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THE SILICA SAND DEPOSITS IN THE WESTERN DESERT OF IRAQ: AN OVEREVIEW

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ABSTRACT

Very large silica sand deposits are documented at the Western Desert of Iraq. These deposits are found in the Ga'ara (Lower Permian), Hussainiyat (Lower Jurassic), Najmah (Upper Jurassic), Nahr Umr (Lower Cretaceous) and Rutbah (Upper Cretaceous) formations. Other exposed formations, such as the Amij Formation (Lower Jurassic) incorporates some thick silica sand horizons but not yet investigated for economic potentiality. Petrographic studies revealed that these silica sands are mostly weakly-cemented quartz-arenite, consisting predominantly of quartz and traces of alkali feldspars, heavy minerals and clay mineral. Some of these deposits are associated with kaolin clays, such as the Ga'ara, Hussainiyat and Amij formations. The Ga'ara and Hussainiyat deposits are of fluvial origin, whereas the Amij, Najmah, Nahr Umr and Rutbah deposits are of fluvio-paralic origin. The X-ray diffractograms revealed that the main associated clay mineral is kaolinite with minor proportions of illite and mixed-layer illite-smectite. The other main admixtures present, beside quartz, are iron oxyhydroxides (mostly goethite) and anatase. Particle size of the silica sand deposits ranges from very fine to coarse but the most common are fine to medium grain size. The shape of the grains is sub-angular to sub-rounded and the Fe_2O_3 ranges between (0.01 – 1.5) %. Follow-up investigations were carried out on five localities to estimate, verify and categorize the quantity and quality of the silica sand deposits. The investigations resulted in estimating 15.9 million m^3 of silica sand on category B, 2.2 million m^3 on category C_1 and 4456.9 million m^3 on category C_2.

رواسب رمال السليكا في الصحراء الغربية العراقية: نظرة شاملة

مازن يوسف تمار أغا و أسماء عبد العزيز العاني

المستخلص

تم توثيق رواسب كبيرة جدا من رمال السليكا في الصحراء الغربية العراقية. توجد هذه الرواسب في تكوينات الگعرة (البرمي الأسفل) والحسينيات (الجوراسي الأسفل) ونجمة (الجوراسي الأعلى) ونهر عمر (الكريتاسي الأسفل) والرطبة (الكريتاسي الأعلى). هناك تكوينات أخرى منكشفة تحوي افاق سميكة من رمل السليكا، مثل عامج (الجوراسي الأسفل)، لكنها لم تخضع لحد الآن للتحريات الجيولوجية لمعرفة الأمكانية الأقتصادية. بينت الدراسات البتروغرافية بأن رمال السليكا هذه هي صخور رملية من نوع الكوارتز-أرينايت ضعيف السمنتة تتكون بصورة رئيسة من الكوارتز مع آثار من الفلدسبارات القلوية والمعادن الثقيلة والمعادن الطينية. توجد رواسب الأطيان الكاؤولينية مع بعض من رواسب الرمل

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السيليكي في تكوينات مثل الگعرة والحسينيات وعامج. تعتبر رواسب الگعرة والحسينيات من أصل نهري بينما تعتبر رواسب عامج ونجمة ونهر عمر والرطبة من أصل شاطئي-نهري. بينت مخططات حيود الأشعة السينية بأن المعدن الطيني السائد في رمال السيليكا هو الكاؤولينايت مع كميات قليلة من اللألايت والطبقات المختلطة من الإلايت-سمكتايت. المعادن من الشوائب غير الطينية في هذه الصخور الرملية هي أكاسيد وهيدروكسيدات الحديد (معظمها الغوثايت). يتراوح حجم الحبيبات الرملية في رواسب رمال السليكا بين ناعم جدا الى خشن ولكن الأكثر شيوعا هو الحجم الناعم الى المتوسط. يتراوح شكل الحبيبات من شبه زاوي الى شبه مدور و تتراوح نسبة Fe_2O_3 بين (0.01 – 1.5) %. بينت التحريات المعدنية اللاحقة في خمسة مناطق لتخمين و التحقق وتصنيف الكمية والنوعية لرواسب السليكا بأن الأحتياطي بصنف B هو 19.5 مليون متر مكعب و بصنف C1 2.2 مليون متر مكعب وصنف C2 4456.9 متر مكعب.

INTRODUCTION

Silica sand is an industrial term includes quartz sand and sandstone (or quartz silica sand) rich in silica and potent for industrial uses such as glass making, metal casting (foundry sand), metal production, chemical production, construction, paints and coatings, ceramics and refractories, filtration and water production, fracking and many other uses. Silica sand is currently exploited from the Erdhuma open pit mine only, mostly consumed in the glass industry (sheet glass, bottles and glasses), metal casting, cement (White and Portland), ceramics and refractories.

Extensive deposits of silica sand are common in the Paleozoic and Mesozoic formations of the Iraqi Western Desert (Fig.1). Siliciclastics, both sand and clay, dominated the Paleozoic successions due to a relative quiescence (Jassim, 2006 and Fouad, 2007) and paleoclimate. During the Mesozoic, carbonates dominated the succession which can be attributed to prevailing climate (mostly tropical). During most of the Mesozoic (Early Jurassic to Late Cretaceous) eight cycles of lower clastic (mostly silica sand) and upper carbonate are recognized (Jassim *et al*., 2006; Jassim and Buday, 2006a, b and c).

Exploration and prospecting for silica sand in Iraq started since the early thirties of the last Century focusing on Najaf – Karbala area, sand-dune fields, Amij, Rutbah and Afaif (Ga'ara Depression) areas. The Ga'ara Depression, specifically the Afaif location, has been reported as a potential area of glass sand since the early thirties (Macfadyen, 1934). This potentiality has been reiterated in later reports (Gubbins, 1938; Leich, 1956). Further investigations, to locate an appropriate source of silica sand for glass industry, were urged in order to satisfy the requirements of the glass factory proposed in the Soviet – Iraq Technical and Economical Agreement, during the late fifties of the last Century. Two sites were favored for their grade, namely Rutbah and Afaif but the latter was eliminated as a source of raw materials due to its remoteness to the marketing center. Rutbah locality was chosen to establish a mine. The mine is named Erudhuma and is located about ten kilometers west of Rutbah Town. The silica sand there is exploited by open-pit mining from the Rutbah Formation (Cenomanian).

