Geologie

Biozonation and Biostratigraphic Limits of the Tarbur Formation around Shiraz (SW of Iran)

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To my Sons, Shervin & Ramin

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Contents

Zusammenfassung

Mehr als 3000m der karbonatischen Tarbur Formation wurden in der Umgebung der Stadt Schiras durch sieben stratigraphische Profile untersucht. Zur Alters bestimmung mittels Foraminiferen der Tarbur Formation wurden davon 900 Dünnschliffe bearbeitet. Die Biozonen dieser stratigraphischen Profile basieren auf den ermittelten Indexforaminiferen. An Hand der ermittelten typischen Biozonen wurde das Alter der Tarbur-Fomationdem Campan-Unterem Paläozän zugeordnet. Es wurden vier Hauptmikrofazies, die Wackstone, Packstone, Grainstone und Boundstone beinhalten, festgestellt. Auf Grund der untersuchten Biostratigraphie ist festzustellen, dass die Obergrenzen der Lithostratigraphie und der Biostratigraphie der Tarbur-Formation nicht übereinstimmen.
Die Schlüssel wörtersind: Tarbur Formation, Biostratigraphie, Biozone, Mikrofazies, Schiras, Iran.

Introduction

The first geological investigations and geological maps in the Zagros Mountain Ranges in southwestern Iran were made by the Anglo-Persian Oil Company Ltd., mainly for oil exploration purposes. The first successful drilling was carried out in 1909 in the Khuzestan area in the Oligocene-Miocene Asmari Limestone Formation, which is still the main oil reservoir in Iran, where the famous Cap Rock of the Early Miocene Gachsaran Formation, consisting of evaporitic sediments, seals it completely. This is the case mainly near the Persian Gulf, since the sediments in the Zagros become progressively younger from northeast to southwest (WELLS, 1968). Therefore, the Limestone

Tarbur Formation, which is far from the oil regions, has not been of special interest to oil companies. The age of the Tarbur Formation has been believed to be Campanian to Maestrichtian (JAMES & WYND, 1965). A detailed study of the Tarbur Formation is important because the boundary of the Upper Cretaceous-Paleocene is not distinct and the distribution of the Tarbur Formation in the Zagros is linear, which could be significant in view of the later discussed migration of troughs of sedimentation. In spite of its importance, the knowledge of the microfacies and biozonation of the Tarbur Formation, which is particularly significant for its foraminiferal constituents, has been negligible so far. Therefore, it is imperative that detailed studies be made of the sedimentary environments that have resulted in different manifestations of the Tarbur Formation. These studies cover the changes in microfacies and biozones, which have provided the environment for the development of at least 7 zones, whose appearance is quite different from the type section carried out by JAMES & WYND (1965) and also from two other sections, one by KHOSRAVI (1968) and the second by KALANTARI (1976). They all failed to carry out statistical studies of microfacies elements such as extraclasts, bioclasts and intraclasts for the interpretation of the sedimentary depositional system of the Tarbur Formation. Moreover, in this study new foraminifers and new lithostratigraphic units have been found.

2. Setting

The geographical and geological settings are described in sections 2.1 and 2.2.

2.1. Geographical Setting

In order to investigate the Tarbur Formation seven geological sections were carried out (Fig.1.).

All of the studied sections are located in Fars province in southern Iran. They are rather close to Shiraz and may be reached in one to two hours by car. Their location and coordinates are as follows:

Kherameh-1 section: This section is located 5km southeast of Kherameh, a town 80 km east of Shiraz. The coordinates of the section are N 29°27′E53°24′ (Fig. 2.1).

Kherameh-2 section: This section is located 20 km southeast of Kherameh. The coordinates of the section are N 29°24′E 53°41′ (Fig. 2.1).

Kuh-e Siah section: This section is located 20km southeast of Kuh-e Siah, a town 90 km southeast of Shiraz, close to the Shiraz-Fars highway. The coordinates of the section are N 29°10′E 53°19′ (Fig. 2.1).

Zarghan section: This section is located 20 km northeast of Shiraz, next to the Shrine of Imamazadeh Zarghan, close to the Shiraz-Marvdasht highway. The coordinates of the section are N 29°28′ E53°20′ (Fig. 2.1).

Kuh-e Chehelcheshmeh section: This section is located 88 km northeast of Shiraz. The coordinates of the section are N 53° 27′ E 29° 20′ (Fig. 2.1).

Kuh-e Khanehkat section: This section is located 82 km northeast of Shiraz. The coordinates of the section are N 53° 30′ E 29° 30′ (Fig. 2.1).

Dariyan section: This section is located 50 km northeast of Shiraz near Dariyan village. The coordinates of the section are N 29° 25′ E 53° 27′ (Fig.2.1).

The complete area is located in a semi-arid region, with a maximum precipitation of 500 mm per year and maximum positive topographic features 2200 m above sea level.

There are several outcrops of the Tarbur Formation northeast and southeast of Shiraz.The chosen Tarbur outcrops have distinct lower and upper lithostratigraphic contacts, which can be seen in the field.

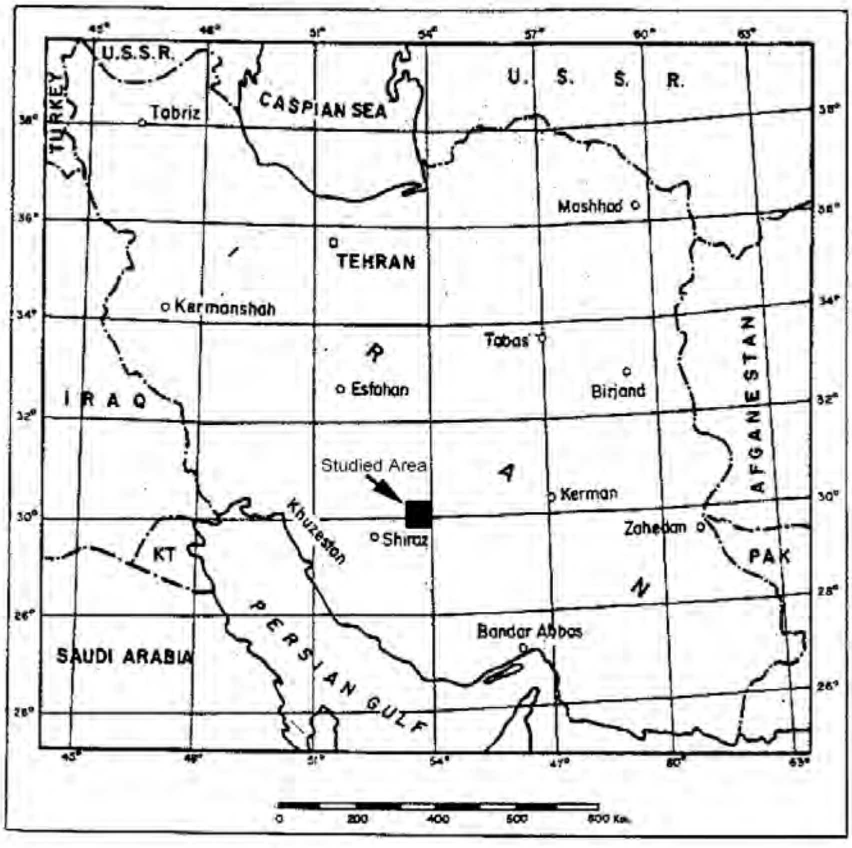


Fig. 1. Outline map of Iran showing the location of Shiraz and some other major cities. The studied area is shown located in a quadrangle near Shiraz

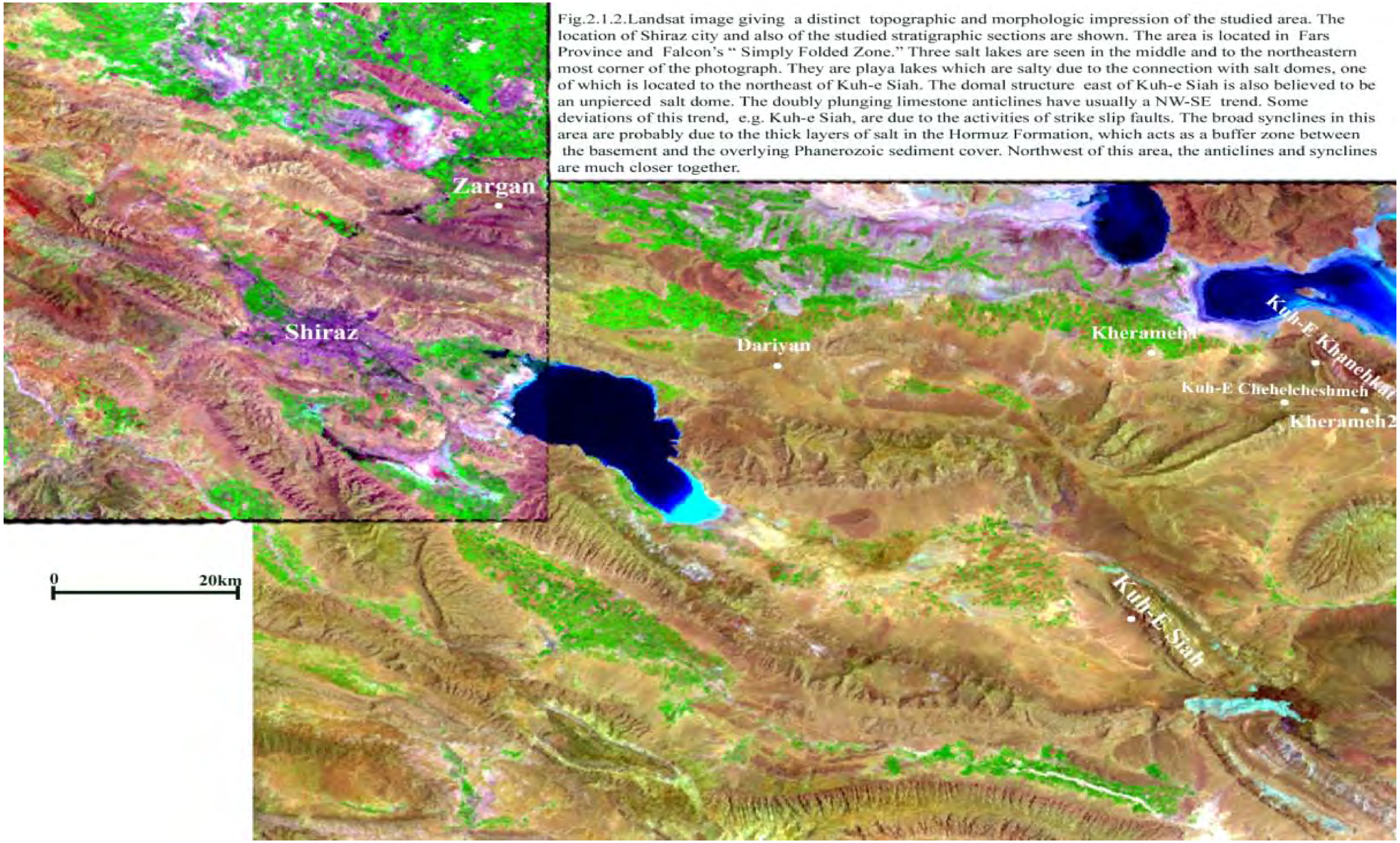


Fig.2.1.2.Landsat image giving a distinct topographic and morphologic impression of the studied area. The location of Shiraz city and also of the studied stratigraphic sections are shown. The area is located in Fars Province and Falcon's " Simply Folded Zone." Three salt lakes are seen in the middle and to the northeastern most corner of the photograph. They are playa lakes which are salty due to the connection with salt domes, one of which is located to the northeast of Kuh-e Siah. The domal structure east of Kuh-e Siah is also believed to be an unpierced salt dome. The doubly plunging limestone anticlines have usually a NW-SE trend. Some deviations of this trend, e.g. Kuh-e Siah, are due to the activities of strike slip faults. The broad synclines in this area are probably due to the thick layers of salt in the Hormuz Formation, which acts as a buffer zone between the basement and the overlying Phanerozoic sediment cover. Northwest of this area, the anticlines and synclines are much closer together.

2.2. Geological Setting

The Zagros Mountain Ranges are located mainly in Southern and Western Iran. Based on data obtained from oil drilling and resulting isopach maps, it is obvious that the axis of the the sedimentary trough and, correspondingly, the front of the mountains have been migrating continously but at different rates from NE to SW since Upper Cretaceous time, probably due to the convergence of the Arabian and the Iranian plates (FARHOUDI, 1978). There have been two major movements (FALCON, 1974). The first movement and resulting crustal shortening occurred in the Upper Cretaceous and produced the prototype of the Zagros Mountain Ranges. This prototype, which is in the northeastern most part of the Zagros Mountain Ranges, experienced a second shortening in the Pliocene. The latter was stronger and is continuing presently, but at a lower rate, including the whole Zagros Mountain Ranges down to the southwestern margin of the Persian Gulf.

The metamorphosed basement of the Zagros Mountain Ranges is covered by 10-12 km sedimentary rocks. They consist of the 1-3 km Infra-Cambrian evaporitic Hormuz Formation (KENT, 1970), overlain by epicontinental terrigenous deposits of Paleozoic age. A remarkable facies change occurred as several thousand meters of mainly miogeosynclinal carbonates with a few marly formations were deposited from Permian to Lower Miocene time. The oncoming tectonic movements produced evaporitic and sandy formations and climaxed in the Pliocene, resulting in the unconformable molasses-type Bakhtyari Formation at the end of this epoch.

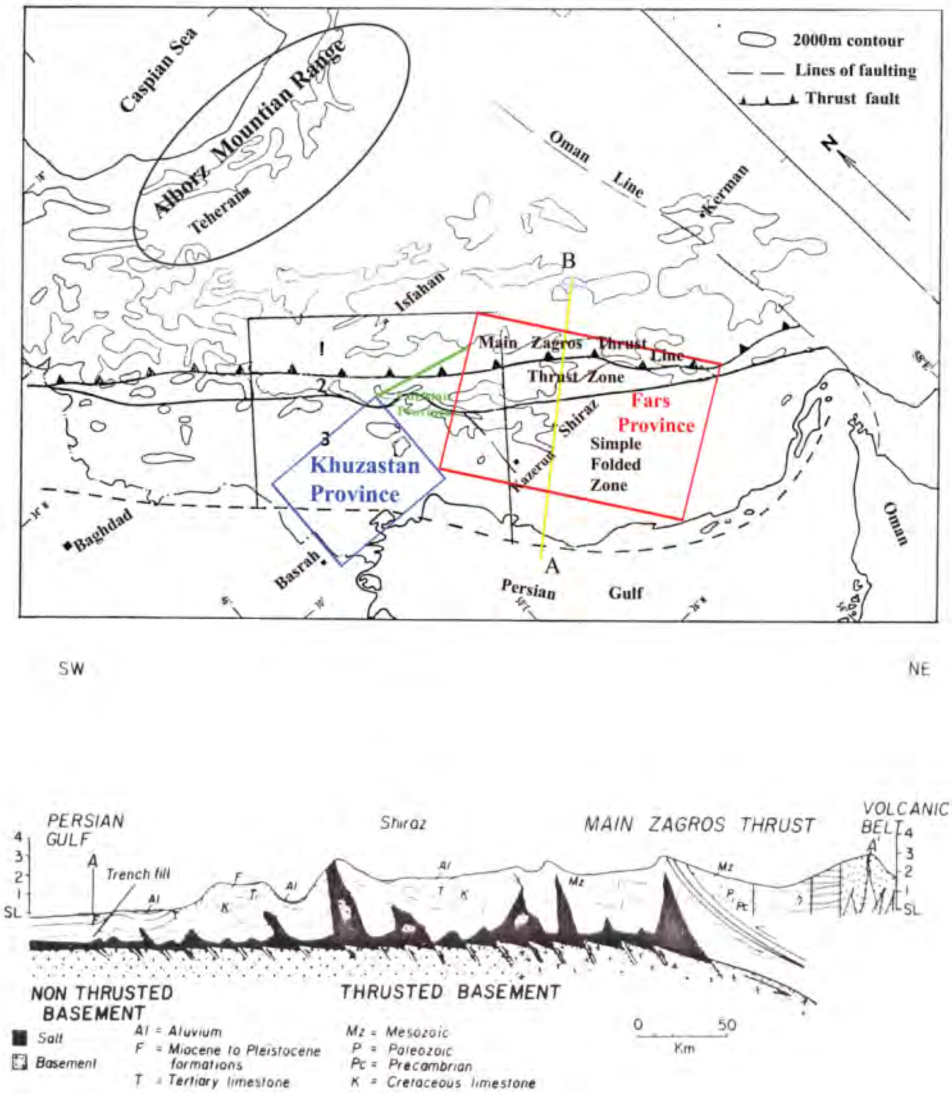
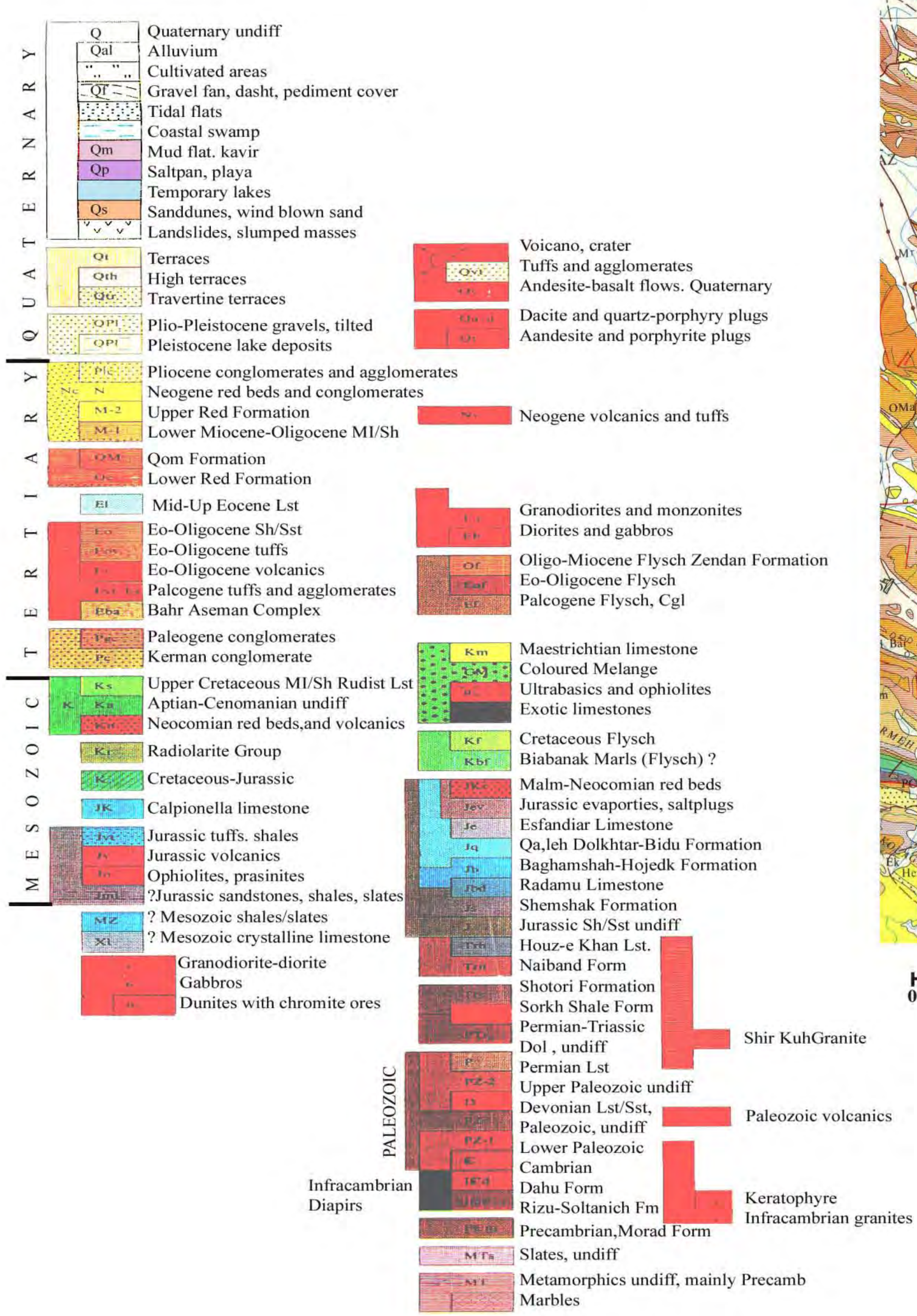


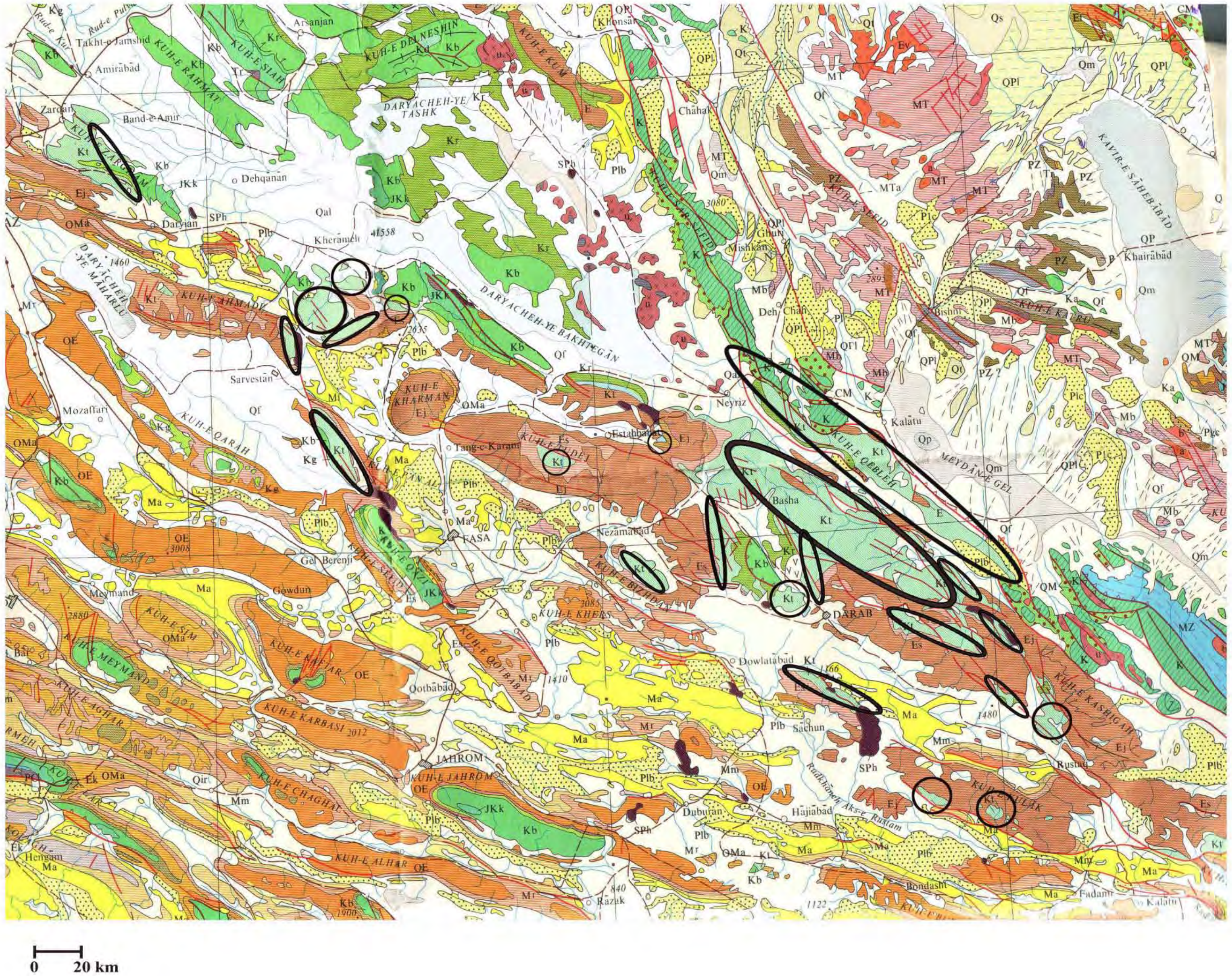
Fig.2.2.Outline map of the Zagros and Alborz Mountain ranges in IRAN and the segments described in text showing the structural zones of the Zagros Range modified from FALCON (1974).There is a geological cross section that show structural geology of some part of studied area which modificd from FARHOUDI (1977). Based on AB cross line, the geological profile is prepared.

2.3. Distribution of the Tarbur Formation

Although the distribution of the Tarbur Formation seems to be linear and in a rather narrow zone parallel and approximately 30-60 km to the SW apart from the Main Zagros Thrust (Fig.2.2.1), stratigraphic settings and sedimentary conditions in tectonic environments appear to control its location and composition. Whereas usually the lower contact of the Tarbur Formation is with the underlying Gurpi Formation and sharp, southwestwards to the interior of Fars, the two formations are interfingering. Near the Main Zagros Thrust, the Tarbur Formation is lying locally on the radiolarites (tectonic setting, Fig.2.3).

Legend





Map 2.3. Distribution of the Tarbur Fm., the Tarbur Formation outcrops are shown by Kt , the Tarbur formation is distributed in line that parllel to Zagros Main Thrust. Also the Tarbur Fm. outcrops are sourrounded by circle and elliptical line that show the Tarbur Fm.

3. Geological Description of the Zagros and Related Areas

FALCON (1974) divided the Zagros into three major zones:

Zone 1, the Zagros "Complex Structural Zone with Metamorphic Rocks".This zone is located at the northeastern side of the Main Zagros Thrust Fault and beyond the studied area. The Main Zagros Thrust has been considered as the suture zone produced by the continued convergence between Arabia and Eurasia, at least from Upper Cretaceous time (FARHOUDI, 1978). The zone is covered mainly by sedimentary rocks, but metamorphic, plutonic and volcanic rocks are also present. Basement rocks and flysch deposits are folded and thrust-faulted. About 5-10 km immediately northeast and southwest of the Main Zagros Thrust, the crush zone consists mainly of shattered limestones.

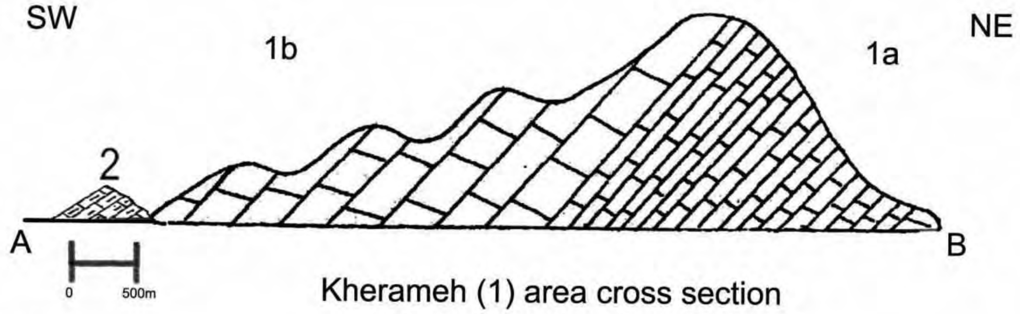
Zone 2 is the Zagros "Thrust or Imbricated Zone". Here, the thrusting is very conspicuous. According to FALCON (1974), the first folding of this zone occurred in Upper Cretaceous time. The zone extends about 80 km from the Main Zagros Thrust to the southwest. The less distinct thrusting to the southwest, in the direction of and in Zone 1, may be explained by the presence of Precambrian (outcropped only in the form of spectacular salt domes mainly in zone 3) and Miocene evaporates (FARHOUDI, 1978). This zone is covered mainly by sedimentary rocks, but there are also patches of ophiolites and radiolarites of Upper Cretaceous age (FALCON, 1974) at the northeast margin of the zone. According to STONELY (1981), some of the radiolarites are older and have been thrust from the northeast to that area. The studied area is actually in Zone 3, but near the border of zone 2.

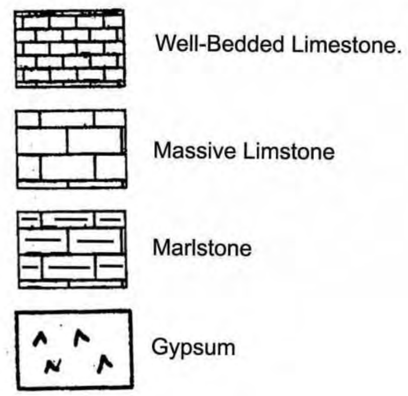
Zone 3, the Zagros "Simply Folded Zone" is located at the southwest margin of the Thrust Zone and continues for on average about 225 km to the Persian Gulf. The folds display the character of simple folding, with long and parallel anticlines and synclines. The intensity of the folding diminishes in amplitude from several thousand meters, and in steepness, from 50 degrees and more seaward. There are some exposed low relief anticlines with NW-SE Zagros Trends in the Persian Gulf with dips of 10-20 degrees. There are even some anticlines at the southwest margin of the Persian Gulf with the "Zagros Trend", while some anticlines with the NS "Arabian Trend" are superimposed by the Zagros Trend (cross-folding) (KASSLER, 1973). The studied area is located in the Simply Folded Zone. The geological cross- sections of the studied sections are shown in Figs. 3.1.1-6.

These geological cross-sections show a relation between the geological formations in the studied area. Moreover, there are geological maps that indicate stratigraphic cross lines. The Tarbur Formation is divided into two lithostratigraphic units.These units are shown as Tb1 (the lower part) and Tb2 (the upper part) in the geological maps and geological cross-sections. In fact, Tb1 indicates medium-bedded to thick-bedded greyish-brown rudist limestone. This portion is the lower part in all of the studied sections, with differences in thickness. It should be noted that Zarghan, Dariyan, Kherameh-1, Kherameh-2, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh are located in the imbricated zone of the Zagros Mountain Ranges. Also, these sections are normal, and sequences of the Upper Cretaceous are distinct in field observations. The lower lithostratigraphic limits of the Zarghan, Dariyan, Kherameh-1 and Kherameh-2 stratigraphic sections are covered by rock falls and have not been outcropped. But a sequence of sedimentary rocks relating to the Cenomanian to Paleocene era in the Kuh-e Khanehkat, Kuh-e Siah and Kuh-e Chehelcheshmeh stratigraphic sections is perfectly observable (Figs.3.2.1 and 3.2.2). Only Kuh-e Siah is located in the Simply Folded Zone of the Zagros. The geological formations are located in the Sarvestan main fault.

3.1. Stratigraphy and Sedimentology

The characteristics and sedimentology of the Zagros were investigated first by JAMES & WYND (1965) and subsequently, by FALCON (l974). The Zagros is the northeastern most part of the Arabian Platform and was covered in the Paleozoic by epicontinental deposits. It became part of the Tethyan Ocean in the Permian, and sedimentation changed to carbonates. A chart of Zagros characteristics was given by JAMES &WYND, 1965 (Fig.3.1.1). Since the Tarbur Formation is of Upper Cretaceous age, the following will only be about the geological situations of Cretaceous to Paleocene time.

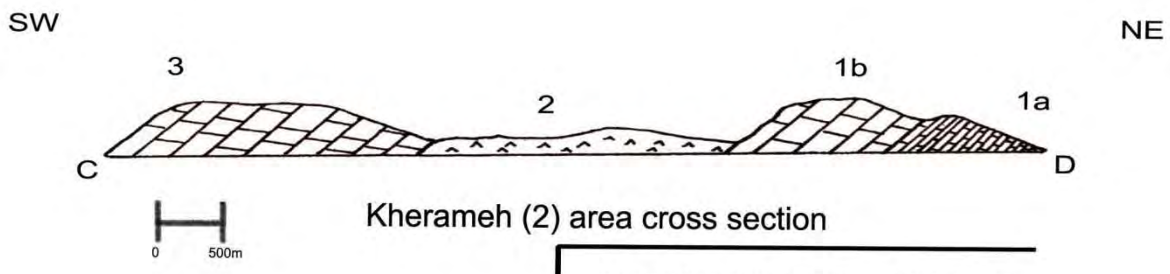




1a: Tarbur Formation (Lower Part)

1b: Tarbur Formation (Upper Part)

2: Sachun Formation (Paleocene)

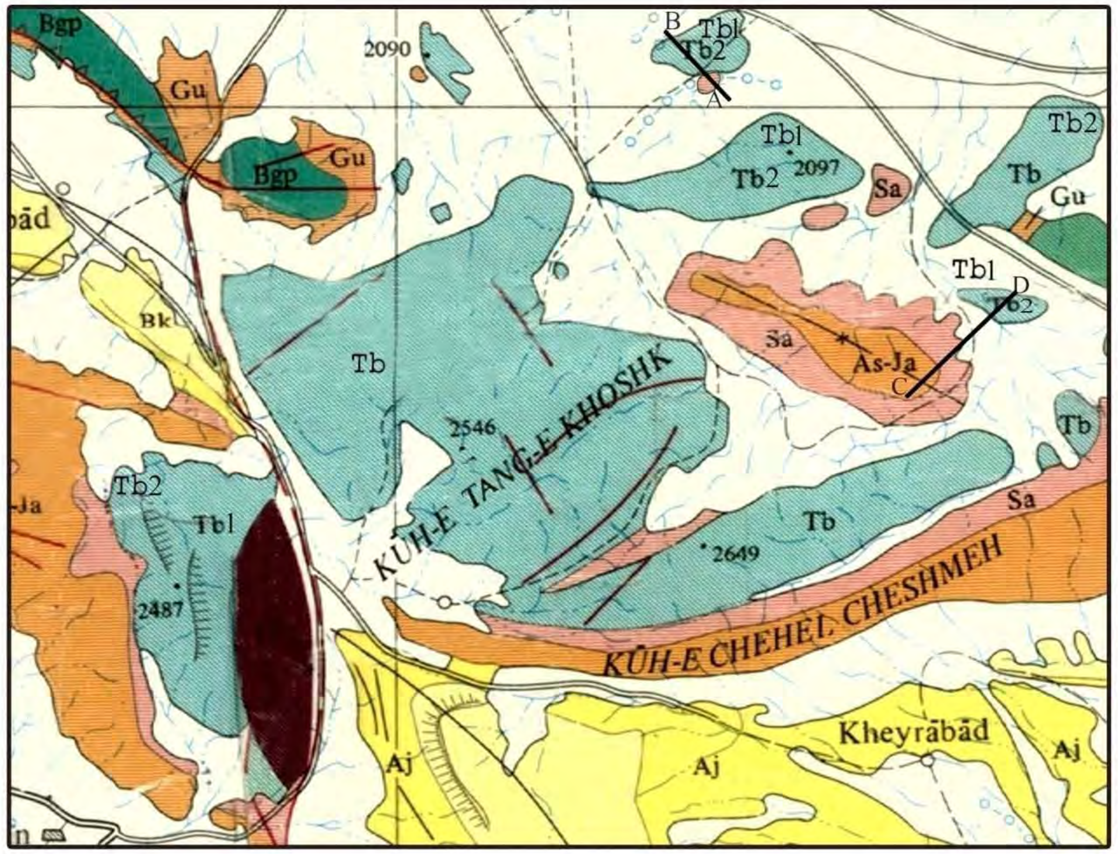


1a: Tarbur Formation (Lower Part)

1b: Tarbur Formation (Upper Part)

2: Sachun Formation (Paleocene)

3 : Jahrum (Eocene)



Scale 2 Km

Legnd of Geological and Topographical Information

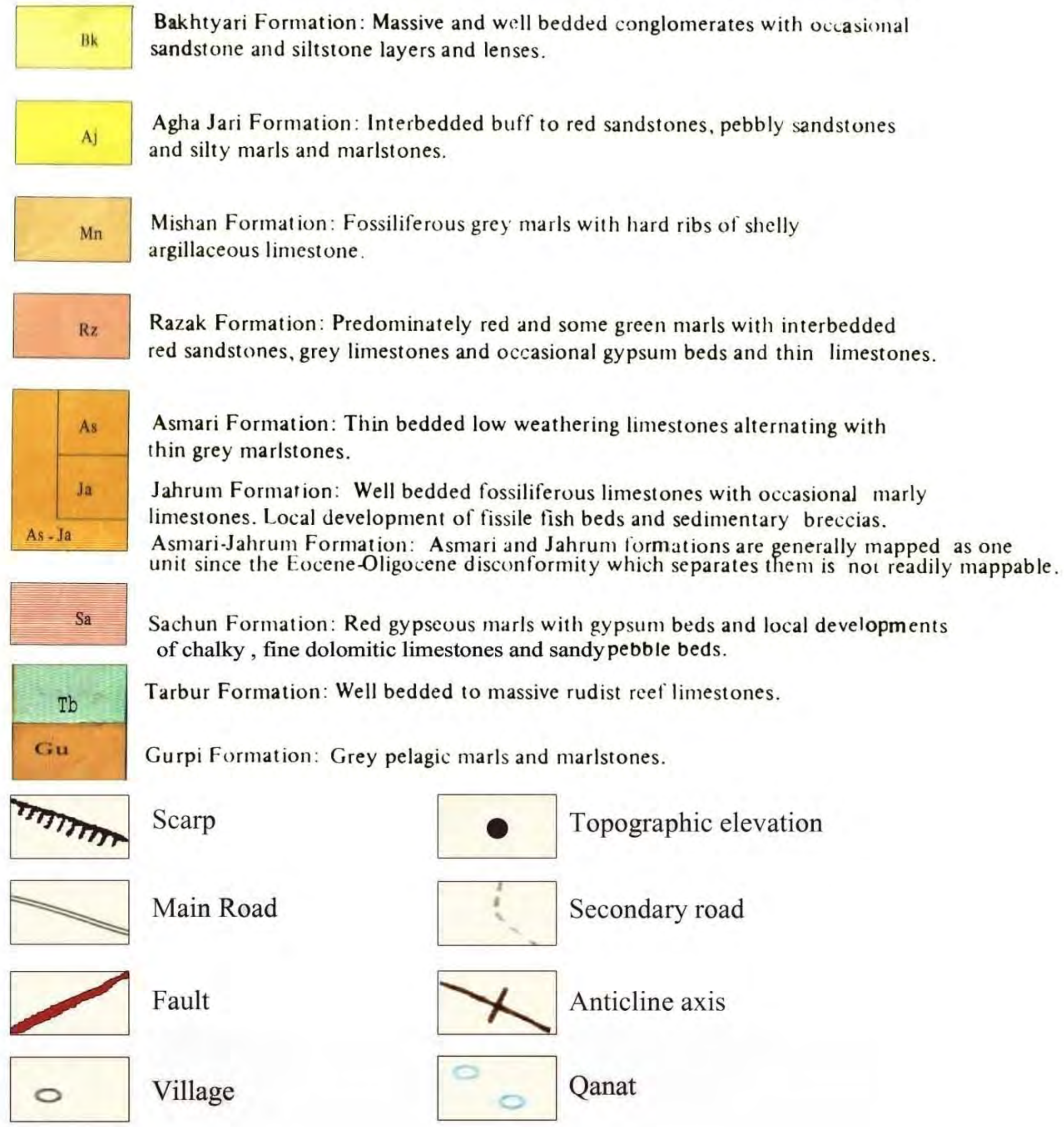


Fig.3.1.1 The geological map of Kherameh area that shows k1 and k2 stratigraphic sections of the Tarbur Formation. The AB cross line shows Geological section of k1, and CD indicates k2 geological section. Also the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part), and Tb2 (upper part) .

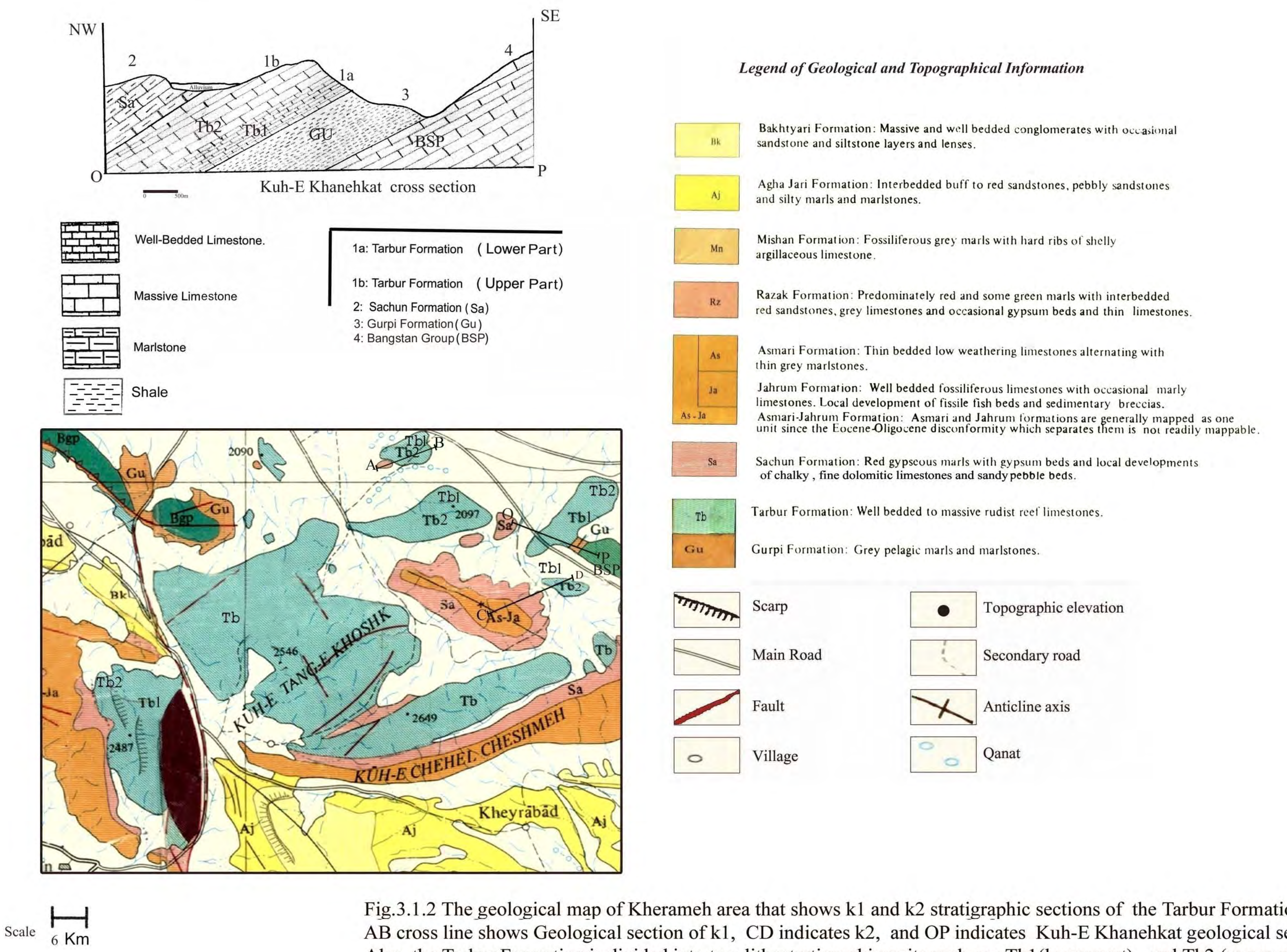


Fig.3.1.2 The geological map of Kherameh area that shows k1 and k2 stratigraphic sections of the Tarbur Formation. The AB cross line shows Geological section of k1, CD indicates k2, and OP indicates Kuh-E Khanehkat geological section. Also, the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part) , and Tb2 (upper part) .

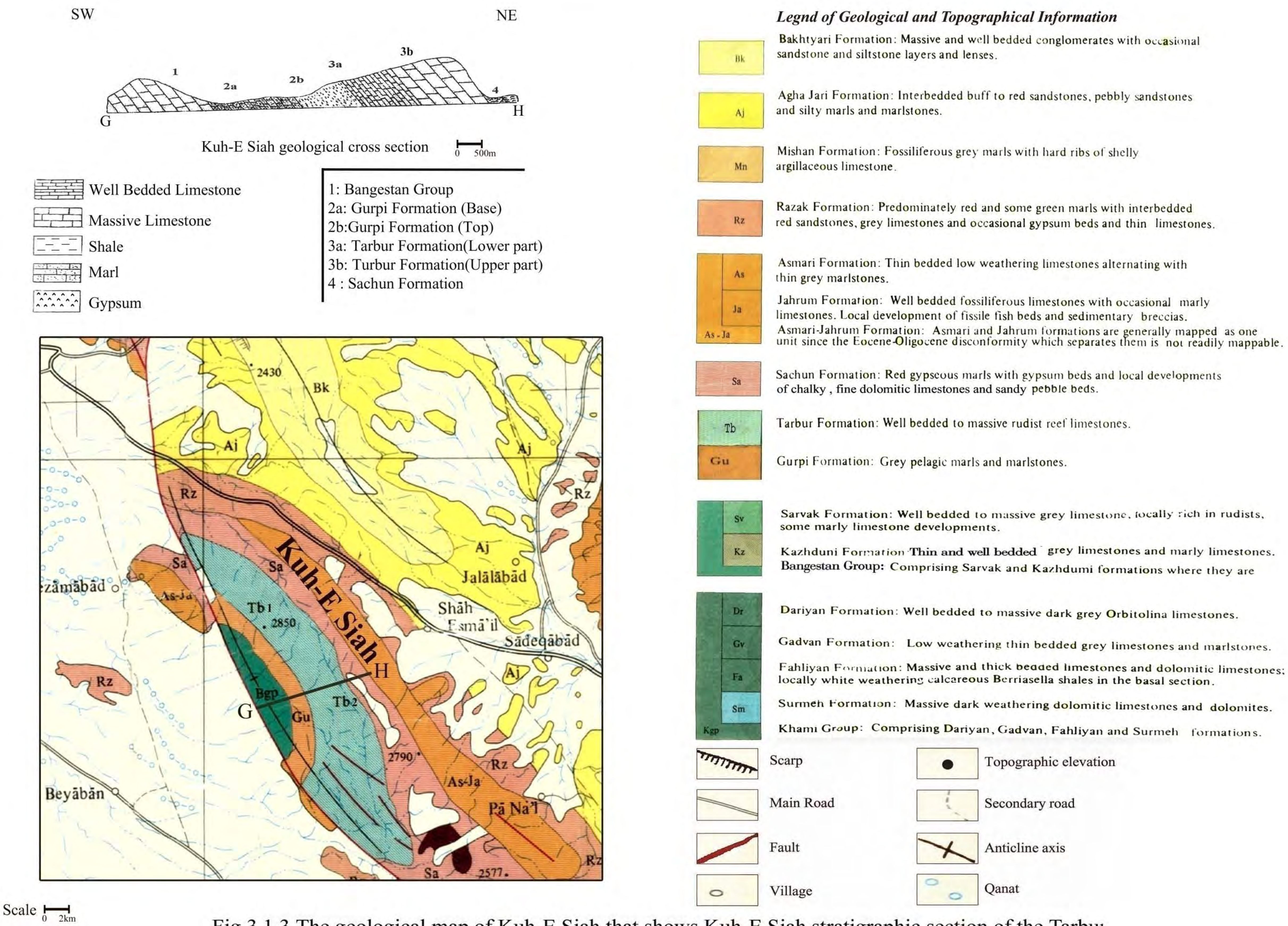


Fig.3.1.3 The geological map of Kuh-E Siah that shows Kuh-E Siah stratigraphic section of the Tarbur Formation. The line GH indicates geological section. Also the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part) , and Tb2 (upper part) .

