A Survey on the condition of Micro Facies, Sedimentary Environment and the Cretaceous Deposits (With Particular Reference to Central Iran)

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Abstract: Micro continent of central Iran is a part of middle Iran that is bounded with ophiolithic suture zones in Sistan, Naiin, Baft, Doruneh fault and Kashmar – Sabzevar ophiolites and is classifiable into Lut block, Shotori upland, Tabas subduction, Kalmard upland, Posht Badam block, Biaze - Bardsir basin and Yazd block by means of long faults which are dextral strike – slip faults and have westwards inclination. In many regions of Iran, except to Zagros, in approximate boundary of early and late Cretaceous, it is observed evidences of tectonic events which are mainly as land generating and can be compared with worldwide Austrian event, in everywhere in Iran except to rare cases (east of Tehran and Yazd). Upper Cretaceous beds in Iran do not have identical facial characteristics and it seems that in contrast to equal sedimentary condition in early Cretaceous, sedimentary basins in upper Cretaceous have been separated from each other and special condition has been dominated in each basin. As a result of that, lithostratigraphic units except to Zagros and Kopet Dagh have not been named and or have local names in upper Cretaceous of Iran. This article is an overview of the condition of Micro-facies, sedimentary environment and the Cretaceous deposits in central Iran.
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1. Introduction

In past, micro continent of central Iran was known as a part of Central Iran zone but according to Stöcklin, this motioned area, after hardening of Precambrian bed rock, had characteristics of platform in Paleozoic and has been turned in a active zone in Mesozoic and Cenozoic. Nevertheless it should be said that major structural pattern in this micro continent is type of separated blocks with main faults which each of them have different characteristics and dynamic of micro continent is not same in everywhere. Current evidences demonstrate that:

Katangan orogeny in this area has been dominated since late Precambrian and prior to a platform regime. Except to Lut block and south western edge which have exposures from Tertiary magmatic rocks, Terrtiary rocks have least abundance in other parts.

In Paleozoic strata in this region, there is important stratigraphic gaps that most important of them are stratigraphic gaps in beginning of middle Triassic (Eifelian Hiatus) and late Carboniferous (Stephanian Hiatus). (Harold G. Reading,1996)

Widespread structural – sedimentary non equality has been resulted in dividing micro continent of central Iran into some blocks as follow.

Lut block, with a length of about 900 kilometers, is most eastern part of micro continent of central Iran. Eastern boundary is specified with Nehbandan fault and flysch zone in east of Iran and western boundary with Naiband fault and Tabas block. On the tectonic map of Iran, (stöcklin and Nabavi), northern boundary of this block is limited to southern Kashmar basin and southern boundary to Jazmurian subsidence. In 1968, Stöcklin divided this zone into two western and eastern parts which have been separated by Shotori Mountains. Next investigations demonstrate that geological characteristics of these two blocks are not analogical. For example, very thick igneous lava with a thickness of 2,000 – 3,000 meters in Lut block in Cenozoic is not observed in Tabas block. Also tectonic movements in late Cimmerian especially middle Cimmerian which is accompanied with metamorphism and relative stability of Lut block, have a few symptoms of land generating. That is why, especially because of new results, with a review in Lut block and then Tabas block, Jazmurian subsidence and Bazman Mountains, as magmatic arc, were eliminated from this block. (Prothero, Donald R.; Schwab, Fred, 1996)

2. Stratigraphic history

Stratigraphic history of Lut block is very similar to other parts of micro continent of central

Iran. However four characteristics is dominated on stratigraphy of Lut block.

1- Considerable impact of early Cimmerian orogeny (Paleobalouch – Rier and Mohafez, 1972) on the rocks older than middle Triassic.
2- Relatively vigorous Folding, volcanism and plutonism in middle Jurassic (middle Cimmerian) particularly in Dehsalam and Chahar Farsakh which are accompanied with hardening and stability of Lut block.
3- Abundant of volcanic rocks in Tertiary system, particularly in Eocene, which with a thickness of 2,000 meters has covered more than half of Lut block.
4- Lacustrine deposits, almost horizontal, in Pliocene – Pleistocene, named Lut formation which is representative of week operation of ultimate folding in this block.

