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Deformational Style of the Soft Sediment (SEISMITES) within the Uppermost Part of the Euphrates Formation, Western Iraq

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Abstract

The Euphrates Formation (Early Miocene) is wide spread formations in central western part of Iraq. It consists of basal conglomerate, well bedded, grey, fossiliferous and hard limestones (Lower Member), chalky like dolomitic limestone, white and massive, green marl, and deformed, brecciated dolomitic limestone and well bedded undulated limestone (Upper Member). The thickness of the formation Iraq is 35-110 m.
The uppermost part of the Euphrates Formation includes Brecciated Unit. The fragments (size 1 – 3 cm) are semi angular to semi rounded, consist of very finely crystalline, silicified limestone, arranged in systematic form, which is parallel to the deformations and undulations that are present in both the brecciated mass and the overlying Undulated Limestone Unit. These characteristics of the fragments indicate that the breccia is not formed due to break in sedimentation, but it is syn-sedimentary breccia.
The genesis and deformation style of the breccia is discussed in this study. The results indicate the seismic effect on the development of the breccia, during the deposition, which means syn-sedimentary origin of the breccia, most probably due to tectonic unrest, which has caused seismic shocks in the depositional area; such sediments are called "seismites".

Keywords: Euphrates Formation, Earthquake, Deformation, Undulation, Seismite, Iraq

1 Introduction

The Euphrates Formation (Early Miocene) is widely exposed in the central western part of Iraq [1, 2] (Figure1). The Euphrates Formation in the type locality consists of "Shelly, chalky, well bedded recrystallized limestone" [3]. The type section proposed by [4]

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includes: 1) Lower Unit (A) consists of 20 m of basal conglomerate, with subrounded limestone boulders and pebbles, derived from Anah Formation. The conglomerate is followed by 10 m of recrystallized, fossiliferous limestone, changing to coralline limestone. 2) Middle Unit (B) consists of alternation of hard limestone and pseudoolitic limestone. 3) Upper Unit (C) consists of green marl and limestone.

The studied area is located in Al-Anbar Governorate, at the central western part of Iraq, the extreme northwestern part of the Iraqi Western Desert (Figure1). The area extends on both banks of the Euphrates River, starting from the Iraqi – Syrian international borders and extends east and southeastwards to wadi Hauran.

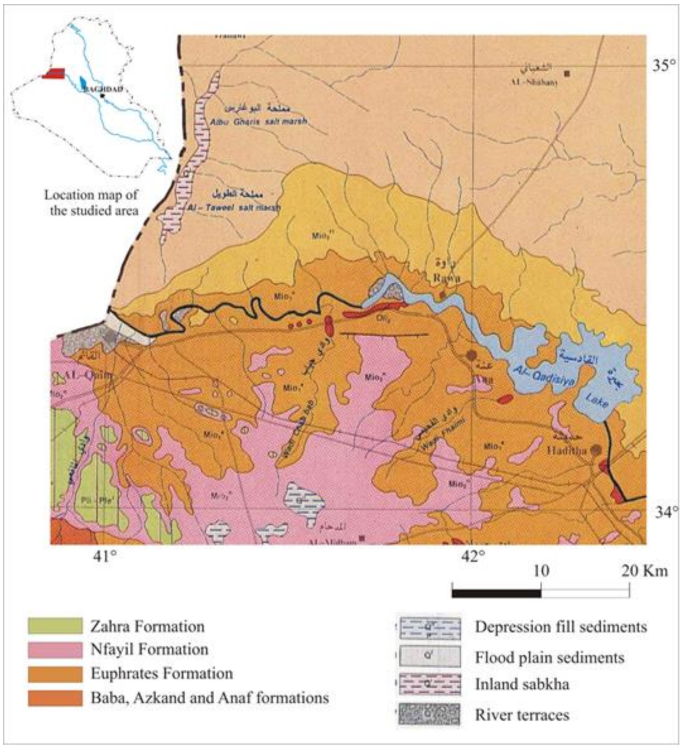

Figure1: Geological and location map of the studied area[2].

