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ARTICLE REVIEW/ THE TECTONIC EVOLUTION OF ERBIL AREA (NE IRAQ) AS A PART OF THE NORTHEASTERN MARGIN OF THE ARABIAN-NUBIAN PLATE THROUGHOUT ALBIAN-EARLY EOCENE

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ABSTRACT

The Albian-Early Eocene tectonic evolution of the Zagros Foreland Basin of the High Folded Zone in the Iraqi Kurdistan region has been studied based on the recent foreland basin system concept. This study showed that during the cretaceous (Albian – Cenomanian) there was a geodynamic shift from a passive margin to a foreland basin system phase, not to an active margin phase as mentioned in the previous studies. The advance of the continental margin of the Arabian-Nubian Plate (ANP) toward the subduction zone imposed a tectonic load leading to the form of a flexural wave. The consequences of the last tectonic event were reflected by the continuous deposition of the Balambo Formation. in a foredeep depozone. This happened concomitantly with a flexural emergence of the continental shelf further to the west forming a forebulge depozone represented by the deposition of reefal facies of the Qamchuqa Formation. These geodynamic changes are considered here to represent the Megasequence boundary between the Tectonic Megasequence (TMS) of AP8 and AP9. The last sequence of the passive margin was the Qamchuqa Formation Which is called the Pre-Orogenic Carbonate Platform and was separated from the Bekhme Formation by regional unconformity (Megasequence boundary). The latter is represented by the Lower Sequence of the foreland basin system, which is called the Syn-Orogenic Carbonate Platform (SCP). During the Middle Campanian, the Zagros foreland basin started with the underfilled stage, and it was entirely clear by the end of the Cretaceous comprising a broad threefold subdivision of depositional realms that translated into three stratigraphic units known as trinity underfilled units of foreland basin system. The lower carbonate unit, the pelagic and hemipelagic unit, and the upper flysch clastic unit are represented by Bekhme, Shiranish, and Tanjero Formations respectively. All of these units were superimposed during basin depocenter migration and became younger toward the southwest in front of progressing the orogenic wedge toward the Arabian Craton. During the late Maastrichtian to Paleocene – Early Eocene, the Zagros foreland basin underwent a transition from underfill to fill the stage. Deep exhumation of the orogenic wedge and ophiolite assemblage had supplied the clastic sediment of the Kolosh Formation into the basin covering the foredeep and most of the forebulge and backbulge depozones.

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INTRODUCTION

The utmost Tectonic events that occurred on the north and northeastern margin of the ANP was the initiation of the Zagros foreland basin as a result of the closer southern new Tethys Ocean during the Late Jurassic-Early Cretaceous (Kazmin *et al*., 1986). The foreland basin evolved when the accretionary complex terranes (Qulqula Radiolarite and Serpentinite-Matrix Mélange) had stacked on the continental margin of the ANP (Aziz, 2008). The Late Cretaceous sequences represent a significant period in the geological history of Iraq (the protruding part of the ANP. These sequences record the starting of New Tethys closure and transition of the ANP margin from passive (embosoming AP8 sequence) to active margin (occupied by AP9 sequence) during early Turonian (Sharland *et al*., 2001). The closure of new Tethys started with the subduction of the ANP oceanic lithosphere underneath Iranian plates, followed by Ophiolite obduction on the ANP continental margin, and hence the initiation of the Proto-foreland basin (Alavi, 1994).

The term foreland basin is not just a longitudinal asymmetric basin extending parallel to the orogenic front, but rather an integrated basin system consisting of several units (depozones) (DeCelles, 2012; DeCelles and Giles, 1996) (Figure 1), and each sedimentary zone includes sediments that have distinctive characteristics.

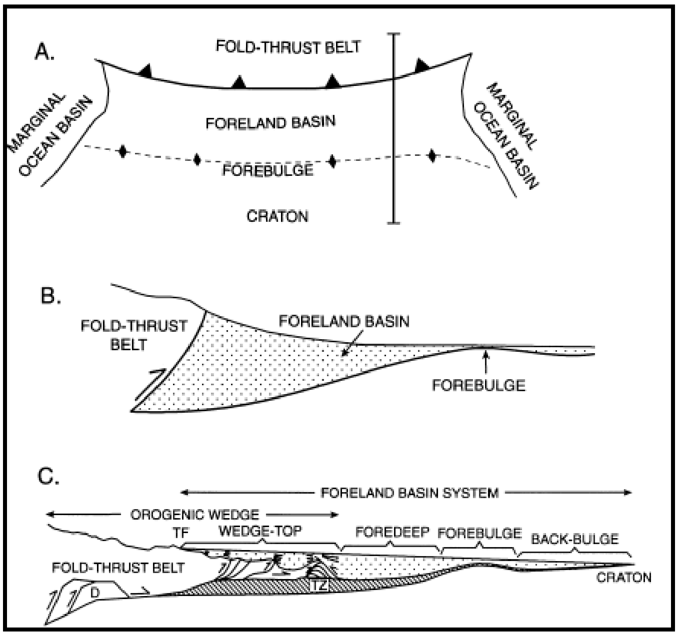

Figure 1: **A)** Schematic map of a typical Foreland basin; **B)** Cross-section showing the wedge shape of the Foreland basin; and **C)** Cross-section showing units of the Foreland basin system (DeCelles and Giles, 1996).

The Foreland basin formed along the northeastern margin of (ANP) throughout the late Cenomanian – Early Turonian as a result of lithosphere flexing due to loading by stacked thrust sheets (Jassim and Goff, 2006). The impact of this transformation led to substantial variations in sedimentation patterns from passive margin characteristics to the foreland basin sedimentation system. Such transformation was passed through many stages that reflected evolution events according to the plate tectonics and deformation of the continental lithosphere (DeCelles and Giles, 1996).

The stable carbonate platform stage ceased at the end of the Early Cretaceous and a stage of orogenic activity started and extended from Turonian till Maastrichtian during which the

Foredeep basin was developed on the Arabian Plate margin (Murris, 1980). Thus, the carbonate platform phase has vanished and the Mesopotamian Foreland basin phase started (Ali *et al*., 2012). In this respect, many authors refer to the Presence unconformity surface as a Megasequence

Boundary separating carbonate sequences of a passive margin from foreland basin sequences (Jacobi, 1981; Lash, 1983; Lash, 1988; Sinclair, 1997a and b; Otonicar,2007). It is called Fore-bulge Unconformity (Otoničar, 2007; Crampton and Allen, 1995).

The unconformity development on the ANP is related to the rising of the Forebulge zone that accompanied the Foredeep basin subsidence in front of the continental lithosphere. This is attributed to the tectonic loads associated with the closure of new Tethys.

Several previous studies (e.g., Sharland *et al*., 2001; Al-Qayim *et al*., 2012; and Lawa, 2018) dealt with the Tectonostratigraphic and sequence stratigraphy of the Zagros folds and thrust belt and they treat this topic from a sedimentary point of view. the present study approached more towards tectonic and tectonostratigraphic aspects within the modern concepts of the foreland basin units, and present models for the development of (ANP) margin from the passive to the foreland basin system phase and not to the active margin, unlike the previous studies.

STUDY AREA

The study area occupies vast areas of the Erbil Area (The Iraqi Kurdistan Region) and the northern realms of Nineveh province. These areas are situated within the High Fold Zone according to the tectonic division of Iraq (Figure 2). The exposed formations extend in age from Jurassic to Quaternary (Figure 3).