"Tabas block" which is located between Naiband fault in east and Kalmard – Kouhbana fault in west, is a part of a structural territory where in its rims and bed is crossed by faults of bed rock so that it has different stratigraphic sequence, proportion to adjacent areas in Paleozoic and Mesozoic and at the end of Mesozoic due to operation of tectonical convergent stresses, most with a trend of east – west, is turned to lands as a result of elevation of lands and uplift of mountains (Ghasemi and et al, 1381). So there is this belief that current morphological – tectonical features of this block is as a result of reactivition of fault structures and old folding in tectonical cycle of Alp. (Siever, Raymond, 1988)

Tabas block is one of regions which its evolutional trend in Paleozoic is not concordant to adjacent areas. For example:

× Gap of Eifelian in this area is not completely clear.

× Upper Carboniferous rocks which are not present in other regions, has been reported in this area.

× Volcanic mafic and intermediate activities, even though negligible, are one of characteristics of Tabas block and from this aspect Tabas block can be compared to Alborz Mountains. Mineralization of Lead, zinc and copper in Permian, Triassic and Jurassic in Alborz has generality in Tabas block too which is evidence for similarity of these two zones.

* vigorous sunsidence is one of characteristics of Tabas block. Before, it was assumed that this subsidence is limited to Shotori and Shirgasht but nowadays it is specified that most portion of block in Paleozoic, especially Mesozoic to Cretaceous, had considerable sunsidence so that there is big volume of Phanerozoic rocks in this block which Paleozoic strata, among them, have a thickness of 2,000-3,000 meters and sometimes up to 10,000 meters in Mesozoic.

"Kalmard block" is a part of micro continent of central Iran which has a north easterly trend and is located between Kalmard fault in east and covered fault of Naiin in west. History of this upland implies to two long emergences, depend on Katangan and early Cimmerian. In other words, in two long time interval this block had had characteristics of upland. (Nichols, Gary, 1999) Oldest rocks of this upland are thick shale – sand stone deposits of Kalmard formation in Precambrian that have been folded due to Katangan event and have been covered by Ordovician deposits (Shirgesht Formation) by an angular unconformity that is evidence of first long sedimentary gap. In this block, Ordovician strata to middle Triassic, in addition to have several consequently sedimentary gaps, are a limited stratigraphic – structural unit among Katangan – early Cimmerian event which have been accumulated in shallow sedimentary environments and procedure of its evolution is completely different from Tabas block. Deposits of upper Triassic have not been reported here and it seems sedimentary gap, due to early Cimmerian, is longer in comparison with Tabas block. Jurassic strata are limited to lias – Middle Douger and lack of younger deposits from middle Douger (Badamo Formation) indicates that long second emergence of this upland has been occurred since middle Douger that orogeny event, in middle Cimmerian, is main inducement for that. (Cambridge, MA, H. G., 1978)

As a structural viewpoint, common trend of folds are north east – south west in northern mid of Kalmard upland that especially have distinct appearance in Palepozoic deposits. Dip of layers is high in eastern side and sometimes is overturned, but is gentler in western side. Operation of reverse longitudinal faults has caused considerable shear structures with similar trend to Kalmard block which Rahbar mountain is one of them. "Biaze – Bardsir subsidence" is located between Posht-e- Badam fault in east and Anar fault in west. Even though many of characteristics in this subsidence such as Precambrian metamorphic bed rock, Paleozoic – middle Triassic platform strata and sand stone - shale deposits in upper Triassic – middle Jurassic are similar to other parts of micro continent but this subsidence has two characteristics, one of them is more vigorous impact of late Cimmerian event which has been accompanied with widespread emersion and metamorphism. Another one, Flysch basins which are representative of basins with vigorous sunbidence and especially it can be observed its upper Cretaceous strata from east of Anar to North of Bardsir. (Reading, H. G, 1996)

"Yazd block" is western part of micro continent of central Iran which is limited to Dorouneh fault to the north and Naiin – Baft ophiolithic band to the west.

