Tikrit Journal of Pure Science
ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)
Journal Homepage: http://tjps.tu.edu.iq/index.php/j

Paleoecology and Depositional Environment of the Govanda Formation in the Kurdistan region, northeast of Iraq

Arkan O. Sharazwri , Azad T. Saeed
Department of Petroleum Geosciences, Faculty of Science, Soran University, Soran, Kurdistan Region, Iraq
https://doi.org/10.25130/tjps.v27i5.17

ARTICLE INFO.
Article history:
-Received: 15 / 7 / 2022
-Accepted: 25/ 8 / 2022
-Available online: / / 2022

Keywords: Paleoecology, Miocene, Govanda, Depositional Environment, Iraq.

Corresponding Author:
Name: Arkan O. Sharazwri
E-mail: arkan.hussien@soran.edu.iq
Tel:

ABSTRACT

The Govanda Formation was deposited during the Early-Middle Miocene Epoch in the intermountain areas between Zagros Suture and Imbricate zones. The Paleoecology and depositional environment of the Govanda Formation has been studied in detail in Mergasor and Penjwen districts for the first time. The formation in these two sections from bottom to top is comprised of thick bedded, oyster and chert bearing conglomerate, pebbly sandstone, red-brown shale and siltstone, fossiliferous limestone and detrital limestone. The formation in Mergasor, Beshkariya Village is 85 m thick and in Penjwen, Gole Village is 60 m thick. The study is based on the detailed microscopic analysis on the benthic and planktonic foraminifera with miscellaneous fossils that exists in the carbonate rocks of the Govanda Formation. Larger and smaller benthic foraminifera include the following genera: *Operculina* sp., *Borelis melo* sp., *Austrotrilina* sp., *Peneroplis* sp., *Meanderopsina* sp., *Miogypsinoids and Miogypsina* sp., *Archaias* sp., *Amphistegina* sp., *Textularia* sp., *Lepidocyclina* sp., *Miliolids*, *Quenquiloculina* sp., *Pyrgo* sp., *Spiroloculina* sp., *Triloculina* sp., *Ammonia* sp., *Elphidium* sp., *Dendritina* sp. and *Rotalia venoti* dominated the limestones of the Govanda Formation. Planktonic foraminifers are mostly includes the following genera: *Globigerinoids* sp., *Globigerina* sp., *Globorotalia* sp. *and Orbulina* sp. Moreover, miscellaneous fossils include corals, coralline red algae, echinoderms, bivalves, ostracods, bryozoans, brachiopods and serpulid worms (*Ditrupa* sp.). The paleoecological condition of the formation was interpreted as follow; the temperature of the Govanda basin ranges between 15-30 °C, nutrient level is between eutrophic to mesotrophic, salinity ranged between normal saline to hypersaline water, light intensity ranging from euphotic to mesophotic and less oligophotic zones, the water depths ranged between 0-120 m, the clastic influx was high in the basin, differences in size and shape within foraminifers of the Govanda Formation indicate various depositional environments and ecological conditions, the water energy was moderate. The environment of deposition is interpreted as being ramp environment. Depending on the different microfauna that exist in the formation, four main zones are distinguished in the ramp model of the Govanda Formation as follows; proximal inner ramp setting which includes open lagoon, distal inner ramp setting which includes back-reef environment, proximal middle ramp setting which includes reef and fore-reef environments, distal middle ramp/ proximal outer ramp setting, which includes open marine environment.

1. Introduction

The Early Miocene starts with relatively slight subsidence and transgression but later in the middle Miocene rapid transgression occurred in the Zagros foredeep basin (Fat'ha basin) and the sediments from the uplifted Zagros thrust sheets or adjacent rising lands in the northeast filled the intermountain basin (Govanda basin) [2]. The first description of the Govanda Formation was defined by Dunnington et al., in [2] at northwest slopes of the Govanda Plateau, near the boundary between Iraqi and Turkish boundary, within the Balambo-Tanjero tectonic zone. Outcrops of the Govanda Formation in the Zagros Suture and Imbricate zones are distributed somewhat patchy starting from the type locality in the Sherwan Mazin area to the Mergasor, Qalandar, Rusty valley, Shahidan valley (Qandil), far to Ranya, Chwarta and Penjwen areas. The Govanda Formation is 126 m thick at the type locality and in nearby areas it reaches 150 m. According to [2], the formation from bottom to the top is comprised of; 6 m polygenic intraformational conglomerate at the base interbedded with sandstone and siltstone, and capped by 20 m of silty limestone with sandy detrital limestone bearing Cretaceous fossils. The overlying 100 m are mostly coralline, fossiliferous reefal limestone locally intercalated by red clastics. According to [2], the formation was deposited within the reef environment. At the type locality, the Govanda Formation is unconformably underlaid by the Late Maastrichtian Tanjero Formation and a few miles to the south near the Zaita village the Govanda Formation lies directly on the Aptian-Albian Qamchuqa Formation [2]. The upper contact is gradational with the undifferentiated Fars Formation consisting mostly of red and brown marl and siltstone with occasional limestone beds. Due to the complex tectonics and closing of the Neo-Tethys Ocean which created separate sub-basins, studies have encountered many challenges in separating these formations.

In this study, the paleoecology and depositional environment of the Govanda Formation will be described in detail. Significant larger and smaller benthic foraminifera, planktic foraminifera and miscellaneous fossils were used to interpret the paleoecology and depositional environment of the Govanda Formation in the studied areas of northeast Iraq.

Study Area

Two outcrop sections were chosen and sampled to be studied in details; they are in the Sulaimani and Erbil governorates of northeastern Iraq (Fig.1). The chosen sections are located in the Zagros fold belt, in which the folds are elongated of northwest southeast direction. The Beshkariya section is located on the southwestern flank of the Piran Mountain about 1 km northeast of the town of Mergasor. Geographically it is located between latitude 36^{o} 50' 54.24" N and longitude 44^{o} 19' 03.16" E. Whereas, Gole section is located on the northeastern flank of the Komari Mountain about 18 kms northwest of the Penjwen town. Geographically located between latitude 35^{o} 45' 58.14" N and Longitude 45^{o} 49' 25.35" E.

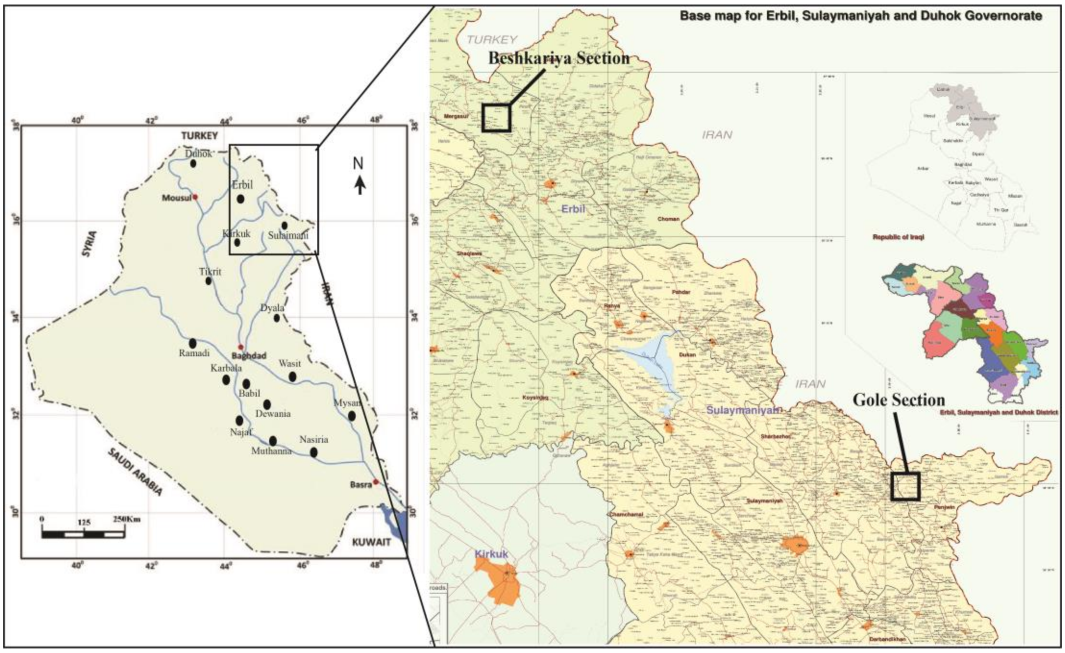


Fig. 1: Location map of the studied sections.

