Benha university	**Fourth Level**
Faculty of science	**Special Geology**
Geology Dept.	**Geochemistry (433 G)**
9 / 1 /2016	**Time: Two Hours**

Examination of Geochemistry (433 G) for the
Fourth level students (Special Geology), Jan. 2016.

Answer the following questions

1. Write short notes for the following: (12 Marks)

a) Goldschmidt's Classification
b) Silica saturation classification
c) An incompatible element
d) Nephelinite
e) Alumina (Al_2O_3) Saturation
f) Physical changes in magma as it ascends

2. a- Discuss the general characteristics of A-, S-, M- and I-type granites? (6 Marks)

b- Write a summary of the differences (Geochemical characterization, Petrography and Geologic Setting) between calc-alkaline and tholeiitic fractionation trends? (6 Marks)

3. Discuss in detail:- (12 Marks)

a- Bowen's Reaction Series.

b- The classification of basalts based on their normative components.

4. Check whether the following statements are correct or not and correct the false if any? (12 Marks)

1- A primary magma: Is the first melt produced by partial melting within the crust, and which has not yet undergone any differentiation.

2- All primary magmas must have > 10% Na_2O by weight.

3- Tholeiitic rocks are Fe-rich, alkali rich, peralkaline and are common in oceanic ridges, intraplate-volcanoes ± convergent margins.

4- Eu, when in its 2+ state, substitutes for Ca^{2+} in plagioclase feldspar more readily than the other rare earths.

5- A calc-alkaline magma is oxidized enough to precipitate significant amounts of the iron oxide magnetite, causing the iron content of the magma to increase as it cools than with a tholeiitic magma.

6- Tholeiitic magmas are reduced; calc-alkaline magmas are oxidized.

7- MORB exhibits a light rare earth enriched pattern; upper continental crust is light rare earth depleted with a positive 'Eu anomaly'.

8- When the parent magmas of basalts crystallize, they preferentially crystallize the more iron-rich and magnesium-rich forms of the silicate minerals olivine and pyroxene.

9- Nickel, with very similar chemical behavior to iron and magnesium, substitutes readily for them and hence is very incompatible in the mantle.

10- Tholeiitic basalts have a higher content of the alkalis, Na_2O and K_2O, than other basalt types. They also characterized by the development of modal nepheline in their groundmass.

11- With the calc-alkaline series, however, the precipitation of magnetite causes the iron-magnesium ratio to remain relatively constant, so the magma moves in a straight line towards the magnesium corner on the AFM diagram.

12- Higher SiO_2 content magmas have higher viscosity than lower SiO_2 content magmas

- **Good Luck –**

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Answer the following questions

1. Write short notes for the following: (12 Marks)

a) Goldschmidt's Classification

Goldschmidt* recognized four broad categories: atmophile, lithophile, chalcophile, and siderophile.

Atmophile elements are generally extremely volatile (i.e., they form gases or liquids at the surface of the Earth) and are concentrated in the atmosphere and hydrosphere.

Lithophile, siderophile and chalcophile refer to the tendency of the element to partition into a silicate, metal, or sulfide liquid respectively.

Lithophile elements are those showing an affinity for silicate phases and are concentrated in the silicate portion (crust and mantle) of the earth.

Siderophile elements have an affinity for a metallic liquid phase. They are depleted in the silicate portion of the earth and presumably concentrated in the core.

Chalcophile elements have an affinity for a sulfide liquid phase.

Siderophile	Chalcophile	Lithophile	Atmophile
Fe*, Co*, Ni*	(Cu), Ag	Li, Na, K, Rb, Cs	(H), N, (O)
Ru, Rh, PdZn, Cd, Hg	Be, Mg, Ca, Sr, Ba	He, Ne, Ar, Kr, Xe	
Os, Ir, Pt	Ga, In, Tl	B, Al, Sc, Y, REE	
Au, Re†, Mo†	(Ge), (Sn), Pb	Si, Ti, Zr, Hf, Th	
Ge*, Sn*, W‡	(As), (Sb), Bi	P, V, Nb, Ta	
C‡, Cu*, Ga*	S, Se, Te	O, Cr, U	
Ge*, As†, Sb†	(Fe), Mo, (Os)	H, F, Cl, Br, I	
	(Ru), (Rh), (Pd)	(Fe), Mn, (Zn), (Ga)	

b) Silica saturation classification

If a magma is oversaturated with respect to Silica then a silica mineral, such as quartz, cristobalite, tridymite, or coesite, should precipitate from the magma, and be present in the rock. On the other hand, if a magma is undersaturated with respect to silica, then a silica mineral should not precipitate from the magma, and thus should not be present in the rock. The silica saturation concept can thus be used to divide rocks in silica undersaturated, silica saturated, and silica oversaturated rocks. The first and last of these terms are most easily seen.

