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Geological study of Aqra Formation for possible use as Portland cement in Chwarta-Mawat area Sulaimani – Iraqi Kurdistan Region

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Abstract

A succession of highly fossiliferous limestone of Aqra Formation is studied geochemically and strati graphically. The outcrops of succession have the thickness, width and length of about 160, 1500 and 30000 meters respectively. The outcrops located in the Chwarta-Mawat area in the Kurdistan Region, northeastern Iraq. An exposed section is selected for field and lab studies, and inspected by eyes and hand lenses. Twelve samples are taken for geochemical analyses and indication of possible use of the succession for Portland cement production. The analysis shows that the whole succession is consist of calcitic limestone which contains more than 95 % of $CaCO_3$, less than 1% MgO, Fe_2O_3, Al_2O_3, Na_2O, and K_2O. The analyses show that the limestone is high grade limestone which is very suitable for Portland cement production. In the area there is good quality and quantity of claystone as correctors' materials for the clinker. These claystone belong to the unit one of the Red Bed Series which extensively exposed directly to the north and northeast of the sampled section of the Aqra Formation. The results show that the Aqra limestone can be used in cement industry. The Ratios of the alumina modulus (AM), Hydraulic modulus (HM), silica modulus (SM) and lime saturation Factor (L.S.F) were also calculated. It was found that these ratios of some samples are compatible to Standards Specifications and other are not therefore some quantity of claystone from lower part of Red Bed Series were added to compensate for the percentage of silica, alumina and iron oxides for the suitable limestone as well as lowering the LSF values to acceptable ranges. It was found that most of the clinker phases of the studied samples have a good agreement with these typical constituents of normal Portland cement.

1-Introduction

Cement is a result of mixing and burning different raw materials at high temperatures in order to achieve specific chemical ratios of lime, silica, alumina and iron in the finished product. The burned mixture is known as cement clinker. After milling and addition of gypsum, it is called cement, which is basically a mixture of calcium silicates and smaller amount of calcium aluminates that react with water and cause the cement to set.

The main cement requirement is to use high Limestone is the source of calcium and clay or mud is source of Si, Al and Fe. Finished cement is produced by using finely grinding of cement clinker (95 percent) together with (5 percent) gypsum (or anhydrite) which helps to delay the setting time of the cement (El-Hafiz et al 2015).The quality of cement clinker relies on the chemistry of the raw materials. Around78- 80% of kiln feed is $CaCO_3$ comes from the limestone (Hung C, et all 2003). Clayey raw material accounts for between 10-15%, although the precise amounts will vary. The only undesirable impurity is magnesium carbonate, which may be found in calcareous rock. The level of magnesia (MgO) in the clinker (burned mixture of limestone and clay) by most international specification for (ordinary Portland cement) should not exceed 5 percent and maximum of 3 percent; this rule excludes dolomite or dolomitic limestones in cement production. Other harmful materials include excessive alkalis (sodium oxide, Na_2O or soda and potassium oxide) that react with amorphous silica in concrete mixture forming silica gel known as concrete cancer (British Geological Survey 2005).

The Portland cement, as fundamental constructional materials, has a critical part in revamping of Kurdistan and giving chances of occupations for the people groups of the region. It could be a reality that cement is the basic building fabric within the world, contributing a really vital part within the industry of numerous nations. Subsequently, the requires and utilize of cement is developing day by day. The aim of this study is to explore new reserves of raw materials for Portland cement production. This exploration is important due to three reasons; the first is that specification of Portland cement in Kurdistan Region is the best and cheaper compared with Iranian cement therefore it is exported to other parts of Iraq. The second reason is that the existed 6 factories have concentrated in the Bazian area and exert high environmental hazard on the area. The third is that there are many factories in rest of Iraq, capacity of the factories in Kurdistan Region is sufficient but for the rest of Iraq, specify the required quantities as there are many factories. The raw materials (limestone rocks and certain type of clay) are not available everywhere in Kurdistan. Finding good quality and reserve of the raw materials is a difficult task which needs field and lab works of geologists.

1.1. Location

The studied area located in the Sulaimanyiah Governorate at 30km to the north of Sulaimani city and about 4km to the southeast of Mawat town on the both sides of Mokaba Valley Stream (extreme upstream of Little Zab River) in northeastern Iraq (Fig.1). The midpoint of sampled section intersected by the latitude of 35^{o} 48^{-} $36.31^{=}$ N and longitude 45^{o} 26^{-} $07.53^{=}$ E. The section is exposed along western side Dolbesk Gorge which scored across Qishlagh–Dere ridge (mountain) by the Mokaba stream that flows northward toward Mawat town and Iranian Border.