Geological and Tectonic Setting

Since the Cambrian, the Arabian plate northern margin has been continuously subjected to marine sedimentation [10; 11]. The Arabian Plate collided with the Eurasian Plate during the Oligocene-Early Miocene, leading to the formation of the Zagros fold and thrust belt which finally caused the termination of the Neo-Tethys Ocean [9]. Carbonate rocks of the

Cenozoic Era act as a fundamental link between older stratigraphic record and the modern depositional environments. The foreland sediments of Neogene Epoch with thicknesses of 1- 6 km in the Zagros fold and thrust belt, make up at least one-third of the entire sedimentary cover of the Arabian crystalline basement [11; 12]. This important part formed in epicontinental and foreland basin environments of the Zagros fold and thrust belt [11; 13]. The Zagros Foreland Basin, which encompasses much of central and northern Iraq, has preserved a thick Miocene succession [55]. In Iraq, the Serikagni, Dhiban, Ghar, Jeribe, Euphrates, Fat'ha, Injana, Mukhdadiya, Bai Hassan, Govanda and Merga Red beds formations represent this succession [3; 43].

During the Miocene Epoch, the primarily replacement of the carbonate foredeep basins by the continental terrigenous deposits in a foreland basin occurred [6]. Throughout the Paleogene and Neogene, carbonate marine environments were occupied by the large benthic foraminifers coexists with dominant mollusks, echinoderms and calcareous algae whereas during the Miocene scleractinian coral reefs had gradually taken over as the most abundant shallow-marine ecosystem in the tropical and subtropical areas [5]. The Balambo-Tanjero trough and Qulqula-Khwakurk zones were folded and uplifted during the Oligocene-Early Miocene "Savian" movement that influencing the Zagros Suture Zone [4]. The basin was enclosed by a large ridge during the Early Miocene, running through the area of the Northern Thrust, Balambo-Tanjero, High Folded Zone and the Butmah-Chemchemal Subzone of the Foothill Zone. The Foothill Zone, the Jezira Subzone (submerged Khlesia High); and the Mesopotamian Zone were all part of the basin's center [4]. In Iraq, the Govanda Formation is an equivalent in age with the Jeribe Limestone Formation, as well as the middle limestones of the Beygur Series in Turkey and the Guri Limestone in Iran can be correlated to the Govanda Formation [3]. The Govanda Formation is characterized by a series of patchy reef bodies that run across a broad zone close to the Zagros Thrust Zone and are widely distributed in the Imbricate Zone, with large areas in Govand and Qalandar Mountains, and Rusty Valley with some patches in Qandil, Ranya, Chwarta and Penjwen. Tectonically, the Beshkariya section is lies in the Balambo-Tanjero and Penjwin-Walash Zones which are two neighboring zones of the Zagros Imbricate and Suture Zones, while the Gole section lies within Qulqula-Khwakurk and Penjwin-Walash Zones [4] (Fig.2). The Tanjero Formation underlies the Govanda Formation unconformably in the type locality and adjacent areas. Moreover, the formation unconformably overly the Qulqula Radiolarian Formation in Penjwen, Gole section and Aqra Limestone Formation in Mergasor, Beshkariya section (Fig.3). The formation is prominent part of the Paleogene-Neogene sequences in the intermountain basin [4]. The lower boundary of the Govanda Formation with the Tanjero Formation is clearly remarkable in most of the areas near the type locality, as indicated by polygenic conglomerates that indicate an erosional surface of between the two formations. The upper part of Tanjero Formation was deposited during the first uplifting phase due to the rising of some parts of Zagros Mountain series which leads to the regression of the sea level and shallowing of the basin. As a result, the upper part of the Tanjero Formation was mostly eroded out at the contact with the Govanda Formation [7]. The upper boundary of the formation is gradational and conformable with Merga Red beds.

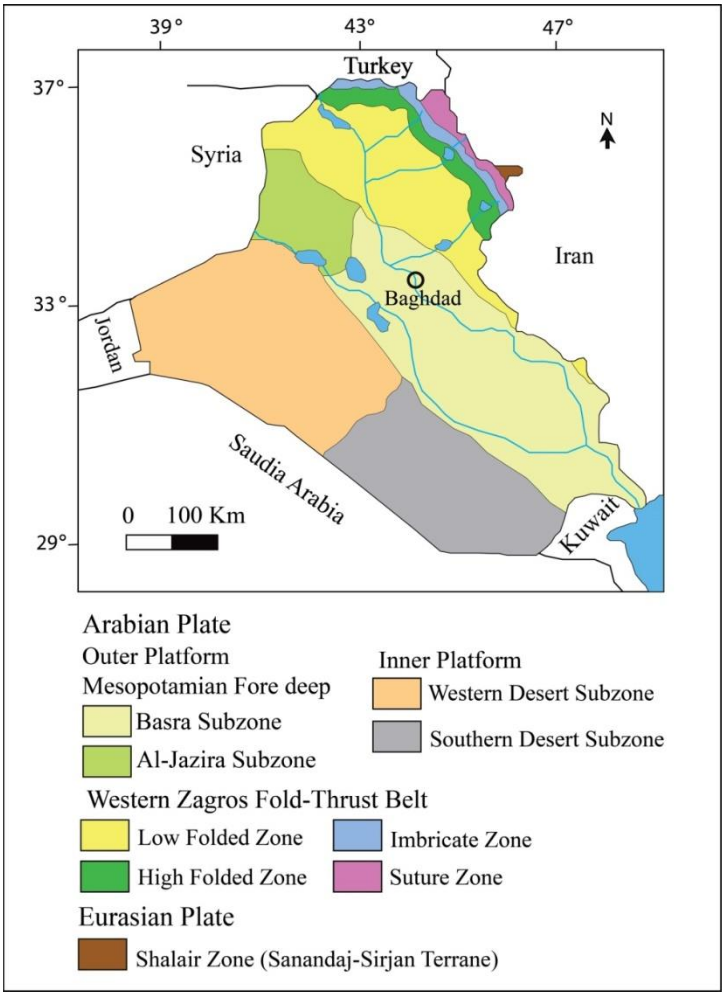


Fig. 2: Tectonic divisions of Iraq showing the studied area [1] and [8].

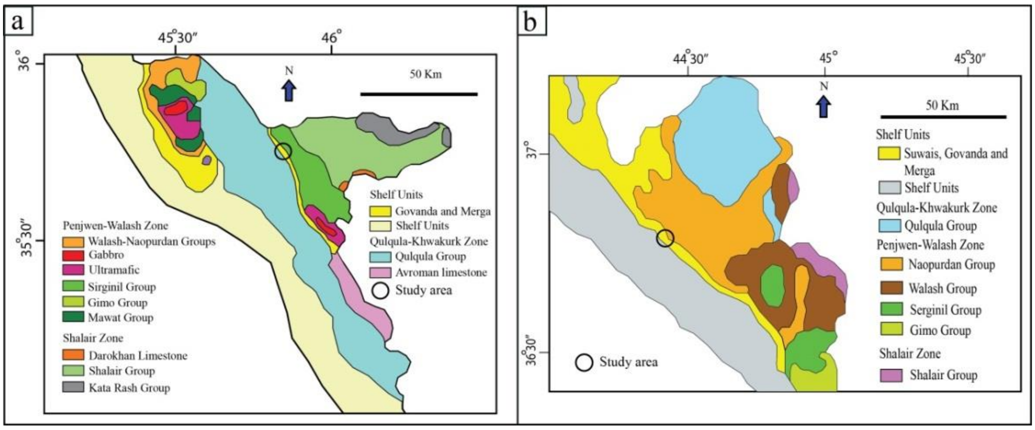


Fig. 3: Geological Map of the a) southern part of the Zagros Suture and b) northern part of the Zagros suture with location of studied sections [4].

2. Materials and Methods

A reconnaissance survey was conducted on seven sections in the area around Mergasor and Penjwen towns, but only two sections were described and sampled. Samples are collected at closely spaced intervals with detailed descriptions from representative outcrop sections (Beshkariya and Gole). The general geology, stratigraphy and structure of the studied areas have been described as well. 107 samples from both sections were collected and described with drawing columnar sections from both studied sections. There were 62 samples from Beshkariya and 45 samples from Gole. In both sections, samples were taken at approximately two-metre intervals or when the lithology changed. Further additional samples have been collected from both the underlying and overlying formations. A total of 80 thin-sections of both studied sections were prepared in the Tehran University, college of science, workshop of Geology department with the collaboration of Petroleum Geosciences department, Soran University. A polarizing microscope was used to examine the thin sections.

