DOI:10.24996.ijs.2017.58.1C.10

Iraqi Journal of Science

ISSN: 0067-2904

Facies Analysis of The Siliciclastic-calciturbidites, Gercus Formation In Dokan Area, Ne-Iraq; New Insight On Deposition Enviroment And Basin Evolution

Saad Zeki A. Kader Al-Mashaikie*, Younis A. Mohammed

Department of Geology, College of Sciences, University of Baghdad, Baghdad, Iraq.

Abstract

Sedimentologic and facies evidences reveal a marine environment for the Gercus Formation. Facies analysis and associated sedimentary structures including graded beddings decide turbidity origin of the rocks. Marine environment is supported by the identifying glauconite and fossils types reported for the first time.

The formation composed of seven lithotypes; shale/claystone, mudstone, sandstone, carbonate, conglomerate, breccias and debris flow, which are arranged in repeated cycles of mixed siliciclastic-carbonate turbidites in a range of gravity-flow regime. The Gercus successions are grouped into four facies associations confirming marine depositional systems, these are (from bottom to top); slump siliciclastic-calciturbidites (dolomite/shale dominated), proximal siliciclastic-calciturbidites (dolomite/sand dominated), distal siliciclastic-calciturbidites (sand/mud dominated) and slope siliciclastic turbidites (sand/clay dominated) respectively.

Petrographic analysis of sandstone units show predominant of lithic fragments, most of it are carbonate with subordinate tuffaceous fragments, chert, chalcedony, volcanic ash, metamorphic and detrital iron oxides grains, with noticeable grains of glauconite. Varieties of marine fossils are identified includes planktonic bivalves and benthic forams of cool water, which support the deeper marine environment. Petrographic examination of carbonate units reveal skeletal grains of benthic and planktonic forams, stromatolite, planktonic bivalves, corals and algae, with non-skeletal grains of chert, chalcedony, tuffaceous fragments, volcanic ash, and volcanic bubbles.

Petrography, lithofacies and lithostratigraphic analysis of the Gercus Formation suggest deposition in developed marine environment, mainly effected by gravity-flow turbidity currents, and displays successive submarine fans of high density turbulent currents in deeper margins. Mixed siliciclastic-carbonate cycles were deposited in intervals of weaning of turbulent currents. Based on clast type and size, it seems likely that a weakly turbulent to laminar gravity-flow phase was present when the flow event entered the basin at the end part of the fan. A change in flow behavior may have led to deposit sand-rich unit with ‘turbidite’ characteristics, which was subsequently grades upwards to clay-dominated unit.

This paper presents new details of lithostratigraphic subdivisions and associations of the Gercus Formation in Koi Dokan area, and new suggested marine environment of deposition. The previous workers suggest continental and probably mixed with deltaic environments in the upper part.

Keywords*:* Gercus, turbidites, gravity flow, Eocene, NE Iraq.

*Email: magnesite2006@gmail.com

التحليل السحني لصخور المتعكرات السليكاتية الفتاتية – الجيرية لتكوين الجركس في منطقة دوكان، شمال العراق: نظرة جديدة في بيئة الترسيب البحرية وتطور الحوض الرسوبي

سعد زكي عبدالقادر المشايخي*، يونس احمد محمد
قسم علوم الارض، كلية العلوم ، جامعة بغداد ، بغداد ، العراق .

الخلاصة

ان الدلائل الرسوبية والسحنية تشير الى بيئة ترسيب بحرية لتكوين الجركس. التحليل السحني والتراكيب الرسوبية المصاحبة مع وجود التدرج الطبقي تشير الى بيئة المتعكرات العميقة لهذه الصخور. ان دلائل البيئة البحرية تدعم بوجود معدن الكلوكونايت ذو الاصل البحري والذي يشار اليه للمرة الاولى.

يتكون التكوين من سبع انواع من الصخور هي: السجيل، الطين والطين الغريني والحجر الرملي و الصخور الجيرية والكونكلومريت والبريشيا والفتات الصخري الزاحف, والتي تتواجد في دورات متعاقبة من رواسب المتعكرات السلسكاتية الفتاتية–الجيرية ضمن نظام جريان الزحف. تترتب تتابعات رواسب الجركس في اربع مجموعات سحنية تثبت البيئة البحرية للتكوين (وهي من الاسفل الى الاعلى) المتعكرات السليكاتية الفتاتية–الجيرية الزاحفة (الدولومايت–السجيل الغالب) والمتعكرات السليكاتية الفتاتية–الجيرية القريبة (الدولومايت–الرمل الغالب) والمتعكرات السليكاتية الفتاتية–الجيرية البعيدة (الرمل–الطين الغريني الغالب ومتعكرات المنحدر القاري السليكاتية الفتاتية–الجيرية (الرمل–الطين الغالب) على التوالي.

تشير الدراسة الصخرية المايكروسكوبية الى ان الحجر الرملي يتكون غالبا من حبيبات الصخور واغلبها من القطع الجيرية مع نسبة اقل وقطع التف والجرت الصوان والكالسيدوني و قطع الصخور المتحولة وقطع اكاسيد الحديد الفتاتية مع نسبة من حبيبات الكلوكونايت. لقد تم تمييز انواع متعددة من المتحجرات البحرية وتتضمن الفورامنيفرا الطافية والستروماتولايت وذات المصراعين الطافية والاسفنج والاشنات مع انواع من الحبيبات الفتاتية منها الصوان والكالسيدوني والتف والرماد البركاني والفقاعات البركانية.

استنادا الى السحنات الصخرية والتحليل الطباقي السحني فأن تكوين الجركس قد ترسب في بيئة بحرية متطورة ومتأثرة اساسا بتيارات التعكر الجذبية المنحدرة الى الاعماق مكونة مراوح تحت بحرية مكونة من تيارات تعكر ذات كثافة عالية.

ان الدورات الترسيبية المختلطة من الرواسب الفتاتية السليكاتية–الجيرية قد ترسبت في فترات ضعف سرعة تيارات التعكر. واستنادا الى نوع وحجم الحبيبات فأنه من الواضح ان تيارات التعكر الضعيفة وطور الجريان الانسيابي لها قد رسبت هذه الرواسب في وقت دخول التيار الى الحوض في الجزء النهائي من المراوح تحت البحرية. وان التغير في نمط جريان التيارات قد يؤدي الى ترسيب رواسب غنية بالرمال وتتميز بالتراكيب الرسوبية لتيارات التعكر والتي بالتالي تتدرج الى الاعلى الرواسب الطينية.

تظهر هذه الدراسة تقسيم جديد مفصل لتكوين الجركس الى وحدات طباقية صخرية من خلال المجموعات السحنية في منطقة دوكان والتي تشير الى البيئة البحرية للترسيب. ان جميع الدراسات السابقة تشير الى البيئة القارية للتكوين مع وجود بيئة الدلتا في الجزء الاعلى من التكوين.

Introduction

The Gercus Formation comprises a part of the Eocene strata in northern Iraq, represented by thick section of clastic sediments. Complete and good sections of these rocks are cropping out in Koi Sanjaq and Dokan areas, NE side of Hiebat Sultan anticline, which lies in the Unstable Folded Zone [1, 4].

The Gercus Formation is basically a clastic sequence consists of fining upwards cyclothems of predominantly red beds. It consists of carbonate-rich sandstones, marls, siltstones and some conglomerates with few carbonate units. The formation particularly lacks fossils and is dated on the basis of its stratigraphic position and palynological study to be middle Eocene age [5, 6]. It occurs along a relatively narrow NW-SE trending belt that extend from eastern to northern Iraq (Figure-1) and extends northwestwards into SE Turkey [7], to the southeast, the Kashkan Formation in Iran [8] seems to be similar in most aspects to the Gercus Formation including age.