Silica Undersaturated Rocks

In these rocks we should find minerals that, in general, do not occur with quartz. Such minerals are:

Nepheline- $NaAlSiO_4$

Forsteritic Olivine - Mg_2SiO_4

Nosean - $6NaAlSiO_4 \cdot Na_2SO_4$

Perovskite - $CaTiO_3$

Melilite - $(Ca,Na)_2(Mg,Fe^{+2},Al,Si)_3O_7$

Leucite - $KAlSi_2O_6$

Sodalite - $3NaAlSiO_4 \cdot NaCl$

Haüyne - $6NaAlSiO_4 \cdot (Na_2,Ca)SO_4$

Melanite - $Ca_2Fe^{+3}Si_3O_{12}$

Silica Oversaturated Rocks.

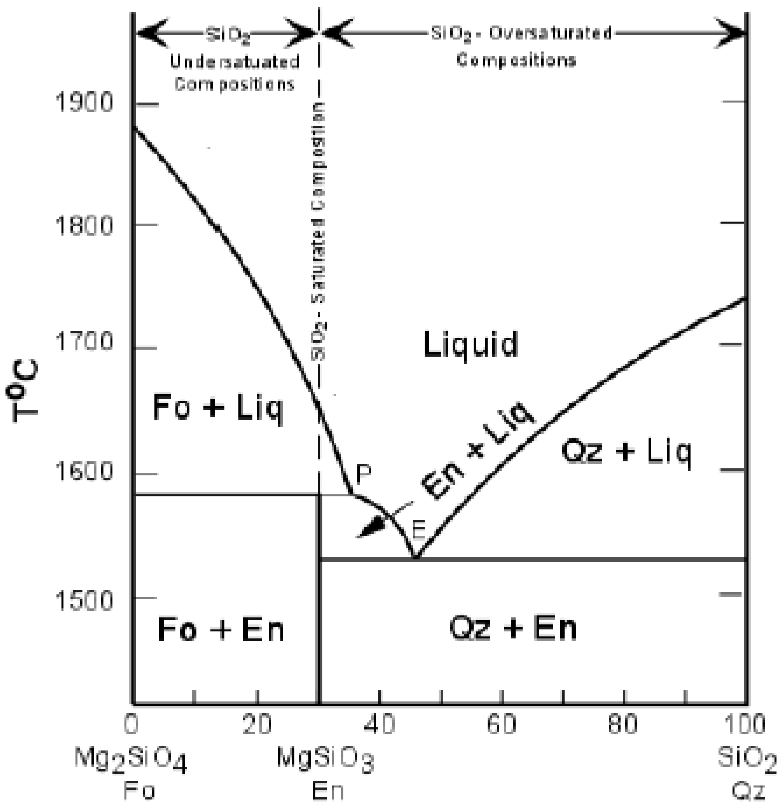
These rocks can be identified as possibly any rock that does not contain one of the minerals in the above list.

If we calculate a CIPW Norm, silica oversaturated rocks will contain normative quartz.

Silica Saturated Rocks.

These are rocks that contain just enough silica that quartz does not appear, and just enough silica that one of the silica undersaturated minerals does not appear.

In the CIPW norm, these rocks contain olivine, or hypersthene + olivine, but no quartz, no nepheline, and no leucite



c) An incompatible element

Incompatible elements are defined as those elements that partition readily into a melt phase when the mantle undergoes melting.

d) Nephelinite

Nephelinite: Is a volcanic rock with normative ol + lots of ne, and modal Ti-augite, Ol, feldspathoids ± phlogopite ± perovskite ± melilite in addition to matrix alkali feldspar.

e) Alumina (Al_2O_3) Saturation

Alumina (Al2O3) Saturation

After silica, alumina is the second most abundant oxide constituent in igneous rocks. Feldspars are, in general, the most abundant minerals that occur in igneous rocks. Thus, the concept of alumina saturation is based on whether or not there is an excess or lack of Al to make up the feldspars. Note that Al2O3 occurs in feldspars in a ratio of 1 Al to 1 Na, 1K, or 1 Ca:

$KAlSi_3O_8$ -- $1/2K_2O : 1/2Al_2O_3$

$NaAlSi_3O_8$ -- $1/2Na_2O : 1/2Al_2O_3$

$CaAl_2Si_2O_8$ -- $1CaO : 1Al_2O_3$

Three possible conditions exist.

