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Effects of Weathering and Erosion on the Geochemistry Of Rocks And Soils

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ABSTRACT

This paper seeks to find the effects of weathering on the geochemistry of rocks and soils. Weathering is characterized by physical disintegration and chemical decomposition of rocks. This is associated with structural transformation of the minerals which make up the rocks. Contact of rocks with either or both water and oxygen promote weathering. Weathering and erosion occur in the upper portion of the Earth's crust and affects igneous, metamorphic and sedimentary rocks. The most common chemical elements in the crust are oxygen, silicon and aluminous and they are all prone to weathering. Also, the most common minerals are feldspars, quartz, pyroxenes and amphiboles and these, also, are prone to weathering. Weathering leads to changes in their chemical composition. After weathering, certain minerals disappear while new ones are created. This depends on the resistance of each mineral to weathering. The chemical processes involved in weathering are hydration, hydrolysis, solution, carbonation, oxidation and reduction. Weathering first destroys any relatively weak bonding agents before the products are further subjected to greater disintegration.Weathering leads to increased pH, leaching of alkaline earth cations and leaching of H4SiO4. In some cases, weathering leads to rust which is a reaction between Fe2+ containing compound, H2O and O2. Solution, carbonation and reduction all involves chemical reaction. With all these changes involving chemical reaction, weathering and erosion therefore has positive impact on the geochemistry of rocks and soils of the Earth's crust.

Keywords: Weathering, Erosion, Hydrolysis, Oxidation and Leaching

I. INTRODUCTION

Weathering and erosion take place within the Earth's crust which is the outermost layer of the earth. The crust is made up of igneous, metamorphic and sedimentary rocks which are all inter convertible. These are caused by internally-driven processes such as plate tectonics, magmatism, metamorphism, orogeny, weathering and erosion. Common rocks in the crust are granite, gabbro, basalt, gneiss and schist. Others are amphibolite, sandstone, shale, and limestone.

Weathering and erosion are the processes that cause and transport sediments, respectively. Sedimentation, burial and lithification are the processes that transform weathering products into sedimentary rocks. Rocks are aggregation of minerals while minerals are aggregates of chemical elements. Consequently, chemical reactions will be taking place in rocks, Alexander, et al, 2016, stated that the rocks and soils of Mubi in Adamawa State, contains silicates, quartz, feldspar, microcline, Albite and orthopyroxene. Most of the soil samples contain high percentage of Al_20_3, K_20, Fe_20_3, SIO_2 and Na_20.

These chemical elements react differently under varying conditions. The most common chemical elements in the crust are oxygen, (46.6%) silicon (27.7%) aluminum (8.1%) iron (5.0%) calcium (3.6%) potassium (2.8%) sodium (2.6%) and magnesium (2.1%). This estimation was based on the relative proportions of different rock types in the crust and their average composition (Sandatlas,2011). Silicon serves as the main element in silicates which are the building blocks of most common rock types. The most common rock types are basalt, granite, schist, gneiss and sandstone, among others. However, silicates are not found in carbonates rocks and evaporites such as gypsum, and rock salt.

Each of these rock types are made up of chemical compounds or elements that react in different ways to changes in their immediate environment. For example a rock containing FeO when exposed to free oxygen in the air are converted to Fe_20_3. This is what occurs when weathering takes place. The inner surface of the disintegrated rock is exposed to free oxygen leading to changes in its chemical composition. When a broken off piece is transported through erosion and deposited in a different environment, changes begin to take place within the rock piece leading to alterations of its chemical composition. Electronic configurations are very important in determining changes in chemical elements. This is why elements in the same group on the periodic table have very similar properties e.g. uranium and thorium tend to form silicates and they are concentrated in the crust while gold and platinum have no tendency to form oxides or silicates but reacts readily with iron and are presumably concentrated in the core.

Grain size and amount of fracturing can affect rates of reaction significantly. Chemical weathering can occur through solution, colloidal suspension, hydration, oxidation and carbonation.

