



INTRODUCTION TO TYPES AND CLASSIFICATION OF ROCKS

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ABSTRACT

Generally rocks can be divided into three major types based on the process of their formation. These are; Igneous rocks, sedimentary rocks and metamorphic rocks. Igneous rocks are formed by the solidification and cooling of magma in volcanic areas, while sedimentary rocks are formed by low temperature accumulation of sediments in tectonic basins and topographical sinks. Metamorphic rocks on the other hand are formed by application of temperature and pressure on pre-existing rocks. Metamorphic rocks therefore form at great depths, but exposed on the surface due to erosion and epirogenic movements. Each of these three rock types can be further classified in terms of; chemistry, how the form and environment of formation. The distributions of these major rock types are critical in regional mapping of natural resources. Igneous is coined from word “ignis” meaning fire and therefore these rocks are good indicators of volcanism and are there associated with geothermal resources and hydrothermal deposits like porphyry copper, and gold etc. sedimentary rocks especially the organic sediments on the other hand are good source rocks and are associated with resources like coal and oil. Sediments are also good proxies for environmental reconstruction, since fossils can be well preserved in these deposits. Metamorphic environments are associated with Gemstones and alteration minerals which form good index minerals as geobarometers and geothermometry. In this paper we look mainly into igneous and metamorphic rocks, their distribution, plate margins and geothermal resources.

1. INTRODUCTION

There are many definitions of rocks, according to (Ehlers and Blatt, 1997). He defines rocks as stuff which the earth is made off. A more acceptable scientific definition of rocks is that; a rock is a natural occurring solid cohesive aggregate of one or more mineral or mineral materials. Rocks are broadly classified into three groups based on their process of formation. The three major rock types are:

1. Igneous rocks;
2. Sedimentary rocks; and
3. Metarmoprphic rocks.

Sedimentary rocks makes up to 66% of the earth’s crust, with 34 % being the igneous and the metamorphics. Igneous rocks however, forms the majority of 34 % (Ehlers and Blatt, 1997).The reason why sedimentary rocks accounts for most of the rocks on the earth’s surface is because they are mainly

found ocean floor basins which accounts to 70% of total area of the earth. The three rock types are further classified based on chemistry, environment of formation and how they are formed.

2. IGNEOUS ROCKS

Igneous rocks are formed from solidification and cooling of magma. This magma can be derived from partial melts of pre-existing rocks in either a planet's mantle or crust. Typically, the melting of rocks is caused by one or more of three processes namely; an increase in temperature, a decrease in pressure, or a change in composition. Igneous comes from word "ignis" meaning fire, it is therefore not surprising that igneous rocks are associated with volcanic activity and their distribution is controlled by plate tectonics. One of the appealing aspects of the plate tectonics is that it accounts for reasonably well for the variety of igneous rocks and their distribution (Carlson et al, 2008). Divergent plates are usually associated with creation of basalts and gabbros especially in the oceanic crust e.g. in the mid-Atlantic ridges. While in the intra-continental areas you can have wide array of rocks from basic, intermediate to the acidic rocks. In the convergent plates usually granites and andesites magmas are produced e.g. In the South America, Indonesia etc.

Igneous rocks are divided into two main categories: Plutonic (intrusive) rock and volcanic (extrusive). Plutonic or intrusive rocks result when magma cools and crystallizes slowly within the Earth's crust. A common example of this type is granite. Volcanic or extrusive rocks result from magma reaching the surface either as lava or fragmental ejecta, forming rocks such as pumice or basalt. The chemical abundance and the rate of cooling of magma typically form a sequence known as Bowen's reaction series (Figure 1), after the Canadian petrologist Norman L. Bowen. The Bowens reaction series explain sequences of crustal formation. The Bowens series is important because it forms basis for explaining igneous mineral and textures.

