IBGM
GIF EVALUATIN - 2017
IRAQI BULLETIN OF GEOLOGY AND MINING
Global Impact Factor
0.936

Iraqi Bulletin of Geology and Mining *Vol.14, No.2, 2018* *p 81 – 96*

NEW DISCOVERY OF OLIVINE/ PYROXENE-RICH SANDSTONES IN THE KOLOSH FORMATION, DYANA AREA, NE IRAQ: AN APPROACH TO PROVENANCE AND TECTONICS OF THE SEDIMENTARY BASIN

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Received: 26/ 10/ 2017, Accepted: 18/ 01/ 2018
Key words: Olivine, Pyroxene, Sandstone, Kolosh Formation, Turbidites, Iraq

ABSTRACT

Abnormal concentrations of fresh olivine and pyroxene grains are reported and studied for the first time in the sandstone beds of the Kolosh Formation in the Dyana area, NE Iraq.

The petrologic study revealed relatively high concentrations of fresh pyroxene grains (18.26%), olivine (8.3%), igneous rock fragments of various compositions (11.35%), altered (17.4%), argillaceous rock fragments (3.5%), carbonate fragments (2.45%), chert (2.3%), serpentine and chlorite (6.18%), plagioclase cf. anorthite and labradorite (5.15%), alkali feldspar cf. sanidine (1.02%), quartz and cristobalite (2.56%), opaque minerals including chrome-spinel (4.0%), argillaceous matrix (16.53%) and carbonate cement (1.2%).

These mineralogical assemblages refer to ultrabasic and basic plutonic igneous sources associated with basic volcanic rocks. The ultrabasic and basic source is suggested to derived from mantle and oceanic crust origin, represented by the ophiolite sequence of Hasan Beg, Rayat, Choman and Galalah areas. These ophiolites were thrusted and emplaced during Late Cretaceous and were associated with volcanic island arc. The thrusted ophiolites were subjected to rapid submarine erosion and deposition and/ or subjected to subaerial erosion. Intense wave action accelerated erosion of beach rocks, removing the light fraction and leaving the heavy minerals insitue. Intense tectonism slumped these sediments into deeper margins by the turbidity currents.

اكتشاف جديد لصخور رمليه غنية بمعادن الاوليفين والبايروكسين في تكوين الكولوش، منطقة ديانا، شمال شرق العراق: مقاربة لتحديد مصدر المعادن وتكتونية الحوض الرسوبي

سعد زكي عبد القادر المشايخي واقبال جاسم محمد

المستخلص

تتناول هذه الدراسة تفسير الوجود غير الاعتيادي لمعدني الأوليفين والبايروكسين في صخور الحجر الرملي لتكوين كولوش في منطقة ديانا والتي تحدد للمرة الأولى. تظهر الدراسة الصخارية للحجر الرملي وجود نسبة مرتفعة من البايروكسين النقي بمعدل 18.26%، نسبة أقل من معدن الأوليفين تصل الى 8.3%، وتبلغ نسبة قطع الصخور النارية الجوفية فوق القاعدية والقاعدية والحامضية والصخور البركانية 11.35%، وتصل نسبة القطع المتغيرة (ومنها حبيبات الأوليفين والبايروكسين والصخور القاعدية) الى 17.4%، وقطع الحبيبات الطينية الى 3.5%، وحبيبات القطع الجيرية الى

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2.45%، وقطع الصوان الى 2.3%، وقطع السربنتين والكلورايت الى 6.18%، وقطع الفلدسبار ومنها معدني الأنورثايت واللابرادورايت الى 5.15%، والفلدسبار القلوي الى 1.02%، ومعدني الكوارتز والكرستوبلايت الى 2.56%، والمعادن المعتمة من ضمنها الروتيل الى 4.0%، والحشوه الطينية الى 16.53%، والمواد الرابطة الجيرية الى 1.2%. تشير هذه التركيبة المعدنية الى أن أصل هذه المعادن يعود الى صخور نارية فوق لقاعدية وقاعدية بالإضافة الى الصخور القاعدية البركانية. إن مصدر الصخور القاعدية وفوق القاعدية المحتمل هو صخور الجبة والقشرة المحيطية والمتمثلة بتتابع الأوفيولايت المتكشفة في جبل حسن بيك ورايات وكلالة وجومان وقلندر ومنطقة سيدكان.

هناك أصلان محتملان لقطع الصخور القاعدية البركانية، الأول تدفق البازلت فوق صخور الجبة في البحر العميق، والثاني تدفق البازلت من الأقواس البركانية المصاحب لصخور الانديسايت. وان الأصل المحتمل لقطع الصخور الطينية هو تيارات التعكر للصخور المترسبة قبلا في المنحدر القاري ويعود أصل القطع الصخرية الجيرية الى الصخور الجيرية المترسبة في العصر الطباشيري المتاخر. إن زحف وتحرك تتابع الأوفيولايت في نهاية العصر الطباشيري متصاحبا مع الأقواس البركانية أدى الى ارتفاع طبفات الأوفيولايت الزاحفة بشكل تدريجي ومتواصل لتتعرض لاحقا تعرية سريعة بعد تكشفها على سطح الأرض أو قليلا تحت مستوى سطح البحر وقد عملت الأمواج الشديدة على تعرية وترسيب سريعين أدت الى نقل الرواسب الخفيفة بعيدا عن الساحل وتركزت فتاتيات المعادن الثقيلة ومنها معدني الأوليفين والبايروكسين التي تم نقلها الى البئة البحرية العميقة بتيارات التعكر التي نتجت عن الحركات التكتونية الفعالة ويحتوي تكوين الكولوش على تراكيب رسوبية مميزة تشير الى أنها تكونت بواسطة تيارات التعكر في بيئة بحرية عميقة.

INTRODUCTION

The Kolosh Formation was not studied in the Dyana area before. The selected section is located in NE extremities of the High Folded Zone near the borders with Iran, very near to the Zagros Thrust Zone (Fig.1). The formation is widely distributed in northeast Iraq, cropping out in the synclines and flanks of anticlines. It consists of successive interbeds of sandstones and mudstones/ shales arranged in graded turbidity cycles. This paper reports a new discovery of olivine/ pyroxene-rich sandstones in the Kolosh Formation in NE Iraq and provides insight for the origin and tectonic provenance of the sandstones in the Dyana area, NE Iraq. Based on petrographic examination, the provenance and source rocks of the sediments are discussed.

The basic volcanic igneous grains were derived from pillow and flow basalt of oceanic crust and from volcanic island arc associated with andisitic eruptions. The argillaceous fragments are the products of intrabasinal erosion by turbidity currents. Whereas the carbonate fragments were derived from Late Cretaceous carbonate rocks deposited around the island arc. Characteristic sedimentary structures of turbidity origin suggest deposition of the Kolosh Formation in deep marine environment.

