



Relation between Walsh and Kolosh Formations and geology of their equivalent metamorphosed greywackes and arenites in Sulaimaniyah Governorate, Kurdistan Region, Northeast Iraq

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ABSTRACT

The previous studies documented the tectonics setting, petrology, and geochemistry of the Penjween area (with Shalair Valley) before 70 years and considered it as an area of igneous rocks, and tectonically composed of three thrust sheets. According to these studies, the area includes two main igneous rock units: The Penjween Ophiolite Complex comprised of gabbro, peridotite, and granitoid intrusions at the south. The second unit is Kata Rash Volcanic rocks (Kata Rash conglomerate of the present study) which are located in the north and northeast and comprised of mafic, intermediate and felsic volcanic rocks. The present study disagrees with the previous documentation of these rocks and changed the claimed Kata Rash Volcanic Rocks and Penjween Ophiolite to metamorphosed conglomerates and coarse sandstones of the proximal facies that belong to metamorphosed sediments of Walsh Formation (or Group) that was deposited in a large Paleocene Foreland Basin. The Walsh Group and Kolosh Formation (as unmetamorphosed, coarse and fine sandstones or greywackes) were deposited as deep basin distal facies in the basin while Kata Rash Conglomerate belongs to coastal facies. All the above five units are deposited by turbidity currents during Paleocene-Eocene and they correlated, in the present study, stratigraphically along the basin paleodip from the present location of the Shalair valley to the south of Sulaymaniyah City. The Naopurdan Formation is recognized for the first time in the Penjween area and its facies and foraminifera are documented and correlated with Sinjar Formation. The above siliciclastic sediments were derived from volcanic source areas inside Iran and depending on the field, lab, and evaluations of the previous studies, the present study drew sedimentary stratigraphic columns and cross-sections for the Penjween and Sulaimanyiah areas and correlated their units along 100 km across the latter two areas. The correlation linked the Kolosh Formation with stratigraphic units of the Penjween area for the first-time supposing deposition during Paleocene-Eocene and sharing the same foreland basin which is aided by the first record of the occurrence of the Kolosh Formation in Chwarta by nanofossils and petrography.

العلاقة بين تكويني والاش وكولوش والجيولوجية ما يعادلها من صخوررملية متحولة من نوعي

جرباواكي و وأرنايت في محافظة السليمانية، إقليم كردستان، شمال شرق العراق

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المخلص

وثقت الدراسات السابقة الوضع التكتوني و نوعية الصخور ، والجيوكيمياء منطقة بنجوين (مع وادي شلير) قبل 70 عامًا واعتبرتها منطقة من الصخور النارية، وتتكون تكتونيًا من ثلاث الصفائح الدفعية. وفقًا لهذه الدراسات ، تشتمل المنطقة على وحدتين رئيسيتين للصخور النارية: وهي معقد بنجوين اوفيو لايتي الذي يتألف من الجابرو والبريدوتايت والجرانيت في الجنوب. الوحدة الثانية هي صخور كاتاراش البركانية (مدملكات كاتاراش في الدراسة الحالية) والتي تقع في الشمال والشمال الشرقي وتتكون من صخور البركانية القاعدية و الحامضية و الوسطية. لا تتفق الدراسة الحالية مع التوثيق السابق لهذه الصخور و غيرت صخور كاتاراش البركانية ومعقد بنجوين اوفيو لايتي إلى مدملكات متحولة وأحجار رملية خشنة متحولة ذات السحنات قريبة من الساحل. هذه الصخور تنتمي إلى راسب متحولة لتكويني (أو مجموعتا) والاش وكولوش التي ترسبت في حوض فورلاندي ذو عمر باليوسيني. ترسبت مجموعة والاش على شكل أحجار رملية غير متجانسة وخشنة اوانعامة ذات لون رمادي(جرباواكي) و ترسبا كسحنات عميقةبعيدة عن الساحل بينما ترسبت مدملكات كاتاراش في منطقة الساحل. جميع الوحدات الخمس المذكورة الاعلاه ترسبت بواسطة التيارات العكرة خلال العصر الباليوسيني - الإيوسيني وتم مضاهاتهن في الدراسة الحالية طبقًا في حوض واحدعلى طول انحدار الحوض القديم من الموقع الحالي لوادي شلير إلى جنوب مدينة السليمانية. تم التعرف على تكوين ناوبردان لأول مرة في منطقة بنجوين وتم توثيق سحناته و محتواه من المتحجرات و تم مضاهاته مع تكوين سنجان نقلت هذه الرسوبيات السليسبكلاستيكية من مصدر بركاني في مناطق داخل إيران. رسمت الدراسة الحالية الاعمدة الطباقية والمقاطع العرضية لمنطقة بنجوين و السليمانية وربطت وحداتها على طول 100 كم و هذا اعتمادًا على العمل الحقلّي والمختبري وتقييمات الدراسات السابقة. ربطت العلاقة بين تكوين كولوش والوحدات الطباقية لمنطقة بنجوين لأول مرة بافتراض ترسبها خلال العصر الباليوسيني-الإيوسيني وتقاسم نفس حوض فورلاندي. و ما ساعد هذا الاستنتاج هو التسجيل تكوين كولوش في منطقة جوارتا لأول مرة بواسطة الأحافير النانوية و نوعية الصخور.

1. Introduction

The Penjween area, including Shalair Valley, is a part of northeast Iraq in the Kurdistan Region and it has a shape of a crocodile head that elongates toward the northeast inside Iran for about 40 km (Fig.1). Tectonically, it is the outer part of the Sanadij-Sirjan Zone (SSZ) and it was under intense geological studies since the fifties of the past century. The earlier studies such as Mc Carthy (1956) [1], and Site Investigations Co. TD., 1960[2], are concerned with Iron ore exploration in the area. These two studies found small lenticular iron ore southeast of Penjween town inside the claimed Penjween Ophiolite Complex.

The previous studies focused on the tectonic, geochemistry, and petrology of the ophiolite and volcanic rocks. Thus, Owesis (1984) [3] drew the first tectonic model of the Penjween area consisting of three thrust sheets (Fig.2a). While Al-Qayim et al. (2012) [4], specified the four thrust sheets, namely ophiolite, serpentinite, Walash, and Qulqula sheets (Fig.2b). Later Ali et al. (2014) [5], added Avroman-Besuton sheets to the area (Fig.2c).

According to the aforementioned authors, the Main Zagros Thrust Fault is passing directly at the southwestern boundary of the Penjween area on which the ophiolite and radiolarite are obducted on the northeastern Passive Margin of the Arabian Plate. They added that the area is a part of the Zagros Suture Zone along which continental parts of the Iranian and Arabian plates collided in addition to thrusting, deformation, metamorphism, and igneous intrusion. The timing of the colliding is controversial since it occurred during Late Cretaceous (Berberian and King, 1981[6], Mohajjel, and Fergusson, 2000) [7], Eocene (Numan, 1997[8], and 2001) [9], late Eocene (Lawa et al.,2013) [10], Oligocene (Koop and Stoneley, 1982) [11], and Early Miocene (Sherkati, and Letouzey, 2004) [12], middle Miocene (Ali et al., 2017[13] and 2019) [14]. The same controversy is true for the obduction of ophiolite and radiolarite on

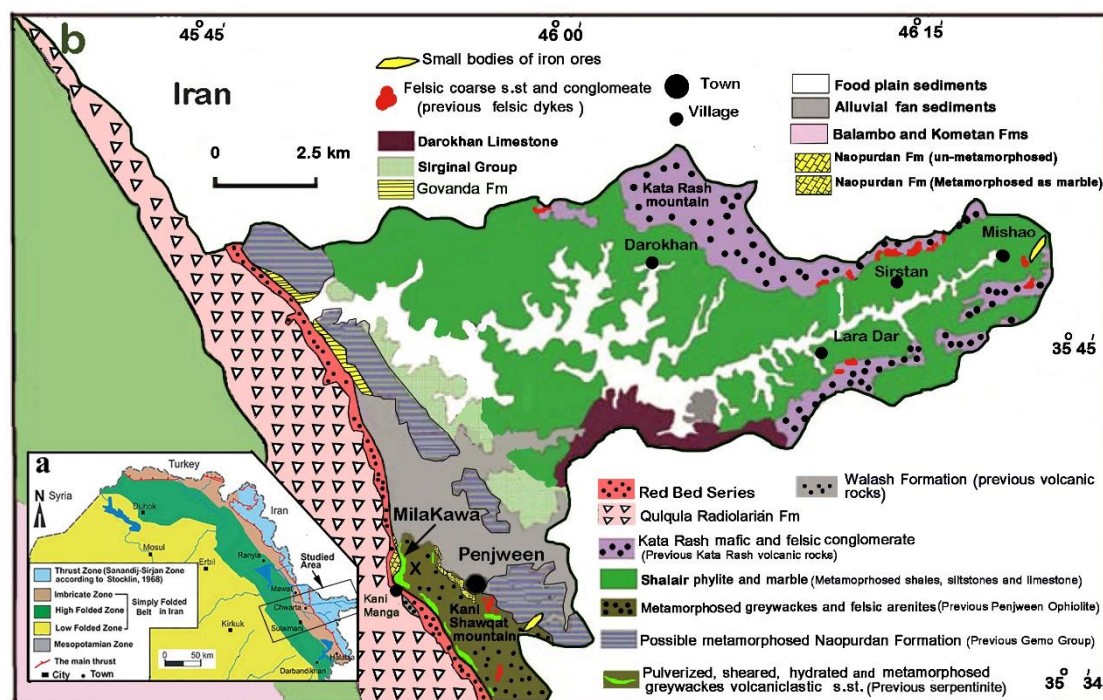


Figure1: **a)** A location map shows the northern Iraq tectonic zones (Jassim and Goff, 2006) [15], **b)** geological map of the Penjween area (modified from Ma, 2008 [1], and Karo, 2015) [19], on which the previous igneous rocks are changed to sedimentary ones.

Arabian Platform Margin. It occurred in Aptian- Cenomanian (Numan, 2001) [9], Coniacian–Campanian (Al-Qayim et al., 2012, p.151[4]), Campanian and Maastrichtian (Jassim and Goff, 2006) [15], Maastrichtian (Ali et al. (2013, p.122) [16], Turonian (Lawa et al., 2013, p.73[10], and Ali et al., 2019) [14], in Oligocene (Zadeh et al., 2017) [17]. The aim of the present study is a reconsideration of the previous conclusions and to introduce an updated revision of the geology of the Penjween area in terms of petrography, stratigraphy, and tectonics aspects to simplify the previously suggested complex geology of the area.