Igneous Rocks and Bowen's Reaction Series

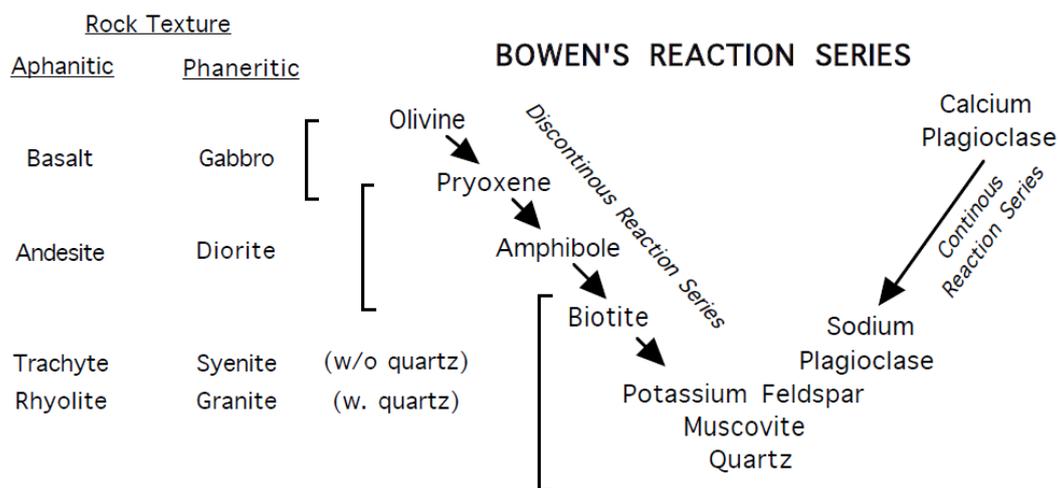


FIGURE 1: Bowens reaction series (Ehlers and Blatt, 1997).

2.1 Types of igneous rocks

Igneous rocks can be differentiated according to their texture, colour and composition. The difference in these three parameters depends on environment of deposition and chemistry of magmas. Below is an explanation on of each parameter as mentioned above.

2.1.1 Texture

When magma cools slowly large crystals form and rock forms phaneritic texture on the other hand if magma cools fast then small crystals form sometime a glassy texture where no minerals form can be achieved this way. It is based on the textural difference that igneous rocks can be divided into either extrusive or intrusive rocks. Examples of both extrusive and extrusive rocks are given in Figure 2 below. Intrusive are rocks that form by magma solidifying before reaching the surface hence forming coarse grained texture while extrusive are those that magma solidify on surface forming fine grained rocks.

2.1.2 Colour

A rock with majorly dark minerals form mafic rocks but with more fractionation during magma cooling lighter coloured mineral are able to form based on Bowens series. Based on this colour difference the rocks can be either mafic or felsic in Figure 2 below shows that as you move from right to left you have more ultra-mafic due to fractionation.

2.1.3 Composition

Igneous rocks can also be classified based on chemistry. This is mainly based on silica content as highlighted in Figure 2 below .When silica is above 75% main minerals that form are feldspars while with reduction of silica more mafic minerals form, hence basis for rock difference.

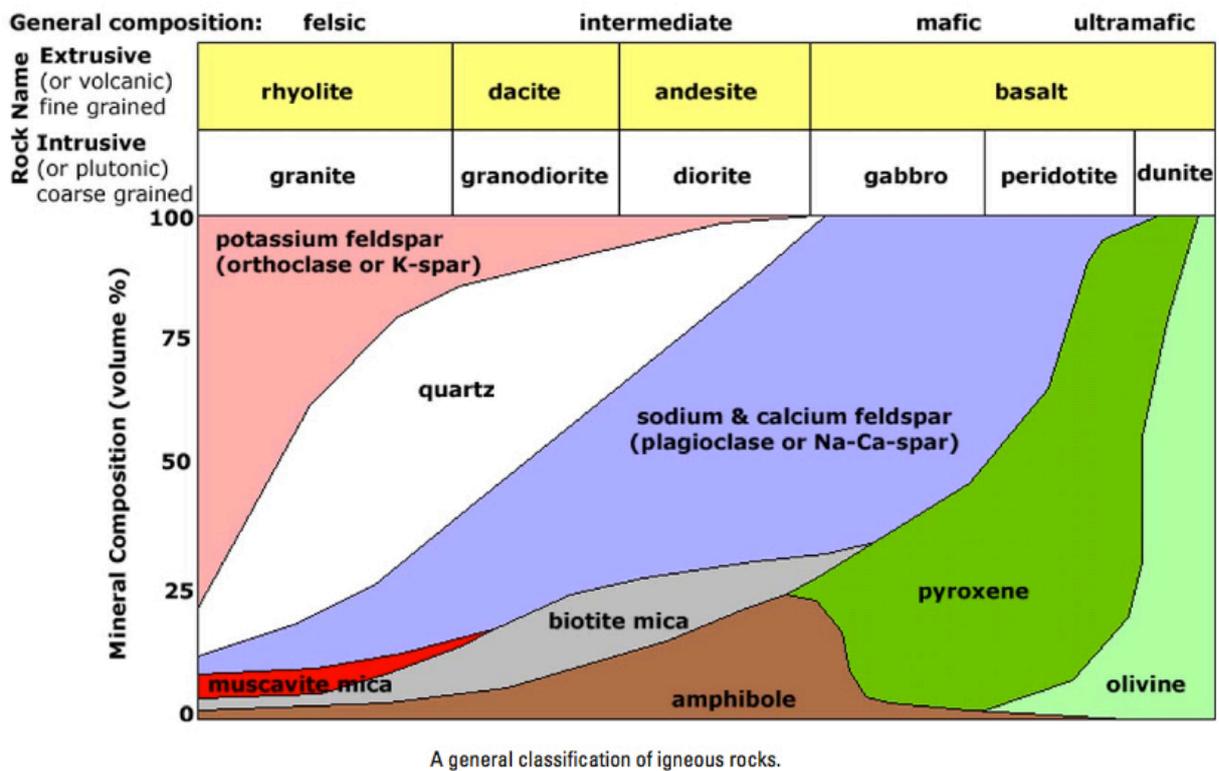


FIGURE 2: Types of igneous rocks based on texture, colour, and chemistry (Ehlers and Blatt, 1997).