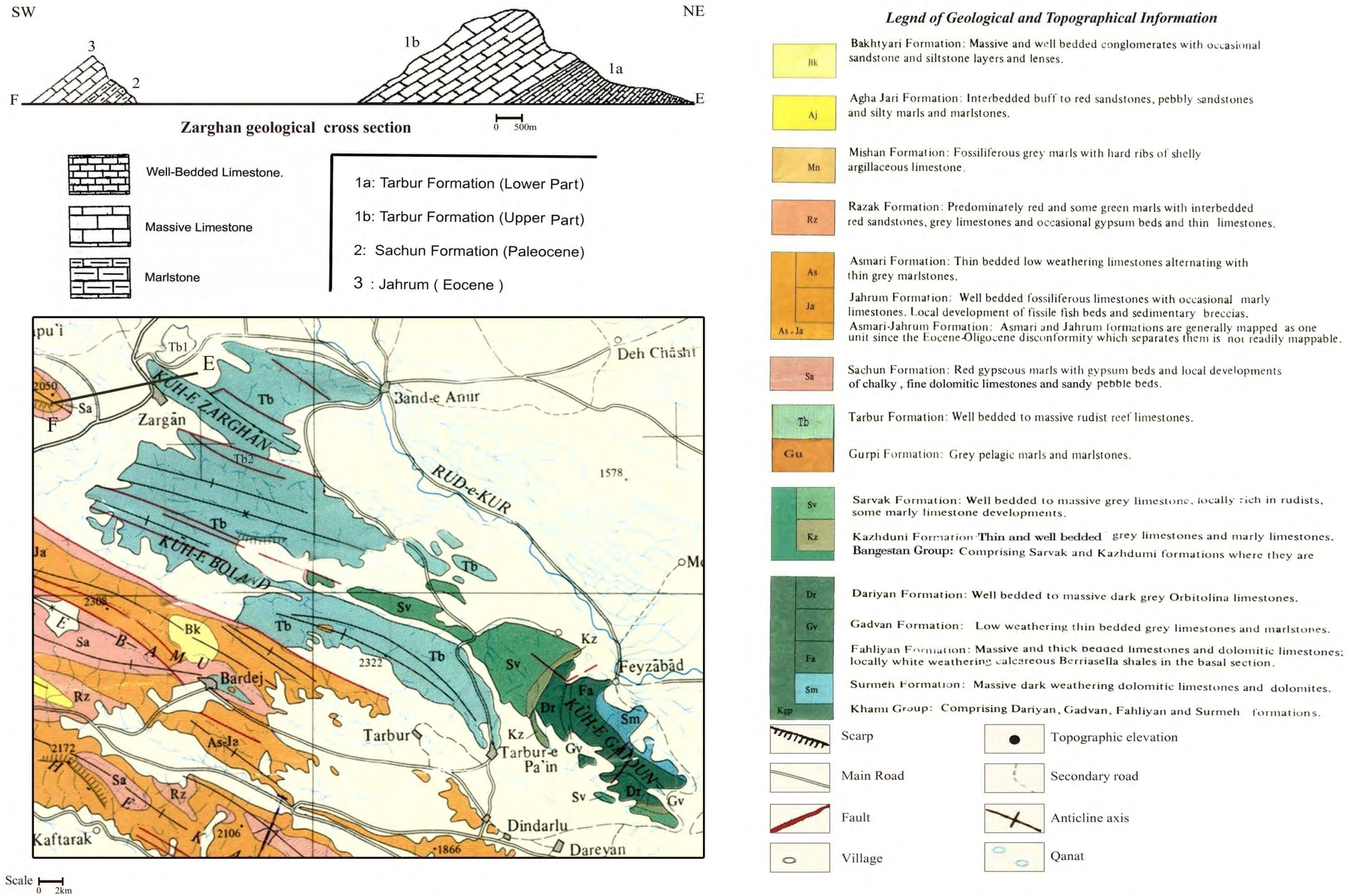
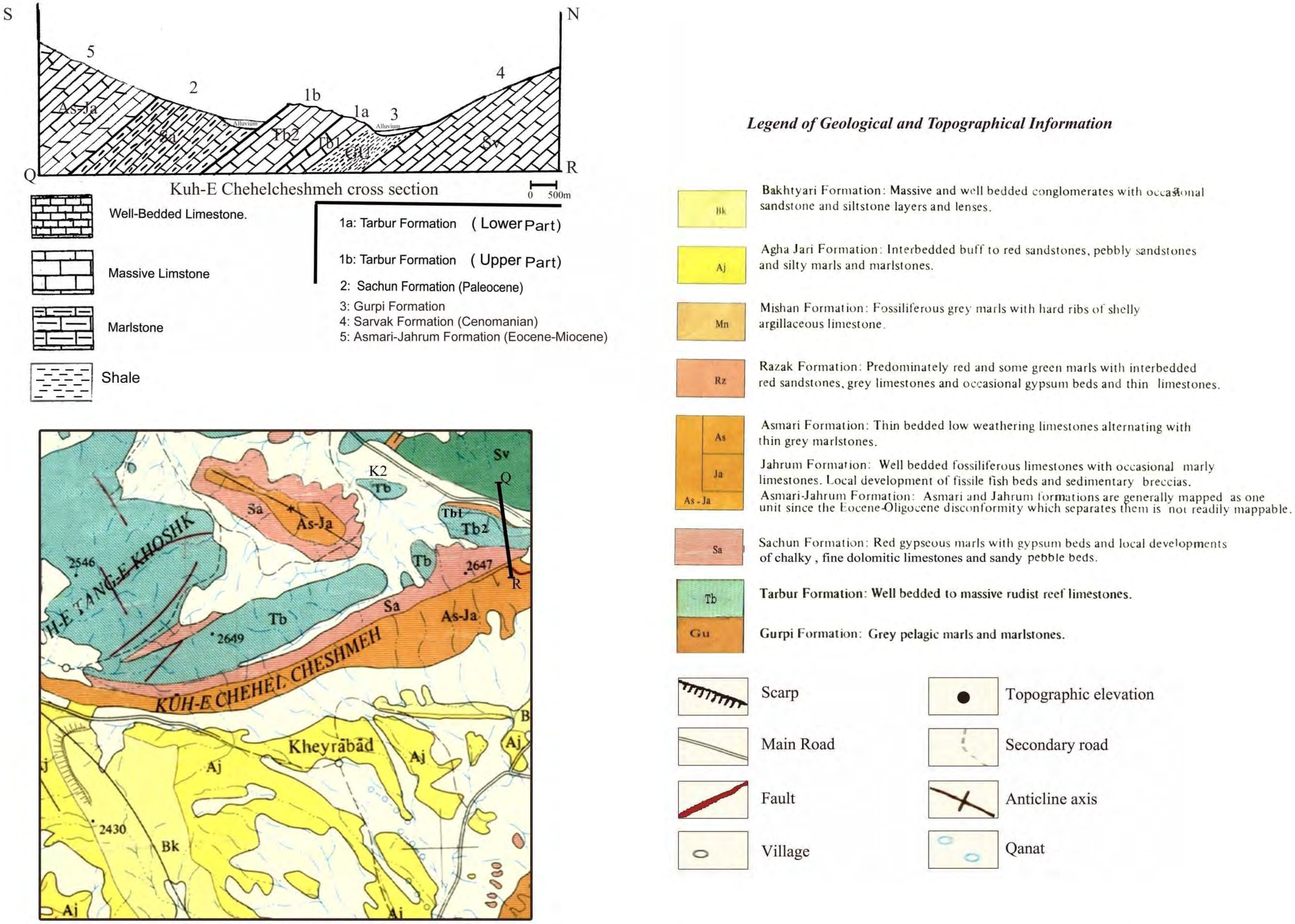
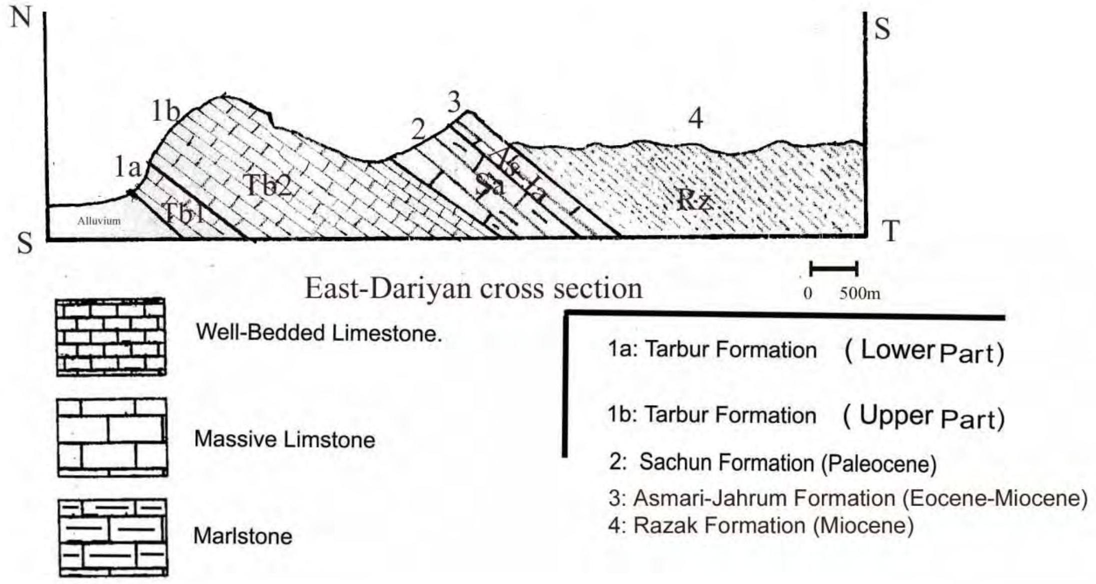


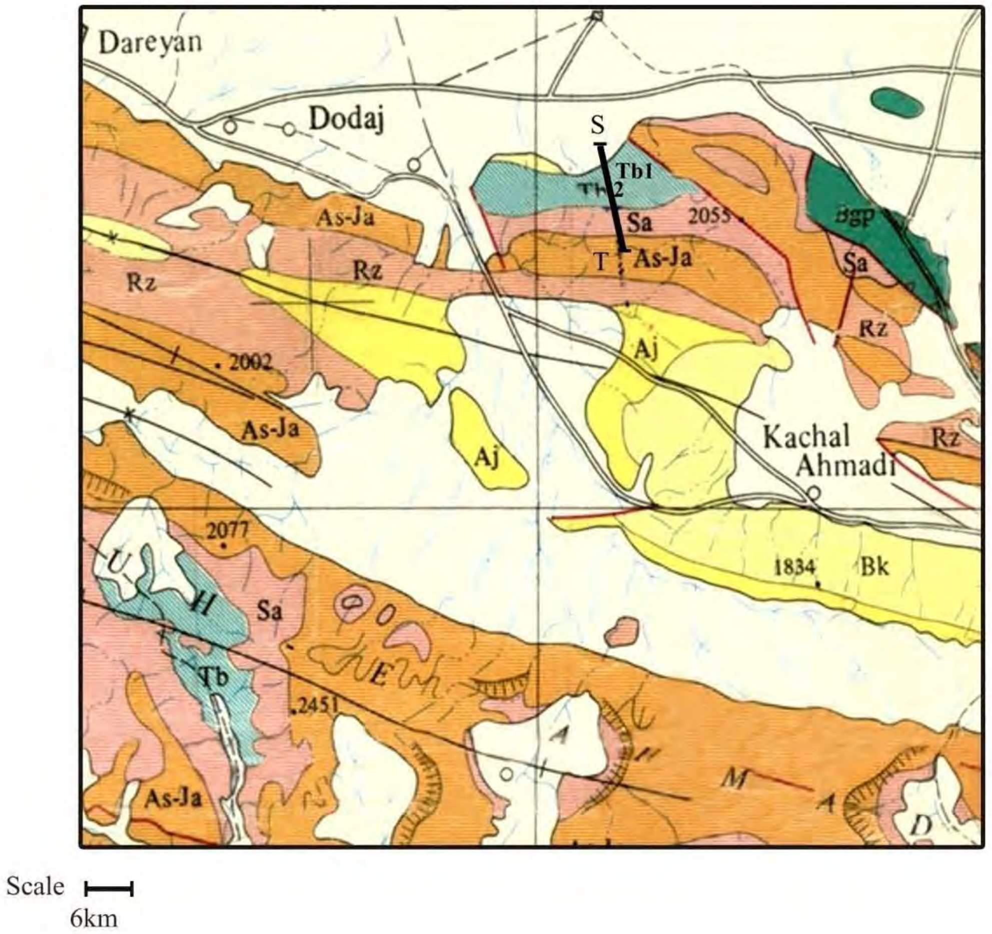
Fig.3.1.4 The geological map of Kherameh area that shows Zarghan stratigraphic section of the Tarbur Formation. The line EF indicates geological section. Also, the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part) , and Tb2 (upper part) .



Scale 6km

Fig.3.1.5 The geological map of Kuh-E Chehelcheshmeh stratigraphic sections of the Tarbur Formation. The QR cross line shows the geological section of Kuh-E Chehelcheshmeh showing.
Also, the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part) , and Tb2 (upper part) .





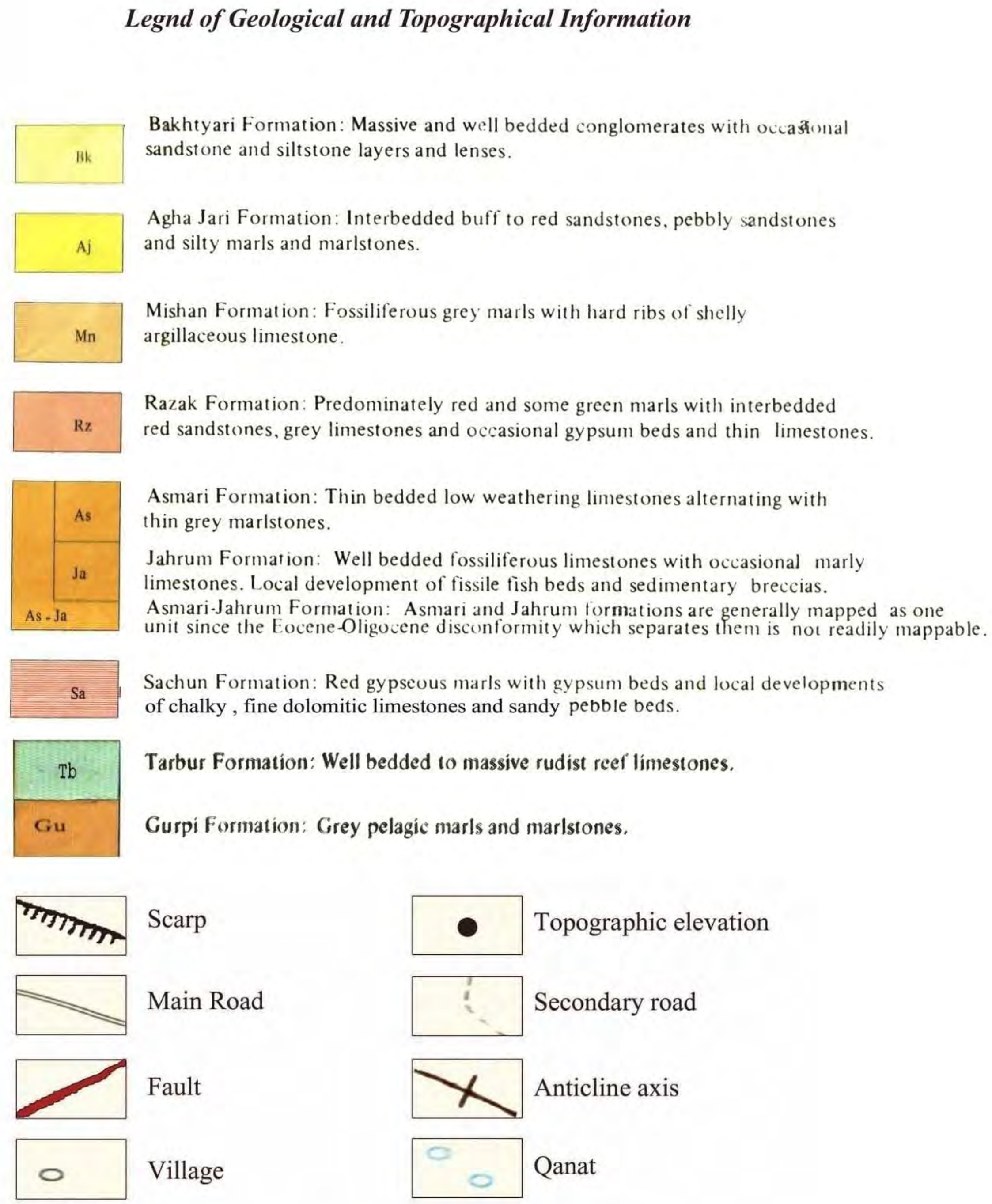


Fig.3.1.6 The geological map of East Dariyan showing stratigraphic sections of the Tarbur Formation. The ST cross line shows the geological section of East Dariyan geological section.
Also the Tarbur Formation is divided into two lithostratigraphic units such as : Tb1(lower part), and Tb2 (upper part) .

3.2.1. The Cretaceous in the Zagros

The Cretaceous to the Paleocene are well outcropped throughout the Zagros and the deposits are entirely of marine origin. The pioneer geologists, mainly from the British Petroleum Company, who worked in this region during the early 20th century, have subdivided the system into the Lower and Upper Cretaceous mainly because they believed there was not enough megafossil control for correlation with the European time scale in the area. Other reasons were the lack of clarity of the Albian-Cenomanian boundary and the presence of regional disconformities at the top of the Aptian, Turonian-Cenomanian and Maestrichtian. Later, the Geological Society of Iran (1995) adopted the boundary of the Albian-Cenomanian for the Lower-Upper Cretaceous, according to the European time-scale for the whole area of Iran. According to unpublished reports by the National Iranian Oil Company (GOLLESTANEH, 1965), there are some indications near the Persian Gulf area that there exists a disconformity at the top of the Jurassic, but this is not paleontologically proved in the Fars Province area.

The Fahliyan Limestone Formation of Lower Cretaceous age was produced in this area. It was at this time, early Cretaceous, that the first known salt intrusion took place in coastal Fars Province at Khormuj (KENT, 1970).

The carbonate sedimentation of the Fahliyan Formation was followed by the deposition of siltyshales and thin-bedded limestones of the Gadvan Formation in Fars and Khuzestan Provinces (Fig. 3.2.1).

The Dariyan Limestone Formation of the uppermost portion of Lower Cretaceous age, the Aptian stage, has been formed in the entire area of

Fars Province and the northeastern part of Khuzestan Province. It contains *Orbitolina* and sometimes rudist fragments. There is a regional disconformity at the top of the Dariyan Formation of Fars and eastern Khuzestan, which marks the final emergence at the end of the Aptian stage.The geological situation was different in Lurestan and the southwestern portion of Khuzestan Province, where the Garau Formation, containing deeper-water black limestone, shale and floods of Radiolaria, was formed and continued through the Aptian stage.

The deposition of bituminous shale, marls and limestone formed the Albian-Turonian Kazhdumi Formation as the area of Fars Province and the adjacent Khuzestan Province submerged.

The Sarvak Formation, shallow-water neritic carbonates, accumulated in Fars Province during the Cenomanian stage. A major regression near the close of the Cenomanian exposed the entire area. Whereas some authors (KASSLER, 1973) believe that the origin of the N-S Arabian Trend goes back to thePaleozoic, according to WELLS (1967), it was produced by regional warping at the end of the Mesozoic time. The exposed surface of the Sarvak Formation was then subjected to sub-aerial processes.

Some erosion took place, and the general weathering of the surface produced the widespread ferroginous staining which is easily seen today.

Whereas Central Lurestan was the location of fine-grained Oligostegina limestone, the Garau Formation, consisting of shale and limestone was formed in northwestern Lurestan and Khuzestan Provinces.

The Surgah Formation was formed in the northwestern part of Lurestan as the continuation of deeper-water sedimentation in the Coniacian stage. It consists of shale and thin argillaceous limestone. The post-Cenomanian disconformity is less pronounced in Lurestan Province, since the basinal sedimentation seems to have continued, particularly in the northwest. This deeper-water sedimentation in Lurestan continued during the Coniacian stage, producing shales and thin argillaceous limestone of the Surgah Formation.

In the Santonian-Lower Campanian the argillaceous limestone became more interbedded with shale partings and is now known as the Ilam Formation.

There was a great transgression in the Campanian in which the Gurpi Formation consisting of shale and marl, with the Lopha Limestone Member and later the Emam Hassan Limestone Member, were formed. The Surgah Formation is not developed in the Khuzestan and Fars area. Here, the Ilam Formation contacts the eroded surface of the Sarvak Formation.

After the Gurpi Formation (consisting of marls and shales throughout the Senonian in interior Fars Province) formed in the Late Campanian-Maestrichtian time, the Tarbur Formation consisted of rudist reefs.

Farther to the northeast of Fars Province, thick sequences of deep-water radiolarites were accumulating at the same time as the Gurpi and Tarbur Formations.

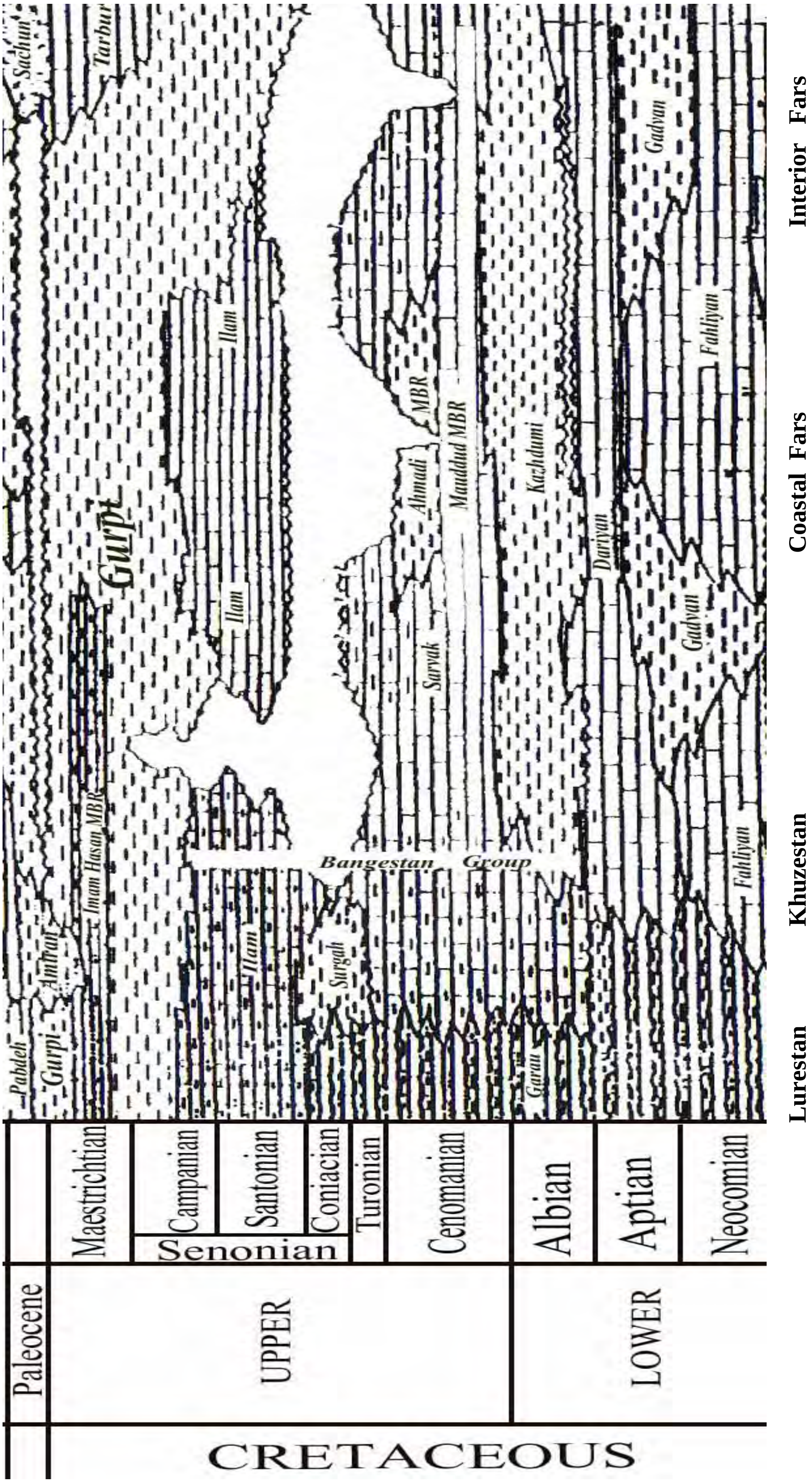
There was a general regression of the sea at the end of the Maestrichtian period, resulting in regional disconformity in Fars and Khuzestan Provinces.

3.2.2. The Tertiary in the Zagros

According to WELLS (1967), there was an elongated ridge in the Tethyan Ocean which separated the main trough in the north from a smaller trough which covered the area from eastern Iraq southeastward through southwest Lurestan and Khuzestan towards central Fars Province (Fig. 3.2.2).

The Pabdeh Formation, consisting of pelagic sedimentation with the deposition of marls and shales, intercalated with some argillaceous limestone formed in the smaller trough.

The Tarbur Formation is overlain by the Sachun Formation of Late Maestrichtian to Early Eocene age. The Sachun Formation consists of gypsum with bands of dolomites changing in short distances to marl and silt towards the northwest. The overlying formation is the dolomitic JahrumFormation of Eocene age. The equivalent formations from Maestrichtian-Eocene time in the southwest of the Arabian Shield are carbonate rocks of the Raduma and Dammam Formations.



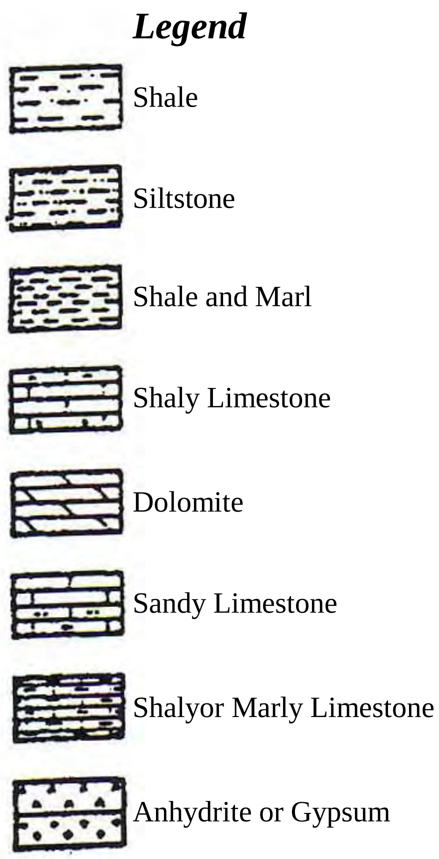


Fig. 3.2.1.Stratigraphic chart of the Zagros (James and Wynd, 1965) in the Cretaceous.

There is a great disconformity between the Dariyan and the Kazhdumi Formations which has been detected by iron nodules observed in the field.

The sediments deposited from the Cenomanian to the Santonian in Interior Fars, Coastal Fars and some parts of Khuzestan are benthic and show disconformities, whereas in Lurestan they are mainly pelagic in that time and show no disconformities. The Tarbur Formation in this study is located inInterior Fars. It has laterally changed to the GurpiFormation.The age of the lower part of the Tarbur Formation varies in Interior Fars, but the age of the upper part has been determined as Maestrichtian by previous studies. This upper part is synchronous with the Laramide orogenic phase.

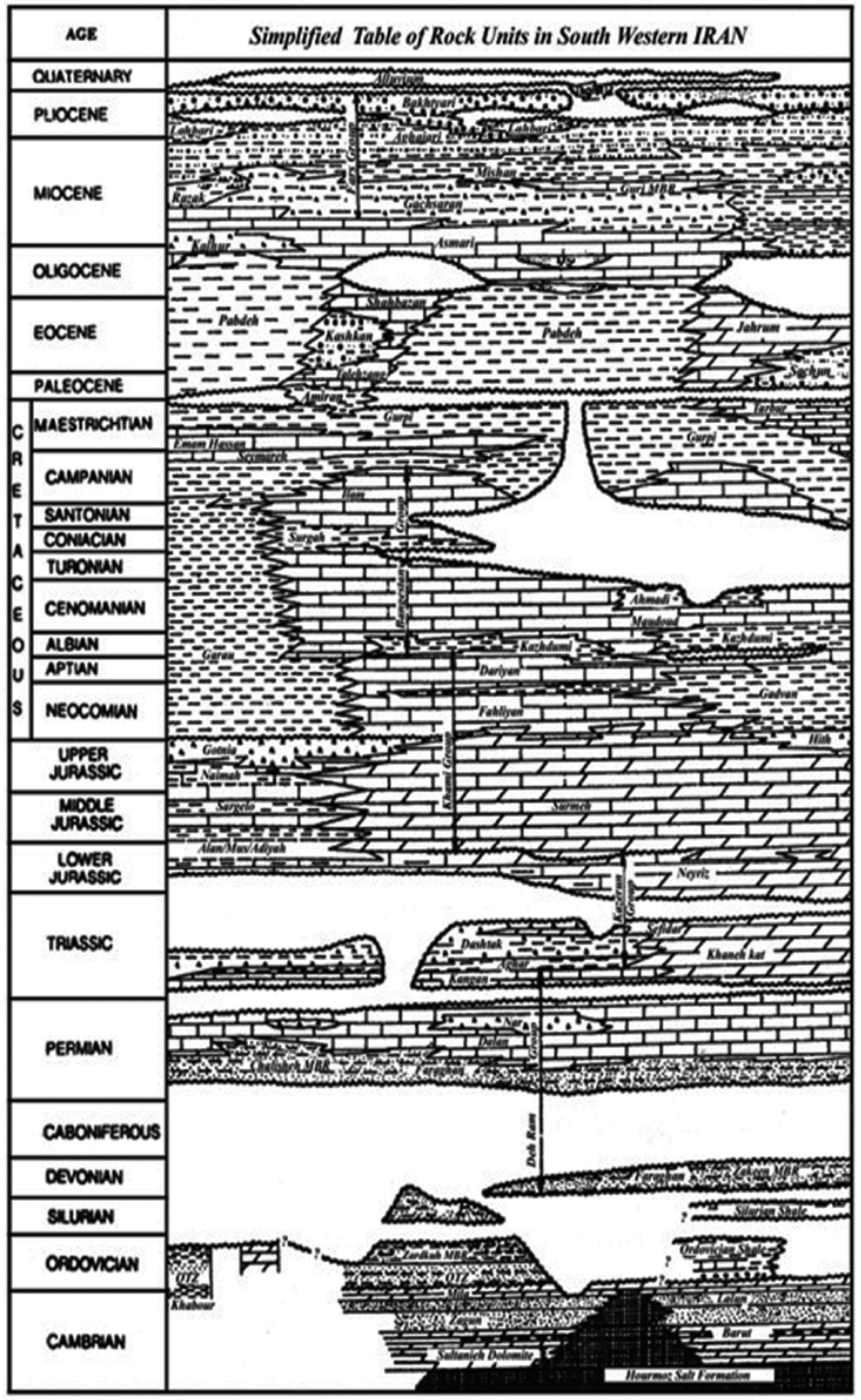


Fig.3.2.2. Stratigraphic chart of the Zagros (Motiee, 1992)

National Iranian Oil Company (N,I,O.C) and Geological servey of Iran studied the stratigraphy of Zagros.This studies have been the field of surface and sob surface geology, espicially, in oil dirilling project and the mappingof some partof the Zagros. This informations are published after twenty years of James &Wynd (1965)studies. It is necessary to note that all of the tectonic activities during Paleozoic to recent time are mainly epirogenic characters. Since there are a little outcrops of Paleozoic rocks, stratigraphic informations about Paleozoic are so little,but, there some evidences about disconformity between Ordovician and Silurian rocks that relates to the Caledonian oragenic phase. Also, there is a great stratigraphic gap between Devonian and Permian sediments, that relates to the Hercynian oragenic phase. Disconfotmity between Permian and Teriassic palatien movments, akd disconformity between Jurassic are related ti early Kimmerian movements. Deposition of sediments is continous during Jurassic to Upper Cretaceous in some part of the western Zagros. Based on N.I.O.C & Geological Servey of Iran, there is most important disconformity between upper Cretaceous and Tritiary (Laramid tectonic phase). As results of upper Eocene to Oligocene movements, there is a disconformity between Jahrum & Asmari formations. The youger disconformities of Zagros are not so important in corresponding with the last disconformities.

3.3. Relation to Previous Works

G.A. JAMES and J.G. WYND (1965) named this formation after the village of Tarbur in Fars Province. STOCKLIN and SETUDEHNIA (1977) have given the following description of the Tarbur Formation.

VAZIRI-MOGHADDAM et al. (2005) published the result of their study on a section of theTarbur Formation in the Kherameh area. According to the geographical coordinates of that section, it is identical with the Kuh-e Chehelcheshmeh section in this study, but contradicts the measurements and observations of this work as follows:

1. The thickness of the former section wasgiven as 724.5 m, whereas it is 360 m in this study. In none of the 7 sections in this study and around the area does the Tarbur Formation have a thickness of more than 450 m.

2. The age of the Tarbur Formation has been given in the former section as the Maestrichtian, whereas in this study the existence of *Orbitoides concavatus* (RAHAGHI, 1976) at the base of the section and *Vania anatolica* (SIREL&GUENDUES, 1985) and *Laffitteina* sp**.** at the top of the section confirm the age of the Campanian to the Paleocene.

3.3.1. Type Locality and Section

Location: The type section was measured at Kuh-e Gadvan, 75 miles north of Tarbur village in Fars Province. The coordinates of the section are E 52°45′05″ N 29°38′01″ (Fig. 3.3.1a).

Thickness: 527.3 m at the type locality.

Lithology: The Tarbur Formation consists of resistant, mainly massive, shelly, cliff-forming, partly anhydritic limestone, bounded by low-weathering units of the Gurpi and Sachun Formations. The underlying Gurpi Formation: The lower contact with underlying marls of the Gurpi Formation is sharp and conformable.The overlying Sachun Formation: The upper contact with the red andgrey-green marl of the Sachun Formation is associated with a zone with ferroginous nodules and concretions which may indicate an erosional period.

Fossils identified: *Monolepidorbis doovillei*, *Omphalocyclus macroporus* (LAMARCK), *Siderolites calcitrapoides* (LAMARCK), *Orbitoides media* (d' ARCHIAC), *Loftusia* sp., *Dictyoconella* sp., *Dicyclina* sp., and *Lepidorbitoides* sp.

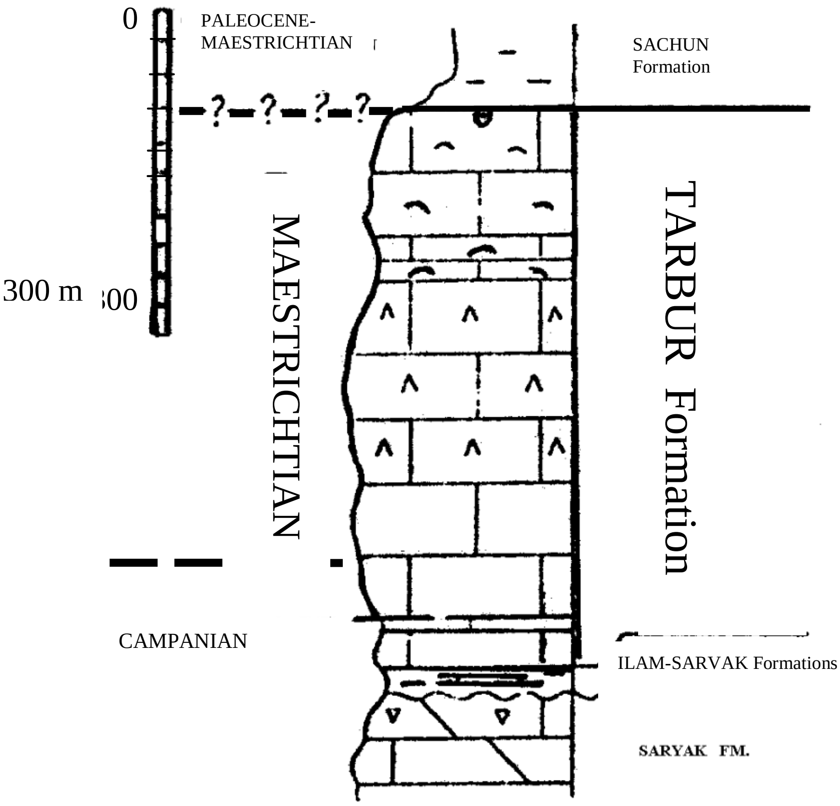


Fig.3.3.1a. Type section of the Tarbur Formation (JAMES & WYND, 1965)

In another study implemented at the same coordinates as those reported by KHOSRAVI (1968), thefollowing discrepancies were noticed with what had been reported before (Fig. 3.3.1b).

Lithology: Well-bedded limestone and massive limestone.

Fossils: *Omphalocyclus macroporus* (LAMARCK), *Lepidorbitoides* sp., *Orbitoides media* (d' ARCHIAC), *Loftusia* sp.

Based on the identified microfossils, the age of the Tarbur Formation has been determined to be from Late Campanian to Maestrichtian. In a further study performed by KALANTARI (1976) in the Kuh-e Ahmadi area, 80 km to the southeast of Shiraz, the thickness of the

Tarbur Formation was reported to be 360m. The lithology consists of high argillaceous organo-detrital limestone, intercalation with grey calcareous, silty shale and dolomitic limestone.

Fossils: *Gavelinopsis menneri, G.voltziana, Siderolites calcitrapoides, Loftusia minor, L. morgani, L.harisoni, Omphalocyclus macroporus.*Based on the identified microfossils, the age of the Tarbur Formation has been determined to be Maestrichtian (Fig. 3.3.1c).

The status of knowledge about the Tarbur Formation and its thickness in different stratigraphic sections is brief; moreover, its biostratigraphic limits are different from section to section. The lower lithostratigraphic limit is not distinct, especially in the type section studied, and the index foraminiferal constituents in the studied sections, which have precisely identified the chronostratigraphic limit, are not distinct between the lower part and the upper part of the Tarbur Formation. Furthermore, there is a general lack of detailed information on the thorough microfacies characteristics in place and time and no thorough statistical study of microfacies elements andtheir relationships to sedimentary environments.

It should be noted that in the KALANTARI (1976) study, which is related to the exploration for petroleum in the Ahmadi Mountains (west of Kuh-e Siah), the only section of the Tarbur Formation with distinct lithographic limits is of Maestrichtian age.

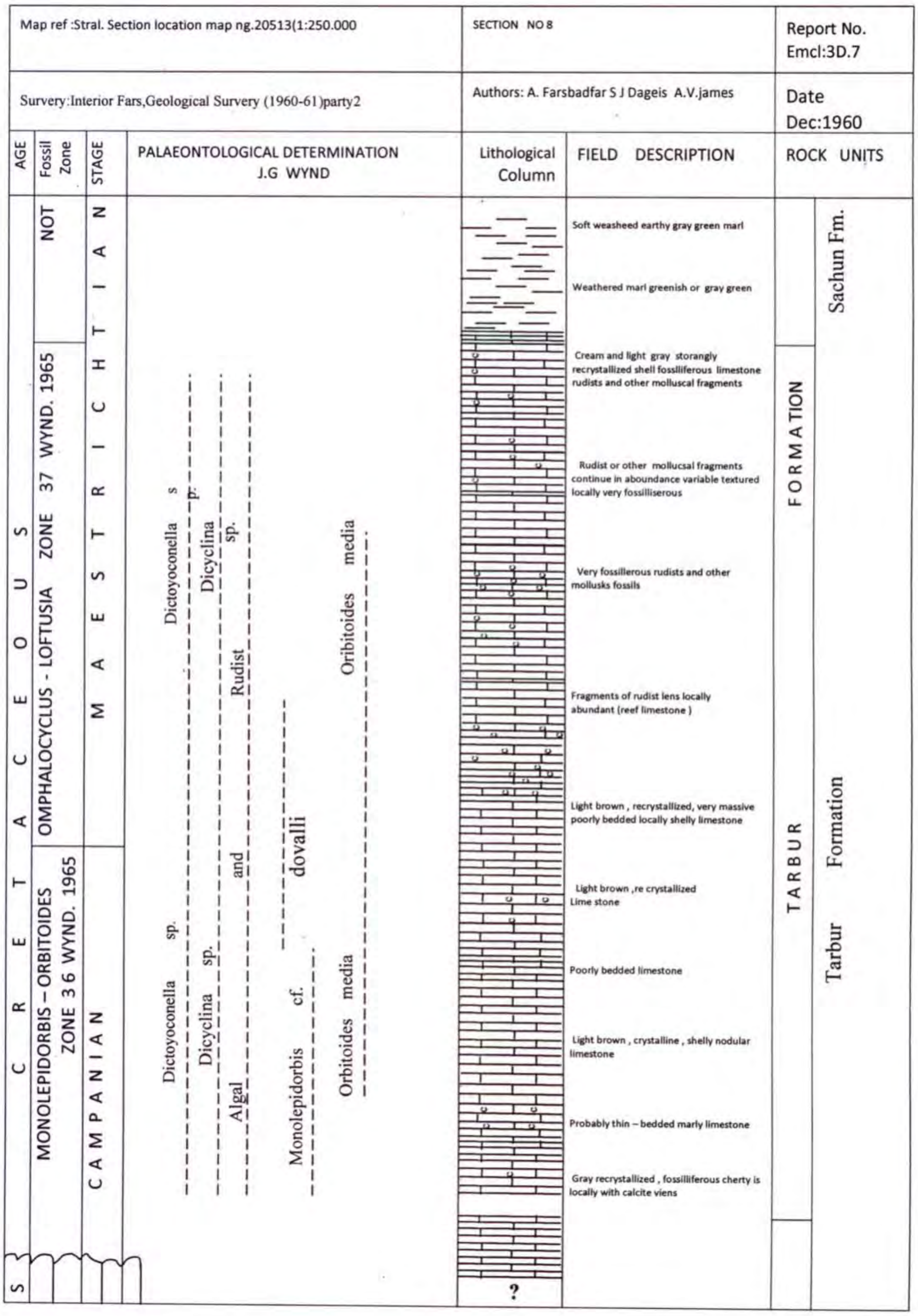
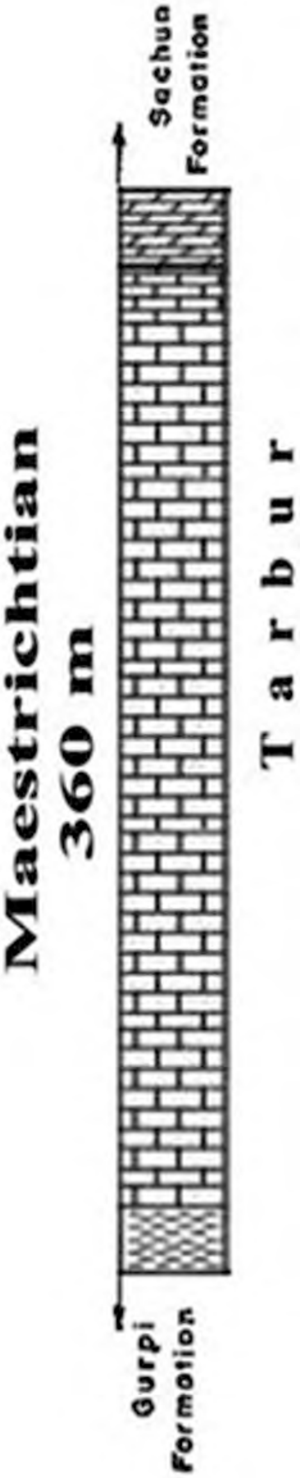


Fig.3.3.1b Stratigraphic column of the Tarbur Formation in Kuh-e Gadvan (Khosravi,1965)

TARBUR FORMATION (Maestrichtian stage)
scale : 1 cm= 30 m



Lithology and faunal description

- grey to whitish grey , organo - detrital slightly dolomitic limestone with a reefal microfouna such as *Loftusia morgani , Loftusia minor , Loftusia harrisoni , Omphalocyclus macroporus* **, Rudist and algal fragments.**

-light gray to buff gray , argillaceous , organo-detrital limestone with *Siderolites calcitrapoides , Omphalocyclus macroporus ,Rotalia cf. trochidiformis and Loftusia coxi*

-Light grey to brownish grey , highly argillaceous organo detrital limstone , intercalation with grey calcareous , silty shale.

- grey calcareous silty shale with *Gavelinapsis menneri, Globorotalites misheliniana , Gavelinopsis valtziana and Gyroidinoides* sp.

- grey to dark brownish grey partly microcrystalline , calcitized,detrital limestone with *Omphalocyclus macroporus , Rotalia cf. trochidiformis , Siderolites calcitrapoides, Lepidorbitoides* sp. , **Rudist and algal remain**

Fig. 3.3.1c. The Tarbur Fm. in the west of Sarvesten area by KALANTARI (1975) N.I.O.C. Oil drilling project

4. Lithologyof the Tarbur Formation

The lithology of the Tarbur Formation consists of massive limestone which has a thickness of 527m in the type section. In this study, the Tarbur Formation is indicated to have different thicknesses. For example, in the Kuh-e Siah section the thicknessis 491 m, in Kherameh-1 202 m, in Kherameh-2 270 m, and in the Zarghan section 776 m. The lithology in these sections consists of two parts:

1- Well-bedded limestone (the lower part)

2- Massive limestone (the upper part).

The thickness of the lower and upper parts is different in the above mentioned sections. As a rule, lithologic characteristics are different in various stratigraphic sections. The geological situation of the Tarbur exposures is explained in section 2.1.2.

Therefore, to the southwest the Tarbur Formation becomes pelagic facies and changes gradually to the Gurpi Formation, so that farther to the northeast, the radiolarites are overlain by the Tarbur Formation. In some areas the Tarbur Formation interfingers with the Gurpi Formation.

4.1. Lithology of the Tarbur Formation in Kherameh-1

The lower part: The main lithology is white well-bedded wackestone, rudist with gastropod remains and foraminiferal debris and finally milkyand white coloured massive and well-bedded wackestone, with a thickness of about 70m (Fig. 4.1). Detailed field descriptions from top to bottom are presented below:

Milky and white coloured, well-bedded wackestone (18 m).

Grey to brown thick-bedded wackestone with gastropod remains (12 m).

Rudist with gastropod remains including foraminiferal debris such as *Murciella cuvillieri, Diyclina* sp., *Orbitoides concavatus* (20 m).

Grey medium-bedded wackestone (8 m).

White well-bedded wackestone (6 m).

Grey to white medium-bedded wackestone (6 m).

The upper part: The main lithology is cream and yellow coloured massive wackestone, grey and cream coloured massive wackestone, and finally, milky and cream coloured massive limestone. The thickness is 132 m. Detailed field descriptions from top to bottom are presented below:

Brownish to grey massive limestone (3.5m).

Milky and cream coloured massive limestone (4 m).

Greyish-brown massive limestone with gastropods, *Orbitoides media* (12 m)

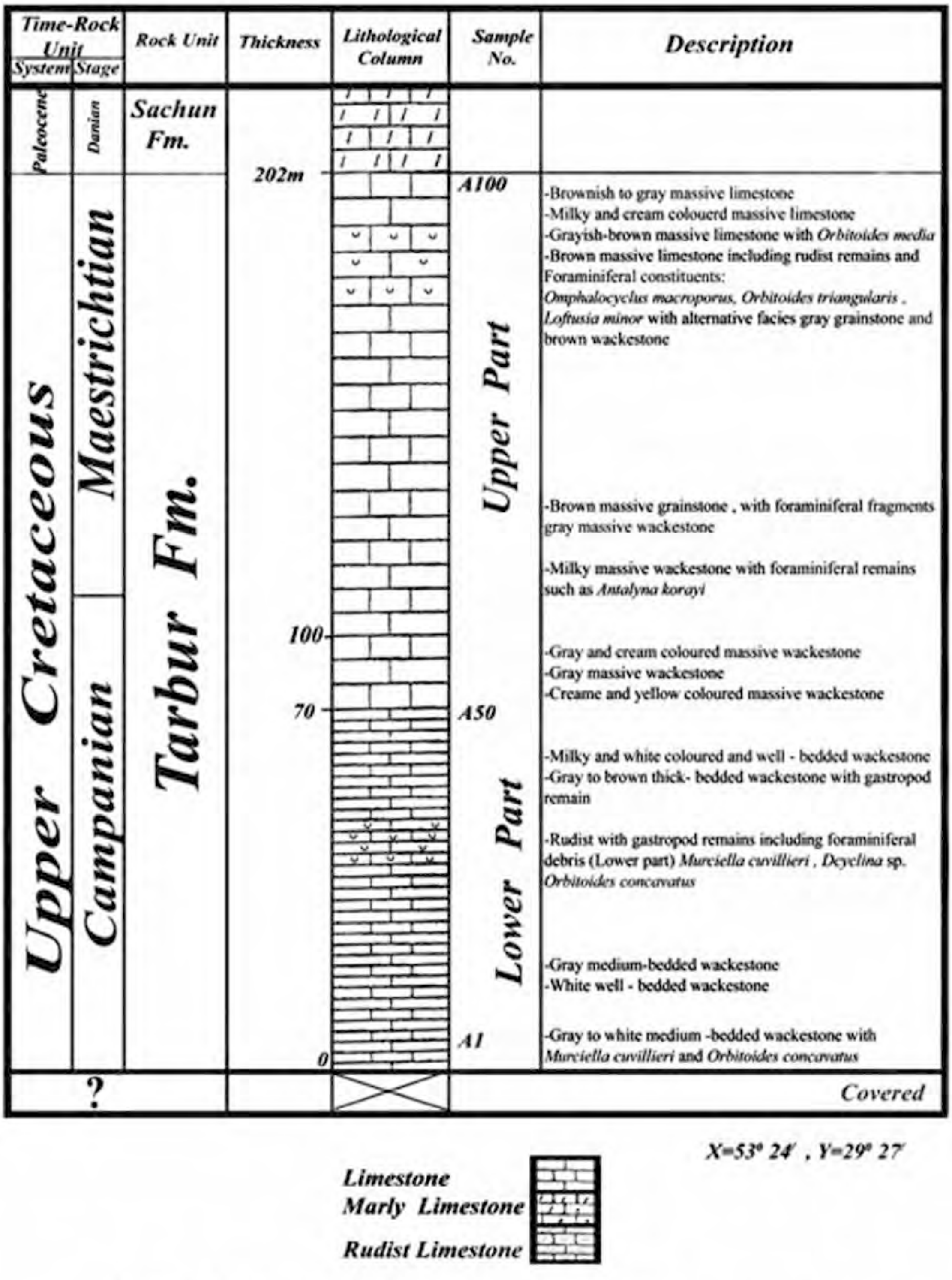


Fig.4.1. Stratigraphic columnar section of Kherameh -1

Brown limestone including rudist remains and foraminiferal constituents :

Omphalocyclus macroporus, Orbitoides triangularis,

Loftusia minor (40 m).

