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PETROLOGY OF THE INJANA FORMATION (UPPER MIOCENE)AT ZAWITA, AMADIYA AND ZAKHO AREA, NORTHERN IRAQ

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Abstract

This study deals with the petrology of Injana Formation (Upper Miocene) at Zawita, Amadia and Zakho areas. The sandstone of Injana Formation is of two typesnamely, litharenite and feldspathiclitharenite. The rock fragments of Injana Formation are mostly sedimentary and hence the sandstones are classified as sedarenite and more specifically chertarenite owing to the predominance of chert rock fragments. The sandstone is mineralogicallysubmature rangingfrom mechanically and chemically stable tounstable. The petrographic studies reveal nearness of source area with arid to semi-arid climate. The source rocks are sedimentary, low- to medium-grade metamorphic and basic volcanic rocks. They are mostly supplied from the rising mountain farther north and east (Taurus and Zagros Ranges) during the Alpine Orogeny induced by the continent-continent collision between Arabia and Eurasia.The mudstone consists of mixture of clay and silt with variable percentages. The major clay minerals are chlorite, kaolinite and mixed-layer illite-smectite. The non-clay minerals are calcite, quartz and subordinate feldspars.

Keywords: Injana Formation, Petrography of sandstones, Mineralogy maturity, Provenance and tectonic setting, Mineralogy of mudstones.

صخارية تكوين انجانة (المايوسين الاعلى) في مناطق زاويته وعمادية وزاخوشمال العراق

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المستخلص

تضمنت هذه الدراسة صخارية تكوين انجانه(Upper Miocene) في منطقة زاويته، عمادية وزاخو. الصخور الرملية في تكوين انجانه نوعان هما(litharenitandfeldspathiclitharenit) . القطع الصخريه لتكوين انجانه معظمها رسوبية والصخور الرملية هيSadarenite واكثر تحديداchertarenite هي نظرا لغلبة حجر الصوان في القطع الصخرية. الصخور الرملية هي معدنيا غير ناضجة وتتراوح ميكانيكيا وكيميائيا من مستقرة الى غير مستقرة. الصخور الرملية تتكون من خليط من الطين والطمى بنسب متغيرة. المعادن الطينية الرئيسيه هي chlorite, kaolinit and mixed – layer illite/smectite والمعادن غير الطينية هيcalcite, quartz and feldspar . تكشف الدراسات الصخريه القرب من منطقة المصدر وان المناخ يكون

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من جاف الى شبه جاف. الصخور المصدرية هي صخور رسوبية ومتحولة من منخفضة الى متوسطة الدرجة والبركانيه القاعدية. يكون تجهيز هذه الصخور في الغالب من جبال شمال شرق نطاق طوروس وزاكروس اثناء تكون جبال الالب الناجمة من تصادم قارة مع قارة بين المملكة العربية واوراسيا. الصخور الطينية تتكون من مزيج من الطين والغرين وبنسب متغايرة. المعادن الطينية الرئيسية هي الكلورايت والكاؤلونايت mixed-layer illite-smectite، اما المعادن غير الطينية هي الكالسايت والكوارتز والفلدسبار.

Introduction

Injana Formation marks the beginning of the molasse deposits formed by the Alpine Orogeny, during the continent-continent collision of Arabian craton with the Anatolian and Iranian microcontinents. It extends as a sheet as part of the Taurus and Zagros Mountain chains and extends further south and southwest. The Injana Formation is widely exposed in Iraq. Several studies on the petrography and provenance of Injana Formation are carried out such asGayara (1976) [1]who investigated Khanuqa area and studied the general petrography.

The aim of this study is to establish the provenance and details of the source area of the sediments of the Injana Formation at Zawita, Amadiya and Zakho area. This can be carried out by petrographic and clay minerals. These areas are selected because they were not studied previously.

Geological setting

The Injana Formation (Upper Fars Formation) is a part of the TectonostratigraphicMegasequenceof the Arabian Plate 11(Latest Eocene to Present Day). This megasequence lasted 34 my and is defined as the package of sediments lying between the unconformity marking both the onset of Red Sea rifting [2] and the first continent-continent collision between Arabia and Eurasia [3], and the present day topographic surface. The TectonostratigraphicMegasequence comprises the Zagros foreland basin sediments deposited following the inversion and followed erosion of the earlier northeast passive and active margins. Red Sea rift sediments deposited following the thermal uplift, doming and rifting along the length of the Red Sea axis. This TectonostratigraphicMegasequence thus represents the recent Foreland Basin history of the Arabian Plate, with sediments firstly infilling the long narrow Zagros foredeep margins, and then prograding southeastwards down the foredeep [4].

The lower contact of the Injana Formation with the underlying Fatha Formation (previously called the Lower Fars Formation) is conformable, placed in the field at the top of the uppermost limestone horizon of the Fatha Formation which is overlain by a thick red and subordinate grey mudstone beds. The upper contact of the formation with the Mukdadiya Formation (previously called the Lower Bakhtiari Formation) is transitional; its upper limit is marked by the first consistent appearance of pebbly sandstone.