2.2 Textures of igneous rocks

2.2.1 Phaneritic texture

Phaneritic textured rocks are comprised of large crystals that are clearly visible to the eye with or without a hand lens or binocular microscope. The entire rock is made up of large crystals, which are generally

1/2 mm to several centimetres in size; no fine matrix material is present. This texture forms by slow cooling of magma deep underground in the plutonic environment.

2.2.2 Aphanitic texture

Aphanitic texture consists of small crystals that cannot be seen by the eye with or hand lens. The entire rock is made up of small crystals, which are generally less than 1/2 mm in size. This texture results from rapid cooling in volcanic or hypabyssal (shallow subsurface) environments.

2.2.3 Porphyritic texture

Porphyritic rocks are composed of at least two minerals having a conspicuous (large) difference in grain size. The larger grains are termed phenocrysts and the finer grains either matrix or groundmass (see the drawing below and image to the left). Porphyritic rocks are thought to have undergone two stages of cooling; one at depth where the larger phenocrysts formed and a second at or near the surface where the matrix grains crystallized.

2.2.4 Glassy texture

Glassy textured igneous rocks are non-crystalline meaning the rock contains no mineral grains. Glass results from cooling that is so fast that minerals do not have a chance to crystallize. This may happen when magma or lava comes into quick contact with much cooler materials near the Earth's surface. Pure volcanic glass is known as obsidian.

2.2.5 Vesicular texture

This term refers to vesicles (cavities) within the igneous rock. Vesicles are the result of gas expansion (bubbles), which often occurs during volcanic eruptions. Pumice and scoria are common types of vesicular rocks.

2.2.6 Fragmental (Pyroclastic) texture

Pyroclastic are rocks blown out into the atmosphere during violent volcanic eruptions. These rocks are collectively termed fragmental. If you examine a fragmental volcanic rock closely you can see why. You will note that it is comprised of numerous grains or fragments that have been welded together by the heat of volcanic eruption. If you run your fingers over the rock it will often feel grainy like sandpaper or a sedimentary rock. You might also spot shards of glass embedded in the rock.

3. METAMORPHIC ROCKS

Metamorphic rocks are basically rocks that have experienced change due to high pressure and temperature below zone of diagenesis. Protolith refers to the original rock, prior to metamorphism. In low grade metamorphic rocks, original textures are often preserved allowing one to determine the likely protolith. As the grade of metamorphism increases, original textures are replaced with metamorphic textures and other clues, such as bulk chemical composition of the rock, are used to determine the protolith. Below is an examination of the role of two agents of metamorphism.

3.1 The role of temperature

Changes in temperature conditions during metamorphism cause several important processes to occur. With increasing temperature, and thus higher energy, chemical bonds are able to break and reform driving the chemical reactions that changes the rock's chemistry during metamorphism. Increasing in temperature can also result in the growth of crystals. In a rock, a small number of large crystals have a

higher thermodynamic stability than do a large number of small crystals. As a result, increasing temperature during metamorphism, even in the absence of any chemical change, will generally result in the amalgamation of small crystals to produce a coarser grained rock. It is a fact that individual minerals are only stable over specific temperature ranges. Thus, as temperature changes, minerals within a rock become unstable and transform through chemical reactions to new minerals. This property is very important to our interpretation of metamorphic rocks. By observing the mineral assemblage (set of minerals) within a metamorphic rock, it is often possible to make an estimate of the temperature at the time of formation. That is, minerals can be used as thermometers of the process of metamorphism.

3.2 The role of pressure

Pressure, the second of the two physical parameters controlling metamorphism and occurs in two forms. The most widely experienced type of pressure is lithostatic. This "rock-constant" pressure is derived from the weight of overlying rocks. Lithostatic pressure is experienced uniformly by a metamorphic rock. That is, the rock is squeezed to the same degree in all directions. Thus, there is no preferred orientation to lithostatic pressure and there is no mechanical drive to rearrange crystals within a metamorphic rock experiencing lithostatic conditions. The second pressure is the directed pressure, this is pressure of motion and action. Plate tectonics provide the underlying mechanical control for all forms of directed pressure. Thus, metamorphism is closely linked to the plate tectonic cycle and many metamorphic rocks are the products of tectonic interactions. As was the case with changes in temperature, changes in pressure, either lithostatic or directed, have important impacts upon the stability of minerals. Every mineral is stable over a range of pressures, if pressure conditions during metamorphism exceed a mineral's stability range the mineral will transform to a new phase. Many of these solid-state reactions involve polymorphic transformation – changes between minerals with the same chemistry and different crystallographic structures. Just as with temperature, mineral assemblages within a metamorphic rock can be used as a barometer to measure pressure at the time of formation.