The Iraq Geological Survey started an ambitious program for detailed geological mapping (Scale 1: 25 000) during the eighties of the last Century (1983 – 1990) which led to mushrooming in the silica sand potential reserves in the Iraqi Western Desert, especially in the Ga'ara Depression (Tamar-Agha, 1986; Tamar-Agha *et al*., 1991 and Tamar-Agha *et al*., 1992a) and east of Rutbah Town (Al-Naqib *et al*., 1986) resulting in huge amounts of silica sand attaining billions of cubic meters. Some of these sandstones in the Ga'ara Depression showed silica content up to 98.5%, Fe_2O_3 content below 0.1% and about 95% of the quartz grains range in size between 100 and 600 µm (Tamar-Agha *et al*., 1991). The overburden is about 1 to 2 meters of soft Quaternary deposits. Furthermore, prospecting and exploration started in the Kilo 180 to outline a deposit to be exploited as an alternative to the Erdhuma

Deposit (Etabi *et al*., 1986). The main reasons for the Kilo 180 exploration were remoteness of the Erdhuma Mine from the glass factory near Ramadi city (320 Km) and not to waste high grade silica sand in the production of sheet glass, bottles, etc. Other potential formations for silica sand resources are the Hussainiyat and Amij formations. The silica sand deposits in both formations are associated with kaolin clays which means that their integrated exploitation reduce the production cost. In addition, during the investigations of the kaolin clay in the Ga'ara Depression, the silica sand in four areas only is assessed.

The aim of this article is to focus on the silica sand deposits at the Western Iraqi Desert, outlining their geological setting, mineralogy, physical properties, chemistry, origin, reserves, mining conditions, technological tests and industrial uses.

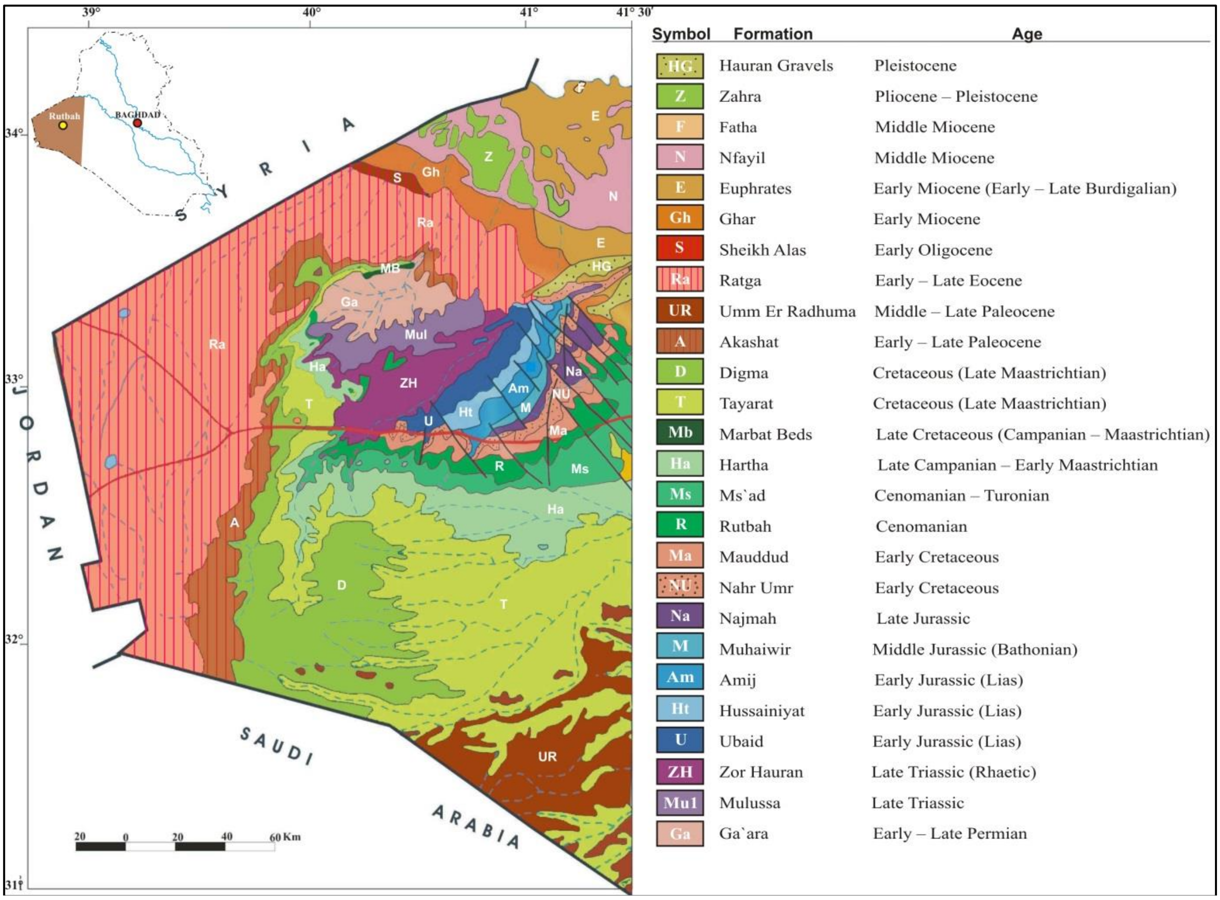

Fig.1: Geological map of the Iraqi Western Desert (after Sissakian, 2000)

GEOLOGICAL SETTING

The Western Desert of Iraq is part of the northern Arabian Platform, which is considered as the stable part of the platform (Jassim and Buday, 2006a; Fouad, 2007 and 2012). The boundary between the two stable and unstable parts of the platform is taken along Anah – Abu Jir Fault Zone (Fouad, 2012). There are no structural boundaries between the Western and Southern deserts of Iraq, and the distinction is strictly physiographic. The region, in general, lacks expressive Alpine-related compressional structures. The exposed Mesozoic and Cenozoic strata are subhorizontal, showing a general N, NE and E regional dip, except the extreme western part of the region where the strata exhibit a westward regional dip (Fouad, 2007).

