Designation and Study of Anticlines- Kurdistan Region-NE Iraq

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Abstract. Iraq is located in the Western Asian continent particularly in the northern Arabian promontory. Iraq approximately lies in center of Middle East. The area of investigation cover northern and northeastern parts of Iraq-Kurdistan Region. Iraq and Kurdistan region are located in the northern Arabian Platform. The study area includes the northwestern extension of the Zagros Mountain range (the Zagros Fold and Thrust belt). Through study of Tectonic analysis, Stratigraphy, Geomorphology and satellite images; we try to constrain new classification with designation of the anticlines and compression stress orientation in Zagros fold belt. The northeastern and northern Iraq contain huge anticlines and synclines. They have been formed as a result of compression stress. These forces formed by collision of Arabia and Eurasian plates during Eocene-Miocene periods. Most of the anticlines characterize by double-plunging symmetrical to semi-symmetrical fold. The shield of the anticlines in the High Folded Zone mostly compose of carbonate sequence from Cretaceous formations. The core has Jurassic-Triassic formations. In the other hand the shield of anticlines in Low Folded Zones are Cenozoic formations. The plunging and terminate anticlines was caused by Cretaceous pre-tilting extensional normal faults. These fault become barriers in front of growing the anticlines longitudinally as example in Kosrat and Shakrok anticlines. The Cretaceous lateral facies change affected on the bend of anticline axis. The northwestern of Azmar anticline and southeastern of Surdash anticline seem to be En-echelon plunging; through this study we find out they are belong to one anticline. The Surdash-Azmar fold Axis shape is Bezier line while passing through facies change between Qamchuqa and Balambo Formations. The same phenomenon can be find in Aqra-Bekhme anticlines by facies change of Aqra-Tanjero formations. In this study, we try to make two or more anticlines to be show as one large anticline. In previous studies they split anticline into two or more anticlines because of having geomorphological features such as valley and lakes. However we try to show that valleys and lake are not barriers and not affect termination of the anticline as shown in Shirin, Bradost, anticlines are one individual anticline.

Keywords: compression stress, Anticline, stratigraphic facies change

1. Introduction

The Kurdistan region/North Iraq is the significance key area for study the anticlines structure. Because NW part of the Zagros Fold belt. The Study area effected by the collision of Arabia-Eurasia Plates. The starting time of the post-collision is in claimed that the post-collisional was in Upper Lutetian
indicating that the collision probably initiated in Late Paleocene-Early Eocene (Mazhari et al. 2009). Nevertheless the Ghasemi and Talbot (2006) conclude that the Neo-Tethys closed during the Early to Middle Eocene. That mean the final resumption of the oceanic domain took place after Late Eocene, and the collision must have started before 23–25Ma in northern Zagros (Agard et al. 2005). On the contrary Allen and Armstrong (2008) argue that the Arabia–Eurasia collision, and the closure of the Neo-Tethys ocean gateway, initiated in the Late Eocene at 35Ma. However depend on McQurrie and Hinsbergen (2013) the collision started in 27Ma. From the result of all these authors conclude the anticlines and folding in NE Iraq initiated from Eocene to the date. Through this research we try to describe the anticlines and the relation to each other.

2. Location of the area and Tectonic Framework:

Iraq is located in the Western Asian continent and more particularly in the northern Arabian promontory. It lies approximately in the center of the Middle East (Fig.1.A). Study area is located in the Northern of Iraq (Kurdistan Region) between Iran in the east, Musil in south, Kirkuk west and Turkey to the north (Fig.1.B). This study mainly concentrated in the area located between the longitudes 43˚ 30′ 00″ E and 45˚ 30′ 00″ E and the latitudes from 35˚ 30′ 00″ N to 37˚00′ 00″ N. As a preliminary view we visit most parts of the Kurdistan Region but we focused on the Erbil and Sulaimanyah provinces areas (Fig.1.B).

The Kurdistan region in Iraq constitutes the northeastern part of the Arabian plate. Depend on the tectonic behavior and a geomorphologic feature, Iraq is divided into three main tectonic zones (Buday, 1980): (1) Unfolded, (2) Folded and (3) Thrust zones. More recently Jassim and Goff (2006) and Aqrawi et al. (2010) proposed the new main tectonic sub-divisions of Iraq summarized in to: (1) Stable shelf, (2) Unstable shelf, (3) Foothill zone, (4) High folded and Imbricated zone (5) Thrust zone or Suture zone (Fig.1-C).

The Low Folded zone is characterized by a thick sedimentary cover, with respect to the unfolded zone, and by long narrow anticlines. The High folded zone is characterized by large and high anticlines cored by Mesozoic formations. The core of anticlines mainly consists in Mesozoic carbonates, and the clastics outcrop on the flanks of the anticlines and in the synclines. This zone covers most of the study area. It was uplifted during part of the Paleogene, before to be strongly folded during the Late Cenozoic collision.

