CHAPTER (I)

INTRODUCTION

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The Western Desert of Egypt covers an area of about 700,000 km^2 and comprises almost two thirds of the whole area of Egypt. It extends 1000 kilometers from the Mediterranean shoreline in the north to the Sudanese border in the south and from 600 to 800 kilometers from the Nile Valley in the east to the Libyan border in the west. However, the exploration efforts were mainly concentrated in the northern part (north of latitude 28°) with minor efforts in the offshore areas. The Egyptian commercial accumulation of hydrocarbons (oil and gas) are divided territorially into three main petroleum provinces; the Gulf of Suez, the northern Western Desert and the Nile Delta. Recently, the most potential exciting news of oil and gas discoveries in Egypt is coming from the northern Western Desert and the Nile Delta petroleum provinces.

In the northern Western Desert petroleum exploration and exploitation started in the year 1966 by discovery of Alamein oil field followed by El-Razzak, Abu El-Gharadig and Yidma oil fields. The Alamein, Yidma and El-Razzak fields produced crude oil from the Lower Cretaceous dolomite pay-zones, while Abu El-Gharadig field produced oil from the Cenomanian clastics of Upper Cretaceous. These fields produced intermediate crude oil from the Aptian Alamein dolomite. The Aptian clastic of Alam El-Bueib Formation is oil bearing in El-Razzak field area. Several discoveries have been achieved since early eighties. Since then, and despite of the sporadic nature of exploration in the early stage, exploration, production and concession bid round activities were continued in the Western Desert at a brisk pace.

1-1. Location

The Bahariya Formation is counted among the most important hydrocarbon reservoirs in the Western Desert of Egypt. It was formed at the beginning of the Cenomanian transgression and consists of sediments deposited under fluvio-marine to shallow marine conditions. The Bahariya Formation type locality is the Bahariya Oasis, Western Desert at Gabal El-Dist which lies about 280 km SW Cairo (see Fig. 1-1). Bahariya Oasis is the lowest point in Egypt, it is surrounded by high escarpments which covers an area of about 1800 km^2 **(Khalifa et al., 2003).** As well as the subsurface Bahariya Formation was studied by several workers from the stratigraphic, tectonic and sedimentological points of view **(Soliman et. al., 1970, El Gezeery et. al., 1972, Franks, 1982, Dominik, 1985,** and **Catuneanu et al., 2006).** The Bahariya Formation was penetrated by most of the drilled wells in the study area. It is mad up of sandstones, siltstones, shale and limestone.

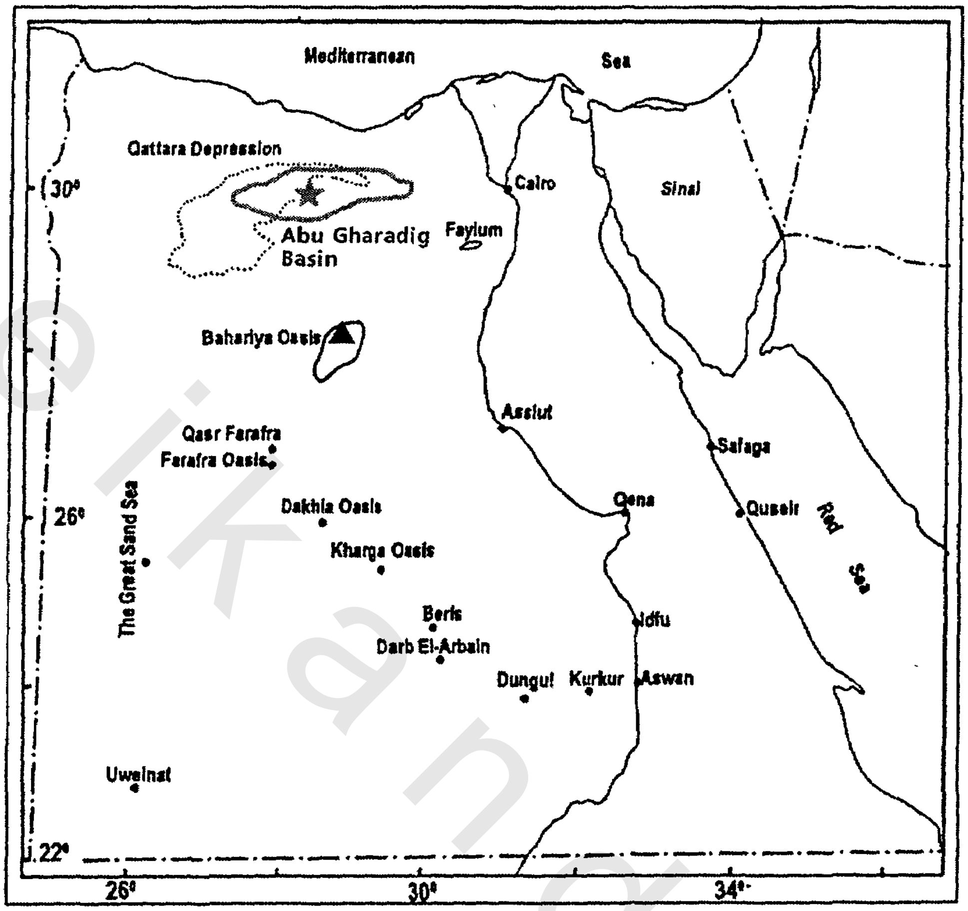

Fig. 1-1 Location map of the well in the Abu Gharadig Basin (star) and of the Bahariya Oasis (triangle) according to **Halisch et al. (2009).**

1-2. Exploration history

Exploration in the Western Desert started during the 1950s, more than half a century later than in the Gulf of Suez. Initially, the Sahara Petroleum Company was granted exploration rights over the entire area. During the four years of Sahara's activities, between 1954 and 1958, the whole concession area was the subject of numerous reconnaissance geological and geophysical surveys. In addition, the area was examined using aerial photography and surface mapping. Oil exploration activity resumed at the end of 1963 when large concessions were awarded to two major oil companies. Phillips Petroleum Company received rights to everything north of latitude 30° N, while Amoco was entrusted with an area south of latitude 30° N and east of longitude 27° E. The entire Western Desert was covered by aeromagnetic surveys over the next ten years.

The first commercial oil discovery in the region was the Alamein Field in 1966. The Aptian Alamein dolomite or dolomitic limestone is the main reservoir, although it shows relatively poor primary porosity. Secondary porosity in the form of vugs or fractures may be as high as 25%. Permeability in this field varies between 30 mD and 2250 mD. From 1969 onwards, the Egyptian General Petroleum Company (EGPC) explored the Siwa area, close to the border with Libya, and investigated some of the blocks relinquished by other operators. By the middle of the 1980s, the number of companies involved in the Western Desert had increased and the size of concessions diminished. A total of 20 fields had been discovered by 1985. In that year, oil exploration in the Western Desert reached a turning point with the discovery of oil and gas in the Jurassic Khatatba Formation sands in Salam Field by Phoenix Petroleum. Its discovery came with the use of better seismic methods in an area which previously had been overlooked. Over 50 commercial oil and gas wells have been developed as a result of drilling of approximately 350 exploratory wells in the Western Desert. The majority of these commercial wells are in the Abu Gharadig, Shoushan and Dahab-Mireir basins. Abu Gharadig Basin is of special interest, its structure having been recognized as a major rift basin which contains numerous localized 'highs'. These features, in NE-SW oriented plunging anticlines, are believed to be fault-controlled at depth and provide a range of reservoir possibilities **(WEC, 1995).** Fig. 1-2 shows a map of oil and gas fields in the Western Desert of Egypt.

