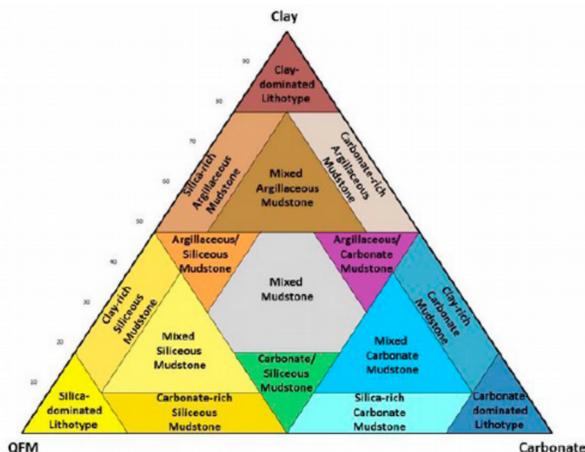


Figure 13. Classification of sedimentary rocks (Gamero-Diaz et al., 2014)

Metamorphism

The classification of metamorphic rocks is based on composition, temperature and pressure of formation, and texture (Fig. 14) - for a comprehensive review see Goete (2002) and https://en.wikipedia.org/wiki/Metamorphic_facies. When muddy rocks undergo increasing heating and deformation under medium metamorphic facies conditions, they transform through slate, phyllite, and schist to gneiss (Fig. 1d). When only the temperature increases, muddy rocks become hornfels with different minerals appearing with increasing temperature (Fig. 14). Increasing pressures produce phase transformations in mineral families that are characteristic of low, medium and high pressure (Fig. 14).