There are two specific characteristics in Yazd block. The First one is Anarak metamorphic rocks and second one is Triassic strata of Nakhlak. In Anarak which is named some times Anarak – khor massif, there are complex of pellet – psamite sediments with carbonate and volcanic rocks, pertaining to continental slope that have been metamorphed as regional and in green schist and blue schist facieses and are accompanied as collided plates to ophiolithes, pelagic limerocks and irregular sediments. Although Davoud Zade and Lench (1981) attributed Anarak ophiolites as a part of oceanic crust of former Tethys, in Harat, which has been exposed after rotation of micro continent in current location but Almasian(1977) believes that Anarak ophiolithes are of upper Protrozoic age and they can be described related to oceanic back arc basins. Triassic strata of Nakhlak (Nakhlak group) have considerable facial differences with other parts of micro continent of central Iran. According to Davoud Zade and et al.,Triassic strata of Nakhlak have similar facies to Aghdarband in Triassic (Aurasia) that as a result of rotation of micro continent in Central Iran, as much as 135° in anticlockwise, have been relocated into present position. It should be said that Nakhlak in Triassic and formations of Nakhlak group and even operation and amount of rotation of micro continent are questionable and needs to review completely.

3. Sediment

Sediment is naturally-occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of fluids such as wind, water, or ice, and/or by the force of gravity acting on the particle itself. Sediments are most often transported by water (fluvial processes), wind (aeolian processes) and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and oceans. Desert sand dunes and loess are examples of aeolian transport and deposition. Glacial moraine deposits and till are ice transported sediments.

Fig1. Sediment in a Gulf

4. Classification

Sediment can be classified based on its grain size and/or its composition.

Grain size

Sediment size is measured on a log base 2 scale, called the "Phi" scale, which classifies particles by size from "colloid" to "boulder".(Fig1) (Table1).

Table1: Classification of Sediment

ϕ scale	Size range (metric)	Size range (inches)	Aggregate class (Wentworth)	Other names
< -8	> 256 mm	> 10.1 in	Boulder	
-6 to -8	64–256 mm	2.5–10.1 in	Cobble	
-5 to -6	32–64 mm	1.26–2.5 in	Very coarse gravel	Pebble
-4 to -5	16–32 mm	0.63–1.26 in	Coarse gravel	Pebble
-3 to -4	8–16 mm	0.31–0.63 in	Medium gravel	Pebble
-2 to -3	4–8 mm	0.157–0.31 in	Fine gravel	Pebble
-1 to -2	2–4 mm	0.079–0.157 in	Very fine gravel	Granule
0 to -1	1–2 mm	0.039–0.079 in	Very coarse sand	
1 to 0	0.5–1 mm	0.020–0.039 in	Coarse sand	
2 to 1	0.25–0.5 mm	0.010–0.020 in	Medium sand	
3 to 2	125–250 µm	0.0049–0.010 in	Fine sand	
4 to 3	62.5–125 µm	0.0025–0.0049 in	Very fine sand	
8 to 4	3.9–62.5 µm	0.00015–0.0025 in	Silt	Mud
> 8	< 3.9 µm	< 0.00015 in	Clay	Mud
>10	< 1 µm	< 0.000039 in	Colloid	Mud

- **Composition**

Composition of sediment can be measured in terms of:

- parent rock lithology
- mineral composition
- chemical make-up.

This leads to an ambiguity in which clay can be used as both a size-range and a composition (see clay minerals).

5. Sediment transport

Sediment builds up on human-made breakwaters because they reduce the speed of water flow, so the stream cannot carry as much sediment load. (Fig2)

Fig2. Glacial transport of boulders.These boulders will be deposited as the glacier retreats.

Sediment is transported based on the strength of the flow that carries it and its own size, volume, density, and shape. Stronger flows will increase the lift and drag on the particle, causing it to rise, while larger or denser particles will be more likely to fall through the flow.

6. Fluvial processes: rivers, streams, and overland flow

Particle motion

Rivers and streams carry sediment in their flows. This sediment can be in a variety of locations within the flow, depending on the balance between the upwards velocity on the particle (drag and lift forces), and the settling velocity of the particle. These relationships are given in the following table for the Rouse number, which is a ratio of sediment fall velocity to upwards velocity. Where:

- w_s is the fall velocity
- κ is the von Kármán constant

u_* is the shear velocity (Table2)

Table2: Relationships for the Rouse number

Mode of Transport	Rouse Number
Bed load	>2.5
Suspended load: 50% Suspended	>1.2, <2.5
Suspended load: 100% Suspended	>0.8, <1.2
Wash load	<0.8

If the upwards velocity approximately equal to the settling velocity, sediment will be transported downstream entirely as suspended load. If the upwards velocity is much less than the settling velocity, but still high enough for the sediment to move (see Initiation of motion), it will move along the bed as bed load by rolling, sliding, and saltating (jumping up into the flow, being transported a short distance then settling again). If the upwards velocity is higher than the settling velocity, the sediment will be transported high in the flow as wash load. As there are generally a range of different particle sizes in the flow, it is common for material of different sizes to move through all areas of the flow for given stream conditions.