Weathering promotes chemical reactions by exposing the surface to water and free oxygen e.g. calcium carbonate dissolving in surface water breaks down to Ca^{2+} and $HC0_3^-$. This has led to geochemical changes. Ions escape more easily from corners and edges of grains, therefore, there are more escapes per volume in small grains than in large grains. Consequently, escape of ions will lead to geochemical alterations. Furthermore, a solution in equilibrium with small grains will be oversaturated with respect to large grains and therefore the small grains should eventually dissolve and the large ones grow at their expense. This can lead to growth of large grains in limestone and conversion of opal to chalcedony and quartz after precipitation.

Colloids are particles ranging in size between 10^{-7}mm and 10^{-3}mm. During weathering and mostly erosion, colloids are formed from abrasion of particles being transported. These colloids are thermodynamically unstable. They are kept dispersed through electric charge and removal of such charge causes flocculation. As a result, most colloidal dispersions are destroyed by addition of electrolytes. Consequently, there would be a change in the geochemistry. Metals migrate through groundwater systems. Since weathering and erosion promotes the movement of ground water, therefore, weathering promotes migration of metals leading to changes in the geochemical composition of such soils.

Truesdale, et al (1955) stated that oxygen dissolution in water when at equilibrium in air reduces with increasing temperature. It has been stated that weathering contributes to oxygen dissolution. This further confirms that weathering and erosion have pronounced effect on the geochemical characteristics of rocks and soils. There is, therefore, the need to discuss the effect of weathering and erosion on the geochemical parameters of rocks and soils. This forms the reason why this article is being written.

II. METHODS AND MATERIAL

AIM

The aim of this paper is to discuss the effects of weathering and erosion on geochemistry of rocks and soils.

SCOPE

To achieve this aim, the paper will highlight the followings:

a. Processes of weathering.
b. Processes of erosion.
c. Common rocks in the crust.
d. Chemical reactions between rocks/soil and water/air.
e. Impact of the reactions on rock/soil chemistry.
f. Implication of these reactions.

PROCESSES OF WEATHERING

Weathering is a process characterized mainly by physical disaggregation and chemical decomposition of rocks transforming structures of more complex minerals into others with simpler structures(Formoso, 2006). It is the breaking down of rocks, soil and minerals as well as wood and artificial materials through contact with the Earth's atmosphere, waters and biological organisms. It mostly occurs in situ with little or no movement. Weathering can take place through physical and chemical means as major processes while biological process is the minor process.

Physical weathering, also known as mechanical weathering, includes processes that fragment and disintegrate rocks into smaller pieces without changing the rock's mineral composition. The agents of physical weathering are cracks, fire, thawing and freezing of water in cracks, pressure release and water absorption by swelling clays. The cracks caused are exposed to chemical action. This will amplify the rate of disintegration.

Chemical weathering is the alteration of the rock into new minerals. It generally occurs where water and minerals are in constant contact. The agents of chemical weathering are oxygen, air pollution, water, carbonic acid and strong acids. These combine with the minerals that made up the rocks to form clays, iron oxides and salts. These are the end points of chemical weathering.
The third form of weathering is biological weathering. This is the disintegration of rocks as a result of actions by living organisms. This also increases the surface area exposed to air and water thereby increasing rate of disintegration. As disintegration occurs, there are changes in the geochemistry of such rocks. Weathering rates are determined by water content, temperature, exposed surface area and the type of minerals within the rocks.

PROCESSES OF EROSION

Erosion is the action of surface processes that remove soil, rock or dissolved materials from one location to the other. It could also be described as the act in which the earth is worn away by water, wind or ice. As they transport the broken fragments, when in high speed, the fragments are deposited when the speed slows down. Erosion is a natural process but human activities can enhance it. Erosion is affected by climate, vegetation cover, topography and tectonics. In the process of erosion, fragments are worn away and depleted. This exposes more surface to oxygen, water and carbonic acid thereby promoting disintegration, which have direct effect on the chemical composition of the minerals.