Despite a limited number of discoveries to date, the Western Desert has enormous potential and may soon emerge as a major petroleum province. Many promising areas await detailed examination and are virtually untested by drilling. A 1990 study concerning the petroleum resources of the Western Desert suggested that approximately 90% of oil and 80% of gas reserves have still remained undiscovered **(EGPC 1992, WEC 1995).**

1-3. Petroleum Geology of the Western Desert

A close examination of oil and gas potential in the Western Desert reveals an area with substantial remaining reserves which have to be intensively explored. Advances in seismic acquisition techniques and processing provide a great benefit in the search for small traps. The poor resolution typical of older seismic data has been a major factor in the relative lack of success in the region.

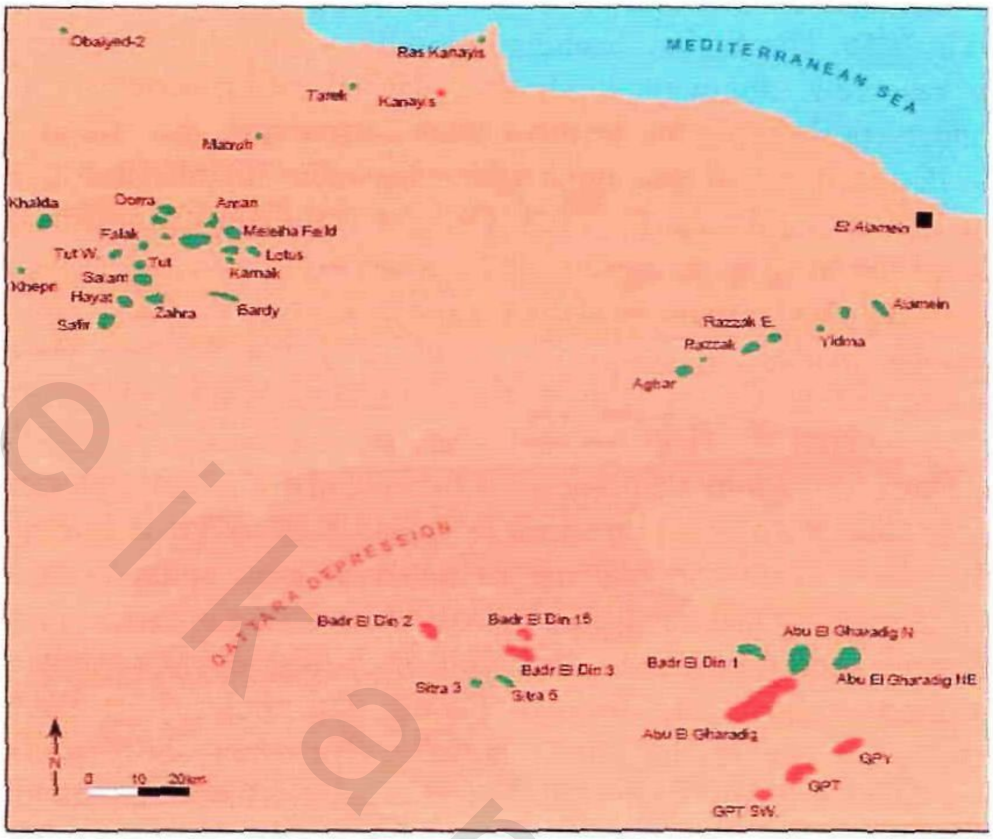

Fig. 1-2 The oil and gas fields in the Western Desert of Egypt **(WEC, 1995).**

In comparison with other areas of Egypt, there has been little application of seismic stratigraphic techniques to estimate hydrocarbon volume, maturation and reservoir quality. Hydrocarbon production in the Western Desert is concentrated in Cretaceous rocks, particularly in Aptian and Cenomanian-Turonian carbonate and clastic reservoirs. Many fields are associated with palaeo-highs where both clastic and carbonate reservoirs have been deposited under relatively high energy conditions. A generalized stratigraphic column in the northern Western Desert of Egypt is shown in Fig. 1-3. Source rocks for the Western Desert are typically shale sequences associated with the transgressive front of Upper Jurassic and Upper Cretaceous carbonates. Few wells have been drilled into strata below the Mesozoic and, as a consequence, information concerning the oil potential of Palaeozoic rocks is scarce. The richest oil-prone kerogens are found within the lower Devonian Zeitun Formation, while gas-prone source rocks lie within the Carboniferous Dhiffah Formation. Black, bituminous shales, which are well known from the Silurian of southern Tunisia and Algeria, may be present at great depth.