Duringthe Late Miocene - Pliocene time major thrusting occurred during the collision of the Neo-Tethyanterranes and the Sanandaj-Sirjan Zone with the Arabian Plate. This event resulted in the uplift of the High Folded, Northern Thrust Zones and the NE parts of the Balmbo-Tanjero Zones and Mesopotamian Zones. The major foredeep formed in the Rutba-Jezira and Salman Zones is uplifted. During the late Miocene and especially the Pliocene, the High Folded Zone was uplifted with increasing intensity. The products of erosion are deposited in the nearby molasse basin characterized by the conglomerates of the Bai Hassan (previously named Upper Bakhtiari) Formation (Figure-1). In the SW the uplifted Stable Shelf was the source of the terrigenousclastics deposit to the NE of the Euphrates Boundary Fault (Dibdibba Formation)[5].

Methods and sampling

Petrology of Injana Formation (Upper Miocene) is studied in three locations from northern Iraq namely, Zawita, Amadiya and Zakho. These sections are chosen with 50 collected samples, 42 sandstone samples and 8 mudstone samples.They are taken from: Zawita section, E 43°9$^{/}$ 50$^{//}$N 36°56$^{/}$17$^{//}$ located on the southern limb of Rabateca Anticline along the main road of DuhokSarsang (western side of the road); Amadiya section E 43°31$^{/}$55$^{//}$, N 37°03$^{/}$26$^{//}$ located on the northern limb of Gara anticline at GeliDerish valley and Zakho section E 42°39$^{/}$25$^{//}$, N 37°05$^{/}$20$^{//}$ located on the northern limb of Bekhair anticline along the main road Zakho (western side of the road) (Figure-1). The thickness of the formation ranges from 140 m to 364 m. The sandstone samples werethin sectionedand stained with Alizarin red S for petrographic study and the eight mudstone samples are investigated by x-ray diffractometry. Four glass smears for each sample of separated clay fraction (-2μm) are prepared according to the method given by [6]. The preparation of glass smears by adding hexametaphosphate solution (calgon) with clay to become suspension solution then pipet the clay suspension onto beaker containing a glass slide. The end step placing the beaker in an oven at 60 C^{o} and allowing the distilled water to evaporate and the clays to settle on the four slides, which were later treated as bulk, normal, heating at 550 C^{o} and ethylene glycol. The X-ray – Diffractometerspecification of D2 phaservolat, cover tube, 30 Kv, 10 MA, 1.5418 nickel filter.

