MINERAL RESOURCES

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ABSTRACT

The Iraqi Western Desert is rich in mineral deposits and industrial rocks. Important deposits were identified including phosphorite, kaolinitic claystone, montmorillonite – palygorskite claystone, quartz-sand, bauxite, flint clay, porcelanite, uranium, ironstone, heavy minerals sandstone, feldspathic sandstone, limestone and dolostone. Most of these deposits are restricted in occurrence to the Western Desert. All of these mineral deposits and industrial rocks are sedimentary in origin including marine and continental deposits. They range in age from Permocarboniferous to Pleistocene, occurring mostly as bedded stratiform deposits with some exceptions such as karst bauxites and flint clays.

The formation of the mineral deposits and industrial rocks in the Western Desert was controlled by paleogeographic and climatic factors. Tectonic and structural factors were important in some cases. The type, specifications and reserves of these mineral deposits provide a very promising potential for future development of this region.

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المستخلص

الصحراء الغربية العراقية غنية بالرواسب المعدنية والصخور الصناعية حيث تم تحديد رواسب مهمة من الخامات تشمل الفوسفات واطيان الكاؤولين واطيان المونتمورلونايت والباليغورسكايت ورمال الكوارتز والبوكسايت والطين الفلنتي والبورسلينايت واليورانيوم والحديد ورمال المعادن الثقيلة ورمال الفلدسبار وحجر الكلس والدولومايت ويلاحظ ان معظم هذه الرواسب ينحصر وجودها في الصحراء الغربية فقط.

كافة هذه الرواسب المعدنية والصخور الصناعية من اصل رسوبي بما في ذلك الرواسب البحرية والقارية. يتراوح عمر هذه الرواسب من البرمي الكاربوني الى البلايستوسين وتظهر معظمها على شكل رواسب متطبقة مع بعض الاستثناءات كما هو الحال في البوكسايت الخسفي والطين الفلنتي.

ان تكون الرواسب المعدنية والصخور الصناعية في الصحراء الغربية قد تحكمت فيه عوامل جغرافية ومناخية قديمة غير ان العوامل البنيوية والتركيبية لعبت هي الاخرى دورا مهما في بعض الحالات. ان نوعية ومواصفات واحتياطيات هذه الرواسب المعدنية تتيح امكانية مشجعة لتطور هذه المنطقة في المستقبل.

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INTRODUCATION

The Western Desert of Iraq is one of the most interesting physiographic provinces in the region. It witnesses a long history of geological and climatic changes and was a well-developed Savana in the Pleistocene, inhabited by Paleolithic man and plenty of animal life (Al-Bassam *et al.*, 1999a and Al-Bassam, 2000a). The term "desert" is applied now only because of the very low rate of rain fall rarely exceeding 100 mm/year. A very fertile soil, though not well developed covers the area.

Interest in the mineral resources of the Western Desert dates back to Paleolithic age when man used local chert to form various types of tools and weapons (Al-Bassam, 2000a) (Fig.1). In the past century the area attracted attention in the year 1900 when a Bedouin postman was said to have collected a mass of gold from the Ga`ara area. This myth was followed up by some celebrities in 1928 – 1934 such as Baron Pfyffer, Mr. J.B. Philby and Mr. W.A. Macfadyen (Government Geologist). A concession was granted to Mr. M.A. Al-Bassam in 1934 to carryout exploration for gold in Ga`ara (Macfadyen, 1934).

Systematic exploration works started in the Western Desert in the early fifties by the Site Investigation Co. (UK) when some reconnaissance surveys were carried out in search for building raw materials and included some geophysical radiometric surveys. Exploration works were rejuvenated by Technoexport (former USSR) in the period 1960 – 1964, aiming at evaluating mineral deposits suitable for industrial uses. Important deposits were evaluated in that short time including phosphorites, quartz-sand, ironstones, kaolinitic claystone and limestone (for cement industry).

Since the late sixties, GEOSURV-Iraq commenced comprehensive regional programs of geological mapping and mineral investigation projects. In the period 1970 – 1993 most of the mineral resources of the Western Desert were explored and evaluated (Fig.2).

At present many important industries in Iraq are based on the mineral resources of the Western Desert. Phosphate fertilizers industry is based on Akashat phosphorites deposit, refractories and ceramic industries are based on Dwaikhla kaolinitic claystone deposit and North Hussainiyat bauxite and flint clay deposits, glass industry uses quartz-sand from Urdhuma mine, cement industry uses many limestone and clay deposits as well as ironstones from South Hussainiyat deposit and montmorillonite claystones from the Safra mine are used as drilling mud.

Subsurface potential for mineral deposits is still not explored and the possibility of finding new mineral deposits is still valid in view of the geological history of the Western Desert and diversity of its lithostratigraphic units (Al-Bassam *et al.*, 1999b).

MINEROGENIC HISTORY

The exposed part of the Paleozoic in the Western Desert is represented by quartz-sand and kaolinitic clay of the Ga`ara Formation (Permocarboniferous). The upper part mostly consists of clays with lenticular sand bodies and the lower part is mostly sand (Tamar-Agha *et al.*, 1992). Ferruginous sandstones and sandy ironstones are occasionally encountered in the sandy sequence. Some of the sandstone bodies are rich in heavy minerals (zircon and rutile) (Ismail, 1989).

The Mesozoic rocks are exposed along the Hauran High. The Triassic units are composed of shallow intertidal carbonates (Mulussa and Zor Hauran formations) where dolostones of high purity may be encountered. The Jurassic units are cyclic with continental clastics at base and shallow marine carbonates at top. This cyclicity is well demonstrated in the Hussainiyat and Amij formations (Middle Jurassic), and reflects eustatic sea-level fluctuations (Jassim *et al.*, 1984). Lateritic pisolitic ironstones and kaolinitic claystones are found at the

Fig. 1: Paleolithic chert artifacts from the Western Desert, Iraq (scale in cm)

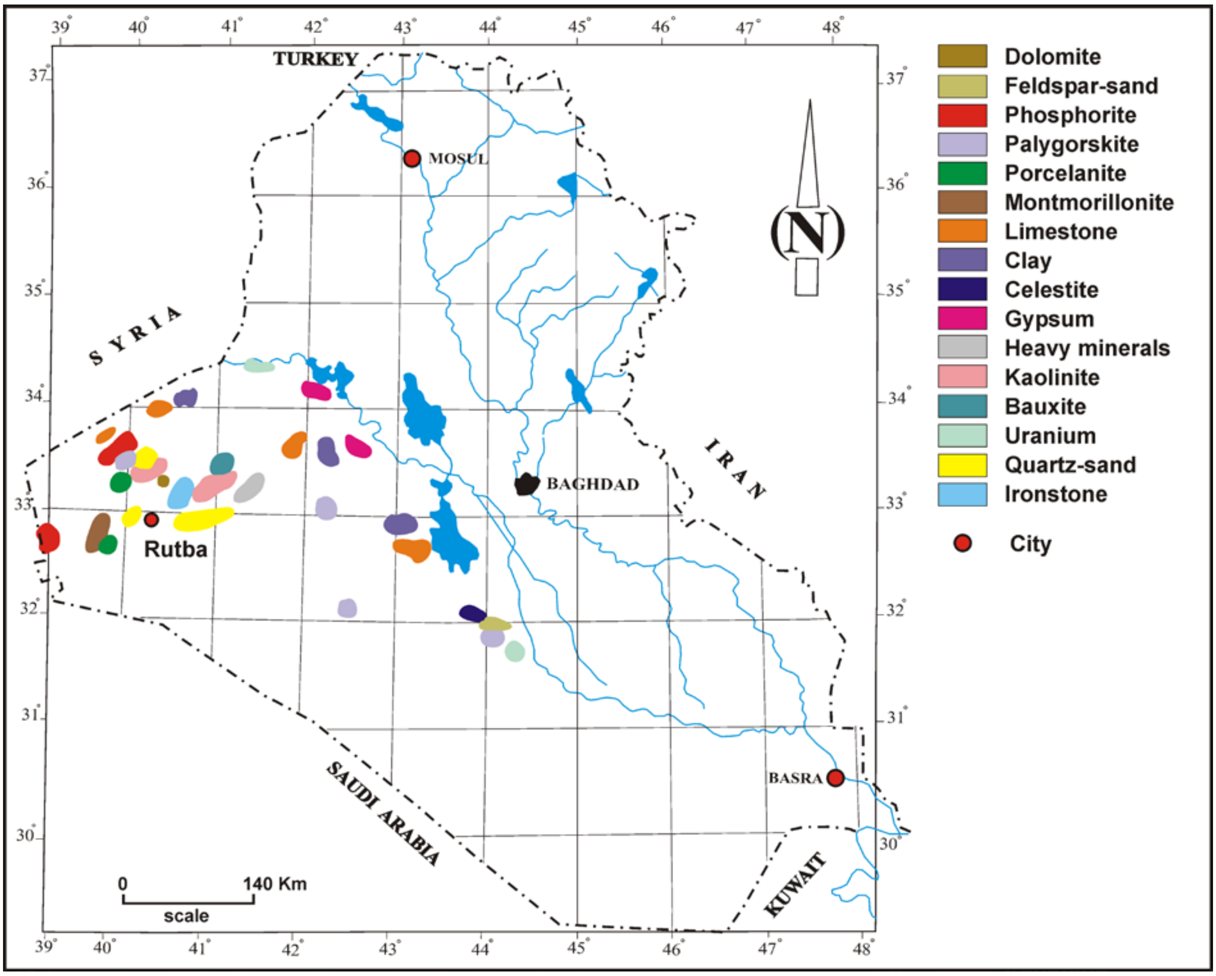

Fig. 2: Distribution of mineral resources and industrial rocks in the Western Desert

base of the Hussainiyat Formation topped by dolostones (Etabi *et al*., 1984 and Houbi, 1984). The clastics part of the Amij Formation is characterized by remarkable enrichment of heavy minerals sandstones (zircon, rutile and monazite) (Mahdi *et al.,* 1993 and Ismail, 1996). Kaolinitic claystones are well developed in this unit (Mahdi and Al-Delaimi, 1999).