STRATIGRAPHIC REVIEW

Bolton (1955) and Dunnington (1958) were the first describe the Kolosh Formation (Paleocene – Lower Eocene) at Kolosh village as a type area north of Koi Sanjaq in the High Folded Zone. Buday (1980) sited that the Kolosh Formation includes intertongue of Sinjar Formation in the upper parts and consists of green to grayish shales and green chert and radiolarite. Bellen *et al.* (1959) subdivided the type section into four units. **Unit a** (144 m) and **Unit b** (30 m) were described as Sinjar Formation, while **Units c** (133.5) and **d** (6 m) include interfingering of Sinjar and Kolosh Formations and **Unit e** (410 m) consists of blue shales and green sandstones of Kolosh Formation, which are also reported from the Taq Taq and northern Kirkuk oilfield (Ditmar *et al*., 1971, in Buday, 1980). Jassim *et al.* (1975) and Jassim and Buday (in: Jassim and Goff, 2006) described 1000 m thick sequence of the Kolosh Formation in Derbendikhan area and included many conglomerate beds with mudstones, siltstones and argillaceous limestones, with some detrital limestone interbeds.

The Kolosh Formation in the type area attains 400 m thick, the upper 120 m represent tongues of Sinjar Formation. The Kolosh Formation was suggested to deposited in a relatively rapid sinking trough and is essentially near-shore neritic sediments (Ditmar *et al*., 1971, in Buday, 1980). Buday (1980) sited that there are no signs of turbiditie or graded bedding, and the grain size of the clastics is diminishing into an open sea calcareous-pelitic sequence. Moreover, the Kolosh Basin is relatively narrow superimposed on platform margins and separated from the geosyncline by uplifted emerged and eroded line (Ditmar *et al*., 1971, in Buday, 1980).

Fossils are not abundant in the Kolosh Formation and the base of the formation was ascertained by Kassab (1976) as Middle Paleocene age, while the Danian is absent. The lower contact in the type locality is clearly unconformable and transgressive with the underlying Tanjero Formation or Shiranish Formation in some areas. The upper contact is unconformable according to Bellen *et al.* (1959). However, the upper boundary in the type area is conformable with the overlying Paleocene – Lower Eocene limestone formations. Bolton (1955) and Buday (1980) claimed that the distribution of the Kolosh Formation was in a relatively narrow trough, trending in a NE – SW direction.

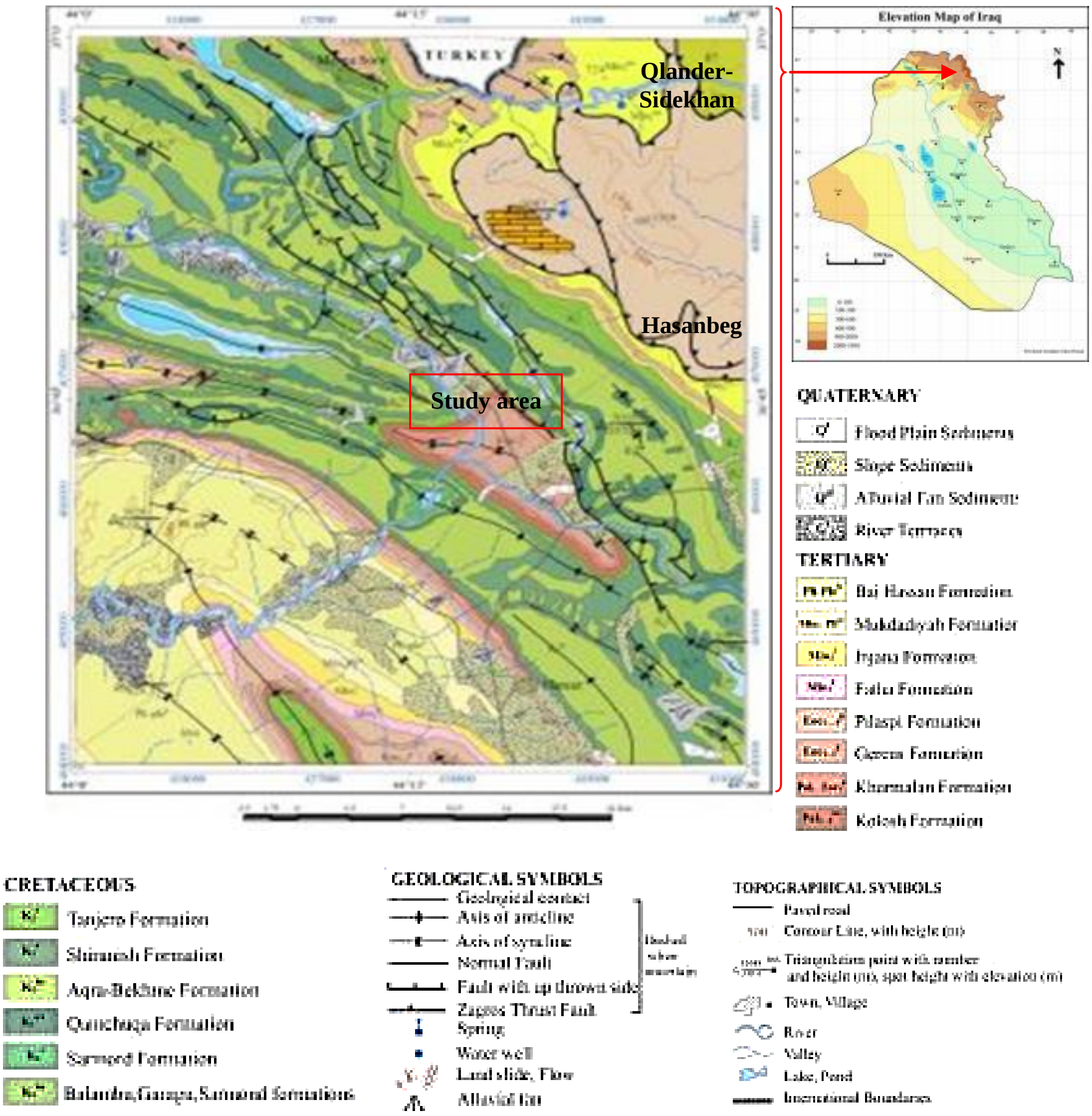

Fig.1: Geological map of Dyana area shows the study area (rectangular) (Geol. map of Erbil and Mahabad, GEOSURV, compiled by Sissakian *et al*. (2014)

MATERIALS AND METHODS

Twenty-five rock samples are collected from the Dyana section of the Kolosh Formation, which is lying 15 Km north of Dyana city NE of Iraq (Fig.1). Thin section slides were prepared, cutting perpendicular to the bedding plane to study the vertical variation in the mineralogical constituents following the procedure listed in Tucker (1988). Detailed microscopic examination of the framework constituents and cementing material was carried out together with point counting of about 500 mineral grains with percentage calculation of each mineral. The sandstone grains are identified according to Kerr (1975), Scholle (1979), MacKenzie and Guilford (1982), MacKenzie *et al.* (1982), Adams *et al.* (1984), Yardley *et al*. (1990), Gribble and Hall (1992), Adams and MacKenzie (2001), MacKenzie and Adams (2007) Barker (2014), and Ghose *et al*. (2014).

