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Stratigraphy, Geometry, and pattern of Imbricated zones, NW Zagros Fold and Thrust Belt in Iraqi Kurdistan Region

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Abstract

The High Folded and Imbricated zones are the formalized name represent the part of the Tectonic sub-division of Iraq and Kurdistan Region of Iraq (KRI). The study of compressional deformation and Stratigraphy are the keys to identify thrust faults structures and define the sequence of thrusting in High Folded and Imbrication zones as a part of Zagros Fold and Thrust Belts. Through this study, we try to describe the compressional thrust faults and stratigraphical unit description. Thrust faults make repetition of the sequences of Jurassic-Triassic Cretaceous sequence over thrust above Cretaceous sequences. In Iran-Iraq border close to Sirwan valley the large thrust faults (Sirwan-Sazan Thrust faults) identify. The fault system makes Triassic formations over-thrust the Valanginian-Albian Balambo Formations. In Balakayati area serious thrust fault exists, which creates twice repetition of Jurassic-Cretaceous formations forming imbrication thrusting system and fault propagation fold. In Bradost-Korek anticlines the Jurassic-Cretaceous formations over-thrust Cenozoic formations. In Kamosk anticline the thrust faults are in the Cretaceous formations. The dimension and the style of the thrust faults are different but generally, most of the decollement layers of the thrusting are the Early Triassic and Middle-Late Jurassic formations. The collection of all these results constrain geological cross-section in Imbricate Zone and restore to obtain the 7.5 km distance of Shortening due to folding and faulting.

Introduction

The Kurdistan-NE Iraq is one of the significant regions for study natural resource and tectonic features because of (1) Kurdistan provinces petroleum-rich area and grow into increase productivity in the future [26]; (2) Kurdistan is part of the Zagros Fault Thrust Belt; (3) the thick sedimentary rock sequences occur and appear as outcrop which is helpful to study the Tectonic evolution and deformation analysis. After 1950 the Iraq and Kurdistan strongly investigated started for petroleum exploration and Geological investigation. Many geological studies developed mainly focusing on stratigraphy and Tectonic [3, 7, 11, 20, 59]. In the last century, many structural cross-sections and structural analyses were done in a different part of the Kurdistan region to give an idea about Subduction and collision [14, 35]. The main aims of this study are to identify thrust faults in the High Folded and Imbricate zones; main detachment layers of the thrusting; detail restoration and balance cross-section in Zagros Folded Zone to determine the shortening length during Subduction and collision.

- **Geological setting of Study area**

Zagros fold and thrust belt is longitudinal belt path through Iran, Iraq, and Turkey as a result of the Eurasia-Arabia collision [11, 62, 68]. Main trend of this belt in Kurdistan (KRI) is NW-SE [2]. Tectonic Features and subdivision of KRI are Low Folded Zone (foothill zone), High Folded Zone, Imbricated Zone and Thrust zone or Suture zone. The Low Folded zone is bounded in the southeast by the Dezful Embayment that develops in southwest Iran, and in the east and northeast by the high anticlines of High folded zone. In the Foothill zone (low folded zone) the thickness of the sedimentary cover is variable. The Precambrian basement may approximately reach the depth of 13km and the Miocene-Pliocene molasses are about 3km thick.

The upper limit of High folded zone is start in the Zakho area at the Turkish border in the northwest and the lower limit is in the Darbendikhan-Halabja area near the Iranian border in the southeast (Fig. 1). The High folded zone is characterized by large and high anticlines cored by Mesozoic formations. This zone covers most of the KRI. It was uplifted during part of the Paleogene. The main folds trend in High Folded zone NW-SE in the eastern part of the range, and E-W in the western part. The average basement beneath the High folded zone is about 8 km deep [35]. The intensity of folding increases northeastward.

The Imbricated zone forms a thin band surrounded by the High folded zone to the southwest and the Thrust Zone to the northeast (Fig. 1). This zone is more intensely folded and faulted than the High folded zone. In fact, except some areas where the Imbricated structures are clearly evidenced, the main structural geometry such as anticlines and synclines styles are very compatible in the Imbricated zone and High folded zone. The Allochthonous units locate in the northeastern Iraqi-KRI. They crop out near the Turkish and Iranian borders. These areas are not easily accessible (Fig. 1). The Suture zone contains outcrops of metamorphic and igneous rocks as well as highly folded and faulted Paleozoic and lower Mesozoic Sedimentary sequences. These unites that belongs to the Nappe are overthrusted on the Arabian plate. The southwestern and western boundaries of the Suture zone with the Imbricated and High folded zones pass from southeast of Sulaimaniyah (Saisadiq and Nalparez area) to the northwest (Mawat and Chwarta area) towards Qaladize, Qandil, Choman and Mergasor areas.

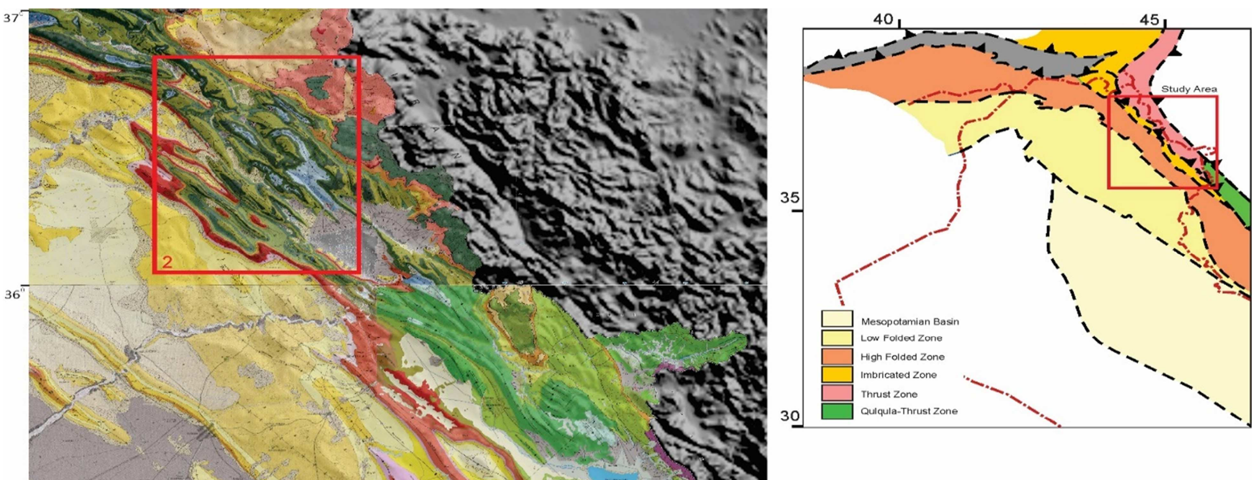

Figure 1: Tectonic subdivision of NW of Zagros Fold and thrust belt in KRI-Iraq (modify from [11]; [35]). The Geological map from Sissakian [60] that shows the location of the study area.

Methodology:

For this research we focus on the (1) outcrops of stratigraphical succession and thrust geometry to identify the thrust faults in different localities in High Folded Zone and Imbricate Zane. Indicating the thrust faults on the map (Google map) and constructing detail cross section to interpret the type of the faulting and construct balanced cross section. The construction of the balanced and restored sections for KRI in High Folded and Imbricate zones. Identification the decollement layers, and in combining information from extensive fieldwork, existing geological maps allow us to conclude the shorting distance. For measure the displacement of thrust fault, we use Pfiffner methods [50]. The method is obtain net slip from displacement graph (relation between Hanging wall and Footwall of the fault).

The Net slip of a fault is the displacement vector connecting originally contiguous points in the hanging wall and footwall. On a fault plane, the offset of planar features measured down dip of the fault is the dip separation. Thus when analyzing a fault on the basis of a cross section, the observed offset is in general an apparent dip separation. Only if cross sections are drawn exactly parallel to the slip direction is the observed apparent dip separation identical to the net slip. Moreover we try to draw the section parallel to the Dip direction.

The steps of Pfiffner method [50] for calculating the thrust displacement (Figure-2) are as below:

1. Draw a cross section as parallel as possible to net slip.
2. Choose an arbitrary origin on the fault trace.
3. Measure the distance of the cutoff points of marker beds from this origin along the fault's trace in the hangingwall.
4. Measure the distances of the equivalent points in the footwall.
5. For each marker, plot the two distances using the footwall (FW) as abscissa and the hangingwall (HW) as ordinate.
6. Points with zero net slip corresponding to tip lines have identical distances on hangingwall and footwall and thus plot on a line inclined at 45° to the axes.

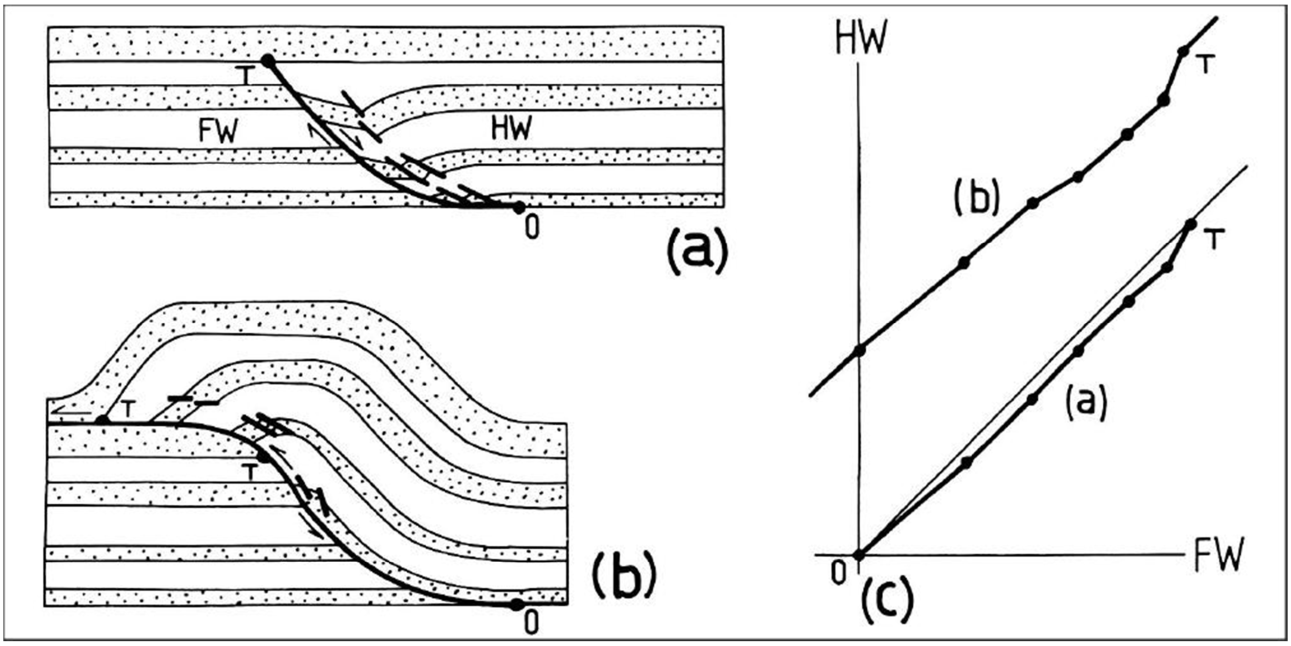

Figure 2: model of reactivated normal fault, a Original state with listric normal fault terminating at T and O. b Fault propagated beyond T and O with reverse sense of slip, c Displacement diagram for a and b [50].

