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Original Research

Study of facies and sedimentary environments of upper Devonian and carboniferous deposits in Abadeh area, Fars province, Iran

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ABSTRACT:

The aim of this research is to investigate facies and sedimentary environment of post-Devonian deposits and pre-carboniferous in Esteghlal Fireclay Mine in Abadeh, surrounded by Zagros Mountain. With a production of about 1 million tons per year, it has the largest reserves of fireclay in the Middle East. After choosing three stratigraphic sections of A, B, and C, and taking 250 samples manually, 10 facies belonging to five facies groups in tidal flat, lagoon, dam, open marine, and delta facies were identified; these 10 facies are: facies 1 (Mudstone with fenestral fabrics), facies 2 (Stromatolite bindstone), facies 3 (Wacke stone / Pelloid Bioclast Pack stone with various fossils), facies 4 (Packstone / Bioclast Grainstone) facies 5 (Packs tone / Bioclast grain stone with intraclast), facies 6 (Pack stone / Echinoid grain stone), facies 7 (Echinoid and Bioclast brachiopod rudstone), facies 8 (Pack stone / bioclast Wacke stone with various fossils), facies 9 as a Clastic facies (Silt stone), facies 10 as a Clastic facies (lichens). The ancient geography situation of this area can be explored through interpreting and an examining this micro-facies. Stratigraphic section (A) with 60 m thickness represents the sedimentation in deltaic environment outside the water (deltaic plain), stratigraphic section (B) with 120m thicknesses represents the sedimentation in deltaic environment underwater (forefront and end of the delta). Carbonated deposits in stratigraphic section (C) with 75m thicknesses is related to a carbonated platform type (Homoclinal ramp).

Keywords

Abadeh, sedimentational environment, facies, facies groups.

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INTRODUCTION

The great part of Abadeh is located in the central Iran. In the studied area, the common boundary of this field with Sanandaj Sirjan field is covered with alluvium and it is not distinguishable completely. According to the topography of the area, the slope and thickness of penetrated layers show that this boundary is over the thrust fault of Abadeh-Surmaq. Esteghlal Fireclay Mine in Abadeh with a longitude of 53 degrees and 42 minutes and latitude of 31 degrees and 55 minutes located in 218 km southeast of Isfahan and 10 km of the northeast of Abadeh (Figure 1 and 2).The area of the mine is approximately 15 square kilometers. It is surrounded by Zagros mountain range. With a production of about 1 million tons per year they have the largest reserves of fireclay in the Middle East (GSI, 1978). In the studied area, penetrated stones are unique to sedimentary and volcanic rocks including stratigraphic rows that range from Devonian-Carboniferous to Quaternary excluding a few sedimentation intervals. Morphology of the area is heavily affected by regional constructions and the nature of penetration's petrology. There is a significant height difference in the region that high protuberance and lowland show the morphology of the region. The direction of all protuberances is NW-SE, which have created a distinctive geomorphologic form following Zagros Mountains and Sanandaj-Sirjanfield. In this area, various rock units are penetrated from Devonian-Carboniferous to recent era.

This study attempts to restore the ancient sedimentary environment by identifying facies. It aims to determine the ancient geographical situation of this region during the sedimentation of post-Devonian and pre-Carboniferous units. For this purpose, three stratigraphic sections are selected and sampling was carried out. The prepared thin sections of samples were studied through lithology and their components are identified and separated.

MATERIALS AND METHODS

Research Method

In the first stage, sedimentary petrology studies start from desert. In order to achieve the mentioned purpose, the desert investigations were performed (Figure 3 to 7). During the sampling, the criterion of selecting the location of samples was facies changes in the first place, and in the absence of change, the

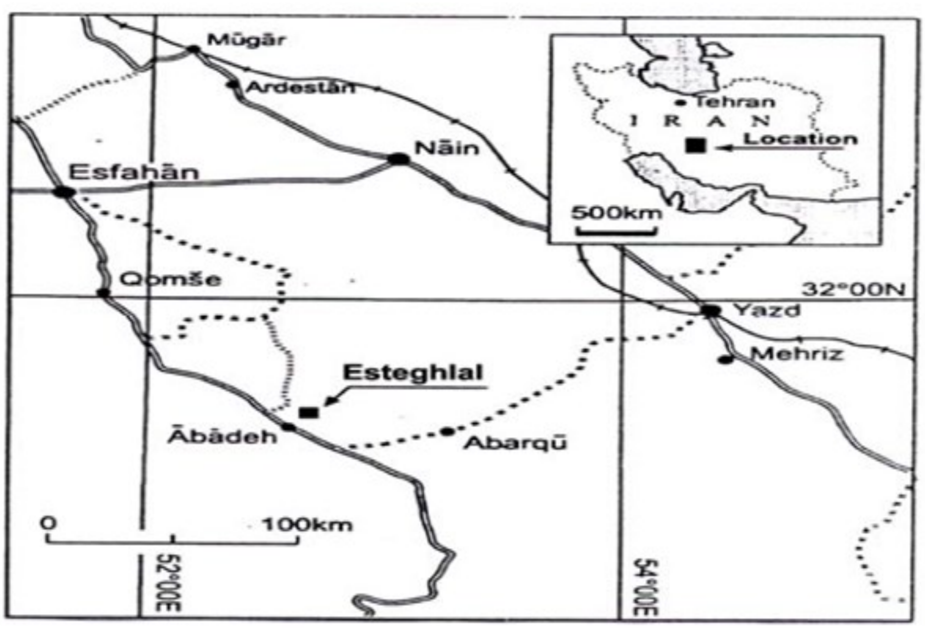

Figure 1. Map of access to the studied area (GGCI, 2001)

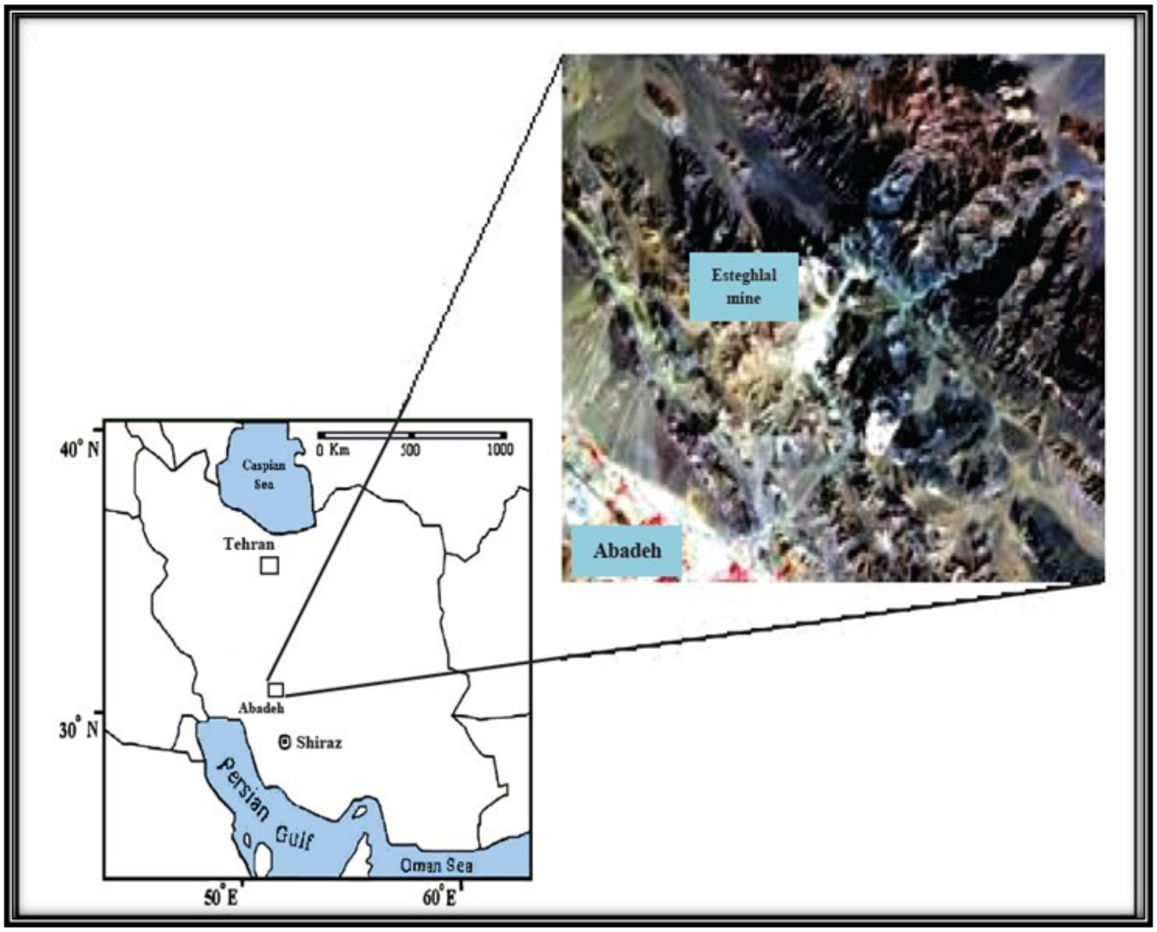

Figure 2. Geographical position of the study area

criterion was more or less uniform is intervals. In the field, 250 samples of stratigraphic sections were selected for providing thin and polished sections. All 250 samples of stratigraphic sections were examined by polarizing microscope to identify facies (Figure 8), and the stratigraphic column related to stratigraphic sections were drawn (Figures 9 to 11).

RESULTS AND DISCUSSION

Microscopic and macroscopic surveys of samples in the studied area have led to identification of eight carbonated micro-facies and two main clastic micro-facies.

The results show that the facies place in four group of open marine, lagoon, tidal flat, and deltaic environment. Each group indicates its environment and possibly its own sub-environments.

A. The group of tidal facies (Tidal flat)

In the studied area, this facies has two sub-facies as follows:

A_1: Mudstone with fenestral fabrics

A_2: Stromatolite Bindstone

A_1: Mudstone with fenestral fabrics

The first facies consists of micrite and regular shaped holes. According to Demico and Hardie (1994), any hole and shape in sedimentary rock or loose sediment that have no intergranular origin are called holes or Fenestral. The holes may be empty completely or part of them may be filled by internal sedimentation or cement. The origins of the holes are:

1.Wetting and drying of carbonated muds in the upper tidal flats (Shinn, 1983).

2. Drying of the surfaces of cyanobacteria masses causes the adjacent sedimentations to rise and cut

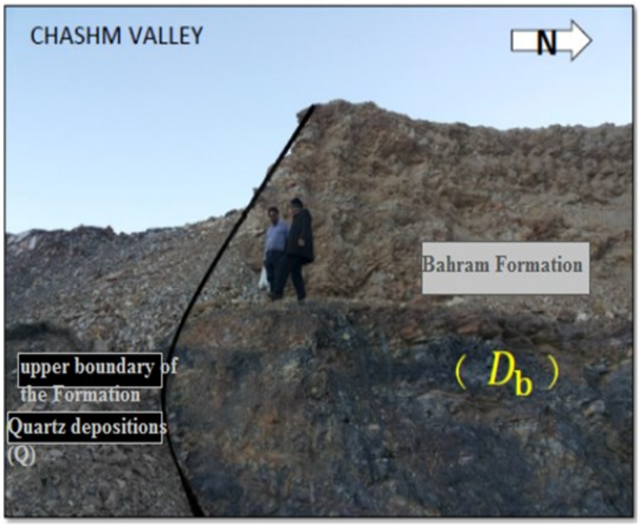

Figure 3. A view of Bahram Formation and its upper boundary with the quaternary deposits

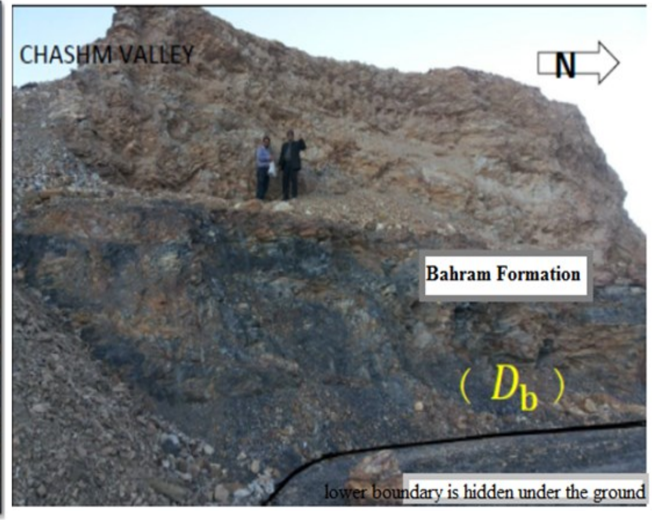

Figure 4. A view of Bahram formation and its lower boundary

(Logan *et al,* 1974).

