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PETROGRAHPIC STUDY OF THE SARMORD FORMATION IN NORTH ZAKHO AREA, NW IRAQ

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ABSTRACT

The Sarmord Formation in the study area is mostly composed of dolostone rich in bituminous materials. Due to the presence of bituminous materials, most of the rocks have dark grey to grey and black color and interbedded with fissile black shale. The present study is mostly based on 23 samples obtained from 5 surface sections and 2 spot samples emphasizing their lithofacies, fossil contents, diagenetic processes, diagenetic environments, distribution of bitumen and environment of deposition. Detailed petrographic examination of the rocks has led to the distinction of four main lithofacies, namely limestone, dolostone, siliceous rocks and shale. Several diagenetic processes are observed to have affected the rocks of this formation including dolomitization, which appear to have been widespread, physical and chemical compaction, neomorphism, leaching and porosity development, cementation, silicification and calcitization (vanished evaporite). Most of the diagenetic processes might have taken place in deep burial environment, shallow subsurface evaporatic environment and submarine environments.

Many types of bitumen accumulation can be distinguished in the studied formation. It occurs as beds, laminae, pore filling, coating, and inclusion and as lining stylolites. The depositional environment was so difficult to be deduced due to the severe dolomitization process, which obliterated the original texture and structures of the rocks as well as the fauna. Nevertheless, the presence of some fauna and the remained texture and structures indicate that the deposition of the formation belongs to deep marine shelf margin environment of normal salinity.

دراسة بتروغرافية لمقاطع سطحية لتكوين سارمورد
في منطقة شمال زاخو، شمال غرب العراق

وفاء فيليب بشير و بسمة اسعد السامرائي

المستخلص

يتكون تكوين سارمورد في منطقة الدراسة بصورة رئيسية من الحجر الدولومايتي الغني بالمواد القيرية والتي تتميز بلونها المائل الى السواد وقسم منها ذات لون رصاصي أو رصاصي داكن كما تتميز بوجود الصلصال الورقي الأسود، حيث يوجد بشكل طبقات مع صخور التكوين الكاربوناتية وغير الكاربوناتية. اعتمدت الدراسة بصورة أساسية على 23 نموذج ملتقط من خمسة مقاطع سطحية ونقطتين وصفيتين مؤكدة على السحنات الصخرية، المكونات الحياتية، العمليات التحويرية، البيئات التحويرية، وتوزيع المواد القيرية، إضافة إلى الظروف الترسيبية للتكوين. من خلال الدراسة الصخرية لصخور التكوين أمكن تمييز أربعة سحنات رئيسية هي الجيرية، الدولومايتية، السيلكية والصلصال.

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تعرضت صخور التكوين لعدة عمليات تحويرية شملت الدلمتة وهي من أكثر العمليات شيوعاً في منطقة الدراسة، التشكل الجديد، الانضغاط الكيميائي والفيزيائي، الإذابة وظهور الفراغات، السمنتة، عملية السلكتة وعملية الكلستة. أكثر هذه العمليات التحويرية حدثت في بيئات تحويرية منطمرة وقسم منها في بيئة المتبخرات تحت السطحية الضحلة وبيئة تحت البحرية.

يوجد القير (البيتيومين) في صخور الدراسة بشكل طبقة صخرية، صفائح رقيقة، مالئا للفراغات والكسور، كمكتنفات، بشكل أغلفة ومبطن لسطوح الستايلولايت، وإنه تكون في وقت لاحق للترسيب. كان من الصعب استنتاج الظروف الترسيبية للتكوين بسبب العمليات التحويرية الشديدة المؤثرة على التكوين والتي أدت الى إخفاء معالم أنسجة وتراكيب الصخور، إضافةً إلى إخفاء المكونات الحياتية ولكن وجود بعض بقايا المتحجرات والأنسجة والتراكيب أمكن إيجاد الظروف الترسيبية والتي تعود الى حافة الرف العميق ذات الملوحة الاعتيادية.

INTRODUCTION

Sarmord Formation lies structurally in the southern part of the Imbricate Zone and the northern part of the Highly Folded Zone of Iraq. The studied area is of complicated topography, consists of high amplitude mountains dissected by deep valleys. The area is defined by longitudes 42° 51' 11.6" to 42° 85' 33" and latitudes 37° 13' 30" to 37° 14' 12" (Fig.1). The area is covered by two topographic maps, no. 91/470 and 91/480 of scale 1: 20 000, which included from west to east six main localities: Shiranish, Gelikafshi, Perbela, Afla, Pandru and Banik.

GEOLOGY OF THE STUDIED AREA

▪ Stratigraphy

In the studied area, the Sarmord Formation (Early Cretaceous) is differentiated by the presence of black bituminous, dark gray-to-gray dolostone and limestone with thin intercalation of fissile shale and this may be considered as a marker to differentiate this formation from the underlying and overlying formations. The lower contact is conformable with Jurassic rocks and taken at the base of black bituminous shale or dolostone (Hassan, 1991). The upper contact with the Qamchuqa Formation is gradational and taken at the base of massive and thickly bedded limestone and dolostone. Buday (1980) assigned a Berriasian – Aptian age to the Sarmord Formation.

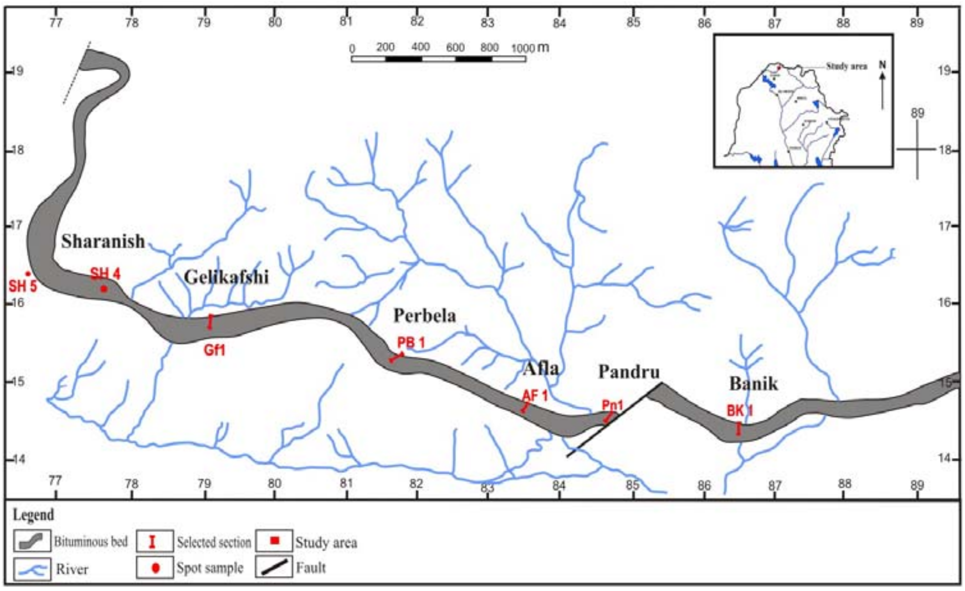

Fig.1: Location map and distribution of surface sections
and spot samples in the studied area (after Khlaif *et al*., 2006)

▪ **Structure and Morphology**

The studied area is located within the Imbricate Zone of the Outer Platform of the Arabian Plate (Fouad, 2012). The area is characterized by rough morphology, steep cliffs and dense valleys, almost bare of soil, except near the main streams, and along gentle slopes, where slope sediments are developed.