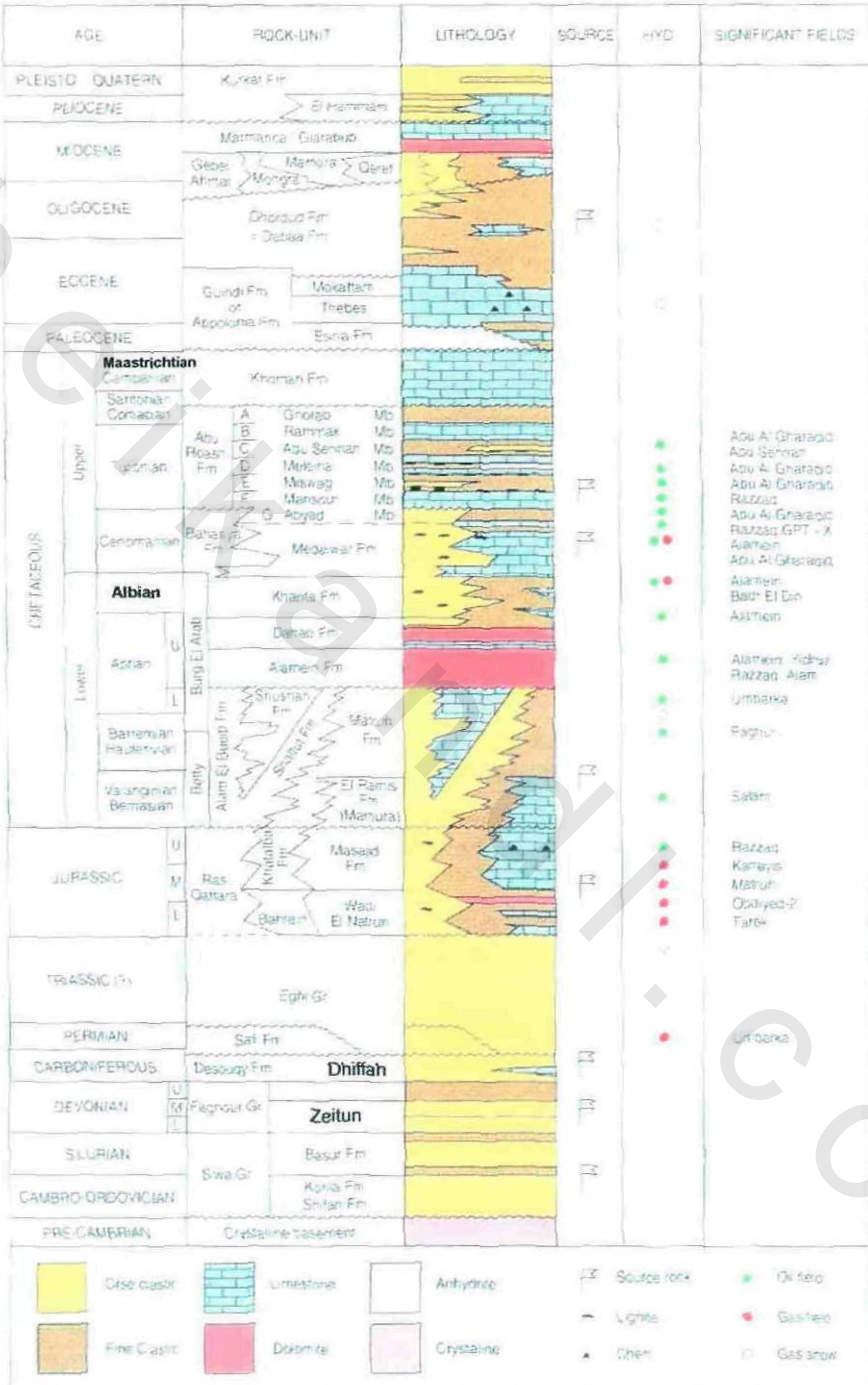

Fig.1-3 Generalized stratigraphic column of the northern Western Desert (**WEC, 1995**).

However, they have not been intersected by any well drilled in Egypt. Mesozoic source rocks include the oil-prone and gas-prone sediments from the Jurassic (Khatatba Formation), Lower Cretaceous (Alam El Bueib Formation) and the Upper Cretaceous (Bahariya and Abu Roash Formations). The most prolific and outstanding source rocks in the Western Desert have been found in the Abu Roash Formation (units 'E', 'F' and 'G'). This Upper Cretaceous source provides good oil source rocks in most parts of the Western Desert and moderate quality gas source rocks in the Umbarka area. Significant amounts of oil, believed to have been generated from this source, are located in the Abu Gharadig and Guindi basins.

Shale sequences intercalated with carbonate or clastic reservoir rocks are the most common type of seal in Western Desert fields. In a few cases, evaporite sequences develop locally and may also provide seals on some fields (e.g. the basal member of the Abu Roash Formation in Alamein Field). Traps are typical of the combined stratigraphic-structural type. Most of the structures being faulted anticlinal features. In many cases, rejuvenation of these horst-like structures led to unconformities, onlapping and erosional pinch-outs **(WEC, 1995).**

A comprehensive geochemical analytical campaign throughout the stratigraphic succession of the Western Desert has shown that potential source rocks are widespread in space and time. Potential source rocks for oil and gas have been identified in the following stratigraphic units:

Upper Cretaceous:	Abu Roash Formation
	Bahariya Formation
Lower Cretaceous:	Alam El Bueib Formation
Jurassic:	Khatatba Formation
Paleozoic:	Early Devonian and Carboniferous Formations

1-4. Stratigraphy

Generally, the African Craton to the south and the Tethyan Sea to the north controlled to a great extent the sedimentary regime of the Phanerozoic sediments in Egypt. These sediments increase in thickness towards the north due to the gentle north to northwest dip of the Pre-Cambrian basement **(Klitzsch 1986, Kuss 1989,** and **Said, 1990).** The more western areas have been transgressed earlier than the more eastern ones, indicating that the dip of the plate was more northwestward than due northward **Klitzsch (1986).** The late Cretaceous tectonic framework is another important factor controlling the distribution of the Upper Cretaceous - Early Tertiary sediments. In northern Egypt, close to the northern edge of the plate, complex, faulted, NE-SW trending anticlines and synclines were developed (Syrian Arc System). This pattern of elongated ridges and basins controlled the type and distribution of the early Tertiary sediments. At the same time the rejuvenation of the Paleozoic and older structural elements (trending NNW-SSE) prevailing at the south resulted in a series of tilted fault blocks. These blocks controlled to a large degree the vertical and lateral distribution of Late Cretaceous – Early Tertiary **(El-Shazly 1977, and Klitzsch, 1986).**

The general stratigraphic succession of the northern Western Desert of Egypt includes different sedimentary sequences ranging in age from Pre-Cambrian to recent **(Said, 1990).** The total thickness, in spite of some anomalies, increases progressively to the NNE from about 1829 m in the southern part to about 7620 m along the coastal area **(El-Bassyouny et al., 1997).** Generally, the stratigraphic section consists mainly of alternating depositional cycles of clastics (sandstone, siltstone, shale and clay) and carbonates as a result of several successive transgressions and regressions of the sea **(Rossi et al., 2002).** A generalized stratigraphic column of the northern Western Desert is shown in Fig. 1-3.

The subsurface litho-stratigraphic sequence in the northern Western Desert was studied by many authors. **Said (1962)** subdivided the litho-stratigraphic column of the Western Desert from base upwardly into three main cycles:

1. Lower clastic division: Pre-Cenomanian, predominantly clastics.
2. Middle calcareous division: from the Cenomanian to the Eocene age, predominantly carbonates.
3. Upper clastic division: from the Oligocene to Recent predominantly clastics.

Barakat (1970) mentioned that all the Jurassic strata in the Western Desert are reported in the subsurface. They have been penetrated by a number of deep wells, which are arranged from east to west, as Abu Roash well no. 1 (thickness 305 m.), Khatatba well no.1 (thickness 365 m.), Wadi El-Natrun well no.1 (thickness 150 m.), and undifferentiated Lower Jurassic in both Betty well no.1 and Ghazalet well no.1.

Ghorab et al. (1971) studied in detail the Cretaceous succession penetrated by eight wells drilled in the northeastern part of Egypt, from top to bottom:

1. Sudr Formation (Maastrichtian – Campanian)
2. Abu Roash Formation (Santonian – Turonian)
3. El-Heiz Formation (Cenomanian)
4. Bahariya Formation (Cenomanian)
5. Kharita Formation (Early Cretaceous)
6. Alamein Dolomite (Early Cretaceous)
7. Alam El-Bueib Formation (Early Cretaceous)

Barakat and Arafa (1972) concluded that the Early Cenomanian in Mersa Matruh well no.1 in the northern Western Desert is characterized by shallow near shore environment with oscillating sea induced possibly by tectonism. By the close of the Cenomanian and the outset of the Turonian, further transgression took place.

