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Origin of the Phacoid Structures within the Chia Gara Formation, Kurdistan Region, Iraq

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Abstract

Special structural shapes exhibit occurrence in the sequence of Chia Gara Formation in the northwestern part of the Zagros belt in Kurdistan region-Iraq. These structures name as Phacoids that have spherical to semi-spherical shape. Constructing concentric zonal features in the carbonate/shale of Chia Gara Formation. These structures are characterized by the presence of ball-like bodies within the host rocks. The diameter of phacoids ranged from 20cm to about 120cm. They are harder than the host rock. Seven outcrop sections, of Chia Gara Formation are reviewed and two of them studied in detail to determining the origin and process of their formation. The phacoids can be conceder as sedimentary key marker to recognize the Chia Gara Formation in the outcrops. Petrographically, the phacoids are mostly organic matter–rich bioclastic lime wackestone. The bitumens are present in sub-parallel lines in a calcareous groundmass. However, the host rock is generally composed of calcareous shale rich in organic matter but barren of fossils. The carbonate phacoids were forming in a competent/incompetent sequence. The mechanism of creating these carbonate phacoids structures are related to the compression stress and diagenesis processes on the carbonate/shale successions. Some phacoids directly formed from the carbonate strata after separated and rolled due to continue compression shear stress that in the final stage form the carbonate phacoid with the aids of diagenesis.

Introduction

The Chia Gara Formation (Tithonian-Berriasian) has been studied by different authors such as *Al-Beyati (1998)* [3], *Bellen (1959)* [8], *Edilbi (2010)* [9], *Edilbi et al. (2017)* [10], *Edilbi and sherwani (2019)* [11], *Hakimi et al. (2018)* [15], *Jassim and Goff (2006)* [16], *Mohialdeen (2007)* [20], *Mohialdeen (2008)* [21], *Mohialdeen et al. (2013)* [22] and *Wimbledon et al. (2016)* [29]. The Chia Gara Formation generally consists of a carbonate-rich succession of limestone and calcareous shale, usually rich in organic matter [21]. *Bellen et al.* (1959) [8] determined a certain zone within the lower part of the Formation, and named this zone as "Phacoid Zone". The Phacoid structures are lenticular in shape. This term mainly used in 1903 by E. Hubert. Generally the Phacoid includes all particle or lenticular inside beds, and they are formed because of compression stress [12], [26].

Location and Geologic setting of the study area

Through this research, many surface sections of the Late Jurassic-Early Cretaceous Chia Gara Formation from Kurdistan region-NE Iraq were reviewed and studied. The selected sections are situated in Thrust Zone, Imbricated Zone and High Folded Zone of Iraq (Fig.1). In this study, we focused on a certain zone within the lower part of Chia Gara Formation which contains phacoid structures. *Edilbi et al. (2010)* [9] identify phacoids in Chia Gara Formation and named as ball and pillow. The main purpose of this study is attempting to recognize this structure and interpret how they formed. After field investigation. Seven sections of Chia Gara Formation were selected and examined; they are; Banik, Sararu, Barsarin, Hanjera, Zini Warte,

Barzinja and Chwala sections (Fig. 1), as well as in the Zini Warte and Chwala sections focused on the petrographic and mineralogical study to explain how these structures formed.

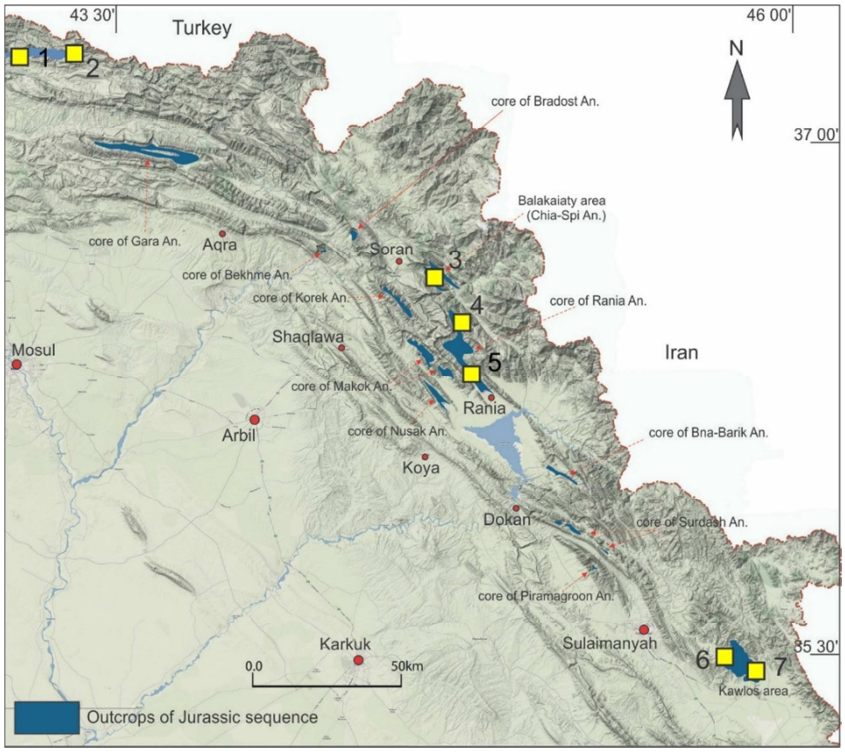

Figure 1: Terrain maps of NE-Iraq (Kurdistan Region). The yellow points show study area locations of exist the phacoids in the Chia Gara formations. The sections are: 1- Banik, 2- Sararu, 3- Barsarin, 4- Zini Warte, 5- Hanjera, 6- Barzinja and 7- Chwala.

The Chia Gara Formation (Tithonian-Beriassian) deposited in a shelf to slope environment [21] and/or euxinic basin condition [2] as a quiet pelagic and reducing basin [11] (Fig. 2). The basin of deposition for Chia Gara Formation was not wide and mostly was a semi graben structure on the passive margin of Tethys Ocean [21], [25]. The Chia Gara Formation is underlain by Barsarin or Gotnia Formations and overlain by Balambo, Sarmord or Garagu formations. The age of the formation is absolutely Late Jurassic to early Cretaceous, i.e. the Jurassic/Cretaceous boundary is locating within this Formation [1], [4] and [29]. The reducing marine depositional environmental conditions of the Late Jurassic-Early Cretaceous limestone sediments in the Kurdistan Region, Northern Iraq, have also been interpreted using geochemistry of major and trace elements [11], [14]. The high carbonate input (i.e.$CaCO_3$) with terrestrial detritus elements (e.g., SiO_2, Al_2O_3 and TiO_2) in significant amounts further confirms that the Late Jurassic-Early Cretaceous limestone sediments were deposited in calcium-rich seawater [27] with detrital materials input [24]. The calcium-rich seawater has also been confirmed by high Sr trace elements [14].