▪ **Previous Works**

The following works were carried out in the studied area:

– The Sarmord Formation was described by Bellen *et al*. (1959) in the type area as a composed of brown and bluish marls, with alteration of marly neretic limestone.
– Chatton and Hart (1960) divided the Sarmord Formation into the lower, middle and upper parts of Sarmord Formation.
– Buday (1980) combined the lower two divisions into the Lower Sarmord Formation, which is considered to be of Berriasian – Aptian age.
– Ma'ala *et al*. (1990) mentioned that the carbonate rocks of the Sarmord Formation are highly bituminous. They found that the formation consist of dark gray to gray dolostone and limestone, with thin intercalation of bluish brown shale and relatively thin beds of sandstone. The rocks are petrographically studied and they found four lithofacies namely dolostone, limestone, shale and sandstone as well as sandy ironstone.
– Al-Amiri *et al*. (1991) described the rocks of the Sarmord Formation in this area as limestone, slightly dolomitized, containing bituminous materials present as coating and as filling the pore space and is latterly formed after deposition.
– Hassan *et al*. (1991) studied petrographically the rocks of this formation and recorded five main lithotypes and microfacies; such as bituminous sparite, ferruginous biosparite and crystalline limestone and bituminous micrite to microsparite and aphanocrystalline, very finely and medium to coarsely crystalline dolomite (fossiliferous, calcareous, ferruginous and intraclasts) and also mentioned that these rocks are affected by many diagenetic processes such as recrystallization, partial dolomitization, calcitization and stylolitization.
– Khlaif *et al*. (2006) classified the rocks of the Sarmord Formation into two classes: The first class included the carbonate and siliceous rocks that are not affected or partially affected with bitumen and occur within underlying and overlying the bitumen bed, and the second class consists of bitumen, dolomitic and calcareous bitumen occurred within the bituminous bed. In this class, the bitumen represents the main component of the rocks, while dolomite and calcite represents the second components.

LITHOFACIES OF THE SARMORD FORMATION

The study of thin sections reveals that most of the rocks have suffered severe diagenetic processes, so it is meaningless to differentiate into microfacies but noteworthy, it can be classified into different lithofacies and each lithofacies is subdivided into many sublithofacies to facilitate the interpretation of their depositional environments. The carbonate rocks of the formation are classified after Folk (1959 and 1962) which is based on the composition of the carbonate. In some instance, some modifying terms can be useful and added adjectively to the main rock name as laminated, bituminous, compacted, and neomorphism. This may help us to establish the conditions under which each type of lithofacies was deposited. In the studied area, the Sarmord Formation is subdivided into four lithofacies, they are mentioned hereinafter.

▪ **Limestone Lithofacies**

The following three sublithofacies are recognized.

– **Neomorphosed Biosparite:** Petrographically, calcite comprises the bulk mineralogical composition with 93%. It is present in the form of medium to coarse anhedral interlocking crystals forming a sort of mosaic texture. The calcite is most probably formed from recrystallization of an originally micritic and microsparitic matrix (Fig.2.A). Fossils remains as ghosts and have mostly affected by neomorphism such as pelecypods having clear coarse and radial calcite. This rock is affected by local dolomitization process at late diagenesis to produce fine to medium crystalline dolomite (5.5%) of anhedral to subhedral form. The rest of the mineral constituents being bitumen matter (1.5%), which is present either as patches or as filling the spaces; between calcite crystals. The essential diagenetic effects include neomorphism and selective late dolomitization.

– **Compacted Biomicrosparite and Compacted Bituminous Biomicrosparite:** Microscopic investigation reveals that calcite is the dominant minerals (85 – 98 %). The calcite is represented by microsparite and sparry calcite that is mostly formed from recrystallization of micrite. Fossils are mostly affected by neomorphism as well as solution, which caused their leaching and then biomolds were filled with clear secondary calcite. The fossils are arranged in one direction, which gave an indication that the sediments were subjected to physical compaction. The recognized fossils are cephalopods and *Bolivina* sp. and ostracods (Fig.2.B). The presence of cephalopods indicates deep-water marine deposits of normal salinity. The rest of the mineral constituents being bitumen matter (2 – 15 %) occur as patches, between calcite crystals, filling stylolite and as coating surface of most crystals. This sublithofacies is also subjected to chemical compaction. In addition, recrystallization of groundmass and fossils, dissolution and cementation affects this sublithofacies.

– **Bituminous Crystalline Limestone (Vanished Evaporite):** Petrographically, calcite represents the main constituent of these rocks with percentage ranges from (75 – 90) %. These crystals are present in prismatic, lenticular, rosette (Fig.2.C), lozenge, and feathery forms, which most probably formed after replacement of evaporites (Fig.2.D). The rocks enclose bitumen matter (10 – 25 %) that are present as patches, between calcite crystals and along the periphery of some crystals of calcite as well as coating surface of crystals. The main diagenetic changes include calcitization (vanished evaporite).

▪ **Dolostone Lithofacies**

This lithofacies is subdivided into the following five sublithofacies.

– **Aphanocrystalline to Very Finely Crystalline Dolomite:** Petrographically, dolomite is considered as the main components. Forms about 98% and with grain size lies between (< 4 – 15) μ. The presence of very fine dolomite gave indication that this dolomite is mostly formed from recrystallization process of aphanocrystalline dolomite. The dolomite of this sublithofacies is considered as the product of early digenetic dolomitization. The rock is slightly porous. The pores are filled with inequigranular, medium and anhedral to rhombohedral secondary dolomite. The rhombic crystals of dolomite are coated by bitumen matter (1%). Other present component is calcite (1%) and occurs as equigranular clear secondary filling veinlets.

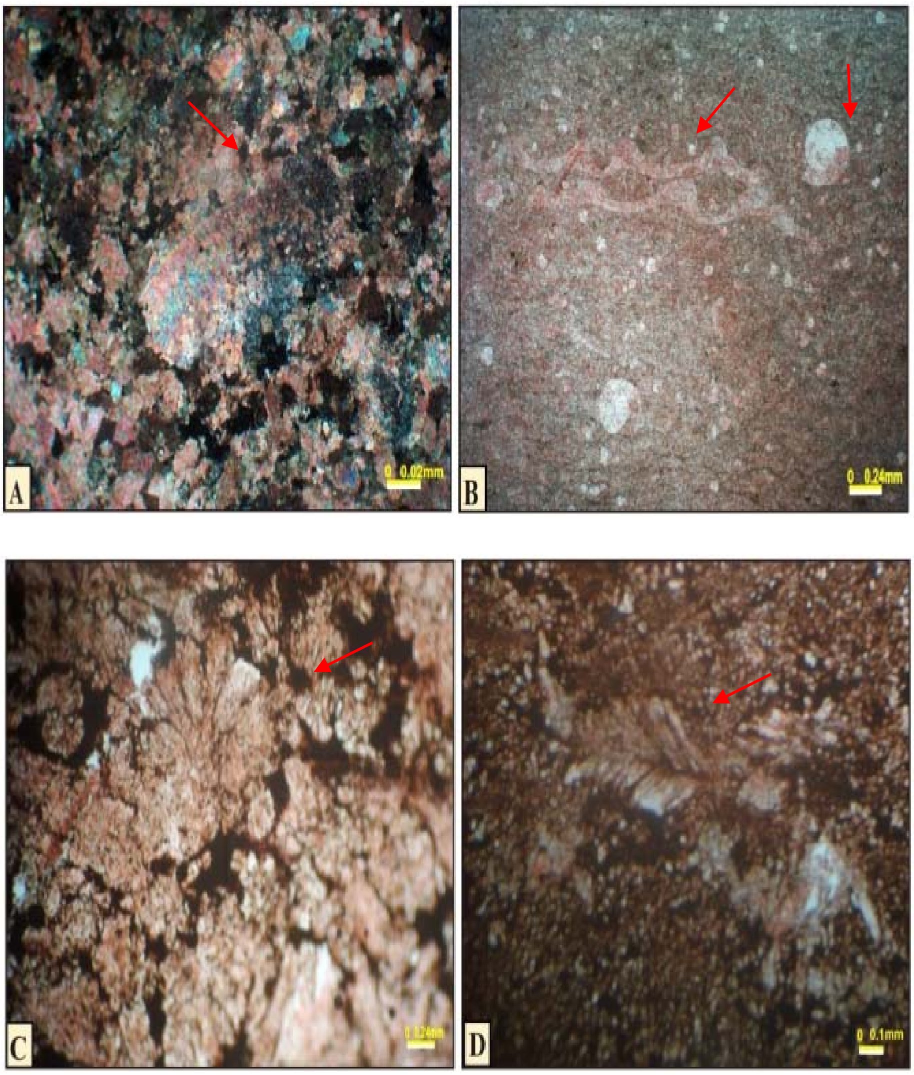

Fig.2: Limestone lithofacies
A) Neomorphosed Biosparite. **B)** Compacted biomicrosparite
C) Bituminous crystalline limestone with rosy texture indicating calcite pseudomorphs after evaporite
D) Compacted and vanished evaporite with feathery texture of the original evaporite mineral