1. If there is an excess of Alumina over that required to form feldspars, we say that the rock is ***peraluminous***. This condition is expressed chemically on a molecular basis as:

Al2O3 > (CaO + Na2O + K2O)

In peraluminous. rocks we expect to find an Al2O3 rich mineral present as a modal mineral such as muscovite [KAl3Si3O10(OH)2], corundum [Al2O3], topaz [Al2SiO4(OH,F)2], or an Al2SiO5 mineral like kyanite, andalusite, or sillimanite.

Peraluminous rocks will have corundum [Al2O3] in the CIPW norm and no diopside in the norm.

2. ***Metaluminous*** rocks are those for which the molecular percentages are as follows:

Al2O3 < (CaO + Na2O + K2O) and Al2O3 > (Na2O + K2O)

These are the more common types of igneous rocks. They are characterized by lack of an Al2O3 rich mineral and lack of sodic pyroxenes and amphiboles in the mode.

3. ***Peralkaline*** rocks are those that are oversaturated with alkalies (Na2O + K2O), and thus undersaturated with respect to Al2O3. On a molecular basis, these rocks show:

Al2O3 < (Na2O + K2O)

Peralkaline rocks are distinguished by the presence of Na rich minerals like aegerine [NaFe+3Si2O6], riebeckite [Na2Fe3 +2Fe2 +3Si8O22(OH)2], arfvedsonite [Na3Fe4 +2(Al,Fe+3)Si8O22(OH)2], or aenigmatite [Na2Fe5 +2TiO2Si6O18] in the mode.

f) Physical changes in magma as it ascends

during the ascending of magma these changes mostly occur:

a) Temperature Drops
    a. Increase in viscosity
    b. Crystallization begins
        i. Increase in viscosity
        ii. Composition becomes more silicic (more polymerized)
            1. Increase in viscosity
        iii. Gases concentrated in melt

b) Pressure Drops
    a. Gases exsolve
        i. H_2O concentration drops
            1. Increase in viscosity
        ii. Bubbles form
            1. Increase in viscosity

2. a- Discuss the general characteristics of A-, S-, M- and I-type granites? (6 Marks)

Type	SiO_2	K_2O/Na_2O	Ca, Sr	A/(C+N+K)*	Fe^{3+}/Fe^{2+}	Cr, Ni	$\delta^{18}O$	$^{87}Sr/^{86}Sr$	Misc	Petrogenesis
M	46-70%	low	high	low	low	low	< 9‰	< 0.705	Low Rb, Th, U Low LIL and HFS	Subduction zone or ocean-intraplate Mantle-derived
I	53-76%	low	high in mafic rocks	low: metal-uminous to peraluminous	moderate	low	< 9‰	< 0.705	high LIL/HFS med. Rb, Th, U hornblende magnetite	Subduction zone Infracrustal Mafic to intermed. igneous source
S	65-74%	high	low	high peraluminous	low	high	> 9‰	> 0.707	variable LIL/HFS high Rb, Th, U biotite, cordierite Als, Grt, Ilmenite	Subduction zone Supracrustal sedimentary source
A	high $\rightarrow$ 77%	Na_2O high	low	var peralkaline	var	low	var	var	low LIL/HFS high Fe/Mg high Ga/Al High REE, Zr High F, Cl	Anorogenic Stable craton Rift zone

* *molar* $Al_2O_3/(CaO+Na_2O+K_2O)$ Data from White and Chappell (1983), Clarke (1992), Whalen (1985)

b- Write a summary of the differences (Geochemical characterization, Petrography and Geologic Setting) between calc-alkaline and tholeiitic fractionation trends? (6 Marks)

Geochemical characterization

Rocks from the calc-alkaline magma series are distinguished from rocks from the tholeiitic magma series by the redox state of the magma they crystallized from (tholeiitic magmas are reduced, and calc-alkaline magmas are oxidized). When mafic (basalt-producing) magmas crystallize, they preferentially crystallize the more magnesium-rich and iron-poor forms of the silicate minerals olivine and pyroxene, causing the iron content of tholeiitic magmas to increase as the melt is depleted of iron-poor crystals. (Magnesium-rich olivine solidifies at much higher temperatures than iron-rich olivine.) However, a calc-alkaline magma is oxidized enough to (simultaneously) precipitate significant amounts of the iron oxide magnetite, causing the iron content of the magma to remain more steady as it cools than with a tholeiitic magma.

