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Zagros Metamorphic Core Complex: Example from Bulfat Mountain, Qala Diza Area, Kurdistan Region, Northeast Iraq

Kamal Haji Karim[1*] and Mayssaa Al-Bidry[2]

[1]University of Sulaimani, Collage of Science, Department of Geology, Iraq
[2]University of Technology, Department of Petroleum Technology, Iraq

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Abstract

Bulfat (Kele Mountain is located northeast of the Qala Diza town at the northeast of Iraq near the border with Iran. The mountain was previously considered as an igneous complex (Bulfat Igneous Complex) of extreme mineralogical, petrological, and structural heterogeneities at the outcrop, hand-specimen and microscopic scales. In previous studies, tens of igneous rocks are indicated in the Complex such as basalt, meta-basalt, gabbro, syenite, metadiabases, diorite, peridotite, serpentinites, nepheline syenite, granitoid-gabbro association, troctolite, olivine gabbro, old gabbro, new gabbro, amphibole-pyroxene gabbro, pegmatites and others. All of these rocks are highly affected by deformations on small and large scales such as folding, normal faulting, ptymagtic folding, mylonitization, crystal bending and crystal boundaries suturing in addition to foliation. Field and lab observations in the present study don't aid the presence of the abovementioned "igneous" rocks and ophiolite on the mountain (in the Bulfat Ophiolite Complex). The present study concludes that all the above mentioned rocks are mixtures of different types of metamorphosed volcaniclastic sandstones, conglomerate, siltstones (greywakes) and shale. These sediments are derived originally from volcanic arcs (Urumieh-Dokhtar Magmatic Arc) with subsidiary amounts of limestone and plutonic igneous rocks clasts. From the remote volcanic arcs, the sediments were transported by turbidity currents to a basin of deposition in the Qaladiza and Bulfat area (as a part of the Sanandij-Sirjan Zone) during the Paleocene-Eocene age. Many evidences are found to prove the sedimentary origin of the rocks of the Complex such as the transition from fresh volcaniclastic sandstones to their mild and intense metamorphosed counterparts, the preservation of planner beddings, sharp erosional surfaces, laminations, grains sorting-roundness, folding, bending of pervious gabbros around marble, submarine channels filled with metamorphosed coarse sandstones. Other evidences are absence of dykes, pillow basalts and volcanic flows, contact metamorphism, hydrothermal mineralization. These sedimentary rocks are regionally metamorphosed to greenschist, amphibolite and pyroxenite facies which can be called schists, mafic-felsic gneisses or granulites and rare migmatite rocks. As parent rocks, all these sedimentary rocks, are deeply buried by tectonic thickening during Eocene, and were partially or totally crystallized by diagenesis and regional metamorphism. Later, during the late Miocene-Pliocene, they were uplifted as a Bulfat Core Complex. Therefore, according to the analysis and discussion of all aforementioned information, the origin of the Complex is formulated in a single model of the core complex, and the deposition of the sedimentary rocks is illustrated by paleogeographic and tectonic models. All previous studies are critically and objectively evaluated and compared to the results of the present study which does not support the occurrence of ophiolites and volcanic rocks in the Bulfat (Qaladiza) area.

Keywords: Bulfat Mountain, Zagros Orogenic Belt, Metamorphic Core complex, Mafic Gneiss, Granulite, Migmatite, Walash-Naoperdan Series, Volcaniclastic Sandstones, Greywackes

1. Introduction

The Bulfat Mountain is located in the northeast of Qala Diza town in northeastern Iraq and trends NW-SE parallel to the Iranian border. Its northwestern part is located inside Iran, and has the width, length, and elevation of 5km, 25 km, 2000m respectively (Figure 1). Tectonically, it is located in the Thrust Zone of Buday (1980), Suture Zone of Jassim and Goff (2006) which is equivalent to the outer part of Sanandij-Sirjan Zone (Ruttner and Stocklin, 1968) in Iran. The mountain has more or less an oval shape, and is surrounded from all sides nearly by sedimentary rocks. According to previous studies, the grade of metamorphism and the igneous rocks increase toward its center.

The Bulfat Mountain was subjected to extensive geological investigations from the late fiftieth of last century till now. According to these investigations, geologically, the mountain is the most complex succession in Iraq. Therefore, geologists applied many geological terms to name the geological setting of the mountain such as the "Bulfat Thrusted Block" Bolton (1958); "Bulfat Igneous complex" (Pshdari, 1983; Buday and Jassim, 1987; Buda, 1993); Bulfat massif (Jassim et al., 1982). Others used terms such as, "The Bulfat block" and "Bulfat Group" (Jassim et al., 2006); Bulfat Complex (Elias and Al-Jubory, 2014). "Bulfat Compex" is used in the descriptions and discussions of the present study.

Researchers have divided the rocks of the mountain into two types; the first type consists of thermally and regionally metamorphosed sedimentary rocks (carbonate and pelites),

* Corresponding author e-mail: kamal.karim@univsul.edu.iq

while the second includes igneous rocks such as basalt, intermediate, basic and ultra-basic intrusive igneous rocks. The origin of the rocks of the complex are controversial, and includes basaltic arc theoleiite and calc-alkaline basalt (Aziz, 1986), volcano-sedimentary of geosynclinal units Jassim et al. (1982); Oceanic intra-arc rift setting (Ali, 2017); Paleocene Oceanic volcanic-arc (Aswad et al., 2016); low-K calc-alkaline magma of basaltic arcs affinity (Aqrawi and Sofy, 2007). Other origins are volcanic arc granite with a dual subduction-zone system (Aswad et al., 2013); rocks of the active margin of the Iranian microcontinent represented by Sanandaj-Sirjan rocks (Elias and Al-Jubory, 2014); subduction-zone system in Iraqi Zagros Zone (Ali, 2015).

The age determination by K/Ar method indicates 40- 45 Ma as the age of the cooling of the intruded basic igneous rocks, but they may have intruded over a somewhat earlier period (Jassim et al., 1982). They added that regional metamorphism affects only Cretaceous rocks or older rocks which makes one presume that they occurred together within the folding in the Laramide orogeny (Upper Cretaceous).

The present study is aimed at presenting several field and lab evidences that would exclude the presence of basalts and plutonic igneous rocks (ophiolite) in the Bulfat Complex. The authors consider that all these rocks are a result of the metamorphism of volcaniclastic sandstones and greywackes, and other sediments derived from volcanic and plutonic igneous rocks. The processes of deposition, burial, diagenesis, and regional metamorphism and uplift are discussed in the framework of a Metamorphic Core Complex model.

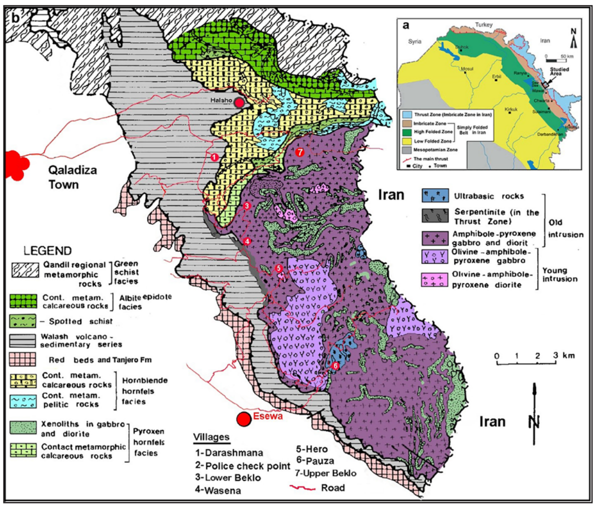

Figure 1. a). Location map (Jassim and Goff, 2006). **b).** Geological map of the Bulfat Mountain area showing the distributions of metamorphic and igneous rocks (Buda, 1993).

1.1. Methodology

The study of the Bulfat Complex is based on fieldwork and microscopic studies. During the years 2010 to 2019, several field trips were conducted to the different parts of the mountain to understand its geomorphology, structure, rock types, their field relations, boundary condition (local and regional geological relations of the complex with neighboring units and complexes) and tectonic setting. During these trips, a total of thirty samples were collected from previously described rocks such as volcanic rocks, metavolcanic rocks, hornfelses, gabbros, syenite, diorite and peridotites. The samples were collected along the paved and unpaved roads that are shown in red line in (Figure 1). Thin sections were prepared for a petrographic study under polarized and stereo-microscopes. The huge published previous data were studied, evaluated, and compared with each other and with the present study. The boundary conditions of the complex were studied on a scale of tens kilometers including the whole northeastern Iraq, and we linked of the obtained boundary conditions to the internal geology of the complex extracting the differences and similarities with other complexes in term of petrology, structure, stratigraphy, and tectonics. As a result, the present study has been set in serious disagreements with previous studies based on the aforementioned attributes of the Complex and its boundaries. These disagreements are justified by field and laboratory evidences and are discussed in detail in several sections.

2. Results

2.1. Absence of volcanic rocks in the Bulfat Complex

According to Jassim et al. (1982), part of the Bulfat Complex consists of ocean-ridge volcanic and sedimentary sequences, which were regionally metamorphosed during Mesozoic. They added that the igneous rocks (metadiabases, basalt, metabasalts, acidic volcanic tuffs, metaandesites and andesite have been metamorphosed at the ocean bottom and preserved their original porphyritic, amygdaloidal textures, in spite of the extensive recrystallization. Aziz (1986) studied spilitized and metamorphosed basalts and andesites inside the Walash-Naoperdan Series (or group) in the Qaladiza area at the southern and western boundaries of the Complex. Ali (2015) studied the same rocks (metabasalts and metaandesite) in detail both petrographically and geochemically in the same area especially around the Halsho and Darashmana villages, and he concluded that they belong to the calc-alkaline basalt of the island- arc setting.