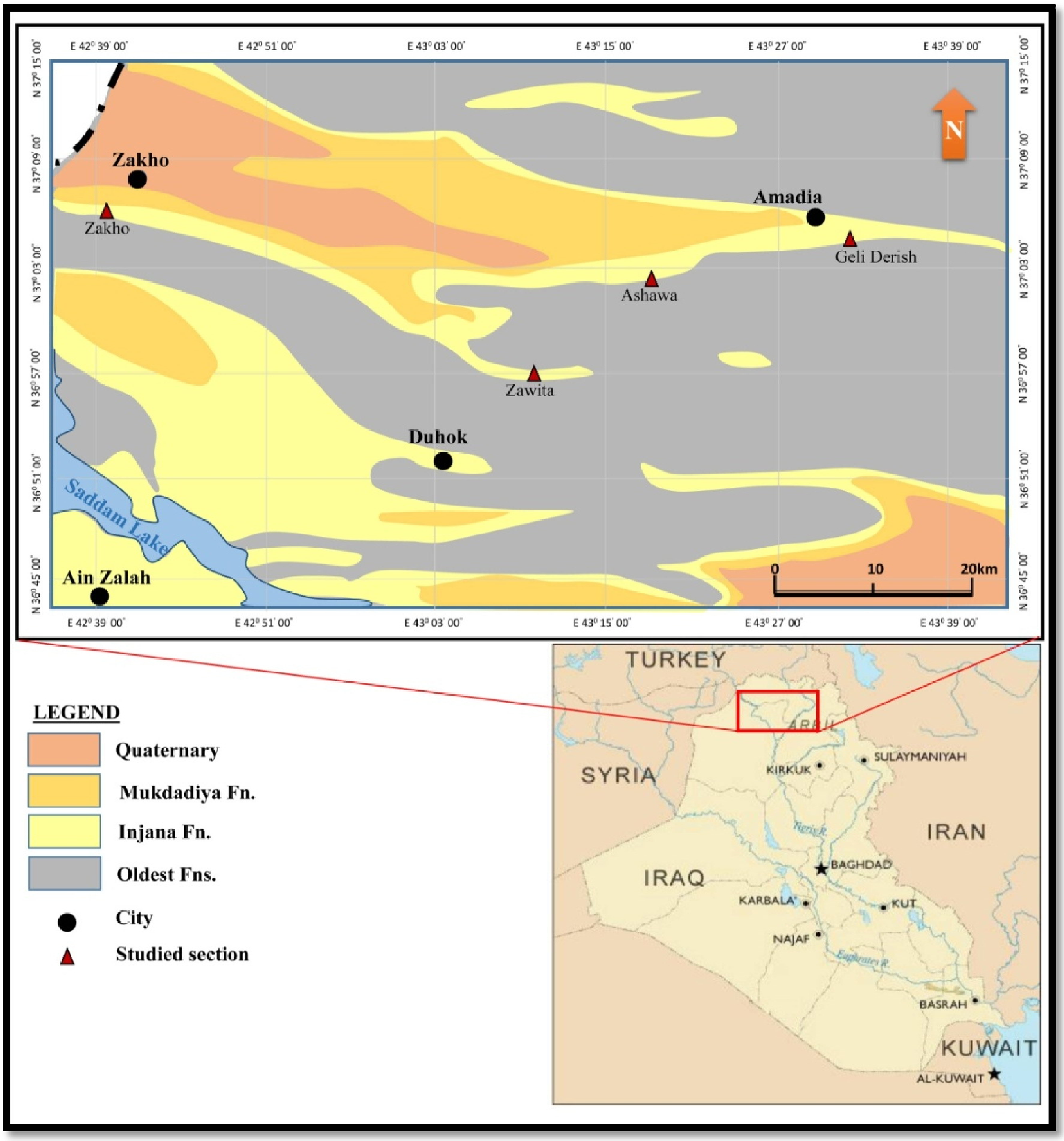

Figure 1- Geological map of the studied area shows the location of the studied sections.

Petrography of sandstones

Fortytwo thin sections are cut perpendicular to the bedding plane for petrographic study followed the procedure listed in [6]. Modal analyses of forty representative samples are carried out by using point counter mechanical stage as suggested by [7]. 500 counts per slide were preformed covering 15 components.

Table 1-Shows the mineralogical constituents of the sandstone rock units of the Injana Formation in the studied sections, withranges and averages of each components.

Component%		**Range%**	**Average%**
Quartz	Even Quartz	1.3-8.8	5.0
	Undulous Quartz	4-18.51	11.25
	Polycrystalline Quartz	0.3-7.0	3.6
	Total Quartz	2.0-11.0	7.0
Feldspar	Alkali feldspar	1.5-8.9	5.0
	Plagioclase	0.4-4.7	3.0
	Total Feldspars	1.0-7.0	4.0
Rock Fragments	Sandstone rock fragment	0.3-3.6	1.9
	Chert rock fragment	0.3-21.5	10.9
	Carbonate rock fragment	0.3-9.2	4.8
	Metamorphic rock fragment	0.8-9.5	5.2
	Plutonic igneous rock fragment	0.3-4.9	2.6
	Volcanic igneous rock Fragment	0.6-4.9	2.8
	Total Rock fragments	0.4-10	5.0
Cement	Carbonate cement	10-32.72	21.4
	Others	0.92-15.4	8.18

Sandstone components: Modal analysis of the sandstones include the averages and ranges, of the percentages of each component in the Injana Formation and given in Table 1.

Quartz:The percentage of quartz ranges between 2and 11%, with an average of 6.6 % (Table 1). Twotypes of quartz were recognized; the monocrystalline and polycrystalline, the monocrystalline types consist of even and undulous extinction quartz.

Monocrystalline quartz: The monocrystalline quartz (unitary quartz) form about 88% of the quartz framework fragments and those with undulose extinction comprise 80% of the monocrystalline quartz. They aregenerally coarse to fine grained and are subrounded in shape**.** Some grains show a clear rim with sharp outlines and other grains arewith inclusions.

Polycrystalline quartz:Polycrystalline quartz(composite quartz) is that which consists of two or more quartz crystal units of different optical orientation[8] and forms about 12% ofthe quartz framework fragments. Polycrystalline quartz in Injana Formation is generally medium size, angular in shape with more or less of equidimentional shape.

Feldspars: The percentage of feldspars in the sandstones of Injana Formation ranges from 0.9 and 6.8% with an average of 3.86% (Table 1). Feldspars are minor constituents of the Injana Formation. They include alkali feldspar (microclineand orthoclase), with an average of 5.2% and plagioclase, with an average of 2.5%. Perthitic grains are also recorded. The feldspargrains are mostly distinctly fresh (without alterations) euhedral and corroded. The fresh feldspars indicate a fragmentation process from igneous rocksaccompanied with short distance of transportation [9], dry to semi-dry climate and source area with rugged topography.

Rock fragments:Rock fragments are amongst the major constituents in the sandstone of Injana Formation which attains percentage ranges between 0.3 and 21.5% with an average of 28.3%. They include carbonates, chert, sandstones, igneous and metamorphic rock fragments. The abundance and characteristics of each of these types are discussed below:

Chert rock fragments- Chert rock fragmentsshow the first the most abundant type of rock fragments as they range between 0.3 and 21.5% with an average of 10.9%. Chert fragments are angular in shape, the types of chert that are identified in the sandstone of Injana Formation are microcrystalline chert, macrocrystallinechert, chalcedonic chert and few grains of nodular chert(Figure -2)

Carbonate rock fragments - The percentage of the carbonate rockfragments in the studied samples ranges between 0.3 and 9.2% with an average of 4.8 %. The carbonate rock fragments include several varieties which are reworked skeletal, and fossiliferous fragment. They are rounded to subrounded in shape, coarse to fine grained in size.Carbonate rock fragments represent special conditions of rapid mechanical erosion rather than chemical dissolution [10].

Igneous rock fragments - Igneous rock fragments includes both volcanic and plutonic igneous rock fragments. The percentage of the igneous rock fragments ranges between 0.45 and 4.92% with an average of 2.68%. The grains are mainly volcanic rock fragments such as andesite, the grain are subangular in shape and medium to fine in size.

Metamorphic rock fragments - The percentage of metamorphic rock fragments ranges between 0.8 and 9.5% with an average of 5.2%. The metamorphic rock fragments include: quartzite rock fragment, schists and greenstones fragments. Some grains are fresh and others are altered.

