Chapter 20

Metallic and industrial rocks and minerals

by

Khaldoun* S. *Al-Bassam and Jaroslav Hak

20.1 Introduction

Systematic exploration for mineral raw materials in Iraq started in the early 1950's. The Site Investigation Co. (UK) implementing an exploration program of local geological mapping and geophysical exploration on various scales in N and NE Iraq. The program also included evaluation of small areas for the cement industry, and some exploratory visits to W Iraq. The main aim of the early exploration was to locate and preliminary evaluate the mineral wealth of Iraq. The information obtained during this survey helped locate some metallic mineral deposits in N and NE Iraq. The exploration work was resumed by Russian teams from 1960-1964, who evaluated mineral deposits suitable for industrial use including phosphorite, native sulphur, quartz sand, dolomite, limestone and ironstone.

GEOSURV commenced comprehensive regional geological mapping and mineral investigation projects that provided new valuable information on the distribution of new resources of mineral raw materials throughout Iraq. These surveys were followed by detailed exploration and prospecting projects that resulted in delineation of several important deposits including phosphorite, sulphur, kaolinitic clays, sedimentary ironstones and building raw materials (limestone, gypsum, gravel, sand, and clay). Meanwhile new mineral raw materials were discovered and appraised in detail, including karst bauxite, flint-clay, celestine, feldspathic sand, heavy mineral bearing sand and montmorillonite-palygorskite clays.

20.2 Minerogenic zonation

The data presented in this book are based mainly on published papers, postgraduate theses and some unpublished internal reports of GEOSURY. The mineral and industrial rock potential was summarised in a map published by GEOSURV at 1:1,000,000 scale (Al-Bassam et al., 1987). Iraq was divided into minerogenic provinces, zones and districts according to the type and origin of the dominant mineral commodity available at the surface or near-surface (Al-Bassam, 1986). The surface and near surface geology and tectonic subdivisions were used to define genetic subdivisions (Fig. 20-1). They comprise:

1) Non-metallic deposits, 2) Marine sedimentary deposits, 3) Marine evaporites, 4) Continental evaporites, 5) Fluvial deposits, 6) Aeolian deposits, 7) Laterites, 8) Bioepigenetic deposits, 9) Metallic mineralization, 10) Low- temperature hydrothermal vein and strata-bound deposits, 11) Placer and secondary deposits, 12) Magmatic deposits, 13) Hydrothermal vein and strata-bound (regionally metamorphosed) deposits, and 14) Volcanosedimentary deposits.

Metallic mineralization is restricted to the Neo- Tethyan Suture Zones and is related to various phases of the plate tectonic history of the region. Low-temperature hydrothermal deposits occur in the Northern Thrust (Ora) Zone, including Pb-Zn, Ba, pyrite mineralization (e.g. the Serguza deposit). Placer and secondary deposits occur in the Balambo- Tanjero Zone and include some chromite placers and secondary Cu minerals in sedimentary clastics derived from the Qulqula-Khwakurk Zone. Magmatic Cr Ni, Cu and Fe mineralization is associated with basic and ultrabasic igneous intrusives (e.g. Mawat Cr-Ni, Cu and Penjween Fe). Hydrothermal and strata-

bound mineralization of Pb-Zn and Fe (e.g. Marapasta) and volcano-sedimentary deposits of Mn-Fe are associated with the Qulqula Group.

The Arabian Shelf units contaln non-metallic minerals and industrial rocks. Marine sedimentary deposits (chemical and biogenic) include phosphorite, limestones and dolomites. Marine evaporites are found in the Jezira Subzone and the Foothill Zone and include gypsum and rock-salt deposits. Continental evaporite deposits include halite salterns in the Jezira Subzone and the Mesopotamian Zone. Fluvial deposits of sand and gravel occur in the Mesopotamia Zone and Foothill Zone. Unique fluvial deposits of feldspar-rich sands with epigenetic celestite mineralization are found (separately) in fan deposits of the Dibdibba Formation, deposited on the W margin of the Mesopotamian Zone (Najaf-Karbala District). Aeolian sand deposits are found in the Mesopotamia Zone as dunes and sand sheets.

Bio-epigenetic strata-bound native Sulphur deposits occur in the area between Fatha in Central Iraq and Mosul in the N where mineralization is restricted to the Middle Miocene Fatha Formation.

Laterite deposits occur in the Western Desert Zone in W Iraq and comprise karst bauxite and ironstone, associated with kaolinitic clays, quartz-sand and heavy-mineral bearing sandstones. A few grains of gold were reported from ferruginous rocks of the Ga'ara depression (MacFadyen, 1935; Antonets et al., 1962 and Vasiliev et al., 1964). Laterite horizons were identified in boreholes in the stable platform indicating possible bauxites.

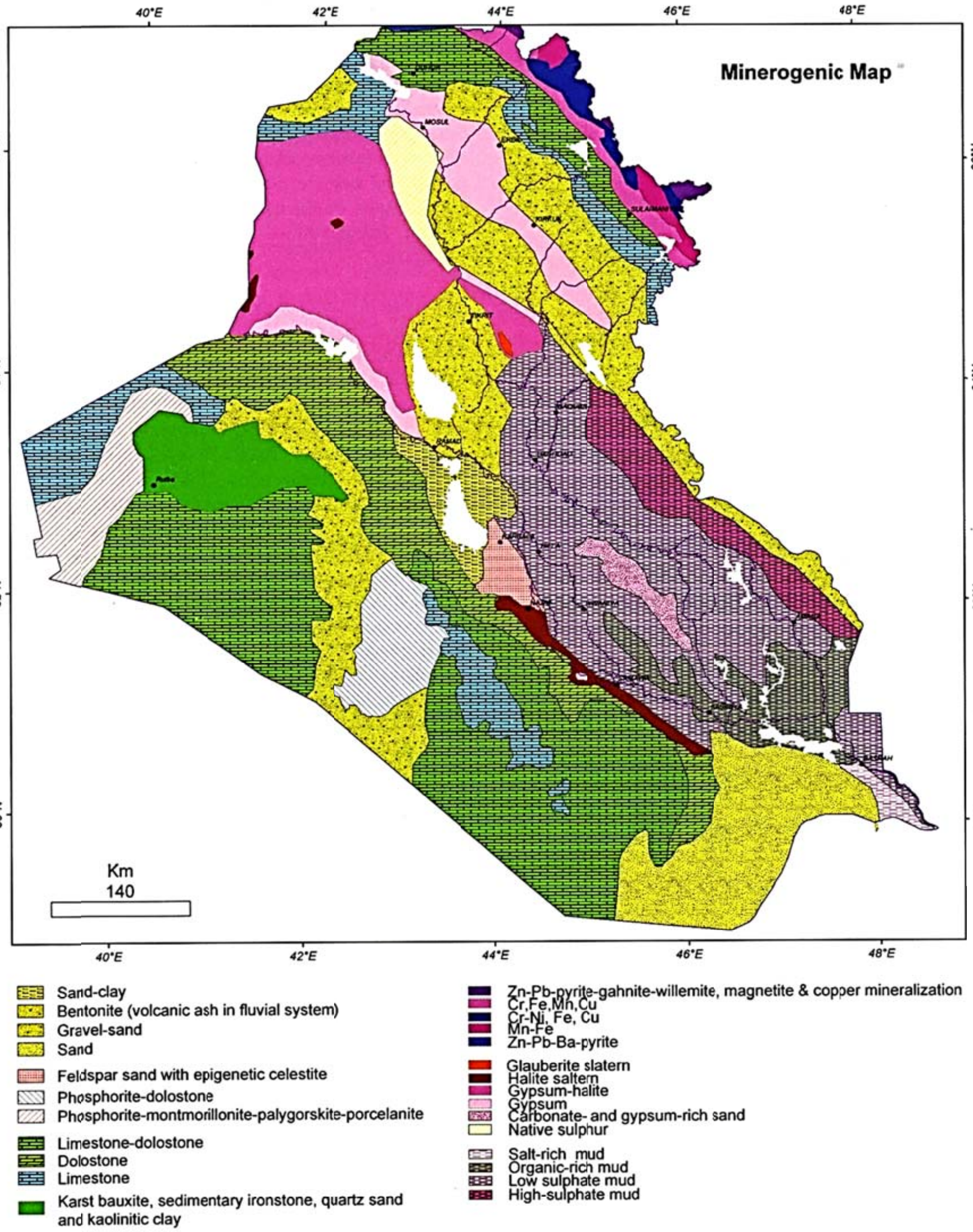


Fig. 20-1: Minerogenic map of Iraq

20.3 Metallic Mineral deposits

Metallic mineral deposits are found in the Zagros Suture Zone in N and NE Iraq. Igneous activity along the NE margin of the Arabian Plate may have been associated with deep-seated fault zones which acted as conduits for upward movement of hydrothermal mineralising fluids. Contact metamorphism occurred around gabbros that were intruded in Cretaceous and Early Tertiary time; hydrothermal mineral deposits may have formed in adjacent rocks layers.