3.3 Classification

Classification of metamorphic rocks depends on textures and its degree of metamorphism. Three kinds of criteria are normally employed in the classification of metamorphic rock. These are:

Mineralogical - The most abundant minerals are used as a prefix to a textural term. Thus, a schist containing biotite, garnet, quartz, and feldspar, would be called a biotite-garnet schist. A gneiss containing hornblende, pyroxene, quartz, and feldspar would be called a hornblende-pyroxene gneiss. A schist containing porphyroblasts of K-feldspar would be called a K-spar porphyroblastic schist.

Chemical - If the general chemical composition can be determined from the mineral assemblage, then a chemical name can be employed. For example a schist with a lot of quartz and feldspar and some garnet and muscovite would be called a garnet-muscovite quartzo-feldspathic schist. A schist consisting mostly of talc would be called a talc-magnesian schist.

Texture- Most metamorphic textures involve foliation. Foliation is generally caused by a preferred orientation of sheet silicates. If a rock has a slaty cleavage as its foliation, it is termed a slate, if it has a phyllitic foliation, it is termed a phyllite, if it has a shistose foliation, and it is termed a schist. A rock that shows a banded texture without a distinct foliation is termed a gneiss. All of these could be porphyroblastic (i.e. could contain porphyroblasts). A rock that shows no foliation is called a hornfels if the grain size is small, and a granulite, if the grain size is large and individual minerals can be easily distinguished with a hand lens.

3.4 Metamorphic grade

The intensity of a metamorphic event through the use of the concept of metamorphic grade (Figure 3). With increasing depth in the Earth, ambient temperature and pressure conditions rise steadily. Thus,

within the continental crust, temperatures vary from approximately 200 °C at 5 km to 800°C at 35 km. While these temperatures are extreme relative to our everyday experiences, they are significantly below the melting point of most rocks. Likewise, lithostatic pressure increases with increasing depth. At 5 km the pressure is approximately 2 kilo bars, or about 2000 times atmospheric pressure. Deeper within the crust, at about 35 km, the pressure increases to some 10 kb. This trend of increasing temperature and pressure within the Earth is defined by a region of commonly encountered metamorphic conditions. Low temperature and pressure setting as low-grade metamorphism usually gneisses, while high temperature and intense pressure is known as high-grade metamorphism in schist environment.

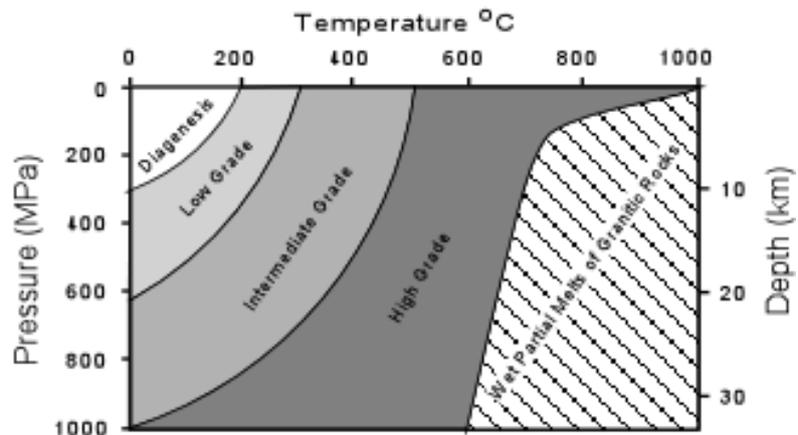


FIGURE 3: Grade of metamorphism gneiss to schist

This trend of increasing temperature and pressure within the Earth is defined by a region of commonly encountered metamorphic conditions. Low temperature and pressure setting as low-grade metamorphism usually gneisses, while high temperature and intense pressure is known as high-grade metamorphism in schist environment.

3.3 Types of metamorphism

3.3.1 Contact metamorphism

Contact metamorphism occurs adjacent to igneous intrusions and results from high temperatures associated with the igneous intrusion (Figure 4). Since only a small area surrounding the intrusion is heated by the magma, metamorphism is restricted to the zone surrounding the intrusion, called a metamorphic or contact aureole. Outside of the contact aureole, the rocks are not affected by the intrusive event. The grade of metamorphism increases in all directions toward the intrusion. Because the temperature contrast between the surrounding rock and the intruded magma is larger at shallow levels in the crust where pressure is low, contact metamorphism is often referred to as high temperature, low pressure metamorphism. The rock produced is often a fine-grained rock that shows no foliation, called a hornfels.