3. Egress of gas released during decomposition of organic material, gas bubbles or trapped air during sedimentation of the host rock and excavation by worms and insects (Folk, 1980; Shinn, 1983; Flugel, 2010)

4. Evaporating molds (Flugel, 2010).

5. Deformation of soft sediments (Folk, 1980).

Mudstone micro-facies with fenestral fabrics is the characteristic of pre-tidal environment (Greensmith, 1976; Tabakh and Utha-Aroon, 1998; Shahkarami *et al*., 2007; Adabi and Mehmandousti, 2008; Flugel, 2010). In the observed sections, bird's-eye or fenestral fabrics is seen as millimeter cavities filled by calcite and the holes on supra-tidal sediments are made during expansion and contraction of deposits and gas bubbles of decaying organic matters and wrinkling of algal masses. It is notable that, mudstone indicates the sedimentation of fine-grained sediment under the condition of low energy which allows the carbonate mud to deposit in calm waters (Folk, 1980; Tabakh and Utha-Aroon, 1998;

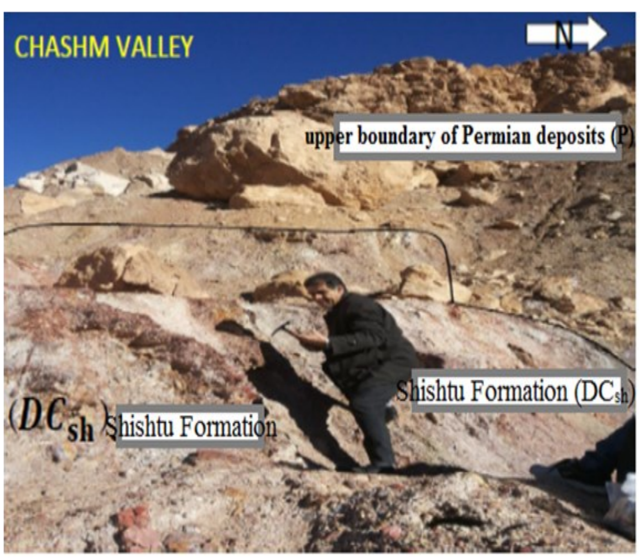

Figure 5. A view of Shishtu formation (DCsh) and its upper boundary

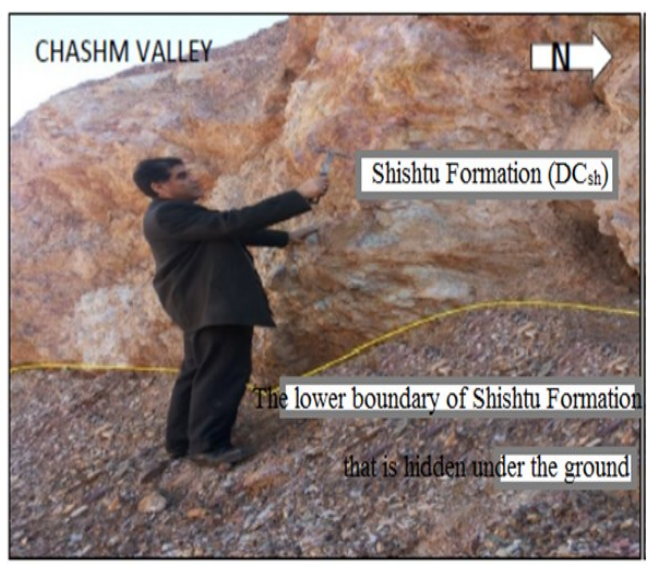

Figure 6. A view of Shishtu formation (DCsh) and its lower boundary

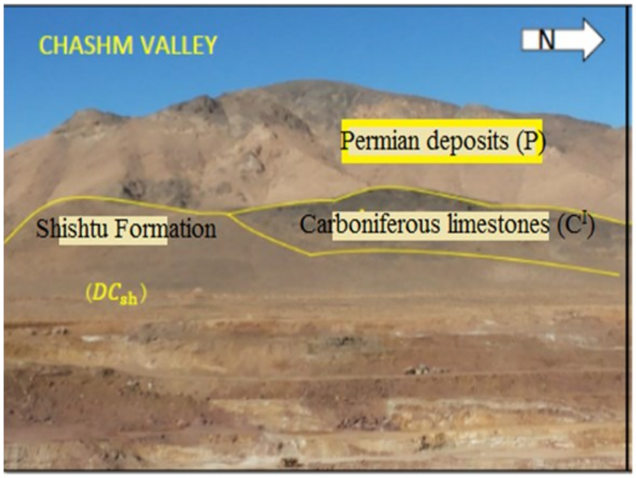

Figure 7. A view of Carboniferous lime stones (CI) and the upper and lower boundaries of this section

Tuker, 2015; Flugel, 2010; Chen *et al.*, 2011). Moreover, fine-grained carbonates can be made by sedimentation of micro crystal carbonate cements (Reid *et al.*, 1992; Weaver, 1989).

Mudstones are formed in two ramp part: lagoon and pre tidal area. The absence of phenomena such as structures that are made by drying, tepee structure, fenestral structures, intraclass, cutting, algal masses (evaporates minerals and microbial) and dolomicrites showed that mudstones were made in lagoon area and not a pretidal one (EL-Azabi and EL-Arabi, 2005; Amirshahkarami *et al.*, 2007; Flugel, 2010; Tavakoli *et al.*, 2010; Sabouhi *et al.*, 2009) (Figure 12).

A_2: Stromatolite bindstone

The lime stones, which their formation depend on bottom dwellers, are called bind stone (Dunhum, 1962) or biolutites (Folk, 1959). Embry and Klovan (1971) classified bind stones as follows:

1.**Framestone**

Mass creatures build a rigid framework during sedimentations.

2. Bindstone

Flat and blade creatures encrust and bind the sediments during sedimentation such as stromatolites.

3. Bafflestone

Stem creatures act as baffles and trap the sediments during sedimentation.

The creatures that construct stromatolite bindstone facies in studied sections are algae that are placed as a flat blade and hinder micrite and skeletal grains. This microfacies consists of stromatolites laminations and are formed in calm tidal flat environments and shallow tidal areas.

Generally, bindstone microfacies are seen in riffs of platform edge on fringy plateau (Flugel's microfacies No.7, 2010) and in riff section of middle and internal ramps (ramp microfacies No.12) (Palma *et al*, 2007; Flugel, 2010).

The association of this microfacies and bioclast wackestone, limited lateral extension and low thickness showed that microfacies were formed in ramp environment. Regarding the upper and lower facies and the form of growing of creatures in the microfacies that are flat, the environment of inner ramp can be considered for sedimentation of this microfacies. It is notable that stromatolite facies are one of the distinctive faceis of tidal flat and grow in environments where they receive the most light and moisture. Such features showed that they are formed in clam environment of tidal flats (Amodio, 2006; Playa and Gimeno, 2006) (Figure 13).

B: Lagoon's facies

In the studied area, facies group in lagoon environment include carbonate facies:

B: Wackestone / Bioclast peloid packstone with various fossils

In this facies, bioclasts such as brachiopod, bryozoan, benthic foraminifera, bivalvia, ostracoda, echinoderms, gastropods and brachiopods thorn are seen in a micrite background. The frequency range of bioclasts is between 10 to 40 percent and the frequency of peloids is 30%. These facies have different skeletal and non-skeletal allochems uniformly that have been mixed. The function of digger creatures is obvious in this microfacies. This facies are formed in neritic

Table 1. Qualitative results obtained from diagrams of X ray (XRD) in Db stratigraphic section

S. No.	Sample's number	Types of identified minerals in relative frequency order (from high to low)
1	Db_3	Pyrophyllite, muscovite/ illite, kaolinite, quartz, goethite, rutile
2	Db_{11}	Pyrophyllite, muscovite/ illite, kaolinite, quartz, goethite, rutile,albite, hematite
3	Db_{21}	Pyrophyllite, muscovite/ illite, kaolinite, quartz,diaspora , rutile, hematite
4	Db_{28}	Pyrophyllite, muscovite/ illite, kaolinite, quartz, goethite,rutile, albite

shallow zone of the sea below the waves. An improper rotation of water and inappropriate living conditions cause the animal group of open marine is limited. The presence of a dark color matrix (micrite), bioturbation, the presence of gastropods and benthic foraminifera that are the indicator of lagoon zone in addition to grain-dominated fabrics and mud-dominated fabrics, and the presence of lagoon peloids showed that they are formed in the lagoon zone (Figure 14).

C: Barrier facies

In the studied area, barrier facies consist of three carbonate subfacies:

C1: Packstone/ bioclastic grainstone

C2: Packstone/ intraclast bioclastic grainstone

C3: Packstone/ echinoderm grainstone (incrinite facies)

Mud matrix is very low in all facies of this belt. High energy of the environment led to wash the mud and mud matrix and the asperity calcite cement between grains were constructed as inter-grain cement. Bioclasts may be micritized. Its sediments are formedin areas above the waves, or areas that are affected by permanent waves.

In C_2 facies, a mixture of skeletal and non-skeletal allochems (intraclasts) can be seen that most of them are round and are sorted very well and it shows the high energy of environment. The phenomenon of washing and exiting micrites among the grains were not done completely so the background of facies includes some micrite and calcite cement. The space between intra clasts is filled with micrite and calcite cement and the lack of sandstone, chert and volcanic fragments in thin sections and the absence of dolomitization phenomena and tectonic deformations in lithoclasts and uncut fossils on the border of lithoclasts showed that the type of lithoclasts in studied thin sections is intraclast. This microfacies corresponds with ramp microfacies No.24 that is formed in tidal flats (Buyukutku *et al*, 2005; Flugel, 2010). The upper and lower microfacies accompanied by this microfacies, moderate to good sorting and roundness of intracalsts confirmed that it can be formed in tidal canals and the continuous round movement of water in these canals cause to mix different allochems.

In C_3 facies, the presence of abundant skeletal

Table 2. Qualitative results obtained from diagrams of X ray (XRD) in DC stratigraphic section

S. No.	Sample's number	Types of identified minerals in relative frequency order (from high to low)
1	Dc_{10}	Pyrophyllite, muscovite/ illite, kaolinite, quartz, goethite, rutile, albite, chlorite (very low)
2	Dc_{26}	Pyrophyllite, muscovite/ illite, kaolinite, hematite, goethite, quartz, rutile
3	Dc_{31}	Pyrophyllite, muscovite/ illite, kaolinite,goethite, quartz, rutile, hematite
4	Dc_{46}	Pyrophyllite, muscovite/ illite, kaolinite, goethite, quartz,rutile
5	Dc_{52}	Quartz, pyrophyllite, muscovite/ illite, hematite, albite, rutile,anatase
6	Dc_{55}	Pyrophyllite, muscovite/ illite, kaolinite, quartz, rutile, halite, gypsum

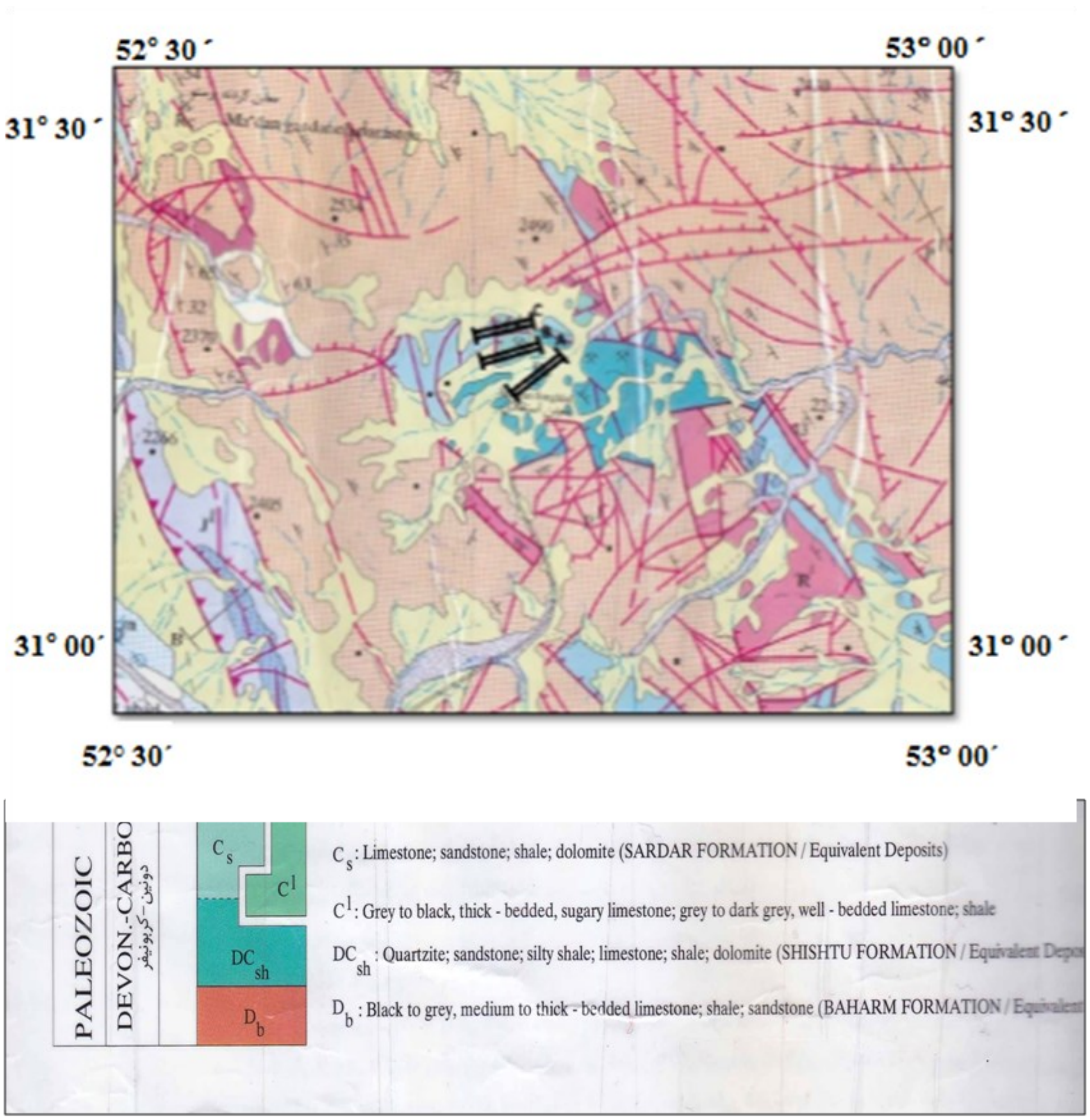

Figure 8. The geographical map of Abadeh sheet that shows the location of studied stratigraphic sections (Adapted from Abadeh map 1:100000)

components such as echinoderms which sometimes are changed to in crinite facies, more than 80% of echinoderm and coaxial cement are around them. Their sizes are more than 1 to 5 mm and skeletal fragments are sorted very well and are rounded.

Its upper and lower microfacies and the frequency of skeletal components of echinoderms showed that this facies were deposited in the vicinity of the open marine and relates to barrier environment.

Generally, barrier facies in our studied area corresponds with microfacies No. 27 (Packstone/ grainstone with dominant skeletal grains) in underwater sand stacks and platforms in internal or middle ramp (Flugel, 2010; Bassi and Nebelsick, 2010) (Figures 15 to 17).

D: Open marine facies

Open marine facies consists of two groups: deep sea facies (Basin) and continental slope facies (Slope). In the studied area, only continental slope facies are observed.