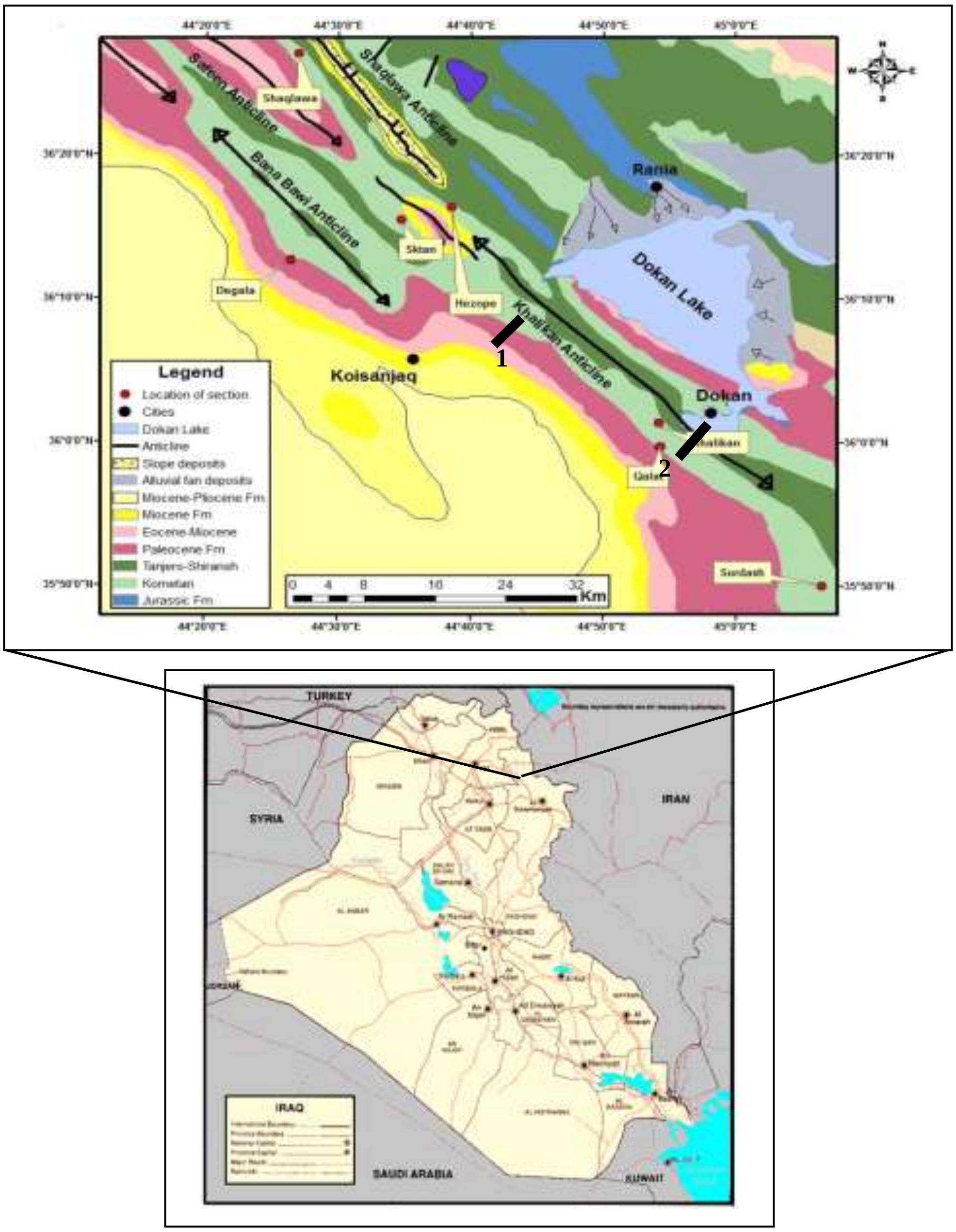


Figure 1- Location and geological maps of the study areas show the studied stratigraphic section (solid black lines) in Hiebat Sultan Mountain in Kalka Smaq locality (2).

The type section of the Gercus Formation lies at Gercus locality in Turkey and a supplementary type section was chosen in Iraq at Dohuk by Wetzel (19470) in [5]. It shows a great deal of lateral variation and it interdigitate and passes laterally westwards and southwestwards (basinward) into lagoonal limestones and marls [9, 5]. To the Northeastwards the formation is wedging out against the landmass, but these limits of the formation are now submerged beneath the thrust blocks. The Gercus Formation shows great variations in thickness in which in the supplementary type section in Duhok area reaching about 850 m (according [5] and 480 m (according [1]).

This paper aims to suggest a new lithostratigraphic subdivision based on detailed field study of lithofacies and associations, stratigraphic sequence relationships, sedimentary structures and detailed petrographic investigation to define new stratigraphic concepts for the Gercus Formation. Moreover, is to suggest new concept for the environment deposition and the basin development through the space and time.

Stratigraphic setting and review

Molasses Gercus Formation is followed the Mid Eocene uplift, which was firstly described in the Gercus region of SE Turkey. It is extended to the Iraqi High Folded Zone [5]. The supplementary type section in Duhok area North Iraq was described by Wetzel (originally referred as Duhok Red Beds) and of 850 m thick red and purple shales, mudstones, sandy and gritty marls, pebbly sandstones and conglomerates. Evaporate lenses of gypsum and halite occur at the top part of the formation. The previous workers observed brown clastics and limestones in the Demir Dagh area [10] and noted that the proportion and grain size of the clastics increase towards north and northeast [2, 4]. The formation is cropping out in the Unstable Shelf of the High Folded Zone, which is submerged along the Northern Thrust Zone; the original depositional limit lay further to the north [2]. The formation shows variable thickness, which is decreasing to 100 m toward the southeast near the Iranian border along the Sirwan (Diyala) River. It shows variable thicknesses on both sides of the Derbandikhan anticline, from 300 m on the northeast limb to 50 m along the southwest limb, due to the growth of the structure in Middle Eocene time [11]. The formation thins toward northeast and southwest due to depositional thinning and facies changes respectively, and is encountered in drilled-wells of Taq Taq (66 m thick) and Demir Dagh (117 m thick) [2]. It attains about 200 m thick of red claystone with subordinate sandstone horizons, and believed to represent fluvio-deltaic facies of the Middle-Late Eocene cycle, which is typical red molasses sequence derived from uplifted areas [1, 2, 3, 12].

The age of the formation is Middle Eocene after [5] and [10] and fossils are very rare and most probably reworked [2, 4]. Palynological data of [6] was dated the Gercus Formation as Late Lower Eocene.

In Derbendikhan area, the lower contact is with Sinjar Formation, and in Duhok area is unconformable with Khurmala Formation as previously reported [11]. [5] was observed an unconformity between the Kolosh and Gercus Formations. In the subsurface of northeast Iraq, it is unconformable overlies various Paleocene-Lower Eocene formations. Basal conglomerates of the Gercus Formation are often contained pebbles of the underlying units. [2] reported conformable and gradationally overlain by the Pila Spi Formation.

Methodology and lithostratigraphic aspects

For the investigation, a typical section lies above Kalka Smaq villages is selected. The studied section lies 3 km above Kalka Smaq village on both sides of the Hiebat Sultan anticline. This sections lies along the main trough axis of the Paleogene foreland basin (Figure- 1). Examinations were carried out for investigation on lithology, petrography, sedimentary structures, lithofacies and on the stratigraphic sequences. Field photographic documentation was enforced for the whole stratigraphic section, for lithologies, sedimentary structures and different lithofacies types. Fifty (50) rock samples are collected from both studied sections. For facies analysis, 90 thin-sections slides are cutting perpendicular to the bedding plane prepared according to the procedure explained in [13]. To define the specific mineralogy and lithology, microphotographs are picking up for different mineralogical constituents using Leitz LaborLux 11 petrographic microscope.

The classification of the Gercus rocks, as indicated here, follows the definitions of [14-19].

Lithostratigraphy (This study)

Field observations have revealed seven lithofacies types, which are distinguished and classified based on the differences of certain sediment characteristics such as grain size, color, sedimentary structures and changes in lithological composition if any. These lithofacies are; shale/claystone, mudstone, sandstone, carbonate, conglomerate, breccias and debris flow. The boundaries between lithofacies types are defined based on such characteristics, however they are generally transitional.

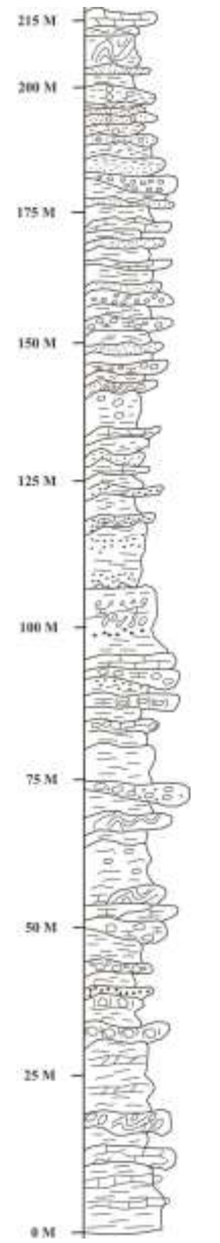
Lithology of the Gercus Formation consists of dark gray, yellowish to grayish brown, pinkish and red, massive, cross-bedded, medium to fine-grained sandstones, little of are pebbly, which is interbedded with thick, fissile and laminated siltstone/shale beds and claystone of gray to red color. These clastic succession are interbedded with carbonate horizons with carbonate breccias and debris flow beds,

Sedimentology

Detailed field observations discuss the sedimentological features of the Gercus Formation, as follows;***The thickness*** of the Gercus Formation attains about 215 m in the Kalka Smaq section (Figures-2 and 3).

The lower and upper boundaries of the Gercus Formation is gradational and conformable with the lower Kolosh Formation and the upper Pila Spi Formation. The lower boundary is grading from dark gray turbidity cycles to gray and reddish gray turbidity cycles. While the upper boundary reveals red mudstone (the last horizon in the Gercus Formation) grading upwards to whitish green marl with local debrite. This carbonate debrite is grades laterally to marls, and upward to laminated shales and limestones respectively. In places, submarine channel filled with carbonate breccias are grading upwards to marl.

Fossils verities are observed in the carbonate horizons contain characteristic fossils types. The carbonate rocks include stromatolites. algae, corals, benthic and planktonic foraminifera and planktonic bivalves. While the sandstone units contain mainly planktonic foraminifer with less benthic types. The fossiliferous sandstone units are rich in preserved organic matters.



Pila Spi Formation

Gradational contact with overlying Pila Spi Formation

50 m Slump and slide sandstone beds grade upward to red argillaceous-matrix, with convolute, load, scoured and flute casts. The most characteristics are sigmodal successive channels filled with fine-grained sandstones overlain successive beds of slumped and fragmented sandstones. These successions overlying with thin, lens and wedge carbonate beds.

55 m Successions of channeled fill carbonate breccias grades to red and dark gray mudstone/shale. Thick slump, scoured, fluted and load casted sandstones are grade upward to gray fissile shale. Successive slump beds of sandstones grade upward to black fissile shale. These successions are interbedded with slumping dolomites, scoured and load casted. The breccia includes large and small clasts. The color is dark gray, brown and reddish color

60-65 m Successive interbedded thick and thin slump sandstones and brecciated dolomite grades to claystone and shale beds. Most of the sandstone and carbonate beds are slumped and channeled, and arranged in turbidity cycles. The beds are scoured, flute and load. Beds are of dark gray, green and red color. These successions are interbedded with carbonate breccias. This part includes little sandstone beds

50-55 m Slumped dolomite with balls structures grades upward to dark gray fissile shale, carbonate breccia, matrix supported clast are carbonate, grades to gray shale interbedded with channeled bedded dolomite/shale couplet, scoured and load casted. In part, some beds are slump, slide and convoluted. This part includes little sandstone beds

Figure 2- Stratigraphic section of the Gercus Formation above Kalka Smaq village in Dokan area shows description of different lithologic units.

Sedimentary structures of specific turbidity origin are recognized through the stratigraphic section c.f. graded beddings, slump, slide deformed and convolute beds, scour, groove, load and flute casts, clay and sand balls and pillows, subaquatic channels, sigmoidal channel with slump structures longitudinal ripple marks and trace fossils e.g. borings and burrows. These are typical characteristic structures of turbidity current and gravity flow regime. These structures were classified and described according to [20, 21, 22, 18, 23, 24, 25].