Abdine and Deibis (1972) divided the Aptian sediments in the northern Western Desert into main rock units: the Lower Aptian clastics and the Upper Aptian carbonates. The Aptian clastics could reach about 305 m of thickness. The Aptian carbonates consist of two units: dolomite and limestone facies enclosing an intermediate clastic division.

Metwalli and Abd El- Hady (1973) suggested that the subsurface section in the Alamein area reflects the characters of both, the stable and unstable shelf condition of sedimentation. The Alamein structure lies at the junction between the stable and unstable shelf contact.

Dia El Din (1974) described the Lower Cenomanian of Bahariya Formation as composed of interbeds of sand–shale and represents a gradational fining upward overlaid by Abu Roash Formation which is predominantly shallow to open marine limestone unit which was deposited on an eroded tilted fault-block of the Lower Cenomanian Bahariya Formation. The lowermost members of Abu Roash Formation show an onlap mode of deposition on the Bahariya tilted fault-block, the (C) and (E) sandstone members of Abu Roash Formation pinch-out stratigraphically within Abu El-Gharadig Field.

Abdine (1974) defined five sedimentary cycles in northern Western Desert from base to top as follows:

1. a clastic facies, comprising the oldest sedimentary rocks, including the Paleozoic and Lower Jurassic formations,
2. a carbonate section of Middle and Upper Jurassic formations,

3. the second cycle of clastics, comprising the total Lower Cretaceous formations,
4. carbonate deposits, ranging in age from Cenomanian to Middle Eocene,
5. the uppermost clastic depositional cycle, including the Upper Eocene, Oligocene, Miocene and younger formations.

Barakat and Arafa (1981) studied the Matruh shale of northern Western Desert and suggested that the Matruh shales penetrated in Mersa Matruh well attain a thickness of at least 1984 m. This rock unit is composed of shales alternating with siltstones and mudstones. It is deposited in deltaic environment with continuously subsiding basin.

Franks (1982) pointed out the transgressive nature of the Cenomanian sediments of the Bahariya Oasis. The vertical transgressive relationship displayed by the Cenomanian succession in Egypt is an expression of the vast marine transgression which covered most part of Sinai, Gulf of Suez and the northern Western Desert during the Cenomanian, following the Albian regessive phase **(Said, 1990).**

Dominik (1985) subdivided the outcropping Bahariya Formation into three members which are (from base to top); Gebel Ghorabi Member, Gebel Dist Member and Gebel El Heiz Member. The transgressive relationship of the members is manifested by the upward gradation of the depositional environment from fluviatile conditions at bottom (Gebel Ghorabi Member) to estuarine conditions (Gebel Dist Member) and finally to lagoonal and shallow marine conditions (Gebel El Heiz Member).

El Dakkak (1987) suggested that the Jurassic succession in the northern Western Desert is made up from base to top by the following rock units:

1. Wadi El-Natrun Formation,
2. Khatatba Formation,
3. Masajid Formation.

Barakat et al. (1988) concluded that the Kharita Formation (Albian) can be separated into two members based on facies distribution. The depositional environment of the Kharita Formation was interpreted as fluviatile regime of meandered and braided alternative in time and space. The Kharita Formation contains good to excellent reservoirs as well as seals.

The exposed sedimentary succession within the Bahariya depression includes different rock units namely, Lower Cenomanian (Bahariya Formation), the Upper Cenomanian (El-Heiz Formation), Turonian-Santonian (El-Hefhuf Formation), Campanian-Maastrichtian (Ain Giffara Formation) and Maastrichtian-Danian (Khoman Chalk) are exposed at Gabal El-Hefhuf, Gabal Topog El Harra and Qala Siwa synclines, which show a general trend of NE-SW direction south of these localities **(Khalifa et al., 2003).**

Catuneanu et al. (2006) have demonstrated that the Bahariya Formation exhibits significant lateral and vertical changes of facies. As a result of their sedimentological studies in the Bahariya Oasis, they specified three major lithological units: unit one consists of interbedded siltstones and sandstones (lower unit), unit two is formed by cross-bedded amalgamated sandstone bodies (middle unit), and unit three is characterized by dark-colored ferruginous sandstones (upper unit). Eight distinct facies associations have been recognized, corresponding to changes in clastic lithology, color, sedimentary structures and stratal stacking patterns. These facies associations reflect shifts in paleo-depositional environments from outer shelf (deepest marine facies recorded in the study area) to shoreface, coastal, and fluvial (high and low energy systems). Catuneanu et al. (2006) described the Bahariya depositional environment as an overall transgression with coastal backstepping comprising several coarsening-upward cyclothems and the deposition of fossiliferous glauconitic siltstones and sandstones. Hence, the environment was shallow marine with tidal fat to marine shelf settings.

1-5. Sedimentary basins

The stratigraphic column in the northern part of the Western Desert (see Fig. 1-3) contains much of the sedimentary succession from Precambrian basement rocks to recent deposits. Sedimentary cover (i.e. the sequence of deposits overlying the basement rocks) thickens northwards, reaching more than 10668 m in the Abu Gharadig Basin before thinning to 2987 m over the Ras Qattara Ridge. Several Western Desert basins have highly deformed sequences of sedimentary rock which were formed as a result of extensive cycles of marine transgression combined with at least three orogenic (mountain-building) phases. The earliest of these phases was the Caledonian Orogeny which occurred during the Middle Palaeozoic. The second phase, the Hercynian Orogeny, took place at the end of the Palaeozoic, while the Alpine Orogeny was a Jurassic-Tertiary phase. A N-S oriented Palaeozoic basin covers wide stretches in the north-western part of the Western Desert. It can be considered as a northern extension of Libya's Kufra Palaeozoic Basin. The "Faghur-Siwa" Basin continental sag, a craton interior basin, contains thick Palaeozoic sequences ranging from Cambrian to Carboniferous. This basin, in common with other North African sag basins, contains no Jurassic or Lower Cretaceous sediments but has a thick Eocene fill. Recent discoveries in the Umbarka area to the east are adjacent to, and probably charged from, updipping Palaeozoic potential sources in the Faghur-Siwa Basin **(WEC, 1995).**