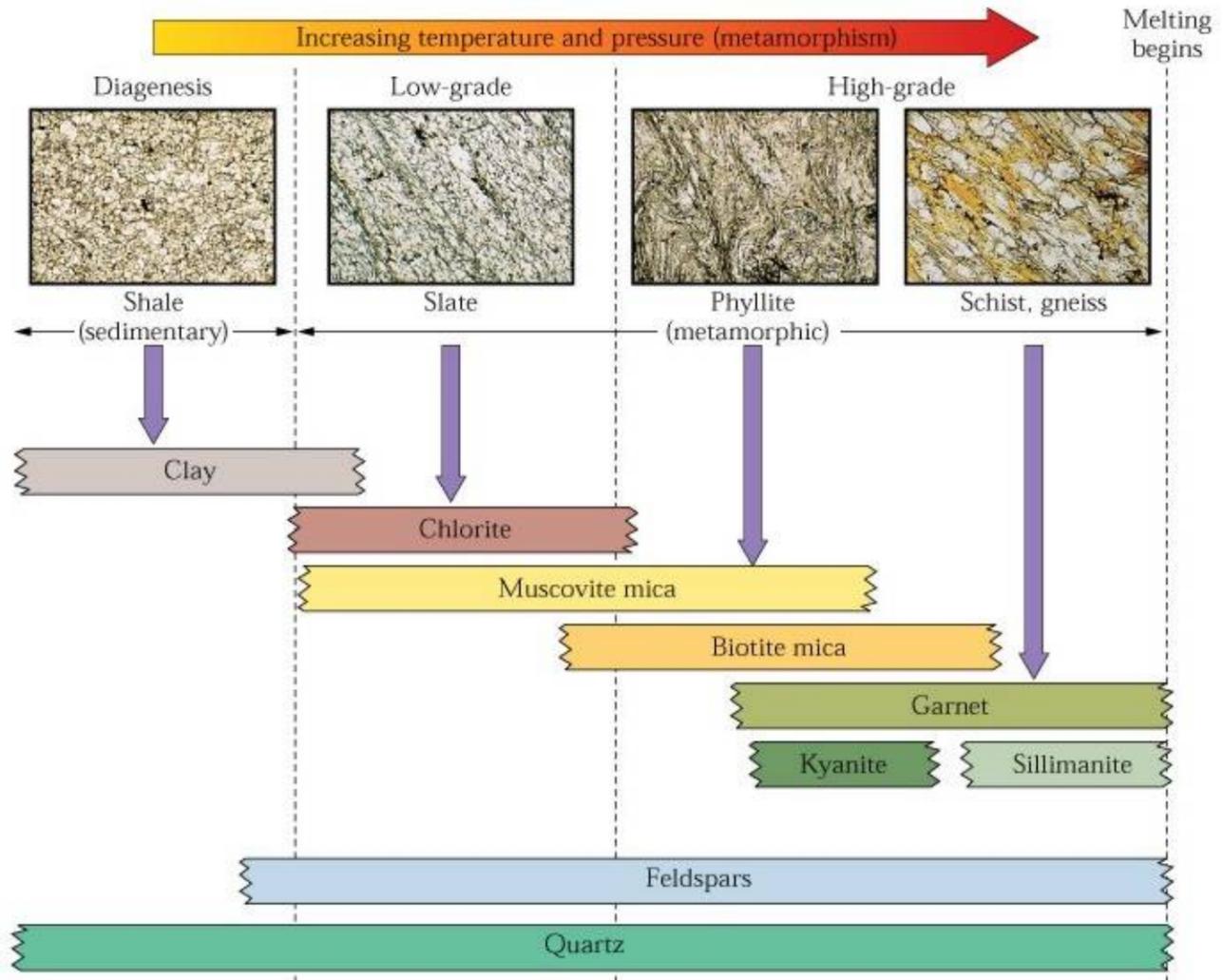


Figure 14. Metamorphic recrystallization of clastic rocks showing different minerals with increasing grade: <https://slideplayer.com/slide/4149787/>

It is another wonderful revelation that during progressive metamorphism (increasing temperature and pressure) the minerals reappear in the reverse sequence to that shown by the igneous minerals, with the addition of some extra minerals e.g. aluminosilicates, and garnet, (Figs. 2 and 15): *SPIRIT RECOLLECTION*. Quartz recrystallizes first followed by other minerals. The type of minerals also vary with composition and pressure (Fig. 14): mafic with Fe/Mg-rich minerals produce chlorite, epidote, biotite, amphibole and pyroxene, whereas clays recrystallize as muscovite and the aluminosilicates (andalusite, sillimanite, kyanite), and plagioclase feldspars gradually change in composition from Na- to Ca-rich. As a consequence, the crystal structure also generally shows the reverse of the igneous order from sheets through double and single chains to island tetrahedra (Fig. 15). The reverse order uses energy from the surroundings as both the temperature and pressure increase with depth. The newly added metamorphic minerals (garnet, and the aluminosilicates) all form island tetrahedra (+ octahedra and dodecahedra in garnet), presumably the result of addition of heat from the surrounding crust and mantle. Garnet also exhibits elastic properties (Erba et al., 2014).