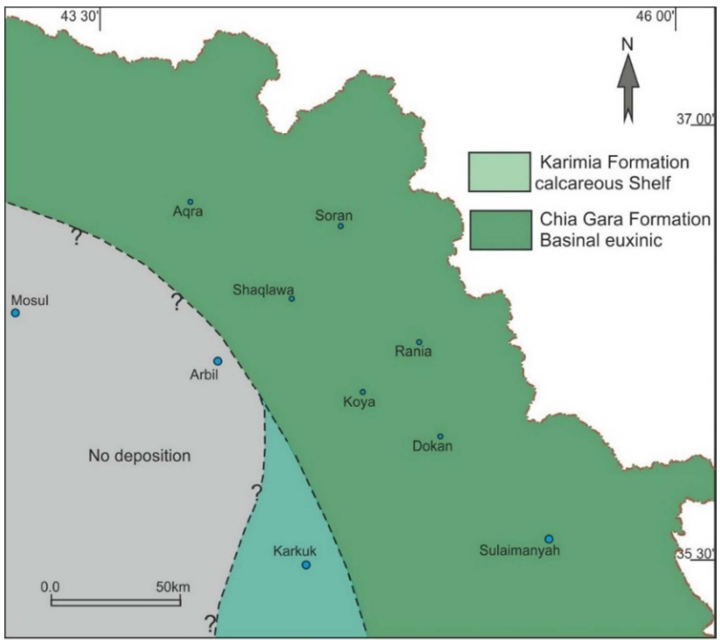

Figure-2: Palaeogeographic map of Kurdistan region during the Tithonian-Valanginian period [2], [5], [6], [7] and [16].

Samples and methodology:

Phacoid structures have been studied from seven sections in Kurdistan region (Fig. 1). Field investigations and measurements carried out for all sections. Two areas, which are Zini Warte and Barzinja sections, were chosen for collecting samples, detailed microscopic study and mineralogical composition by using thin sections, and XRD device.

Stratigraphy of Chia Gara Formation and description of Phacoids:

As previously mentioned seven locations were selected to study these Phacoid beds in the Chia Gara Formation (Fig. 1). In order to describe and interpret this phenomenon within the formation, the stratigraphy of the Tithonian-Berriasian sequences in all these sections were described:

1-Banik Section:

This section occupies the northern part of Kurdistan Region, near Zakho district (Fig. 1) and has attracted the interest of numerous researchers. The Banik Village is locating at about 25 km northeast of Zakho City, Duhok Governorate in Kurdistan Region. The area is situated within the High Folded Zone of Iraq [7], [9], [14]. The Banik section also lies in a rugged terrain where the section of Jurassic rocks is exposed along a relatively narrow valley in which Banik Village lies (Fig. 3). The phacoid structure is not clear because of the abundance of trees in the area. However, the entire section was not measured. Some phacoids were identified within the lower part of the formation ranging in diameter from 50cm to 100cm (Fig.6A). They are hosted in shale or calcareous shale rocks (Fig. 3). *Sherwani and Edilbi* [11] studied the formation from the same section and measured the whole section which was around 60m. The lithology is homogenous with repeated alternation between shale and thin bedded argillaceous limestone.

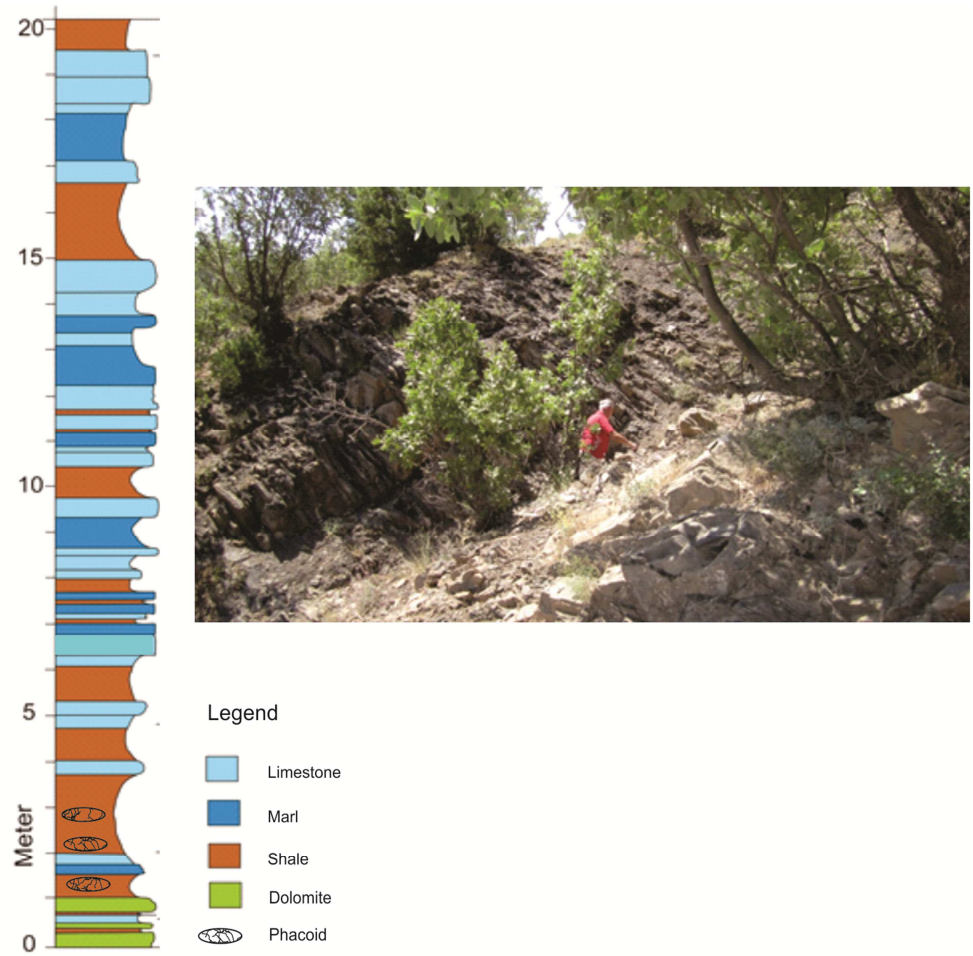

Figure 3: Stratigraphic section of a part of the Chia Gara Formation from Banik Village, Kurdistan (modified from *Hakimi et al. (2015)* [14]).