Submarine channels, are characteristic structure of high energy gravity flow and turbidity currents lead to form submarine outwash fans (Pl/1A). Small and large size channels were recognized in the lower and upper parts of the formation. It is commonly associated with the graded beddings, debris flows, ball and pillows, and slump disturbed structures.

Graded beddings, are the most common type in the Gercus Formation (Pl/1B) comprises turbidity Bouma cycles. In parts, all of the turbidity cycle subdivisions (Ta, Tb, Tc, Td, Te) were observed and in the other parts some of these subdivisions (Tc, Td and Te) are identified. Debris flow and very few conglomerates are recognized underlying the graded turbidity cycles, in which the pebbly sandstone grades upwards to fine-argillaceous-siltstone and fissile shale/claystone beds.

Load casts, are erosional characteristic structures of the turbidity current and was identified in the studied sections (Pl/1C). It was recognized at the upper surface of the fine-argillaceous mudstone, shale and claystone beds. Load casts are heel-shaped hollows, scoured into mud bottoms, each hollow is generally infilled by sand, contiguous with the overlying bed.

Scour and fill structures are observed in all parts of the formation, as isolated, elongate or U, or v-shaped depressions, and sometimes are slightly or moderately sinuous over various distances (Pl/C).

Flute casts are observed in all of the stratigraphic units of the formation as crescent or horseshoe-shaped depressions without obstacles and of various shapes e.g. narrow elongate to broad transverse scours (Pl/1D).

Groove casts; are striation grooves recognized in the upper surface of dark gray shale and claystone beds (Pl/1E). The groove cast comprises the sliding surface of the overlying bed/or bed sets over a more lubricant clay surface after saturated with waters [18, 23, 24, 25].

Ball and pillow structures, are of various sizes of sand and clay balls and pillows of random distribution in the beds (Pl/1F) of sandstones and fine-argillaceous claystones and shales. It is a common characteristic structures of turbidity currents action.

Slump and slide deformed beds, structures are identified as bed and/or group of beds, implying internal deformation of coherently deformed beds to totally disturbed strata (Pl/1G,H) [18, 23, 25]. Thicknesses of the beds range from 0.5 to 3 m. The distinct slump and slide deformed structures are observed in the sandstones and mudstones beds as well as the carbonate debris flows and breccias.

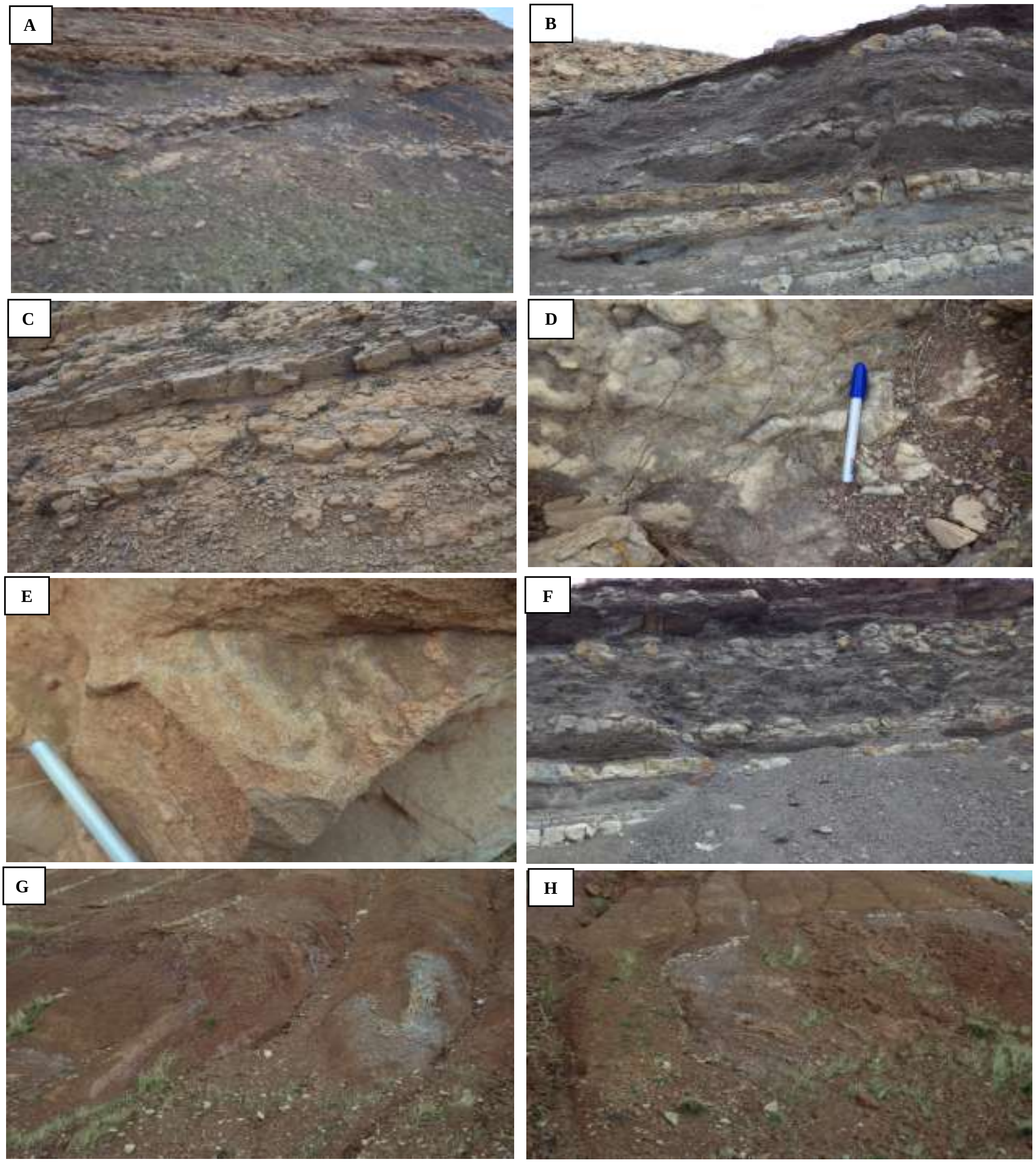


Plate 1- Field photographs show primary sedimentary structures observed in the Gercus Formation. **A)** Submarine channels in the middle part **B)** Graded beddings, **C)** Load, scour and fill structures, **D)** Flute casts, **E)** Groove casts, **F)** Sand and clay balls and pillow structures, **G,H)** Slump, slide and convolute beddings. **(Pencil=10 cm).**

Convolute beddings are recognized in the successions of the studied units of the formation. Large scale of convolute beddings is observed in the lower unit (Pl/1G,H).

Ripple marks, are identified in the sandstone and dolomite horizons. Some are longitudinal and others are multi-directional ripples of wavy and extends in all directions, which recognized in the middle part of the formation. It is. It is formed by the collision of the currents with standing water and oscillate in various directions [18, 24]. While the wavy type is of small scale.

Cross stratifications, several types of cross beddings and laminations are recognized in the sandstone horizons e.g. normal, tabular and hummocky stratification.
Biogenic structures, observed as burrows and borings of animal activity in the sandstones horizons and in the surface contact with fine-argillaceous sediment. Large and small burrows were recognized with Plant remains and debris are also recognized in the shale horizons of the lower part of the formation.

Petrography

According to the classification of [26] and [27] the sandy group is mainly composed of lithic arenites. In several samples from the sandstone beds, the matrix content is very low and less than 2%. Considering the total chert and chalcedony (5-10%) and the total carbonate lithic fragments (50-55%). Tuffaceous, volcanic ash and bubbles are also recognized and attains about (5-10%) (Pl/2,A-F). In the Gercus Formation, the main cementing materials are carbonates, with subordinate ferruginous cement.
Some sandstone beds have noticeable glauconite grains (Pl/2A) and are less than 1%. Other lithic fragments like metamorphic are rare abundance as well as quartz, feldspars and argillaceous fragments. The size of the sandy particles can be generally characterized as fine sands. The main content of the heavy mineral fractions is opaques include magnetite, hematite, ilmenite, chromite with subordinate zircon, tourmaline, hornblende and garnet. Applied of [28] Diagram of tectonic setting and provenance suggest that the Gercus sediments are derived from dissected arc in active tectonic setting associate with few metamorphic rocks.
Petrography of carbonate units' show varieties of fossils with different grains mostly of volcanic origin c.f. tuffaceous fragments, volcanic ash and bubbles, chert, chalcedony, spherules…etc (Pl/2 G,H)

Facies analysis

The identified lithologies and facies types are repeated through the stratigraphic section, these are; shales/claystones, sandstones, carbonates, carbonate breccias, conglomerate, and debris flow. Each of these lithotypes can classified into several characteristic facies types.

Shale/claystone facies

Shale facies is one of the main constituents of the Gercus Formation. It is thick and thin beds of 0.5 up to 2-3 m. Concerning grain size, it is a mixture of clay and few silt fraction with predominance of clays [26, 29]. Sedimentary structures are horizontal laminations, resulting from the presence of silty lamina.