Two main fault systems are recognized in the Iraqi Western Desert, the NW – SE and N – S trending fault systems. The NW – SE trending faults are strike-slip faults and named by Fouad (2007) Hauran Fault System. These faults are well developed in the central part of the Western Desert. Al-Mubarak and Amin (1983) and Al-Bassam *et al*. (2004) described these faults as a vertical horst and graben forming normal faults that are partly associated with horizontal displacement. The N – S trending faults are restricted to the southern part of the Western Desert named by Fouad (2007) the Nukhaib Fault System. However, some of these faults have been deleted in the recent Geological Map of Iraq (Sissakian and Fouad, 2012). The Hail – Rutbah Arch passes through the Iraqi Western Desert and has a series of highs such as Rutbah, Ga'ara and Khleissia (Abu Rasain), separated by several lows. It influenced the deposition on its both sides and acted as a divide separating different basins and sediments distribution (Al-Bassam *et al*., 2004)

The Ga'ara Formation is the oldest exposed lithostratigraphic unit in the Western Desert of Iraq and represents the only exposed Paleozoic unit (Fig.1). It belongs to the Arabian Plate Tectonostratigraphic Megasequence (AP5) of Sharland *et al*. (2001), which represents Late Stephanian to Ufimian age and later modified by Jassim (2006) to Westphalian-Ufimian (Syn-Hercynian). Palynological studies showed that the age of the Ga'ara Formation is Lower Permian (Raee Al-Balha, 1989). The exposed part of the formation exceeds 100 m in thickness, comprised of repeated fining-upwards successions (Fig.2) consisting of sandstone and mudstone (silty claystone and claystone). Facies analysis and sandstone thickness map (Fig.3) revealed that these successions represent meandering river systems (Tamar-Agha, 1986). The sandstones form about 35% of the column in the southern rim of the depression and about the total thickness in the northern rim. The northern part represents a lower stratigraphic unit named Rumliya Unit by Tamar-Agha *et al*. (1997).

The sandstones of the Ga'ara Formation are generally white to beige or variegated colour and consist predominantly of quartz (Salman, 1977; Sadiq, 1985; Tamar-Agha, 1986 and 1991). Mudstone forms the major lithology of the Ga'ara Formation in the southern part of the Ga'ara Depression, representing the upper part of the exposed sequence. The colour of the siliciclastics (sandstones and mudstones) is variable ranging from white, pale grey, black, yellow, red, violet, etc. and on many occasions the colour changes over a short distance. The mudstones are soft to medium tough, ferruginous in places (containing up to 56% Fe_2O_3).The iron oxides and hydroxides are present as pisolites, oolites, concretions and stains. Silt and sand admixtures are commonly found, increasing especially in the lower part of the mudstone beds. Plant debris and rootlets are also frequent. In some cases the mudstones are rich in organic matter and occasionally with pyrite concretions. The mudstone represent deposition in the river overbanks, mud plugs abandoned channels and ox-bow lakes.

The Hussainiyat Formation, in parts, shows similar lithology and facies pattern (fining-upward successions) to the Ga'ara Formation (Al-Bassam and Tamar-Agha, 1998; Tamar-Agha *et al*., 2016). The meandering nature of the channel system is well portrayed in the sandstone sequence of the Hussainiyat Formation, indicated by the sandstone isothickness map (Fig.4). The subsurface lithostratigraphic units, such as Khabour, Akass and Bir Al-Rah Formations also consist of quartz-rich sandstone and kaolinitic mudstone and in some intervals considerable amount of illite is recorded (Sadiq, 1985, Tamar-Agha *et al*., 1992b and Al-Juboury and Al-Hadidy, 2009).