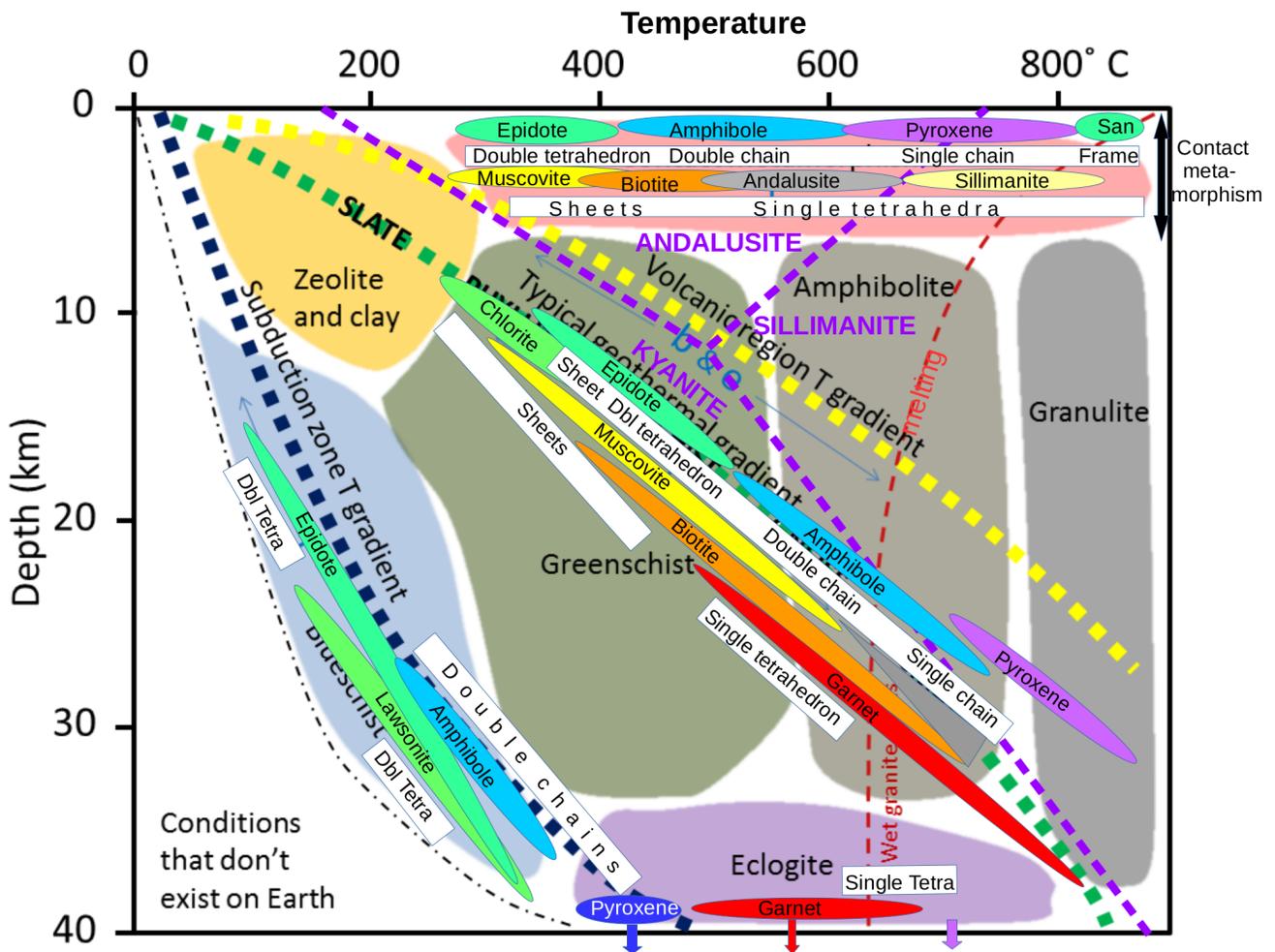


Figure 15. Temperature and pressure gradients controlling metamorphic facies: low pressure (slate, hornfels), medium pressure (zeolite, greenschist, amphibolite, granulite), and high pressure (blueschist and eclogite). Stability of mineral families shown as ellipses depicting their pulsating growth. Tectonic context for the pressure gradients ranges from pluton contacts through volcanic arcs and typical geothermal gradients to subduction zone.

The mechanism of recrystallization involves a process called solid state diffusion in response to chemical potential or compositional gradients, and are enhanced with increasing temperature and pressure (Watson and Baxter, 2007). Diffusion within a crystal occurs because there are always atoms missing (vacancies), which means that crystals are always ready for movement of atoms through the vacancies and channels. Atoms oscillate about a generally fixed position, occasionally jumping to a neighboring site – oscillations become greater with increasing temperature. Diffusion beyond the individual crystal is also enhanced by increasing temperatures and occurs by intragranular (volume) diffusion, grain-boundary film (grain-boundary diffusion), and bulk fluid migration. Diffusion may occur either with the concentration gradient leading to higher entropy (greater disorder), or with the chemical potential gradient (uphill diffusion)(Watson and Baxter, 2007): *WARMTH/LOVE ENHANCED BY MOISTURE/FLUID PROVIDES THE ENVIRONMENT FOR CREATIVITY*. The results of diffusion are observed as metamorphic banding in rocks and in compositionally zoned crystals (Fig. 16). Crystal productivity is pulsating with a change of volume that starts slowly increasing to a maximum before decreasing again (Fig. 15).