2. Materials and Methods

We achieved sedimentological observations, measurements and later interpretations in tens of locations on the outcrops of the both claimed Kata Rash Volcanic Rocks and the Penjween Ophiolite Complex. At each location, our study recorded clast shape, possible mineralogies, grain caliber, sorting, beds-laminae thickness, erosional and depositional structures, bed shape, beds attitudes, and lateral beds extent. When uncertainty arises in a certain bed or succession, the boundary condition is inspected for hundreds of meters for lateral changes and to find more features. We took suitable samples for thin section studies in the Penjween ophiolite, Naopurdan, Walash, and Kolosh Formations. The XRD is used for mineralogical correlation between the two latter formations with each other and with claimed ophiolite rocks. The entire previous studies are reviewed and their field features and evidence are revisited to see whether contradict the results of our study or not. The nannofossil study is applied for proving the occurrence of the Kolosh Formation in the Chwarta-Mawat areas. The geochemical analyses are not performed due to two factors; the first is the availability of tens of this type of study on ophiolite and volcanic rocks of Iraq and Iran. The second is the belief of the present authors who think, according to field evidences, that the rock constituents of the Penjween area consist of metamorphosed mafic or felsic sedimentary rocks. This belief is based on the commonness of sedimentary structures and textures in which the rock clasts (volcanic lithic clasts and crystalloclasts) were transported from remote source areas inside Iran to the present locations. Therefore, the geochemistry and zircon aging reveal the attitudes of the source areas, not the properties of the rocks in the Penjween area and their depositional time.

The present study principally depended on fieldwork during which achieved the boundary condition and sedimentary structures inspection of the rocks on the scale of millimeters to several hundreds of kilometers. Frankly, the present study followed the reverse modeling for developing the stratigraphy and origin of the rocks

of the Penjween area by which new models and tectonic settings are established depending on our collected data without considering previous outputs. However, the present study benefited from published documents of the previous studies for analyzing the claimed Ophiolite and volcanic rocks of Northern Iraq.

3. Results and discussion

3.1. Kata Rash Volcanic Rock Group

According to available data, Buday (1980) [20], and Jassim et al. (1983) [21], applied the name “Kata Rash Volcanic Rock Group” to volcanic rocks in the Shalair valley as part of the Penjween area while Buday and Jassim, (1987[22]) applied the “Shalair Valley volcanicity” for the same rocks. According to these authors, the group consists prevalently of volcanic rocks such as andesite, dacites, rhyodacites, rhyolite, and basaltoid rocks in addition to pyroclastics. They further added that more basic varieties are prevalent at the bottom of the group, whereas in the middle and at the top more acidic varieties are frequent.

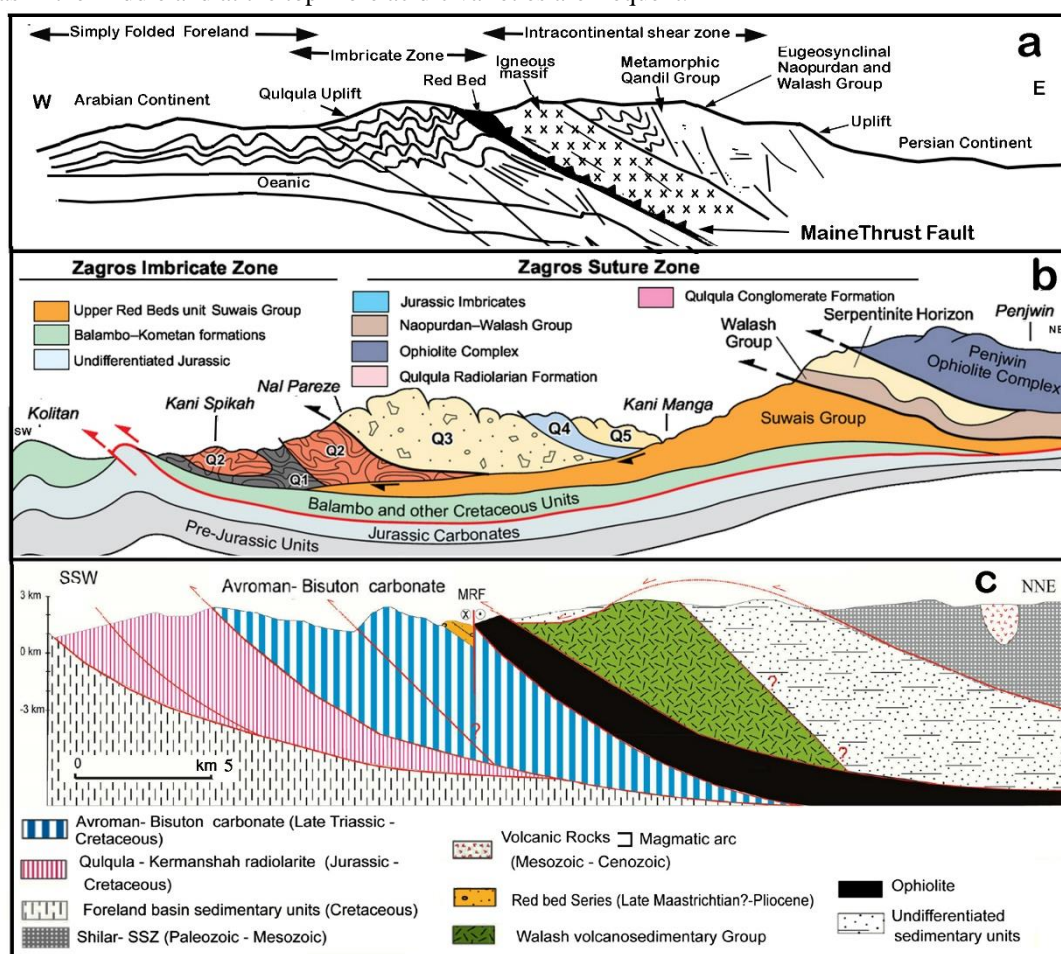


Figure 2: Previous tectonic settings, considered the Penjween area as several thrust sheets (allochthonous sheets) of different rocks of Igneous, metamorphic and sedimentary, a) Owesis (1984) [3], b) Al-Qayim et al. (2012) [4], and c) Ali et al. (2014) [5].

These claimed volcanic rocks are located on the mountains that surround the Shalair valley on its northern and southern sides. They referred to the intrusion of some granodiorites, granites, and quartz diorite dykes into the group. The group is named after the Kata Rash Mountain on the northern side of the Valley (Fig.1). Numan (1997) [8], (Fig.3a), Jasim and Goff (2006[15]), and Abdulzahra et al. (2018) [23] (Fig.3b) attributed these rocks to volcanic arc developed on the SSZ continental block while Ali et al. (2019) [14], interpreted the Kata–Rash volcanic rocks as an intra-oceanic Cretaceous (108 Ma) arc fragment in the Neo-Tethys Ocean. Abdzahra et al., (2018) [23] found mafic (relatively) gravel-sized enclaves inside the granitoid bodies inside Kata Rash volcanic rocks, and they are called microgranules enclaves (Fig.4a and b). In Iranian SSZ, a few kilometers to the east of the Shalair valley, Azizi and Stern (2019[24], their fig. 2) found similar enclaves and attributed them to magma

mixing. In the southeast part of the latter area, Mahmoudi et al. (2011) [25] found the same type of mafic enclaves, which they called “angular mafic xenoliths”.

In contrast to the above ideas, the present study did not find any indications of volcanic and plutonic igneous rocks in the valley and on its mountainsides. The claimed mafic and felsic igneous rocks are metamorphosed mafic and felsic conglomerates and coarse sandstone which include gravels and granules conglomerate in addition to badly sorted pebbly sandstones that are derived from a remote volcanic arc and not related to their present locations. Although the micro-granules in the conglomerate are several centimeters in diameter (the gravel-sized clasts), the previous studies suggested them as micro-granule enclaves. These gravels have sharp boundaries and are bounded by sands, and silt-size matrix. Whereas any signals of assimilation, magma mixing, or altered boundaries are not observable around them. The clasts are different in lithologies and their long axes are arranged parallel to the layer boundaries (bedding plane) which indicated deposition by water currents.

Our fieldwork did not find volcanic rocks in all areas of the claimed Kata Rash, this is true for volcanic flow, cones, vent (root), edifices, and caldera. Karim and Abioui (2021) [26] found a similar conglomerate in several places on Avroman Mountain between Qulqula and Avroman Formations and directly on the conglomerate of the Tanjero Formation. Karim and Ghafur (2021) [27] recorded the same type of conglomerate inside the Walsh Formation (group) 100 m above the Shiranish Formation in the Mawat area (1 km south of the Gabra village). Many claimed felsic dykes (granitoid or dioritic dykes) are recorded by Ali et al. (2017) [28], Abdulzahra and Hadi (2017) [29], and Abdulzahra, et al. (2019) [23] in and around the Kata Rash group (present conglomerate) but when inspected in the present study; their presence as a dyke is not proved since they cut nothing and not associated with mineralization, contact metamorphism, and digitation into country rocks. Both the claimed volcanic rocks and dykes occur as lenticular bodies, meters to tens of meters thick which represent channelized conglomerate and badly sorted pebbly sandstone that resemble more or less the volcanic cones.

The previous works supposed the occurrence of these claimed volcanic rocks and their felsic dykes as intrusions and extrusion on the phyllite rocks. However, quartz grains revealed their sedimentary origin by manifesting the clastic (detrital) appearance in the form of roundness and wearing of boundaries and edges during transportation (Fig.4). Moreover, the occurrences of phyllite gravel-sized clasts (enclaves) are not observable in the present study or in the previous ones. Therefore, there are no signals for attribution of these gravel-sized clasts to magma mixing or xenoliths (enclaves) (Fig.5).

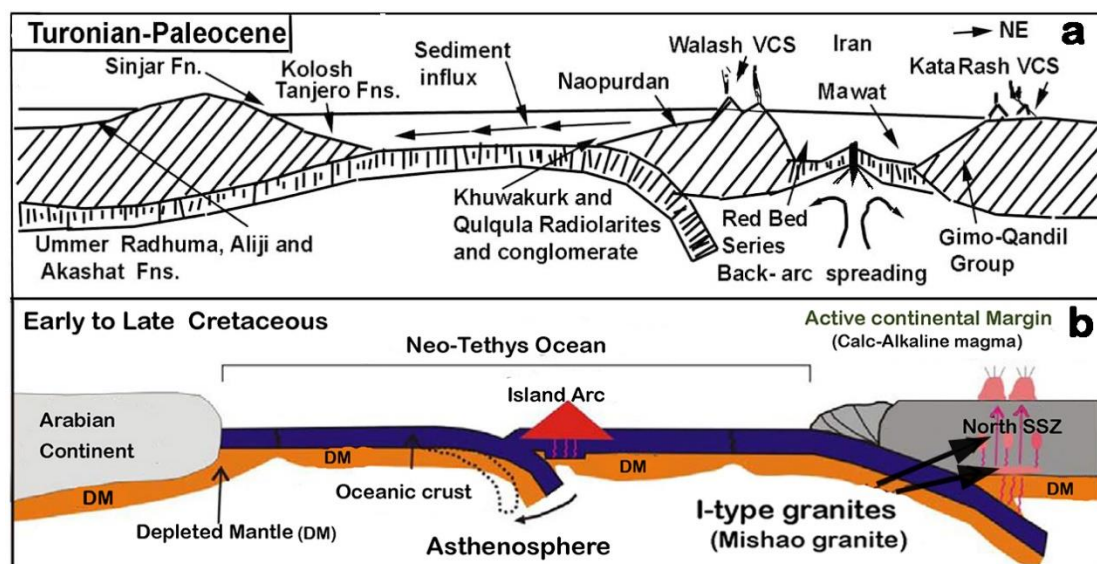


Figure 3: Previous tectonic model of Iran and Iraq during the late Cretaceous in which the Kata Rash and Walsh Groups were assumed as an island arc by a) Numan (1997) [8] and b) Abdulzahra et al. (2018) [23] (see Mishao granite)