The Cretaceous period witnessed the most important events of mineral formation in the Western Desert (Al-Bassam, 1984). An exceptionally wet and warm period in the Early Cretaceous (Al-Amiri, 1994) have resulted in the karstification of the exposed parts of the Ubaid Formation carbonates (Early Jurassic) and bauxitization of the kaolinitic claystones filling the karsts giving rise to numerous karst bauxite and flint clay deposits found in the Western Desert (Al-Bassam, 2005). Fluvial and fluviomarine deposits of quartz-sand are characteristic features of the Albian and Cenomanian units (Nahr Umr and Rutba formations, respectively) (Al-Azzawi *et al*., 1996).

Phosphorites first appearance in the Iraqi Western Desert was in the Maastrichtian (Digma Formation) (Al-Bassam and Karim, 1992). They are well developed north and west of the Hauran High. These phosphorites are part of the Tethyan phosphorite belt (Late Cretaceous – Eocene). They are associated with montmorillonite – palygorskite claystones and porcelanites which make, together, a distinguished facies package.

The maximum development of the phosphorites in the Western Desert was manifested in the Paleocene when thick deposits of ooidal – pelloidal phosphorites were laid down associated with carbonates, claystones (montmorillonite – palygorskite) and silica (chert and porcelanite). Phosphorite development continued in the Western Desert till the Middle Eocene, but seized to exist after that.

Enormous deposits of high purity limestone were developed in the Eocene (Ratga and Dammam formations). The Early Miocene also witnessed extensive carbonate development manifested in the Euphrates Formation. These carbonate rocks are useful for cement industry as well as building stones.

Along the Euphrates Fault Zone and Anah Fault Zone (eastern and northern parts of the Western Desert) a remarkable syngenetic and epigenetic uranium mineralization was recorded in the upper parts of Euphrates Formation (Al-Kazzaz and Mahdi, 1991). Bitumen showings occur along the Abu Jir Fault Zone in Abu Jir and Ain Jabha (west of Ramadi). They are believed to be seepages of deep and destroyed hydrocarbon deposits (Fouad, 2004).

The Middle Miocene evaporitic sequence (Fat`ha Formation) is not well-developed in the Western Desert, but some gypsum deposits of this age are recorded in the northern parts of the Western Desert near Heet along the Euphrates River (Mansour and Toma, 1983)

Fluviatile deposits of sand and clay dominated the Late Miocene, Pliocene and Pleistocene in the Western Desert. Some palygorskite deposits were found in the Injana Formation (Late Miocene) in Najaf area (Abdul Hassan, 1999 and Al-Bassam and Al-Baidari, 2000). Celestite mineralization of limited extentsion was noticed in the Injana and Dibdibba formations (Al-Bassam, 1995 and Abdul Hassan and Al-Quwaizi, 1999). Enormous deposits of silica-sand (mostly quartz) are supplied by the Dibdibba Formation (Pliocene – Pleistocene) in the Najaf – Karbala Plateau. Feldspathic sandstones are occasionally found in these sandstone deposits in the Najaf area (Al-Ka`aby and Najim, 1999).

Small showings of palygorskite claystone were recorded in the Zahra Formation (Pliocene – Pleistocene) (Tamar-Agha *et al.*, 2000). Quaternary deposits are generally not well developed in the Western Desert. Depression-fill deposits provide suitable clayey material for cement industry. Terraces of the great canyons like Hauran and Swab provide suitable aggregates of gravel and sand for building purposes. The economically interesting geological units are listed in Table (1).

Table 1: Minerogenic stratigraphy in the Western Desert

Age	Geological Unit	Raw Material
Quaternary	Depression fill deposits Terraces	Clay (for cement) Gravel and sand
Pliocene – Pleistocene	Zahra Formation	Palygorskite
Pliocene – Pleistocene	Dibdibba Formation	Silica-sand, celestite and feldspar-sand
Late Miocene	Injana Formation	Celestite and palygorskite
Middle Miocene	Fat`ha Formation	Gypsum
Early Miocene	Euphrates Formation	Limestone, dolostone and uranium
Eocene	Ratga Formation	Limestone and phosphorite
	Dammam Formation	Limestone and dolostone
Paleocene	Akashat Formation	Phosphorite,montmorillonite – palygorskite and porcelanite
Late Cretaceous	Digma Formation	Montmorillonite – palygorskite, porcelanite and phosphorite
	Rutbah Formation	Quartz-sand
Early Cretaceous	Nahr Umr Formation (Nwaifa Formation) *****	Quartz-sand Bauxite and flint clay
Middle Jurassic	Amij Formation	Heavy minerals and kaolinitic claystone
Early Jurassic	Hussainiyat Formation	Ironstone and kaolinitc claystone
Triassic	Mulussa and Zor Hauran formations	Dolostones
Permocarboniferous	Ga`ara Formation	Kaolinite, quartz-sand, ironstone and heavy minerals

***** Informal name

MINEROGENIC PROCESSES

The Western Desert of Iraq is part of the Arabian Plate. In the Late Paleozoic, continental deposition dominated the region where clastics (clay and sand) were brought by rivers from Arabian Shield lying in the south and southwest, via rivers, to the lower relief flood plain following natural gradient. The quartz-sand of the Ga`ara Formation was deposited as channel-lag deposits, whereas the kaolinitic clays represent over banks and flood plain deposits (Tamar-Agha *et al.*, 1992). Placer deposits of some heavy minerals often accompanied the sandstone bodies in this sequence. Frequent short episodes of lateritization gave rise to thin horizons of pisolitic ironstone within the claystone as ferricrete horizons. Iron cementation of some sandstone lenses was most probably brought about by Fe-rich groundwater in later stages.

The opening of the Tethys in the Triassic and the drifting of Gondwana brought about changes in the sedimentary regime in the Arabian Plate margins. Shallow seas in the Early Triassic gave rise to the dolostone of the Mulussa and Zor Hauran formations. Frequent breaks in sedimentation and oscillation of sea level over gently sloping plate margins gave rise to cyclic sedimentation of clastics – carbonate sequences of the Jurassic units. The clastics were rich in kaolinitic claystone, quartzitic sandstone and Fe-oxides.

Relatively thick ferricrete horizons were developed within soil in the Early Jurassic under lateritic conditions. Reworking of the ferricrete by rivers and mixing with sand gave rise to the ironstone deposit of the Hussainiyat Formation (Al-Bassam and Tamar-Agha, 1998) (Fig.3). Heavy minerals (zircon, rutile and monazite) were concentrated in thin horizons in the beach deposits of the Amij Formation. Most of the clastics in the Jurassic were brought from the weathered rocks of the Arabian Shield complexes under tropical and semi-tropical climate.