Sandstone rock fragments - Sandstone rock fragments are composed of cemented fragments of older sandstone, their percentage ranges between 0.3 and 3.6% with an average of 1.9%. The fragments are sub-angular tosub-rounded.

Cement: The percentage of cement in the Injana sandstone ranges between 10.0 and 32.7% with an average of 21.4%.Carbonate cement is abundant in the Injana sandstone. It occurs in several forms, as large crystals of sparite or microsparite, syntaxial growth and dense micritic crystal filling the void spaces between the detrital constituents.

Others: These groups include all the subordinate minerals such as biotite, muscovite, chloriteand unidentified fragments and opaque grains predominantly of iron oxides. The shape of these grains is mostly angular, as inferred from the marked and conspicuous yellow and red coloring and staining.Its percentage ranges between 0.92 and 15.4% with an average of 8.18%.

Sandstone classification: The sandstones of Injana Formation are composed of quartz (both monocrystalline and polycrystalline), feldspars (alkali feldspar and plagioclase), and rock fragments (sedimentary, igneous, and metamorphic rock fragment), sedimentary rock fragments include carbonate, chert and sandstone.According to Pettijohn's classification [10] the sandstones are litharenite (Figure-3A) whereas according to [11] it is classified as litharenite and feldspathiclitharenite (Figure- 3B).

Litharenites are of immature composition that implies high rate of sediment production from supra-crustal sources followed by short transport distance. Much fluviatile sandstones are litharenite [8]. Boggs stated that "litharenites are compositionally immature sandstones that originate under conditions favoring the production and deposition of large volume of relatively unstable materials" [12].
Feldspaticlitharenite are commonly texturally immature or submature. Most feldspathiclitharenite are derived from granitic crystalline rocks, such as granite or metasomatic rocks containing abundant potassium feldspar.Further reclassification according to Folk′s scheme [11] showed that the Injana sandstones are sedarenite (Figure -4A), and more specifically chertarenite (Figure -4B).