Geologic Setting

Calc-alkaline rocks typically are found in the arcs above subduction zones, commonly in volcanic arcs, and particularly on those arcs on continental crust.

Tholeiitic basalts are the most common volcanic rocks on Earth, as they are produced by submarine volcanism at mid-ocean ridges and make up much of the ocean crust. MORB, the acronym for typical mid-ocean-ridge basalt, is a type of tholeiitic basalt particularly low in incompatible elements. In contrast, alkali basalt is not typical at ocean ridges, but is erupted on some oceanic islands and on continents, as also is tholeiitic basalt.

Petrologic origin

Calc-alkaline rocks are thought to be genetically related by fractional crystallization and to be at least partly derived from magmas of basalt or andesite composition formed in the Earth's mantle. Trends in composition can be explained by a variety of processes. Many explanations focus on water content and oxidation states of the magmas. Proposed mechanisms of formation begin with partial melting of subducted material and of mantle peridotite (olivine and pyroxene) altered by water and melts derived from subducted material. Mechanisms by which the calc-alkaline magmas then evolve may include fractional crystallization, assimilation of continental crust, and mixing with partial melts of continental crust.

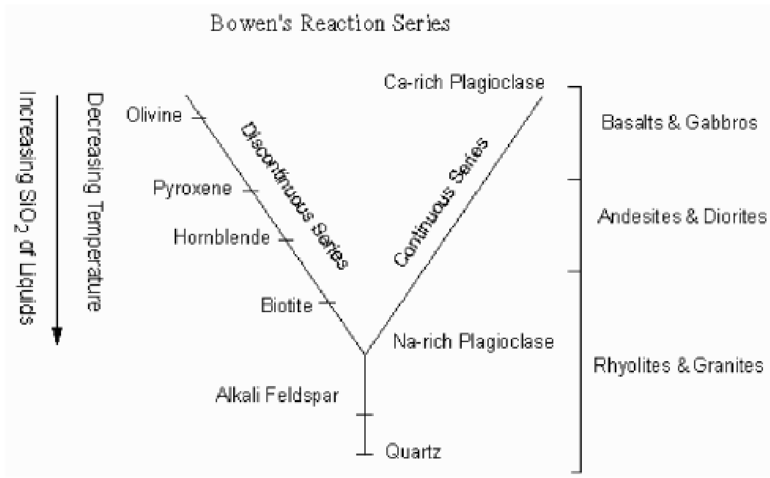
Tholeiitic rocks (e.g. tholeiitic basalts) like all basalt, the rock type is dominated by clinopyroxene plus plagioclase, with minor irontitanium Oxides. Orthopyroxene or pigeonite may also be present in tholeiitic basalt, and olivine, if present, may be rimmed by either of these calcium-poor pyroxenes. Tridymite or quartz may be present in the fine-grained groundmass of tholeiitic basalt, and feldspathoids are absent. Tholeiitic rocks may have a fine, glassy groundmass, as may other types of basalt.

3. Discuss in detail:- (12 Marks)

a- Bowen's Reaction Series.

Bowen's Reaction Series

Norman L. Bowen, an experimental petrologist in the early 1900s, realized this from his determinations of simple 2- and 3-component phase diagrams, and proposed that if an initial basaltic magma had crystals removed before they could react with the liquid, that the common suite of rocks from basalt to rhyolite could be produced. This is summarized as Bowen's Reaction Series.



Bowen suggested that the common minerals that crystallize from magmas could be divided into a continuous reaction series and a discontinuous reaction series.

The continuous reaction series is composed of the plagioclase feldspar solid solution series. A basaltic magma would initially crystallize a Ca-rich plagioclase and upon cooling continually react with the liquid to produce more Na-rich plagioclase. If the early forming plagioclase were removed, then liquid compositions could eventually evolve to those that would crystallize a Na-rich plagioclase, such as a rhyolite liquid.

The discontinuous reaction series consists of minerals that upon cooling eventually react with the liquid to produce a new phase. Thus, as we have seen, crystallization of olivine from a basaltic liquid would eventually reach a point where olivine would react with the liquid to produce orthopyroxene. Bowen postulated that with further cooling pyroxene
would react with the liquid, which by this time had become more enriched in H2O, to produce hornblende. The hornblende would eventually react with the liquid to produce biotite. If the earlier crystallizing phases are removed before the reaction can take place, then increasingly more siliceous liquids would be produced.

b- The classification of basalts based on their normative components.