As shown in Fig. 1-4, the basins of the Western Desert display a variety of alignments, their orientations being controlled by the tectonics of each orogenic period. The basin axes and depocentres (points where the sediment is thickest) were shifted continuously during basin development. This is reflected in the variable thickness of sediments across the region. In general, total sediment thickness in the Western Desert increases progressively to the NNE. On a large scale, the stratigraphy can be thought of as alternating cycles of carbonate and clastic deposition. The thickest Palaeozoic sediments (over 3048 m) are found in the Faghur-Siwa Basin which was formed during the Palaeozoic by crustal down warping and faulting. Jurassic sequences reach their maximum thickness (2134 m) in the Natrun Basin. The Abu Gharadig Basin is an E-W oriented graben containing more than 10668 m of sediment, including 2134 m of Upper Cretaceous strata. The northern basins (Matruh, Shushan, Dahab-Mireir and Natrun) initially formed as a single rift, perhaps during the Permo-Triassic, which developed into a pull-apart structure. Marine conditions are first recorded in the Jurassic and Cretaceous sequences. Later tectonic events are presumed to have split the original basin into a series of smaller compartments. The initial rift system, as seen in the Abu Gharadig Basin, was probably controlled by normal faults. Sedimentary fill in the Guindi Basin is mainly of Eocene age. The early history of the basin followed the same extensional pattern as Abu Gharadig Basin. The Guindi Basin contains thick Eocene limestone and very thick Albian of Cenomanian sediments. Overall depth to basement is greater than 6096 m **(WEC, 1995).**

Western Desert basins can be distinguished from slowly subsiding features such as the Sharib-Sheiba High which has been an elevated structure or 'high' since the Palaeozoic. A number of wells have been drilled on the Sharib-Sheiba High but none has shown even minor amounts of oil. The shifting of depocentres in a consistently subsiding area such as the Western Desert has produced a wide range of sedimentary environments many of which provide favorable conditions for hydrocarbon generation and entrapment.

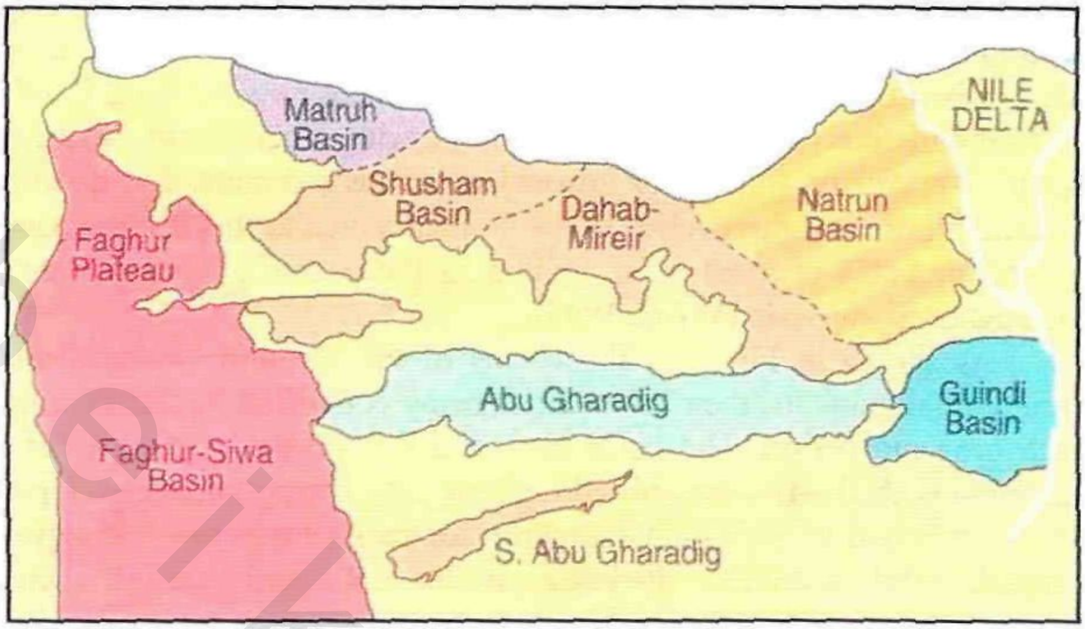

Fig.1-4 Sedimentary basins of the Western Desert **(WEC, 1995).**

The first Mesozoic deposit in the Western Desert was the early Jurassic Bahrein Formation, a continental sequence. This was followed by shallow marine sediments during the Middle Jurassic.

Lower Cretaceous clastic sequences record a marine transgressive cycle consisting of a relative sea level rise, and subsequent fall. This cycle begins with fluvio-continental sediments at the base (Neocomian) followed by transitional, nearshore - deltaic sediments during the Lower Aptian and Albian. The transgression reached its maximum during the Middle and Upper Aptian with deposition of the Alamein Carbonates in a restricted marine / lagoonal environment. A return to continental deposits at the end of the Lower Cretaceous (Upper Albian to Lower Cenomanian) completed the cycle **(WEC, 1995).**

1-6. Structural settings

Egypt lies at the northeastern margin of the African plate which consists of the basement rocks of the East Sahara Craton and the Arabo-Nubian shield over which a number of intracratonic basins have formed **(El-Emam et al., 1990).** The sedimentary section overlying the igneous and metamorphic basement regionally thickens northwards **(Said, 1962).** Egypt can be broadly divided into four structural divisions. These are the Hinge Zone and Unstable Shelf in the north, and the Stable Shelf and the Arabo-Nubian Craton in the south **(Said, 1962).** The central portion of the Western Desert covers the transition zone between the Stable and Unstable Shelves. Most of the seismic evidence for the structure of the Western

Desert shows the subsurface to be composed of a series of low relief horst and graben structures interposed with faults of large throw. In places however a more complex history emerges with Upper Cretaceous wrench features such as compression ridges, flower structures and reverse faults, evident around the margins and within the Abu Gharadig Basin. Alpine age reverse faults and south directed thrusts can be seen along the Mediterranean coast.

Moustafa et al. (1998) suggested that, three main tectonic deformations affected northern Egypt, these are:

1- Jurassic - Early Cretaceous rifting
2- Late Cretaceous - Early Tertiary wrenching
3- Miocene and post Miocene extension

In general, the Western Desert is characterized by a southwestward thickening Paleozoic section and northward thickening prism of the Mesozoic and Tertiary strata, which is interrupted by the major E-W trending Sharib-Sheiba high. This regional uplift separates the Abu El-Gharadig Basin from the coastal basins (Matruh, Shushan, Dahab-Mireir and Natrun). The coastal basins are filled with Mesozoic and Cenozoic strata. These basins are superimposed, at least in the west, over the Paleozoic basin extending eastward to Libya and termed the Siwa Basin **(Taha, 1992).** The Kattaniya High is a horst block in the eastern part separating the Natrun Basin from the Guindi Basin. The Guindi Basin, at least at times, is an eastward extension of Abu El-Gharadig Basin (**EGPC, 1992).**

The overview of **EGPC (1992)** reveals that six major geotectonic cycles or phases can be recognized in the Phanerozoic in the Western Desert, these are: Caledonian Cycle (Cambrian-Devonian), Variscan--Hercynian (Late Paleozoic), Cimmerian/Tethyan (Triassic-Early Cretaceous), Sub-Hercynian-Early Syrian Arc (Turonian-Santonian), Syrian Arc main phase (Paleogene) and the Red Sea phase (Oligocene-Miocene).