3. Results and Discussion:

General Lithology

The lithology and thickness of the Govanda Formation is not the same everywhere. In this study, the Govanda Formation shows the same difference in lithology and thickness. The thickness of the formation in the Beshkariya section is 85 m (Fig.4a) and from bottom to top comprises of; 2 m red-brown, thick bedded, hard, sub-angular conglomerate containing pebbles of igneous rocks, metamorphic rocks, chert and limestone. 8 m red and grey, soft siltstone and shale, sometimes intercalated with detrital limestone beds. 40 m yellowish-grey to pinkish-grey, hard, thick bedded, very fossiliferous, sandy (detrital) limestones. 35 m medium to thick bedded, white grey, very hard, fossiliferous limestone. The thickness of the formation in the Gole section is 60 m (Fig.4b) and from bottom to top consists of; red-brown, medium bedded, conglomerate containing rich Oyster fossils and pebbles of igneous rocks, metamorphic rocks, chert and limestone. 3 m thin-medium bedded, greenish-grey, pebbly sandstones sometimes intercalated with thin shale layers. Intercalation between thin to medium bedded, yellowish-grey, fossiliferous, detrital limestone and thin beds of greenish-grey to red brown shale and siltstone. 15 m grey and pinkish, hard, well bedded, fossiliferous, coralline sandy (detrital) limestones. 20 m thin to medium bedded, fossiliferous limestone locally, white grey, very hard, sometimes nodular in appearance. The Govanda Formation in the Beshkariya section is unconformably underlaid by the Maastrichtian Aqra Formation and in Gole section is unconformably underlaid by the Middle Jurassic-Early Cretaceous Qulqula Radiolarian Formation. The upper contact of the formation in both studied sections is with the Merga Red Bed Formation.

Fig. 4: Field photograph of the a) Beshkariya section and b) Gole section.

Paleoecology

Corals, larger benthic foraminifera, calcareous algae, bryozoans, echinoderms and mollusks dominated the Neogene shallow water carbonate habitats [51]. Benthic foraminifera are extremely useful in reconstructing paleoecology and paleoenvironmental conditions. The paleoecological conditions of some biota found in the Govanda Formation are represented in table (1). The most important fossils that have been documented in the Govanda Formation in the studied areas include benthic and planktonic foraminifers, corals and coralline red algae with subordinate echinoderms, bivalves, ostracods, bryozoans and serpulid worms. Larger and smaller benthic foraminifera (*Operculina* sp., *Borelis melo* sp., *Austrotrilina* sp., *Meanderopsina* sp., *Peneroplis* sp., *Miogypsinoids sp., Miogypsina sp., Amphistegina sp., Textularia sp., Archaias sp., Lepidocyclina* sp., *Miliolids*, *Quenquiloculina* sp., *Pyrgo* sp., *Triloculina* sp., *Ammonia* sp., *Elphidium* sp., *Dendritina* sp. and *Rotalia Venoti*) dominated the limestones of the Govanda Formation. Planktonic foraminifers are mostly includes *Globigerinoids* sp., *Globigerina* sp., *Globorotalia* sp. and *Orbulina* sp. Moreover, miscellaneous fossils include corals, coralline red algae, echinoderms, bivalves, ostracods, bryozoans, brachiopods and serpulid worms (*Ditrupa* sp.). Some bryozoans are represented by *Tubucellaria* sp., Echinoderms are represented by echinoid spines, and pelecypods include oysters, ostrea and gryphaea. Corals are mostly of scleractinian colonies and coralline red algae. Serpulid worms include *Ditrupa* sp.

Temperature, nutrition, salinity, depth, light, substrate, and water energy all influence the distribution and abundance of fossils such as foraminifera and other miscellaneous fossils in present and ancient sedimentary settings [14; 15; 16; 17; 18; 20]. The following sections will describe and link the environmental conditions with fossils that are found in the Govanda Formation;

Temperature

The temperature during the Miocene time was around 7–8°C warmer than present day [51]. Different organisms live in specific temperature ranges, temperatures of 23–25 °C are ideal for coral reefs [63]. Larger benthic foraminifer lives in the tropical and subtropical marine settings with typical 18–20 °C temperature range. In the summer, many of them can tolerate in the water easily when the temperature reaches 25 °C [19]. Temperatures ranging from 16 to 40°C are indicated by the prevalence of *Triloculina* sp. (PI, Fig.6) and *Quinqueloculina* sp. (PI, Fig.2) [17]. Corals (PII, Fig.4) and benthic foraminifers (including *Triloculina* sp. and *Quinqueloculina* sp.) are discovered in almost all parts of the Govanda Formation mainly middle and upper parts. *Ammonia* sp. (PI, Fig.4) thrives at temperatures ranging from 5 to 30 °C, it is found in the middle part of the Govanda Formation. Borelis species are very abundant in the whole parts of the formation and lives in temperature around 25°C. The discovered biota indicates that the average temperature of the Govanda basin varies between 15-30 °C.

Nutrient level

The amount of accessible food is one of the most critical elements that control the diversity of species [21]. Foraminifers, for example benthic species reflects marine nutrient levels. Coral reefs, in particular, thrive in low-nutrient settings and are quickly strangled in high-nutrient conditions [22]. Increased nutrient levels promote the growth and development of red algae (PIII, Fig.3), whereas decreased nutrient levels promote coral growth and development [23]. Most phototrophic carbonate producers flourish in shallow marine conditions, so, coralline red algae populations become dominant [62]. The coralline red algae are found in middle and upper parts of the formation. The presence of Miliolids (PI, Fig.1) with different ratio in the whole parts of the Govanda Formation suggests high nutrient levels. Presence of *Ammonia baccari* in the middle part and Ostrea (Bivalve) in the middle part of the Govanda Formation indicates eutrophic normal marine environment. According to these results, it is suggested that the nutrient level in the basin of the Govanda Formation varies between eutrophic to mesotrophic.

Salinity

The existence of porcelaneous benthic foraminifera such as *Dendritina* sp. (PII, Fig.7), *Peneroplis* sp. (PI, Fig.8), *Archaias* sp. (PI, Fig.7), *and Meandropsina* sp. (PII, Fig.6) with miliolids suggests high-saline conditions ranging between hypo-hypersaline [25]. These kinds of foraminifera exist in the whole parts of the Govanda Formation. The presence of a large number of miliolids in the formation indicates decreased circulation or eury-hyaline conditions and sometimes miliolids can live in sand shoal environment of normal salinity [59]. Miliolids are normally evidence of a restricted lagoon environment [60]. Bryozoans (PII, Fig.3) are mostly found in the middle and upper parts of the Govanda Formation and indicate normal salinity water. Bryozoans are famous for their tolerance in wide salinity environments [48]. *Rhaphydionina* sp., *Lithophyllum* sp. and *Lithothamnion* sp. are found mostly in the middle and upper parts of the Govanda Formation, they live in waters with salinities ranging from 30-40 ppt. The presence of *Triloculina sp.* and *Quinqueloculina* sp. with a large ratio in the Govanda Formation suggests normal marine, saline to hypersaline environment with salinity range of more than 30‰. Existence of *Ammonia* sp. in the middle part of the formation suggests hyposaline to hypersaline lagoons and inner ramp areas. The above results show that the salinity in the Govanda basin ranged between normal saline to hyper saline water.