The present field and petrographic studies oppose the presence of volcanic rocks around and on the Bulfat Mountain. There are clear signals that all the above mentioned volcanic rocks are fresh or slightly to moderately metamorphosed volcaniclastic sandstones, conglomerates (greywackes) and shales (Figure 2). These sediments were derived from different mafic and felsic igneous source areas (mainly basaltic terrains) with possible subsidiary limestone sources. These source areas supplied the basin with volcaniclastic sandstones rich in feldspars, pyroxene, and olivine with minor quartz and possible limestone clasts. The fresh sedimentary rocks (greywakes) are exposed to the south of Beklo, Darashimana, Halsho and Gira villages in addition to the area around Darwina, Badin and Shodan villages.

The first signal is gradation from unmetamorphosed volcaniclastic sediments to slightly and then to moderately metamorphosed ones when one walks from the southern boundary to the core of the Bulfat Complex (Figure 3). In spite of mild or intense metamorphism, the traces of the original textures (sorting and roundness of the grains) and structures (laminations and beddings) are preserved in most rocks (Figures 5-6). These rocks are affected, more or less, by regional metamorphism which is imparted schistosity and foliation in pelitic rocks but not to the degree of destroying the original depositional structures and textures. Due to the preservation, the metamorphosed laminated sediments look like mafic and felsic hornfels (Andrew, 1984), schists, basic or acidic gneisses while they are similar to gabbro or peridotite when the structures are destroyed.

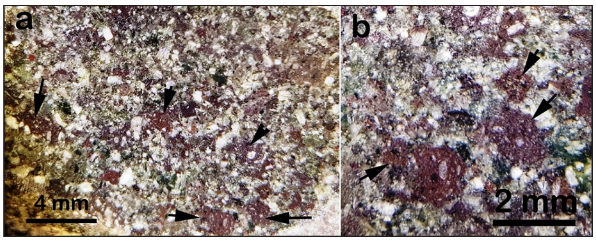

Figure 2. The rock previously claimed as basalt (under stereomicroscope) consists of volcaniclastic sandstone which shows some degrees of sorting and roundness, the volcanic clasts are indicated by black arrows.

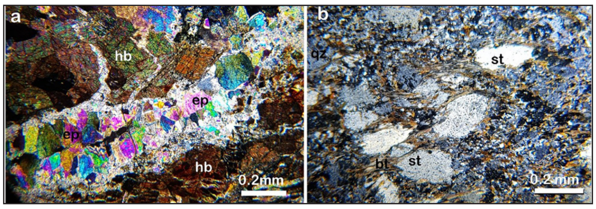

Figure 3. Medium grade metamorphic rocks (schists) under XPL in Shilana valley along the old unpaved road to the Peak of Bulfat Mountain. **a).** Epidote-hornblende schist, s. no. 2, 500 west of Police station. **b).** Staurolite- biotite- muscovite schist, s. no.4, 200m to the west of the police station.

The second is a clear preservation of beddings and laminations of the sedimentary parent rocks (Figures 4-5). In the hand specimens and in thin sections, the white and dark laminae are clearly visible which represent feldspar and hornblende or pyroxene rich bands. The third signal for the sedimentary origin is the textures of thin sections of the metabasalt of Aziz (1986, p.32) and Ali (2015, p.248) which show clear sorting and roundness of the grains of the "metabasalt" rocks without any evidence of basaltic flow textures. It can be observed in (Figures 7a-b) that the rock is a medium-grade metamorphic rock (amphibolite facies) and consists of hornblende and plagioclase. Nearly all grains (clasts) have approximately the same size (mechanically-sorted) with rounded edges but irregular (mechanically abraded) boundaries, and they are neither euhedral nor subhedral. The same properties are observable from the two thin sections of Mohammad and Aziz (2013) of Pauza ultramafic rock. The first one exhibits an irregularly broken periphery of a coarse hornblende clast which is surrounded by finer ones in schistose texture (Figure 7c). The second shows granular anhedral olivine clasts with fine matrix of same mineral in surrounding areas (Figure 7d). Mafic or felsic granulite (Gorayeb et al., 2017) is the types of metamorphic rocks that can be considered for some rocks on the mountain. This later article included photos of granulites (p.335) that are similar to those published by Ali (2015) and Mohammad and Aziz (2013) for metabasalt and ultramafic rocks.

These characteristics include the preservation of original sandstone grains in which rock textures are preserved during metamorphism. In Figure (7a), the interstitial spaces between the grains are filled with irregular and anhedral hornblende crystals resembling the irregular intergranular cement of sandstone. These crystals are metamorphosed from a fine-grain matrix which was derived from a volcanic arc and filled the interstitial spaces between clasts. In this connection Dietrich (1960) referred to the possibility of the distinction of some sedimentary clastic-grain shapes in gneisses. Many thin sections of the quartz rich metamorphic rocks are compared with other volcaniclastic sandstones in other parts of the world (see Sharp and Robertson, 2002; Schmincke and Von Rad, 1979). The results were very comparable in the view of roundness, sorting and irregular boundaries (Figure 8). Before metamorphism, the sedimentary grains already acquired a parallel diagenetic orientation due to compaction and the intense tectonic stress in the synorogenic stress of the Zagros Belt. These diagenetic orientations enhanced the further development of the schistosity, foliation, and banding during the regional metamorphism.

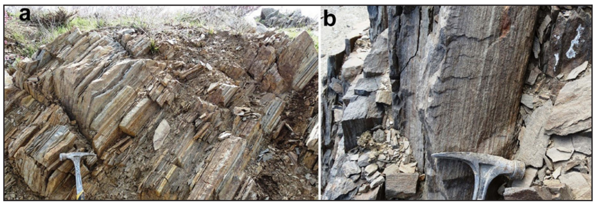

Figure 4. Metamorphosed volcaniclasitc greywakes and shale. **a).** preserved original bedding. **b).** preserved millimetric sedimentation laminae on the head of Shilana Valley 300 m to the north of police check point at latitude and longitude of 36o 11' 32.89" N and 45o 17' 00.86" E.

Figure 5. Horizontal alternation of metamorphosed fine- and coarse-grains of volcaniclastic sandstones (greywackes) beds and marls beds. Previously, these rocks were treated most possibly as volcanic siliceous tuff. They are located at the latitude and longitude of 36° 9' 17.56" N and 45° 14' 41.51" E.

Figure 6. Same alternation at vertical attitude at latitude and longitude of 36° 9' 17.5 6" N and 45°14' 41.51" E, between Darashimana and Lower Beklo villages.

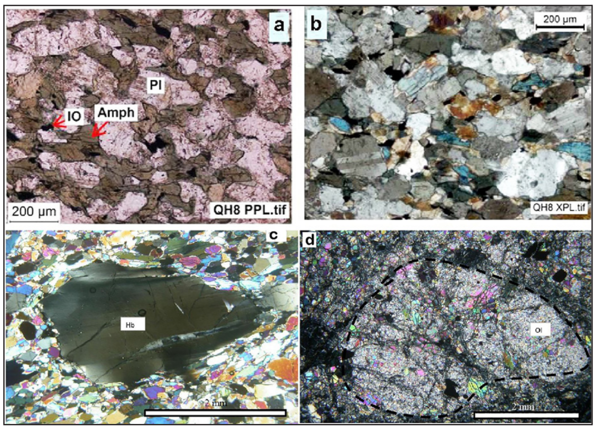

Figure 7. Two thin sections of metabasalt of Ali (2015), the authors think that they show the sorting, and roundness of the cloudy crystals of plagioclase and sutured contacts; **a).** The inter-granular matrix of (possible silt-size volcanic grains) is recrystallized to anhedral hornblende. **b).** Sorting and the anhedral characteristics of the grains of the original volcaniclastic sandstone derived from the erosion of porphyritic volcanic source area. c and d). Thin section photos of ultramafic rock of Pauza (Bulfat Mountain) (Mohammad and Aziz (2013), **c).** The authors think this shows an abraded boundary, granular, anhedral and schistose texture, **d).** Granular and anherdal olivine grains with a fine matrix of the same minerals.

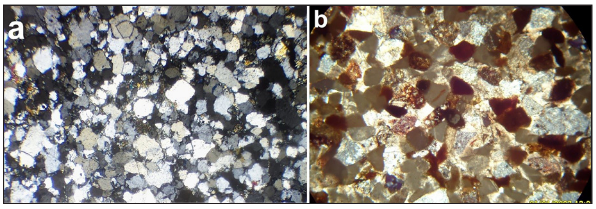

Figure 8. a). metamorphosed quartz rich sediments of Bulfat Complex, s.no.8 XPL, quartz overgrowth can be seen in the upper center. It is compared with; **b).** sandstone of Tanjero Formation) the results are both very comparable in the view of roundness, sorting, grain- interlocking and irregular boundaries, XP light, the lengths of the two photos are 1.5mm.