2 Previous Work

Many workers have studied the Euphrates Formation in the involved area, but a little was mentioned about the origin of the brecciated rocks that form the uppermost part of the formation. The hereinafter mentioned workers studied the formation:

- Bolton [5] reported about abundant brecciated horizons, within the upper parts of the Euphrates Formation, he explained the brecciation is attributed to slumping and escape of gases with possibility of earthquakes triggering the slumping processes, during the deposition.
- Bellen et al. [3] described the Euphrates Formation in the type locality as "Shelly, chalky, well bedded recrystallized limestone".
- Al-Mubarak [6] divided the Euphrates Formation in Al-Qaim and Anah vicinities into three members: 1) Lower Member consists of basal conglomerate, followed by

dolostone and dolomitic limestone. 2) Middle Member consists of white, fossiliferous limestone, alternated with pseudoolitic chalky like limestone. 3) Upper Member consists of alternation of grey limestone with green marl. Moreover, Al-Mubarak [6] considered the brecciated rocks, which overly the Middle Member as a part of the Fatha Formation. However, latter on the brecciated rocks were grouped with the Euphrates Formation [4], and the Upper Member was announced as a new formation and called Nfayil by [7].

- Al-Jumaily [8] in Al-Kherish vicinity, south of Al-Qaim and southwards, mapped the Euphrates Formation as informal units, without considering them to belong to the Euphrates Formation, the informal units are: 1) Unit A1 consists of chalky limestone, well bedded, locally shows cross bedding, marked by fossils. 2) Unit A consists of chalky, fossiliferous, well bedded limestone.
- Tyracek and Youbert [9] adopted the subdivisions of [6,8] of the Euphrates Formation, in the area extending from Anah until wadi Hauran, including, Haditha, K3 and T1 areas. They divided the Euphrates Formation into three members: 1) Lower Member consists of basal conglomerate, followed by shelly dolomitic limestone, limestone and dolostone. 2) Middle Member consists of bedded, chalky dolostone and dolomitic limestone with horizons of green marl. 3) Upper Member consists of massive dolomitic limestone, highly deformed and brecciated, with thin horizons (2 – 5 cm) of silicified limestone. Followed by well bedded, highly undulated limestone.
- Ibrahim and Sissakian [10] in Rawa – Al-Baghdadi vicinity, adopted the subdivision of [6] for the Euphrates Formation, in the southern part of Al-Jazira Area. They divided the formation into two members: 1) Lower Member consists of two units: Basal Clastic Unit, which is composed of limestone fragments and pebbles (8 m thick), followed by Dolomitic Unit of (5 – 15) m thickness. 2) Middle Member consists of two parts: The lower part is composed of grey massive fossiliferous and dolomitic limestone, while the upper part consists of well bedded chalky dolomitic limestone, interbedded with grey to whitish grey marl; the thickness is (25 – 40) m. 3).Whereas the Upper Member, which consists of green marl horizon, brecciated horizon and crystalline limestone was considered as the lowermost part of the Fatha Formation.
- Jassim et al. [4] divided the Euphrates Formation into three units: 1) Lower Unit (A) consists of 20 m of basal conglomerate, with subrounded limestone boulders and pebbles, mainly derived from Anah Formation. The conglomerate is followed by 10 m of recrystallized, fossiliferous limestone, changing to coralline limestone. 2) Middle Unit (B) consists of alternation of hard limestone and pseudoolitic limestone. 3) Upper Unit (C) consists of alternation of grey limestone with green marl.
- Mahdi et al. [11] divided the Euphrates Formation, in Haditha – Hit vicinity into the following units: 1) Fhaimi Unit (corresponds to the Lower Member of [6]; it is subdivided into three facies: a) Coralline Facies consists of fossiliferous dolomitic limestone, with corals. b) Fhaimi Facies consists of grey, shelly dolomitic limestone and dolostone. c) Haditha Facies consists of white chalky limestone and dolostone. 2) Akhdar Unit (corresponds to the Middle Member of [6]; it is subdivided into four facies. a) Lower Akdhar Facies consists of chalky like dolostone. b) Lower Haqlan Facies consists of fossiliferous dolostone. c) Upper Akhdar and Upper Haqlan Facies, the two facies are almost similar to each other. They consist of fossiliferous, chalky like dolostone. d) Uglat Horan Facies consists of shelly limestone and dolostone. 3) Ezghadan Unit (corresponds to the Brecciated Unit of [6, 9, 10]. It is divided into three facies: a) Ezghadan Facies consists of intercalation of marl, marly dolostone and white dolostone. b) Al-Waziyah Facies consists of fossiliferous, chalky like dolostone. c) Hauran Facies consists of marl,