Based on the results and conclusions mentioned by different authors (e.g. **Meshref, 1982, Abdel Aal and Moustafa, 1988, Sultan and Halim, 1988, Bayoumi and Lotfy, 1989, EGPC, 1992, Abdel Aziz, 1994, Khalil and Denchy 2000),** the main structural elements of the northern Western Desert can be outlined as follows:

Three major fold trends of different ages in the Western Desert are determined. **The first one**, which is detected in the subsurface, trends north-south, affecting the Paleozoic rocks. **The second** fold trend is northeast-southwest, which was active during the Upper Cretaceous - Lower to Tertiary time (Syrian Arc system). This fold trend is recognized on surface exposures while it is detected in the subsurface by geophysical surveys. **The third** fold trend is the northwest-southeast which characterizes the Tertiary surface rocks particularly in the Siwa-Moghra-Wadi El Natrun district. On the other hand, faulting is evidenced in the Lower Cretaceous sediments of the northern Western Desert and strike faults are parallel to the Syrian arcs, believed to be contemporaneous with Late Cretaceous folding through rejuvenation of old Tethyian faults. Other faults trending northwest to southeast are detected crossing the anticlinal structures, mapped in the northern Western Desert.

In general, the Paleozoic basins and ridges represent long north-south features, which suggest possible basement faulting. During the Jurassic, the major basin changed its trend slightly to occupy a northwest-southeast direction. This main trend is interrupted by north-south embayment and ridges. The embayment was in the form of wide gulfs separated by wide ridges. The narrow and elongated nature of the Paleozoic ridges was not reflected during this age. The Lower Cretaceous basin in the north Western Desert can be dealt with as one major basin extending from Salam in the northwest to the Nile Basin in the northeast. There are three sedimentary basins of Upper Cretaceous age (Abu El-Gharadig, Umbarka-Alamein and the Nile Basin). These basins follow an east - northeast to west - southwest trend. The largest of which is the Abu El-Gharadig Basin. The Guindi Basin of Tertiary age is located to the east from the Abu El-Gharadig Basin, and is connected with the Western Desert foreland.

1-7. BED-1 Field

BED- 1 Field is a part of the Badr El-Din Concession, 300 km west of Cairo and to the west of Abu Gharadig Field (see Fig. 1-1). In 1979 Shell Winning N.V. applied for Badr El Din Concession. The agreement was ratified in June 1980. The seismic and geological studies led to the drilling of BED 1-1 in December 1981. The primary objectives were the Abu Roash and Bahariya sands. Kharita and Alamein Formations were regarded as secondary objectives. Alamein Formation was not penetrated for technical reasons. Consequently, two exploration / appraisal wells were planned to penetrate Kharita reservoirs in similar structural setting. Both wells proved Kharita Formation to be hydrocarbon bearing and BED 1-3 tested oil in Bahariya Formation as well. BED 1-4 proved the western extension of the closure and BED 1-5 was proposed as a further out step on the western extension, again the well confirmed the extension. The area was reevaluated and attention reverted to Abu Roash Formation, so BED 1-6 was drilled to test Abu Roash "C" & "E" reservoirs with the Bahariya as a secondary objective on the main horst block of BED-1 Field. The well confirmed the structure and oil was found in Abu Roash "C", "D" & "F" units. BED 1-7 was drilled in 1987 to evaluate Abu Roash Formation in terms of volumetric and reservoir development in the down dip extension. The well proved that Abu Roash "C", "D" and "F" are hydrocarbon hearing and was completed on Abu -Roash "F". BED 1-8 was proposed to appraise the western extension of BED-1 Field and to approve additional reserves in the Kharita Formation. The well provided an additional drainage point for more efficient recovery. BED 1-9 drilled in April 1988 penetrated 7 m of oil bearing sand in Abu Roash "E", however the production test indicated a very poor reservoir performance and minor reserves. The well was suspended for a future Abu Roash "C" test. A 3D seismic survey was carried out in 1989 which enhanced the understanding of BED-1 Field a lot. BED 1-10 was drilled in 1991 to provide a mid flank Kharita oil producer. The well tested 23 m of oil bearing sand in Bahariya Formation. The well was completed on the Kharita Formation. BED 1–11 was proposed to study the structural configuration of the northern flank of the field a mid way between BED 1-5 and 1-8. The well was completed on Bahariya Formation **(EGPC, 1992).**

The present study is carried out using more than 80 core samples from a depth below 3500 m from an exploration drilling in Abu Gharadig Basin. The samples were obtained from the Bahariya Formation. At each depth, a pair of cylindrical plug samples with a diameter of about 2.5 cm and an average length of 4 cm was extracted from the original whole core. So-called H-samples were taken parallel and so-called V-samples perpendicular to the layering. The sample set can be subdivided into two major types of samples as shown in Fig. 1-5. Samples of the first type are characterized by visual indications of flaser bedding or lamination structures. Independent of the intensity of flaser bedding structures, all samples of this type are regarded as laminated samples (laminated samples). Samples of the second type show no obvious flaser bedding or lamination structures. This type will be referred to as samples without lamination (non-laminated samples). According to a visual inspection, the sandy part of both types can be regarded as sandstones containing 5-15% glauconite, minor amounts of detrital muscovite, and diagenetic kaolin as a cementation mineral. Additional clay minerals do not occur **(Halisch et al., 2009).**

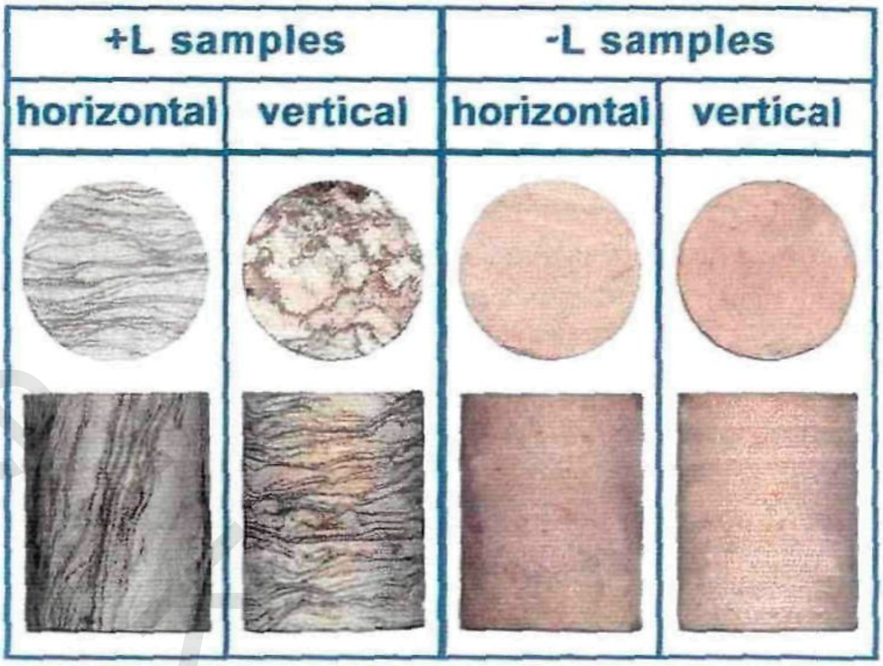

Fig. 1-5 Classification of the cylindrical sandstone samples into horizontal and vertical samples and into laminated and non-laminated samples according to **Halisch et al. (2009)**.