Grey massivewackestone (11 m).

Brown massive grainstone with foraminiferal fragments (10 m).

Grey and cream coloured massive wackestone (11 m).

Milky massive wackestone with foraminiferal remains such as *Antalyna korayi* (15 m).

Cream and yellow coloured massive wackestone (8 m).

Grey massive wackestone (10 m).

4.2. Lithology of the Tarbur Formation in Kherameh-2

The lower part: milky well-bedded limestone with grey coloured inter-beds including rudist and foraminiferal remains, 110m in thickness (Fig. 4.2).Detailed field descriptions from top to bottom are presented below:

Milky to brown medium-bedded limestone (13 m).

Grey to brown medium-bedded limestone with coral remains (20 m).

Milky well-bedded limestone with grey coloured inter-beds including rudist and foraminiferal remains (40 m).

Grey thick-bedded limestone with foraminiferal debris (22 m).

Grey to brown medium-bedded limestone with *Omphalocyclus macroporus* (15 m).

The upper part: milky and grey massive limestone, milky massive limestone with rudist, grey massive limestone, and finally, cream and light-grey coloured massive limestone with iron nodules remains, 160mm in thickness. Detailed field descriptions from top to bottom are presented below:

Cream and light-grey coloured massive limestone with iron nodules remains (40 m).

Grey to cream thick-bedded to massive limestone with gastropod debris (16 m).

Grey massive limestone (20 m).

Greyish-brown massive limestone whose weathered colour is brown with foraminiferal remains such as:

Orbitoides media (25 m).

Milky massive limestone with rudist fragments (30 m).

Brown massive limestone with rudist fragments (15 m).

Milky and grey massive limestone with fossil remains (14 m).

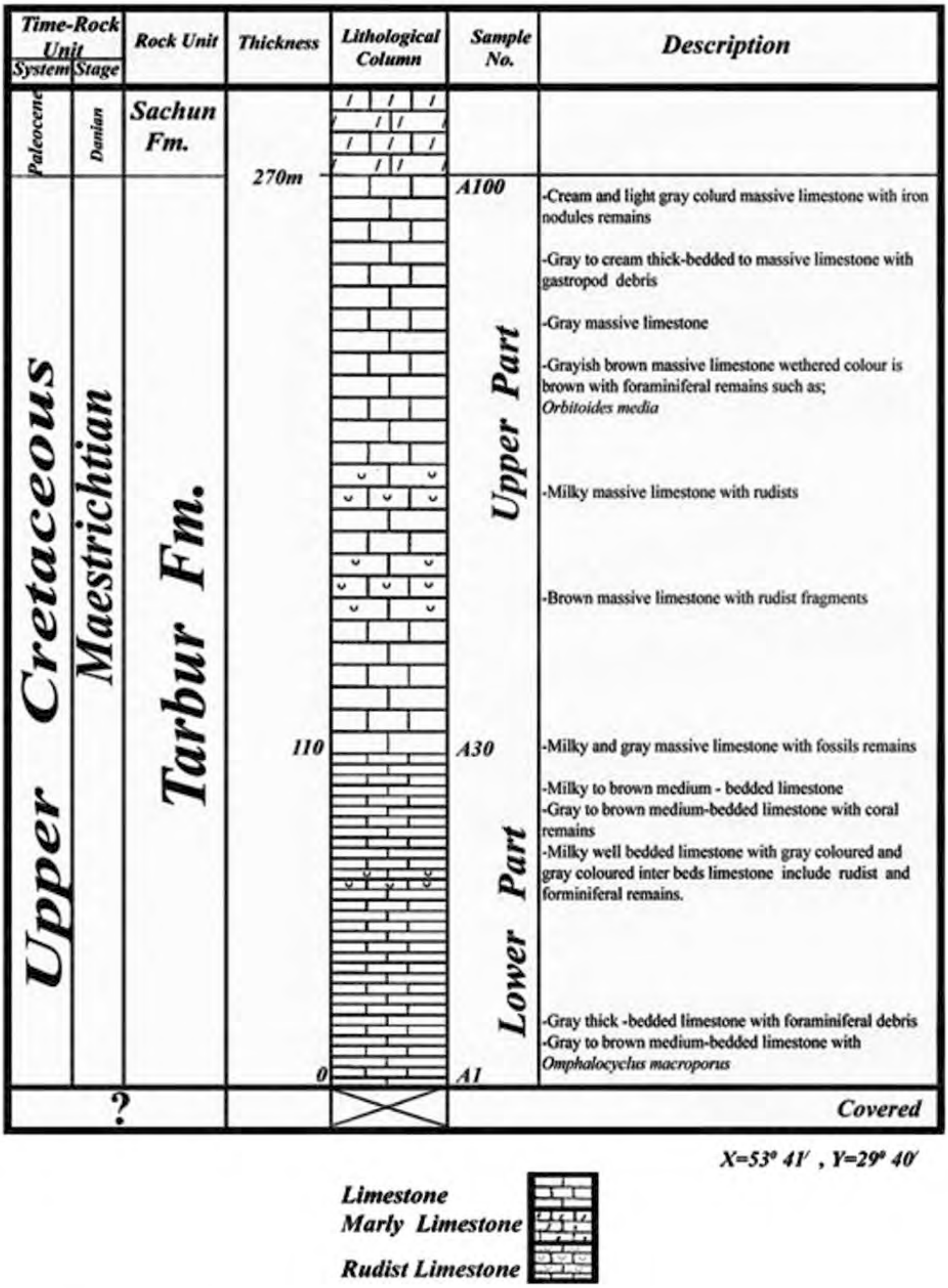


Fig.4.2. Stratigraphic columnar section of Kherameh-2

4.3. Lithology of the Tarbur Formation in Kuh-e Siah

The lower part: the lithologic characteristic is mainly milky well-bedded limestone with grey coloured interbeds with rudist remains, milky and white coloured well-bedded limestone with iron nodules and rudist remains, 204 m in thickness (Fig.4.3).Detailed field descriptions from top to bottom are presented below:

Milky and white coloured well-bedded limestone with iron and rudist remains (46 m).

Milky to brown well-bedded limestone with coral remains (30 m).

Milky to cream medium-bedded limestone (45m).

Milky to grey medium-bedded limestone with rudist fragments (31m).

Milky well- bedded limestone with grey coloured inter-beds with rudist remains (52m).

The upper part: The main lithology is white massive limestone, iron nodules, rudist remains and gastropod fragments, 287m in thickness. Detailed field descriptions from top to bottom are presented below:

White massive limestone, iron nodules and rudist remains including gastropod fragments (35 m).

Grey to brown massive limestone with rudist remains, and foraminiferal remains such as *Laffitteina* sp. (90 m).

White massive limestone with rudist including foraminiferal remains (39 m).

White to grey massive limestone with gastropod fragments (50 m).

Milky to grey massive limestone including *Goupillaudina shirazensis* (73 m).

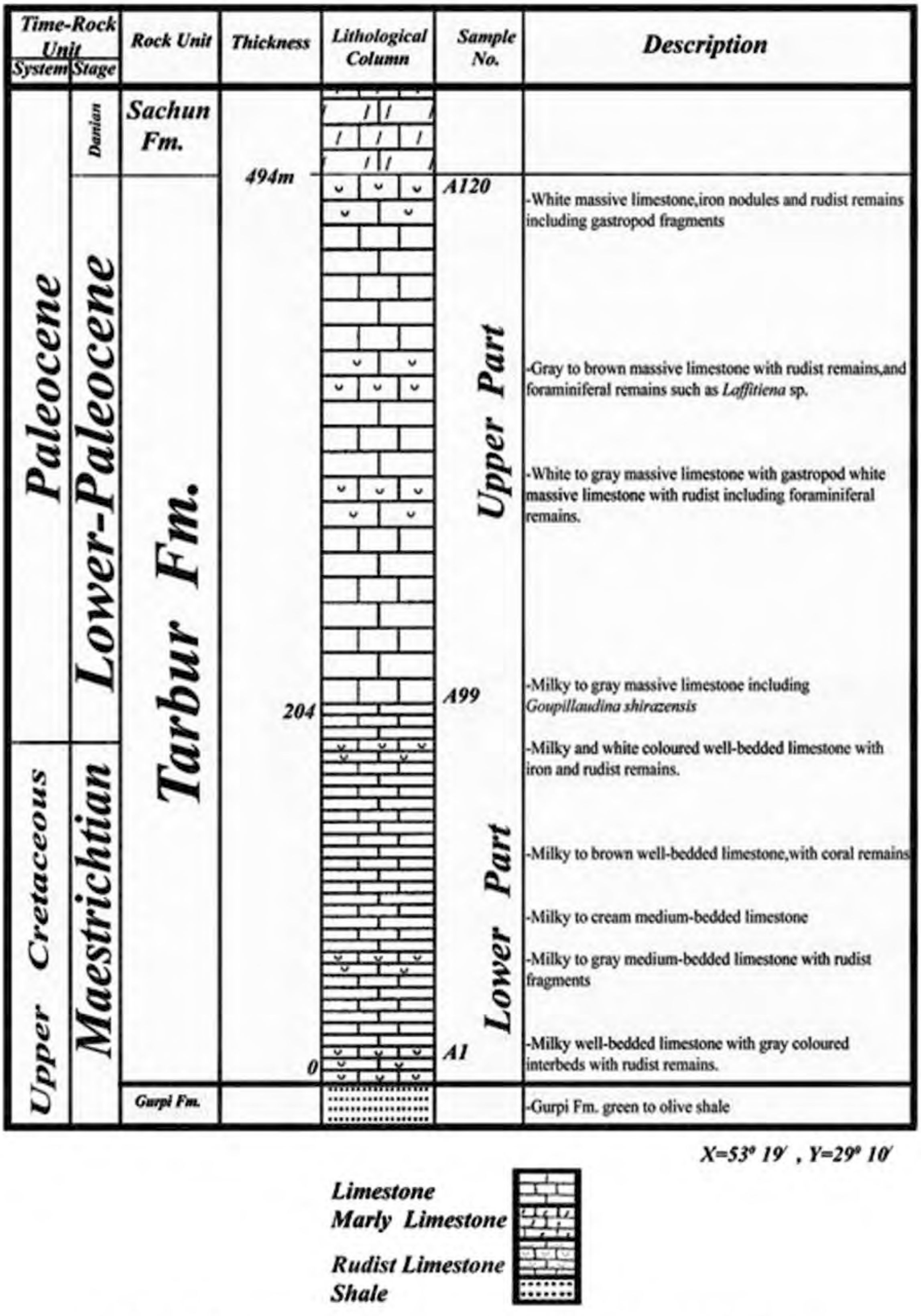


Fig.4.3. Stratigraphic columnar section of Kuh-E Siah

4.4. Lithology of the Tarbur Formation in Zarghan

The lower part: It consists mainly of milky well-bedded limestone with shell fragments, grey well-bedded limestone with rudist fragments, 282 m in thickness (Fig. 4.4). Detailed field descriptions from top to bottom are presented below:

Grey well-bedded limestone (57 m).

White to grey well-bedded limestone with foraminiferal debris (73 m).

Grey well-bedded limestone including rudist fragments (19 m).

Brown well-bedded limestone with rudist fragments (62 m).

Milky well-bedded limestone including gastropod and shell fragments (21 m).

Grey well-bedded limestone with rudistfragments (50 m).

The upper part: It consists of grey to cream massive limestone with crushed shells of gastropods, 494 m in thickness. Detailed field descriptions from top to bottom are presented below:

Grey massive limestone with Hippurites and gastropods (33 m).

Grey to white massive limestone with gastropods (20 m).

Brown massive limestone with Hippurites and foraminiferal remains such as *Broeckinella* sp. (37 m).

Grey and cream coloured massive limestone with large rudists and shell fragments debris (gastropods-pelecypods) in some of the recrystallization parts including microfossil remains (57 m).

Brown to grey massive limestone with *Rotalia skourensis* (101 m).

Grey massive limestone (83 m).

Cream massive limestone with foraminiferal remains (98 m).

Brown to grey massive limestone with Hippurites (65 m).

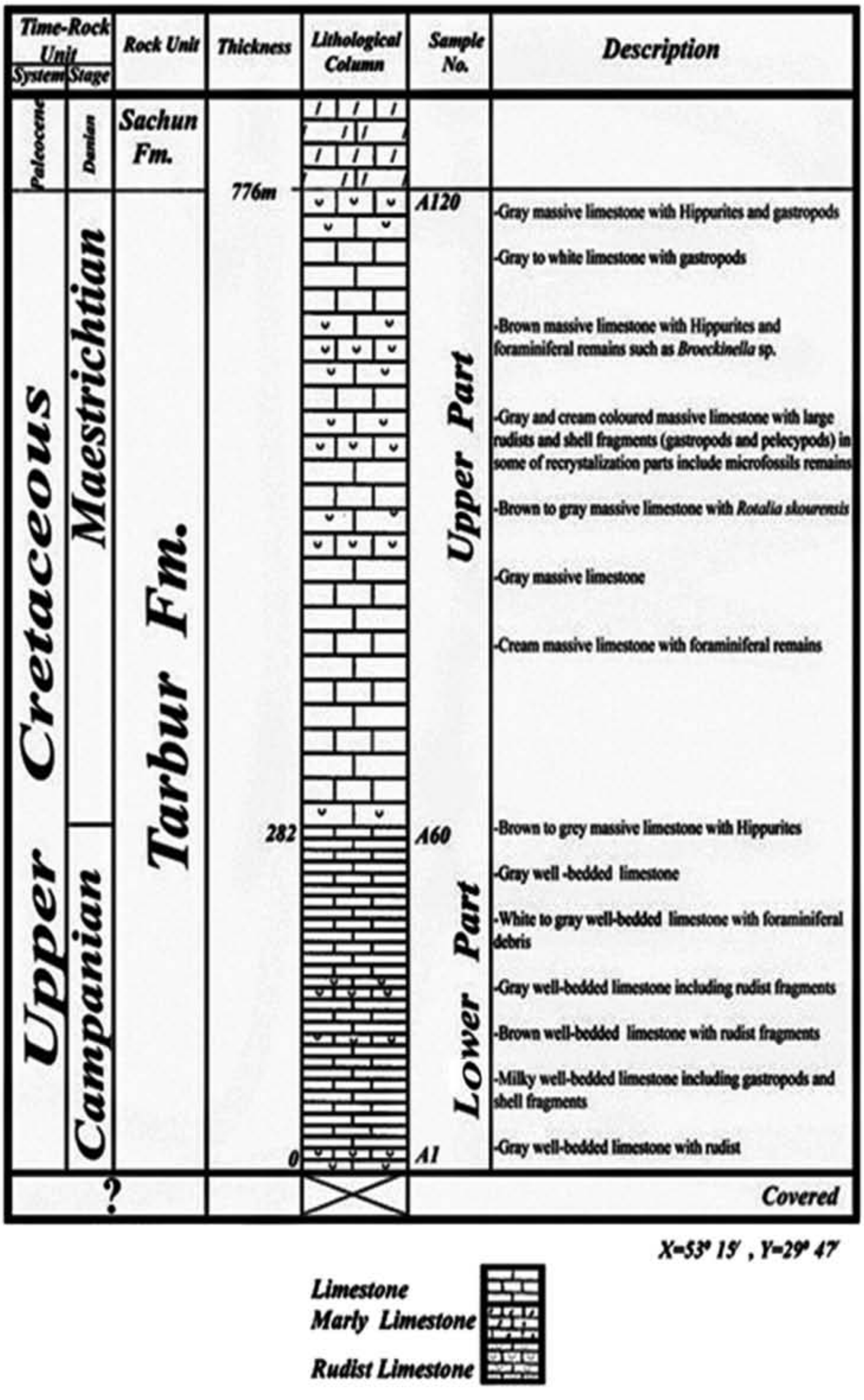


Fig.4.4. Stratigraphic columnar section of Zarghan

4.5. Lithology of the Tarbur Formation In Kuh-e Chehelcheshmeh

The lower part: The lithological characteristic here is mainly well-bedded green to reddish yellow ferroginous limestone to thick-bedded, dark-grey rudist limestone, 240 m in thickness (Fig.4.5).

Detailed field descriptions from top to bottom are presented below:

Thick-bedded, cream to white and dark-grey weathered colour karstic limestone (32 m).

Thick-bedded, dark-grey and light-brown to yellow weathered colour, karstic limestone with fossil fragments (14 m).

Thick-bedded, light-grey and cream to yellow weathered colour, karstic limestone with fossil fragments (13 m).

Thick-bedded, dark grey and yellow to cream weathered colour, karstic limestone with large crystals of calcite and fossil fragments and corals (21 m).

Thick-bedded, dark grey and brown to grey weathered colour, karstic limestone with fossil fragments and rudists (35 m).

Thick-bedded, cream and brownish yellow weathered colour, with large crystals of calcite and fossil fragments and rudists (13 m).

Thick-bedded, grey to brown and brownish cream weathered colour, karstic limestone with large crystals of calcite and fossil fragments (20 m).

Thick-bedded, pinky to white and cream to white weathered colour, karstic, ferroginous limestone with large crystals of calcite and fossil fragments (10 m).

Thick-bedded, pinky to white and brownish yellow weathered colour, massive limestone and rudists (5 m).

Well-bedded, green and reddish yellow weathered colour, ferroginous limestone (20 m).

The upper part: The main lithology is massive limestone, milky and grey to cream to white karstic with ferrificated limestone, 120 m in thickness. Detailed field descriptions from top to bottom are presented below:

Massive limestone, cream to white and bright grey weathered colour, massive and karstic, ferroginous (15 m).

Massive limestone, cream to white and a bright grey weathered colour, karstic with gastropods (20 m).

Massive limestone, cream to white and a bright grey weathered colour, with large crystals of calcite (31 m).

Massive limestone, cream to white and a bright grey weathered colour, karstic (10 m).

Massive limestone, milky and grey to cream weathered colour, karstic with large crystals of calcite (12 m).

Massive limestone, milky and grey to cream weathered colour, with fossil fragments and gastropods (8 m).

Massive limestone, milky and grey to cream weathered colour, karstic, ferroginous with large crystals of calcite and fossil fragments and rudists (7 m).

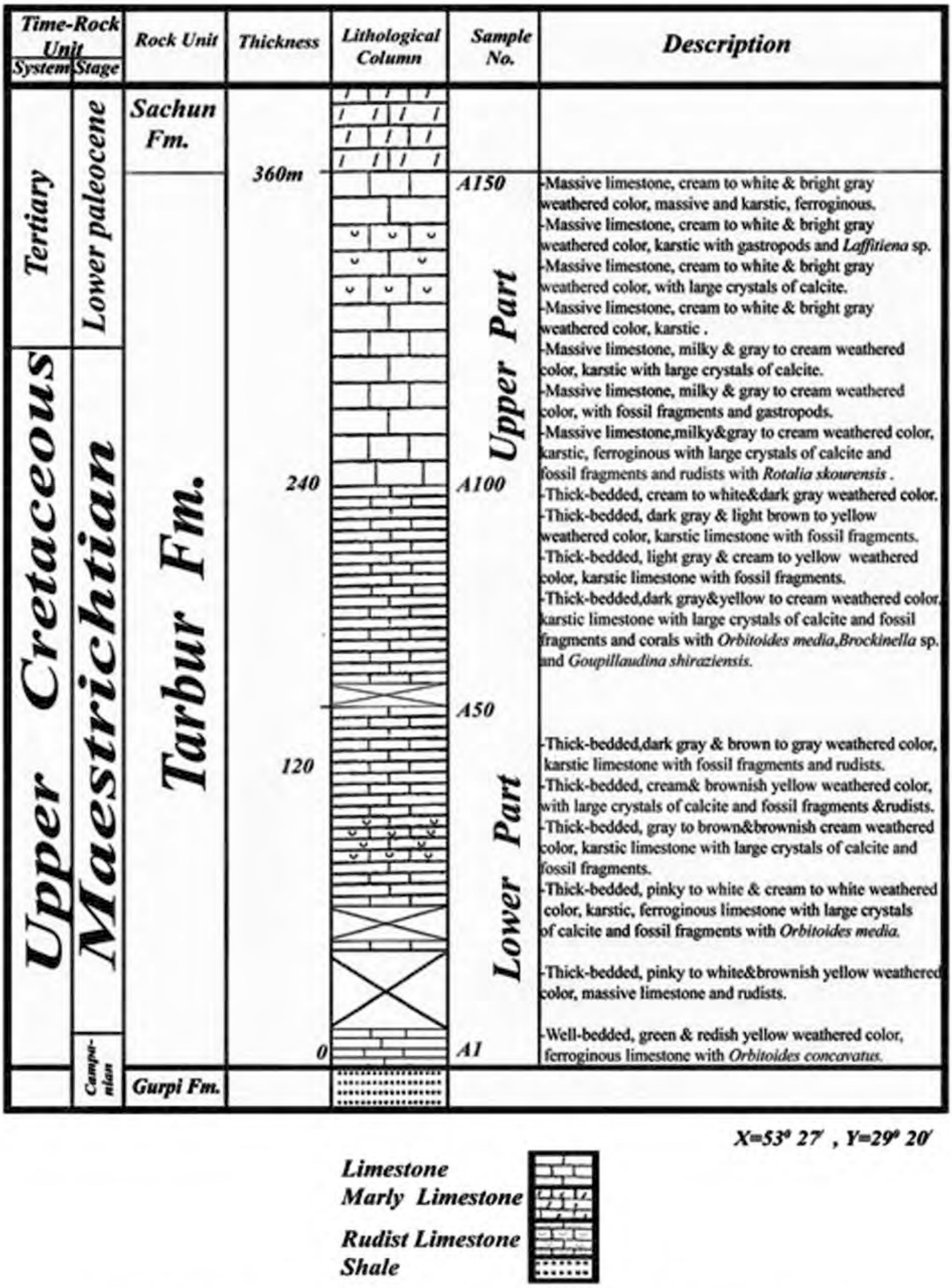


Fig.4.5. Stratigraphic columnar section of Kuh-E Chehelcheshmeh

4.6. Lithology of the Tarbur Formation in Kuh-e Khanehkat

The lower part: The lithological characteristic is mainly very thick-bedded pinkish cream to light-grey limestone with corals to very thick-bedded cream to milky and grey to green weathered brecciated limestone, 220 m in thickness (Fig. 4.6.). Detailed field descriptions from top to bottom are presented below:

Very thick-bedded, cream to milky and grey to green weathered colour, brecciated, karstic limestone with large rudists (30 m).

Very thick-bedded, cream to light-brown and grey to yellowish brown weathered colour, brecciated, karstic limestone (12 m).

Thick-bedded, yellowish cream and blackish grey to dark brown weathered colour, slightly brecciated, low fractured (17 m).

Thick-bedded, grey cream and brown to red weathered colour limestone (18 m).

Thick-bedded, cream and light brown weathered colour limestone (35 m).

Very thick-bedded, yellowish cream and light brown to dark grey weathered colour, slightly brecciated limestone (8 m).

Thick-bedded, cream and yellowish cream weathered colour limestone (6 m).

Very thick-bedded, pinkish cream to light-grey and grey to brown weathered colour limestone with corals (14 m).

Very thick-bedded, yellowish cream and brown to yellow weathered colour, clearly brecciated, highly fractured, slightly ferroginous limestone (10 m).

The upper part: Massive light cream to yellow and dark-brown to red weathered limestone with bivalvia, and gastropods to massive pinkish cream and brown to an orange weathered colour, and ferrificated with

116m. Detailed field descriptions from top to bottom are presented below:

Massive pinkish cream and brown to orange weathered colour, karstic, ferroginous limestone, fossil fragments (20 m).

Massive cream and dark-brown to reddish grey weathered colour, karstic, ferroginous limestone, fossil fragments (14 m).

Massive yellowish cream and brown to grey weathered colour, karstic, ferroginous limestone with fossil fragments (12 m).

Massive light-cream to yellow and brown to grey weathered colour massive limestone (30 m).

Massive light-cream to yellow and brown to grey weathered colour massive limestone (25 m).

Massive light-cream to yellow and dark-brown to red weathered colour massive limestone (8 m).

Massive light-cream to yellow and dark-brown to red weathered colour limestone with bivalvia and gastropods (7 m).

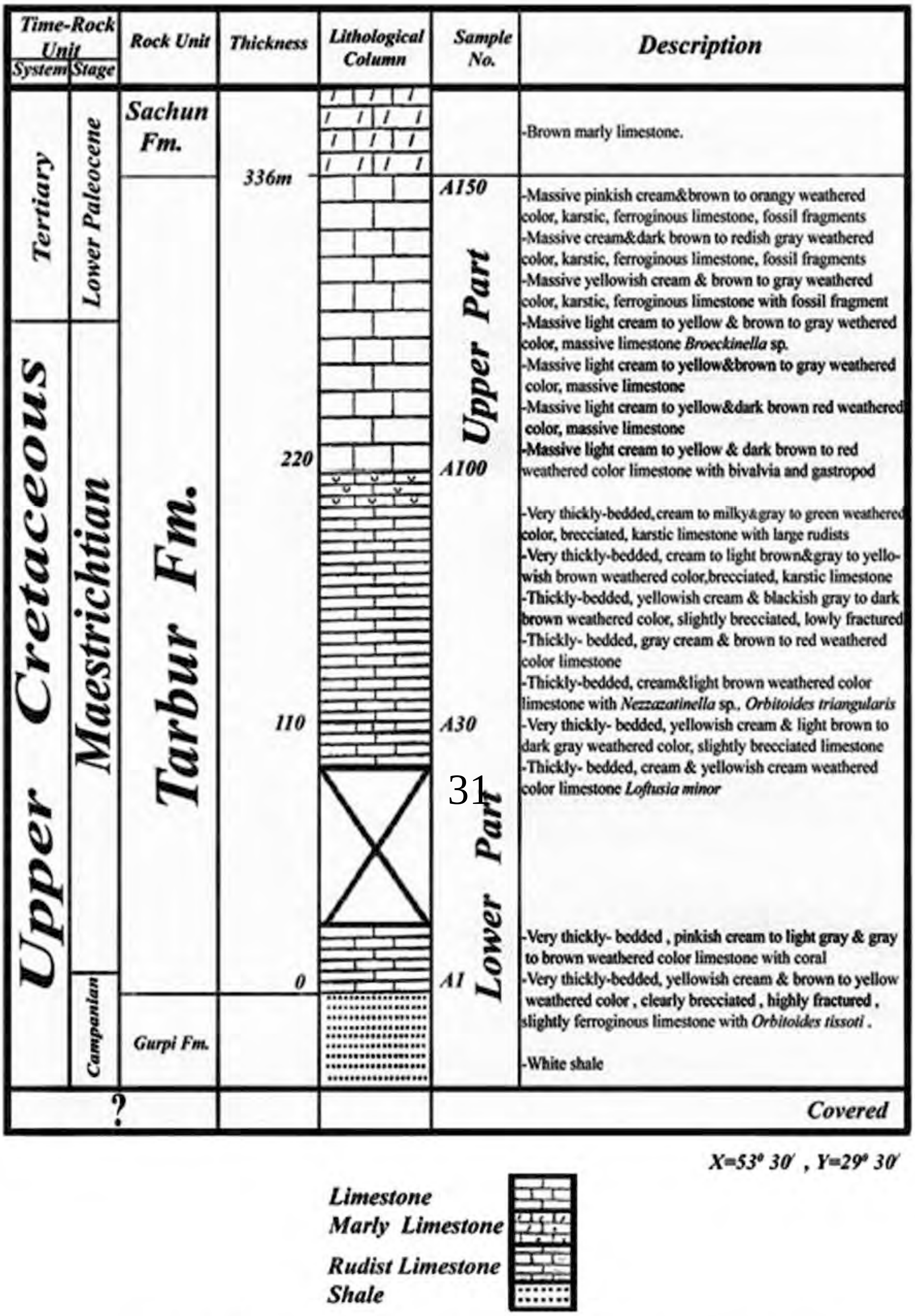


Fig.4.6. Stratigraphic columnar section of Khanehkat

4.7. Lithology of the Tarbur Formation in East of Dariyan

The lower part: The lithological characteristic is mainly well-bedded dark-brown limestone with rudists and well-bedded grey to brown limestone with rudist fragments to well-bedded brown limestone with rudists, 140m in thickness (Fig.4.7). Detailed field descriptions from top to bottom are presented below:

Well-bedded brown limestone with rudists (35 m).

Medium-bedded cream to grey limestone (22 m).

Medium-bedded brownish to grey rudist limestone (11 m).

Well-bedded brown limestone slightly brecciated (9 m).

Well-bedded grey to cream rudist limestone (35 m).

Thick-bedded brown to grey limestone with calcite veins (4 m).

Well-bedded grey to brown limestone with rudist fragments (10m).

Well-bedded dark brown limestone with rudists (14 m).

The upper part: Massive grey to white limestone having weathered light-grey to massive cream coloured limestone, foraminiferal fragments (308m). Detailed field descriptions from top to bottom are presented below:

Massive cream limestone with foraminiferal fragments (70 m).

Massive cream to brown limestone with rudist fragments (42 m).

Massive white to milky limestone with bivalvia (35 m).

Massive white to dark-grey limestone slightly ferroginous (21 m).

Massive light-brown limestone with foraminiferal debris and rudist fragments (62 m).

Massive grey limestone with bivalvia (70 m).

Massive white to grey limestone whose weathered colour is light-grey (8 m).

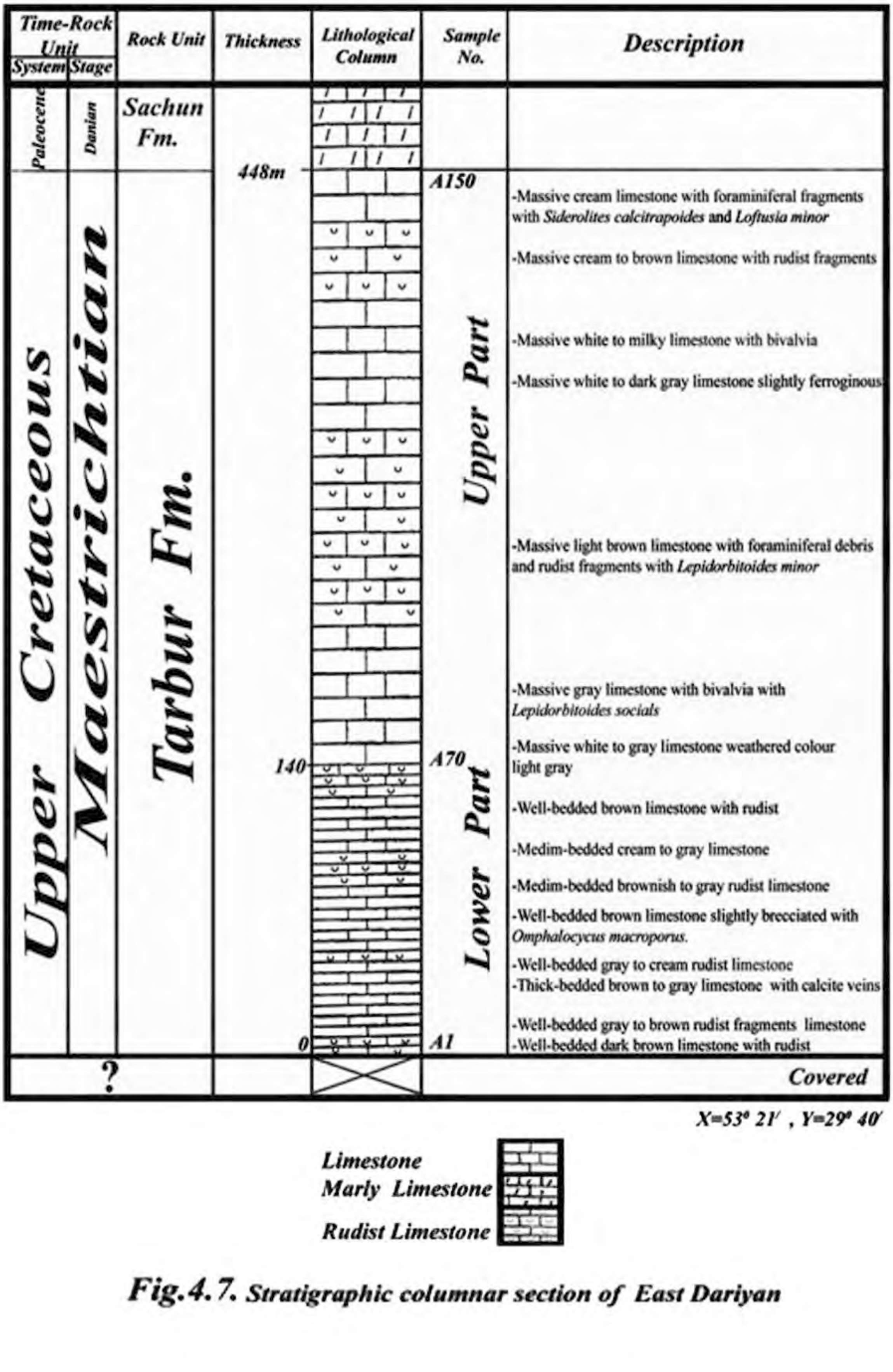


Fig.4.7. **Stratigraphic columnar section of East Dariyan**

5. Organic Constituents of the Tarbur Formation

Many groups of organic constituents are detectable in the Tarbur Formation. These organic remains mainly include rudist fragments, but Foraminifera determine the biozonation of the studied sections. The other groups of organic remains are not important in the biozonation, but some of them are indicators of portions of the reef structure.

Organic components of the Tarbur Formation are divided into six groups: rudist fragments, coral remains, gastropod shells, foraminifera and reworked foraminifera, and algal remains. These groups are briefly discussed below.

5.1. Calcareous Algae

The most important observed macroflora in the Tarbur Formation is the dasycladaceae group. This group of green algae is distributed in the back reef facies (lagoon). As green algae do not accumulate in agitated environments, dasycladaceae are not observed in grainstone and packstone. Turbulence in high energy environments prevents accumulation of these algae in these facies. The green algae is distributed in the photic zone of aqueous environments. However, diversification of dasycladaceae is very limited. Only two taxa are identified in the Tarbur Formation in this study (Figs. 5.1.1,2).

Fig. 5.1.1. ***Salpingoporella dinarica*** **observed in wackestone facies indicating light penetration and low agitation of the sedimentary basin in Kherameh-2**

These are *Salpingoporella dinarica* and *S. turgida*. They are observed only in the Kherameh-2 section. There is no evidence that indicates distribution of dasycladaceae. They usually appear in the middle portion of the upper part of theTarbur Formation in the Kherameh section. They are mainly accumulated in a part of the Late Maestrichtian. As dasycladacea is a photosynthesizing flora and the maximum effective depth of light penetration in water is 200 m, these algae are an indicator of the photic zone.

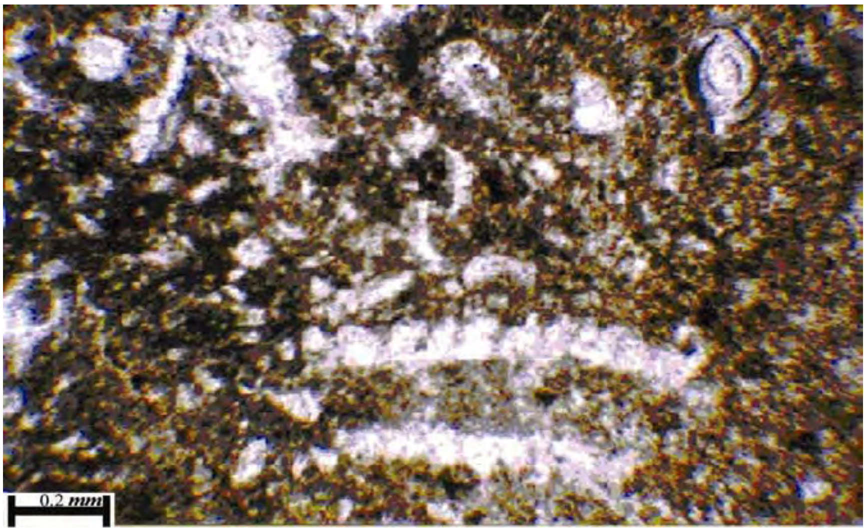


Fig. 5.1.2.*Salpingoporella turgida* observed in wackestone facies of the Kherameh-2 section

5.2. Microplanktons and Nanoplanktons

The Tarbur Formation has very few pelagic foraminifera. The only pelagic foraminifera observed in this study belonged to the Kherameh-2 section.

This means that the Tarbur Formation's sedimentary basin was very far from the oceanic basins. There is no evidence of the pelagic biofacies, either in the back reef or in the fore reef facies. Therefore, the fore reef side of the reef mass has no planktonic organism constituents.

Although the fore reef sedimentary environment in all of the studied sections indicates more agitation conditions than that of theback reef, which is an indicator of the surfzone of waves, there are no pelagic foraminifera to estimate the true distance of the reef mass from the pelagic environment, even though nanoplankton also existed in the warm brackish waters in the middle of the oceanic environment.

There is no evidence that shows the existence of nanoplanktons when the Tarbur Formation was formed. Moreover, as the shells of nanoplanktons are deposited after death, accumulation of nanoplanktons in the Tarbur Formation facies indicates that the tectonic setting of the Tarbur reef is not related to the ridge in the middle of an ocean.

5.3. Foraminifera

There are different genera, taxa and ranges of accumulation of foraminiferal debris in the stratigraphic sections. Foraminifera are the index of paleoecologic environments. For example, the Miliolidae family is the index of back reef facies, and the Orbitoididae family indicates the fore reef facies.

There are many taxa that were observed in the studied sections. These foraminiferal constituents are observed in all of the typic microfacies ofthe Tarbur Formation. Although these foraminifera belong to the benthic form of foraminifera, there are many factors that indicate the paleoecologic environments of foraminifers. Therefore, foraminifers are a good indicator of depositional conditions. There are also some transported foraminifers in the studied sections which are even well-preserved. The identification of foraminifera is based on LOEBLICH and TAPPAN (1989), BOARDMAN et al. (1987), SIREL and GUENDUEZ (1985), KALANTARI (1976), MEHRNUSH and PARTOAZAR (1977), RAHAGHI (1976) and POKORNY (1963).

Family: Calcarinidae SCHWAGER, 1876

Genus: Siderolites LAMARCK, 1801

Siderolites calcitrapoides LAMARCK, 1801 (Figs. 5.3.1,2).

Test large, globular proloculus followed by planispiral and involute coil to about four whorls, more than twelve chambers in the final whorl, two to seven large coarse spines, wall calcareous, size 0.4 to 1mm. These taxa are observed in the Zarghan and Kuh-e Siah sections. The canal system is well developed and this appears connected with the thickening of the wall. It is observed with *Omphalocyclus macroporus* in the packstone of theTarburFormation.

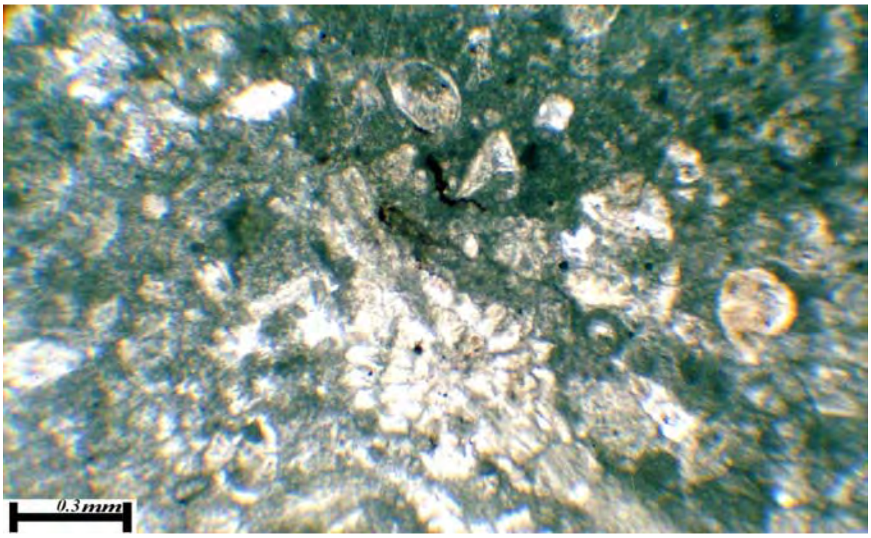


Fig. 5.3.1. *Siderolites calcitrapoides* in the lower part of the Kuh-e Siah section, transverse section

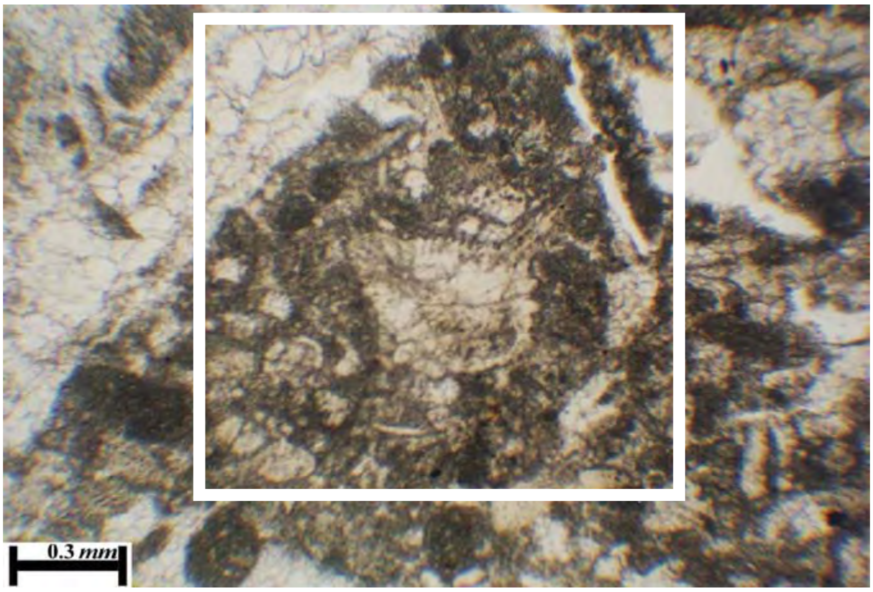


Fig. 5.3.2.*Siderolites calcitrapoides* in the lower part of the Kuh-e Siah section, transverse section

Family: Orbitoididae SCHWAGER, 1876

Genus: Omphalocyclus BRONN, 1853

Omphalocyclus macroporus LAMARK, 1816 (Figs. 5.3.3,4).

Test discoidal, biconcave, centrally depressed and thickest at the periphery, early stage of microspheric generation with a small irregular coil that is not in the plane of the adult test, megalospheric embryo consisting of two to four chambers, the equatorial chambers rapidly increasing in thickness, size generally 3-6 mm. These taxa are observed in the Kuh-e Siah, Kherameh-2, Kuh-e Chehelcheshmeh, East of Dariyan, and Zarghan sections. They associate with *Lepidorbitoides minor, L.socialis,* and *Siderolites calcitrapoides.*They indicate Maestrichtian age.

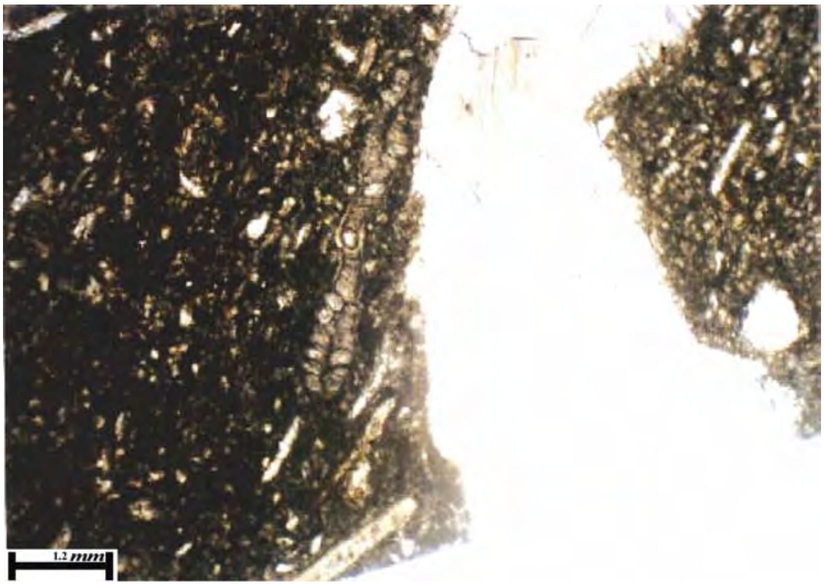


Fig. 5.3.3.*Omphalocyclus macroporus* in the lower part of the Kuh-e Siah section, longitudinal section

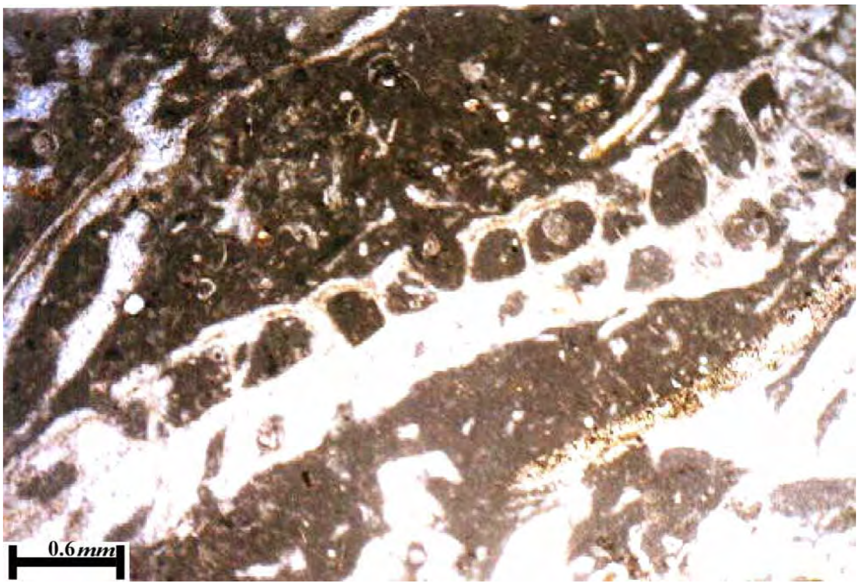


Fig. 5.3.4.*Omphalocyclus macroporus* in the upper part of the Kherameh-2 section, sublongitudinal section

Systematics:

Family: Orbitoididae SCHWAGER, 1876

Genus: Orbitoides D'ORBIGNY, 1842

Orbitoides media D'ARCHIAC 1837, (Figs. 5.3.5,6).

Test large, rarely up to 5 cm in diameter, lenticular, symmetrically biconvex to plano- convex, megalospheric test commonly with four chambered embryo, consisting of vertically, but not horizontally compressed round to oval protoconch, a veniform deuteroconch, the four embryonic chambers being surrounded by a thick perforated wall, base of arcuate median chambers clearly separated from the base of others of the same cycle. *Orbitoides media* is observed in all of the stratigraphic sections. The association of this taxon is *Orbitoides concavatus, O.apiculata, Omphalocyclus macroporus* and *Broeckinella* sp..