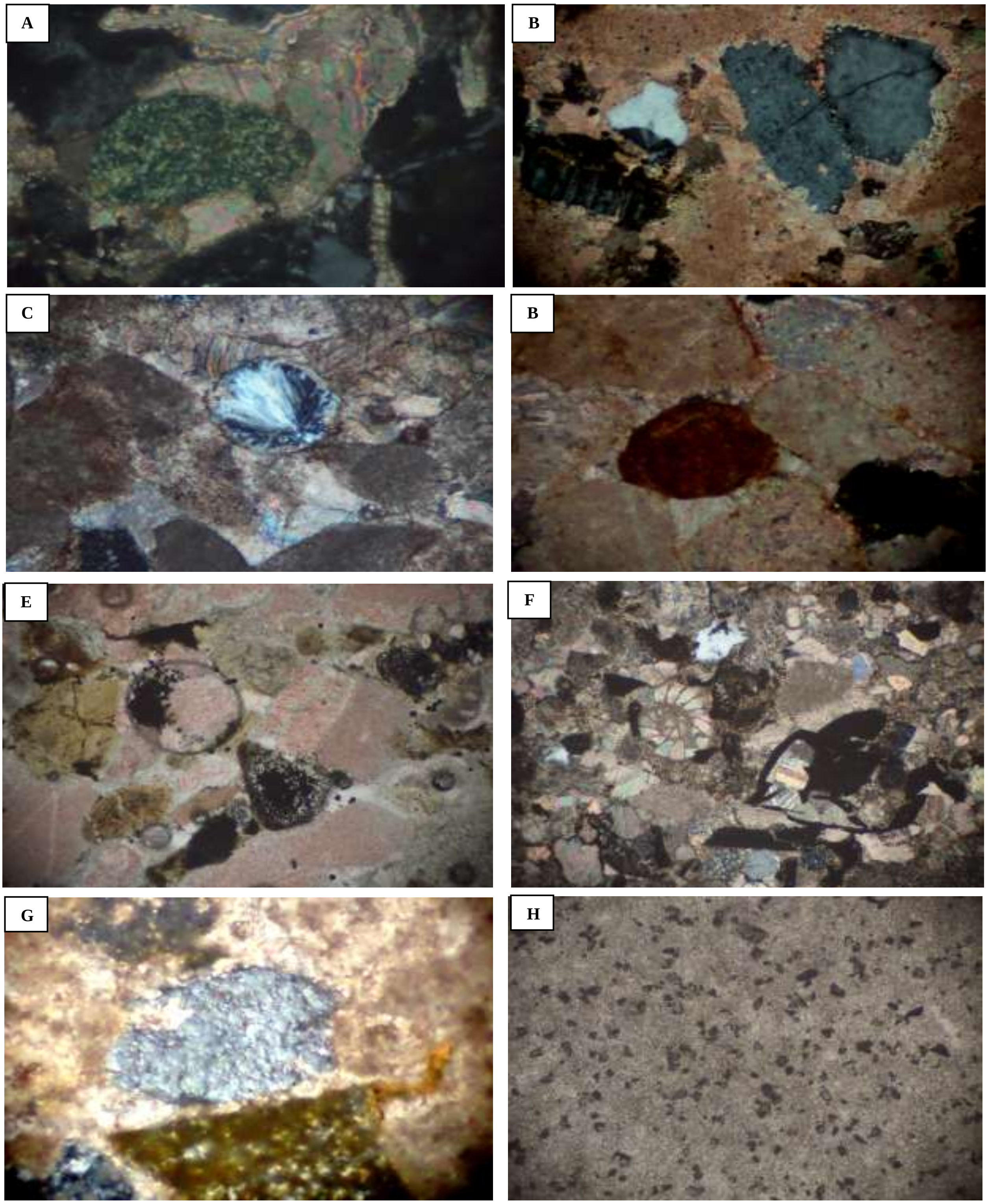


Plate 2- Photomicrographs show mineralogical components of the sandstone and carbonate units in the Gercus Formation (CNx40X). Glauconite grain, **B)** Cristobalite, quartz, feldspar and carbonate fragments, **C)** Chalcedony and carbonate fragments, **D)** Argillaceous with iron oxide cement, **E)** Volcanic spherule, **F)** Fossiliferous sandstone, **G)** Cristobalite, quartz, feldspar and carbonate fragments **H)** volcanic ash in carbonates.

The geometries are strata like and the upper boundaries are sharp, scoured, fluted and grooved, while the lower are gradational. Clay balls and pillows with convolute structures were reported in this lithofacies. It represents the upper subdivision (Te) of the turbidity cycle. Several facies types of shale are observed;

Laminated shale facies are recognized in the lower and middle parts of the formation**.** This facies is very thin laminated and reveals deformational structures e.g., convolute and slump structures, ball and pillows, scoured surface, flute cats…etc. it attains 0.5 to 1 m in thickness and of dark gray to black in color. Laminated shale is grading form the underlying carbonate breccias or sandstone bed representing Te subdivision of the turbidity cycle.

Fissile shale facies are mostly recognized in the lower part of the formation and characterized by fissility property**.** It attains 1 to 1.25 m in thickness and of dark gray to black in color. This facies reveals deformational structures e.g., convolute and slump structures, ball and pillows, scoured surface, flute cats…etc. Fissile shale is grading form the underlying carbonate breccias, dolomite breccias or sandstone bed representing Te subdivision of the turbidity cycle.

Thick massive claystone facies comprise very thick and massive claystone beds. It is almost of gray and red color and ranges in thickness from less than 0.5 meter to 2 m. Massive claystone facies represents subdivision Te of the turbidity cycles. Clay balls and pillows are present with load and flute casts. No fossils were observed in this lithofacies.

Claystone/siltstone couplet facies is composed of very laminated claystone/siltstone interbeds. It attains 1 to 1.5 m in thickness and of dark gray to brownish gray in color. It is grading from sandstone or carbonate beds as (Te) division of turbidity cycle and recognized in the middle and upper parts

Sandstone facies

The sandy facies mainly include sand and silty sand. The thickness of the sandy beds is usually 0.5 to 2 m. Frequently, graded beddings in fining upwards turbidity cycles were encountered, but subordinately, massive beds could be observed as well as planner and cross-laminations. The lower boundary of individual bed is mainly sharp, flat, less irregular, with scours and the upper is grading to the shaly facies.

Very fine-grained sandstone facies composed of very fine-grained, very well sorted and massive to deformed beds. It is of about 0.5 to 1.5 m thick and of dark gray to brownish gray in color. This facies reveals disturbance and disorganized due to slumping deformation.

Cross-bedded sandstone facies composed of fine to very fine-grained, and dark gray to brownish gray in color. This facies attains 0.25 to 0.7 m in thickness. Several types of cross-beddings are observed c.f. normal, hummocky, and trough types. This facies are observed in the lower and upper parts of the formation, which grades upwards to mudstone and fissile shale beds as a part of turbidity cycles.

Rippled sandstone facies composed of very fine-grained sandstone and of brownish gray color. This facies attains 0,25 to 1.5 m in thickness and of brownish green color. Sometimes, this facies shows little deformation due to slump action and grades upwards to mudstone and fissile shale beds in a turbidity cycles.

Thick and thin sandstone facies composed of fine-grained sandstone, which attains 0.25 to 1 m in thickness and of red to gray in color. Some beds of this facies show disturbance and disorganizes due to slump action. Thick massive and thin beds of sandstones are observed in the Gercus Formation mostly grades upwards to mudstone and fissile shale beds as a part of turbidity cycles.

Carbonate facies

Several types of lithofacies are observed of carbonate types these are;

Dolomite facies composed of dark gray, thick and massive dolomite beds. It is observed in the all the stratigraphic units of the Gercus Formation from bottom to top. This facies attains about 1 m or more less and grades upwards to dark gray and black fissile shale in turbidity cycles.

Limestone facies composed of whitish yellow to drab color and observed as massive thin and thick beds. It is observed in the stratigraphic units of the Gercus Formation from bottom to top. This facies attains about 0.5 m, which grades upwards to dark gray and black fissile shale in turbidity cycles.

Dolomitic limestone facies composed of yellow gray color and observed as massive thin and thick beds. It is observed in all of the stratigraphic units of the Gercus Formation from bottom to top. This facies attains about 0.25 to 0.5 m, which grades upwards to dark gray and black fissile shale in turbidity cycles. It sometimes grades to red mudstone lithotype.

Carbonate breccias and debris flow facies

Several types of carbonate breccias are recognized in the Gercus Formation, these are;

Dolomite breccias facies composed of dark gray, thick bed (c.f. 1-1.25 m thick) of fragmented dolomites, which is supported by marly dolomite materials. This facies is grading upwards to black to dark gray fissile shale in siliciclastic-calciturbidite cycles.

Balls and pillow dolomite facies composed of dark gray, thick bed (c.f. 1 m thick) of dolomites composed essentially of dolomite balls and pillows structures, which is supported by marly dolomite materials. It grades upward to black /dark gray fissile shale in siliciclastic-calciturbidite cycles.

Slump/slide carbonate breccia facies composed of gray, thick bed (c.f. 1 m thick) composed essentially of dolomite and limestone fragments, which is supported by dolo-marly materials. This facies is grading upwards to dark gray fissile shale in siliciclastic-calciturbidite cycles.

Carbonate debris flow facies composed of accumulation of dense carbonate fragments of different sizes. It attains 1 to 2 m in thickness and of whitish drab in color. The lithology of this facies composed of various dolomite, dolomitic limestone and limestone fragments. Debris flow facies represents the accumulation of very coarse-grained c.f. fragments, in the entrance of submarine channel fan to the basin.

Mudstone facies composed of argillaceous clay and silt fractions mostly of red color. This facies attains thicknesses ranges from 0.5 up to 3 m. it represents the Te subdivision of the Bouma turbidity cycles. This facies reveals deformational structures and disturbance c.f. slump and convolute structures.

Microfacies analysis and depositional environment of carbonate units

Petrographic examination of the carbonate units reveal eight (8) microfacies types these are; foraminiferal packstone/mudstone, foraminiferal wackestone, algal mudstone, stromatolite framestone, radiolarian calcisphere packstone, foraminiferal dolomitic wackestone, algal foraminiferal packstone, foraminiferal dolo wackestone (Pl/3A-H). These microfacies suggest reef to for-reef environment with deeper marginal setting evident from the presence of radiolaria and calcisphere fossils. Moreover, the associated carbonate breccias and debris flows refer to the slump of the carbonate ramp sediments to deeper margins.