The forth is the rocks that are claimed to be igneous rocks can be seen in horizontal, oblique and vertical tilted conditions in the same area; they underwent the same folding directions and intensities of the marbles and fresh volcaniclastic rocks that are at the boundary of the complex (Figures 4-7). Therefore, if these rocks are volcanic or plutonic rocks, they must be of a synsedimentary eruption or intrusion, which must show a basaltic flow, pillow basalts, volcanic cone, ropy and amygdaloid and dilatation (local swell between sediments) structures in addition to glassy texture and contact metamorphism. During field work, the present authors did not find any of these structures. Additionally, they found two types of successions (rocks). The first includes fresh thick successions of volcaniclastic sandstone described in the previous paragraphs. The second is a successions dominated by marl with a subordinate impure sandstone (now changed to light and dark metamorphosed greywackes); these successions are very similar to the acidic tuff recorded in previous studies, especially the marl, in most places, is a friable easily-weathered and slightly-metamorphosed with a light grey color resembling wood ashes (Figures 6-7).

The fifth evidence is the presence of large lensoidal bodies, bedding, lamination and erosional surfaces in the previous gabbros and peridotites on the Bulfat Mountain. The lensoidal bodies have a length of 4-40 and a thickness of 0.2-6 meters of volcaniclastic coarse sandstones which were metamorphosed and recrystallized to coarse-grained basic gneisses (Figure 9). Hamasalh (2004) considered these rocks as ultramafic rocks, while Mohammad and Aziz (2013) studied the exsolution lamellae in the orthopyroxene of lherzolite from the Pauza ultramafic rocks; they concluded that the lamellae are formed in a deep mantle.

Some of the rocks (previously claimed to be igneous rocks) exhibit large lensoidal shapes reflecting the submarine channels in which they were deposited (Figure 9). While most others are regularly bedded, laminated, cross-bedded and show sharp erosional surfaces between fine-grain mafic beds and coarse-grain felsic beds (Figure 10a). The paleocurrent can be predicted from the lensoidal shape of the channels which is pointing nearly towards the south. The same types of channels are found near the Waras village on the Mawat Complex where the rocks previously considered as volcanic rocks. The abovementioned south direction of the paleocurrent can be observed from the Waras channel too (Figure 10b).

The strongest evidence (the sixth evidence) for the sedimentary origin of the previous Bulfat ophiolite is the clear gradation between fresh volcaniclastic sandstones (greywackes), around the Complex, and their low and high grades of metamorphosed equivalents in the center of the Bulfat Complex. Geologists can see this gradation (zoning) while walking from the boundary to the core. Due to the stacking of tens of different sedimentary rocks and the intense folding, the metamorphic zoning does not have a certain shape or regular boundaries. Therefore, it is difficult for most geologists to delineate easily the boundaries of zoning of the complex but the progressive metamorphism is very clear from the boundary to the center of the complex.

Figure 9. Submarine channels filled with coarse-grained metamorphosed volcaniclastic sandstones directly to the south of Pauza village on Bulfat Mountain. These rocks are considered as mafic igneous rocks in the previous studies.

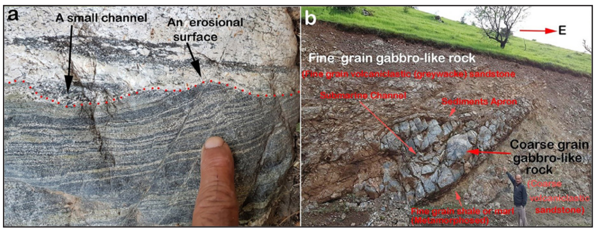

Figure 10. a). an erosional surface, a small channel and laminations in the metamorphosed volcaniclastic sandstone (previously considered as a gabbro), a section of road cut at 1km north of Ganau village east of Esewa town, Bulfat Mountain. **b).** Submarine channel filled with metamorphosed coarse-grain volaniclastic sandstones scored in metamorphosed fine-grain volcaniclastic sandstones at the 500 m southwest of Waras village, at the latitude and longitude 35° 47’ 13.87’’ and 45° 30’ 18.41’’respectively. Previously, its location was believed to be the volcanic rocks.

2.2. Absence of dykes and bosses

Buday and Jassim (1987) reported the intrusion of various small size pegmatitic dykes and boss-like bodies into the calcareous and pelitic rocks of Bulfat Complex. They added that the dykes consist of white coarse-grained feldspar, and they cut across older intrusions and country rocks. Buda (1993, p.36) recorded many white feldspar-rich pegmatite dykes in the plutonic and metamorphic rocks. He added that they have different composition depending on their occurrences, and that the feldspar dykes in the pyroxene-amphibole gabbro and diorite are rich in sodium (An32). He further added that Dykes, in olivine gabbro or diorite are rich in calcium (labradorite, An56), which commonly has been altered to zoisite and prehnite.

The present authors, has not observed dykes and bosses in the Bulfat Complex and in the whole Northern Iraq. In the complex, they observed two types of bodies, the first one is a succession of a dark coarse-grain alternation of felsic and mafic volcaniclastic sandstones which are tightly and isoclinally folded during tectonic deformations, and they look like small dykes or bosses. This succession is now metamorphosed regionally to rocks which resemble gabbro or diorite. In the folds, the white (feldspars) and dark (pyroxenes) sedimentary laminations are bending 180 degrees, this bedding is true for the associated marble and calcsilicate layers (Figures 11a and 12). A close look revealed that there is not even one millimeter of contact metamorphism between the rocks claimed to be gabbro and the marble in the fold. If the succession in the photo is restored to a horizontal condition before deformation, it would look exactly like the contact between Kolosh and Sinjar Formations as appear from the photos (11b) at 500 m southwest of the Kalk Smaq village in the Dokan Area. The interesting fact is that both successions of Kalka Smaq (near the Low Foded Zone) and Bulfat Complex are of the same age (Paleocene-Eocene) (Figures 11a and b). Most of the metamorphosed limestone occurs as pure calcite marble, while it contains silicate minerals in the core of the Complex where metamorphism is maximum (Figure 11b).

The second type constitutes are faulted large and small veins in all metamorphosed volcaniclastic and marble rocks of the studied area which most probably and incorrectly were identified previously as dykes. These veins extend for several meters cutting across layering, and generally have a wedge-shape since they become narrower at one end (Figure 13). These veins are originally fractures generated before metamorphism during tectonic burial and deformationa. Later, they were filled with calcite and were then replaced predominately by plagioclase, quartz with subordinate amphiboles or pyroxene during regional metamorphism. During metamorphism, they were transformed to coarse-grain rocks similar to granitoids or dioritic rocks. In this regard, Spotl et al. (1999) mentioned replacement of calcite by plagioclase (albite) under high temperatures and in deep burial diagenetic environments (in presence of brine fluid). They added that the replacement ranges from high-grade diagenesis (150-200 °C) to lower green schist facies (300-350 °C), and in the siliciclastic sediments, the replacement began earlier and on a large scale.

Korh et al. (2011) recorded many albite veins in greenschist facies metabasites or in sheared and banded volcano-sedimentary rocks with sharp contacts with their host rocks, without alteration haloes. They added that they are, generally, centimeteric to decimetric wide, and in some places can be traced for several meters. Albite veins are monomineralic or may occur in association with quartz. They further added that the albite is coarse-grained (up to 1 cm) and well- crystallized, without preferential orientation, and the veins were often emplaced in the shear zones' postkinematic phase.

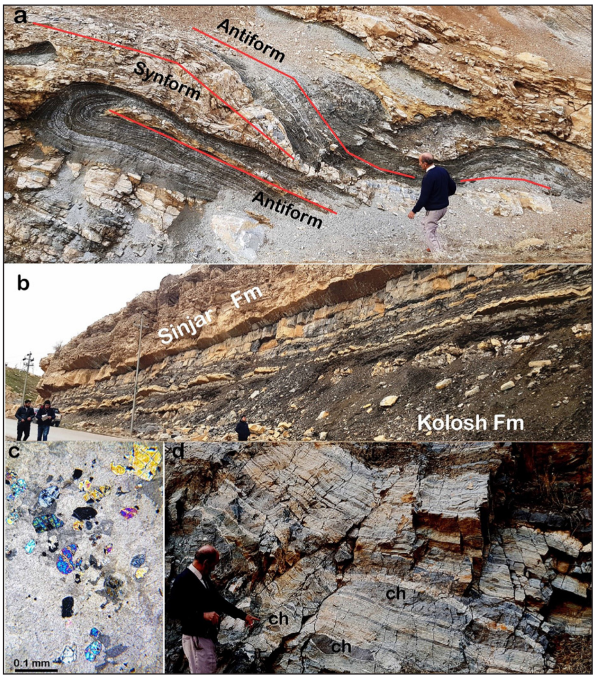

Figure 11. a). Intensive deformation limb-on-limb antiforms and a synforms (bended 180 degrees and overturned toward southwest, the red lines are traces of axial plain of folds. It is regionally metamorphosed volcaniclastic sandstone (greywacke) overlain by marble (limestone) without contact metamorphism. They were considered previously as layered gabbro, a section along the road cut at latitude and longitude of 36° 9' 55.18" N and 45°15' 9.64" E on the paved road to Kele Border Check point. **b).** If the succession in the photo (a). is restored to a horizontal condition before deformation, it would look exactly like the contact between Kolosh and Sinjar Formations as appears from the photos (b) at 500 m southwest of Kalk Smaq village Dokan area. The rocks of both photos nearly have the same ages (Paleocene-Eocene). **c).** Calc-silicate rock with olivine (colored grains) and calcite (grey) near the Iranian border on the paved road on the top of the Bulfat Mountain, s.no.11, XPL. d) The alternation of the felsic and mafic-rich layers of volcaniclastic sandstones with small channels (ch) at 300 m west of Beklo village. These rocks were previously considered as gabbro and diorite.