1-8. Mineralogical investigations

The sedimentary structures identified in the sample thin sections of the Bahariya Formation show characteristic features of deposition in a relatively low-energy, sub- to intertidal zone, as **Athmer (2006)** has described the results of her mineralogical and geological investigations. Flaser bedding develops on tidal flats during the turn from flood to ebb tide, when transport energy reaches its lowest level so that fine material like clay and silt sinks down and gets deposited between sand ripples. The fine sandy layers of the sandstones are mainly composed of quartz (70-80%), glauconite (5-15%), feldspar (1-2%), muscovite (1-2%), and rutile (1-2 %). Apatite, zircon, and hornblende are present as accessory minerals.

Cementation minerals are kaolinite and subordinate calcite as well as quartz overgrowths. The angular to subrounded quartz grains show concave-convex contacts which indicate a deep burial (see Fig. 1-6). Feldspar appears as plagioclase and microcline which often are heavily etched or totally decomposed to honeycomb structures. Muscovite is mostly aligned along the sedimentary beddings. The mica minerals have a fibrous shape and are lightly twisted, which is another indication for deep burial (see Fig. 1-7).

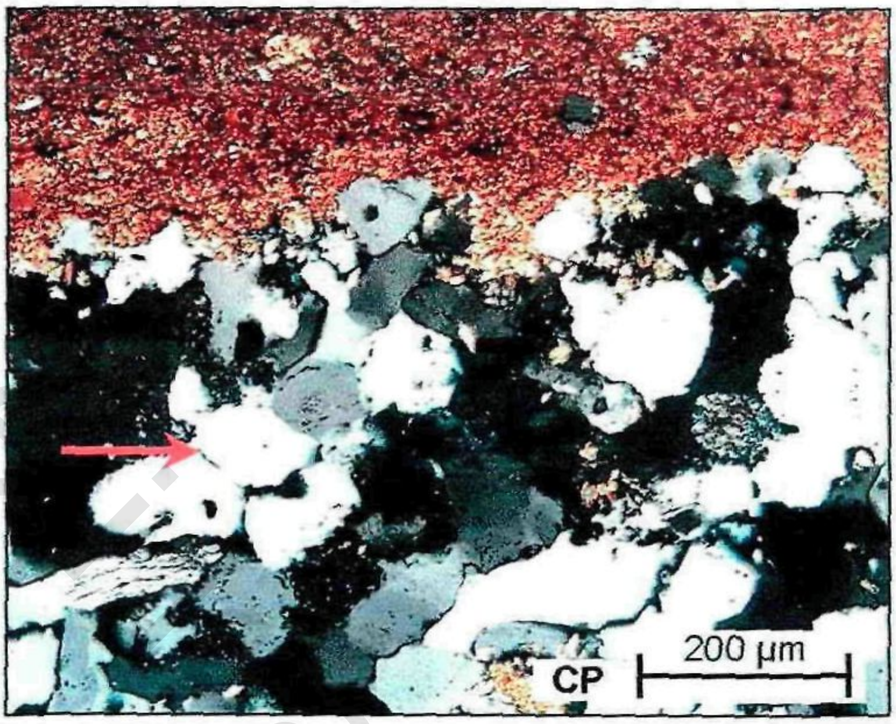

Fig. 1-6 Thin section image of sample 74 H with contact to flaser bedding **(Halisch et al., 2009)**. The red arrow points at a concave-convex contact of quartz grains. (CP - Crossed polarizer).

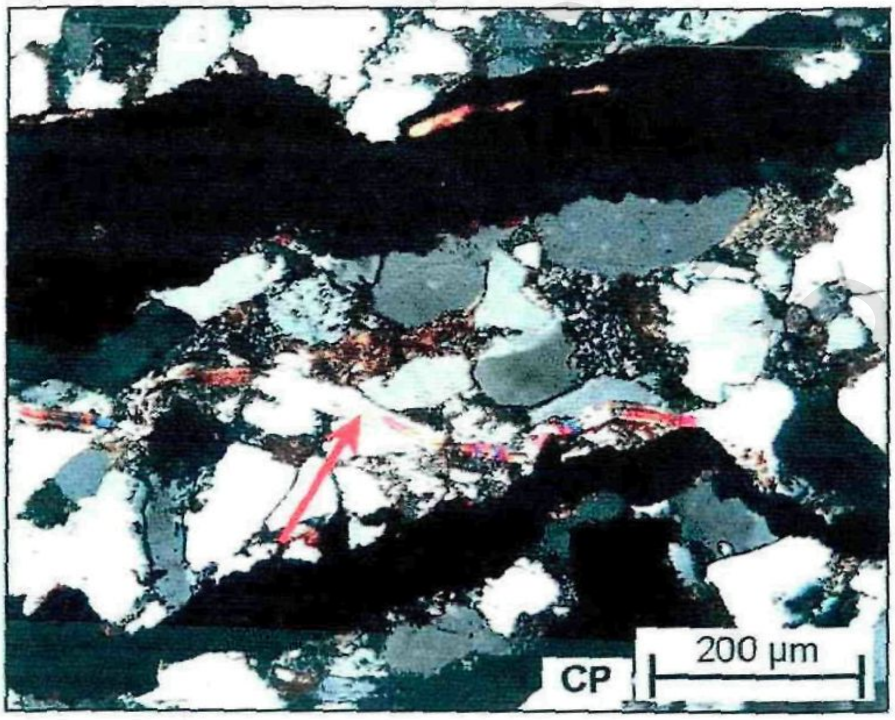

Fig. 1-7 Thin section image of sample 43 H showing twisted mica (red arrow) within a sandy layer, sandwiched between two flaser layers **(Halisch et al., 2009)**. (CP - Crossed polarizer).

Several samples contain oval to tuber-like shaped intraclasts up to several millimeters in size and composed of clay minerals as well as fine sandy to silty quartz. Furthermore, pyrite can be found in the center or as seam. The occurrence of such zonated structures is typical for the intertidal zone.

Concerning the contribution to anisotropy effects, the flaser bedding could play the decisive role, especially when it is abundant and creates a barrier for vertical permeability due to the high amount of clay minerals. Fig. 1-8 shows stress related secondary fracture porosity occurring in the laminated samples parallel to the flaser layers. These fractures mainly appear within the flaser layers but also close by. The type of propagation that also affects quartz grains shows that the fractures were not created by core handling, although the core (the plugs) was photographed at surface pressure.