2-Sararu section, Duhok:

The Sararu Village is located in Kurdistan Region of northern Iraq about 6 Km northeast of Qumri village on the main road in Barwari Bala, Duhok Governorate (Fig. 1). Geologically, the Sararu Village is locating within Ora Thrust Zone. The information of this section was taken from Edilbi et al. [10] who studied Baluti Formation in this area and mentioned to Chia Gara Formation too. The phacoids in this section are large and the longitudinal length are parallel to the bedding plane (Figs. 4).

Figure 4: Phacoids in the shale of chia Gara Formation in Sararu Formation [10].

Figure 5: Field photographs for the Phacoid zone within the lower part of Chia Gara Formation (Tithonian-Beriassian), from different sections in Kurdistan : (A) Banik section, (B) Chwala section (C) Barsarin section, (D) Hanjera section, , (E)Zini Warte section, (F) Barzinja section.

3-Barsarin section:

This section is locating in Barsarin village (Rwanduz, Hawler Governorate) within the Imbricated Zone of the Foreland Basin (Fig. 1). *Sherwani and Edilbi* [11] identified 198m as total thickness of Chia Gara Formation (Fig. 6). The lower contact of Chia Gara with Barsarin Formation (Kimmeridgian) and upper contact with the Sarmord Formation (Valanginian - Aptian). The lower part mainly comprises 5-45 cm thick shale with argillaceous limestone and black limestone. The Phacoid structures are common and mostly arranges parallel to the bedding plane (Fig. 5C).

4-Hanjera section:

The Chia Gara Formation crops out in the northeastern limb of Shawri Anticline, Rania Area, Sulaimani (Fig.1). The age of Chia Gara Formation in this area is Tithonian-Berriasian [1]. The phacoids cropped out in the area inside the shale layers of Chia Gara Formation. The shape of the phacoids are similar to the ellipsoids, and the diameter exceeds 50cm (Fig. 5D).

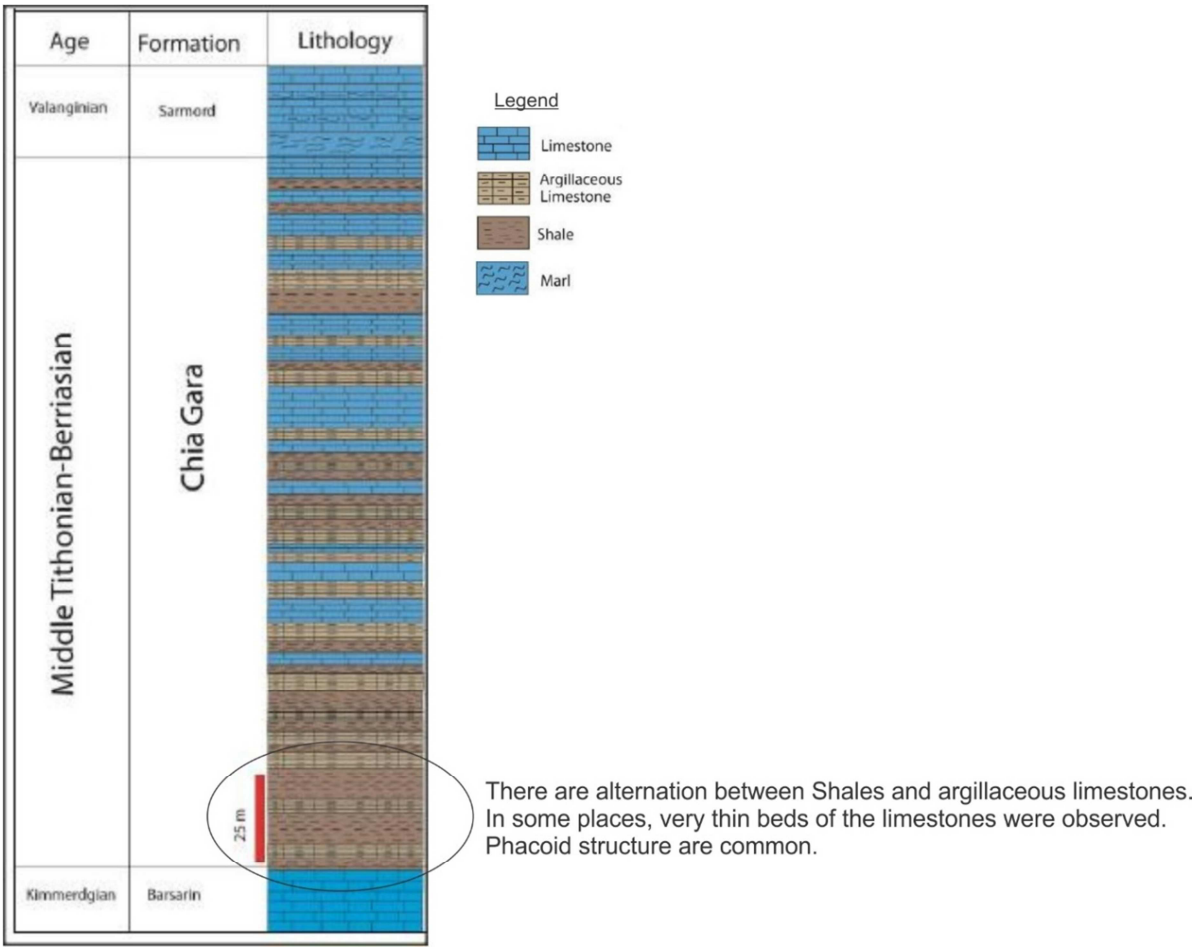

Figure 6: Stratigraphic Column of the Chia Gara Formation in Barsarin section [11].