Metallic mineral deposits have been studied since the 1950's. A survey of heavy minerals in stream sediments was scheduled for the 1980's and early 1990's to help detect metallic mineral deposits but was not fully implemented due to the Iraq-Iran and Gulf wars.

The overall economic potential for metallic minerals is generally poor, because of the inaccessibility of the rugged mountain areas which lack infrastructure, the low grade of the deposits and lack of processing facilities. Low-grade sedimentary Iron ores on the Stable Platform are unsuitable for use in the metal industry but might be useful for production of resistant cement.

20.3.1 The principal minerogenic features of the Zagros-Taurus sutures

The geology of the Zagros-Taurus suture is favourable for the occurrence of metallic mineral deposits of hydrothermal origin connected directly or indirectly with igneous activity. The deposits were formed within the Northern Thrust Zone and the Zagros Suture units (see Chapters 4 and 6). The Northern Thrust Zone represents a ridge that developed at the plate margin whereas the Zagros Suture formed within the Neo- Tethyan oceanic domain. The Northern Thrust Zone contalns base metal deposits with barite, pyrite mineralization, rare copper and some siderite veins. The Zagros Suture is characterised by copper and iron ores; lead and zinc mineralization is rare, although one base metal deposit (Marapasta) is the most promising in Iraq. Some indications of nickel, chromite, manganese ores and asbestos were also identified in the area.

20.3.2 Mineralization of the Northern Thrust Zone

The Northern (Ora) Thrust Zone is located near the border with Turkey. It is about 140 km long and 20 km wide and built mainly by Mesozoic carbonates. Palaeozoic rocks (Ordovician to Permian) outcrop in the cores of two major anticlines (Ora and Kaista). Buday (1970) and Buday and Vanecek (1972) considered that the Northern Thrust Zone has been thrust obliquely to the south over the platform units. The major structural features are ramp anticlines offset by reverse faults.

Base metal occurrences in the Northern Thrust Zone occur in two districts (Vanecek 1972), the western district NE of Zakho and the eastern district to the N of Amadiya (Fig. 20-2). They represent hydrothermal vein mineralization. The western district includes seven occurrences of lead and zinc mineralization accompanied by barite. The most important of these is the Berzanik deposit which is restricted to a fault zone of NE-SW strike in the Upper Permian Chia Zairi Formation limestones and dolomites. The total length of the mineralised zone is about 1200 m associated with three outcrops of gossans with barite. The mineralization consists of barite, limonite, galena, sphalerite, smithsonite, calcite, siderite and ankerite. Similar outcrops of barite veins and grossans with Pb-Zn mineralization were also found near Alanish, Patruma-Massis, Banik, Shiranish Islam, Lefan and Bosol.

In the eastern district of the Northern Thrust Zone McCarthy (1955) described a Cu-Pb occurrence about 6 km W of Ora village which may have been the site of an ancient mine. It comprises a vein striking NW-SE, about 1 m thick from which malachite, azurite, chalcocite and possibly even galena were obtained. Other occurrences include Gire Zivi (Silver Hill) and the Skefta Totaye. These deposits are located near the contact of the Chia Zairi limestones and the Mirga Mir shales at an altitude of about 2100 m ASL. They consist of a tectonic breccia of limestone fragments cemented by barite and quartz. Barite veins and pockets, stained with malachite and azurite, are up

to 0.5 m thick. A chunk of altered limestone with veinlets of barite and fluorite was found close to these outcrops. Fluorite veinlets, up to 1.5 cm thick, are comprised of massive, mediumgralned, light violet to light green fluorite. This is the only occurrence of fluorite in Iraq. Pebbles and fragments of galena (2 cm) in scree were found near Benavi in 1961 (Mironov and Sitchenkov, 1962). A calcite vein let with galena in dark grey dolomitic limestone in the lowest part of the southern slope of the Kurra Darmani Mountaln, about 0.5km NW Benavi village was found by Vanecek (1972).

The largest known deposit of base metals in the Northern Thrust Zone is in Serguza (Duri Serguza) about 17 km NW of Amadia (Fig. 20-1). It was studied by AL-Bassam et al. (1982). Wetzel (1950) described abundant hematite breccias consisting of angular fragments of hematite enclosed in ferruginous limestone of the Upper Cretaceous Hadiena Formation. This breccia was described as a coarse ferruginous sandstone (5-6 m thick) (McCarthy (1955), and as a hematite sandstone by Boukhtoyarov and Yewlentyev (in Vanecek, 1972). The breccia extends for at least 1 km in a 20-30 m thick interval as noted by Ibrahim Al-Rawi in 1970 (Vanecek, 1972). Microscopic studies show this horizon is a fine-grained breccia consisting of calcite grains in a ferruginous carbonate matrix. Abundant siderites veins of hydrothermal origin up to several metres thick occur in fault zones near the Serguza deposit.

Some gossans of unknown origin were reported from localities at Moi, Kani Mase, Benavi, Seraru and Noola. These gossans have relatively simple mineralogy, and dolomitic host rocks of Perrnian- Triassic age. They are associated regional thrust faults; the mineralization usually occurs in the hanging walls.

Two occurrences of gossans with galena, pyrite, chalcopyrite, sphalerite in quartz gangue occur near Herki and Stuni. Buday and Jassim (1987) assumed that this region belongs to the Shalair Zone. The Herki area is now considered part of the Northern Thrust Zone. The mineralization is located NW of Mega Sur village (Vanecek, 1972). Some iron ores were also reported from this region.

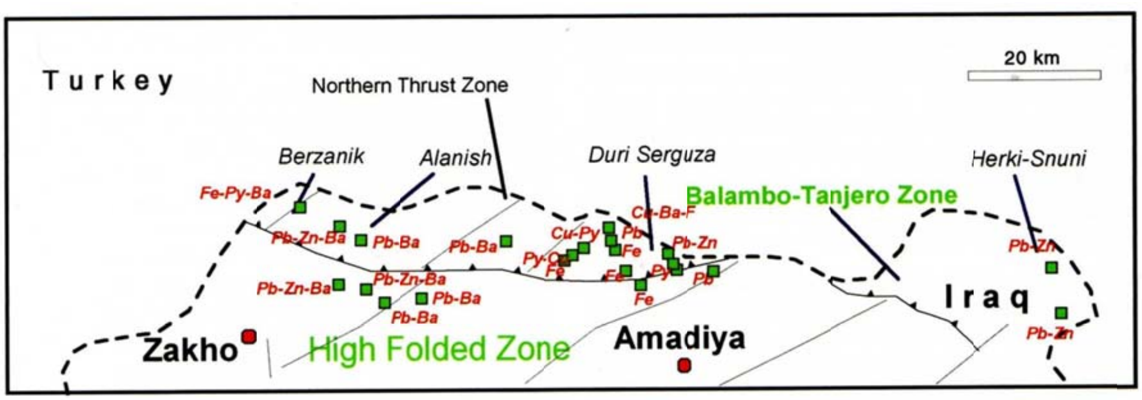


Fig. 20-2: Mineral occurrences of the Northern Thrust Zone

20.3.2.1 Serguza lead-zinc deposit and its origin

The Serguza area was mapped geologically at 1:20,000 and 1:2,000 scales (Mironov and Sitchenkov 1962), the larger scale was later updated by Aqif et al. (1971). Geophysical SP measurements (Abbas 1971) and a soil geochemical survey were conducted by Mironov and Sitchenkov (1962) and later by Al-Bassam (1980). Ore mineralogy was studied by Al-Bassam (1972) and Al-Bassam et al. (1982). AlQaraghuli and Lange (1978) investigated the minor and trace element content of the primary and oxidized ore minerals.

The deposit is situated about 17 km NW of Amadiya Town in an area dominated by Middle and Upper Triassic limestones and dolomites, and mudstones and siltstones of Miocene and Eocene age. The highly faulted and brecciated Triassic rocks form the high mountains and cliffs whereas Tertiary rocks, being usually softer, represent the lower parts and valleys. Three major tectonic structures were recognized in Serguza. These are: 1) An E- W striking thrust fault accompanied by a thick zone of brecciated massive Middle Triassic dolomites. 2) A NE-SW highly crushed SE-dipping fault zone. 3) A crush zone with a WNW-ESE trend.