Facies associations

Based on facies types, facies successions and rock sequence, the Gercus Formation is subdivided into four facies associations comprised stratigraphic units and certain depositional system, (form bottom to top);

Unit-A, FA1 Slump siliciclastic-calciturbidites (dolomite/shale dominated)

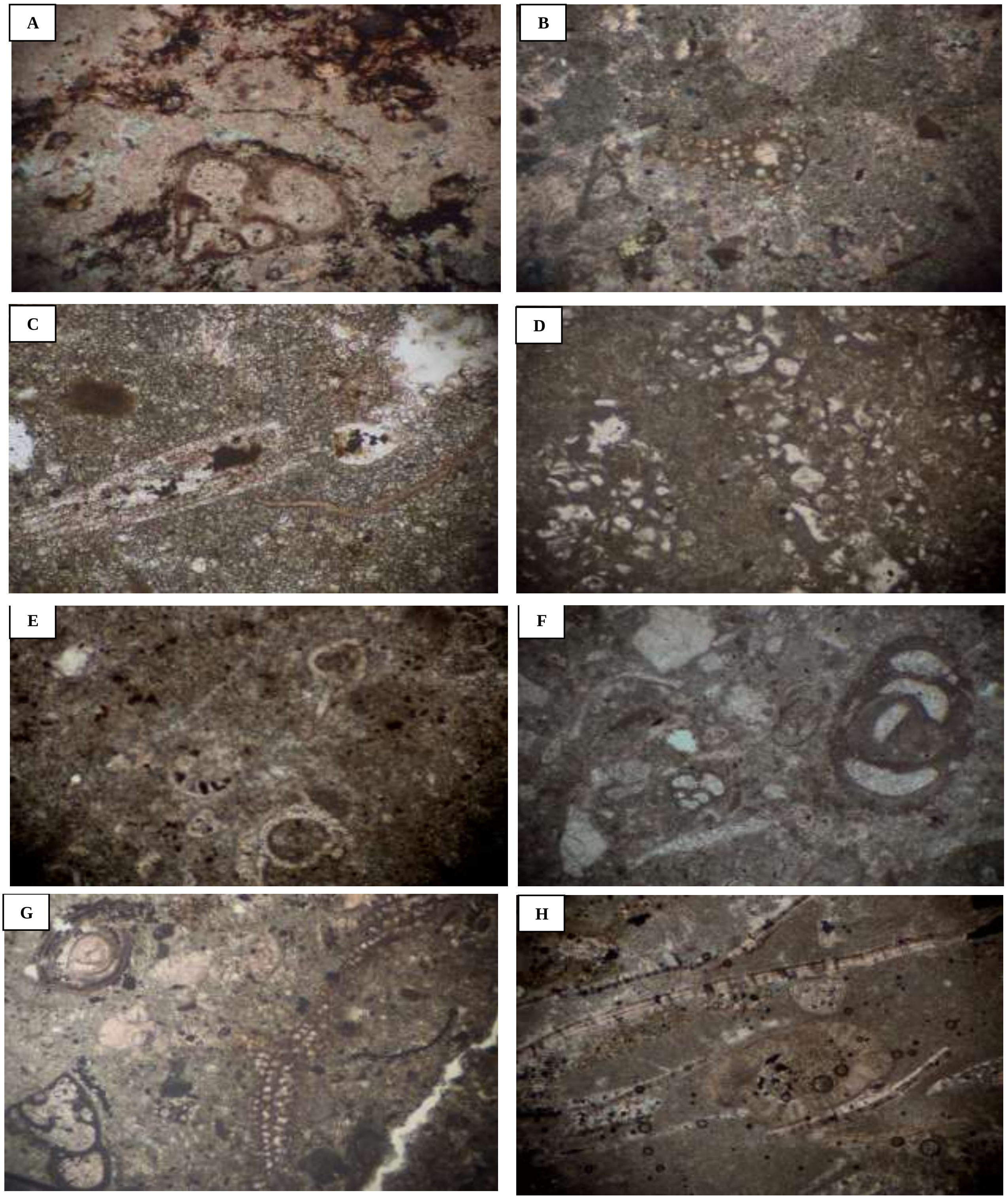
FA1 composed of cyclic repetitions of thick fluted, scoured, load casted, balls and pillows dolomites, dolomite breccias and dark gray dolomites, grading upwards to black and dark gray fissile shales. This unit reveals characteristic sedimentary structures of turbidity origin c.f. ball and pillows, flute, groove, scour and load casts, submarine channels, slump and convolute beddings, trace fossils, plant remains…etc., the most characteristics is the graded beddings. The dominated lithology is dolomite, dolomite breccias and fissile shale beds.

Unit-B, FA2 Proximal siliciclastic-calciturbidites (dolomite-sand/shale dominated),

This unit composed of cyclothems of interbedded thick dolomites, dolomite breccias and fine-grained sandstones, grading upwards to dark gray fissile shales, which reveals characteristic sedimentary structures of turbidity origin c.f. ball and pillows, flute, groove and load casts, debris flows, submarine channels, slump and convolute beddings…etc. There is one conglomerate bed recognized have a lens shape and most probably of submarine channel. This conglomerate is grading upwards to sandstone and shale in turbidity cycles. The dominated lithology is sandstones, dolomite and fissile shale beds.

Unit-C, FA3 Distal siliciclastic-calciturbidites (sand/mud dominated)

This unit composed of repeated cycles of thick gray to brownish gray sandstones, dolomites, debris flows and breccias, grading upwards to dark gray fissile shales and red and grayish mudstones. This unit is characterized by sedimentary structures of turbidity current origin c.f. ball and pillows, flute, groove and load casts, debris flows, submarine channels, slump and convolute beddings, collapse channel levee…etc. The dominated lithology is sandstones, dolomite and fissile shale beds. The shale horizons in this unit are black color and reveals waxy organic matters.



Plat 3-Photomicrographs show the microfacies types in the carbonate units in the Gercus Formation (CNx40X).

A) foraminiferal packstone/mudstone, **B)** foraminiferal wackestone, **C)** algal mudstone, **D)** Stromatolite framestone, **E)** radiolarian calcisphere packstone, **F)** foraminiferal dolomitic wackestone, **G)** algal foraminiferal packstone, **H)** foraminiferal dolo wackestone.

Unit-D, FA4 Slope siliciclastic turbidites (sand/clay dominated)

This unit composed of interbedded cycles of thick brownish gray sandstone, dolomitic limestone, carbonate breccias, grading upwards to gray and red mudstones. It reveals characteristic sedimentary structures of turbidity origin c.f. ball and pillows, flute, groove and load casts, debris flows, disturbed disorganized beds, submarine sigmoidal channels, slump and convolute beddings…etc. The dominated lithology is sandstones, dolomite and red mudstone beds.

Interpretation and discussion

Arrangement of Bouma turbidites in the Gercus Formation, which are composed of lens like conglomerate, pebbly sandstones, fine-grained sandstones and fissile shale/claystone subdivisions in fining upward cycles. These cycles are associated with deformed slump beds, carbonate breccias and debris flows as described in all facies association units and represent developed marine environment.

FA1 unit preserved between the gradational surface of the lower Kolosh Formation and the overlying transgressive surface of FA1 of marine turbidites in the lower unit [17, 18, 30, 31, 32]. The latter surface is on lapped by slump siliciclastic-calciturbidite cycles deposited in deeper marine conditions. Subaqueous streams of gravity flows are displaying, which is the proposed origin for debris flows, breccias, conglomerates and pebbly sandstones facies. These facies types are locally preserved on the original bounding surface or in submarine channels [17, 18, 19, 33]. Submarine gravity flows and associated fans incorporate streams are originated by annual turbidity currents most probably created by tectonic events. This interpretation is based on the presence of slump, slide and convolute structures and limited lateral extent of the debris flows, breccias and conglomerate beds [14, 16, 17, 18, 32, 34, 35]. Moreover, the Gercus Basin is a part of foreland basin situated in active subduction zone of Zagros Belt [2, 4]. The units FA1, FA2, FA3 and FA4 successions display analogies with Bouma turbidity sequences as evidenced by:

1) Cyclic repetition of fining upward successions i.e., graded beddings, 2) Upward grading of pebbly sandstone and massive, parallel laminated, rippled sandstones grades to thick shale/claystone bed, 3) Observable lateral extension. 4) Associated with specific sedimentary structures of turbidity origin c.f. slump, slide, convolute, disturbed deformed beds, load, scour, groove and flute cats, graded beddings…etc.

Mechanism of the settle down sedimentary gravity flows have been discussed and applied to deep sea fan models in great deal of literatures (c.f. [16, 17, 18, 19, 23, 35-41].

Mud flows c.f. red argillaceous matrix mudstone, and high to low density turbidity currents have been discussed in the recent papers, for various formations (e.g., [36, 42-51]). Although, many authors have restricted the fact of turbidity currents by formation of rhythmite referring to the annual significance of varve (very fine sandstones and/or siltstone/mudstone couplets) [52-60]. Re-deposition processes are carried out if sub aquatic marginal fans, deltas and other sediments build-up are unstable over steep slopes due to either rapid sedimentation, increased overburden sediments, storm action or shocking of earthquakes. The current mechanisms caused the coarse to fine sand sized sediments are related to sediment gravity flows, followed by high density current flows can be applied the terms of [41]. The range of successions from coarse to gravelly turbulent flow e.g. subdivision Ta of Bouma cycle and subdivision Tb-sandstones, to more light laminar sandy flows e.g. subdivision Tc and Td, with tract suspension flows comprise flat laminations and occasional rippled cross laminations. The upper shale or claystone horizon of Te division of Bouma cycle representing suspended sediments of turbidity currents [17, 18, 19]. Faint lamination of some gravelly basal horizons may comprise increases in shear rate under steady flows and developed depressive's pressures [15, 41, 61].

However, actual interpretations by [61] for deep marine carbonate, breccias, and [51] of conglomerate genesis based on lithofacies relationships and sequence context. Intercalated of 1-2.5 m thick tabular body of carbonate breccias or conglomerate within un-deformed turbidity successions is representative for debris flows in which clasts are supported by strength and floated sand-clay water fluid.

Shallow water graded sand-beds were discussed by several authors with vertical successions resemble deep water turbidites as related to storm effects [14, 15, 62- 66]. Deposition of initial phase of storms are emplaced sand on the shelf, and later reworking of sand by storm wave action [67].

In FA2 and FA3 units, no typical hummocky cross-stratifications or wave related ripple marks have been observed, and the following structures may reject the storm sequences as defined by [14, 65, 66, 67]:

Units FA2 and FA3 reveal scoured base, flute and load casts, with massive and graded aspect of the basal subdivision Ta-pebbly sandstone and massive sandstone beds-Tb. These are characterized by non-frequent un-rippled lamination in Tb subdivision of Bouma cycle and absence of complex polygonal ripples which may represent small scale hummocky cross-stratifications as described by [68, 69, 70].