- **Basin evolution of the KRI**

In Kurdistan thick sedimentary sequences “more than 10Km thick” [11] exist that appear as out crops or in the subsurface (Fig. 3) that deposited from Cambrian to Pleistocene with some Hiatuses or Gaps. The Stratigraphic identification such as Lithology, Thickness Contact situation are depends on the fieldwork and previous studies. The basement in the Kurdistan region overlay by a thick sequence of Sedimentary sequences (10-15 Km thick) [11]. These sedimentary sequences deposited from Cambrian to Pleistocene with several abrupt and gaps [11, 14, 20].

- **Paleozoic event**

In the Paleozoic Arabian Plate was part of the long and wide northern passive margin of the Gondwana bordered by the Paleo-Tethys Ocean [16, 43, 56, 61]. The Ordovician Sequence is exposed in northern Kurdistan. They are Khabour Quartzite-Shale and Pirispiki red beds Formations [8, 14] (Fig. 3). In the Upper Ordovician a major Hiatus was identified especially in Iraq and SW Iran. This major Hiatus extend up to the Early Carboniferous [17, 66]). During the Silurian thick marine mudstone and sandstone sequences deposited during the passive subsidence of the proximal parts of Proto-Tethys in southwestern and western Iraq. These sequences might be eroded due to the uplift during the Devonian [10]. The Hercynian event on the Arabian plate started before the Late Carboniferous. According to Ruban [52] a major uplift already occurred during the Devonian associated with a major unconformity in northern Iraq in the Upper Devonian [8, 11, 47]. Then in Iraq shallow marine sediments deposited (Ora, Kaista and Harur formations) (Fig. 3). The Late Carboniferous to Early Permian was a period marked by a major regional unconformity in the Arabian plate. Most of the authors believed that the Neo-Tethys opened in Early Permian [28, 46, 54]. Otherwise some authors assume that the opening is Middle Permian in age [13, 18, 29, 42, 51, 63]). The opening of the Neo-Tethys was followed by a northern drift of the Gondwana blocks [40].

- **Mesozoic event**

In Iraq shallow-marine sediments deposited (Chia Zairi Formation) during the Middle Permian to Early Triassic time (Fig. 3). The Early Triassic depositional facies in the northeastern Arabian Plate are characterized by abundant clastics over most of the region located east of the Rutbah–Khleissia high. This indicates an episode of regression, and The KRI was a part of passive margin of the Neo-Tethys rifts [11]. The KRI and southern Iraq covered by the passive margin in a form of the lagoonal longitudinal basin “Mesopotamian Basin” by the existing of a submerge Bestun platform [11, 35]. In KRI the lagoonal facies of Early Triassic represent Mirgamir, and Beduh Formations [14, 19] (Fig. 3). In the Halabja area whole the Early Triassic Sequence cropped out clearly. During the Middle Triassic extensional tectonics developed associated with the opening of the Neo-Tethys in the northern and eastern margins of the Arabian Plate [25, 35]. These extensional tectonics were associated with the intrusion of alkali basalts in eastern Turkey [49]. In northern Iraq the shallow carbonate facies (dolomite, shale and limestone) of the Geli khana Formation (Fig. 3) represent the middle Triassic [35]. In the Late Triassic the whole stable shelf in Iraq was flooded by the Neo-Tethys Sea [20]. In the Central and northern part (KRI) the carbonates and evaporates of the Kura chine Formation deposited [58]. Otherwise the Shale facies of Baluti Formation conformably overlay the Kura chine formation [20].

In the Early Jurassic the Arabian Plate started to shift toward the north and the rifting was active. The eastern Mediterranean basin opened during this period and creates a new passive margin to the east of the Arabian Plate [69]. Marginal marine clastics, evaporates and shallow water carbonates deposited in the northern Arabian plate until the Mid-Toarcian [35]. In KRI the early Jurassic sedimentation is represented by the Sarki and Sehkanian formations [2, 14]. During the Middle Jurassic the northern and northeastern passive margins of the Arabian Plate were marked by a phase of general sea level rise [30]. Eustatic sea-level fluctuations combined with minor fault movements probable created seaways that allowed deep-marine branches of the Neo-Tethys to penetrate into the Carton, forming intra-shelf basins such as the Gotnia basins [69]. The Gotnia basin was more restricted in the Late Jurassic with deposition of evaporates. In Kurdistan, Central Iraq and Salman zone, the Sargelu, Naokelekan, Gotnia and Barsarin formations were deposited during the Middle-Late Jurassic times [14, 20, 35]. In KRI the Chia Gara Formation (Middle Tithonian-Berriasian), considered as a part of the tectono-stratigraphic Megasequence AP8 as a top of Jurassic to Lower Cretaceous sequence [57]. The Arabian Plate is marked by a unconformity in late Valanginian. The sediments were deposited on open platforms and intra-shelf of the Arabian Plate [69]. Jassim [35] and Aqrawi [11] mentioned a narrow oceanic domain opened in the northeastern edge of the Arabian plate during the late Tithonian. The Qulqula Group started depositing in the trench of Neo-Tethys located in front of the Sanandaj-Sirjan Zone [34]. In KRI the carbonate platform margins aggraded and locally prograded into the Balambo-Garague basin during the Berriasian-Albian times. During Early Cretaceous, the Arabian platform remained a wide stable basin with the shallow shelf dominated by carbonate deposition [41]. In the Hauterivian-Barremian times the southern margin of the Sanandaj-Sirjan Zone was active during the Cretaceous with the northward subduction of the Neo-Tethys oceanic crust [6, 15, 45, 48, 67]. On the opposite margin the oceanic crust of the Neo-Tethys was obducted in the Late Cretaceous onto the Arabian passive continental margin (from Turonian to Campanian) [6]. The Albian–Cenomanian–Turonian interval is one of the most important for the petroleum systems on the Arabian Plate. Large volumes of hydrocarbon are hosted within clastic (mostly Albian) and carbonate (largely Cenomanian–Turonian) reservoirs in Oman, United Arab Emirates, Qatar, Kuwait, Iran and Iraq [32]. During this period the Zagros proto-foreland basin (Zand et al., 2013), with the initial phase of closure of Neo-Tethys. Throughout this period, global sea-level was high, particularly in the Cenomanian–Turonian [30]. The platforms and open-marine carbonate deposited widely in the Arabian Plate [23]. In Kurdistan the thick sequence of shallow carbonate of the Qamchuqa Formation deposited. The micro-continents that separated from the Arabian plate During the Late Cenomanian-Turonian the southern of the Qulqula conglomerates Neo-Tethys deposited and outer-shelf or sub-basinal facies deposited in northern and northeastern Kurdistan [24, 35]. In the Arabian Plate the Turonian is variably preserved and often absent. The unconformable contact with the overlying Coniacian layers marks a time gap of approximately 4 Ma [23]. During the Upper Turonian-Lower Campanian period deposited mixed siliciclastic-carbonate of the middle shelf to sub-basinal depositional system [9, 53].

The late Cretaceous in Kurdistan can be divided into three phases: pre-drowning (Qamchuqa Formation), syn-drowning or transitional (Gulneri Shale and Dokan limestone formations), and post drowning phases (Kometan Formation). Generally in Kurdistan there is a gap between the Turonian and the upper Campanian deposits [20, 24]. The convergence between Arabia and Eurasia (central Iran) initiated in the Early Cretaceous and accelerated during the Late Cretaceous [15, 55, 64, 67]. This convergence was consumed in the northeastward subduction of Neo-Tethys beneath the eastern Eurasian. In the Late Cretaceous a collision between an island arc and the northern Arabian passive margin occurred, initiating the emplacement the Ophiolite onto the northern Arabian margin from Cyprus in the west and Oman in the east [44].

Narrow foreland basin restricted between the ophiolitic thrust sheets in the northeast and the hinterland of Arabian Platform in southwest. The obducted ophiolites and radiolarites sequences were elevated above sea level during the Campanian-Maastrichtian [6], and then eroded and re-deposited in the foredeep basin as flyschs. These flyschs are known as Tanjero Formation in Iraq and Amiran Formation in Iran. In Northern KRI the Shiranish and Tanjero formations were deposited in the narrow foreland basin. The Tanjero Formation is considered an early foreland basin. The Tanjero Formation combined tectonically with the underlying Shiranish Formation in a single basin, which is sometimes called initial Zagros Foreland Basin. The bulge morphology of the foreland basin have direct effect to change the Shiranish and Tanjero formations to reefal carbonate of Bekhme and Aqra formation. The heterogeneous of the forebulge from northwest to south are the direct factors to appear these facies change [70].