1.2. Geomorphology

The studied area is mountain terrain which characterized by high contrast topography with high mountains than 2000 m high from sea level and deep valleys. The sampled section is located in the main valley in the Mawat-Chwarta area which contain many ridges, the main one is Qishlagh–Dere ridge which is approximately 250 m high and formed by vertical erosion of the above-mentioned stream and elongated from Qshlagh village south of Mawat to Dolbesh village and has the of trending NW-SW (Fig. 2).

The Aqra formation is exposed along the both side of the ridge and its scarp side face toward southeast and has the slope angle of about 55 degrees while dip slope faces opposite and has the slope of 25 degrees. The Qishlagh–Dere ridge consists mainly of limestone of Aqra Formation and many lateral thrust faults can be seen along its length in several locations along the scarp slope and they are studied by Karim and Solaiman (2012). By these faults, the Aqra Formation is separated into imbricated sheets below and above a succession of Red layers of Tanjero Formation These Red layers and the imbricated sheets are studied by Karim (2004) and Karim et al. (2017) respectively.

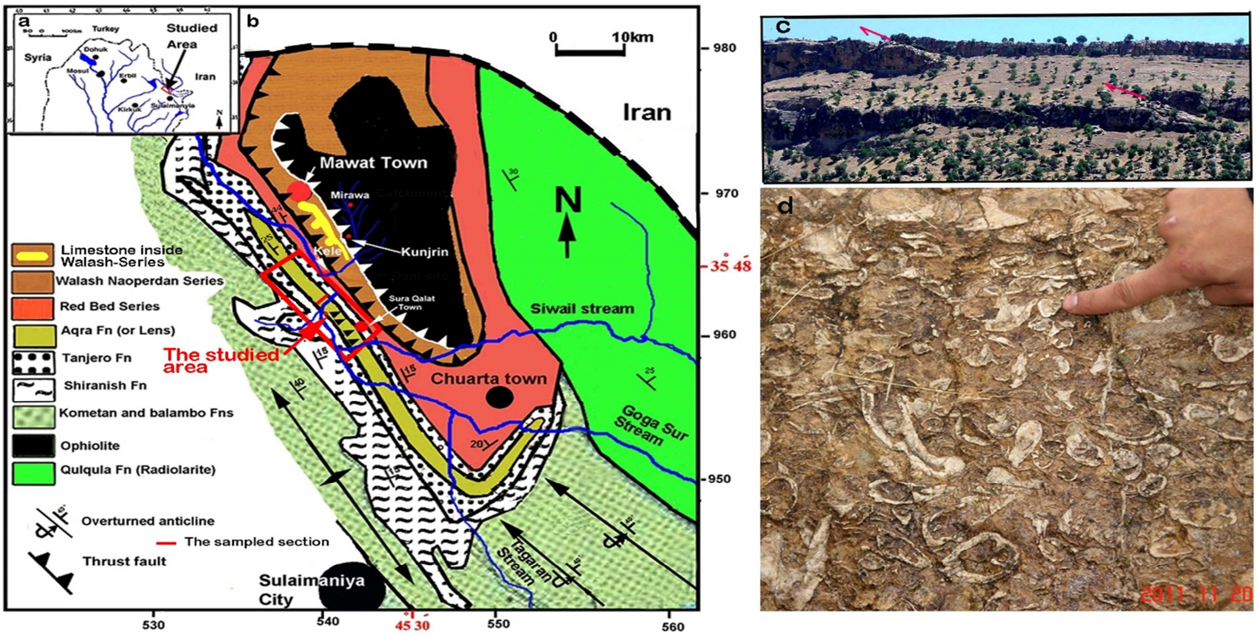


Figure-1(a and b) location and geological map Chwarta-Mawat area shows the sampled section and available outcrops of Aqra Formation which can be used for cement raw materials (modified from Mehaidi, 1975). c) Thrust fault in the studied area directly at the west of Suraqalat town, d) hand specimen of the Aqra Formation shows rudist skeletons.

1.3. Geological setting of the area

The studied area is located inside the imbricated Zone of Buday (1980) where the synclines and anticlines are overturned southeastwardly or reversely faulted and thrusted (Fig.1c). By overturning and faulting the folds are stacked and the apparent thickness of the formations doubled in many places. Due to these deformations, the studied area has complex geological setting which shows highly deformed outcrops of all kind of rocks of sedimentary, metamorphic and igneous. The latter two rocks are exposed at the northern boundary of the studied area, while only sedimentary rocks are exposed in the southern part.

The geological complication of the area attributed to its location exactly at the boundary between Thrust and Imbricated Zones of Buday and Jassim (1987) and Jassim and Golf (2006). According to Karim (2006) the studied area is located between two large normal faults that transformed the area to a graben. The studied area was part of the continental margin Afro-Arabian plate (or Neo-Tethys margin) during Jurassic and Early Cretaceous while it had changed to foreland basin during Late Cretaceous (Karim, 2004 and Ameen, 2008). This transformation (change) was due either to the obduction of ophiolite (Buday, 1980; Buday and Jassim, 1987; Jassim and Goff, 2006) or to the Iranian and Arabian plate continental collision (Karim, 2004; Karim and Surdashy, 2006). Geographically, ophiolite (Late Cretaceous) and Naoperdan Series thrust sheets occupy the northern part of the area. The carbonates of early and late Cretaceous ages are exposed in the south and southwest of the study area.