The main part of the sulphide ore body is located at the tectonic contact between the Triassic and Tertiary rock units. It is a massive pyrite body which contalns nests and small veins of sphalerite and galena. The oxidized part of the ore body extends several hundred meters east and west of the sulphide body as 5-10 m thick gossans, conformable with the Middle Triassic dolomite beds.

Microscopic studies of ore minerals reveal two generations of sulphide minerals. The first generation of sulphides shows sedimentary structures: banding, lamination and micro-folding. The second generation appears in small veins and as impregnations in breccia zones, frequently associated with secondary dolomite and quartz. The ore minerals are highly deformed, brecciated and recrystallized. The sulphides form intergrowths with the dolomite; calcite occurs more frequently in the oxidized zone.

Pyrite represents the major sulphide mineral occurring as fine to medium crystalline aggregates, highly fractured and deformed massive concentrations, and also as euhedral crystals in country rocks. Colloform textures are rare. In the brecciated zones the fragmented pyrite is often cemented by galena or sphalerite and is relatively enriched with arsenic. Its Ni content is much higher than that of Co (Co/Ni ratio of 0.1) indicating a sedimentary origin (Cambel and Jarkovsky 1967).

The first generation of galena occurs as aggregates, filling fractures and cracks between the pyrite crystals. A second generation of galena occurs in country rock dolomites as scattered aggregates together with sphalerite. Galena may have suffered flow-like deformation. It is poor in silver and contalns high amounts of antimony characteristic of a sedimentary origin (Vaugham, 1976; Mercer, 1976).

Sphalerite occurs mainly as massive dark grey concentrations in the main pyrite ore body. Second generation sphalerite is usually lighter in colour forming veinlets and filling cracks in the dolomite host rock. The sphalerite has suffered deformation and fracturing. It contalns tiny inclusions of second-generation pyrite. It has very low iron and manganese contents. The remobilized sphalerite is almost depleted in iron. Cd and Ge contents are relatively high. These geochemical features are typical of low temperature strata bound sphalerite (Vaughan 1976, Hall and Heyl, 1968).

Gangue minerals comprise dolomite and quartz. Dolomite displays different textures, and is usually associated with second-generation sulphides in small veins. Quartz is associated mostly with galena and sphalerite, appearing in small veins within country rocks and as scattered crystals in the main ore body. Secondary minerals are represented by major limonite and goethite

accompanied by minor cerussite usually replacing the galena partly or completely, and very minor smithsonite.

The average ore grade of the Seguza Pb-Zn deposit is: 9.7% Zn, 5.7% Pb and 10.9% Fe (mostly as pyrite). The silver content (62 ppm) is related to the Pb content of the galena. Copper content in the ore is very low (384 ppm); arsenic (As) concentrations are relatively high with an average of 4467 ppm. Cadmium (443 ppm) correlates well with zinc, and antimony is shared between galena and sphalerite, averaging 153 ppm in the ore body.

The chemistry of the ore minerals is shown in Table 20-1. Geochemical differences between the two generations of sulphides indicate different conditions of formation. The second generation of these sulphides may have formed at higher temperatures than the primary sulphides, following intense Late Tertiary tectonic deformation.

The Middle Triassic carbonates comprise light grey dolomite and dark grey calcareous limestone. The ore occurs in highly brecciated and recrystallized dolomites. The Tertiary dolomites contaln higher amounts of clastic components (quartz, clay minerals and iron oxides). The Middle Triassic dolomites contaln the highest amounts of Pb, Zn, Ag, Cu and F which are not related to the clastic fraction.

20.3.2.1.1 Sulphur isotopes

Hand picked samples of galena; sphalerite and pyrite were analyzed for their sulphur isotopic composition. The results are summarized in Table 20-2 (the page 292).

Differences in isotopic composition of the samples suggest the original material was inhomogeneous. However, the trend $\delta^{34}S_{py} > \delta^{34}S_{sph} > \delta^{34}S_{ga}$ indicates that these minerals are close to isotopic balance. The narrow spread of the 834S values around zero suggests that only minor biologic activity occurred during formation of the sulphides (Jensen 1967). Marine sulphate bearing waters could have been the parental fluid from which sulphides precipitated. However, a volcanic-exhalative origin is also possible.

20.3.2.1.2 Genesis of the deposit

The model age t 6-7 and t 8-7 was calculated, using a method employed by the Czech Geological Survey. The results suggest that galena from the Serguza deposit is 140-160 Ma old ~ate Jurassic-Early Cretaceous). The results have a relatively large error range of ±40Ma.

The Serguza lead-zinc-pyrite deposit has indications of both a syn-genetic (including early diagenetic) sedimentary origin, and an epigenetic hydrothermal origin. The occurrence of primary ore minerals is stratigraphically controlled by the Middle Triassic dolomites but the ore did not necessarily form during the Triassic. The ore initially formed after deposition of the host carbonates (probably with anhydrite) and before folding. Iron, base metals, and most sulphur were probably derived from very low temperature metal-bearing chemically active solutions. Remobilization of these ores, during Late Tertiary deformation, led to the formation of second-generation galena, sphalerite and pyrite. These minerals were epigenetically re-precipitated in crush zones, fault planes and small cracks and fractures in the Triassic and Tertiary rocks. The mineral deposits may occur preferentially in recrystallization solution breccias in the Triassic carbonates which formed by dissolution of anhydrite.

The Serguza deposit with its simple mineralogy, Triassic dolomitic host rock, strata-bound features and geochemical characteristics is similar to other Alpine strata-bound Pb-Zn deposits of the Mediterranean belt described by Antonijevic (personal communication, 1980). This mineralization may be the result of volcanicity associated with the early rifting of the Southern Neo-Tethys (Chapter 3).

Table 20-1: Minor and trace elements of the Serguza deposit ore minerals. Contents are in ppm except for Fe, Pb, and Zn and As in pyrite which are all in %. Data on the ore body average composition are calculated from data published by Al-Qaraguli and Lange (1978). The analyzed dolomites are ore-bearing

Galena	Ag	Sb	Bi	Cu						
First generation	448	3000	85	310						
Second generation	620	1500	357	530						
Sphalerite	**Fe**	**Sb**	**Mn**	**Cu**	**Cd**	**Ge**	**Ga**			
First generation	1.0	1600	20	850	2250	135	6			
Second generation	0.1	950	280	430	2870	270	140			
Pyrite	**Co**	**Ni**	**Mn**	**Cu**	**As**					
First generation	6	78	16	110	1.32					
Second generation	5	51	19	260	0.16					
Dolomite	**Fe**	**Pb**	**Zn**	**Ni**	**Cu**	**Cd**	**Ag**	**As**	**Ga**	**Mn**
M Triassic	2.23	0.09	0.92	48	17	20	1	160	1	290
Younger veins	0.60	0.06	2.01	510	40	70	3	100	12	770
Ore body	**Fe**	**Pb**	**Zn**	**As**	**Cu**	**Sb**	**Cd**	**Ag**		
Sulphide	10.87	5.68	9.69	4467	384	153	443	62		
Oxidised	45.63	0.29	0.61	588	152	14	44	137		

Table 20-2: Sulphur isotopic composition of major sulphide minerals

Mineral	ã^{34}S (per mill)
Galena	- 1.8
Galena	- 2.6
Sphalerite	- 0.4
Sphalerite	0.0
Pyrite	+ 0.2
Pyrite	+ 3.6

20.3.3 Mineralisation in the Zagros Suture

Buday (1970) distinguished three tectonic units in NE Iraq thrust belt: the intermontane Tertiary foredeep or Intermediate Zone, the Cretaceous Qulqula Nappes, and the Tertiary Nappes. In this book the Qulqula Zone is referred to as the Qulqula-Khwakurk Zone; the Tertiary nappes are divided into the Penjween- Walash and the Shalair Zones. The Shalair Zone is an integral part of the Sanandaj-Sirjan Zone of Iran (see Chapter 6). The distribution of mineral deposits of the Zagros Suture is shown in Figs. 20-2, 20-3 and 20-4.

Three types of Iron mineralization are found in the Zagros Suture: 1) contact metasomatic or skarn deposits, 2) magmatic segregation deposits, and 3) hydrothermal veins and lenses of siderite. The major iron occurrences of contact metasomatic character are concentrated near Penjween (Fig. 20-4). The largest one is the Asnawa deposit, located about 3.5 km SSW of Penjween Town. Two

NE-SW trending zones containing magnetite were recognized. Magnetite occurs in small lenses in siliceous limestones and schists in the lower unit of the Penjween Group accompanied by minor pyrrhotite, pyrite, chalcopyrite and arsenopyrite. Teretenko and Khadikov (1961) classed the mineralization as contact metasomatic and considered that it originated along the contact of diorite intrusion in the carbonates of the Penjween Group.