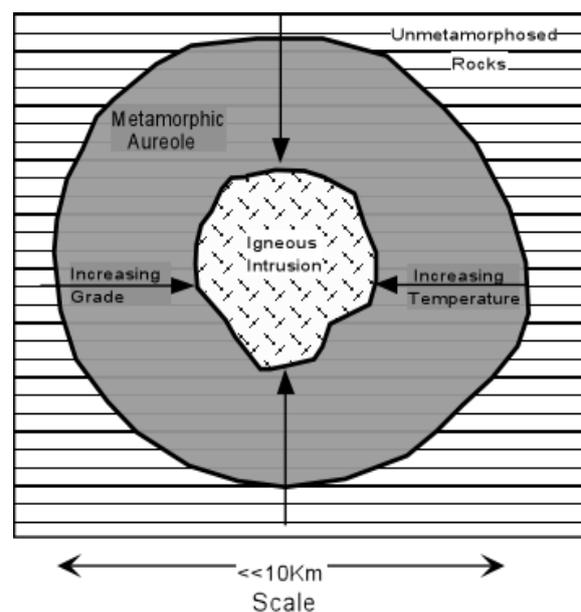


Figure 4: Metamorphic aureole

3.3.2 Regional metamorphism

Regional metamorphism occurs over large areas and generally does not show any relationship to igneous bodies. Most regional metamorphism is accompanied by deformation under non-hydrostatic or differential stress conditions. Thus, regional metamorphism usually results in forming metamorphic rocks that are strongly foliated, such as slates, schists, and gneisses. The differential stress usually results from tectonic forces that produce compressional stresses in the rocks, such as when two continental masses collide. Thus, regionally metamorphosed rocks occur in the cores of fold/thrust mountain belts or in eroded mountain ranges. Compressive stresses result in folding of rock and thickening of the crust, which tends to push rocks to deeper levels where they are subjected to higher temperatures and pressures.

3.3.3 Cataclastic metamorphism

Cataclastic metamorphism occurs as a result of mechanical deformation, like when two bodies of rock slide past one another along a fault zone. Heat is generated by the friction of sliding along such a shear zone, and the rocks tend to be mechanically deformed, being crushed and pulverized, due to the shearing. Cataclastic metamorphism is not very common and is restricted to a narrow zone along which the shearing occurred.

3.3.4 Hydrothermal metamorphism

Rocks that are altered at high temperatures and moderate pressures by hydrothermal fluids are hydrothermally metamorphosed. This is common in basaltic rocks that generally lack hydrous minerals. The hydrothermal metamorphism results in alteration to such Mg-Fe rich hydrous minerals as talc, chlorite, serpentine, actinolite, tremolite, zeolites, and clay minerals. Rich ore deposits are often formed as a result of hydrothermal metamorphism.

3.3.5 Burial metamorphism

When sedimentary rocks are buried to depths of several hundred meters, temperatures greater than 300°C may develop in the absence of differential stress. New minerals grow, but the rock does not appear to be metamorphosed. The main minerals produced are often the Zeolites. Burial metamorphism overlaps, to some extent, with diagenesis, and grades into regional metamorphism as temperature and pressure increase.

3.3.6 Shock metamorphism (impact metamorphism)

When an extra-terrestrial body, such as a meteorite or comet impacts with the Earth or if there is a very large volcanic explosion, ultrahigh pressures can be generated in the impacted rock. These ultrahigh pressures can produce minerals that are only stable at very high pressure, such as the SiO₂ polymorphs coesite and stishovite. In addition they can produce textures known as shock lamellae in mineral grains, and such textures as shatter cones in the impacted rock.

3.4 Metamorphic facies

The changes in mineral assemblages are due to changes in the temperature and pressure conditions of metamorphism. Thus, the mineral assemblages that are observed must be an indication of the temperature and pressure environment that the rock was subjected to. This pressure and temperature environment is referred to as Metamorphic Facies (Eskola, 1920). The sequence of metamorphic facies observed in any metamorphic terrain, depends on the geothermal gradient that was present during metamorphism. Figure 5 below highlights metamorphic facies depending on temperatures and pressures (Winter, 2001). Each facies has specific index minerals as described in Table 1 below (Spear, 1993).

4. IGNEOUS ACTIVITY, METAMORPHISM AND PLATE TECTONICS

Plate tectonics is the mechanism behind motion of crustal plates. It is still a controversial hypothesis though it explains very well volcanicity and igneous activity. Through this mechanism heat is transferred from deeper levels of the earth through plate margins (Kearey et al., 2009). At these environments igneous activities and metamorphism is widespread. Figure 6 shows the two plate tectonic environments i.e. convergent plate margins and divergent plate tectonic margins. Convergent tectonic margins are areas around *ring of fire* covering Indonesia, Philippines and South America in the Andes region. Divergent plate margins are the mid-Atlantic ridge and the African Rift Valley. At these margins major geothermal resources occur e.g. in Philippines, Indonesia, Iceland and African countries within Rift valley. Below is a further description of plate margins environments.