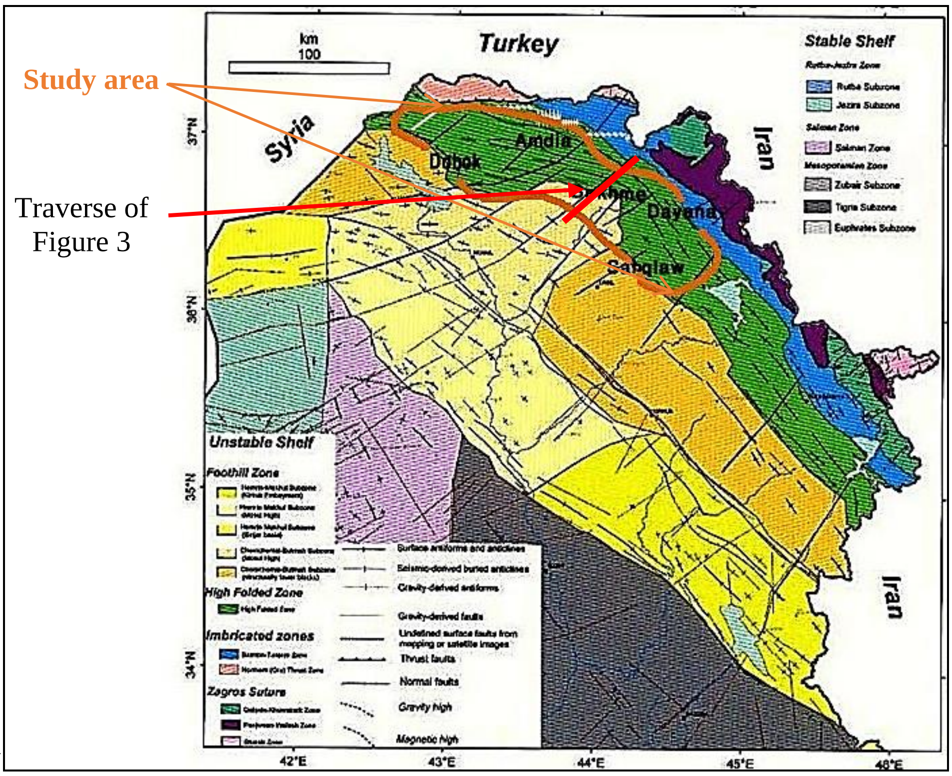

Figure 2: Tectonic Zones of the unstable shelf showing the location of the study area (Jassim and Goff, 2006).

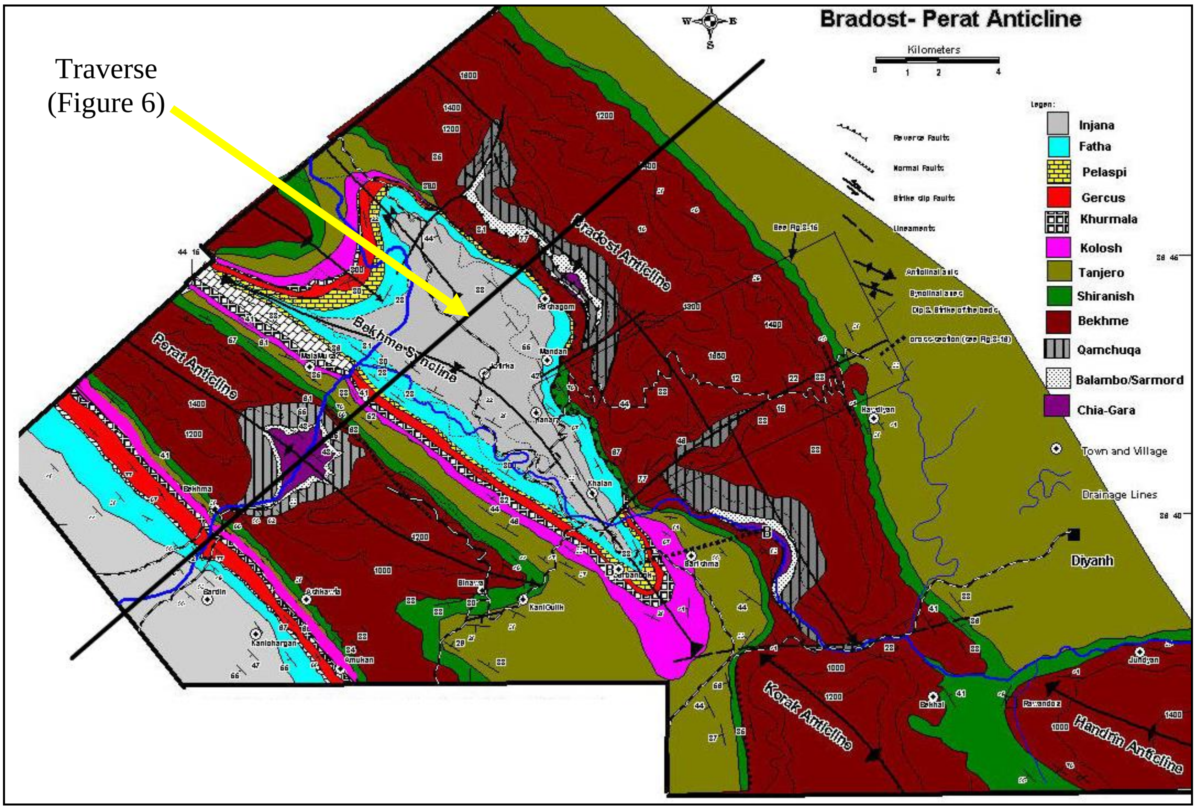

Figure 3: Geological map of the study area modified after (Omer, 2005).

The investigated area is a part of the folded zone of the Zagros-Taurus Orogenic belt that extends about 2000 Km from south Turkey passing throughout northern Iraq to southwestern Iran. This Orogenic belt forms a significant portion of the Alp-Himalayan collision zone (Alavi, 2004; Berberian and King, 1981). The width of the Iraqi fold zone reaches about 200 Km and has been divided based on fold intensity into Imbricate Fold-Thrust and Simple Folded zones (Ameen, 1992), The latter is divided, in turn, into two subzones, which are the High Fold and Foothill Zones.

The present work aims to investigate the initiation and tectonic evolution of the Zagros foreland basin during the Early Cretaceous – Early Eocene in northern Iraq, and thus to comprehend the tectonic role in the distribution of geological formations and their stratigraphic interrelationships within the study area. The significance of this study is also to give a better understanding of the foreland basin depozones and finally to propose tectonic models that demonstrate these goals.

EVOLUTION OF ARABIAN-NUBIAN PLATE (ANP) MARGIN IN THE STUDY AREA

During the Albian-Cenomanian, the ANP lithospheric margin was exposed to the ophiolite emplacement processes (Numan, 1997). The consequence of this was a broad and slight depression and the rising wave encompassed all the carbonate platform including the Qamchuqa Formation and the deep basin of the Balambo Formation, this resulted in the initiation of the *Forebulge* and vast marine regression that encompassed most of the carbonate platform, and hence setting a regional unconformity on the north and northeastern parts of the ANP (Murris, 1980). This flexural wave resulted as the ANP passive margin approached the subduction zone and increased tectonic load on it contemporaneously with the deposition of the Balambo Formation. This indicates that the continental lithosphere had approached the subduction zone and the Zagros Proto foreland basin formed during the Cenomanian (Znad,2013) . However, as the initiation of foreland basins includes partial subduction of the continental lithosphere (Monlar and Gray, 1979; Dickinson, 1974), the Arabian plate margin perhaps had contributed to the subduction process leading the margin to subsided with increasing tectonic load. The geodynamic evolution of the ANP margin and initiation and development of the proposed Zagros foreland basin system in the study area might be apportioned into the following stages (Figure 4).