The Imbricated zone forms a narrow strip bounded by the High folded zone to the southwest and the thrust zone to the northeast (Fig. 1-C). This zone is supposed to be more intensely folded and faulted than the High folded zone. The Thrust zone represent the allochthonous units constitute the northeastern most Iraqi-Kurdistan.

3. Methodology:

Main tool used are Stratigraphy and Structure. For the Stratigraphy we try to study the sequences formed the anticlines, horizontally and vertically facies variation. This research not concentrate on the morphological feature description of the anticline. However we study the fault and related to the anticlines. Therefore for fault analysis based on the inversion of reasoning Wallace (1951) and Bott (1959). The idea of solving the inverse problem has given rise to many numerical methods (Angelier, 1975; Carey, 1976; Angelier et al, 1982; Angelier, 1983, 1984; Michal, 1984; Reches, 1987; Angelier, 1990). In this work, we have almost exclusively used the method of direct inversion developed (INVD) by Angelier (1975, 1990).
3

Figure-1: A-Map of Middle, location of Iraq and surrounding countries; B- Location of the Study area, C- Location of Study area depend on the Tectonic sub-division of Iraq (Al-Kadhimi et al., 1996)

Through this research we try to show and discuss the large anticlines in the northeast of Iraq-Kurdistan region. Due to security reason we can’t reach to make field work. These anticlines that we study are:

3.1. Azmar Anticline:

Azmar anticline located northeastern of Sulaiymanyah city (Fig.2). The anticline is about 43km length. The core of this anticline is composed of early Cretaceous rocks of Balambo Formation that crop out along the Sulaiymanyah-Azmar main road. The sedimentary sequence consists in fine grained limestone, marls or friable papery shales of Berriasian to Barremian age (Ahmed et al, 2015). This sequence is equivalent of the Lower Balambo Formation. In addition, part of this sequence is belongs to the Sarmord Formation (Ahmed et al., 2014; Kariem et al., 2013). In the northeastern flank of the Azmar anticline and toward the northeast the basinal facies of the Balambo Formation progressively change into well-bedded hard limestones intercalated with thin marly layers. This facies represent the upper part of the Lower Balambo Formation. In the flank of Azmar anticline covered by fine grained, well-bedded carbonate facies containing chert nodules interbedded with thin layers of papery shales and marls of the Kometan Formation (Kariem et al., 2013, Kariem and Ahmed, 2014).

The Shiranish Formation directly lies above the Kometan Formation that characterized by rhythmic alternations of marls and marly limestones. The thickness of the marly limestone and marl in each bundles of the lower part of Shiranish Formation is approximately the same, while toward the upper part of the formation the thickness of the marly beds increases in each bundle (Fig. 3).
3.2. Piramagroon Anticline

The Piramagroon anticline is an enormous asymmetrical anticline located in the northwest of Sulaimanyah city (Fig. 2). The core of this anticline is highly weathered. It displays the Middle-Late Jurassic and Early Cretaceous sequences. In the core the Middle-Late Jurassic sequence crops out in a small area above the Zewe village. The Jurassic sequence in the core of the Piramagroon anticline is generally composed of alternations of hard dark well-bedded broken limestones with layers of papery shale. Band of cherts belonging to the Sargelu Formation and Stromatolitic limestones of the Barsarin Formation can also be seen in this area (Ahmed, 2007). The Balambo Formation in this area is much thinner than in the Azmar Anticline. It is composed of alternations of basinal fine grained limestones with papery friable marls containing several species of ammonites. The Sarmord Formation is a friable and weathered sequence. This formation about 540m thick is composed of rhythmic alternations of marls and marly limestones of Hatrevian-Baremian age (Kariem and Khanaqa, 2017).
Figure 3: Stratigraphic column of the main 9 anticlines in NE-Iraq Kurdistan. The Thickness for some formations where measured such as Kometan, Shiranishare, Tanjero, Bekhme and Kolosh and other estimate measure in the field. The Age identification of the Formation are from Ahmed et al. (2016), Kariem et al. (2013), Aqrawi et al. (2010), Jasim and Guff (2006), Buday (1980), Bellen et al. (1959).

The Qamchuqa Formation forms the shield of the Piramagroon Anticline (Fig. 4). The formation, like in the type section, is composed of thick hard massive reefal limestone and dolomitic limestone. The Qamchuqa Formation is about 400-500m (Fig. 3). The outcrops of Kometan Formation appear above the Qamchuqa Formation in the high and steep slope area and below the Shiranish and Tanjero
formations in the gentle slope area. The Shiranish and Tanjero formations crop out in the downward flanks of the Piramagroon Anticline (Fig. 3).