The rudist rich Aqra Formation (Fig.1d) exposed to the southwest of Mawat and Chwarta towns as a narrow L-shaped belt about 34 km wide along both sides of the river Qalachuallan-Mokaba (downstream of the river Goga Sur) (Fig.1b). The synclines and anticlines are not recognized due to imbrication and overturning, and all strata dip about 25 degrees northeastward.. In this area, the Aqra Formation is having reefal setting and it changes to turbidities facies toward the south where it interbedded with upper part of Tanjero Formation in area around Sulaimani city and Dokan Town (Sadiq, 2009 and Karim et al 2015). Different carbonate rocks from various location of Sulaimani area were studied and evaluated for their suitability of using as raw material in cement industry such as (Amin, 2014, Mirza et, al, 2016 and Mirza and Fatah, 2018).The limestone for cement production is not restricted to Aqra Formation but there is Walash-Naoperdan Series which contain thick succession of calcitic limestone and their outcrops are very close to studied section of Aqra Formation in the present study (Fig.1b). This succession is suitable for cement production and contains many species of large foraminifera such as nummulites, alveolinas and lipidocyclinas (Mirza et al 2016). The thin sections study of limestone of the Series shows that it consists of pure limestone (calcite) and don’t contain any dolomite or silica.

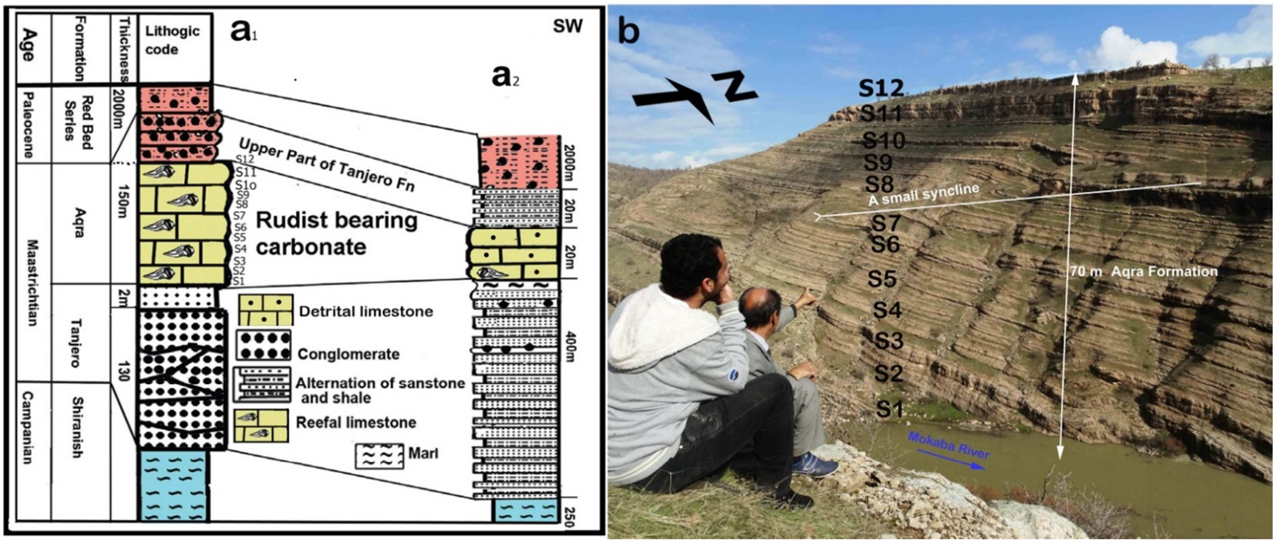


Figure-2 **a**1) stratigraphic column of the studied area shows position of Aqra Formation and samples , a2) stratigraphic column of the Sulaimani and Dokan area shows position of Aqra Formation as detrital limestone (calciturbidite), **b**) succession of the Aqra Formation along western side of Dolbesk Gorge shows location of samples.

1.4. Methodology

The samples for industrial study collected by channel sampling, twelve samples from limestone of Aqra Formation (Fig 2) and one sample of claystone from lower part of Red Bed series were collected. The thickness range between10-12 m and have a lateral extension of 50-60m. The limestone samples were collected along one traverse; each collected sample weighted about 3 Kg. The Geochemical analysis for the limestone samples was carried by XRF type (Thermo-ARL Advant ´XP + X-ray fluorescence spectrometer) at Mass Cement Factory in Sulaimani city. While the geochemical analysis for one sample from the middle part of Red Bed series was carried out at GeoAnalytical Laboratory, School of Earth and Environmental Science, Washington State University using XRF.