Yoder and Tilley (1962) classified basalts into four different types based on their **normative minerals**. Although this is a chemical classification, the norms of many basalts (especially those which are totally crystalline and almost devoid of phenocrysts) come very close to their modes. This classification, which also applies to basaltic magmas.
1) quartz tholeiitic
2) olivine tholeiitic
3) alkali olivine basaltic (AOB)
If we were to consider the feldspathoidal magmas as well, we can define a fourth type of "basaltic" magma: "basanitic".
The characteristics of rocks resulting from the wholesale crystallization of these magmas are summarized in the table:

Series	**Norm**	**Mode**
Qz-tholeiite	**qz + hy**	**Hy**
Ol-tholeiite	**hy + ol**	**Hy and/or Ol**
AOB	**ol ± ne**	**Ol**
Basanite	**ol + ne**	**Ol + Ne**

A fifth type of basalt which is not part of Yoder and Tilley's (1962) classification but is nonetheless recognized is the **high Al2O3 basalt** considered in many cases as the parental magma for many calc-alkaline rocks. These basalts are phenocryst - poor and are characterized by Al2O3 contents > 17 weight %.

4. Check whether the following statements are correct or not and <u>correct the false if any</u>? (12 Marks)

1- A primary magma: Is the first melt produced by partial melting within the **<u>crust</u>**, and which has not yet undergone any differentiation. **(False)**

A primary magma: Is the "first melt" produced by partial melting within the **<u>mantle</u>**, and which has not yet undergone any differentiation.

2- All primary magmas must have **<u>> 10% Na_2O</u>** by weight. **(False)**

All primary magmas must have **<u>> 10% MgO</u>** by weight.

3- Tholeiitic rocks are Fe-rich, alkali **<u>rich</u>**, **<u>peralkaline</u>** and are common in oceanic ridges, intraplate-volcanoes ± convergent margins. **(False)**

Tholeiitic rocks are Fe-rich, alkali **<u>poor</u>**, **<u>metaluminous</u>** and are common in oceanic ridges, intraplate-volcanoes ± convergent margins.

4- Eu, when in its 2+ state, substitutes for Ca^{2+} in plagioclase feldspar more readily than the other rare earths. **(True)**.

5- A calc-alkaline magma is oxidized enough to precipitate significant amounts of the iron oxide magnetite, causing the iron content of the magma to **<u>increase</u>** as it cools than with a tholeiitic magma. **(False)**

A calc-alkaline magma is oxidized enough to precipitate significant amounts of the iron oxide magnetite, causing the iron content of the magma to **<u>remain more steady</u>** as it cools than with a tholeiitic magma.

6- Tholeiitic magmas are reduced; calc-alkaline magmas are oxidized. **(True)**.

7- MORB exhibits a light rare earth **enriched** pattern; upper continental crust is light rare earth **depleted** with a **positive** ‘Eu anomaly’. **(False).**

MORB exhibits a light rare earth **depleted** pattern; upper continental crust is light rare earth-**enriched** with a **negative** ‘Eu anomaly’.

8- When the parent magmas of basalts crystallize, they preferentially crystallize the more **iron-rich and magnesium-rich** forms of the silicate minerals olivine and pyroxene. **(False).**

When the parent magmas of basalts crystallize, they preferentially crystallize the **more magnesium-rich and iron-poor** forms of the silicate minerals olivine and pyroxene

9- Nickel, with very similar chemical behavior to iron and magnesium, substitutes readily for them and hence is very **incompatible** in the mantle. **(False).**

Nickel, with very similar chemical behaviour to iron and magnesium, substitutes readily for them and hence is very **compatible** in the mantle.

10- **Tholeiitic** basalts have a higher content of the alkalis, Na_2O and K_2O, than other basalt types. They also characterized by the development of modal nepheline in their groundmass. **(False).**

Alkali basalts have a higher content of the alkalis, Na_2O and K_2O, than other basalt types. They are also characterized by the development of modal nepheline in their groundmass

11- With the calc-alkaline series, however, the precipitation of magnetite causes the iron-magnesium ratio to remain relatively constant, so the magma moves in a straight line towards **the magnesium corner on the AFM diagram**. **(False).**

With the calc-alkaline series, however, the precipitation of magnetite causes the iron-magnesium ratio to remain relatively constant, so the magma moves in a straight line **towards the alkali corner on the AFM diagram.**

12- Higher SiO_2 content magmas have higher viscosity than lower SiO_2 content magmas. **(True)**.

- Good Luck –