This facies group has two sub-facies as follows:

D_1: Brachiopod and echinoderm bicalstic rudstone

D_2: Packstone/ bioclastic wackestone with various fossils

Bioclastic rudstone contains brachiopod and

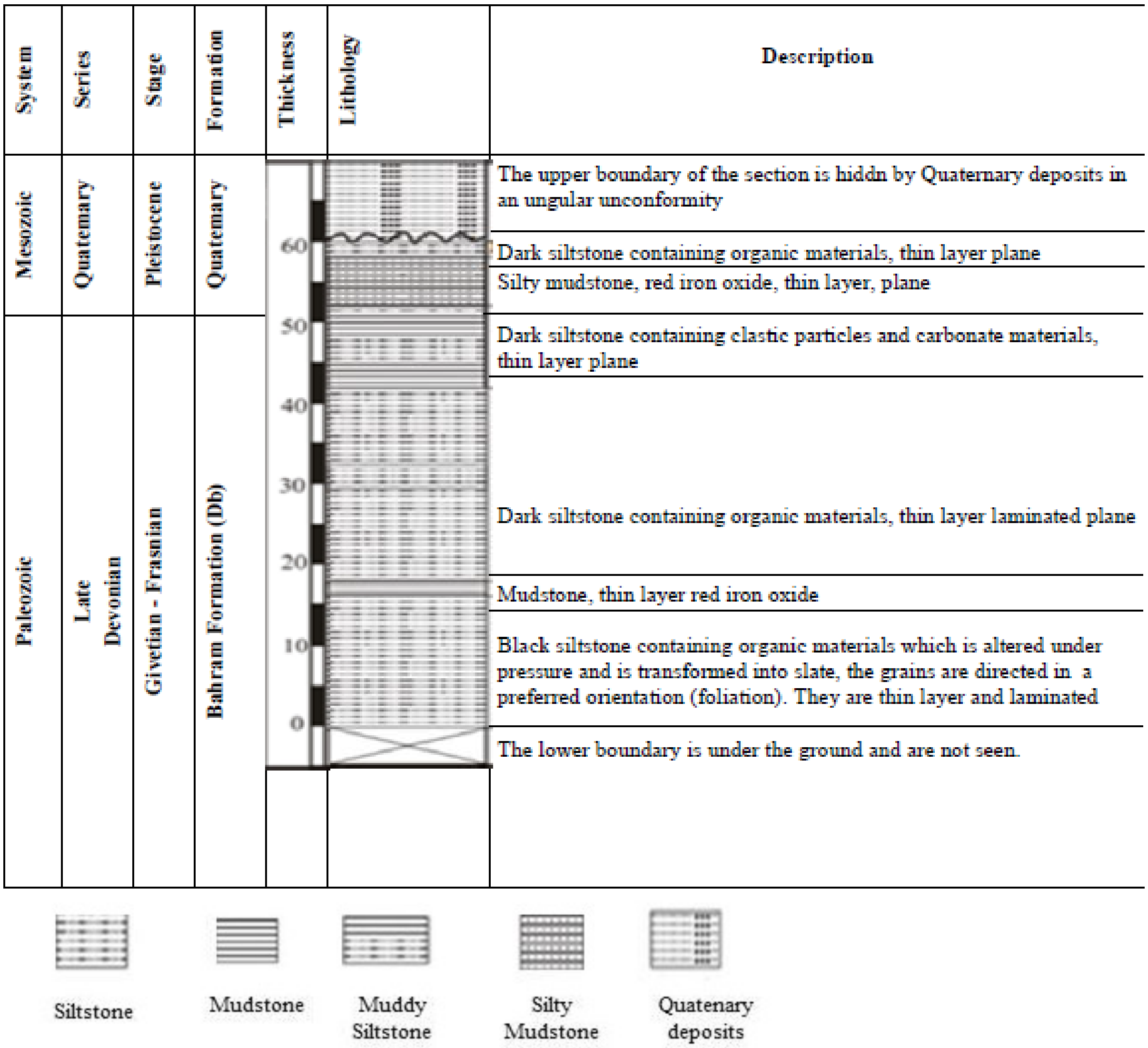

Figure 9. Stratigraphic column of bahram formation in section (A)

echinoderms and the size of more than 10% of skeletal fragments is 2 to 5 mm, and the grains and particles are in contact.

In second facies, packstone/ bioclastic rudstone contains brachiopod, echinoid, bivalve, and gastropod accompanied by shell parts; the components of various organisms are mixed uniformly in this microfacies and the function of digger creatures is obvious in the microfacies. The presence of clay and lack of clastic grains showed that these facies are formed in neritic shallow zone of the sea with free flow of water below the waves and under low energy condition. Some of bioclasts are micritized in the microfacies. The fabric and size of skeletal grains and its similarity with barrier bioclasts indicated that sedimentation is done in open marine environment near the barrier (Figure 18 and 19).

Clastic petrofacies and their sedimentary environment

A: Fine grained clastic rocks

According to Folk's classification (1974), in the studied area, the facies of fine grained clastic rocks is divided into siltstone, mudstone, fine-grained sandstone and claystone.

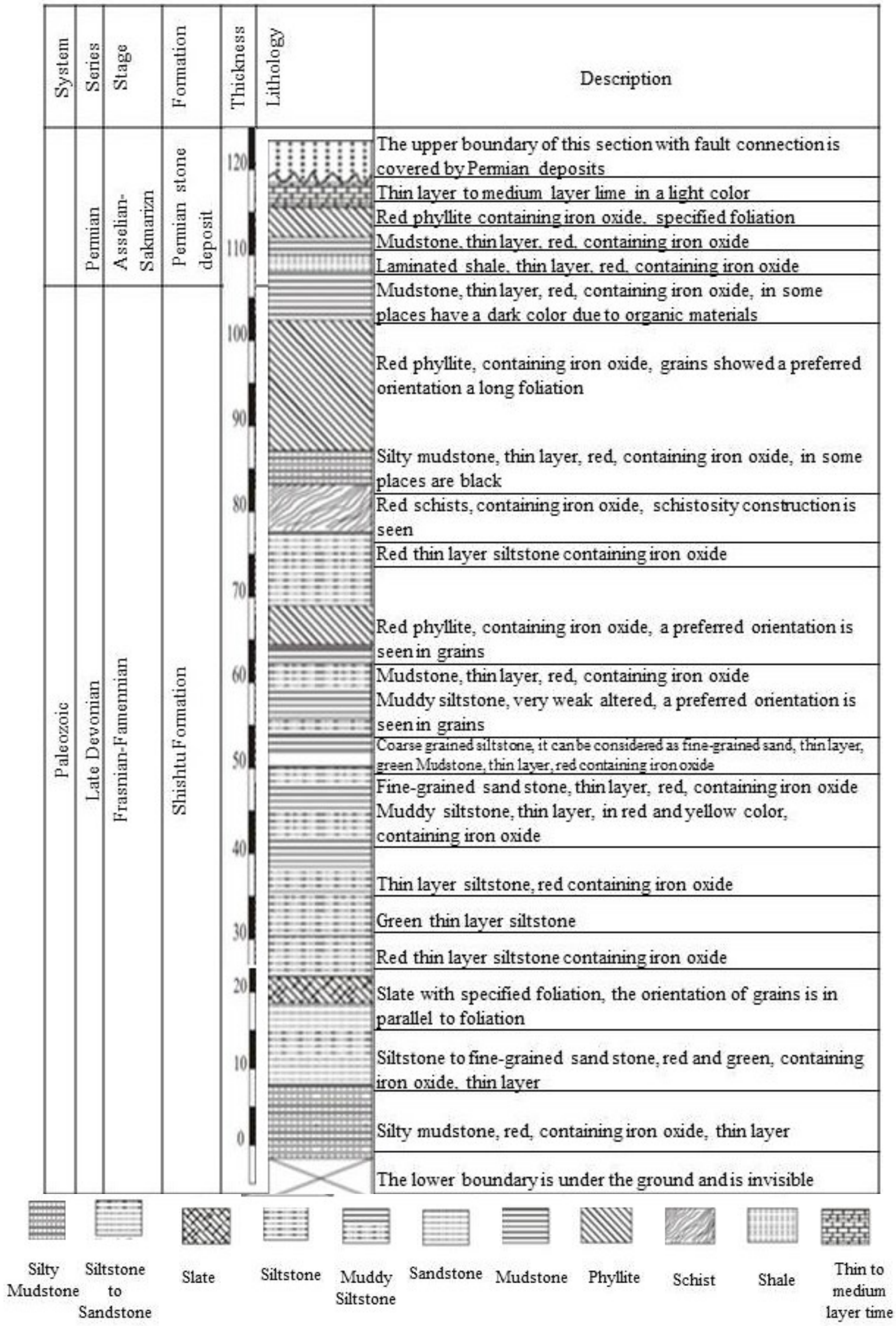

Figure 10. Stratigraphic column of Shishtu formation in section (B)

A_1: Siltstones

The size of silt varied from 1/16 to 1/256 mm. They are seen in the composition of sediments in different environment including coastal, deltaic environment with high eolian sediments, but they are not as important as sandstones and shale. Silts are less connected with each other but much involved in the construction of shale formations so that silts constitute

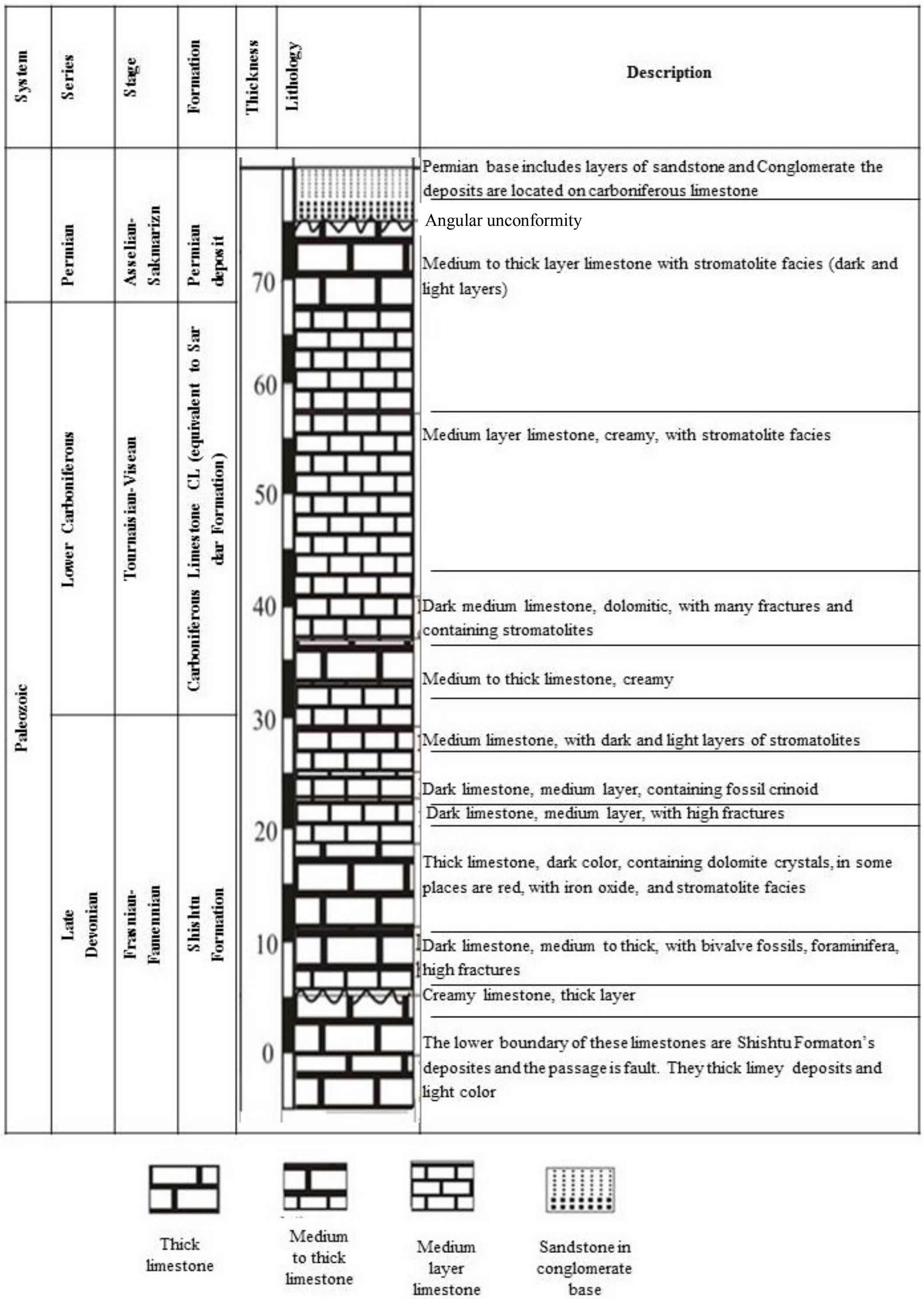

Figure 11. Stratigraphic column of carboniferous lime stones in section (C)

½ to 1/3 of shale's volume. Siltstones are the hard kind of silt accompanied by matrix. The percentage level of silt grain is more than 90% compared with sand, and the proportion of clay and silt is more than 1:2 (Folk, 1974). In the studied area, this category of fine-grained clastic rocks in microscopic thin sections contain 65% to 70% of quartz particles as big as silts, and 15 to 20% of other grains that have the same size (such as biotite, muscovite, complex clay, carbonaceous material, and iron minerals), about 7% to 9% of quartz grains have

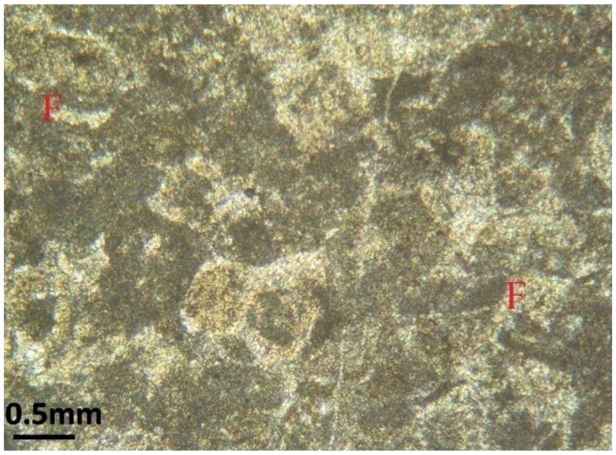

Figure 12. Microscopic view of mudstone with fabric fenestral (F) in natural light, fenestrals (F) have irregular shapes. The representative of supratidal environment

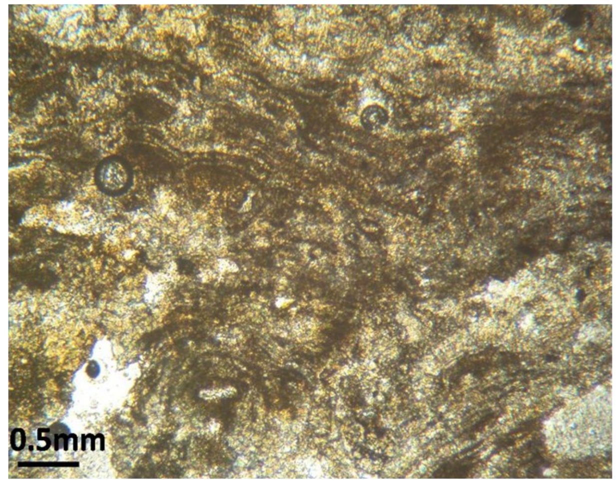

Figure 13. Microscopic view of stromatolite lime stone (stromatolite bind stone) in natural light, the representative of inter tidal environment

equal size with very fine-grained sand and 20 to 25% of them are clay minerals, chlorite, kaolinite, micrite. The sorting and texture handling is poor to moderate. The effects of lamination and bioturbation are seen in most samples especially those which have high percentage of clay and organic matter. Given its extension, high thickness, the placement and relation to stratigraphic sections (C), and according to Lunau *et al*. (2005)'s Law that states the unit sets of sedimentary sequences that lay laterally adjacent to each other relates to adjacent sedimentational environment and based on the evidence of deltaic environment, sedimentational environment relates to tidal deltaic environment and coastal tidal flat environment (Figure 20).