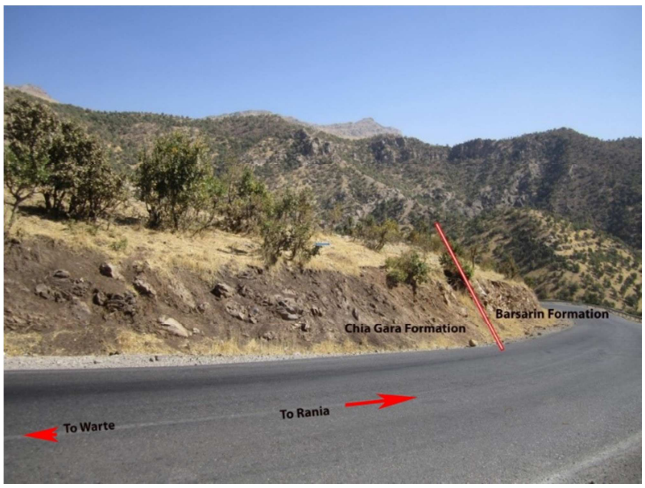

Figure 7: Field photo of the studied section, showing the Barsarin and Chia Gara formations and the boundary between the both.

5-Zini Warte section:

The selected section for this study is locating on the road cut of Zini Warte Mountain near Warte Village (Fig. 1). The Chia Gara and Barsarin formations are cropped out on the road cut and the samples have been collected from this section. The measured section is about 35m (Fig.7). The phacoid structures are large, and they are arranged as a series (Fig. 5E).

6&7- Barzinja and Chwala Village sections:

This area is located in the southeastern part of the Sulaimani-Azmar area, between the Saisadiq and Nalparez districts (Fig. 1). The geological situation in this area is complex due to the folding and thrusting. The lower contact of the Balambo Formation with the Tithonian-Berriasian beds of Chia Gara Formation is conformable. The Chia Gara Formation in Kaulos area is composed of an unbroken succession of well-bedded dark limestones and thin layers of shales. The shale layers interbedded between the dark beds of limestone, and generally very thin because of the stretching induced by the folding. In the southeastern Barzinja district, close to the Chinara and Zilzilla villages, phacoids exist with diameter 1-1.5m (Figs. 5 B and F). The source and process of forming these phacoids are questionable [1].

Through the field study more than ten phacoids found which are exposed in the area (Fig. 8). The phacoids depend on the place of occurrence are two types: first type, on the surface, where they are cropping out and after sliding or slumping from their origin places downward to another place due to the gravity. Second type, is in situ, remain in the place of formation and occur inside the beds of Chia Gara Formation. The Shape of the phacoids is like the egg, or ellipsoid or cylindrical shape (Fig. 8), mostly where broken due to the weathering process. The sizes are heterogenic, with diameters less than 10cm until large size with diameter more than 1m were found (Fig. 8). The phacoids shape similar to onion with occurs of zone of development and growth, have black sphere in the center covered by the concoidal layers cover this center to form the egg shape (Fig. 5F).

Figure 8: Large size of phacoids cropping out near the main road of Barzinja Village, Sulaimani, Kurdistan.

Morphology and dimensions of Phacoids

Bellen et al. (1959) mentioned that the lower part of Chia Gara Formation composed of yellowish marly limestone and shales consistent zone of Phacoid. As well as in all study areas these disc-like concretions are occurring within the lower part of Chia Gara Formation. The diameter range from 20cm to about 2.0m, with a thickness from 20cm to 50cm. These discs-like structures are laid parallel to bedding planes, usually seen the edge of them out of the beddings or the host. In rare cases such as in Chwala Village the entire of the disc separated from the host and falls on different sides. Generally the host is soft and dark shale or calcareous shale, while the concretions are harder (limestone or dolomitized limestone) and sometimes with internal bedding. The size and the component of the phacoids are different from locality to another; for example in the Banik and Barsarin sections they are small as compared to other sections (Fig. 5). The phacoids are mostly limestone or dolomite such as in Banik, Sararu, Barsarin, Hanjera, and Chwala sections, however in Zini Warte and Chwala the phacoids are dark with existing of high amount of organic matter (Fig. 5).

Petrography

Samples from the phacoids and the host rocks have been studied to elucidate the relation between the phacoids and surrounding rocks. The petrography of phacoid in Barzinja area mostly wackestone rich in solid organic matter (bitumen) with existing of small crystals of dolomite and calcite (Figs. 9A and B). The petrography of host rock is shale rich with organic matter and no fossils are observed (Fig. 9C).

However, in Zini Warte area the rock is argillaceous limestone (phacoid lens) rich with organic matter (bitumen), rich in radiolarian molds, calcispheres, Ostracods, and ammonite bioclasts (Fig. 10).