2. Result and discussion

2.1. Geochemistry

Cement chemistry in general and in Portland cement largely depends upon the geochemistry of its raw materials, i.e., limestone and clay (Rao et al. 2010). Approximately 75 % of Portland cement raw materials consist of lime (CaO) bearing materials (Lea, 1976 and Rao et. al. 2011). The major elemental chemistry of the limestone samples from Aqra Formation are represent in (Table 1). Geochemical analysis revealed that the limestones contain lime as major constituent varies between 47.79 % to 55.23 % and this due to high calcite content in limestone with an average 95.31%, followed by Loss On Ignitions LOI an average is 41.572 % (Table 1). The samples shows positive correlation with LOI (Fig.3A) which generally attributed to carbonate minerals and classified as a component of chemical composition that indicates the amount of burnt carbon in the material (Bediako and Amankwah 2015).

Silica, Alumina, iron and Magnesia form the minor constituents, as alkalis (soda and potash) and SO_3 are present in traces. The SiO_2 contents in limestone varies between (0.47 % to 5.28 % except sample number 2 which is the SiO_2 content is 14.02% and this is may be due to detrital quartz grains. The CaO and SiO_2 are negatively correlated due to two different mineral phases of CaO (from calcite) and SiO_2 (from quartz) that are not related (Fig. 3B).

According to Duda (1985) the limestone will be suitable for cement industry if the SiO_2 content is less than 6.75%. Hence the studied samples can be directly used in cement industry. Along with the other constituents that are usually important is MgO it ranges between 0.3 % to 1.31 % (Table 1) which might have been resulting from the magnesium–rich calcite shells or due to post depositional digenesis (dolomitization). Standard magnesium concentration in the clinker is limited to less than about 5% because it might cause destructive expansion in mortar and concert (Thanoon, 1999, Bouaza et al. 2016; Mirza et al. 2016 and Mirza and Fatah, 2018). SiO_2, $A1_2O_3$, Fe_2O_3

(in addition to CaO) of the limestone occur as the fundamental ingredients that compose the cement but should be within allowable limits.

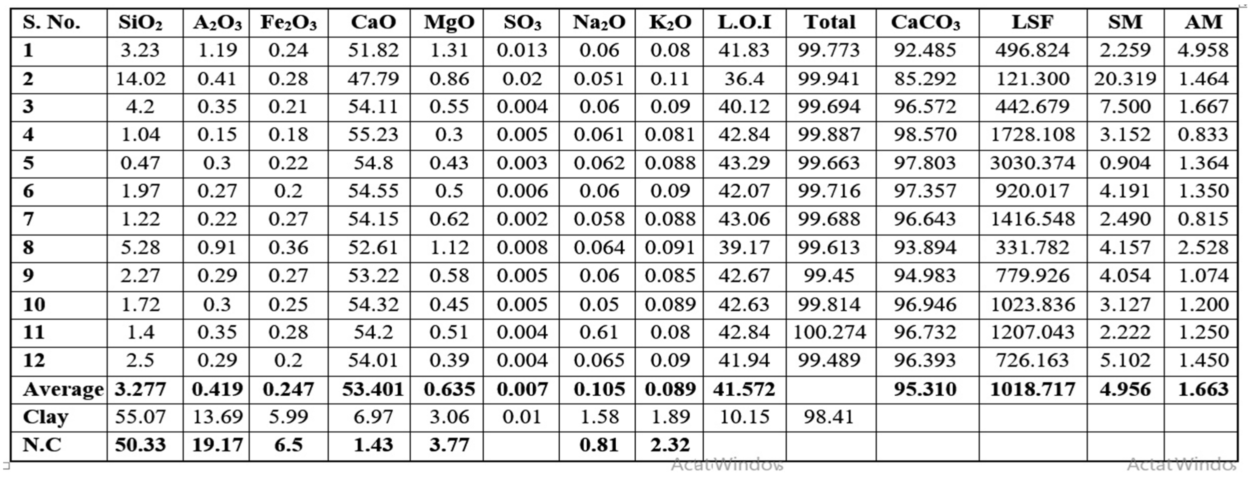
The alkalis and volatile contents respectively (Na_2O, K_2O), (SO_3), the percentages are too low in all samples that will not have a meaningful effect on the final quality of the cement produced or on manufacturing process. The clay is used as raw material for production of ordinary Portland cement and it is considered as the main source for providing SiO_2, Al_2O_3 and Fe_2O_3. One sample of clay (C) has been analyzed for major elemental components, (Table 1). The result shows that the SiO_2 is the most abundance oxide of about 55.7%. The composition of studied clayey sample was compared to normal clay (N.C) (Table 1). It appears that all oxides in this sample are more or less comparable to that of normal clay except CaO % content which is about (6.97%) manifold higher in the studied clay as compared to that of normal clay, this is due to the presence of thin carbonates bed within claystone.

