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Petrology and provenance of the sandstone channel succession within the Jurassic Loralai Formation, Sulaiman Fold-Thrust Belt, Pakistan

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Abstract

The Sulaiman Fold-Thrust Belt, Pakistan contains thousands of meters thick Mesozoic succession, which was deposited at the northwestern passive margin of the Indian Plate within the Palaeo-Tethys. The Jurassic Loralai Formation is an important part of the sedimentary succession of the Sulaiman Fold-Thrust Belt, which is mainly composed of limestone with minor proportions of shale, marl and sandstone. Sandstone succession within the Loralai Formation has neither been reported nor described before, which is hereby reported from the Feroz-e-Kan and Ziarat Morh sections, southwest of the Muslimbagh Town. In the Feroz-e-Kan Section approximately 30 meters thick channelized sandstone succession is exposed. Petrology of these sandstones was studied and modal analysis carried out in order to classify and understand their detrital modes and provenance. Sandstone has been classified as sub-lithic arenite. Their Qt-F-L plot indicate a Recycled Orogen, Qm-F-Lt plot indicate mostly Quartzose Recycled (partly Craton Interior) Orogen and Qp-Lvm-Lsm plot suggest Collisional (Suture Belt) Orogen. We propose that detritus of sandstone of the Jurassic Loralai Formation has been derived from the Indian Craton situated east-southeast of the study area. Its close resemblance with the sandstone of the Late Cretaceous Pab and Mughal Kot formations indicate that the Indian Craton had been their common source terrain throughout the Jurassic-Cretaceous times.

Keywords: Loralai Formation; Sandstone channel succession; Petrology; Provenance

1. Introduction

The Sulaiman Fold-Thrust Belt, Pakistan contains thousands of meters thick Mesozoic succession (Fig. 1, Table 1), which was deposited at the northwestern passive margin of the Indian Plate within the Palaeo-Tethys. The succession was first mapped and its lithology briefly described by the Hunting Survey Corporation (1961), however, they have not been studied thoroughly before. Facies within the Mesozoic through Paleogene succession from northwest to southeast shows an overall general shift from deep to shallow marine reflecting basin evolution of the passive margin (Abbas and Ahmed, 1979).

The name Loralai Limestone was introduced by Williams (1959), and later accepted by the Hunting Survey Corporation (1961), for the Jurassic limestone of the Sulaiman Belt. The Zamarai Tangi, near the town of Loralai, was designated as its type section by Hunting Survey Corporation (1961), however, it is widely exposed in Qila Saifullah, Loralai and Pishin Districts (Fig. 1). The lower part comprises dark grey, micritic and argillaceous limestone interbedded with shale and marl. Some beds contain Toarcian ammonites (Shah, 2009). Shale is abundant in the lower part and may constitute up to 40% of the succession. The upper part is mainly thin to thick bedded micritic limestone with minor shale and marl as thin partings. We prefer to name it “Loralai Formation” as it comprises mixed lithological characters including shale, marl and sandstone. The formation in general is composed of very finely crystalline (micritic and biomicritic) limestone. However, in some localities it is partly arenaceous, oolitic, intraclastic, and locally posess characters of turbidites (Kassi, 1986; Kassi and Khan, 1993; Kassi and Khan, 1997). In addition to the dominantly limestone and shale lithology of the Loralai Formation, terrigeneous sandstone successions are also present in the Feroz-e-Kan and Ziarat Morh sections (Fig. 1), which are hereby reported first time.