Fig. 5.3.5.*Orbitoides media* in the upper part of the Zarghan section, longitudinal section

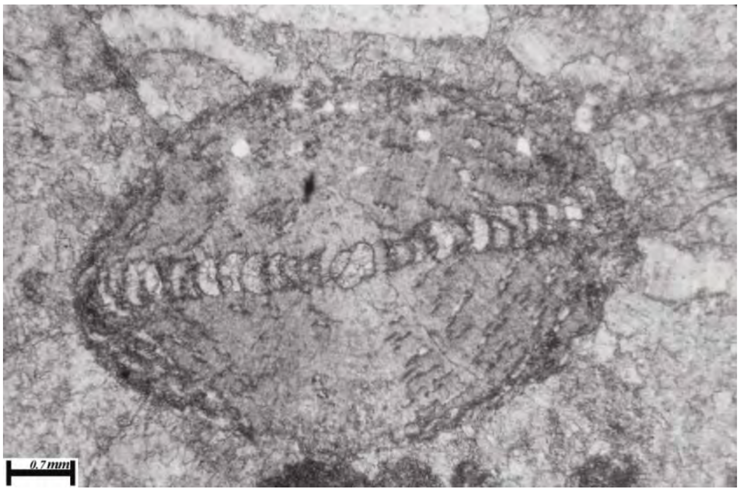


Fig. 5.3.6.*Orbitoides media* in the lower part of the Kherameh-1 section, longitudinal section

Family: Lepidorbitoididae VAUGHAN, 1933

Genus: Lepidorbitoides A.SILVESTRI, 1907

Lepidorbitoides socialis LEYMERIE, 1851 (Fig. 5.3.7).

Test lenticular, biconvex, granular ornamentation, size 5 mm. This is the same as *Lepidorbitoides minor*, but high biconvex and larger than the other, early equatorial chambers arcuate, later ones spatulate to quadrangle. It is observed in the Kherameh-2 and Kuh-e Siah sections. This taxon is observed in the Dariyan and the Kuh-e Siah. It is observed with *Lepidorbitoides minor, Omphalocyclus macroporus, Orbitoides media*, in the grainstone and packstone of the Tarbur Formation.

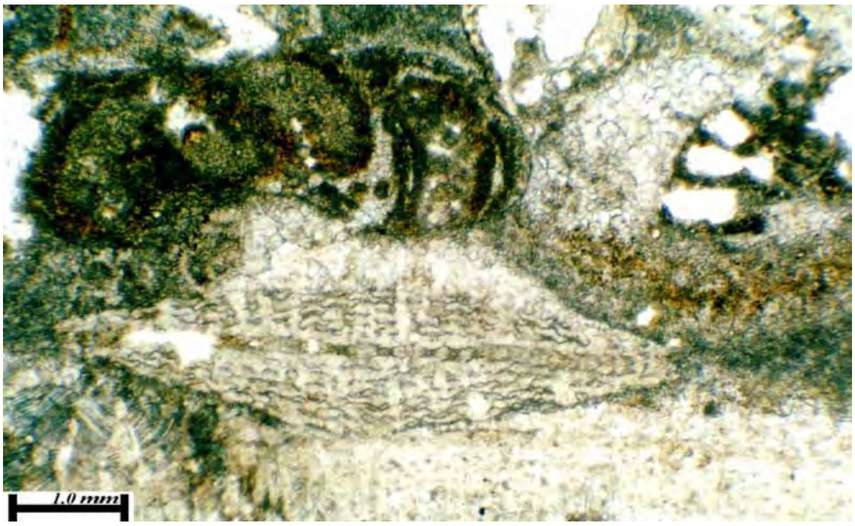


Fig. 5.3.7.*Lepidorbitoides socialis* in the lower part of the Kuh-e Siah section, sublongitudinalsection

Family: Lepidorbitoididae VAUGHAN, 1933

Genus: Lepidorbitoides A.SILVESTRI, 1907

Lepidorbitoides minor SCHLUMBERGER, 1901 (Fig. 5.3.8).

Test flattened to biconvex, lenticular, large, biocular embryo, the two surrounded by a very thick common wall, early equatorial chambers arcuate, later ones spatulate to hexagonal, size 5.3 mm. It is observed in the Kuh-e Siah and Dariyan sections. It is also observed with *Lepidorbitoides socialis*, *Omphalocyclus macroporus*, *Orbitoides media* in the grainstone and packstone facies of the Tarbur Formation.

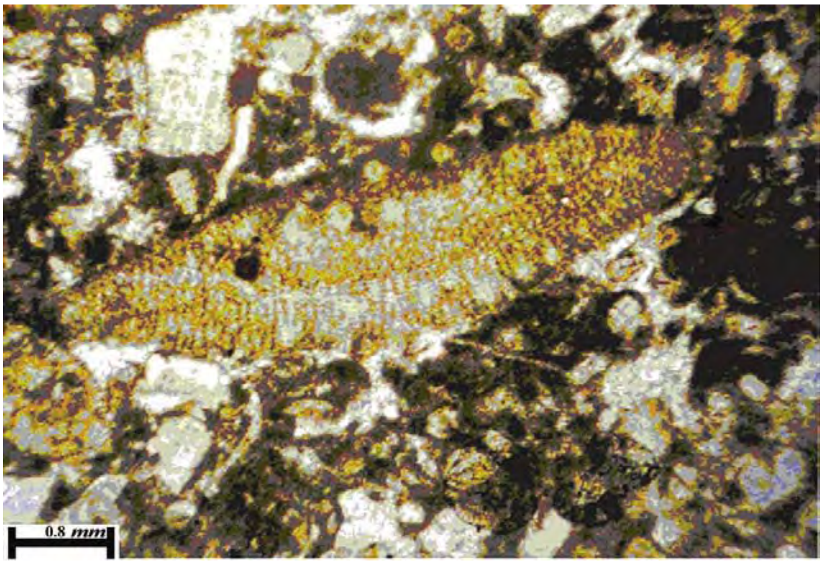


Fig. 5.3.8.*Lepidorbitoides minor* in the lower part of the Kuh-e Siah section, longitudinal section

Family: Orbitoididae SCHWAGER, 1876

Genus: Orbitoides D'ORBIGNY, 1848

Orbitoides apiculata SCHLUMBERGER, 1901 (Fig. 5.3.9).

Test discoidal, free biconvex, in megalospheric form, four embryonic chambers surrounded by a thick perforated wall, arcuate chambers biside by embryonic zone, size normally 2 mm. This taxonis observed in Kherameh-1, Kherameh-2, Kuh-e Chehelcheshmeh, and East of Dariyan. It is associated with *Omphalocyclus macroporus, Lepidorbitoides minor, L. socialis*. It indicates Maestrichtian age.

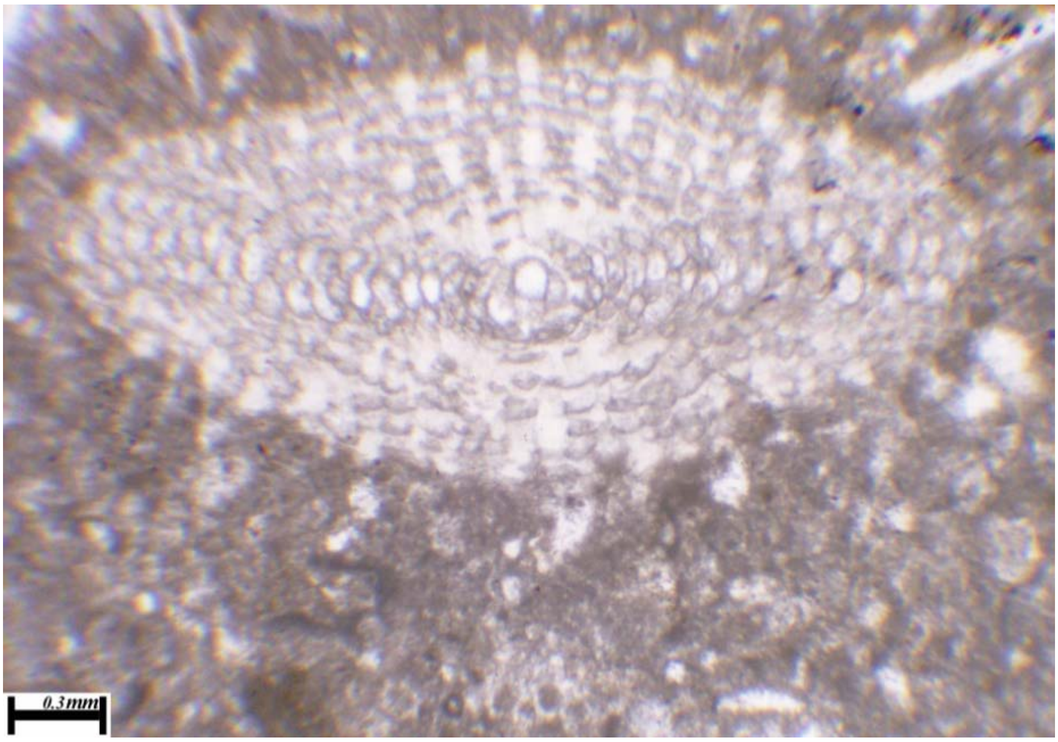


Fig. 5.3.9.*Orbitoides apiculata* in the upper part of the Kherameh-2 section, longitudinal section

Family: Orbitoidinae SCHWAGER, 1848

Genus: Orbitoides D'ORBIGNY, 1848

Orbitoides tissoti SCHLUMBERGER 1902 (Fig.5.3.10).

Test large, about 1 mm in size, discoidal, bisymmetric and biconvex to asymmetrical, proloculus four chambers, thickening wall, especially in the peripheral zone of test, large equatorial chambers and arcuate. It is detected in the Zarghan and Kuh-e Khanehkat sections. It is associated with *Orbitoides concavatus* and *Murciella cuvillieri*. It indicates Campanian age.

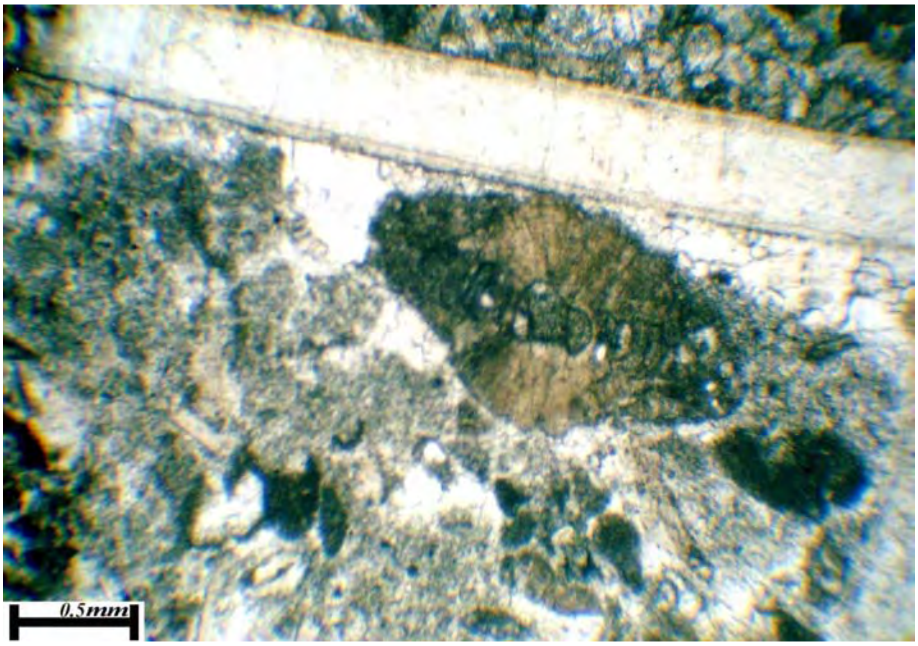


Fig. 5.3.10. *Orbitoides tissoti* in the lower part of the Kuh-e Khanehkat, longitudinal section

Family: Loftusiidae BRADY, 1884

Genus: Loftusia BRADY, 1840

Loftusia minor COX, 1937 (Figs. 5.3.11,12,13).

Test large, fusiform to subcylindrical, in longitudinal section axis nearly 1.5 to 5.5 mm and smaller, diameter 1-2.0 mm, large globular proloculus, 0.3 mm in diameter, septa and endoskeletal pillars distinctly agglutinated, 3-4 whorls. It is observed in the Kherameh-2, Zarghan,Kuh-e Chehelcheshmeh, East of Dariyan, and Kuh-e Khanehkat sections. It associates with *Omphalocyclus macroporus, Lepidorbitoides minor, L.socialis, Siderolites calcitrapoides, Loftusia minor*. It indicates Maestrichtian age.

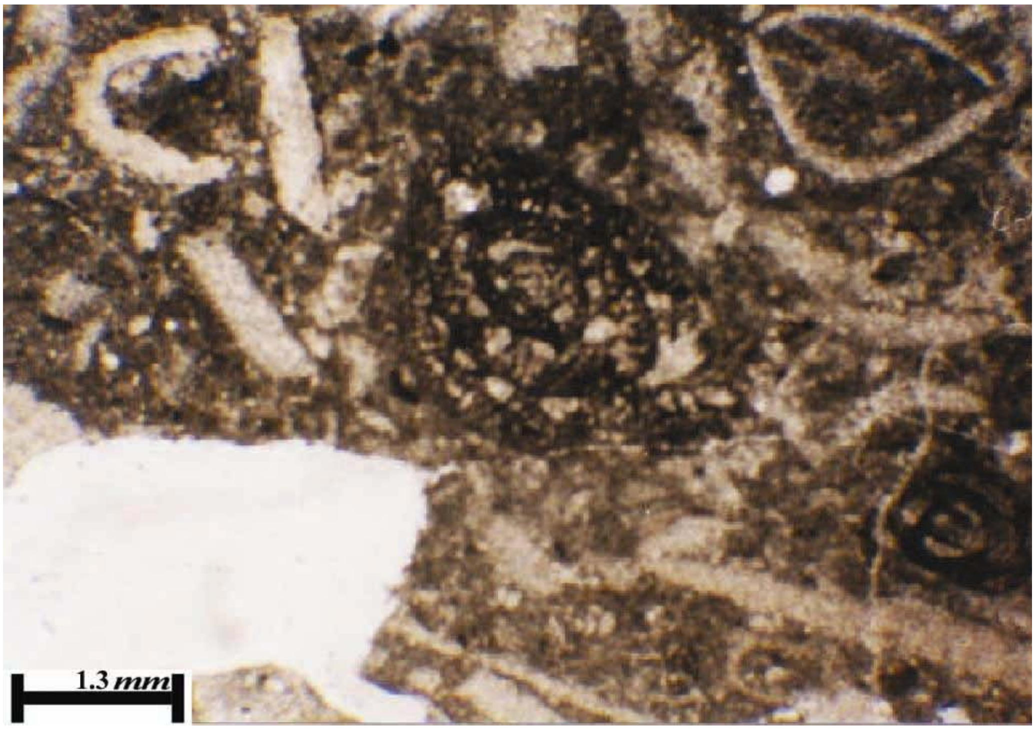


Fig. 5.3.11.*Loftusia minor* in the upper part of the Kherameh-2 section, subaxialsection

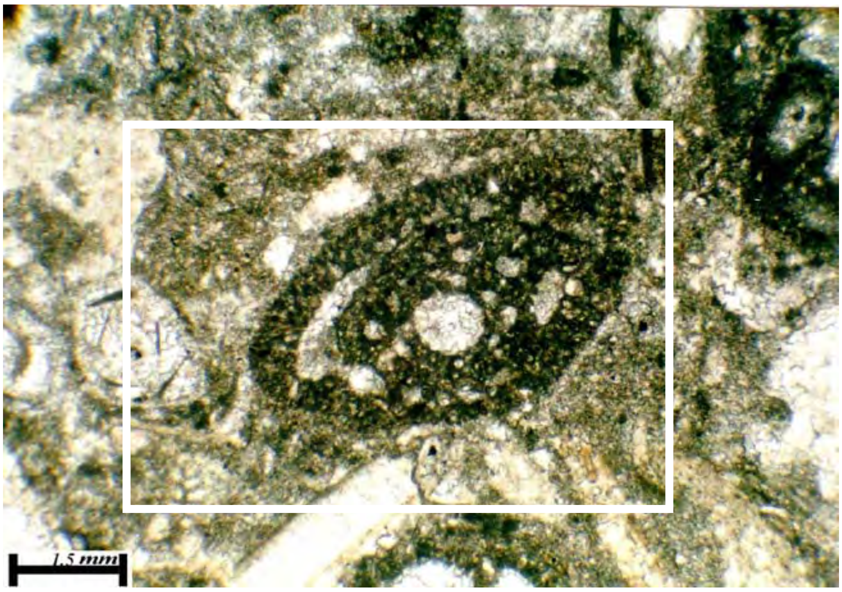


Fig. 5.3.12.*Loftusia minor* in the upper part of the Kuh-e Khanehkat, axial section

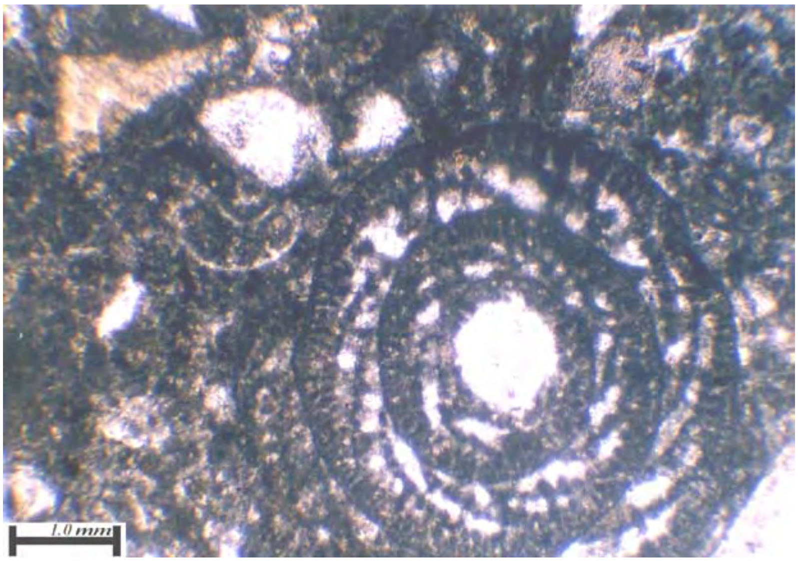


Fig. 5.3.13.*Loftusia minor* in the upper part of the Kuh-e Chehelcheshmeh, sagittal section

Family: Orbitolinidae MARTIN, 1980

Genus: Dictyoconella HENSON, 1948

Dictyoconella complanata HENSON, 1948 (Fig. 5.3.14).

Test large nearly 3 mm in height, peneropliform, early microspheric chambers planispirally enrolled, megalospheric, later age uncoiled, wall calcareous, imperforate, microgranular, and may include agglutinated particles. There are some pillars that divide into some chambers. It is observed in the upper part of the Zarghan, Kuh-e Chehelcheshmeh, East of Dariyan, and Kuh-e Khanehkat sections. It associates with *Orbitoides triangularis, Rotalia skourensis, Loftusia minor, Dictyoconella complanata.* It indicates Maestrichtian age.

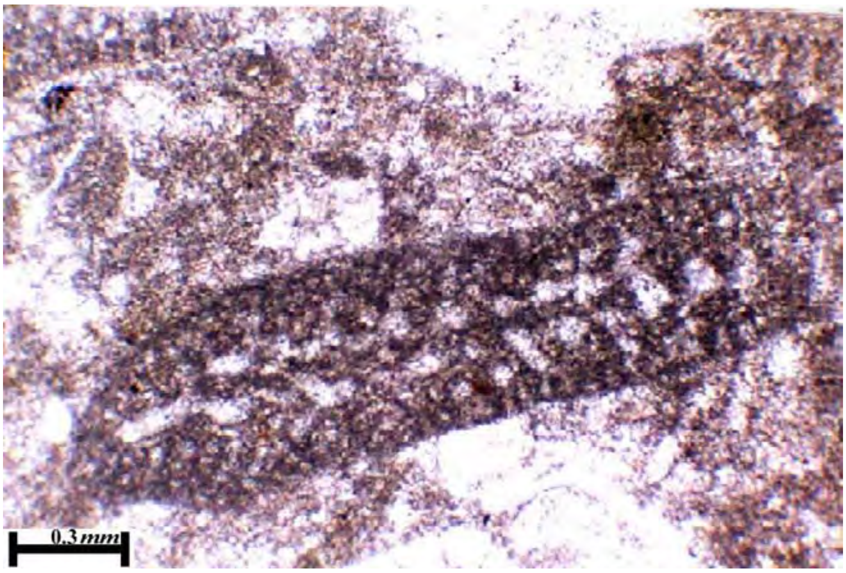


Fig. 5.3.14.*Dictyoconella complanata* in the upper part of the Zarghan section, longitudinal section

Family:Pseudorbitoididae RUTTER, 1935

Genus: Rotalia LAMARCK, 1804

Rotalia skourensis HENSON, 1948 (Fig. 5.3.15).

Test biconvex, 0.5-0.6 mm in size, test trochospiral. All whorls are visible in the equatorial sections. The umbilical plugs are divided into pillars by anastomosing fissures, which are later closed by secondary deposits. It is observed in the Kherameh-1, Zarghan, Kuh-e Siah, Kuh-e Chehelcheshmeh, Kuh-e Khanehkat and East Dariyan sections. It indicates Maestrichtian age.

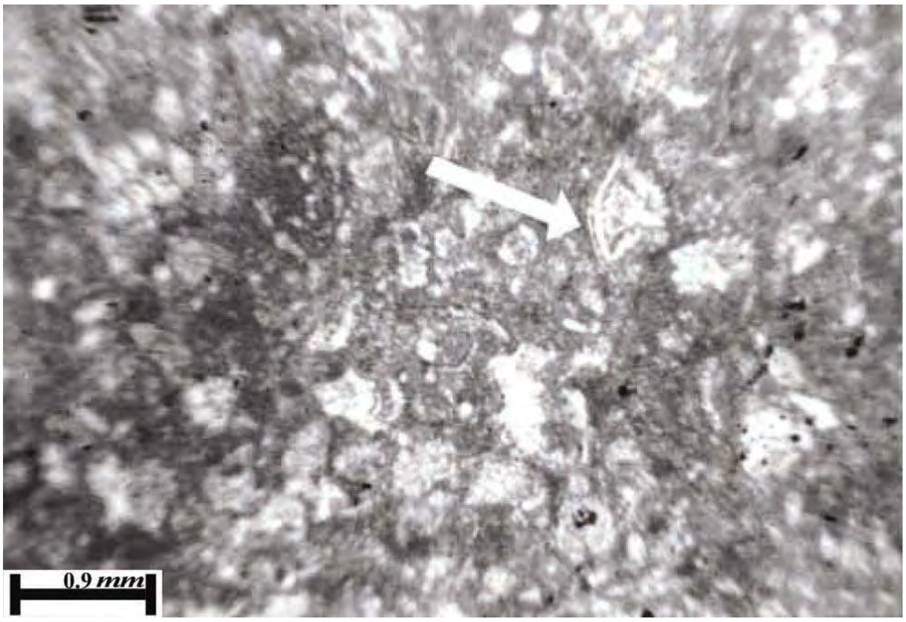


Fig. 5.3.15. ***Rotalia skourensis*** **in the upper part of the Zarghan section, subsagittal section**

Family: Cyclamminidae MARIE, 1941

Genus: Broeckinella HENSON, 1948

Broeckinella sp. HENSON, 1948 (Fig.5.3.16).

Test free, 2 mm in size and 0.3 mm in diameter, large proloculus about 0.5 mm, thickening wall and agglutinated. There are many walls that divide into many chambers, gradually becoming large. It is detected in the Kuh-e Siah, Kuh-e Khanehkat, Kuh-e Chehelcheshmeh and Dariyan sections. It associates with *Goupillaudina shirazensis, Antalyna korayi, Orbitoides apiculata, Omphalocyclus macroporus, Lepidorbitoides minor, L.socialis, Loftusia minor*. It indicates Maestrichtian age.

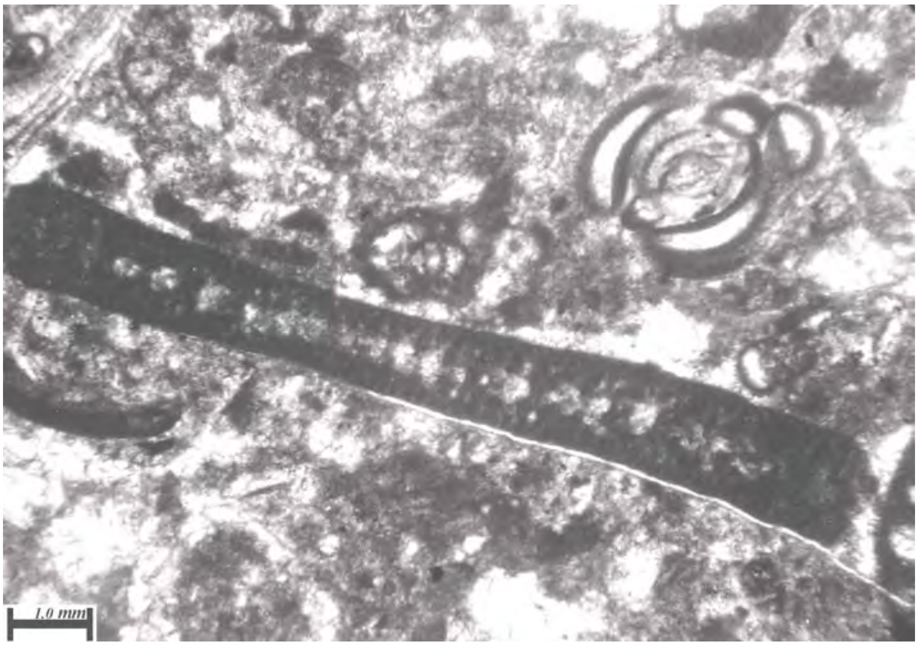


Fig. 5.3.16. *Broeckinella* sp. in the upper part of the Zarghan, longitudinal section

Family: Rotaliidea EHRENBERG, 1839

Genus: Laffitteina MARIE, 1964

Laffitteina sp. (Fig. 5.3.17).

Test lens form, without symmetry, slightly trochospiral and bivolute, umbilical sides thick, double septa with intraseptal channels, wall hyaline calcareous, 1.1 mm in size. It is observed in the upper part of the Kuh-e Siah, Kuh-e Chehelcheshmeh, and Kuh-e Khanehkat sections. It associates with *Vania anatolica*, therefore it indicates the Lower Paleocene.

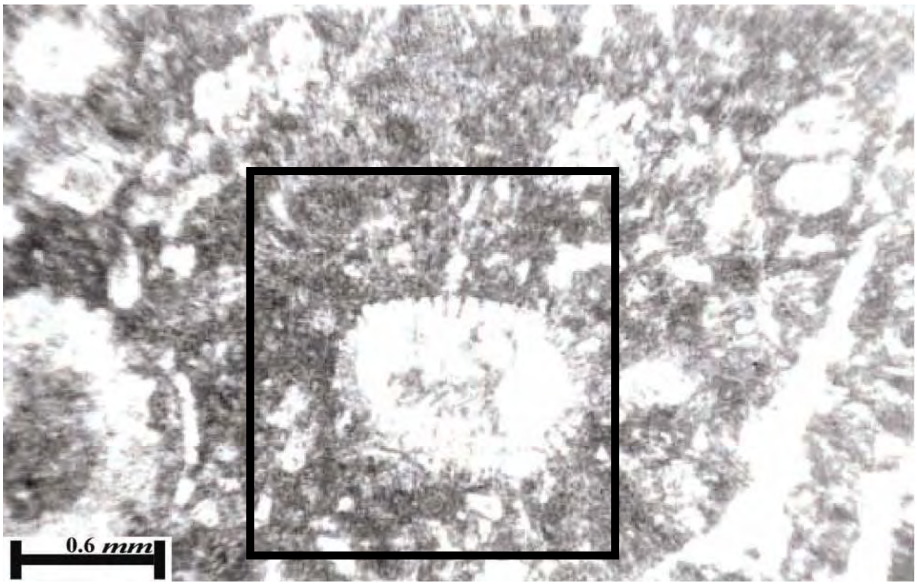


Fig. 5.3.17. *Laffitteina* sp. in the upper part of the Kuh-e Chehelcheshmeh section, sublongitudinal section

Family: Rhapydioninidae KEIJZER, 1945

Genus: Murciella FOURCADE, 1966

Murciella cuvillieri FOURCADE, 1966 (Fig. 5.3.18).

Test planispiral and involute in early stage, later uncoiling and vectilinear, cylindrical or flattened and flabelliform in the adult, size up to 1.6 mm in length, globular megalospheric proloculus by flexostyle and then by planispirally enrolled chambers. Early coiling involute, later evolute, and finally uncoiled. It is observed in the Kuh-e Khanehkat, Kuh-e Chehelcheshmeh, Zarghan, and Kherameh-1 stratigraphic sections. It is observed with *Orbitoides media* and *O.concavatus* in the wackestone of the Tarbur Formation.

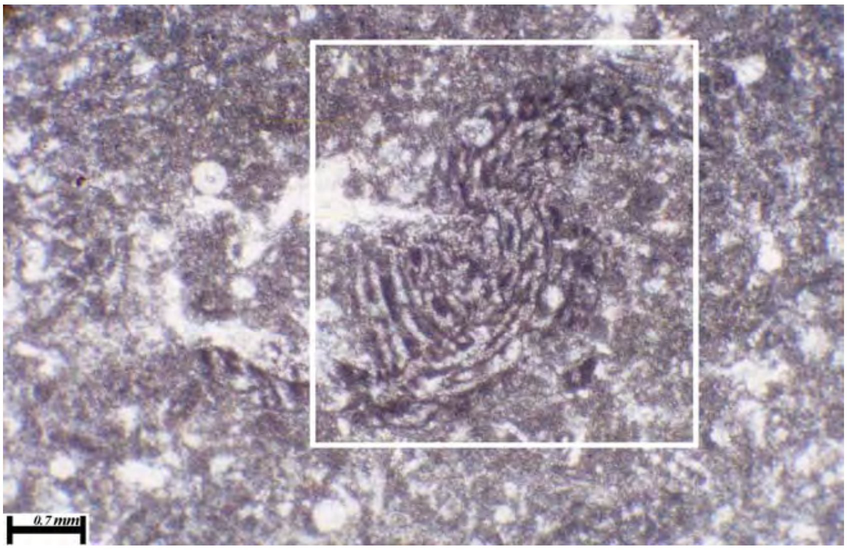


Fig. 5.3.18.*Murciella cuvillieri* in the lower part of the Zarghan section, sagittal section

Family: Orbitoididae SCHWAGER, 1876

Genus: Orbitoides D'ORBIGNY, 1848

Orbitoides concavatus RAHAGHI,1976 (Figs. 5.3.19,20).

Test discoidal, free, planoconvex to biconcave, embryonic chambers consisting of three chambers in megalospheric, equatorial chamber arcuate. The final chambers are larger than primitive chambers, wall imperforate and hyaline. These taxa are associated with *Orbitoides media* and *Murciella cuvillieri* and indicate Campanian age. The size is 5 mm. This taxon is observed in the lower part of the Zarghan section.

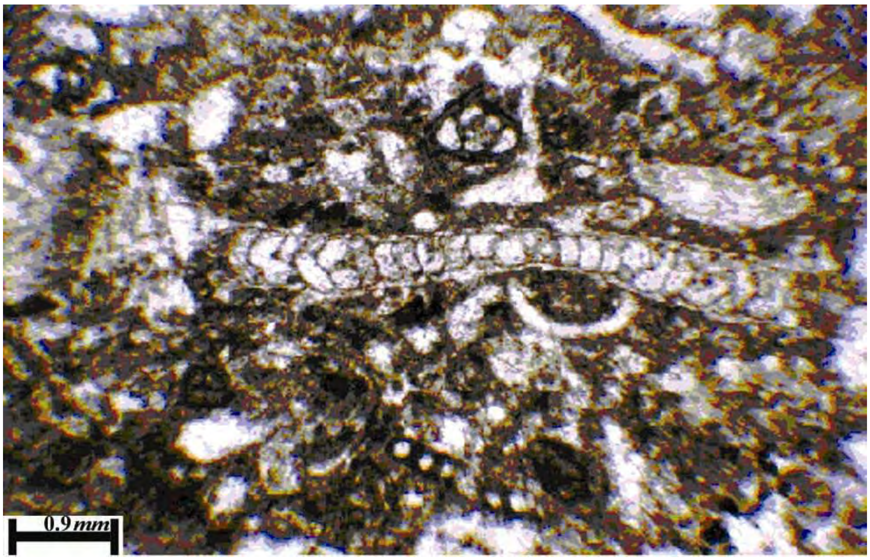


Fig.5.3.19.*Orbitoides concavatus* in the lower part of the Zarghan section, longitudinal section

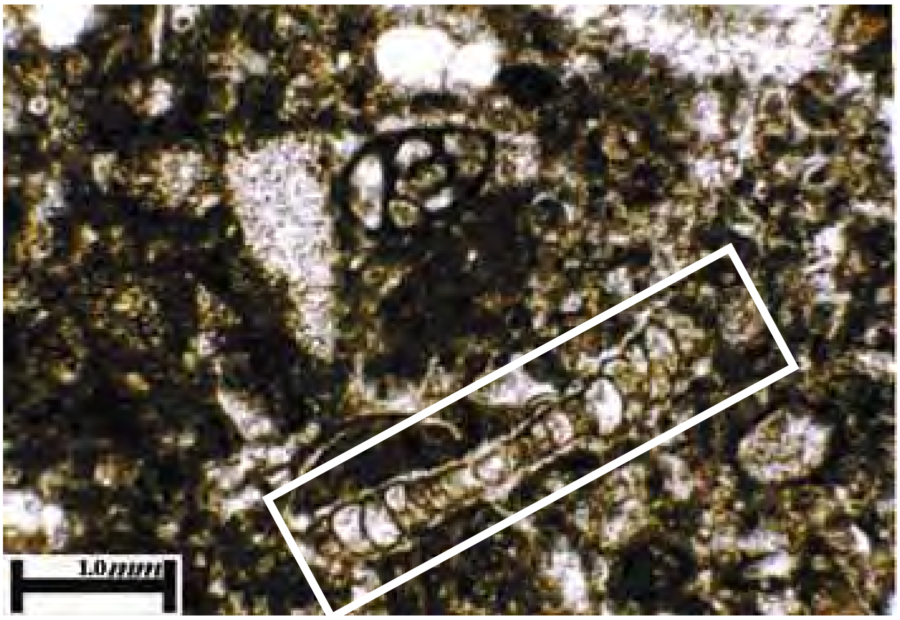


Fig. 5.3.20.*Orbitoides concavatus* in the lower part of the Zarghan section, longitudinal section

Family: Osangulariidae LOEBLICH & TAPPAN, 1964

Genus: Goupillaudina MARIE, 1958

Goupillaudina shirazensis RAHAGHI, 1976 (Fig. 5.3.21).

Test large normally up to 2.5mm in diameter, lenticular, biconvex, discoidal, weakly trochospiral to nearly planispiral, involute in early stage, later evolute, final chamber occupying one-third to one-half of the circumference, wall calcareous, and finely perforate. It is observed in the Kuh-e Siahand East Dariyan sections. It is associated with *Omphalocyclus macroporus, Lepidorbitoides minor, L.socialis, Orbitoides media, Goupillaudina shirazensis,* indicating Maestrichtian age.

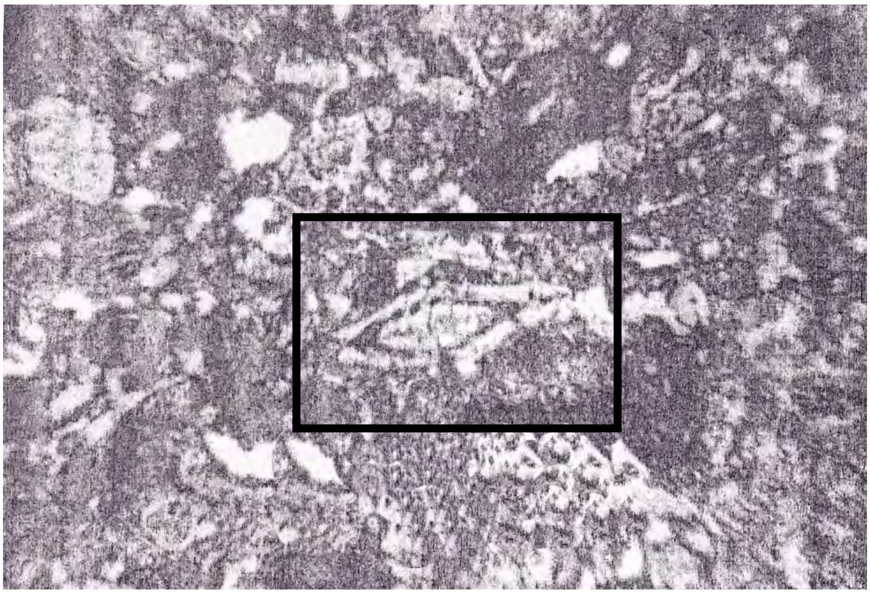


Fig. 5.3.21.*Goupillaudina shirazensis* in the lower part of Kuh-e Siahsection, axial section

Family: Nezzazatidae HAMAOUI and SAINT-MARC, 1970

Genus: Nezzazatinella DARMOIAN, 1976

Nezzazatinella sp. DARMOIAN, 1976 (Fig. 5.3.22).

Test slightly trochospiral, spiral side is flated. Last whorl includes 10-14 elongated chambers. The sutures are slightly curved, coiling involute, wall microgranular, calcareous.

Large aperture and curve located on the umbilical side, 1.2 mm in size. It is observed in the lower part of the Kherameh-2, Kuh-e Chehelcheshmeh, East Dariyan, and Kuh-e Khanehkat sections. It associates with *Orbitoides apiculata, Omphalocyclus macroporus, Loftusia minor, Siderolites calcitrapoides, Antalyna korayi*. It indicates Maestrichtian age.

Fig. 5.3.22.*Nezzazatinella* sp. in the lower part of the Kherameh-2 section, sagittal section

Family: Orbitoidinae SCHWAGER, 1876

Genus: Orbitoides D'ORBIGNY, 1848

Orbitoides triangularis RAHAGHI, 1976 (Fig.5.3.23).

Commonly triangle forming sections, 4mm diameter in size, equatorial chambers starting in one point with three directions in 120, these chambers are arcuate or rectangular. The peripheral angles of tests are arcuate. The equatorial chambers are surrounded by peripheral chambers, wall imperforate and hyaline, It is observed in the Zarghan and Kherameh-1 sections. It associates with *Orbitoides media, O.apiculata, Rotalia skourensis, Omphalocyclus macroporus*. It indicates Maestrichtian age.

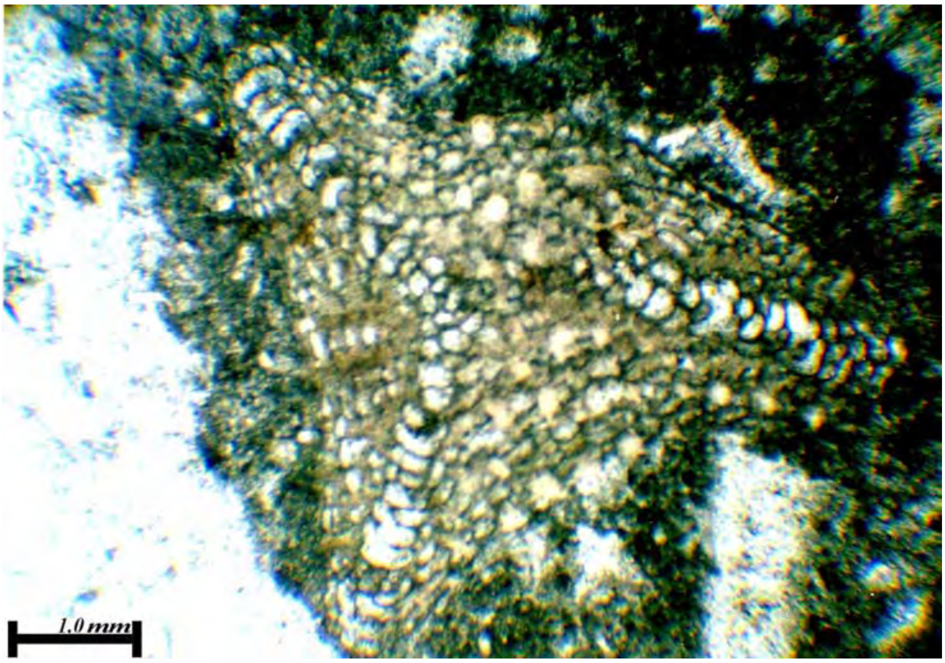


Fig. 5.3.23. *Orbitoides triangularis* in the upper part of the Kherameh-1, subsagittal section

Family: NezzazatidaeHAMAOUI and SAINT-MARC, 1970

Genus: Antalyna FARINACCI & KOEYLUEOGLU, 1985

Antalyna korayi FARINACCI &KOEYLUEOGLU, 1985(Fig.5.3.24).

Test trochospiral and bivolute, spiral plane convex, umbilical plane concave.In the primary stage coiling is irregular (streptospiral). The wall is microgranular, calcareous and imperforate simple septa.

The aperture is distributed in the last chamber, usually 1.9 mm in size. It is observed in the upper part of the Kherameh-1 section to middle and upper part of this section, the lower part of Kherameh-2 and Kuh-e Siah, East of Dariyan, and Kuh-e Chehelcheshmeh sections.

It associates with *Omphalocyclus macroporus, Lepidorbitoides minor, L. socialis, Loftusia minor, Orbitoides triangularis, O. apiculata, Siderolites calcitrapoides, Antalyna korayi.* It indicates Maestrichtian age.

Fig. 5.3.24. ***Antalyna korayi*** **in the upper part of Kherameh-2 section, sublongitudinal section**

Family: Spirocylinidae MUNIER- CHALMAS, 1887.

Genus: Vania SIREL & GUENDUEZ, 1985

Vania anatolica SIREL & GUENDUEZ, 1985 (Fig. 5.3.25).

Test large, up to 6.5 mm in diameter, discoidal, biconcave, bilaterally symmetrical, periphery moderately rounded, short planispiral stage of a few undivided in the microspheric test, later chambers spreading and successively flabelliform, reniform, and finally annular, interior subdivided by radially arranged beams and intercalated secondary beams, those of successive chambers aligned, with short rafters parallel to the septa forming a subepidermal network; wall finely agglutinated, imperforate; aperture consisting of two alternating rows of pores on the periphery.It associates with *Laffitteina* sp. It indicates Lower Paleocene age. It is observed in the Kuh-e Chehelcheshmeh and Kuh-e Khanehkat sections.

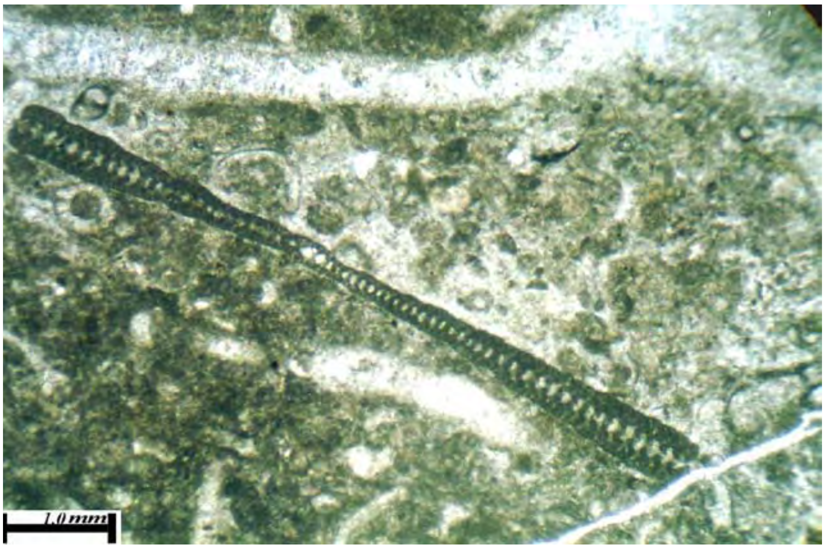


Fig. 5.3.25. *Vania anatolica* in the upper part of the Kuh-e Chehelcheshmeh section, longitudinal section

5.4. Corals

Coral fossils are seldom observed in the Tarbur Formation. However, they are usually associated with Foraminifera and rudist fragments. The coral colonies are seldom observed in the Kherameh-2 section (Fig. 5.4.1). Some coral colonies are detected with secondary calcite filling (Fig. 5.4.2). in the Kuh-e Khanehkat stratigraphic section. Corals are not common in bioclastic elements of the Tarbur Formation, but they associate with foraminifers, algal remains and rudist debris. Solitary corals are more commonly observed than colonies. Transverse sections of these corals are detected in thin sections. As usual, corals are observed in wackestone of the upper part of the studied sections. There are no corals in the studied grainstones and packstones of the Tarbur Formation. All of the detected corals are well preserved without any evidence of transportation. This indicates that the corals lived in no agitation and far from wave action. The association of coral with various taxa is an indicator of their ages. Since the corals are associated with algal remains, they were in a light penetration zone under the wave action zone.

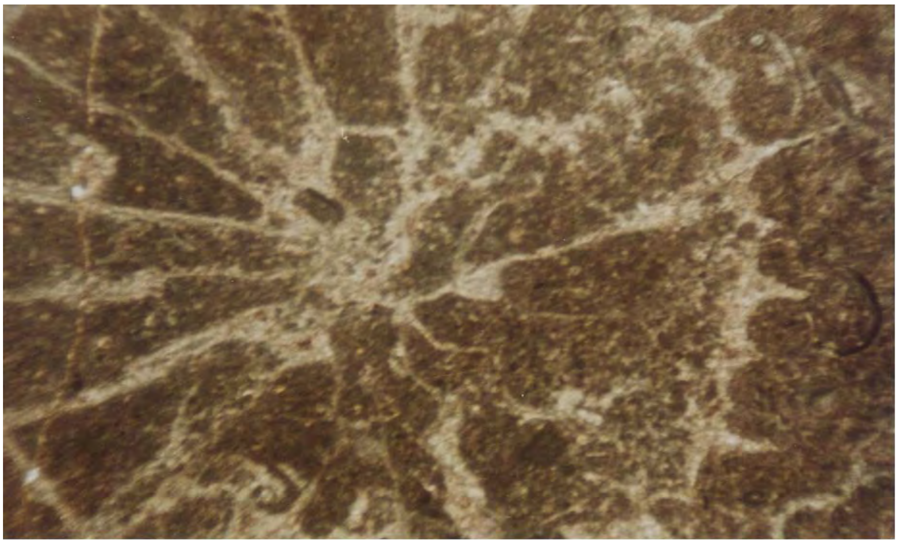


Fig. 5.4.1. Solitary coral in the the upper part of the Tarbur Formation (Kherameh-2 section), magnification × 2.5

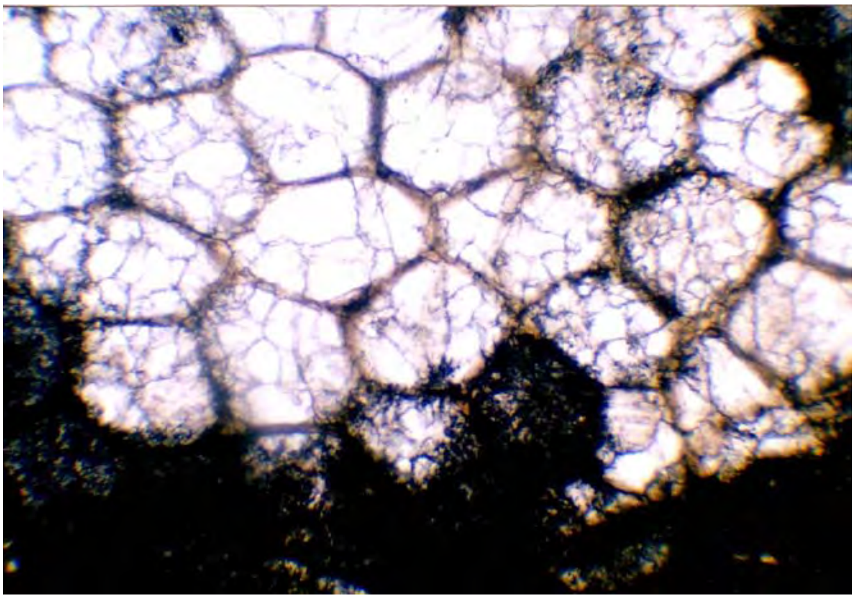


Fig. 5.4.2.Sparry calcite filling in the coral colony in the upper part of the Kuh-e Khanehkat section, magnification × 2.5

5.5. Gastropods

Gastropods are mainly observed in the back reef of the Tarbur Formation. They baffle fine sediments (Fig.5.5). Gastropods are rarely observed in the Zarghan, Kuh-e Khanehkat, Kuh-e Chehelcheshmeh andEast Dariyan sections on the top of the Tarbur Formation. They are an indicator of back reef facies.