7. Fluvial bed forms

Sediment motion can create self-organized structures such as ripples, dunes, antidunes on the river or stream bed. These bedforms are often preserved in sedimentary rocks and can be used to estimate the direction and magnitude of the flow that deposited the sediment. (Figs.3-5).

8. Surface runoff

Overland flow can erode soil particles and transport them downslope. The erosion associated with overland flow may occur through different methods depending on meteorological and flow conditions.

- If the initial impact of rain droplets dislodges soil, the phenomenon is called rainsplash erosion.
- If overland flow is directly responsible for sediment entrainment but does not form gullies, it is called "sheet erosion".

If the flow and the substrate permit channelization, gullies may form; this is termed "gully erosion".

Fig 3. Modern asymmetric ripples developed in sand on the floor of the River. Flow direction is from right to left.

Fig 4. Sinuous-crested dunes exposed

Fig 5. Ancient channel deposit in the Stellarton Formation

9. Key fluvial depositional environments

The major fluvial (river and stream) environments for deposition of sediments include:

1. Deltas (arguably an intermediate environment between fluvial and marine)
2. Point bars
3. Alluvial fans
4. Braided rivers
5. Oxbow lakes
6. Levees

7. Waterfalls

Aeolian processes: wind

Wind results in the transportation of fine sediment and the formation of sand dune fields and soils from airborne dust.

Glacial processes

Glaciers carry a wide range of sediment sizes, and deposit it in moraines. (Fig6)

Fig6. Glacial sediments

10. Mass balance

The overall balance between sediment in transport and sediment being deposited on the bed is given by the Exner equation. This expression states that the rate of increase in bed elevation due to deposition is proportional to the amount of sediment that falls out of the flow. This equation is important in that changes in the power of the flow changes the ability of the flow to carry sediment, and this is reflected in patterns of erosion and deposition observed throughout a stream. This can be localized, and simply due to small obstacles: examples are scour holes behind boulders, where flow accelerates, and deposition on the inside of meander bends. Erosion and deposition can also be regional: erosion can occur due to dam removal and base level fall. Deposition can occur due to dam emplacement that causes the river to pool, and deposit its entire load or due to base level rise.

11. Shores and shallow seas

Seas, oceans, and lakes accumulate sediment over time. The sediment could consist of terrigenous material, which originates on land, but may be deposited in either terrestrial, marine, or lacustrine (lake) environments; or of sediments (often biological) originating in the body of water. Terrigenous material is often supplied by nearby rivers and streams or reworked marine sediment (e.g. sand). In the mid-ocean, living organisms are primarily responsible for the sediment accumulation, their shells sinking to the ocean floor upon death. Deposited sediments are the source of sedimentary rocks, which can contain fossils of the inhabitants of the body of water that were, upon death, covered by accumulating sediment. Lake bed sediments that have not solidified into rock can be used to determine past climatic conditions.

12. Key marine depositional environments

The major areas for deposition of sediments in the marine environment include:

1. Littoral sands (e.g. beach sands, runoff river sands, coastal bars and spits, largely clastic with little faunal content)
2. The continental shelf (silty clays, increasing marine faunal content).
3. The shelf margin (low terrigenous supply, mostly calcareous faunal skeletons)
4. The shelf slope (much more fine-grained silts and clays)
5. Beds of estuaries with the resultant deposits called "bay mud".

One other depositional environment which is a mixture of fluvial and marine is the turbidite system, which is a major source of sediment to the deep sedimentary and abyssal basins as well as the deep oceanic trenches. Any depression in a marine environment where sediments accumulate over time is known as a sediment trap. (Tanley, Steven M., 1999).