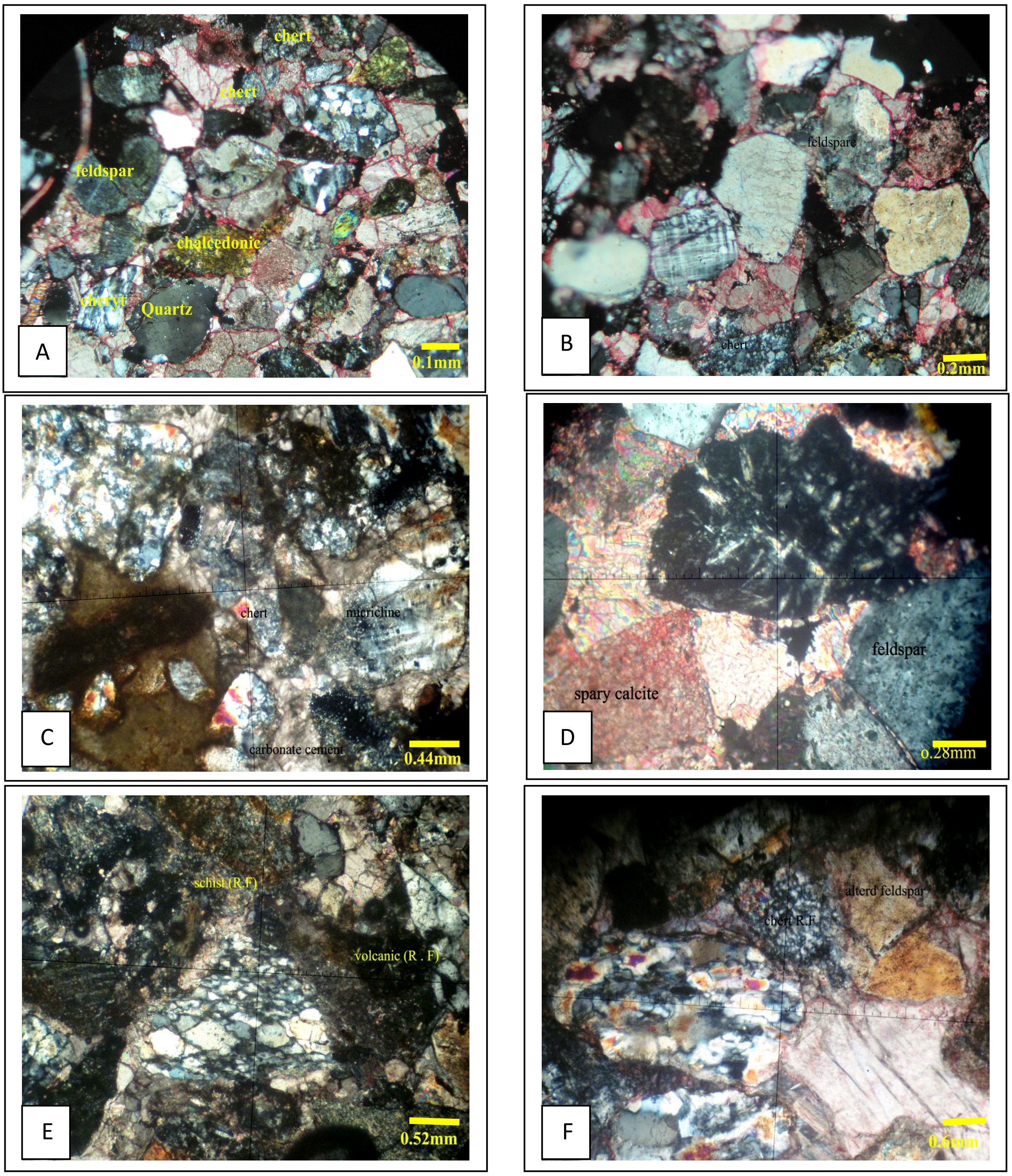

Figure- 2.(A) : Monocrystalline and polycrystalline with undulos extinction, ZW19, XPL.(B) : Feldspar orthoclase and microcline with cross hatching, ZK4, XPL. (C) : Carbonate skeletal rock fragment, ZW17, XPL. (D): Volcanic igneous rock fragment, A11, XPL. (E): Metamorphic rock fragment, A10, XPL. (F): Chert rock fragment (microcrystalline), ZW13, XPL.

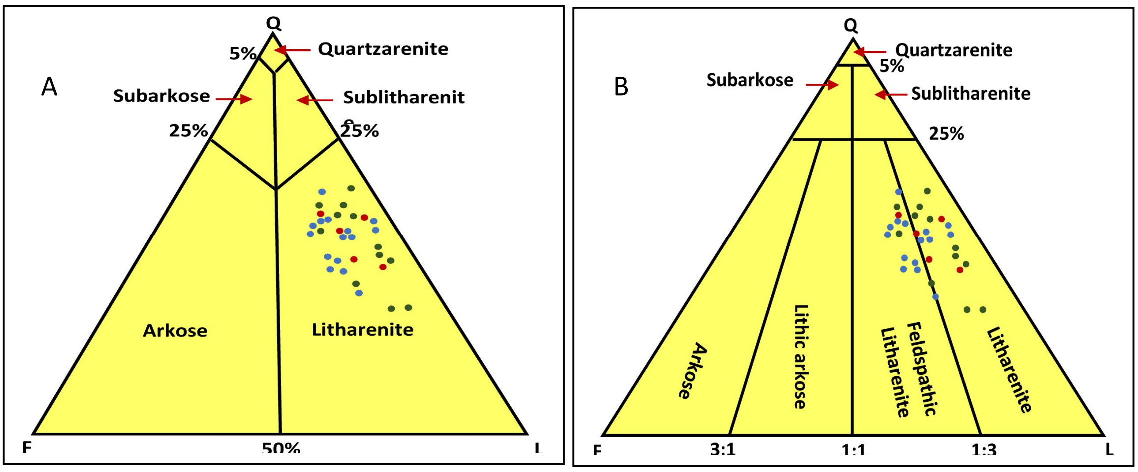

Figure 3- A Plot of sandstone samples on the ternary diagram of Pettijohn (1987), B classification of the sandstone of Injana Formation based on Folk (1974).

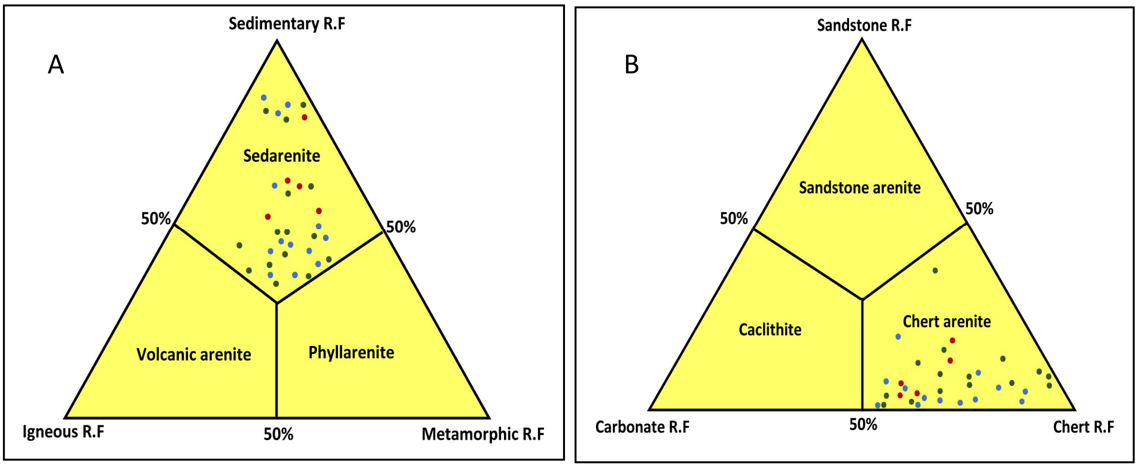

Figure 4- A Plot of Injana sandstone on the ternary diagram reflecting terminologies based on types of rock fragments of Injana Formation (based on Folk, 1974) , B The relative percentage of types of sedimentary rock fragments based on Folk (1974).

Mineralogical maturity

Mineralogical maturity (also called compositional maturity) is defined by [9] as the extent to which clastic sediment approaches the ultimate end product to that is derived by the formative processes operate upon it.He gave an index of compositional maturity, calculated from the ratio [(quartz + chert) / (feldspar + rock fragments)]. This index is determined for each sample of the Injana Formation sandstones (Table 2). The calculated index values for the studied samples show that the index of maturity ranges between 1 and 3.7% with an average of 2.35%,thus theInjana sandstones are mineralogicallysubmature.