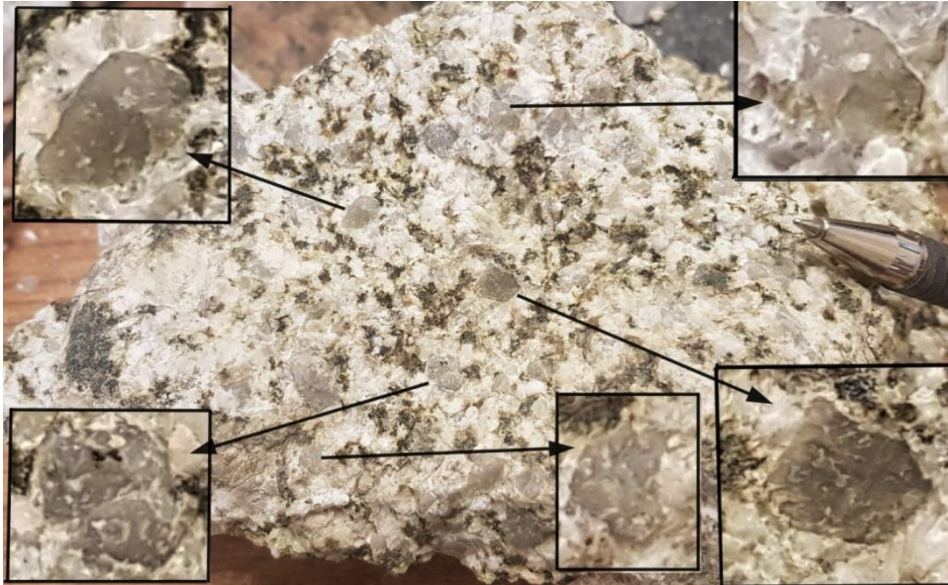


Figure 4: Detrital quartz grain in quartz feldspar, hornblende arenite (or microconglomerate) previous diorite in Shalair valley (2km southeast of Mishao village)

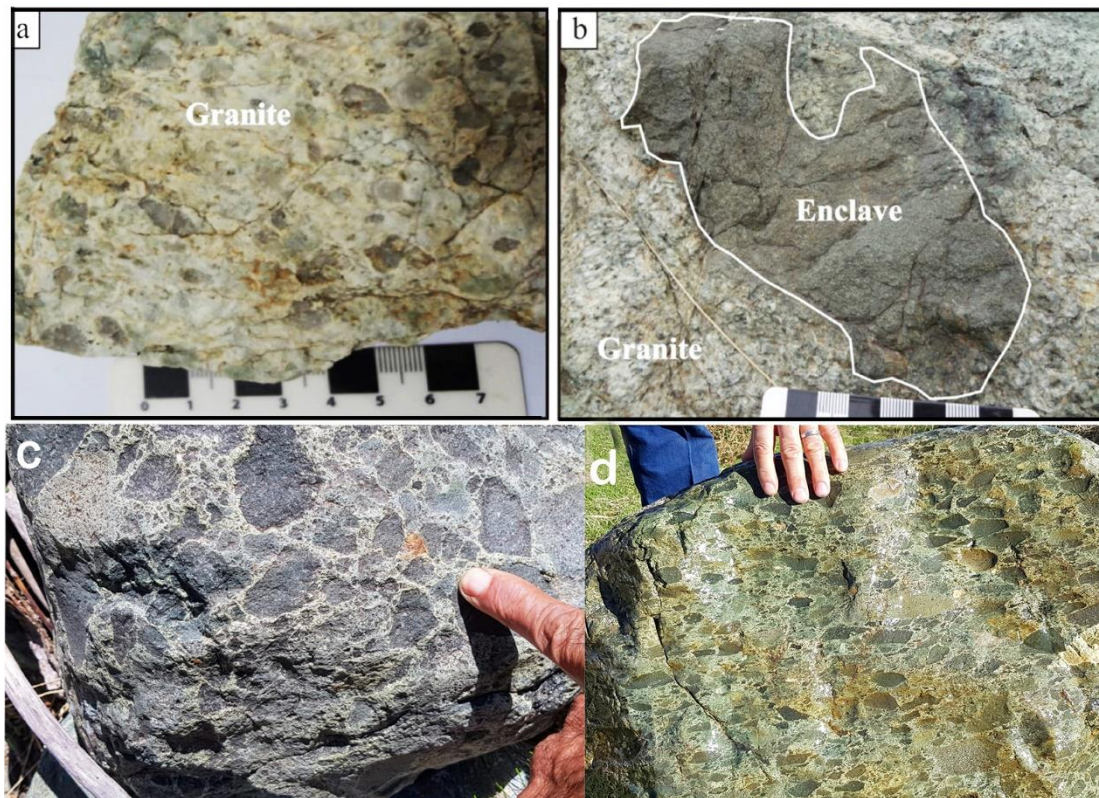


Figure 5: Metamorphosed conglomerates (derived from the volcanic arc) as proximal facies of the Walsh Formation which is considered by Abdulzahra et al. (2018) [23], as mixing of magma with enclaves (a and b), the conglomerate of the same formation near Darokhan village (c and d) of the present study.

3.2. Penjween Ophiolite Complex

This complex occupies a small part of the Penjween area in its southern sector and extends from the south of Penjween town to its west. Buday (1980) [20] called it “Penjween gabbroic intrusions”, while Jassim and al-Hassan (1977) [30], Buday and Jassim (1987) [22] and Al-Qayim et al. (2012) [4] named it “Penjween Ophiolite Complex”. According to these authors, it is comprised mainly of gabbro, peridotite, pyroxenite, and serpentinite.

Inside this complex, Abdulla (2015) [31], Ismail et al. (2020) [32], and Mohammad et al. (2020) [33] studied many granitoid dykes, which belong to the Late Cretaceous age.

Our extensive field and laboratory studies do not prove the occurrence of the above rocks and suggest reconsidering the presence of ophiolite in the Penjween area. We concluded the aforementioned rocks are different types of metamorphosed volcanoclastic sandstones (greywackes and arenites) such as pyroxene, plagioclase, amphibole, olivine, and hornblende arenites or wackes. The claimed granitoid dykes are channelized or bedded deposits of plagioclase and quartz arenites with subsidiary hornblende and other minerals. These arenites and wackes are originally turbidite sediments (volcanoclastic or greywackes) that were deposited by turbidity currents and then metamorphosed during burial in high tectonic stress due to the tectonic loading and metamorphism are very common in all orogenic belts.

When sedimentologist enters the complex and walks on the hills, mountain peaks, and valleys will identify pretty quickly the deposition of these rocks by sedimentation in the marine basin. Although all the sediments regionally metamorphosed, they persevered most of their sedimentary structures and textures such as millions of laminations and thousands of beds in addition to widespread graded bedding, erosional surface, and granular textures (Fig.6). The most important property of these rocks is planer bedding surface which is undisputable evidence of their sedimentary origin since the gabbro or peridotite are impossible to have bedding surface (Fig.6). However, tectonic brecciation and pulverization obliterated these structures and textures in several small areas. In rare cases, the mafic volcanoclastic sandstones (greywackes) are so intensely pulverized and sheared that transformed into massive and amalgamated bodies which are previously called serpentinite in which serpentinization and shearing are observable even on a millimetric scale, especially on the southwestern boundary of the Penjween Ophiolite Complex (present metamorphosed greywackes) on the Milakawa Mountain at 1km north of Kani Manga village. As concerned to the other ophiolites and volcanic rocks outside the Penjween area in northern Iraq, Karim and Al-Bidry (2020) [34], Karim et al. (2020) [35], Karim and Abioui (2021) [26], and Karim and Ghafur (2021) [27] studied many of them objectively and amended them to sedimentary successions. In these successions, the latter studies found ten of evidence confirming their new sedimentary origin. The sedimentary and tectonic signals that concluded in the latter four studies are applicable to rocks of the Penjween areas too.

Not only the sedimentary structures and textures manifest the depositional nature of the rocks of the claimed ophiolite but the directions of their components aid it. In this context, the long directions of most of the claimed dykes in the Penjween are directed generally toward the south or southwest. This direction is clear for 7 dykes on the published map of the Penjween area by Ismail et al. (2020) [32], this is true for 3 iron ore bodies on a map of the latter area by (Karim et al., 2016) [36]. Outside the area, the same direction of the dykes is observable on the maps of Ismail et al., (2017, p.1075) [37] who studied the Pushtashan Ophiolite at 50 km to the northwest of the Penjween area. The southward-directed claimed dykes deserve rethinking about their origins, especially Karim and Abioui (2021) [26], and Karim and Ghafur (2021) [27] proved that the dykes in Avroman and Mawat area are channelized sedimentary rock. This direction (as southward paleocurrent direction) agrees with a decrease in grain size caliber from gravel, sand, silt, and clay from northeast to southwest (Figs.4 and 6).

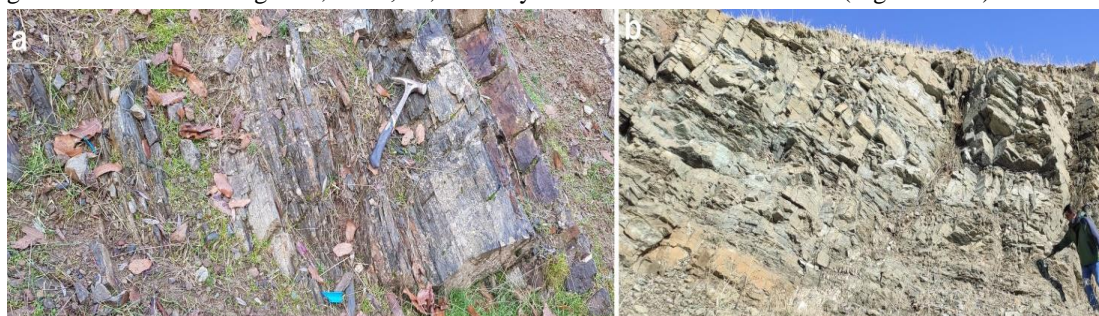


Figure 6: The whole Penjween Ophiolite comprised of bedded sedimentary succession, a) at the 1 km east of Penjween town at 35° 37'15.97" N and 45° 55' 57.11" E, b) at the central part of ophiolite on the Kani Shawkat Mountain at 35° 35' 04.26" N and 45° 57' 35.10" E. High viscosity magma cannot deposit these layers of sharp boundaries and high contrast mineralogies in addition of presence of planer bedding surfaces which are direct evidence of sedimentary rocks.