- **Cenozoic event**

During the Paleocene-Eocene times the Arabian Plate was still part of the African Plate. This later continued to move northwards with respect to Eurasia Plate during this period. The Africa-Eurasia convergence was mainly absorbed in the Subduction zone beneath southern Eurasia. For Jassim and Goff [35] the final existing of the Paleocene-Eocene calc-alkaline basic and intermediate rocks with local igneous intrusions in Turkey, NE Iraq and SW Iran conclude that during Paleocene-Eocene was the time of final closure of the Neo-Tethys Ocean. During the Paleocene-Eocene times emerged lands and elevated mountain ranges grew in the northeastern part due to the propagation of the obduction. These uplifted areas were the major source of siliciclastic sediments that supplied the marine basin of Kolosh during the Paleocene and Gercus Formation during the Paleocene-Eocene. In the northeastern edge of the Arabian Plate in Kurdistan-Iraq, the Suwais Red Beds were deposited in a molasse basin [11]. In the High Folded Zone the reefal carbonate facies of the Sinjar and Khurmala formations were deposited besides the Kolosh Formation during the Late Paleocene-Early Eocene. In the Early Eocene time, the Naopurdan Unit was deposited in a forearc basin in the far northeast part of Kurdistan. At the end of the Late Eocene time the Neo-Tethys was probably closed [35] or in its final closure stage. The suture of Arabia-Central Iran along the Main Zagros Thrust was completed in the Oligocene [65].

The Gercus Formation in KRI area was deposited in an outer back erg constituted by an alluvial-fan system, stream flow, and sheetflood deposits associated with deflation lags/desert pavements, aeolian sandstones, and caliches [33]. The Pila Spi and Avana formations deposited on the hanging wall of the Zagros Front fault [11]. During the Oligocene time, the Arabian Plate migrated toward the northeast in response to the start of sea-floor spreading in the Gulf of Aden [11]. The Oligocene units in Iraq are collectively known as the Kirkuk Group. In the Oligocene the NE Kurdistan (Chemchamal Butmah Subzone) was a high land area. Consequently the Oligocene succession does not exist, and an unconformity is recorded between the upper Oligocene and the lower Miocene [14].

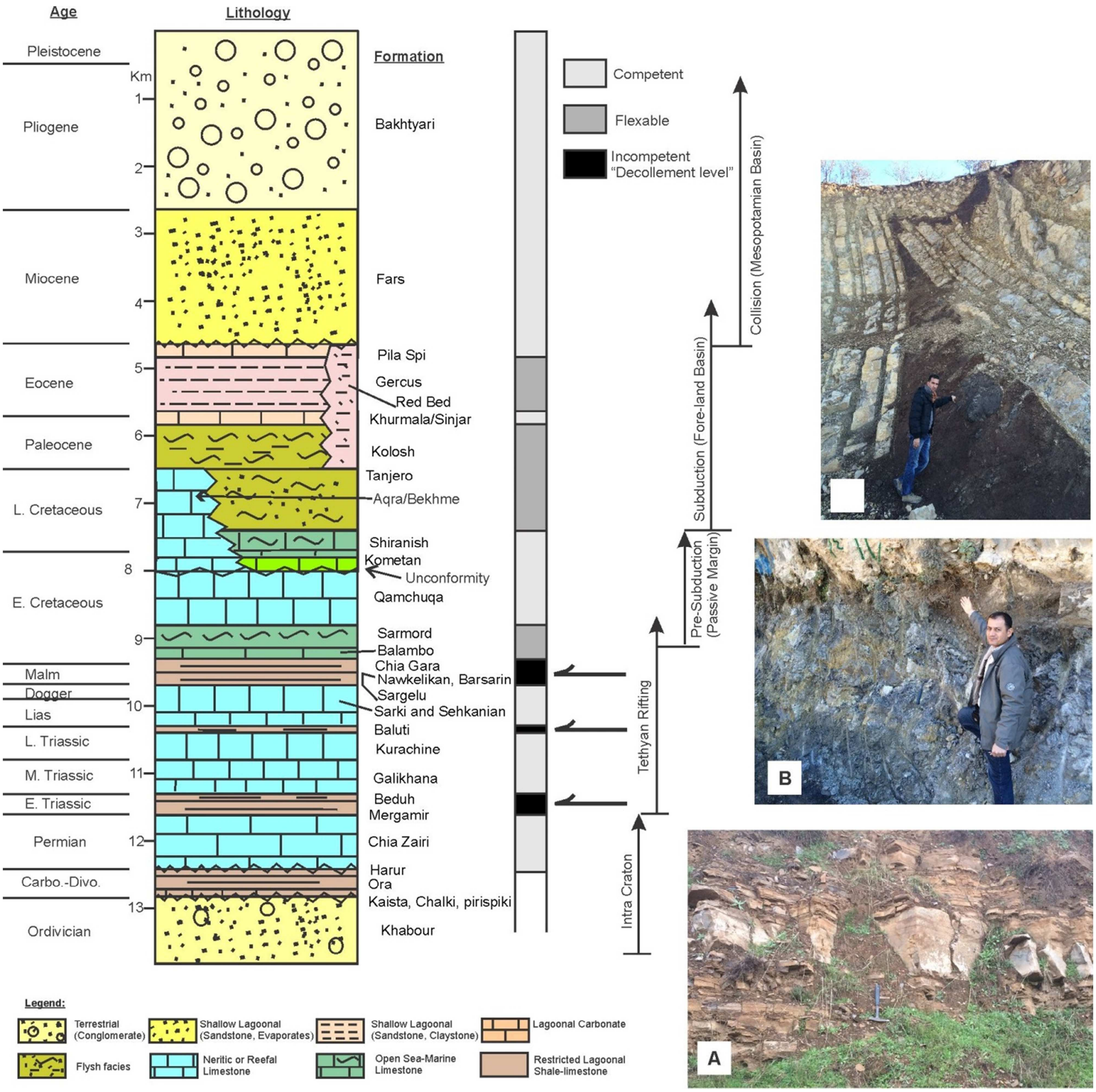

Figure 3: Stratigraphic profile of the KRI in Imbricate and High Folded Zone. The Stratigraphic Sketch combined with main detachments, competent and incompetent sequences. The right part of the figure shows the evolution event of Zagros fold and thrust belt. Information of age and Thickness of Some formations take from [11, 14, 20, 35]. In the right photo is A. alternation limestone and Shale of Mirga Mir Fm. (Sirwan Vally), B. Shale Zone in the upper part of Baluti Fm. and C. alternation of Shale and limestone of Chia Gara Fm. (Halabja area).

The Mesopotamian basin that developed in the early Middle Miocene was narrow. Shallow facies deposited in a lagoon (Jeribe Formation) during this period. In the Middle-Late Miocene the compression started again along the suture zone [35]. A new foreland basin formed in northeastern Iraq and southwestern Iran, where the sediments of the Lower Fars and Upper Fars formations deposited. In the Late Miocene the sea-floor spreading in the Red Sea and Gulf of Aden was active. The final closure of the Neo-Tethys was not completed until the Miocene when Central Iran collided with the northeast Arabian margin [44]. Probably this compression formed the folded zone in Iraq [11].

In the Pliocene the Arabian Plate and Sanandaj-Sirjan zone was sutured. During the Pliocene the compression resulted in progradation of large scale alluvial fans into the foreland basin (Bakhtiary Formation). During this period the fluvial lacustrine sediments covered most of the northeast and eastern part of the Arabian Plate. During the Pleistocene the Kurdistan and Iraq was an emerged land with erosion and the development of the Tigris and Euphrates river systems [11].

- **Stratigraphy of Study area**

Through Detail field work has been done in the imbricate zone to describe the physical properties, thickness and stratigraphic position of the Triassic, Jurassic and Cretaceous formations as below:

Mirga Mir Formation (Early Triassic)

The formation belongs to the Early Triassic period specifically the age is Werfenian [14]. In the study area (Halabja-Sirwan valley) this Formation exposed as a small scarp area on the border of Iraq-Iran near Sazan village (Fig. 4). The Mirga Mir Formation is the oldest sequence that crops out in the Halabja area. Only the upper part of the Mirga Mir Formation emerges in this area as well as the lower part is submerged by the water of Sirwan stream. The lithofacies of the formation clearly recognize in the field because the sequence is shale domain the Mirga Mir Formation located below the red marker beds of the formation. Lithofacies descriptions of the Mirga Mir Formation from Bottom (that mean bottom of the sequence above the Sirwan water not the actual bottom of the formation) were can be divided into these lithofacies: Thick bedded limestone, Marl and Limestone (5m thick), Shale and Limestone (50m thick), Detrital limestone (5m thick).

Beduh Formation (Early Triassic)

The formation first designated by *Wetzel* in 1950 [14]. The upper part near the contact with Geli Khana Formation shows clay terrigenous sediments and bioturbation, indicate shallowing or sub-aerial exposures. The lithofacies of the Beduh Formation is a good marker in the field to recognize the Triassic sequences; because the reddish color in outcrop is very obviously seen. The Beduh Formation is known as Beduh shale Formation due to highly shale content but in Halabja area the formation contents high amount of clay than shale. Thickness of Beduh Formation in Sirwan Valley is about 39-40m thick. Depend on the field description we can divide the formation into three lithofacies from Bottom to top: Limestone-shale lithofacies (15m thick), Limestone-Sandstone-Shale (10m thick) and Limestone-Clay-Shale (15m thick).

Geli Khana Formation (Middle Triassic)

The formation was highly deformed with existing of the recumbent fold and compression faults (Fig. 4-A). We describe lithology and measuring the thickness of the formation in the Rashaw valley. Depend on the lithofacies types in this section we subdivided Geli Khana Formation into three parts: Dolomite-Limestone-Shale *(Lower Member* 120-150m thick) (Fig. 4-A), Limestone contains chert-Shale *(Middle Member* 110-130m thick) (Fig. 4-B) and Limestone-Shale-Marl *(Upper Member* 230-250 m thick) (Fig. 4-C).