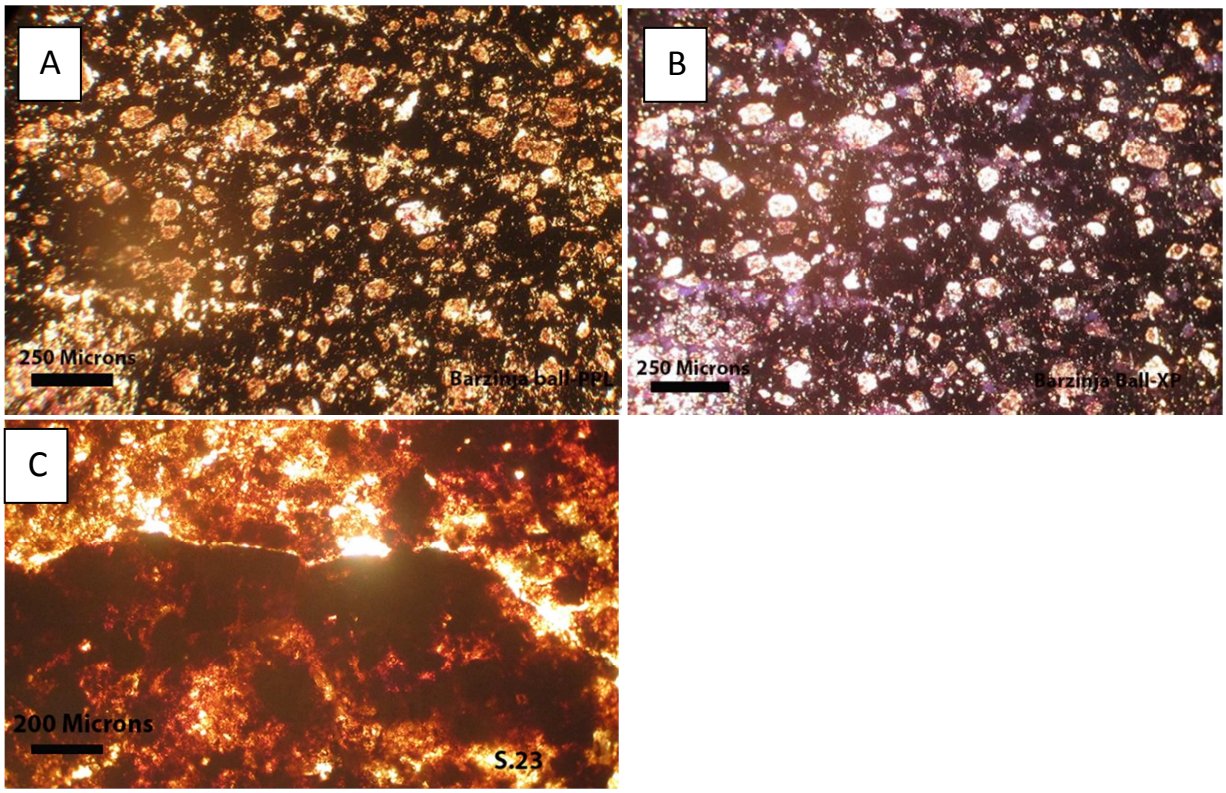

Figure 9: Photomicrographs of Phacoid structure under microscope: showing dolomite grains in organic matter rich matrix; (A) under Plane Polarized Light and (B) under Crossed Polar Light. (C) The host rock which is shale (the samples collected from Barzinja area).

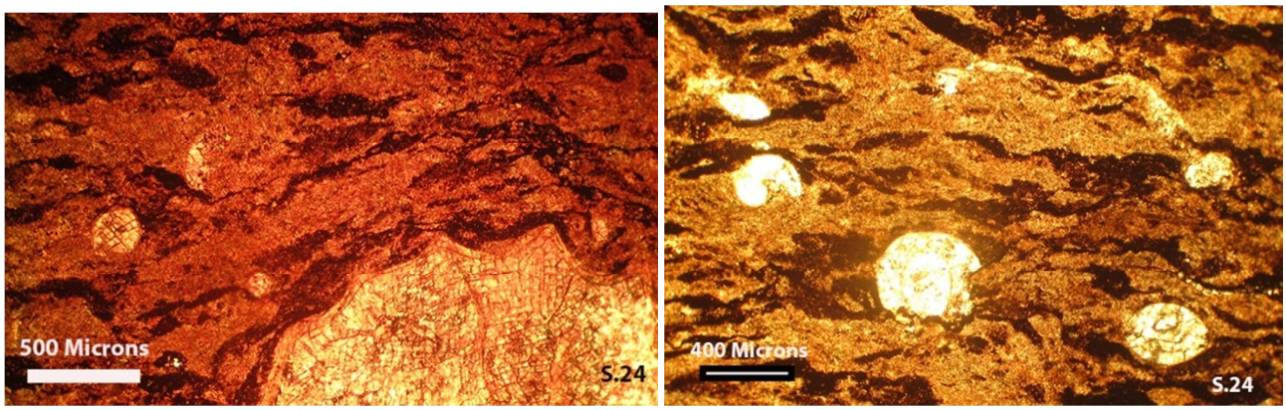

Figure 10: Both photos are for sample in Zini Warte section, which is from the phacoid lens. Left: argillaceous limestone rich in organic matter (black bands) with ammonite bioclasts and one small Ostracods (the sample stained with Alizarin Red solution). Right: the same sample without Alizarin RS, ostracods and ammonites are present.

X Ray Diffractgram interpretation

To understand the mineralogical composition of these phacoids and the hosts, samples have been studied using the XRD device from the two sections (i.e. Zini Warte and Barzinja sections).

Barzinja area: The host rock is pure limestone with some of the clay minerals (Fig. 11A), while the phacoids are very rich in dolomite and calcite, also some quartz is present (Fig. 11B).

Zini Warte area: The host rock is shale or calcareous shale rich with clay minerals (i.e. illite/palygorscite+ chlorite/kaolinite) (Fig. 12A). The phacoids in this section are mostly pure limestone with a small amount of clay minerals (Fig. 12B). These two different results give us to conclude that the phacoids may formed in more than one way.

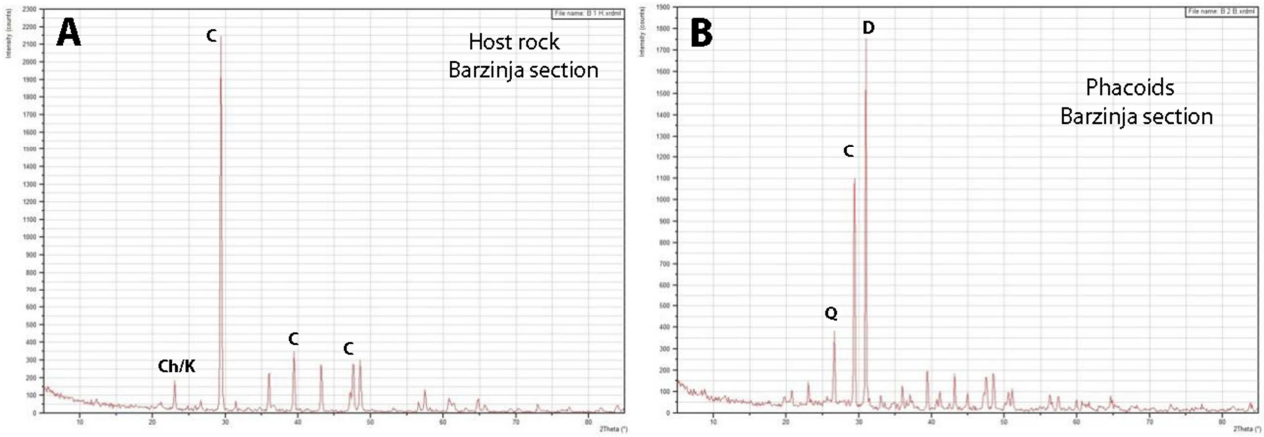

Figure 11: XRD chart for samples of Barzinja section. A- The diffractgram of Host rock, and B- diffractgram of the Phacoid structures. C: Calcite, D: Dolomite. Q: Quartz, Ch/K: Chlorite? Kaolinite