dolomitic limestone and massive dolostone. 4) Undulated Limestone Unit consists of undulated and deformed limestone, locally slightly fossiliferous. 5) Ahmar Unit consists of fossiliferous, brecciated marly dolostone, with shelly limestone, overlain by bedded limestone.

- Fouad et al. [12], in Anah vicinity, divided the Euphrates Formation into six units: 1) Conglomeratic Unit consists of basal conglomerate; pebbles are derived from Anah Formation. 2) Shelly Unit consists of fossiliferous dolostone, dolomitic limestone, locally coral colonies occur. 3) Lower Chalky Unit consists of massive, fossiliferous and chalky like dolostone. 4) Upper Chalky Unit consists of well bedded, fossiliferous, oolitic and chalky like dolostone. 5) Brecciated Unit consists of alternation of green marl, with white marly dolostone and dolomitic limestone. Overlain by highly warped and brecciated alternation of green marl and marly dolostone. 6) Undulated limestone Unit consists of thinly bedded, slightly fossiliferous, undulated limestone.
- Fouad [13] also attributed the intense deformation in the Brecciated Unit of the uppermost part of the Euphrates Formation to seismic shocks, due to earthquakes.

From reviewing the executed previous works, it is clear that only Bolton[5] and Fouad [13] mentioned about the seismic effect on the development of the Brecciated Unit in the uppermost part of the Euphrates Formation, which shows soft sediment deformation structures within sedimentary beds disturbed by seismic waves from earthquakes [14,15].

3 The Euphrates Formation

In this study, only the uppermost part of the Euphrates Formation will be dealt with, and will be emphasized on, because it is the main objective of this study. The deformed and brecciated part of the formation has given different names by different workers; as mentioned in the previous work, and was considered to belong to soft sediment deformation structures within the Euphrates Formation only by [5] and [13]. However, Al-Mubarak [6], and Ibrahim and Sissakian [10] considered the Brecciated Unit as the Fatha Formation.

The uppermost part of the Euphrates Formation consists of two units: Brecciated Unit and Undulated Limestone Unit (Figure 2). The main constituents are briefly described hereinafter; based on [16,17].

Figure2: Top and Bottom: Brecciated Unit overlain by the Undulated Limestone Unit, forming the Upper Member of the Euphrates Formation. Note the deformation style and intensity of the deformation and syn-sedimentary structures.

The Brecciated Unit is divided into two parts: The lower part consists of green marl; in form of bed or lenses (1 – 2) m in thickness. Locally, this bed disappears. The upper part consists of fragments of silicified and fine crystalline limestone of grey color. The shape of the fragments is angular and sub-rounded, ranges in size from few millimeters up to 3 cm, which are cemented by green marl and/ or dolomitic limestone. The Brecciated Unit is highly deformed, the deformation increases upwards without controlled direction, which may be related to slumping as a result of earthquakes [5], associated with many sedimentary structures like load cast, convolute bedding, honey comb, slump and flame structure (Figures 2 and 3). The amplitude of the deformation ranges from few centimeters up to 5 m, but generally it is in a range of 0.5 m. The fragments are locally arranged as parallel to the deformation of the deformed bedding planes, or randomly distributed. The thickness of this horizon is (8 – 16) m [11,12]. The upper part of the Brecciated Unit consists of fragments range in size from (1 – 5) cm, angular to sub-angular (Figure 4), chalky limestone, cemented by calcareous material; the thickness of the upper part is 6 m. Such deformed sediments, as those within the Brecciated Unit, are called as "Seismites" [18].