– **Medium to Coarsely Crystalline Dolomite:** Microscopic investigation reveals that the dolomite is the dominant mineral of this sublithofacies, ranging from (95 – 100) %. The dolomite crystals are present in rhombohedral to subhedral forms with a minor amount of anhedral shapes. Some of the rhombohedral crystals show zoning due to the difference in the amount of Ca/ Mg ratio. The grain size ranges from (0.16 – 0.56) mm (Fig.3A). Clear anhedral to rhombohedral coarse crystals of dolomite are found to fill the fracture; as in sample no. PB1/1. The sediments contain bituminous materials of (2 – 5) %. These materials are present as filling the pore space between dolomite crystals. In addition, clays are also present and did not exceed more than 2%, filling the space between dolomite crystals. The essential diagenetic changes influence on this sublithofacies are late diagenetic dolomitization, recrystallization, selective dissolution and porosity development, such as vug and intercrystalline and latterly cementation.

– **Bituminous Fine, Medium and Coarsely Crystalline Dolomite:** Petrographic examination shows that the dolomite comprises the main mineralogical component with a percentage lies between (65 – 90) % present in rhombohedral forms in addition to anhedral and subhedral present either as isolated crystals or as aggregates with (0.14 – 0.28) mm in diameter (Fig.3B). Other components of this sublithofacies are represented by bituminous matter (10 – 70 %), which was found as coating surface of dolomite crystals, as patches and inclusion within dolomite crystals. Iron oxides are also present in trace amount as well as secondary calcite filling pores. In some rocks, the rhombic crystals of dolomite are subjected to complete dissolution left behind intracrystalline pores or dolomolds (rhombic-shaped voids).

– **Bituminous Fine to Medium Crystalline Intraclastic Dolomite:** Petrographically, dolomite comprises the bulk mineralogical composition, with 89% and present in form of fine crystals (0.02 mm), which partially affected by recrystallization to produce medium crystalline dolomite (0.13 mm). This is proved by the presence of some dispersed patches of fine dolomite through the medium crystalline dolomite. Most of the dolomite crystals have rhombic shape. Some of the medium to coarse dolomite (0.16 – 0.26 mm) are found to fill the pores having rhombic shape and distinct zoning. The intraclasts are completely dolomitized. The included intraclasts (10%) are irregular in shape and having different sizes (Fig.3C). The recognized intraclasts are aphanocrystalline dolomite contaminated with bitumen, fine dolomite, very fine dolomite and laminated dolomite. This lithofacies contains bitumen matter (10.5%) present as coating dolomite crystals and filling the space between dolomite crystals. Silica (0.5%) is also observed and is present as chalcedonic quartz and often occurs in spherulitic growth structure in a radiating arrangement as pore filling. The presence of such intraclasts gave indication for the eroded of partly or wholly consolidated carbonate sediments; from nearby and then transported and deposited in adjacent layers by waves or currents disturbing the seafloor.

– **Laminated Bituminous Coarsely Crystalline Dolomite**: Microscopic investigation exhibits that the essential mineral of this rock is dolomite (85%). The crystals of dolomite are mostly rhombohedral in shape with average size of 0.36 mm. Some of the crystals show zoning (Fig.3D). The rock contains bitumen (15%); present as filling the pore space between dolomite crystals and arranged in parallel lines with dolomite crystals. The most common sedimentary structure of this rock is lamination. This lamination is mainly due to change in composition and color difference (light dolomite oriented parallel to dark bitumen lamina).

- **Siliceous Rock Lithofacies**

The following two sublithofacies are recognized.

– **Dolomitic Siliceous Rock:** Microscopic investigation reveals that the silica is the predominant minerals (60%), in addition to dolomite (30%), calcite (5%), and bituminous material (5%). Silica is present in form of spherical bodies, rounded outlines, and ranging in size from fine to medium crystals (0.032 – 0.11 mm). These spherical bodies occur often in a radiating arrangement forming spherulitic growth structure or composed of micrograined quartz. Chert fragments and Radiolarian sp. mostly represent them. In addition, silica is also present as a replacement mineral, replacing dolomite crystals as well as shell fragments, while the micritic envelope is still present. Dolomite crystals are mostly anhedral and rarely rhombohedral partially replaced by silica. Calcite is mostly secondary filling rhombic dolomite and also veinlets. Bitumen matter occurs as patches, dots, coating on spherical bodies and as inclusion within spherical bodies (Fig.4A1 and A2).

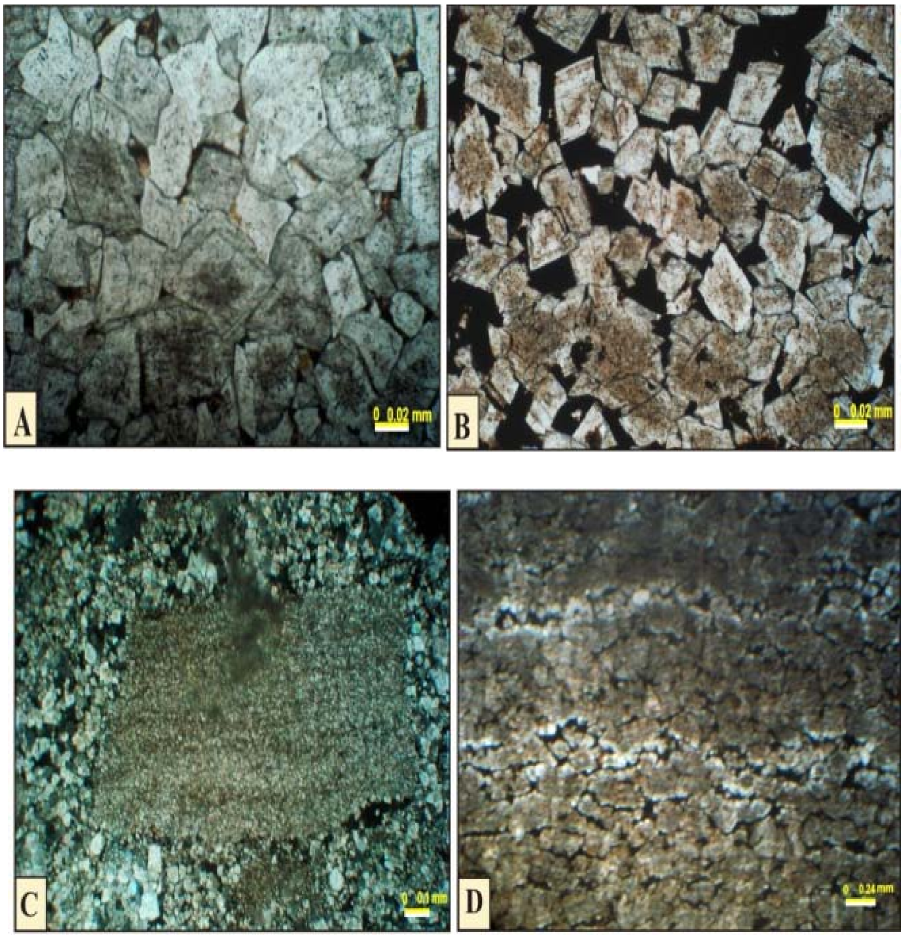

Fig.3: Dolostone lithofacies
A) Medium and coarsely crystalline dolomite
B) Bituminous medium and coarsely crystalline dolomite
C) Bituminous fine to medium intraclastic dolomite showing laminated intraclasts
D) Laminated coarsely crystalline dolomite

– **Bituminous Siliceous Rock:** Petrographic investigation reveals that the silica is considered as the main component with a 67%. It occurs as spherical bodies consisting of chert spherules and *Radiolaria* sp., fine to medium crystalline quartz and chalcedony. Other components present are bitumen matter 30% which occurred as inclusion within spherical bodies and as impregnated in the form of homogenous penetration. The rock encloses many veinlets filled by clear secondary calcite 3%. The main diagenetic changes are silicification and cementation of veinlets (Fig.4B).