**Figure-4:** NE flank of the Piramagroon Anticline, the picture take from Mergapan Village.

### 3.3. Surdash Anticline

The anticline located between Sulaiymanyah city and dukan city, has a NW anticline axis that separated from Piramagroon Anticline by the Dolarut-Shadala Syncline. This NW limb is clearly plunged into the Dukan Lake but the SE limb is not clear to plunge or is continuous with the Azmar anticline. From this research we try to discuss is double plunging or not? Because depend on (Hakari, 2011) the southeastern plunge of the Surdash Anticline is an en-echelon with the northwestern plunge of the Azmar Anticline otherwise depend on the GEOSURV maps the anticline have is continuous axis with Azmar Anticline.

The core of the anticline, deeply eroded where most of the Cretaceous and Jurassic sequences are exposed. The early Jurassic carbonate sequence of Sarki and Sehkaniyan formations crops out in the core of the Surdash Anticline near the Sehkaniyan village. The Middle and upper Jurassic sequences are well exposed in the core of the Surdash Anticline near the Sargelu village (Fig.5). The Sargelu Formation is composed of black bituminous limestones and dolomitic limestones intercalated with brownish papery shales with characteristic black chert bands in its upper part (Fig.5-A). The thickness of the formation in this area ranges from 40 to 130m. The Naokelekan Formation comprises laminated argillaceous bituminous limestone and dolomitic limestone with coal and shale horizons. The thickness of the formation in this area is approximately 20-30m. The Barsarin Formation is composed of dolomitic limestones with brecciated layers and shales (Fig.5-C). The Barsarin Formation is 20-30m thick. The Chia Gara Formation consists of thin bedded limestones and calcareous shales containing rich ammonite faunas. It grades upward to yellowish marly limestones and shales. Its thickness ranges between 100 and 200m (Fig.3). The upper contact seems to be conformable with the Balambo Formation (Fig.5-B and D; Fig.3).

The Balambo Formation in this area is thinner compared to than in the Azmar area. The Balambo formation in the core of the Surdash anticline is Berriasian-Valanginian age (Ahmed et al., 2014; Bellen et. al., 1958). It represents the Lower Balambo Formation. The outer core of the Surdash
Anticline is occupied by the argillaceous carbonates of the Hauterivian-Barremian Sarmord Formation (Fig-5-D). The Qamchuqa Formation covers most of the shield of the Surdash Anticline forming high cliffs. This formation is composed of a repetition of dolomite and limestone units (Fig-5-D). The dolomite part are generally thick successions of massive and coarse crystalline dolomite. The limestone dominate part are well-bedded light grey limestone and massive limestone. The Qamchuqa Formation is about exceed 700m thick (Fig. 3).

Figure-5: Formations in the core of Surdash Anticline (Near Sargelu village). A- Limestone beds intercalation with chert band and shale of Sargelu Formation. B- Vertical beds of Chia Gara and Balambo formations. C- Brecciated dolomitic and limestone contorted beds of Barsarin Formation conformably overly by Chia Gara Formation.

Effect of terminate Qamchuqa reefal on Azmar, Surdash, and Piramagroon anticlines:

The SE plunge of the Surdash Anticline and NW plunge of the Azmar Anticline is termination of lateral extension Qamchuqa Formation. The area between Azmar and Surdash Anticlines the Aptian-Albian sequence laterally facies change. This area is important due to the transition between the Early Cretaceous facies; i.e. the Balambo and Qamchuqa formations. Northwest of this area in the Surdash Anticline, the Early Cretaceous sequence consists from bottom to top, the Balambo, Sarmord, Qamchuqa, and Kometan formations. However, in the Azmar anticline the succession is Lower Balambo Formation and Sarmord Formation (Ahmed et al., 2015). The Upper Balambo Formation is probably Aptian-Albian in age (Ahmed et al., 2016). The Kometan Formation overlaying the Upper Balambo Formation. The two Cretaceous successions in the Surdash and Azmar anticlines show that the more than 700m thick of reefal limestone of the Qamchuqa Formation, which is Aptian-Albian in age (Amin, 2008; Ahmed et al., 2016; Bellen et al., 1958) laterally changes to the less than 100m thick of Upper Balambo Formation. The large variation in thickness, hardiness and elasticity between Qamchuqa and Upper Balambo formations create the echelon shape. As well as most possibly lateral facies change and strike-slip fault affect to plunge the SE of Piramagroon anticline. Aziz et al. (1999),
from a low seismic activity in the Sulaiymanyah area, identified one long trend strike-slip faults (Chaqchaq Fault) that cross the Chaqchaq valley, Dolarut Syncline, and the northwestern limb of the Azmar Anticline. They claim that the lateral facies changes during the Early Cretaceous between the Qamchuqa-Sarmord formations and the Balambo Formation is essentially controlled by the deep Chaqchaq faults. More recently, Al-Hakary (2011) assumed again that this lateral facies change is related to the activity of the Chaqchaq normal fault during the Tithonian to Cenomanian period.