STRATIGRAPHIC DETAILS

The studied section is lying 15 Km north of Dyana town, Erbil Governorate, NE Iraq, where the thickness of Kolosh Formation in this area is about 170 m (Figs.1 and 2). Lithologically, the Kolosh Formation is composed of muddy sandstones, mudstones/ shales, pebbly sandstones, chaotic mudstone, fossiliferous sandstone and limestone. Very thin beds of siliceous composition are observed within the mudstone beds. Trace fossils are identified in both sandstones and muddy limestones. All beds are arranged in graded Bouma turbidity cycles (Fig.2). Most beds are bioturbated and deformed revealing characteristic sedimentary structures of turbidite origin.

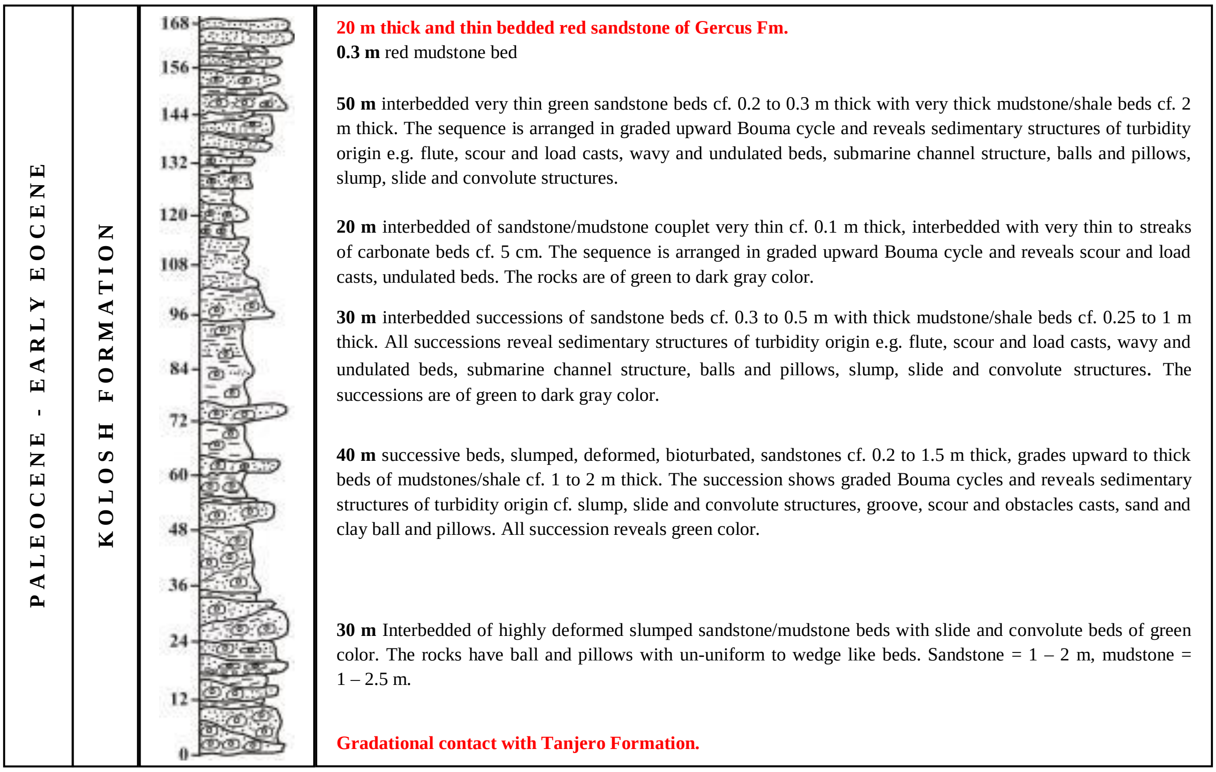

Fig.2: Lithostratigraphic log of the studied sequence of the Kolosh Formation in the Dyana area, NE Iraq

Sedimentary structures are identified based on Bouma and Brouwer (1964), Selley (1976), Stow, 1986; Mutti, 1992; Einsele (2000), Stow (2012) and Pickering and Scott (2016), which are mainly characteristic of turbidity origin cf. graded beddings, ball and pillows, slump slide and convolute beds, scour, load and groove casts, submarine channels, wavy and undulated beds. Most of the sandstone and mudstone horizons are arranged in fining upwards graded beddings and reveals Bouma cycles (Fig.3). Most beds are composed basically of balls and pillow structures as well as load and scoured surface. Some mudstone beds show groove casts. Deformational structures are represented by slump and slide beds and sometimes convolute beddings. Trace fossils are recognized in the upper surface of the sandstone beds cf. burrows, Thalassinoide, borings and trails.

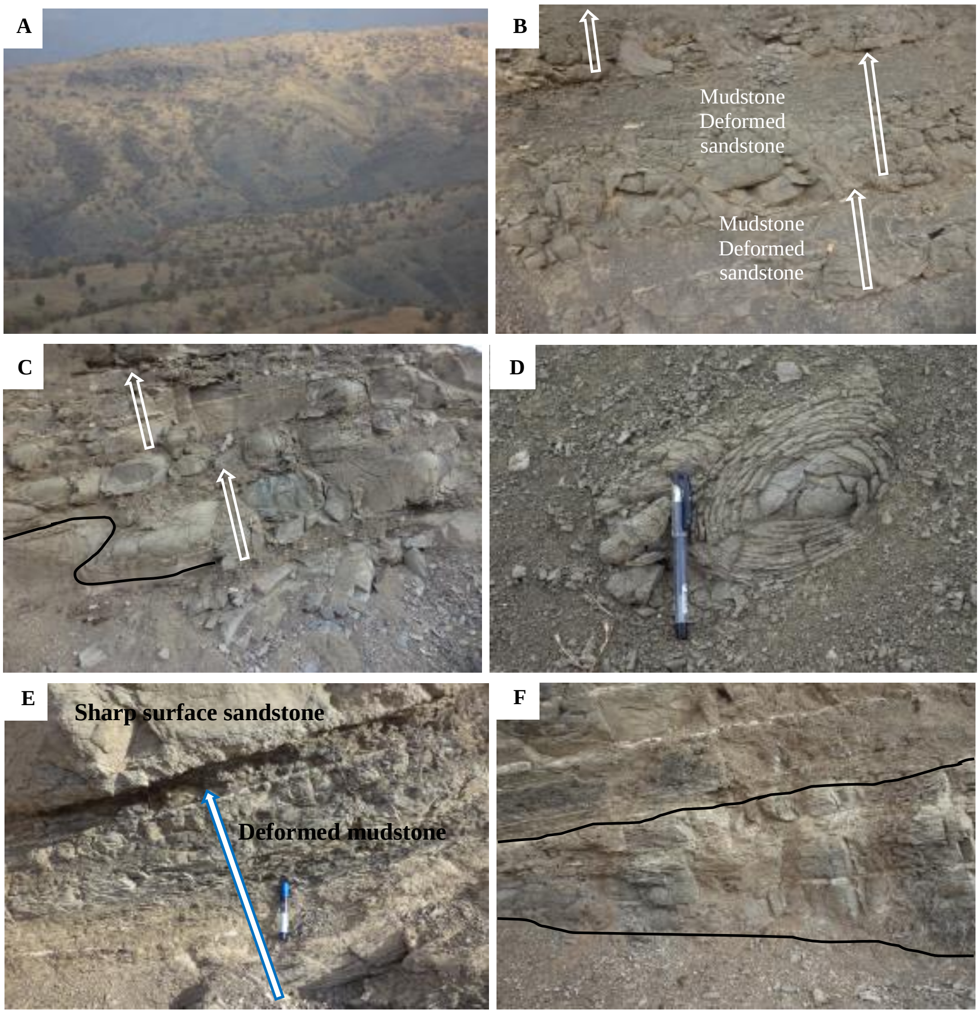

Fig.3: Field photographs present the sedimentological features and sedimentary structures observed in the Kolosh Formation in Dyana area (arrows refer to the Bouma cycles pencil = 10 cm)