A_2: Mudstones and clay stones

These clastic stones in the studied area show themselves as mud and clay siltstones in thin microscopic sections, and sometimes they are formed as complete mudstone. Due to the presence of organic materials, the separation by polarizing microscope is difficult but it was done with the help of couriers of

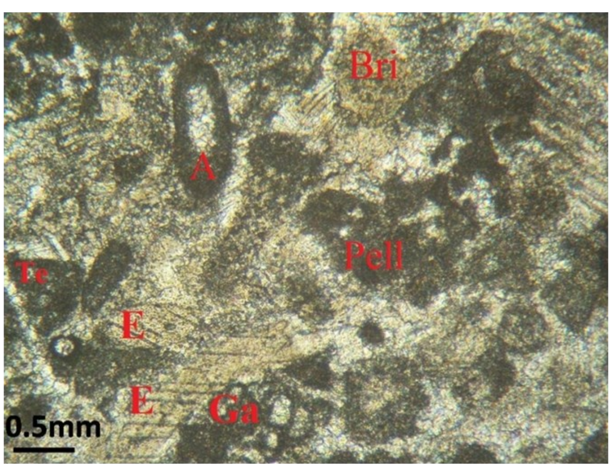

Figure 14. Microscopic view of wackestone–peloid bioclast packstone containing gastropod (Ga) with a micrite cover, parts of echinoidea (E) and Tetra taxis foraminfra (Te) that are completely micritized, brachiopods thorn (A) and peloid (P11), the representative of lagoon environment

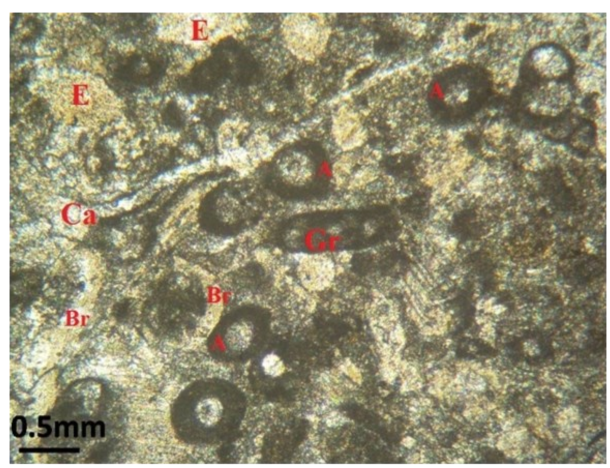

Figure 15. Microscopic view of Pack stone–bioclastic grain stone containing brachiopods thorn (A) that is micritized, fractures filled with sparic calcite (Ca), echinoderm components (E), echinoderms, brachiopods components (Br) and Grapestone (Gr), the resentative of barrier environment in C1subfacies

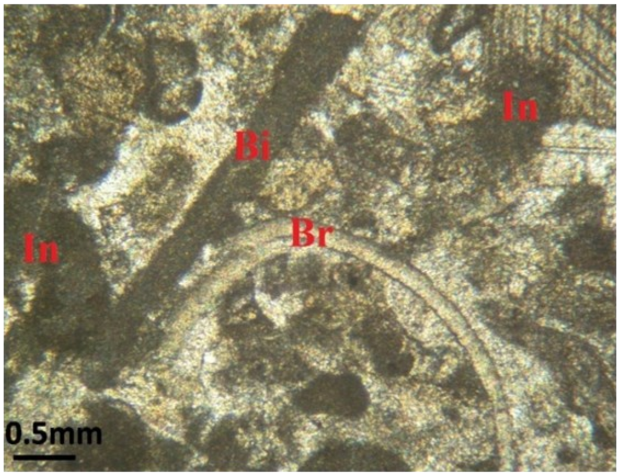

Figure 16. Microscopic view of Pack stone– bioclastic intraclasts grain stone with sparite cement containing full micritized Bivalves (Bi), micrite intraclasts (In), brachiopods (Br), the representative of barrier canals, C_2 subfacies

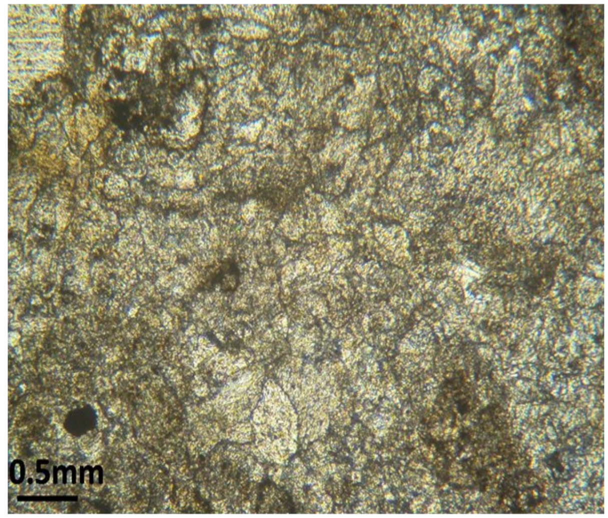

Figure 17. Microscopic view of pack stone- echinoderm grainstone (incrinite facies), the representative of barrier environment, C_3 subfacies

XDR (the study of clay minerals), as chlorite and kaolinite clay minerals was detected in microscopic study, the couriers of XRD ray confirm this issue. Generally, fine to very fine-grainedstones (siltstones and mudstones-claystones) in the studied area are in the form of thin layer calcareous shale with red, yellow, dark gray to black color and sometimes have clay-lime form containing organic materials that are laminated. But mudstones in thin sections are in the form of muddy siltstones (siltstone –mudstone). Generally, this group contains 40% to50% of quartz in the form of silt and clay, about 50% of clay – micrite matrix with organic materials, 30% to 50% of iron oxide, 10% to 15% biotite and muscovite and other components, and sometimes the effect of lamination and biotic disturbance are obvious in it. According to mentioned reasons, the placement and its relation with siltstones which includes these sediments, and according to Smoot (1983), there are three ways to determine the sedimentational environment of fine-grained sediments (shale):study of diffusion and distribution of different

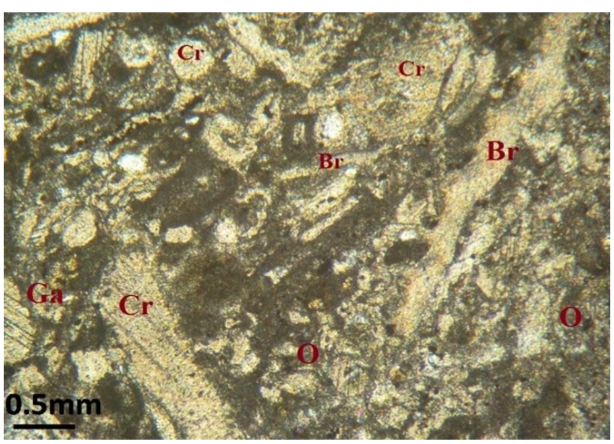

Figure 18. The microscopic view of brachiopod and echinoderm bioclastic rudstone containing parts of echinoderm (Crinoid, Cr), brachiopod (Br), gastropod (Ga) and ostracods (O), the representative of open marine environment, subfacies D_1

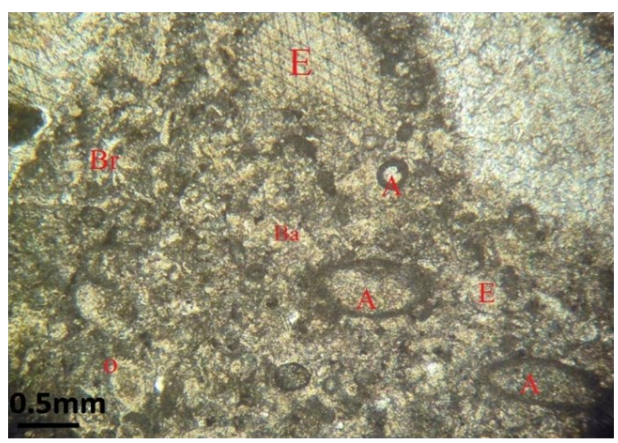

Figure 19. Microscopic view of packstone-bioclastic wacke stone with various fossils containing parts of echinoderm (E), brachiopod (Br), ostracods (O), brachiopod thorn (A) and bivalves (Ba), the representative of open marine environment, subfacies D_2

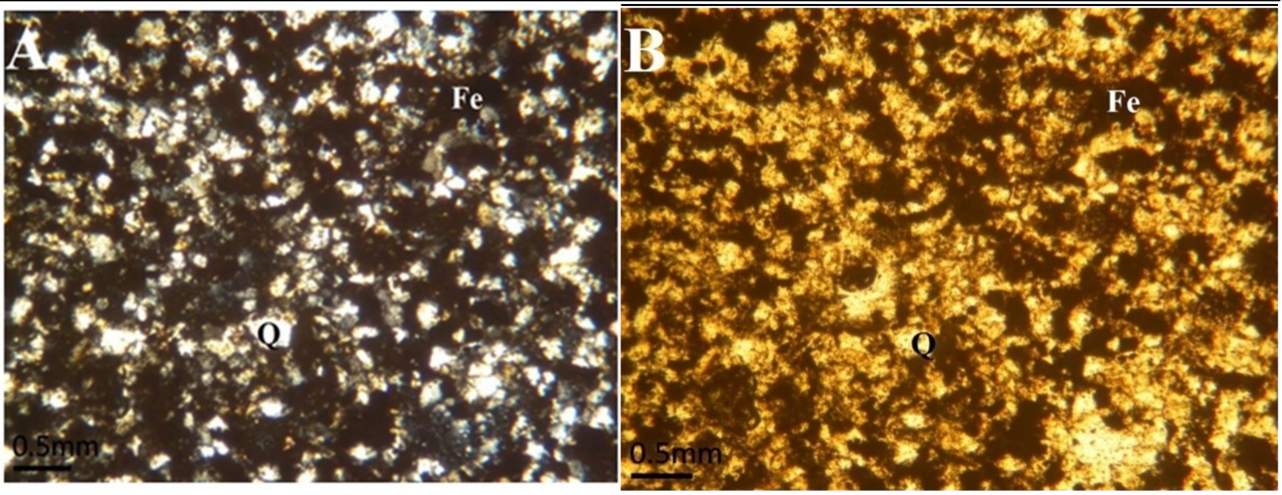

Figure 20. Siltstone microfacies, fields containing iron oxide (hematite), clay minerals and micrite, polarized light (A) and natural light (B)

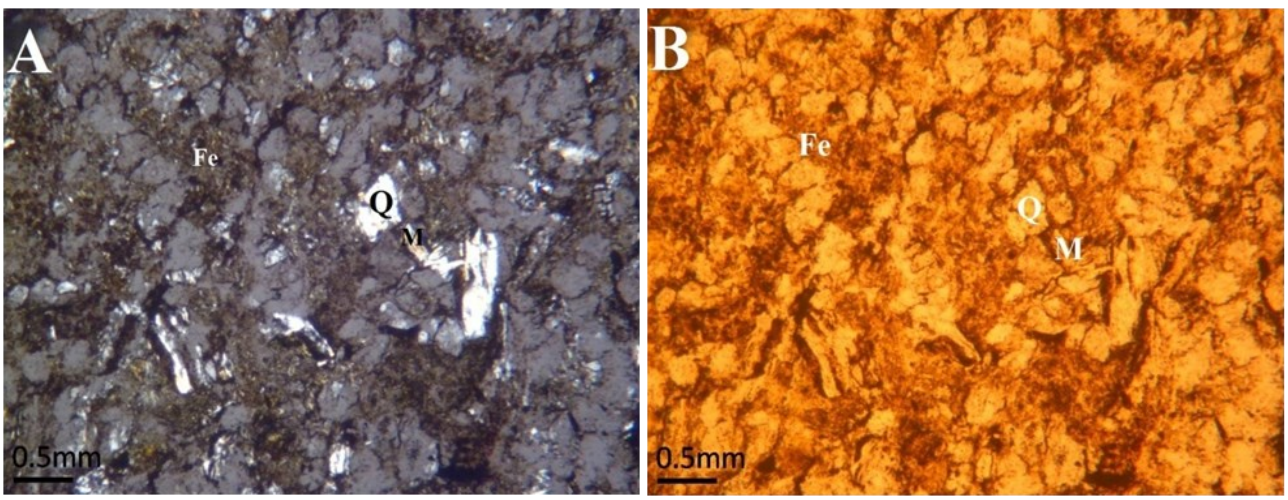

Figure 21. Mud stone microfacies containing chlorite and hematite nature, mica sheets (biotite and muscovite) and quartz's grains; due to decomposition biotite has released iron which is observed as hematite and in red color. Polarized light (A) and natural light (B)