Figure-6: Tiran map of Surdash, Azmar and Pirmagroon anticlines. Stratigraphic correlation show the Early Cretaceous lateral facies change. The photo in the right show disappear facies of Qamchuqa Formation toward East. The Age of the Formation are from Ahmed et al. (2016), Bellen et al. (1959) and Buday (1980).

3.4. Kosrat anticline:

The 25km long Kosrat Anticline is one of the main structures of Dukan area. The Kosrat anticlines border the Dukan Dam depression to the southwest. The Paleocene-Miocene sequences outcropping southeast of the Dukan area form a continuous ridge, the Haibat Sultan Mountain, which is a cuesta topped by Paleocene-Eocene of Kolosh, Sinjar and Pila Spi formations (Fig.7). A thick friable mainly clastic Late Cretaceous-Paleocene sequences crops out between the southwest limb of the Kosrat Anticline and the northeastern flank of Kikasmak-Haibat Sultan cuesta.

The limbs of the Kosrat Anticline are formed by the hard Cretaceous carbonate rocks of the Kometan and Qamchuqa formations. Miocene-Quaternary deposits exist as patches in several places on the Kosrat Anticline (Karim and Taha, 2012) (Fig.7). The Cretaceous deposits cover most of the middle part of the Dukan area and the Cenozoic sequences the southwestern and southern parts.

The stratigraphy of Kosrat anticline is relatively simple. The contacts between the formations are easy to recognize on the field from lithological contrasts and facies variations. The core of the Kosrat Anticline is cored by the thick hard massive reefal limestones and dolomitic limestones of the
Qamchuqa Formation. The Dukan Formation is exposed along the road to the Dukan Dam and in the flank of the Dam. It is composed of thick well-bedded limestone. The thickness of the Dukan Formation is of 4-5m and it is Cenomanian in age (Ahmed et al. 2015). The southeastern plunge of the Kosrat Anticline, in the area surrounding the Dukan-Khalakan road displays well-bedded fine grained stylolitic limestone of the Kometan Formation with contain chert alternating with thin layers of shale. The Formation is about 100-120m thick in this section (Fig.3 and 7).

The Shiranish Formation is well developed close to the SW limb of Kosrat Anticline in the. Shiranish Formation is particularly well exposed in the road-cuts of the Dukan-Khalakan main roads where the Shiranish Formation directly lies above the well-bedded limestone facies of the Kometan Formation. The Shiranish Formation in this area is characterized by rhythmic alternations of marls and marly limestones. The Tanjero Formation directly overlies the Shiranish Formation (Fig.3 and 7). The contact between these formations is conformable and clearly recognize in the field by an abrupt change in the color from the light gray of the carbonate and marly layers of the Shiranish Formation and the dark reddish gray sandstone and shale of the Tanjero Formation. The Tanjero Formation in this area is well developed and composed of a rhythmic alternation of shales and sandstones. The Kolosh Formation is composed of a thick alternation of dark friable marls, shales, siltstones, and claystones and occasionally marly limestones. The thickness of the formation in the cliff of Klkasmak is of about 300-400m (Fig.3 and 7).

Figure-7: Geological map of Kosrat anticline and Klkasmaq monocline (Ahmed, 2013).

3.5. Extensional regimes (Pre-tilting Normal Faults)

This fault systems types are widely developed in the Kosrat anticline and surrounding. The Normal faults exist in Kometan, Shiranish, and lower part of Tanjero formations. Most of the normal fault systems are pre-folding. Depend Al-Kubaisi & Barnoon (2015) they believed the normal faults in the Kosrat anticline affecting the hanging wall block in response to the contraction displacement during
the collision event. The faults are in the SW flank of Kosrat anticline and the Dukan Dam (Table-1 and Fig.8).

Table-1: Site numbers and locations of the Faults sites of the Kosrat Anticline (Dam area)

| Site number | Latitude   | Longitude  |
|-------------|------------|------------|
| 1           | 35:57:04.0 | 44:57:05.1 |
| 2           | 35:57:29.3 | 44:55:27.5 |
| 3           | 35:57:23.8 | 44:55:06.6 |
| 4           | 35:57:54.3 | 44:54:04.0 |
| 5           | 35:58:08.5 | 44:54:05.5 |
| 6           | 35:57:29.3 | 44:55:27.5 |

The faults are located in the both plunging of Kosrat anticline. The population of faults in sites-3, 4 5 and 6 are pre-tilting conjugate extensional system. The site-2 is pre-tilting normal. As well as site 1 are conjugate normal fault.