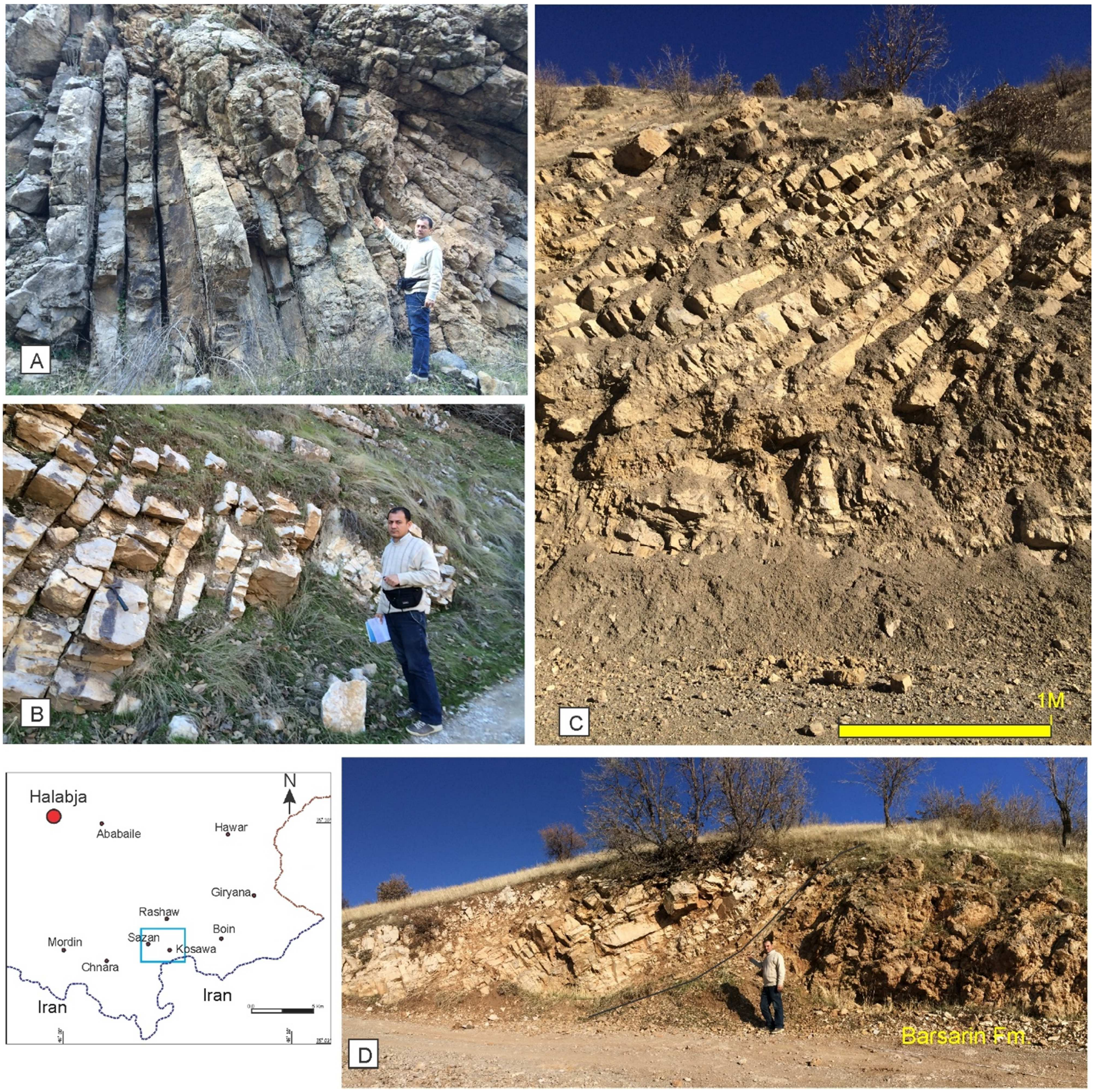

Figure 4: Carbonate/Shale beds of Triassic-Jurassic formations in Halabja area. A- Geli Khana Fm. lower part B- Geli Khana Fm. middle part C. Geli Khana Fm. upper part D. Contact between Chia Gara and Barsarin Formations.

Kura Chine (Late Triassic)

The thickness of the formation in Sirwan Valley is about 350 to 375m thick. Lithofacies is generally homogenous from the lower to the upper part of the formation that composed of dark brown to black limestone and dolomitic limestone (Fig. 5-A) with occur of very thin papery shale between them. The limestone and dolomitic limestone in some localities exposed as thick well bedded but in some localities they are massive that construct high cliffs. Rarely the formation contain a chert band inside the limestone beds. There are thin layers of gypsum as rhythmic with limestone located in the upper part of the formation. However, the thickness of Kura Chine Formation are huge but in our opinion the formation cannot consider to being a good reservoir because of the high dolomitization and low fracturation.

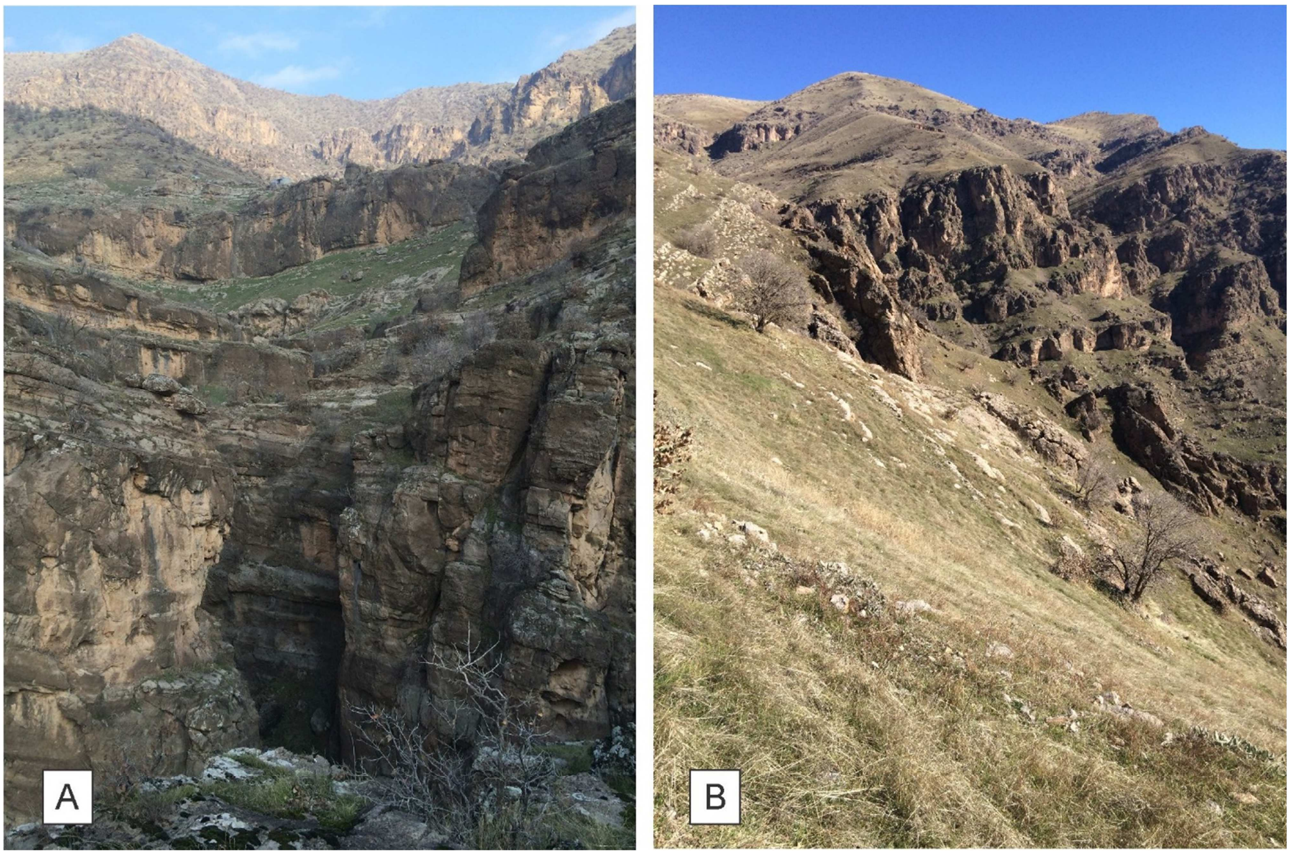

Figure 5: Massive Thick sequence of reefal limestone A. Kura Chine Formation (Halabja area-Boin Village), B. Sarki and Sehkaniyan formations.

Baluti Formation (Late Triassic)

In the study area (SE Halabja) the outcrop of Baluti Formation where easily recognize in the field and can be a key marker bed for Triassic Sequences (Fig. 3). The total thickness is about 39-40 meters. The lithofacies of Baluti Formation is mostly homogenous that composed of an alternation of marl-shale with detrital silicify limestone and dolomitic limestone. The marker layers the occur in the upper part of Baluti Formation are 1-2 m thick of dark gray to black shale with contains high organic matter (Fig. 3). Lithofacies of Baluti Formation in Halabja area most possibly not similar to the type section because the formation is not completely composed of shale, however the marl and silicify carbonate constrain a large amount of the formation.

Sarki and Sehkaniyan formations (Early Jurassic)

In the study area is difficult to distinguish the contact between Sarki and Sehkaniyan formations. Because both formations are lithologically carbonates (Dolomite and limestone). Therefore we study and measure the Sarki and Sehkaniyan formations together as one package. Sarki Formation composed of dark brown massive to thick well bedded dolomitic limestone with contain chert and occur of gypsum as patch or spot in the lower part of Sarki Formation. Sehkaniyan Formation mostly composed of hard gray dolomite and dolomitic limestone rarely alternated with thin layer of shale (Fig. 5.B). The diagenesis especially dolomitization extremely affected the carbonates of Sehkaniyan Formation. Diagenesis lead increases the hardness and compatibility of the cement in the carbonates. Total thickness of this carbonate sequences in the Bafri Miri section is about 630m thick. The lower part of this section (Sarki Formation) is highly dolomitization, less fracturing, and no any oil seepage.