Beds of facies association units are most probably generated by gravity flow processes in fore slope in subaqueous fan fed by turbidity currents. These are supported by lateral extent, consistent development of Bouma cycle subdivisions, absence of angular cross-beddings, and repetitive successions. Repeated successions reflect episodic pulses of dense sediment laden turbidity currents swept down the fan.

The boundary surface between FA1 and FA2 units is on lapped by thick slumped nodular limestone bed of FA2 unit, which is interpreted as the start of another submarine fan. This limestone has exceptional thickness 2-2.5 m when compared to modern [35, 71, 72, 73] or ancient models [74, 75, 76]. The study sited new stratigraphic aspects, which are not discussed and reported previously;

1. The study newly report marine environment for the Gercus Formation where the previous studies suggested fluvial environment, probably mixed with deltaic in the upper most part. One of the most important evidence for marine environment is the presence of glauconite grains in approximation of many sandstone beds [77-84].

2. The identification of marl and fossiliferous and dolomitic limestones interbedded with successive siliciclastic turbidity cycle strongly evident the marine environment. The fossils include stromatolites, marine algae, planktonic and benthic foraminifera, planktonic bivalve and radiolaria are strong evidences for marine environment.

3. Some of Gercus sandstone horizons includes varieties of fossils and organic debris c.f. planktonic forma, corals and calcisphere, which support the marine environment.

4. The study reveals cyclic repetitions of turbidity cycles, identified in all stratigraphic units, and caped with carbonate horizons, which are strong evidence of marine environment.

5. The Gercus Formation is situated between the underlying deep-marine turbidites of Kolosh Formation and overlying Pila Spi Formation of carbonate breccias of deeper marine margins. It is not accepted to suggest fluvial environment for a formation bounded between two deeper marine formations.

6. The turbidity cycles of the Kolosh Formation are continuous in all units of the Gercus Formation. Moreover, the Gercus Formation displays gradational boundary with the underlying Kolosh and overlying Pila Spi Formations. The boundary is grading upwards form red mudstone to marl and marly limestone with calcareous debrites. The debrites bed extends for 3 to 5 m and is laterally changes to marl, which is later grading upwards to limestone rocks. The previous studies pointed that the carbonate debrite bed is a basal conglomerate between the Gercus and Pila Spi Formations.

7. Gercus Formation reveals specific varieties of sedimentary structures, interpreted as of turbidity and gravity flow origin, c.f. sand and clay balls and pillows, load, flute, gutter, scour and groove casts, graded beddings, laminar stratifications, disturbed deformed beddings, slump, slide and convolute structures.

8. The carbonate units of the lower part in the Gercus Formation is suggested here as a part of the Gercus Formation and not belongs to the Khurmala or Sinjar Formations. This is due to;

A. The carbonate facies in the Gercus Formation composed of slump/slide and convolute beds as well as ball and pillows dolomite beds. While the Khurmala and Sinjar Formations are quite different.

B. There are several beds of carbonate breccias in the lower and middle parts of the Gercus Formation which are quite differ and not reported in the Khurmala and Sinjar Formations.

C. The carbonate rocks are arranged in siliciclastic-calciturbidite successions, grading upwards to thick black and dark gray fissile shale, which are not match those in the Khurmala and Sinjar Formations.

D. The successions of siliciclastic-calciturbidites reveal successive submarine channels with scour, flute, gutter and groove casts, slump, slide and convolute beds a typical sedimentary structures of turbidity origin, which are also not recorded in both Khurmala and Sinjar Formations.

E. The presence of successive black and dark gray shale in the lower part of the Gercus Formation are quite differ from the Khurmala and Sinjar Formation.

F. The reported depositional environment of the Khurmala and Sinjar Formation is outer shelf, fore-reef, reef, back reef, lagoon and intertidal zones respectively. While the lower part of the Gercus Formation is deeper marine environment and is quite differ from Khurmala and Sinjar Formations.

G. The presence of planktonic forams, calcisphere, radiolaria and planktonic bivalve reject the idea of the Khurmala and Sinjar tongue, which are differ in fossils content.

H. Khurmala and Sinjar tongues of Early Eocene age are recorded in the upper part of the Kolosh Formation. While the carbonate units in the lower part of the Gercus Formation are underlying with several red sandstone and mudstone beds as well as overlying it.

I. The reported thicknesses of the Khurmala and Sinjar Formations are very thick and reaches up to 20 m. While carbonate units of the lower part of the Gercus Formation are of 0.5 to 1.25 m thick.

J. The presence of submarine channels mostly associated with debrite beds refer to the deposition in the mouth of the submarine fans, which are not reported in Khurmala and Sinjar Formations.

The depositional model for the Gercus Formation is related to tectonic activity and intense volcanic eruptions at the northeastern border of the foreland basin. Volcanics are 3000 m thick successions of Eocene, which are cropping out directly at the Iraq-Iran boarder [85-92]. These volcanoes are the source of detrital volcanic fragments and the red argillaceous matrix mudstone flows in the Gercus successions (Figure-3), which is interbedded with the siliciclastic-carbonate in graded upwards turbidity cycles. Progressive subduction formed earthquakes vibration that led to slump the accumulated sediments on the slope to deeper margins. Moreover, continuous subduction resulted more volcanic eruptions and continuous red mud flows to the basin

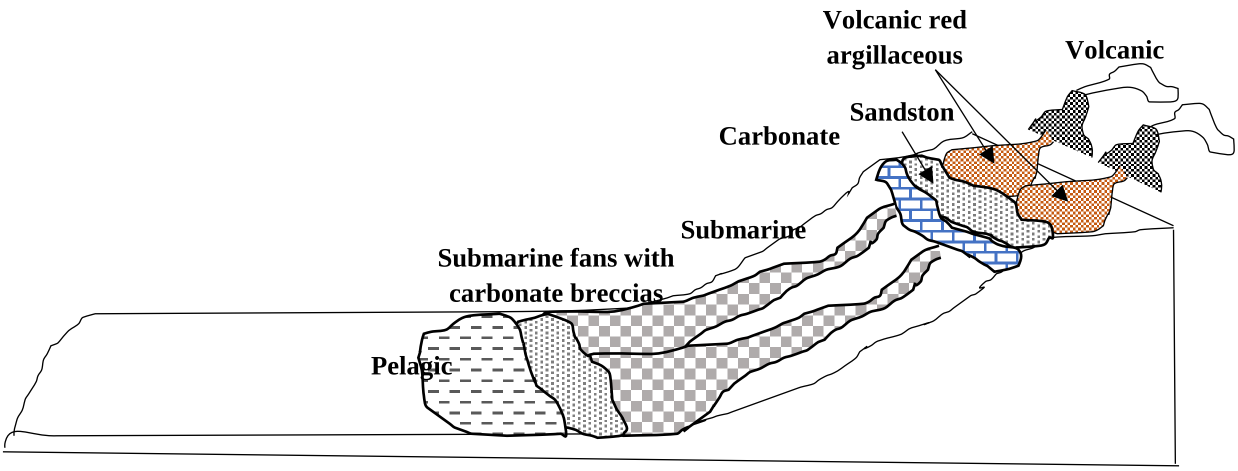


Figure 3- Schematic diagram shows the depositional environment and tectonostratigraphic evolution of the Gercus Basin and sedimentation during Middle Eocene time

Subduction movements creates rift extension acting perpendicular to the general direction of the subduction in complex stresses pattern, which is responsible for the deepening of the basin and forming the slump/tectonic carbonate breccias, debris flows and turbidity cycles.

The stratigraphic successions and sedimentological characters of the Gercus Formation suggest an interesting marine environment in the stratigraphic column of north Iraq. The Cretaceous-Paleocene-Eocene sequences of Neo-Tethys represent continuous sedimentation in deep marine to deeper shelf environments under strong action of turbidity currents.

Conclusion

The Gercus Formation is cropping out in a belt parallel to the Zagros Thrust Belt in the High Folded Zone of northern Iraq. Stratigraphically, it is distributed from NE to NW margins and encountered in several oil wells in the oil fields of northern Iraq. Petrographically, the formation is mainly composed of lithic arenite sandstones of red, green, gray and yellowish in color. The Gercus successions represent cyclic repetitions of grading upwards turbidity Bouma cycles and gravity flow sedimentation interbedded with carbonate horizons. The turbidity cycles composed of sandstones grade upwards to planner stratified sandstones, cross-bedded sandstones, siltstones and fissile shales/mudstone beds. The graded successions reveal varieties of specific turbidity sedimentary structures c.f. slump, slide and convolute deformed and disturbed beds, sand and clay balls and pillows, gutter casts, flute, scour, groove and load casts, planner stratifications and submarine and sigmoidal channels.

These turbidity cycles, sedimentary structures and the relationship between the Gercus successions display marine environment supported reistrictly with the presence of glauconite grains. Five main facies types are observed in the Gercus Formation, these are; Shale/claystone, Sandstone, Carbonate, Carbonate breccias and debris flow, Mudstone facies. These facies types can be subdivided into several facies types as;

Laminated shale, fissile shale, thick massive claystone, claystone/siltstone couplet, very fine-grained sandstone, ripples sandstone, thick and thin sandstone, dolomite, limestone, dolomitic limestone, dolomite breccias, balls and pillow dolomite, slump/slide carbonate breccia, carbonate debris flow mudstone.

The carbonate units reveal eight (8) microfacies types these are; foraminiferal packstone/mudstone, foraminiferal wackestone, algal mudstone, stromatolite framestone, radiolarian calcisphere packstone, foraminiferal dolomitic wackestone, algal foraminiferal packstone, foraminiferal dolo wackestone. Microfacies types suggest sedimentation in fore-reef to open sea environment and developed to deeper margins, which are evident from associated carbonate breccias and debris flows.

Facies types are grouped in four distinctive facies associations, these are from bottom to top; FA1 slump siliciclastic-calciturbidites (dolomite/shale dominated), FA2 proximal siliciclastic-calciturbidites (dolomite-sand/shale dominated), FA3 distal siliciclastic-calciturbidites (sand/mud dominated), FA4 slope siliciclastic turbidites (sand/clay dominated).