▪ **Shale Lithofacies**

This lithofacies was not studied petrographically. In the studied area, some of the rocks of the Sarmord Formation are interbedded with dark brown shale. The shale is mostly fissile, breaking into sheets. The presence of shale with carbonate or non-carbonate rocks indicates deposition in relatively deep water below wave base.

Figures (6, 7, 8, 9 and 10) show the lithologic sections for Sarmord Formation in the studied area.

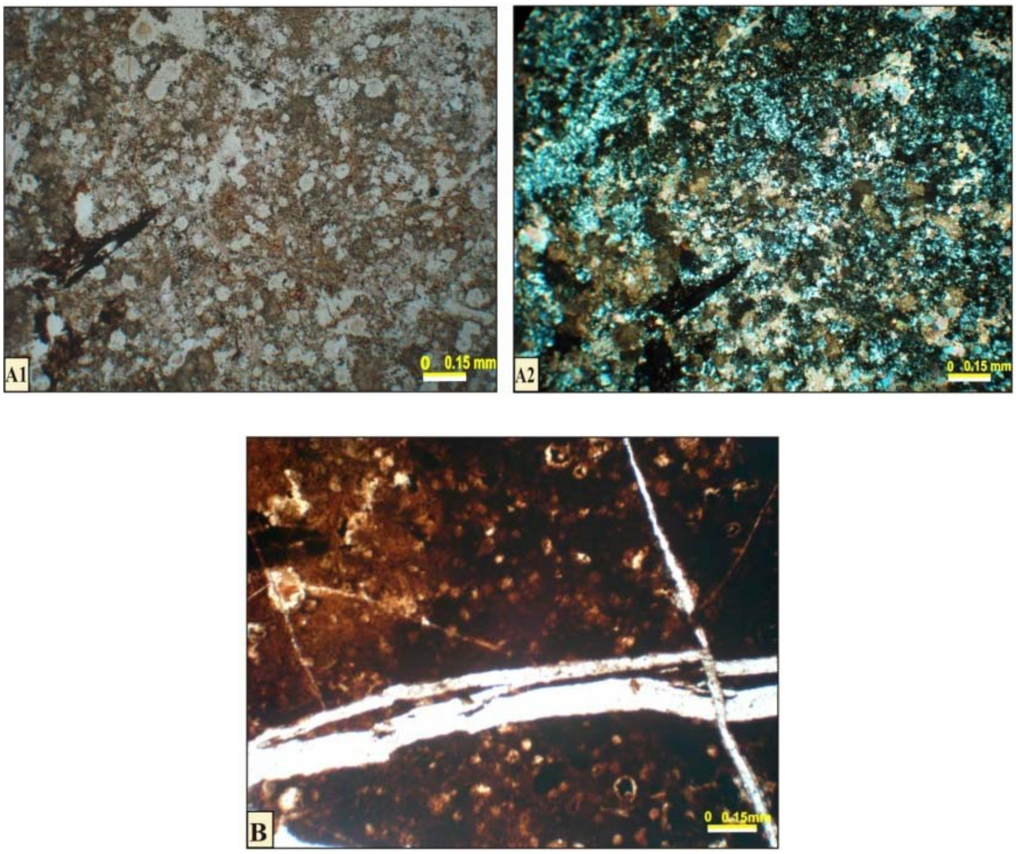

Fig.4: Siliceous rock
A1) Dolomitic siliceous rock composed of chert nodules and *Radiolaria* sp. preserved as microquartz, megaquartz and chalcedony in PPL
A2) The same as A1, but in XPL
B) Bituminous siliceous rock showing intersecting veinlets, filled with secondary calcite

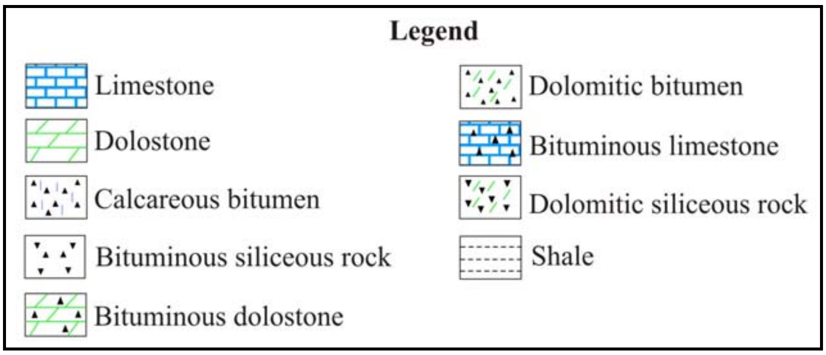

Fig.5: Legend for Figs. (6 to 10)

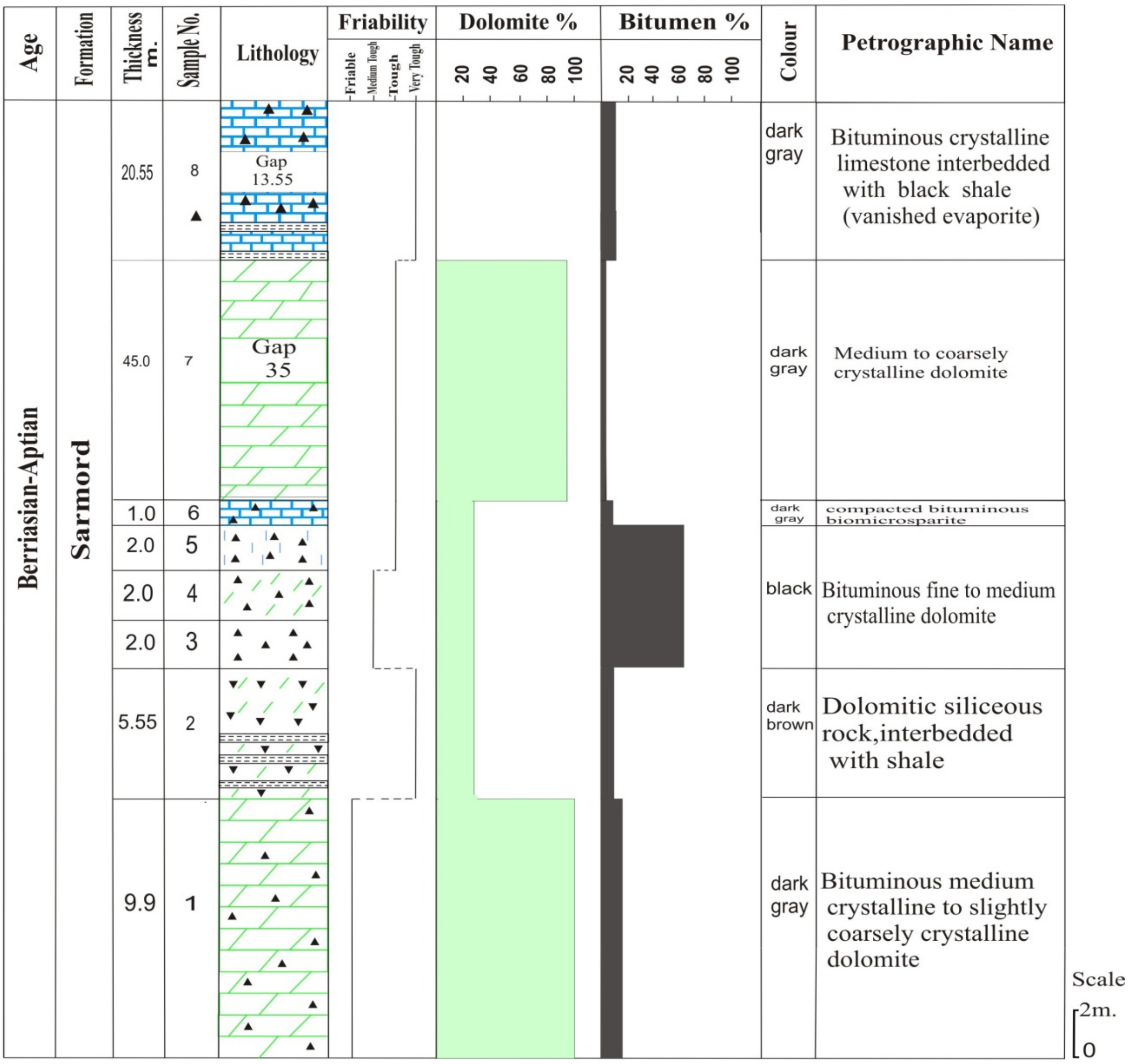

Fig.6: Lithological column showing lithofacies and distribution of dolomite and bitumen of Sarmord Formation at Banik section (BK1)