Light intensity: The Benthic foraminiferal modern forms exist in the upper part of the light zone within tropical carbonate platforms [24]. Larger perforate foraminifers such as *Elphidium* sp. (PI, Fig.3), *Operculina* sp. (PII, Fig.8) and *Miogypsina* sp. (PII, Fig.5) are characterized by hyaline walls and are the most important indicators for the reconstruction of the paleoenvironmental model in warm, shallow marine environments under photic zone [14; 61]. Those kinds of foraminifers are very well documented in the most parts of the Govanda Formation. *Amphistegina* sp. (PII, Fig.1) and *Operculina* sp. are observed in waters with 5 % light intensity levels [26]. The existence of larger benthic foraminifers in large ratio with red algae, echinoid, coral and Melobesioids (*Lithothamnion* sp. *and Mesophyllum* sp.) indicate deposition in the middle ramp environment within oligophotic zone [18; 27; 28]. These are very well observed in the Govanda Formation. The occurrence of green algae and reef building corals with a large number of porcelaneous imperforate foraminifers are good indictors of the photic zone in tropical carbonate platforms [14]. The occurrence of *Miliolids* sp., *Archaias* sp., *Peneroplis* sp. and *Borelis* sp. (PII, Fig.2) suggests existence of a seagrass-dominated environment under the photic zone. Those kinds of foraminifer are observed in both studied sections and generally indicates lagoonal environment [29; 44]. The presence of the Hyaline Larger Foraminifers such as *Lepidocyclina* sp., *Operculina* sp, and *Amphistegina* sp. with red algae is index fossils of the oligophotic zone [30]. Planktonic foraminifer such as *Orbulina* sp. (PIII, Fig.6), *Globigerina* sp. (PIII, Figs.4&5), *Globigerinoides* sp. (PIII, Fig.7) and *Globorotalia* sp. (PIII, Figs.5&8) are indictors of the deposition below the photic zone and suggests a deep and calm water open marine environment [14]. Planktonic foraminifers are mostly found in the middle and upper parts of the Govanda Formation. A high distribution of *Operculina* sp., *Amphistegina* sp., *Textularia* sp., planktonic foraminifers and *Ditrupa* sp. indicates the deposition within the euphotic zone [24; 28; 31]. These genera are very well observed within the Govanda Formation. The existence of echinoids (PIII, Fig.2) and bryozoans indicate deposition in the middle ramp within oligophotic zone [14; 24; 32; 54]. Depending on these results, it is concluded that the light intensity in the basin was ranging from euphotic to mesophotic and less oligophotic zones.

Depth

The existence of planktonic forams such as *Globigerina* sp., *Globigerinoides* sp., *Globorotalia* sp. and *Orbulina* sp. in the upper part of the Govanda Formation suggests open marine environment with deep and quiet water in the distal middle ramp to the proximal outer ramp. The presence of *Operculina* sp., *Miogypsinoids* sp. and *Amphistegina* sp. indicates wide depth range but are more common between 40-70 m depth and suggests the deposition in the tropical to subtropical environments when exists with *Borelis sp.*, *Lepidocyclina* sp. and *Archaias* sp. [15; 16; 33; 34]. As mentioned before, these genera are abundant in the Govanda Formation especially in the middle and upper parts of the formation. Red algae are abundant in all parts of the formation that indicates water depth between 30–50 m within the oligophotic zones [33; 18]. The presence of large number of *Borelis melo* indicates clear, warm and shallow water with the depth range around 33 m [17]. *Peneroplis* sp. occurs in the middle and upper parts of the formation and indicates water depth of 30 m in the shallowest part of the slope [35]. The presence of *Rhaphydionina urensis*, *Lithophyllum* sp., *Sporolithon* sp. and *Lithothamnion* sp. suggests depth ranges between 10 - 125 m. The dominance of *Quinqueloculina* sp. and *Triloculina* sp. in the rocks of the Govanda Formation indicates temperate to tropical conditions of water depths between 12 - 18 m [20; 49]. *Ammonia* sp. indicates shallow, brackish water conditions of 0 - 50 m depth. According to the above results and the existence of mentioned fossils, the Govanda Formation was supposed to be deposited in the water depths between 0-120 m.

Substrate

Operculina sp. found on soft sediments or substrates with low sand content such as limestone and marl [16; 63]. *Borelis* sp. is dominant in depositional environments rich in carbonate sediments. *Archaias* sp., *Operculina* sp. and *Lepidocyclina* sp. have the abilities to tolerate in depositional environments having clastic influx up to 40 %, their numbers decrease with the increasing of the clastic influx. *Miogypsina* sp. is less sensitive with clastic influx [42; 63]. *Austrotrillina* sp. (PI, Fig.2) mostly tolerates in low turbulence waters. About 15 % of the rocks of the Govanda Formation are purely clastic and located in the lower part of the formation, 30 % is sandy limestone or detrital limestones and 55% of the total thickness of the formation is fossiliferous limestone with the minimum sand content. The above mentioned foraminifera species are very well representative with the conditions and clastic influx that exist in the Govanda Formation.

Water energy

Water energy is another important criterion that is very useful in building the paleoecology of the basins. Miliolids (*Triloculina* sp., *Quinqueloculina* sp., *Pyrgo* sp. (PI, Fig.5), *Austrotrillina* sp.), *Dendritina* sp., *Archaias* sp., *Peneroplis* sp., *Miogypsina* sp., *Elphidium* sp., *Amphistegina* sp., Coralline algae and echinoderms indicates medium and sometimes high energy environment [36]. These fossils are widely distributed in the Govanda Formation and interpreted to be lived in lagoon, back reef-reef-fore reef environments with medium energy currents. The abundance of corals in the middle and upper parts of the formation suggests medium energy shallow water environment. Red algae which are found in most parts of the formation indicate moderate wave energy and some can tolerate in very high energy waters [49]. Thus, the energy of the water in the basin most possibly moderate water energy.

Size and Shape

The size and shape of the shells in benthic foraminifera can give important information about the depositional environment [34; 21; 14]. Generally, perforate foraminifera with small size and thick walls live proximal middle ramp, while increasing of size and test flattening of the hyaline foraminifers suggest distal middle ramp [37; 33]. The Govanda Formation contains most kinds of perforate, imperforate, porcelaneous and hyaline foraminifera with different shell size and test shape. These differences in size and shape within foraminifers indicate various depositional environments and ecological conditions.

Table 1: Paleoecological conditions and elements of the Govanda Formation in the studied sections

Component	Temperature	Nutrient level	Salinity	Light	Depth (m)	Water Energy
Corals, Coralline Red Algae, Bryozoa, Echinoids, Some Miliolids	20–25 °C	Oligo-Mesotrophic	Normal - Saline water	Meso-Euphotic	10-80	High
Red algae	10-25 °C	Eu-Mesotrophic	Normal-Slightly Saline	Eu-Mesophotic	30-50	Moderate-High
Archaias, Peneroplis, Meandropsina, Dominant Miliolids, Dendritina, Borelis	18–25 °C	Eu-Mesotrophic	Saline-Hyper saline	Mesophotic	Less than 35	Moderate-High
Operculina and Miogypsina, Lepidocyclina, Amphistegina	15–30 °C	Mesotrophic	Normal-Slightly Saline	Meso-Oilgophotic	40-70	Moderate-High
Ammonia, Oyster, Ostrea	20–35 °C	Eutrophic	Normal-Slightly Saline	Meso-Euphotic	Less than 60	High
Planktonic foraminifers	5-20 °C	Eu-Mesotrophic	Normal-Saline	Oligophotic	More than 50	Low

Depositional Environment

The environmental conditions at the time of formation are reflected in carbonate deposits produced by organisms. As a result, carbonate sediments and rocks serve as multiproxy archives for reconstructing paleoenvironmental conditions [46; 47]. Carbonate environments were thought to occur only in tropical warm seas until the end of the 1960s [18]. During the Miocene, worldwide temperatures were warmer than they were during the Oligocene or now [18]. Larger benthic foraminifera become abundant carbonate producers worldwide during the Miocene [38]. According to [13], the Zagros Basin during the Oligocene-Miocene was located close to 30° N. This idea suggests that the Govanda Formation deposited in tropical to subtropical waters. In clear, tropical to subtropical seas, corals and larger benthic foraminifera are the most successful shallow benthic carbonate producers [34].

The Govanda Formation represents a complex sedimentary system with a difference in lithologies (conglomerate, sandstone, shale and dominant carbonates), depositional geometries, and the geological formation boundaries. In this research, the distribution of benthic and planktonic foraminifera with miscellaneous fossils in the Govanda Formation is used as a tool for paleoenvironmental implications. . According to [64] the depositional environment of the Govanda Formation in Penjwen area was high energy, shallow and normal-marine sea which consists of fore-reef, reef and back-reef. [65] Have identified the depositional environment of the Govanda Formation as reef, fore-reef, back-reef depending on the microfacies analysis.

The foraminiferal species in the Govanda Formation well linked with the modern and ancient warm-water carbonate platform. Carbonate ramps are carbonate platforms which have a low gradient depositional slope from a shallow-water shoreline or lagoon to a basin floor [39]. In Iraq and Iran, the Oligocene-Miocene shallow water basins in the Zagros foreland basin are dominated by carbonate ramps. On the base of the fair weather wave base (FWWB) and the storm wave base (SWB), [39] has subdivided ramp depositional systems into; (1) the inner ramp, between the upper shore face and fair weather wave base, (2) the middle ramp, between fair weather wave base and storm wave base and (3) the outer ramp, below normal storm wave base down to the basin plain [39].