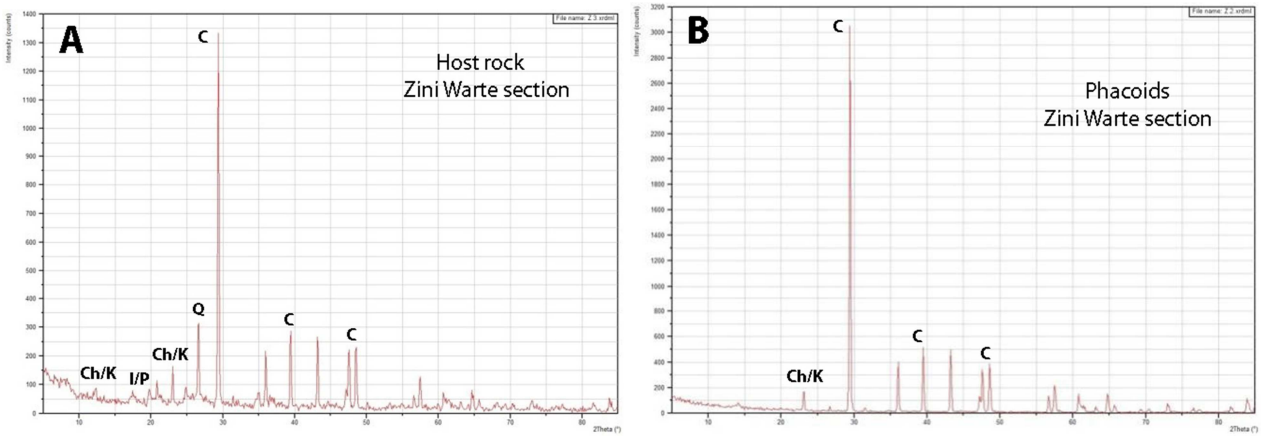

Figure 12: XRD chart for samples of Zini Warte section. A- Chart of Host rock, and B- Chart of the Phacoid structures. C: Calcite, D: Dolomite. Q: Quartz, Ch/K: Chlorite? Kaolinite, I/P: Illite/Palygorscite

Interpretation of the formation of these phacoids

Previously many authors identified the phacoid in the mélange and Nappe zones, such as phacoid sandstone in the mélange and accretionary prism of the subduction [12], [13], [18], [19], [23]. The phacoid shape exists in the pegmatite fabric of the subduction zone in Italy [28]. The phacoid formed as a result of shear stress and they formed with the existing of a rhythmic sequence of Competent and incompetent beds [12], [26]. The orientation of the phacoids is the key to the compression stress orientation [26] (Fig. 13). Depend on the fieldwork and laboratory results we assume models to how these phacoids may formed:

Model-1:

This model explain that the phacoids formed when the sequence is thick shale restricted between two limestone beds (Fig. 14-1). Fracture developed in the horizontal shale/limestone sequence (Fig.14-2) as a result of decompression stress. Dissolution of $CaCO_3$ from limestone and partially deposited in the pores of shale (Fig. 14-3) through the fractures form a body of mixture carbonate-shale-organic matter in the incompetent shale beds. During the compression regime the sequence folded. This folding form beds thrust as a resulting of shear stress. During progressing the shear stress the body rolling and a final result from the phacoids (Fig. 14-4).

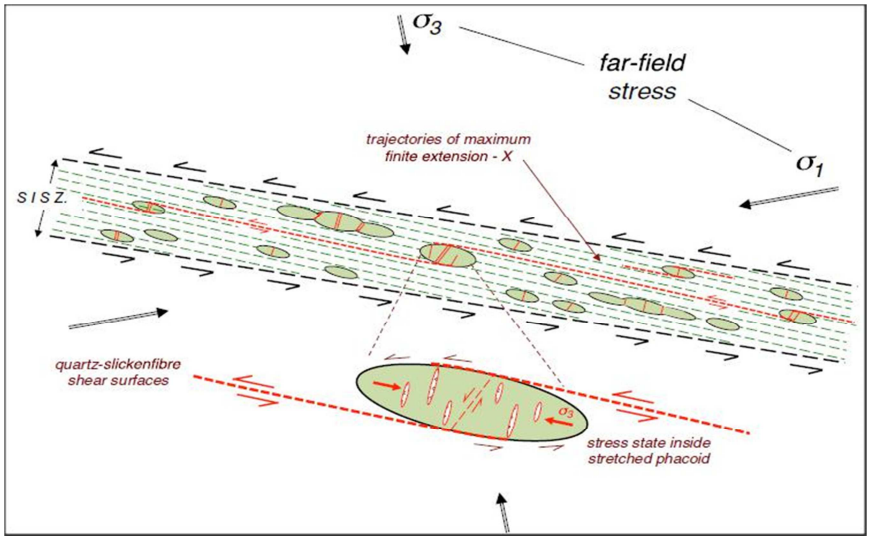

Figure 13: Schematic model explain the phacoids orientation and related to the shear stress and direction of the main stress parameters [26].