- **The Albian Stage**

A shallow water carbonate platform of the Qamchuqa Formation was extended overwide area on the continental shelf of the north and northeastern ANP passive margin throughout the Albian. Whereas, the Balambo Formation was deposited as autochthonous sediments in bathyal parts of the ANP passive margin. However, the parautochthonous radiolarite sediments were deposited on the oceanic lithosphere of such plates (Aswad, 1999). The Pre-Albian Subduction of the New Tethys Oceanic lithosphere was accompanied by volcanic activities represented by Bonenite rocks (Farago, 2006). these volcanic activities may be attributed to the subduction closer to the Paleo-Mid Oceanic Ridge or Infant Arc domain (Aswad *et al*., 2011).

The convergence rate of the Nubia-Arabian and Eurasian plates was increased from 2 – 3 cm/y to 5 – 6 cm/y throughout Early Albian – Early Campanian (Agard *et al*., 2011). This sudden increase in the convergence rate and its inconvenience with the subduction rate also had consequences of stress concentration on the subducting Nubia-Arabian plate. Such load accumulation led to the initiation of another subduction zone far away from the first in north Zagros, close to the ANP margin (Aziz *et al*., 2011). The precursors of this new subduction and the increasing load of accretionary prism close to ANP margin had applied tectonic load on such margin. This load resulted in a flexural wave manifested by the continuation of Balambo Formation deposition. This subsidence coincided with the *forebulge* uplifting where the Qamchuqa Formation was deposited, as well as the initial signs of the *backbulge* depozone where the Jawan Formation was deposited in the Lagoonal-Sabkha environment West of the Kirkuk area (Jassim and Karim, 1984).

This period follows approximately the pattern, which is found in the preceding Aptian stage, shallow water carbonate platforms, and Intra-shelf basins were dominated on the ANP margin (Dunnington, 1958). Their equivalent parts in the Iranian Zagros, Oman, and Emirates are represented by rich rudist shallow water carbonate platform and the intra-shelf basin which is characterized by Olicogestenal fauna facies (Piryaei *et al*., 2010). In the ANP margin impermeable Albian lagoonal-anhydritic sediments deposited on the intrashelf basin (Dunnington, 1958).

Such basins like these were formed in northern Iraq, where the sediments of the Jawan Fn. Were deposited to the west of Kirkuk and the south of the Qalian well area (Figure 5) (Aqrawi *et al*., 2010). Also, Dunnington (1958) referred to the development of another basin north of Mosul, where deep argillaceous and clayey facies of the Sarmord Formation. were deposited. The Intra-shelf basin development might represent the inception of *Backbulge* Depozone evolution, according to the modern Foreland basin system concept (DeCelles, 2012; DeCelles and Giles, 1996).

The sedimentary environments, which were formed on the continental shelf of ANP during the Middle Albian may indicate a regional marine regression (Murris, 1980). this might be related to the Bulge rising stages due to plate margin flexing up associated with the new Tethys closure.

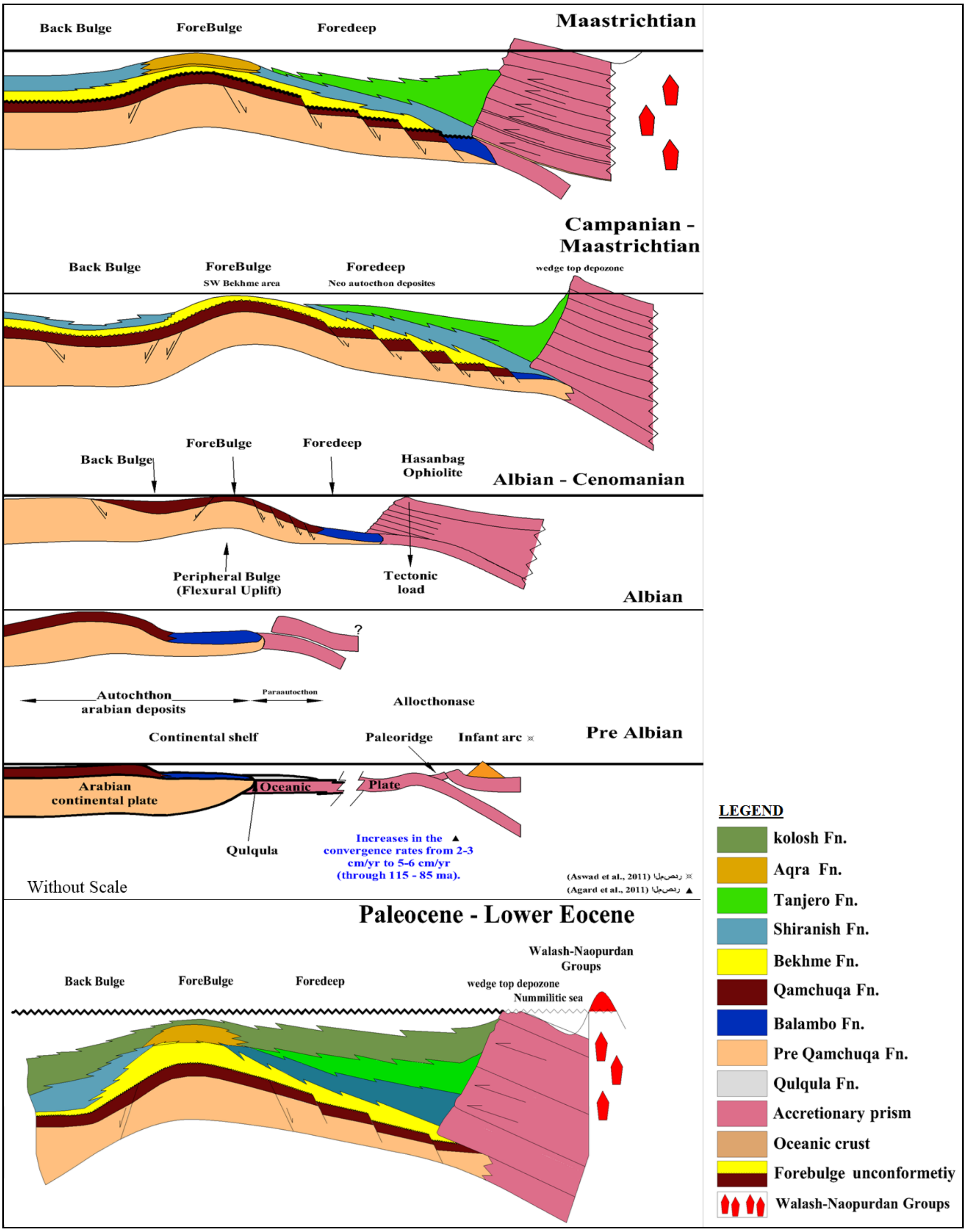

Figure 4: Expected Geodynamic development of the Arabian–Nubian plate in the study area.