In this study, four main zones can be distinguished in the ramp environment according to the facies distribution:

1- Proximal inner ramp setting which includes open lagoon in this study and characterized by *Quenquiloculina* sp., *Lithophyllum* sp., *Pyrgo* sp., *Archaias* sp., Small *Rotalia*, *Discorbis* sp., *Marginopora* sp., *Ammonia* sp., *Elphidium* sp., *Miliolids* sp., *Austrotrillina* sp., *Meandropsina* sp., *Peneroplis* sp., *Rhaphydionina* sp., *Textularia* sp., *Dendritina* sp., *Triloculina* sp.

2- Distal inner ramp setting which includes back-reef environment and characterized by Corals, *Borelis melo* sp., *Triloculina* sp., *Miogypsinoides* sp., *Miogypsina* sp., *Archaias* sp., *Rhaphydionina* sp., *and Austrotrillina* sp.

3- Proximal middle ramp setting which includes reef and fore-reef environments and dominated by Coralline algae, Corals, Echinoderm, *Nummulites* sp., *Operculina* sp., *Miogypsina* sp., *Cycloclypeus sp.*, *Amphistegina* sp., Brachiopods(PIII, Fig.1), Echinoids, Bryozoa and Red algae.

4- Distal middle ramp/ proximal outer ramp setting which includes open marine environment and dominated by some kinds of Coralline algae, *Nummulites* sp., *Lepidocyclina* sp. with planktonic foraminifers including *Globigerinoids* sp., *Orbulina* sp., *Globorotalia* sp., and *Globigerina* sp..

Paleoecological index fossils can be greatly found in the inner ramp depositional settings such as perforate and porcelaneous foraminifera. Perforate foraminifera moderately existed in the Govanda Formation which includes: *Amphistegina* sp., *Miogypsina* sp. and *Ammonia beccarii*. Larger porcelaneous foraminifers were dominant in the limestone rocks of the Govanda Formation and include: *Archaias* sp., *Dendritina rangi, Meandropsina* sp., *Meanderopsina anahensis, Meanderopsina iranica*, *Peneroplis* sp., *Peneroplis evolutus, Peneroplis thomasi* and *Borelis melo curdica*. The Miliolids occur in a large number in the Govanda Formation that includes: *Quenquiloculina* sp., *Austrotrilina asmariensis, and Austrotrilina howchini, Triloculina trigonula, Triloculina tricarinata* and *Pyrgo* sp. Most of the recognized benthic foraminifers in the Govanda Formation are indicators for the inner ramp depositional setting and suggests the deposition in a seagrass-dominated environment of the photic zone, as indicated by the occurrence of *Peneroplis* sp., *Archaias* sp., *Meandropsina* sp., and *Borelis* sp. Large existence of *Miliolids* sp., *Dendritina* sp., *Meandropsina* sp. and *Austrotrillina* sp. in the lower and middle parts of the Govanda Formation suggests deposition in the upper photic zone of the low-energy, shallow, open lagoon depositional environment. The *Austrotrillina* sp. can tolerate in restricted lagoonal settings but also can live in nutrient-rich back reef environments. Large occurrence of *Triloculina* sp. and *Quinqueloculina* sp. that are mostly found in the lower and middle parts of the Govanda Formation indicate deposition in inner ramp, normal marine, saline-hypersaline environment. They also can live in the reef settings as they are parts of the most dominant foraminifers in the modern Great Barrier Reef, Australia [52]. *Elphidium* sp. was mostly found in the lower and middle parts of the Govanda Formation and indicates very shallow water. *Ammonia* sp. suggests shallow water environment may point to lagoons and inner ramp areas. The Govanda Formation contains large numbers of Alveolinids, Miliolids, *Dendritina* sp., *Peneroplis* sp., and *Austrotrillina* sp. that mostly live in shallow water environment of the inner ramp. These fossils are evidence of relatively saline-hypersaline environments with limited circulation in upper parts of the photic zone [14]. The Miliolids coexisting with coral debris, coralline algae and wide distribution of benthic foraminifers such as *Pyrgo* sp., *Pyrgo bulloids, Austrotrilina asmariensis, Austrotrilina howchini, Archaias* sp., *Archaias hensoni, Archaias Kirkukensis, Ammonia baccari, Peneroplis thomasi, Peneroplis evolutus, Elphidium* sp., *Elphidium* sp.*14.*, *Dendritina rangi, Triloculina trigonula, Triloculina tricarinata, Quinqueloculina* sp., *Meanderopsina iranica* and *Meanderopsina anahensis* mostly suggests shallow, quiet (low energy) lagoonal environment, generally inner ramp setting [36].

The indicators for the existence of the middle ramp environment are very well observed in this study as represented by middle ramp fossils. The middle ramp setting is characterized by occurrence of coralline red algae, Bryozoans, Echinoids, Nummulites, *Operculina* sp., *Amphistegina* sp., planktonic foraminifers (*Globigerinoids* sp., *Globigerina* sp., *Globorotalia* sp. *and Orbulina* sp.). These fossils less exist in the middle part and more observed in the upper part of the Govanda Formation. Similar to the modern Indo-Pacific, *Operculina* sp. lives in reefal environment [53]. *Operculina* sp. exists in normal saline, warm, low-medium energy water of open marine environment, and. *Operculina* sp. relatively shows high ecological tolerances compared to other biota [21]. *Operculina* sp. is generally found in the middle and upper parts of the Govanda Formation. The occurrence of red algae together with rotalia species suggests a proximal middle ramp setting. They can be seen in the middle and upper parts of the Govanda Formation. The presence of *Borelis melo* sp. in very shallow waters is rare and mostly lives in reefal settings with medium energy [20; 40; 41]. *Borelis melo curdica* and *Borelis melo melo* are among the most significant species occur in the middle and upper parts of the Govanda Formation, while few exist in the lower part too. According to [45], *Miogypsina* sp. lives in shallow waters reaching 50–80 m depth. *Amphistegina* sp. indicates the distal part of the middle ramp [44]. The planktonic foraminiferal species are absent in the lower part of the formation and limited in the middle part, this proves that the middle part of the formation is deposited in the reefal shallow marine environment. Moreover, planktonic foraminifers including: *Globigerina* sp., *Globigerinoids* sp., *Globorotalia* sp. *and Orbulina* sp. are normally present in the upper part of the formation which indicates the deposition in the deeper parts of the middle ramp and may include inner parts of the outer ramp too. The presence *Globigerina* sp., and *Globorotalia* sp., with *Miogypsina* sp. and *Operculina* sp. suggests the deposition in quiet, low energy, normal saline and deep water setting of distal middle ramp and starting of the outer ramp environment [29; 47; 56; 57; 58]. This situation is best documented in the upper part of the formation. The existence of euryhaline fossils including; bryozoans, brachiopod, echinoid, red algae and few bivalves together with planktonic foraminifers such as *Globigerina* sp., *Orbulina* sp., *Globigerinoides* sp. and *Globorotalia* sp. suggests open marine environment with deep and quiet water.

This association is clearly observed in the upper part of the Govanda Formation. Bryozoans tolerate in a wide salinity range, and most of them are marine animals, but a few species exist in fresh waters too. Echinoids live in normal marine environments, while Echinoderms are mostly marine animals. *Ditrupa* sp. is totally marine with hypersaline-water. The presence of Corals and coralline red algae in the lower and middle parts of the formation suggests shallow water setting with warm, euphotic and low to medium energy conditions. Fragments of echinoids, algae and bryozoans are well observed in the middle part of the formation and mostly deposited in the proximal middle ramp setting within a photic zone. The presence of Rhaphydionina urensis, Lithophyllum, Sporolithon, and Lithothamnion indicates reef and lagoonal environments [50]. These are well observed in the middle part of the Govanda Formation. Oysters play an important role as ecosystem engineers and as paleoecological indicators. The ability to withstand significant changes including temperature, salinity, sediment load and dissolved oxygen makes oysters exceptionally tolerant organisms. The presence of Oysters generally suggests shallow marine environments.