13. Environmental issues

Erosion and agricultural sediment delivery to rivers

One cause of high sediment loads from slash and burn and shifting cultivation of tropical forests. When the ground surface is stripped of vegetation and then seared of all living organisms, the upper soils are vulnerable to both wind and water erosion. In a number of regions of the earth, entire sectors of a country have become erodible. For example, on the Madagascar high central plateau, which constitutes approximately ten percent of that country's land area, most of the land area is devegetated, and gullies have eroded into the underlying soil in furrows typically in excess of 50 meters deep and one kilometer wide.[citation needed] This siltation results in discoloration of rivers to a dark red brown color and leads to fish kills. Erosion is also an issue in areas of modern farming, where the removal of native vegetation for the cultivation and harvesting of a single type of crop has left the soil unsupported. Many of these regions are near rivers and drainages. Loss of soil due to erosion removes useful farmland, adds to sediment loads, and can help transport anthropogenic fertilizers into the river system, which leads to eutrophication. (Cross, T. A.; Homewood, P. W., 1997)

14. Sedimentary depositional environment

In geology, sedimentary depositional environment describes the combination of physical, chemical and biological processes associated with the deposition of a particular type of sediment and, therefore, the rock types that will be formed after lithification, if the sediment is preserved in the rock record. In most cases the environments associated with particular rock types or associations of rock types can be matched to existing analogues. However, the further back in geological time sediments were deposited, the more likely that direct modern analogues are not available (e.g. banded iron formations). (Tables 3-5)

Table 3: Continental Sedimentary Environments

	ALLUVIAL FAN	FLUVIAL	LACUSTRINE	DESERT (DUNES)	PALUDAL
Rock Type	Breccia, conglomerate, arkose	Conglomerate, sandstone, siltstone, shale	Siltstone, shale, limestone, or evaporites (gypsum)	Quartz arenite (sandstone) or gypsum	Peat, coal, black shale, siltstone
Composition	Terrigenous	Terrigenous	Terrigenous, carbonate, or evaporite	Terrigenous or evaporite	Terrigenous
Color	Brown or red	Brown or red	Black, brown, gray, green	Yellow, red, tan, white	Black, gray, or brown
Grain Size	Clay to gravel	Clay to gravel (Fining upward)	Clay to silt or sand (Coarsening upward)	Sand	Clay to silt
Grain Shape	Angular	Rounded to angular	---	Rounded	---
Sorting	Poor	Variable	Variable	Good	Variable
Inorganic Sedimentary Structures	Cross-bedding and graded bedding	Asymmetrical ripples, cross-bedding, graded bedding, tool marks	Symmetrical ripples, lamination, cross-bedding, graded bedding, mudcracks, raindrop prints	Cross-bedding	Laminated to massive
Organic or Biogenic Sedimentary Structures	---	Tracks, trails, burrows	Tracks, trails, burrows, rare stromatolites	Tracks, trails	Root marks, burrows
Fossils	---	Rare freshwater shells, bones, plant fragments	Freshwater shells, fish, bones, plant fragments	---	Plant fossils, rare freshwater shells, bones, fish

15. Recognition of depositional environments in ancient sediments

Depositional environments in ancient sediments are recognised using a combination of sedimentary facies, facies associations, sedimentary structures and fossils, particularly trace fossil assemblages, as they indicate the environment in which they lived.

16. Depositional Environments

Landscapes form and constantly change due to weathering and sedimentation. The area where sediment accumulates and is later buried by other sediment is known as its depositional environment. There are many large-scale or regional, environments of deposition, as well as hundreds of smaller sub-environments within these regions. For example, rivers are regional depositional environments. Some span distances of hundreds of miles and contain a large number of sub-environments, such as channels, backs wamps, floodplains, abandoned channels, and sand bars.

Table 4: Transitional Sedimentary Environments

	DELTA	BARRIER BEACH	LAGOON	TIDAL FLAT
Rock Type	Sandstone, siltstone, shale, coal	Quartz arenite, coquina	Siltstone, shale, limestone, oolitic limestone or gypsum	Siltstone, shale, calcilutite, dolostone or gypsum
Composition	Terrigenous	Terrigenous or carbonate	Terrigenous, carbonate, or evaporite	Terrigenous, carbonate, or evaporate
Color	Brown, black, gray, green, red	White to tan	Dark gray to black	Gray, brown, tan
Grain Size	Clay to sand (Coarsening upward	Sand	Clay to silt	Clay to silt
Grain Shape	---	Rounded to angular	---	---
Sorting	Poor	Good	Poor	Variable
Inorganic Sedimentary Structures	Cross-bedding, graded bedding	Cross-bedding, symmetrical ripples	Lamination, ripples, cross-bedding	Lamination, mudcracks, ripples, cross-bedding
Organic or Biogenic Sedimentary Structures	Trails, burrows	Tracks, trails, burrows	Trails, burrows	Stromatolites, trails, tracks, burrows
Fossils	Plant fragments, shells	Marine shells	Marine shells	Marine shells