Figure3: Different sedimentary structures in the Brecciated and Undulated Limestone Units of the Euphrates Formation, also note the brecciation and deformation style and intensity

The Undulated Limestone, which is highly contorted (undulated and deformed) (Figs.2 and 3), is thinly well bedded, light brown and grey, recrystallized and fossiliferous. The undulation varies in width and shape; it ranges from less than 1 m up to 10 m; in width, whereas their amplitudes range from few centimeters up to 5 m, occasionally parallel to the deformation of the underlying Brecciated Unit. Locally, the undulated limestone is intervening with the lowermost part of the underlying brecciated part [6]. The thickness of the limestone ranges from (0.5 – 20) m; the thickness of the Upper Member ranges from (25 – 38) m.

3.1 Deformation Style

The brecciated Unit exhibits number of deformational features (Figures 2, 3, 4 and 5). These features increase generally upwards. Slumping and sliding as well as folding, occasionally overturned, and reverse and thrust faulting are common features in the rocks. Convolute bedding, brecciation, sedimentary boudinage, load cast and flame structures are also present, especially at the upper part of the Brecciated Unit. Flame structures are sound, occasionally penetrating through the overlying Undulated Limestone Unit (Figures 2 and 5).

Figure4: The uppermost part of the Brecciated Unit of the Euphrates Formation. Note the intense deformation and brecciation

Locally, thin horizons; not more than (1 – 2) cm of very fine crystalline limestone occur, indicating clearly the deformational style, showing the amplitude of the deformation. Occasionally, these horizons are broken (may be faulted and/ or destroyed due to deformation) into small pieces; not more (1 – 5) cm in length (Figure5). Such deformational form is hardly preserved in completely lithified sediments; therefore, they are good indication that these deformations were developed during burial, and are syn-sedimentary structures developed most probably due to seismic shocks created by earthquakes and/ or due to tectonic unrest, since the deformed rocks, in the uppermost part of the Euphrates Formation are present only nearby the contact between the Inner and Outer Platforms.

As in majority of other seismites, two of the seismite zones [14] occur within the Brecciated Unit: segmented and rubble [19]. The first zone, without micro faults, is marked by the existence of fragmented thin layers and laminae (Figure 5), as well as by collapsed structures or by remains of Skolithos type cylindrical, vertical galleries. The rubble zone is characterized by thin and discontinuous laminae, possibly of algal-mat nature, with quasi-parallel arrangement (Figure 2). Without offering the complete image of the seismite defined by [14], the above mentioned zones suggest the effects of a liquefaction process induced by seismic vibrations. This process produced the fragmentation of the laminae and of the biogeneous sedimentary structures consolidated during the early diagenesis phase [19].

The presence of boudinage structure within the Brecciated Unit is good indication for syn-sedimentary extension structure, whereas compression wrinkles are indication for syn-sedimentary compression structure [20]. Both structures are present in the Brecciated Unit of the Upper Member of the Euphrates Formation. The later confirms the presence of the compressional forces exerted by the Savian Orogeny during Early Miocene and onwards.