A) General view of Kolosh outcrops north of Dyana town. **B)** Graded Bouma turbidity cycles of sandstone and mudstone beds (1 m) show balls and load casts. **C)** Deformed graded Bouma cycles (1 m) show ball, load casts and convolute beddings. **D)** Sand ball observed in sandstone bed. **E)** Graded Bouma cycle shows convolution in the mudstone bed. **F)** Wedge beds of sandstones and mudstones overlies with graded Bouma cycles (1.5 m). The whitish gray thin streaks are of muddy limestone.

Note all graded turbidity cycles composed of Tc and Td and/ or Te divisions of Bouma cycles

The lower is gradational with Tanjero Formation and the upper part of the formation grades upwards to the Gercus Formation. Based on the previous studies, the age of the Kolosh Formation is Paleocene – Lower Eocene. The digenetic features are (a) compaction of some mudstone beds and development to shale-like, (b) development of large concretions, (c) bioturbation in parts and (d) faulting.

PETROLOGY

Thin section slides are carefully studied to identify the mineralogical constituents of the olivine/ pyroxene-rich sandstone beds. The modal analysis and average percentages are shown in Table (1). Below is brief description of the main mineral:

Table 1: Average percentages of the mineralogical constituent in the studied sandstone of the Kolosh Formation in Dyana section

Components	Average modal %	Components	Average modal %
Olivine	8.3	Chlorite	1.56
Pyroxene	18.26	Serpentinite MRF	4.42
Altered fragments (Fe-Mg minerals)	17.40	Igneous rock fragments	11.35
Plagioclase-Feldspar	5.15	Chert and chalcedony	2.3
Alkali Feldspar	1.02	Carbonate rock fragments	2.45
Quartz	2.05	Argillaceous fragments	3.5
Cristobalite	0.51	Argillaceous matrix	16.53
Opaque minerals	3.8	Carbonate cement	1.2
Rutile	0.2		

– **Olivine:** Forsterite, fayalite, monticellite and chondrodite minerals of olivine group are identified in most of Kolosh sandstones with an average percentage of 8.3% (Fig.4A-E). They are mostly prismatic, angular to subangular and are less common than pyroxene. Some olivine grains are fresh and others are uralitized, and some others showing iron oxides and serpentine along the fractures.

– **Pyroxene:** Clino- and orthopyroxenes are identified based on the extinction angle and petrographic properties. The average percentage of the pyroxene minerals is about 18.26%.

– **Clinopyroxene:** Diopside, Enstatite, Jadeite, Spodumene, Hedenbergite, Pigeonite and Aegirine-augite are identified in the Kolosh sandstones. These grains are mostly fine and angular to sub angular grains and almost prismatic in shape (Fig.4F-H, Fig.5C-G). They are recognized in all of the studied sandstone horizons of the Dyana section. Most of the clinopyroxene grains are fresh and other grains are altered to iron oxide or uralite in the center and a rim pyroxene is still fresh. Most of the grains are prismatic of angular shape.

– **Orthopyroxene:** Enstatite and Hypersthene are identified in the Kolosh sandstone beds (Figs.5A and 5B). They are mostly prismatic, angular to subangular, almost fresh with subordinate altered grains and less common than clinopyroxene.

– **Altered grains:** The altered grains are present in relatively high percentages in the Kolosh sandstones attaining an average of 17.4%. The grains of pyroxene, olivine, ultrabasic fragments and basic fragments show various degrees of alteration mostly to iron oxides and/or to uralitized pyroxene (Fig.5G). The grains are altered to brown and dark brown in the center while the edges are still fresh.