Since gastropods are mainly observed in wackestones with dasycladaceae, they are detected in wackestones that relate to low kinetic energy environments. Whereas wackestones are deposited in both back and fore reefs, dasycladaceae are observed only in back reef. Gastropods are also detected with dasycladaceae, and gastropods of the Tarbur Formation are an indicator of back reef.

Fig. 5.5.Gastropod shell in the Tarbur Formation (Zarghan section), magnification × 2.5

5.6. Bivalvia (Rudists)

The main organic constituents of the Tarbur Formation association are rudist fragments. Rudist debris is principally accumulated at the base of theTarbur Formation. In many transverse sections of rudist teeth, there is a baffling structure. This is especially observed on the top of the upper part of the Tarbur Formation in the Zarghan section (Fig. 5.6).

Rudist particles are 1.5 to 0.2 cm in size. Large particles are mainly observed in the wackestone facies, while fine particles are observed in the packstone and grainstone facies. Also, particles larger than 1.5cm are observed in boundstone facies. The maximum rate of these particles is 50% in Kuh-e Siah, in which the minimum percent is about 2%. Maximum rudist particles are observed in the lower part of the Tarbur Formation of the Zarghan section and are about 49%. The minimum rate of rudist particles is observed in the Kherameh-1 section. It should be noted that the maximum percentage of these particles, about 30%, is observed in the packstone facies. The maximum percentage of the rudists is about 70%.

Increase in the strontium concentration mainly relates to the rudist contents in all of the studied stratigraphic sections. Although well-preserved rudists are not detected, there are some Hippurites remains that have baffled sediments, especially in the upper part of the Zarghan section (Fig. 5.6). Usually rounded and angular particles of rudists are sorted together. In fact, these particles are detected in the packstone facies, particularly in the lower part of the Kuh-e Siah section. Rudist particles are mixed with the other bioclasts, for example foraminifers, gastropods, algal remains, and other microfacies elements. Therefore, rudist particles are the main bioclast elements that build up the Tarbur Formation. They are observed in all index microfacies of the Tarbur Formations with different accumulations. The rate of rudist particles is 10-25% in wackestone, 25-40% in packstone, 25-30% in grainstone, and finally, over 80% in boundstone facies.

Rudist particles are a good indicator of the kinetic energy of the sedimentary basin. The rate of angular particles in microfacies or transported rudist fragments is an indicator of the kinetic energy of waves in the reef mass.

Rounded rudist fragments are an indicator of the transportation of rudist particles as aresult of wave action during the time before diagenesis. As usual, rounded particles are observed in all of the identified microfacies, especially in wackestones. On the other hand, angular particles are usually detected in packstones. Variations of rudist accumulation are the same as the strontium concentration.

Fig. 5.6.Rudist fragments in the Tarbur Formation (Zarghan section).Hippurites and Radiolites are observed in all of the microfacies of the Tarbur Formation, magnification × 2.5

5.7. Reworked Foraminifera

Reworked Foraminifera are rarely found in the Kherameh-2 section (Fig. 5.7). They are not common in the Tarbur Formation. Reworked foraminifers are *Alveolina cretacea,* which are observed in the Sarvak Formation. These reworked foraminifers are observed in the base of the Tarbur Formation. Since the chambers of these foraminifers are filled with iron oxide, the Sarvak Formation outcrops were partly situated above the sea level when the Tarbur Formation was depositing, showing some folding of the area.

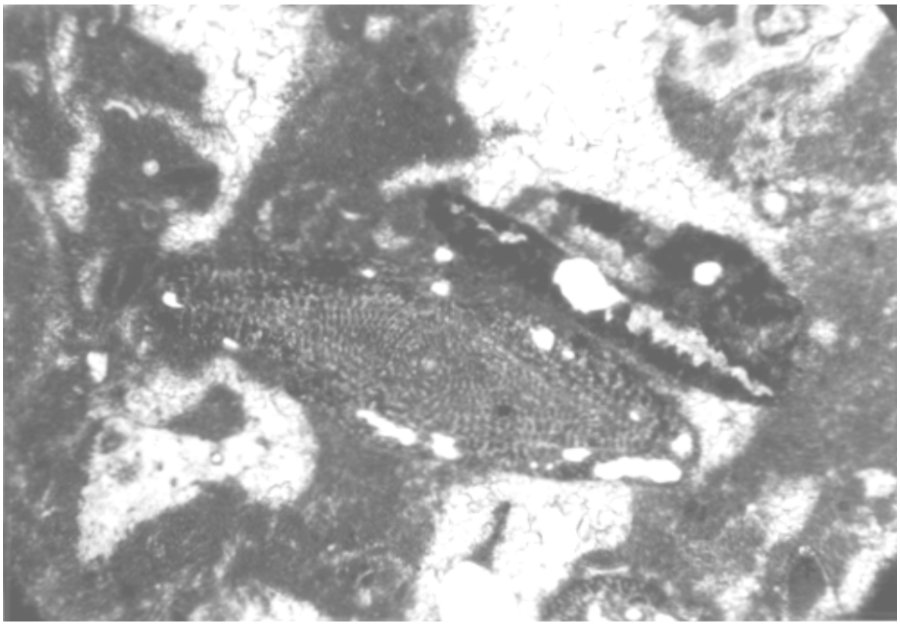


Fig. 5.7. *Alveolina cretacea* in the Tarbur Formation (Kherameh-2 section), magnification × 2.5

Although benthos is defined as the bottom of the sea, especially of the deep oceans (Webster's New Collegiate Dictionary, 1962), the benthic environment in this study is no deeper than 200 m. The benthic facies have distinct characteristics. Knowledge of the fauna that inhabited the benthic environment facilitates the identification of the microfacies. Foraminifera are the most important indicator taxa of the benthic environment. All of the taxa in the studied sections were of fauna that couldnot exist at depths greater than 200 m. These genera which lived in the benthic sediments include *Orbitoides, Omphalocyclus, Antalyna, Dictyoconella, Siderolites, Goupillaudina* and *Laffitteina.* Moveover, dasycladaceae are observed in the photic zone of the Kherameh-2 section.

In addition to the foraminiferal biofacies, the rudist and coral remains support the contention of the benthic environment of the studied sections.

Lithofacies is further proof showing the benthic nature of the research sites. Packstone, grainstone and boundstone are formed in the benthic environment. Packstone and grainstone are especially deposited in the area of wavebase influence.

Wackestone consisting of dasycladaceae, coral, and rudist debris indicate the photosynthesizing depth. As dasycladaceae are usually dominant in back reef with low energy sediment, wackestone, which contains these algae, is an indicator of back reef facies.

These facies have been deposited below the wave base influence, but not deeper than 200 m. Furthermore, the concurrence of lithofacies and biofacies, especially Foraminifera, indicates that these wackestones have been deposited in a depth of less than 50 m. The back reef wackestones are observed in the upper part of the Tarbur

Formation, which underlies the Paleocene Sachun Formation, which mainly consists of evaporites.

The wackestones observed in the lower part of the Tarbur Formation are related to the fore reef facies. These wackestones, which alternate with fore reef packstone and grainstone, were deposited below the wave base level influence.

5.8. Foraminiferal Biozones in the Tarbur Formation

Biozonation of the Tarbur Formation is based on index foraminiferal constituents. There are many biozones that are identified in the studied stratigraphic sections. These biozones identified a Campanian boundary between Maestrichtian and Paleocene time. Normally, these biozones are assemblage zones, but in order to determine the Paleocene, an acro-zone or assemblage zone is used, too. In fact, in order to determine the boundary between the Upper Cretaceous and Paleocene, it is necessary to refer to PRICE et al. (1996), SAHAYIAN et al. (1996), SEYFERT and SIRKIN (1979), and KALANTARI (1976) .

5.8.1. Biozone of the Kuh-e Siah

This biozone is named *Rotalia skourensis*, an assemblage zone that is the first biozone of the Kuh-e Siah. *Siderolites calcitrapoides* is the index fossil of the base of the Tarbur Formation, and it has a thickness of 225 m.

The foraminifer associations are: *Omphalocyclus macroporus, Goupillaudina shirazensis, G.*sp.,*Orbitoides media, Lepidorbitoides minor, L. socialis, Minoxia* sp.*, Sirtina* sp.*, Trochospira* sp.*, Dicyclina schlumbergeri*, and *Orbitoides media*. These fossils are observed throughout both the upper and the lower part.

Actually, *Orbitoides media* is situated in an interval zone which includes *Lepidorbitoides socialis, L. minor, Antalyna korayi, Loftusia* *minor*, *Minoxia* sp., *Rotalia* sp., *Trochospira* sp., and *Dicyclina schlumbergeri*. The age of the *Rotalia skourensis* assemblage biozone is Maestrichtian.

The *Laffitteina* sp. biozone is the second biozone. Actually, when the *Rotalia skourensis* assemblage biozone disappears, *Laffitteina* sp. appears. It appears in the upper to uppermost part of the lithostratigraphic limit of the Tarbur Formation in this section. The age of the *Laffitteina* sp. is the Lower Paleocene (Fig. 5.8.1). Therefore, the biostratigraphic limits of the Kuh-e Siah are the Maestrichtian to the Lower Paleocene. The first biozone is the Maestrichtian and the second one is the Lower Paleocene.

5.8.2. Biozone of the Zarghan

The first biozone is identified by the presence of *Orbitoides concavatus*. Foraminiferal associations of the first biozone are: *Orbitoides tissoti*, *O. media*, *Murciella cuvillieri*, *Dicyclina* sp., *Minoxia* sp., *Coskinolina* sp.. The entire lower part belongs to the first biozone. The second biozone is identified by the presence of *Orbitoides apiculata*. Foraminiferal associations of this biozone are: *Omphalocyclus macroporus*, *Orbitoides media*, *Dictyoconella* sp., *Rotalia skourensis*, *Coskinolina* sp., *Loftusia minor*, *Rotalia skourensis*, and *Broeckinella* sp.

The age of the first biozone is Campanian and that of biozone number two is Maestrichian (Fig.5.8.2). Therefore, the biostratigraphic limits of the Zarghan section are the Campanian to Maestrichtian.

5.8.3. Biozone of Kherameh-1

The first biozone is named *Murciella cuvillieri*, which is associated with *Broeckinella* sp., *Trochospira* sp., and *Minoxia* sp..The thickness of this biozone is 70 m.

The second biozone is identified by the presence of *Omphalocyclus macroporus*, which is associated with *Orbitoides media, O.concavatus, O.triangularis, Antalyna korayi, Rotalia skourensis, Trochospira* sp., and *Minoxia* sp. (Fig.5.8.3).

The age of biozone *Murciella cuvillieri* is Campanian and that of the second one is Maestrichtian. Therefore, the biostratigraphic limits of the Kherameh-1 section are Campanian to Maestrichtian.

5.8.4. Biozone of Kherameh- 2

There is only one biozone that is detectable in this stratigraphic section. It is named the *Omphalocyclus macroporus* sub-zone and *Antalyna korayi*sub-zone.The age of this biozone is Maestrichtian (Fig.5.8.4). Therefore, the biostratigraphic limits of the Kherameh-2 are Maestrichtian. The *Omphalocyclus macroporus* assemblage sub-biozone associates with *Antalyna korayi, Lepidorbitoides minor, Coskinolina* sp., *Minoxia* sp.. With the disappearance of the *Omphalocyclus macroporus* assemblage sub-biozone, the *Loftusia minor* biozone appears. It associates with *Antalyna korayi, Orbitoides media, O.apiculata, O. tissoti, Dictyoconella* sp., *Broeckinella* sp., *Salpingoporella dinarica* and *S. turgida*. Also, *Omphalocyclus macroporus* and *Loftusia minor* relate to the Maestrichtian; therefore, the age of these biozones is Maestrichtian.

5.8.5. Biozones of the Kuh-e Khanehkat

The first biozone is named *Orbitoides concavatus*, which relates to the Campanian. The thickness of this biozone about 10 m. These taxa associate with *O.tissoti* (Fig. 5.8.5). The second biozone is named *Dictyoconella complanata,* which relates to the Maestrichtian. This biozone is an assemblage zone that consists of *Orbitoides media, O. triangularis, Loftusia minor, Broeckinella* sp., *Rotalia skourensis, Dictyoconus* sp. and *Nezzazatinella* sp.. This biozone includes some parts of the lower and the upper part. With the disappearance of this assemblage zone, the *Vania anatolica* biozone has started in the middle of the upper part of the Tarbur Formation. This biozone is related to the Lower Paleocene; therefore, the age of the Tarbur Formation is Campanian to Lower Paleocene.

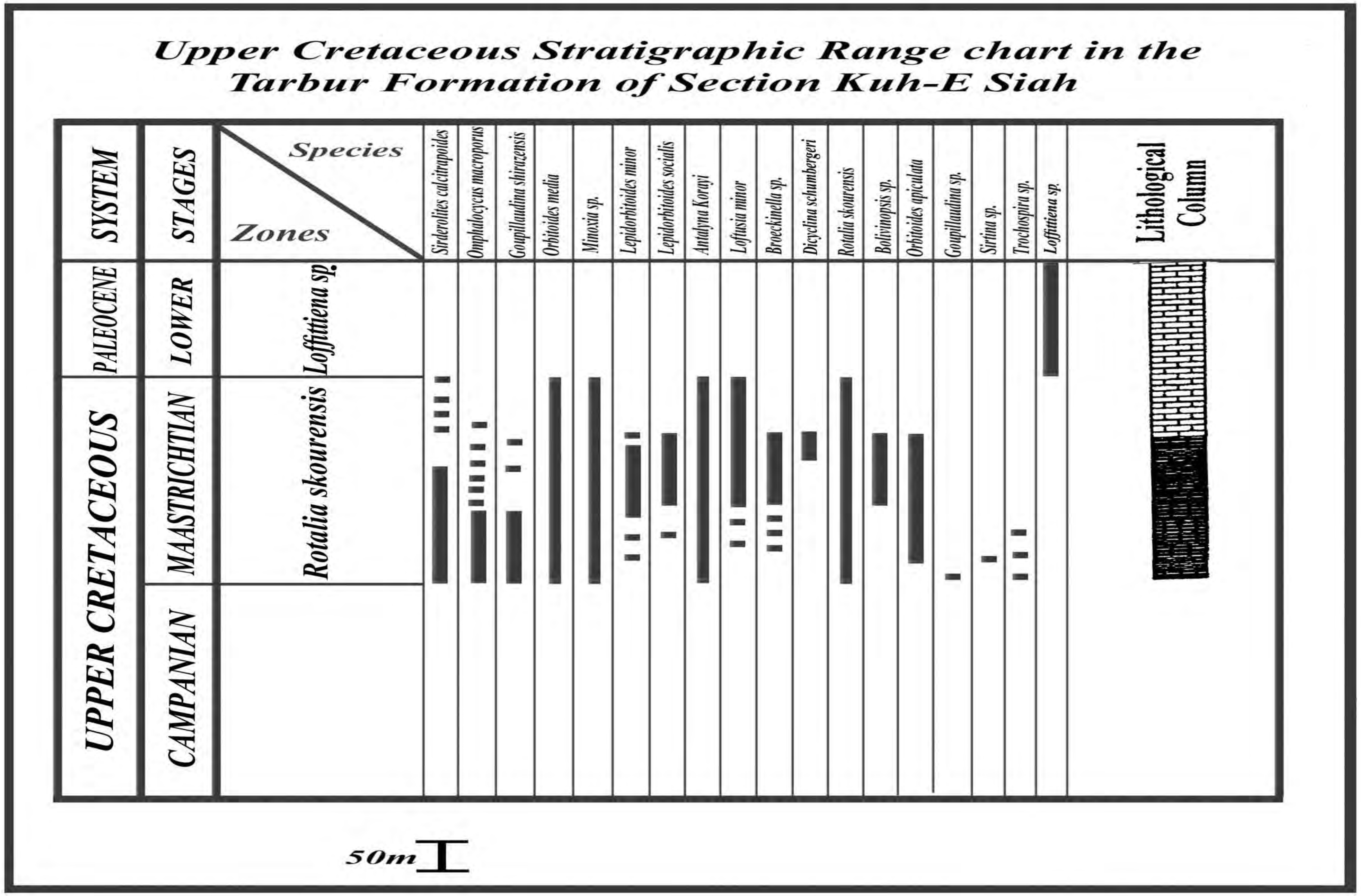
5.8.6. Biozones of the Kuh-e Chehelcheshmeh

At the Kuh-e Chehelcheshmeh stratigraphic section, the first biozone is *Orbitoides concavatus,* which associates with *O.media* (Fig. 5.8.6). In fact, *O. media* is an interval biozone. The thickness of this biozone is about 6 meters and with the disappearance of the *O.concavatus* (the age of this biozone is Campanian) biozone, the *Rotalia skourensis* biozone, which is an assemblage biozone, appears. This biozone includes *Orbitoides media, O. apiculata, Dictyoconella complanata, D.* sp.*, Dicyclina schlumbergeri, Loftusia minor, Goupillaudina shirazensis, Omphalocyclus macroporus, Antalyna korayi, Dictyoconus* sp., *Nezzazatinella* sp., *Broeckinella* sp., *Salpingoporella dinarica,* and *S.turgida.*The age of this assemblage biozone is Maestrichtian. With the disappearance of the *Rotalia skourensis* assemblage biozone, the *Vania anatolica* assemblage biozone appears. This biozone consists of *Vania anatolica* with *Laffitteina* sp.. The age of this biozone is Lower Paleocene. In addition, there are three biozones in this stratigraphic section, therefore, the biostratigraphic limits include the Campanian to the Lower Paleocene.

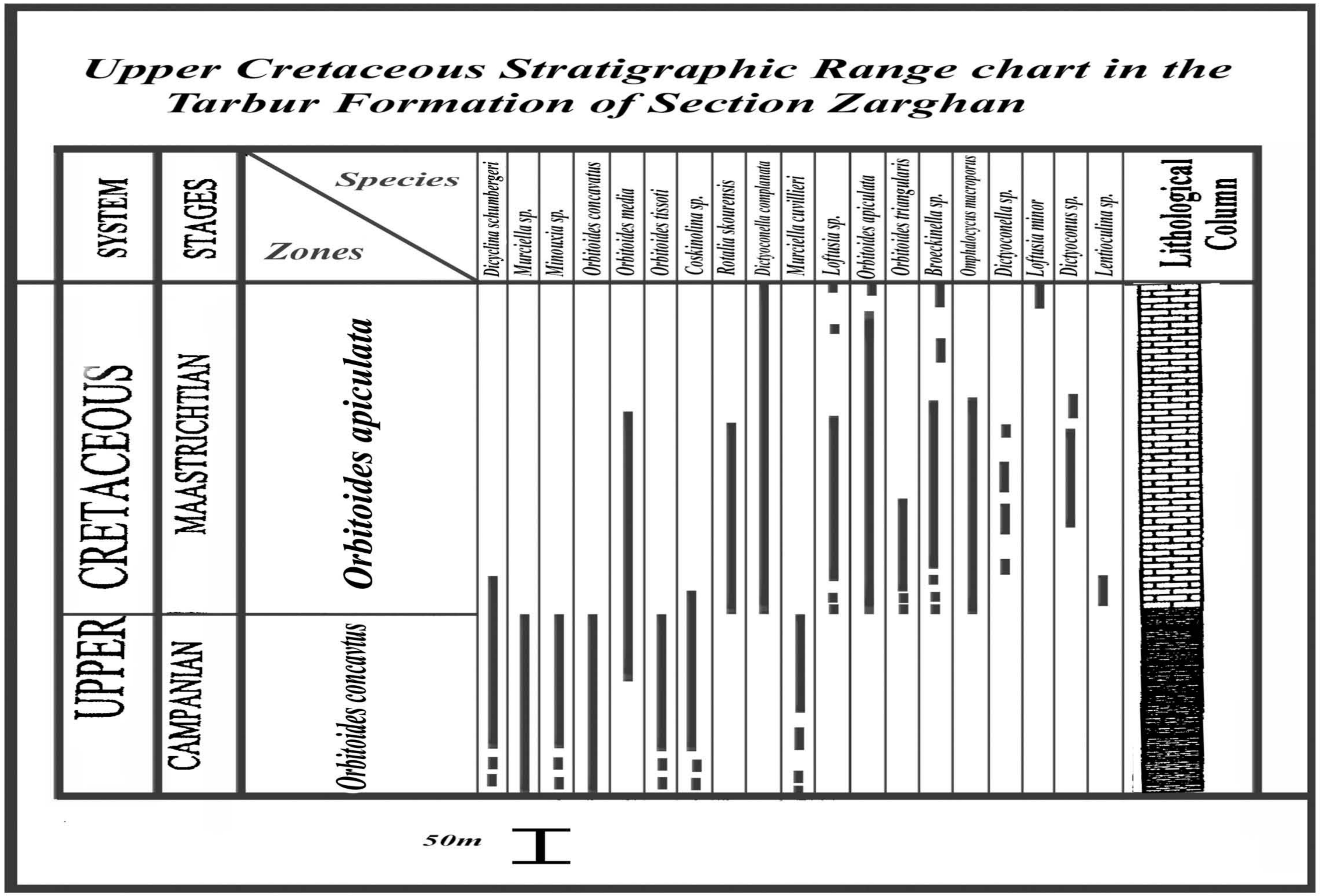
5.8.7. Biozone East of Dariyan

The first taxa that appear in this stratigraphic section are *Omphalocyclus macroporus*, which are observed in the whole lower part and more than the middle of the upper part in this section (Fig.5.8.7).

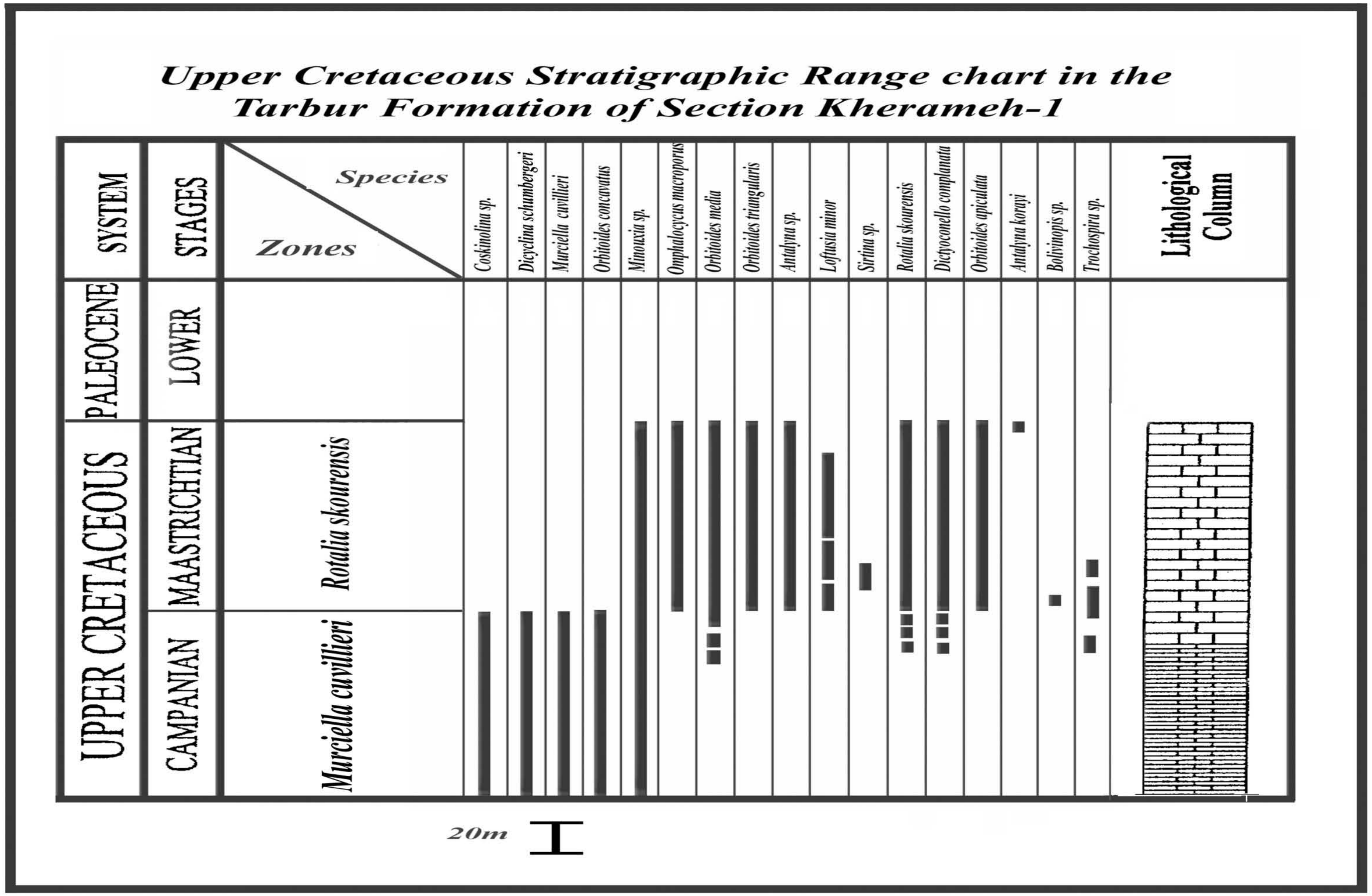
These taxa are associated with *Rotalia skourensis, Orbitoides apiculata, O. media, Antalyna korayi, Dicyclina schlumbergeri, Broeckinella* sp.and *Nezzazatinella* sp. in the lower part of the Tarbur Formation, and they are associated with *Goupillaudina shirazensis, Antalyna korayi, Lepidorbitoides minor, L.socialis, Dictyoconella complanata, Orbitoides media, Dictyoconus* sp., *Salpingoporella dinarica,* and *S.turgida.* Furthermore, the *Antalyna korayi* interval biozone overlaps with *Omphalocyclus macroporus* and is observed in the uppermost part of the Tarbur Formation. These taxa associate with *Lepidorbitoides minor, L.socialis, Loftusia minor* and *Siderolites calcitrapoides.* Therefore, the addition of these biozones indicatesthe Maestrichtian. It should be noted that *Orbitoides media* appears in both Campanian and Maestrichtian biozones of the studied section. Therefore, it is not an index taxa in the TarburFormation. But foraminifers such as *Orbitoides concavatus* and *Murciella cuvillieri* indicate the Campanian, and *O.apiculata,* and *Omphalocyclus macroporus, Antalyna korayi, Dictyoconella complanata,* and *Rotalia skourensis* indicate the Maestrichtian.



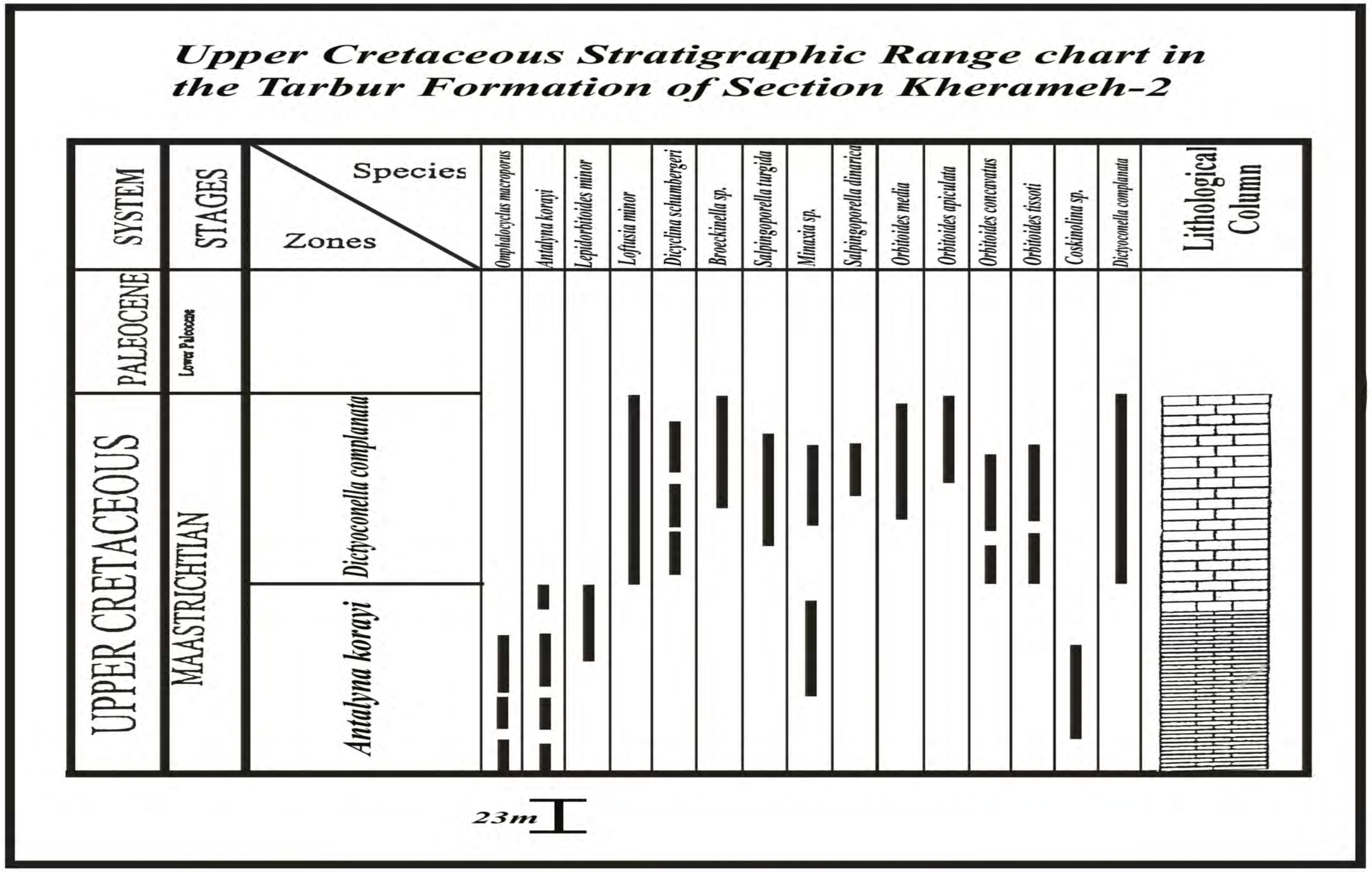
5.8.1. Biozones of the Tarbur Formation in Kuh-e Siah



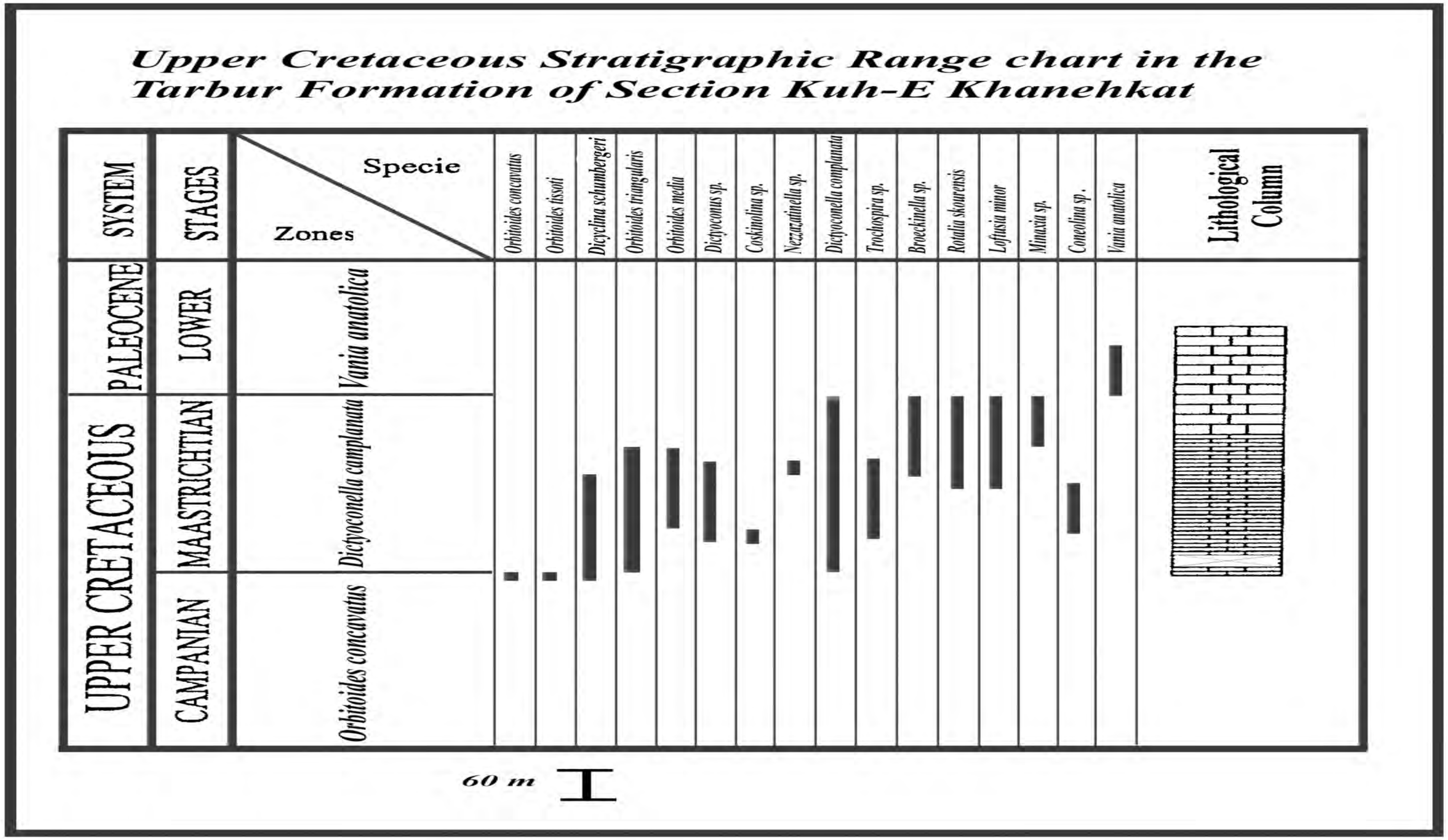
5.8.2. Biozones of the Tarbur Formation in Zarghan



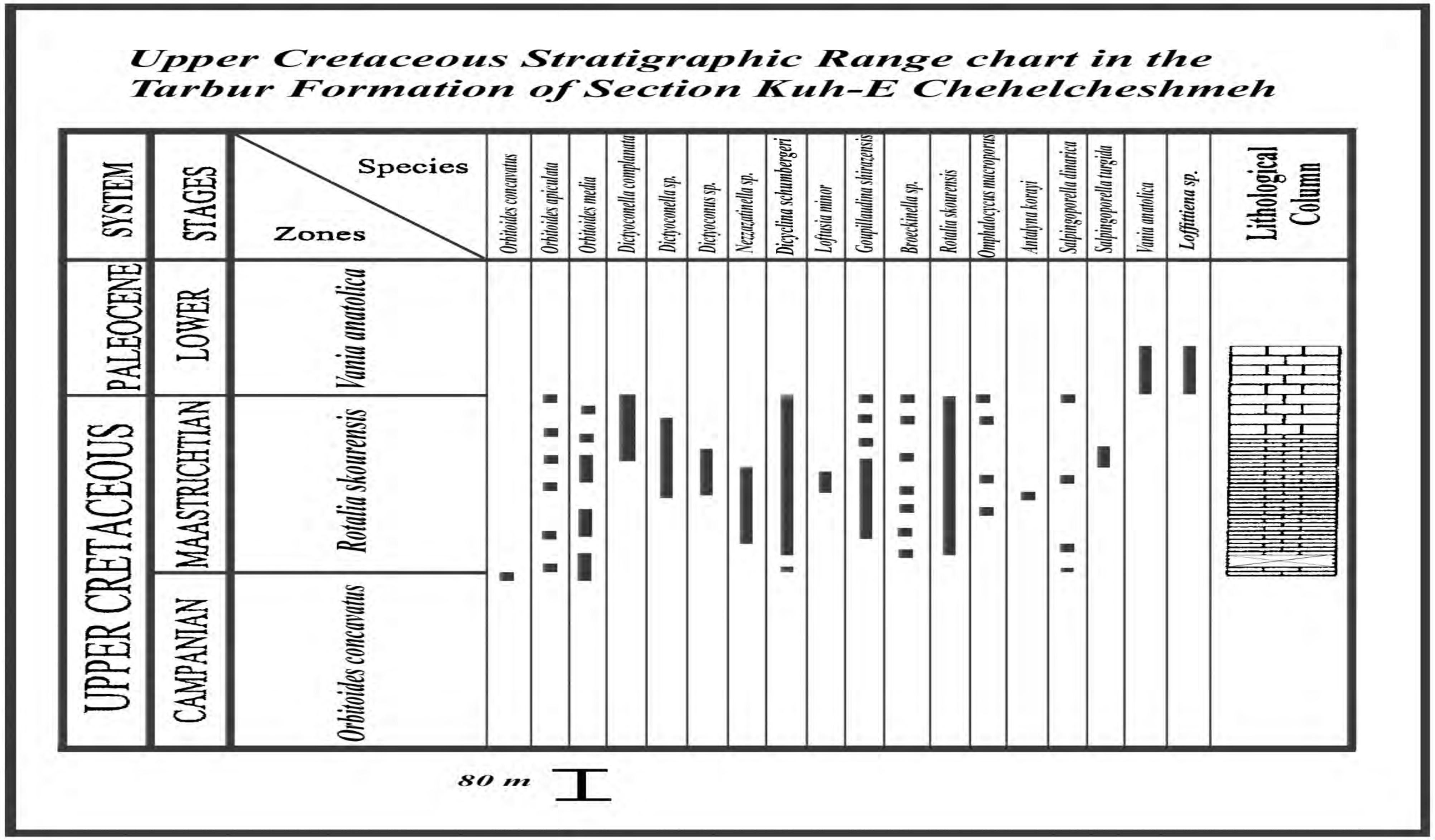
5.8.3. Biozones of the Tarbur Formation in Kherameh-1



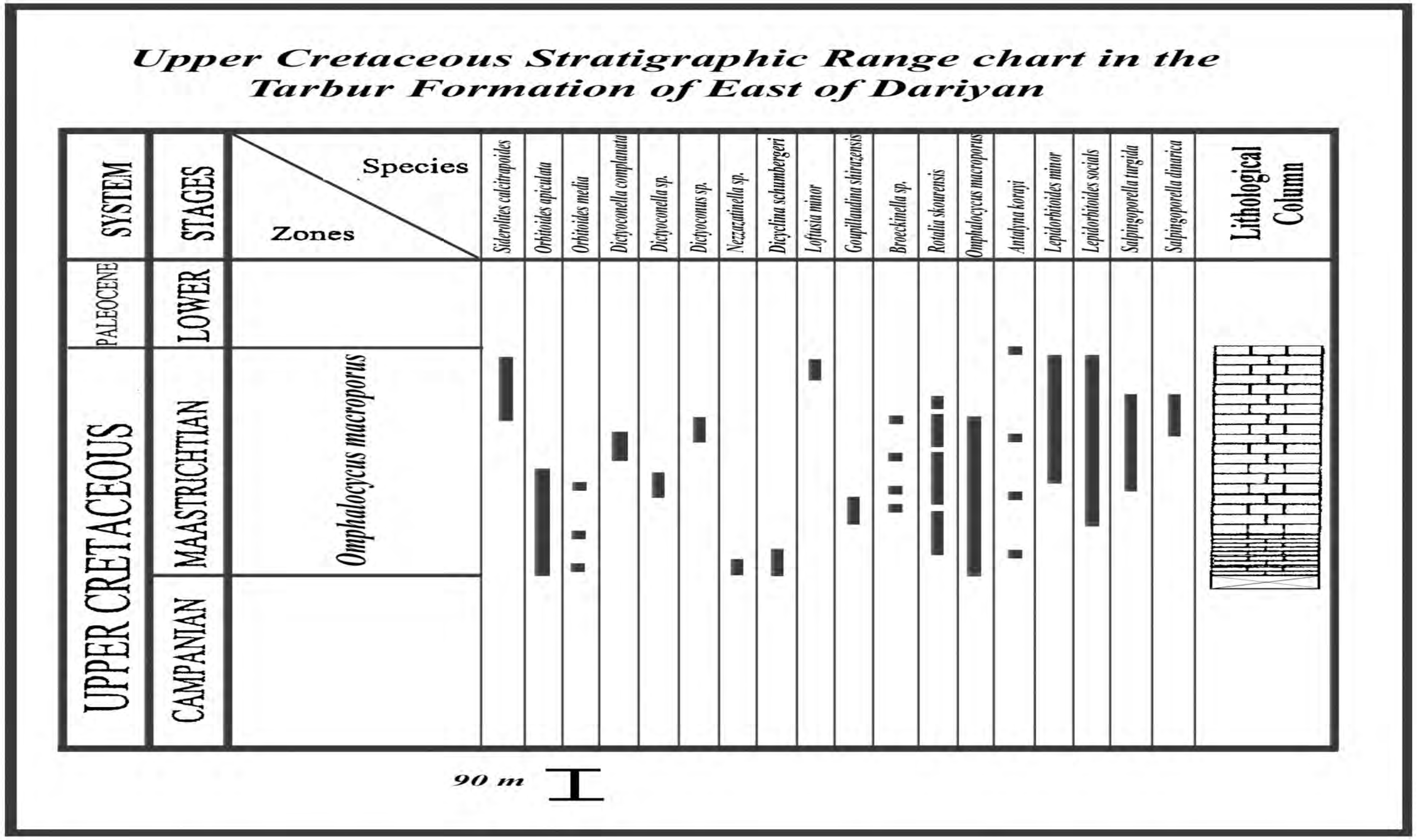
5.8.4. Biozones of the Tarbur Formation in Kherameh-2



5.8.5. Biozones of the Tarbur Formation in Kuh-e Khanehkat



5.8.6. Biozones of the Tarbur Formation in Kuh-e Chehelcheshmeh



5.8.7. Biozones of the Tarbur Formation in Dariyan

5.8.8. Discussion of Biostratigraphic Limits in the Cretaceous and Tertiary

The main foraminifers that are identified in the studied sections of the Tarbur Formation are index foraminifers. These taxa indicate the boundary between Campanian and Maestrichtian ages. Segregation of the Campanian and Maestrichtian is observable in the Zarghan, Kherameh-1, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh sections. In fact, *Orbitoides concavatus,O. tissoti* and *Murciella cuvillieri* are indicators of Campanian age. Disappearance of these foraminifers is detected at the end of the Campanian era. Simultaneously with the end of the Campanian era, the Maestrichtian foraminifers biozone is detectable. Generally, Maestrichtian foraminifers include *Dictyoconella complanata, Orbitoides apiculata, O.triangularis, Omphalocyclus macroporus, Antalyna korayi, Lepidorbitoides minor, L.socialis, Loftusia minor, Rotalia skourensis, Broeckinella* sp. and *Goupillaudina shirazensis.* In addition, there are many diverse foraminifera that indicate the Maestrichtian in the studied sections. Therefore, the boundary between the Campanian-Maestrichtian is distinct with the determination of foraminifer ranges. Principally, Maestrichtian foraminifers are observed more often than Campanian foraminifers, therefore, diversity of foraminifers is mainly detectable in the Maestrichtian. However, Campanian foraminifers are also index taxa. Since the Tarbur foraminiferal constituents include Paleocene foraminifers, the boundary of the Cretaceous-Tertiary is the most observed biostratigraphic event that identifies foraminifers in the studied sections.Based on micropaleontological study of sections of the Tarbur Formation, the Lower Paleocene foraminifers are only observable in the Kuh-e Siah, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh stratigraphic sections. In fact, with the disappearance of Maestrichtian foraminifers, the

Lower Paleocene foraminifers are only observable in the Kuh-e Siah, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh stratigraphic sections. Actually, with the disappearance of Maestrichtian foraminifers, the Lower Paleocene is detectable in the Tarbur Formation. It should be noted that lithologically there is segregation of the Cretaceous-Tertiary boundary in many stratigraphic sections of Iran and other stratigraphic sections of the world. But there is no disconformity evidentbetween Maestrichtian and Lower Paleocene sediments of the Tarbur Formation (Figs.5.8.1., 5.8.5. and 5.8.6.). Correspondence of foraminiferal constituents of the Tarbur Formation with the lithostratigraphic boundaries of the studied sections indicates that the upper biostratigraphic limit, especially, is determined by the Sachun Formation, which has different lithological characteristics than the Tarbur Formation. This lithological segregation is observable in all of the studied sections. However, identification of the Lower Paleocene foraminifers (*Vania anatolica* and *Laffitteina* sp.) is an indicator of different biostratigraphic limits only in the Kuh-e Siah, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh stratigraphic sections. According to previous stratigraphic studies of the Zagros (JAMES & WYND, 1965), which were confirmed between the Cretaceous and Tertiary, it is logical to conclude that biostratigraphic and lithostratigraphic disconformity is not detected in all of the stratigraphic sections in the Zagros.

5.8.9. Upper Cretaceous-Lower Paleocene Foraminiferal Biozonation of theTethyan Realm

Upper Cretaceous biozonation of the Tethyan realm has been carried out by many researchers. Since the studied area was a part of the Tethys during the deposition of theTarbur Formation, I will present the pelagic and benthic foraminiferal biozonations of the Tethys that have been established before and then compare the Tarbur foraminiferal biozonation with the last biozonations of the Tethyan realm.

According to BOUDAGHER-FADEL (2008,2002), ANGIOLINI et al. others (2006), PERMOLI SILVA and VERGA (2004), HUBER (2003), PIGNATTI (1998), BANNER and SIMMONS (1994), CAUS (1988), SARTORIO and VENTURINI (1988), ARNAUD-VANNEAU (1980), JAMES and WYND (1965), and HENSON (1948), there are foraminiferal biozonations in some parts of the Tethyan realm which are criteria for age determination of region successions especially in hydrocarbon explorations. Actually, there are many biozones which have been established in pelagic and benthic facies of the Tethys.

BOUDAGHER-FADEL (2008) has summarized he stratigraphic distribution of index benthic foraminifers in the Tethyan realm (Fig.5.8.9a). In this figure (range chart), foraminifer distribution is presented at the level of genera. Based on JAMES and WYND (1965), *Lepidorbitoides* sp., *Loftusia* spp., *Monolepidorbis* spp., *Omphalocyclus macroporus* have presented as typical foraminifers in the type section of the Tarbur Formation which is located in Interior Fars. These benthic foraminifers are an index of Upper Campanian to Maestrichtian in this region. Also pelagic facies of the Gurpi Formation are developed in Interior and Coastal Fars.