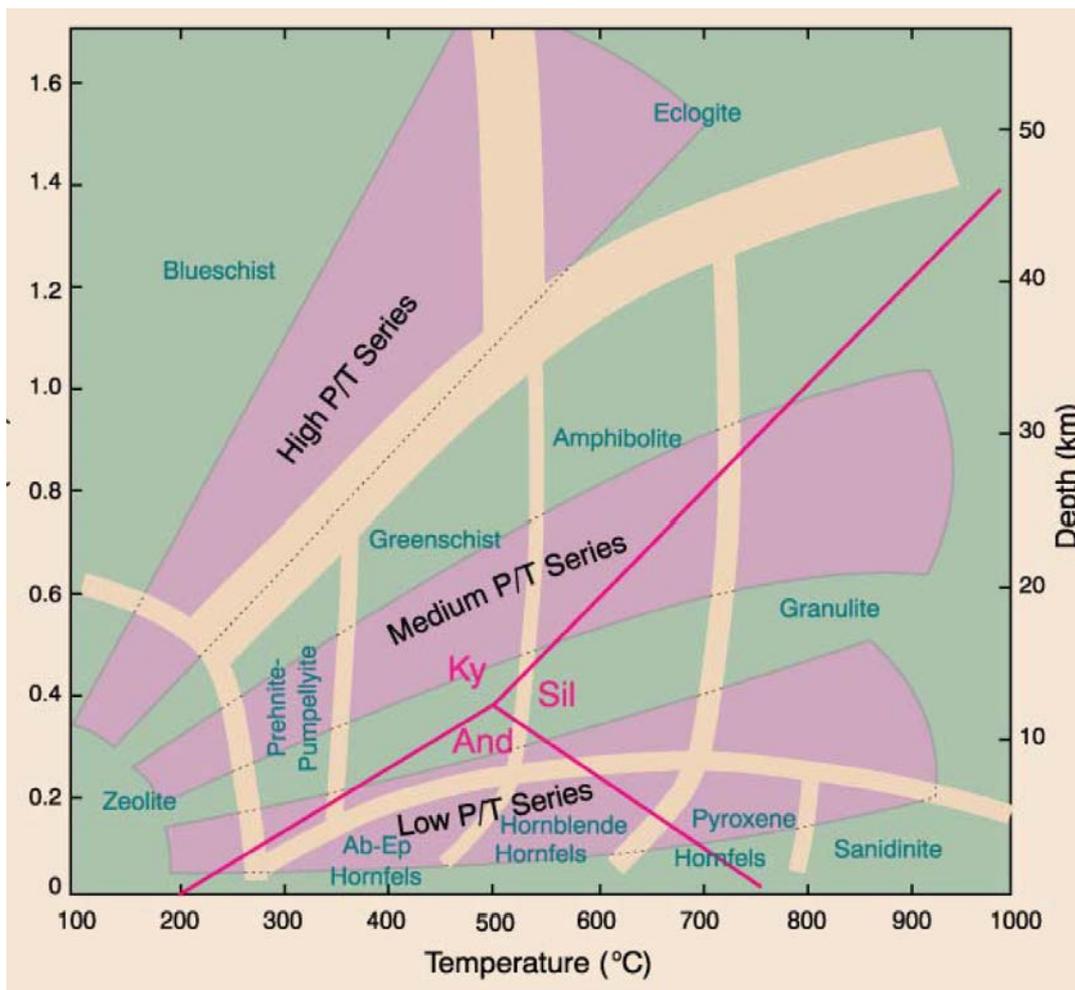


FIGURE 5: Metamorphic faces (Winter, 2001)

TABLE 1: Index minerals for the metamorphic facies (Spear, 1993)

Zeolite zeolites: especially laumontite, wairakite, analcime
Prehnite-Pumpellyite prehnite + pumpellyite (+ chlorite + albite)
Greenschist chlorite + albite + epidote (or zoisite) + quartz \pm actinolite
Amphibolite hornblende + plagioclase (oligoclase-andesine) \pm garnet
Granulite orthopyroxene (+ clinopyroxene + plagioclase \pm garnet \pm hornblende)
Blueschist glaucophane + lawsonite or epidote (+albite \pm chlorite)
Eclogite pyrope garnet + omphacitic pyroxene (\pm kyanite)
Contact facies

4.1 Divergent plate boundary

Earth plates are made of rigid lithosphere and the plastic asthenosphere. In the divergent boundaries usually basic igneous rock types are produced. Asthenosphere is usually close to the surface in the order of 5 to 10 km. It is usually plastic since temperatures are lower than those required for melting. When this zone is upwelled the pressure is reduced and melting occurs due to decompression from deeper levels hence melting. Beneath the divergent boundary the asthenosphere is wellled upward and decompression occurs (Figure 7). At this environments Igneous of volcanic activities are pretty common and with the temperatures and pressure metamorphism also is with spread.