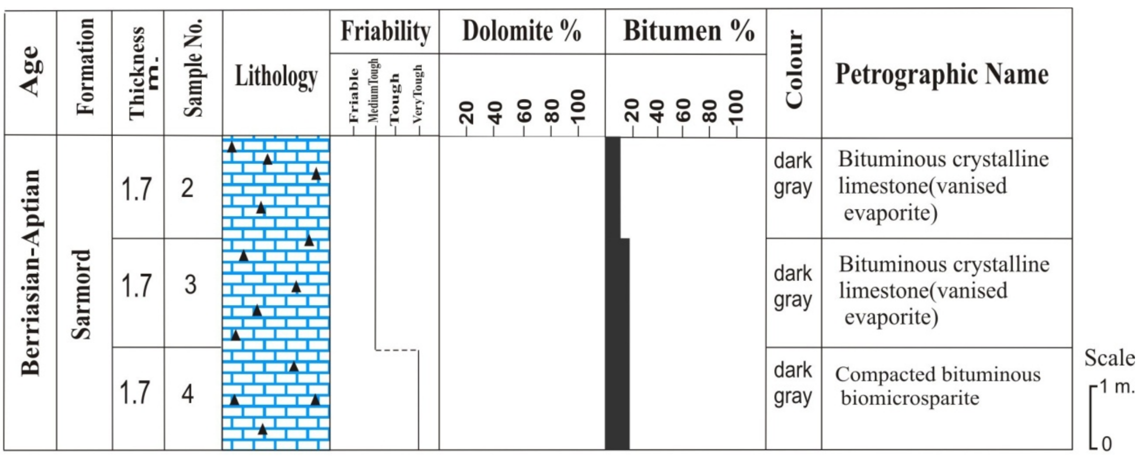

Fig.7: Lithological column showing lithofacies and distribution of dolomite and bitumen of Sarmord Formation at Afla section (AF1)

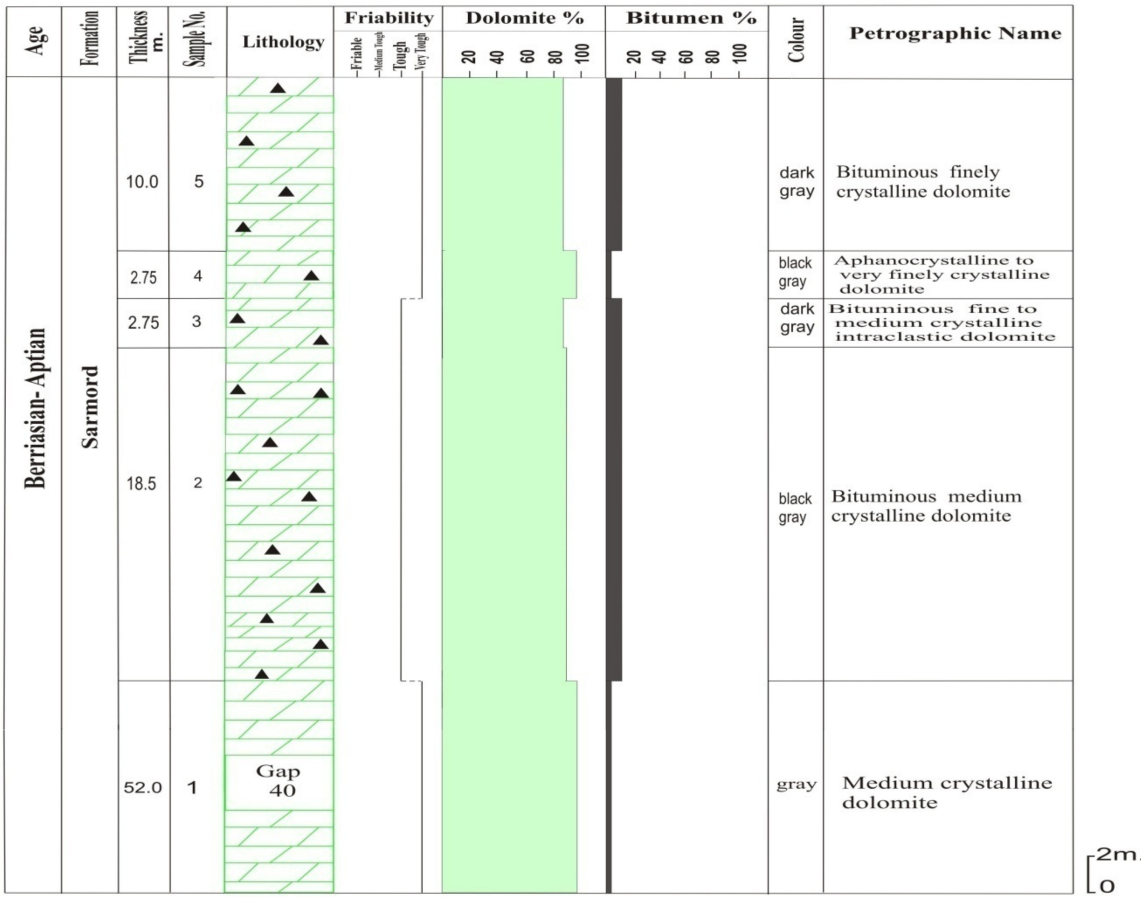

Fig.8: Lithological column showing lithofacies and distribution of dolomite and bitumen of Sarmord Formation at Pandru section (PN1)

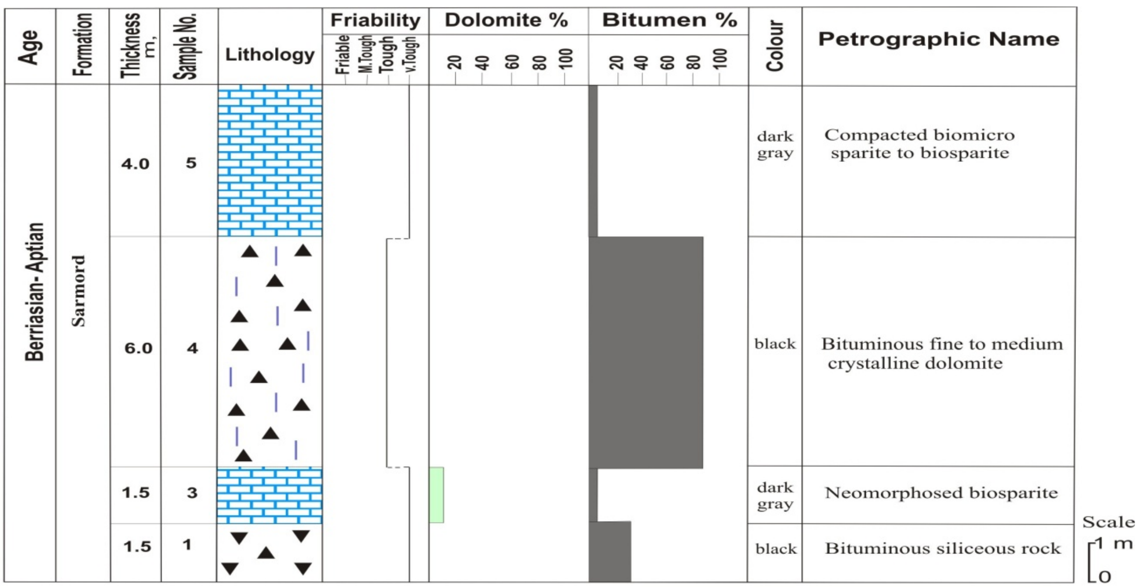

Fig.9: Lithological column showing lithofacies and distribution of dolomite and bitumen of Sarmord Formation at Gelikafshi section (GF1)