Table 2- Mineralogical maturity index (MMI) = [(quartz + chert) / (feldspar + rock fragments)] of the sandstone rock units of Injana Formation.

Sample number	MMI	Sample number	MMI
A1	1.1	ZK7	1.7
A4	1.8	ZW5	2
A5	2.4	ZW6	2
A6	1.8	ZW7	2
A7	1.8	ZW8	1.8
A8	1.4	ZW10	3.3
A9	1.3	Zw11	2.7
A10	1.5	ZW12	1.9
A11	1.7	ZW13	1.5
A12	3.4	ZW14	2.1
A13	2	ZW15	1.5
A14	1.8	ZW16	1.7
A15	1	ZW17	2
ZK1	1.6	ZW18	3.3
ZK2	3.7	Zw19	1.8
Zk4	1.6	Zw20	1
ZK5	2.1	-	-

Based on Bjorlykke (1983), the maturity of the sandstone of Injana Formation is immature also and varied from mechanically and chemically stable to unstable(figure- 5A) stability of the sandstone of Injana Formation

Provenanceand tectonic setting

The composition of sandstone reflects the character of provenance and the nature of sedimentary processes within the depositional basin. Provenance and depositional basin are governed by the tectonic regime, which in turn control the distribution of the types of sandstone [10], [14].

From the Qt-F-L plot (Figure- 5B), recycled orogenic provenance is envisaged, whereas in the Qm-F-L diagram all points except two plot in the field mixed and transition recycled provenances according to [15] diagram (Figure- 6A).The field of "Transitional recycled"is zone of plate convergence, where collision of major plates creates uplifted source areas along the collision suture belt [12]. Two cases can be found in this respect:The first case is two continental masses collide, uplifted source rocks are typically sedimentary and metamorphic rocks. Detritus stripped include: abundant sedimentary –

metasedimentary rock fragments, moderate quartz; and high ratio of quartz and feldspars.The second case is continental mass collides with magmatic arc complex, uplifted source rock may include deformed ultramafic rocks, basalts, and other oceanic rocks, and variety of other rock types such as greenstone (low grade metamorphosed basic igneous rock), chert, argillite (low grade metamorphosed shale).The sandstone of the Injana Formation is found in the first case of the respect.

From the Qp-Qmun-Qmu quartz plot, (Figure-6B). The source of the quartz is low and medium (to high)rank metamorphic rocks [16].

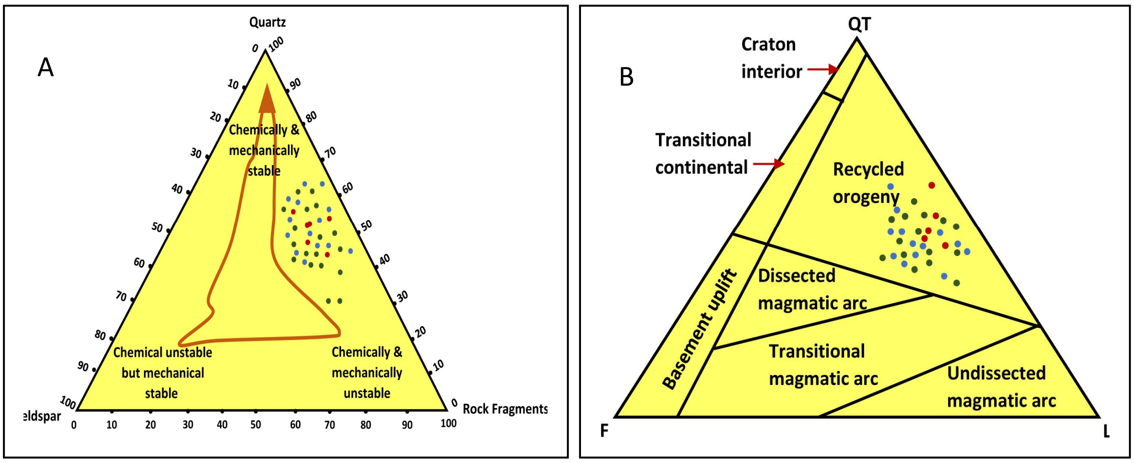

Figure 5- A: Ternary diagram of the stability of the sandstone of Injana Formation (based on Bjorlykke, 1983). B: plot of sandstone sampleson the ternary diagram of Dickinson (1985).