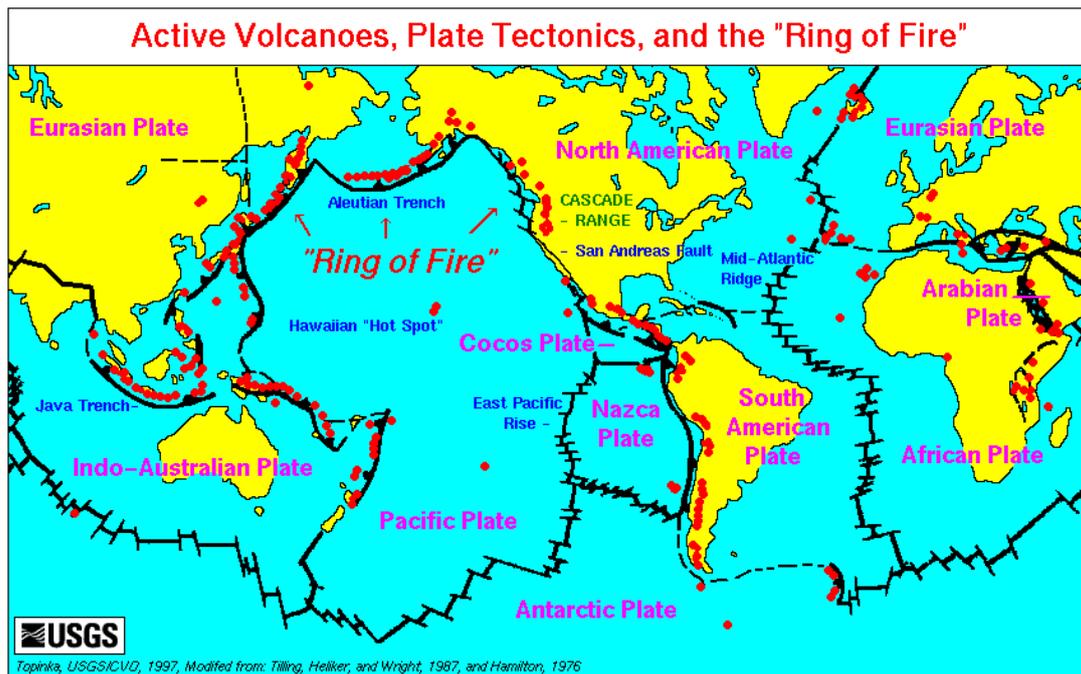


FIGURE 6: Plate tectonics and igneous provinces (Dive and discover, 2014)

4.1.1 Intraplate zones

Igneous activity away from plate margin is unusual however, such hotspots exist due to mantle plumes e.g. in Hawaii, and yellow stone national park.

4.1.2 Convergent plates

Intermediate and silic magmas are clearly related to convergence plate and subduction (Figure 8).

4.2 Geothermal resources

Different types of geothermal resources occur, namely. Those associated with volcanicity or igneous environments, sedimentary /geopressurised environments and to lesser extent metamorphic or dry rock system. The systems associated with igneous or volcanic environments are by far more and are high enthalpy resources making them very attractive for development. Example of such resources are found in Kenya within igneous provinces of the Rift Valley,

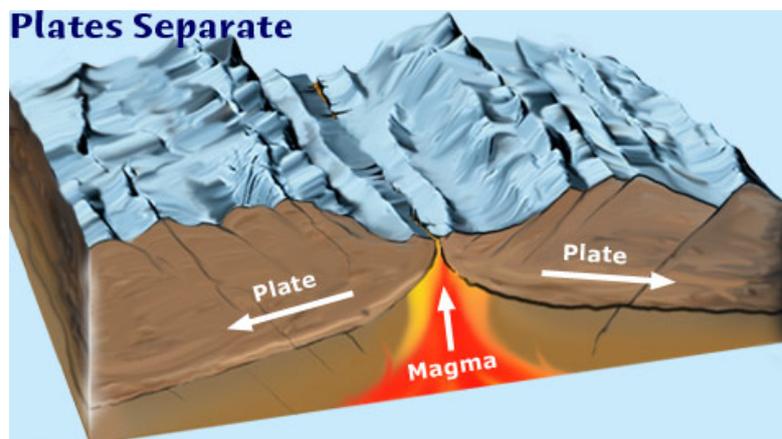


FIGURE 7: Divergent plate boundary (Dive and discover, 2014)