The iron mineralization at Mishav, in the easternmost part of the Shalair Valley, consists of nine small magnetite-hematite bodies in limestones, andesite tuffs and porphyries of the Shalair and Katar Rash Group. The iron minerals occur in skarns containing garnet and actinolite. The mineralization appears to be related to small granodiorite intrusions that penetrate volcanosedimentary units. Similar mineralization in the Katar Rash Group was reported elsewhere in the Shalair Valley.

Skarn-type magnetite mineralization was also described by Bolton (1956) from the Marapasta area in the Qandil range of the Zagros Suture Zone, NE of Ranya. Buday and Vanecek (1971) described some siderite veins at this locality.

Iron mineral deposits of magmatic origin occur as magmatic segregations associated with chromite, or are related to serpentinization of ultramafic bodies. Magnetite-chromite bodies are restricted to two main districts: Penjween and Rowanduz. Numerous small vein-like and irregular magnetite bodies accompanied by chromite occur in ultramafic rocks (mostly serpentinized peridotite) in the Penjween intrusive massif. The most extensive mineralisation in the Penjween Massif occurs at three localities: Karigapla, Buban and Kani Manga. Similar iron mineral deposits are associated with chromites in the Mawat massif. The chromite-magnetite mineralization in the Rowanduz area is confined to small serpentinite bodies in two localities near Darband Rayat (Rowanduz Valley); they occur in three zones with 8 small bodies. Vasilijev and Pentelkov (in Vanecek 1972) related this mineralization to hydrothermal alteration of primary ferruginous conglomerates. Loletti (in Vanecek 1972) considered this deposit to be of contact metasomatic origin. The iron mineralization is accompanied by about 4% Cr203, and Ni, Cu and Co concentrations of 0.5-2%. Iron mineralization in serpentinite containing 2-3% Cr203 and about 0.5% Ni was reported adjacent to these ore deposits near the Babakrawa village. High Cr and Ni contents may indicate magmatic segregation of the Derband Rayat magnetite. Mafic and ultramafic rocks have been altered to serpentinite at Shetna Sheikhan NE of Rowanduz. The serpentinite intrudes limestones; six small chromite lenses accompanied by magnetite were reported by Polnikov and Nikolayev (1962). At Darband Rayat the ultramafic rocks are overthrust by Tertiary volcanosedimentary rocks of the Naopurdan Group.

Chromite occurrences were described by Vanecek (1972) in the Mawat Massif. They occur in serpentinized peridotite near Kurra Dawi village. Placer chromite was reported from Kani Sard NE of Sulalmaniya which were probably derived from the Mawat Massif.

Manganese ores are mostly restricted to the Qulqula Group and are exposed between Sulalmaniya and Penjween. Some manganese occurrences were also reported NE of Ranya (Vanecek 1972). The association of these manganese deposits with the radiolarian chert suggest a deep oceanic origin, possibly related to manganese nodule formation. Manganese minerals such as psilomelane, pyrolusite and manganite occur as coatings, crusts and nests. The only manganese deposit in Iraq, which is clearly related to volcanicity, is at Gola, NW of Penjween where psilomelan and pyrolusite occur in five zones at the contact of a basaltic intrusion with cherty slates of the Qulqula Group. These deposits are probably of exhalation origin (SmirnovNelidov 1962).

Small veins of Nickel mineralization were described by Vasiliev and Pentelkov (1962) at nine sites near the Bard-iZard village in the Darband Rayat area. They contaln niccolite, rarnmelsbergite, arsenopyrite, pyrite, carbonates and secondary annabergite and morenosite. Some nickel and cobalt contents were also reported in serpentinized peridotite in the Penjween Massif and are accompanied by arsenic in the Hero Valley in the Bulfat region.
Copper ores in the Zagros Suture occur in two forms: disseminated mineralization in ultramafic and mafic magmatic rocks and as hydrothermal mineralization in quartz veins. Copper occurrences are widespread but most are not of economic interest; they are related to serpentinised ultramafic rocks and gabbros of the Penjween, Mawat and Bulfat massifs and to metavolcanites. Copper mineralization is represented by coatings of malachite and azurite, or disseminated grains of chalcopyrite accompanied by pyrite. The copper ores at Bir Achminda-Benosa in the Bulfat Massif are associated with phyllites of the Walash Group intercalated with crystalline limestone and greenstone (meta-andesite). The mineralization consists of malachite, chalcocite, chrysocolla, limonite (replacing pyrite) and quartz. More than ten copper occurrences containing malachite and Cu-bearing pyrite were reported near lira village east of Qalat Dizeh town where they are related to phyllites and epidote-bearing schists of the Bulfat Group cut by granite dikes (Vanecek 1972). Copper ores of probable hydrothermal origin were investigated by Roulkovsky (1962) near Spidareh village in the Pushtahashan Valley of the Qandil Range. They comprise local veins and impregnations in tuffaceous phyllites, norites and quartz-albitophyres. They contaln quartz, chalcopyrite, pyrite, sphalerite and malachite. Some copper and nickel mineralization was reported in serpentinite bodies outcropping for a distance of about 8 km near Galala (Darband Rayat), E of Rowanduz.

Copper deposits in the Waraz area of the Mawat Massif were studied by GEOSURV in the early 1970's. Electromagnetic surveys were conducted. In 1990, detailed mapping in the area was carried out. A 300 m deep exploration borehole was drilled. Copper is associated with metabasalts (> 600 m thick) of the Mawat Group, as lenses of malachite between volcanic flows or as disseminated chalcopyrite within the volcanics. The borehole data showed that chalcopyrite is disseminated throughout the metabasalts but is sometimes concentrated in basalt flows (Saad Z. Jassim, personal communication).

Vanecek (1972) reported several lead and zinc occurrences in the Zagros Suture; the most important is the Marapasta deposit. Weak base metal mineralization, in a steeply dipping NE-SW striking quartz-marcasite zone extending for about 5 km near Sirnah, was described by Bolton (1956).
A few grains of placer gold were described by Smirnov and Nelidov (1962) in the Shalair Valley (N of Deza village) which were thought to be derived from small intrusive bodies of granite, granodiorite and quartz porphyry exposed at several sites in the valley. However, the location of the placers suggests they were derived from the volcanics of the Katar Rash Group exposed on the northern flank of the Shalair anticline. Gold is known to be associated with arc volcanics (dacites) in the Andes (Vanecek, 1994, p. 279).

Fig. 20-3: Distribution of metallic mineral deposits and occurrences in the N part of the Zagros Suture (after Vanecek, 1972)

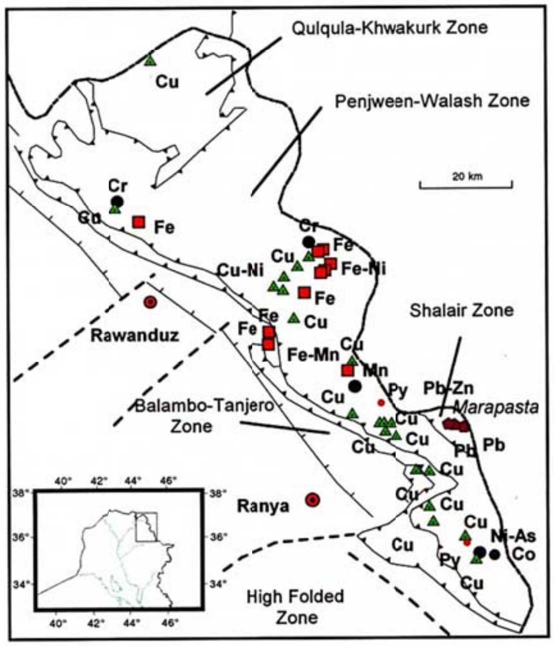
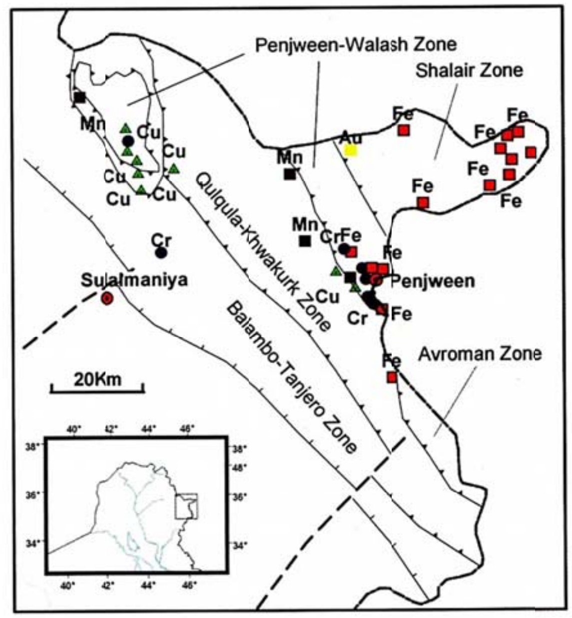


Fig. 20-4: Distribution of metallic mineral deposits and occurrences in the S part of the Zagros Suture (after Vanecek, 1972)



20.3.3.1 The Marapasta base metal deposit and its origin

The Marapasta locality is one of the most important base metal deposits in Iraq. The Marapasta area was studied by Bolton (1956), Polnikov and Nikolayev (1961), Akif and Vanecek (1972),Vanecek (1972), Akif et al.(1973), Sattran et al.(1973) and Hak et al. (1983). Exploration geochemistry and geophysics studies were conducted by (Al-Bassam 1977) and (Nahab and Rahman 1974) respectively. Al Bassam and Akif (1977) studied the ore petrology of the deposit. Hak et al. (1983) provides information on ore petrology, the chemistry of major and minor minerals, and isotope studies and discusses the origin of the deposit.