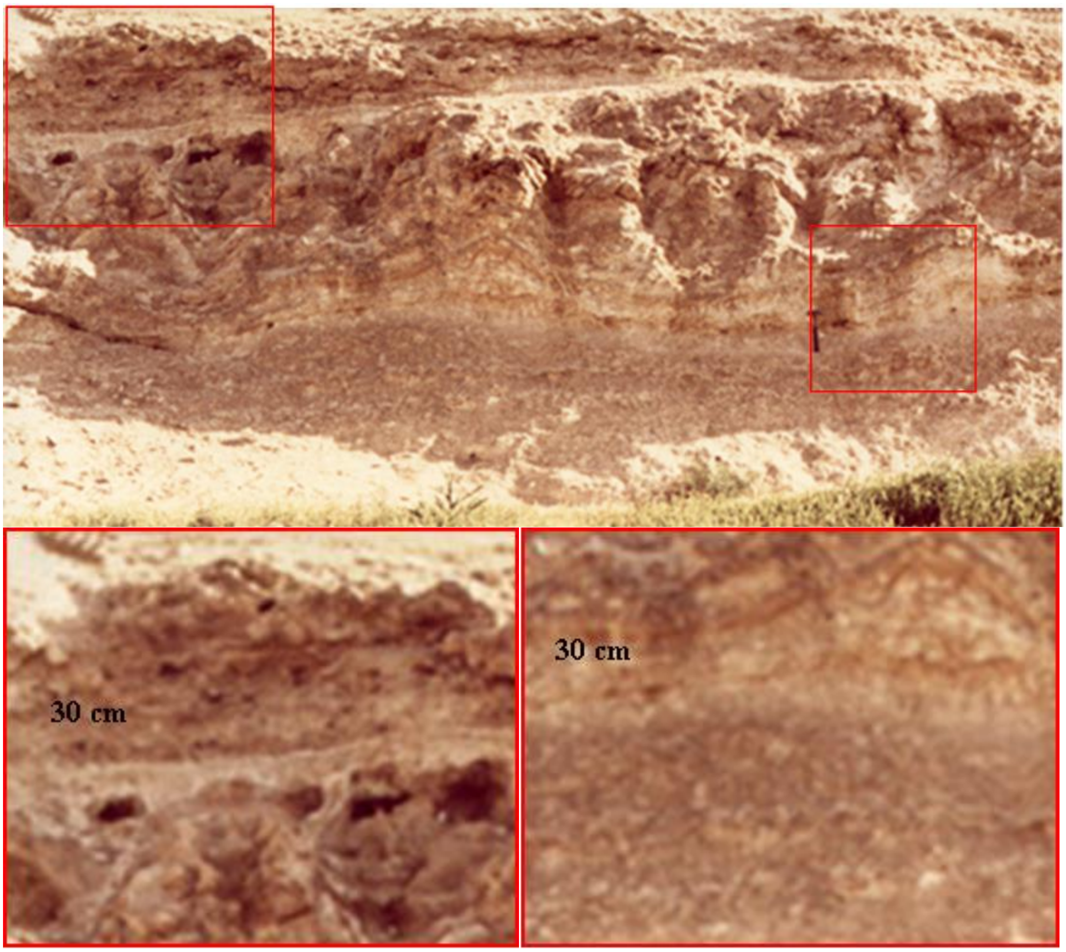

Figure5: Deformational structures in the Brecciated and Undulated Limestone Units. Left and Right are tow enlargements to show the details of the deformation style. Note the deformation style of the bedding planes and the brecciation intensity.

3.2 Deformation Intensity

The Brecciated Unit is characterized by intense deformation features. These features are characterized by two major characters: First, they lack any spatial preferred orientation, and they did not bear any geometrical relationship to the major or minor structures of the area. Second, the deformational features are limited to a group of adjacent beds that are sandwiched between essentially undeformed beds [13]. These characteristics are definitive criteria of soft-sediment (or syn-sedimentary) deformation [21]. However, locally, the small fragmented silicified limestone fragments follow the deformation style, which is also followed by the overlying undulated limestone, although the undulation's amplitude is higher than that of the deformation in the brecciated rocks, especially in the lowermost part of the undulated limestone.
The wave length of the deformation ranges from (< 1 – 10) m, whereas the amplitude ranges from (< 1 – 5) m (Mahdi et al., 1985). The soft-sediment deformation features in the involved area are broadly grouped according to their morphology into two types [13]:

3.3 Folds or Convolute Structures

A broad variety of minor folds ranging from tight to gentle are recorded. Fold wavelengths vary between few centimeters up to few meters; while their amplitudes vary between few centimeters to less than 5 m. Folded layers may show some thickness variation across the folds. Moreover, some folds are accompanied with minor faults; others are detached from the underlying layers.

3.4 Intrusive Sedimentary Dykes

They are composed of brecciated sedimentary material injected vertically or at high angle from below. It is commonly referred to as "clastic dykes" [22, 23]. The size of these features, in the area rarely exceeds 3 m.
The soft sedimentary deformation features are extensively distributed throughout the studied area, which extends from Al-Qaim to northeast, east and southeast wards, passing through Rawa, Anah, Haditha, Haqlaniya, Baghdadi and Hit (Figure1). Towards southeast they disappear along Wadi Hauran, almost in parallel line to the extension of Abu Jir Fault Zone, which forms the contact between the Inner and Outer Platforms of the Arabian Plate [24]. Such features are considered as an important paleoseismic indicator [23, 25, 26], which point to such activity in the area during deposition of the uppermost part of the Euphrates Formation (late Early Miocene).