Table 5: Marine Sedimentary Environments

	REEF	CONTINENTAL SHELF	CONTINENTAL SLOPE AND RISE	ABYSSAL PLAIN
Rock Type	Fossiliferous limestone	Sandstone, shale, siltstone, fossiliferous limestone, oolitic limestone	Litharenite, siltstone, and shale (or limestone)	Shale, chert, micrite, chalk, diatomite
Composition	Carbonate	Terrigenous or carbonate	Terrigenous or carbonate	Terrigenous or carbonate
Color	Gray to white	Gray to brown	Gray, green, brown	Black, white red
Grain Size	Variable, frameworks, few to no grains	Clay to sand	Clay to sand	Clay
Grain Shape	---	---	---	---
Sorting	---	Poor to good	Poor	Good
Inorganic Sedimentary Structures	---	Lamination, cross-bedding	Graded bedding, cross-bedding, lamination, flute marks, tool marks (turbidites)	Lamination
Organic or Biogenic Sedimentary Structures	---	Trails, burrows	Trails, burrows	Trails, burrows
Fossils	Corals, marine shells	Marine shells	Marine shells, rare plant fragments	Marine shells (mostly microscopic)

These depositional sub-environments can also be thought of as depositional landforms, that is, land-forms produced by deposition rather than erosion. Depositional environments are often separated into three general types, or settings: terrestrial (on land), marginal marine (coastal), and marine (open ocean). Examples of each of these three regional depositional settings are as follows: terrestrial-alluvial fans, glacial valleys, lakes; marginal marine-beaches, deltas, estuaries, tidal mud and sand flats; marine-coral reefs, abyssal plains, and continental slope. During deposition of sediments, physical structures form that is indicative of the conditions that created them. These are known as sedimentary structures. They may provide information about water depth, current speed, environmental setting (for example, marine versus fresh water) or a variety of other factors. Among the more common of these are: bedding planes, beds, channels, cross-beds, ripples, and mud cracks. Bedding planes are the surfaces separating layers of sediment, or beds, in an outcrop of sediment or rock. The beds represent episodes of sedimentation, while the bedding planes usually represent interruptions in sedimentation, either erosion or simply a lack of deposition. Beds and bedding planes are the most common sedimentary structures. Rivers flow in elongated depressions called channels. When river deposits are preserved in the sediment record (for example as part of a delta system), channels also are preserved. These channels appear in rock outcrops as narrow to broad, v- or u-shaped, "bellies" or depressions at the base of otherwise flat beds. Preserved channels are sometimes called cut-outs, because they "cut-out" part of the underlying bed. Submerged bars along a coast or in a river form when water currents or waves transport large volumes of sand or gravel along the bottom. Similarly, wind currents form dunes from sand on a beach or a desert. While these depositional surface features, or bed forms, build up in size, they also migrate in the direction of water or wind flow. This is known as bar or dune migration. Suspended load or bed load material moves up the shallowly inclined, upwind or upcurrent (stoss) side and falls over the crest of the bed form to the steep, downwind or down current (lee) side. If the bed form is cut perpendicular to its long axis (from the stoss to the lee side) one would observe inclined beds of sediment, called cross-beds, which are the preserved leeward faces of the bed form. In an outcrop, these cross-beds can often be seen stacked one atop another; some may be oriented in opposing directions, indicating a change in current or wind direction. When a current or wave passes over sand or silt in shallow water, it forms ripples on the bottom. Ripples are actually just smaller scale versions of dunes or bars. Rows of ripples form perpendicular to the flow direction of the water. When formed by a current, these ripples are asymmetrical in cross-section and move downstream by erosion of sediment from the stoss side of the ripple, and deposition on the lee side. Wave-formed ripples on the ocean floor have a more symmetrical profile, because waves move sediments back and forth, not just in one direction. In an outcrop, ripples appear as very small cross-beds, known as cross-laminations, or simply as undulating bedding planes. When water is trapped in a muddy pool that slowly dries up, the slow sedimentation of the clay particles forms a mud layer on the bottom of the pool. As the last of the water evaporates, the moist clay begins to dry up and crack, producing mud cracks as well as variably shaped mud chips known as mud crack polygons. Interpreting the character of any of the sedimentary structures discussed above (for example, ripples) would primarily provide information concerning the nature of the medium of transport. Mud cracks, preserved on the surface of a bed, give some idea of the nature of the depositional environment; specifically that it experienced alternating periods of wet and dry. All clastic and organic sediments suffer one of two fates. Either they accumulate in a depositional environment, then get buried and lithified (turned to rock by compaction and cementation) to produce sedimentary rock, or they are reexposed by erosion after burial, but before lithification, and go through one or more new cycles of weathering-erosion-transport-deposition-burial. (Motiei, H., 1994).