Sargelu Formation (Middle Jurassic)

This Formation is composed of bituminous to dolomitic limestones intercalated with brownish papery shales with black chert bands in the upper part (Fig. 5-F). The depositional environment of the Sargelu Formation fluctuated between a quiet pelagic reducing basin (which was frequently deep enough to approach the CCD surface) and shallower basin [12]. The Sargelu Formation is classified as the prior source rocks for the main Cretaceous reservoirs. Based on the paleontology (especially *Posidonia* assemblage) the Age of the Sargelu Formation is Uppermost Liassic at the base and Bathonian at the top [14, 20]). The thickness of the Sargelu Formation is about 50m.

Naokelekan Formation (Late Jurassic)

It is composed of laminated argillaceous bituminous limestone and dolomitic limestone with coal horizons. The Formation deposited in an euxinic environment [35]. The age of the Formation is Middle Callovian-Early Kimmeridgian (Howarth, 1964 in [35]). The total thickness is approximately 20-30m. The uppermost unit is composed of mottled beds.

Barsarin Formation (Late Jurassic)

The lithology of the Barsarin Formation composed of dolomitic limestone with contains fluffy texture and brecciated limestone. The formation is characterized by occuring stromatolites in the limestone. The Thickness of the formation in Soran area about 20m thick but in Halabja area we found only 8m thick carbonate of Barsarin Formation overlay by Chia Gara Formation (Fig. 4-D). The lithology of this 8m is composed of fluffy and brecciated limestone with occur dissolve Stromatolitic feature. The brecciated intra slumping grain of carbonate related to the dissolution of anhydrite. The carbonate facies and anhydrite indicate that the formation deposited in the margin of the Gotnia lagoonal basin.

Chia Gara Formation (Late Jurassic-Early Berriasian)

Generally the lithology of the Chia Gara Formation is uniform throughout Iraq it is composed of two basic rocks thin bedded limestone and calcareous shale [20]. The age of the formation is Late Tithonian in the base and Early Berriasian in the top [2]. In the study area the formation is clearly identified in the outcrops by cutting the road of Halabja-Chnara and Balakaiaty area (Fig. 3 and 6-E). Chia Gara Formation in these two locations is composed of thin bedded limestone and calcareous shale, with exist of phacoid structure. These phacoid formed due to compression stress during the collision [4]. The thickness of the Chia Gara Formation is about 130 to 140m thick.

Balambo Formation (Berriasian-Baremian)

The Balambo Formation was first described by Wetzel in 1947 [14] in the Sirwan Valley in the imbricate zone, Balambo Formation represented only by the lower part (Berriasian –Valanginian) [5]. The thickness of the Formation are variable from area to another, in Halabja area exceed 500m otherwise in Balakaiaty area about 100m thick. The Formation composed of rhythmic alternation of well bedded fine grain limestone with shaly/marl with occur of Chert nodules. The age of Balambo Formation in Halabja area is possibly Berriasian-Turonian because all the Qamchuqa, Sarmord and Kometan laterally change to Balambo Formation.

Qamchuqa Formation (Aptian-Albian)

The Qamchuqa Formation in the in the Gali Rawanduz composed of thick coarse crystalline dolomites, detrital limestones, argillaceous limestone and massive limestone units (Fig. 5). The Qamchuqa Formation passes eastwards to the Upper Balambo Formation in Surdash - Azmar anticlines due to large extensional faults during Aptian-Albian [5]. The fossil content allows to firmly establishing the age of the Lower Qamchuqa Formation is as Hauterivian till Aptian [20], and the age of the Upper Qamchuqa Formation is the Albian [14, 22]. The thickness of the formation is about 800m of carbonate reefal facies (Fig. 5). This formation form the shield of the main anticlines in the Imbricated and high Folded Zone that competent behavior of the Qamchuqa Formation and is the main factor to Form large broad anticlines such as Harir, Korek and Bradost anticlines [1].

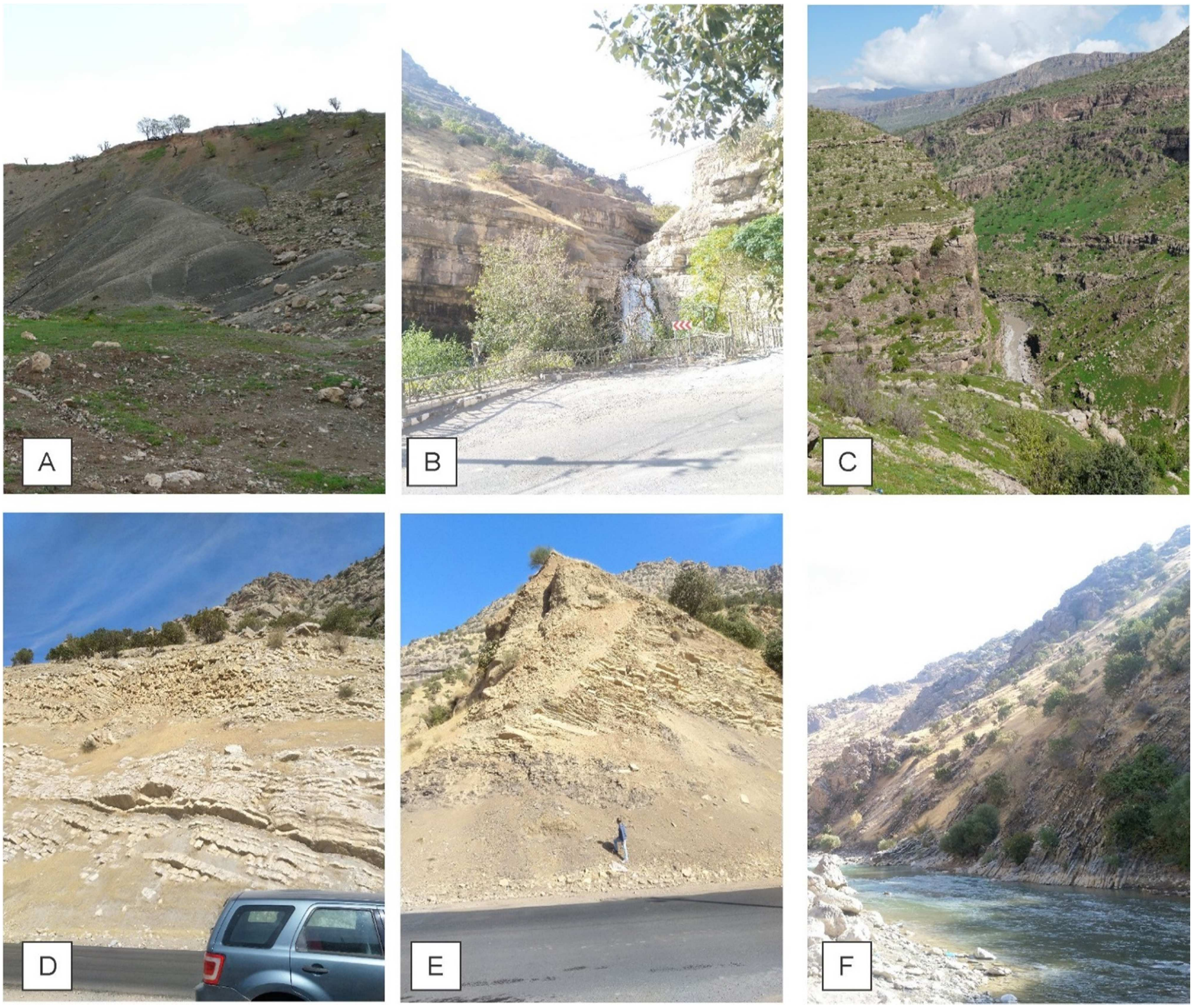

Figure 6: field photo shows the lithofacies of the Cretaceous Formation in Soran area A. Tanjero Fm. (Dar Alsalam Village) B. Bekhme Fm. (Gali Ali Bug waterfall) C. Bekhme-Qamchuqa Fm.s (Rawanduz Gorge) D. Sarmord Fm. (Tanun Anticline) E. Chia Gara Fm. (Choman road) F. Sargelu Fm. (Choman road).

Kometan Formation (Turonian)

The Formation composed of well bedded fine grained globigerinal limestone containing chert nodules, with existing Stylolites parallel to the layers. The thickness of the Kometan Formation is about 120m in Soran area. Kometan Formation disappears in the Cretaceous Sequence in those areas with exist Bekhme Formation. Most possibly the Formation lateral equivalent to Bekhme Formation [36]. Bradost and Bekhme anticlines. The lower contact of the Kometan Formation with the Qamchuqa is unconformable and the upper contact is unconformable with the Shiranish Formation. The age of the Kometan Formation determined from the foraminifera species, is Turonian at the base and perhaps Santonian at the top [14].

Shiranish Formation (Campanian)

The Shiranish formation is the most widespread in all parts of Kurdistan. The lithology of formation composed of an alternation of white gray limestone alternated with blue marls. The thickness of the Shiranish Formation is variable from area to another, in Dukan 280m, Zozic anticline 200m, Balakaiaty areas 300m, however in Bakhme anticlines is 48m thick. The Formation if above the Kometan Formation the age is Early to Late Campanian but if above Bekhme Formation The age is only Late Campanian [5].

Bekhme Formation (Late Cretaceous)

The Bekhme Formation was first introduced by *Wetzel* (1950). The type section is in the Bekhme Gorge in the core of the Bekhme anticline cuts by the Greater Zab River [14]. The thickness of the Bekhme Formation in the Study area about 300m thick. The formation comprises of dolomite, massive limestones, detrital limestones and basal conglomerate in the lower part. The total thicknessis about 300m in Gali Ali bug gorge (Fig. 5-B). The Formation well developed in the front of Balakaiaty Thrust faults toward western in Handren, Bradost, Bekhme and Harir anticlines.

Tanjero Formation (Campanian-Maastrichtian)

The Tanjero Formation was first described by Dunnington in 1952 [14]. The type section is near the Halabja town. In the Soran area the formation is composed of alternation of marl and sandstone. In Balakaiaty area (Dar-Alsalam village) the main characteristic of the Tanjero Formation is the occurrence of thick reefal limestone body in the upper part of the formation. This body is about 10 to 50m thick. The Tanjero formation in the Dar-Alsalam section is 1035m thick. Generally the thickness of the formation about 1000m, however in the area with existing Bekhme Formation the thickness reduce to 50m thick The age of the Tanjero Formation is Upper Campanian- Maastrichtian [35, 37-39].