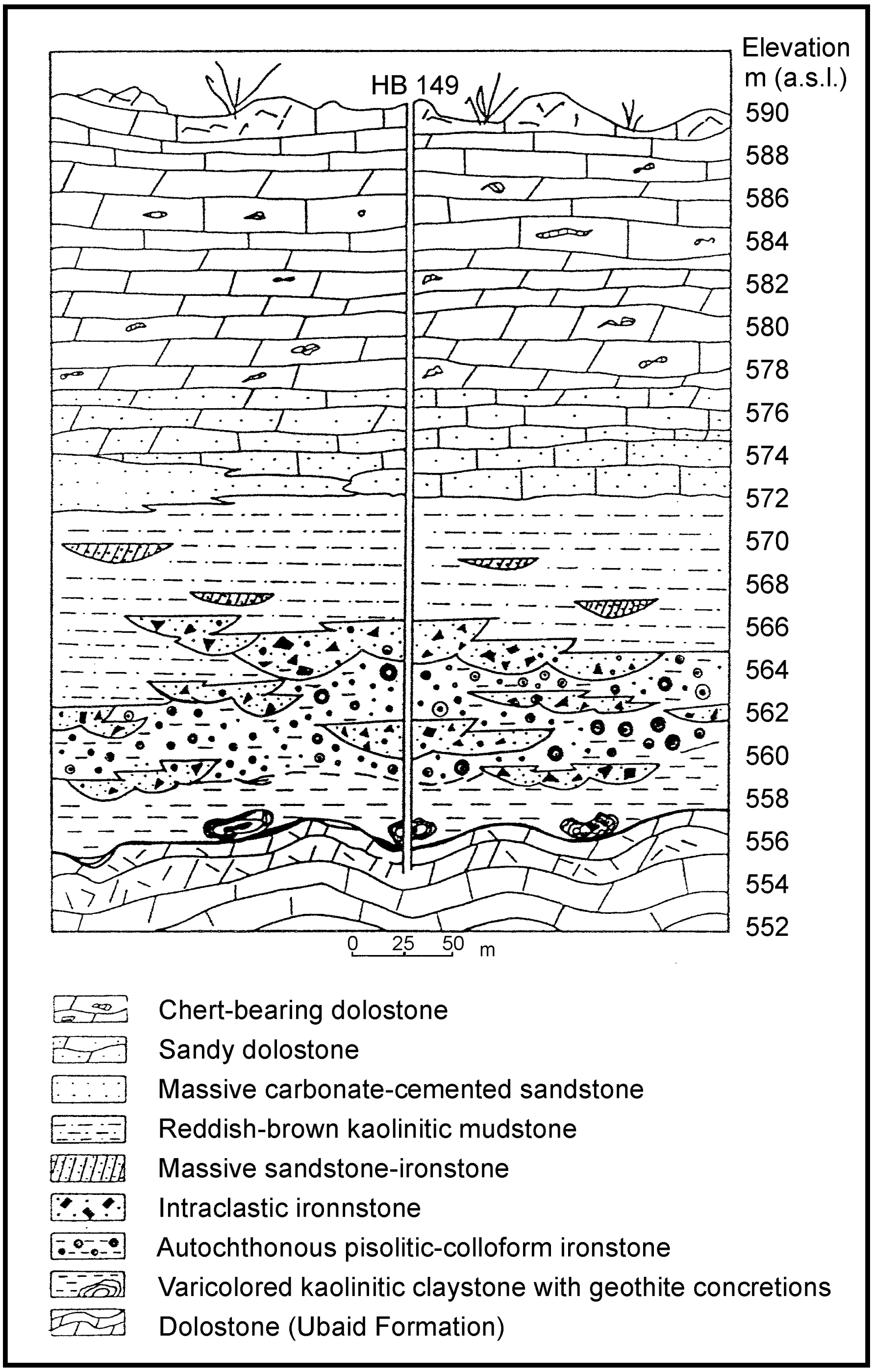

Fig. 3: Geological section in the Hussainiyat ironstone deposit
(Al-Bassam and Tamar-Agha, 1998)

Rain-Forest climatic conditions in the Early Cretaceous were the main controlling factor in the development of the karst bauxites and associated flint clays in the Ubaid Formation (Al-Bassam, 1996) (Fig.4). Parent materials of these bauxites are believed to have been derived from the Hussainiyat clastics (Al-Bassam, 2005). The supply of mature clastics, dominated by quartz-sand, continued, from the Arabian Shield complexes until the Cenomanian, manifested by the Nahr Umr and Rutbah quartz-sand deposits.

The transgressive nature of the Late Cretaceous sea, the tectonic activity at the Arabian Plate margins and the narrowing of the Tethys as well as the paleogeographic position of the Western Desert, brought about significant changes in the sedimentary regime of the region and changes in the climatic conditions, which were reflected in the type of mineral deposits formed at that time. Continental deposits were reduced and gave place to marine deposits. The clay minerals suites also changed from Al-rich (kaolinites and flint clay) to Al-poor (smectites and palygorskites). Marine sedimentary phosphorites are the most important of the mineral resources formed at that time. They were associated with montmorillonite, palygorskite and porcelanite, making a characteristic sedimentary package, often stacked in a cyclic or rhythmic alternation (Fig.5).

This pattern of sedimentation continued and climaxed in the Paleocene as far as phosphorites are concerned (Figs. 6 and 7). The genesis of Iraqi phosphorites is believed to be mainly biogenetic, where phosphate precipitation was brought about via a microbial role, at and below sediment – water interface (Al-Bassam, 1976 and Al-Bassam *et al*., 2000a). The Western Desert phosphorites are part of the Tethyan phosphogenic belt. Regionally, they may be related to upwelling episodes in the Tethys Sea (Sheldon, 1981) and locally controlled by structural setting (Al-Bassam, 1984).

The porcelanites are biogenetic; they were formed from the diagenetic dissolution and mobilization of sponge specules and diatoms. These silica-rich organisms were flourishing along the shallow parts of the sea rich in silica and phosphate brought about by upwelling deep oceanic water (Al-Bassam *et al*., 2000b).

Smectite origin is not well understood. However, its origin should be thought of in relation to the chemistry of marine water during upwelling episodes, being rich in silica, and the relative alkalinity of the shallow parts of the sea, as well as the generally reducing character of the inner shelf environment. Palygorskite formed from smectite under more alkaline conditions (Aswad *et al*., 2000). These claystones are actually black shales rich in carbonaceous matter (Al-Bassam and Al-Haba, 1990).

Marine processes continued to control the formation of industrial rocks and minerals till the Middle Miocene. Enormous marine sedimentary carbonates (limestone and dolostone) were deposited in the Eocene and Early Miocene (Ratga, Dammam and Euphrates formations).

Remarkable and probably unique uranium deposits in the carbonates of the Euphrates Formation were developed by the end of Early Miocene. Tectonic unrest activated some of the old fault systems along the Euphrates River, which allowed for U-rich solutions to ascend upward, together with bitumen and H_2S. The shallow intertidal parts were enriched with uranium, which was precipitated in the interstitial pore environment, bellow sediment – water interface, under reducing conditions (Al-Bassam *et al*., 2006). Epigenetic mobilization of uranium resulted in the formation of new deposits (Al-Atia and Mahdi, 2005). The evaporitic character of the Middle Miocene sea resulted in the gypsum deposits of the Fat`ha Formation, rarely found in the Western Desert.

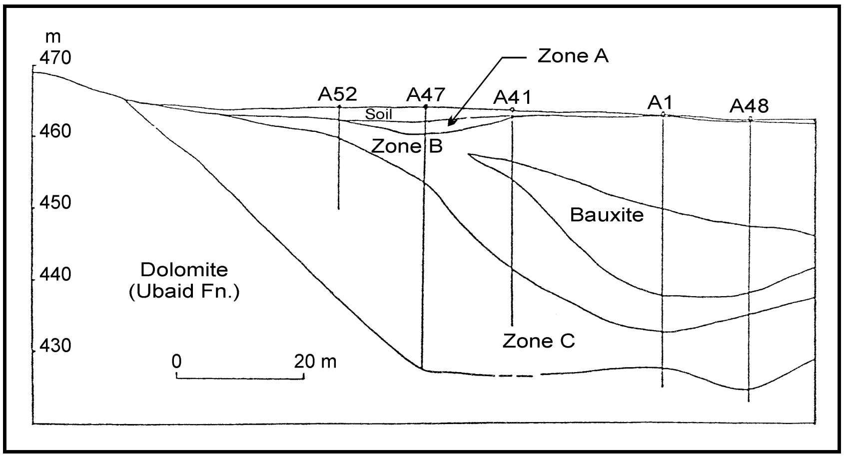

Fig. 4: Cross section showing zonation in the karst-fill deposits of the Hussainiyat bauxites (Mustafa *et al.*, 1994)

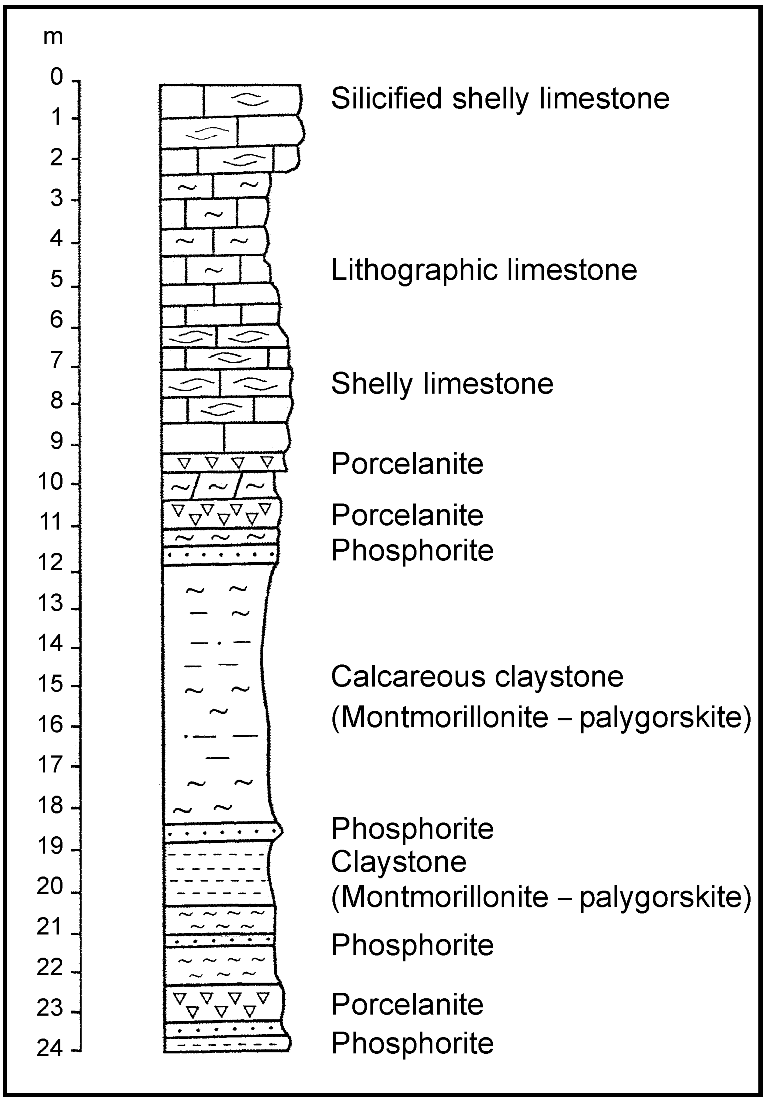

Fig. 5: Geological columnar section of the Digma Formation in Wadi Al-Jandali (Al-Bassam *et al.*, 2000b)

Continental process returned to dominate the formation of mineral resources in the Western Desert after the Middle Miocene, under relatively arid and warm climate. Palygorskite of fluvial origin was developed in the Injana Formation from a smectite precursor under fluvial (brackish) environment (Al-Bassam and Al-Baidari, 2000).