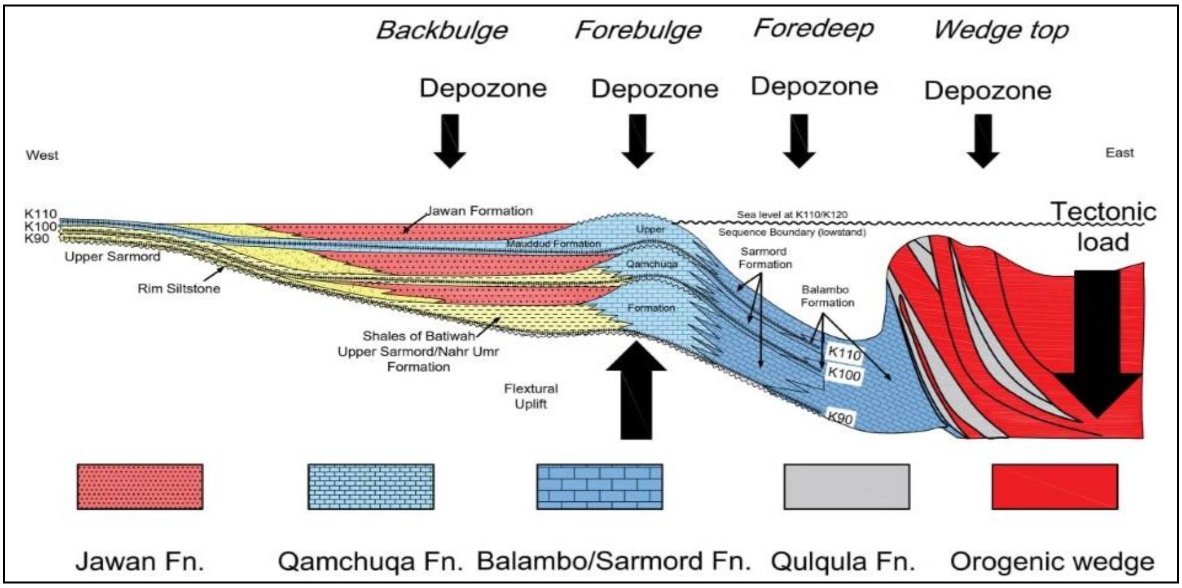

Figure 5: A geological cross section extending east-west across the Kirkuk area in northern Iraq illustrating the sedimentary facies during Albian – Cenomanian, (Modified after Aqrawi *et al*., 2010).

- **The Late Albian – Late Cenomanian stage**

Subducting of the oceanic lithosphere of the ANP continued towards north and northeast, while the submarine orogenic wedge progressed oppositely towards the Arabian craton. In the meantime, the deposition pattern of the Balambo Formation continued in the *Foredeep* (depozone) basin. The Bulge features appear to be clarified through shallowing upward continental shelf lithofacies, represented by upward successions of rudist-rich reefs and the lagoon environment of the Qamchuqa Formation (Ameen, 2008). In this respect, Patton and O'Connor (1988) refer that the appearance of reef facies is of preliminary indicator for approaching the continental shelf from the subduction zone. They also stated that the facies' shallowness is a consequence of the Flexural Bulge growth. In this context, the evolution of the orogenic wedge comprising accretionary prism and obducted ophiolite complexes was continued throughout this stage (Numan, 1997).

The mechanical coupling between the continental lithosphere and the oceanic lithosphere allows the continental lithosphere to be affected by the subduction processes even before it enters the trench (Jacobi, 1981). This effect is represented by the flexural uplift, and then the erosion of parts of the sequences of the continental shelf, and the emergence of forebulge depozone, which is represented in the study area by the Qamchuqa Formation. Mathematical models of Stockmal *et al.*, 1986a have shown, that the carbonated continental shelf may suffer from flexural uplift in response to the oceanic lithosphere subduction at a distance of about 250 Km from the trench. The first expression of the Swell or Bulge appears on the continental margin in the structurally attenuated parts of the lithosphere. (Patton and O´Connor, 1988). On the other hand, Robertson (1987a) states that the subductional trench became adjacent to the continental lithosphere of ANP during the Cenomanian-Turonian. They suggested that the tectonic load had caused the uplifting of the ANP margin, and then the erosion of about 600 m of carbonate platform sediments in the stratigraphic record of the continental shelf in northwest Oman.

The stratigraphic record of the whole sequences of the ANP margin through the late Cenomanian indicates the start of intense regional tectonic control on sedimentation patterns

(Murris, 1980; Harris *et al*., 1984). The extension of the continental lithosphere caused the initiation of normal faults generally trending parallel to the *Foredeep* depozone basin, for instance, the Oman foredeep basin which formed during the Late Cretaceous. In the light of the modern foreland basin system concept, the extension associating normal faults on top of the developing *Forebulge* may represent the beginning of flexural uplift for the *Forebulge* depozone associated with the foredeep depozone basin formed in response to tectonic loads on continental plate margin (Jacobi, 1981; Cohen, 1982). Besides that, the extension impact causes further initiation and development of normal faults due to continental lithosphere failure as it approaches the subduction trench (Lash, 1983).

- **The Late Campanian – Maastrichtian**

Murris (1980) indicated that the flexure of the ANP continental margin and its rise synchronously with the New Tethys closure throughout the Middle Albian – Cenomanian had caused a wide marine regression, and thus a regional unconformity overall the ANP plate margin. This scenario corresponds well with the tectonic setting associated with the deposition of the Qamchuqa Formation In our study, which embodies the Forebulge depozone. In this context, Sharland *et al*. (2001) attributed that unconformity to the transformation of the ANP margin from the passive phase (Tectonic Megasequence AP8) to the active margin phase (Megasequence AP9). whereas, the current study regards the aforementioned regional unconformity as a transformation from passive margin to foreland basin system phase at under fille stage.

Unconformity between passive margin and sequences of foreland basin system is documented in all foreland basins (Sinclair, 1997a). In the present study, this unconformity separates between the pre-orogenic carbonate platform, Qamchuqa Formation, and the Synorogenic Carbonate Platform (SCP) dissected by faults (Bekhme Formation).

The period of erosion or no deposition at the type locality of Bekhme Formation in the study area continued until Campanian (Bellen *et al.*, 1959), and this was represented by *forebulge unconformity* between Qamchuqa Formation (Late Albian) and Bekhme Formation (Campanian). This indicates a transition from a passive margin to a foreland basin phase at the underfill stage, whereas the deposition of Balambo Formation was continued in the *foredeep* depozone basin until the end of Turonian or Early Campanian (Chatton and Hart, 1961). The continuation of deposition of the Balambo Formation until Early Campanian was probably due to continuous subsidence in the *foredeep* depozone basin under the influence of the tectonic load exerted from thrust sheets and accretionary prism complex on the continental margin.

The obduction of the Ophiolite complex of the New Tethys oceanic crust over the ANP margin and its emergence above sea level has reached its climax throughout the Late Campanian – Early Maastrichtian (Jassim and Goff, 2006). Such Ophiolite emplacement has increased the subsidence amplitude of the flexure wave (increased subsidence of *foredeep* depozone basin) associated with the increase of *forebulge* depozone rise. This wave also has activated antithetic basement normal faults behind the fore bulge and has led to the evolution of a deep *backbulge* depozone (Znad, 2013). During this period the Zagros foreland basin started to form in an underfille stage on the ANP continental lithosphere.