- Sirwan-Sazan Thrust zone

Shallow carbonate sequences of Triassic-Jurassic formations crop out in Southeast of Halabja area (Fig. 7). Most of the sequences are domain and restricted facies (Marl and Shale). Recognize, distinguish and identify lower and upper boundaries of each Triassic-Jurassic formations are difficult. During extensive field work our team was able to find and describe most of Triassic-Jurassic formations. For identifying these successions, we concentrate on some distinguish lithofacies and bed markers. From the oldest (Early Triassic) to youngest (Tithonian) we identify Triassic-Jurassic formations as follow: Mirga Mir, Beduh, Geli Khana, Kurra Chine, Baluti, Sarki, Sehkaniyan (possibly Sargelu and Naokelekan occur), Barsarin and Chia Gara formations.

Through this research we identified two main thrust faults and pointed on the map (Fig. 7), except the main Zagros Thrust Zone (the Nappe). The identification is due to intensive field work in the area. These compressional thrust faults formed and deformed the Triassic sequences and repeated twist time (Fig. 7). These thrust faults formed due to NE-SW compressional stress during the Arabia-Eurasia collision. The main motive for choosing and studying these faults is that they are the only area in Zagros Fold and Thrust belt which, the thrusts are in the Triassic sequences out crops.

The thrust pattern partially parallel to the Zagros thrust fault (Fig. 7). The decollement layers of the thrust faults is incompetent layers of Mirga Mir and Beduh formations. We can deduce that the Mirga Mir and Beduh formations are main decollement thrust in most Imbricated Zone in sub surface.

The thrust displacement are not regular, the displacement is shrinkage in the floor and growths along the roof and the Triassic sequence generally slightly inclined. In Sirwan-Sazan zone serial imbrications along thrust faults branching off the detachment. The thrust faults maintain narrowly set ranges in the angle of intersecting the bedding. Bed-discordant dip segments are ramps, and bed-parallel segments are flats [21]. Dip variations in Sirwan-Sazan thrust faults are fault bends. The Up-dip displacement of layered series along dip-segmented thrust faults generates fault-bend folds but they are eroded and only a flank of folding remain (Fig. 7).

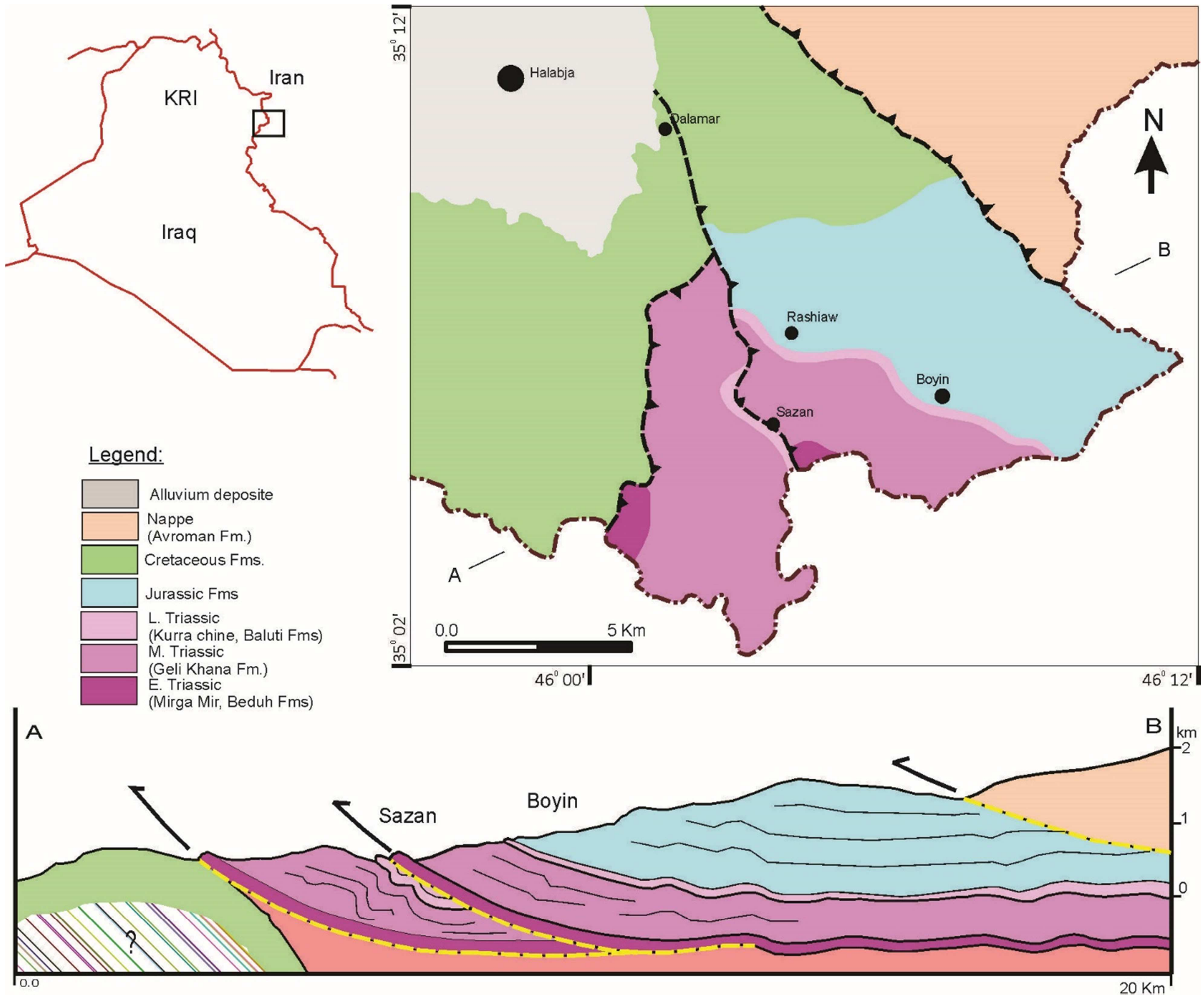

Figure 7: thrust zone in Halabja-Sirwan valley area. The map is geological map of the area and the section show the NE-SW sequence and the thrust faults. The section explains the Mirga Mir Formation as a detachment layer of the thrusting. The northeastern thrust is the main Zagros Thrust belt (Avroman Formation).

- Balakaiaty Thrust Zone

On the Soran-Choman main road the out crops of Cretaceous-Jurassic sequence repeated triple time. Its interesting geological phenomenon. The repetition of these sequence due to two main thrust faults in imbricated Zone. These thrusts identified and plot on Geological map by Sissakian [60]. However, through this study we intensively study the Balakaiaty are in the view of Stratigraphy and structural. Two thrust faults exist in the area except the main thrust Nappe of Zagros belt (Fig.8).

These thrust faults are deep-root thrust fault. From the field work we plotted the trace of these thrust fault on the new geological map we able to draw schematic cross section of the thrust zone (Fig. 8). The cross section in Figure-8 show the thrust zone are Imbricate thrust system type and each thrust fault is fault propagation fold, because the both Zozik and Tanun anticline formed during the development of thrust faults.

The Jurassic-Cretaceous formations cropped out in ZoziK, Tanun anticlines and thrust faults are facies shale/carbonate of Sargelu, Naokelekan, Barsarin and Chia Gara formations (Fig. 6-E and F, Fig.8). The decollement layers of the thrusting are Sargelu Formation, which evidence one of the main decollement layer in KRI (Fig. 3). The Cretaceous successions in the Handren Anticline differ from Zozik and Tanun anticlines. In Handren Anticline the Cretaceous succession from the oldest to younger are: Balambo, Sarmord, Qamchuqa, Bekhme, Shiranish and Tanjero formations, as well as in imbricated thrust zone the succession are: Balambo, Sarmord, Qamchuqa, Kometan, Shiranish, Tanjero and Aqra formations.