Aridity and groundwater supply of strontium along the Euphrates Fault Zone resulted in celestite precipitation in thin lenticular horizons of limited extension within the Injana and Dibdibba formations (Al-Bassam, 1997). The general aridity of the climate was interrupted by wet periods, which brought immature clastics from the Arabian Shield complexes to the Mesopotamian basin. The feldspar-rich sandstones of the Dibdibba Formation (Pliocene – Pleistocene) are good example of these clastics. They are believed to be fan deposits (Ghalib, 1988). Aridity and continental deposition are also manifested in the palygorskite-rich claystones of the Zahra Formation (Al-Bassam *et al*., 1999a), as well as in the depression fill clayey deposits of the Quaternary, where immature soils are developed.

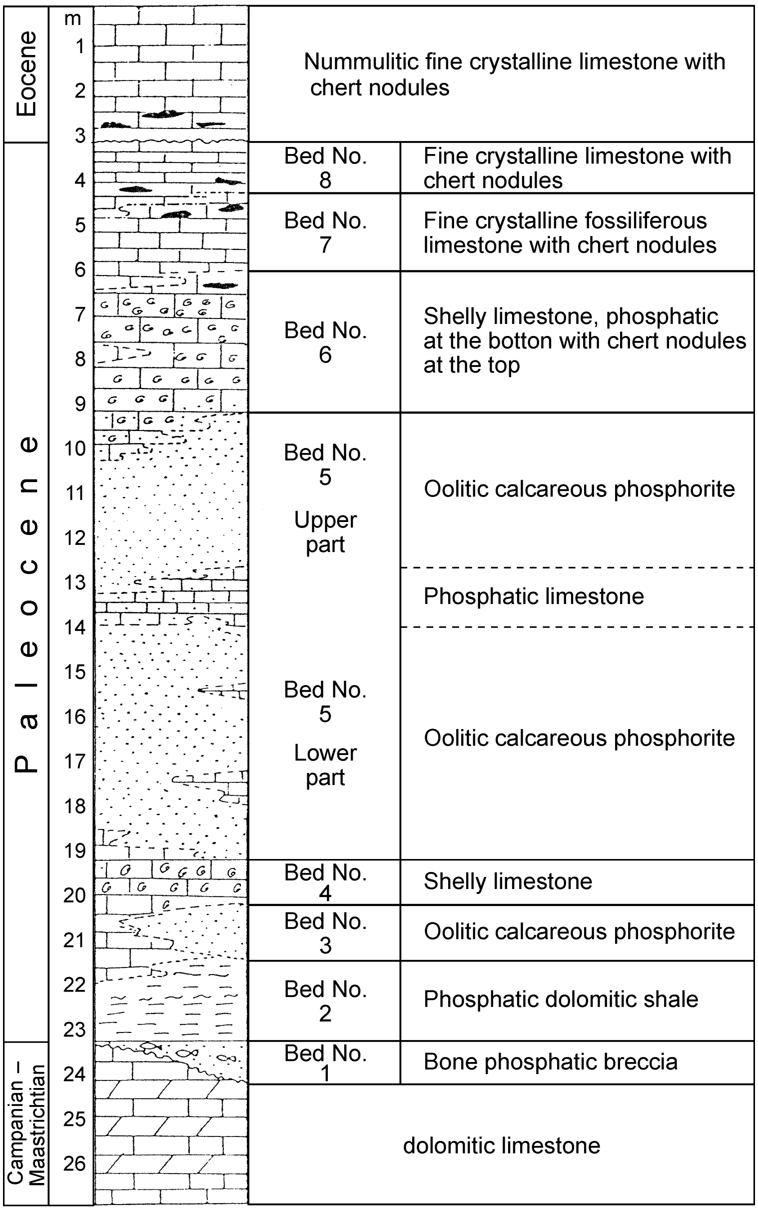

Fig. 6: Lithological columnar section in the Akashat phosphorites deposit (Paleocene) (Al-Bassam, 1976)

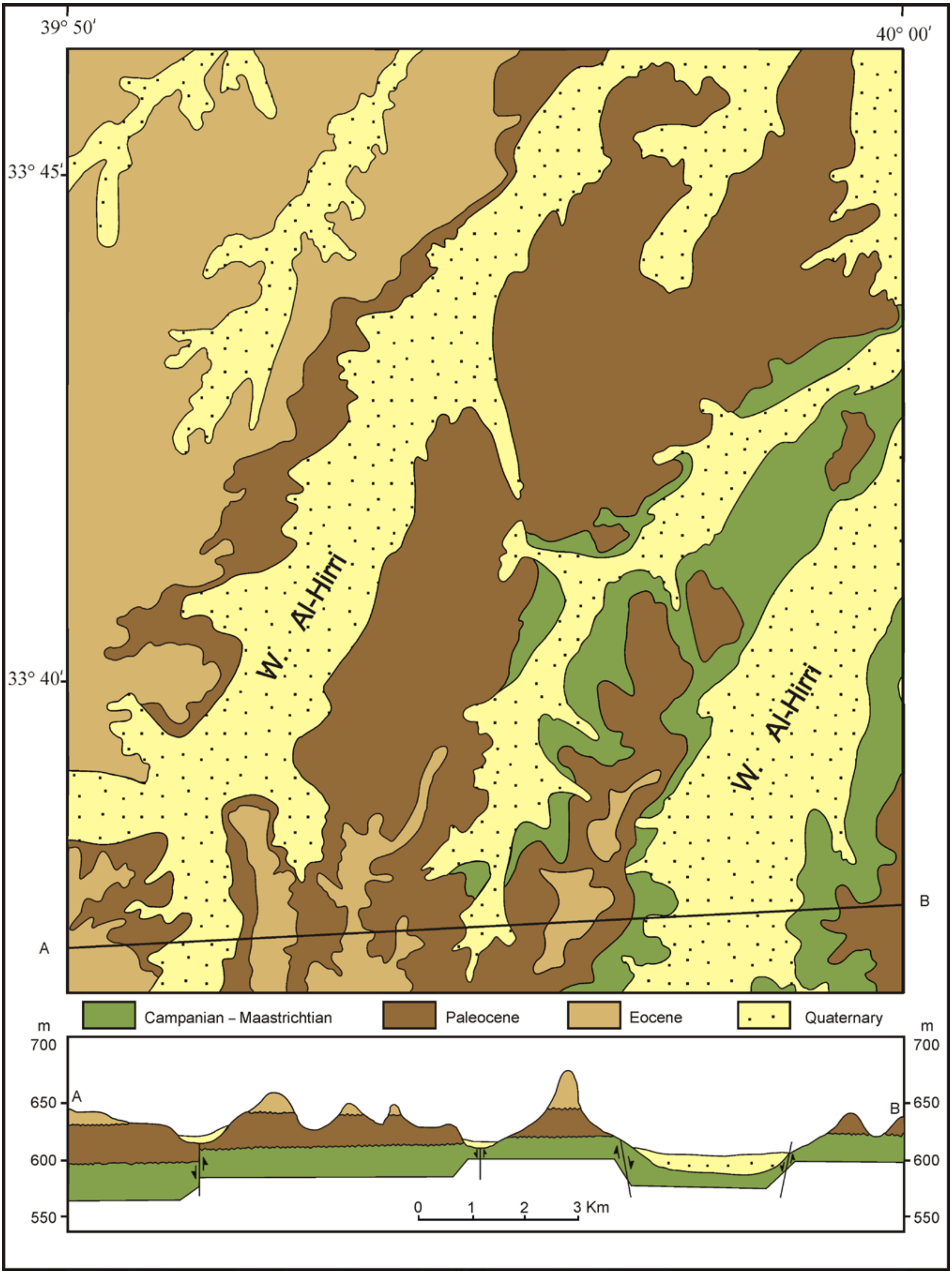

Fig. 7: Geological map of the Akashat area (Dawood, 1965)

SPECIFICATIONS OF THE MINERAL RESOURCES

- **Quartz-sand**

Huge deposits of quartz-sands are encountered in the Nahr Umr (Albian) and Rutbah (Cenomanian) formations in the Western Desert estimated by about 75 m.t. (Etabi *et al*., 1986). More than 20 m thick deposits extend in an E – W direction for more than 100 Km along Baghdad – Amman highway. In addition, the lower part of the Ga`ara Formation (Permocarboniferous) consists almost entirely of quartz-sand deposits. These deposits were derived from granitic source rocks and probably older sedimentary rocks of the Arabian Shield. They were transported by rivers to the depositional sites in the Iraqi desert.