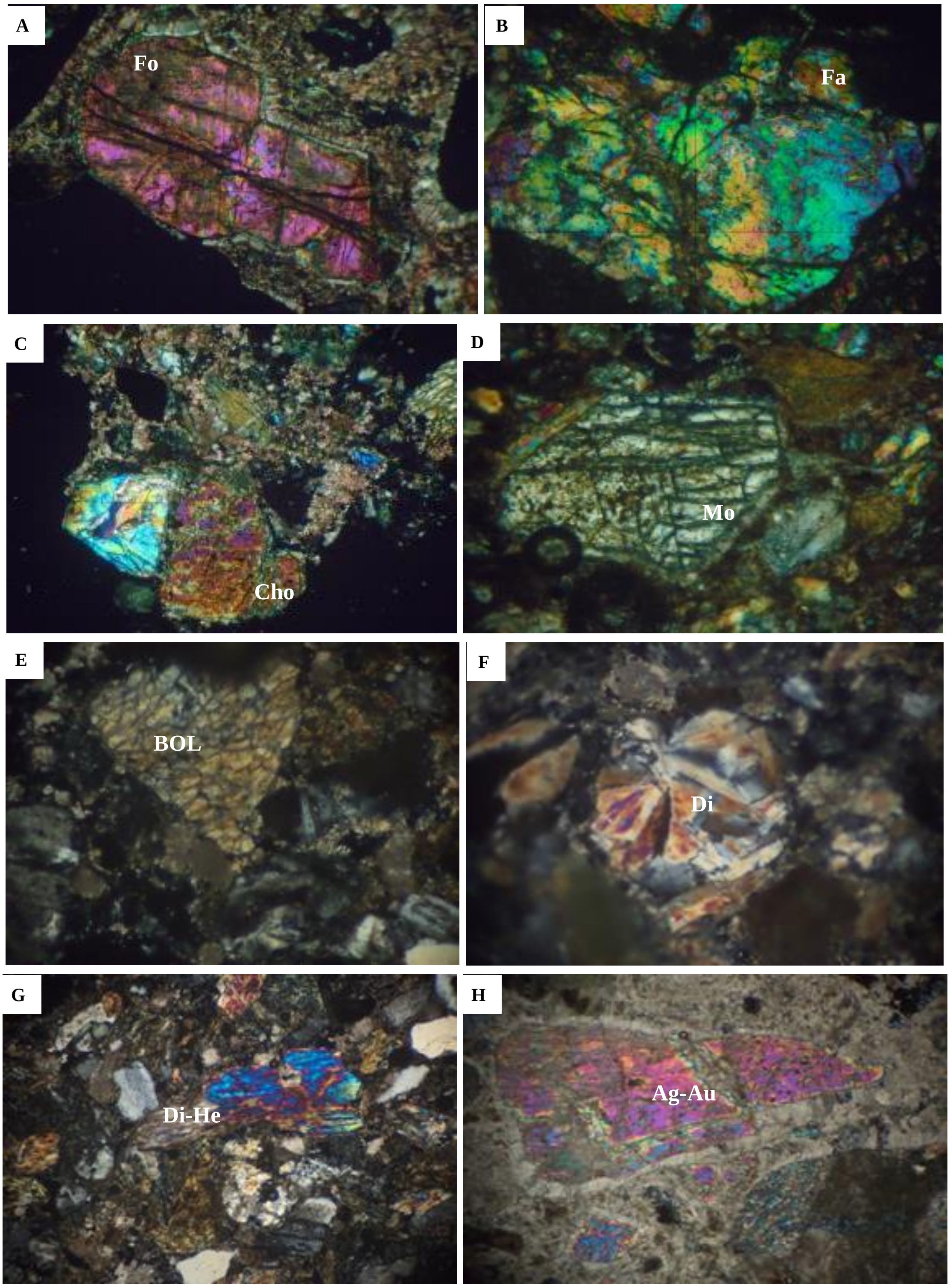

Fig.4: Photomicrographs of olivine and pyroxene minerals identified in the Kolosh Formation in Dyana section (CN x 100X)
A) Forsterite (Fo), **B)** Fayalite (Fa), **C)** Chondrodite (Cho), **D)** Monticellite, **E)** Brecciated olivine (BOL), **F)** Clinopyroxene-Diopside (Di), **G)** Clinopyroxene (Diopside-Hedenbergite) (Di-He), **H)** Clinopyroxene (Aegirine-Augite) (Di-He)

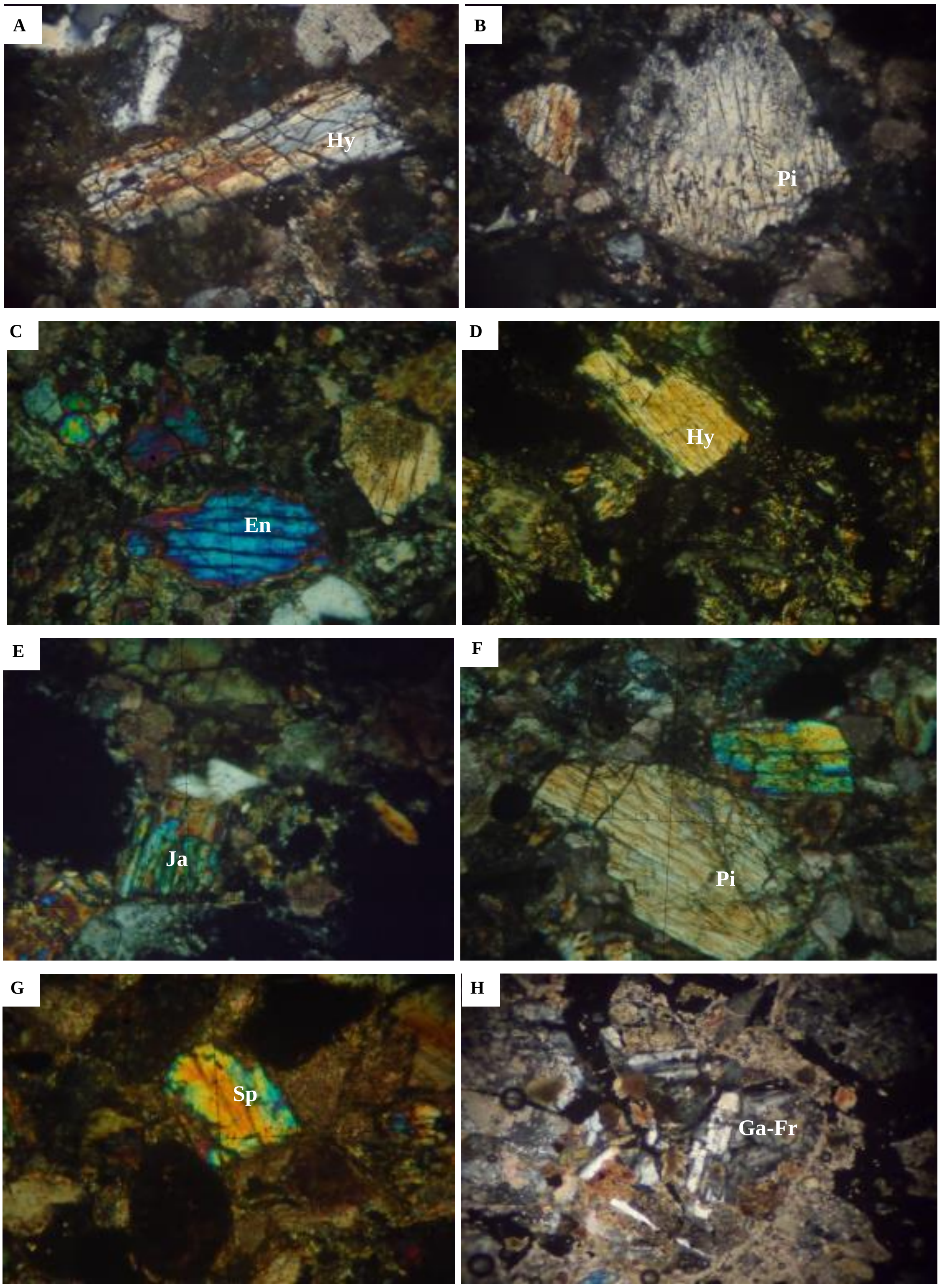

Fig.5: Photomicrographs of pyroxene and rock fragments identified in the Kolosh Formation in Dyana section (CN x 100X)
A) Hypersthene (Hy) **B)** Hypersthene and Pigeonite (Pi), **C)** Enstatite (En), **D)** Hypersthene, **E)** Jadeite (Ja), **F)** Pigeonite and spodumene, **G)** Spodumene (Sp), **H)** Gabbro fragment (Ga-Fr)

– **Feldspar:** plagioclase and alkali-feldspars are recognized in the studied sandstone units. Ca-plagioclase is the major type composed mainly of anorthite with minor bytownite and labradorite (Fig.6G and 6H). The alkali-feldspar is composed of orthoclase and sanidine with few perthite grains. The feldspar grains are mostly prismatic, fine, angular to subangular and attain about 6.17%. Some grains show sericite or carbonate replacement but keeping the original shape.

– **Quartz:** A few quartz grains (2.05% of total grains) are recognized in the sandstone units, of fine and subangular to subrounded shape (Fig.6H).

– **Cristobalite,** grains are of few amount and attains about 0.51%. These grains are fine, angular to subangular grains.

– **Rock fragments:** Varieties of rocks fragments are identified in the Kolosh sandstones e.g. igneous (ultrabasic, basic and acidic, intrusive and extrusive types), sedimentary (argillaceous, chert and carbonate) and rare metamorphic fragments, of average percentage 15 – 20%.