According to the above results, the depositional environment of the Govanda Formation is represented as a ramp environment which includes open lagoon, back-reef, reef, fore-reef and open marine environments (Fig. 5). The Govanda Formation started the deposition in a very shallow and high energy water environment as indicated by existence of chert, limestone and oyster-rich conglomerates under warm climatic and normal salinity conditions with a depth range less than 5 m. Later, transgression took place and water environments occupy the basin that led to the deposition of succession of sandstone, shale and detrital, fossiliferous limestones with the abundance of warm, saline, shallow marine fossils such as larger and smaller benthic foraminifers, mollusks and corals, followed by the deposition of interfingering detrital limestone and fossiliferous limestones which indicate further transgression of the basin. This facies contains reef and back reef facies which shows an alternation of tropic-subtropic regions, mesotrophic-oligotrophic, and high-medium energy water with depth range of less than 50 m. Moreover, transgression continued in the basin and sedimentation continued in reef to fore-reef facies at the middle to upper parts of the formation with mesotrophic to oligotrophic nutrient levels and low-medium energy water which is emphasized by the existence of *Operculina* sp., *Amphistegina* sp. and red algae. Finally, the presence of few kinds of planktonic foraminifers in the upper part of the formation indicates highest level of transgression in the basin in which sedimentation occurred in warm, normal saline, calm, deep water distal middle ramp to the proximal outer ramp environment of depth between 50-120 m. Thus, from this study it is also achieved that the Miocene Govanda basin was certainly deeper than what previously mentioned as shallow reefal environment.

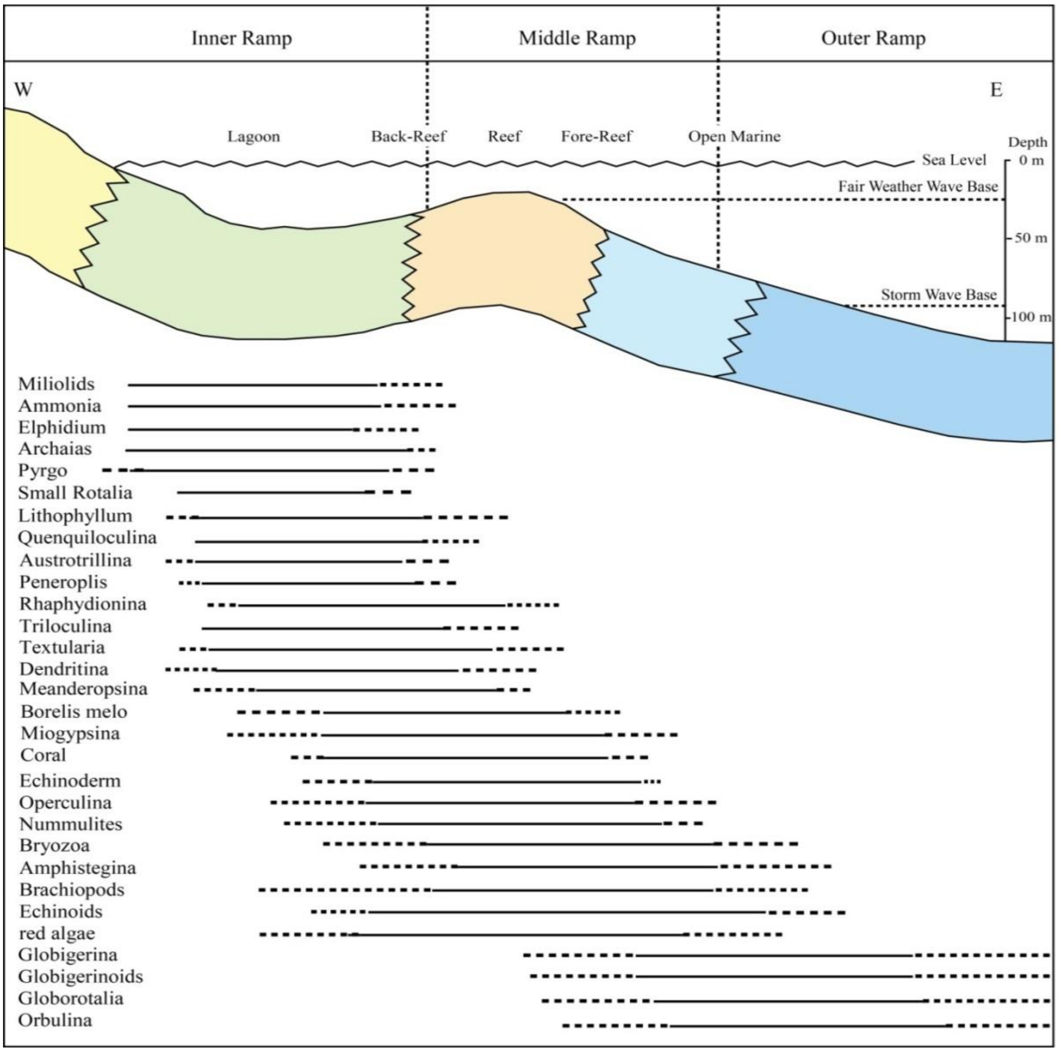


Fig 5: Depositional environment of the Govanda Formation enhanced with the microscopic photos of environmental index fossils.

4. Conclusion

- Paleoecology and paleoenvironment of the Govanda Formation are examined using benthic and planktonic foraminifera with miscellaneous fossils.
- Larger and smaller benthic foraminifera including: *Operculina* sp., *Borelis melo* sp., *Austrotrilina* sp., *Peneroplis* sp., *Meanderopsina* sp., *Miogypsinoids and Miogypsina* sp., *Amphistegina* sp., *Archaias* sp., *Textularia* sp., *Lepidocyclina* sp., *Miliolids*, *Quenquiloculina* sp., *Pyrgo* sp., *Spirolina* sp., *Spiroloculina* sp., *Triloculina* sp., *Ammonia* sp., *Elphidium* sp., *Dendritina* sp. and *Rotalia venoti* dominated the limestones of the Govanda Formation.
- Planktonic foraminifers are mostly includes *Globigerinoids* sp., *Globigerina* sp., *Globorotalia* sp. *and Orbulina* sp. Moreover, miscellaneous fossils include corals, coralline red algae, echinoderms, bivalves, ostracods, bryozoans, brachiopods and serpulid worms (*Ditrupa* sp.).
- The paleoecological condition was interpreted as follow; the temperature of the Govanda basin ranges between 15-30 °C, nutrient level is between eutrophic to mesotrophic, salinity ranged between normal saline to hypersaline water, light intensity ranging from euphotic to mesophotic and less oligophotic zones, the water depths ranged between 0-120 m, the clastic influx was high in the basin, differences in size and shape within foraminifers of the Govanda Formation indicate various depositional environments and ecological conditions, the water energy was moderate-high energy environment.
- The documented evidences shows that the Govanda Formation been deposited in a ramp depositional environment. Four main zones distinguished in the ramp model of the Govanda Formation in this study as follow;

1. Proximal inner ramp setting which includes open lagoon
2. Distal inner ramp setting which includes back-reef environment
3. Proximal middle ramp setting which includes reef and fore-reef environments
4. Distal middle ramp/ proximal outer ramp setting which includes open marine environment

Plate I

1. *Miliolids sp.*, lower part of Beshkariya section, 5X, XPL. SNo.(G3)
2. *Austrotrilina sp.*(red arrow) and *Quenquiloculina sp*. (green arrow), lower part of Beshkariya section, 5X, XPL. SNo.(G4)
3. *Elphidium sp.*, lower part of Gole section, 5X, XPL. SNo.(P3)
4. *Ammonia sp.*, lower part of Beshkariya section, 5X, XPL. SNo.(G6)
5. *Pyrgo sp.*, lower part of Beshkariya section, 5X, XPL. SNo.(G9)
6. *Triloculina sp.*, lower part of Gole section, 5X, XPL. SNo.(P6)
7. *Archaias sp.*, lower part of Beshkariya section, 5X, XPL. SNo.(G10)
8. *Peneroplis sp.*, middle part of Gole section, 5X, XPL. SNo.(P8)

Key words: PPL: plane-polarized light XPL: cross-polarized light
SNo.: Sample number