There are many evidences to prove the absence of dykes; the first is the lack of a sign of dilatation among hundreds of the inspected claimed intrusions, which is expected to be the main evidence of the forceful intrusion of igneous rocks into sedimentary or igneous rocks (Figure 12). The second is the absence of cross-cutting relations of the claimed basic or granitic dykes with layers of host rocks (volcaniclastic, calcareous and pelitic rocks) (Figure 11). In contrast, all of the claimed basic and ultrabasic claimed dyke-like bodies always extend parallel to the original layers of the volcaniclastic sandstones (Figures 11-12). The third is the absence of a chilled border and metamorphism across the boundaries of the rocks claimed to be dykes; if they were hot and magmatic materials, they must have chilled borders of fine-grain hornfels or have gradation boundaries. The forth is the record of Buda (1993) in which he mentioned that dykes cut both plutonic igneous and metamorphic bodies. This record is important since it means that the dykes ascended after the intrusion of main igneous bodies and the metamorphism. This statement debilitates the idea of the igneous dykes and sustains the idea of the calcite and plagioclase veins and fractures, since the dyke commonly bifurcated from (or associated with) igneous intrusions and predate main metamorphism.

2.3. Presence of para-gneiss, granulite and migmatite

Many evidences can be presented to manifest the occurrence of paragneisses and granulite on the Bulfat Mountain. One of these evidences is the frequent presence of coarse-grain rocks regularity banded with light and dark colored minerals (Figure 14). In addition to banding, all linear and platy minerals have parallel arrangements forming foliation and lineation. These rocks were considered as gabbros in many localities of the mountain by previous studies; however, Aswad et al. (2013, p.111) observed a rhythmic layering in the gabbro (in the Rashid valley) which consisted of labradorite (light) and dark (mafic) minerals of augite and hornblende. Additionally, they described one type of gabbro as "pseudogranitoid gneiss" due to the foliation of pyroxene which is equivalent to the present para-gneiss.

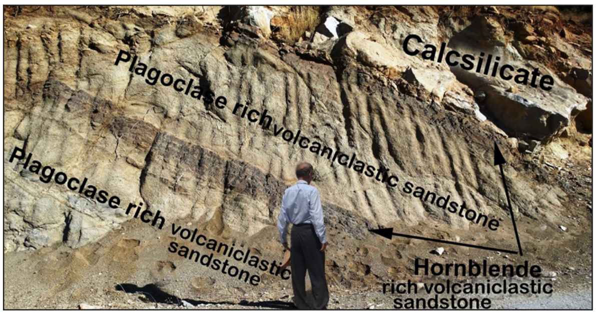

Figure 12. A tilted sequence of felsic and mafic beds of metamorphosed volcaniclastic sandstone (plagioclase and hornblende rich layers) on Bulfat Mountain with marble at the top, at the latitude and longitude of 36° 10' 37.02" N and 45°16' 32.89" E. The marble is originally a shallow reefal carbonate of Naoperdan Formation.

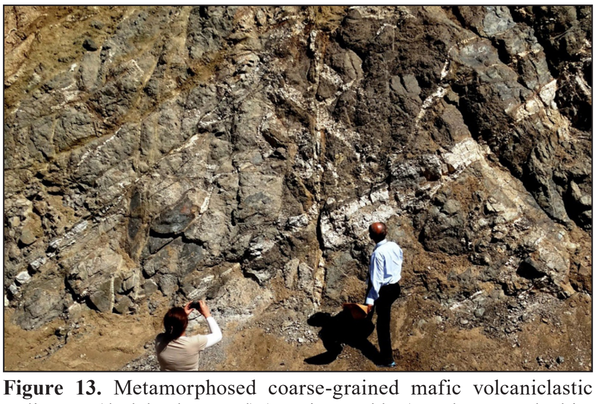

Figure 13. Metamorphosed coarse-grained mafic volcaniclastic sediments (dark background) (previous gabbro) cut by several white discordant and concordant faulted veins (possibly earlier calcite veins), which are regionally metamorphosed to dominant white plagioclases, quartz and amphiboles. Location: at the latitude and longitude of 36° 11' 21.07" N and 45°17' 07.68" E.

The second evidence is the recording of possible migmatite which is an incipient local melting of the gneiss or granulite rocks (Figures 15b and 16). These migmatite bodies have uneven boundaries (surfaces) and irregular aerial distributions; at some places, they are 3 meters long and 2 meters thick. The bodies are not intrusions since they have no connection, from any sides, to the surroundings and are encircled by relatively finer-grain granulite from all sides. The migmatites are extremely coarse-grained with dominant plagioclase and miner amounts of hornblende or nepheline. In these migmatites, the crystals are randomly distributed (Figure 15). But we do not excluded a deformed channel (filled with coarse felsic grains), as origin of these bodies, since the areas of their occurrences are intensely deformed and their shapes are more or less lensoidal.

The third evidence is the published geological map by Buda (1993) which shows many long and zig-zag bending bodies of the xenoliths inside the claimed igneous rocks of the complex in the central and southeastern part of the Bulfat Complex. These xenoliths are numerous and cover half of the outcrop of the previous gabbros and diorites (Figure 1b). These voluminous and numerous bodies (now exist as low- or medium-grade metamorphosed volcanoclastic sediments) are unusual, and need further explanations than the previous ones. The explanation provided by this study refers to the common origin of the host gneisses (or granulites) and xenoliths, each one is part of different lithologies of the same volcaniclastic succession. The porous coarse-grain greywackes are metamorphosed to gabbros or diorites-like rocks, while the siltstones and marls are partially metamorphosed and remained as the xenoliths. The shallow burial of the xenoliths (sedimentary successions) is possible; therefore, they are mildly metamorphosed as the cover rocks of the Complex, while the deeper buried rocks changed to paragneiss or granulite. Another possibility for the origin of the xenoliths is the preservation of some depositional properties of the original thermally-resistive rocks of the sedimentary successions (laminated impervious beds after metamorphism). In contrast, the non-resistive associated sedimentary rocks changed to felsic and mafic gneisses which are treated by many authors as gabbros (Figure 14a).

The fourth evidence is the inability of the petrology (under microscope in mm scale) and geochemistry to solve the controversy of the origin of the Bulfat metamorphic and igneous rocks due to their high diversities as recorded by the previously mentioned authors. These two methods cannot show if the rocks' constituents (such as olivine, pyroxene, and plagioclase grains or crystals) are transported for long distance from their sources or they are indigenous (home-grown) and crystallized in the Bulfat area from magma. But our fieldworks inside and outside the complex (boundary condition studies) decoded the origin of these rocks, that are previously studied, as peridotite, serpentinite–matrix mélange, serpentinite, granitoids, melanocratic gabbro, Nepheline syenite, diorite, granitoid-gabbro association, xenoliths in gabbro and diorite, pseudogranioid, troctolite, olivine gabbro, old gabbro, new Gabbro, amphibole-pyroxene gabbro, metadiabases, basalt, metabasalts, andesite, meta- and acidic tuff. In their study, Al-Hamed et al. (2019)

recorded five types of pegmatites in the Complex.

The metamorphic rocks are also numerous too, and include many types of hornfelses-like rocks and schists. One may ask how and why all these rocks do coexist over several square killometers and are exposed as thousands of beds (layers)? The present study answers this question via suggesting a simple common origin for all of these metamorphic and igneous-like rocks. The answer is the suggestion of a sedimentary origin which can solve the mystery of the rocks swarming of the Bulfat Mountain. The sedimentary origins can group them all in one geochronological, geochemical, tectonical, and petrological framework which is the Metamorphic Core Complex. The mineralogy of both exposed metamorphic rocks and their parent sedimentary rocks were nearly similar; they were derived from the erosion of remote igneous source terrains (basaltic arc) far inside the Iranian territory. The detritus from the arc were transported to the Bulfat area during Paleocene-Eocene by turbidity currents, and were deposited in the deep basin. The water energy and hydraulic activities were separated and increased the concertation of certain minerals as vast beds or as localized lensoidal channels. After the metamorphism, they yielded different rocks; therefore, the metamorphism to gabbro-like or peridotite-like and other rocks was possible especially with the availability of all essential materials, porosity, entrapped seawater, and the different mixtures of volcaniclastic clasts of mafic and felsic mineralogies.

Therefore, the progressive metamorphism of units such as the Walash-Naoperdan Series will give all types of metamorphic and "igneous rocks" since they contain all types of silicate and carbonate sediments that produce different types of the igneous-like rocks, gneisses, ganulites and marble, and calcsilicate rocks when thermally or regionally metamorphosed. The progressive metamorphism of pure and impure sandstones (greywakes) and shales will produce felsic and mafic gneisses or granulites. Their content of marl and calcareous shale will produce a rock similar to the siliceous tuff by low-grade metamorphism, while by high-grade they remain as layered xenolith because they are resistive to thermal metamorphism relative to other rocks.

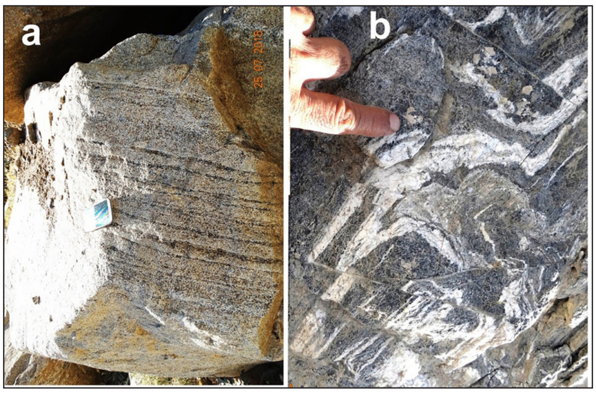

Figure 14. a). Gneiss on Bulfat Mountain at the eastern boundary of the Hero Village. **b).** possible partial melting inside metamorphosed mafic volcaniclastic forming felsic migmatite but a felsic-rich layer is not excluded.