The Marapasta area is situated about 1.5 km from the Iranian border, about 6 km behind the thrust front at an altitude of 2000-2400 m ASL. The rocks were subdivided by Buday and Vanecek (1971) into two series: the Qandil Series and the Marapasta Series (correlated with the Shalair Group); the Marapasta Series has been thrust over the Qandi1 Series. The layering in the Marapasta Series rocks dips at about 30°-40° to the NNE. The host rocks are phyllites, locally tuffaceous, and massive deformed lenticular recrystallized limestones that are fractured and brecciated. These rocks are part of a thrust sheet which has been transported for a considerable distance. The underlying Qandil Series comprises alternating beds of grey and white sheared limestones.

There are two main systems of faults recognized in Marapasta. Reverse faults strike NE-SW and normal faults strike NW-SE. Some thrust faults have been reactivated during movement on younger NW-SE trending thrust faults, creating a complex fault pattern. Ore occurs in three localities: Seh Kutchika which is the highest peak in the area (2410 m ASL.), Darman about 800 m NW of Seh Kutchika

. (2200 m ASL) at the edge of a steep gully, and Narta about 1 km E of Seh Kutchika (2100 m ASL). The ore bodies are folded, fractured, faulted and locally recrystallized, and covered by gossans particularly at Seh Kutchika. The country rocks are similarly deformed. Trenches dug to

evaluate the deposits failed to establish any structural relationship between them. Bolton (1956) suggested that the main ore body was situated at Seh Kutchika and that the lower occurrences are due to landslides.

Mafic and ultramafic intrusive rocks outcrop near Qandil, a few kilometres NW, Wand SW of Marapasta. According to Akif et al. (1973), sills occur locally in the "Marapasta Series"; blocks of sills have been found in the scree. The sills are 2-30 m thick and at least 100-200 m wide. They comprise diabase, olivine basalt and diorite porphyry.

The mineralisation consists of two different assemblages. One assemblage consists of galena, sphalerite, pyrrhotite, pyrite, marcasite and rare arsenopyrite. Another "skarntype" assemblage consists of magnetite, willemite, gahnite, and rare garnet and nickeline. Secondary minerals smithsonite, limonite and cerussite frequently occur.' The mineral assemblages have different textures. The first assemblage is characterised by orientated linear textures in massive and banded sulphides and occurs at Darman and at Narta. The skarn assemblage occurs at Seh Kutchika. The skarn assemblage appears to be either younger than the strata-bound deposit or contemporaneous, but of different chemical composition. The strata-bound assemblage is characterized by sphalerite with a consistent iron content of about 9% Fe. Sphalerite of the skarn assemblage has low iron content «0.5%) (Table 20-2), and is sometimes compositionally zoned with cores richer in Fe than the rims. Both sphalerite occurrences have Mn, Cd and Cu contents.

Magnetite is characterized by a relatively high content of Ti and N; the concentrations of Cr, Co, Mn and Zn are below the detection limits of the electron probe. The intimate intergrowths of most minerals made the examination of minor and trace elements in individual minerals difficult using emission spectrometry. Ag, As, Ba, Ca, Co, Cr, Cd, Cu, Ga, Ge, **In,** K, Mn, Na, Ni, Sn, Ti, V, Y, Yb and Zr consistently occur in the major minerals: magnetite, pyrrhotite, pyrite, galena and sphalerite in minor or trace amounts. Contents of AL, Mg and Si are high in mixtures of rock and gangue minerals. B, Be, Mo, Sb, Sc, Sr and Te are present in very low concentrations. Bi was found in one galena sample.

The lead model age of the deposit was determined to be 180-200 Ma ± 30 Ma (Table 20-4).

Table 20-3: Electron probe analyses of sphalerite in weight%. 1) Sphalerite with poikiloblastic magnetite and minor nickeline enclosed by galena. 2) Sphalerite adjacent to partially oxidized galena. 3) Sphalerite partially altered to willemite. 4) Unaltered sphalerite enclosed by galena. 5) Sphalerite adjacent to galena in pyrrhotite (partially altered to pyrite and marcasite). 6) Sphalerite pod with inclusions of carbonate with pyrite, marcasite and arsenopyrite. 7) Sphalerite enclosed by pyrite. 8) Sphalerite with rare pyrrhotite blebs in contact with pyrrhotite and pyrite. 9) Sphalerite near arsenopyrite in pyrrhotite. 10) Sphalerite with galena, marcasite, arsenopyrite. 11) Clear sphalerite adjacent to galena pyrite and sphalerite with abundant pyrrhotite inclusions. 12) Sphalerite with pyrrhotite, galena, pyrite and arsenopyrite

	1	2	3	4	5	6	7	8	9	10	11	12
Locality	Seh Kutchika	Seh Kutchika	Seh Kutchika	Seh Kutchika	Darman	Darman	Darman	Darman	Darman	Darman	Darman	Darman
No of analyses	5	2	2	1	5	3	1	3	3	3	2	2
Zn	66.14	67.93	66.40	64.82	57.69	58.28	57.37	57.29	56.95	57.78	57.20	56.57
Fe	0.45	0.08	0.10	0.40	8.16	8.42	9.66	9.60	9.89	9.69	9.36	9.68
S	33.03	33.61	33.20	32.37	33.72	33.25	33.83	33.76	33.39	33.79	33.96	33.79
Total	99.62	101.62	99.70	97.60	99.58	99.94	100.87	100.94	100.23	101.26	100.52	100.04

Table 20-4: Lead model age of galena from Marapasta. The model age t_{6-7} and t_{8-7} has been calculated using a method employed at the Czech Geological Survey, Prague and carried out by Dr J. Legierski

Locality	Pb^{204}	Pb^{206} Pb^{206}/Pb^{204}	Pb^{207} Pb^{207}/Pb^{204}	Pb^{208} Pb^{208}/Pb^{204}	t_{6-7} Ma t_{8-7} Ma
Seh Kutchika	1.351	25.02 18.52	20.35 15.80	52.28 38.70	180 180
Seh Kutchika	1.341	25.01 15.89	20.01 15.89	52.28 38.90	180 190
Darman	1.346	24.98 18.56	20.38 15.88	52.29 38.85	190 200
Ore body Z	1.348	25.01 18.55	20.36 15.84	52.28 38.78	180 190

20.3.3.2 Comments on the ore genesis

Early studies suggested the mineralization had a hydrothermal metasomatic origin in which a "skarn-type" mineral assemblage rich in zinc and iron preceded the lead sulphide formation (Akif et al., 1973). Later observations based mostly on microscopy and chemistry suggest a different origin for the Marapasta deposit. The finer-grained massive or banded sulphide material has a metamorphic texture. The ore bodies at the Darman locality occur in phyllitic slates and marbles; associated mafic volcanic rocks suggest that the ores initially formed in a volcanogenic sedimentary environment. The ores and country rocks were probably later affected by low-grade metamorphism. The consistent sphalerite composition and textures (e.g., porphyroblastic pyrite and evident foliation) support this model.

The older strata-bound Pb-Zn deposit may have been fractured allowing flow of solutions rich in silica and oxygen, which resulted in formation of silicates and oxides of zinc and iron, where faults intersected ore-bearing strata. During this water-rock interaction zinc and iron would have been mobilised from the original strata-bound deposit to form secondary minerals, later metamorphosed to willemite, zincite, magnetite, gahnite, garnet and chlorite. Removal of sulphur led to the formation of pyrite-marcasite that frequently replaced pyrrhotite in banded ores (bird's eye texture). Younger pyrite veinlets cutting the banded ores and even pyrite porphyroblasts in adjacent rocks may have formed during this process. However pyrite may have been an original

constituent of the sedimentary rocks and recrystallized during metamorphism. Original sphalerite and galena may have been remobilized by hydrothermal solutions prior to the formation of the magnetite ore. Wall rock alteration (indicated by oxide mineral assemblages) suggests this process may have occurred.