Figure 8: google map with geological map show the location of the extentional faults. All the extentional faults (sites 1, 2, 3, 4, 5 and 6) sterionets show pre-tilting normal fault system. The upper photo explain the NW plunging of Surdash anticline and the lower photo show the plunging of Kosrat and Surdash in the Dukan Lake.
3.6. Anticlines surrounding the Dukan Lake:

This area was highly deformed, folded and thrusted, during the Late Cenozoic Zagros orogeny. The main anticlines in this area are the Rania, Makuk, Nusak, Kamosk and Bnabarik anticlines. All these axes of the anticlines trend NW-SE oriented.

The Rania, Makuk, Handren, and Nusak anticlines in the north and northwest otherwise the Kalaw anticlines and Bnabarik in the south and southeast of Dukan Lake (Fig.9). These anticlines were extensively eroded, the Early-Late Jurassic sequence (Sarki, Sehkanian, Sargelu, Naokelekan, Barsarin and Chia Gara formations) crops out in the core of these anticlines. There is no lateral facies change and variation in the lithology that can be observed in the Middle and Late Jurassic sequences in all these anticlines. The Cretaceous rocks cover most part of the anticlines. The oldest Cretaceous formation in this area is the basal Lower Balambo Formation. The outcrops of this latter formation are composed of alternations of fine grained well-bedded basinal limestones containing ammonites and marls. The overlying Sarmord Formation crops out in the core of most of the anticlines. In Qandil area the Sarmord Formation possibly laterally changes to the Middle part of the Balambo Formation. The outcrops of Qamchuqa Formation cover a large part of this area and generally form the shield of Rania, Makuk, Nusak, Kamosk and Bnabarik anticlines. This formation is composed of a repetition of dolomite and limestone units (8 units). The dolomite units generally comprise thick succession of massive and coarse crystalline dolomites. The limestone units are well-bedded light grey limestone and massive limestone. The Qamchuqa Formation in the core of the Rania and Makuk anticlines is 600-700m thick. Toward the northeast near Qandil area the Qamchuqa Formation disappears and latterly changed in to the basal facies of the well-bedded limestone with chert bands and shales of the Upper Balambo Formation.

The type locality of the Kometan Formation is located in the eastern and northeastern flank of Rania anticline. This formation is not very thick (40-100m). The Kometan Formation is composed of hard well-bedded limestones alternating with thin layers of shale with chert nodules. In the Nusak and Makuk anticlines, there is no real typical well-bedded limestone of the Kometan Formation. Here possibly the Bekhme Formation directly lays above the Qamchuqa Formation, or possibly the Kometan Formation was eroded during the Coniacian-Santonian times. Especially in the area between the Makuk and Rania anticlines. Bellen et al. (1959) claimed that the Bekhme Formation exists sporadically in the Rania area.

Through the Google map and other terrain maps clearly show the Ranya and Bna-Barik anticlines as well as Nusaik and Kalaw anticlines are in the same trend. If we subtract the Dukan depression (Dukan Lake) the Ranya and Bna-Barik anticlines appear as one great anticline. From point of view and depend on the structural of anticline the Ranya and Bna-Barik is better to joint to gather as one dabble plunging  anticline. The same phenomenon acceptable of Nusaik and Kalaw.

The plunging of all these anticline toward in the Dukan Lake possibly related to the Dukan depression that this depression formed due to extensional faults formed in the Campanian- Maastrichtian (Ahmed et al., 2016). Many Normal fault associate with anticlines such as in Ranya Anticline two large scale normal fault exist in the both sides (Sissakian et al., 2016)
3.7. Bekhme Anticline

The Bekhme Anticline is located in the high folded zone. The carbonate beds of the Late Jurassic sequences crop out in the core of the Bekhme Anticline in the Bekhme gorge. It possibly belongs to the Chia Gara Formation. Most of the core of the Bekhme Anticline that crops out in the Bekhme gorge belongs to the Early Cretaceous sequence, composed of the limestones and shales of the Lower Balambo Formation and marls and marly limestones of the Sarmord Formation. A thick massive sequence of limestones and dolomitic limestones constitutes the shield of the Bekhme Anticline. This huge sequence of carbonate belongs to the Qamchuqa and Bekhme formations. The lower part, belonging to the Qamchuqa Formation, is approximately 400-500m thick. The Qamchuqa Formation in the Bekhme gorge appears as massive to well-bedded limestones containing fragments of macro-fossils indicating a shallow environment.

The Bekhme gorge is the type locality of the Bekhme Formation composed of reefal massive limestones 300-350m thick. This formation forms the outer shield of the Bekhme Anticline. The lower contact of the Bekhme Formation with the Qamchuqa Formation is unclear. The previous studies support two main ideas. One reports an unconformity with occurrence of a thick basal conglomerate and the other supposes a conformable contact without any sub-aerial erosion at the contact between the Qamchuqa and Bekhme formations.

We do not observed any thick basal conglomerate in the carbonate sequence in the Bekhme gorge. However, we found a 1m-thick (or less) bed of conglomerate. The pebbles are an intra-formational issued from the same carbonates that exist above and below this conglomerate.