Figure 15. a). A possible migmatite body in side granulite or gneiss with irregular boundaries and isolated from all sides, a section along a road cut at the peak of Bulfat Mountain at 200 m east of the police check point. **b).** A small pegmatite body inside gneiss on the Bulfat Mountain at 300m south of the police checks point on the peak of the mountain. In both photos, channels filled by coarse-grain felsic sandstone are not excluded.

The fifth evidence is the highly-deformed (sheared and foliate) and cloudy textures of the most rocks claimed to be diorite, gabbros and peridotites which appear, under polarizer microscope, as stressed and sutured grains (Figure 16). The cumulate and adcumulate textures of the igneous rocks (Wager et al. (1960) are not observed in all of the inspected thin sections. The stressed and deformed rocks which are claimed to be mafic and ultramafic rocks (especially around Pauza village) are discussed in detail by Hamasalh (2004). In thin sections, most of the texture of these rocks shows foliations, but non-foliated granular and coarsely-crystallized textures are not rare especially at the center of the Complex; they are composed of plagioclase, pyroxene and olivine (Figure 16). Mafic granulite (Yu et al., 2019 and Gorayeb et al., 2017) is the best name to be used for these granular and high-grade facies which are lacking crystal zoning and cumulate textures.

The Walash-Naoperdan Series occurs around the Bulfat and Mawat complexes (at least, at the south, southwest and southeast) apparently below the Red Bed Series, and consists (as previously indicated) of a mixture of volcanic rocks, sedimentary rocks, and carbonate sediments. But the present study inferred that the series does not contain volcanic rocks; instead, it consists of volcaniclastic sandstone, shale and greywacke (Figure 17) that was derived mainly from the volcanic (basaltic arc) source areas. These sediments can produce the gabbro or diorite-like rocks after metamorphism and crystallization.

Between Beklo and Wasena villages and on the eastern side of the unpaved road, a clear succession of a metamorphosed coarse-grained dark volcaniclastic succession can be observed about 10m thick (Figure 17); it was considered by Buda (1993) as gabbro. This succession is very similar to the fresh and coarse sandstone successions near Darawena and 1 km south of Darashmana villages. The same succession occurs in the south Mawat Complex between the Bard Pan and Gabara villages, and consists of a thick succession of fresh volcaniclastic sandstones; that is very similar to the metamorphosed succession near the Belko village on the Bulfat Mountain in outcrop alternation (Figures 17-19).

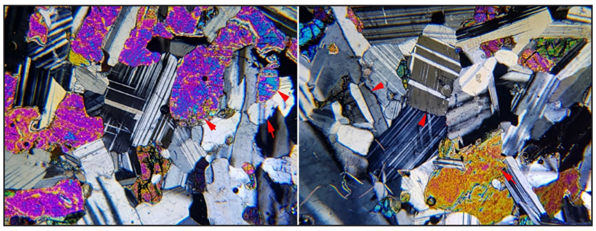

Figure 16. coarse crystalline previous gabbro (present mafic granulite resulted from metamorphosed coarse-grain volcaniclasts sandstones which have sutures boundaries (red arrows) and no cumulate texture 500m to the west of the Iranian police station on the border on the Bulfat Mountain, s.no.12, XPL

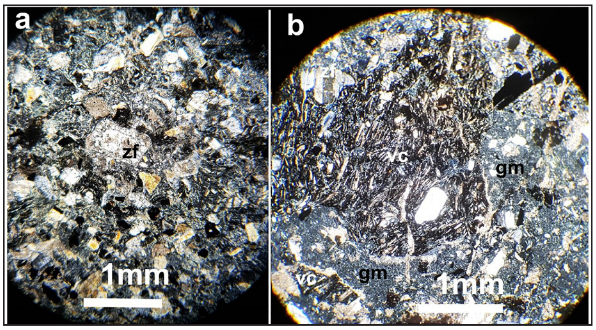

Figure 17. a). Volcaniclastic sandstone of Walash-Naoperdan Series (in Mawat area) derived from volcanic source area and mostly consists of zoned plagioclase (zf) volcanic clasts under XP light, S.no. 15. **b).** The same sandstone shows large clast (grain) (vc) of volcanic rocks with fine-grained groundmass (gm).

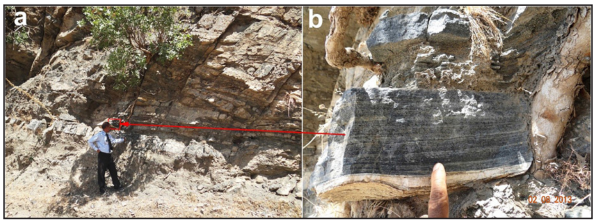

Figure 18. a). Metamorphosed succession of well-bedded and laminated volcaniclastic sandstone composed mainly of hornblende and plagioclase, exposed between the Beklo and the Wasena village at the latitude and longitude of 36° 9' 2.74" N and 45° 16' 0.32" E. **b).** A close-up photo of the laminated bed in the red circle shows regular and parallel laminations, the present study assumes that they are originally sedimentary and belong to the Walash-Naoperdan Series.

Figure 19. Comparison between: **a).** stacking pattern of the layered hornfels-like rocks (near the Beklo village) and **b).** Fresh the volcaniclastic sandstone (greywacke) of the Walash-Naoperdan Series at 3km east of Mawat town on the road to the Gabara village.

The sixth evidence is the well-known idea of the open-system processes and the multiple-sources of the intruded gabbroic magma of the Wadi Rashid gabbro by Aswad et al. (2013). This idea supports our sedimentary origin theory of the Bulfat Complex and the presence of gneiss rocks, since most complete open system is a sedimentary basin, which was supplied at different times and places by different sediments from tens of source areas and environments. However, this open system of the sedimentary rocks hosts possible small localized closed systems due to the sandwiching of different rocks by others of different mineralogical and textural properties. These closed systems produce unexpected metamorphic rocks in small areas where, in some cases, several metamorphic rocks can be seen along few meters a head (Figure 12). In contrast to the present study, Elias and Al-Jubory (2014) studied the provenance and tectonic setting of the metapelites deposits in the Bulfat Complex, and concluded that pelites may have been originally derived from an old post-Archean granitic upper continental crust.

The seventh evidence is the diversities of the age determination of the different rocks of the Bulfat Complex which implies the same ages of the rocks claimed as igneous and the metamorphic rocks. Nearly, all the determined ages by radioactive methods ranged between 33 and 45 million years. The age determination (by the $^{40}Ar/^{39}Ar$ method) of the metamorphism of the pelitic rocks far from the bodies (claimed as igneous) by Karo et al. (2018) is 35 Ma, while the age determination of igneous rocks crystallization by Karo, (2015), Ali (2017) and Jassim et al. (1982) is 41, 39, and 40- 45 Ma, respectively.

From these ages, two facts are clear, the first is a difference in the age of the crystallization of igneous rocks, and the second is the age similarity of the metamorphic rocks that are far from and close to the claimed intrusions. A 10 Ma difference in age implies metamorphism and magmatism are not related in particular if the same method was used on the same minerals.

In the magma, the biotite is last mineral that crystallizes, so its age must be younger than the country rocks which crystallize when the magma is near its peak temperature. Furthermore, the age of biotite reflects the age of the closure temperature of biotite with regard to the isotopes used.

3. Discussion

3.1. Possible Metamorphic Core Complex (MCC)

The previous tectonic models of the Ophiolite Complex cannot answer all questions about the origins of the diverse rocks that are arranged in successions of thousands of layers in a small geographic area with cross beddings, erosional surfaces, and tens of thousands of laminations. Additionally, there is a clear gradation between pure (unmetamorphosed) greywackes and their low- or high-grade metamorphic equivalent rocks (basic and felsic gneisses and granulites). This is true about the controversy and discrepancy regarding their types and geologic settings. The field and lab observations as well as the literature reviews convinced the present authors to propose a new tectonic model which is Metamorphic Core Complex (MCC). This model can probably solve the problems regarding the mixture of numerous dissimilar sedimentary, metamorphic, and igneous-like rocks in highly sheared and uplifted small areas.

Ring (2014) defined MCC as a rock complex which resulted from a horizontal lithospheric extension; it forms in the low-viscosity lower crust when the extension occurs at high rates and deformations occur within the upper crust in localized detachment faults. They are oval-shaped and usually updomed (anticlinal) structures in which midcrustal basement rocks of higher metamorphic grade have been tectonically juxtaposed against low-grade upper crustal rocks.

According to Coney (1980), metamorphic core complexes are normally characterized by a heterogeneous, older metamorphic-plutonic basement terrain overprinted by low-dipping lineated and foliated mylonitic and gneissic fabrics. Furthermore, a sedimentary cover terrain is typically weakened and sliced by numerous subhorizontal younger-on-older faults. He further added that between the basement and the cover terrains is a detachment fault and/or steep metamorphic gradient with much brecciation and kinematic structural relationships indicating sliding or detachment. MCC is defined by Lister and Davis (1989) as a crust structure which resulted from major continental extension, when the middle and lower continental crust is dragged out from beneath the fracturing, extending the upper crust. Deformed rocks in the footwall are uplifted through a progression of different metamorphic and deformational environments, producing a characteristic sequence of (overprinted) meso- and microstructures.