4 Tectonic Style of the Studied Area

The studied area is located in both Outer and Inner Platforms of the Arabian Plate. The area, south and north of the Euphrates River is located within the Inner Platform, and Outer Platform; within the Jazira Zone, respectively [24].
The Early Miocene (25 – 17 Ma) witnessed the final marine transgression on the eastern and northern parts of the Western Desert. Different Middle Miocene sedimentary facies were deposited on both sides of Anah – Abu Jir Fault Zone, which forms the eastern and southeastern margins of the studied area. The sediments contain extensive

syn-depositional (soft-sediments) deformational features along most of the zone, indicating the seismic activity of Anah – Abu Jir Fault System at that time [12, 13, 27].
Recent activity is evident along Anah – Abu Jir Fault Zone. The continuous subsidence of Al-Jabha sag pond within Abu Jir Fault Zone is an example to the current activity of the zone. The successive terrace like lithified bitumen flows around the periphery of the depression pointing out to continuous widening and deepening of the depression (Figure 6). Each active period of extension was accompanied with eruption of bitumen flow and formation of a new step like terrace. At least five stages of bitumen terraces are preserved around the depression. The youngest level is the higher one, they are separated from each other by a horizons of Aeolian sand mixed with reworked bituminous materials pointing to the quite periods between the successive eruptions [28].
Other geomorphological evidences were recorded by [29,30] along the Euphrates River and Anah anticline. Moreover, these evidences collectively indicate the active nature of the Euphrates – Anah – Abu Jir mega lineament of the northern Arabian Plate. The continuous changing in trends of valleys and accumulation of terraces around them is another evidence for the activity of the Abu Jir Fault Zone [31].

Figure 6: Successive terraces of bitumen flows around the peripheryof Al-Jabha Depression (southwest of Ramadi city)

The sudden gas explosion at Abu Jir village in the Western Desert in 1982 provides another interesting example. The gas seeped out through newly formed cracks in the ground and went into flame as witnessed by the local villagers (Figure7). However, this event remained unknown to the geologist and others until recorded for the first time by [27]. This fire is called "Sea'aria" by the local villagers, which means "Little Hell", but the author give it the name "Abu Jir Eternal Fire" in tribute to the famous "Kirkuk Eternal Fire" [28].

Figure 9: "Little Hell" or Sea'aria as called by the local villagers.A burning gas leakage, called the Abu Jir Eternal Fire [28].

5 Results

The uppermost part of the Euphrates Formation in the central western part of Iraq, along the upper reaches of the Euphrates River, is intensely deformed. It shows many sedimentary structures with different amplitudes and sizes. Some of them exhibit minor folding and faulting [13]. Such deformational style in sedimentary rocks indicates syn-sedimentary deformation in soft sediments, which is one of the indications that the deformation had occurred due to seismic shocks [5,13].
The rocks of the Brecciated Unit are of "seismite" type, because they exhibit deformational features, which are developed due to seismic shocks, during deposition of the sediments. However, landslides in deep sea water develop such features too.

6 Discussion

Those sediments, which show soft-sediment deformation, should have deformed during sedimentation or shortly after, during the first stages of the deposition. This is because the sediments need to be "liquid-like" or unconsolidated for the deformation to occur [18]. Such deformational features are very common in the Brecciated Unit of the uppermost part of the Euphrates Formation in the studied area, therefore, they have deformed during deposition and/ or shortly after deposition. The presence of slump structures in the sediments of the Brecciated Unit indicate that the sediments were not consolidated yet, and they often are faulted [18]. Such minor faults were recognized by [12] and mentioned by [13, 28].
The presence of clastic dykes and sand volcanoes in the Brecciated Unit [12, 13,28] are good indication that the involved sediments are of "seismites" type, which are sedimentary beds disturbed by seismic waves from earthquakes [15]. Such deformations are also known as non-tectonic (sedimentary) deformations [32]. These may be interrelated, as tectonic shocks can lead to pressure gradient that induce the deformation of surficial, non-consolidated sediments. In particular, the topmost sedimentary layer can

become strongly disorganized, if it consists of material that is susceptible to shock-induced deformation [32]. This is a typical case in the Brecciated Unit and the overlying Undulated Limestone Unit, both represent the uppermost part of the Euphrates Formation, which in term represent the uppermost part of Early Miocene sediments, in the studied area. The Brecciated Unit includes marl, limestones and dolostone, which have different mechanical behavior during deformation; therefore, such deformational features are easily developed within them.