COMMON ROCKS IN THE CRUST

The continental curst is the layer of igneous, sedimentary and metamorphic rocks that form the continents and the areas of shallow continents. The bulk composition of the rocks is felsic. The common rocks in the crust are granite, gabbro, basalt, gneiss and schist. Others are amphibolite, sandstone, shale and limestone. These rocks are not uniformly distributed and occur in various percentages. The oceanic crust is much thinner than the continental crust. It is composed largely of basaltic rocks. The continental crust is much more variable and structurally complex. Sedimentary rocks are stable only in the upper parts of the crust. They are metamorphosed in the deeper parts into various metamorphic rocks while igneous rocks are common on the surface, especially in the volcanically active regions. Important sediments are sand, clay, mud and limy mud. Sedimentary rocks like limestone sandstone, clay stone are widespread. Though, less than 1% by volume, halite and gypsum are also available in the continental crust. The important igneous rocks are granite, granodiorite, gabbro, basalt, diorite and andesite, among others. The common metamorphic rocks are slate, schist, quartzite, marble, gneiss and amphibolites. Similarly, according to Marshall and Fairbridge, the most common chemical elements and their percentages are oxygen, 46.6%, silicon, 27.7%, aluminium, 8.1%, iron, 5.0% and calcium 3.6%. Other less common minerals are potassium, 2.8%, sodium, 2.6% and magnesium, 2.1%. This estimation was based on the relative proportion of different rock types in the crust and their average composition.

More than 90% of the crust is composed of silicate minerals. Among these, the most abundant are plagioclase feldspar, 39%, alkali feldspar, 12%, quartz, 12%, pyroxenes, 11%, amphiboles, 5%, micas, 5% and clay minerals, 5%. The rest of the silicate family comprises 3% of the crust while only 8% of the crust are non-silicates. These are carbonates, oxides and sulfides, among others.

CHEMICAL REACTIONS BETWEEN ROCKS, SOILS, WATER AND AIR

Weathering is a process characterized mainly by physical disintegration and chemical decomposition of rocks. In this process, complex minerals are transformed into similar structures. For example, during weathering, tectosilicates can be transformed to phyllosilicates, at 1:1 ratio. Also, minerals such as kaolinites, iron oxides, aluminum oxide which are stable at low temperatures and pressure can replace higher temperature and pressure minerals. This supergene alteration is dependent on climate, topography, nature of rock, biosphere influence and drainage conditions.

The most important process during weathering is hydrolysis of silicates. It is characterized by increasing pH, leaching of alkaline/ alkaline earth cations and leaching of H_4Si0_4. Formation of Kaolinite implies partial leaching of H_4Si0_4.

$2KAlSi_3O_{8s,c,K\text{-feldspar}} + 11H_2O_l = 4H_4Si_2O_5(OH)_{4s,c,kaolinite} + 2K^+_{aq} + 2OH^-_{aq}$

Where S is solid, C is crystalline, aq is aqueons and L is liquid.

Minerals have various degrees of resistance to weathering. During chemical weathering, rocks and minerals are decomposed by various chemical processes. Chemical weathering takes place mainly at the surface of rocks and minerals(Agriinfo, 2015).

Certain minerals disappear while some secondary products are formed. The smaller the fragments, the greater the surface area available per unit volume, for weathering. The effectiveness of chemical weathering is directly dependent on chemical composition of the minerals and rocks. For example, quartz reacts more slowly to weathering than olivine or pyroxene. The chemical processes involved in weathering include hydration, hydrolysis, solution, carbonation, oxidation and reduction. Water is the main cause of chemical weathering. Some minerals dissolve completely in water e.g. halite that has the same formula as NaCl, dissolves in water while in the atmosphere, small amounts of $C0_2$ dissolve in rain water. The water and CO_2 react to form a weak acid. After falling to the ground, the rain water moves through the soil, picking up additional CO_2 from decaying plants to form a stronger acid. This breaks down minerals in rocks. In this process, the rocks may also break into smaller process. The oxygen in the air is also involved in chemical weathering. Many common minerals contain iron. When the minerals dissolve in water, the oxygen in the air and the water combine with the iron to produce iron oxides, which is rust. This rust forms a coating that colours the weathered rocks, making them appear brownish. A typical example is quartz which is white but after weathering it turns brown.

Hydration is the combination of water molecules with a particular substance or mineral, leading to a change in structure. Soil forming minerals in rocks do not contain any water but they undergo hydration when exposed to humid condition. This leads to swelling and the minerals loose its luster and become soft.