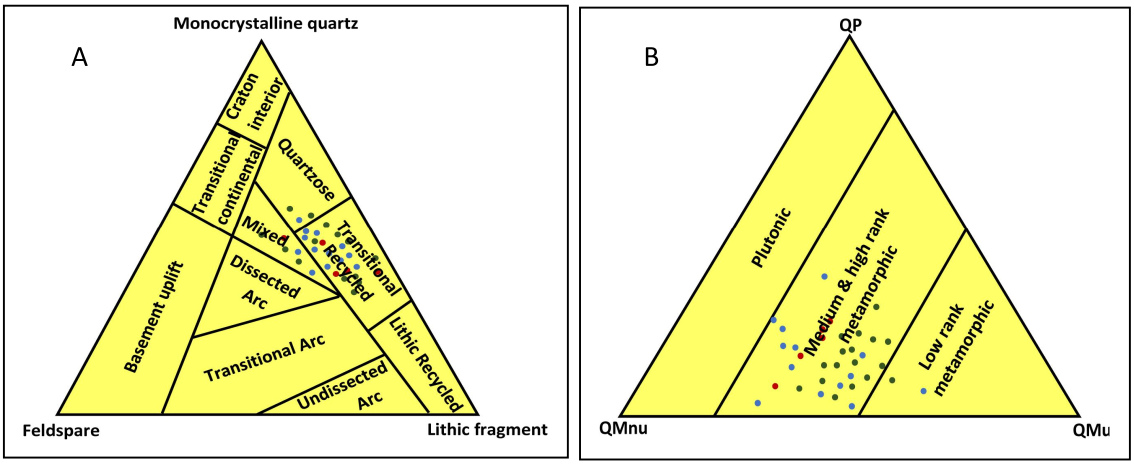

Figure 6- A Provenance diagram showing the relationship between framework composition of the sandstone and tectonic setting (after Dickinson et al, 1983), B plot of sandstone in the ternary diagram of Basu et al, (1975).

Mineralogy of the Mudstones

X-ray diffractograms reveal that the non-clay minerals are dominantly calcite, quartz and feldspar. The clay minerals are chlorite, illite, mica and kaolinite.Identification of each mineral type was based on the following cumulative criteria:

Non - clay minerals: This group includes:

Calcite - Calcite is identified by reflections at 3.03Å. It is a major mineral component in the clay fraction of Injana mudstone. This is in direct agreement with carbonate percentages in sandstones.

Quartz - Quartz ranks second abundant mineral all studied samples of Injana mudstone. It is identified by reflections at 7.02Å.In some samples, the (003) and $(11\bar{1})$ peaks of illite and kaolinite interfere with the (101) major peak of quartz, resulting in an increase in the estimated relative abundance of quartz.

Feldspar - Feldspar identified in the range 3.22-3.18 Å in several samples. Exact grouping of these minerals is not possible due to its low percentage in the clay fraction of the mudstones.

The presence of both calcite and quartz as major and abundant components is very well related to the sandstone mineralogy, a fact stressing the similar and common source rocks.

Clay minerals: This group includes:-

Chlorite– Chlorites have their (001) peaks at 14º - 14.4Å depending on the individual species. Peak positions are unchanged by ethylene glycol, upon heating to 550 ºC (001) chlorite peak may increase dramatically whereas Fe – chlorite and the higher – order peaks may be weakened [18]. The chlorite minerals are common components of low-grade green schists, of igneous rocks as hydrothermal alteration products of ferromagnesian minerals and common constituents of argillaceous rocks in both detrital and authigenic forms [19].

Kaolinite - Kaolinite group are identified by 7 Å (001)and 3.58 Å (002) peaks which upon heating 550 ºC disappear [18]. All members of the kaolinite group form primarily during hydrothermal alteration or weathering of feldspars under acid condition.

Illites -Illites are identified by 10 Å (001) and 3.3Å (003) reflections. Peaks remain unaltered by ethylene glycol and heating to 550 ºC [20]. Illite group which are the dominant clay minerals in argillaceaus rocks, form by theweathering of silicates (primarily feldspar and mica), through the alteration of other clay minerals, and during the degradation of muscovite [19].

Mixed-layered clay - Interpretation of XRD spectra from mixed-layer clay cannot be satisfactorily achieved with conventional XRD methods, as mixed layered species are present in physical mixtures that include the simple clay types. Accordingly multiple analyses are needed as well as computer generated XRD patterns to discriminate the clay layers.

Mixed-layer clays can form by weathering, involving the removal or uptake of cations, hydrothermal alteration, or removal of hydroxide interlayer and in some cases, may represent an intermediate stage in the formation of swelling minerals from non-swelling minerals or vice versa [21]; and [22]. The presence of mixed - layer clay minerals in the studied samples are basically of detrital origin. In such cases, due to weathering chlorite to may from regular and randomly interstratified mixed-layered clay minerals most likely smectite/illite following a typical weathering sequence:

The abundance of the clay minerals indicates that basic igneous and metamorphic rocks as well as recycled sedimentary rocks seem to be major contributors to the formation of clay minerals in the source area. The formation of chlorite and illite is taken to represent condition where intensive leaching of the cations is prevented and hence represent arid to semi-arid climate (Figure-8).The clay minerals assemblage in the studied samples seems to be of detrital origin supplied by the source area with little effect of digenesis and or transformed during transportation.The clay minerals present in the studied area suggest that the environment of their formation at the source areas is likely to be characterized by arid to semi arid climate which is dominated in the region at present.