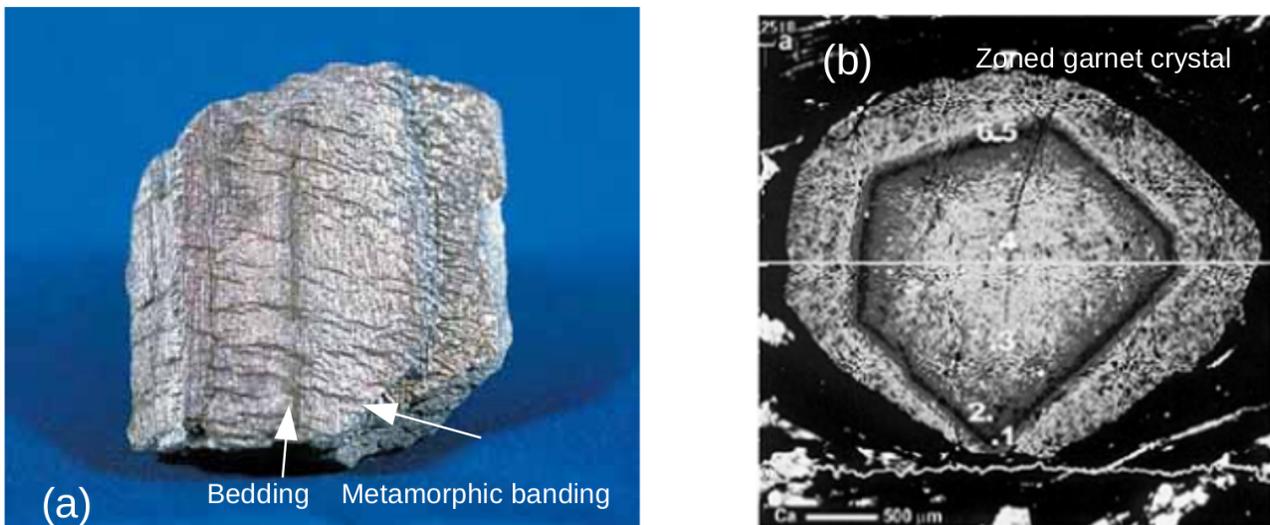


Figure 16. photographs of: (a) bedding versus metamorphic banding, and (b) a zoned garnet crystal

Melting

The temperature in the earth rises with depth (generally 25–30°C/km, but ranging between 10°C/km at subduction boundaries to 200°C/km at mid-oceanic ridges) causing the rocks and minerals to melt: this occurs in the reverse sequence to that recorded in igneous rocks (Fig. 2, Table 1) *SPIRIT RECOLLECTION*.

Melting is controlled by temperature, pressure and composition. The melting temperature of rocks depends on the type of mineral present, each of which has a different melting point, and on the presence fluids, which lowers the melting temperature. As melting proceeds small globules may merge and invade the surrounding solid rocks producing migmatite – these may eventually rise to intrude at high levels or extrude on the surface. Rocks melt as a result of decompression (e.g. at mid-oceanic ridges where two plates are moving apart), introduction of volatiles above subduction zones, and conduction where magma rise in the crust. Melting the continental crust containing quartz and feldspar (e.g. muddy sandstone, felsic igneous rocks, gneiss) initially produces a similar granitic liquid, whereas melting of the mantle initially forms mafic magma or basaltic liquid: *WARMTH/LOVE EVENTUALLY LEADS TO DEVELOPMENT OF SOCIETAL CONSENSUS*.

Table 1. Melting Temperatures of Igneous and Metamorphic minerals (°C) (metamorphic minerals underlined)

Mineral	(°C)	Bond strength (vu)	Structure
Olivines	1880	0.35-1	Island tetrahedra
<u>Sillimanite</u>	<u>1810</u>		<u>Island tetrahedra</u>
<u>Plagioclase anorthite</u>	<u>1550</u>		<u>Framework</u>
Pyroxenes	1390	0.35-1	Single chain
<u>Garnet</u>	<u>1300</u>		<u>Island tetrahedra/octahedra/dodecahedra</u>
Amphiboles	1200	ca. 2	Double chain
<u>Kyanite</u>	<u>1100</u>		<u>Island tetrahedra</u>
<u>Andalusite</u>	<u>NA</u>		<u>Island tetrahedra</u>
Micas	1100		Sheets
<u>Plagioclase: albite</u>	<u>1100</u>		<u>Framework</u>
Orthoclase feldspar	1000	0.1-1	Framework
Quartz	700	1	Framework

vu = valence units

EARTH CALLING HUMANS – WHAT DO YOU HEAR?