$2Fe_20_3 + 3H_2O = 2F_20_3 . 3H_2O$

Hematite (Red) Limonite (yellow)

$Al_20_3 + 3H_2O = Al_2O_3.3H_20$

Bauxite (Anhydrous aluminum oxide)

$CaSO_4 + 2H_2O = Caso_4.2h_2O$

Anhydrite Gypsum

$3(MgO. FeO.S_iO_2) + 2H_20 = 3MgO.2S_iO_2. 2H_2O + S_iO_2 + 3H_2O$

Olivine Serpentine

From the above reactions, hydration as a means of weathering, has great impact in the geochemistry of soils. Hydrolysis is the dissociation of H_2O into H^+ ad OH^- ions which in turn chemically combine with minerals to bring about changes like exchanges, decomposition of crystalline structure and formation of new compounds. Water, therefore, acts as a weak acid on minerals.

$KAlSi_30_8 + H_2O = HAlSi_30_8$

Orthoclase Acid salt

Clay

$HAlSiO_8 + H_2O - Al_20_3 . 3H_2O + 6H_2 Si 0_3$

Recombination Hydrous Aluminium Silicic acid

$Mg Si0_4 + 4H^= + 40H^-$ $oxide_{2mg}{}^{2+} + 40H^- + H_4SiO_{4=}$

Forsterite silicic acid in solution

Solution is the ability of some substances present in rocks to dissolve in water. Such substances include NaCl. When they dissolve, the products area washed away and the rocks form holes. This action is more pronounced when the water is acidified by dissolution of organic and inorganic acids such as halite and NaCl.

$NaCl + H_20 = Na^= \rightarrow Na^+, Cl^-$ and H_2O

The effect of this on the geochemistry of rocks or soils cannot be over emphasized.

Carbonation is the formation of carbonic acid when CO_2 is dissolved in water.

$2H_2O + CO_2 \rightarrow H_2CO_3$

The carbonic acid attacks many rocks and minerals to bring them into solution. The effect is more pronounced in limestone. The removal of the cement that holds particles together leads to their disintegration.

$$CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2$$

Calcite (Slightly soluble) — Calcium Bicarbonate (Readily Soluble)

With this reaction, the chemistry of the solid or rock has been altered confirming that weathering has effect on rock or soil geochemistry.

Oxidation is the process of adding oxygen to minerals. It is more active in the presence of moisture and it results in hydrated oxides e.g minerals containing Fe and Mg.

$$4\ Feo\ (\text{Ferrous oxide}) + O_2 \rightarrow 2Fe_2O_3\ (\text{ferric oxide})$$
$$4\ Fe_3O_4\ (\text{Magnetite}) + 0_2 \rightarrow 6Fe_20_3\ (\text{Hematite})$$
$$2\ Fe_2O_3\ (\text{Hematite}) + 3H_20 \rightarrow 2Fe2O3.3H2O\ (\text{Limonite})$$

Reduction is the opposite of oxidation. It is the removal of oxygen from a compound. It is important in changing the soil colour to grey, blue or green. This occurs as ferric iron is converted to ferrous iron compounds. Reduction normally takes place under condition of excess water or in water logged condition,

$$2F_{e2}O_3(\text{Hematite}) - O_2 \rightarrow 4FeO\ (ferrous\ oxide\ in\ reduced\ form.$$

Pacheco and Van der Weijden (1996) pointed out that not all the minerals present in the various rocks of the plutonite are important as weathering reactants. This was why different degrees of weathering are found in different parts of the Findao Area. They used the SiB algorithm to relate water composition to weathering reaction. They assumed that dissolved silica and bicarbonate are exclusively produced by chemical weathering of the dominant primary minerals to secondary clay mineral.

From the above, it is observed that during chemical weathering, igneous and metamorphic rocks can be regarded as involving destruction of primary minerals and the production of secondary minerals. This transformation changes the chemistry of the medium which is either rock or soil.