The sandstone consists of (95 – 99) % quartz and generally less than 1% Fe_2O_3. Occasional thin claystone lenses may be encountered, as well as some sandstone lenses are cemented with secondary calcite. The quartz grains are generally (0.1– 0.5) mm in size and subrounded to subangular in shape. The Ga`ara Formation quartz-sands are generally finer in grain size, though some coarse grained sandstone lenses may be encountered in the upper parts of the section (Shaposhikov and Babushkin, 1961; Al-Murib, 1985 and Tamar-Agha *et al*., 1992).

- **Heavy minerals sandstones**

Heavy minerals are found in considerable concentrations in two main rock units; the sandstones of the Ga`ara Formation and those of the Amij Formation (Permocarboniferous and Middle Jurassic, respectively) (Al-Najim, 1987; Mahdi *et al.*, 1993 and Tamar-Agha *et al*., 1992). Both are exposed in the Western Desert. Zircon and rutile are the main heavies in the former and zircon, rutile and monazite in the latter.

Up to 11% heavy minerals were reported in the Ga`ara sandstones, of which (40 – 87) % are opaques (mean 65.8%), (9 – 41) % zircon (mean 20.8%) and (1 – 11) % rutile (mean 5.1%) (Ismail, 1989). The Ga`ara zircon is Hf-rich with considerable concentrations of Y and rare earths, whereas the rutile is Nb-rich with considerable concentrates of Cr and V (Table 2). The Ga`ara sandstone deposits are believed to be mainly fluvial in origin as meandering river-channel deposits (Tamar-Agha *et al.*, 1992).

The heavy minerals in the sandstones of the Amij Formation consists of (54 – 76) % opaques (mean 65%), (7 – 19) % zircon (mean 11.7%), (5 – 15) % monazite (mean 8.9) % and (3 – 11) % rutile (mean 8.8%) (Ismail, 1996). The zircon is rich in Hf, Y and Th, whereas the rutile is rich in Cr (Table 3). The Amij sandstones are considered as beach deposits by many workers on the basis of sedimentary structures and morphology.

Table 2**:** Chemical analyses of zircon and rutile in the sandstones of the Ga`ara Formation (Ismail, 1989)

Wt%	**Zircon**	**Wt%**	**Rutile**
SiO_2	32.23	SiO_2	0.21
ZrO_2	40.84	TiO_2	97.84
HfO_2	21.85	Cr_2O_3	0.28
Y_2O_3	2.21	V_2O_3	0.35
ThO_2	0.85	Fe_2O_3	0.13
UO_2	0.21	Al_2O_3	0.15
Al_2O_3	0.15	Nb_2O_5	0.34

Table 3: Chemical analyses of zircon, rutile and monazite in the sandstones of the Amij Formation (Ismail, 1996)

Wt%	Zircon	Wt.%	Rutile	Wt.%	Monazite
SiO_2	30.61	TiO_2	98.04	SiO_2	0.28
ZrO_2	57.65	FeO	0.47	ThO_2	4.41
HfO_2	7.03	SiO_2	0.18	UO_2	0.51
Y_2O_3	2.03	Al_2O_3	0.23	La_2O_3	13.03
ThO_2	0.56	CaO	0.38	Ce_2O_3	28.28
UO_2	0.18	MgO	0.02	Pr_2O_3	2.57
Al_2O_3	0.18	Cr_2O_3	0.33	Nd_2O_3	13.64
				Sm_2O_3	1.66
				Gd_2O_3	0.25
				P_2O_5	29.63

- **Feldspathic sandstone**

The sands and sandstones of the Dibdibba Formation (Pliocene – Pleistocene) in the Najaf area contain appreciable concentrations of feldspar (mainly potash feldspar) (Al-Ka`aby and Najim, 1999). They contain about 15% feldspar, 70% quartz and 15% rock fragments of igneous and sedimentary origin (Sadik, 1997). The feldspar is concentrated in the coarse fraction as angular to rounded grains, generally more than 0.5 mm in size and may reach up to 10 mm.

These deposits were derived from the mechanical disintegration of granitic rocks in the Arabian Shield and were transported by rivers to the depositional sites where they formed a fan-shape deposit (Ghalib, 1988). The reserves are estimated by about 2.3 m.t. (Al-Ka`aby and Najim, 1999). The chemical composition is shown in Table (4).

Table 4**:** Chemical analyses of the feldspar-bearing sandstones in the Najaf area (Al-Bassam *et al.*, 1999c)

Wt. %	Raw sandstone	Sieved (+710 µ m)
SiO_2	88.7	86.2
Al_2O_3	3.7	1.1
CaO	0.9	0.4
MgO	0.5	0.2
K_2O	1.5	2.8
Na_2O	0.7	1.3
L .O .I	2.1	0.4

- **Kaolinitic claystones**

Kaolinitic claystones in Iraq are restricted in occurrence to the Western Desert and in age to the pre Cretaceous units; no significant kaolinite deposits are known after the Jurassic. The upper parts of the Ga`ara Formation (Permocarboniferous) in the Ga`ara are characterized by kaolinitic claystone deposits of various types including white and colored varieties. They are also known in the lower parts of the Hussainiyat Formation (Early Jurassic) along Wadi Hussainiyat and in the Amij Formation (Middle Jurassic) at Wadi Amij (Mahdi *et al*., 1990 and Mahdi and Al-Delaimi, 1999).

The Jurassic kaolinites are highly ferruginous and of lower grade (Table 5). Flint-clays are known as karst-fill deposits of Early Cretaceous age in association with bauxite and bauxitic clay in very restricted localities in the Western Desert (Mustafa *et al*., 1994 and Al-Rubaii, 1997). All kaolinitic claystone deposits of Iraq were transported, as kaolinites, with other clastics from source areas in the south and southwest and were deposited in a fluvial system. The total reserves are estimated by about 1200 m.t. (Mahdi and Al-Delaimi, 1999).

Table 5**:** Chemical analyses of main kaolinitic claystone and flint-clay deposits (Jargees and Santrucek, 1975; Al- Kindy *et al.*, 1984; Al-Khafaji, 1989 and Mahdi and Al-Delaimi, 1999)

Wt.%	**Ga'ara Fn.**		**Hussainiyat Fn.**		**Amij Fn.**	**Karst-fill Flint-clay**
	White	**Colored**	**NE***	**SW***		
SiO_2	48.1	51.1	50.7	45.0	48.0	38 – 45
TiO_2	1.1	1.5	1.4	1.9	1.5	1.4 – 3.0
Al_2O_3	35.7	28.7	28.7	31.0	29.0	35.0 – 41.5
Fe_2O_3	0.9	7.0	5.5	5.5	6.1	0.5 – 2.0
L.O.I	12.7	10.3	9.6	12.3	11.0	13 – 12

***** relative to Wadi Hussainiyat

▪ **Montmorillonite and palygorskite claystones**

Montmorillonite and palygorskite are the dominant clay minerals in Iraq from Late Cretaceous onward. Whereas kaolinite is more dominant in the older units. This was attributed to climatic changes (Al-Bassam, 1996).

Extensive montmorillonite-rich marine sedimentary claystones are known in the Digma Formation (Late Cretaceous) and to a lesser extent in the Akashat Formation (Paleocene) in association with phosphorites (Al-Bassam and Al-Sa`adi, 1985). The reserves are estimated by about 22 m.t. These clystones are originally black shales, rich in carbonaceous matter (Al-Bassam and Al-Haba, 1990). They were oxidized to yellow and green claystones in surface and near-surface sections.

Palygorskite is associated with montmorillonite in these deposits (Fig.8) and becomes the dominant clay mineral in shallow, near-shore areas of the basin. It is believed that both minerals are genetically related and most of the palygorskite in these deposits formed from a montmorillonite precursor (Al-Bassam, 2000b). The thickness of the montmorillonite – palygorskite claystones in theses units range from (1 – 10) m. They are calcareous and slightly phosphatic (Table 6). Thin palygorskite beds were also investigated in the Injana Formation near Najaf (Abdul Hassan, 1999 and Al-Bassam and Al-Baidari, 2000).