The NE-flank of Bekhme anticline in the entrance of the gorge in the site of the Bekhme Dam project. In this section the Shiranish Formation covers the Bekhme Formation. The contact is sharp but conformable. The lower part of the Shiranish Formation is composed of hard gray limestones alternating with thin layers of marls and the upper part of friable limestones. The total thickness of the Shiranish Formation is 48m. The overlaying Tanjero Formation is composed of alternations of marls, limestone and sandstones. The thickness of the formation is 51m. The Kolosh Formation in this section is about 400-500m thick. It is composed of dark shale, clay and beds of detrital limestone. The 10-15m thick reefal to lagoonal limestone of the Khurmala Formation overlies the Kolosh Formation.
The SW-flank of the Bekhme section is located on the Bekhme main road close to Bekhme Village in the southwestern entrance of the Bekhme gorge. The Shiranish formation in this section also conformably overlies the reefal limestones of the Bekhme Formation. The total thickness of the Shiranish Formation in this section is of 104m. The Tanjero Formation stratigraphically overlays the Shiranish Formation. It is 145m thick in this section. The Kolosh Formation conformably overlies the Tanjero Formation. The limestone beds of the Khurmala Formation conformably overlay the Kolosh Formation, are 32m thick in this section.

In the southeastern plunge of the Bekhme Anticline the thickness of Shiranish Formation is 145m and Tanjero Formation is 265m. Indicate the formations triple time thicker than in the flank of Bekhme Anticline (Bekhme Gorge). The thick thicknesses is related to the large pre-tilting extensional Late Cretaceous normal fault in the SW plunging of Bekhme Anticline. The normal faults only south dipping normal faults have been recognized. The fault initiated possibly during Early-Late Campanian.

Due to this fault possible during Early to Late Campanian the lower part of Shiranish Formation deposited rather than Bekhme Formation. Because the Shiranish Formation directly overly upper Qamchuqa Formation due to exist of hard ground erosional surface with bioturbation indicating a non-deposition or erosional period (Carlton and Michael, 1984; Bromley, 1996; Vinn and Mark, 2010) during Coniacian-Santonian times. The terminate lateral extension of Bekhme Formation in the NW plunge of Bekhme Anticline and exist of large pre-titling normal fault are factor to stop the growth and plunge the Bekhme Anticline.

3.8. Aqra Anticline

This anticline characterize by long arch anticline with axis orientation NW-SE slightly change WNW-ESE. The core of anticline possible Early Cretaceous sequences. The shield mostly covered by the thick hard dark carbonate reefal sequence of Aqra-Bekhme Formations. The type section of Aqra Formation is located in this anticline near the Aqra city by Dunnington et al. (1959). In this research we concentrate the plunging of Bekhme and Aqra anticlines area (Bjil area). Because the end of this two anticline seem to be an en-echelon plunging.
Figure 10: Satellite image showing the location of the Chnara, Bekhme and Aqra anticlines. The Stratigraphic correlation show the Maastrichtian facies change between Aqra Formation in the west and Tanjero Formation in the East.

Near the NW plunge of Bekhme Anticline the marl and limestone of the Shiranish Formation overlies the reefal limestone of the Bekhme Formation, elastic deposits of the Tanjero and Kolosh formations overlay the Tanjero Formation. The total thickness of these three formations reaches approximately 200-300m. The 50m thick lagoonal limestones of the Khurmala Formation overlay the Kolosh Formation. Here, there is no occurrence of the Aqra Formation facies. In Bjil villages in the southwestern flank of the Bekhme Anticline. Here, the reefal limestones of the Aqra Formation are clearly exposed. They form a thick sequence of limestone overlying the Bekhme Formation. As well as the lagoonal limestone of the Khurmala Formation is directly overlays the reefal limestones of the Aqra Formation without any angular unconformity. That mean no any beds of Shiranish and Tanjero Formation exist.

In the eastern plunge of the Aqra Anticline along the Bjil Village road (Fig. 10) is similar to Aqra type section. The Aqra Formation directly overlays the Bekhme Formation and the Khurmala Formation disconformably covers the Aqra Formation. However, in the northern flank of the Aqra Anticline marl and clastics beds, possibly belonging to the Kolosh Formation underlay the Khurmala Formation and overlays the Aqra Formation (Fig. 3). The thickness of this clastic sequence is of about 10-15m.