The marine transgression started with the continued approach and advance of tectonic load, and the lithological characteristics of the underfilled stage trinity (Sinclair, 1997a), had been elucidated as the carbonate platform began to form which dissected by normal faults due to the resulting tensile stresses from the bending and extension of the continental lithosphere (*forebulge* depozone rise), and increasing subsidence of the *foredeep* depozone. The anticipated developments of normal faults arise due to brittle deformation on the foreland plate in most flexure areas because of tensional stress intensification (Bradley and Kidd, 1991). The Bekhme Formation represents this carbonate platform and due to the various models proposed for this Formatio, such as (Al-Shireedah, 2009; Ali, 2010), the present study has adopted a geodynamic term from (Otoničar, 2007) known as SCP for Bekhme Formation.

As a result of subsidence wave advancement and migration of depocenters ahead for advancing tectonic load and retreat of the *forebulge* depozone, this originating platform (SCP) was buried in the study area gradually in subsequent stages (within the same deposition cycle) by pelagic and hemipelagic sediments of the intermediate unit of the trinity represented by Shiranish Formation. This coincided with the entry of the clastic flysch sediments of the foredeep depozone basin represented by the Tanjero Formation (upper unit of foreland basin stratigraphic trinity). These clastic sediments resulted from rapid erosion of emerged Ophiolite (Jassim and Goff, 2006). However, Southwest of the *forebulge* at a deep *backbulge* depozone, the ambiance was convenient for the deposition of the Shiranish Formation (Figure 3).

- **Latest Maastrichtian**

The deposition of foreland basin trinity units continued during the underfill stage in the *foredeep* depozone basin, and the SCP Bekhme Formation had been drowned successively towards the Arabian craton as a consequence of continued advances of orogenic wedge and basin fill migration for the trinity units. Bekhme Fn. has been developed on the Qamchuqa *forebulge* depozone. However, to the Northwest of the Bekhme area (toward Aqra-Gara-Amadia) the *forebulge* depozone was exposed and then subsided slightly due to tectonic load advancement, to become a convenient site for reef and rudist growth of the Aqra Formation. Which grades to the Shiranish Formation towards the Southwest (*backbulge*), whereas it inter-tongues as bioclast-rich limestone towards the Northeast (*foredeep)* basin with both Shiranish and Tanjero Formations (Figure 4).

- **Paleocene – Early Eocene**

The transition from the Mesozoic Era to the Cenozoic Era was defined by the Ap9/ Ap10 boundary in the Arabian plate sequence stratigraphy. This transition marks the end of a significant period of Arabian plate tectonics, that is the cease of new Tethys Ophiolite ascent over the North and Northeastern ANP continental margin (Sharland *et al*., 2001). The cease of Ophiolite obduction at Late Cretaceous- Paleocene in Northern Iraq was caused by a collision of Hasanbag Ophiolite – Arcs (92 – 106 m.y aged) with the Northeastern continental margin of ANP (Ali *et al*., 2012).

The Ophiolite obduction is followed by a period of relative cease of motion between ANP and the Eurasian plate during the Paleocene. This produced a progradational accumulation of sediments in the *foredeep* basin, with clast/carbonate constituents derived via erosion of the obducted Ophiolite complex from the northeastern side of the basin (Daly, 1990). In this respect, Murris (1980) refers to the dimming of orogenic perturbations at the end of the Maastrichtian and the calm to the sedimentary basin in Northern Zagros (referring to Iraq). This was accompanied by the Isostical rise of the Orogenic zone that had led to supplying the basin with reworked clastic derived from thrust wedge (Radiolarite and Ophiolite). Thus, in this period, the foreland basin had entered the filled stage. The slow-down rate of orogenic wedge progression combined with an increase in the exhumation rate of Orogenic wedge resulted in the transition of the basin from an underfilled to filled stage

(*Sinclair and Allen, 1992* in Sinclair, 1997a). This filled state is represented by the deposition of the Kolosh clastic Formation in the *foredeep* depozone basin zone which has migrated towards the southwest relative to

basinal axis of Tanjero Formation. And also, by the deposition of Kolosh Formation with great thickness in *backbulge* depozone. The increase upward of calcareous units in the Kolosh Formation reflects upward shallowing of basin facies. But forebulge areas occupied by the Aqra Formation remained exposed throughout the Paleocene. The aerial distribution of the Kolosh Formation in the study area has been greatly affected by foreland basin evolution (Znad and Al-Jumaily, 2019).

- **Under Fill Tectonic Model of the Zagros Foreland Basin**

Global models for the development of the Foreland basins vary according to their assumption of lithosphere behavior under a tectonic load that may be elastic (Jordan, 1981) or viscoelastic (Beaumont, 1981). Also, Stockmal *et al.*, (1986a) developed a model that includes the transition from the rifted passive margin to the thrust and folding zones and the consequent development of the Foreland basins within the framework of plate tectonics, with the effect of other variable factors such as elastic thickness and thermal age, and the Elastic thickness is associated with thermal dating i.e., the age of the passive margin, as well as the structure of the margin and its shape before the subduction process. The tectonic position of the ANP margin coincides with the model (Stockmal *et al.*, 1986b), which also confirmed that the effective elasticity was affected by the thermal history. This model dealt with a modern rifted continental margin (10 million years ago) and an ancient continental margin (120 million years old) associated with an orogenic wedge, either with high relief, such as the height of the Himalayas, or with low topography, such as the Zagros Mountains. The North and Northeastern rims of ANP are considered a mature margin since it is rifted during the Permian-Triassic, that is, about 100 million years before the impact of the tectonic load on it during the Albian-Cenomanian.

As the orogenic wedge progresses, the *forebulge* depozone recedes toward the craton, followed by a surface of unconformity arising between the passive margin succession and the Foreland basin phase sequences in the underfill stage. According to this model, the basement faults can be reactivated which enhances the uplifting of the *forebulge* depozone, and in this regard, Jacob (Jacobi, 1981) identified normal and reverse faults parallel to the Appalachian Orogeny front in West America extending for more than 1.5 Km, and he concluded that these faults were re-active during the repeated rising and lowering of the continental shelf.

The accumulation of evidence from studies on the deformation of the Eastern and Northern ANP boundaries during the Early Late Cretaceous due to the closing of the New Tethys Ocean and the amplification of the tectonic load represented by the development of the accretionary prism and ophiolites obduction (Berberian and King, 1980; Cohen, 1982; Robertson, 1987a; Roberston, 1987b; Alavi, 2007; Emami, 2008; Homke *et al.*, 2009; Fouad, 2010) indicates the possibility of a deformational loading of the passive continental margin and the resulting birth of the Zagros Foreland basin towards the Arabian craton that included a specific stratigraphic sequence with unconformities surfaces (Bellen *et al.,* 1959; Sharland *et al*., 2001).

According to the subductional Models and the proximity of the continental margin to the subduction Zone and the accumulation of deformational load (folds, creeping faults, ANPpes) on the ANP margin, the response of the lithosphere was represented by the subsidence and formation of the foredeep basin and its accompanying *forebulge*. The accumulation of the tectonic load over the edge of the ANP and its progression towards the South and Southwest through the Valanginian to the Albian i.e., during the deposition of the Qamchuqa Formation in the study area, had led to the rise and fall of the Qamchuqa Formation basin several times under the influence of the tectonic load's oscillations (Loading and Relaxation). The alternation of lagoonal and reefal facies within the Qamchuqa Formation reflects that oscillation in the tectonic setting (Ameen, 2008).