Limestone saturation factor (LSF): The LSF is a ratio of CaO to the other three main clinker oxides and is measured as: LSF=100 CaO/ (2.8 SiO_2+1.2 $A1_20_3$+0.65 Fe_2O_3). Often, this is referred to as a percentage and thus multiplied by 100 (Rao et al. 2011). The LSF factor is limited to assure that the lime in the raw materials, used in the cement manufacturing is not so high, when LSF>100% the ordinary clinker always contains some free lime (Alemayehau and Sahu, 2013). The free lime target is normally about 0.5 to 1.5% CaO free (Alemageha, et al., 2013). High LSF requires high heat consumption for the burning of the clinker inside the kiln, thus giving more strength to the cement, but this means more fuel consumption, which leads to high production costs and damage to the kiln walls (Al-Auweidy, et al, 2013; and Mirza & Fatah 2018). As well as the LSF controls the ratio of alite to belite in the clinker, a clinker with a higher LSF will have higher proportion of alite C_3S to belite C_2S than a clinker with lower LSF (RaO, et al., 2011).

Typical LSF values in modem clinkers are 90-100. Values above 100 indicate that free lime is probably to be present in the clinker (Rao, et al, 2011 and Amin, 2014, Bouaza et al. 2016). From the composition of analyzed studied samples and calculated LSF values depending on the final equation limestone saturation factor (LSF) which was supposed by (Lea and parker, 1935) and mentioned in (Alao,1979) and modified by many, especially (Duda, 1977) (Table 1). Most samples have LSF values above the limits required for high -quality cement. Thus, it evident that for manufacturing of Portland cement some quantity of clay must be added to compensate for the percentage of silica, alumina and iron oxides for the suitable limestone as well as lowering the LSF values to acceptable ranges (Table 2).

Silica modulus (SM): The silica modulus represents the proportion of SiO_2 to the total Al_2O_3 and Fe_2O_3. The amount of melting phase in the burning zone is a function of SM; thus, when SM is high the amount of melting is low & vice versa [Alemayehu and Sahu, 2013]. Portland cement clinker, typical SM is ranges between 2.0 and 3.0 (Rao, et al., 2011). The SM for the most current samples shows large variation ranges between 0.904 to 20.319 (Table 1). It means that the SiO_2 content of these samples is higher and must be decreased to under the specified limits for cement production. The chemical compositions of the limestone have been modified by adding clay to keep the SM within the specified limits (Table 2).

Table-1: Geochemical analysis of Aqra limestone samples (1-12), clay samples from Red Bed Series (C) and normal clay composition (N.C)



S. No.	SiO_2	A_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I	Total	$CaCO_3$	LSF	SM	AM
1	3.23	1.19	0.24	51.82	1.31	0.013	0.06	0.08	41.83	99.773	92.485	496.824	2.259	4.958
2	14.02	0.41	0.28	47.79	0.86	0.02	0.051	0.11	36.4	99.941	85.292	121.300	20.319	1.464
3	4.2	0.35	0.21	54.11	0.55	0.004	0.06	0.09	40.12	99.694	96.572	442.679	7.500	1.667
4	1.04	0.15	0.18	55.23	0.3	0.005	0.061	0.081	42.84	99.887	98.570	1728.108	3.152	0.833
5	0.47	0.3	0.22	54.8	0.43	0.003	0.062	0.088	43.29	99.663	97.803	3030.374	0.904	1.364
6	1.97	0.27	0.2	54.55	0.5	0.006	0.06	0.09	42.07	99.716	97.357	920.017	4.191	1.350
7	1.22	0.22	0.27	54.15	0.62	0.002	0.058	0.088	43.06	99.688	96.643	1416.548	2.490	0.815
8	5.28	0.91	0.36	52.61	1.12	0.008	0.064	0.091	39.17	99.613	93.894	331.782	4.157	2.528
9	2.27	0.29	0.27	53.22	0.58	0.005	0.06	0.085	42.67	99.45	94.983	779.926	4.054	1.074
10	1.72	0.3	0.25	54.32	0.45	0.005	0.05	0.089	42.63	99.814	96.946	1023.836	3.127	1.200
11	1.4	0.35	0.28	54.2	0.51	0.004	0.61	0.08	42.84	100.274	96.732	1207.043	2.222	1.250
12	2.5	0.29	0.2	54.01	0.39	0.004	0.065	0.09	41.94	99.489	96.393	726.163	5.102	1.450
Average	**3.277**	**0.419**	**0.247**	**53.401**	**0.635**	**0.007**	**0.105**	**0.089**	**41.572**		**95.310**	**1018.717**	**4.956**	**1.663**
Clay	55.07	13.69	5.99	6.97	3.06	0.01	1.58	1.89	10.15	98.41				
N.C	**50.33**	**19.17**	**6.5**	**1.43**	**3.77**		**0.81**	**2.32**						