Plate I

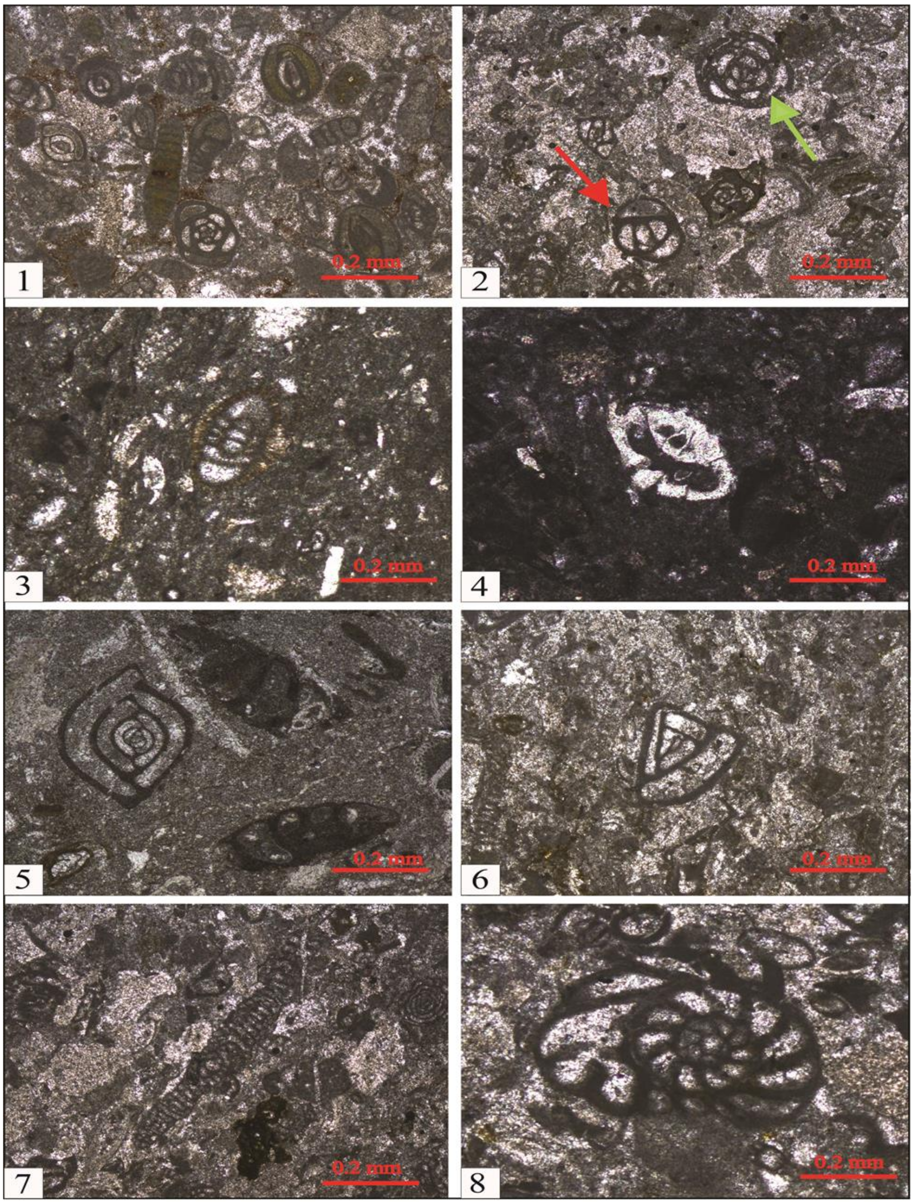


Plate II

1. *Amphistegina sp.*, middle part of Beshkariya section, 5X, XPL. SNo.(G113)
2. *Borelis melo curdica*, middle part of Gole section, 5X, XPL. SNo.(P14)
3. Bryozoa, middle part of Beshkariya section, 5X, XPL. SNo.(G17)
4. Coral, middle part of Gole section, 5X, XPL. SNo.(P18)
5. *Miogypsina sp.*, middle part of Beshkariya section, 5X, XPL. SNo.(G22)
6. *Meanderopsina sp.*, middle part of Gole section, 5X, XPL. SNo.(P21)
7. *Dendritina sp.*, middle part of Beshkariya section, 5X, XPL. SNo.(G23)
8. *Operculina sp.*, upper part of Beshkariya section, 5X, XPL. SNo.(G26)

Key words: PPL: plane-polarized light XPL: cross-polarized light
SNo.: Sample number

Plate II

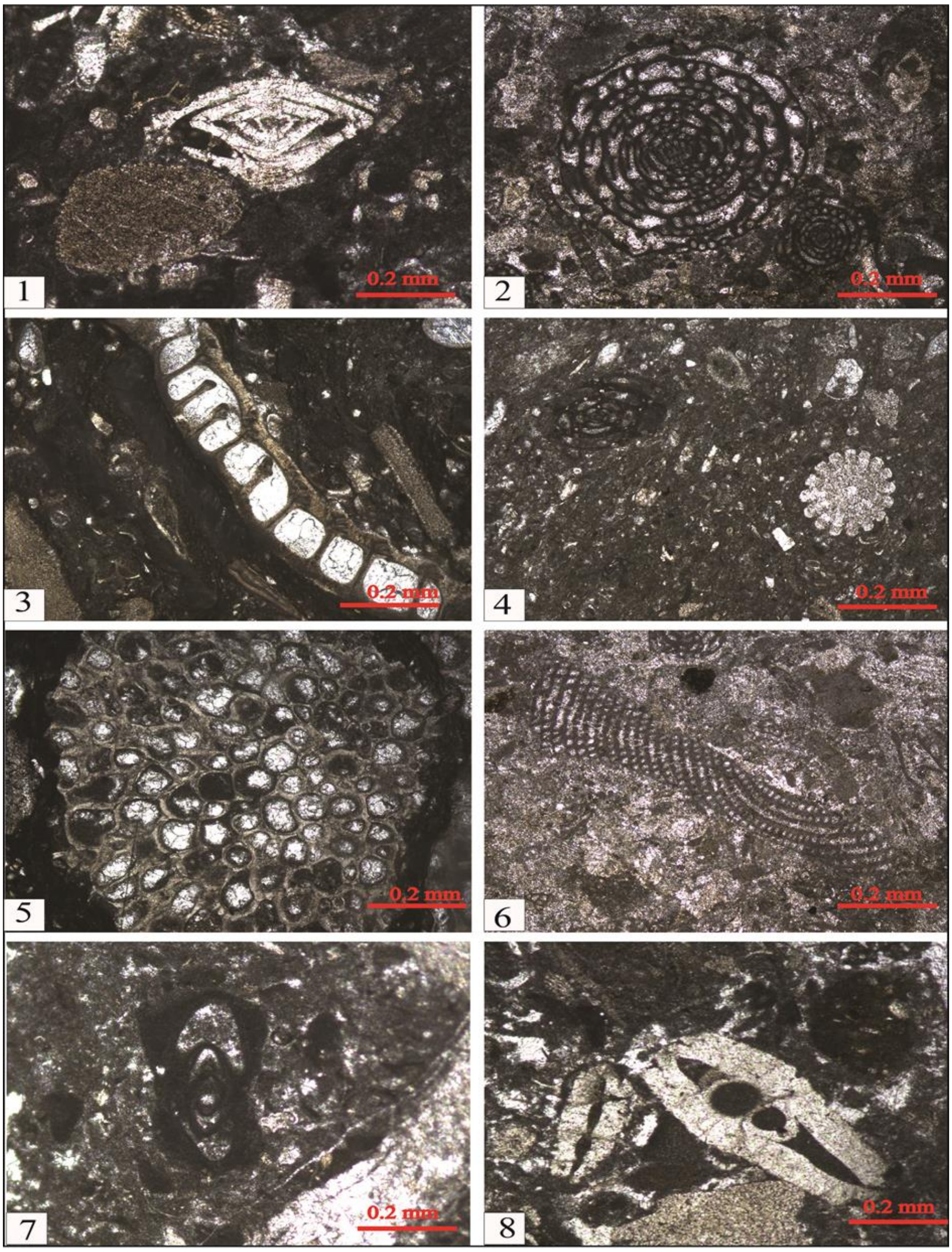
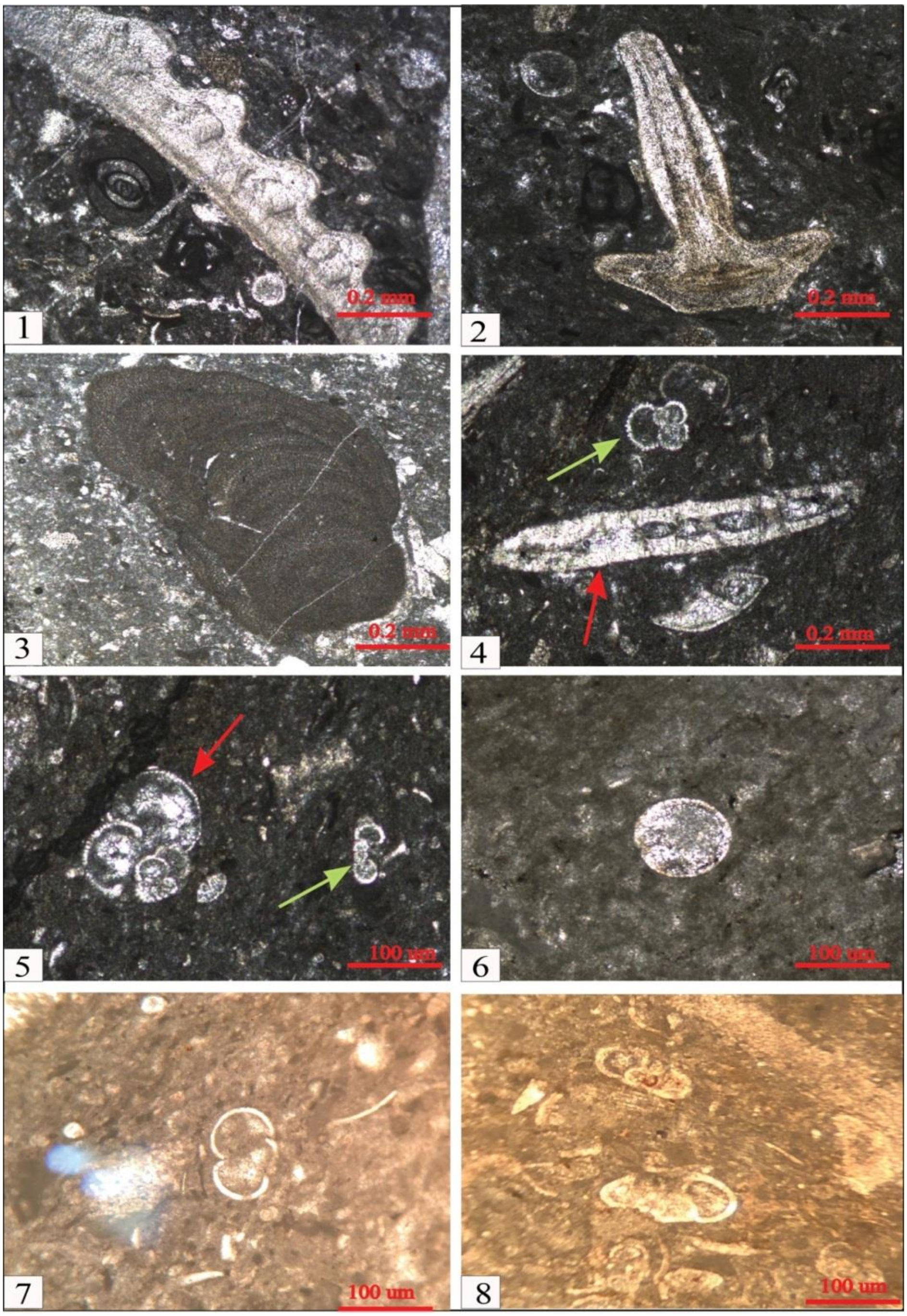