The lateral facies change between Aqra and Tanjero formations in plunging of Aqra and Bekhme anticlines are the main factor to form an en-echelon shape. From top view through satellite image the Bekhme and Aqra anticline seem to be one Anticline. Through this research we conclude also the Aqra Formation overlays the Bekhme Formation in Aqra Anticline and the geographical distribution of the Aqra Formation is restricted compared to the Bekhme reefal platform.
3.9. Korek Anticline:

The Korek Anticline is located between the Harir-Makuk anticlines in the southwest and the Handren Anticline in the northeast is the longest and highest anticline of this zone. The northwestern plunge of the anticline is in the Gali Ali Bag gorge area. This gorge is constituted a huge carbonate sequence belonging to the Qamchuqa and Bekhme formations. That means that the shield of the Korek Anticline is composed of a carbonate sequence belonging to both the Qamchuqa and Bekhme formations. The Korek anticline is extensively folded, faulted and weathered. The Jurassic and Early Cretaceous formations is exposed in the core of the structure. The marls and limestone of the Shiranish Formation directly overlay the Bekhme Formation. In the southwestern flank and northeast plunge of the Korek anticline the thick limestone beds of the Qamchuqa and Bekhme formations are vertical and locally southward thrusted over the Shiranish Formation. Close to the plunging area in the Khalifan City occurrence of normal faults bordering the northwestern plunge of the Korek Anticline.

![Diagram of Korek, Handren and Bradost anticlines with relation to the pre-tilting normal fault and rawanduz canyon. The below photo explain the Jurassic-Early Cretaceous sequences in the core of Korek anticline.](image)

**Figure 11:** plunging of Korek, Handren and Bradost anticlines with relation to the pre-tilting normal fault and rawanduz canyon. The below photo explain the Jurassic-Early Cretaceous sequences in the core of Korek anticline.
3.10. Harir Anticline

The Harir Anticline is located between the Kamosk and Bekhme anticlines. The shield is constructed of hard massive thick-bedded limestones. From Omer (2006) this carbonate sequence belongs to the Bekhme Formation. The surrounding borders of the anticlines are occupied by the Shiranish Formation. We collected several samples in these latter beds all around the anticline in order to determine the age of the first marly layers covering the carbonate.

In the northeastern flank, near the road to Malakan area, the Shiranish Formation does not directly overlay the massive limestones. However 30-40m thick of well-bedded limestones alternating with very thin-layers of shales and containing chert nodules. All of them provided Kometan Formation. The Shiranish Formation directly overlay these carbonates bed. If these beds are belong to Kometan Formation, explain the shield of Harir Anticline is Qamchuqa Formation not Bekhme Formation.

3.11. Bradost and Shirin

The Bradost Anticline is located between the Bekhme Syncline and the Soran-Mergasor area. The anticline is thrusted over the Tertiary sequences in northeastern flank of Bekhme Syncline (Fig. 12). The anticline is asymmetrical and the core, intensively eroded and thrusted, exhibits the Jurassic formations (Fig. 12).

The Thrust faults in the Bradost anticline related to continuous fold thrust sequence of tectonic deformation with Triassic decollement surfaces and the different orientations of the various folds and thrusts could be related to the shape of the Alpine thrust region (Shihab and Al-Obaidi, 2016). Depend on Csontos et al. (2012) they believe the southernmost elements of thrust belt are the Bekhme and Aqra anticlines. However depend on field visit we identified the southwestern thrust is the Bradost anticline (Fig. 12).

The shield of the Bradost anticline is composed of a thick sequence of massive carbonate including limestones and dolomitic limestones. The lower part of these carbonates belongs to the Qamchuqa Formation and the upper part to the Bekhme Formation because in the Gali Zanta gorge that cuts the northwestern limb of the Bradost Anticline the carbonate sequence is very thick (exceed 600m) and identical to the sequence of the type section of the Bekhme Anticline. In addition the Shiranish Formation above this limestone is Late Campanian in age (Ahmed et al., 2014). That means that the Bekhme syncline, Bradost and Bekhme anticlines belong to the shallow reefal Bekhme platform during the Early Campanian.

The Shirin Anticline is located between Chnara and the Nappe Zone. From the field investigation we conclude that the shield of the Shirin Anticline is Qamchuqa and Bekhme Formations. The Aqra reefal facies not developed in these area. Because the facies of the Shiranish and Tanjero formations are conformably overlay the reefal thick carbonate. This Carbonate is most possibly the Bekhme Formation not Aqra Formation. The plunging of the Shirin and Bradost anticlines are the Gali Zanta Gorge (Fig.12).
Figure 12: Over-thrust of Handren anticline over the Cenozoic formations. The map and figure show the continuous Bekhme-Qamchuqa formations in both Shirin and Bradost anticline in Gali Dore.

3.12. Shakrok Anticline

This structure is located between the Makuk and Nusak anticlines in the northeast and the Merawa Syncline in the southwest. The southeastern limb of the anticline marks by late Cretaceous sequences different from the Kosrat Anticline. Because in this anticline the Late Campanian Shiranish Formation directly overlays the hard reefal facies without any Early Campanian sediments of the Shiranish Formation and Turonian of the Kometan Formation (Ahmed, 2016).