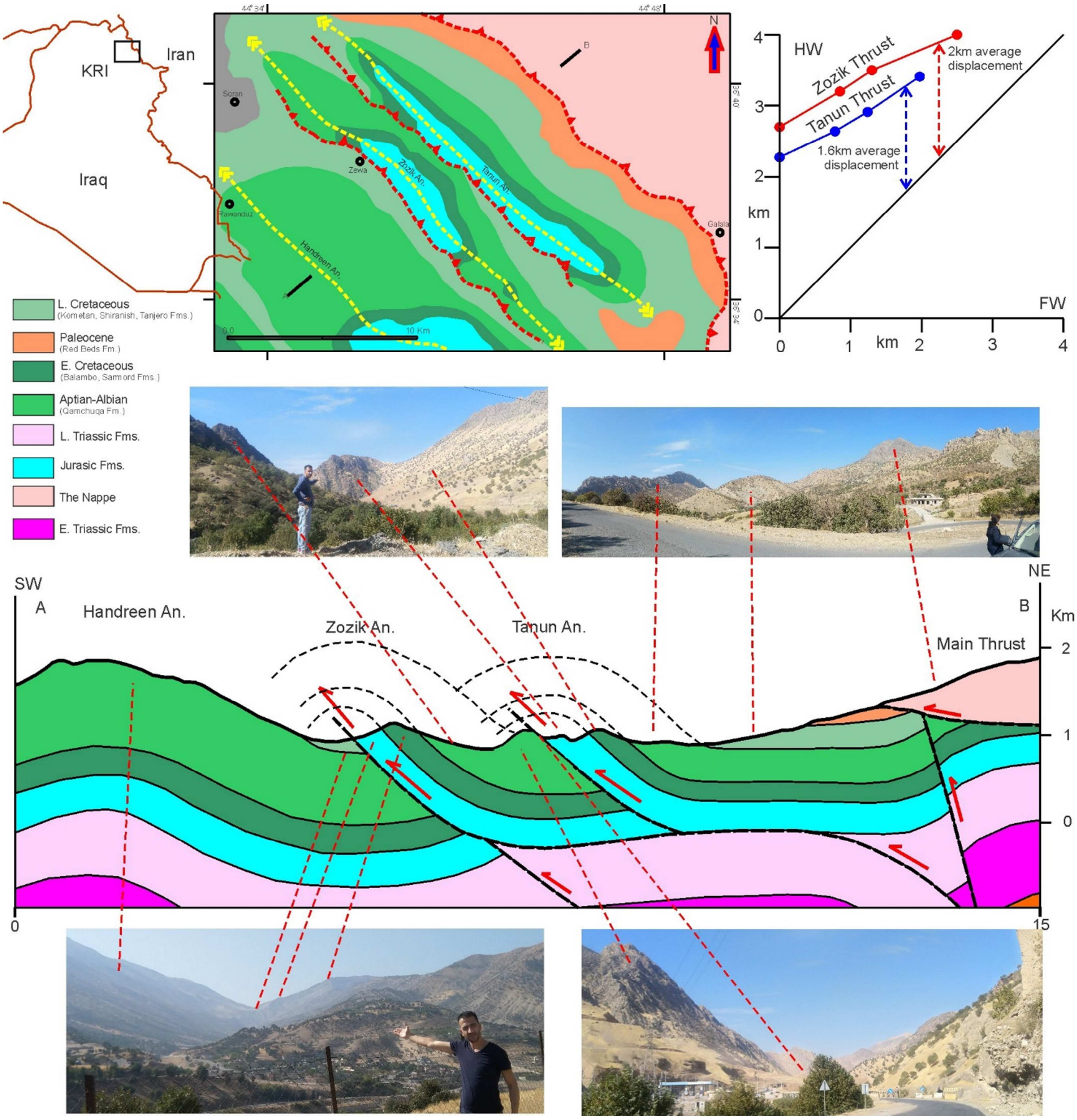

Figure 8: Thrust zone in the Balakaiaty area. The above map is geological map of the area and the section is NE-SW section of the area show the imbrication thrust faults and fault propagation fold (Tanun and Zozic anticlines), that thrust over the Handren anticline with Jurassic-Cretaceous repeated twice time. The north eastern part is the main Zagros thrust belt (the Nappe). The graph is the estimate displacement of the thrusting using method Pfiffner [50] the HW is Hanging-wall and FW is Foot-wall.

- **Bradost-Korek Thrust fault**

This fault is located in the front of south-western flanks of Bradost and Korek anticlines in the High Folded Zone (Fig. 9). The surface length of the fault is more than 40 km and it's clearly appeared in the Google map. Depend on the *Omer* (2005) the Bradost Anticline effected by three main thrust faults, however in our field investigation we found only one thrust Fault. The Bradost-Korek thrust fault NE dipping that overthrust Cretaceous-Jurassic sequence over Palaeocene-Eocene sequences (Fig. 9). The thrust is progressed with the formation of Bradost and Korek anticlines because the Bekhme Formation bedding are nearly vertical in the front of hanging wall of the thrust fault (Fig. 9) and the fold axis of the Bradost Anticline shows a recumbent fold. The cross section of figure-9 explain the Bradost and Korek anticlines are formed due to the thrust, evidence the type of the thrust is fault propagation fold. The trend of Bradost-Korek thrust fault has the same trend of Balakaiaty thrust faults and Zagros Thrust belt (Nappe). Indicate these thrusts are formed during the compression stress of Arabia-Eurasia collision. The Jurassic sequence cropped out detachment layers of the Bradost-Korek thrust fault are Early Triassic formations (Fig. 9)

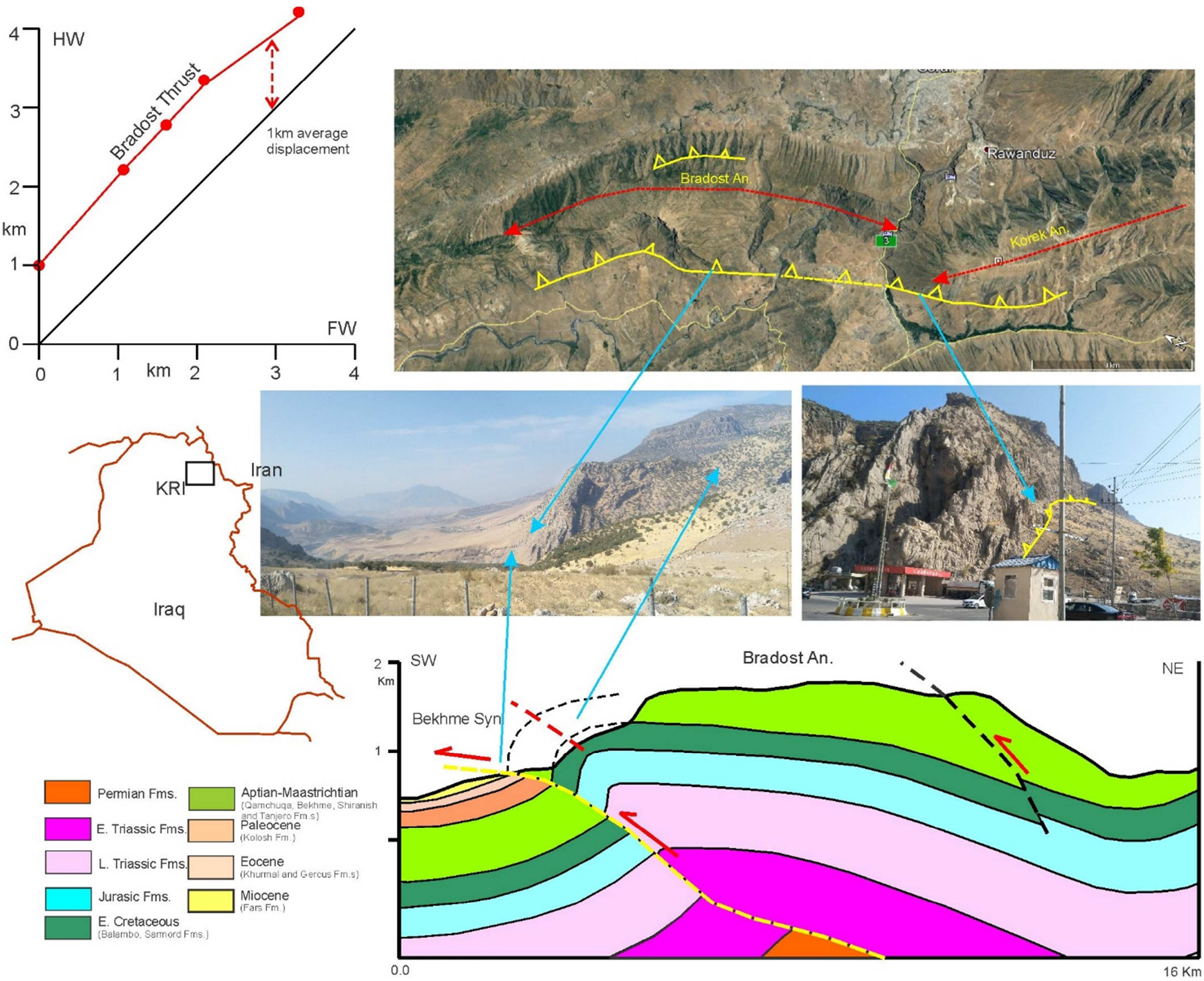

Figure 9: Bradost-Korek thrust fault. The map above is the Google map shows the Bradost and Korek anticlines and thrust trend in the surface. The cross section (NE-SW trend) perpendicular to the Bradost Anticline show the fault propagation thrust faults. The cretaceous-Jurassic sequences in the hanging wall overthrust Palaeocene-Eocene formations. The two photos show the over thrusting Bekhme-Qamchuqa formations over Palaeocene-Eocene sequences. The graph is the estimate displacement of the thrusting using method Pfiffner [50].

- Kamosk Thrust fault

The area is in the High Folded Zone in the front of Imbricated zone. Serial anticlines arranged parallel to each other Shakrok, Kamosk and Pelewan anticlines (Fig. 10). The surface trace of the Kamosk Thrust fault also parallel to these anticlines. The compression highly affected the area such as disappear Shiranish Formation due to strike-slip faults [2]. The area is also a transitional zone between lateral facies change of Bekhme-Kometan formations [36]. The dip direction of the fault is NE, with the same orientation of all thrust faults and the dip angle of the thrust is high. The trace of the fault in the surface is in the front of Kamosk Anticline indicate the folding and thrusting form in the same event of compression stress. The displacement of the Kamosk thrust fault is low if compared to Bradost-Korek and Balakaiaty thrust faults. However, the type is similar to the Bradost-Korek thrust fault because the Kamosk is fault propagation fold (Fig. 10).