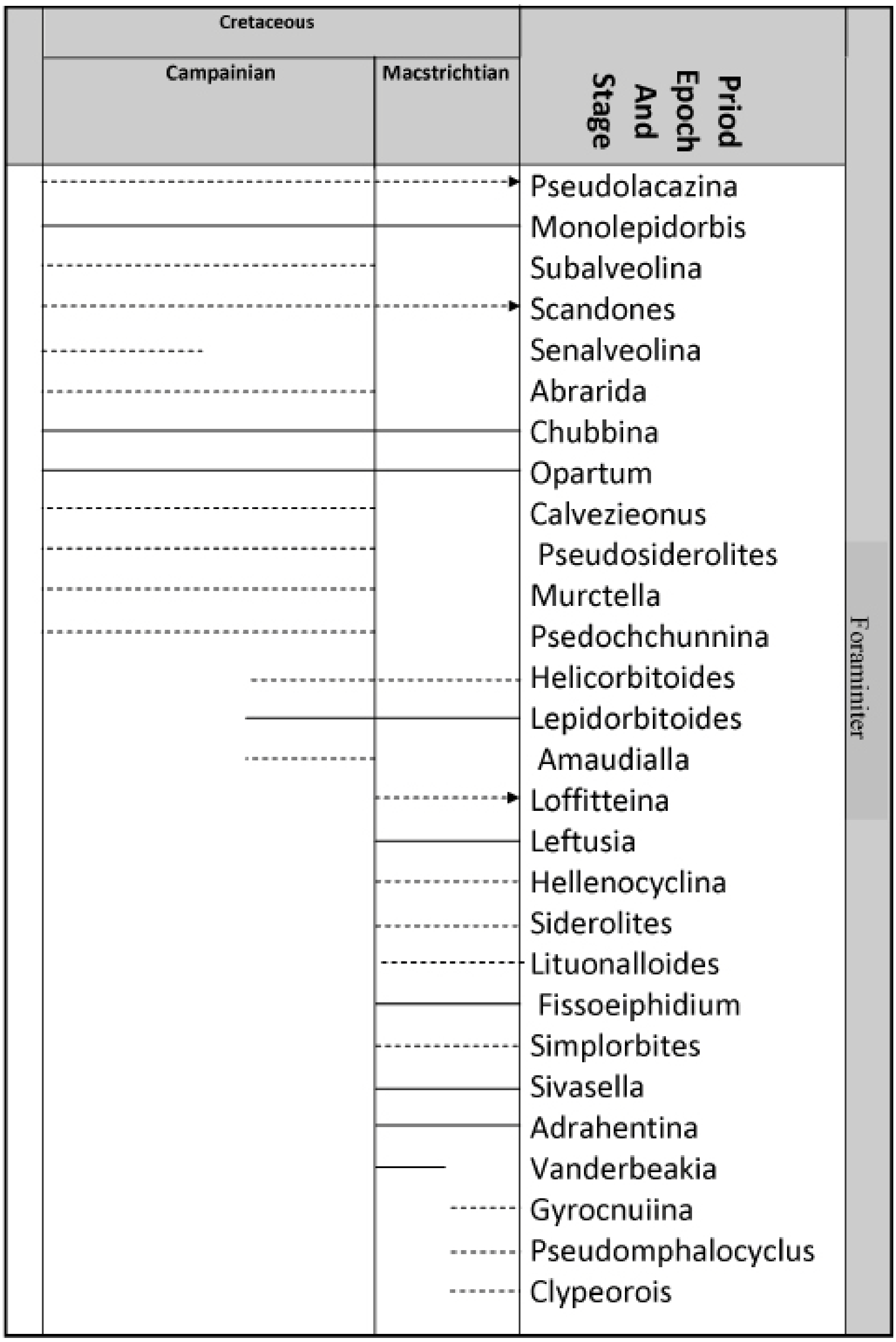


Fig. 5.8.9a.Upper Cretaceous benthic foraminiferal biozone of the Tethys Realm byBoudagher-Fadel (2008)

Khuzestan, which consists of planktonic foraminifers such as: *Globotruncana elevata, Glt. calcarata, Glt.gansseri, Glt.stuarti, Glt.contusa, Glt. stuartiformis, Abathomphalus mayaroensis*. According to WYND (1965), the Gurpi Formation has identified *Globotruncana elevata elevata* in the Lurestan area (West of Iran), which is assigned to the Campanian. Often this biozone consists of *Globotruncana calcarata, Glt. arca, Glt. fornicata,* and *Glt. conica*. The *Globotruncana elevate elevata* biozone is comparable with the *Monolepidorbis-Orbitoides* assemblage zone in Interior Fars. Also, in order to determine the Maestrichtian, the *Omphalocyclus-Loftusia* assemblage is presented (WYND, 1965), which is comparable with the *Globotruncana stuarti-Pseudotextularia varians* assemblage zone and *Abathomphalus mayaroensis* biozone. According to WYND (1965), Lower Paleocene is determined by appearance of the *Globorotalia-Globigerina-Globigerina daubjergensis* assemblage zone which is recognizable in Lurestan and Coastal Fars (Pabdeh Formation). WYND has not identified biozone in Interior Fars, whereas the Sachun Formation consists of *Miscellanea* sp., *Glomalveolina* sp. and rarely of *Opertorbitolites* sp.. The comparison of WYND's biozones of the Upper Cretaceous and Lower Paleocene between Lurestan and Interior Fars is present in Figure 5.8.9b.

In addition, biozonation of the mountain ranges is assigned to the Eastern Tethyan realm.

Zone / Stage	Lurestan	Formation	Interior Fars	Formation
L.paleocene	*Globorotalia velascoensis* *Glo.pseudomenardii* *Glo. rex* *Glo. wilcoxensis* *Glo. palmerae*	Pabdeh Fm.	*Glomalveolina sp.* *Miscellanea sp.* *Opertorbitolites sp.*	Sachun Fm.
Maestrichtian	*Abathomphalus mayaroensis* *Glt. stuarti* *Glt. stuartiformis* *Glt. gansseri* *Glt. contusa* *Glt. lapparenti* *Heterohelix sp.* *Pseudoguembelina sp.*	Gurpi Fm.	*Loftusia sp.* *Lepidorbitoides sp.* *Omphalocyclus macroporus*	Tarbur Fm.
Campanian	*Globotruncana elevata* *Glt. calcarata* *Glt.arca*		*Monolepidotbis sp.* *Orbitoides media*	

Fig.5.8.9b.Biozonation of pelagic foraminifers of the Gurpi (Upper Cretaceous) and Pabdeh Formations (L-Paleocene) in Lurestan, the Tarbur (Upper Cretaceous) and Sachun Formations (L-Paleocene) in Interior Fars Area (WYND, 1965) SW Iran, Eastern Tethys Realm

Based on PERMOLI SILVA and VERGA (2004), biozonation of Upper Cretaceous planktonic foraminifers of the west of the Tethyan realm is shown in Figure 5.8.9c. According to PERMOLI SILVA and VERGA, Campanian is determined from the base to the top by the *Globotruncana elevata* zone, *Globotruncana ventricosa* zone and *Globotruncana havanensis* and *Globotruncana aegyptiaca* zone, and there are three Maestrichtian biozones which consist, from the base to the top, of the *Gansserina gansseri* zone, *Contusotruncana contusa* zone, and *Abathomphalus mayaroensis* zone.

In addition, there is a comparable table of biozones of the Tarbur Formation of the studied stratigraphic sections, WYND's biozones (east of the Tethyan realm).

Campanian	Maestrichtian	L- Paleocene	
Glt.aegyptiaca Glt.ventricosa Glt.elevata	Abathomphalus mayaroensis Contusotruncana contusa Ganssorina gansseri		West of Tethys
Glt.elevata Glt. calcarata	Globotrancana stuartifomis Abathomphalus mayaroensis	Globorotalia velascoensis	East of Tethys
	Rotalia skourensis	Laffittiena sp.	Kuh-e Siah
Orbitoides concavatus	Orbitoides apiculata		Zarghan
Murciclla cuvillieri	Rotalia skourensis		Kherameh-1
	Antalyna korayi Dictyoconella complanata		Kherameh-2
O.concavatus	Dictyoconella complanata	Vania anatolica	Kuh -e Khanehkat
O.concavatus	Rotalia skourensis	Vania anatolica	Kuh- e Chelcheshmeh
	Omphalocyclus macroporus		Dariyan

Fig.5.8.9c.Comparison of foraminiferal biozonation in some parts of theTethys Realm and studied stratigraphic sections of the Tarbur Formation

5.9. Paleoecology of Foraminifera in the Tarbur Formation

The five factors listed below determined the ecological conditions under which the studied factors of the Tarbur Formation were living:

1- Depositional system, 2- Kinetic energy or currents, 3-Salinity, 4- Temperature, 5- Depth.

The reef ecosystem in reality is a complex system. However, some of the factors which relate to the Campanian-Maestrichtian age are different from the same factors in recent times. For example, water temperature, organism association, and situation arrangement factors of the observed foraminifera are the key factors in finding out the paleoecological conditions of the Tarbur Formation.

Depositional system: Different groups of Foraminifera are observed in the back reef facies of the Kuh-e Siah section. The Orbitoidinae family is mainly observed in the fore reef facies. Agglutinated walls of Foraminifera are present in the back reef sediments. This indicates the existence of allochems materials which mainly accumulate in the back reef environment. Moreover, the presence of dasycladaceae indicates that the depth of water during back reef formation was less than 200m.

Kinetic energy or currents: As a rule, fore reefs are formed in the high energy environment of the wave base. The Foraminifera taxa observed in the fore reef facies, for example, *Omphalocyclus macroporus* and *Siderolites calcitrapoides,* were more turbulence resistant than the taxa that inhabited the back reef facies.

The Foraminifera with agglutinated walls used suspended particles which were transported from the reef mass, or from the coast. These Foraminifera include *Loftusia minor*, *Dictyoconella* sp., *Coskinolina* sp. and *Murciella cuvillieri*. These taxa are related mainly to the wackestone facies, which are formed below a depth of 15m.

Salinity: One of the important parameters in the ecology of Foraminifera is salinity. Main groups of Foraminifera families can live in brackish water. Also, many taxa are observed in both back reef and fore reef facies in the studied sections; therefore, salinity factors are similar in all of the stratigraphic sections. For example, *Orbitoides media* spanned the entire duration of both the Campanian and Maestrichtian ages. But on the other hand, the geochemical evidence, especially the variations of strontium in each stratigraphic section, indicates a temperature variation which shows falling temperature. Therefore, salinity is decreased in the boundary of the Campanian-Maestrichtian, and flows during the Maestrichtian. It should be noted that salinity is a function of temperature. Another example of the disappearance of some taxa is *Murciella cuvillieri*, even if it is only observed in the Campanian.

It is probable that these taxa could tolerate only a limited amount of salinity. Therefore, salinity decreased from the Campanian to the Maestrichtian age. Finally, taxa such *as Dicyclina* sp., *Murciella cuvillieri, Orbitoides tissoti,* and *O.concavatus* tolerated the Lower Campanian salinity, while in taxa with a higher salinity the tolerance level had allowed their continued existence in the lower-level saline Maestrichtian sea.

Temperature: It is a well-known fact that, thermal energy, among other things, governs sea water circulation and solubility of salts, the two main factors in the living environment of Foraminifera. Mass extinction of some Foraminifera has been attributed to their narrow range of tolerance to change in water temperature. Therefore, the taxa observed in the Kuh-e Siah, Zarghan, and Kherameh-1sections had probably tolerated a gentle change in temperature.

However, these taxa disappear at the top of the Kuh-e Siah section and *Laffitteina* sp., which belongs to the Lower Paleocene, replaces them. This was due to a decrease in sea water temperature.

Depth: Depth influences pressure, temperature, nutrition of sea water, and light penetration. Lithofacies characteristics show that the Tarbur Formation was deposited in a sea not deeper than 200 m.

Some of the observed Foraminifera occupied the sea floor near the wave base. On the other hand, the degrees of roundness and angularity of crushed bioclasts indicate that waves crushed them near the sea level. Also, these sediments consist of some taxa of orbitoids; therefore, the sediment of the studied fore reef belongs to the shallow waters (not deeper than 15 m). The wackestones, which are alternately deposited with packstone and grainstone, are related to the fore reef wackestone (TUCKER's model, 1994). Therefore, these wackestones were formed in the deeper wave base.

The protected lagoons have high-low energy facies which prograded in the upper part of the Tarbur Formation. Although the kinetic energy of the fore reef is higher than of the back reef, the grainstone and packstone that are formed in the back reef environments to these facies indicate high energy lagoonal facies (depth of wave base effect). On the other hand, the lagoon wackestone also indicates the low energy of back reef environments.

6. Microfacies of the Tarbur Formation

Investigations of the Tarbur microfacies studies indicate many typic microfacies of reef sedimentary environment. Biofacies and lithofacies evidence has been found in quantitative and qualitative studies. In this investigation we have made an identification of bioclast and the statistical study of allochems. Based on the DUNHAM (1962) classification, microfacies of the Tarbur Formation have been studied. In this study, allochem elements have also been identified. These microfacies elements include bioclast, intraclast and extraclast. In order to interpret sedimentary conditions by use of microfacies, it is necessary to refer to FLUEGEL (2004), SCHNEIDER (1998), PROTHERO and SCHWAB (1996), READING (1996), CAUS (1995), TUCKER (1994), JAMES and

MACINTYRE (1985), KALANTARI (1976), JAMES (1984), FOLK (1974), DUNHAM (1962), PETTIJOHN (1957).

Also, in order to carry out both micropaleontologic and microfacies investigations, field and laboratory processes were conducted as follows:

Primary studies: In order to interpret the tectonic and stratigraphic variations of the studied area, first the primary studies in the field of photogeological research must be studied. After field observation of stratigraphic sections, sampling was carried out based on changes in layering, particularly in the lower part, while the sampling in the upper part of the Tarbur Formation was based on one sample per 50 cm thickness.

In the laboratory all samples were coded in order to prepare thin sections.

Laboratory studies: 1. Micropaleontological study; 2. Microfacies study; 3.Geochemical studies.

Preparation: This stage was done first, for microfacies and micropaleontological studies, and secondly, for geochemical studies.

For this purpose, some samples were selected from the lower and upper parts of the Tarbur Formation and then plaques measuring 13 cm with a thickness of 0.5 cm were selected.

Quantitative studies: All studies were done particularly forthe allochem elements. Based on these studies, the distribution rate was estimated, and the classification of microfacies was done according to DUNHAM (1962). In this way, the identification was based on two-thirds of the lithological and microfacies characteristics. Measurement of the condensation of the allochem elements was based on the chart for the visual percentage estimation.

6.1. Microfacies Terminology

All of the nomenclature of the microfacies studied in this research is based on DUNHAM's main principle, which in microfacies identification was based on the amount of mud supported grains occurring as microfacies elements (Table 6.1).

The interpretation of the microfacies of the Tarbur Formation in view of the sedimentary environment has a direct relationship to DUNHAM’s terminology. Many authors have used his terminology in the study of the reefs. It is essential, however, to realize that other terminologies, besides those of DUNHAM'S, are in use today.

<table>
<tr><td colspan="6">Original components not organically bound together during deposition</td></tr>
<tr><td colspan="3">no carbonate mud</td><td colspan="3">contains carbonate mud</td></tr>
<tr><td colspan="3">grain-supported</td><td colspan="3">mud-supported</td></tr>
<tr><td colspan="2"></td><td colspan="2">allochems<%10</td><td colspan="2">allochems>%10</td></tr>
<tr><td>GRAINSTONE</td><td colspan="2">PACKSTONE</td><td colspan="2">WACKESTONE</td><td>MUDSTONE</td></tr>
</table>

Table 6.1. DUNHAM’s classification (1962)

6.2. Systematic Introduction of Microfacies

Four main types of microfacies have been identified. They are:
wackestone, packstone, grainstone and boundstone

6.2.1. The Wackestone of the Tarbur Formation

These microfacies components consist of bioclasts, intraclasts and extraclasts. The accumulation of bioclasts, especially that of rudist fragments, is larger than those of the other microfacies elements. The distribution of wackestone is mainly found in the upper part of theTarbur

Formation in the Kuh-e Siah section, mainly in the lower part of the Kherameh-1 section, and finally, mainly in the lower and upper part of the Kherameh-2 section (Fig.6.2.1). Bioclasts are rounded to angular debris range. Generally, gastropod bioclasts are observed in the uppermost part of the Tarbur Formation.Also, foraminifer debris is well-preserved in the facies. Hexacoralia taxa are detected in the wackestones and have not been found in the other microfacies of the Tarbur Formation.

The most common foraminiferal taxa that are observed in the wackestone facies are *Orbitoides media, O.concavatus, Rotalia skourensis, Vania anatolica* and *Laffitteina* sp.. The wackestones are observed alternately with special packstones in the lower part of the Tarbur Formation in the Kuh-e Siah section, some parts of the lower Tarbur Formation in the Zarghan section, and the upper part of the Tarbur Formation in the Kherameh-1, but wackestone facies is widely distributed in the whole of the Kherameh-2 stratigraphic section.

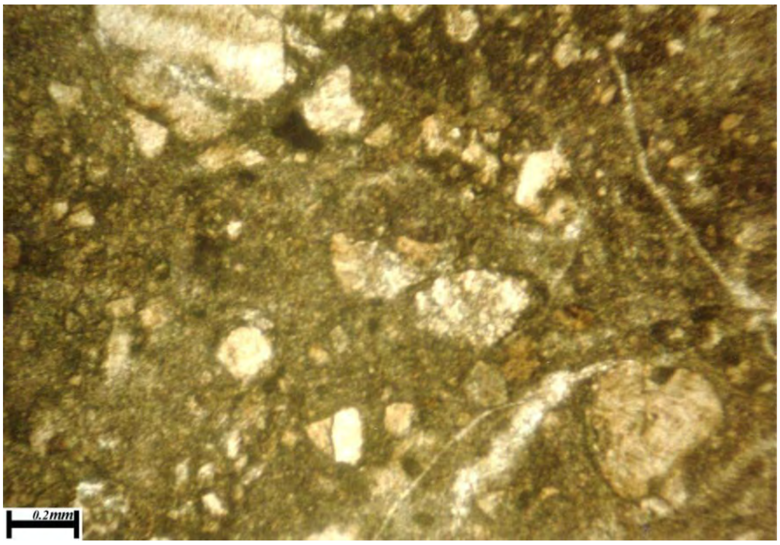


Fig.6.2.1.Wackestone of the Tarbur back reef

6.2.2. The Packstone of the Tarbur Formation

The greatest quantityof bioclasts belongs to packstone facies. This facies alternates with wackestone and grainstone in the lower part of the Tarbur Formation in the Kuh-e Siah section. As in the Kuh-e Siah, it is also observed in the lower and the upper parts of the Tarbur Formation in the Zarghan section. Alternately, packstone is also present in the upper part of the Tarbur Formation in the Kherameh-1 section. It is rarely observed in the narrow layer of the lower and upper part of the Tarbur Formation in the Kherameh-2 section (Fig. 6.2.2). Bioclasts are rudist and orbitoid fragments in the packstone facies. The particles are 0.5-2 mm in size. Some of these particles are angular, while others are rounded to sub-rounded.

The main microfacies elements of the packstone facies are rudist fragments and other components such as orbitoid fragments; extraclasts and intraclasts are not so important because of their lower percentage.

It should be noted that bioclasts are mixed with the other microfacies elements in some of the packstones. Usually, only bioclasts (rudist fragments with foraminiferal debris) are the main microfacies elements in the Kuh-e Siah stratigraphic section. The packstone facies are deposited in the lower part of the Tarbur Formation in the Kuh-e Siah section, some parts of the lower part and uppermost part of the Zarghan section, and the upper part of the Kherameh-1 section.

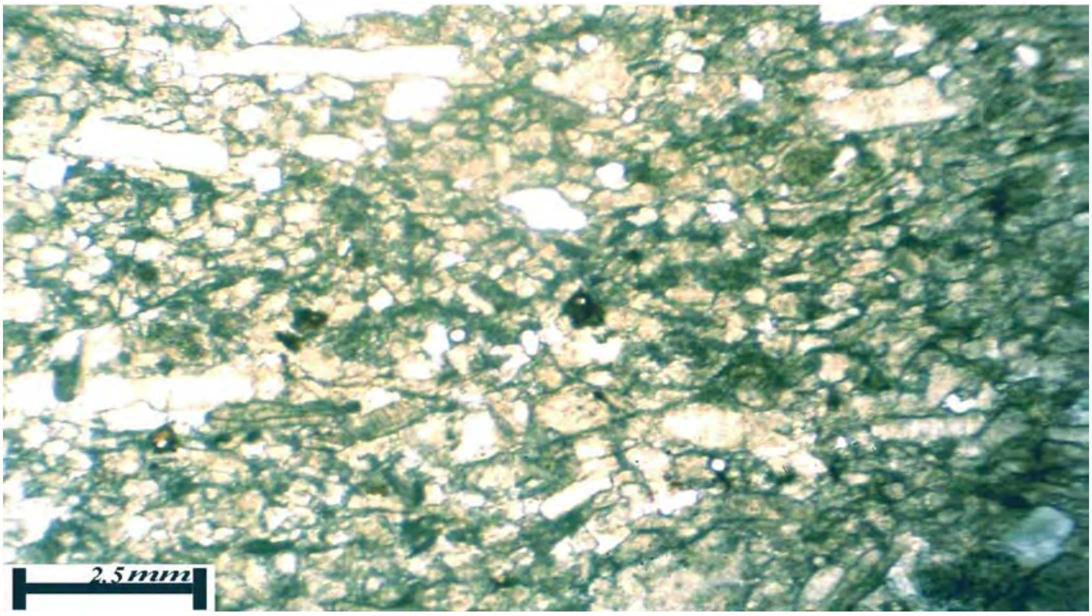


Fig. 6.2.2. Packstone of the Tarbur Formation
(Kuh-e Siah section)

6.2.3. The Grainstone of the Tarbur Formation

The grainstone facies consists mainly of the accumulation of bioclasts (rudist fragments, Foraminifera, etc.) and a low concentration of intraclasts and extraclasts with sparite cement, often well-preserved Foraminifera. It is observed only in the lower part of the Tarbur Formation in the Kuh-e Siah section, alternating with packstone and wackestone, rarely at the base of the lower and the upper parts of the Tarbur Formation in the Zarghan section, mainly in the upper part of the Kherameh-1 section and rarely in the Kherameh-2 section, and it is observed in a narrow layer in the upper part of the Tarbur Formation in this section (Fig. 6.2.3).There is weak sorting in the grainstone facies. Usually microfacies elements are well-rounded in this facies. These elements include transported rudist fragments, untransported rudist fragments, intraclasts, extraclasts, and foraminiferal debris. Microfacies elements are 2 mm to 20 mm in size.

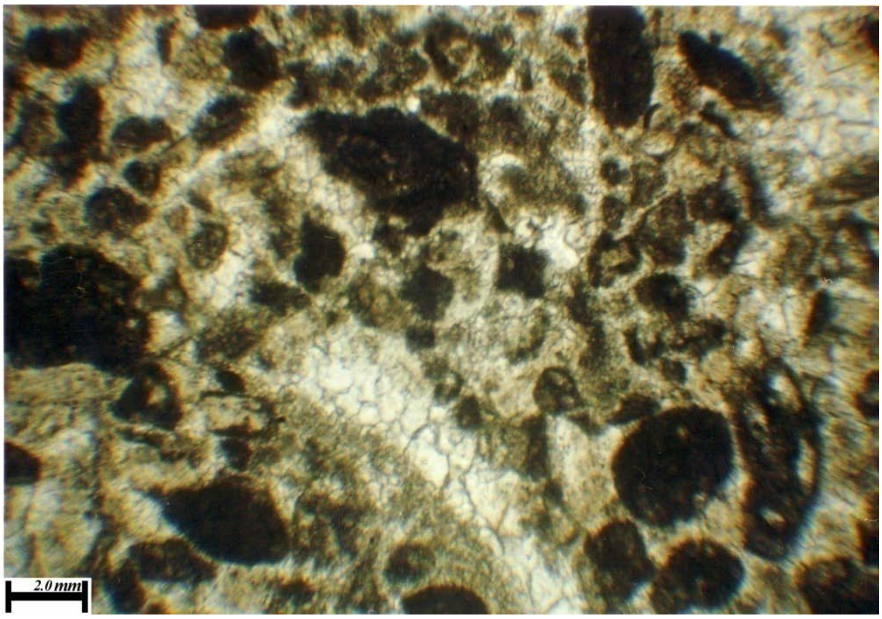


Fig. 6.2.3. Grainstone of the Tarbur Formation (Zarghan section)

6.2.4. The Boundstone of the Tarbur Formation

This consists of large rudist and coral debris. This facies is observed in the middle of the lower part of the Zarghan section, on the top of the upper part of the Kherameh-1 section, and at the base of the upper part of the Kherameh-2 section (Fig 6.2.4). Baffling is observed in the longitudinal section of coral solitary remains, but it is observed in coral remains as a colony. Actually, the coral remains are not common in the Tarbur microfacies of the studied sections. In addition, large rudists and rare colonies of corals are the main bioclast components that indicate boundstone facies.

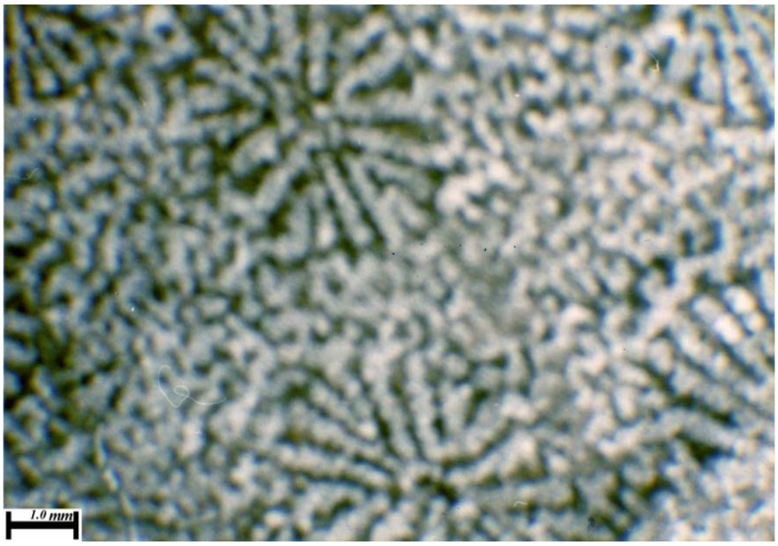


Fig. 6.2.4. Coral Colonies in the Tarbur Formation (Kherameh-2 section)

6.3. Distribution of Microfacies of the Tarbur Formation

Type microfacies that are observed in each of the stratigraphic sections are indicators of sedimentary conditions. Generally, variations of microfacies are observed in the lower part of all stratigraphic sections, but a change in microfacies is not observed in the upper part of the Tarbur Formation in the Kuh-e Siah section.

In addition, the most common type microfacies that is observed is wackestone and the rarest microfacies that is detected is boundstone. The maximum accumulation of wackestone is detected in the Zarghan and Kherameh-2 sections, and the minimum wackestone accumulation is observed in the Dariyan.

6.3.1. Distribution of Microfacies of the Tarbur Formation in the Kuh-e Siah section

The lower part: The amount of change in the lithostratigraphic characteristics is larger than that of the other stratigraphic sections.

This part includes alternately grainstone, packstone, and wackestone. It terminates in wackestone.

The upper part: This part is entirely composed of wackestone. The percentage of microfacies elements, which are bioclasts, intraclasts and extraclasts, is less than in the lower part of the Tarbur Formation.

Diversity of microfacies occurs in the lower part. Therefore, although each microfacies has been formed in a distinct sedimentary environment, sea level changes have altered the reef structure. This alteration belongs to Late Maestrichtian time. In later times, the wackestone sedimentary environment prevailed in some part of the lower, and the entire of the upper part of the Tarbur Formation. These sections were deposited in the uppermost of Late Maestrichtian to Lower Paleocene times (Fig.6.3.1). Variations of microfacies in the lower part indicate a change of sedimentary environment. Since the wackestones that alternate with packstones and grainstones are observed without any algal remains, these wackestones are related to the fore reef wackestones. But as the terminal wackestones of the lower part and the whole of the upper part consist of algal remains, it can be concluded that these wackestones are related to the back reef only.

6.3.2. Distribution of Microfacies of the Tarbur Formation in the Zarghan section

The lower part: Lithologically, this part is composed of medium-bedded limestone, which consists of packstone and grainstone. The deposition is a thin boundstone in the middle.

The upper part: The lithologic character is massive limestone, which mainly includes wackestone in the base and packstone at the top. The percentage of bioclasts in the upper part is less than that of the lower part.

As in the Kuh-e Siah section, the base to middle of the lower part of the Zarghan section indicates changes in microfacies, which relate tothe Campanian age. The boundary of the Campanian-Maestrichtian does not show any change in the microfacies.There is only change in microfacies in the Late Maestrichtian (Fig.6.3.2). In addition, wackestone facies is the main microfacies observed in the Zarghan section.

6.3.3. Distribution of Microfacies of the Tarbur Formation in Kherameh-1 section

The lower part: The lithologic character is medium to thick-bedded limestone, which is mainly composed of wackestone.

The upper part: This is massive limestone, which alternately consists of wackestone and grainstone. The upper part terminates in packstone.

The percentage of microfacies elements in this part is not very different from the lower part.

Variations of microfacies started in the boundary of the Campanian-Maestrichtian and in the entire stage of the Maestrichtian in this section. The main part of the Campanian has no diversity in microfacies in this section (Fig.6.3.3). Changing of the microfacies started in the Late Campanian and can be observed during the Maestrichtian. The main microfacies observed is grainstone.

6.3.4. Distribution of Microfacies of the Tarbur Formation in the Kherameh-2 section

The lower part: The lithologic character is medium-bedded limestone, which mainly includes wackestone with a narrow band of packstone.

The upper part: The lithologic character is massive limestone, which consists alternately of wackestone, packstone, grainstone, and boundstone. This section terminates in wackestone.

Finally, changes in microfacies are observed continuously in the Maestrichtian in this section (Fig. 6.3.4). Maestrichtian sediments show variation in microfacies in all stratigraphic sections. In fact, the main microfacies of this stratigraphic section is wackestone, but changes of microfacies in both the lower and the upper part indicate changes in depositional conditions. Since variations of microfacies are detected in both parts of the Tarbur Formation, a change in sea level is a distinct phenomenon that is observed during the Maestrichtian period.

6.3.5. Distribution of Microfacies of the Tarbur Formation in the Kuh-e Khanehkat section

Wackestone alternates with packstone and grainstone in the lower part of the Tarbur Formation in the Kuh-e Khanehkat section (Fig. 6.3.5). Wackestone is detected in the boundary between the Campanian-Maestrichtian, and the Cretaceous-Tertiary. In addition, grainstone is mainly observed in the lower part. Packstone is seldom detected in this stratigraphic section. Variations of microfacies in the upper part include wackestone that alternates with packstone, grainstone and boundstone.

In addition, the main microfacies of the upper part is wackestone. Although boundstones are detected in the upper part, they are not so important in this portion. They are only observed in the middle of the upper part.

6.3.6. Distribution of Microfacies of the Tarbur Formation inKuh-e Chehelcheshmeh section

The first microfacies of the Tarbur Formation in Kuh-e Chehelcheshmeh is wackestone (Fig. 6.3.6). In fact, wackestone facies alternates with grainstone and packstone facies.

Packstones and grainstones are widely distributed in the lower part of the Tarbur Formation in this section.

Alternation of packstone and grainstone is detected in the boundary of the Campanian-Maestrichtian. Variations of microfacies are observed during the Maestrichtian, but there is no change in microfacies in the Cretaceous-Tertiary. The main microfacies detected in the upper Tarbur Formation is wackestone. Therefore, the lower part of the Tarbur Formation is affected by wave base influence. In fact, the lower Tarbur Formation microfacies indicates higher kinetic wave energy during sedimentation than the upper Tarbur microfacies in this section. In view of the distribution of microfacies, Kuh-e Chehelcheshmeh is similar to the Kuh-e Siah section. Wackestone facies terminates the microfacies of this stratigraphic section.

6.3.7. Distribution of Microfacies of the Tarbur Formation in the East of Dariyan section

The type microfacies of the East of Dariyan section is wackestone facies in the lowermost part of this stratigraphic section (Fig. 6.3.7). But the main microfacies of this section is packstone, which alternates mainly with grainstone microfacies. In fact, wackestone is more observable in the lower part than in the upper part. However, packstone is the main microfacies detected in both the lower and the upper part, and the section also terminates in packstone.

Like the other packstones in the studied sections, it includes mainly bioclasts, extraclasts, and intraclasts. After packstone, the most important microfacies is grainstone. It has been detected in both the lower and the upper part. It is observed in the lower to the upper part boundary. Since identificatian of microfossils indicates that the age of the Tarbur Formation is Maestrichtian, all variations of the microfacies relate to the Maestrichtian.

Because of different conditions of grainstone and packstone deposition, it is an obvious conclusion that variations of microfacies are the result of higher fluctuation of the sea level.

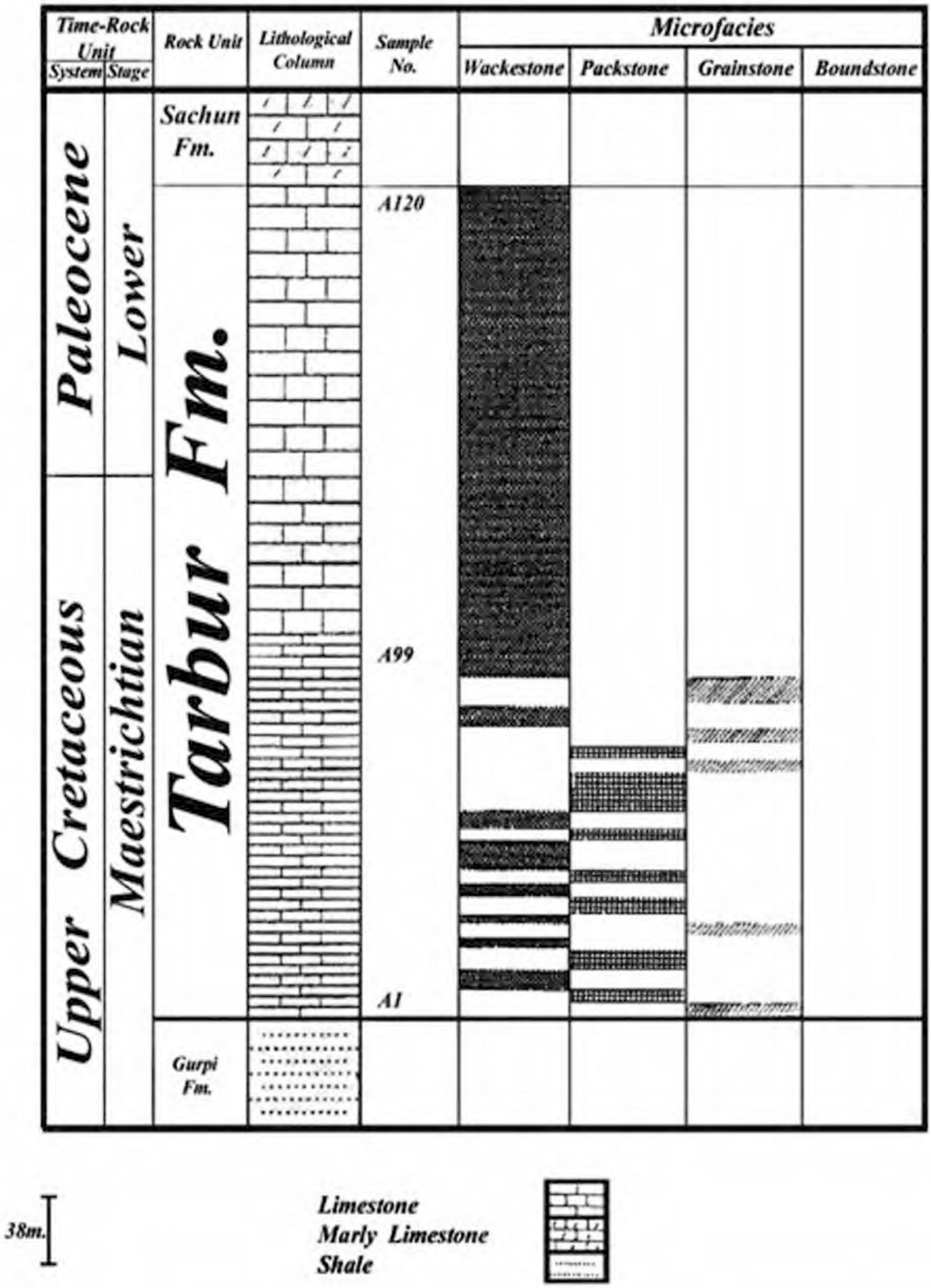


Fig.6.3.1. Distribution of microfacies in Kuh-E Siah stratigraphic section

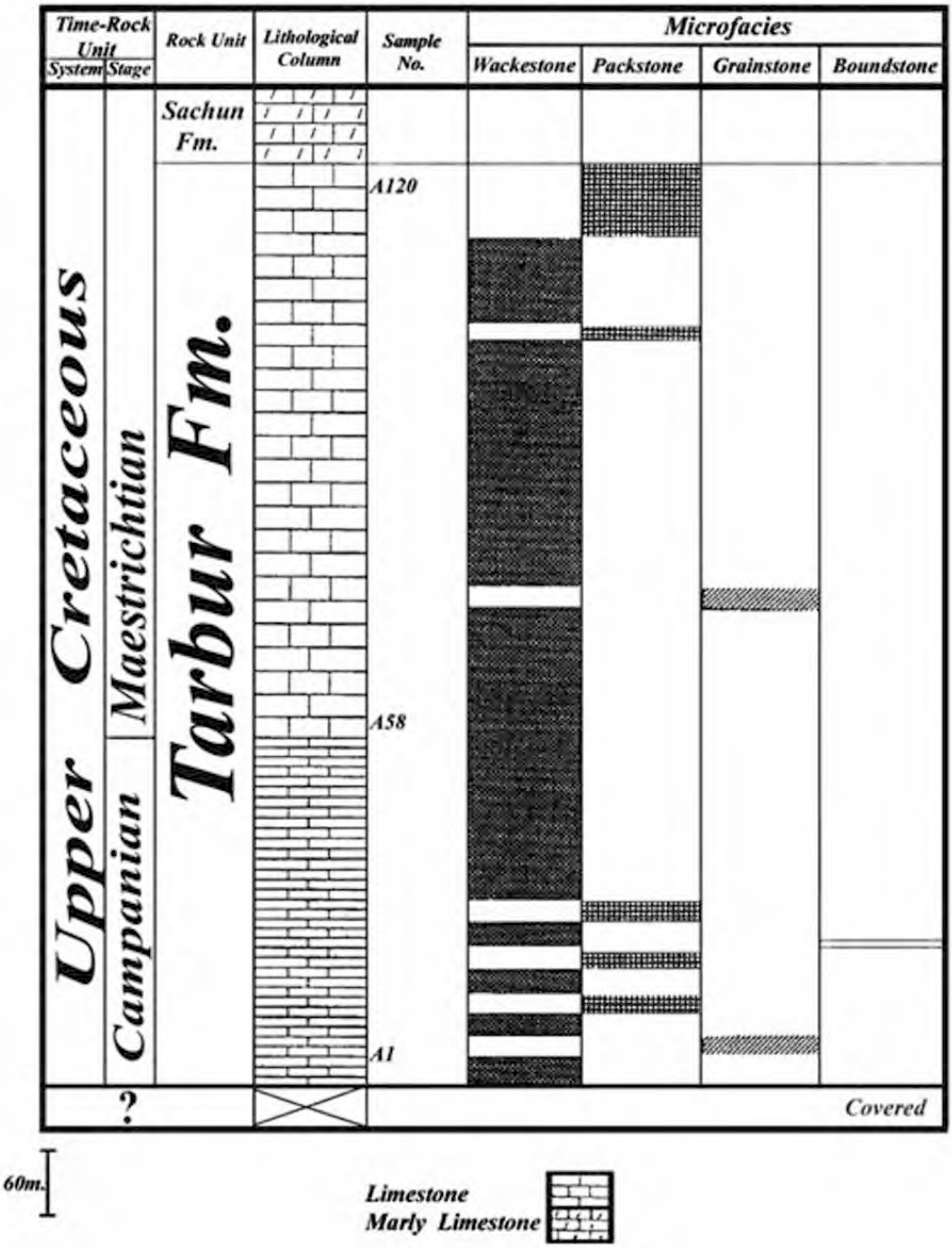


Fig.6.3.2. Distribution of microfacies in Zarghan stratigraphic section

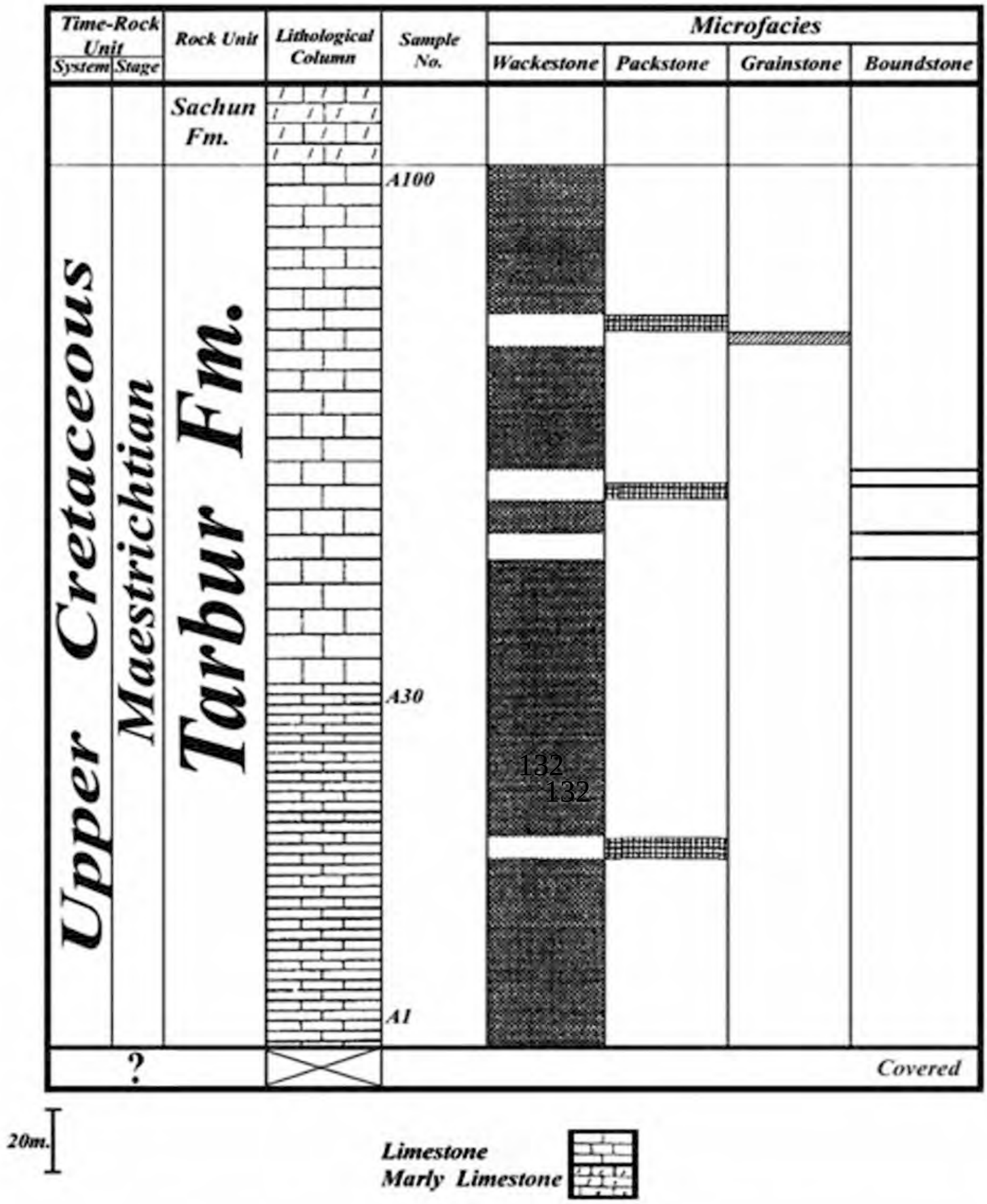


Fig.6.3.3. Distribution of microfacies in Kherameh-2 stratigraphic section

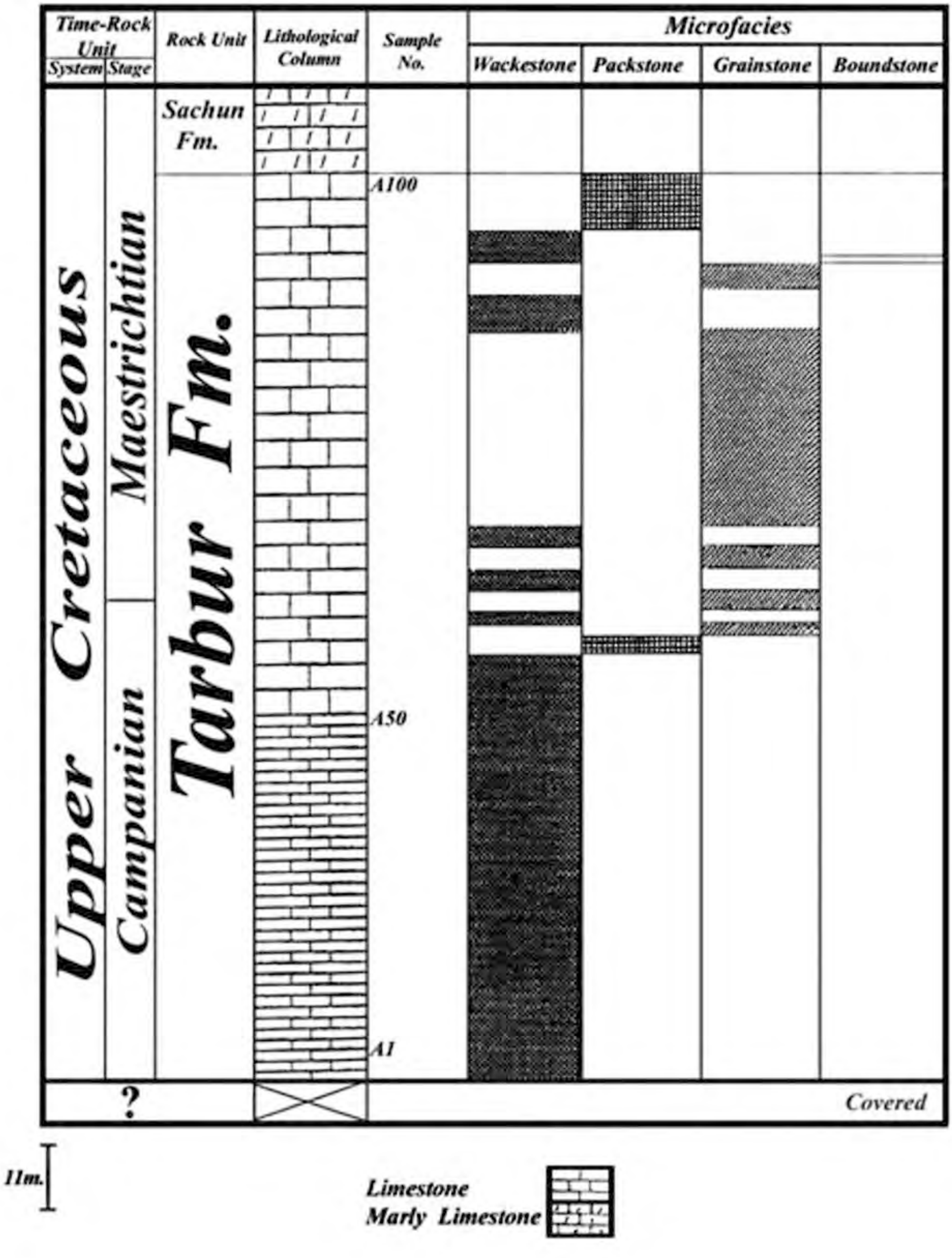


Fig.6.3.4. Distribution of microfacies in Kherameh-1 stratigraphic section

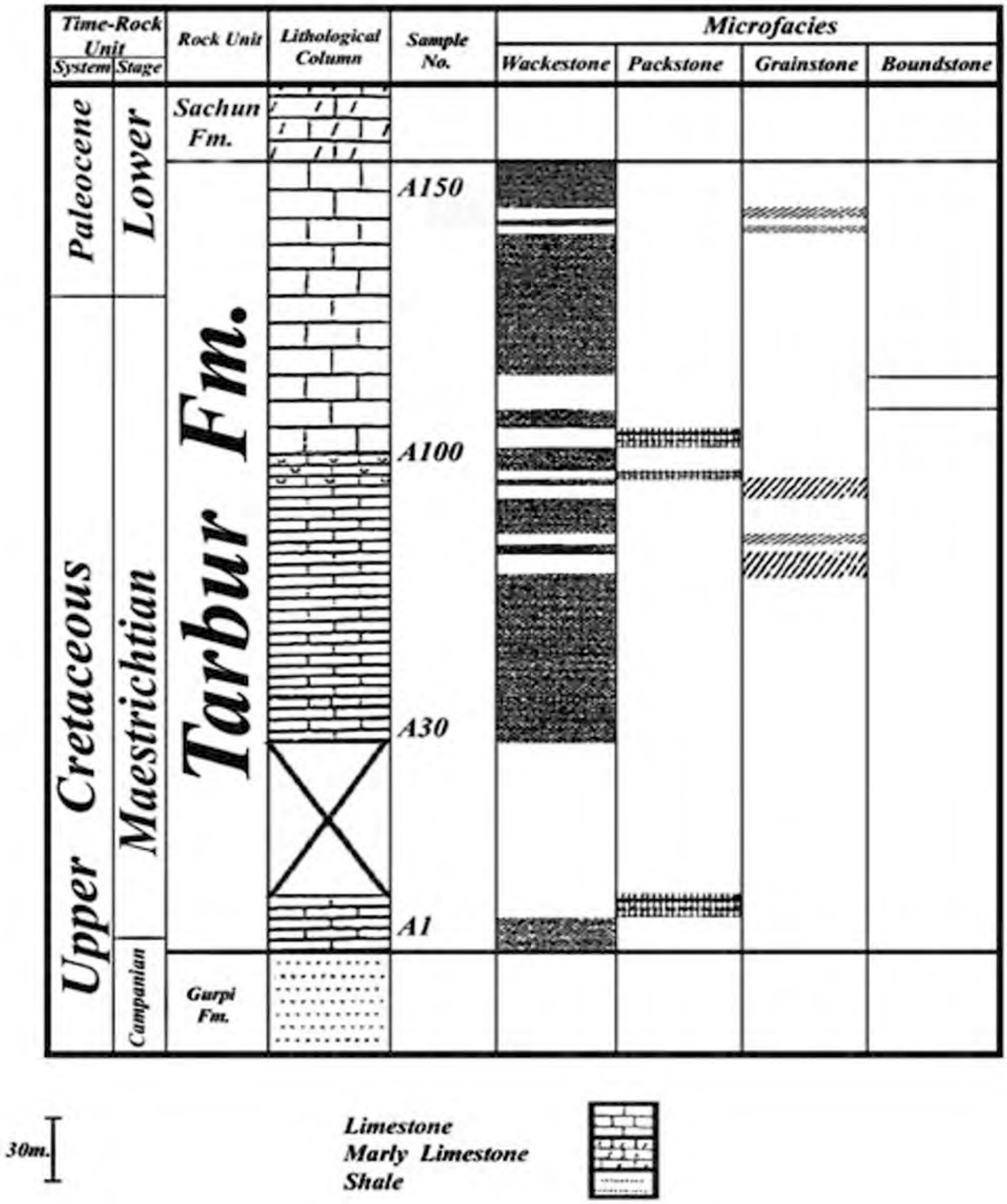


Fig.6.3.5. Distribution of microfacies in Kuh-E Khanehkat stratigraphic section

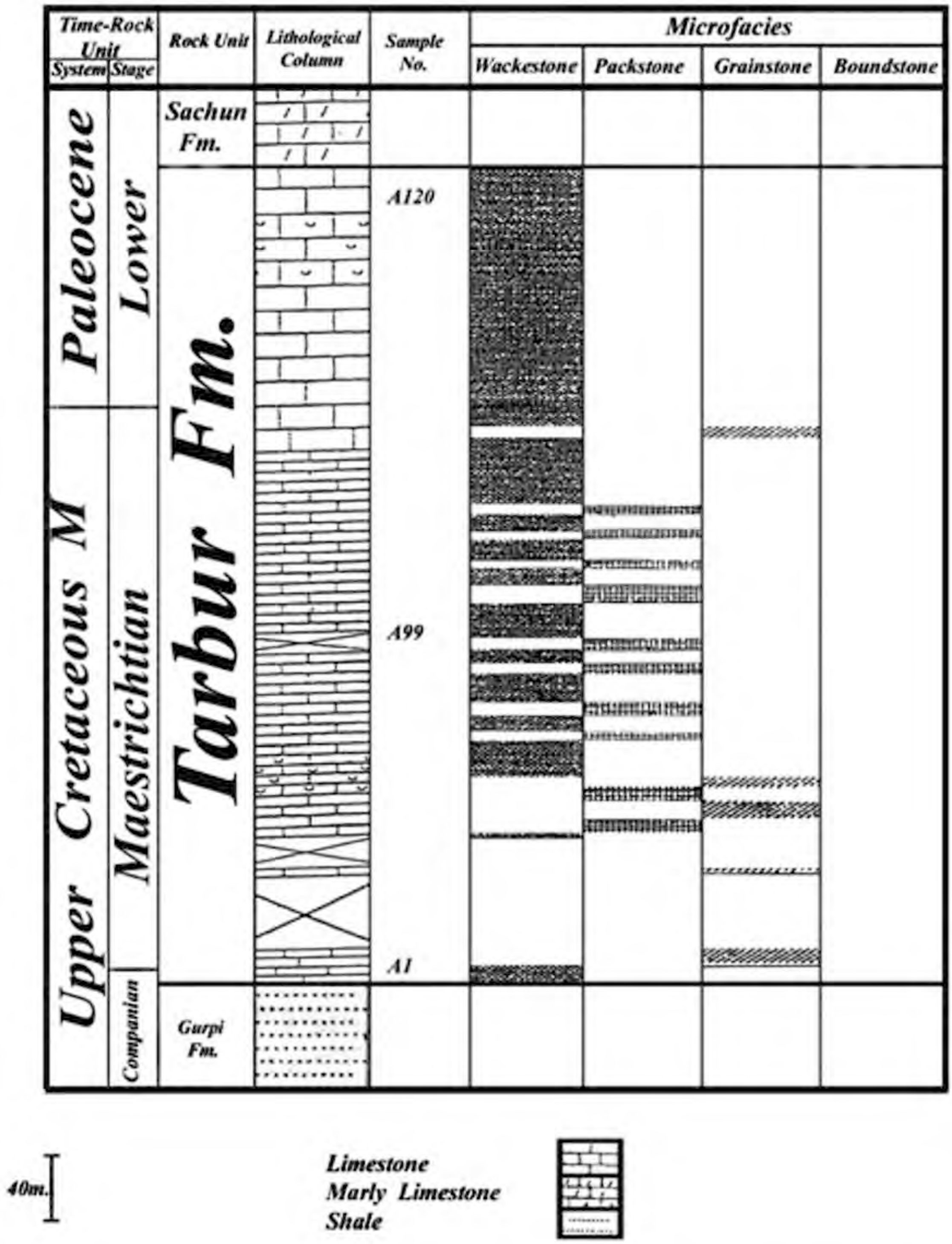


Fig.6.3.6. Distribution of microfacies in Kuh-E Chehelcheshmeh stratigraphic section