Omer (2006) assumed that the core of the anticline is composed of the carbonates of the Qamchuqa and Balambo formations and the shield of the limestones of the Bekhme Formation, while the Shiranish Formation overlies the Bekhme Formation. The shield and core of the anticline is composed of thick well-bedded limestone and dolomitic limestone, conformably covered by the Shiranish Formation. Between the Saktan and Hiran villages the thickness of the Shiranish Formation suddenly decreases. A possible reason is that a pre-folding NE-striking normal fault was active during the Late Campanian. The fault does not affect the Tanjero and Kolosh formations.

3.13. Safeen Anticline

Safeen Anticline is a long narrow-shaped Anticline located between the Merawa and Smaquli synclines. This Anticline is the key for the interpretation of the basin evolution during the Late Cretaceous. Many previous works deal with the morphology, folding and tectonic evolution of the Safeen Anticline such as Omer (2006), Bretis (2010) and Bretis et al. (2011). Omer (2006) described the stratigraphic succession of the Safeen Anticlines. From the Bottom to the top he defined: (1) massive limestones and dolomitic limestones of the Qamchuqa Formation; (2) 220-450 m of calcareous massive limestones assigned to the Bekhme Formation; (3) 90m of Shiranish Formation with the lower part composed of limestone and the upper part of marls and shales, and (4) clastics of the Tanjero and Kolosh formations. Later Sharbazheri (2008) and Bawa (2008) described from bottom
to top in the southwestern flank of the anticline the following succession: (1) Qamchuqa Formation; (2) 20m of limestones belonging to the Dukan Formation; (3) 25m of limestone containing chert nodules of the Kometan Formation; (4) 45m of marls and marly limestones, and (5) the clastics of the Tanjero and Kolosh formations. Bawa (2008) mentioned that in the northeastern flank of the anticline the marls and marly limestones of the Shiranish Formation directly overlay the limestone beds of the Qamchuqa Formation.

The Shiranish Formation in this place overlay the thick sequence of massive limestones and dolomitic limestones alternating with thin layers of shale. Only the upper part of this sequence crops out in the top of the anticline. Here the Late Campanian beds of the Shiranish Formation unconformably overlays without angular unconformity the upper part of the Qamchuqa Formation.

In the southeastern plunge of the anticline several normal faults affected the area. One conjugate set forms the gorge perpendicular to the axis of the Safeen Anticline close to the southeast plunge. In both sites of the gorge the well-bedded limestone with thin layers of marls lie directly above massive hard limestones and dolomitic limestones. In the southeastern part of the gorge limestones alternating with marls of the Shiranish Formation directly overlays the hard massive limestones and dolomitic limestones possibly belonging to the Qamchuqa Formation.

In the southwestern flank of the Safeen anticline the same Late Cretaceous stratigraphic succession can be observed. Here also the Late Campanian marly layers of the Shiranish Formation overlay the Late Albian-Cenomanian massive limestones of the Qamchuqa Formation. The lower part of the Shiranish Formation lithologically appears as well-bedded light gray limestone, similar to the limestone facies of the Kometan Formation observed in the Hizop area.

Close to the northwestern plunge of the Safeen Anticline we studied extensional fault sets in the Shiranish Formation. The normal fault populations constitute a pre-tilting conjugate system of normal faults. The orientation of the σ3 axis after back-tilting is NNE-SSW (Fig. 13).

In the northeastern flank of the Safeen Anticline in Shaqlawa City the clastic beds of the Kolosh Formation are well exposed in the Shaqlawa City where they are more than 300m thick and the Gercus Formation disconformably overlays the Kolosh Formation. Here the reefal limestones of the Khurmala Formation do not exist, non-deposited or more probably eroded because in the Shaqlawa city a 0.5-1m thick conglomerate layer can be observed between the Kolosh and Gercus formations. The limestone of the Pila Spi Formation forms the southwestern flank of the Merawa Syncline and a monocline.
Figure 13: satellite terrain map of Safeen Anticline and the conjugate pre-tilting normal faults locate in the both plunging side of the anticline.

Figure 14: Geological map of NE-Iraq with trend and names of anticlines (modify from GEOSURV map).
4. Conclusion:

This study coverage the large area of NE of Iraq. The main Anticlines formed during the collision between Eurasia-Arabia Plates. The Main folds oriented NE-SW or ENE-WSW. The Hard brittle thick sequence carbonate of Qamchuqa, Bekhme formations form the shield of the anticlines. These sequence have the direct affect to form large arch resulting of forming huge anticlines. The perpendicular faults on the fold axes especially late Cretaceous faults have great impact to plunging and terminate folding because they act as barrier. Generally the anticlines in northeastern of Iraq formed as results of NE-SW compressional Arabia-Eurasian collision stress. Finally the extract of this research is the new map (Fig.-14) modify from GEOSURV Iraq map that illustrate all the anticline names with fold axes trends.

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