Table 6: Chemical composition of montmorillonite and palygorskite claystones (Al-Bassam and Al-Sa'adi, 1985; Al-Bassam *et al.*, 1989; Al-Bassam and Al-Baidari, 2000 and Aswad *et al.*, 2000)

Wt.%	**Montmorillonite**		**Palygorskite**	
	Digma Fn.	**Akashat Fn.**	**Digma Fn.**	**Injana Fn.**
SiO_2	56.8	62.7	57.9	53.50
Al_2O_3	15.7	13.3	12.6	13.30
Fe_2O_3	5.1	5.4	6.2	17.50
CaO	4.5	3.4	1.8	1.30
MgO	3.4	4.5	8.6	9.50
K_2O	0.6	0.5	0.6	3.50
Na_2O	1.1	0.5	1.4	0.70
L.O .I	9.5	8.3	10.5	10.00

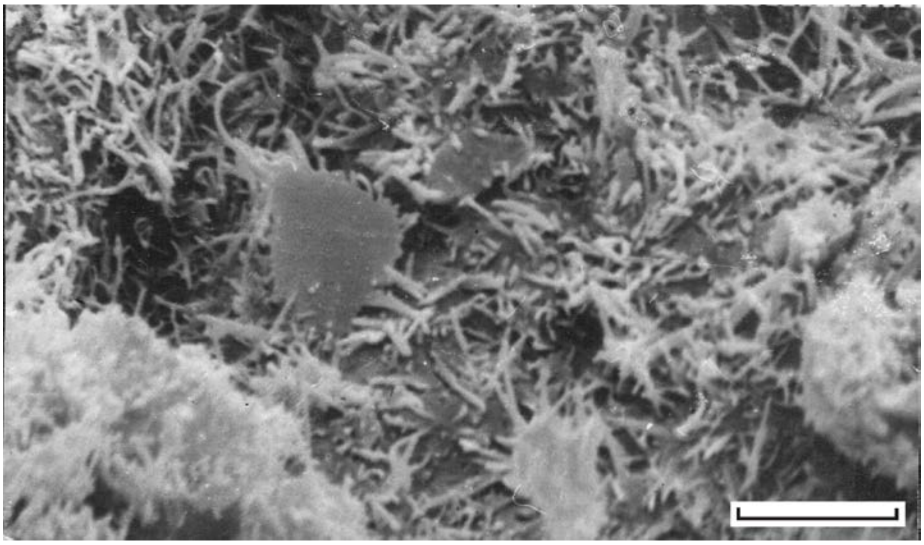

Fig. 8: SEM photomicrograph showing montmorillonite – palygorskite genetic relation in the Injana Formation deposits, Najaf area (bar = 5 micrometers)

- **Quaternary clays**

These are mixtures of clay and silt, often sandy, and were deposited in the playas and topographic depressions in the Western Desert. They are fluvial deposits, in which there is a mixture of clay minerals, dominated by montmorillonite, chlorite, palygorskite, illite and a kaolinite and non-clay mineral mostly carbonates and quartz (Al-Sinawi *et al.*, 1973). These deposits represent important commodity for cement and brick industries. Typical chemical analyses are shown in Table (7).

Table 7: Chemical composition of Quaternary clays
(Toma, 1977; Gulli, 1980 and Nadir, 1981)

Wt.%	Jabha	Mugur Al-Thib	Ain Al-Zarga
SiO_2	33.6	33.1	43.5
Al_2O_3	6.5	6.7	10.1
Fe_2O_3	3.7	3.54	5.05
CaO	24.4	25.4	16.76
MgO	4.3	2.9	4.19
K_2O	0.33	0.9	
Na_2O	0.08	0.27	2.56
L.O .I	23.7	24.23	18.3

- **Ironstone**

The Hussainiyat sedimentary ironstone deposit is the main ironstone deposit in Iraq. It is located in the Western Desert of Iraq, in the SE parts of Wadi Hussainiyat within the Hussainiyat Formation (Early Jurassic). The ironstone is about 3 m in thickness, pisolitic, oolitic, intraclastic and concretionary in texture (Fig.9), associated with kaolinitic mudstones and/ or with quartzose sandstone. The mineralogy consists of goethite, hematite, kaolinite and quartz. The average chemical and minerals composition of the Hussainiyat ironstone deposit is shown in Table (8). The reserves are estimated by about 60 m.t. (Etabi, 1984).

The ironstone and the associated clastics are overlying an unconformable surface of the Ubaid Formation (Early Jurassic). Iron and the associated clastics were transported by rivers from deeply weathered source rocks in the Arabian Shield. Iron was mostly attached to clay fraction and organic matter. After deposition, iron concretions were mostly formed by bacterial build-up in swamps and marshes and were subsequently embedded in organic-rich kaolinitic mud. Pisolites and oolites grew *in situ* in the kaolinitic soil at the upper limit of a fluctuating water table, forming a groundwater laterite blanket (ferricrete) under oxidizing pedogenic conditions and seasonally wet climate. The iron intraclasts were formed by the reworking of the ferricrete by flowing ephemeral streams and rivers and were redeposited as channel lag deposits with sand and other clastics (Al-Bassam and Tamar-Agha, 1998).

The upper parts of the sandstone unit of the Ga`ara Formation in the NW rim of the Ga`ara Depression is highly ferruginous and can be classified as an ironstone. It consists of almost equal proportions of hematite and quartz. The iron minerals are epigenetic and form the cementing material in the sandstone. The ore bodies are discontinuous, lens-like, their length is (200 – 300) m and thickness (1 – 2) m (Petranek and Jassim, 1980 and Tobia, 1983).

Table 8: Chemical and mineralogical composition of the Iraqi ironstone (Tobia, 1983 and Al-Bassam and Tamar-Agha, 1998)

Hussainiyat Formation				**Ga'ara Formation**			
Wt. %		**Mineralogy %**		**Wt. %**		**Mineralogy %**	
SiO_2	32.0	goethite – hematite	42	SiO_2	50.5	goethite – hematite	42
Fe_2O_3	38.4	kaolinite	41	Fe_2O_3	39.0	kaolinite	5
Al_2O_3	16.3	quartz	13	Al_2O_3	1.9	quartz	50
H_2O	9.4	others	4	H_2O	5.1	others	3

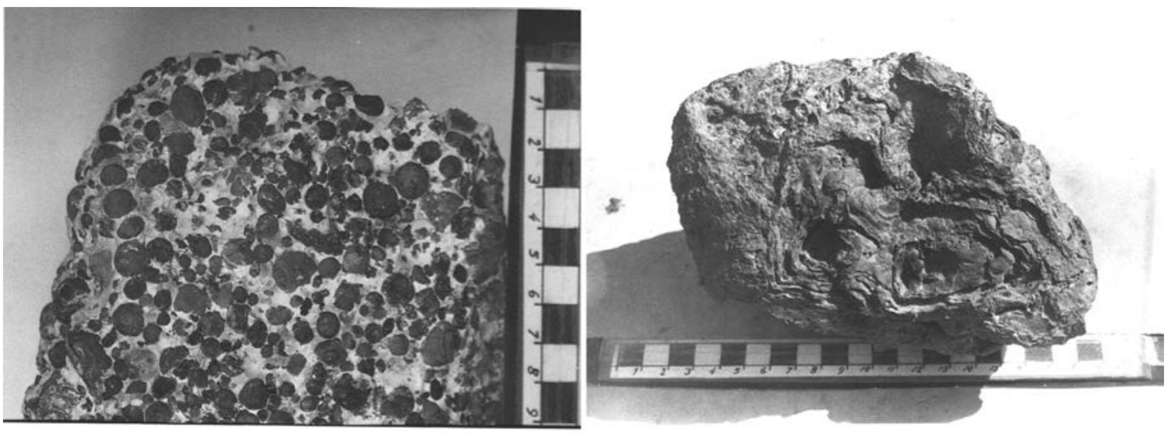

Fig. 9: Hussainiyat Ironstones

Left: Iron pisoids in kaolinitic matrix **Right**: Iron concretion (scale in cm)

▪ **Karst bauxite**

Bauxite and bauxitic kaolinites were discovered filling up to 70 m deep karsts in the carbonates of the Ubaid Formation (Early Jurassic) in the Western Desert. The reserves are about 1 m.t. (Mustafa *et al.*, 1994). The karst-fill deposits consist of several fining upward cycles of quartzose sandstone and kaolinitic claystone with (or without) bauxite and bauxitic flint-clay lenses in the middle (Mustafa *et al.*, 1994).

The mineralogy of the bauxite deposits consists of boehmite and to a lesser extent gibbsite. Non-bauxitic minerals include kaolinite, quartz and hematite (Al-Bassam, 2005). The bauxite minerals are colloformic in texture including pisoids, ooids and pelloids (Fig.10). All grades of bauxitization are found in these deposits. However, high quality bauxites are missing. The chemical composition is reported in Table (9).

The age of the karst-fill deposits is controversial, but many workers agree it is Early Cretaceous. The author believes it is Aptian and the bauxitization event took place at the Aptian – Albian boundary as an equivalent climatic event to the bauxite profile at Zabira in Saudi Arabia (Al-Bassam, 1996).