The suggested depositional model of the Gercus Formation related to tectonic activity, reveals intense volcanism, which are lying at the northeastern border of the foreland basin of Iraq, comprising 3000 m thick sequences of Eocene volcanic rocks and ash. These volcanoes are the source of detrital volcanic fragments in the carbonate and siliciclastic rock units of the Gercus Formation. It is also the source of the red mudstone beds, which are interbedded with the siliciclastic-carbonate beds in graded upwards turbidity cycles.

References

1. AL-Rawi, Y. T. **1980**. Petrology and sedimentology of the Gercus red bed Formation (Eocene) northeast Iraq, *Iraqi jour*. Sci. **21**: 132-188.
2. Jassim S.Z. and Goff J.C. **2006**. *Geology of Iraq*. Dolin Prague and Moravian Museum. Brno, Czech Republic, 341p
3. Al-Qayim, B., Al-Shaibani, S. K. and Nissan, B. **1988**. Stratigraphic evolution of Paleogene sequence, Hiebat Sultan northeast Iraq, *Iraqi geol. Jou*. **21(**2): 51-63.
4. Aqrawi, AM., Goff, CJ., Horbury, DA. and Sadooni NF. **2010**. *The petroleum geology of Iraq*. Scientific Press, UK. 424p.
5. Bellen, R. C. Van, Dunnington, H. V., Wetzel, W., and Morton, D. M. **1959**. *Lexique stratigraphique international, Asie,* Fasc., 10a, Iraq: Center Natl. Recherche Sci., Paris, 333 p.
6. A-Ameri, T. K, Al-Dulaimy, A. S., Ibrahim, Y. K. and Amin, B. M. **2004**. Age evaluation of Gercus Formation using stratigraphic ranges of identified palynomorphs northern Iraq, *Jour. Geol. Soc. Iraq*, v. No. pp.
7. Tasman, C. E., **1949**. Stratigraphy of Southeastern Turkey: *AAPG Bull.*, **33:** 22-31.
8. James, G. A., and Wynd, J. G., **1965**. Stratigraphic nomenclature of Iranian oil consortium agreement area, *AAPG Bull*., **49:** 2182-2245.
9. Dunnington, H. V. **1958**. Generation, migration, accumulation and dissipation of oil northern Iraq; in Weeks, G. L. (ed.), Habitat of oil, a symposium, *AAPG Bull.,* Tulsa
10. Ditmar, V. and Iraqi–Soviet Team. **1971**. *Geological conditions and hydrocarbon prospects of the Republic of Iraq (Northern and Central parts).* Manuscript report, INOC Library, Baghdad.
11. Jassim, S. Z., Al-Shaibani, S. K. and Ajina, T. M. **1975**. Possible Middle Eocene block movement in Derbendikhan area, northeast Iraq, *jour. Geol. Soc. Iraq,* **special issue:** 139-145.
12. Ameen, B. M., **1998**. *Sedimentological study Gercus Formation in Northeast Iraq*. Unpubl. M.Sc. Thesis, Univ. of Baghdad. 103 p.
13. Tucker, M.E. **1988**. *Technique in Sedimentology*. Blackwell scientific publication: 394 p.

14. Walker, R.G., Duke, W.L. and Leckie, D.A. **1983**. Hummocky stratification: significance of its variable bedding sequences: discussion and reply. *Geol. Soc. Amer. Bull.*, **94**: 1245–1249.
15. Walker, R.G. **1984**. Facies Model. Geosciences Canada, Reprint series publication: 615 p.
16. Reading, H.G. **1986**. *Sedimentary environments and facies*. Blackwell Scientific Publication: 317 p.
17. Einsele, J. **2000**. *Sedimentary basins, Evolution, Facies and Sediment budget*. Springer-Verlag. Berlin: 628p.
18. Walker, J. and James, A. **1998**. *Facies models in response to sea level changes*. c Canada Geosciences: 454 p. Geotext-1, Geological association of Canada.
19. Posamentier, H. W., and Walker, R. G. **2006**. *Facies Models Revisited*. SEPM, Lura J. Crossey and Donald S. Mcneill, Editors of Special Publications, SEPM Special Publication **84**, Tulsa Oklahoma, U.S.A. 527P.
20. Selley, R. C., **1976**. *An introduction to Sedimentology*. Academic Press, London, New York, San Francisco. 408p.
21. Reineck, H. E., and Singh, I. B. **1980**. *Depositional Sedimentary Environments with reference to terrigenous clastics.* Second revised and update edition. Springer-Verlag, Berlin Heidelberg New York 1980, 549p.
22. Collinson, J. D., and Thompson, D. B. **1982**. *Sedimentary Structures*. George Allen & Unwin, London, Boston, Sydney. 194p.
23. Mutti, E., **1992**. *Turbidite Sandstone*. Istituto di Geologia, Universit'a di Parma, Agip, S.P.A. 275p.
24. Stow AVD. **2012**. *Sedimentary Rocks in the Field A Color Guide*. ACADIMIC PRESS, Elsevier. 320p.
25. Pickering, K.T. and Scott, R, N. **2016**. *Deep marine systems, processes, deposits, environments, tectonics and sedimentation*. AGU and WILEY and Sons, UK, 657p.
26. Pettijohn, F. J., Potter, P. E. and Seiver, R. **1973**. *Sand and sandstone*, Springer- Verlag, N. Y., 618 p.
27. McBride, E.E. **1963**. A classification of common sandstones. *J. Sed. Petrol*., 33: 664–669.
28. Dickinson, W.R. **1985**. Interpreting provenance relations for detrital modes of sandstone. – In: Zuffa, G.G. (ed.): Provenance of arenites. 333-361; *NATO ASI Series C*: vol. 148. Reidel Dordrecht. 40
29. Folk, R. L. **1974**. *Petrology of sedimentary rocks*. Hemphill's, Austin, Texas: 170 p.
30. Demarest, J. M. and Kraft, J. C. **1987**. Stratigraphic records of Quaternary sea levels: implications for more ancient strata. In: Nummedal, D., Pilkey, O.H. and Howard, J.D. (eds.): *Sea-level fluctuation and costal evolution*. Soc. Econ. Pal. Min., Spec. Publ., **41**: 241-260.
31. Nummedal, D. and Swift, D.J.P. **1987**. Transgressive stratigraphy at sequence-bounding-unconformities; some principles derived from Holocene and Cretaceous examples. In: Nummedal, D., Pilkey, O.H. and Howard, J.D. (eds.): Sea-level fluctuation and costal evolution. *Soc. Econ. Pal. Min*., Spec. Publ., **41**: 241–260.
32. Deynoux, M., Proust, J.N. and Simon, B. **1991**. Late Proterozoic glacially controlled shelf sequences in western Mali (West Africa). *Jo. Afr. Ear. Sci*, **12**(1–2): 181–198.
33. Ocatavenuno, O. **2006**. Principles of Sequence Stratigraphy. Elsevier, Amsterdam, Netherland. 375p.
34. Conybeare, C.E.B. **1979**. *Lithostratigraphic analysis of sedimentary basins*. Academic Press Inc, London, 554p.
35. Kurtz, D.D. and Anderson, J.B. **1979**. Recognition and sedimentologic description of recent debris flow deposits from the Ross and Waddell Seas Antarctica. *J. Sed. Petrol.*, **49**: 1159–1170
36. McCabe, A.M., Dardis, G.F. and Hansvey, P.M. **1984**. Sedimentology of a Late Pleistocene submarine complex, Country Down, Northern, Island. *J. Sed. Petrol.*, **54**: 716–730.
37. Bouma, A.H. and Brouwer, A. (eds.) **1964**. *Turbidities*. Development in Sedimentology, 3. Amsterdam, Elsevier: 264 p.
38. Carter, R.M. **1975**. A discussion and classification of sub aqueous mass-transport with particular application to grain-flow, slurry-flow and fluxoturbidites. *Earth Science Review*, **11**: 145–177.

39. Middleton, G.V. and Hampton, M. A. **1976**. Sub aqueous sediment transport and deposition by sediment gravity flows. In: Stanley, D.J. and Swift, D.J.P. (eds.): *Marine sediment transport and environmental management*. Wiley: 197–218.

40. Nardin, T.R., Hein, F., Gorsline, D.S. and Edwards, B.D. **1979**. A review of mass movement processes, sediment and acoustic characteristics, and contrasts in slope and base-of-slope systems versus canyon-fan basin floor systems. *Soc. Econ. Pal. Min.*, Spec. Publ., **27**: 61–73.

41. Lowe, D.R. **1982**. Sediment gravity flow: II. Depositional models with special reference to the deposits of high-density turbidity currents. *J. Sed. Petrol.*, **52**: 279–297.

42. Evanson, E.B., Dreimanis, A. and Newsome, J.W. **1977**. Subaquatic flow tills: a new interpretation for the genesis of some laminated till deposits. *Boreas*, **6**: 115–133.

43. Rusnak GA, and Nesteroff WD. **1964**. Modern turbidites: terrigenous abyssal plain versus bioclastic basin. In. Miller, R. L., (Ed.), *Papers in marine geology*, 488-507. New York: MacMillan.

44. Hicock, S.R., Dremanis, A. and Boster, B.E. **1981**. Submarine flow tills at Victoria, British Columbia. *Can. J. Earth Sci*., **18**: 71–80.

45. Powell, R.D. **1981**. A model for sedimentation by Tide-water glaciers. *Ann. Glciol,* **2**: 129-134.

46. Babonneau, N. Savoye, B. Cremer, M. and Bez, M. **2010**. Sedimentary architchure in meanders of a submarine channel: Detailed study of the present Congo turbidite channel (Zaiango Project). *Jo. Sed. Res.* **80:** 852-866.

47. Gazdzicki, A., Gradzinski, R., Proebski, S. and Wrona, R. **1982**. Pholalid *Penitella* borings in glaciomarine sediments (Pleistocene) of King Georges Island, Antarctica. *Neues Jahrb. Geol. Paläont. Monatsh*., **12**: 723–735.