3.3 Naopurdan (Shaly) and Walsh (Volcanic) Groups (Series)

Bolton, (1958) [38], defined these two groups in the Thrust Zone of Iraq in the Suture Zone between Arabian and Iranian Plates and each group has more than 1000m of thickness. Buday (1980) [20], and Jassim and Goff (2006) [15] discussed in detail the problems of controversy in their distribution, age, lithology, stratigraphy, and their mutual relations. According to these authors, the Naopurdan Group consists of fossiliferous limestone, clastic sedimentary rocks (shale, greywackes, and conglomerate) with a minor share of volcanic rocks. On the contrary, the Walsh Group is mainly composed of basic and intermediate volcanic rock (both volcanic flow and pyroclastics) with interbedded flysch-like sediments (shale, red mudstones, cherty siltstones, sandstones, and conglomerates). Ali, et al. (2013) [16] and Aswad et al. (2014) [39] accepted the two groups as back-arc and arc rocks that developed inside the new Tethys Ocean far from their present location and their plagioclase aging indicated Eocene-Oligocene age for the two groups. Jones et al. (2020) [40] referred to the two groups as the Walsh-Naopurdan volcanic arc that occurred between the deposition of the Tanjero Formation and the upper Red Beds during the closure of the Neo-Tethys Ocean in the Miocene.

The field works of the present study for more than 20 years in entire northern Iraq have concluded two facts; the first is the two groups are originally one sedimentary succession of two formations not two groups which were deposited in one basin and nearly during the same age. The previous separation into two groups was due to intense tectonic deformations in the suture Zone between the Iranian and Arabian plates by which the succession locally fragmented into several parts that separated and dislocated from each other. These processes have repeated some intervals several times by which the true thickness is highly exaggerated and their stratigraphy distorted. The low-grade metamorphism of the succession with the aid of the later erosion of some of their parts exacerbated the study of its origin in the past. In the Mawat and Bulfat areas, Karim (2021) [22], Karim and Al-Bidry (2020) [23], Karim and Ghafur, (2021) [24] changed the two groups to two formations in their cross sections, stratigraphic columns and geologic maps of the above two areas.

The second is the absence of volcanic rocks in the two groups either as pyroclastic rocks or as volcanic flow. What is called volcanic rocks, belong to two types of sedimentary rocks, the first one is badly sorted mafic volcanoclastic sandstone of wackes types (greywackes) or arenite, while the second type is conglomerates and pebbly sandstone whose clasts (gravels) and matrixes are derived from remote volcanic arc source area that located inside Iran. Neither the present study nor the previous ones published photos of channelized or sheeted volcanic flows, cones, vents, volcanic bombs, and pillows. The previous studies depended on the geochemical and petrological study for indication of the origin of the rocks in the area. however, these two methods can not indicate if the rocks are crystallized in situ or transported from other places as weathering and erosion products especially when metamorphosed. The previous studies considered the badly sorted and angular mafic gravels inside the un-metamorphosed conglomerates as pyroclastic debris while in the metamorphosed equivalent rocks as enclaves. In other connection, the badly sorted sandstones with large sizes of crystalloclasts and volcanic lithoclasts (detritus) may look like the porphyritic texture of the volcanic rocks. When calcite or albite replaces the granules of pebbly sandstones, they may look like amygdaloidal volcanic rocks. The inspection of the boundary conditions of the rocks of two groups on the scale of millimeters (under microscopes) and hundreds of kilometers, clearly reveals their sedimentary origins.

Moreover, the restoration of the tectonic deformation shows agreement of the deposition of the succession with the sedimentary model of the turbidite deposition that occurs now in the Gulf of Bengal and the Arabian Sea in the Makran area. Therefore, the present study changed the two groups into two formations, the first is the Naopurdan Formation, which is comprised of reef and fore reef fossiliferous limestone of the Early-Middle Eocene. The second is the Walsh Formation, which consists mainly of basic and acidic volcanoclastic sandstones, shale, and conglomerate of the Paleocene- Early Eocene. It is possible that the two formations may interfinger locally, therefore the interbeds of the lithologies of the two formations can be observable in some places.

3.4. Walsh and Naopurdan Groups in Penjween area

Buday (1980) [20] mentioned the occurrence of the two groups in the Penjween area and Oweiss (1984) [3] followed the idea of the latter author and described Walsh and Naopurdan Groups and put them at the top of the thrust sheets of the Penjween area (Fig.2a). Jassim et al. (1983) [21] mentioned the identical aspects of the

volcano-sedimentary rocks (Walash-Naoperdan Groups) in the Penjween area and the same rocks in Bulfat and Mawat areas concerning their lithofacies, geological history, and their stratigraphic position. The same idea is configured by the tectonic models of the Penjween area by Ali et al. (2013) [16] (Fig.7a) and that of the Bulfat area by Aswad et al. (2016) [41] (Fig.7b) and that of Qalander and Hasanbaga by Ali et al. (2017) [13] (Fig.7c). The similarity of the tectonic setting of the Walash- Naoperdan Groups (presents Walash and Naoperdan Formations) are observable in the three above areas. Although Walash-Naoperdan was previously mentioned in the Penjween area but it is not defined lithologically, or stratigraphically and did not plot on a map and the previous studies found only their claimed volcanic rocks.

Besides the literature approval of the groups, there are three indications for their occurrence in the Penjween area. The first is the occurrence of two outcrops of Middle Eocene limestone above Walash Formation, the first one is located directly at the southwestern boundary of the metamorphosed Walash Formation (previous Penjween Ophiolite Complex), 1.5 km north of Kani Manga village on the south-western side of the Mila Kawa Mountain (Figs. 1 and 8). This outcrop consists of fine-grain limestone that belongs to wackestone microfacies and contains different species of nummulite and alveolina foraminiferas. These fossils are observable on outcrop surfaces and under microscopes photographed (Figs.9 and 10). The second outcrop is located on the Mila Kawa mountain on the paved road between the latter village and Penjween town. This outcrop consists of coarse grain detrital limestone (packstone microfacies) and it contains, in addition to the nummulite and alveolina, species of lepidocyclina (Figs.11,12 and 13). The limestone of this outcrop is thin-bedded and highly deformed and fragmented inside the greywacke and shale of the Walash Formation. Directly to the northeast of this outcrop, the greywacke of the latter formation is pulverized and serpentinite which was previously ascribed to Ophiolite rocks. This outcrop is considered Middle Miocene Govanda Formation by Karim et al. (2018) [42] but they admitted that it contained reworked Eocene nummulites.

The second indication is an outcrop of un-metamorphosed volcanoclastic sandstone (greywackes) located 500 m south of the Kani Manga village (Fig. 14). The sandstone is laminated and has different colors, weathering light brown while fresh color is light green or dark grey. The sandstone consists mainly of badly sorted plagioclase, hornblende crystalloclasts, and rare olivine ones while toward the top some limestone and chert grains appear. This outcrop belongs to Walash Formation but was separated from its metamorphosed northern part (previous Penjween Ophiolite Complex) by a reverse fault that uplifted the complex after its metamorphism. The third indication is the occurrence of the thick regionally metamorphosed limestone (marble) on the top of the metamorphosed Penjween volcanoclastic sandstones (previous Penjween ophiolite) (Fig. 15). This metamorphosed limestone (marble) with its underlying metamorphosed greywackes is very analogous to the Naopurdan and Walash Formations in the Bulfat and Mawat Core Complexes concluded by Karim and Abioui (2020) [26] and Karim and Ghafur (2021) [27]. This type of stratigraphic setting of carbonate-siliciclastic pairs with fossil-rich limestone that overlies the siliciclastic or volcanoclastic sandstones is common in northern Iraq. These couple lithologies are such as Aqra-Tanjero, Sinjar-Kolosh, Pila Spi-Gercus Formations. Therefore, the present study considers the two formations as a pure sedimentary succession of clastic and carbonate facies deposited in the Paleocene-Eocene foreland basin. Previously, Ali et al. (2013[4] and 2017) [17] and Aswad et al. (2016) [41] and (2011, p.815) [43] (put the deposition of the two formations (groups) in the back-arc and Island arc settings (Fig.7).

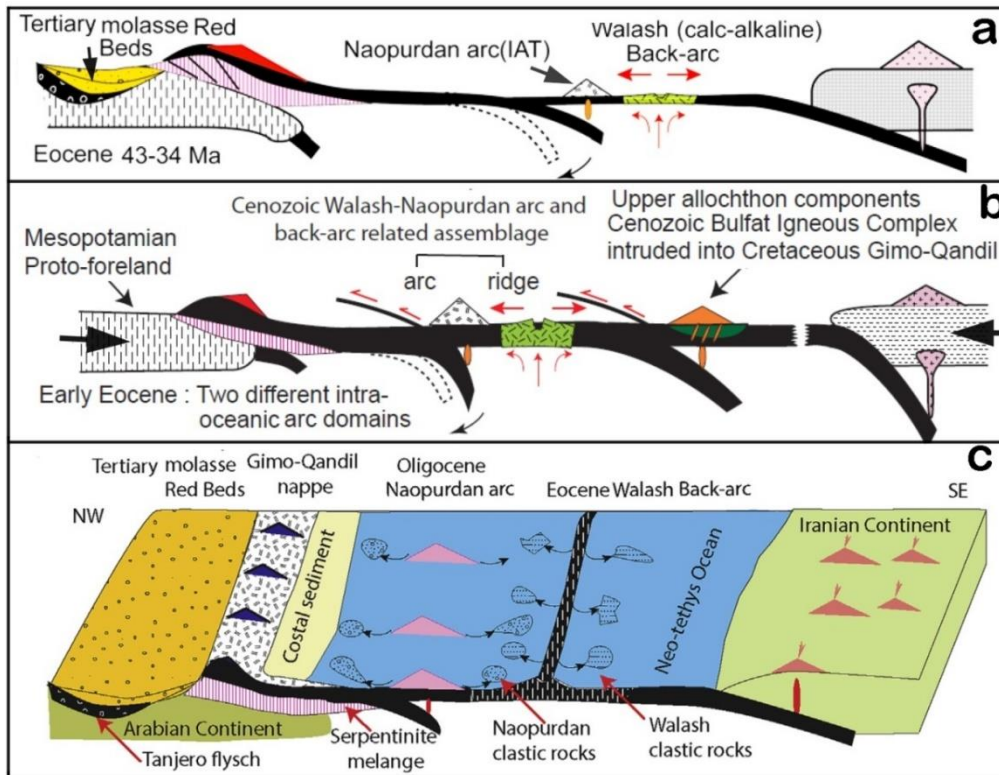


Figure 7: tectonic models of Penjween (a) and Bulfat (b) and Hasanbag-Qalander areas (c) by Ali et al. (2013) [16] and Aswad et al. (2016) [41] and Ali et al. (2017) [13] respectively. The similarity of the tectonic setting of the Walsh-Naopurdan Groups (presents Walsh and Naopurdan Formations) are observable in the three areas.



Figure8: An outcrop of the Naopurdan Formation at 1.5 km north of the Kani manga village, directly at the southwestern boundary of the previous Penjween Ophiolite Complex (present Penjween Metamorphic Core Complex) at 35° 35' 54.72" N and 45° 55' 04.73" E.