Table 9: Chemical composition of the karst bauxite (Mustafa *et al.*, 1994 and Al-Rubaii, 1997)

Wt%	Range	Mean
SiO_2	17.7 – 22.3	20.6
Al_2O_3	47.7 – 60.9	55.6
Fe_2O_3	0.4 – 1.6	0.7
TiO_2	1.2 – 4.3	2.6

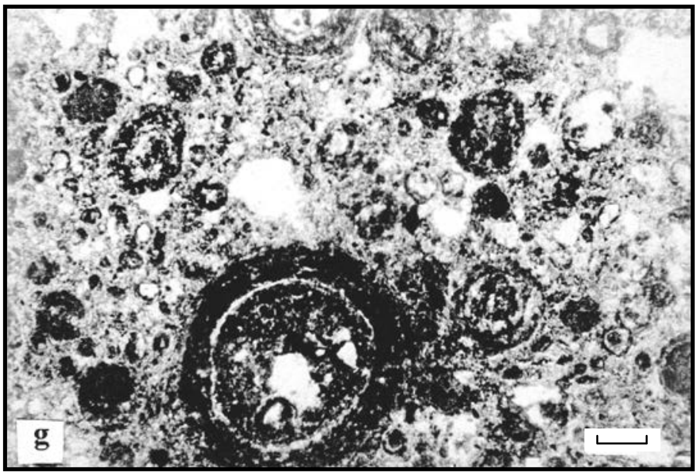

Fig. 10: Colloform texture of the karst bauxite, (ppl., bar = 1.0 mm)

- **Phosphorites**

The phosphorite deposits of Iraq are part of the Tethyan phosphogenic province which extends from Senegal and Mauritania in the west to Iraq, Iran and Turkey in the east, passing through almost all the North African and East Mediterranean countries. These are marine sedimentary deposits, which range in age from Late Cretaceous to Eocene. They are granular in texture, associated with limestones, black shales (mostly smectite), porcelanite and chert.

The reserves of the Iraqi deposits are estimated by about 10000 m.t. (Al-Bassam *et al.*, 1990). They are found in the Western Desert as thin beds in the Digma Formation (Maastrichtian), thick beds in the Akashat Formation (Paleocene), where the maximum phosphogenesis occurred in Iraq, and as thin to thick horizons and beds in the Ratga Formation (Eocene). The thickness of the phosphorite beds varies from (0.5 – 12) m. The texture varies from intraclastic – bioclastic phosphorites in the Cretaceous deposits, to pelloidal – ooidal phosphorites in the Paleocene deposits (Fig.11) and mostly peloidal, coprolitic or intraclastic in the Eocene deposits. The cementing material is usually calcite, but some siliceous varieties are common. Francolite is the only phosphate mineral in the Iraqi deposits (Al-Bassam, 1976 and 1992). The composition of some of the known phosphorite deposits is shown in Table (10).

The Iraqi phosphorites, as with all Tethyan deposits, were deposited under special paleogeographic conditions that initiated P-rich deep oceanic upwelling on shallow shelf areas (Sheldon, 1981). Francolite was deposited at and below sediment – water interface via a biogenic phase (Al-Bassam, 1976). A recent study has shown clear evidence of microbial role in the formation of the Iraqi phosphorites (Al-Bassam *et al*., 2000a).

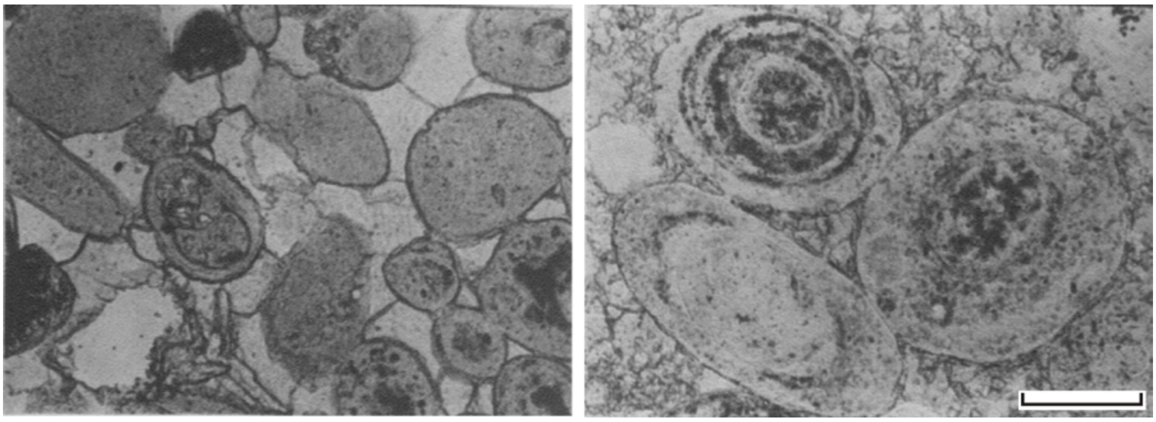

Fig. 11: Phosphate peloids (Left) and ooids (Right) in calcite cement (ppl., bar = 0.1 mm)

Table 10: Chemical analysis of some Western Desert phosphorites (Al-Bassam, 1976; Al-Bassam *et al*., 1983 and Al-Bassam and Hagopian, 1983)

Wt.%	Digma Fn. (Maastrichtian)	Akashat Fn. (Paleocene)	Ratga Fn. (Eocene)
P_2O_5	25.6	22.1	20.8
SiO_2	10.1	1.8	0.4
Al_2O_3	0.8	0.3	0.1
CaO	40.9	53.0	54.4
MgO	0.2	0.5	0.4
SO_3	1.7	1.4	1.1
Na_2O	0.7	0.8	0.5
F	3.3	2.9	2.4
L.O.I	11.4	16.7	20.5

- **Porcelanites**

These are siliceous rocks, composed of opal-CT (crystoballite – tridymite crystal stratification) (Fig.12) and are derived from biogenic (mostly diatoms) amorphous opalline silica. They are part of the phosphorites-bearing sequences of the Maastrichtian and Paleocene in the Western Desert (Digma and Akashat formations, respectively). Several porcelanite horizons were identified, (0.5 – 1.0) m thick, associated with shale, phosphorite and chert (Al-Bassam and Al-Sa`adi, 1985 and Al-Bassam *et al.*, 2000b). The chemical composition is shown in Table (11). The reserves are estimated by about 1.8 m.t. (Al-Bassam *et al.*, 2000b).

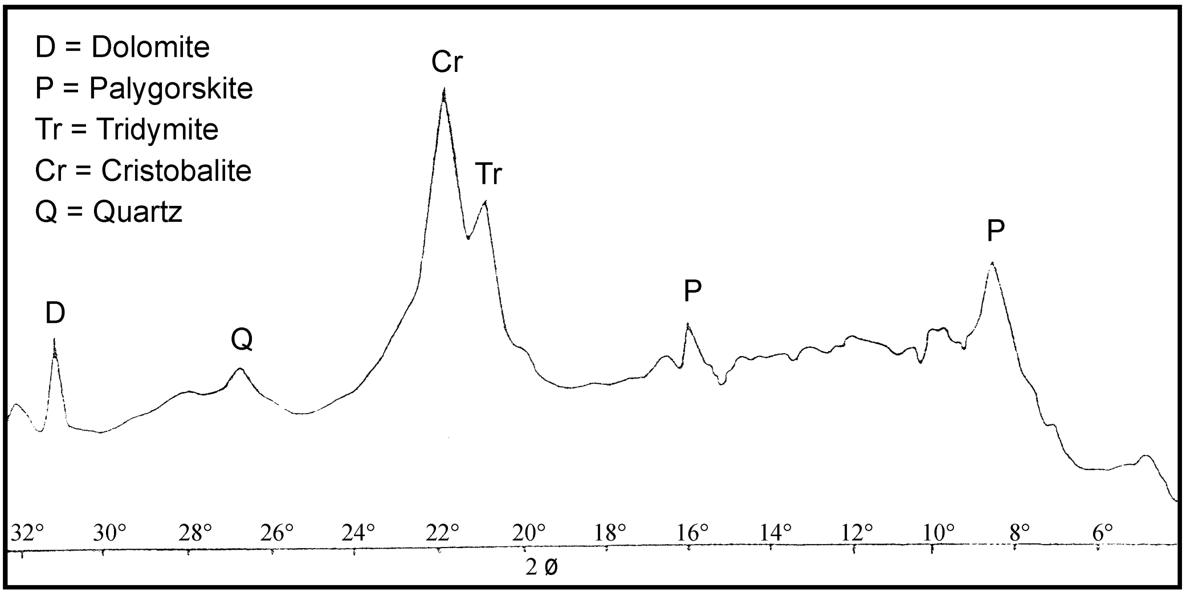

Fig. 12: X-ray diffractogram of porcelanite from the Digma Formation (Late Gretaceous) (Al-Bassam *et al*., 2000b)

Table 11: Chemical composition of some Iraqi porcelanites
(Al-Bassam and Al-Sa`adi, 1985 and Al-Bassam *et al*., 2000b)

Wt. %	Maastrichtian (3 horizons)	Paleocene
SiO_2	58.0 – 82.2	77.8
Al_2O_3	1.1 – 3.8	3.0
Fe_2O_3	0.5 – 1.5	0.6
CaO	0.8 – 9.9	5.3
MgO	2.7 – 8.3	1.1
Na_2O	0.4 – 1.2	2.3
P_2O_5	0.7 – 2.3	n.a.
L.O .I	5.4 – 17.4	8.5

▪ **Limestone**

Huge deposits of high quality limestone are found in the Western Desert. The main limestone-bearing units are the Eocene, Miocene and to a lesser extent Pliocene – Pleistocene (Dammam, Ratga, Euphrates and Zahra formations). Most of the economic limestone deposits, however, are found in the Dammam, Ratga and Euphrates formations (Mansour and Petranek, 1980) (Table 12).