The present deformational features in the Brecciated Unit, which are indication for syn-sedimentary deformation caused by seismic shocks, might be however, developed due to submarine landslides too. Submarine landslides also could be triggered due earthquakes and gas hydration. A number of studies have indicated that gas hydration lie beneath many submarine slopes and can contribute to the triggering of landslides [33].The studied area is characterized by gas hydration and associated features. Good examples are the gas and bitumen seepages in Hit, Abu Jir and Jabha Areas; also the present eternal fire in Abu Jir village (Figure 9) is another indication.

The presence of cone-shaped contorted beds, pillows, chaotic beds, collapse structures, tabular depressions (Figs. 2, 3, 4 and 5) in the Brecciated Unit and the overlying Undulated Limestone Unit are good examples for soft-sediment deformation structures. Such deformational features are also indications for syn-sedimentary deformations caused due to seismic shocks [32]. These features may have been caused by earthquake-induced shocks, but it may alternatively be due to simple pressure resulting from differential loading (Lowe, 1975, and Jones and Omoto, 2000 in [32]). But, the frequent repetition of deformative forces, as evident from frequent repetition of the deformational features, strongly suggests earthquakes with close aftershocks. Such cases are witnessed by [15,16]. Moreover, [32] also considered the fact that sedimentation took place in a tectonically active basin, a seismic origin of many of deformed layers is by far more likely than any other origin. The tectonic activity of the studied area is proved by many indications; the most significant one is the presence of the active Abu Jir Zone [13,28].

Soft-sediment deformation structures are common to most sediment-gravity flow system. Gravity flows are mixtures of water and sediment and are often rapidly deposited due to flow collapse. This rapid deposition traps interstitial fluid in the sediment and results in high, unstable pore pressure. Most soft-sediment deformation is related to fluid-escape due to squeezing out of excess water from the pores of sediment during compaction. The style of soft-sediment deformation structures changes with progressive burial, going along with a change of the main controlling factors. In unconsolidated sediments near sediment-water interface pore pressures can equilibrate by either gradual or rapid fluid escape. Rapid dewatering in many cases is triggered by rapid deposition of dense sediment over less dense, water-rich sediment creating reversed density stratification. Under these conditions, pore water pressure rise above overburden pressure, the underlying low-density sediment is fluidized and intrudes the overlying unconsolidated sediments. Structures created by such a process are load casts and flame structures (ball-and-pillows and convolute bedding) [34]. Such style deformation of soft-sediments is also very common, but with the presence of active tectonic evidences, the seismic shocks caused deformations are more likely. Therefore, the present deformational features in the studied area are caused by seismic shocks, rather than those formed due to dewatering.

According to [26] "the recognition of seismites is hampered by the fact that earthquakes are just one of the trigger mechanisms that induce soft-sediment deformation. A combination of three or four of the following characteristics, in layers with an abundance of such structures, is commonly considered diagnostic for an earthquake origin [35,36,37]: (1) the restriction of the soft-sediment deformation structures to discrete stratigraphic horizons; (2) lateral continuity of the deformation structures over long distances; (3) recurrence of such deformed layers over time; (4) consistent deflection of paleocurrent trends from their usual pattern, within the deformed unit; (5) confinement between undeformed strata or strata with deformations distinctly different in origin; and (6) a preferred association with wedges of intraclastic breccias, conglomerates and massive sandstones. When reviewing the aforementioned 6 characteristics, in the involved area; the following facts can be seen. 1) The deformation is restricted to the Upper Member of the Euphrates Formation, 2) The deformation extents to about 140 Km, inside Iraq and continues westwards into Syria, 3) The deformation is not found in other stratigraphic units, 4) The presence of deformed and broken rock fragments within the Brecciated Unit, without constant orientation, confirms this character, 5) This character is also present between the rocks of the Euphrates Formation, the Lower and Upper Members, the rocks are not deformed in the former and deformed in the latter, and 6) The existence of many beds of conglomerate and breccia with wedge shape, fulfills this character. Therefore, five among six characters are present in the rocks of the Brecciated Unit, indicating active seismicity during deposition.