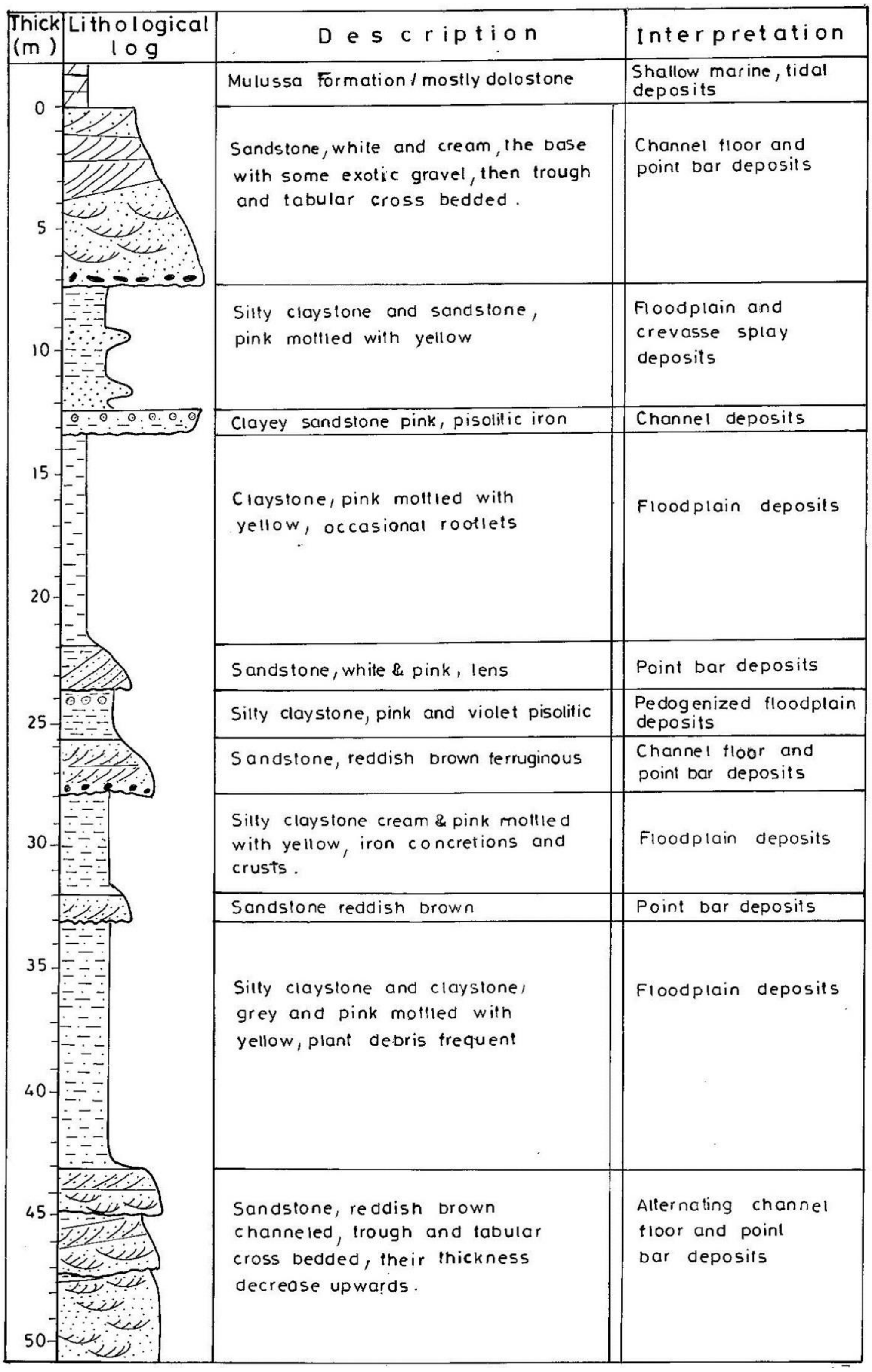

Fig.2: Representative columnar section for the Ga'ara Formation at the Afaif area, the Ga'ara Depression (after Tamar-Agha, 1986)

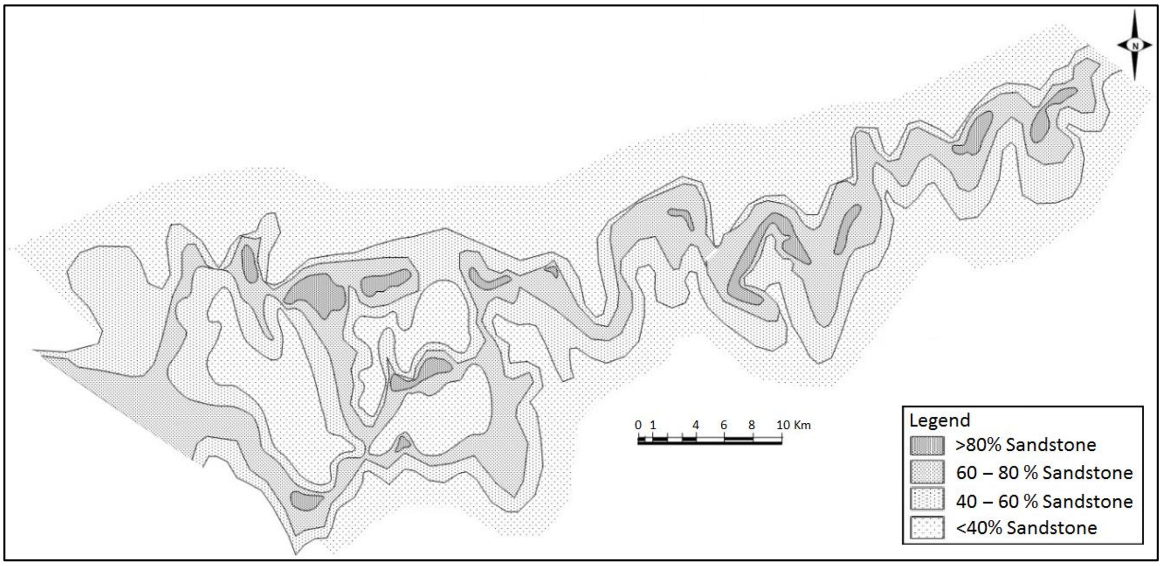

Fig.3: Sandstone percentage isolines map for the exposed uppermost 50 m of the Ga'ara Formation at the Ga'ara Depression (Tamar-Agha, 1986)

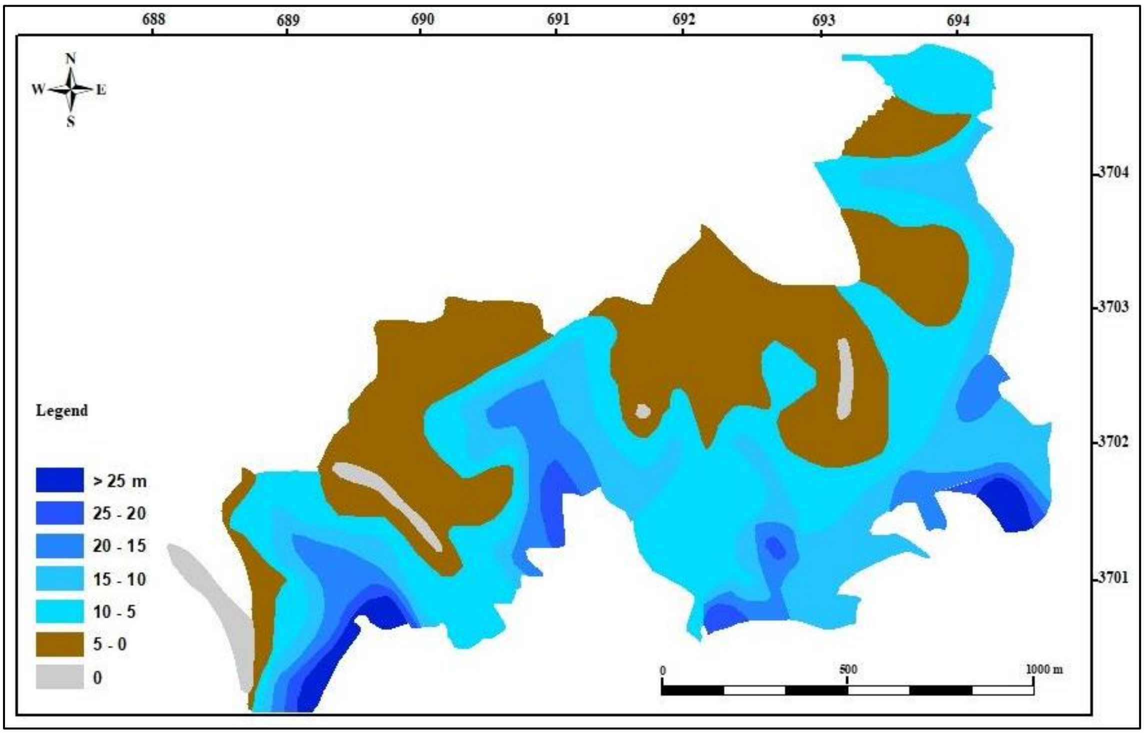

Fig.4: Sandstone isothickness map in the kaolin clay exploration area, Hussainiyat Formation, northeast Hussainiyat area (redrawn from Mahdi and Al-Hamad, 1990)