The unconformity boundary between the Qamchuqa and Bekhme formations according to (Bellen *et al*., 1959), which extends for a period of (16 – 20) million years, indicates that the upper part of the Qamchuqa Formation was exposed to weathering and erosion.

The convergence between ANP and the Iranian plate had continued During the Late Albian – Early Campanian, combined with the increase in the tectonic loads (submarine orogenic wedge), this had led to a deepening of the *foredeep* depozone basin and increased the tensile stresses on the upper parts of the Qamchuqa *forebulge* due to the flexural uplift, the horizontal stresses and reactivation of successive foreland vergency normal faults enhances this bulging. these faults are synchronous with the deposition of the SCP of the Bekhme Formation. The flexural uplift of the forebulge has also led to the development of suture vergence faults specific to a deep *backbulge* depozone, (Figure 3). The climax of climbing and emergent the ophiolite and thrust sheets occurred during the Campanian - Maastrichtian (Jassim and Goff, 2006). Thus, the characteristics of the Foreland Basin system in the underfill stage became clear. The accretionary prism complex, creeping plates, and ophiolite formed the *wedge-top* depozone in conjunction with the typical deposition of the trinity units of the underfilled stage in the *foredeep* depozone basin (Figure 6), and this scenario is similar to what happened in other Foreland basins in the world according to the illustrations of (Sinclair, 1997a). The trinity units consist of the carbonate platform deposits of the lower unit (Bekhme Fn.), the pelagic and hemipelagic central unit deposits (Shiranish Formation), and the upper clastic flysch unit which derived from the orogenic wedge (Tanjero Formation). The depocenters' axes of the three units of the *foredeep* basin are commonly superimposed during basin migration in front of tectonic load advances.

The *forebulge* represented by the Qamchuqa Formation was the base on which the SCP of the Bekhme Formation developed in the parts that were inundated with succession as a result of the progression of the flexural wave due to the advance of the tectonic load, while the western parts of the *forebulge* remained exposed (Figure 7).

The *backbulge* depozone depth was appropriated to the deposition of the Shiranish Formation to the south, southwest, and southeast of the *forebulge*. Although the Shiranish Formation was deposited during the compressive phase of Zagrose orogeny, it is deposited in an extension environment both in the foredeep and in the backbulge (Znad *et al*., 2020)

During the Maastrichtian, a sea transgression occurred as a result of the impact of the tectonic subsidence, which led to the immersion of the *forebulge* towards the west and northwest (Aqra – Gara – Amadiyah), and thus provided a suitable environment for the growth of reefs rich rudist of Aqra Formation unconformable over Qamchuqa Formation as in Gara area (Figure 8).

The deposition of the Shiranish Formation continued in the *foredeep* and the *backbulge* basins, while deposition of the Tanjero Formation was restricted in the *foredeep* depozone because the *forebulge* was an obstacle to the crossing of the sediments of the Tanjero

Formation toward the *backbulge* depozone basin along the line connecting Between the Southwest limbs of the Harir, Perat, Aqra, Gara, and Mutin anticlines.

The upper parts of the Shiranish Formation in a *backbulge* depozone vary laterally to equate the lower parts of the Aqra Formation, especially in the outcrops extending between Gali Zanta and Gali Bekhme in the Southwest parts, where the gradual change from marly limestone of Shiranish Formation to the fossiliferous limestone of Aqra Formation, such variations were recorded between the shallow and deep environments of the Cretaceous Formations in other localities of Northern Iraq (Karim *et al*., 2012).

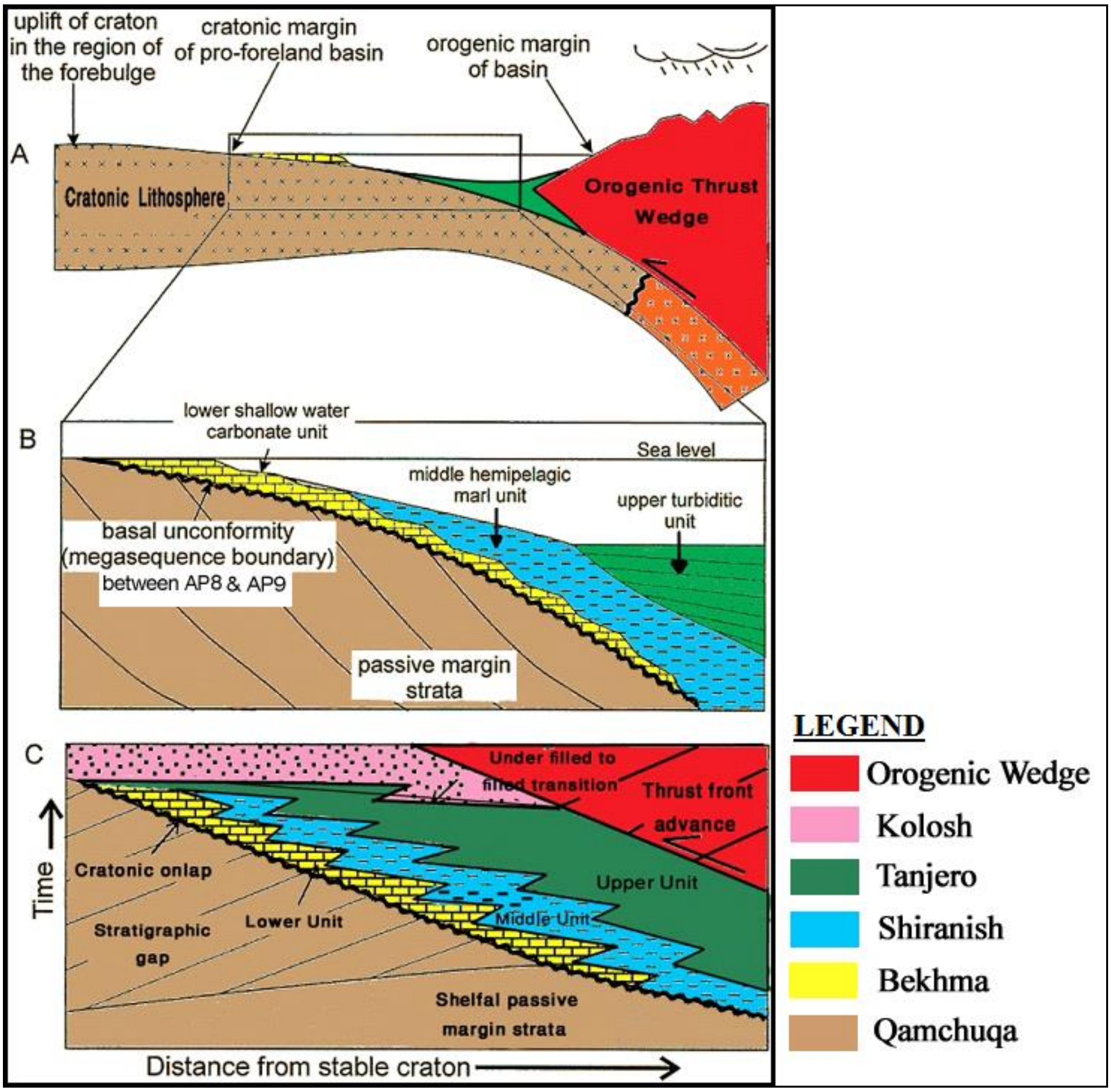

Figure 6: Model of the trinity underfilled stage units form (Sinclair, 1997a). Indicated by the units of the Foreland Zagros Basin underfilled stage according to this study.