Huet et al. (2011) mentioned that the development of MCC corresponds to a mode of lithospheric continental stretching that follows collision. They added that the rheological layering of the crust inherited from collision is a first-order parameter controlling the development of extensional structures in post-orogenic settings. 'Cold' MCC can develop, if the crust is made of a strong nappe thrust on the top of weaker metamorphic cover and basement units. Okay and Satir (2000) summarized MCC in the mountain belt of western Turkey Kazdağ mountain range which is associated with a rapid exhumation in which gneiss, amphibolite, and marble are metamorphosed at 5kb and 640 C°. They added that the unmetamorphosed cover rocks, ductile shear Zone, mylonite and normal fault (brittle deformation) occurred at an upper level.

These characteristic features can be observed on the Bulfat Mountain including the ductile deformation (Figures 9 and 17), the foliated mylonitic, and the gneissic texture (Figures 14 and 21) and surrounding of Metamorphoc rocks by unmetamorphed sediments (Figures 1 and 16 see Walash Series, Red Bed Series and Tanjero Formation).

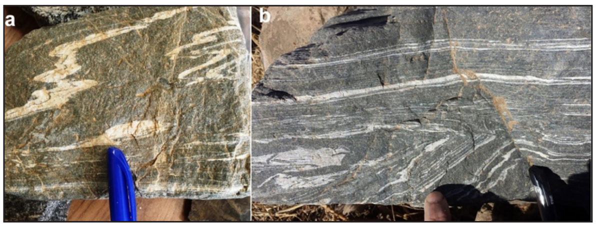

Figure 20. Intense deformation of the metamorphosed greywacke (with sedimentary felsic and mafic-grain-rich laminae), a) as ptygmatic folding of previous fractures, b) folding of white and black laminae in form of synforms and antiforms. These folds are deformed before metamorphism during tectonic burial.

The MCC occurs in different tectonic settings such as extension, compression, and shields settings. According to DeCelles (2004) and Crittenden et al. (1980), the Cordillera belt is a fold thrust belt that was developed during Jurassic-Tertiary. They added that the belt contains more than twenty-five large bodies of MCCs, and extends from Canada to Mexico passing through central USA. In these MCCs, Vanderhaeghe et al. (1999) discussed the role of partial melting in generation of migmatites and granitic bodies (Figure 15a) which later underwent late-orogenic collapse, and exhumation of high-grade rocks in the hinterland of a thermally mature orogenic belt. As for the Zagros orogenic belt, Alizadeh et al. (2010, p.338) discussed geochronology in a metamorphic core complex (or gneiss dome).

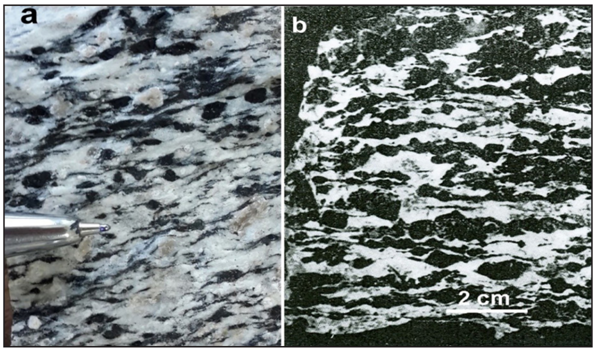

Figure 21. a). Augen and foliated gneiss (mylonitic gneiss) on Bulfat Mountain 400 m to the east of the police check point. **b).** the same type of rock was reported by Jassim et al. (1982) near Beklo village and is considered by them as Pyroxene amphibole gabbro.

The overall shape, rock types, and tectonic position (location) of the latter MCC are very similar to those of the Bulfat and Mawat MCC, only being older (77 my). The Bulfat MCC is associated with extension and normal faulting both locally and regionally. On a local scale, many normal faults can be seen which occurred after metamorphism (during uplifting) (Figure 22). On a regional scale, Karim, (2006) discussed in details the occurrence of a normal fault (Mawat fault) at the south eastern boundary of the Complex (Figure 23). At the northern boundary of the Complex, Mohajjel and Rasouli (2014, p.68) drew a normal fault which extends tens of kilometer inside Iran parallel to the Complex long axis. In the past, Karim et al. (2009, p.61) considered the Bulfat Mountain as horst, and drew two normal faults at its northwest and southwest boundaries (Figure 23a). All other works on MCC agreed that it has a domal shape (anticline); these include Coney (1980, p12), Daczko et al. (2009) and Charles et al. (2012); previously, Jassim et al. (2006, p.304) has shown the Bulfat Mountain as an anticline.

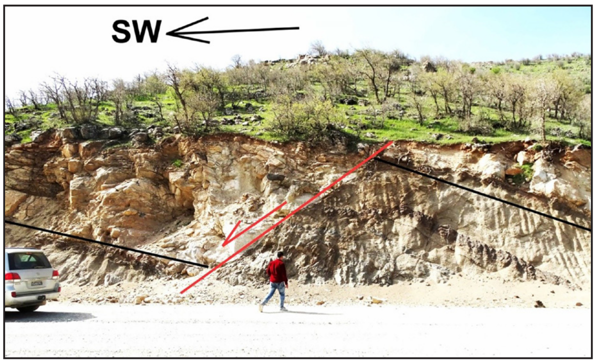

Figure 22. A normal fault (as a sign of extension) in the metamorphosed greywacke and felsic sandstone overlain by limestone (marble) at the southwestern boundary of the Bulfat Complex at the latitude and longitude of 36° 10' 36.92" N and 45° 16' 32.49" E.

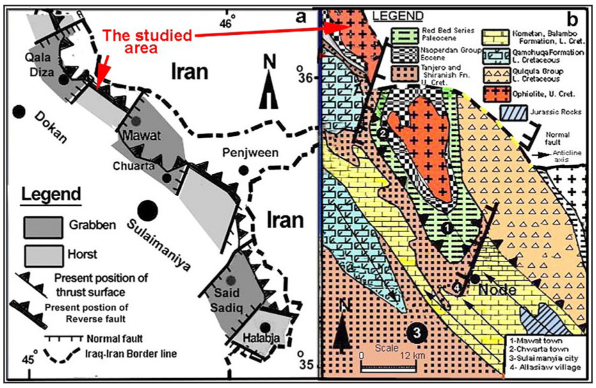

Figure 23. Two maps showing the Bulfat Mountain bounded by two normal faults (horst) from the northwest and the southeast. a) Karim et al. (2009) and b) Karim (2006).

3.2. Depositional Basin of the sediments of the Bulfat Core Complex

According to Aswad et al. (2016), the plutonic rocks of the Bulfat Complex were emplaced into the ophiolite bearing terrain (Albian-Cenomenian) shortly after the 45Ma. They added that the Walash-Naopurdan volcanic activity and the intrusion of the multiphase Bulfat Complex indicate the presence of a dual subduction-zone system in the Iraqi Zagros Zone. Based on geochemical signatures, Ali (2017) attributed the dikes in the Bulfat area to an extensional tectonic environment, such as an intra-arc rift. Karo (2015) considered the Bultat metapelites as a probable derivation from the active continental margin (with an arc affinity) of the Sanadaj-Sirjan Zone.

The sediments of the Bulfat metapelites were derived from the active margin of Iranian microcontinent of the Sanandaj-Sirjan Zone (Elias and Al-Jubory, 2014). The Igneous intrusion in the Bulfat area occurred during the final stage of the primary Cretaceous folding (i.e. most probably in the Laramide orogeny) and the metamorphism affected only Cretaceous rocks (Jassim et al., 1982). Aqrawi, and Sofy, (2007) attributed Bulfat igneous intrusions to a volcanic arc basalt affinity.

The field and lab works in the present study disagree with the above suggested origins of the rocks of the Bulfat Complex. Conversely, indicate that the rocks of the Bulfat MCC are metamorphosed volcaniclastic sandstones (greywackes) and shales. They were deposited after continental collision and the generation of the foreland basin. Their source areas were a terrestrial land consisting mainly of basaltic and andesitic sources (with possible plutonic ones) of the Urumieh-Dokhtar Magmatic Arc. These sources include old and uplifted sediments derived during earlier ages from the arc (Figure 24). After erosion, these sediments were transported and deposited in the Zagros Foreland basin during Paleocene-Eocene by turbidity currents. The model in the latter figure illustrates the Paleocene morphology of the depositional features of the submarine turbidity fan which consists of submarine canyon, gulleys, different type of channels, levees and lobs surface. According to Deptuck and Sylvester (2018), each feature of the submarine fan has its sediment types ranging from silts to conglomerates. Therefore, by this model, the reasons behind the different type of the sediments in mineralogy and caliber can be explained in the Bulfat area. In the channels, different types of clean-coarse sandstones (arenite) of a single or several minerals were deposited, while on the lobe surfaces and levees clay, silt and fine-grain dirty sandstone (greywackes) were lain down. In the channels, the hydraulic sorting of the grain was active due to density and grain-shape sieving. Therefore, in some channels, the gravity sorting induced placer deposits of clasts consisting of olivine or spinel chromium or pyroxene or iron ore which are not rare in the Bulfat, Mawat and Penjween complexes.