Table 12**:** Chemical composition of some limestone deposits
(Mansour and Petranek, 1980 and Sa'eed, 1988)

Wt. %	Dammam Fn.	Ratga Fn.	Euphrates Fn.
CaO	54.20	54.20	53.50
MgO	0.19	0.24	0.65
SiO_2	1.65	1.79	1.20
Al_2O_3	0.12	0.27	0.60
Fe_2O_3	0.08	0.13	0.15
SO_3	0.38	0.38	0.18

▪ **Dolomite**

The main dolomite deposits in the Western Desert are found in Mulussa and Zor Hauran formations (Late Triassic), Ubaid, Hussainiyat and Amij formations (Jurassic), Ms`ad and Hartha (Cretaceous), Umm Er Radhuma and Dammam (Paleogene) and Euphrates (Miocene). High quality dolomites, suitable for industrial purposes, are available in many of these rock units (Al-Bassam, 1984) (Table 13).

Table 13: Chemical composition of some dolomite deposits (Al-Bassam, 1984)

Wt.%	Zor Hauran Fn.	Hussainiyat Fn.	Dammam Fn.	Euphrates Fn.
CaO	30.13	30.76	29.55	29.40
MgO	20.62	19.50	20.48	18.35
SiO_2	2.33	2.08	2.08	5.24
Al_2O_3	0.53	0.14	0.31	1.69
Fe_2O_3	0.51	0.51	0.15	0.97
SO_3	0.26	0.07	0.36	0.74

▪ **Gypsum**

Almost all the economic gypsum deposits of Iraq are found in the Fat`ha Formation (Middle Miocene). They are thickly bedded deposits, formed by evaporation in closed or semi-closed marine basins in association with carbonates and claystones. Few deposits are found in the Western Desert where gypsum horizons are recorded in the Fat`ha Formation near Heet. Typical chemical analyses are shown below (Mansour and Toma, 1983).

SO_3 (43 – 46) %, CaO (32 – 33) %, I.R. (1 – 2) %, Fe_2O_3 and Al_2O_3 <0.1 %, H_2O (19 – 21) %.

▪ **Celestite**

Small occurrences of celestite were recorded in the Injana and Dibdibba formations in the Najaf – Karbala area (Al-Bassam, 1995; Al-Baidari, 1997 and Abdul Hassan and Al-Quwaizi, 1999). The celestite mineralization is lenticular in nature, (0.5 – 1.0) m thick, associated with mudstone and sandstone and present as cementing material in various horizons. The celestite is present as euhedral crystals of various sizes (Fig.13) with inclusions of calcite and aragonite. Up to 43% celestite was recorded in some samples, associated mainly with quartz, calcite, aragonite and palygorskite in fluvially-deposited clastic units (Al-Bassam, 1995).

It is believed that the celestite is epigenetic deposited from Sr-rich ground waters seeping through various springs in the area along the Euphrates Fault Zone. It was formed by direct crystallization and also by replacement of aragonite and calcite (Dawood, 2000).

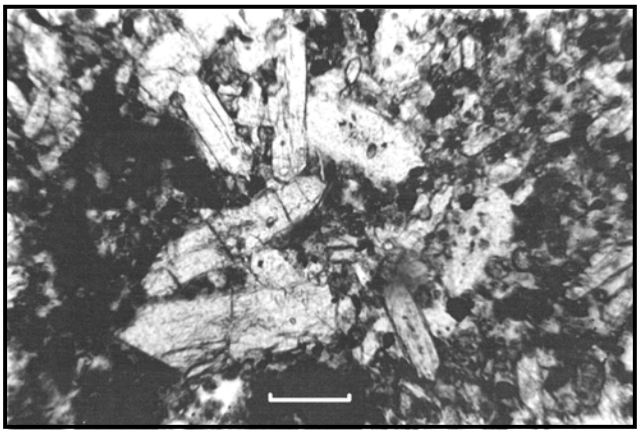

Fig. 13: Euhedal crystals of celestite from Injana Formation (ppl., bar = 0.5 mm) (Al-Bassam, 1995)

▪ **Uranium**

The upper part of the Euphrates Formation (Early Miocene) is characterized by anomalous uranium concentrations along the desert side of the Euphrates River basin. The uranium anomalies form a belt extending from Al-Qaim in the north to Samawa in the south. Uranium concentrations in the carbonates of the Euphrates Formation ranges from (10 – 300) ppm, concentrated in several horizons. Two genetic types were identified; a syngenetic and an epigenetic mineralization (Al-Qazzaz and Mahdi, 1991).

Uranium enrichment in the Early Miocene carbonates was related to deep-seated faults of the Euphrates Zone (Mahdi *et al*., 2005) and to the Anah Fault Zone (Al-Bassam *et al*., 2006). These faults were reactivated in the Early Miocene (Bolton, 1954 and Fouad, 2004). Uranium-rich groundwater from Paleozoic aquifers ascended, through conduits and fracture zones along these faults, to the surface together with bitumen and H_2S. Uranium, as urano – organic complexes and/ or pitchblend, was deposited in the interstitial environment below sediment – water interface (Al-Bassam *et al.*, 2006). Epigenetic mobilization and precipitation of secondary uranium took place under continental conditions in some localities such as Abu Skhair (Al-Atia and Mahdi, 2005) and Al-Qaim (Al-Fadhli and Abdul Qadir, 1969).

Uranium is found in the marine sedimentary phosphorites of Iraq (Late Cretaceous – Early Tertiary) in variable concentrations reaching up to 100 ppm. Most of the uranium is believed to be present in the francolite structure as U^{4+} substituting for Ca^{2+} (Al-Bassam, 2007).

INDUSTRIAL POTENTIAL OF MINERAL RESOURCES

The type, quality and reserves of the identified mineral resources and industrial rocks in the Western Desert provide a very promising potential to establish many industries in this part of Iraq. One of the most important of these industries is phosphate fertilizers and phosphoric acid production. In an agricultural country such as Iraq, phosphate fertilizers may be considered a strategic commodity. The phosphorite reserves are enormous (10 billion tones) and in view of the availability of sulfur resources in Iraq, phosphate fertilizer production can be significantly enlarged to become one of the main chemical industries in the region (Al-Bassam, 1984).

Montmorillonite – Palygorskite claystones are important raw materials for drilling mud (Al-Uqaily *et al*., 1991 and Al-Bassam *et al*., 1994). In an oil country like Iraq, these claystones are essential in exploratory and development drilling of oil fields. Moreover, they are important filter-aids, together with porcelanite. They can be used in decolorizing vegetable and mineral oils (Al-Ajeel *et al*., 1999, Al-Ajeel *et al*., 2000 and Al-Bassam *et al.*, 1995), treatment of industrial water (Al-Bassam *et al.*, 2001), treatment of radioactively polluted areas (Al-Sa`adi and Al-Ajeel, 1999), lining of sanitary hazardous waste-disposal sites (Al-Bassam *et al.*, 2002), treatment of low-fertility soil (Al-Ajeel and Khalil, 2003).. etc.

Kaolinitic claystones, feldspar-sandstones and quartz-sandstones are essential raw materials for ceramic industries. The available reserves and specifications encourage expanding this industry in Iraq. Quartz-sand provides very important raw material for a large-scale glass industry.

Bauxite, kaolinitic clay and quartz-sand are important in refractories production of the Al-type. Whereas, dolomite can be used in the production of magnesia bricks essential for cement plants. The former is produced on a very small scale and the latter is not produced, but tests proved that the Western Desert dolomites can be used to produce Mg-type bricks (Al-Taie *et al.*, 1985).

All the essential raw materials for Portland cement industry are available in the Western Desert in sufficient reserves and suitable specifications. These are limestone, clay (Quaternary clay), gypsum and ironstone. A strategic cement industry can be established on these raw materials. Moreover, white cement production can be also expanded on the basis of large reserves of white color limestone and flint clay (Al-Ubaidi and Al-Bassam, 2005).

CONCLUSIONS

- The Iraqi Western Desert contains valuable mineral resources and industrial rocks ranging in age from Permocarboniferous to Pleistocene. Some of these resources are limited in occurrence to this part of Iraq and are not available else where in the country. Phosphorites, bauxites, kaolinitic claystones, quartz-sandstones and montmorillonitic claystones are the most important of these resources.
- The geological history of this region witnessed great changes in paleogeography, climate and tectonism, which gave rise to various types of mineral deposits formed by different minerogenic process. Continental mechanical deposits include quartz-sand, feldspathic sand, heavy minerals-sand and kaolinitic claystone. Marine deposits are phosphorites, montmorillonite – palygorskite claystones and uranium. Evaporites include gypsum and celestite. Laterites include ironstone, bauxite and flint clay.
- The great reserves and high diversity of the mineral resources in the Western Desert make this province very promising in future development of mining and other industries using mineral raw material such as cement, glass, ceramics, refractories, fertilizers and other chemical industries.

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