The Jurassic – Cretaceous succession (Table 1) at the Iraqi Western Desert comprises seven distinct clastics – carbonates inner shelf cycles, ranging from Hettangian (Early Jurassic) to Cenomanian (Late Cretaceous). Each cycle comprises a lower siliciclastic unit and an upper carbonate unit; with gradational contact or separated by a hiatus. These units are: Ubaid, Hussainiyat, Amij, Muhaiwir, Najmah, Nahr Umr, Mauddud, Rutbah and Ms'ad formations. These cycles fall into three Arabian Plate Tectonostratigraphic Megasequences of

Sharland *et al*. (2001) and Jassim and Buday, 2006a; Jassim and Buday, 2006b), namely AP 6, 7 and 8. The Ubaid, Hussainiyat and Amij formations belong to AP 6, Muhaiwir and Najmah formations belong to AP 7 and Nahr Umr, Mauddud, Rutbah and Ms'ad formations belong to AP 8. All clastic members of these cycles consist of quartz-rich sandstones and the Jurassic units consist of both sandstone and kaolin claystones (Al-Naqib *et al*., 1986; Etabi *et al*., 1986 and Tamar-Agha *et al*., 2016).

Table 1: Stratigraphic column of the Jurassic – Cretaceous succession that comprises the eight clastics – carbonates inner shelf cycles

Era	Period	Epoch	Age	Formation
Mesozoic	Cretaceous		Turonian	Ms'ad
			Coniacian	
			Cenomanian	Rutbah
		Lower	Albian	Nahr Umr and Mauddud
			Aptian	
			Berriasian	
			Barremian	
			Valanginian	
			Hauterivian	
	Jurassic	Upper	Tithonian	
			Kimmeridgian	
			Oxfordian	Najmah
		Middle	Callovian	
			Bajocian	
			Bathonian	Muhaiwir
			Aalenian	
		Lower	Toarcian	
			Pliensbachian	Amij
			Sinemurian	Hussainiyat
			Hettangian	Ubaid
	Triassic	Upper	Rhaetian	Zor Hauran

PETROLOGY OF THE SILICA-SANDS

A summary of petrographic and mineralogical studies carried out by different authors, for hundreds of sandstone samples, collected from the Iraqi Western Desert, for successions extending from the Khabour to the Rutbah formations (Upper Ordovician to Upper Cretaceous) are outlined here (Philip *et al*., 1968; Salman, 1977; Tobia, 1983; Sadiq, 1985; Tamar-Agha, 1986; Al-Naqib *et al*., 1986; Etabi *et al*.,1986; Tamar-Agha, 1991; Al-Juboury and Al-Hadidy, 2009; Al-Juboury *et al*., 2013).

- **Petrography**

– **Grain size:** The grain size of the concerned sandstones was either estimated under polarizing microscope or by dry sieving. The grains range from coarse to very fine sand size with occasional granules and pebbles are encountered, but the grain size, in general, ranges from fine to medium size. Nevertheless there is sometimes distinct variation and characterization. The grain size in the sandstones of the Khabour, Akass and Amij formations is very fine to fine, in the Ga'ara, Najmah and Rutbah formations the sandstones are of fine to medium grain size, whereas in the Hussainiyat Formation the sandstones are of fine to coarse size.

– **Grain shape:** The shape of the framework fragments in the silica sand deposits is subangular to rounded. The sandstones that are believed to have deposited in fluvial realms, such as those of the Ga'ara and the Hussainiyat formations, are more angular, whereas those deposited in paralic and inner shelf environments consist of some more rounded grains. The reason could be attributed to some eolian influence.

– **Sorting:** In general, the studied sandstones at the Iraqi Western Desert are sorted to well sorted. The older Paleozoic sandstones are less sorted than the younger Paleozoic and Mesozoic sandstones and those sandstones deposited in non-fluvial realm are better sorted.

– **Maturity:** Maturity describes the composition and texture of grains in sandstones, resulting from sediment transportation. During transportation the unstable minerals may diminish or vanish to leave more stable minerals, such as quartz. Maturity can be compositional (or mineralogical) or textural. The sediments are mature when the grains are well-sorted and well-rounded owing to weathering and/ or abrasion of the grains during transportation and consist of stable minerals. The sandstones under study are generally very rich in ultrastable minerals beside quartz such as zircon, tourmaline and rutile (ZTR), they exhibit high roundness of the grains and are devoid of matrix and hence they can be rated as supermature to mature sandstones.

- **Mineralogy**

Mineralogical studies revealed that quartz is the most abundant mineral in the silica sand deposits (about 81 – 98 %) of all the detrital components with scarce alkali feldspars, rock fragment, heavy minerals and clay minerals. The older Paleozoic sandstones (Khabour and Akass Formations) contain very low matrix content but the rest of the sandstones are almost devoid of matrix. The Khabour and Akkas formations (Ordovician – Silurian) show the least percentage of quartz grains ranging from (81 – 93) % (Al-Juboury and Al-Hadidy , 2009; Al-Juboury *et al*., 2013) whereas the younger formations are richer in quartz as its values range from (93 – 98) % (Philip *et al*., 1968; Salman, 1977; Tobia, 1983; Sadiq, 1985; Tamar-Agha, 1986; Al-Naqib *et al*., 1986; Etabi *et al*.,1986).

The quartz grains are mostly monocrystalline and the overwhelming majority of them show even extinction. The polycrystalline quartz grains are variable being about 18% in the Hussainiyat Formation sandstones and about 2% in the Rutbah Formation sandstones. The feldspars are minor component, mostly alkali feldspar such as orthoclase, microcline and albitic plagioclase. They range from (0.5 – 2.7) %. The higher percentages are encountered in the Khabour Formation. Rock fragments are also a minor component (0.5 – 2.0 %), they are even less frequent than the feldspars. Heavy detrital accessories, known as heavy minerals, range from (0.01 – 2.0) %, both opaque and transparent assemblages are identified. The opaque minerals are the major constituents of the heavies, ranging from (20 to 82) % (mean about 55 %). The transparent heavy mineral assemblages are represented by the ultrastable minerals (ZTR) and subordinate proportions of the less stable minerals, such as staurolite, epidote, amphiboles and pyroxenes.