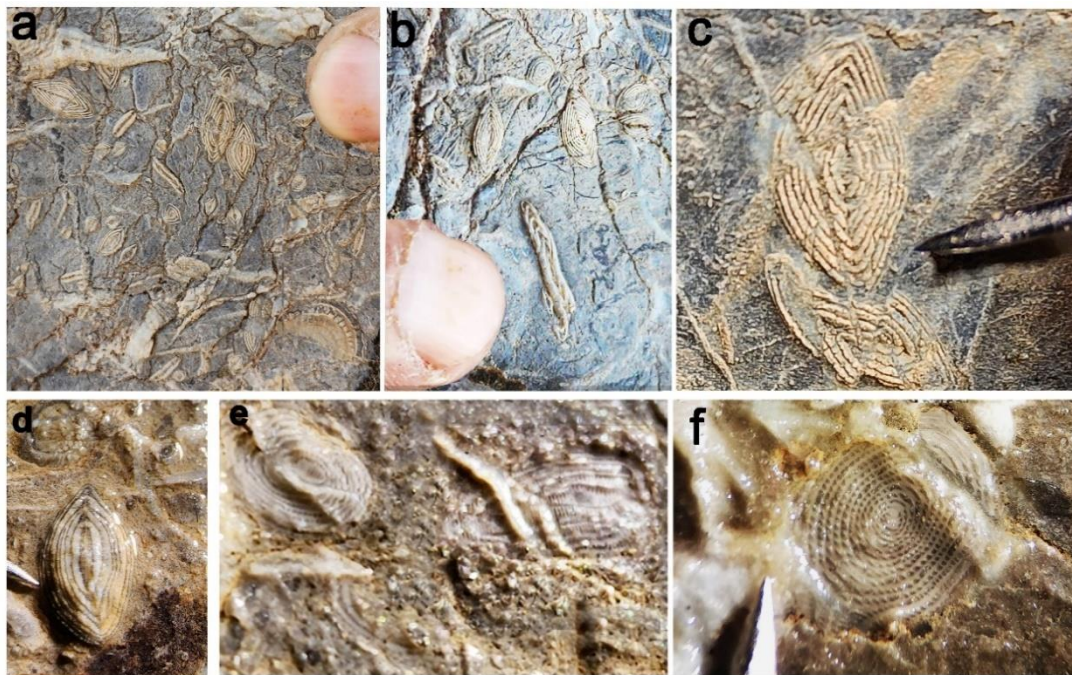


Figure 9: Middle Eocene nummulites and alveolinas of the Naoperdan Formation at 1.5 km north of the Kani manga village, directly at the southwestern boundary of the previous Penjween Ophiolite Complex (present Penjween Metamorphic Core Complex) at 35° 35' 54.72" N and 45° 55' 04.73" E. **a, b, c**) photographed on the outcrop that is shown in fig.8. **d, e** and **f**) a nummulite and alveolinas photographed under a stereomicroscope on broken surfaces.

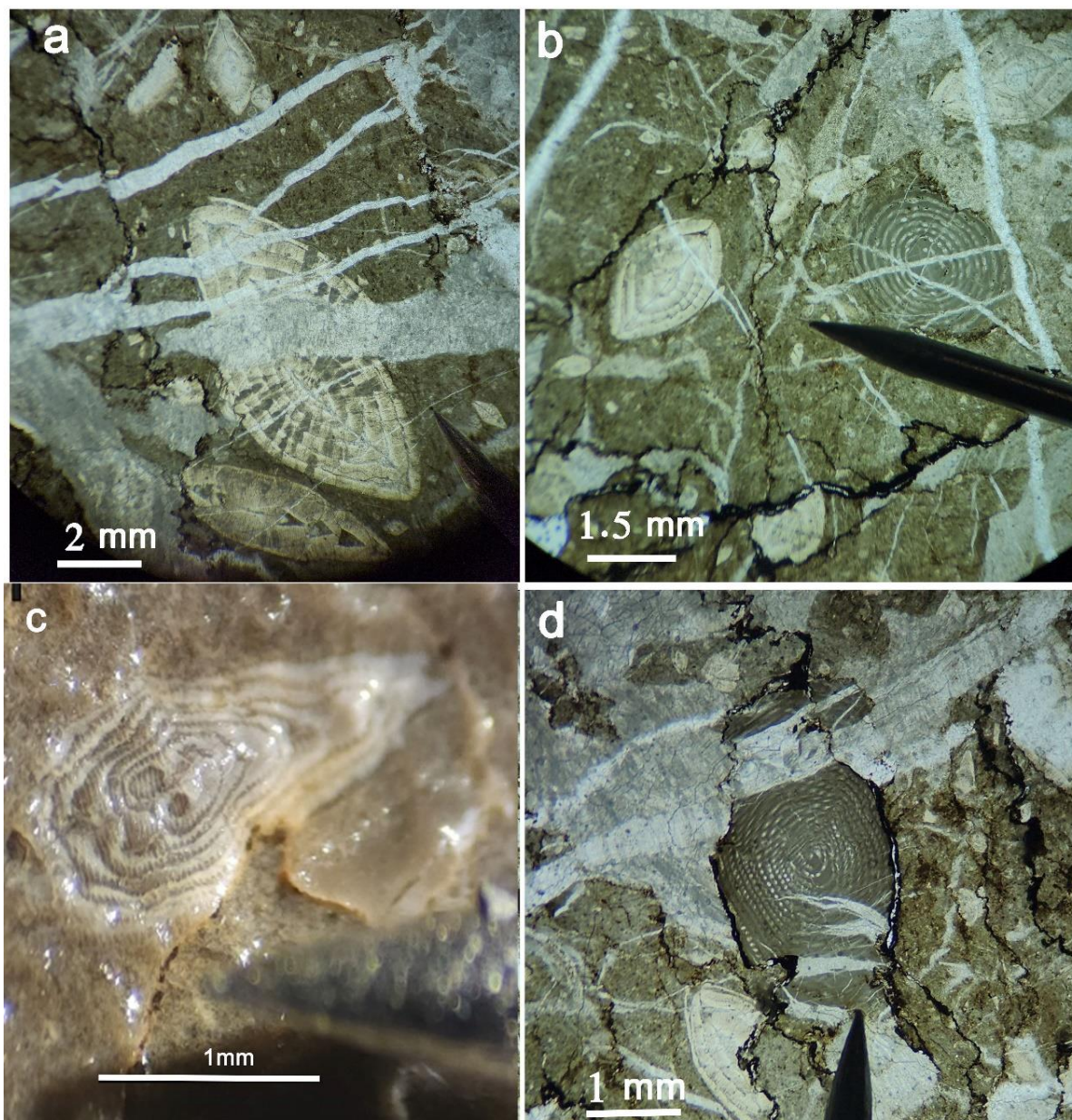


Figure10: Microphotographs of Naoperdan Formation on the Mila Kawa Mountain, **a)** Early-Middle Eocene *Nummulites beaumonti*, **b)** *Alveolina ovulum* and *Nummulites globulus* **c)** *Alveolina frumentiformis* and **d)** *Alveolina elliptica*



Figure11: a) alternation of thin beds of nummulitic limestone and greywacke on the peak of the Mila Kawa Mountain on the paved road between Kani Manga village and Penjween town at the contact of the Penjween Ophiolite complex (present Penjween Metamorphic core complex). b) an example of Middle Eocene Nummulites and alveolinas in the thin beds of the Naoperdan Formation, at 35° 36' 12.43" N and 45° 54' 46.01" E.

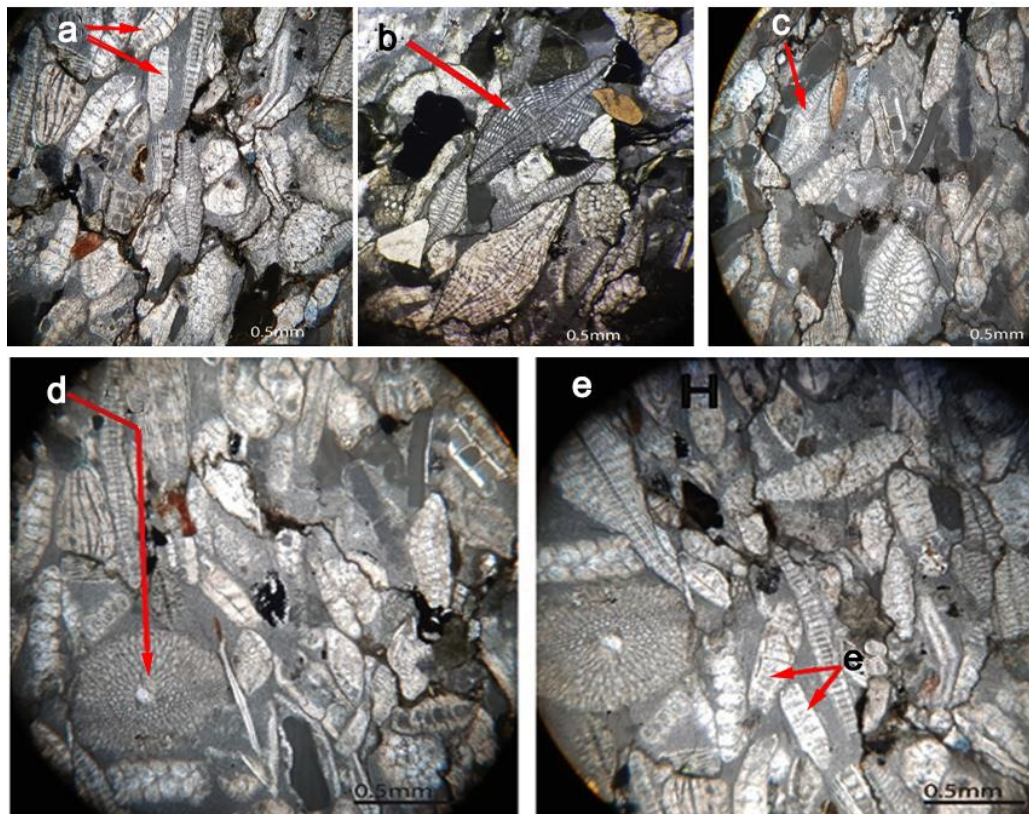


Figure12: Thin section of different species of benthonic foraminifera (Nummulite and discocyclus) (Early-Middle Eocene) of Naoperdan Formation in Penjween area, in Milakawa section under a polarized microscope, a) *Assilina granulosa*, b) *Discocyclinadispansa*, c) *Lepidocyclus* sp. d) *Sphaerogypsina*, e) *Smalina* sp