This might be a considerable contribution to increase the horizontal permeability. The flaser bedding is composed of clayey-silty, partly carbonaceous layers that contain many small pyrite framboids and minor rutile. Fig. 1-9 shows framboidal pyrites that appear mostly aligned like in a pearl necklace. Such a pyrite framboid embedded in a clay matrix is shown in Fig. 1-10. Due to oxidation, the layers contain minor limonite or other iron hydroxides **(Halisch et al., 2009).**

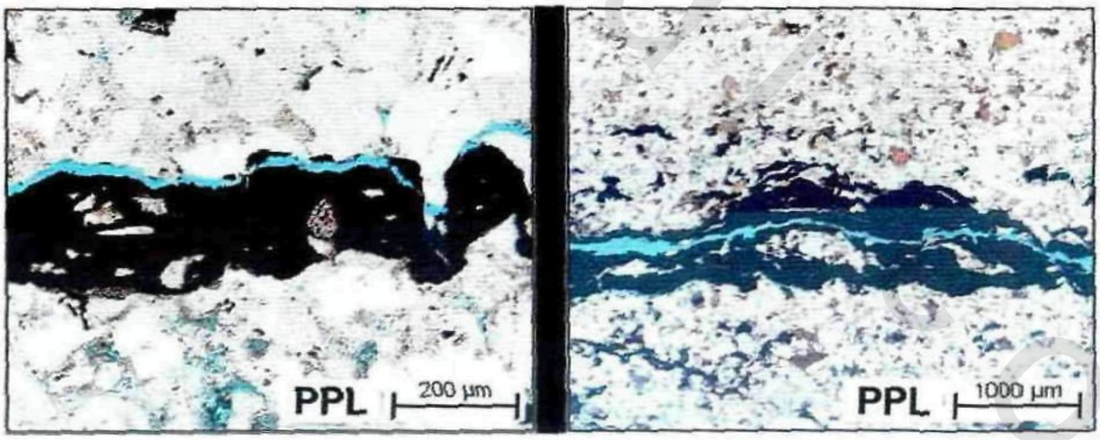

Fig. 1-8 Thin section images of two different sandstone samples (left-hand side 31 H; right-hand side 43 H) showing secondary fracture porosity (blue) parallel to flaser layers **(Halisch et al., 2009)**. (PPL: Plane-polarized light).

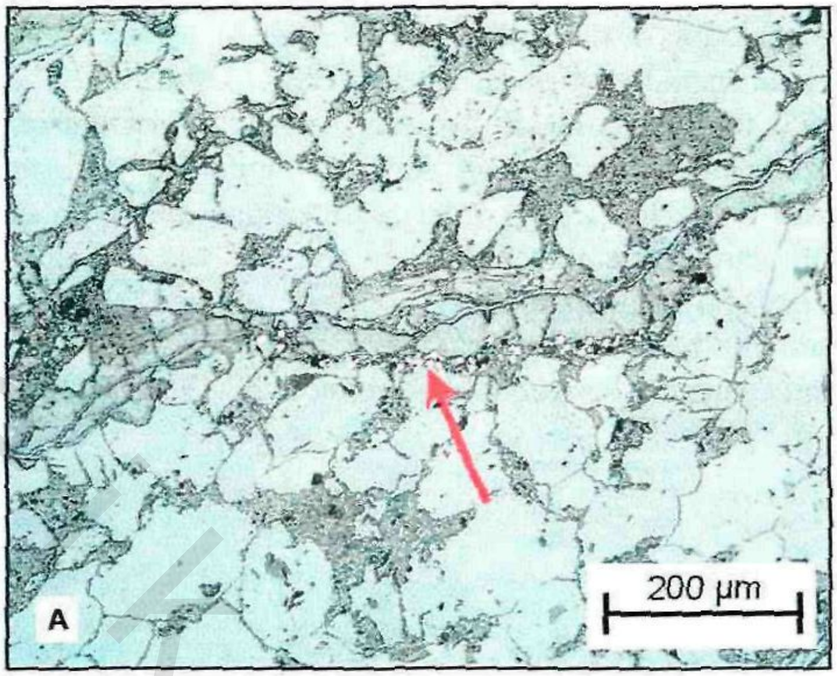

Fig. 1-9 Microscopic image of sample 43 H under reflected light showing high reflective framboid pyrites which are aligned like a pearl necklace within a flaser layer **(Halisch et al., 2009)**.

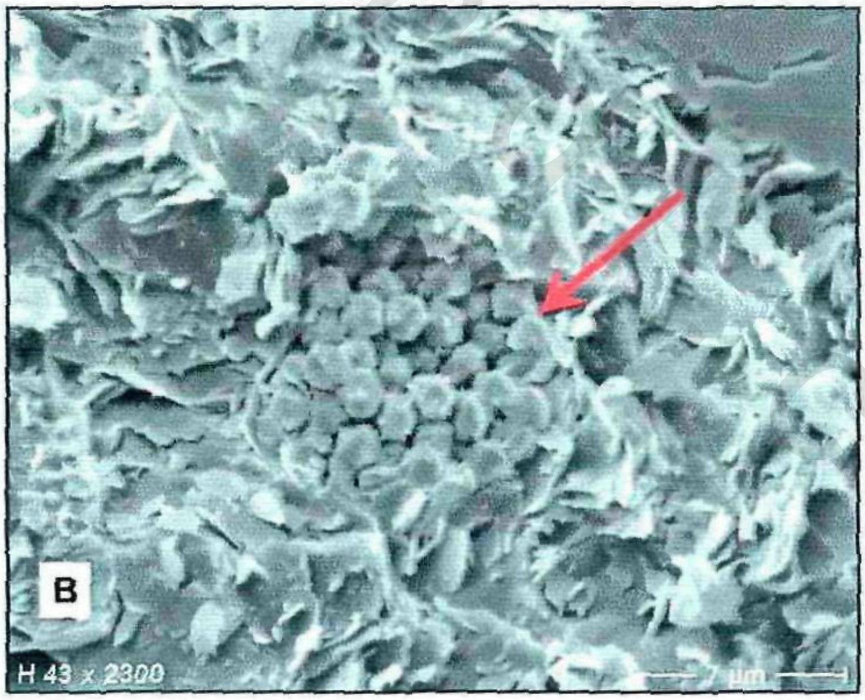

Fig. 1-10 SEM micrograph of sample 43 H showing pyrite crystals within a framboid (red arrow) in a clay matrix **(Halisch et al., 2009)**.

1-9. Aim of study

The objective of the study is to determine the effect of anisotropy on the directional parameters such as resistivity, permeability, seismic wave velocity and thermal conductivity. The coefficient of anisotropy will be determined. Statistical analysis for all, laminated and non-laminated samples will be performed in order to determine the effect of lithological changes on petrophysical properties. In addition, the relationships between different petrophysical parameters will be studied. The samples were investigated in the petrophysical laboratories at Ain Shams University (Egypt) and Clausthal University of Technology (Germany).