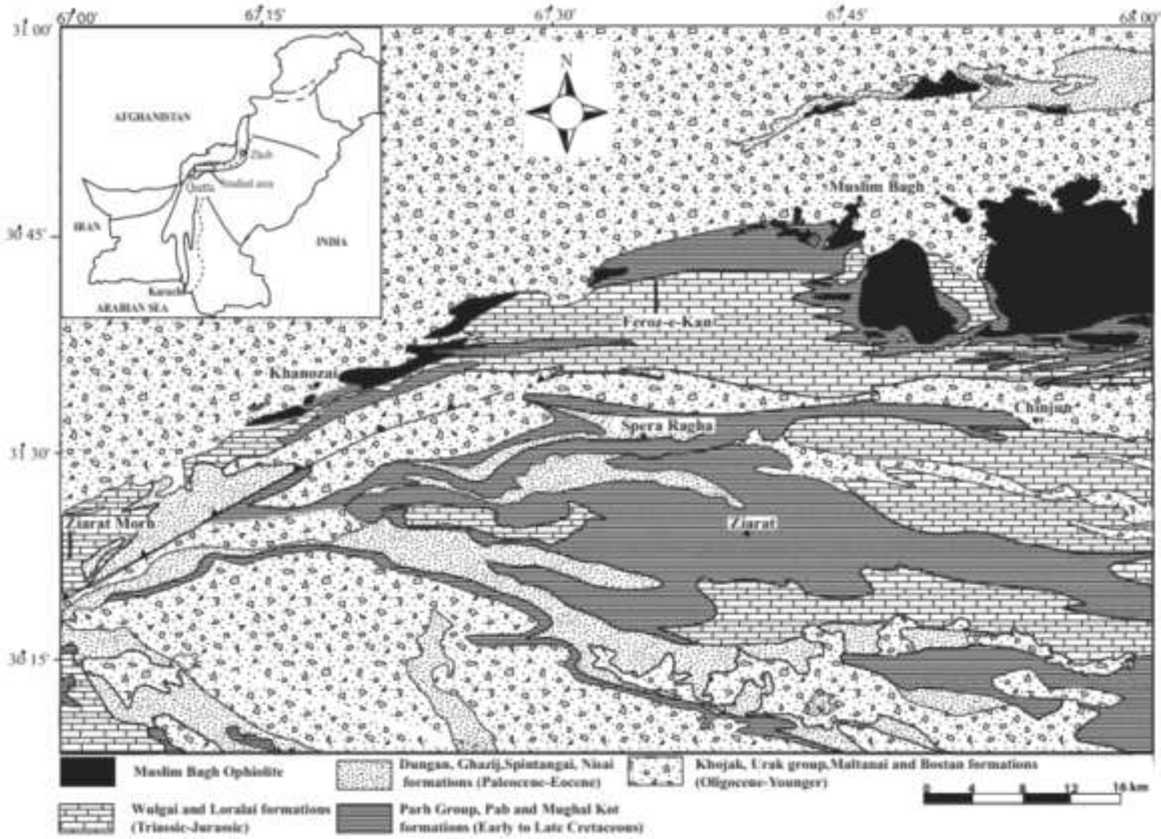


Fig. 1. Geological map of part of the western Sulaiman Fold-Thrust Belt, (modified after Hunting Survey Corporation, 1961) showing locations of the studied sections.

The formation conformably and transitionally overlies the Triassic Wulgai Formation, whereas its upper contact with Lower Cretaceous Sember Formation of the Parh Group is disconformable (Table 1). Williams (1959), Woodwards (1959) and Hunting Survey Corporation (1961) assigned an Early Jurassic age to the Loralai Formation. Later on, Otsuki et al. (1989) obtained Toarcian fossils from its lower part. Fossils recorded in the Loralai Formation include *Nejdia sp., Protogrammoceras sp., and Phymatoceras sp.* Some poorly preserved ammonites were also found in the upper part of the Loralai Formation of the Zamarai Tangi and Mara Tangi sections. The lower age limit is clearly late Liassic, however, the upper limit may extend up to Bajocian (Otsuki et al., 1989).

This paper describes the sandstone petrology and provenance of newly discovered sandstone succession within the Jurassic Loralai Formation of the Feroz-e-Kan and Ziarat Morh sections. Attempt has been made to classify and determine detrital mode, provenance of the sandstone.