17. Sedimentary structures

Sedimentary structures are those structures formed during sediment deposition. Sedimentary structures such as cross bedding, graded bedding and ripple marks are utilized in stratigraphic studies to indicate original position of strata in geologically complex terrains and understand the depositional environment of the sediment. (Fig7).

18. Soft sediment deformation structures

Soft-sediment deformation structures or SSD, is a consequence of the loading of wet sediment as burial continues after deposition. The heavier sediment "squeezes" the water out of the underlying sediment due to its own weight. There are three common variants of SSD:

- load structures or load casts (also a type of sole marking) are blobs that form when a denser, wet sediment slumps down on and into a less dense sediment below.
- pseudonodules or ball-and-pillow structures, are pinched-off load structures; these may

also be formed by earthquake energy and referred to as seismites.

- flame structures, "fingers" of mud that protrude into overlying sediments.
- clastic dikes are seams of sedimentary material that cut across sedimentary strata. (Fig8)

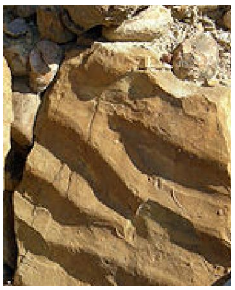

Fig7. Ripple marks in a siltstone

Fig8. Soft-sediment deformation in etched section of carbonaceous sandstone bed of Reedsville Formation

19. Secondary sedimentary structures

Secondary sedimentary structures form during the diagenesis of a sedimentary rock. Common secondary structures include Liesegang rings, cone-in-cone structures, raindrop impressions, and vegetation-induced sedimentary structures.

The term "Facies" can also refer to distinctive facial expressions associated with conditions such as Williams syndrome. (Fig9).

In geology, facies are a body of rock with specified characteristics. Ideally, a facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment. The term facies was introduced by the Swiss geologist Amanz Gressly in 1838 and was part of his significant contribution to the foundations of modern stratigraphy, which replaced the earlier notions of Neptunism.

Fig9. Eolianite carbonate facies (Holocene)

20. Facies types

Sedimentary facies

Sedimentary facies are bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment. Generally, facies are distinguished by what aspect of the rock or sediment is being studied. Thus, facies based on petrological characters such as grain size and mineralogy are called lithofacies, whereas facies based on fossil content are called biofacies. These facies types are usually further subdivided, for examples, you might refer to a "tan, cross-bedded oolitic limestone facies" or a "shale facies". The characteristics of the rock unit come from the depositional environment and original composition. Sedimentary facies reflect depositional environment, each facies being a distinct kind of sediment for that area or environment. Since its inception, the facies concept has been extended to related geological concepts. For example, characteristic associations of organic microfossils, and particulate organic material, in rocks or sediments, are called palynofacies. Discrete seismic units are similarly referred to as seismic facies**. (Fig10)**

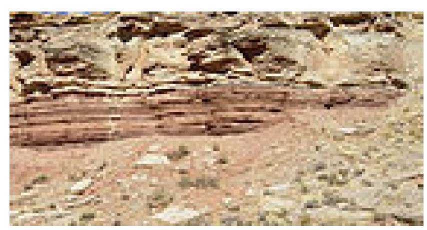

Fig10. Middle Triassic marginal marine siltstone and sandstone facies exposed

21. Metamorphic facies

The sequence of minerals that develop during progressive metamorphism (that is, metamorphism at progressively higher temperatures and/or pressures) define a facies series.