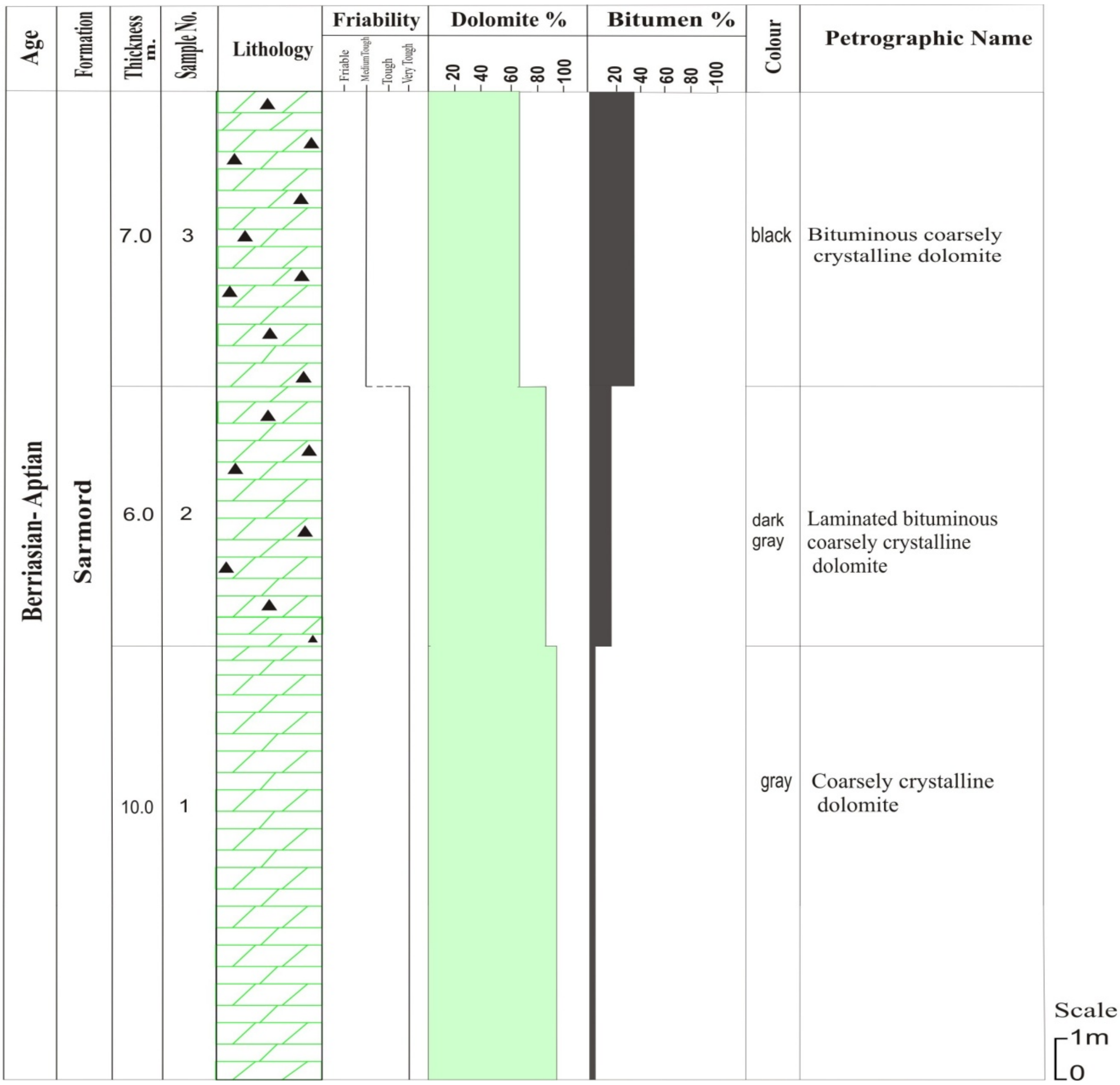

Fig.10: Lithological column showing lithofacies and distribution of dolomite and bitumen of Sarmord Formation at Perbela section (PB1/1)

DIAGENETIC PROCESSES

The study of diagenetic processes is important for several reasons. They can considerably modify sediments, both in term of their composition and texture, and in many cases, original structures are completely destroyed; as well as extremely affects sediments′ porosity and permeability properties, which control sediments′ potential as a reservoir for hydrocarbons. These processes include five types, they are described hereinafter.

- **Dolomitization**

In the present study, staining with Alizarin Red S (Friedman, 1959) and petrographic studies of thin sections have shown that the Sarmord Formation in the area under discussion is highly dolomitized and two genetic types of dolomitization are distinguished. This study also involved the origin of the dolomite.

– **Early Diagenetic Dolomitization:** This process is very limited in the study area and confirmed by the presence of aphanocrystalline to very finely crystalline dolomite and may be formed when the brine from seawater come in contact during early diagenesis.

– **Late Diagenetic Dolomitization:** This process is the dominant type and confirmed by varying crystal sizes (fine, medium and coarse) as well as most of the crystals have rhombohedral to subhedral shapes. Some of the crystals show very well developed zoning. Anhedral crystals are also present but in trace amount. In the studied area, this process is very extensive. Tucker (1981) related this process to tectonic structures; such as faults and fold axes. An important consequence of this type of dolomitization is that the porosity is increased. Dolomite has a more compact crystal structure than calcite so that theoretically the complete dolomitization of a limestone results in a porosity increase of 13% as long as there is no subsequent compaction or cementation. This feature of dolomitization is important for hydrocarbon reservoir potential.

Origin of Dolomite: Several models have been proposed to explain dolomite formation like: supratidal dolomitization, seepage reflux, evaporative pumping, mixing zone dolomitization, local source and subtidal dolomitization. Several authors (e.g. Curtis *et al*., 1963, Deffeyes *et al*., 1965, and Illing *et al*., 1965) believe that most dolostone in the geological record have formed under the influence of hypersaline solutions, moreover dolomite is often associated with evaporates. Hanshaw *et al*. (1971), Badiozamani (1973), and Folk and Land (1975) proposed an alternative model for dolomite formation. They suggested that dolomite may form most readily by a reduction in salinity, particularly in a shizohaline environment (alternating between hypersaline and phreatic mixing zone). Folk and Land (1975) noticed that dolomite crystals formed from such a model are characteristically limped (rhombohedral to subhedral). Badiozamani (1973) stated that the fact of mixing of freshwater and seawater is readily attainable under many conditions; suggesting that this type of dolomitization should be widespread and substantial volumes of ancient dolostone should be attributed to this model. This model could occur in shallow subsurface of evaporatic environment, where hypersaline brines come into contact with freshwater, and the shallow to deep burial phreatic environment, where freshwater mixes with seawater buried with the sediments. The model of mixing dolomitization as evident from the petrographic study provides that the most satisfactory explanation for the origin of most of the dolostone of the Sarmord Formation in the studied area.

- **Physical and Chemical Compaction**

This process normally occurs after burial in the subsurface and may be affected by many factors such as amount of overburden, duration of burial stress, pore water chemistry, clay content of the carbonates, pre- compaction diagenesis (early cementation and dolomitization), stability of the minerals and hydrocarbon liquids. In the present study, the limestone lithofacies is subjected to both of physical and chemical compaction. The criteria used to estimate the effect of physical compaction is the preferred orientation of the components of the rocks parallel to the bedding, whereas the chemical compaction is represented by the presence of stylolites (Fig.11).