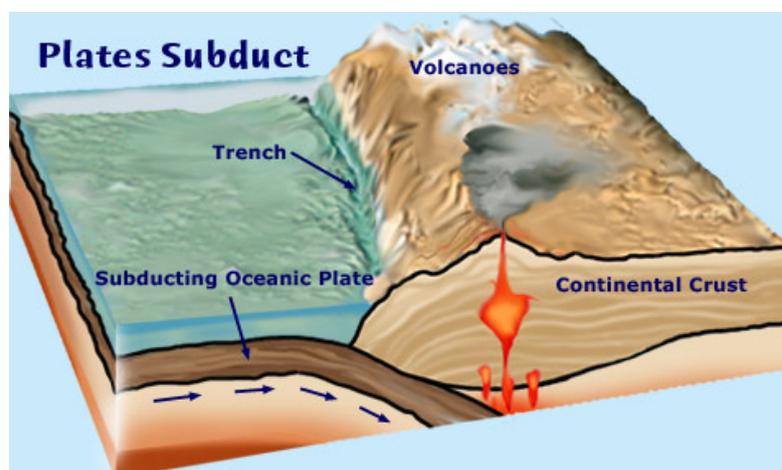


FIGURE 8: Convergent plate boundary (Dive and discover, 2014)

Iceland, Hawaii etc. Only in a few places like Hawaii are intraplate activities associated with geothermal are found.

5. SEDIMENTARY ROCKS

Sedimentary rocks are formed by the deposition of material at the Earth's surface and (or) within bodies of water. Sedimentation is the collective name for processes that cause mineral and/or organic particles (detritus) to settle and accumulate or minerals to precipitate from a solution. Sediments can be detrital, chemical or organic sediments. Detrital sediments are mechanically eroded from pre-existing rocks. Chemical sediments on the other hand are fluid precipitates or evaporates deposited in various environments. Sedimentary rocks are important in regard to resources like limestone deposits, coal and oil. They are also important geologically in interpretation of earth's history (Carlson et al, 2009). Below is Table 2 with descriptions of some common sedimentary rocks which include; sandstone, limestone, shale, conglomerate, and gypsum.

TABLE 2: Examples of sedimentary rocks

Rock name	Description
 <p data-bbox="544 1133 675 1160">Limestone</p>	<p data-bbox="743 909 1390 1205">The rock is classified as chemical or organic sediment depending on how it forms. It is composed primarily of calcium carbonate. The rock can form in two ways either by organically from the accumulation of shell, coral, algal and fecal debris or from chemically from the precipitation of calcium carbonate from lake or ocean water. Limestone is used in many ways. Some of the most common are: production of cement, crushed stone and acid neutralization</p>
 <p data-bbox="544 1435 715 1462">Conglomerate</p>	<p data-bbox="743 1211 1390 1379">This is a clastic sedimentary rock that contains large (greater than 2 millimetres in diameter) rounded particles. The space between the pebbles is generally filled with smaller particles and/or chemical cement that bind the rock together.</p>
 <p data-bbox="544 1682 663 1709">Sandstone</p>	<p data-bbox="743 1469 1390 1637">This primarily a clastic sedimentary rock made up mainly of sand-size (1/16 to 2 millimetre diameter) weathering debris. Environments where large amounts of sand can accumulate include beaches, deserts, flood plains and deltas</p>
 <p data-bbox="544 1928 600 1955">Coal</p>	<p data-bbox="743 1727 1390 1850">This purely organic sedimentary rock that forms mainly from plant debris. The plant debris usually accumulates in a swamp environment. Coal is combustible and is often mined for use as a fuel.</p>

6. CONCLUSION

- Three major types exist on the earth, these include sedimentary, igneous and metamorphic rocks. The classification is based on how these rocks form;
- Sedimentary rocks forms the largest share of the rocks on the earth's surface;
- Rocks are important in mapping of natural resources with Plate tectonics playing major role in various rock type distribution and abundance;
- Igneous and metamorphic rocks are both encountered in geothermal environments;
- Igneous rocks especially very recent are good indicators of volcanism hence heat source for geothermal system to exist; and
- Sedimentary rocks play a major role in reconstruction of earth's history also important resources like coal and oil can be found in sedimentary environments. Geopressurised geothermal systems are also hosted in sedimentary terrains.

REFERENCES

- Carlson, D.H, Plummer, C.C and Hammersley, L., 2008: *Physical geology, earth revealed*. McGraw-Hill. New York, NY 100200.
- Discover and dive, 2014: *Ring of fire*. Website: www.divediscover.whoi.edu
- Ehlers, G.E. and Blatt, H., 1997: *Petrology, Igneous sedimentary and metamorphic*. CBS publishers and distribution.4596/1-A new delhi-11000, India.
- Eskola, P., 1920: The mineral facies of rocks. *Norsk. Geol. Tidsskr.* 6 (1922), 143-194.
- Kearey, P., Klepeis, K.A, and Vine, J.F., 2009: *Global tectonics*. John Wiley and sons Ltd West Sussex P0198SQ, United Kingdom.
- Spear, F.S., 1993: *Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths*. Mineralogical Society of America, Washington, D.C., 799 pp.
- Winter D.J., 2001: *An Introduction to Igneous and Metamorphic Petrology*. Prentice hall.