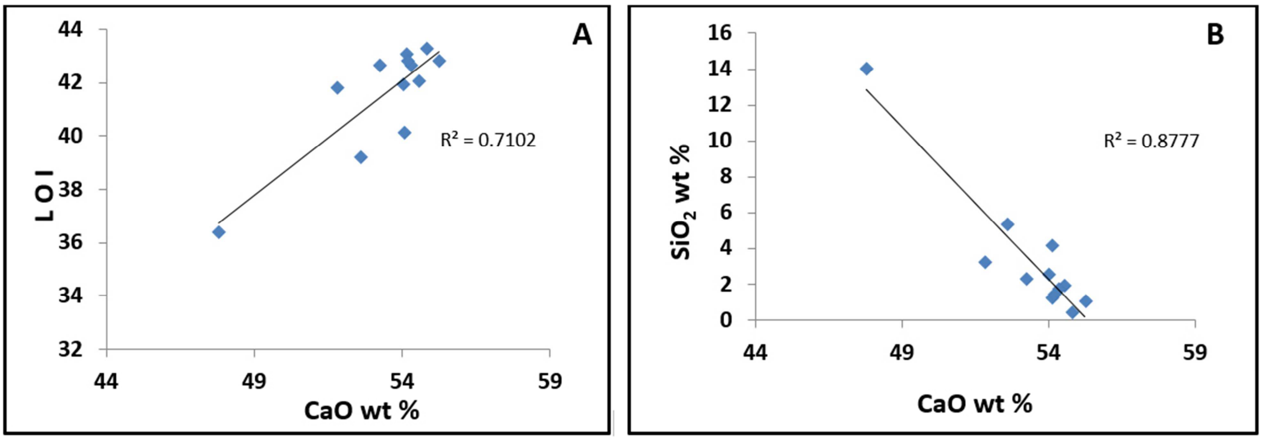


Figure-3A): CaO vs. LOI plotting and appearing positive correlation; B: CaO vs. SiO_2 plotting appearing negative correlations

Aluminum Modulus (AM): The aluminum modulus is determined by the proportion of aluminum to iron oxide: AM= Al_2O_3/Fe_2O_3. Generally, AM values range from 1.5 to 2.5 and more (Aldieb and Ibrahim, 2010). The rise in clinker AM means that there will be proportionally more aluminate and less ferrite in the clinker. A higher AM and low SM, result in fast setting of the cement, and this requires the addition of higher gypsum rate to regulate the setting time (Aldieb and Ibrahim, 2010). The AM for the present samples varies from 0.81 to 2.52, except sample number one is 4.96 (Table 1) and generally are low therefore the chemical composition of the limestone was adjusted by addition clay to keep the AM within the mentioned limits (Table 2).

2.2- Implication in cement production and characteristics of raw mixture composition:

When the essential component needed in cement raw mixture is not present in necessary amount, corrective ingredients are used as correctors. Thus, example for the completion of silica content the sand and high silica clay are used as correctors [Duda, 1985]. The aim of calculating the composition of raw mixture is to determine the quantitative proportions of the raw material for the clinker to give the desired chemical and mineralogical composition (Mirza and Fatah 2018). The proportion of raw mix composition for the present samples were calculated and depending on the final equation limestone saturation factor (LSF) which was supposed by Lea and Parker, (1935 in Alao 1979) and modified by many authors, especially Duda (1977). Due to a wide variety in LSF values ranging from 121.30 to 3030.37 and most of the studied samples had values above the required limits for high quality cement, consequently the claystone from Red Bed Series have been brought to limestone in proportion 1:3 to set pointing clinker (Tables 1 & 3).

The selected presumed LSF value for this study is 0.94 and the expected mixing ratio of both claystone with limestone was 1:3 (Table 3). Comparing the composition of raw mixture with the required standard specification for normal Portland cement it have been proved that all the materials meet the specification required for clinker production and have a composition close to that of so-called normal Portland cement (Table 2). The LSF value range between 92.47 to 94.20 and except mixture (1+ C) is 78.22 in a raw mixture composition. The SM, AM are keeps within standard limits ranges between 2.66 to 3.24 and 1.96 to 2.56 respectively in raw mixture except mixture (2+C) the SM is 8.61 and this due to high content of SiO_2 in limestone (sample 2 =14.02%), (Tables 1 and 3).