– **Igneous rock fragments:** Intrusive and extrusive igneous of ultrabasic, basic and acidic types fragments are identified in the sandstone beds, which attain average of about 11.35%, these are:

- **Intrusive igneous rock fragments:** Intrusive ultrabasic igneous grins are identified as pyroxenite, lherzolite, heirzburgite and peridotite (Fig.6A-C). The basic intrusive is gabbro fragment (Fig.5H). These are fine-grained, angular to subangular, fresh with subordinate altered grains. Some of ultrabasic grains are serpentinised along the fractures or altered some crystals in the fragment. Granitic fragments are acidic intrusive type, fresh, fine and angular to subangular grains (Fig.5E). Basaltic and andisitic grains of extrusive type are identified (Fig.6D). These grains are angular to subangular and fine-grained. Most of these grains are fresh and un-altered.

- **Sedimentary rocks fragments:** Argillaceous fragments, subordinate chert fragments and Few limestone (includes fossils) and siltstone fragments are recognized (Fig.6A, E and F). The average percentage is 8.25%. These are fine and subangular to rounded grains.

- **Chert and chalcedony:** They are more abundant than quartz grains, with an average of 2.3%. They are angular to subangular and composed of microcrystalline quartz (Fig.6E). Chalcedony grains are rounded, composed of radiating silica and sometimes filled with opal-CT. Radiolarian fossils are also identified filled with chert and/ or chalcedony.

- **Cement:** Argillaceous matrix is the main type of identified cementing materials with little carbonates. The percentages of the muddy matrix reach >16.53% suggesting greywacke sandstone type (Pettijohn, 1975), while carbonate is of 1.2%.

The Dickenson's diagram of the provenance and tectonic setting cannot be applied for the Kolosh sandstones because of including high percentages of the pyroxene and altered grains (cf. 20 – 40%).

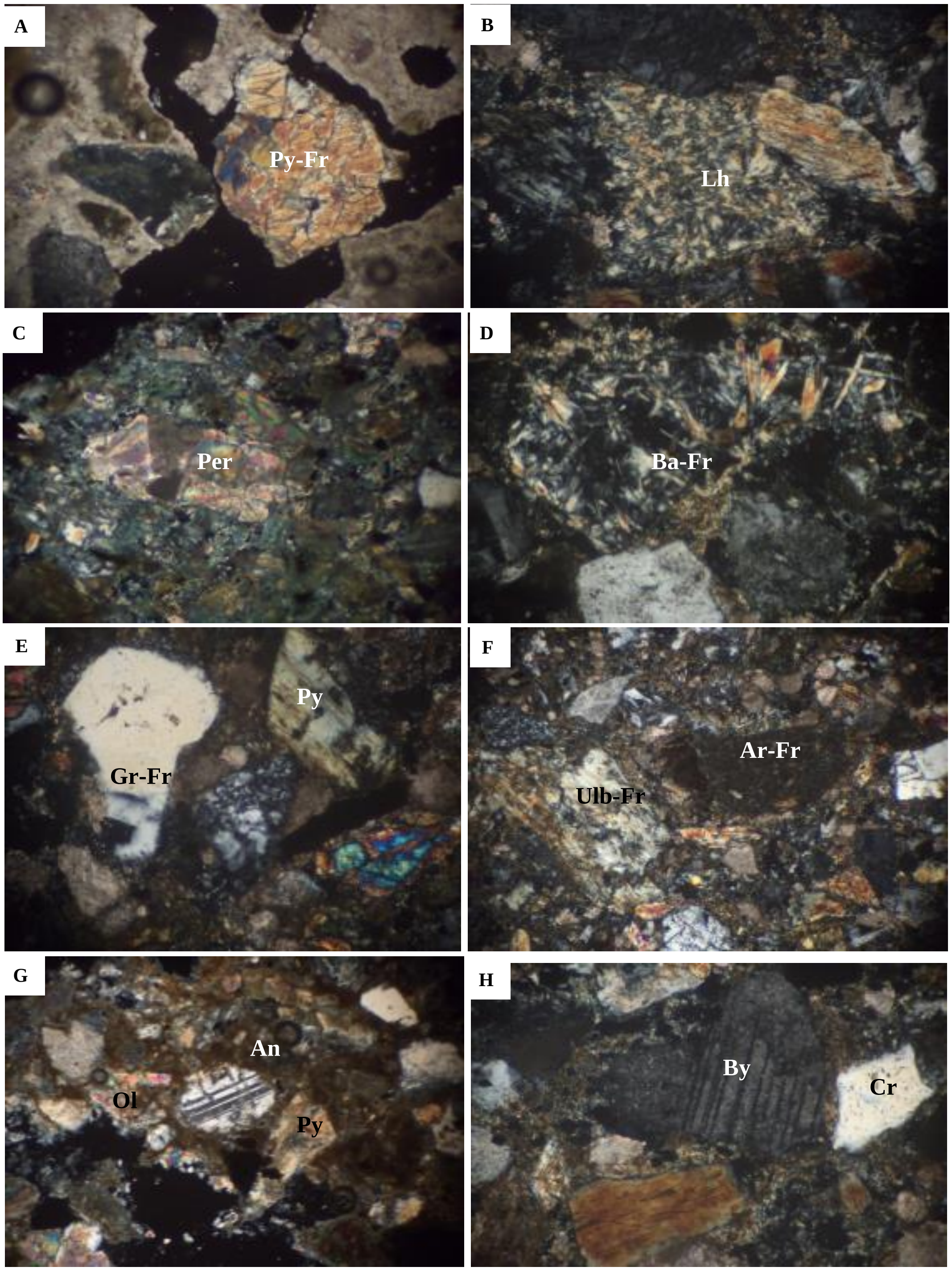

Fig.6: Photomicrographs of pyroxene and rock fragments identified in the Kolosh Formation in Dyana section (CN x 100X)
A) Pyroxenite fragment (Py-Fr), **B)** Lherzolite fragment (Lh), **C)** Peridotite fragment (Per), **D)** Basalt fragment (Ba-Fr), **E)** granite (Gr) and chert (Ch) fragments with pyroxene and olivine, **F)** Argillaceous (Ar) and ultrabasic fragments (Ulb), **G)** Anorthite (An) with olivine (Ol) and pyroxene (Py), **H)** Bytownite (By), pyroxene(Py) and cristobalite (Cr).
H) Orthopyroxene (Aegirine-Augite)

DISCUSSION

- **Composition of source rocks**

The Kolosh Formation and the upper part of the Tanjero Formation are exposed in the Dyana area at the boundaries of the Thrust Zone near Jabal Hassan Beg Mountain. Based on field observations the sedimentological characters and characteristic sedimentary structures suggest deep marine setting of sedimentation originated by turbidity currents.

The sandstone beds of the Kolosh Formation reveal high percentages of olivine and pyroxene grains accompanied with ultrabasic and basic rock fragments. These assemblages are related to the provenance and tectonic evolution of the Zagros Foreland Basin and surrounding areas during the sedimentation of the Kolosh Formation. The identified mineral assemblages reveal various potential tectonically-controlled source rock complexes (cf. oceanic crust, mantle, continental crust and volcanic arcs). The presence of augite and diopside associated with ultrabasic rock fragments (cf. peridotite tectonite, harzburgite, lherzolite, dunite and pyroxenite) suggest ophiolitic mantle origin (Kerr, 1975; MacKenzie and Guilford, 1982; MacKenzie *et al*., 1982; Adams *et al*., 1984; Gribble and Hall 1992; Ghose *et al*., 2014).