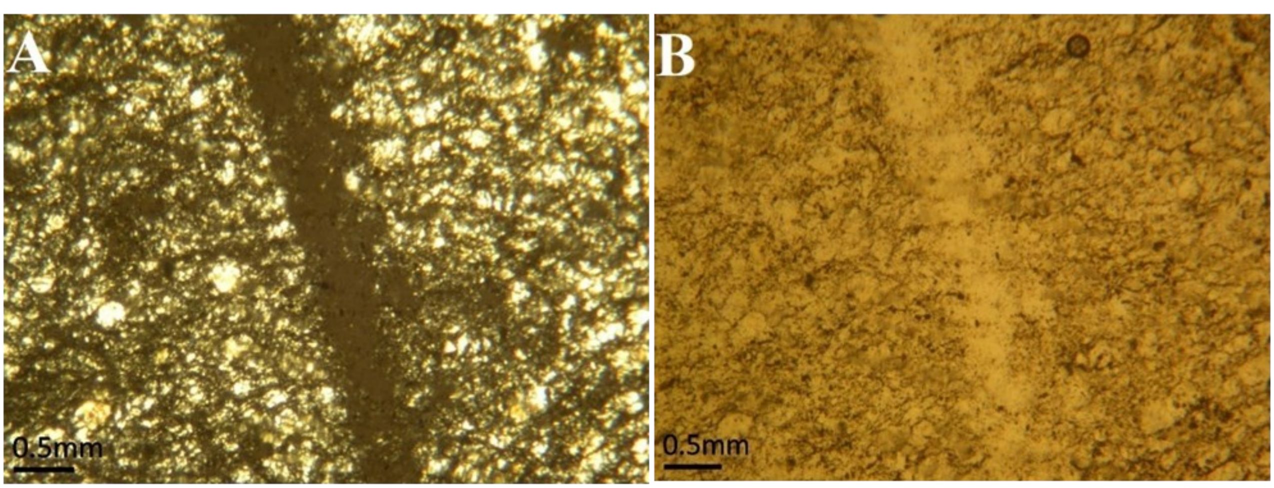

Figure 22. Silty mudstone microfacies, containing clay and iron oxide, quartz grains with good sorting and rounding, calcareous grains (micrite) which are chopped up in silt size, polarized light (A) and natural light (B)

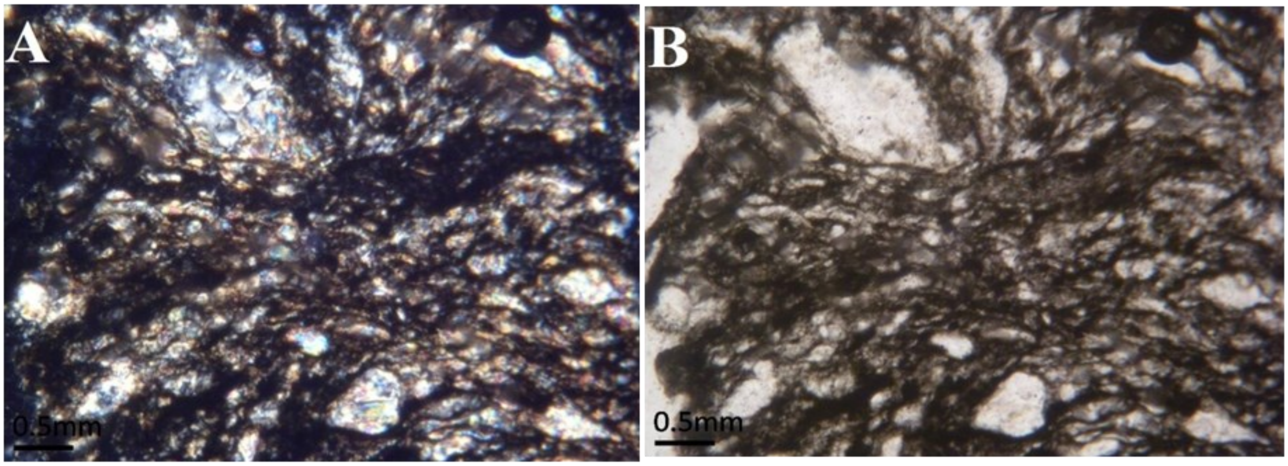

Figure 23. Microscopic view of black siltstone in delta plain which apparently has converted to a phyllite due to the pressure, polarized light (A) and natural light (B)

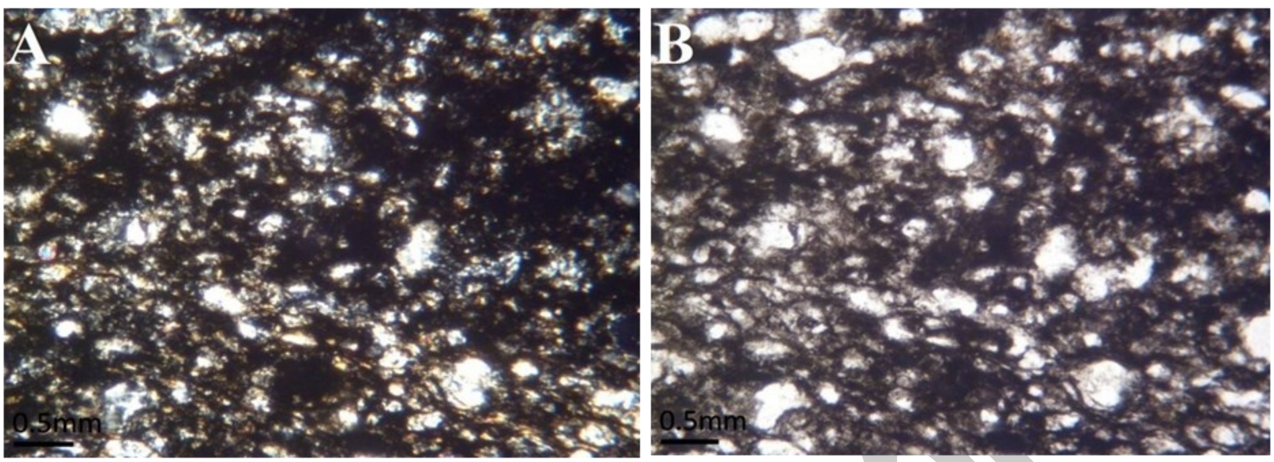

Figure 24. Microscopic view of black siltstone in delta plain, quartz grains and mica flake in a dark background containing carbonaceous materials, polarized light (A) and natural light (B)

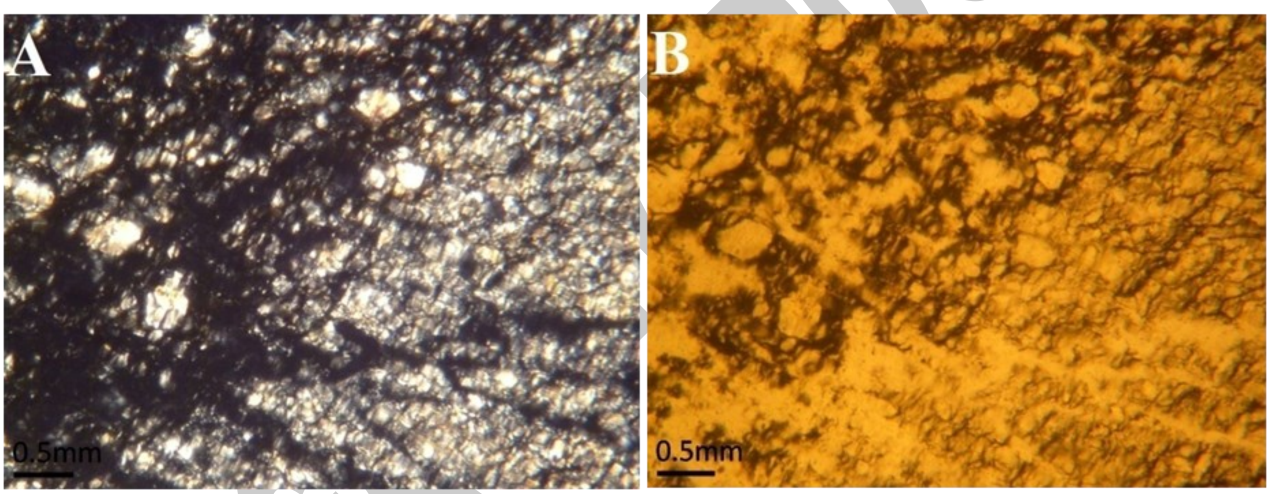

Figure 25. Microscopic view of black siltstone in delta plain, it is converted to slite due to methamorphism in a dark background containing carbonaceous materials, and quartz grains with mica flakes, polarized light (A) and natural light (B)

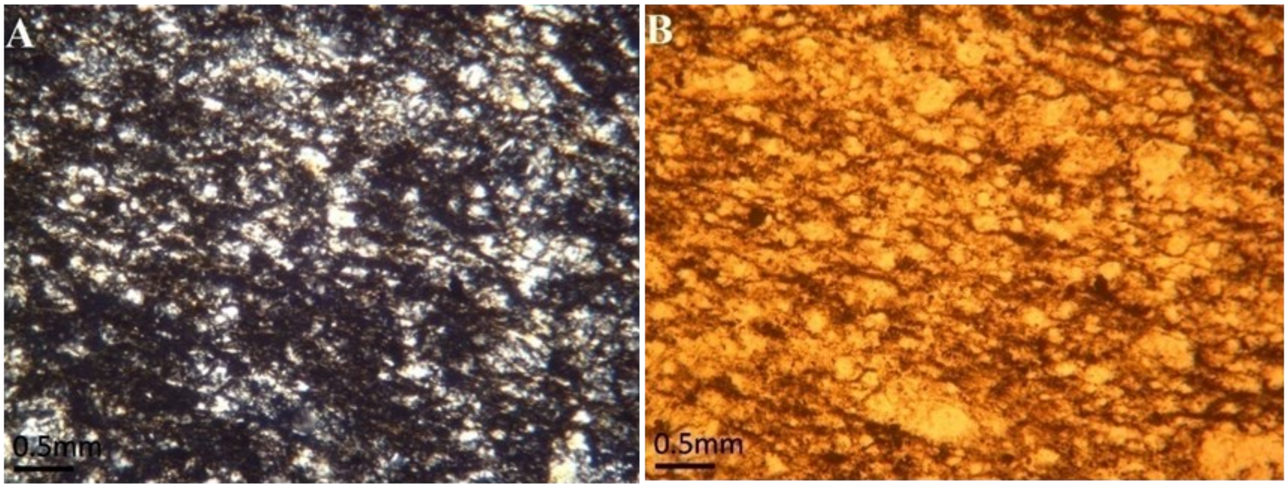

Figure 26. Microscopic view of phyllite in delta plain, which is created by medium-grade metamorphism of shale and mud stones, a series of foliation is seen obviously, and quartz grains show the preferred orientation very well, in back ground containing carbonaceous materials, and quartz grains with mica flakes, polarized light (A) and natural light (B)

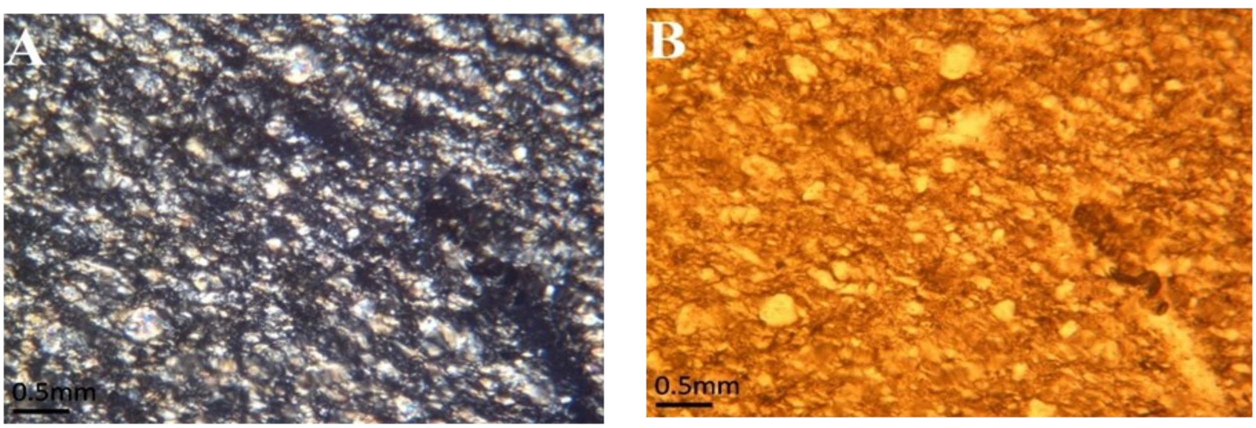

Figure 27. Microscopic view of muddy siltstone related to delta plain, in a, also clay-size calst particles, polarized light (A) and natural light (B) background containing carbonaceous materials, and quartz grains, mica sheets, very fine-grained and dispersed hematite which led to the creation of red color