A-*Clinker Phases:*

The Portland cement properties are mainly determined by the proportion of its four principle clinker phases which are the impure forms of Ca_3SiO_5 (alite), Ca_2SiO_4 (belite), $Ca_3Al_2O_6$ (tricalcium aluminate) and C_4AF (tetracalcium aluminate ferrite). Other phases such as periclase (MgO), quartz (SiO_2), free lime (CaO), etc. may also be present in minor quantities, usually less than 1%w (Dutta, 2011; Mirza and Fatah, 2018). The C_3S and C_2S in the studied samples range between (54.54-71.84) and (19.40-23.90); except mixture (1+C) is 7.27, 67.11 (Table 3). The C_3A and C_4AF of the studied samples are ranges between (9.29-13.39) and (6.76-8.03) respectively, except mixture (2+C) is 3.52 and 3.07 in C_3A and C_4Af respectively (Table 3). Comparison of the values of phase mineral constituent in studied samples (Table 3) with typical constituent of normal Portland cement by Newman & Choo (2003) and Brandt (2009) (Tables 2) indicate that these values are in a better agreement with these typical constituents of normal Portland cement.

Table-2: Mineralogical composition percentage of Portland cement, (Newman & Choo, 2003 and Brandt, 2009).

Cement Notation	**Mineral Name**	**Typical level (Mass %)**	**Typical range (Mass %)**	**Chemical composition**
C_3S	Alite	57	38- 60	$3CaO. Si O_2$
C_2S	Belite	16	15- 38	$2CaO. Si O_2$
C_3A	Aluminate	9	7- 15	$3CaO. Al_2 O_3$
C_4AF	Ferrite	10	6- 18	$4CaO. Al_2 O_3. Fe_2 O_3$

B-Clicker Properties:

Some important properties of clinker were calculated. These properties include (Hydraulic modulus (HM), Minimum burning temperature (MBT), Burnability index (BI) and Liquid phase at the burning zone (L.Ph.)) The (HM) has the following form: $CaO / SiO_2 +Al_2O_3 +Fe_2O_3$ and is generally limited to 1.7-2.3 (Aldieb and Ibrahim, 2010). The hydraulic modulus of excellent quality cements was about 2 and cements with HM less than 1.7 showed mostly insufficient strength when cement had poor stability of volume with HM = 2.4 and more (Rao, et al., 2011). In general, the HM values for the studied samples are of excellent quality which is less than 2.4 (Table 3). The MBT represents the degree in which the liquid phase begins to appear in the furnace, and depends on the ratio of (Al_2O_3, Fe_2O_3) in the raw mix, but (Fe_2O_3) has greater effect. The proportion of lime and silica causes augmentation in value which is better not to be less than (1250 °C), since only after this temperature (C_3S) is begins to appear (Chatterjee, 1979). The MBT is calculated using this equation: $MBT°C = 1330 + 4.51 * C_3S – 3.74 * C_3A – 12.64 * C_4AF$. The MBT of clinker in the studied samples above this range except clinker (1+C), is lower than this range (Table 3).(BI) It is expressed as the percentage between the phase (C_3S) to total phases (C_3A + C_4AF) as follows: $BI = C_3S/ C_3A + C_4AF$, Susceptibility depends on the chemical composition of the burning mixture of raw mix, since any change in the composition leads to a change in susceptibility burning, the rate of BI in cement ranging between 2.6 to 4.5 (Al-Ali, 2004). This ratio has good susceptibility burning. The B.I of clinker of the studied samples ranges from 0.00 to 10.90 and this indicates that most of samples nave not concides with acceptable ranges. (L.Ph.) the liquid phase of the studied samples was calculated as follows:

$L.Ph. \% = 3.0 Al_2O_3 + 2.25 Fe_2O_3 + MgO + K_2O + Na_2O + SO_3$ (1450 °C).The acceptable ranges of L.ph in cement clinker at temperature 1450 °C ranging between 23% to 27%. The L.Ph. of the studied samples ranges between (22.77 to 26.59) %, except mixtures (2+C) is 10.34% and (1+C) is 30.33% (Table 3). Accordingly, most the studied samples have acceptable values. To reduce the liquid phase, SR must be increased by adding higher amount of sand to the mixture because sand is the main source for SiO_2, but for increasing liquid phase SR must be decreased (Mirza and Fatah 2018).

Table -3: Cement clinker composition with LSF of 94 calculated from binary combination of Aqra limestone (12 samples) and claystone from middle part of Red bed series sample (C) with SR, AR, main miner phase component in clinker.