X-ray diffractometry (XRD) of the associated mudstones of the Ga'ara, Hussainiyat and Amij formations revealed that the major clay mineral present is kaolinite with minor proportions of illite and mixed-layer illite – smectite (Tamar-Agha, 1997). The other main admixtures present are quartz, iron oxyhydroxides (mostly goethite) and anatase. In general, the mineralogy of the sandstone in all formations concerned is almost similar, but there is a slight difference in their primary textures. Ultimately, these sandstones are exclusively quartzarenite but some of the older Paleozoic sandstones are sublitharenite or subarkose. The younger sandstones are mostly exposed and are poorly cemented although some lenses are well cemented by silica or calcite cements (Fig.5). The silica-cemented sandstones show desert varnish, such as those in the southwestern and northeastern part of the Ga'ara Depression (most probably silicrete) as well as at the Hussainiyat area.

Fig.5: Sandstone samples show poikilotopic cement from the sandstones of the Ga'ara, Amij and Rutbah formations

PROVENANCE AND DEPOSITIONAL ENVIRONMENT

Detailed petrological studies of the silica sand and sandstones showed that the source rocks consist basically of granitoids (acid and intermediate plutonic rocks and gneisses) with some older sedimentary siliciclastics rocks. The parent rocks suffered from moderate weathering in the source area. The feldspars were almost completely altered in the source area, in wet weather, within an almost flat terrain to produce large amount of clay and sand particles. The associated clay minerals are mostly kaolinite with subordinate illite and mixed-layer illite-smectite, whereas the sand is mostly composed of quartz and is almost devoid of feldspars. The kaolinite particles are frequently coated with iron oxides and hydroxides. (Philip *et al*., 1968; Salman, 1977; Tobia, 1983; Sadiq, 1985; Tamar-Agha, 1986 and 1991; Al-Naqib *et al*., 1986; Al-Youzbaki, 1989; Tobia *et al*., 2014 and Tamar-Agha *et al*., 2016).

The sediments of the Ga'ara Formation are derived from plutonic and metamorphic complexes of the Arabian Shield as well as older sedimentary rocks (mostly siliciclastics) transported by rivers and then deposited in continental (fluviatile and lacustrine) environments with possible near-shore and wind action contribution (Philip *et al*., 1968; Salman, 1977; Tobia, 1983; Sadiq, 1985; Tamar-Agha, 1986 and 1991; Tobia *et al*., 2014). Sediment recycling is an influential process in the source area. In the early Paleozoic, the change in the quartz content coincides with the change in clay-mineral suite, as it has been demonstrated that the clay-mineral assemblage changes from illite predominance to kaolinite (Tamar-Agha *et al*., 1992b). The change in the sandstone composition and clay mineral assemblage can be attributed to paleoclimate induced by paleogeography (position of the Iraqi Western Desert concerning the latitudes) and/ or source rocks.

In at least two occasions, namely the Ga'ara and the Hussainiyat formations, the weathered detritus were transported by rivers (Figs.3 and 4) as quartz-rich sand and kaolinite-rich clay. The rivers sorted these sediments remarkably well, depositing the sand in the interweaving channel course whereas the fines (i.e. silts and clays) were deposited in the interchannel flats (overbanks and ox-bow lakes) or in the abandoned channels. Facies analysis of the Ga'ara Formation, particularly at the southern rim of the depression, showed that it comprises sandstones and mudstones in repeated fining-upwards successions, which characterize fluvial deposition. This rhythmic nature results from both lateral channel migration (point-bar sequence) and vertical channel aggradation inferring meandering rivers (Tamar-Agha, 1986; Mahdi and Al-Hamad, 1990; Al-Bassam and Tamar-Agha, 1997 and Tamar-Agha *et al*., 2016). Facies analysis of the other lithostratigraphic units, such as Amij, Najmah, Nahr Umr and Rutbah formations, combines fluvial and paralic origin, i.e. transitional environment, such as delta, beach and inner-shelf environments (Al-Naqib *et al*., 1986; Al-Zubaidi, 1988; Al-Hadithi, 1989).

RESOURCES OF THE SILICA-SANDS

Follow-up investigations have been carried out on five localities to estimate, verify and categorize the quantity and quality of the silica sand deposits. These localities are Erdhuma, Kilo 180, South Ga'ara (southern rim), Rumliya (floor of the Ga'ara Depression) and Rutbah (Fig.6). The investigations resulted in estimating 15.9 million cubic metres of silica sand on category B, 2.2 million cubic metres on category C_1 and 4456.9 million cubic metres on category C_2 (Table 2 and references therein).

- **Erdhuma Silica Sand Deposit**

Geological prospecting and exploration was focused on this locality in 1961 by a joint Soviet and Iraqi team in order to prepare raw materials for the Glass Factory near Ramadi city (Technoexport, 1961). The raw materials were to be consumed in manufacturing of sheet glass, bottles, cups and glasses. Ten million tons were outlined of the Rutbah Formation (Upper Cretaceous) at about 12 kilometres west of Rutbah town. The average thickness of the industrial layer is 22.15 m, the overburden is 15.0 m and the stripping ratio is 0.68. The grain size of 92% of the sand in this deposit ranges between (0.1 – 0.5) mm (Fig.7). Average SiO_2 is 98.43 %, Fe_2O_3 is 0.07 % and Al_2O_3 is 1.16 % (Technoexport, 1961). Exploitation of the reserve started since the establishment of the glass factory, but the reserve was consumed in other industries such as foundry, white cement, ceramics and refractories. The mine need to be rehabilitated and designed to avoid wasting superior quality silica sand.

Table 2: Estimated silica sand reserves at the Western Iraqi Desert. The category B reserve in Erdhuma silica sand deposit includes category B_2 (Russian norms).