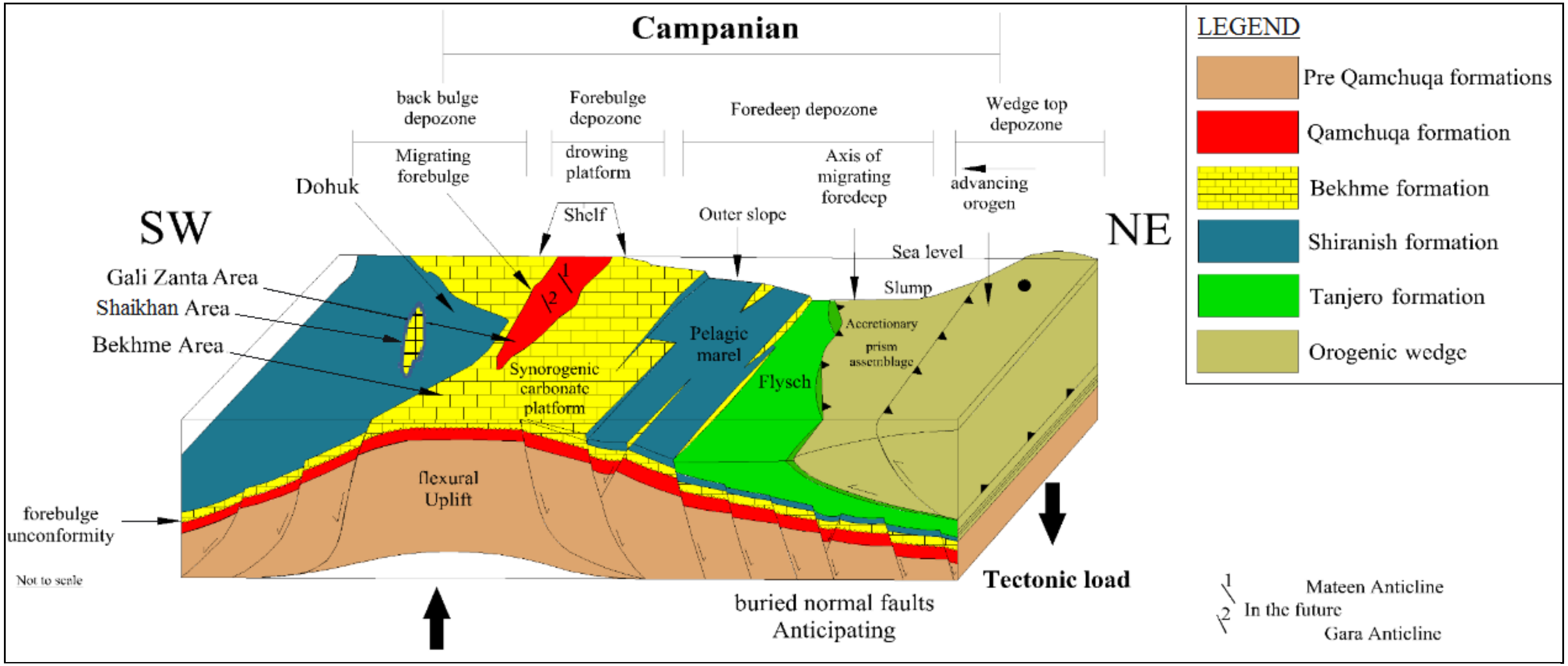

Figure 7: Tectonic model of the Foreland-Zagros Basin in the study area in underfill stage during the Campanian. Modified from model of (Bradley and Kidd, 1991) in Appalachian orogeny in western North America.

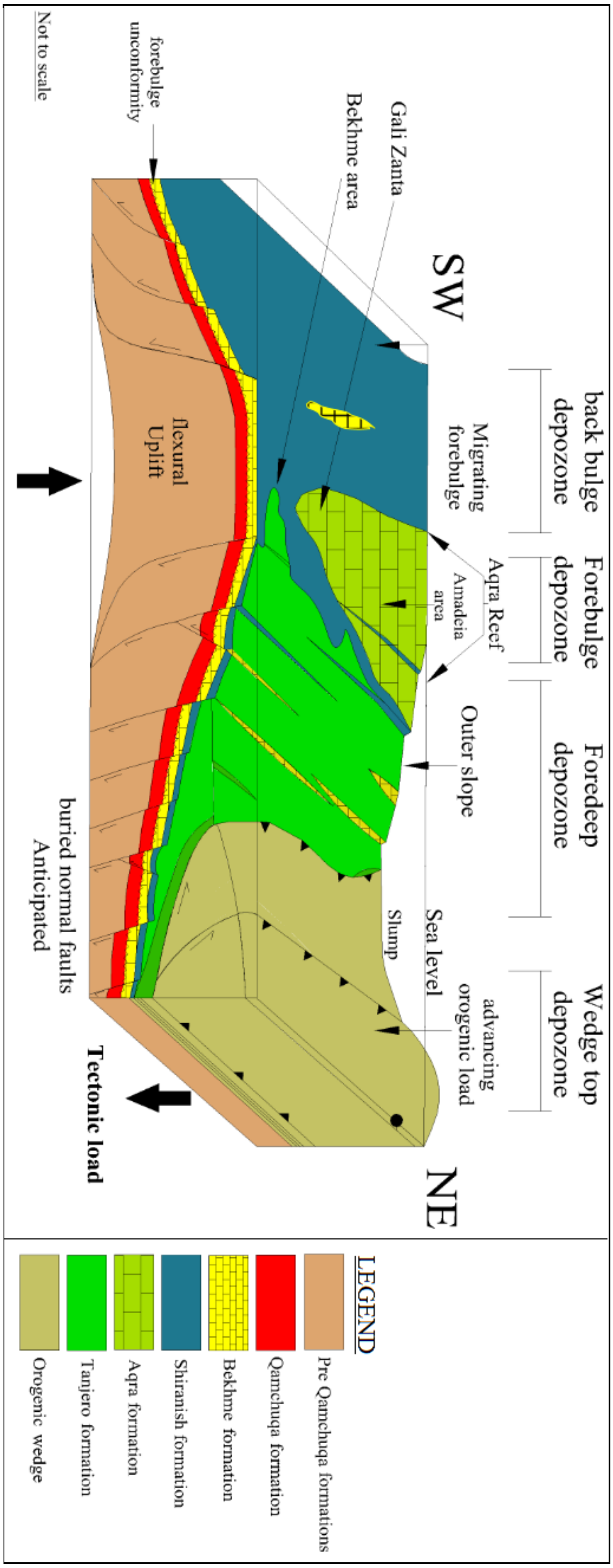

Figure 8: The tectonic model of the Foreland-Zagros Basin in the study area is an underfilled stage during the Maastrichtian.

The lateral variation of the Aqra Formation to the Shiranish Formation towards the Southwest as well as towards the Northeast has been clarified in a cross-section extending (Northeast-Southwest) through the Mosul toward Aqra area (Chatton and Hart, 1961), (Figure 9). This section has been marked with the Foreland-Zagros basin system depozones proposed in the present study.