48. Domack, E.W. **1982**. Sedimentology of glacial and glacial marine deposits on the George V Adeline continental shelf, East Antarctica. *Boreas*, **11**: 79–97.

49. Visser, J. N. J. **1983a.** Submarine debris flow deposits from the Upper Carboniferous Dwyka tillite formation in the Kalahari Basin, South Africa. *Sedimentology*, **30**: 511–523.

50. Visser, J.N.J. **1983b**. The problem of recognizing ancient sub aqueous debris flow deposits in glacial sequences. *Trans. Geol. Soc. S.Afr.*, **86**: 127–135.

51. Eyles, C. H, Eyles, N. and Miall, A.D. **1985**. Models of glaciomarine sedimentation and their application to the interpretation to the ancient glacial sequences. *Palaeogeogr. Palaeoclimat. Palaeoecol*., **51**: 15–84.

52. Kuenen, P.H. **1951**. Mechanics of varve formation and the action of turbidity currents. *Geol. Foren. Stockholm Forhand*., **73**: 69–84.

53. Agtenberg, , F.P. and Banerjee, I. **1969**. Stochastic model for the deposition of varves in glacial lake Barlow-Ojibway, Ontario, Canada. *Can. J. Earth Sci*., **6**: 625-652.

54. Banjeree, I. **1973**. Sedimentology of Pleistocene glacial varves in Ontario, Canada. Nature of the grain-size distribution of some Pleistocene glacial varves in Ontario, Canada. *Geol. Surv. Canada Bull*., **226**: 1-60.

55. Gustavson, T.C., Ashley, G.M. and Bouthroyd, J.C. **1975**. Depositional sequence in glaciolacustrine deltas. In: Jopling, A.V. and Mcdonald, B.C. (eds.): Glaciofluvial and glaciolacustrine sedimentation. *Soc. Econ. Pal. Min*., Spec. Publ., **23**: 264–280.

56. Ashley, G.M. **1975**. Rhythmic sedimentation in glacial Lake Hitchcock, Massachusetts, Connecticut. In: JOPLING, A.V. and MCDONALD, B.C. (eds.): Glaciofluvial and Glaciolacustrine Sedimentation. *Soc. Econ. Pal. Min.* Spec. Publ., **23**: 304–320.

57. Harrison, S. **1975**. Turbidities origin of glaciolacustrine sediments, Woodrock Lake, Pennsylvania. *J. Sed. Petrol*., **45**: 738–744.

58. Mackiewicz, N.E., Powell, R.D., Carlson, P.R. and Molina, B.F. **1984**. Interlaminated ice-proximal glaciomarine sediments in Muir Inlet, Alaska. *Marine Geol.*, **57**: 113–147.

59. Schluchter, C. (ed.) **1979**. Moraines and varves. *Balkema*: 441 p.

60. Aalto, K. R. **1976**. Sedimentology of a mélange: Franciscan of Trinidad, California. *J. Sed. Geol.*, **46**: 913–929.

61. Cook, H.E, and Enos, P. (eds.) (1977). *Deep-water carbonate environments*. Society of economic, paleontologist and mineralogists. Special publication, **25**, p.336.

62. Kelling, G. and Mullin, P.R. **1975**. Graded limestones and limestone quartzite couplets: possible storm deposits from the Moroccan Carboniferous. *Sedimentary Geol.*, **13**: 161–190.

63. Breanchley, P. J., Newall, G. and Stainstreet, I.G. **1979**. A storm surge origin for sandstone beds in an epicontinental platform sequence, Ordovician, *Norway. Sed. Geol*., **22**: 185-217.
64. Hamblin, A.P. and Walker, R.G. **1979**. Storm dominated shallow marine deposits: the Fernie-Kootenay (Jurassic) transition; Southern Rocky Mountains. *Can. J. Earth Sci*., **18**: 1673–1690.
65. Dott, R.H. and Bourgeois, J. **1982**. Hummocky stratification significance of its variable bedding sequences. *Geol. Soc. Amer. Bull*., **93**: 663–680.
66. Dott, R.H. and Bourgeois, J. **1983**. Hummocky stratification significance of its variable bedding sequences: discussion and replay. *Geol. Soc. Amer. Bull*., **94**: 1249-1251.
67. Brenchley, P.J. **1985**. Storm influenced sandstone beds. *Modern Geol*., **9**: 369-396.
68. Guillhicheau, F. **1983**. *Les depots de tempests. Le modele de L'Ordvicien moyen ouest armoricani. These 3ed cycle*, Univ. Bretagne Occ., Brest, France: 223 p.
69. Brenchley, P.J. **1985**. Storm influenced sandstone beds. *Modern Geol*., **9**: 369–396.
70. Brenchley, P.J., Romano, M. and Gutierrsz -Marco, J.C. **1986**. Proximal and distal hummocky cross stratified facies on a wide Ordovician shelf in Iberia. In: Knight, R.J. and Mclean, J.R. (eds.): Shelf sands and sandstones. *Can. Soc. Petrol, Geol. Mem*., **II**: 241–255.
71. Swift, D.J.P., Parker, G., Landredi, N.W., Perillo, G. and Pigge, K. **1978**. Shore face-connected sand ridges on American and European shelves: a comparison. *Est. Coast. Mar. Sci*., **7**: 257–273.
72. Swift, D.J.P. and Field, M. **1981**. Evolution of a classic sand ridge field: Maryland Sector, North American inner shelf. *Sedimentology*, **28**: 461–482.
73. Stubblefield, W. L., Mcgraill, D.W. and Kersey, D.G. **1984**. Recognition of transgressive and post transgressive sabridges on the New Jersey continental shelf. In: Tillman, R.W. and Siemers, C.T. (eds.): Siliciclastic shelf sediments. *Soc. Econ. Pal. Min*., Spec. Publ., **34**: 1-23.
74. Boyles, M.J. and Scott, A.J. **1982**. A model of migrating shelf bar sandstones in upper Mancos shale's (Campanian), northwestern Colorado. – Amer. Assoc. Petrol. Geol. Bull., **66**: 441–508
75. Osleger D.A., and Montanez, I.P. **1996**. Cross-palteform architecture of a sequence boundary in mixed siliciclastic-carbonate lithofacies, Middle Cambrian, southern Great Basin, USA. *Sedimentology*, **43**, 197-217.
76. Shurr, G.W. **1984**. Geometry of shelf sandstone bodies in the Shannon sandstone of southeastern Montana. In: Tillman, R.W. and Siemers, C.T. (eds.): Siliciclastic shelf sediments. *Soc. Econ. Pal. Min*., Spec. Publ., **34**: 63–83.
77. Conybeare, C.E.B. 1979. *Lithostratigraphic analysis of sedimentary basins*. Academic Press Inc, London, 554p.
78. Scholle, P. A. 1979. A Color Illustrated to Constituents, Textures, Cements, and Porosities of Sandstones and Associated Rocks. *AAPG Memoir*, **28**, 201p.
79. Keer, P.F **1975**. *Optical Mineralogy*. 3rd edition, McGRAW-HILL BOOK COMPANY, 442p.
80. Tucker, M.E. **1991**. *Sedimentary Petrology, An Introduction to the Origin of Sedimentary Rocks*. Blackwell scientific publication: 260 p.
81. Chaftez, H. S., and Reid, A. **2000**. Syndepositional shallow-water precipitation of glauconitic minerals. *Sedimentary Geology*, **136** (2000) 29–42
82. Scholle, P. A., Dana and Ulmer-Scholle. **2003**. A Color Guide to the Petrography of Carbonate Rocks: Grains, textures, porosity, diagenesis. *AAPG Memoir* **77**, 459p.
83. Chaftez, H. S. **2007.** Paragenesis of the Morgan Creek Limestone, Late Cambrian, central Texas: Constraints on the formation of glauconite. *Deep-Sea Research* II **54** (2007) 1350–1363.
84. Relu. D, Mihaele R and Dobrinescu C. M. **2012**. Lower Cretaceous lithofacies of the black shales rich Audia Formation, Tarc_au Nappe, Eastern Carpathians: Genetic significance and sedimentary palaeoenvironments. *Cretaceous Research*,, **38** (2012) 52-67.
85. Baranpurian, N. Emami, M.H., Mansor Vossoughi Abedini, M.V., and Dabiri, R. **2014.** Mineral Chemistry and Thermobarometry of the Upper Eocene Volcanic Rocks in NE Tafresh, Iran. *Open Journal of Geology*, 2014, **4**: 612-621.
86. Beygi, S., Nadimi, A., and Safaei, H. **2016.** Tectonic history of seismogenic fault structures in Central Iran. *Journal of Geosciences*, **61:** 127–144.
87. Chiu, H.Y., Chung, S.L, Zarrinkoub, M.H., Mohammadi, S.S.M., Mohammad Mahdi Khatib, M.M., and Iizuka, Y**. 2013.** Zircon U–Pb age constraints from Iran on the magmatic evolution related to Neo-Tethyan subduction and Zagros orogeny. *Lithos* **162–163**: 70–87.

88. Davarpanah, A. **2009.** *Magmatic evolution of the Eocene volcanic rocks of the Bijgerd Kuhe Kharchin area, Uromieh-Dokhtar Zone, Iran*. Unpublished M.Sc. Thesis, Georgia State University, Department of Geosciences, 138p.

89. Ghasemia, A., and, C.J. Talbot, C.J. **2005.** A new tectonic scenario for the Sanandaj–Sirjan Zone (Iran). *Journal of Asian Earth Sciences* xx (2005) 1–11.

90. Mehdipour Ghazi, J., and Moazzen, M. **2015.** Geodynamic evolution of the Sanandaj-Sirjan Zone, Zagros Orogen, Iran. *Turkish J Earth Sci* (2015) **24**: 513-528.

91. Mohajjel, M., and Fergusson, CI. **2014.** Jurassic to Cenozoic tectonics of the Zagros orogen in northwestern Iran. *International Geology Review*, **56** (3), 263-287.

92. Verdel, C., Wernicke, B.P., Hassanzadeh, J., and Guest, B. **2011.** *A Paleogene extensional arc flare‐up in Iran. Tectonics*, **30**, TC3008.