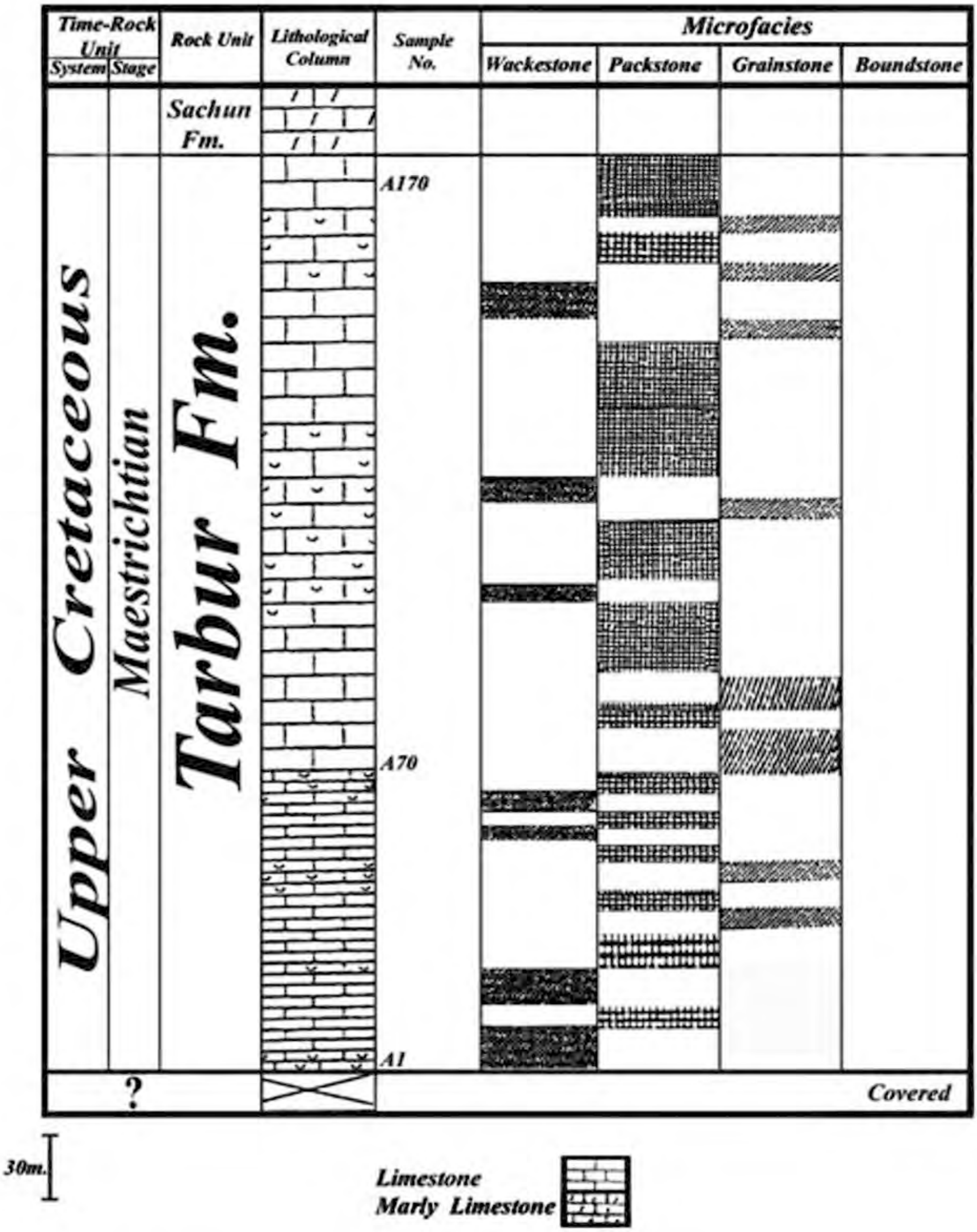


Fig.6.3.7. Distribution of microfacies in East of Dariyan stratigraphic section

6.3.8. Comparison of Identified Microfacies of the Tarbur with Standard Microfacies Types (SMF)

According to FLUEGEL (2004), facies of carbonate rocks is different from stratigraphic relationships of rock bodies, sedimentary structure, and litho-and biofacies. For the classification of microfacies, the term Standard Microfacies Types (SMF) is used. Actually, Standard Microfacies is a criterion of microfacies and a sedimentary environment, particularly in reef rock bodies. Since the Tarbur Formation is a reef rock unit, thedetermination of SMF is a way to describe the identification of the sedimentary environment of the Tarbur Formation facies. Microfacies investigations of the Tarbur Formation indicate four Standard Microfacies in all the studied stratigraphic sections, namely: SMF 5, SMF 6, SMF 7, and SMF 8. The succession of these Standard Microfacies Types depends on tectonic activities and morphologic characteristics of the sedimentary basin. Actually, because of different tectonic movements of the Upper Cretaceous and Lower Paleocene in the imbricated zone of the Zagros, the Standard Microfacies Types of each stratigraphic section are not comparable to other successions of Standard Microfacies Types of stratigraphic sections of the Tarbur Formation in this study.

Based on FLUEGEL (2004), SMF 5 is named allochthonous bioclastic grainstone, rudstone, packstone and floatstone or breccia. In this Standard Microfacies Type, densely packed whole fossils and fossil fragments are detected. Grainstone of the Tarbur Formation consists of foraminiferal debris and rudist fragments (Fig. 6.3.8a), which is comparable to Standard Microfacies Type 5.

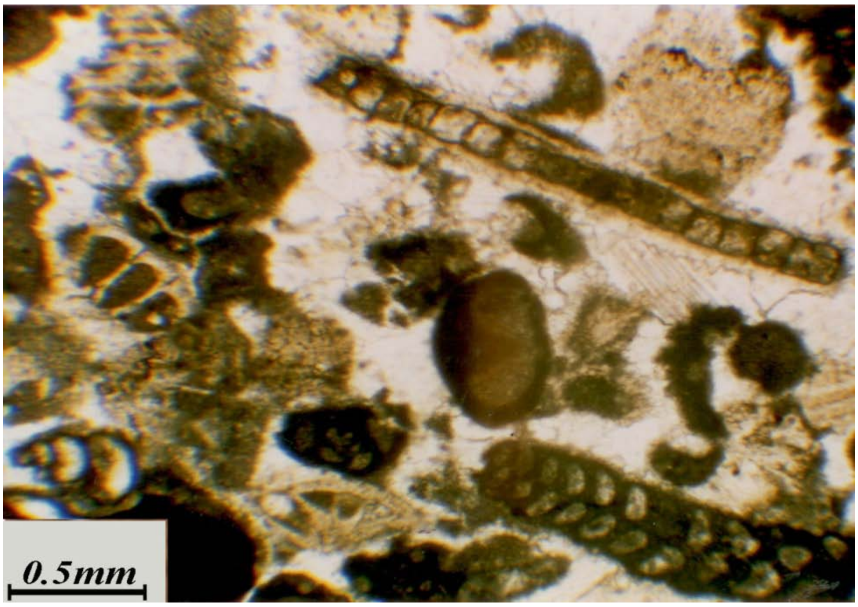


Fig.6.3.8a: SMF 5, which is grainstone with organic grains (foraminifers and rudist fragments) inthe Tarbur Formation

Generally, the foraminifers are transported from other parts of the Tarbur reef and some of them are autochthonous, but rudist fragments are usually transported.

Packstone of SMF 5 is rarely detected, whereas grainstone is mainly dominant. Microfacies elements of SMF 5 packstone are composed of rudist fragments and rarely of foraminifers with calcareous hyaline wall (Orbitoides taxa and Rotaliids). Rudist fragments are usually transported and between 0.3 to 0.5 mm. in size (Fig.6.3.8b). SMF 5 is deposited in a fore reef position and reef slope or back reef setting. Separation of these sedimentary environments is reflected in the dasycladaceae, which are generally observed in the upper part of all stratigraphic sections of the Tarbur Formation.

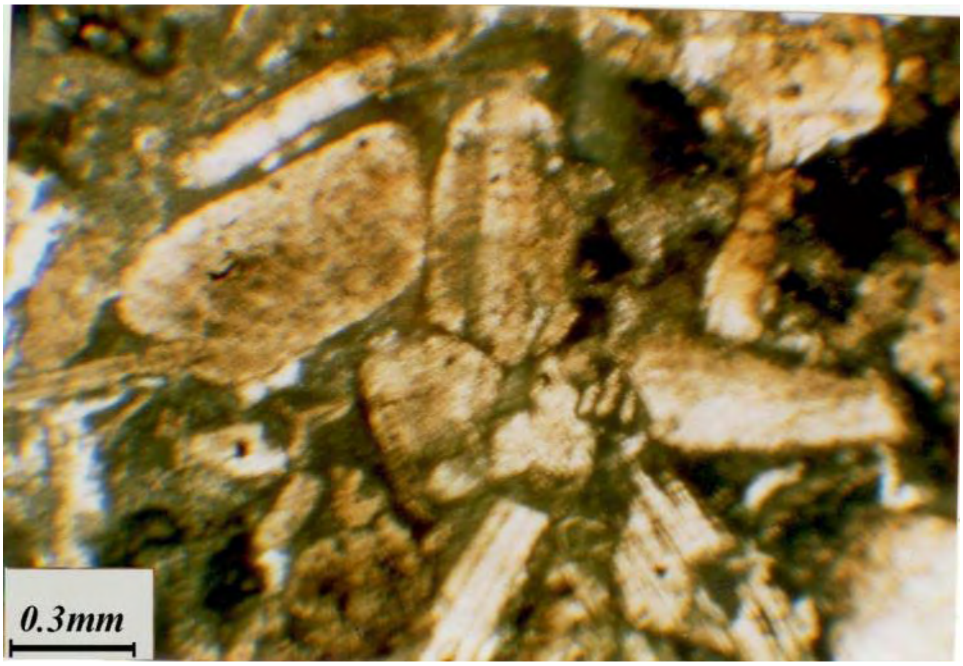


Fig.6.3.8b: Packstone of SMF 5 with rudist fragments which are not densely grained

Based on FLUEGEL (2004), SMF 6 is mainly composed of coarse gravels of biogenic material which is generally derived from reef tops or flanks and deposited in a high energy slope setting. Standard Microfacies Type 6 has been identified in the studied stratigraphic sections. This SMF has been detected in both the upper and lower parts of Zarghan, Kherameh-1, Kherameh-2, Dariyan, Kuh-e Khanehkat, and Kuh-e Chehelcheshmeh and the lower part of Kuh-e Siah. The main biogenic component of SMF 6 in the studied sections is rudist fragments (Fig. 6.3.9c). These biogenic gravels are usually angular to sub-angular and 1-3mm in size. Foraminifers are not common in this Standard Microfacies Type. In addition, highly dense rudist fragments with low matrix content are characteristic of the SMF 6 in the studied stratigraphic sections of the Tarbur Formation.

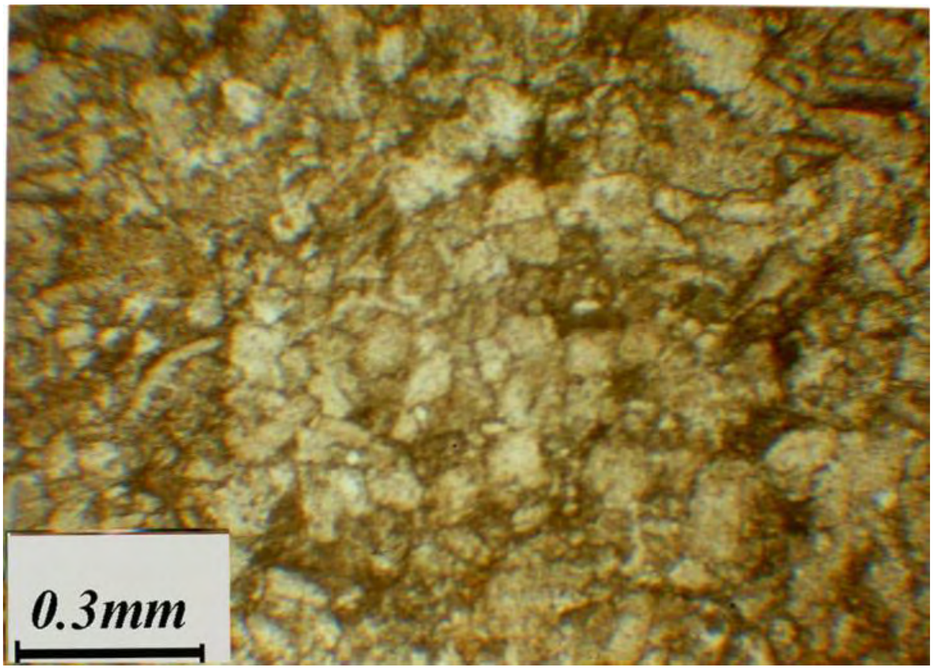


Fig.6.3.8c. Densely packed reef rudstone (SMF 6) containing mainly angular to sub-angular rudist fragmentsmaking uppackstone

Another Standard Microfacies Type is SMF7, which is named organic boundstone. Boundstone is always characterized by in-situ organic build-ups. They appear as framestone (Figs. 5.4.2, 5.6, and 6.2.4), bafflestones, and bindstones. SMF 6 is not common between Standard Microfacies Types of the TarburFormation stratigraphic sections. Framestone and bafflestone are dominant as boundstone facies in the studied stratigraphic sections. Asusual rudists (particularly Hippurites) and corals are the main reef builders ofthe Tarbur Formation. Whereas rudists appear dominant, corals are less frequent than rudists in the Tarbur Formation. However, coralsare observed in some stratigraphic sections in both patterns of framestone (Fig. 6.2.4) and bafflestone (Fig. 6.3.8d). They are detected inthe upper part of Kherameh-1, Kherameh-2 as bafflestone and Kuh-e Khanehkat as framestone.

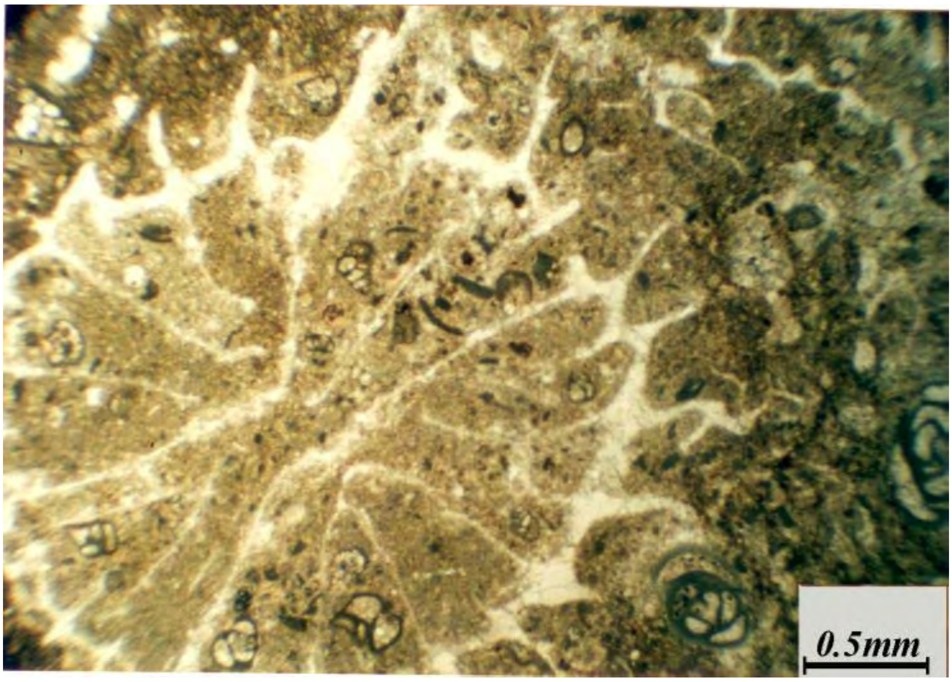


Fig.6.3.8d. SMF 7 is shown in this figure with a baffle pattern of organic boundstone. Solitary corals appear as bafflestone in the Tarbur Formation, but rarely appear in the upper part of Kherameh-2

Standard Microfacies Type 8 is a more common SMF than other Standard Microfacies Types in the Tarbur Formation. In this facies, predominantly sessile organisms rooted in micrite and some mobile organisms are found. In addition, two types of wackestones are identified, reflecting the sedimentary environments which are recognizable in the Tarbur Formation exposures. Usually dasycladaceae, foraminifers, gastropods and rudists with micritic matrix establish this SMF in the Tarbur Formation. Often, foraminifers with imperforate and agglutinate walls, which are associated with salpingoporella, are common in the Standard Microfacies Type 8 (Fig.6.3.8e). Fossil remains are not reworked, but there may be some few millimeters of crushed rudist fragments.

Because dasycladaceae with imperforate and agglutinate wall foraminifers with micritic matrix are predominant, this SMF is related to shelf lagoon deposition.

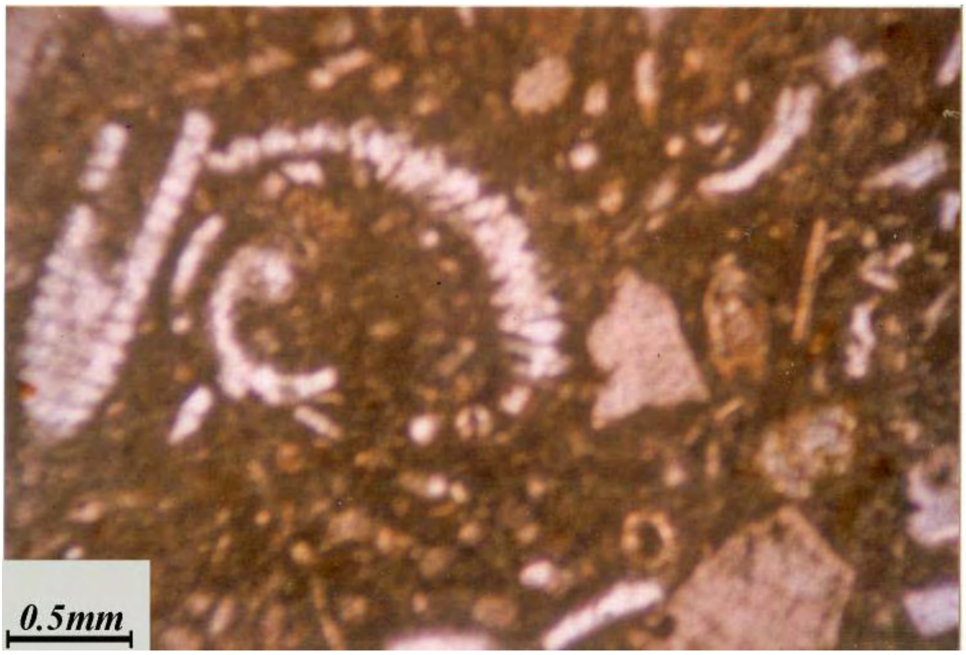


Fig.6.3.8e. SMF 8 of the Tarbur Formation with dasycladaceae which shows shelf lagoon deposition

Some wackestone of the Tarbur Formation is composed of foraminifers, particularly Orbitoid andRotaliid. Imperforate foraminifers and rudist debris without dasycladaceae which is assigned to the low-energy environments below wave base are not dominant. Orbitoides taxa are usually uncrushed and well preserved, whereas rudist fragments are transported. Rudist fragments are different in size, often less than a few millimeters in diameter.This wackestone is generally dectected in the lower part of the stratigraphic sections of the Tarbur Formation that is reflected onthe outer and mid-setting (Figs.6.3.8f,g). However, both types of SMF 8 are recognizable in all the studied stratigraphic sections.

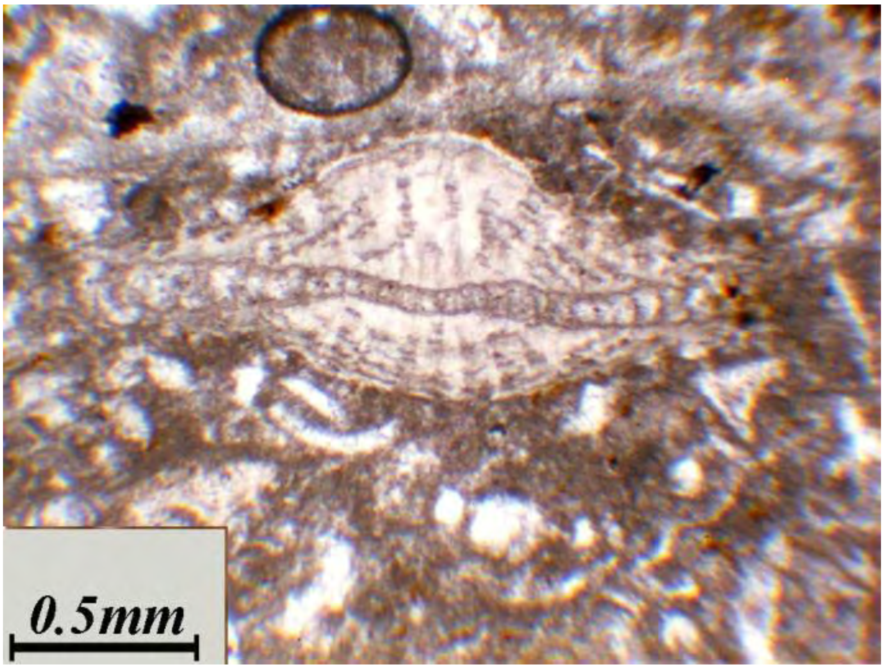


Fig.6.3.8f. Wackestone of SMF 8 which is deposited in the mid ramp, below the fair-weather wave base

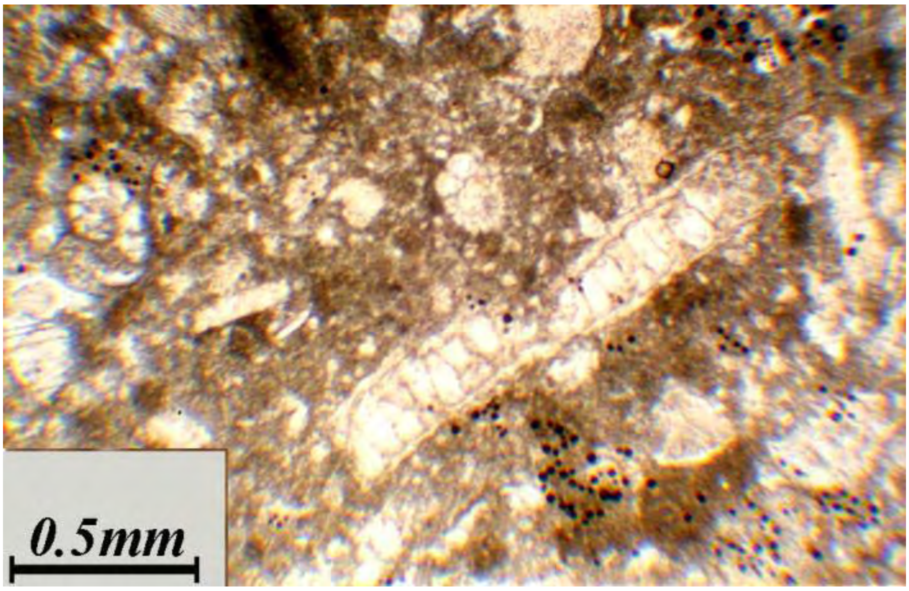


Fig.6.3.8g.SMF 8 consisting of Orbitoides concavatus, and Rotaliids with micritic matrix, which is assigned to the lower part of Kuh-e Khanehkat.

6.4. The Percentage of Microfacies Elements of the Tarbur Formation

In order to identify sedimentary conditions, statistical estimation of microfacies elements is used as a method. Variations of the percentage of microfacies elements are an indicator determining agitation in the sedimentary environment. Since bioclasts are more significant in the Tarbur microfacies, variations of the bioclast percentage could be indicators of the growth of organisms during sedimentation.

It should be noted that the distribution of microfacies elements is one of the main ecological factors of the distribution of Foraminifera, especially in reef depositional systems.

6.4.1. The Percentage of Microfacies Elements of the Tarbur Formation in the Kuh-e Siah section

Rudist bioclasts are the main microfacies component at the base of theTarbur Formation in the Kuh-e Siah section. The percentage of these bioclasts is about 50% of the total bioclasts, which are continuously in the packstone and the grainstone facies. These bioclasts gradually decrease in the upper part of the Tarbur Formation microfacies elements. The accumulation of rudist material (back reef wackestone) is shown in Fig. 6.4.1. One of the other main microfacies elements is extraclasts. They indicate agitation of the sedimentary basin. The maximum percentage of these extraclasts is about 25% of the total of microfacies elements (in the middle of the lower part of the Tarbur Formation).

Also, intraclasts are distributed in the entire Kuh-e Siah section. Usually intraclast variations are similar to the bioclast variations.

In summary, the increase of extraclasts is a function of the turbidity of the sedimentary basin; therefore, the lower part of the Tarbur Formation in this section is more agitated than the upper part of the Tarbur Formation.

6.4.2. The Percentage of Microfacies Elements of the Tarbur Formation in the Zarghan section

Rudist bioclasts are fewer than 50% in the entire Zarghan section, but in the portion of the lower part, they increase to over 90%, which is boundstone facies.

In summary, the amount of bioclasts is about 50% at the top of the upper part of the Tarbur Formation in the Zarghan section (Fig. 6.4.2).

Diversity of other bioclasts (corals, foraminifers, gastropods and algae) is less than the rudist debris; however, Foraminifera make up the most bioclastic components in the Tarbur microfacies in this section.

The maximum percentage of extraclasts is about 10%, especially in the lower part of the Tarbur Formation in this section. The percentage of intraclasts is somewhat continuous and about 15%.

6.4.3. The Percentage of Microfacies Elements of the Tarbur Formation in the Kherameh-1 section

The maximum percentage of bioclasts is about 25% in the Kherameh-1 section (Fig. 6.4.3). In the Zarghan and Kuh-e Siah sections, the bioclast diversity is greater than that of the other microfacies elements. Rudist bioclast is continuously the most frequent component, followed by Foraminifera and the other bioclasts. There is no evidence of the presence of calcareous algae in the Tarbur Formation, but gastropods are rarely observed. As in the other stratigraphic sections, extraclasts are observed more in the lower parts than in the upper part of the Tarbur Formation.The maximum percentage of extraclasts is about 20%; on the other hand, the extraclasts average about 8% in the upper part.

The maximum percentage of intraclasts is about 20% in the lower part, but the percentage of intraclast decreases continuously to about 8%. The bioclast curve is diverged to the intraclast curve, and it is noticed that the percentage of extraclasts in the lower part of the Tarbur Formation is lower than in the upper part in this section. Therefore, the lower part is more agitated than the upper part.

6.4.4. The Percentage of Microfacies Elements of the Tarbur Formation in the Kherameh-2 section

The variations of bioclasts are more frequent in distribution inthe Kherameh-2 section than inthe Kherameh-1 section. The maximum accumulation of bioclasts is about 70% at the base of the Tarbur Formation (Fig. 6.4.4).

The maximum percentage of extraclasts is about 25% and larger than in the upper part. Usually, the percentage of intraclasts is higher than that of the extraclasts. The percentage of intraclasts is higher in the upper part, but the intraclast curve is diverged to the bioclast and extraclast curve. It should be noted that the percentage of extraclasts and intraclasts in the lower part is higher than in the upper part in this stratigraphic section. Therefore, the lower part is more agitated than the upper part.

The bioclast curve is converged to the extraclast curve. Rudist fragments are the major bioclastic components, but Foraminifera, calcareous algae, and corals are less impressive than the microfacies in this section.

6.4.5. The Percentage of Microfacies Elements of the Tarbur Formation in the Kuh-e Khanehkat section

The maximum percentage of bioclasts is about 46% in the Kuh-e Khanehkat stratigraphic section (Fig. 6.4.5). The maximum of bioclasts is observed in the middle of the lower part, and the middle and top of the upper part of this section. This stratigraphic section has a low content of extraclasts, butthe percentage of extraclasts in the base of the section is somewhat higher than in the other parts. The variation of intraclast accumulation is relatively convergent to the bioclast curve. As with the bioclast curve, the maximum percentage of intraclasts is observed in the middle of the lower part of the Tarbur Formation in this section.

6.4.6. The Percentage of Microfacies Elements of the Tarbur Formation in the Kuh-e Chehelcheshmeh section

The maximum percentage of bioclast constituents of the Kuh-e Chehelcheshmeh stratigraphic section is observed at about 50% in the upper part (Fig. 6.4.6). However, generally the bioclast accumulation percentage is between 15% and 30% in the lower part, and 20% to 40% in the upper part. As in the other studied sections, the main bioclast component is rudist fragments. The maximum percentage of extraclasts is observed to be about 12% in the lower part of the Kuh-e Chehelcheshmeh section. In addition, the percentage of extraclasts in the lower part is higher than in the upper part. Generally, the average percentage of intraclasts is about 5% in both the lower and the upper part in this section.

6.4.7. The Percentage of Microfacies Elements of the Tarbur Formation in the Dariyan section

The maximum percentage of bioclasts of the Dariyan section is about 40% in the upper part of the Tarbur Formation (Fig. 6.4.7). Bioclast constituents increase in the rudist limestone in this stratigraphic section. As in the other studied sections, the accumulation of extraclasts in the lower part is higher than in the upper part. The maximum percentage of extraclasts is 10% in the lower part of this section. The intraclast curve is convergent to the bioclast curve.

6.4.8. Discussion of the Percentage of Microfacies Elements of the Tarbur Formation in the Studied Sections

Investigations of statistical studies of microfacies elements show that most microfacies components consist of bioclasts. The accumulation of bioclasts increases where rudists increase.The percentage of bioclasts is rarely over 50%, and normally it varies between 5% and 45%. Since these bioclasts include rudist fragments, foraminifers, algal remains, gastropods and rarely reworked foraminifers, it is logical that the Tarbur Formation is an organodetrital carbonate facies. Correspondence of bioclasts in different sections indicates that the minimum average of bioclasts, which is about 25%, relates to the Kherameh-1 section and the maximum average, which is about 45%, relates to the Zarghan section. Therefore, the development of organic constituents is generally more observable in the Zarghan stratigraphic section than in the Kherameh-1 section. The bioclast curve indicates that bioclast accumulation is mainly observable in the lower part of the Tarbur Formation in the Kuh-e Siah, Kherameh-1, Kuh-e Khanehkat, Kuh-e Chehelcheshmeh and Dariyan sections. But bioclast accumulation is detected in the upper part of the Zarghan and Kherameh-2 sections. In fact, the development of bioclasts is a function of the paleoecologic factor. It is clear that the development of bioclasts confirms the growth conditions of organisms during sedimentation. Although extraclasts are minor components of microfacies elements, and although they occur inlow quantities amongthe whole of the microfacies elements, they are an indicator of agitation of the sedimentary basin. The maximum percentage of extraclasts is detected as about 22% in the middle of the lower part of the Kuh-e Siah section. Statistical investigations of the extraclast percentage show that extraclast percentage variations are 0-22%. The extraclast percentage in the lower part of all the studied sections is higher than in the upper part. Therefore, the lower part of the Tarbur Formation shows greater disturbance than the upper part. Generally, extraclast variations are in relation to the bioclast variations. Since rudist fragments are the major bioclastic components and, in fact, sea wave activities are the main factor causing crushed rudists, it is clear that sea wave activities caused the transport of extraclasts in the Tarbur Formation.

The percentage of intraclasts is between the extraclast and bioclast percentages.Variations of intraclast percentage are about 0-25%. The maximum percentage of intraclasts is detected in the lower part of the Tarbur Formation in the Zarghan section. Investigations of intraclast percentage variations indicate that, as extraclasts accumulate, the percentage of intraclasts in the lower part is higher than in the upper part of all studied sections. Also, the intraclast curve is generally in relation to the bioclast curve, just as extraclasts and intraclast variations are a function of sea wave activities. In other words, the intraclast percentage can be an indicator of agitation in the sedimentary basin. Since the previous conclusion about extraclast percentages indicates a higher accumulation of extraclasts in the lower part, the intraclast percentage is further evidence to confirm disturbance of the lower part of the Tarbur Formation.

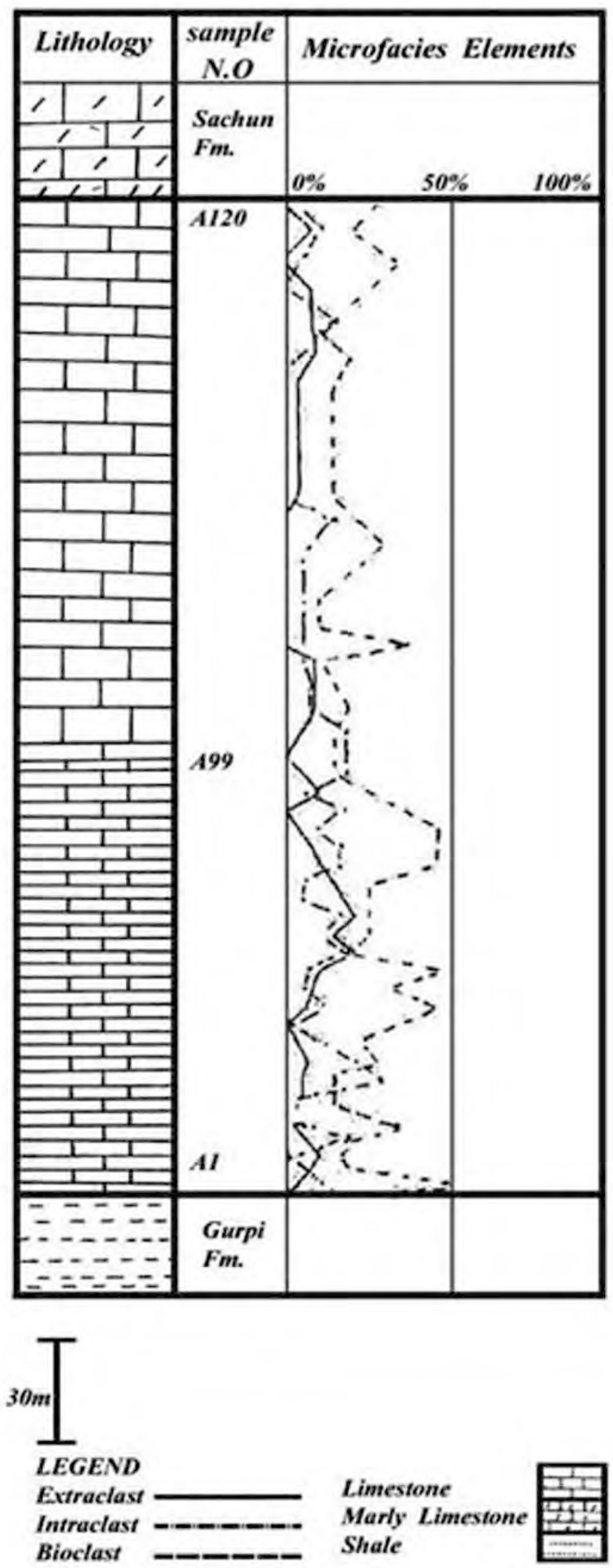


Fig.6.4.1. Distribution perecent of microfacies elements in Kuh-E Siah stratigraphic section

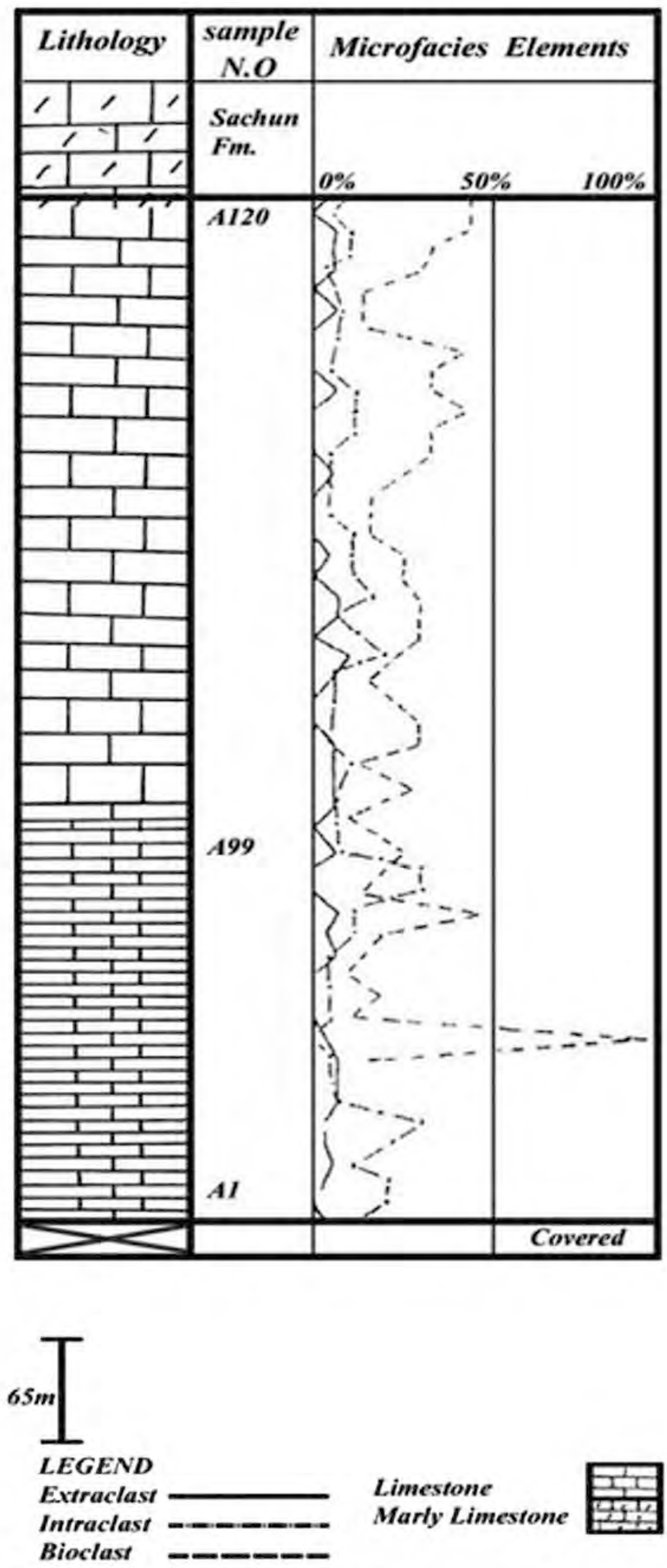


Fig.6.4.2. Distribution perecent of microfacies elements in Zarghan stratigraphic section

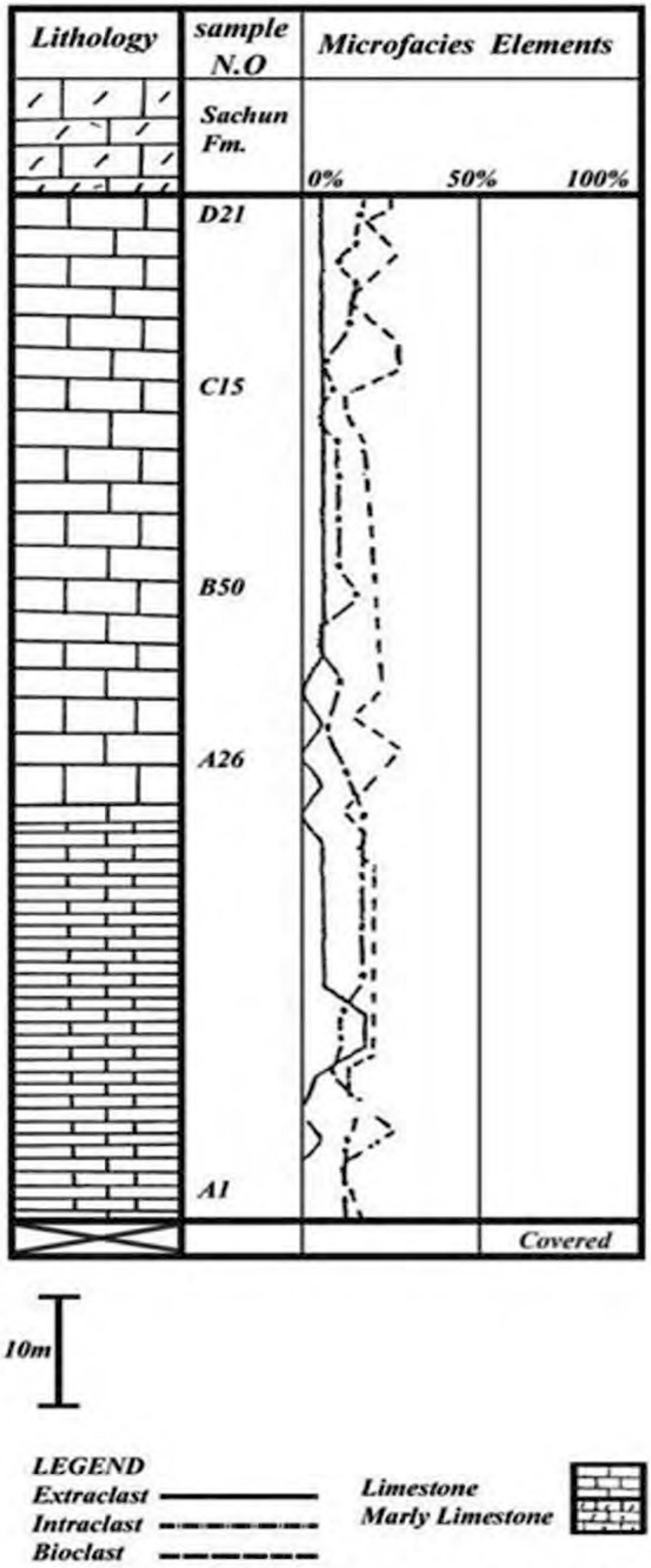


Fig.6.4.3. Distribution perecent of microfacies elements in Kherameh-1 stratigraphic section