Name of deposit	Category B (millions of m^3)	Category C_1 (millions of m^3)	Category C_2 (millions of m^3)	Reference
Erdhuma Silica Sand	3.37	0.19	--	Technoexport (1961)
Kilo 180 Silica Sand	9.2	2.2	0.8	Etabi *et al*. (1986)
South Ga'ara Silica Sand	--	--	304.2	Tamar-Agha *et al*. (1992a)
Rumliya Silica Sand	--	--	4000	Present work
Rutbah Silica Sand	--	--	151.9	Al-Naqib *et al*. (1986)
Total Reserves	12.57	2.2	4456.9	

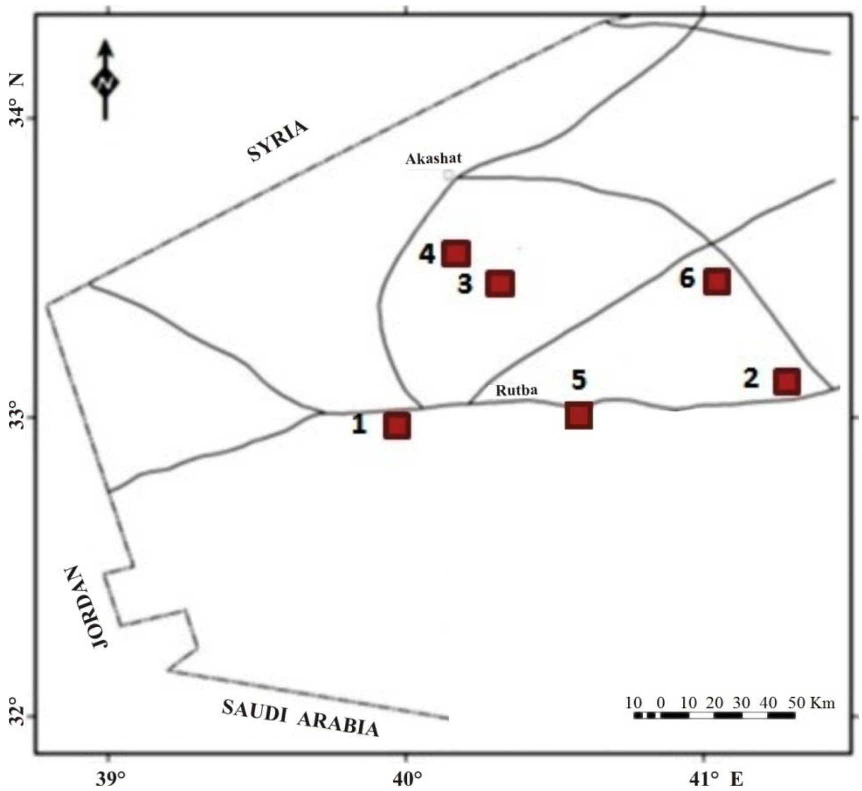

Fig.6: Location map of the investigated silica sand deposits: **1)** Erdhuma, **2)** Kilo 180, **3)** South Ga'ara, **4)** Rumliya, **5)** Rutbah and **6)** Hussainiyat

Fig.7: Hand specimen of Erdhuma sandstone (Rutbah Formation)

- **Kilo 180 Silica Sand Deposit**

This locality is about 180 Km west of the Ramadi city, along the old Ramadi – Rutbah road. Geological prospecting and exploration for silica sand started in this location in the mid-eighties of the last Century to satisfy the urge for finding reasonable silica sand deposit nearer to the glass factory west of the Ramadi city and of lower grade to avoid wasting of superior grade of Erdhuma silica sand. The total estimated reserve of silica sand in the Kilo 180 deposit is 12.2 million cubic meters (Categories B, C_1 and C_2). The average thickness of the industrial layer is 14.11 m, the overburden is 5.45 m and the stripping ratio is 0.39. The average SiO_2 is 94.53%, which is below the required specification for the glass industry, and Fe_2O_3% is 0.39, which is above the required specification for this industry. Washing with water in the laboratories of the Iraq Geological Survey raised the SiO_2 content to 96.0 % and lowered the Fe_2O_3 content to 0.26 % (Etabi *et al*., 1986).

- **South Ga'ara Silica Sand Deposit**

Detailed geological mapping, prospecting and exploration program was carried out at the Ga'ara Depression in two stages. The first stage was in 1983 and reported by Tamar-Agha (1986), and the second stage was carried out in the period (1986 – 1990) and reported by Tamar-Agha (1992a). Emphasis in both stages was on white and coloured kaolin clays but some lenses of silica sand, associated with the clays, were found interesting and deserve attention. The follow-up investigations for the kaolin clays were carried out in thirteen localities. Four localities were particularly interesting for the estimation of silica sand and deserved evaluation, for the purity and high grade of the sand deposits. The silica sands are present in lenses, having shoestring geometry, representing the active channels of meandering stream system. The sandstone channels represent inner burdens and/ or inclusions for the kaolin clays. These locations are West Wadi Tayyarah, North Wadi Tayyarah, South Sufi and Ubairan. Three localities are situated at the southern rim of the Ga'ara Depression and one locality (South Sufi locality) is situated at the floor of the depression. The evaluation of the data of the four localities resulted in the estimation of about 304.2 million cubic meters of reserves on category C_2. The characteristics of the reserves are given in Table (3).

Table 3: Characteristics of reserves of the Ga'ara silica sand deposits (Russian norms) (after Tamar-Agha *et al*., 1992a)

Name of deposit	No. of boreholes	Average total thickness (m)	Reserve (Volume million m^3)	Stripping ratio	SiO_2%			Fe_2O_3%		
					Min.	Max.	Ave.	Min.	Max.	Ave.
West Wadi Tayyarah	100	8.1	24.6	2.1	95.49	97.27	96.38	0.28	0.41	0.35
North Wadi Tayyarah	45	8.0	115.2	1.9	95.62	96.16	95.83	0.47	0.48	0.48
South Sufi	52	5.9	141.3	2.1	93.64	96.18	95.30	0.38	1.10	0.65
Ubairan	18	9.6	18.1	0.97	96.32	96.32	96.32	0.34	0.34	0.34

- **Rumliya Silica Sand Deposit**

During the course of prospecting and explorations at the Ga'ara Depression, subsurface mapping at the floor of the depression was necessary. A rectangular network (5 x 1 Km) of core-drilled shallow boreholes (about 50 meters deep) was drilled. The results show that the Rumliya Unit of the Ga'ara Formation (Tamar-Agha, 1991; Tamar-Agha *et al*., 1997) is almost exposed at the floor of the Ga'ara Depression, with veneer cover of Quaternary deposits. The Rumliya Unit is encountered in the deep keyhole (well KH5-1) which was drilled at Ghadir Al-Sufi at the central part of the depression. The thickness of the Rumliya Unit in well KH5-1 is 135 m (drilling depth 45 – 180 m). It has sheet geometry and is composed almost exclusively of silica sand.