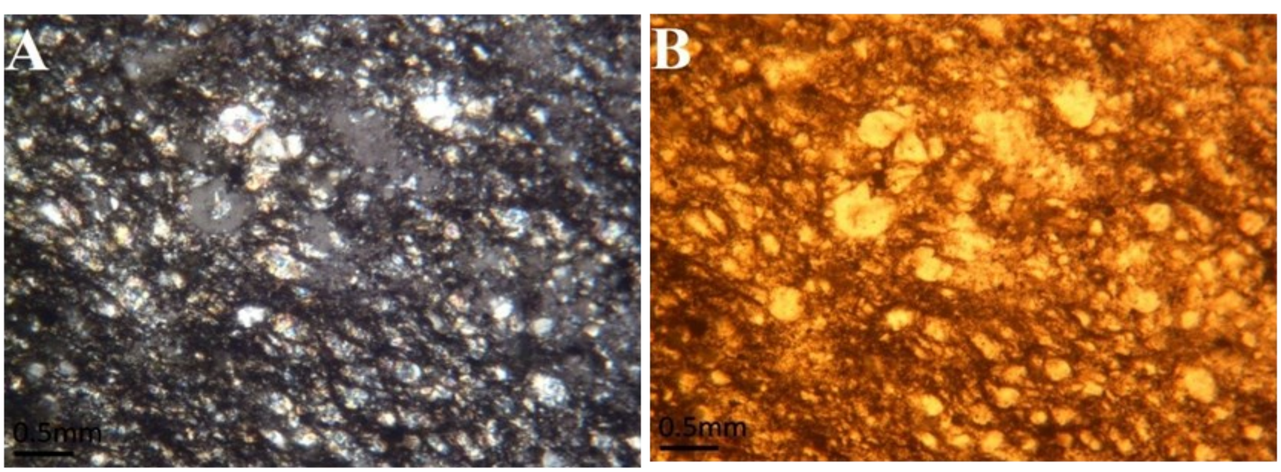

Figure 28. Microscopic view of dark muddy siltstone related to deltaic plain, in a background containing carbonaceous materials, clay minerals and quartz grains, mica sheets, very fine-grain and dispersed hematite which led to the creation of red color and is converted to slite due to low-grade metamorphism, polarized light (A) and (B)

phyllosilicates from the coast to the deep areas of the basin, study of distribution of clastic quartz, field spot, and related minerals toward the basin and finally characteristics of shale's direction to detect the plan of old flows. There are plans that show the distribution of different types of phyllosilicates in shallow marine basins which are located on the continents, and on the other hand, the geothermal gradiant is relatively small in these basins; therefore diagenetic processes cannot have a significant effect on the nature of the phyllosilicates. So these plans are developed very well in deltaic environments and they can be used on the studies area. The position of clay minerals in these plans is as follows: high kaolinite is related to the costal margin of basin or above the delta, low kaolinite is related to the front of delta, facies with mixed clay of the layer is related to the head part of delta, illite facies is related to the end part of the delta and the deepest part of basin. These cases are seen in the samples of studies area (it is mentioned in the section of clay minerals), so the sedimentary environment of these units (in the studied area) is related to delta which was under the influence of tide and shallow sea, and contains sediments with siltstone and mudstone a few millimeters thick along with disturbed horizons by other creatures, and sometime the sediments have high amount of organic material. It is notable that on deltaic sequences, like what is happening in British Upper Carboniferous and Mississippi in the east of North America and our studied area, clay soils are known as sub soil or coal clay which is found under the coal beds. These soils are formed under warm and humid conditions and are typically bulky and are associated with plant's root. If subjected to excessive leaching they may be rich in kaolinite (Staub and Cohen, 1978). Some of these sub soils are known fire clay which has refractory quality. Some of kaolinite-rich layers are found inside or top of coal beds and are named ton steins which was formed by alteration of volcanic ash (Tuker, 2015; Spears, 2012) (Figure 21 and Figure 22).

Study of clay minerals in studied area

To determine clay mineralogical composition and to complete microscopic survey of clay minerals from the studied stratigraphic sections, ten samples were tested by XRD tests. Four samples belonged to Db stratigraphic section, and the others belonged to Dc stratigraphic section. In sampling stage, we have tried to categorize the studied samples based on their apparent characteristics and their location in the stratigraphic sequence of each section, also sampling intervals should be observed in such a way as to cover the intended thickness that consisted of samples with high characteristics. The list of minerals ranging from the most prevalent to the rarest one; the samples studied by XDR, are presented in Tables 1 and 2.

Most of the constituent minerals of samples in Db stratigraphic section include: kaolinite, quartz, muscovite/ illite, pyrophyllite and to a lesser extent, rutile, hematite, goethite, albite and diaspora.

In Dc stratigraphic section, the most minerals of samples include: kaolinite, quartz, muscovite/ illite, hematite, goethite and to a lesser extent rutile, chlorite, albite, anatase, halite and gypsum that correspond with the geological zone of this deposit. In samples, dryness decreases to the depth of the kaolinite basin and chlorite is observed. Kaolinite is a stable clay mineral that is created during weathering processes and often has a destructive origin and is focused near the coastline. Based on the pattern of distribution and dispersion of these minerals by factors such as differences in particle size, differences in flocculation and flocculant size, kaolinite mineral flocculate in sea water and create large flocculants. Therefore, this mineral has a high concentration in the coastal areas. Clastic illites act as kaolinite in sea water and therefore are deposited together (Yeganeh *et al*., 2012). The clastic chlorite

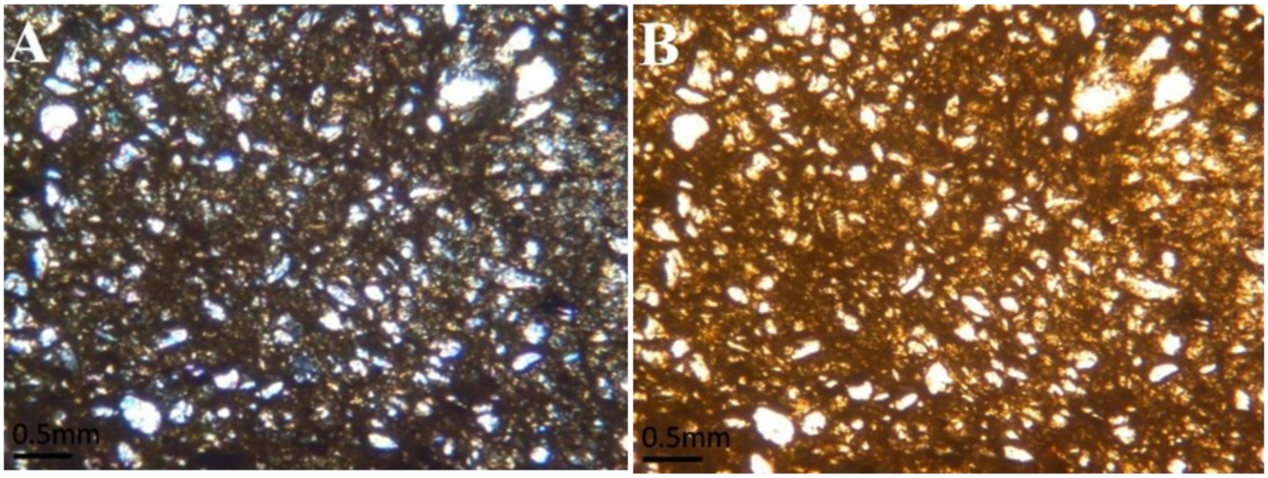

Figure 29. Microscopic view of siltstone of delta front, with chlorite-hematite dough, fine-grained dough was grown in rock during low grade metamorphism which results from the decomposition of biotite and contains quartz grain with poor sorting, polarized light (A) and natural light (B)

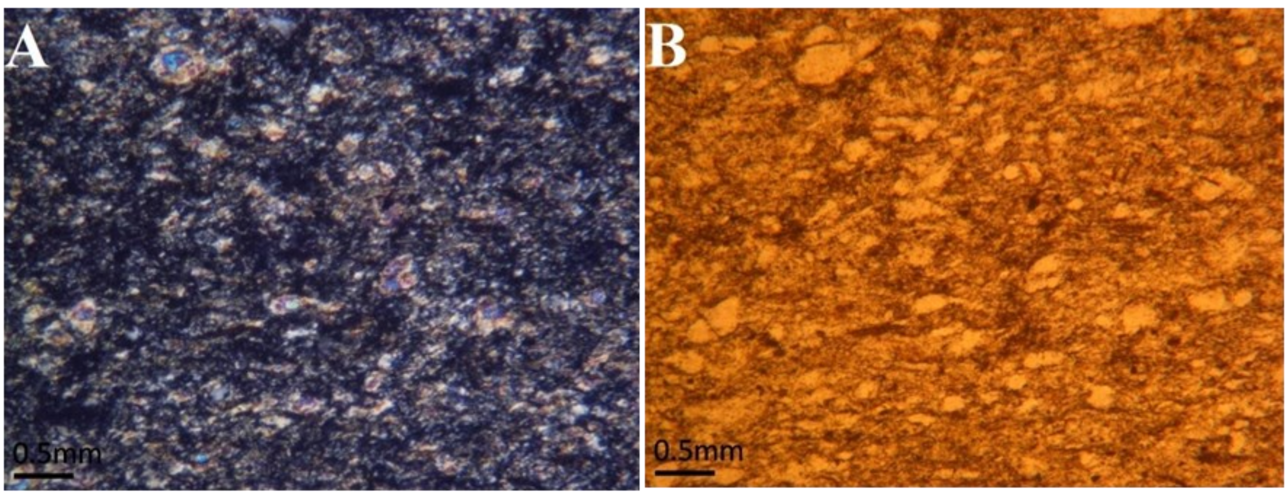

Figure 30. Microscopic view of slate due to the low-grade metamorphism of siltstone, related to delta front, the foliation is obvious, containing chlorite dough; the quartz grains indicate elongation in the direction of foliation, polarized light (A) and natural light (B)

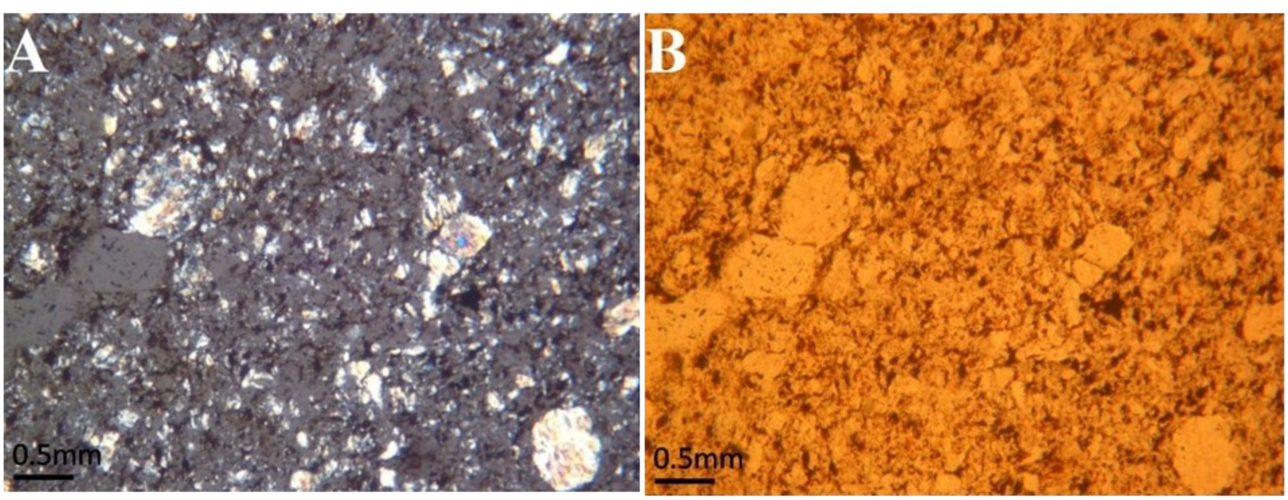

Figure 31. Microscopic view of siltstone, containing quartz grains and mica sheets (biotite and muscovite) in an iron oxide background (hematite) and opac minerals, polarized light (A) and natural light (B).

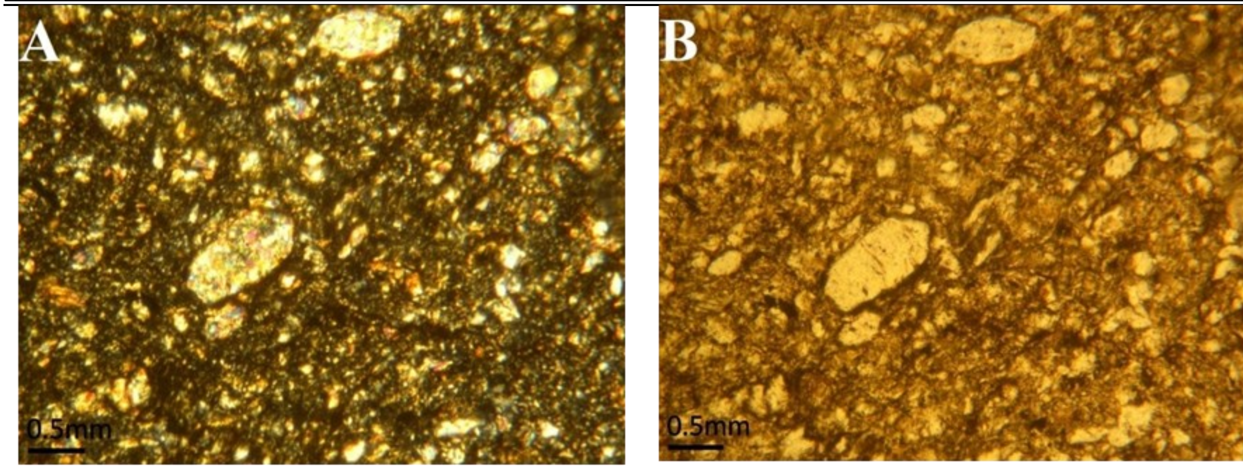

Figure 32. Microscopic view of muddy siltstone, related to front delta; in muddy part containing iron oxide (hematite and limonite), quartz grains are coated by iron oxide, polarized light (A) and natural light (B).