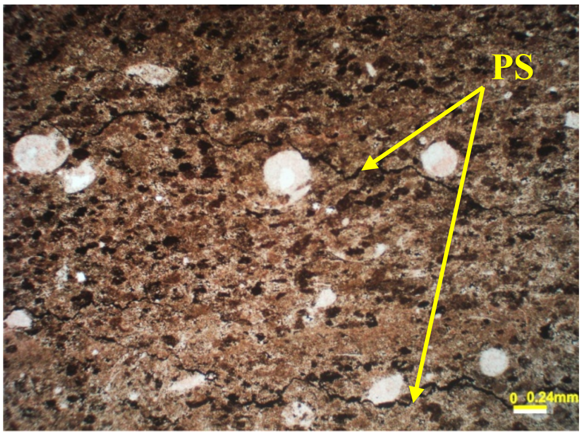

Fig.11: Parallel sets of low peak amplitude stylolites lining
with bituminous material (PS)

The main kinds of stylolites recognized in our study are horizontal, irregular low peak amplitude and parallel sets of horizontal stylolites; depending on classification of Logan and Semeniuk (1976). These stylolites are filled with bituminous materials and generally regarded as the result of pressure solution involving solutions around points of contact between adjacent grains in response to pressure (usually the weight of the overburden) and also affected by tectonic pressure as most of these rocks contain many veinlets filled with secondary calcite (Wanless, 1979).

▪ **Neomorphism**

Neomorphism includes all the in-situ transformation, by solution re-precipitation, between one mineral and itself or a polymorph (El-Saiy and Jordon, 2007). These transformations involve inversion of aragonite to calcite and mainly calcite to calcite "recrystallization" (Bathurst, 1983). This process affects both dolostone and limestone lithofacies.

– **Neomorphism of Limestone:** Two types of neomorphism processes are recognized in the carbonate rocks of the study area, inversion and recrystallization.

Inversion: This process involves transformation of aragonite to calcite by solution and in situ precipitation in an aqueous environment. This process is indicated by the preservation of the original shell fragments by fibrous and sometimes by fibrous and radial calcite. In the studied area, the inversion commenced during deep burial mainly caused by the unstable nature of the aragonite.

Recrystallization: Most recrystallization processes in the studied area are of aggrading type in which coarse crystals grow at the expense of the finer crystals. This process is mostly observed in limestones that are affected by compaction, so it is expected to occur in deep burial diagenetic environment. The alteration product of micrite (< 4μ), has been called microsparite (4 – 10 μ) and sparry calcite (> 10μ). Friedman (1964) agree that where microsparite and sparry calcite form the groundmass; it is most probably resulted from recrystallization of originally micritic matrix and most authors agree that, recrystallization begins in the matrix and latter attack the fossils as a result, most of them remains as ghosts.

– **Neomorphism of Dolomite:** This process includes increase in size from aphanocrystalline dolomite to very finely crystalline dolomite and also fine dolomite into medium and coarsely crystalline dolomite. This process either partially or wholly affects the dolomite rocks. The shape of the dolomite crystals is also included within this process. In the studied area, most of the fine and medium crystals are euhedral rhombs to subhedral, with patches of coarse crystalline anhedral dolomite. This relationship suggests that the anhedral dolomite is the product of neomorphism of euhedral and subhedral dolomite. Gregg and Sibley (1984) stated that the euhedral dolomite is produced below a critical roughening temperature (< 50º C), while the anhedral dolomite formed from neomorphism of euhedral and subhedral dolomite at elevated temperature, above the critical roughening temperature (CRT) after burial. Shukla (1986) has suggested a revision downward to about 35º C.

- **Leaching and Porosity Development**

Porosity is lost or reduced through cementation, compaction and pressure solution and gained through solutions, dolomitization and tectonic fracturing (Murray, 1960) and (Choquete and Pray, 1970). Several types of pores of secondary types are recognized in Sarmord Formation:

– **Intraparticle Porosity:** It occurs within individual particles or grains, particularly within the skeletal grains. This is caused by partial solution of fossils (Fig.12A).

– **Intracrystalline Porosity (dolomolds):** This type of porosity is indicated by the presence of rhombic pores randomly scattered throughout the groundmass (Fig.12B). It is commonly produced by solution of calcite constituents or by dedolomitization through contact with meteoric groundwater (Evamy, 1967).

– **Fractures and Veinlets:** These pores may be formed through pressure solution and tectonic movements. In siliceous rich rock, they are also common and formed in deep marine diagenetic environments (Fig.12C).

– **Intercrystalline Porosity:** This type of porosity arises from the pore space between dolomite crystals. The pore space can be partially or wholly filled with bituminous materials, thus reducing the intercrystalline porosity.

– **Vugs:** This type of porosity represents solution enlargement of fabric-selective pores presumably due to interface of meteoric water with seawater in subsurface environment.

- **Cementation**

The rocks are cemented by two types of minerals; calcite and dolomite.

– **Cementation by Calcite:** The major types, which can be recognized is the granular calcite mosaic, which is composed of more or less equi-dimensional crystals. Bathurst (1958) used the term granular to refer to cement between particles only. This however, does not always seem to be the case and granular mosaic is a common cavity fill such as veinlets, biomolds, vugs, and intercrystalline as well as a cement between allochems. He also found that this type of cement has taken place in several different diagenetic environments and over a lengthy period, usually after compaction in submarine environments, in subaerial environment; also in deep marine environment. In the studied area, the possible sources for $CaCO_3$ are found due to the pressure solutions within limestone, which is required to produce partial to full cemented limestone, as well as solution of $CaCO_3$ mainly of skeletal grains aragonite from calcareous shale interbedded with the limestone.

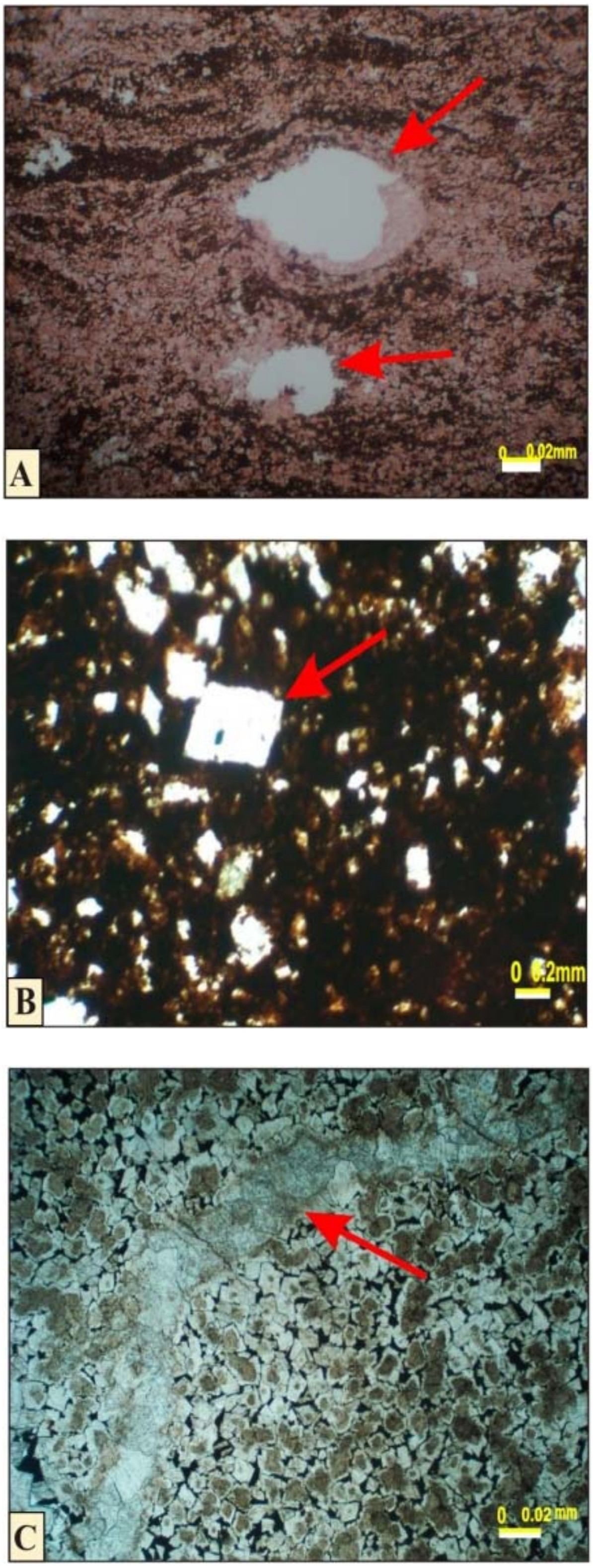

Fig.12: Leaching and porosity development
A) Intercrystalline and intrapartical porosity
B) Intracrystalline porosity (dolomolds)
C) Fracture filled with clear anhedral to rhombohedral of coarse crystals of dolomite cement

– **Cementation by Dolomite:** In the studied rocks, medium to coarse rhombohedral and subhedral clear dolomite crystals are found to fill fracture and vugs in most of the rocks of the dolostone lithofacies (Fig.12C). Dolomite occurs as pore filling indicate precipitation in shallow subsurface burial diagenesis.