During Paleocene-Eocene, the foreland basin, in which the volcanclastic sediments of the Bulfat Complex are deposited, occupied part of the Sanandij-Sirjan Zone of Iran and the whole Iraq. The collision occurred during Campanian and Maastrichtian when the Arabian and Iranian plates collided; consequently, at the first stage, the radiolarites and limestone uplifted close to Arabian Passive Margin and were followed by volcaniclastic sediments (rocks) uplift during. These latter rocks started erosion and provided sediments to the basin (Sanandij-Sirjan Zone) including Bulfat area during Paleocene-Eocene. In the same time, the influx of sediments from the arc (Urumieh-Dokhtar volcanic arc) was continuous too (Figure 24). According to Karim (2004) and Karim and Surdashy (2005) these uplift (obductions) led to the subsidence of the Arabian Passive Margin and the generation of foreland basin during Early Maastrichtian.

During the Paleocene-Eocene age, a thick succession of volcaniclastic sandstones and shales was deposited in the highly subsiding foreland basin. Stratigraphically, they were called in Iraq the "Walash-Naoperdan Series," which consists of clastic and carbonate sediments without volcanic rocks. Later, they were buried deeply by the tectonic loading (thickening) of the crust, and due to this burial, they were intensely deformed both brittlely and ductilely (Figures 19-20).

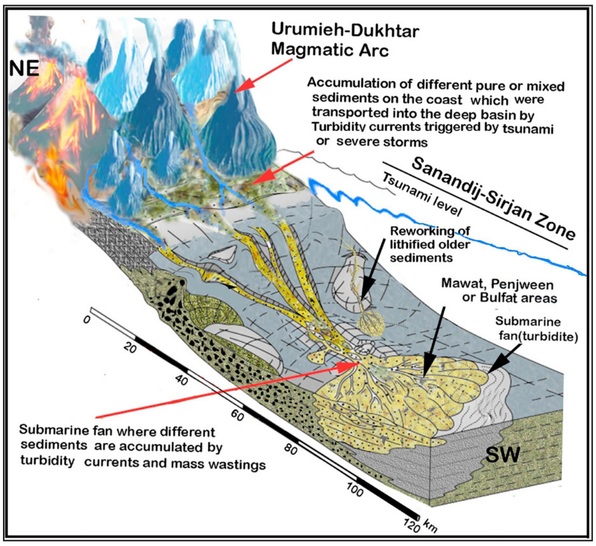

Figure 24. Simplified paleogeographic and tectonic model of the depostion of mafic and felsic valcaniclastic sandstones (and other sediments) by turbidity currents sourced mainly from Urumieh-Dokhtar Magmatic Arc and trassported to the Iraqi part of the Sanandij-Sirjan Zone (Bulfat and Mawat areas). In future works, a more realistic model will be considered.

The deep subsidence had buried and metamorphosed all the sediments regionally under different temperatures and stresses. The deeper parts were metamorphosed up to amphibolite and granulite facies rocks such as gneisses and granulites in addition to rocks similar to hornfels (Figures 18b and 20) which are previously called gabbros, peridotites or syenite. The shallow buried part is characterized by green schist facies which were previously called metabasalts. These rocks grade upward to unmetamorphosed volcaniclastic sediments and limestone which were previously considered as volcanic rocks and xenoliths respectively (Figures 1-2); they are mainly exposed around the MCC. During the Upper Miocene-Pliocene, the Metamorphic Core Complex was uplifted, and was then exposed weathering and erosion (Figures 25-26). This erosion had supplied huge quantities of conglomerates and sandstone to the progressive southward withdrawal of the Upper Miocene-Pliocene Upper Bakhtiary Basin.

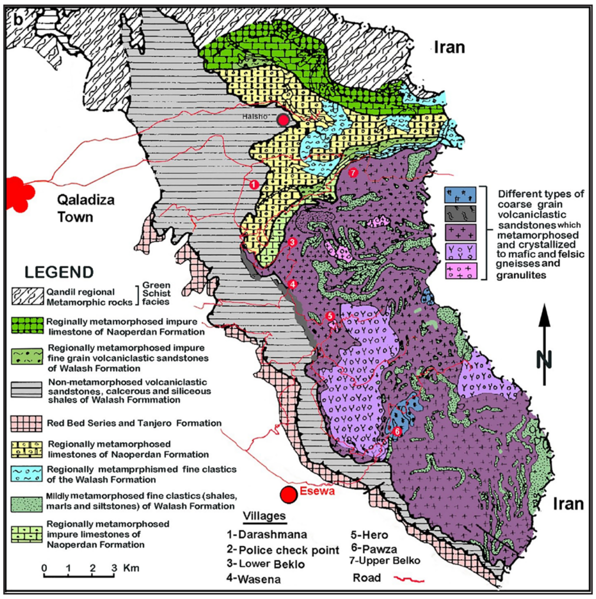

Figure 25. A geological map of the Bulfat Metamorphic Core Complex on which the rock names of the metamorphosed volcaniclastic sandstones and other sedimentary rocks of the present study are plotted. In the future, the rock boundaries need more accurate mapping.

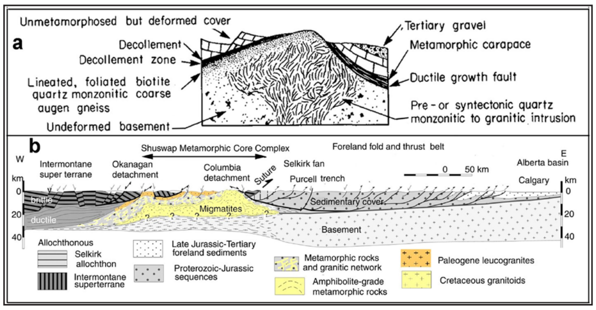

Figure 26. Two Tectonic Models of Metamorphic Core complexes. a). Davis and Coney (1979) and b). Vanderhaeghe et al. (1999).

4. Conclusions

1- The previous "Bulfat Ophiolite Complex" is changed to the Bulfat Metamorphic Core Complex, and the presence of ophiolite and volcanic rocks in the Bulfat and Qaladiza areas is not supported.

2-All exposed rocks in the Complex consist of either fresh volcaniclastics sediments (sandstone, conglomerate, greywackes and shale) or their regional metamorphosed equivalents rocks.

3- Basalts, metabasalt, and plutonic igneous rocks of previous studies are not found on the Bulfat Complex.

4- Most metamorphosed rocks preserved their original sedimentary structures and textures such as the planar beddings, laminations, cross beddings, folding, cross bedding, erosional surfaces, and their granular textures.

5- The Complex consists of thousands of layers of more than ten rock types which all metamorphosed regionally to green schists and amphibolite facies, and locally to gneisses and granulites.

6- Due to the preservation of sedimentary structures (laminations), the metamorphic rocks look like different types of hornfels.

7- All of the rocks previously described as dykes are neither dyke nor sill; rather, they are metamorphosed coarse-grain felsic or mafic sandstones deposited in the submarine channel.

8- The origins of the rocks of the Bulfat Complex are sediments that were originally transported to the Bulfat area from the Urumeh-Dokhtar Magmatic (basaltic) Arc by turbidity currents during Paleocene -Early Eocene. During the Late Eocene- Miocene, they were buried and metamorphosed; however during the Late Miocene-Pliocene they were uplifted.

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References

Al-Hamed S.T., Aswad K.J., Aziz N.R. (2019). Classification of Composite Pegmatite via Staining and Digital Image Processing in the Bulfat Complex, Qala Deza, NE (Iraq). In: Doronzo D., Schingaro E., Armstrong-Altrin J., Zoheir B. (Eds.). Petrogenesis and Exploration of the earth's Interior. CAJG 2019. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham.

Ali, S.A. (2015). Petrogenesis of metabasalt rocks in the Bulfat Complex, Kurdistan region, Iraqi Zagros Suture Zone, Kirkuk University Journal, Scientific Studies (KUJSS) 10 (3): 242-258.

Ali, S.A. (2017) 39 Ma U-Pb zircon age for the Shaki-Rash gabbro in the Bulfat Igneous complex, Kurdistan Region, Iraqi Zagros Suture Zone: rifting of an intra-Neotethys Cenozoic arc, Ofioliti 42 (2): 69-80.

Alizadeh, A., Martınez M.L., Sarkarinejad, K. (2010). 40Ar-39Ar Geochronology in a gneiss dome within the Zagros Orogenic Belt, Comptes Rendus Geoscience 342: 837–846.

Andrew, A.S. (1984). P-T-X (CO,) conditions in mafic and calc-silicate hornfelses from Oberon, New South Wales, Australia, J. metamorphic Geol 2: 143-163.

Aqrawi, A.M., and Sofy, M.M. (2007). Petrochemistry and Petrogenesis of Bulfat Mafic Intrusion, Qala Dizeh, Iraqi National Journal of Earth Sciences 7(1): 33-60.

Aswad, K.J., Ali, S.A., Al-Sheraefy, R.M., Nutman, A. P., Buckman, S., Jones, B.G., Jourdan, F. (2016). 40Ar/39Ar hornblende and biotite geochronology of the Bulfat Igneous Complex, Zagros Suture Zone, NE Iraq: New insights on complexities of Paleogene arc magmatism during closure of the Neotethys Ocean, Lithos 266–267: 406-413.

Aswad, K.J., Al-Sheraefy, R.M., Ali, S.A. (2013). Pre-collisional intrusive magmatism in the Bulfat Complex, Wadi Rashid, Qala Deza, NE Iraq: geochemical and mineralogical constraints and implications for tectonic evolution of granitoid-gabbro suites. Iraqi National Journal of Earth Sciences 13 (1): 103-137.