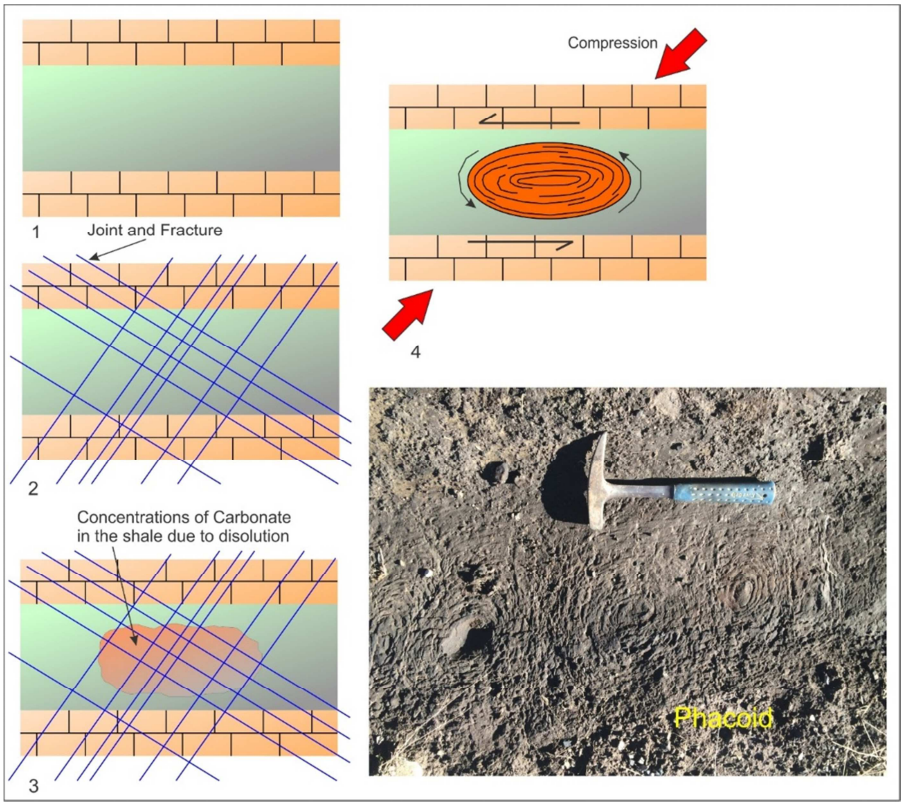

Figure 14: Formation and development of the Phacoids as a result of dissolution with simple shear stress. The right down figure is support example of phacoids in Chwala section.

Model-2:

We assume this model for the thick shale/thin limestone with compression shear stress. The phacoids are directly produce from the limestone beds (Fig. 15). Because the phacoids formed in sequence with high ratio of incompetent/competent with shear stress [12]. If the competent/incompetent sequence effected by the compression stress the first step initiate reverse or strike-slip fault with the folding (Fig. 15-1). During the continuous compression the limestone break apart inside the shale as a separate block (Fig. 15-2). Organic matter inter limestone blocks through fractures, in the same time the outer carbonate blocks dissolved (Fig. 15-3). The limestone blocks rolling if the shear stress continuous progression and final result is forming the phacoids (Fig. 15-4).

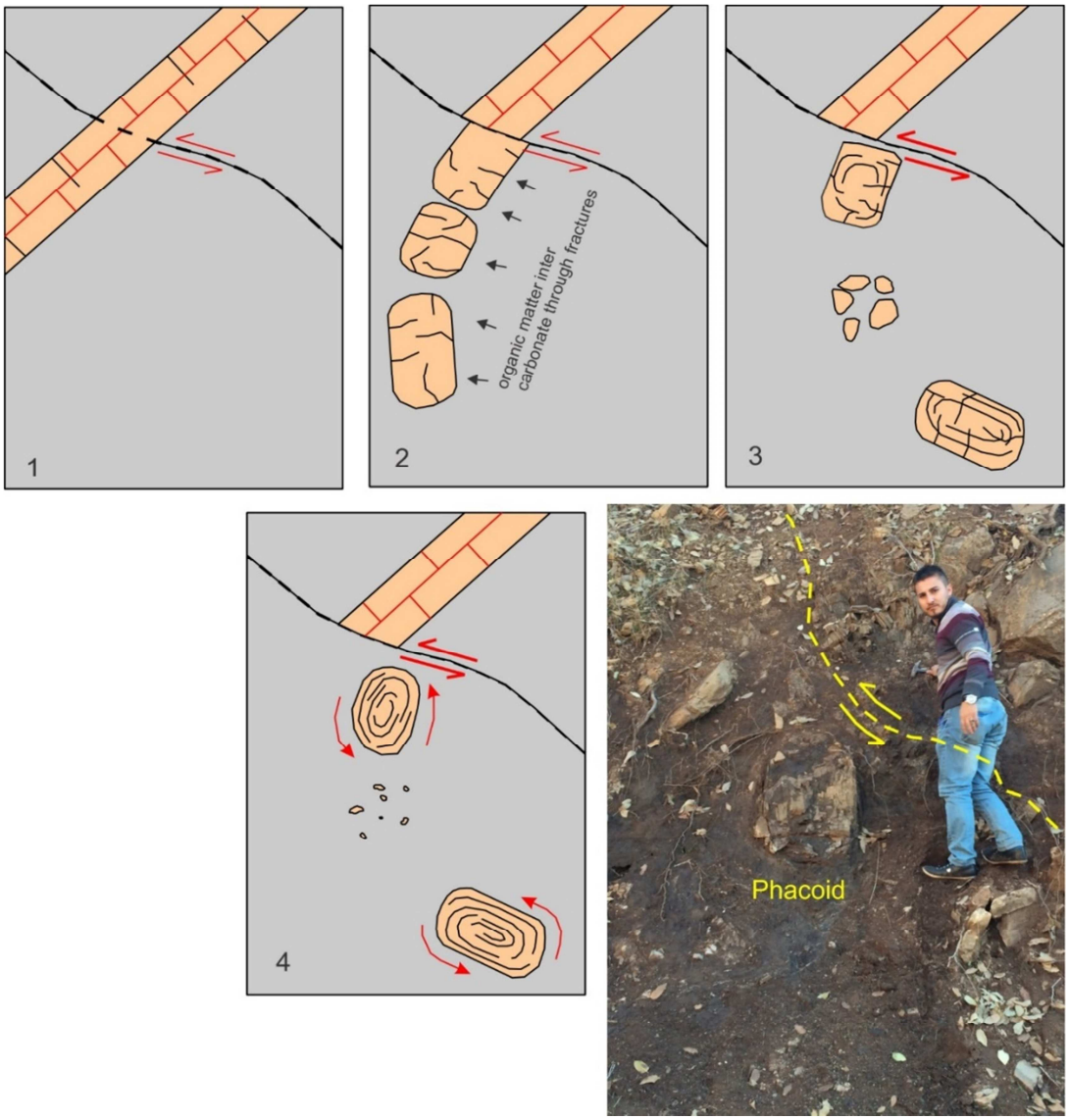

Figure 15: Formation and development of the Phacoids as a result of compression stress and break apart of limestone in competent/incompetent sequence. The right down figure is support example of phacoids in Chwala section.