▪ **Silicification**

In the present study, the silicification took place during late diagenesis. It takes the form of selective replacement of dolomite crystals and replacement of fossils as well as the development of chert fragments. The main types of diagenetic silica are microquartz as found in chert fragments and radial chalcedonic quartz, which occurs in a radiating arrangement forming a spherulitic growth structures as filling pores (Fig.13).

In the case of selective replacement of dolomite, the silica is most probably formed from groundwater mixed with sea water. In deeper environment, the radiolarian is considered as the main source for silicified shell fragments and development of chert fragments.

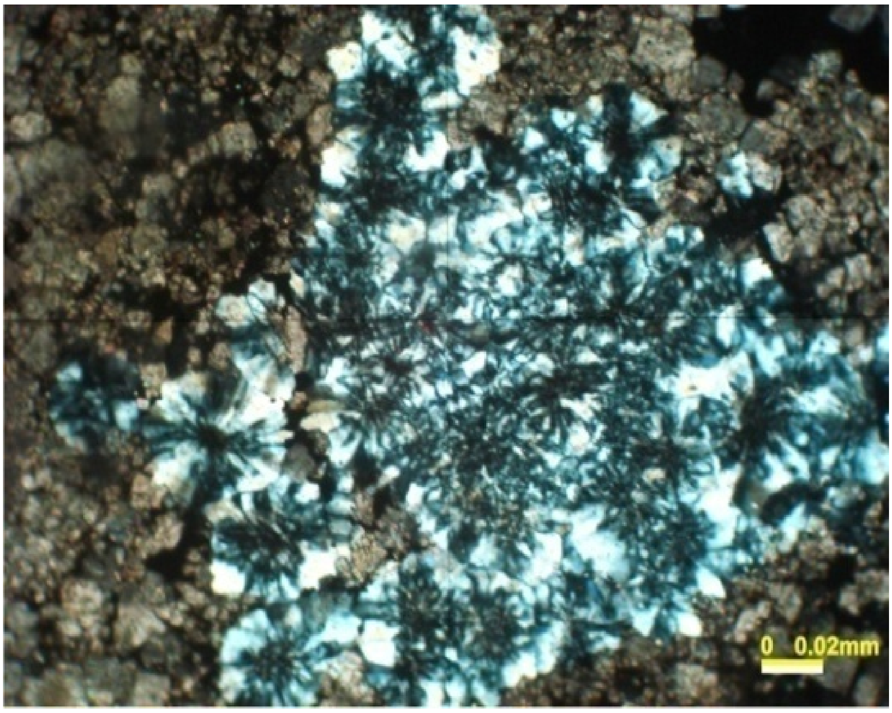

Fig.13: Selective silicification showing chalcedonic silica occur in spherulitic growth structure and in radiating arrangement

▪ **Calcitization (Vanished Evaporite)**

Calcitization of former sulfates is very common in the rocks of the study area. The crystal shapes of the original evaporite minerals are usually retained on replacement to produce pseudomorphs. Pseudomorphs of gypsum are easily recognized by their lenticular, lozenge, rosettes and feathery shapes. The authors believe that such replacement takes-place in shallow subsurface of evaporatic environments.

DEPOSITIONAL ENVIRONMENT

In the study area, the depositional environment was difficult to deduce due to the late diagenetic processes which severely affected the original textures and structures of the rocks as well as fauna. However, few fossils such as cephalopods in compacted biomicrosparite to sparite, pelecypods in neomorphosed biosparite and radiolarian in siliceous rocks are encountered. The presence of such fauna may indicate deep shelf margin environment of normal salinity (Flugel, 1982). Also the presence of some characteristic features such as chert fragments, spherical calcareous bodies in compacted bituminous biomicrosparite, the formation of bitumen and the presence of shale are related to the SMF-3 of Wilson (1975). He believed that such fauna and lithology characterize deep shelf margin (facies belt 3) as shown in Fig. (14). According to the above discussion, the Sarmord Formation might belong to the deep shelf margin of normal salinity.

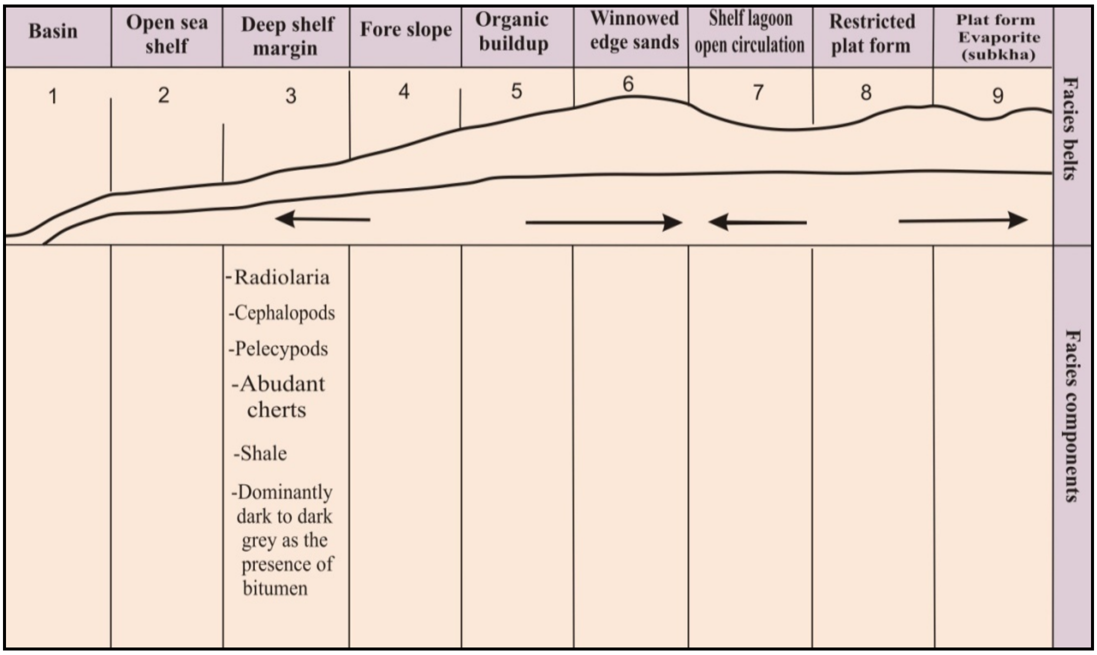

Fig.14: Depositional environment of Sarmord Formation and their facies characteristics depending on facies scheme (after Wilson, 1975 and Flugel, 1982)

CONCLUSIONS

The detailed petrographic study of the Sarmord Formation indicated the following results:

- The formation contains thick beds of dolomite especially in Banik, Shiranish, Perbela, and Pandru localities. The presence of high quality of dolomite in the aforementioned localities may be suitable for industrial purpose as building materials and also it can be used for refractory furnace linings and a source of carbon dioxide. In Gelikafshi locality, the dolomite is less common and rare in Afla locality.
- The most important occurrences of bitumen lie in Shiranish and Banik localities and less important locality in Gelikafshi. The bitumen is used mainly for paving roads, as waterproof substance and as low-grade fuel.

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