Aziz, N.R. (1986). Petrochemistry, petrogenesis and tectonic setting of spilitic rocks of Walash volcanosedimentary Group in Qala Diza area, NE Iraq. Unpub. M. Sc. Thesis, Univ. of Mosul, 181pp.

Bolton, C.M.G. (1958). The geology of the Raniya area. Site Inv. Co. report, S. O. M. library, report no. 271, Baghdad.

Buda, G.Y. (1993). Igneous petrology of the Bulfat area (North-East Iraqi Zagros Thrust Zone) Acta Mineralogica-Petrographica, Szeged 34: 21-39.

Buday, T., (1980). Regional Geology of Iraq: Vol. 1, Stratigraphy (Eds.). Kassab, I.I.M and Jassim S.Z.D. G. Geol. Surv. Min. Invest. Publ. 445 p.

Buday, T. and Jassim, S.Z., 1987. The Regional Geology of Iraq: Tectonism Magmatism, and Metamorphism. I.I. (Eds.). Kassab, I.I.M and Abbas, M.J. Baghdad, 445 p.

Charles, N., Gumiaux, C., Augier, R., Chen, Y., Faure, M., Lin, W., Zhu, R., (2012). Metamorphic core complex dynamics and structural development: field evidences from the Liaodong Peninsula (China, East Asia). Tectonophysics 560–561:22–50.

Coney, P.J. (1980). Cordilleran metamorphic core complexes: An overview, in Crittenden, M.D., Coney, P.J., Davis, G.H. (Eds.). Cordilleran metamorphic core complexes: Geological Society of America Memoir 153: 7-13.

Crittenden, M.D., Coney, P.J., Herbert Davis, G., Hamilton Davis, G., (1980). Cordilleran Metamorphic Core Complexes, Geological Society of America, memoir 153, 490p.

Daczko, N.R., Caffi, P., Halpin, J.A., Mann, P. (2009). Exhumation of the Dayman dome metamorphic core complex, eastern Papua New Guinea J. metamorphic Geol. 27: 405-422.

Davis, G.H., and Coney, P.J. (1979). Geologic development of the Cordilleran metamorphic core complexes, Geology 7: 120-124.

DeCelles, P.G. (2004). Late Jurassic to Eocene evolution of the Cordilleran Thrust Belt and Foreland Basin System, Western U.S.A. American Journal of Science 304:105–168.

Dietrich, R.V. (1960). Banded Gneisses, Journal of Petrology 1(1): 99-120.

Deptuck M.E., and Sylvester Z (2018). Submarine Fans and Their Channels, Levees, and Lobes. in: Micallef, A., Krastel, S., Savini, A. (Eds.). Submarine geomorphology: Cham, Switzerland, Springer, p. 273–299, http://doi.org/10.1007/978-3-319-57852-1_15.

Elias, E.M., and Al-Jubory, Z.J. (2014). Provenance and tectonic setting of the metapelites deposits in the Bulfat Complex, NE-Iraq, Arabian Journal of Geosciences 7(9): 3589–3598.

Gorayeb, P. S.S., Pimentel, M.M., Armstrong, R., Galarza, M.A. (2017) Granulite-facies metamorphism at ca. 570-580 Ma in the Porangatu Granulite Complex, central Brazil: implications for the evolution of the Transbrasiliano Lineament, Brazilian Journal of Geology 47(2): 327-344.

Hamasalh, F.R. (2004). Petrochemistry, petrogenesis and tectonic setting of the Pauza Ultramafic rocks, Bulfat Complex, Northeast Iraq, Kurdistan region, MSc. Thesis, University of Sulaimani. P.115.

Huet, B., Le Pourhiet, L., Labrousse, L., Burov, E., Jolivet, L. (2011). Post-orogenic extension and metamorphic core complexes in a heterogeneous crust: the role of crustal layering inherited from collision. Application to the Cyclades (Aegean domain) Geophys. J. Int. 184: 611–625.

Jassim, S.Z., Buda, G., Neuzilová, M., Suk, M. (1982). Metamorphic development of the Iraqi Zagros Ophiolite Zone, Kryst. Alinikum 16:21-40.

Jassim, S.Z. Suk. M. and Waldhausrova, J. (2006). Magmatism and metamorphism in the Zagros Suture in Jassim and Goff, Geology of Iraq. Published by Dolin, Prague and Moravian, p.298-325.

Karim KH (2004). Basin analysis of Tanjero Formation in Sulaimaniya area, NE-Iraq. PhD thesis, University of Sulaimani University, 135p.

Karim, K.H. (2006). Some sedimentary and structural evidence of possible graben in Chuarta-Mawat area, Sulaimanyia area, NE-Iraq. Iraqi, Jour. Earth Sci. 5 (2): 9-18.

Karim, K.H. and Surdashy, A.M. (2005). Tectonic and depositional history of Upper Cretaceous Tanjero Formation in Sulaimanyia area, NE-Iraq. Journal of Zankoy Sulaimani 8(1): 1-20.

Karim, K.H., Fatagh, A.I., Azad Ibrahim, A., Koy, H, (2009). Historical development of the present day lineaments of the Western Zagros Fold-Thrust Belt: A Case study from Northeastern Iraq, Kurdistan Region. Iraqi Journal of Earth Sciences 9 (1): 55-70.

Karo, N.M. (2015). Metamorphic evolution of the Northern Zagros Suture Zone (NZSZ), Dissertation, zur Erlangung des akademischen Grades, Doctor rerum naturalium (Dr. rer. nat.) in der Wissenschaftsdisziplin “Mineralogie Institut für Erd- und Umweltwissenschaften Mineralogie, 127p.

Karo, N.M., Oberhänsli, R., Aqrawi, A.M., Elias, E.M., Aswad, K.J., Sudo, M. (2018). New 40Ar/39Ar age constraints on cooling and unroofing history of the metamorphic host rocks (and igneous intrusion associates), the Bulfat Complex (Bulfat area), NE-Iraq, Arabian Journal of Geosciences 234: 1-11.

Korh, A.E., Schmidt, S.T., Vennemann, T., Ulianov, A. (2011). Trace Element and O-Isotope composition of polyphase metamorphic meins of the Ile de Groix (Armorican Massif, France): Implication for fluid flow during HP Subduction and Exhumation Processes, in: Dobrzhinetskaya, L. F., Faryad, S.W., Cuthbert, S. (Eds.). Ultrahigh-Pressure Metamorphism, Elsevier Inc.: 243-291.

Lister, G.S., and Davis, G.A. (1989). The origin of metamorphic core complexes and detachment faults formed during Tertiary continental extension in the northern Colorado River region, U.S.: Journal of Structural Geology 11: 65–94.

Mohajjel, M., and Rasouli, A. (2014). Structural evidence for superposition of transtension on transpression in the Zagros collision zone: Main Recent Fault, Piranshahr area, NW Iran, Journal of Structural Geology 62: 65-79.

Mohammad, Y.O., and Aziz, N.R.H. (2013). Exsolution lamellae in orthopyroxene of lherzolite from the Pauza ultramafic rocks, NE Iraq: evidence of deep mantle signature in the Zagros Suture Zone, International Journal of Geography and Geology 2 (9):102-115.

Okay, A.I., and Satir, M. (2000). Coeval plutonism and metamorphism in a latest Oligocene metamorphic core complex in northwest Turkey. Geol. Mag. 137 (5): 495–516.

Pshdari, M. (1983). Mineralogy and geochemistry of contact rocks occurring around Hero and Asnawa, NE-Iraq. Unpub. M. Sc. Thesis, Mosul University. 139p.

Ring, U. (2014). Metamorphic Core Complexes, Encyclopedia of Marine Geosciences Springer Science DOI 10.1007/978-94-

007-6644-0_104-4.

Ruttner, A., and Stocklin, J. (1968). Generalized tectonic map of Iran, ca. 1:10 000 000: IN: Stocklin, J. Structural history and tectonics of Iran: A review. American Association of Petroleum Geologists Bulletin 52 (7): 1229-1258.

Schmincke, H.U., and Von Rad U. (1979). Neogene evolution of Canary Island volcanism inferred from ash layers and volcaniclastic sandstones of DSDP site 397 (LEG47A), Initial report of the Deep Sea Drilling Project, volume XLVII part 1, Washington.

Sharp, T.R., and Robertson, A.H.F. (2002). Petrography and provenance of volcaniclastic sands and sandstones recovered from the Woodlark rift basin and Trobriand forearc basin, Leg 180. In Huchon, P., Taylor, B., and Klaus, A. (Eds.). Proc. ODP, Sci. Results 180, 1–58.

Spotl, C., Longstaffe, F.J., Ramseyer, K., Dinger, B. (1999). Authigenic albite in carbonate rocks - a tracer for deep-burial brine migration? Sedimentology (1999) 46: 649-666.

Vanderhaeghe, O., Teyssier, C., Wysoczanski, R. (1999). Structural and geochronological constraints on the role of partial melting during the formation of the Shuswap metamorphic core complex at the latitude of the Thor–Odin dome, British, Columbia, Can. J. Earth Sci. 36: 917–943.

Wager, L.R., Brown, G.M., Wadsworth, W.J., (1960). Types of Igneous Cumulates, Journal of Petrology 1(1): 73-85.

Yu, S., Li, S., Zhang, J., Sun, D., Peng, Y., Li, Y. (2019). Linking high-pressure mafic granulite, TTG-like (tonalitic-trondhjemitic) leucosome and pluton, and crustal growth during continental collision, GSA Bulletin 131 (3-4): 572–586.