Further work on the origin of the deposit is required. The existence of strata-bound metamorphosed ores however has been confirmed. Laterally extensive banded Pb-Zn ores may thus occur in the area. In Turkey several deposits in the ophiolitic zone of the Tauride are believed to be of volcanogenic-sedimentary origin (Akif et al.l973 and Bernard 1971). Large lead-zinc deposits in Iran (the largest is at Anguran) are thought to have been formed by metasomatism in carbonate rocks and may also be of volcanogenic-sedimentary origin.

20.4 Non-metallic mineral and industrial rocks

20.4.1 Non-metallic minerogenic stratigraphy

Outcropping non-metallic mineral and industrial rocks range in age from Permian to Recent. The stratigraphic distribution of non-metallic mineral deposits is shown in Table 20-5. On the Stable Shelf the Palaeozoic strata contaln quartz-sand and kaolinitic clay of the Ga'ara Formation (Permocarboniferous). The Mesozoic rocks of the Stable Shelf (surrounding Rutba Uplift) comprise dolomites (Upper Triassic), lateritic ironstone (Lower Jurassic), heavy mineral bearing sandstones (Middle Jurassic), karst bauxite and quartz-sand (Lower Cretaceous) and phosphorites with montmorillonite- palygorskite- porcelanite associations (Upper Cretaceous and Palaeogene). Mesozoic carbonates also occur in the Unstable Shelf area in cores of anticlines in the High Folded and Foothills zones.

Barite occurrences are recorded in the Triassic and Jurassic units of the Northern Thrust Zone. Marbles formed during regional metamorphism of carbonate units of the Qandil Series. Hydrothermal activity in the Northern Thrust Zone was associated with barite mineralization in the Cretaceous carbonates of Shiranish and Aqra and Bekhme formations.

The Tertiary sediments on the Stable Shelf and parts of the Unstable Shelf contaln phosphorite, claystone (montmorillonite-palygorskite) and porcelanite. Palaeogene limestones and dolomites occur on the Unstable Shelf. Igneous activity along the active margin of the Arabian Plate locally led to the formation of marble in the Walash Group.

The Neogene sequences contaln extensive Lower Miocene carbonates in the Unstable Shelf (Euphrates Formation). The Middle Miocene units contaln evaporite deposits; gypsum and rock salt deposits are common in the Jezira and Foothills zones. Bio-epigenetic stratiform native sulphur deposits formed during the Pleistocene. Pliocene fresh water limestones contaln smectite-palygorskite claystones (Zahra Formation). The Quaternary sediments are dominated by fluvio-lacustrine and aeolian clastic deposits, inland sabkha and salt deposits.

Table 20-5: Minerogenic stratigraphy of the non-metallic minerals and industrial rocks in Iraq (Al-Bassam, 1986)

Age	Western and Southern Deserts	Mesopotamian Zone	Jezira and Folded Zone	N and NE Thrust Zones
Permian	kaolinite, quartz-sand, dolomite sedimentary Fe heavy minerals			
Triassic	Dolomite			barite, limestone
Jurassic	lateritic Fe, sand, kaolinite dolomite, heavy minerals			barite
Cretaceous	karst bauxite, quartz-sand, phosphorite, montmorillonite palygorskite, porcelanite		limestone	marble, barite igneous rocks
Palaeocene	phosphorites, porcelanite montmorillonite			marble, igneous rocks
Eocene	limestone, phosphorite, dolomite		dolomite, limestone	marble, igneous rocks
Oligocene			limestone, dolomite	
Miocene	clay, sand, limestone, dolomite		native Sulphur, gypsum dolomite, rock-salt, limestone	
Pliocene	Sand	Sand and gravel	Bentonite, palygorskite veins, gravel and sand	
Pleistocene	sand and gravel	Sand and Clay	gravel and sand, clay glauberite, halite	

20.4.2 Deposits

20.4.2.1 Kaolinitic claystone

Kaolinitic claystone deposits occur in Pre-Cretaceous units in the Western Desert. The upper part of the Ga'ara Formation (Permocarboniferous) in the Ga'ara area contalns white and multi-coloured kaolinitic claystones. They also occur in the lower part of the Hussainiyat Formation (Lower Jurassic) along Wadi Hussainiyat and in the Amij Formation (Middle Jurassic) at Wadi Amij (Mahdi and Al-Delaimi, 1999). The Jurassic kaolinitic deposits are highly ferruginous and of low grade (Table 20-6). Flint-clays occur as karst-fill deposits of Early Cretaceous age associated with bauxite and bauxitic clay in very restricted localities in the Western Desert (Al-Rubali, 1997). All kaolinitic clay's of Iraq were transported as kaoline from source areas in the S, SW and Wand were deposited in a fluvial system.

Table 20-6: Chemical composition of montmorillonite and palygorskite claystones (Al-Bassam et al., 1989; Al-Bassam and Al-Sa'adi; 1985; Zainal, 1977; Aswad et al., 2000; Al-Sayegh et al., 1976)

Wt. %	Ga'ara Fn.		Hussainiyat Fn.		Amij Fn.	Karst-fill
	white	coloured	NE	SW		Flint clay
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
LOI	12.7	10.3	9.6	12.3	11.0	13–15

20.4.2.2 Montmorillonite and Palygorskite

Extensive montmorillonite-rich marine sedimentary claystones occur in the Upper Cretaceous Digma Formation and to a lesser extent in the Palaeocene Akashat Formation in association with phosphorite (Al-Bassam and Al-Sa'adi, 1985). These claystones were originally black shales, rich in carbonaceous matter (Al-Bassam and Al-Haba, 1990). Palygorskite is associated with montmorillonite in these deposits and is the dominant clay mineral in shallow, near- shore areas of the basin (AL-Bassam, 2000). The montmorillonite-palygorskite claystones in these units are 1-10 m thick. They are calcareous and slightly phosphatic (Table 20-7).

Palygorskite veins were discovered in the Mukdadiya (Lower Bakhtiari) Formation in N Iraq at Jabal Maqlub and Ba'ashiqa. They are vertically or steeply dipping and 1 to 50 cm thick. The veins probably formed by direct precipitation from solution, either by pedogenic or hydrothermal processes (AL-Sayegh et al., 1976). Montmorillonite and palygorskite are the dominant clay minerals in Iraq from the Upper Cretaceous and Tertiary formations. Kaolinite is more dominants in older rocks; this may be due to climatic factors (AL-Bassam, 1996).

Table 20-7: Chemical composition of montmorillonite and palygorskite claystones (Al-Bassam et al., 1989; Al-Bassam and Al-Sa'adi; 1985; Zainal, 1977; Aswad et al., 2000; Al-Sayegh et al., 1976)

	Montmorillonite		**Bentonite**	**Palygorskite**	
Wt%	**Digma**	**Akashat**	**Mukdadiya**	**Digma**	**Mukdadiya**
SiO_2	62.7	56.8	51.0	57.9	60.2
Al_2O_3	13.3	15.7	20.2	12.6	11.2
Fe_2O_3	5.4	5.1	2.4	6.2	0.8
CaO	3.4	4.5	7.7	1.8	0.3
MgO	4.5	3.4	5.0	8.6	10.2
Na_2O	0.5	1.1	0.7	1.4	0.2
K_2O	0.5	0.6	0.4	0.6	0.2
LOI	8.3	9.5	11.3	10.5	16.1

20.4.2.3 Bentonite

Small deposits and occurrences of bentonite "sensostricto" occur in the Mukdadiya Formation (Pliocene) in Jabal Hemrin South, 120 km NE of Baghdad and along the Baghdad-Kirkuk highway. These deposits formed by alteration of a volcanic ash horizon deposited in a fluvial basin. They are associated with tuffs and fluvial clastics. Glass shards indicate these deposits are of volcanic origin (Zainal, 1977).

Montmorillonite clays also occur in playas and topographic depressions in Mesopotamia, in desert depressions, and in synclinal areas in the Foothills and High-Folded zones. They are associated with fluvial deposits, with other clay minerals: chlorite, palygorskite, illite and kaolinite, and with carbonates and quartz (Alsinawi et al., 1977, Al-Hilali 1980 and Shanshal, 2004». These deposits are an important raw material for the cement and brick industry. Typical chemical analyses are shown in Table 20-8.