2. Methods and materials

The sandstone succession was studied at two sections of Feroz-e-Kan and Ziarat Morh (Figs. 1 and 2). The Feroz-e-Kan section mostly comprises limestone and shale in its lower part, however, its upper part contains channelized sandstone and limestone interbedded with shale. The limestone is thin to thick bedded, finely crystalline micritic, partly arenaceous and possesses various types of primary sedimentary structures, such as hummocky cross-stratification, parallel lamination, cross-bedding and longitudinal ridges. Limestone beds are amalgamated, lenticular, having erosive bases and oxidized undulatory top surfaces with iron concretions. Limestone succession generally show thickening-up cycles. Shale is dark greenish grey, which weathers to light brown, and contain iron concretions. Sandstone succession is present in the uppermost part of the formation, having an overall thickness of 30 m. Thickness of the sandstone beds range from 4 to 200 cm; they are lenticular, showing pinch and swell morphology, hummocky cross-stratification, parallel lamination (Plate 1a), trough cross-bedding, flute casts, load casts (Plate. 1b) and longitudinal ridges. Most of the sandstone beds display erosive bases, lanticular channel morphology (Plate 1c) and stacking pattern, i.e. the overlying bed mostly truncate the lower beds. Sandstone beds mostly pinch out laterally within a distance of 10 to 15 meters. Orientations of the sandstone channels and associated sole marks indicate current flow generally towards NW.

The Ziarat Morh section (Fig. 1) is dominated by limestone, marl and shale; however only a single sandstone bed was also observed. Limestone is finely crystalline micritic, however, some of the beds are arenaceous. The limestone is brownish grey to dark grey and medium to thick bedded. Bedding planes are undulatory and some have oxidized top surfaces. The limestone succession displays pinch and swell morphology, parallel-lamination, hummocky cross-stratification, low-angle cross-bedding, and longitudinal ridges at their bases. Three readings of orientations of the longitudinal ridges were taken which vary between 160^0 and 180^0 and current directions are towards NNW. The succession has been intruded by numerous doloritic sills, which range in thickness from 3 to 40 m and extend laterally for hundreds of meters. Sandstone is very light gray, medium to fine grained and its thickness is 50 cm, which is tabular and laterally traceable for tens of meters through the outcrop.

Table 1. Stratigraphic succession of the Sulaiman Fold-Thrust Belt, Pakistan (modified after the Hunting Survey Corporation, 1961).

Age	Group	Formation	Lithology
Pleistocene		Lie Conglomerate	Conglomerate, sandstone
Miocene-Pleistocene	Urak Group	Uzda Pusha Formation, Shin Matai Formation, and Urak Formation	Sandstone, claystone and conglomerate
	Disconformity (Angular unconformity in some areas**)**		
Middle-Late Eocene		Spintangi Limestone	Limestone, shale and sandstone
Early Eocene		Ghazij Formation	Claystone, siltstone, conglomerate, limestone and coal seams
Paleocene		Dungan Formation	Limestone and shale
	Disconformity		
Late Cretaceous		Pab Formation, Mughal Kot Formation, Fort Munro Formation and Bibai Formation	Sandstone, siltstone, shale, limestone, *in- situ* basic volcanic rocks, volcanic conglomerate, breccia and mudstone
Early-Middle Cretaceous	Parh Group	Sember Formation, Goru Formation and Parh Limestone	Limestone (bio-micritic), marl and shale
	Disconformity		
Jurassic		Loralai Formation	Limestone with minor shale, marl and sandstone
Triassic		Wulgai formation	Shale and minor limestone
	Base not exposed		