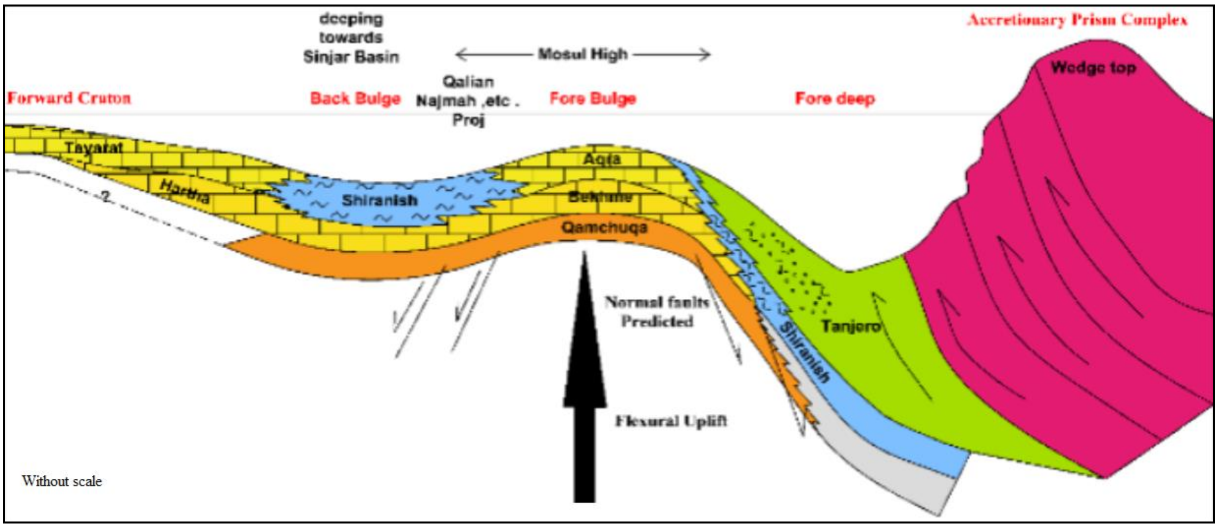

Figure 9: A cross-section extending Northeast - Southwest showing the relationship between the Late Cretaceous sequences, Modified from (Chatton and Hart, 1961).

During the Paleocene, the Zagros foreland basin entered a filled stage represented by the deposition of the Kolosh Formation. The deposits of the Kolosh Formation are those fragments that are derived from the orogenic wedge and the reworked clastics of the Tanjero Formation. The progression of the eustatic rise towards the basin caused by the processes of exhumation and erosion in the orogenic wedge was accompanied by the cratonward migration of the depocenter of the sedimentary basin. Therefore, the depocenter of the Kolosh basin is shifted towards the south and southwest of the Tanjero basin in the foredeep depozone (Znad and Aljumaily, 2018).

The Kolosh Formation overlies Tanjero Formation in the foredeep depozone basin, (Figure 10). Generally, the contact between them did not show any sedimentary evidence of an unconformable surface. However, biostratigraphic studies indicate the presence of an uncomfortable surface between them in the Bekhme area (Malak, 2010).

As for the Northeastern margin of the *forbulge* depozone on which the Aqra Formation was deposited, as, in the Guli-Zantah area (the Northern limb of the Aqra Anticline), sandy, silty, and calcareous facies were deposited with a thickness of up to 30 meters on the boundary with the Aqra Formation that may be equivalent to the Kolosh Formation.

The Kolosh/ Khurmala Formations along the Southern limb of the Aqra Anticline extend east of the Atrush district to the plunge of Gara and Mateen Anticlines to the western side of the Khabur River.

This interdigitation extends towards the Southwest (behind the *forebulge*) to be Kolosh Formation which is located unconformably above the Shiranish Formation in the the Duhok and Shaqlawa areas. As for the area extending from Aqra -Gara-Amadia, it was exposed during the Paleocene Era, and it contributed to the supply of the *back bulge* depozone by carbonate rock detritus. In this regard, most of the rock fragments of the Kolosh Formation in the area around the Aqra fold consist of carbonate rock fragments and the remains of coral structures belonging to the Aqra Formation (Al-Naqeeb, 1989).

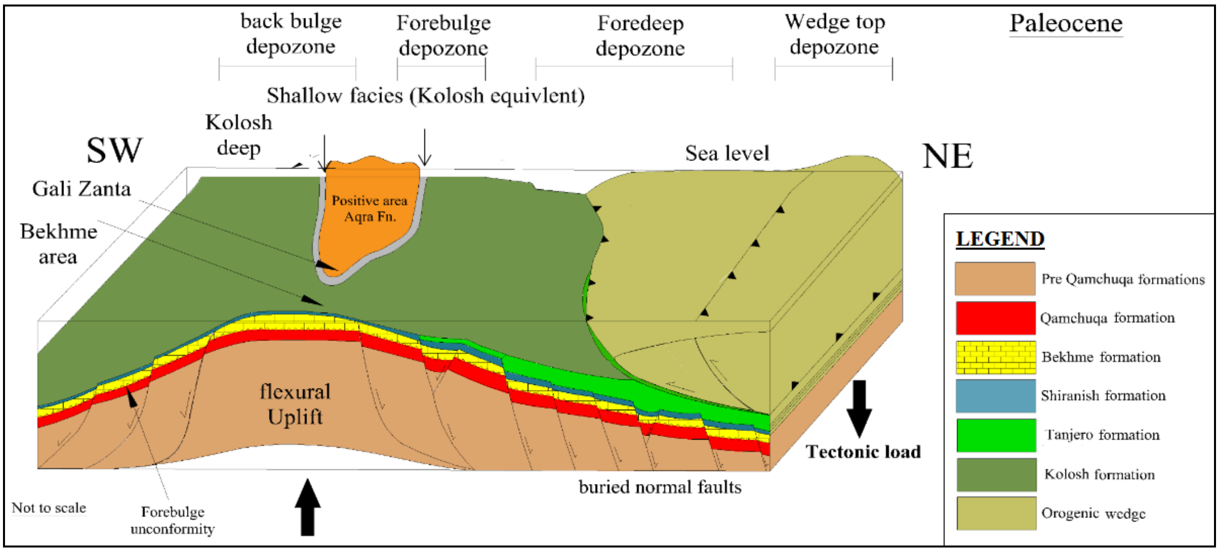

Figure 10: The tectonic model of the Foreland-Zagros Basin in the fill stage in the study area during the Paleocene.

CONCLUSION

- The Continental crust of the ANP has been transformed from the passive margin phase to the foreland basin system phase during the Cenomanian.
- The Forebulge unconformity has been separated between the sequences of the passive margin (AP8) and the foreland basin system (AP9). These sequences are represented by the pre-orogenic carbonate platform of the Qamchuqa Formation and the stratigraphic units of the underfilled stage.
- The typical stratigraphic units of the under-fill stage are represented by the lower unit of the Synorogenic Carbonate Platform (SCP) of the Bekhme Formation, the middle pelagic and hemipelagic unit of the Shiranish Formation, and the upper clastic flysch units of the Tanjero Formation.
- The development of the Zagros foreland basin underwent two stages during the study period, which were underfilled and filled stages.

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