Plate III

1. Brachiopoda, upper part of Gole section, 5X, XPL. SNo.(P28)
2. Echinoid spine, upper part of Beshkariya section, 5X, XPL. SNo.(G31)
3. Red algae, upper part of Gole section, 5X, XPL. SNo.(P29)
4. *Globigerina* sp. (green arrow) and *Assilinoids sp*. (red arrow), upper part of Beshkariya section, 5X, XPL. SNo.(G35)
5. *Globigerina sp and Globorotalia sp*. (red arrow), upper part of Gole section, 10X, XPL. SNo.(G38)
6. *Orbulina sp.*, upper part of Gole section, 10X, XPL. SNo.(P34)
7. *Globigerinoids sp.*, upper part of Beshkariya section, 10X, XPL. SNo.(P39)
8. *Globorotalia sp.*, upper part of Beshkariya section, 10X, XPL. SNo.(G41)

Key words: PPL: plane-polarized light XPL: cross-polarized light
SNo.: Sample number

Plate III



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البيئة القديمة والبيئة الترسبية لتكوين كوفندة في إقليم كردستان ، شمال شرق العراق

اركان عثمان شارة زوري ، آزاد طاهر سعيد

قسم علوم الأرض البترولية ، كلية العلوم ، جامعة سوران ، سوران ، اقليم كردستان ، العراق

الملخص

تم ترسيب تكوين كوفندة خلال عصر الميوسين المبكر المتأخر في المناطق داخل الجبال بين مناطق فوالق زاحفة والتشابك تابعة لسلسلة جبال زاكروس. تمت دراسة علم البيئة القديمة والبيئة الترسيبية لتكوين كوفندة بالتفصيل في مقاطعتي ميرغاسور وبينجوين لأول مرة. يتكون التكوين كوفندة في هذين المكشفين من الأسفل إلى الأعلى من تكتلات كثيفة، والحجر الرملي المرصوف بالحصى، والصخر الزيتي الأحمر والبني، والحجر الجيري الأحفوري، والحجر الجيري الرملي. يبلغ سمك التكوين في ميرغاسور ، قرية بشكريا 85 متراً ، وفي بنجوين ، قرية غولي 60 متراً. تعتمد الدراسة على التحليل المجهري المفصل على فورامنيفرا القاعية والعوالق مع الحفريات المتنوعة الموجودة في صخور الكربونات في تكوين كوفندة. سيطرت أكبر وأصغر قاع فورامنيفرا على الحجر الجيري لتكوين بما في ذلك: *Operculina* sp. ، *Borelis melo* sp.، *Austrotrilina* sp.، *Peneroplis sp.*، *Meanderopsina* sp.، *Miogypsinoids* و *Miogypsina* sp. ، *Archaias* sp.، *Amphistegina* sp.، *Textularia* sp.، *Lepidocyclina* sp.، *Miliolids*، *Quenquiloculina* sp.، *Pyrgo* sp.، *Spirolina* sp.، *Spiroloculina* sp.، *Triloculina* sp.، *Ammonia* sp.، *Elphidium* sp.، *Dendritina* sp.، *Rotalia venoti*. تكوين كوفندة تشتمل فورامنيفرا العوالقية في الغالب على *Globigerinoids* sp. و *Globigerina* sp. و *Globorotalia* sp. و *Orbulina* sp. . علاوة على ذلك ، تشمل الحفريات المتنوعة الشعاب المرجانية، والطحالب الحمراء المرجانية، وشوكيات الجلد ، وذوات الصدفتين، والبوستراودس، والبريوزوان، وذراعيات الأرجل، والديدان السربولية (*Ditrupa* sp.) . .تم تفسير الحالة البيئية القديمة للتكوين على النحو التالي؛ تتراوح درجة حرارة حوض كوفندة بين 15–30 درجة مئوية، ويتراوح مستوى المغذيات بين المغذيات ومتوسط التغذية، وتراوحت الملوحة بين المياه المالحة العادية إلى المياه شديدة الملوحة، وتتراوح شدة الضوء من المناطق المليئة بالحيوية إلى المناطق المتوسطة وأقل قلة، وتراوحت أعماق المياه بين ٠– 120 مترًا ، كان التدفق البطني مرتفعًا في الحوض، وتشير الاختلافات في الحجم والشكل داخل مصفاة تكوين كوفندة إلى بيئات ترسيبية وظروف بيئية مختلفة، وكانت طاقة الماء معتدلة. يتم تفسير بيئة الترسيب على أنها بيئة منحدرة. اعتمادًا على المتحجرات الدقيقة المختلفة الموجودة في التكوين، يتم تمييز أربع مناطق رئيسية في نموذج المنحدر لتكوين كوفندة على النحو التالي؛ إعداد المنحدر الداخلي القريب الذي يتضمن البحيرة المفتوحة، وإعداد المنحدرالداخلي البعيد الذي يتضمن بيئة الشعاب الخلفية، وإعداد المنحدر الأوسط القريب الذي يتضمن بيئات الشعاب المرجانية والشعاب المرجانية الأمامية، والمنحدر الأوسط البعيد / المنحدر الخارجي القريب، والذي يتضمن بيئة بحرية مفتوحة.