Cretaceous

Name of Cretaceous system is derived from chalk deposits in Northern Europe which is longest period, 75 million years in Mesozoic. (Setudehnia, A., 1978)

22. Cretaceous in Iran

Boundary of Jurassic – Cretaceous has not been described properly In Iran and it is believed by all geologists in Iran that this boundary is identified with late Cimmerian tectonic event which is type of orogeny event. But new results demonstrate that on the contrary of current imagination, in most of regions in Iran, boundary of Tithonian (late Jurassic) and Berriasian (early Cretaceous) epochs are transitional and representative of deep environments. In other words, this event that named early Cimmerian has occurred in beginning of early Cretaceous and after Berriasian epoch and probably in Neocomian (prior to Barremian) that has been resulted in widespread emersion of earth from water and dominance of continental situations. That is why except to Zagros, flysch - bearing basins in east of Iran and Makran are composed of red clastic deposits, after Cimmerian event, which has reached by a transitional passing to Orbitholin – bearing carbonate strata in Barremian – Aptian. These mentioned clastic strata (Shurijeh in Kopet Dagh, Sangestan in Central Iran, Noghreh Formation and …) do not have index fossil and as a stratigraphic viewpoint are known more of Neocomian age. Orbitholin – bearing limestone are most distinct strata from early Cretaceous of Iran which have considerable extent in Alborz (Tizkuh), Kopet Dagh (Tirgan formation), Central Iran (Shahkuh and Taft Formation) and Zagros Mountains (Darian and Fahlian Formation). In widespread zones (except to Makran – Zabol flysch zone), Orbithloin – bearing limestone in Aptian – Barremian with transitional passing, sometimes discontinuously (Zagros), reach to grey – greenish shale - marl deposits which have Ammonites as Beudanticeras in Albian that have been named Kajdomi Formation in Zagros, Dare Zanjir in Central Iran and Sarcheshmeh and Sanganeh in Kopet Dagh. Nevertheless, there is no Albian shale in regions where erosional cycles, depend on Austrian events, are vigorous.

23. Conclusion

In many regions of Iran, except to Zagros, in approximate boundary of early and late Cretaceous, it is observed evidences of tectonic events which are mainly as land generating and can be compared with worldwide Austrian event, in everywhere in Iran except to rare cases (east of Tehran and Yazd). Upper Cretaceous beds in Iran do not have identical facial characteristics and it seems that in contrast to equal sedimentary condition in early Cretaceous, sedimentary basins in upper Cretaceous have been separated from each other and special condition has been dominated in each basin. As a result of that, lithostratigraphic units except to Zagros and Kopet Dagh have not been named and or have local names in upper Cretaceous of Iran. One of characteristics from late Cretaceous of Iran is iteration of tectonic movements depend on events which can be compared with sub Hercynian cycle. That is why sedimentary gaps and erosional cyles as subformation are iterative in upper Cretaceous of Iran. Ultimate sedimentary gap in Cretaceous has been occurred after Maastrichtian which can be compared with Laramide event which has ended Cretaceous system. Besides sedimentary deposits, a part of Cretaceous rocks in Iran is as extrusive lava flows or intrusive bodies. (Yazdi, M., Bahrami, A., Vega, F.J., 2009)Volcanic rocks of Lower Cretaceous can be observed in Alborz and more in Sanandaj – Sirjan zone (Eghlid, Haji abd, Kabudasrahang, Orumieh, Mahabad,). Volcanic rocks in upper Cretaceous have origin in mantle which has been formed in latest phases of formation of ophiolite and in deep basins and have formed a part of Cretaceous ophiolite sets of Iran. Intrusive masses, pertaining to late Cretaceous, have radiometric age as much as 64 – 70 million years which have exposures particularly in Sanandaj – Sirjan zone (Hamdan, Broujerd, Arak …). Intrusive bodies of Bazman are also representative of beginning of subduction of Oman oceanic crust beneath Makran of Iran which has been active since late Cretaceous (64 million years ago). Besides magma activities, process of oceanogenesis, formation of oceanic crust, enclosing of suture zone of Neo Tethys in Zagros and Central Iran, thrusting of oceanic crusts over continental margins and finally mineralization process with magmatic origin imply to dynamism of Geodynamic of Iran in Cretaceous.

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