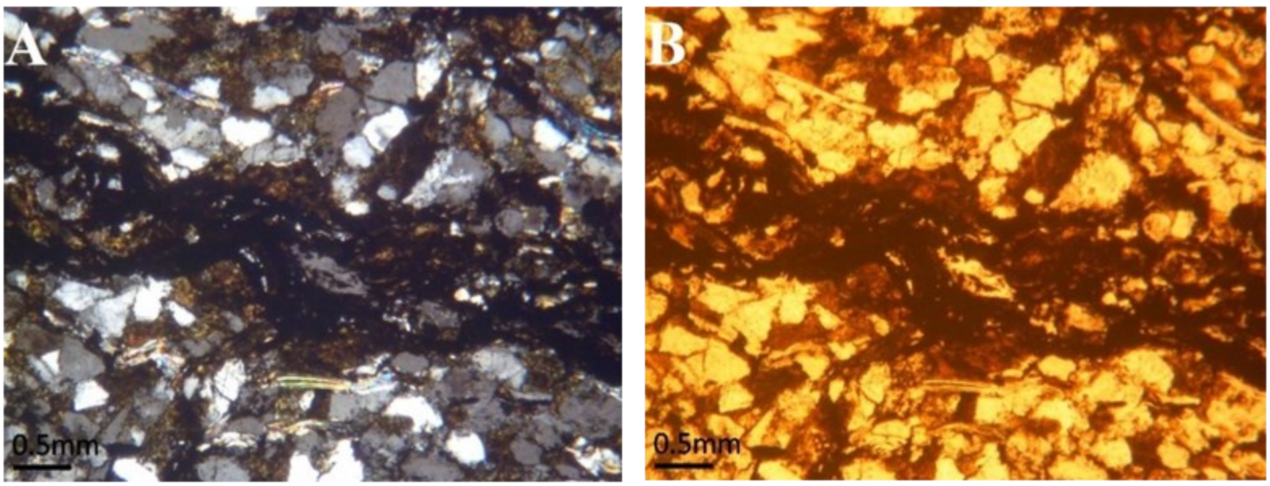

Figure 33. Microscopic view of fine-grained sand stone, related to subfacies of canals in front delta, containing quartz grains with good and angular sorting, muscovite and biotite sheets, single crystal quartz grains are with undulose extinction. Due to the decomposition of biotites, the iron is released and it is seen as the filling cement of iron oxide, polarized light (A) and natural light (B)

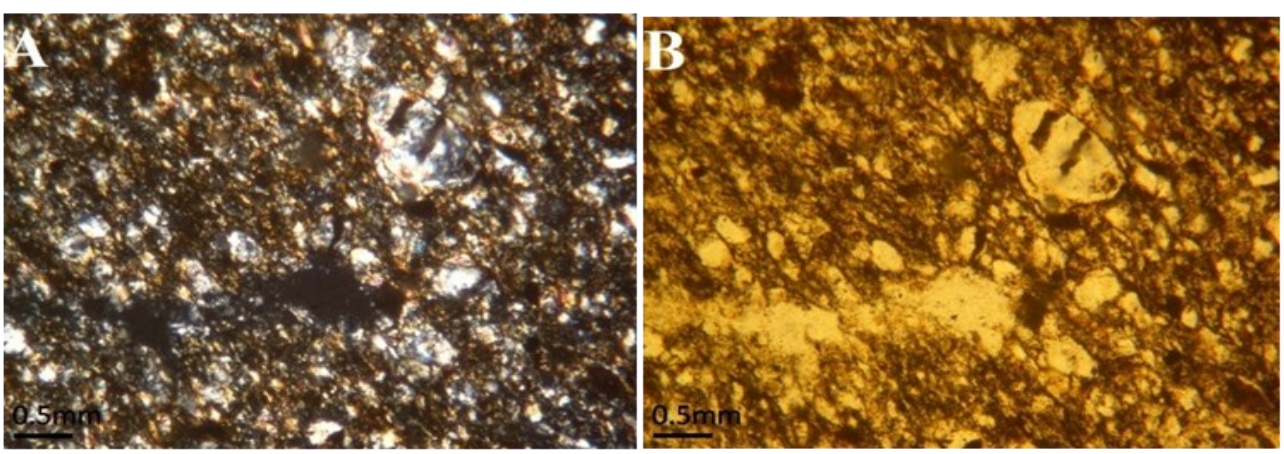

Figure 34. Microscopic view of muddy siltstone, related to subfacies of canal in front delta; in muddy part containing iron oxide (hematite and limonite), quartz grains are coated by iron oxide; a preferred orientation is seen in clastic grains of quartz (the slate texture is shown, low grade metamorphism); polarized light (A) and natural light (B).

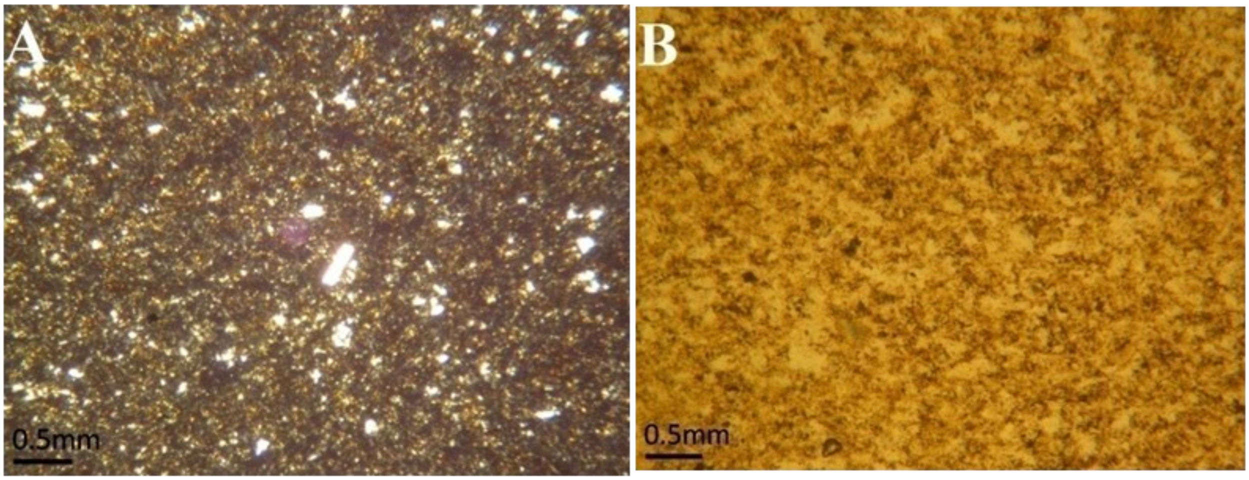

Figure 35. Microscopic view of mud stone, related to subfacies of canal in front delta, containing iron oxide (hematite and limonite, chlorite) and quartz grains, polarized light (A) and natural light (B)

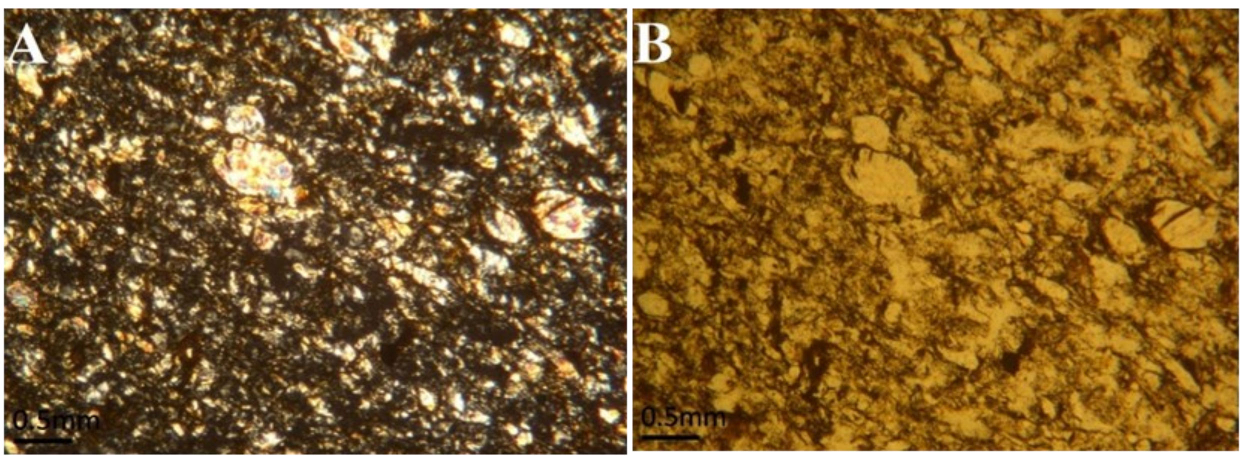

Figure 36. Microscopic view of siltstone, related to front delta, background with fine-grained stones (clay) and containing iron oxide (hematite) and quartz grains, mica sheets (biotite and muscovite), polarized light (A) and natural light (B)

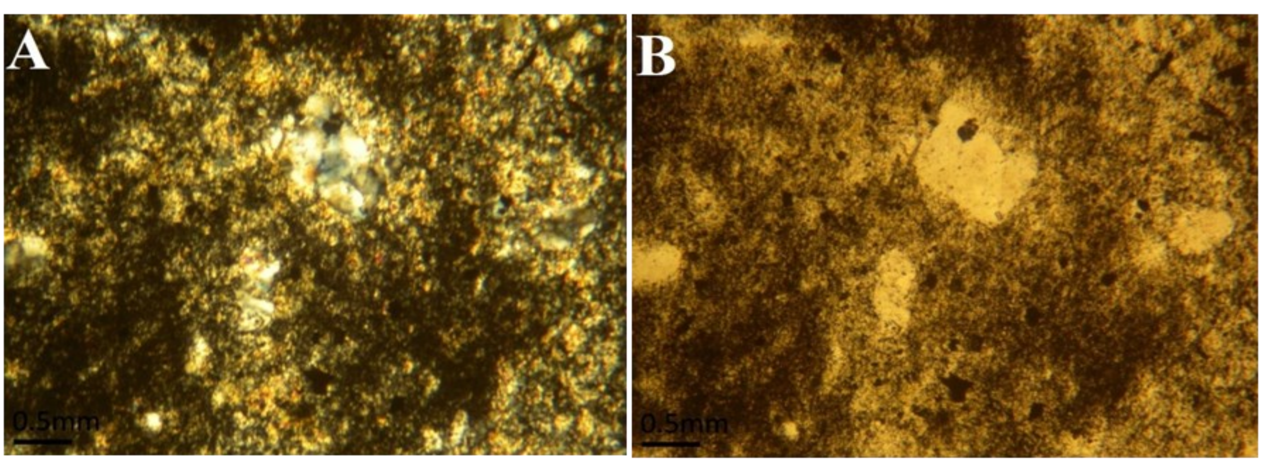

Figure 37. Microscopic view of silty mudstone, related to prodelta, in some places the accumulation of clay material caused by clotting (folliculation of clays) is obvious in dark color; polarized light (A) and natural

flocculates slowly in seawater so it goes more distance in sea before sedimentation.

Based on the evidence above and documents such as the combination of clay minerals, one has tried to introduce the sedimentation environment and the condition of each sample and to use the obtained results to justify the predicted sediment model. According to the studies, samples of Kaolinite clay, muscovite / illite, pyrophyllite are mainly related to delta environments, over the tide and coastal regions of limited open marine, which correspond with environmental condition and predicted conditions in ideal sediment model of the area.

Interpretation of deltaic facies in studied area

In stratigraphic sections A and B in the studied area, due to facie changes in stratigraphic column and survey of lateral relations of facies (because some facies are not continuous in the studied area and transform to other facies laterally, for example filler sediments of canal at delta front, such that the filler fine-grained sandstone of canal laterally change to siltstone and mud stone (very fine-grained sediments)). This transformation helps us to detect the sediments of delta front. The presence of coal beds in sediments of prodelta that includes delta plain of the studied area is very important.

In addition, the available information on the stratigraphic situation of the area is very important, because in order to interpret the studied sediments, their lateral and vertical relations with other sediments are very important. Stratigraphic cut (A) is related to the delta plain section below the marsh facies. The vast swamp area is covered with herbaceous plants. The sediments of this area consist of fine-grained particles as small as silt and clay. In this area, clastic fine-grained sandstones include black siltstone, red mudstone, black muddy siltstone, silty mudstone, slate metamorphic rock, phyllites. Black siltstones containing carbonaceous material shave been converted into slate due to low grade metamorphism and pressure, and quartz grains have found a preferred orientation (foliation) in a specific direction. Phyllite has been formed by medium-grade metamorphism in mudstones and shale. Muddy siltstone has an organic and carbonaceous nature, and clay-size clastic particles are seen. Silty mudstone contains very fine-grained and dispersed hematite that led to the creation of red color. The presence of coal layers indicated the high growth of plants in the swamp. After the death of plants, they formed the premature coal layers. Generally, organic matter is high in these sediments and is a good source for the production of hydrocarbon materials (gas) (Figure 23 to Figure 28).

Stratigraphic cut (B) is related to the front part of delta and its end part. The sediments in the front part of delta consisted of fine-grained sandstone, siltstone, silty mudstone, muddy siltstone, slate, phyllite, schist (they are formed due to low-grade to medium-grade metamorphism and a series of foliation and schistosity is clearly seen), which contain iron minerals such as chlorite and hematite. It is notable that the sediment of canal is seen which the size of its grains is scratching upward.

Generally, as far as we come close to the sea, the sizes of particles are reduced, because the energy of the environment decreases. So the grains become smaller so that there is only fine-grained mudstone, shale, slate, phyllite (that is created by metamorphism of mudstone) and very fine-grained of oxide iron at the end part of the delta. At the end of the delta, there is an accumulation of clay minerals and organic materials in a dark color. Lamination in shale is obvious. The veins and pores are filled with calcite. Lamination is seen in phyllites which were made by metamorphism of mudstone. Quartz grains showed a preferred orientation and elongation along foliation and clay layers are bent

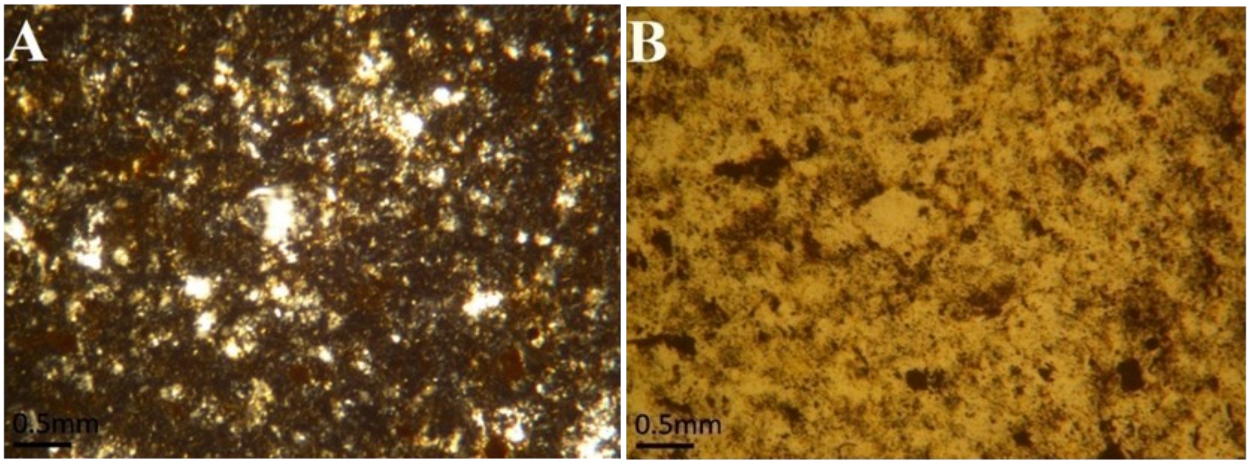

Figure 38. Microscopic view of mudstone, related to prodelta, dark parts containing clay and iron oxide; polarized light (A) and natural light (B)