The Zagros Thrust Zone includes peridotites, which range from lherzolite to dunite through harzburgite. These rock types and mineral associations are similar to those of forearc peridotites which are represented by fertile alpine mantel lherzolite to dunite and are depleted in tectonite harzburgite (Mohammed, 2008). It is suggested that these ultramafic bodies are huge fragments of supra subduction zone of residual mantle peridotites (Ismail *et al*., 2009) Serpentinization is observed in along basal fractures and cleavages of olivine and pyroxene and ultrabasic fragments (Gribble and Hall, 1992), as complementary processes during the evolution of the ultramafic part of the ophiolite sequence adjacent to the Foreland Basin. Serpentinization of peridotite is thought to have taken place during the subduction stages before collision of the Arabian Plate with the Iranian Plate (Mohammed, 2008). Diopside diallage is usually derived from coarse-grained gabbro and basalt and usually accompanied by forstertic olivine (Gribble and Hall, 1992). Omphacite is similar to diopside, augite and jadeite, which are found exclusively in eclogite (cf. high T and P conditions). Hedenbergite is usually derived from peridotite and fayalite ferrogabbro (Gribble and Hall, 1992).

Augite is essential mineral in peridotite, gabbro, basalt and olivine gabbro. Pigeonite may be derived from basalt, diabase and dolerite, whereas, Aegirine-augite compose an essential member in the trachyte and basalt, while spodumene is a rare mineral and is derived from Li-granite (Gribble and Hall, 1992). Enstatite occurs in all types of basic igneous rocks. Mg-rich orthopyroxene occurs in ultrabasic igneous rocks (cf. pyroxenite, harzburgite, lherzolite, serpentinite and picrate with Mg-olivine) (Gribble and Halls, 1992). Hypersthene is found in gabbro, norite and andesite (Kerr, 1975; Barker, 2014; Ghose *et al*., 2104). Mg-rich olivine (e.g. forsterite, monticellite) is an essential mineral in most ultrabasic igneous rocks (cf. dunites, peridotites and picrites). Olivine forsterite and chrysolite are derived from peridotite, olivine gabbro and basalt. More Fe-rich olivine (e.g. fayalite) is derived from alkali basalt, ferrogabbros and trachyte (Gribble and Hall, 1992). Monticellite is derived from basalt and chondrodite is derived from high grade metamorphic rocks (Kerr, 1975; MacKenzie *et al*., 1982; Adams *et al*., 1984; Yardley *et al*., 1990; Barker, 2014; Ghose *et al*., 2014).

The altered grains show various degree of alteration and found in relatively high percentages and composed mainly of uralite. Most of the altered grains are derived from basic and ultrabasic rock fragments as well as olivine and pyroxene. The ca-plagioclase members

An95-An55 cf. anorthite, bytownite and labradorite, are characteristic minerals of ultrabasic and basic igneous rocks cf. peridotite, harzburgite, lherzolite, gabbro, and basalt. Anorthite is derived from ultrabasic intrusive igneous rocks cf. peridotite, pyroxenite, harzburgite and lherzolite and from gabbro. Bytownite and labradorite is derived mainly from basalt and gabbro (Kerr, 1975; MacKenzie *et al*., 1982; Gribble and Hall, 1992; Ghose *et al*., 2014). The alkali-feldspar varieties are derived from acidic intrusive and extrusive igneous rocks. Orthoclase and perthite are derived from granites, while sanidine and cristobalite are derived from acidic and intermediate extrusive igneous rocks cf. rhyolite, trachyite and andesite (Kerr, 1975; Scholle, 1979; MacKenzie *et al*., 1982; Adams *et al*., 1984; Gribble and Hall, 1992; Barker, 2014; Ghose *et al*., 2014).

Rock fragments are important indicators for source rocks and provenance. The most important abundant types in the Kolosh sandstones were derived from intrusive ultrabasic and intrusive and extrusive basic igneous rocks (cf. pyroxenite, lherzolite, heirzburgite, peridotite, gabbro and basalt). These rock types are derived from mantle and oceanic crust sources represented by ophiolite sequence (Kerr, 1975; MacKenzie *et al*., 1982; Gribble and Hall, 1992; Ghose *et al*., 2014). The basalt and andesite fragments are derived from volcanic arc (Gribble and Hall, 1992; Ghose *et al*., 2014).

The sedimentary rock fragments were derived from various sources. Intrabasinal argillaceous mudstone grains are most probably derived from mudstone beds by effect of turbidity currents. The limestone fragments are derived from Cretaceous carbonate formations. The chert and chalcedony rock fragments are suggested to derive from acidic volcanic rocks of arc and/ or deep marine radiolarian beds of ophiolite sequence (Walker and James, 1998; Einsele, 2000; Ghose *et al*., 2014; Pickering and Scott, 2016).

- **Potential local source rocks**

The anomalous concentrations of olivine and pyroxene grains in the Kolosh sandstones are suggested to derive from two sources; thrusted ophiolite sequences and flow of basaltic lava from island arc. The emplacement of the Neotethyan oceanic crust took place during Late Cretaceous (118 – 97 Ma), while the emplacement of Hasan Beg ophiolite complex was (106 – 92 Ma) ago (Sarmad *et al*., 2013). Along the southern Neotethys suture, the Outer Zagros Orogenic Belt crops out. The OZOB includes Rayat, Piranshahr, Kermanshah, Neyriz, and Haji-Abad Ophiolites, is the result of the Late Cretaceous collision between the Sanandaj – Sirjan and the Arabian Shield (Ajirlu *et al*., 2016).

The deposition of deep-marine sediments of radiolarian chert of the Qulqula Group and carbonates of Arabian passive-margin is dated to Valanginian – Turonian (140 – 89 Ma), which constrains initial orogenesis and early subsidence of the Zagros Foreland Basin to about 90 Ma (Alavi, 2004; Homke *et al*., 2009; Ali *et al*., 2012; Sarmad *et al*., 2016). The provenance data of the clastics in the Tanjero Formation (Maastrichtian), Kolosh Formation and Suwais Red Beds (Paleocene – Eocene) reveal partial derivation from basic and ultrabasic sources related to ophiolite emplacement (Homke *et al*., 2009; Saura *et al*., 2011; Ajirlu *et al*., 2016). Several pre-Tertiary tectonically-derived igneous rock complexes may have served as source rocks to the sandstones of the Kolosh Formation in the studied area.

– **The Kata Rash igneous complex:** Sarmad *et al*. (2016) suggested that the Kata – Rash igneous rocks comprise a remnant arc of Cretaceous age, and the arc fragment is broadly similar in age to those of Late Cretaceous peri-Arabian ophiolite belt in other countries as well as other late Cretaceous Zagros suprasubduction zone assemblages. This refers to the great lateral extent of Late Cretaceous arc systems in the consumption of the Neotethys Ocean.