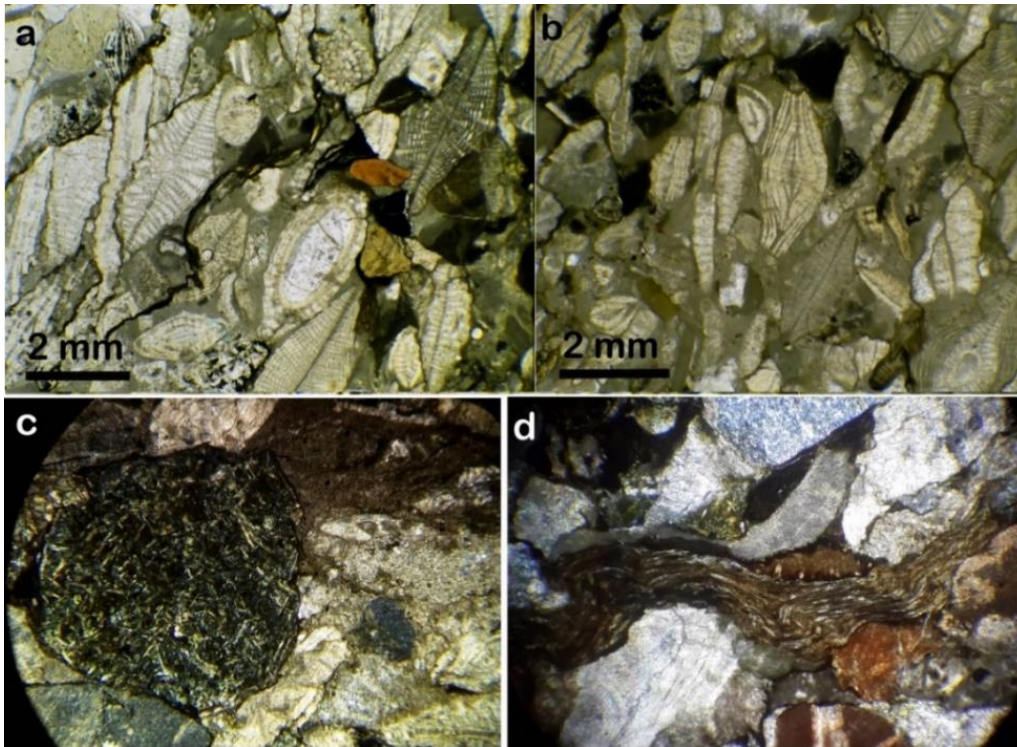


Figure 13: Microphotographs of Naoperdan Formation on the Mila Kawa Mountain, directly at the southwestern boundary of the previous Penjween Ophiolite Complex (present Penjween Metamorphic Core Complex) at $35^{\circ} 36' 12.48''$ N and $45^{\circ} 54' 43.91''$ E, **a** and **b**) Early -Middle Eocene nummulite and lepedocyclina, **c**) Volcanic lithic clast surrounded by deformed nummulites, **d**) deformed and folded shale clast surrounded other limestone and chert clasts.



Figure 14: There is one locality where the Walsh Formation is not metamorphosed in the Penjween area, this locality is located 500 m south of the Kani Manga village on the right side on the road to the Penjween, at $35^{\circ} 34' 40.80''$ N and $45^{\circ} 55' 10.89''$ E.

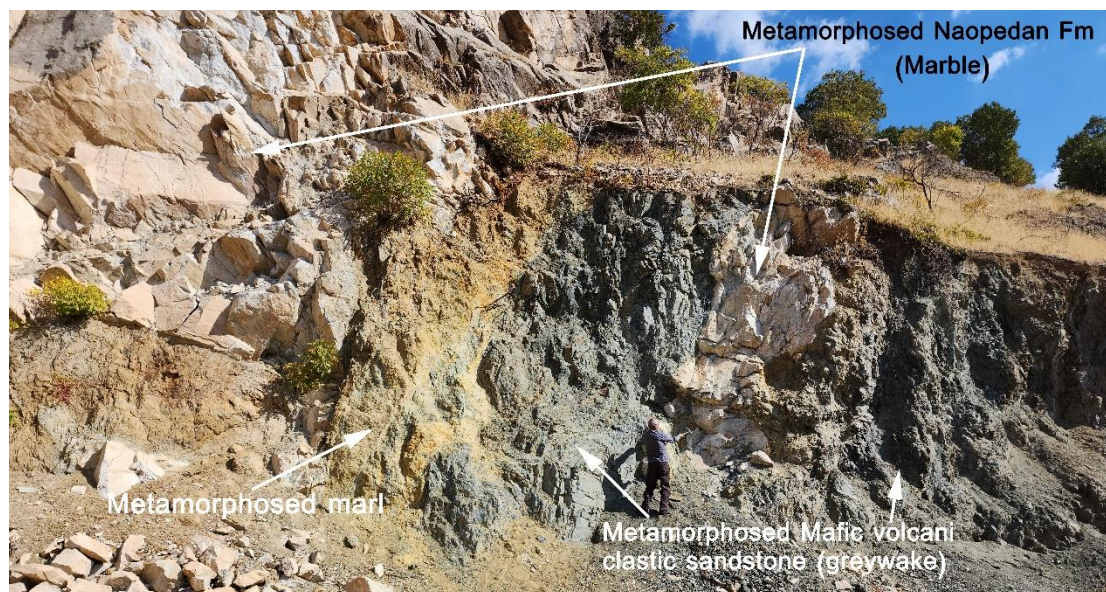


Figure 15: the contact between metamorphosed Walash and Naoperdan Formation in the western boundary of the Penjween Town at $35^{\circ} 37' 10.92''$ N and $45^{\circ} 56' 07.95''$ E. There is no contact metamorphism and the boundary is sharp, all metamorphosed regionally to the low greenschist facies

3.5 Relation of the Kolosh Formation with the rocks of the Penjween area

The Kolosh Formation is a Paleocene turbidite stratigraphic unit exposed about 50 km southwest of the Penjween area and has more than 400 m thickness which is comprised mainly of dark grey sandstone and calcareous shale (Jassim and Goff, 2006) [15]. The Formation is famous for its deep marine environment and deposition by turbidity currents in which Mashaikie and Mohammed (2018) [44] found olivine/ pyroxene-rich sandstone beds in the Dohuk area. Ali et al. (2019) [45] studied the geochemistry of the shales inside the formation and concluded sourcing from an island arc.

Our field study revealed consisting of the formation in many places of igneous rock detritus such as different types of crystalloclasts of plagioclase, amphiboles, pyroxenes, olivine, and volcanic lithoclasts. These clasts mainly occur in the Sirwan Valley, Dokan, and Zarayeen areas in addition to the southwest of Sulaimani city where the formation consists mainly of plagioclase and hornblende with subsidiary olivine, pyroxene, and iron oxides. The XRD diffractograms and thin sections of the Kolosh and Walsh Formations in addition to ophiolite rocks show close relation in mineralogical similarity (Fig.16). Not the thin section and XRD results signify close relation but their grain sizes and thicknesses agree with all siliciclastic sedimentological models of the foreland basins and continental margins. This study found a link between Kolosh (inside High Folded Zone) and Walsh Formations (inside the Thrust Zone). This link is located in the Imbricate Zone near Tagaran village at 4km south of Chwarta town and consists of a dark grey succession of sandstone, pebbly sandstone, and conglomerate with interbed of shales and these lithologies can be called greywackes. The nannofossils study of shales in the Chwarta area indicated the Paleocene age of deposition and proved its relation to the Kolosh Formation lithologically and paleontologically (Figs.17, 18, and 19). When the distance and depth of the basin are considered, the mineralogical constituents of the Kolosh Formation in the Chawrta and Sulaimanyiah areas are nearly similar to those of the Kata Rash Conglomerate, greywackes of the Penjween area (both its metamorphose and unmetamorphosed greywackes). This similarity and linking, enable us to correlate the rock and stratigraphy of the Kata Rash conglomerate, claimed ophiolite, Walsh formation, and Kolosh Formations in a single basin (Figs. 19, 20,21and 22).

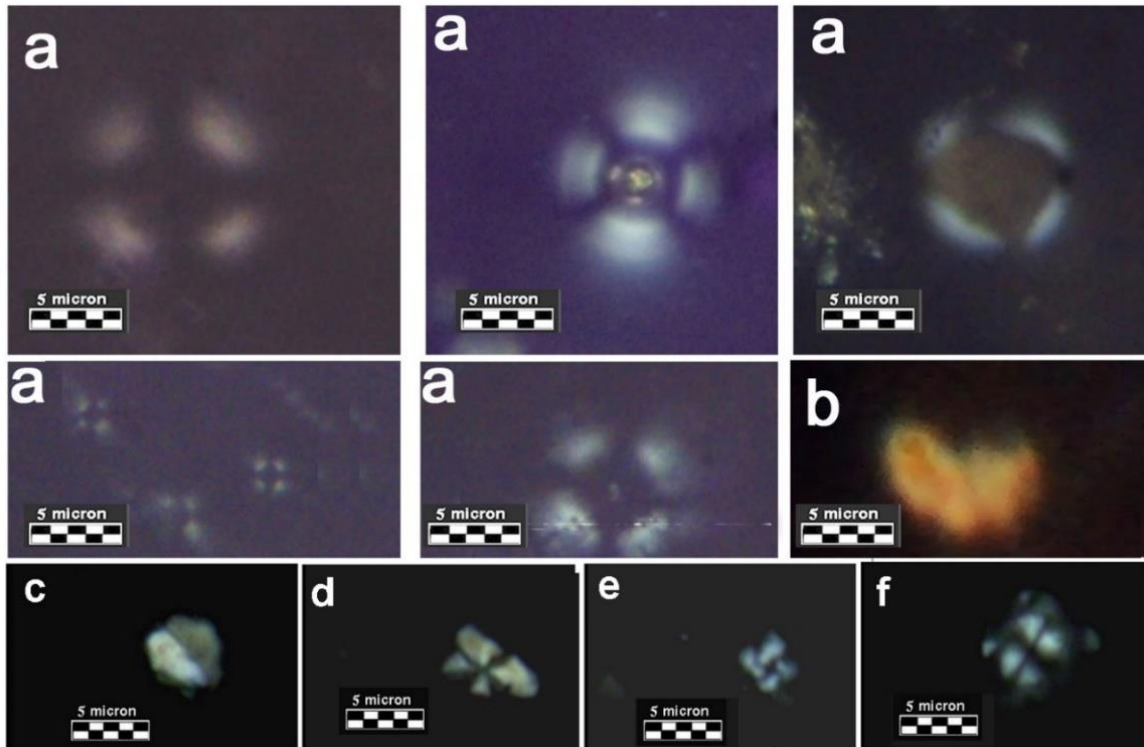


Figure 17: Several Paleocene nannofossils in the Kolosh Formation (as greywackes) in Chwarta area
a) *Ericsonia robusta*, s.no. K1, b) *Fasciculithus thomasi*, s.no. K7, c) *Fsciculithus* s.no. K20, d) *Sphenolithus*, s.no. K20, e) *Cyclicargolithus*, s.n. k20, f) *Coccolithus*, s.n.K20.



Figure 18: a) Kolosh Formation at 6 km south of Chwarta Town about 200 m southwest of Tagaran village, it consists of about 120 m of sandstone (greywackes), conglomerate and shales of volcanic origins, b) The conglomerate of the formation consists of gravels of volcanic detritus.