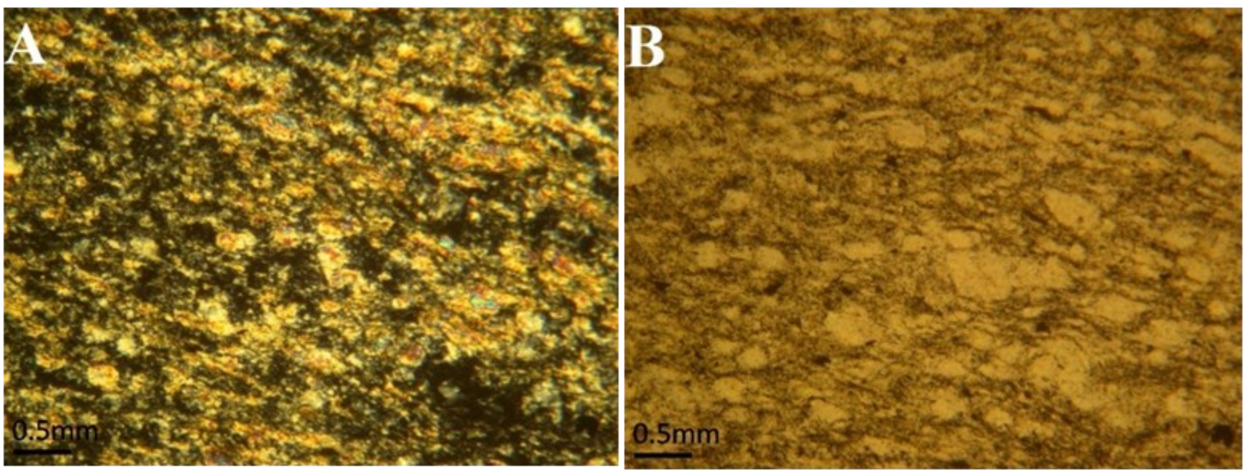

Figure 39. Microscopic view of phyllite, related to prodelta, clay layers are bent and wound around quartz grains; the quartz grains show an elongation and a preferred orientation, polarized light (A) and natural light (B)

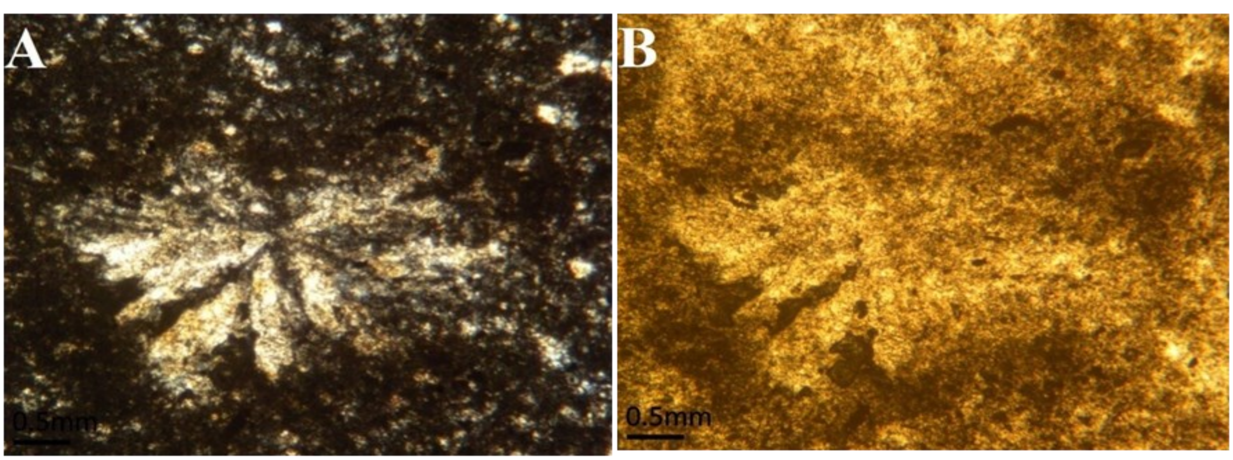

Figure 40. Microscopic view of mudstone, related to prodelta, containing iron oxide; in some places, the accumulation of clay minerals and organic materials is seen in a dark color, polarized light and natural light (B)

and wound around quartz grains (Figure 29 to 41). In general, the stratigraphic section A indicated sedimentation in deltaic environment outside the water (deltaic plain) and stratigraphic section B represents sedimentation on under water environment (delta front and prodelta). The studies show that the basin subsidence is the result of the sediments of region because the sea basin was progressed by the constant subsidence and sea sediments are located above deltaic sediments (Tabakh and Aroon, 1998; Logan *et al*., 1974; Demico and Hardie, 1994).

Schematic block diagram for sedimentational model of upper Devonian and lower carboniferous in Abadeh region

Based on the analysis of the results obtained from the examination of microscopic thin sections, X ray tests and the comparison of obtained results and standard models of microfacies distribution in different environments (which were presented by Wilson (2012) and Flugel (2010), sedimentational model of upper Devonian and lower carboniferous in the studied areas of central Iran are presented (Figure 42).

CONCLUSION

The important results from the study of sedimentations of upper Devonian and Lower Carboniferous in Abadeh region, Fars, Iran, are as follows:

1. In this study, 10 facies were identified in 5 facies group of open marine environment, barrier environment, lagoon environment, tidal flat, and deltaic environment.

2. The mentioned facies groups are formed in a carbonate platform (Homoclinal ramp type**)** and delta intermediate environment, so that the tidal flat includes facies 1 (Mudstone with fabric fenestral), facies2 (Stromatolite bindstone), lagoon environment includes facies 3 (Wackestone / Pelloid Packstone with various fossils), facies 4 (Packstone / Bioclast Grainstone), facies 5 (Packstone / Bioclast grainstone with intraclast), facies 6 (Packstone / Echinoid grainstone), open marine environment includes facies 7 (Echinoid and bioclast brachiopod rudstone), facies 8 (Packstone / bioclast Wackestone with various fossils), and delta intermediate environment includes facies 9 as a Clastic facies (Siltstones), facies 10 as a Clastic facies (mudstone).

3. In general, this research can show us the old geographic situation of the region during the sedimentation of upper Devonian and Lower Carboniferous in the studied area. Therefore, the survey of stratigraphic column and microfacies determine the

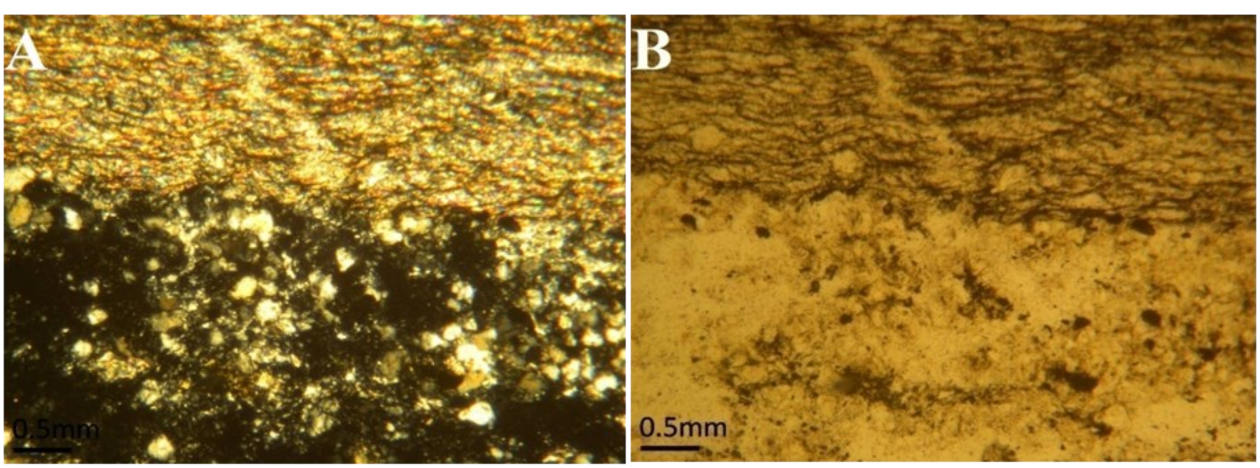

Figure 41. Microscopic view of mudstone, converting to phyllite (medium-grade metamorphism), related to prodelta, a series of foliation and (king bound) folds is obvious, polarized light (A) and natural light (B)

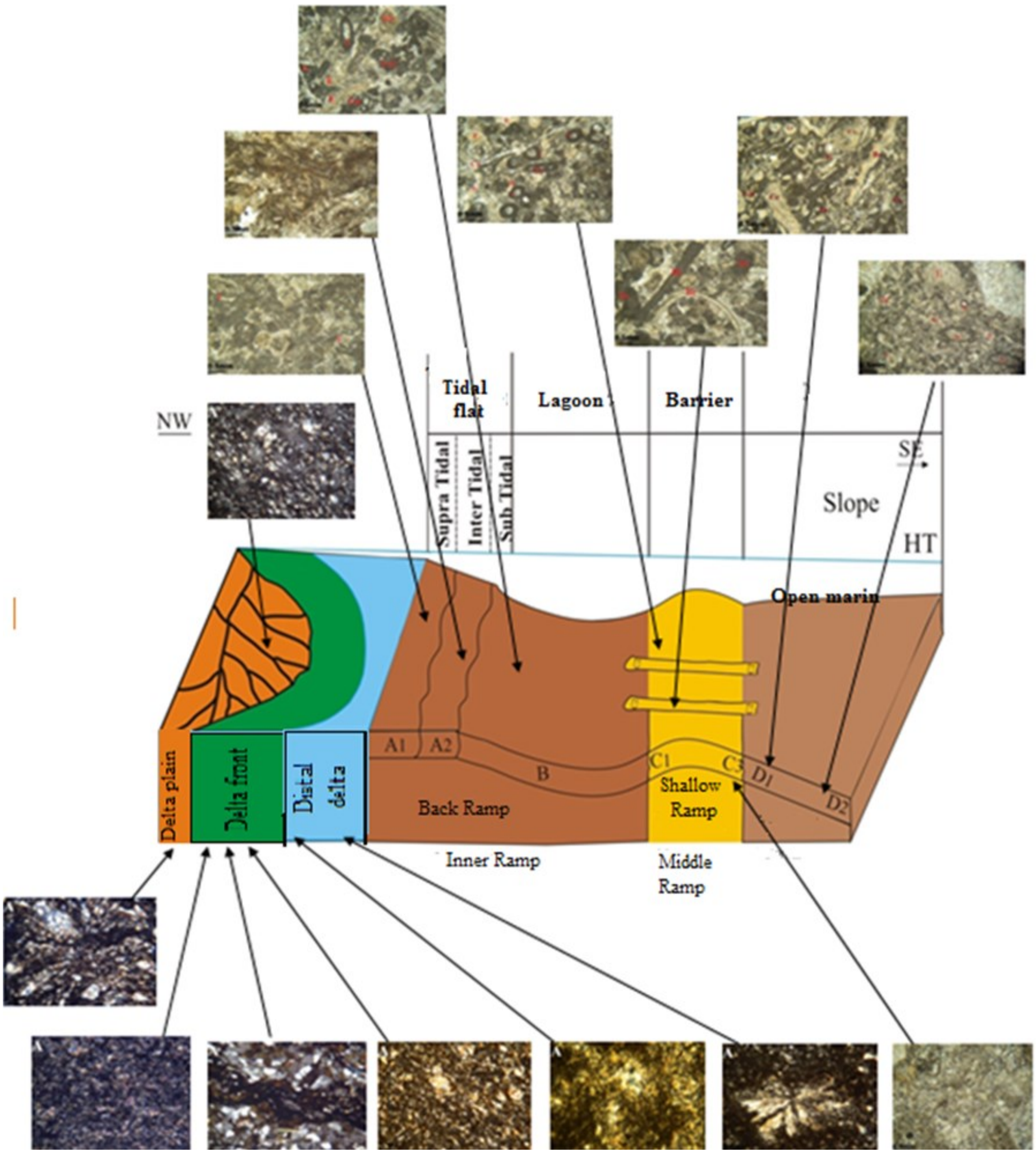

Figure 42. Sedimentational model of upper devonian and lower carboniferous in Abadehregion, Fars, Iran

types of carbonate and clastic microfacies of studied sections and the comparison of obtained results indicated the components of litho facies and their vertical changes: Stratigraphic section (A) with a thickness of 60 meters indicated the sedimentation in deltaic environment outside the water (delta plain) and stratigraphic section (B) with a thickness of 120 meters indicates the sedimentation in deltaic underwater environment(delta front and prodelta) and carbonate sedimentation in stratigraphic section (C) with a thickness of 75 meters is related to Homoclinal carbonate ramp.

4. In stratigraphic sections A and B in the studied area, due to facies changes in stratigraphic column and survey of lateral relations of facies (because some facies are not continuous in the studied area and transform to other facies laterally, for example filler sediments of canal at delta front, such that the filler fine-grained sandstone of canal laterally change to siltstone and mudstone (very fine-grained sediments)). This transformation helps us to detect the sediments of delta front. The presence of coal beds in sediments of prodelta that includes delta plain of the studied area is very important.
5. In stratigraphic section (C), based on Walther law, the facies, which are laid laterally adjacent to each other, are the product of sedimentational environments. Based on the field observations and laboratory studies and Walther law, the absence of clastic particles facies of shallow environments in the sedimentation of deep areas, the lack of falling, sliding and turbidite facies, and expansion of the tidal facies, it is possible to consider the sedimentary environment of these carbonate deposits in the stratigraphic section (C) as a homoclinal ramp (a carbonate platform).
6. Studies showed that the basin subsidence is the result of the sediments of region because the sea basin was progressed by the constant subsidence and sea sediments are located above deltaic sediments.
7. In some cases such as facies 9 (siltstones) and facies 10 (mudstones), it points to degradation conditions that have a direct reproductive linkage to active tectonics.

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