The similarity of the rock cycle with the life cycle of animals and plants requires a change in mind set from regarding rocks as dead to viewing them as alive, and this arises from realizing that the earth is alive (Steiner, 1912; Lovelock, 1979; Keppie, 2018). Spiritual research into rocks and the Rock Cycle reveals several pearls of wisdom for humans – naturally this is incomplete as each individual will hear different things – the reader is encouraged to determine what they hear:

1. The first hurdle is to comprehend the contrasting **time** frames, where the ca. 100 year, human life span is relatively short compared with the millions of years required to encircle the Rock Cycle.
2. The complete Rock Cycle generally rotates in one direction (**directionality**), although shortcuts do occur). The complete Rock Cycle brings to consciousness two main thought processes: **Spirit Beholding** and **Spirit Recollection** (Steiner, 1913, 1922; Morelli, 2015). Cooling and crystallization of igneous rocks and their recrystallization during weathering involves Spirit Beholding, where one develops our sense impressions of the object, thinking about its component parts and their relationships, imagining the steps of the process that created it (the living earth created magma from which igneous and sedimentary rocks formed). On the other hand, warming, metamorphic recrystallization and melting recapitulates the sequence in reverse order and involved Spirit Recollection, where one focuses inwardly picturing the events in the reverse order of their occurrence, and even in reverse motion. Such Spirit Beholding and Recollection were succinctly expressed by Steiner (1924) in the Foundation Stone Meditation and in his Leading Thoughts #95-99 (Steiner, 1973).
3. The Rock Cycle shows both 1st- and 2nd-order alternations of contraction and expansion (Figs. 1, 2, 8 and 15), a phenomenon involving **Polarity**, or opposites, and the balancing between them, e.g. lucifer versus ahriman, materialism versus spiritualism, physical versus ideal (Steiner, 1920, 1988; Goethe, 2009). At a smaller scale, atoms and SiO bonds in crystals are in perpetual oscillatory motion about their equilibrium positions: such synchronous motion is similar to communal dance, which builds a strong social bonds. With increasing warmth (metamorphism) can break free to migrate to form new crystals and bands: love facilitates leaving the nest to embark on creativity and spiritual exploration.
4. Crystallization of igneous rocks progresses from minerals consisting many elements to just single SiO₂ (quartz), a process called **Intensification** (Steiner, 1928; Goethe, 2009), i.e. the emergence of the spiritual from out of the material as a result of the creative activity of Nature, or a state of ever-striving ascent toward perfection and the fullest expression of the potential inherent in the underlying idea or

Urphenomen. Increasing warmth during metamorphism leads to the formation of the new aluminosilicate family (andalusite, kyanite, sillimanite: Fig. 15), Al_2SiO_5 : love facilitates the creation of new families.

5. Progressive cooling and crystallization of igneous rocks **evolves**: (a) in complexity; (b) by increasingly sharing oxygen atoms between tetrahedra (from zero to four) that involves overcoming increasing repulsion, ionic potential, and bond strength between silica, Si^{4+} ; (c) increasing size (atomic number) of the elements that make up the crystals; and (d) decreasing charge from Fe^{+2} through Mg^{+2} , Ca^{+2} , Na^{+1} to K^{+1} accompanied by substitution of Al^{+3} for Si^{+4} (Fig. 6). **Evolution** overcomes increasing resistance to sharing and cooperation, leading to stronger relationships, increased sharing, diversity, cooperation and accommodation. Quartz is last mineral to crystallize and has the most evolved crystal structure, a single helix that is an intermediate form between minerals and the DNA double helix of plants and animals. During metamorphic recrystallization, warmth (love) facilitates the same tendencies (Fig. 15).

6. Weathering of igneous minerals proceeds in the **same sequence** as that observed in igneous rocks (Fig. 11). Similarly, melting of minerals occurs in the same order as metamorphic recrystallization (Figs. 15 and Table 1). These sequences follow the first **karmic** law: “as you sow, so shall you reap”, i.e. heredity follows the first karmic law (Steiner, 1906). Increasing warmth eventually leads to melting and formation of magma: i.e. societal consensus of basic human rights.

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