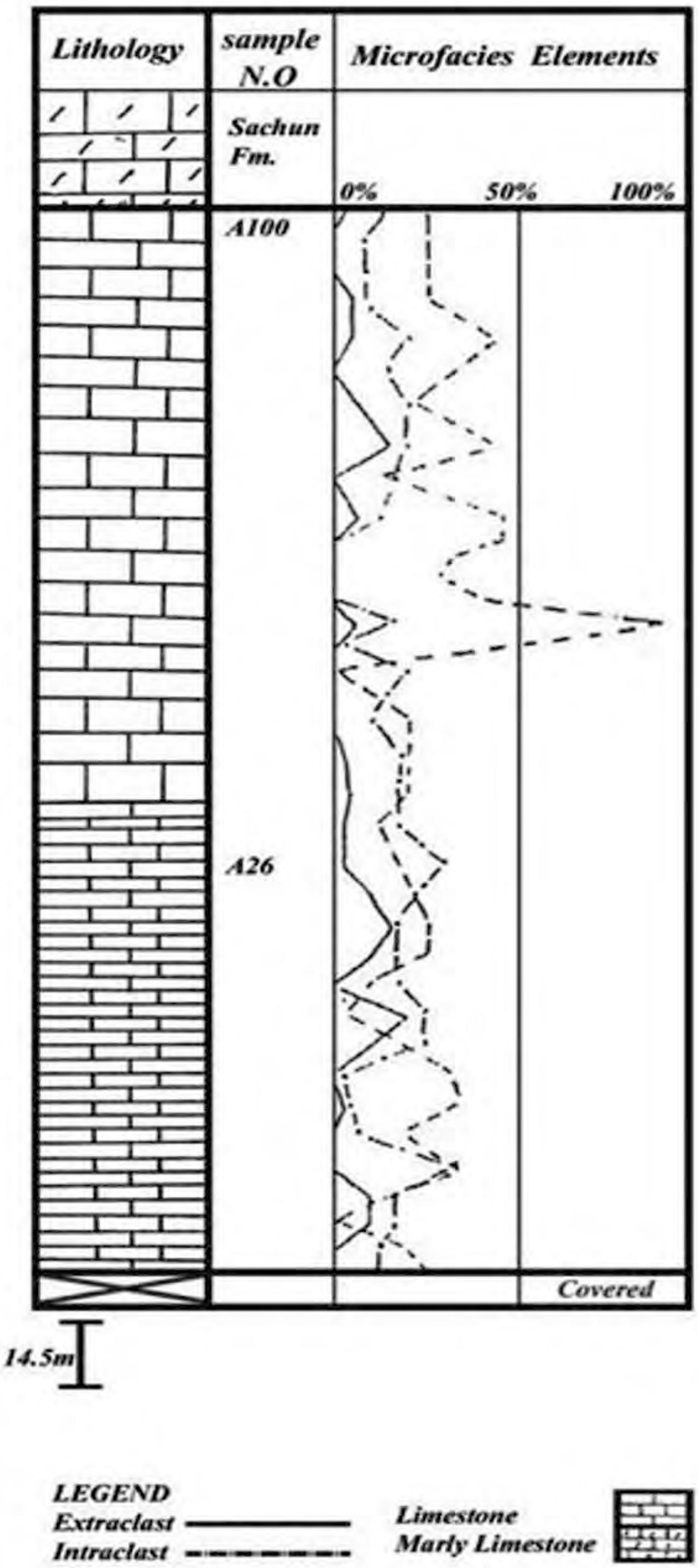


Fig.6.4.4.Distribution perecent of microfacies elements in Kherameh-2 stratigraphic section

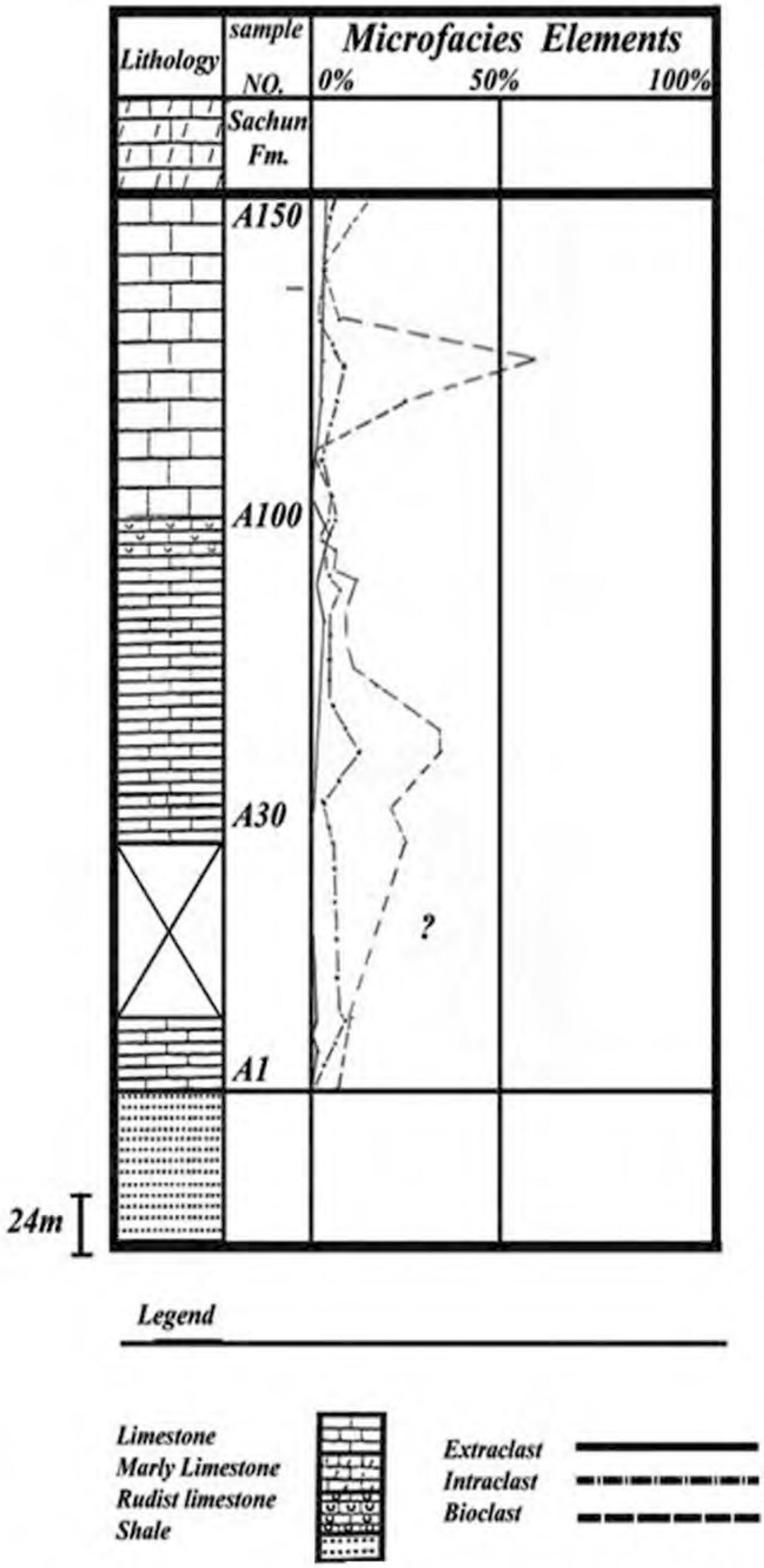


Fig.6.4.5. Distribution percent of microfacies elements in East of Kuh-E Khanehkat stratigraphic section

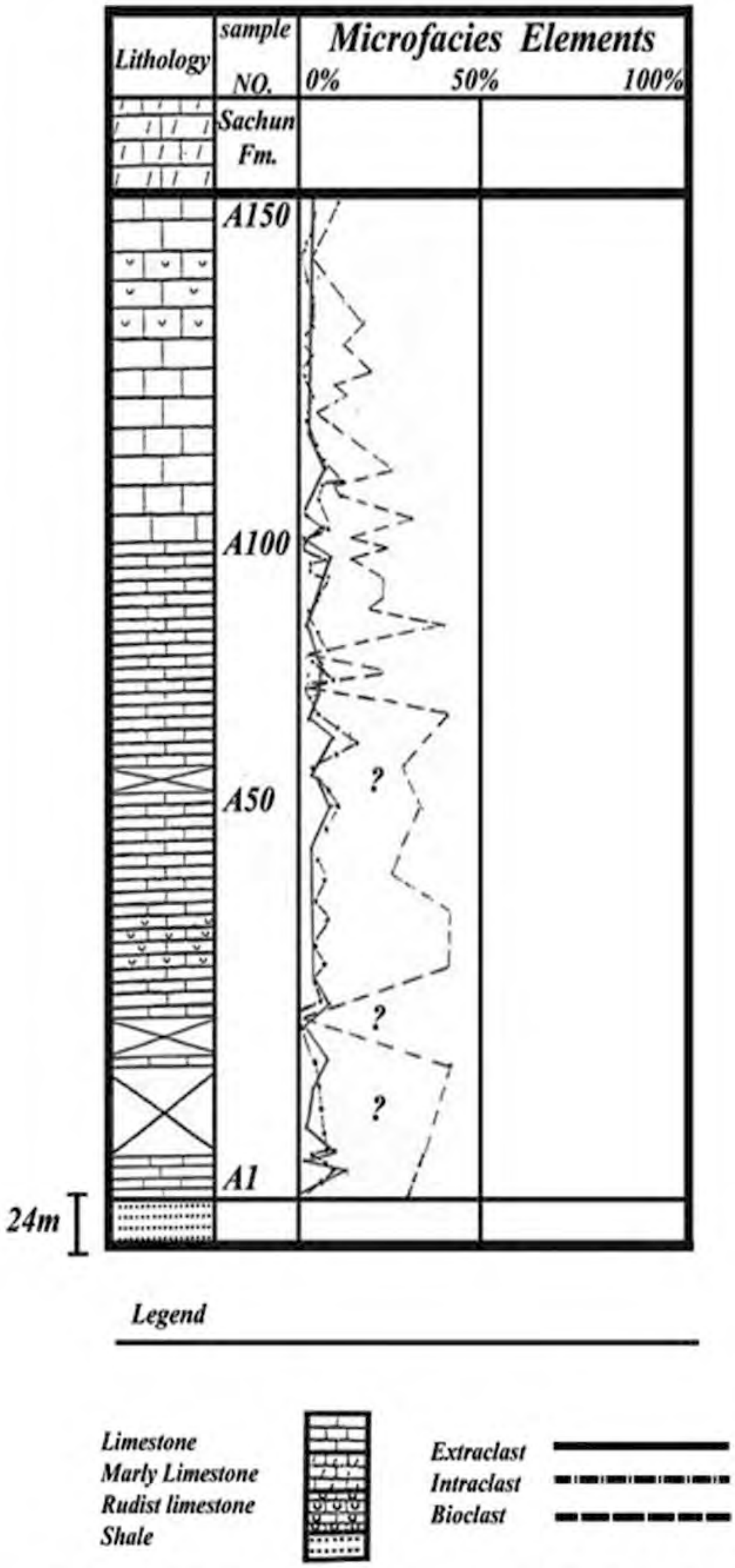


Fig.6.4.6 . Distribution percent of microfacies elements in East of Kuh-E Chehelcheshmeh stratigraphic section

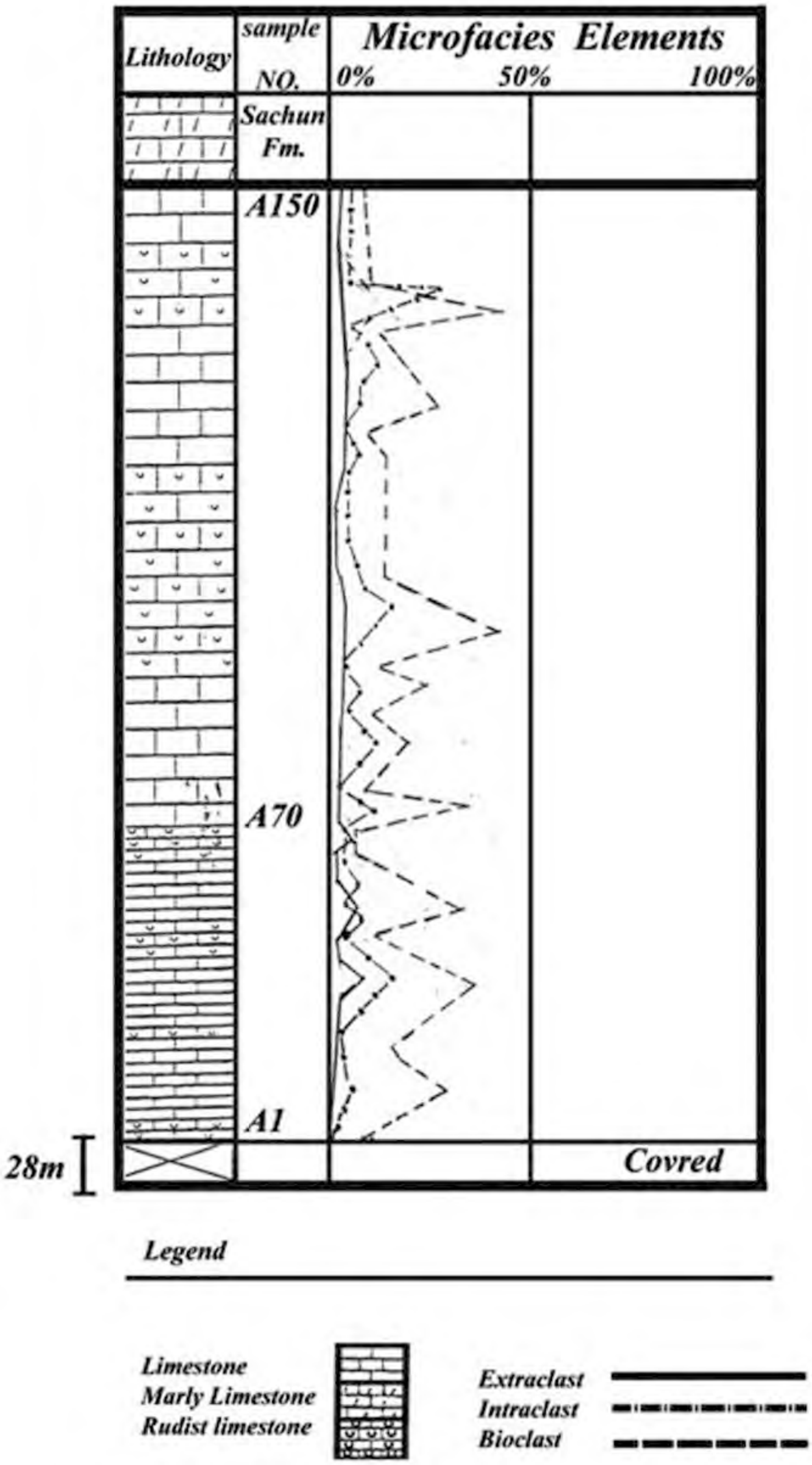


Fig.6.4.7. Distribution percent of microfacies elements in East of Dariyan stratigraphic section

6.5. Diagenetic Interpretation

Preservation of microfacies elements such as bioclasts, intraclasts and extraclasts proves that there is no evidence that secondary diagenetic process has occurred in the Tarbur Formation.

Total preservation of Foraminifera, corals, and rudist fragments without dolomitization is an indication of the primary diagenetic process. Also, preservation of the sedimentary structure, which is related to a reef builder, for example, baffling, and other evidence used as the indices of reef, indicate the primary diagenetic phenomenon.

Further proof of this conclusion is geochemical evidence. Since about 90% of each sample is composed of $CaCO_3$ as calcite, no diagenetic process occurred after primary diagenesis. It should be noted that the solution of $CaCO_3$ after the diagenetic process caused microporosity formation (Fig.6.5.1). The microporosity types include vug, fracture, cavern, and rarely moldic.

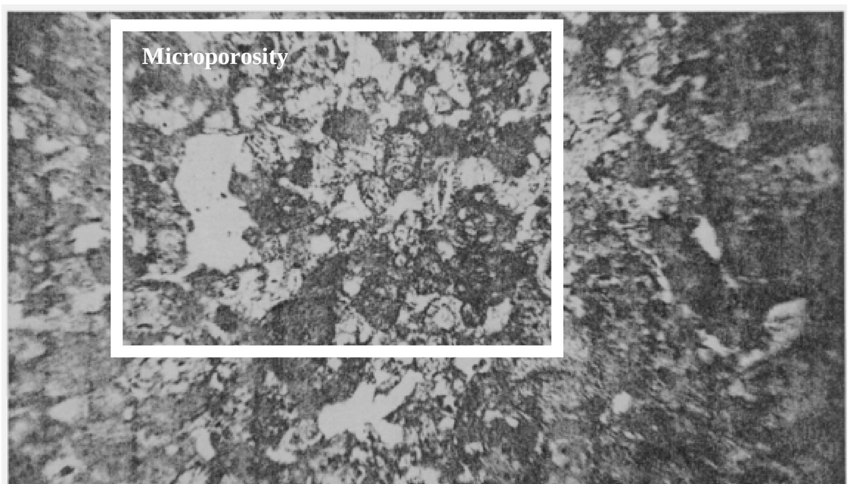


Fig. 6.5.1. Microporosity in the Tarbur Formation, magnification × 2.5

Also, dolomitic neomorphism is rarely observed, and only in the Kuh-e Khanehkat section (Fig. 6.5.2). Secondary dolomite relating to the subaerial diagenetic phase during deposition is observed in the middle of the upper part of the Tarbur Formation. Although dolomitic features are not observed in the other parts of the Tarbur Formation in this section, dolomitic neomorphism is a syndepositional phenomenon.

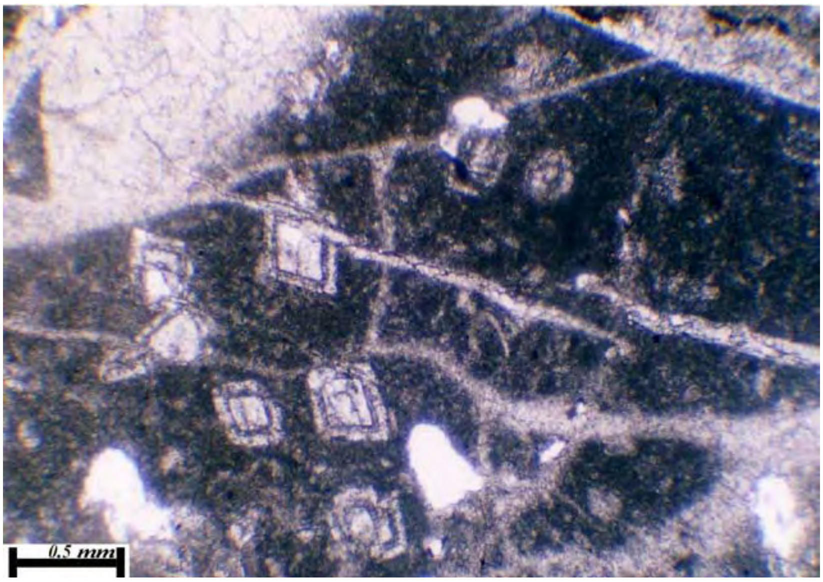


Fig. 6.5.2. Dolomitic limestone of the middle of the Kuh e-Khanehkat section

Some of the fractures are porous and filled up by sparry calcite.

Another diagenetic factor is ferrification. This process usually takes place under oxidation conditions in sedimentary basins, especially in grainstone facies.

7. Synthesis

Paleontologically, microfacies are indicators of paleogeographic isotopy, interpretation of autigene material and identification of both the biostrome and bioherm stages of the Tarbur Formation in the studied sections. It should be noted that field observations, geological map investigations and simultaneous microfacies studies are an indicator of the reconstruction of paleogeographic conditions discussed later in section 7.7.

7.1. Biostrome and Bioherm Process

Two types of layering are observed in the Tarbur Formation which may be used as structural classification criteria:

1- Medium to thick-bedded limestone

2- Massive limestone

Furthermore, in all of the stratigraphic sections studied so far, the lower part of the Tarbur Formation indicates the history of the biostrome characteristics, while the upper part shows the bioherm characteristics (HODGES,1987). In the sedimentary depositional system of the Tarbur Formation, the first stage is the biostrome process, whichforms the lower part, "well-bedded" limestone, in all the studied sections. Usually, the second stage is the bioherm process which thickens the upper part (massive limestone).

According to the lithological study of the Tarbur Formation, well-bedded limestones are observed with different thicknesses in all the studied sections. In fact, well-bedded limestone is an indicator of discontinuous sedimentation. A change in the rate of sedimentation is the first stage of the Tarbur Formation which is detectable in the studied sections. The maximum thickness of well-bedded limestone is found in the Zarghan section (Fig.7.1.1), while the minimum thickness relates to the Kherameh-1 section

(Fig.7.1.2). In addition, well-bedded limestone observable in the lower part of the studied sections is the biostrome part of the Tarbur Formation, which includes rudist fragments. Only well-bedded limestone that has bounded between the Gurpi Formation in the lower lithostratigraphic limit is detectable in the Kuh-e Siah, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh, and massive limestone in the upper lithostratigraphic limit. The massive limestone overlies the well-bedded limestone part in all of the studied sections. The thickness of this part differs from section to section. The maximum thickness of this part is observed in the Zarghan section, and the minimum thickness is detected in the Kherameh-1 section.The massive limestone part is an indicator of a more continuous rate of sedimentation. The Sachun Formation overlies the massive limestone unit. Since the lower and the upper parts of the Tarbur Formation are of different thicknesses in different stratigraphic sections, the biostrome and bioherm parts are different, in both time and location. Investigations of micropaleontological data confirm that biostrome of the Tarbur Formation was deposited at a different time. Biostrome was deposited in some parts of the Maestrichtian age in the Kuh-e Siah, Kherameh-2, Kuh-e Khanehkat, Kuh-eChehelcheshmeh, and Dariyan sections. Also, the biostrome of the Tarbur Formation was deposited in the Campanian,and there isalso some part of this stage in the Zarghan and Kherameh-1 sections.

Based on MACINTYRE (1985), biostrome, in its primary stage of formation, has alternately grainstone, packstone to wackestone, and is also named the stabilization stage. All of the studied sections contain this stage, especially the Kuh-e Siah and Zarghan sections. The second stage in this terminology is colonization, which consists of bafflestone, floatstone and wackestone facies. It is noted that this stage is normally relatively thin compared with the reef structure as a whole. This stage is not distinct in the studied section.The third stage is diversification, consisting of framestone to wackestone. The wackestone facies is widespread in the upper part of the studied sections. Facies relating to the bioherm stage of the Tarbur Formation terminates with this stage.

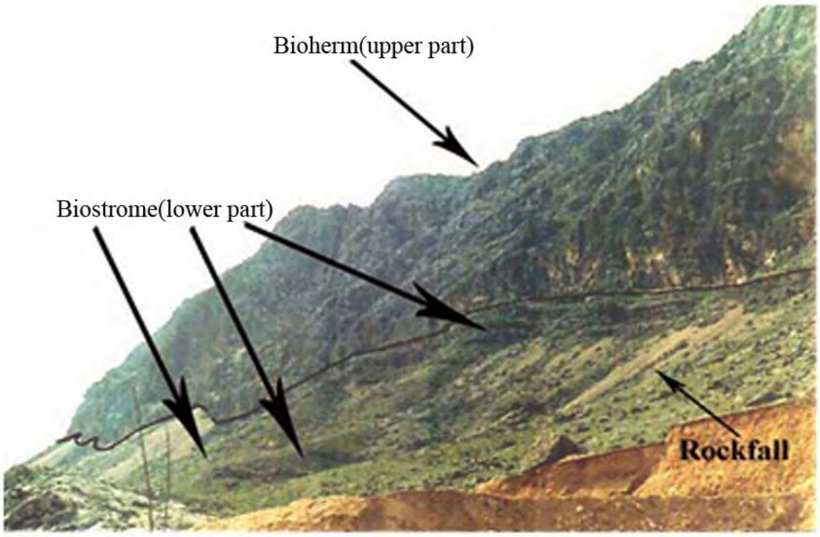


Fig. 7. 1. 1. The distinct boundary between the lower and upper Tarbur Formation is observed, and well-bedded limestone of the Zarghan section is underlain by the massive upper part. Layering of the lower part is clearly sharp, but some of the lower part of the Tarbur Formation is covered by rock fall from the upper part. In fact, the lower part of the Tarbur Formation is biostrome and the upper part is bioherm.

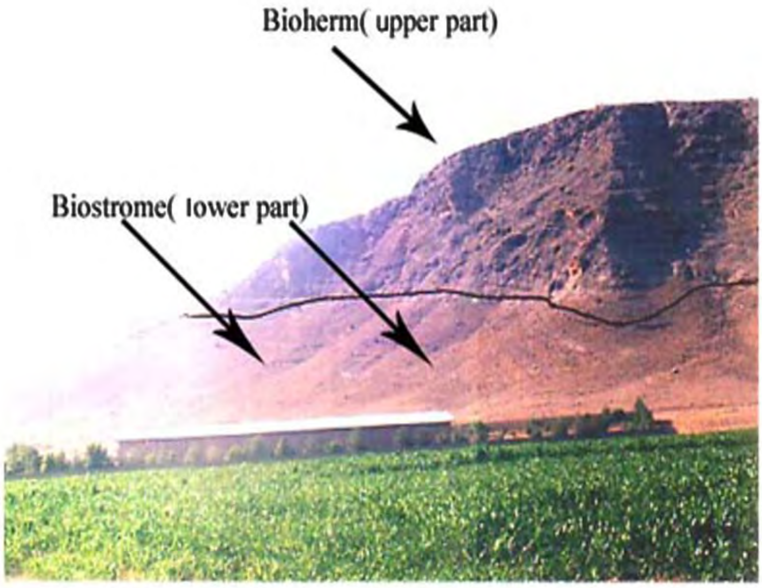


Fig. 7.1.2. The lower well-bedded limestone in the Kherameh–1 section is the least thick of the studied sections situated in the lower part of the Tarbur Formation. This is the biostrome stage of the Tarbur Formation and the massive upper part overlies the biostrome part. It can be seen that the biostrome part of the Tarbur Formation is mainly covered by rock fall of the massive upper part.

7.2. Transport Mechanism

The most important factors in this process are the force of waves and, to a lesser extent, their direction. There is some evidence that indicates the direction and force of waves in the Tarbur Formation, as follows:

1- Allochem materials size
2- Bioclast (foraminifera)
3- Degree of crushing of allochems.

Allochem materials are divided into three main components: extraclasts, bioclasts, and intraclasts. The main extraclast source is the continent. The extraclasts observed in the lower part of the Tarbur

Formation have been transported by rivers or waves that washed the shore line. These extraclasts are observed in all of the studied sections.

The main component of the reef sediment is bioclasts, which orginated in the reef mass. However, the wave action also crushed the organic reef elements and transported them to the edge of the reef mass. It is noted that the rudist debris, especially in the fore reef environment, was deposited in the fore reef, but seldom on the reef mass or the back reef environment.

However, there is no evidence to prove the existence of reworked dasycladaceae in thefore reef environment in the Tarbur Formation. Therefore, dasycladaceae have not been transported to the fore reef.

Gastropod shells are not observed in the fore reef either. The lagoon (back reef environment) and, on the other hand, the crushed bioclast debris from the reef mass were transported to the back reef.

Very angular fore reef sediments are observed in all of the studied sections. However, there are some extraclasts which were transported from the continent. Although fore reef sediments are widely observed in the lower Tarbur stratigraphic sections, transportation and deposition of the sediments depended on the reef position and wave activities. The size of the bioclasts indicates a rapid deposition of the sediments. The rate of deposition also depends on the rate of transportation.

The shallowness of the water at the edge of the back reef facilitated rapid transportation. However, the slow depositional system in the main back reef facies did not lead to rapid sediment transportation.

7.3. Authigene Materials

The main component of authigene materials is rudist fragments that were deposited in all of the reef facies of the Tarbur Formation. It is noted, however, that the density of bioclasts in the fore reef facies is higher than that of the back reef facies. Therefore, the organic remains of the fauna that inhabited the precursors of what was to become the Tarbur Formation were already deposited in some parts of the reef.

The calcium carbonate which was deposited as a cement between particles, is another authigene material in the Tarbur Formation, and is divided into two components: 1-Organic constituents (as bioclasts), and 2-Calcium carbonate that was deposited by a chemical reaction as a cement.

7.4. Clastic Materials

Clastic materials are divided into four groups: extraclast, intraclast, SiO_2 and reworked fossils. Extraclasts are accumulated in the Lower Tarbur Formation in all of the studied sections. The existence of extraclasts indicates agitation turbulence of the basin during sedimentation. The maximum percentage of extraclasts is observed in the lower part of the Tarbur Formation (about 25%) in the Kuh-e Siah, Kherameh-2, and Kherameh-1 sections. The extraclasts are composed of calcium carbonate. The maximum percentage of intraclasts is observed in the lower part of the Tarbur Formation of the Zarghan section (about 32%). Intraclasts are angular to sub-angular in structure.

7.5. Nutrition Conditions

Foraminifers are heterotrops with pseudopodia. Therefore, they foraged for algae in the reef facies. Moreover, as dasycladaceae they densely populated the upper part of the Tarbur Formation. Although foraminifers may feed on bacteria, there is no evidence of the existence of bacteria in that formation. Foraminifers also benefited from the organic debris in the lower part of the Tarbur Formation. As the major facies observed in the reef is baffle facies and the minor one frame facies, the medium was apparently muddy and silty and mixed with the organic debris, which was trapped in the intraparticle space of the reef. Foraminifera, therefore, fed on detritus in the calcareous ooze, too.

7.6. Paleogeography

As was emphasized in section 2.2., the Zagros sedimentary basin subsided in the Late Campanian age, and the shaly depositional system that relates to the Gurpi Formation was formed due to this catastrophic event. Moreover, the Tarbur Formation was deposited at the same time, very close to the subsidence axis.

These reefs are discontinuous and distributed in liniation form. They were always near the sea level. The Tarbur Formation, having lateral facies, changed to the Gurpi Formation, but to the north-east the reefs were located in the open marine. Therefore, radiolarite sediments were deposited in the other (Central Iran) sedimentary basinand were transported as exotic blocks (Map 2.3).

These sediments consist of thin-bedded chert and silty limestone interbedded with flysch sediments. These sediments are related to the Cretaceous era.

The studied stratigraphic sections are related to the liniation of the Tarbur Formation depositional system. Although these reefs are discontinuous, they are parallel to the Zagros Main Thrust. Since the Zarghan, Kherameh-1 and Kherameh-2 sections are closer to the Zagros MainThrust than theKuh-e Siah section, their biostratigraphic limits differ from section to section. Also, the microfacies observed in the studied stratigraphic columnar sections are more variable than those of the Kuh-e Siah section. There is another theory about the paleogeographic situation of the studied sections of the Tarbur Formation. The distribution of Sachun outcrops mainly decreases towards the south-west (Fig.2.3). Furthermore, the Gurpi Formation to the south-west of the Tarbur Formation relates to theTuronian-Maestrichtianera. It is overlain by the PabdehFormation (Paleocene-Eocene) inthese regions. Sachun outcrops that overlay the Tarbur Formation are observed only in the interior Fars Province. Therefore, the back reefs of the Tarbur outcrops are towardsthe north-east. The Sachun Formation has prograded on the Tarbur Formation as regressive facies at the end of the Cretaceous, while some Tarbur stratigraphic sections such as the Kuh-e Siah, Kuh-e Khanehkat and Kuh-e Chehelcheshmeh werestill below sea level. Therefore, the lower lithostratigraphic limits of the Sachun Formation outcrops are heterochronous with the lower lithostratigraphic limits of the Pabdeh Formation. In addition, the Gurpi Formation appears as fore reef facies where the regions are located in the south-west of the Tarbur Formation outcrops, and the Sachun Formation appears as back reef facies onlyatthe end of the Cretaceous or as regressive facies that overlay the Tarbur Formation.

7.7. Phyllogenic Characteristics

There are some foraminiferal families that consist of many genera such as: Orbitoididae *(Orbitoides media, O.concavatus, O.apiculata, 0.triangularis* and *Omphalocyclus macroporus).*

Some species, like *Orbitoides concavatus,* are observed inthe Campanian age, but other species such as *Orbitoides apiculata, O.triangularis,* and *O. media* are observed in the Maestrichtian age. Nezzazatidae is another foraminiferal family that is observed in the Tarbur Formation. Two main genera are observed in the studied sections, namely *Nezzazatinella* sp., which indicates Campanian age, and *Antalyna korayi,* which indicates Late Maestrichtian age.

Orbitolinidae is the family that consists of two genera with two species, *Dictyoconus* sp. and *Dictyoconella* sp.. All of these species indicate Maestrichtian. Finally, Lepidorbitoididae also consists of two main genera with three species, *Lepidorbitoides minor, L. socialis* and *Sirtina* sp. These genera are observed in the Maestrichtian. In addition, there are many foraminiferal families that indicate benthic sediments in the Tarbur Formation in Fars Province.

These families include Orbitoididae, Lepidorbitoididae, Nezzazatidae, Orbitolinidae, Rhapydoninidae, Cyclamminidae, Pfenderinidae, Osangulariidae, Calcarinidae, Loftusiidae and Rotaliidae. The paleoecological conditions of the Tarbur depositional system provided the media for different families to nurture in that paleoenvironment.

7.8. Taphonomic Characteristics

Based on paleontological and microfacies data of the Tarbur Formation, bioclasts are benthic forms.These bioclasts are mainly rudist fragments, benthic foraminifers, algae, gastropods and rarely reworked foraminifers. Rudist fragments, benthic foraminifers, algae and gastropods belong to Tarbur sedimentary environments. Although some bioclasts are observed with transportation effects, all of them are detected in the environment where they lived. Therefore, these bioclasts are synchronous and isotopic. Transportation of rudist debris and foraminifers in various microfacies occurred in the way of intraformational transportation. This is all paleoecologic proof implying similarity of bioclasts with microfacies. Also, investigations of micropaleontology indicate that there is no evidence of preservation of pelagic foraminifers or nanoplanktons. tcaf nI, causes of heterotopy and allotopy in Tarbur microfacies have not been detected. Since there are effects of transportation of bioclasts, especially in rudist fragments, some foraminiferal genera are observed in microfacies that have not been detected yet; for example, orbitoids are generally reported in the high kinetic energy of open marine in the fore reef facies. Since orbitoids are mainly detected in the main microfacies of the Tarbur Formation, the existence of different families of foraminifers in various microfacies is an indicator of subisotopy. It should be noted that micropaleontological studies show that genera which have been identifiedare in situ. There are rarely intraformational transportation effects in the foraminiferal constituents, therefore various foraminifers have lived and are buried in different conditions of the sedimentary basin. It should benoted that rarely reworked foraminifers are detected. The arrangement of reworked microfossils with typical foraminifers of the Tarbur Formation is an indicator of heterochronism. This phenomenon is rarely detected in the Kherameh-2 and Kuh-e Khanehkat sections.

8. Conclusion

The study of stratigraphic columnar sections in this investigation has led to many conclusions about the identification of lithostratigraphic units, a new biozone, geochemical stratigraphic characteristics, the identification of biostratigraphic limits and correlation, conclusions of statistical studies in the field of microfacies elements, and the distribution of marker microfacies.

8.1. Lithostratigraphic Units

The Tarbur Formation is divisible into two different lithologic units as members in view of layering. In other words, the Tarbur Formation consists of two portions in all studied sections. The segregation of these parts is presented in sections 4.1-7. The study of the litho characteristics of the Tarbur Formation indicates that the lower Tarbur is biostrome in all of the studied sections, whereas the upper Tarbur is in bioherm form. But differences of thickness in each portion of each stratigraphic section indicate different rates of subsidence and sedimentation of each section. The maximum rate of subsidence in these sections is related to the Zarghan section with 776 m and the minimum rate of subsidence to the Kherameh-1 section with a thickness of 202m. It should be noted that, based on micropaleontological studies in the stratigraphic sections, the age of both the Zarghan and the Kherameh-1 sections has been determined asCampanian to Maestrichtian. Therefore, there were different depositions of carbonaceous sediments at the same time. Also, the age of the stratigraphic sections, for example, of the Kuh-e Khanehkat and Kuh-e Chehelcheshmeh, is Campanian to Lower Paleocene, but the thickness of the Zarghan section is greater. It should be noted that increase in thickness relates simultaneously to the rate of deposition of sediments and subsidence.

It is obvious that both the rate of sedimentation over time and the rate of subsidence of the Zarghan section are higher than in the other studied sections. Different thicknesses of both the lower and upper parts of the Zarghan, as compared with the other sections, show different rates of sedimentation and subsidence.

8.2. Biostratigraphic Units and Biocorrelation

Based on previous studies (JAMES & WYND, 1965; KHOSRAVI 1968; KALANTARI, 1976), without identification of any biozones, the present study of different stratigraphic sections identified two different Campanian-Maestrichtian biozones. These investigations have found new taxa and new biozones. These biozones identify the age of each lithostratigraphic unit. Campanian biozones consist of:

Murciella cuvillieri

Orbitoides concavatus

Maestrichtian biozones consist of:

Antalyna korayi

Dictyoconella complanata

Orbitoides apiculata

Loftusia minor

Rotalia skourensis

Omphalocyclus macroporus.

In fact, the determination of the biostratigraphic limits of the Campanian and Maestrichtian stages in the studied sections is based on index foraminifera.

These taxa do not depend on the microfacies, and only *Loftusia minor*is usually observed in wackestone, but it is not common. Campanian and Maestrichtian biozones are identified by assemblage zones. For example, the Campanian biozone generally consists of *Orbitoides concavatus*, *O.tissoti*, *Murciella cuvillieri*, and the Maestrichtian biozone consists of:

Orbitoides apiculata, *O.triangularis*, *Antalyna korayi*, *Dictyoconella complanata*, *D.*sp., *Rotalia skourensis*, *Omphalocyclus macroporus*, *Loftusia minor*, *Lepidorbitoides minor*, *L.socialis*, *Goupillaudina shirazensis*, *G.*sp..

These taxa are detected with different frequencies. A difference of frequency in these foraminifers relates to paleoecologic conditions, for example, wave action, depth of water, nutrition conditions, and reproduction. Therefore, each Maestrichtian biozone is introduced by a corresponding taxon. These taxa are common in all studied sections.

Paleocene biozones are identified by only two taxa, but only one of these is common in the Paleocene portion of the studied sections. The Paleocene biozone consists of *Vania anatolica* and *Laffitteina* sp. biozones. Generally, the sections, for example the Kuh-e Siah, the Kuh-e Khanehkat, and the Kuh-e Cheheleheshmeh, consist of Paleocene sediments which in the Tarbur Formation are detected in the upper part; therefore, the Cretaceous-Tertiary boundary is an intraformational boundary and, although tectonic activity causes the disappearance of Maestrichtian taxa, the Tarbur lithostratigraphic unit is detectable.

In addition, the Tarbur Formation, in view of its perfect biostratigraphic limits, consists of three biozones of foraminifera.

Biostratigraphic investigations of the studied sections are based on the identification of benthic foraminifers. There are many taxa that are detected in the Tarbur Formation. According to the lithostratigraphic limits, it should be noted that the Tarbur Formation is bounded by two different lithologies. The underlying formation is the shaly Gurpi Formation, and the overlying formation is marly and of evaporitic sediments of the Sachun Formation. Therefore, lithostratigraphic limits are distinctive; the taxa that are index microfossils are dominant in the lithostratigraphic classification. But it shouldbe noted that the stratigraphic range of these taxa are not a function of lithologic classifications and change in microfacies. Some genera, such as *Orbitoides media,* are observed in both the lower and upper part, or *O.concavatus* is observed in the limited domain of the lower part of the Kuh-e Chehelcheshmeh section.

Since reefs are a mobile system of ecology, the appearance or disappearance of genera depends on the adaptation of taxa over time. Some paleoecologic factors, such as sedimentary conditions, are not distinct from the domain of appearance. This phenomenon is not common to some genera, as *Orbitoides apiculata* is observed in both packstone and grainstone of the Kuh-e Siah. However, Campanian and Maestrichtian association foraminifers are a distinct assemblage of foraminifera, based on the identification of index foraminifers and determination of their domain. The biostratigraphic limits of the Tarbur Formation are the Campanian to the Lower Paleocene; although some studied stratigraphic sections are the Campanian to the

Maestrichtian, the Zarghan, the Kherameh-1 and some others are of Maestrichtian age. In order to correlate stratigraphic sections, it is better to determine first the datum line. It should be noted that the Zarghan, Kherameh-1, Kuh-e Khanehkat, and Kuh-e Chehelcheshmeh sections have a distinct Campanian-Maestrichtian boundary. This boundary is an intraformational boundary. This segregation is detected by identification of index Campanian and Maestrichtian taxa.

Another intraformational boundary identified as Maestrichtian-Lower Paleocene is introduced. This boundary is detected in the Kuh-e Siah, Kuh-e Chehelcheshmeh and Kuh-e Khanehkat sections. To choose a datum line, the boundary of the Campanian-Maestrichtian, which is observed in four stratigraphic sections, namely the Kherameh-1, Kherameh-2, Zarghan and Dariyan, is preferable to the boundary of the Maestrichtian-Lower Paleocene, which is observed in only in three of the stratigraphic sections, namely Kuh-e Chehelcheshmeh, Kuh-e Khanehkat, and Kuh-e Siah (Fig.8.2). The thickness of Campanian sediments of the Tarbur Formation is about 3m in the Kuh-e Khanehkat and the Kuh-e Chehelchesmeh sections, butis about 80 m and 270 m in the Zarghan and Kherameh-1 sections respectively.

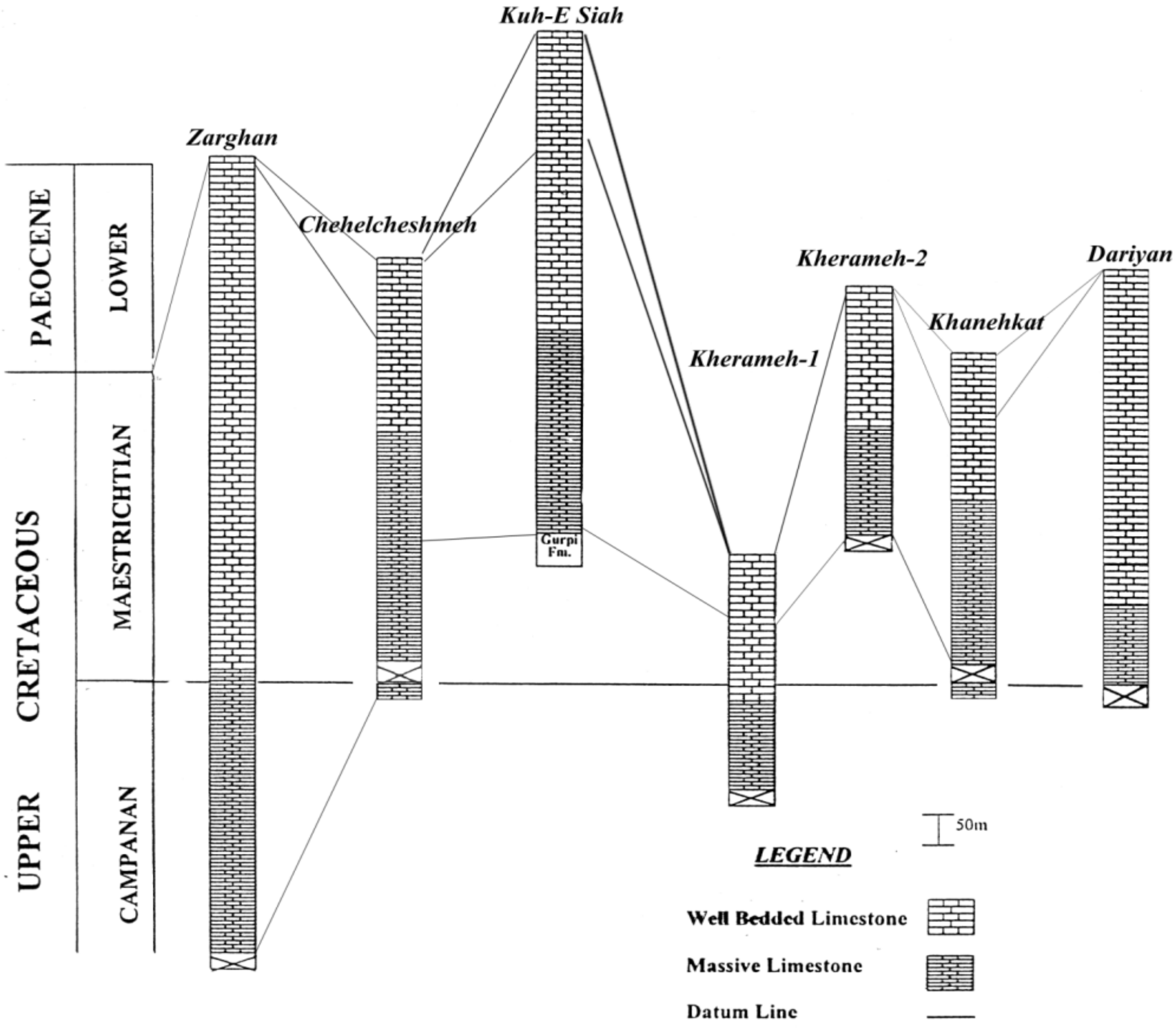


Fig.9.2. Biostratigraphic correlation of Seven stratigraphic sections of the Tarbur Formation

8.3. Microfacies

Microfacies studies of the studied stratigraphic sections indicate two major phenomena: 1- percentage of microfacies elements, 2-type of microfacies and its distribution in stratigraphic columnar section in time. Conclusions from the microfacies elements percentage show that the rate of extraclasts in the lower part is larger than of the upper part in all the studied sections. In fact, the rate of extraclasts in the lower part is a function of the biostrome process. At first, rudists grow and sediments accumulate in the mixture of shell fragments. Although intraclasts are not important, they indicate agitation without diagenesis of sediments in the sedimentary basin. In fact, intraclasts are fragments of the bottom of the sedimentary basin that are crushed by wave action. Bioclasts are the main microfacies elements that are generally observed in the microfacies of the Tarbur Formation. The most important bioclasts are rudist particles.

Also, the bioclast curve (Figs. 6.4.1.-7.) is an indicator of rudist growth in the Tarbur Formation the other bioclasts are not as important as rudist fragments.The ratio of rudists to the other bioclasts is 50%. Thedevelopment of rudists is an indicator of convenient paleoecologic conditions such as salinity, temperature, nutrition, etc. Variations of depositional conditions are a function of the eustatic curve and subsidence. Observations of all studied sections indicate that changes in microfacies occurred during the Maestrichtian. This phenomenon is detected in all stratigraphic sections that are located in the Imbricated Zone of the Zagros. Often, in the Campanian-Maestrichtian boundary, there is a change in microfacies, too. This event is detectable in the Kuh-e Khanehkat, Kuh-e Chehelcheshmeh and Kherameh-1sections. Although change in microfacies is the result of a variation of sedimentary conditions, change in sea level is a distinct event. Since there is no change in microfacies in the Campanian-Maestrichtian boundary of the Zarghan section, variations of the last stratigraphic sections (Kuh-e Khanehkat, Kuh-e Chehelcheshmeh and Kherameh-1) relate to a little subsidence. As a result, it is an indicator of continuous sedimentation in portions of the upper part of the Tarbur Formation. Rudist particles are 1.5 to 0.2 cm in size.Large particles are mainly observed in the wackestone facies, whereas fine particles are observed in the packstone and grainstone facies. Also, particles larger than 1.5 cm are observed in the boundstone facies. The maximum rate of these particles is 50% in Kuh-e Siah; the minimum percent is about 2%. Maximum rudist particles are observed in the lower part of the Tarbur Formation of the Zarghan section at about 49%. The minimum rate of rudist particles is observed in the Kherameh-1 section. It is noted that the maximum percentage of these particles is observed in the packstone facies, which is about 30%. Finally, the maximum percentage of the rudists is about 70%.

The increase in the strontium concentration mainly relates to the rudist content in all of the studied stratigraphic sections. Although well-preserved rudists are not detected, there are some Hippurites remains that have baffled sediments, especially in the upper part of the Zarghan section (Fig. 5.6). Usually, rounded and angular particles of rudists are sorted together. In fact, these particles are detected in the packstone facies, especially in the lower part of the Kuh-e Siah section. The rudist particles are mixed with the other bioclasts, such as foraminifers, gastropods, algal remains, and the other microfacies elements. Therefore, rudist particles are the main bioclast element that builds up the Tarbur Formation. This is observed in all of the typical microfacies of the Tarbur Formations, with differences in accumulation. The rate of the rudist particles is 10-25% in the wackestone, 25-40% in the packstone, 25-30% in the grainstone and finally over 80% in the boundstone facies.

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