During this work, the following reserve estimation was carried out based on the results given in Tamar-Agha *et al*. (1991). The total boreholes of the rectangular network are 218, but 67 boreholes were chosen considering their grade, thickness of the industrial bed, thickness of overburden and stripping ratio. Average thickness of the industrial bed is

10 metres (5.0 to 42.0 m) and the overburden is 12.3 m and hence the stripping ratio is 1.23. The volume of the silica sand estimated is four billion m^3. Total channel samples collected are 521and the sample length ranged from 1 – 4m although mostly are two metres. The SiO_2 ranges between (93.0 – 98.7) % (mean = 97.4 %). The Fe_2O_3 ranges between (0.01 – 0.6) %, (mean = 0.33). All samples were dry sieved and about 95 % of the quartz grains range in size between (100 – 600) µm.

- **Rutbah Silica Sand Deposit**

The detailed geological survey east of Rutbah led to the discovery of exposures of silica sand in the clastic unit of the Najmah Formation (Al-Naqib *et al*., 1986). The exposures extend as a strip from about 12 Km west of Rutbah town to about 65 km east of the town. The exploration program involved excavating 73 trenches and drilling of four shallow core-boreholes. The investigations led to the estimation of about 151.9 million m^3 (Table 1) of silica sand with SiO_2 ranging between (94.29 – 99.1) % with an average of (96.94) %. Thickness of the industrial bed ranges between (3.7 – 7.9) metres. The majority of the grains range in size between (100 – 500) µm and their shape ranges from subangular to well rounded. Roundness is directly proportional with grain size.

TECHNOLOGICAL TESTS

Technological tests on silica sand are carried out by many researchers and academicians. The tests are conducted to assess their suitability for limited industries such as glass, foundries, ceramics, refractories, silicon and silicones industries. Further tests can be carried out to assess the suitability of silica sand in many other industries such as construction, ceramics, paints, fillers, plastics, chemical production, coatings, water filtration, agriculture, abrasives, sand blasting and fracking. Some of the tests carried out so far are outlined below, solely in the ceramic realm:

Al-Azzawi and Aly (1983) studied the suitability of Iraqi raw materials in the production of electro-porcelain and chose the Erdhuma silica sand as one of the ingredients. Al-Kaiysi (1989) assessed the suitability of Iraqi clays and Erdhuma silica sand to prepare slip for ceramic casting. Al-Mashaykhi (1991) assessed the suitability of the Ga'ara silica sand in manufacturing stoneware ceramics. Al-Haza'a and Tamar-Agha (2004) used the Erdhuma silica sand in the preparation of unglazed acid-resistant tiles. Al-Bassam *et al*. (2004) studied the suitability of the Erdhuma silica sand in manufacturing ceramic balls for ball mills. Al-Azzawi (2008) used the Erdhuma silica sand in the production of tableware porcelain.

The laboratories of the Iraq Geological Survey were engaged with upgrading the silica sand. Al-Ajeel *et al*. (1988) succeeded in upgrading the Kilo 180 silica sands by any of the simple physical beneficiation methods. They used screaning and desliming, scrubbing, ball milling and floatation to render the sands suitable for glass making and to suit the specifications required by the Ramadi Glass Factory. For the Rutbah silica sand to reach the required specification, a combined scrubbing and floatation was required. Al-Tayyar *et al*. (2011) designed pilot-plant experiments for upgrading of Kilo-180 sand for use in glass and foundry industries.

Mustafa *et al*. (2012) upgraded the Erdhuma silica sand, for silicon and silicone industries. Quartz sand product, with the composition (SiO_2: 99.49%, Fe_2O_3: 0.011%, Al_2O_3: 0.23%, TiO_2: 0.03%, MgO <0.01%, SO_3: <0.04%, Na_2O: 0.03%, K_2O: 0.02%, P_2O_5: 0.01% and L.O.I: 0.09%), was obtained by applying the following beneficiation techniques: autogenesis grinding, dry screening (150 µm), attrition, scrubbing and wet screening. The product henceforth satisfies the raw material of MG-Silicon production. Further experiments followed this achievement (Mustafa and Fleah, 2014) and ended by a pilot plant design for the upgrading of the Erdhuma silica sand for silicon and silicone industries (Mustafa *et al*., 2014).

CONCLUSIONS

Prospecting and exploration programs through decades by the Iraq Geological Survey revealed billions of tons of reasonable to high quality silica sand at the Western Iraqi Desert (around Rutbah town, Ga'ara Depression, Kilo 180, Hussainiyat and Amij areas). The investigated silica sand are of fluvial and/or paralic origin. Follow-up investigations were carried out on five deposits to estimate, verify and categorize the quantity and quality of the silica sand deposits. The investigations resulted in estimating 15.9 million m^3 of silica sand (at Erdhuma and Kilo 180) on category B, 2.2 million m^3 on category C_1 (at Kilo 180) and 4456.9 million m^3 on category C_2 (at the Ga'ara Depression and the vicinity of Rutbah town).

RECOMMENDATIONS

- It is recommended that further tests should be carried out on all investigated silica sand deposits in order to assess their suitability for the currently established and future industries, with special emphasis on the silicon industries. The large amount of silica sand deposits estimated at the Iraqi Western Desert highly encourages the expansion and development of the present industries, and to establish new industries which largely depend on this mineral commodity. The assessment should include the determination of the amount and type of upgrading required for each deposit to meet the specifications needed.
- The study of the possibility of upgrading the silica sand deposits (by pulverizing, air-floating, water-washing, etc.) and bagging in order to bring them to the specifications required for local consumption or export.
- The Erdhuma silica sand is currently wasted in the manufacturing of sheet glass, foundry, wall tiles and many other industries. It is recommended to stop the use of Erdhuma silica sand in such industries since they do not require high purity and this mineral commodity is by no means cheap.

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