	Requirments	**1+c**	**2+c**	**3+c**	**4+c**	**5+c**	**6+c**	**7+c**	**8+c**	**9+c**	**10+c**	**11+c**	**12+c**
Raw mix	X=	0.256	0.065	0.214	0.25	0.254	0.239	0.245	0.196	0.231	0.24	0.242	0.231
	Y=	0.744	0.935	0.786	0.75	0.746	0.761	0.765	0.804	0.769	0.76	0.758	0.769
	SiO_2	16.73	16.75	15.28	14.77	14.56	14.87	14.63	15.21	14.67	14.74	14.60	14.85
	Al_2O_3	4.45	1.29	3.25	3.59	3.76	3.53	3.57	3.46	3.44	3.57	3.63	3.44
	Fe_2O_3	1.74	0.66	1.47	1.66	1.71	1.61	1.70	1.48	1.61	1.65	1.69	1.56
	CaO	40.37	45.14	44.05	43.19	42.68	43.21	42.62	43.69	42.56	42.98	42.80	43.17
	MgO	1.77	1.01	1.10	1.00	1.11	1.12	1.23	1.51	1.16	1.09	1.14	1.02
	SO_3	0.01	0.02	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01
	Na_2O	0.46	0.15	0.39	0.45	0.45	0.43	0.44	0.37	0.42	0.42	0.85	0.42
	K2O	0.55	0.23	0.48	0.54	0.55	0.53	0.54	0.45	0.51	0.53	0.53	0.51
	L.O.I	33.76	34.70	33.74	34.71	34.91	34.48	35.04	33.51	35.20	34.87	34.97	34.63
	ToTal	99.83	99.94	99.76	99.92	99.75	99.78	99.76	99.69	99.58	99.86	100.21	99.61
Clinker	SiO_2	25.32	25.67	23.14	22.65	22.46	22.78	22.60	22.99	22.79	22.68	22.38	22.85
	Al_2O_3	6.73	1.97	4.93	5.51	5.80	5.41	5.52	5.23	5.34	5.49	5.57	5.29
	Fe_2O_3	2.63	1.01	2.22	2.54	2.64	2.46	2.62	2.24	2.51	2.54	2.58	2.40
	CaO	61.10	69.20	66.72	66.24	65.83	66.16	65.84	66.02	66.11	66.14	65.60	66.44
	MgO	2.68	1.54	1.66	1.54	1.71	1.72	1.90	2.28	1.81	1.67	1.75	1.57
	SO_3	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Na_2O	0.69	0.23	0.59	0.69	0.70	0.66	0.68	0.55	0.65	0.65	1.30	0.65
	K2O	0.83	0.35	0.73	0.83	0.85	0.81	0.83	0.68	0.79	0.81	0.81	0.79
	L.O.I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	ToTal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100	100	100	100
Ratio	LSF*	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00
	LSF**	78.22	93.94	94.20	94.02	92.47	93.87	93.92	93.94	93.90	93.95	94.19	94.04
	SR	2.71	8.61	3.24	2.81	2.66	2.90	2.78	3.08	2.91	2.82	2.75	2.97
	AR	2.56	1.96	2.22	2.17	2.20	2.20	2.11	2.33	2.13	2.16	2.16	2.20
clinker phases	C_3S%	7.27	71.84	59.45	56.87	54.54	56.38	55.39	55.69	56.46	56.38	55.82	57.81
	C_2S%	67.11	19.40	21.49	22.04	23.26	22.77	23.02	23.90	22.74	22.49	22.06	21.92
	C_3A%	13.39	3.52	9.29	10.29	10.89	10.16	10.20	10.06	9.90	10.25	10.38	9.95
	C_4AF%	8.00	3.07	6.76	7.73	8.03	7.49	7.97	6.82	7.63	7.73	7.86	7.31
clinker properties	H.M.	1.76	2.42	2.20	2.16	2.13	2.16	2.14	2.17	2.16	2.15	2.15	2.18
	M.B.T	1211.62	1602.03	1477.86	1450.25	1433.77	1451.60	1440.94	1457.37	1451.19	1193.97	1443.58	1461.13
	B.I	0.34	10.90	3.70	3.16	2.88	3.19	3.05	3.30	3.22	0.00	3.06	3.35
	L.Ph.	30.33	10.34	22.77	25.30	26.59	24.95	25.87	24.25	24.91	25.33	26.38	24.28

3- Conclusions

1- Field observation indicated that the limestone samples of Aqra Formation are partly crystallized and dominantly composed of calcite. They have a simple mineralogy, yet they have similar contents of silica and lime. CaO with LOI shows a positive correlation while CaO with SiO_2 shows a negative correlation due to mineralogical factors. Silica modulus, aluminum modulus, hydraulic modulus and lime saturation factor from geochemistry data suggested that the samples of Aqra formation from the selected studied area can be utilized for cement production except one sample which is contain high silica.

2-Comparison of the values of phase minerals with typical constituent of normal Portland cement by Newman & Choo (2003) and Brandt (2009) indicates better values agreement with the typical constituents of normal Portland cement hence the Aqra limestone of studied area can be utilized for cement making. The studied area characterized by high quality and quantity of claystone as additive materials for the clinker.

3-These claystone are belong to the unit one of the Red Bed Series which extensively exposed directly to the north and northeast of the outcrops of the Aqra Formation.

4- In addition to Aqra Formation, the studied area contains Naoperdan Formation which is suitable for cement production.

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