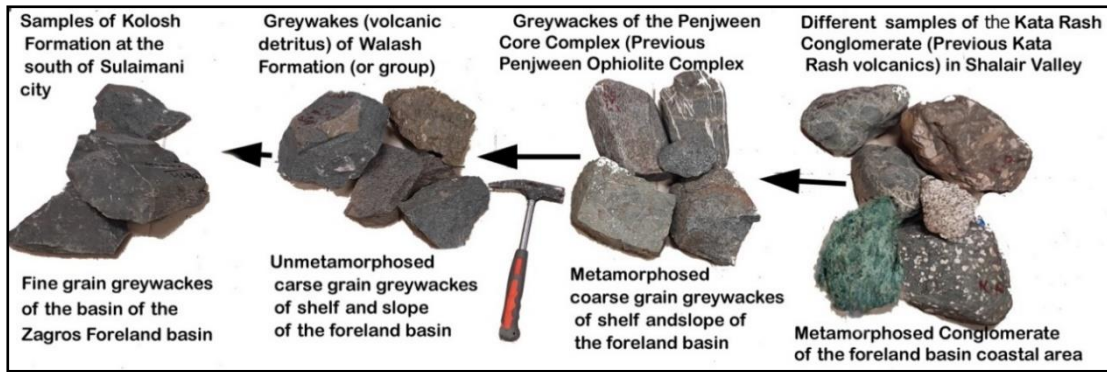


Figure 19: Comparison of the rocks of the Paleocene along its paleodip for 100 km distance from the head of Shalair valley to the south of Sulaimani city. There is a close correlation between these rocks from mineralogical and sedimentological aspects.

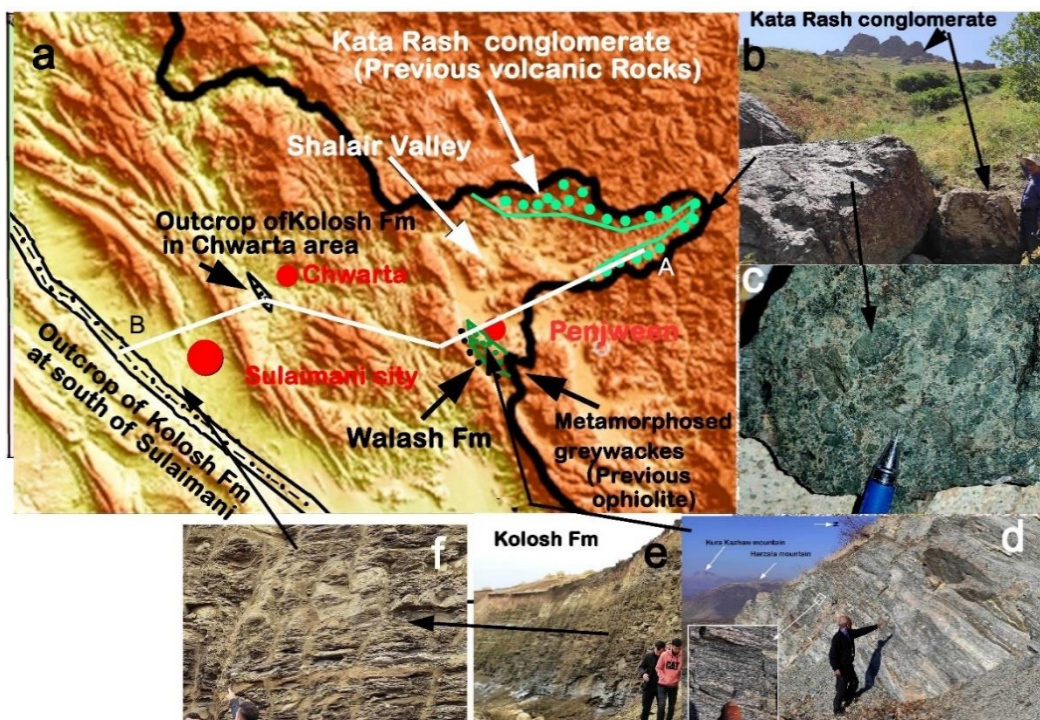


Figure 20: a) Digital elevation map of the Penjween and Sulaimani area shows the outcrops of Kata Rash Conglomerate (b and c), Penjween Greywackes (previous ophiolite) (d), Walsh Formation, Kolosh formation in Chwarta and Sulaimani areas (e and f), the white line (AB) represents the extent of the basin modeled in the figure (21).

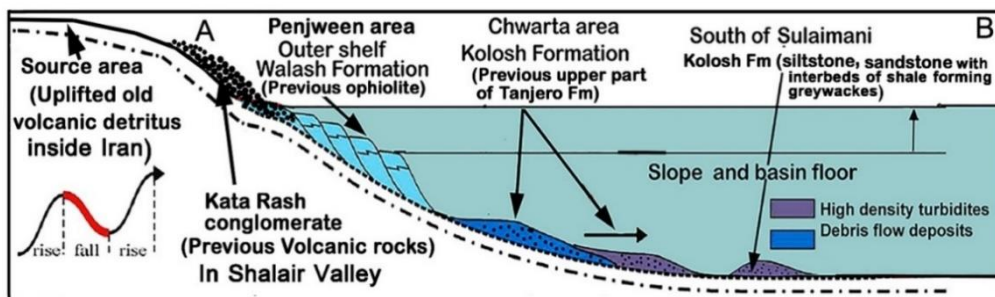


Figure 21: A cross-section of Penjween- South of Sulamani city during the Paleocene shows the location of Kata Rash Conglomerate (as coastal facies), metamorphosed Walsh Formation (slope facies), Kolosh Formation

(deep turbidite facies in a foreland basin) in Penjween, Chwarta, and Sulaimani areas respectively (see the line AB and X₁X₂ in the figs. 21 and 22a).

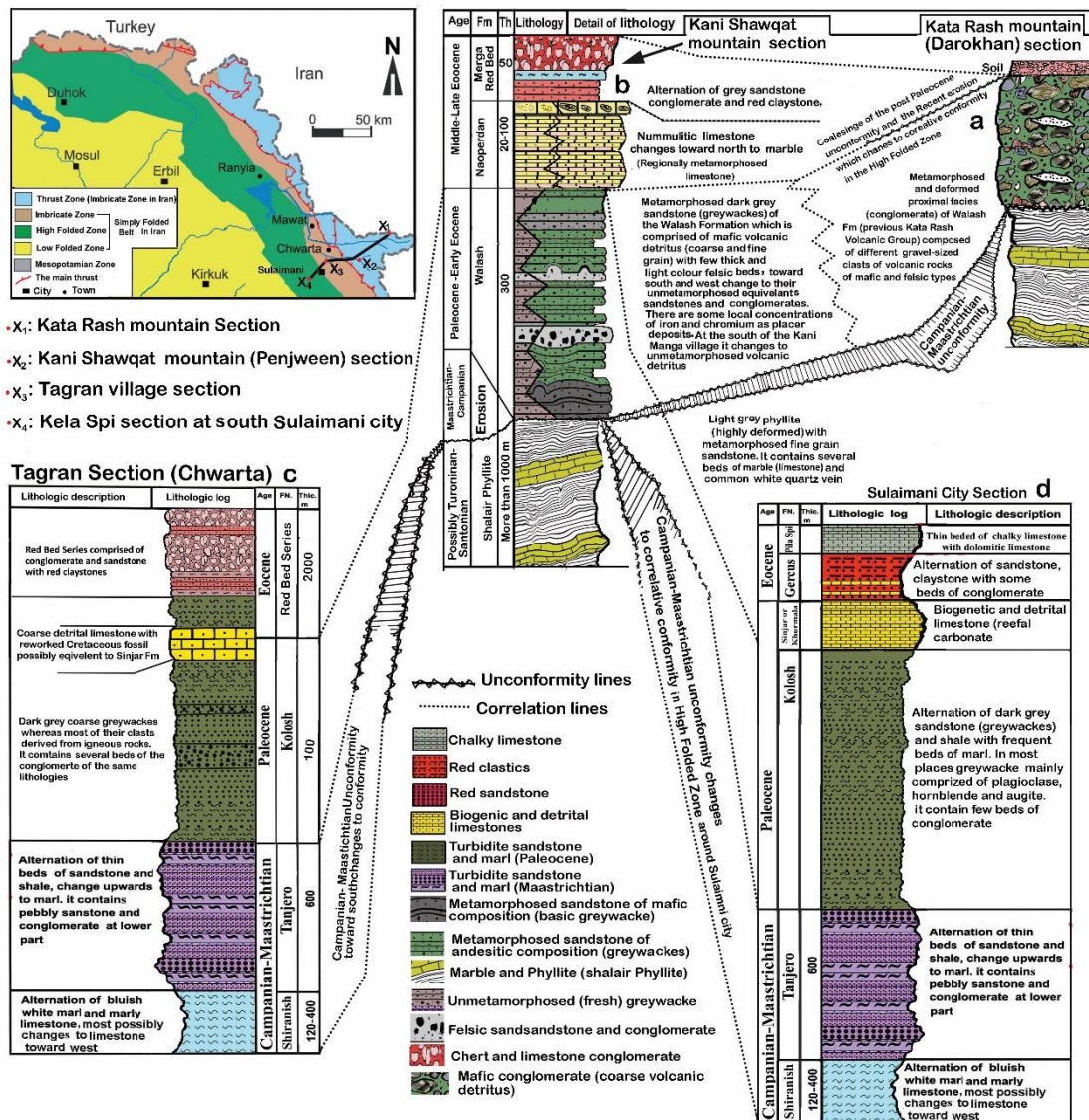


Figure 22: Correlation of Kata Rash Volcanic Rocks (present Kata Rash Conglomerate), Walsh and Kolosh Formations in addition to their relations to the Campanian-Maastrichtian unconformity. a) traverse of the correlation along the lines X₂-X₄ on the tectonic map of Jassim and Goff (2006), a, b, c, d) are correlated sections of the Darokhan, Kani Shawqat mountain, Tagaran, and south Sulaimani city sections.