Table 20-8: Chemical composition of Quaternary clays (Shanshal, 2004)

Wt. %	Range	Mean
SiO_2	30.8-53.4	38.7
Fe_2O_3	2.3-4.3	3.4
Al_2O_3	6.6-8.7	7.6
CaO	15.3-20.3	18.3
MgO	2.4-5.9	4.2
SO_3	0.3-7.2	2.1
LOI	14.9-25.3	20.6

20.4.2.4 Phosphorite

The phosphorite deposits of Iraq are part of the Tethyan phosphogenic province extending from Senegal and Mauritania in the W to Iraq, Iran and Turkey in the E. They 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.

Thin beds of phosphorite occur in the Digma Formation (Maastrichtian). Thick beds occur in the Akashat Formation (Palaeocene) and in the Ratga Formation (Eocene). The phosphorite beds are 0.5-12 m thick. The Digma and Akashat Formation phosphorites have an intraclasticbioclastic and a pelloidal-ooidal texture respectively.

Coprolites and phosphorites with intraclastic textures occur in the Eocene deposits. The cementing material is usually calcite; some siliceous cemented phosphorites occur. Francolite is the only phosphate mineral in the Iraqi deposits (AL-Bassam, 1976 and 1992). The chemical composition of some of the known phosphorite deposits is shown in Table 20-9.

The Iraqi phosphorites, (like all Tethyan phosphorites) were deposited under special palaeogeographic conditions by upwelling of deep oceanic phosphate rich waters onto shallow shelves (Sheldon, 1981). Francolite was deposited at and below the sediment-water interface via a biogenic phase (AL-Bassam, 1976). A recent study has shown clear evidence of microbial activity in the formation of the Iraqi phosphorites (AL-Bassam et al., 2000a).

Table 20-9: Chemical analysis of some Iraqi phosphorites (Al-Bassam, Al-Dahan and Jamil, 1983; Al-Bassam, 1976; Al-Bassam and Hagopian, 1983)

Wt.%	Digma Fn. Maastrichtia	Akashat Fn. Palaeocene	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
LOI	11.4	16.7	20.5

20.4.2.5 Porcelanites

These are siliceous rocks, composed of opal-CT (cristobalite-tridymite crystal stratification) derived from biogenic amorphous opal silica (mainly from diatoms). They are part of the phosphorite-bearing sequences of the Maastrichtian and Palaeocene in the Western Desert (Digma and Akashat formations respectively). Several porcelanite horizons were identified as 0.5-1.0 m thick layers associated with shale, phosphorite and chert (AL-Bassam and Al Sa'adi, 1985; AL-Bassam et al., 2000b). Their chemical composition is shown in Table 20-10.

Table 20-10: Chemical composition of some Iraqi porcelanite (Al-Bassam and Al-Sa'adi, 1985; Al-Bassam et al., 2000b)

Wt%	Maastrichtian (3 horizons)	Palaeocene
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	–
LOI	5.4-17.4	8.5

20.4.2.6 Native Sulphur

Native Sulphur deposits and occurrences in Iraq are stratigraphically controlled in the Middle Miocene rocks of the Fatha Formation. The Fatha Formation consists of two members; the lowermost member contalns Sulphur deposits in the crests of some anticlines. The Sulphur-bearing horizons comprise secondary calcite, sulphur and some aragonite. Their original lithology comprised gypsum and anhydrite (Al-Sawaf, 1977). Sulphur originated via bioepigenetic alteration of primary gypsum induced by reduction and oxidation processes under favourable structural and hydrogeological conditions in close association with hydrocarbons (Jassim et al., 1997). Gypsum beds were reduced by e bacteria *(Desulfovibrio desulphuricans)* in hydrocarbon-rich brines flowing from the underlying confined Euphrates Formation to form H_2S during periods of low infiltration of meteoric water. The H_2S gas was then oxidised by reaction with water which flowed into the formation during periods of higher meteoric water infiltration leading to the deposition of economic Sulphur deposits (Jassim et al., 1997).

The Sulphur-bearing horizons are up to 108 m thick, with a sulphur content of 10-30% (average 23%); the Sulphur is present as coarsely-crystalline native Sulphur, filling pores, nests and caverns or as bands alternating with layers of secondary calcite and hydrocarbons.

Most of the native Sulphur deposits and occurrences of Iraq occur in a zone extending from Mosul to Fatha (Fig. 20-1). The Sulphur formation in these deposits may have occurred during the Pleistocene (Jassim et al., 1997). The Iraqi deposits are the largest known occurrence of stratiform bioepigenetic native Sulphur in the world (Barker et al., 1979).

20.4.2.7 Gypsum

Almost all the economic gypsum deposits of Iraq occur in the Middle Miocene Fatha Formation (Lower Fars). They are thick bedded and formed by evaporation in closed or semi-closed marine basins in association with carbonates and claystones. The main deposits are found in the Foothill Zone where more than ten gypsum horizons are recorded in the Fatha Formation. A typical chemical analysis (Mansour and Toma, 1977) is: S03 43--46%, CaO 32-33%, Fe203+ Al_20_3 <0.1%, H_20 19-21 % and Insoluble Residues 1-2 %

20.4.2.8 Halite

Thick rock-salt deposits are recorded in subsurface sections within the Middle Miocene Fatha Formation and the Lower Miocene Dhiban Formation. They were deposited in the central parts of large evaporitic basins in association with gypsum. Thick rock-salt deposits are encountered in three main areas in Iraq: South of Sinjar, S of Kirkuk and between Amara and Kut. The total thickness of the salt beds in these basins ranges from 80 to 165 m; they mostly occur in the lower and middle parts of the Fatha Formation (Dimitrov et al., 1983 and Mustafa et al., 1984). The Lower Miocene Dhiban Formation also contalns thick salt layers near Sinjar.

Several salterns of Quaternary age contaln >95% halite which is being seasonally deposited from groundwater brines. The source of the brines is believed to be deep-seated aquifers in contact with rock salt deposits. Many of these salterns with halite occur in the Jezira area but the largest salt playa is located near Samawa in S Iraq (AL-Baldari, 1988 and Al-Badri et al., 1990).

20.4.2.9 Thenardite and Glauberite

These salt deposits are found in the Shari Lake saltern located 30 km E of Samarra Town. Thenardite (Na2S04) constitutes up to 13% of the 10 cm thick halite salt crusts. Glauberite [Na2Ca (S04hJ occurs in concentrations of up to 50% in the underlying 6.5 m thick clayey sediment (Jassim, 1979). The lateral sequence of salts from the edge to the centre of the saltern is: gypsum-gypsum and glauberiteglauberite-glauberite and thenardite-halite.

Glauberite may have formed due to an increase in the Na" concentration of the brine after precipitation of gypsum, by alteration of gypsum in contact with the brine into glauberite. Alternatively glauberite may have precipitated directly from a brine rich in Nat, $Ca+^{2}$ and $S04-^{2}$ (Jassim et al., 1999). Some species of salt-tolerant bacteria may have caused the oxidation of H2S produced from the disintegration of plant remains to form $S04-^{2}$ thus enhancing the formation of sulphate minerals (Jassim et al., 1998).

20.4.2.10 Barite

Almost all barite occurrences in Iraq are located in the Northern Thrust Zone within the Upper Permian Chia Zairi and the Upper Cretaceous Shiranish formations. They are usually associated with Zn-Pb-pyrite occurrences as veins up to I m thick. Most of these occurrences are believed to be of low-temperature hydrothermal origin and stratigraphically controlled. Samples from Berzanik and Lefan occurrences were reported to contaln 77% and 83% BaS04 respectively (Mironov and Sitchenkov, 1962 and Stevens, 1953).

20.4.2.11 Celestite

Small occurrences of celestite were recorded in the fluvial Injana and Dibdibba formations in the Najaf-Karbala area (AL-Bassam, 1995 and AL-Baldari, 1997). The celestite deposits are lenticular cemented horizons (0.5-1.0 m thick) in mudstones and sandstones. The celestite is present as euhedral crystals with inclusions of calcite and aragonite. Up to 43% celestite was recorded in some samples, associated mainly with quartz, calcite, aragonite and palygorskite (ALBassam, 1995). The celestine is believed to be epigenetic, precipitated from Sr-rich ground waters seeping through springs along the Euphrates Boundary Fault Zone. It formed by direct crystallization and also by replacement of aragonite and calcite (Dawood, 2000).