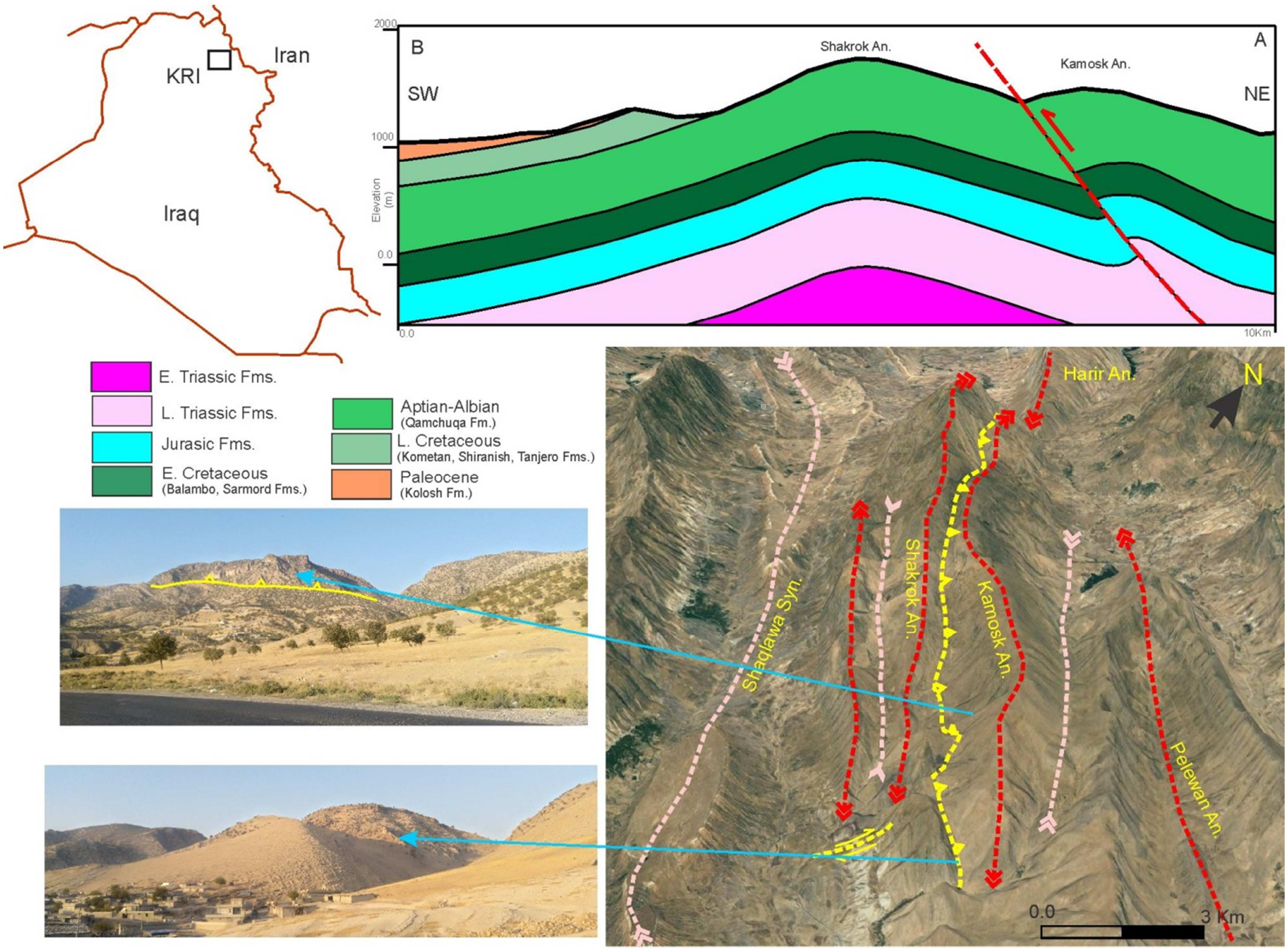

Figure 10: Kamosk thrust fault. The map in the right is the Google map shows the Shakrok, Kamosk and Pelewan anticlines and thrust trends on the surface. The cross section (NE-SW trend) perpendicular to the Kamost-Shakrok anticlines show the fault propagation fold. The cretaceous-Jurassic sequences in the hanging wall overthrust Palaeocene-Eocene formations. The two photos show the over thrusting Bekhme-Qamchuqa formations over Palaeocene-Eocene sequences.

- **Shortening distance in the Imbrication Zone:**

Many Authors made balance and restoration cross section for KRI with using different cross section trends such as [27, 31]. All these authors complete restoration for KRI to explain the historical events and basin evolution during Subduction, Obduction and collision. However, we prepare the restoration just to found the horizontal shortening strain happened during the Collision that produce the Imbrication Zone. Nevertheless, we create detail cross sections NE-SW trend that started from the root of the Nappe to the border of Imbrication and High Folded zones. In Figure 11 shows the trend of the cross section, with the total distance of the section is 36km length.

Figure 11.A is detail assumption cross section of the area resulted from field data, Google map and GEOSURV map [60]. For found the shortening distance we must restoration the section and restore the stratigraphic bedding to horizontal situation. The Shortening in Imbrication zone is due to NE-SW stress Arabia-Eurasian collision. Main deformation happens in the area are thrusting and folding. However, we need to measure all the thrusting displacement and repair folding strata to straight horizontal layers.

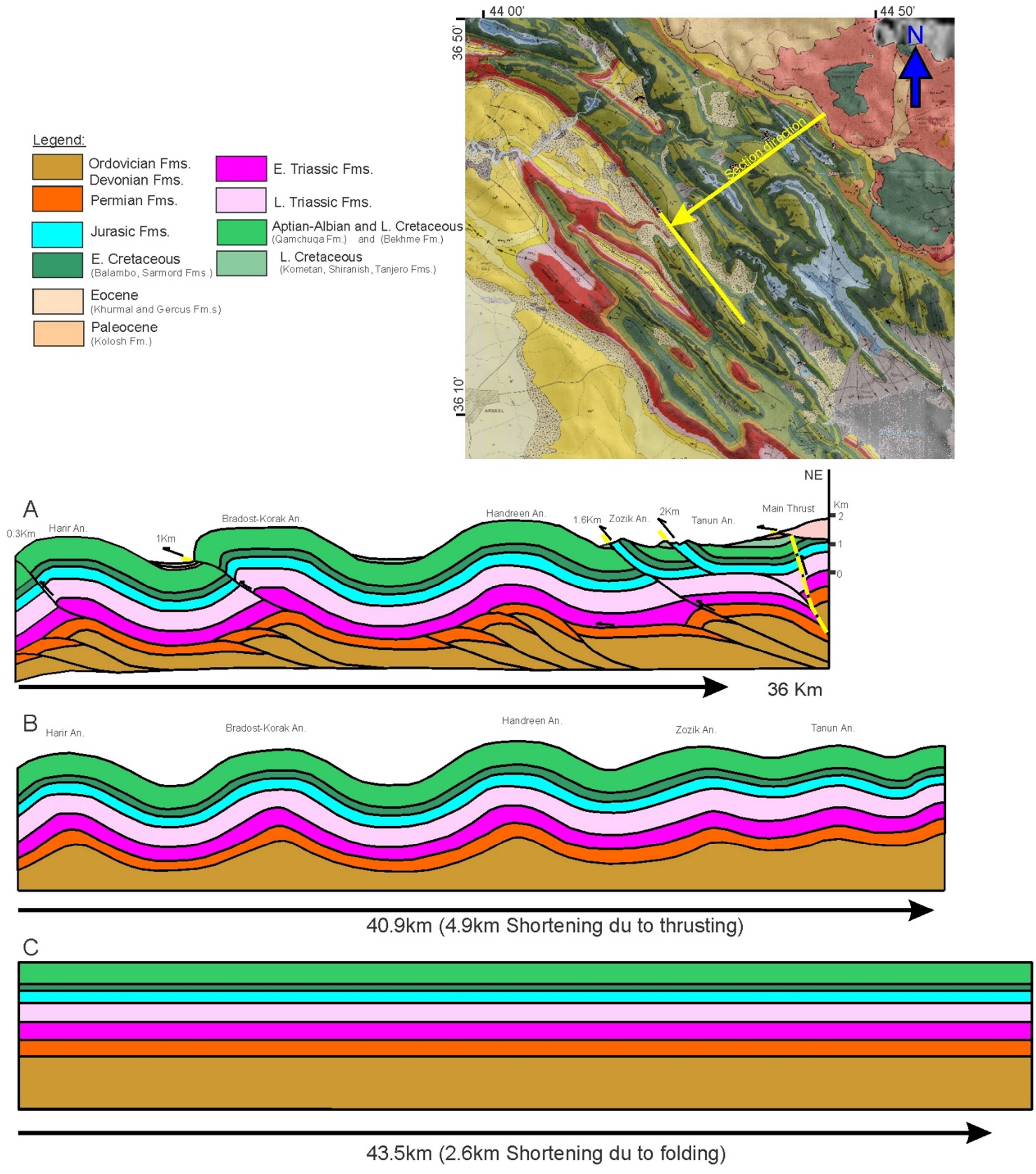

Fig. 11: Restoration cross section of NE-SW trend in Imbricate Zone. A. Assumption detail cross-section consist of all thrust fault and folding in the area. B. the cross-section restores only the thrust faults (note: we extract the Cenozoic sequence because we haven't sufficient data for this periods) and result is 4.9 km shortening due to thrusting. C. restore the beds to before collision and result is 2.6 km shortening due to folding. The map above is direction of cross-section [60].

For measure the displacement of thrust fault, we use Pfiffner methods [50]. We found the net slip of Balakaiaty, Bradost-Korek and Kamosk thrusts. The Balakaiaty thrust faults are composed of imbricate fault propagation fold (Zozik and Tanun thrust faults) and the displacements are large. The displacement of Zozik fault thrust is about 2km and 1.6 km for the Tanun Thrust fault (Fig. 8). However we measure the thrust displacement for Bradost-Korek and Kamosk with using the Pfiffner methods. The result of Bradost-Korek is 1km displacement (Fig. 9) and 0.3km for Kamosk thrust fault. Moreover the total shortening in Imbrication zone due to thrusting is 4.9 km (Fig. 11-B). To found the total shortening in Imbrication Zone we need to restore all the folding (anticlines and Synclines) and repair the bedding to horizontal situation. This procedure need extensive data collection of inclination of the bedding but in general we restore the section and the result is 2.6Km shortening obtained (Fig. 11-C). Finally, the percentage of shortening happen in the Imbrication Zone through the Arabia-Eurasia Collision is 7.5km.

Conclusion

Detail study of Imbricated Zone in the view of Stratigraphy and structural pattern especially thrust faults. For first time large thrust faults in Halabja-Sirwan area identify with repeat Triassic sequence twice time. Early Triassic and Middle-Late Jurassic incompetent layers are act as detachment layers for all thrust faults in KRI. The behaviors and pattern of the thrust faults are similar in Imbricate Zone, characterizes by imbricate thrust fault and fault propagation fold thrust system types. Extensive shortening in Imbricate Zone are due to the Thrusts fault system with total shortening about 4.9 km length. The designated area as Imbricate Zone in Tectonic Subdivision of Iraq is correctly selected because the area hold all property of imbrication zone.

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