The presence of highly deformed beds within the Brecciated Unit and the overlying Undulated Limestone Unit (Figs, 2, 3, 4 and 5); with frequent repetition, indicates frequent repetition of deformative forces, thus; strongly suggests earthquakes with close aftershocks ([14]1984; Owen, 1995; Bose et al., 1997, in [32]).

The presence of the aforementioned syn-depositional structures (Figs. 2, 3, 4 and 5), which have confirmed that the existing deformed beds in the Brecciated Unit are formed due to earthquakes during deposition and prior to total lithification, and the nature of the existing structures and their distribution suggest that the magnitude of the earthquakes responsible for the present structures was likely higher than 5 (in order to produce sediment liquefaction) and probably reached intensity as high as 7 or more (Richter scale), as confirmed by [38]. The assumption of [38] that the "basin architecture suggests that the foci of these earthquakes were located close to the fault-controlled borders of the basin or within the basin itself" holds good with the presence of the active Euphrates – Abu Jir Fault Zone, which forms the eastern limits of deformed rocks, since no deformation exists within the rocks of the Euphrates Formation east of the mentioned active zone. The activity within the basin is also confirmed by the growing of Anah anticline, which is inverted grabben [13, 24, 27, 39].

Field evidences indicate that the intensity of the deformation increases in amplitude and wave length in areas were the active Abu Jir Fault Zone meets the Euphrates Zone, represented by the growing Anah anticline. Those areas are limited to the upper reach of the Euphrates River [6, 8, 9]; within Iraq and extend northeast wards in the Jazira Area, north and northeast of the Hadith town [10]. Towards east, northeast and southeast of the active Euphrates – Abu Jir Fault Zone, the deformation and brecciation disappear within the Upper Member of the Euphrates Formation [10, 11, 17, 40, 41].

The increase of the soft sediments deformation in the aforementioned area is attributed to tectonic unrest, represented by earthquakes within the deeper parts of the depositional basin, which needs more time for lithification. This is confirmed by the deposition of the Nfayil Formation [7], which is deep water environment; instead of the Fatha Formation, which is deposited in closed lagoons. Therefore, where the Fatha Formation is deposited above the Euphrates Formation, no deformation can be seen in the uppermost part of the Euphrates Formation, because the basin was shallow and the sediments were lithified more quickly, besides the sedimentation was continuous from the Early Miocene (Euphrates Formation) to the Middle Miocene (Nfayil and Fatha formations).

7 Conclusions

The following can be concluded from this study:

- The uppermost part of the Euphrates Formation, which is called the "Brecciated Unit" includes different deformational features, which prove "seismite" type of syn-deformational structures.
- The deformational features in the Brecciated Unit are syn-sedimentary structures, developed before lithification of the sediments.
- The deformational features are developed due to seismic shocks during the deposition of the sediment, indicating tectonic unrest during Early Miocene.
- Deformational features such as those present in the Brecciated Unit could also be created due to dewatering and associated events, and/ or due to under sea water landslides, but with the presence of many indications of active tectonics in the studied area, suggest that the deformational features were created due tectonic unrest creating seismic shocks.
- The restriction of brecciation and deformation in the uppermost part of the Euphrates Formation along the contact between the Inner Platform and Outer Platform of the Arabian Plate, especially along northern part of tectonically active Euphrates and Abu Jir Fault Zones, especially nearby the growing Anah anticline, indicates and confirms the earthquake origin for the deformed and brecciated rocks, which represent seismites.
- The presence of such syn-depositional structures with the recorded intensity indicates earthquakes of magnitude ranging from 5 – 7, on Richter scale.
- The restriction of the syn-depositional sedimentary structures in areas limited by the active Euphrates – Abu Jir Fault Zone, indicates that the foci of the earthquakes were located close to the fault-controlled borders of the basin, and the growing Anah anticline, which is an inverted grabben, indicates that the foci were also within the basin itself.

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