3.6. The first arrival of volcanic detrital and crystalloclasts to northern Iraq

The extensive exposures of the rocks of the Campanian-Paleocene basin depocenter are available in the High Folded Zone in the Sulaymaniyah, Erbil, and Duhok Governorates (Fig.1a). In this depocenter, stratigraphic units such as Shiranish (Campanian), Tanjero (Maastrichtian), and Kolosh (Paleocene) Formations were deposited and are now well exposed. Jassim and Goff (2006) [15], Karim and Surdashy (2005) [46] concluded the development of the foreland basin after the uplift of ophiolite and radiolarites during Campanian. According to the latter articles, the radiolarites were first uplifted then followed by ophiolite. This uplift generated the first terrestrial land as a nucleus of the present Zagros collisional belt and its erosion resulted in the deposition of the latter three formations in the foreland basin. In Northern Iraq, the siliciclastic depocenter of the Zagros Foreland Basin encloses much information concerning the tectonic and lithology of source areas during the Late Cretaceous and Tertiary. In the succession of the depocenter, there is a record of the first main influx of volcanic

detritus (previous ophiolite-derived sediments) in the early Paleocene. The volcanic clasts include fine and coarse sands and conglomerates which are exposed at several localities such as near the Dokan Dam site, Sirwan valley, and Chwarta areas at 35° 56' 09.80" N and 44° 56' 18.26" E, 35° 07' 26.67" N and 45° 52' 42.66" E, 35° 40' 29.12" N and 45° 31' 41.41" E respectively (Figs.21 and 22). The detritus and crystalloclasts, either as sandstones or conglomerates were transported, from source areas to the deeper part of the foreland basin and mixed with hemipelagic fossils-rich sediments by debris flow during catastrophic events such as tsunamis, hurricanes, and large earthquakes. The hemipelagic sediments allow a thorough investigation of the age of the associated volcanic clastic detritus by fossils such as nannofossils and planktonic foraminifera. Therefore, the stratigraphic horizon of the first arrival of the volcanic detritus is aged Paleocene by planktonic foraminifera and nannofossils biozonation inside hemipelagic sediments that host volcanic detritus by Sharbazheri et al. (2011) [47], Al Nuaimy et al. (2020) [48] and Kharajiany et al. (2020a [49] and b [50]). However, the late Maastrichtian age is not excluded since there are some greywackes inside the upper part of Aqra in the Mawat and Chwarta areas. Previously Homke et al. (2009) [51] recorded this influx inside the Amiran Formation (Iraqi Kolosh Formation) of northeastern Iran and called it Ophiolitic turbidite. In Iraq, this influx is not only related to High Folded Zone but to the imbricate and Thrust Zone which coincide with the slope and shelf (Bulfat, Chwarta, and Mawat areas) of the Maastrichtian and Paleocene Foreland basin. In these latter areas, the metamorphosed volcanic detritus (greywackes) was previously considered ophiolites and volcanic rocks. The previous studies aged the fresh or metamorphosed greywackes (previous ophiolite) by the zircon method and obtained different ages of the Late Cretaceous. Karim and Abioui, (2020) [26]; Karim and Al-Bidry (2020) [34]; Karim and Ghafur (2021) [27] studied the internal and external (boundary conditions) properties of the claimed ophiolites and volcanic rocks of northern Iraq and concluded that they are metamorphosed greywackes. They argued the zircon aging of these rocks and inferred that all the previously studied zircons are detrital crystalloclasts of sediments. They considered these zircons as the product of long-distance transportation and reworked them several times, so they yield older age of crystallization not the age of the sedimentary depositions. Therefore, the age, mineralogy and basin of Kata Rash conglomerate (previous volcanic rock), greywacke (ophiolite), Walsh formation and Kolosh are all the same.

3.7. Changing the geological map of the Penjween area

The Penjween area has the most complex setting and deformed rocks in the whole of Iraq due to its occurrence inside the Sanandaj-Sirjan Zone (Crushed Zone of Wells, 1969) [52]. It elongates about 35 km inside this zone and inside Iranian territory. Therefore, unlocking the origin of its metamorphosed rocks is a difficult task, especially within a few meters several types of rocks are observable as an alternation of layers of different colors and mineralogies. Albeit of the metamorphism, in most places, the sedimentary layers, structures, and textures are preserved. However, in some localities, the layers are so intensely deformed and pulverized that they become massive and homogenous, therefore, their origins are obscure when they are studied without attention to boundary condition consideration. Yet, when their study is connected to boundary conditions their origins are disclosed. This disclosure is due to the lateral gradation of pulverized bodies to undeformed layered succession and the sedeformations are observable at the boundary of the Penjween Core Complex (previous ophiolite Complex) where the greywacke sheared and hydrated to the different minerals of hornblende, serpentine, chlorites. Therefore, drawing a map to satisfy all observed petrologies and mineralogies in the field is impossible. Therefore, the present study is modified the map published previously by Ma'ala, (2008 [18] and Karo, (2015) [19]. The present study changed all the previous igneous rocks to metamorphosed sedimentary rocks of either greywacke, felsic-mafic arenites, or conglomerates (Fig.1b). These rocks are associated with interbed shales and marls which are metamorphosed into sheared slate or phyllite and in some places, the metamorphosed marls resemble volcanic ash. Naoperdan Formation, as a fossiliferous limestone succession, is recorded and plotted on the map for the first time. In addition to the geological map, a geologic cross section (Fig. 23), and a depositional model (Fig.24) are drawn for the Penjween area to stress the sedimentary origin of the rocks of the Penjween area without exception.

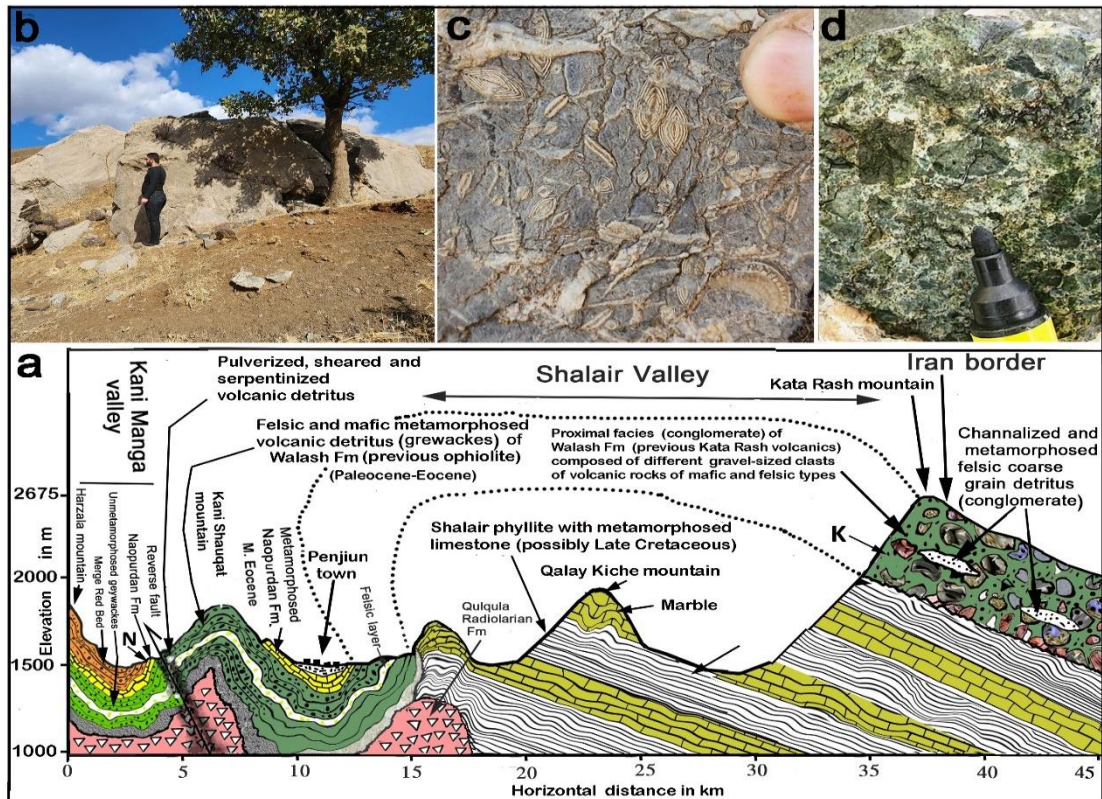


Figure 23: a) Geologic cross-section of the Penjween area passing through Penjween town and Darokhan village. b, c) outcrop and its nummulites the Naopurdan Formation at N location, c) hand specimen of Kara Rash Conglomerate at K location on the cross-section.

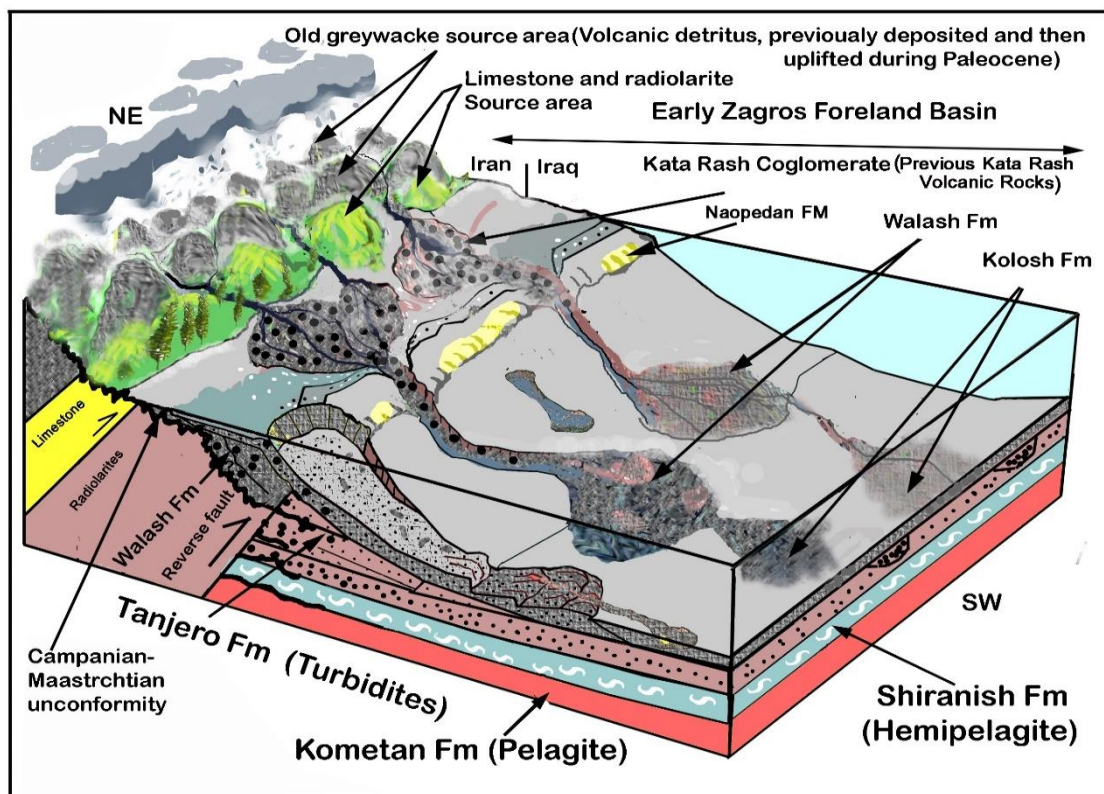


Figure 24: paleogeographic and tectonic model during Paleocene-Early Eocene shows the deposition of the Kata Rash conglomerate, Walsh, and Kolosh Formations.

Conclusions

The study discussed the stratigraphy of the Penjween area (including Shalair valley) and gives new consideration to its volcanic, ophiolite, and metamorphic rocks. The results proved, with tens of evidence, that the claimed igneous and marble are sedimentary succession belonging to Walash and Naoperdan formations and deposited during Paleocene by turbidity currents. These two formations and Kata Rash Conglomerate are correlated with the Kolosh and Sinjar Formation in High Folded Zone which was deposited in a single Foreland basin during Paleocene -Eocene. The Kolosh Formation is found for the first time in the Chwarta area and extensive field and lab work failed to find direct evidence of the previously claimed igneous rocks, they are sedimentary rocks derived from uplifted volcanoclastic sediments (previously deposited) inside Iran during the Jurassic and Cretaceous. Later reworked and deposited in the Penjween, Mawat, and Bulfat areas during Paleocene-Eocene.

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