20.4.2.12 Ironstone

The Hussainiyat sedimentary ironstone deposit of the Liassic Hussainiyat Formation is the main iron deposit in Iraq. It is located in the Western Desert, in the SE parts of Wadi Hussainiyat. The ironstone is about 3 m thick, pisolitic, oolitic, intraclastic and concretionary in texture, and is associated with kaolinitic mudstones and orthoquartzite. The deposit consists of goethite, hematite, kaolinite and quartz. The average chemical and mineral composition of the Hussainiyat ironstone deposit is shown in Table 20-11.

The ironstone and the associated clastics unconformably overlie a weathered and karstified surface at the top of the Liassic Ubaid Formation. Iron and the associated clastics were transported by rivers from deeply weathered source rocks in the Rutba Uplift in the SW. Iron were mostly attached to the clay fraction and organic matter. After deposition, iron concretions were mostly

formed by bacterial build-up in swamps and marshes. They 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 ferric rete by ephemeral streams and rivers and were redeposited as channel lag deposits with sand and other clastics (Jassim, 1982; 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 ironstone. It consists of almost equal proportions of hematite-goethite and quartz. The iron minerals are epigenetic and form the cementing material in the sandstone. The ore bodies are discontinuous, and occur as lenses 200-300 m long and 1-2 m thick (Petranek and Jassim, 1980 and Tobia, 1983).

Table 20-11: Chemical and mineralogical composition of the Iraqi ironstones (Al-Bassam and Tamar-Agha, 1998; Tobia, 1983)

Oxides/minerals %	**Hussainiyat Fn.**	**Ga'ara Fn.**
SiO_2	32.0	50.5
Fe_2O_3	38.4	39.0
Al_2O_3	16.3	1.9
H_2O	9.4	5.1
Geothite-hematite	42	42
kaolinite	41	5
quartz	13	50
others	2	3

20.4.2.13 Karst Bauxite

Bauxite and· bauxitic kaolinite were discovered infilling deep karsts up to 70 m deep in the carbonates of the Liassic Ubaid Formation in the Western Desert. The karst-fill deposits consist of several fining upward cycles of quartz sandstone and kaolinitic claystone with (or without) bauxite and bauxitic flint-clay lenses in the middle (AL-Rubali, 1997).

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, 1998). The bauxite minerals are colloformic in texture including pisoids, ooids and pelloids. All grades of bauxitization are found in these deposits.

However, high quality bauxites are absent. The chemical composition is reported in Table 20-12. The age of the karst fill deposits is controversial. The authors believe they formed in the Aptian and that bauxitization occurred at the Aptian-Albian boundary at the same time as the bauxite profile at Zabira in Saudi Arabia (Al-Bassam, 1998).

Table 20-12: Chemical composition of the karst bauxite (Al-Rubaii, 1997)

Oxides	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

20.4.2.14 Quartz sand

Massive deposits of quartz-sands are encountered in the Nahr Umr (Albian) and Rutba (Cenomanian) formations in the Western Desert. These deposits are >20 m thick and extend in an E- W direction for more than 100 km along the Baghdad-Amman highway. In addition, some Lower Permian sand layers below the Ga'ara depression floor consist almost entirely of quartz. These deposits were derived from granitic source rocks in the Arabian Shield or have been recycled from Palaeozoic sedimentary rocks in the Wand Sw.

The sand consists of 95-99% quartz and generally <1 % Fe203' Occasional thin clay lenses and sandstone lenses cemented with secondary calcite occur. The quartz grains are generally 0.1-0.5 mm in size and sub-rounded to subangular. The Ga'ara Formation quartz-sands are generally fine grained; some coarse grained sands occur in the upper parts of the formation (Shaposhikov and Babushkin, 1961, Shaker, 1983 and Tamar-Agha et al., 1992).

20.4.2.15 Heavy mineral bearing sandstone

Heavy minerals occur in considerable concentrations in the sandstones of the Lower Permian Ga'ara Formation (Table 20-13) and the Liassic Amij Formation (Table 20-14) in the Western Desert. Zircon and rutile are the main heavy minerals in the Ga'ara Formation. Zircon, rutile and monazite are the main minerals in the Amij Formation.

opaques (mean 65.8%), 9-41% zircon (mean 20.8%) and 1-11% rutile (mean 5.1%). The Ga'ara zircons are Hf-rich with high concentrations of Y and rare earths, whereas the rutile is Nb-rich with high concentrations of Cr and V (Table 20-12). The Ga'ara sandstone deposits were probably deposited in meandering river channels (TamarAgha et al., 1984).

Table 20-13: Chemical analysis of zircon and rutile in the Ga'ara sandstones (Ismail, 1989)

Oxides%	Zircon	Oxides%	Rutile
SiO_2	32.23	SiO_2	0.21
ZrO_2	40.84	TiO_2	97.84
HfO_2	20.85	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 20-14: Chemical analysis of Zircon, Rutile and Monazite from Amij Formation, W Iraq (after 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
$Y2O_3$	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	Nd_2O_3	13.64
Al_2O_3	0.18	Cr_2O_3	0.33	Sm_2O_3	1.25
				Gd_2O_3	1.66
				P_2O_5	29.63

20.4.2.16 Feldspathic sands

The sands and sandstones of the Dibdibba Formation (Pliocene) in the Najaf area contaln appreciable concentrations of feldspar (mainly potash feldspar). The sand gralns comprise 15% feldspar, 70% quartz and 15% rock fragments of igneous and sedimentary origin (Sadik, 1977). The feldspar is concentrated in the coarse fraction as angular to rounded grans, generally more than 0.5 mm (and up to 10 mm) in size. The sands were derived from the mechanical

disintegration of granites in the Arabian Shield and were transported by rivers into Iraq where they formed fan deposits (Ghalib, 1988). Their chemical composition is shown in Table 20-15.

Table 20-15: Chemical analysis of the feldspar-bearing sands in the Najaf area (Al-Bassam et al., 1999)

Oxide%	Raw sand	Sieved (+710 μm)
SiO_2	88.7	86.2
Al_2O_3	3.7	1.1
MgO	0.5	0.2
CaO	0.9	0.4
Na_2O	0.7	1.3
K_2O	1.5	2.8
LOI	2.1	0.4

20.4.2.17 Limestone

Huge deposits of high quality limestone deposits are found in Iraq. The main limestone-bearing units are the Triassic and Cretaceous units in the Thrust Zone, the Miocene units (Serikagni, Euphrates and Fatha formations) in the Foothills and Folded Zone and the Eocene, Miocene (Dammam, Ratga and Fatha formations) in the western and southern deserts. Most of the economic limestone deposits are in the Dammam, Ratga, Euphrates and Fatha formations (Table 20-16) (Mansour and Petranek, 1980).

Table 20-16: Chemical composition of some limestone deposits (Mansour and Petranek, 1980; Sa'eed, 1988)

Oxide %	Dammam Fn.	Ratga Fn.	Euphrates Fn.	Fatha Fn.
CaO	54.20	54.20	53.50	47.60
MgO	0.19	0.24	0.65	1.6
SiO_2	1.65	1.79	1.20	9.80
Al_2O_3	0.12	0.27	0.60	1.37
Fe_2O_3	0.08	0.13	0.15	1.65
SO_3	0.38	0.38	0.18	0.63

20.4.2.18 Dolomite

The main dolomite deposits in Iraq are found in the Folded Zone, and in the Western and Southern deserts. In the Folded Zone the Upper Eocene Pila Spi Formation is the main dolomite-bearing unit. In the Western Desert, the following formations contaln thick beds of dolomite: Upper Triassic Mulussa and Zor Hauran, the Liassic Ubaid and Hussainiyat, the Upper Cretaceous M'sad and Hartha, the Palaeogene Umm Er Radhuma and Dammam, and the Lower Miocene Euphrates. High quality dolomites, suitable for industrial purposes, are available in many of these formations (Table 20-17).

Table 20-17: Chemical composition of some dolomite deposits (Al-Bassam, 1984)

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

20.4.2.19 Marble

Marble is found in the Penjween-Walash Zone (Qandil Series) at Gimo, Kani Kuwish and Rawkan, and in the Walash Group (Palaeogene) at Galala, Kewarta, Darband and Rayat. The marbles formed by regional and local metamorphic processes. Some unmetamorphosed carbonate rock units are suitable for use as decorative stones (orthomarble) especially the Pila Spi Formation (Eocene) at Salahuldin, Derband Bazyan and Derbendikhan areas (Mansour et al., 1979).

20.4.2.20 Industrial igneous rocks

Granites in the Katar Rash Volcanic Series and gabbro in the Mawat and Bulfat igneous complexes may have some economic value as decorative stone. Basalt flows within the Shalair and Katar Rash Series, may be useful for rock-wool production. Nepheline syenite dykes in the intrusive complex of Bulfat may be useful in the ceramic industry.