III. RESULTS AND DISCUSSION

Impact of the Reaction on Rock and Soil Chemistry

Sedimentary rocks, are made up of primary and secondary minerals, therefore, weathering acts initially to destroy any relatively weak bonding agents. The particles are freed and can be individually subjected to weathering. Pacheco and Van der Weijden (1996) in their study of water-rock interactions in Fundao Area of Central Portugal, discovered that in applying the weathering algorithm all dissolved silica and bicarbonate are produced by chemical weathering. On the other hand, all dissolved chloride, sulphate and nitrate are produced by other sources. In spite of the high background concentration derived from pollution, they were able to assess the contribution of weathering to the water chemistries. Department of Earth Sciences, Durham University carried out research on understanding the processes of weathering and erosion as preserved in chemistry of soils, rivers and groundwaters. It was discovered that much of the silicate weathering and organic carbon production occurs in soils while rivers play a central role in exporting metal ions as well as the solid and dissolved carbon mobilized by weathering and erosion. They concluded that these processes negate CO_2 imput by the weathering and oxidation of fossil organic carbon from sedimentary rocks. They stated further that soil ecosystem development is regulated by the supply of nutrients from rock weathering, the dissolution of silicate minerals, the decomposition of organic matter and atmospheric deposition.

One of the most common solution weathering is carbonation which is the absorption of atmospheric CO_2 by water to form H_2CO_3.

$$CO_2 + H_2O \rightarrow H_2CO_3$$
$$H_2CO_3 + CaCO_3 \rightarrow Ca(HCO3)2$$

Similarly, limestone rock chemically dissolves away much quicker than most other rocks with just CO_2 in the water.

$CaCO_3$ +	CO_2 +	H_2O	$\rightarrow Ca(HCO3)2$
Solid Limestone	Aqueous carbon Dioxide	Liquid water	Aqueous

Dolomite weathers chemically through this process

$$CaMg\,(CO_3)\; +\; 2H_2O\; +\; 2CO_2\; \rightarrow Ca2+\; +\; Mg2+\; +\; 4HCO3^-$$

Implications of These Reactions

Weathering through hydrolysis involves increased pH, leaching of alkaline/alkaline earth cations and leaching of H_4SiO_4. This increased pH will reduce the acidity of the soil while leaching alters chemical composition of the rock by removing or adding some chemicals. Rust is formed from combination of iron in minerals with oxygen from the atmosphere thereby increasing the oxygen content of the soil. Hydration impacts greatly on the geochemistry of soils by introducing H_2O to the minerals in the process of formation of limonite from hematite, hydrous aluminum oxide from bauxite and gypsum from anhydrite.

In solution, substances that dissolve in rocks alter the chemical composition of the groundwater and the host rocks or soils. Such chemical alteration leads to a change in the geochemistry of the soil. Similarly, carbonation which is the formation of carbonic acid when CO_2 is dissolved in water, promote the attack of many rocks by the weak acid. For example, the removal of the cement that holds particles together in calcite leads to the formation of calcium bicarbonate which is readily soluble. The effect of the solubility is a change in geochemistry of the rock. Removal of oxygen from a compound, which is reduction, changes the colour of the soil as well as the chemical composition. This obviously have great impact on the geochemistry of such soils.

IV. CONCLUSION

Weathering is characterized by physical disintegration and chemical decomposition of rocks. This is associated with structural transformation of the minerals which make up the rocks. This is, in most cases, followed by erosion and subsequent deposition. Contact of rocks with either or both water and oxygen promote weathering. Weathering and erosion occur in the upper portion of the Earth's crust and affects igneous, metamorphic and sedimentary rocks. The most common chemical elements in the crust are oxygen, silicon and aluminous and they are all prone to weathering. Also, the most common minerals are feldspars, quartz, pyroxenes and amphiboles and these, also, are prone to weathering. Weathering leads to changes in their chemical composition. After weathering, certain minerals disappear while new ones are created. This depends on the resistance of each mineral to weathering. The chemical processes involved in weathering are hydration, hydrolysis, solution, carbonation, oxidation and reduction. Weathering first destroys any relatively weak bonding agents before the products are further subjected to greater disintegration.

Weathering leads to increased pH, leaching of alkaline earth cations and leaching of H4SiO4. In some cases, weathering leads to rust which is a reaction between Fe2+ containing compound, H2O and O2. Solution, carbonation and reduction all involves chemical reaction. With all these changes involving chemical reaction, weathering and erosion therefore has positive impact on the geochemistry of rocks and soils of the Earth's crust.

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