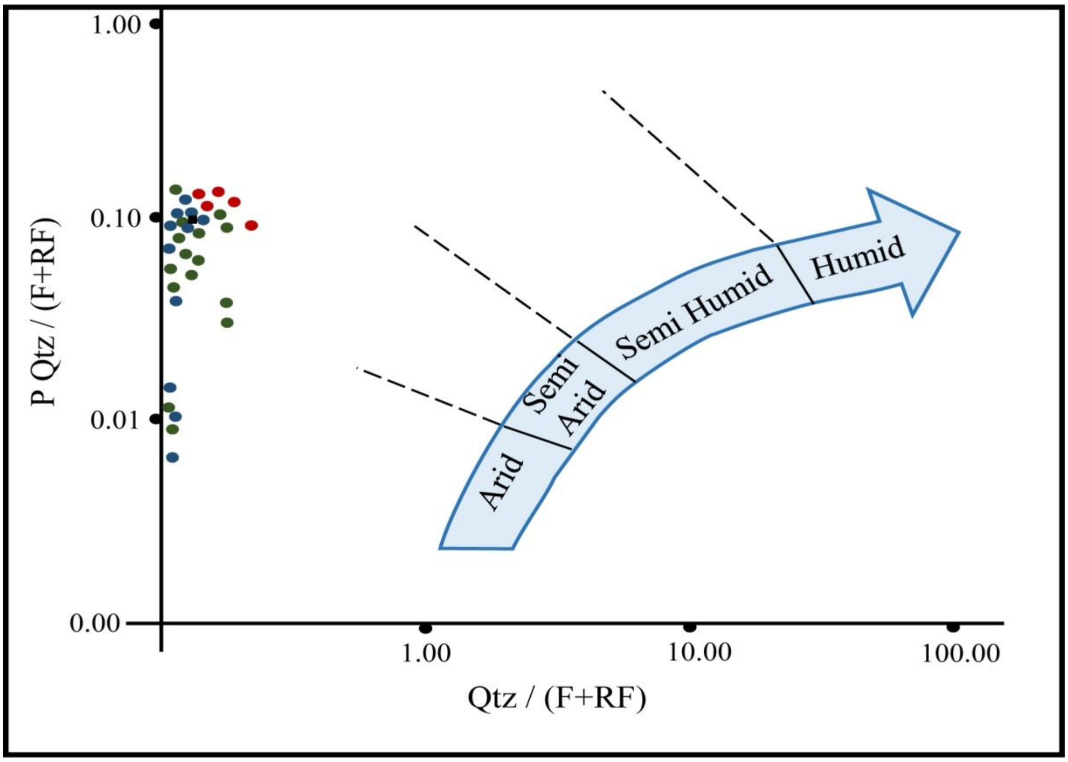

Figure 8-Average and ranges of sandstone Injana Formation represent the climat

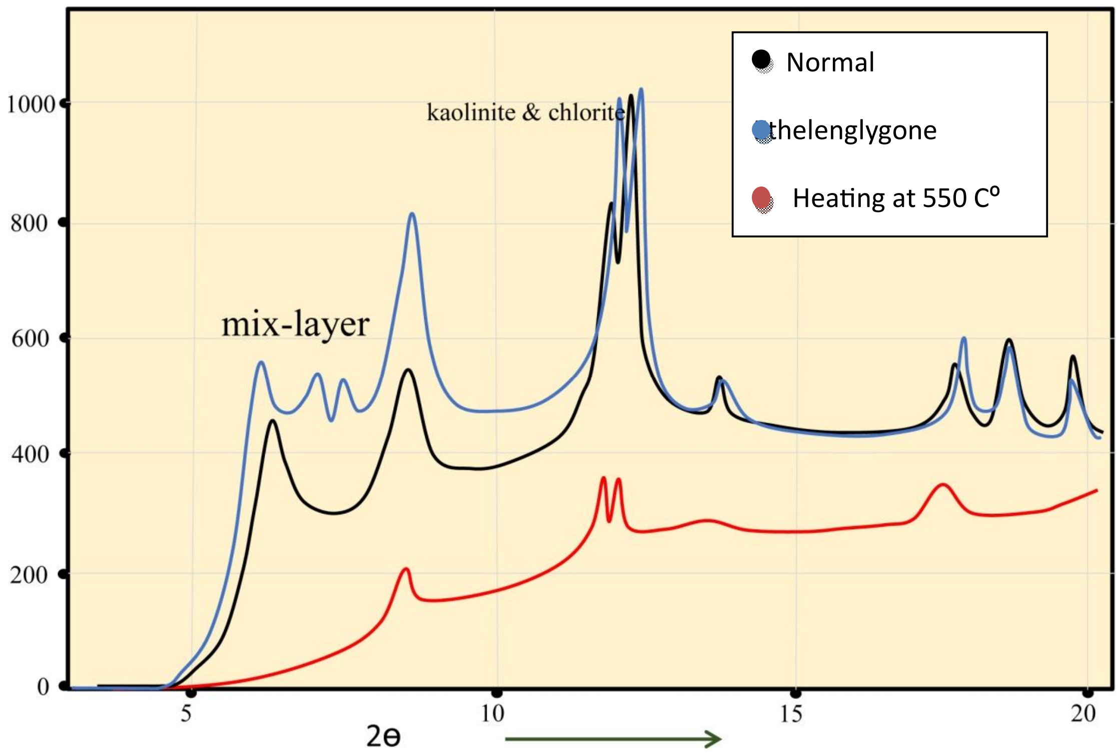

Figure9- X-ray diffractograms for shows the clay mineral components in thesample ZW3 from Zawita section.

Conclusions

The sandstone of Injana Formation was derived from near source area.The maturity of sandstone of the Injana Formation is mineralogicallysubmature ranges from mechanically and chemically stable to unstable.Tectonic provenance of the sandstone Injana Formation is transitional and mixed recycled orogen. The source of the quartz is low and medium to high rank metamorphic rocks.The mineralogy of the clay fraction of Injana mudstone leads to be climate arid to semi-arid.

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