– **The Rayat Ophiolite mantle:** The Rayat Ophiolite mantle sequence in the northeast corner of Iraq (30 Km from Dyana area) consists of serpentinised peridotites, serpentinite, tectonite harzburgite, lherzolite, and dunite with Cr-spinel (Ismail *et al*., 2009). They are mantle residues with distinct geochemical signatures of both mid-ocean ridge and supra subduction zone affinities. The crustal sequence includes gabbro, dibasic dikes, rare pillow basalts and radiolarite overlain by Late Cretaceous pelagic limestone. Rayat Ophiolite is extended to Piranshahr area in NW Iran, and to the Cilo Ophiolite in SE Turkey (Ismail *et al*., 2009; Ajirlu *et al*., 2016). The Rayat ophiolitic mélange is mainly composed of Peridotite and sheared serpentinite, of which the protolith is harzburgite. This is common to the mantle section of the Tethyan ophiolites such as the Oman ophiolite (Ismail *et al*., 2009). The Chromitite in the Rayat peridotite are similar to the mantle chromitite and Moho transition zone chromitite (upper mantle zone) of the Tethyan ophiolites (Ismail *et al*., 2009).

– **Galalah-Choman ultramafic/ mafic rocks:** Galalah area is situated about 25 Km from Dyana locality. The rock units in the area consist of 50 m brecciated and pillow lavas alternating with ultramafic/mafic volcanoclastic rocks, and above with 40 m massive serpentinite and mélange marble of heterogeneous composition (mixture of calcite, chlorite, and serpentinite). This sequence is overlain by thin layer of radiolarian chert and Red Beds tectonically separated by crush zone (Sarmad *et al*., 2013). Choman area is situated about 27 Km from Dyana locality. It is composed mainly of variable thicknesses of pillow lava, about 200 m thick, interbedded with volcanic ash, tuff, and breccia (Sarmad *et al*., 2013). Galalah and Choman rocks consist of pillow and flow lava interbedded with ultramafic/ mafic rocks, overlying serpentinite rocks. They can be suggested as other sources of olivine and pyroxene grains in the Kolosh sandstones. It can also be the source of ultrabasic, basic intrusive and extrusive basaltic igneous fragments.

– **Hasan Beg Mountain succession:** The Hasan Beg Mountain is situated between Sidekhan and Dyana areas, where the studied section of Kolosh Formation is lying very near to the mountain. Hasan Beg igneous complex comprises remnant of the Late Cretaceous ophiolite-arc system that developed within the Neotethys Ocean and was subsequently accreted to the Arabian plate during the Late Cretaceous to Paleocene (Ali *et al*., 2012). It consists predominantly of calc-alkaline basaltic andesite to andesite cut by micro gabbro and diorite dikes indicate Albian – Cenomanian age (106 – 92 Ma) (Ali *et al*., 2012; Sarmad *et al*., 2013). Hasan Beg Mountain rock units start at the bottom with pillow lavas with sheared and highly weathered chlorite slate, due to intense deformation, forms the contact between the lower pyroclastic metavolcanic rocks and the upper part of metasediment (cf. slate, shale, and sandstone. The overlying metasediment is composed of highly fossiliferous black shale interbedded with about 20 m thick of sandstone lenses. These rocks are overlain by radiolarian chert. The total thickness of the Hasanbeg sequence is about 1000 – 2000 m, variable in thicknesses is due to thrusting (Sarmad *et al*., 2013).

– **Qalander-Sidekhan sequence:** The Qalander Mountain is located at about 20 Km from Dyana locality. Jabal Qalander is composed of (from bottom to top) Tanjero and Aqra Formations (Late Cretaceous) at the bottom, which are separated by tectonic contact from the overlain Govanda Limestone of Early – Middle Miocene age, succeeded by Middle – Late Miocene Red Bed sandstones overlies with tectonic slice of Naopurdan metavolcanic rocks (Sarmad *et al*., 2013).The Naopurdan rocks in the Qalander area is divided into three parts:

i) The lower part of metavolcanic is composed mainly of basalt flows, **ii)** The middle part is variable in thicknesses averaging about 50 m, composed of pillow lavas, brecciated lavas, and inter-pillow ash. Many dolerite dykes are cutting across the Qalander successions, in which pillow and flow lavas are about 450 m thick, and **iii)** The upper part contains coarsening upward sequences of sandstones to conglomerates which contain pebbles of basalt, serpentinite, and marble. These strata appear to have been derived from the erosion and rapid deposition of the igneous rocks, most probably from Naopurdan and Walash metavolcanic successions (Aziz *et al.*, 1993). The Sheikhan Mountain, located northwest of Qalander Mountain, shows the same successions of the Qalander Mountain with limestone exposures of Govanda Formation and Naopurdan successions, with a layer of tectonic breccia (Sarmad *et al*., 2013).

- **Sedimentary processes**

Ophiolites are suggested as the main source of olivine and pyroxene mineral grains in the studied sandstones. They consist of a variety of pyroxene/ olivine-rich rock assemblages including peridotite tectonite, lherzolite, serpentinised spinel peridotite, pyroxenite, serpentinite chromitite, harzburgite, gabbro and basalt with basaltic lava flows. The Cretaceous ophiolite complexes of the Zagros Zone were exposed in the Early Tertiary and were amenable for subaerial and shallow submarine erosion along the shorelines. Intense subaerial erosion enhanced rapid mechanical disintegration of the ophiolites, evidenced by the fresh olivine and pyroxene grains in the studied sandstones. Submarine wave action, in shallow margins, induced concentration and accumulation of the heavier fraction of the detritals rich in olivine and pyroxene grains according to the model presented and discussed by Calvo (2003). Later slumping of these olivine/ pyroxene-rich sands by turbidity currents transported them deeper in the basin where they were finally deposited as part of the turbidite sequence. Tectonic activity and seismicity in the foreland margin usually create turbidity currents and slumping of the heavy fraction of the sand accumulations in the shallow parts to deeper parts of the basin (Stow, 1986; Mutti 1992; Middleton, 1993; Renyck and Witmer, 2008).

CONCLUSIONS

The anomalous concentrations of fresh olivine and pyroxene in the Kolosh sandstones were derived from wide varieties of pre-Tertiary ultrabasic/ basic intrusive and extrusive igneous rocks in the region. Olivine and pyroxene were derived from tectonite peridotite, pyroxenite, lherzolite, harzburgite, basalt and dolerites, basically from Rayat and Hasan Beg ophiolites, the nearest to Dyana area. The radiolarian chert and carbonates with ophiolite rocks in Rayat, Choman, Galalah and Hasan Beg are suggested as sources of chert and carbonate rock fragments in the Kolosh sandstones. The fresh olivine and pyroxenes grains are the products of rapid subaerial and submarine erosion of the thrusted mantle and oceanic crust sheets. Intense wave action accelerated erosion on the beach and accumulated concentrations of the heavy olivine and pyroxene. These sediments were slumped to deeper parts of the basin by the tectonically-induced turbidity currents.

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