Model-3:

This assumption is similar to the method of forming ball and pillow in sandstone/Clay [17] (Fig. 16). This model apply of sequence of rhythmic limestone/shale. This sequence in the first step affected by loaded stress and formation of fractures in the limestone beds (Fig. 17-1). The fracture developed and expanded because of dissolution of the limestone. The limestone beds break apart to blocks (Fig. 17-2). The organic matter from the shale inter to the limestone blocks (Fig. 17-3). Change the overload stress to simple shear stress during folding the limestone blocks rolling and the result is forming the phacoids (Fig. 17-4).

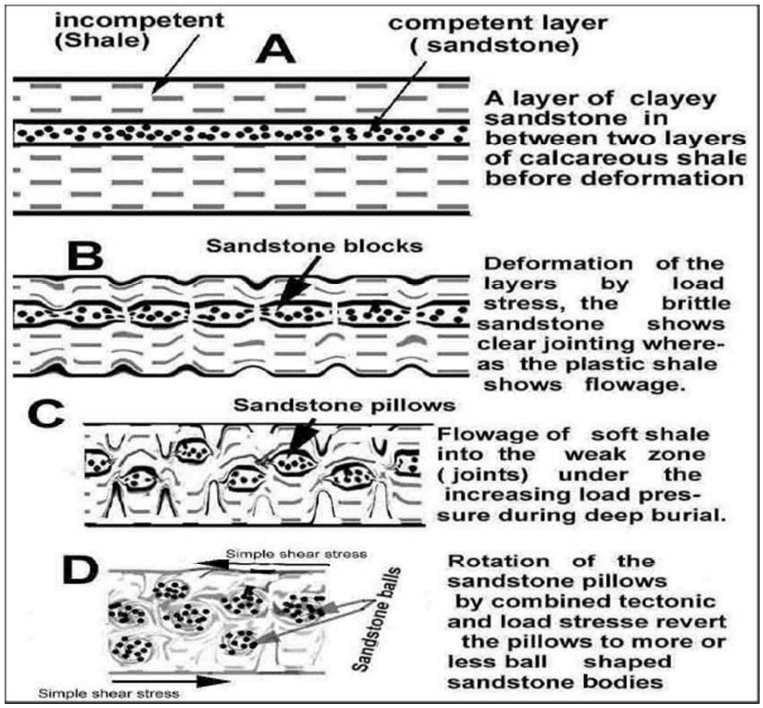

Figure 16: A conceptual model for development of ball and pillow structure [17].

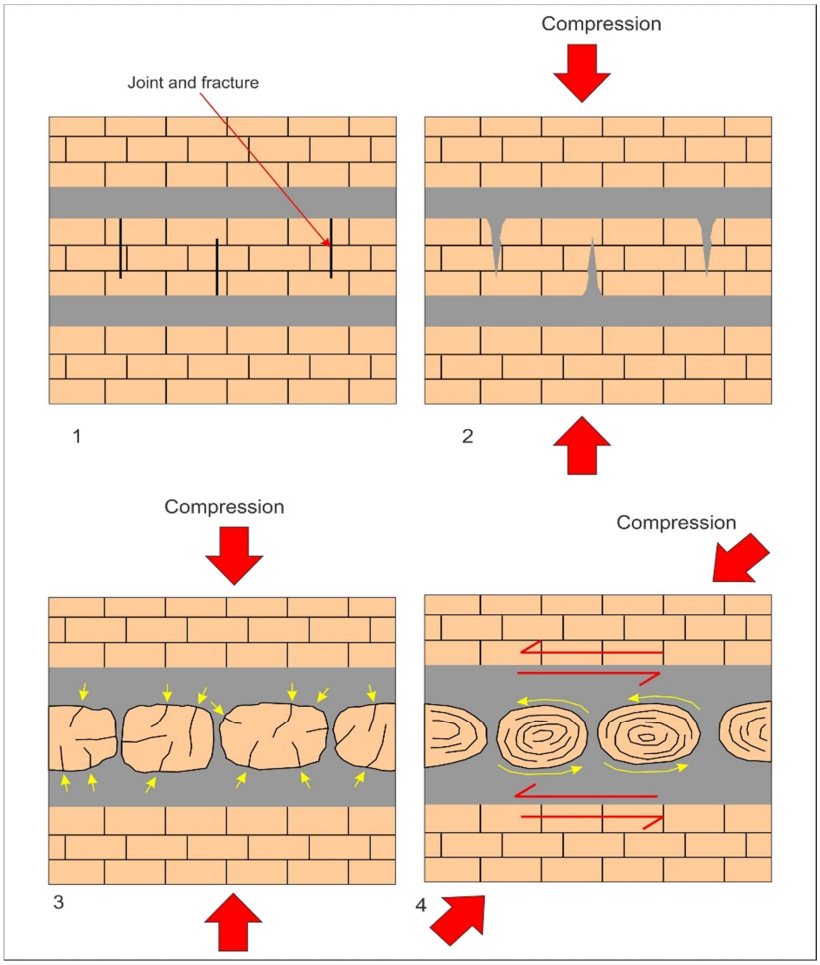

Figure 17: Formation and development of the Phacoids as a result of compression stress and break apart of limestone with existing fractures. Formation of phacoids as result of shear stress.

Conclusion

The Phacoid structures discover in different localities in Kurdistan region in lower part of Late Jurassic – Early Cretaceous Chia Gara Formation. Through this research constrain new definition of phacoid structures that are not only exist in the mélange sediment however occur in deep lagoonal carbonoclastic facies. The shale richness of lower part of Chia Gara Formation in all sections was the main factor for distribution of Phacoids in the formation. Petrography and mineralogical examination for the host rocks and phacoid structures indicate to clear difference in lithology and mineralogy. Two essential factors were responsible for creating the phacoids; first is the occurrence of sequence of competent/incompetent beds (i.e. limestone/shale) and the second is simple continuous shear compression stress. The study of these carbonate phacoids within the lower part of Chia Gara Formation revealed two important clues; first the carbonate phacoids are post depositional bodies, and the second determine main compression stress axis from phacoid orientation.

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