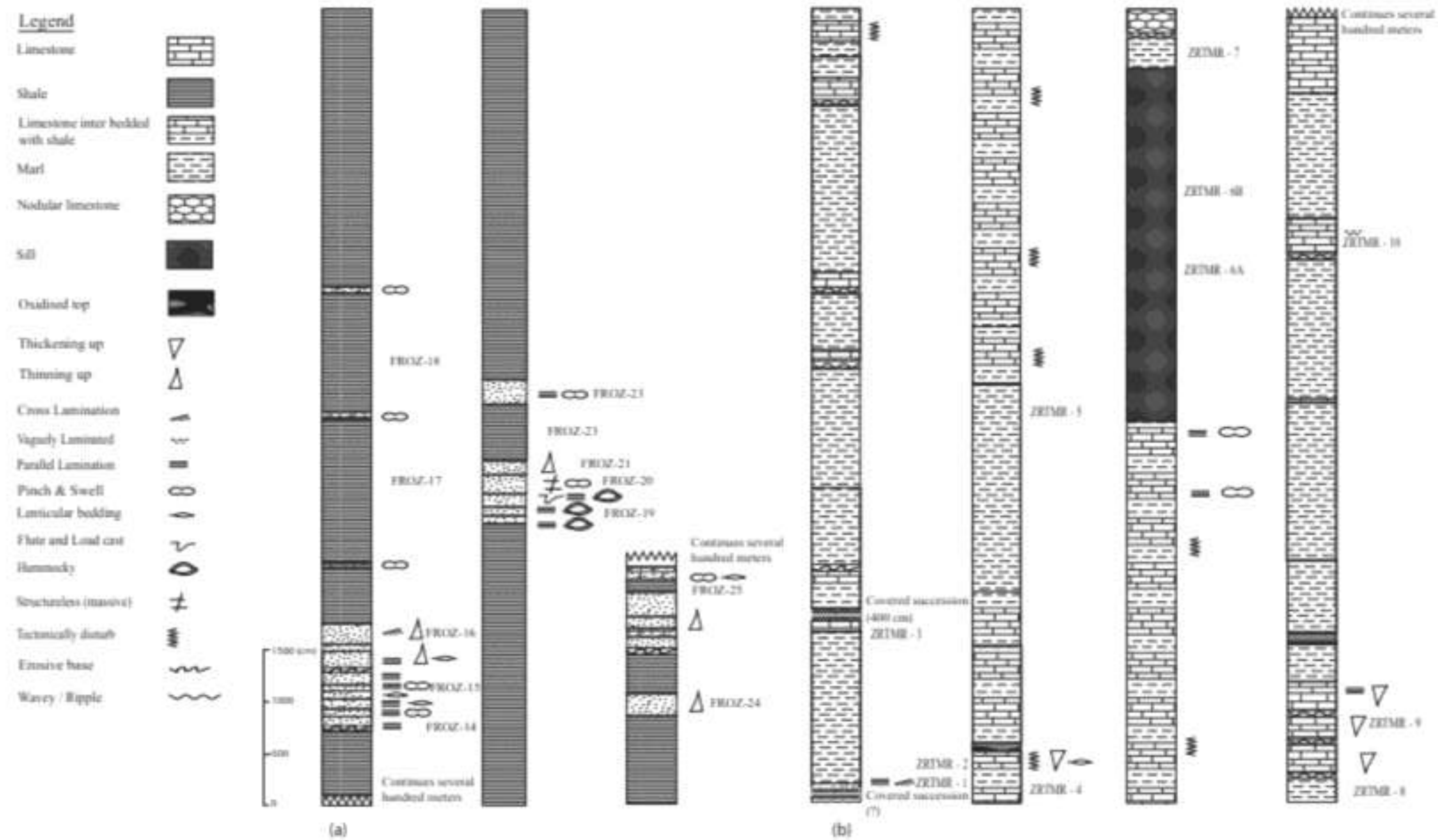


Fig. 2. Sedimentary log of Loralai Formation (a) Feroz-e-Kan and (b) Ziarat Morh sections.

Sandstone petrology is based on the study of 7 thin sections, obtained from a 30 m outcrop of the Feroz-e-Kan Section, and one thin section from the Ziarat Morh Section. Thin sections were studied under the Polarizing Microscope and Scanning Electron Microscope. Studies under the Scanning Electron Microscope were carried out using a model Jeol JSM 6400, equipped with a link system of Energy Dispersive X-ray micro-analyser (EDAX). Polished thin sections of sandstone were coated with carbon, using a Leica Emitech K950 Evaporator. Samples were also coated with gold for examining in Secondary Electron (SEI) and their Backscattered Electron (BSC) micrograph analyzer. The SEM–BSC micrographs were labeled using Adobe Photoshop software.

3. Sandstone petrology

3.1. Texture

The sandstone samples are mostly fine grained; however, some beds are medium grained, subangular to subrounded (Plate 2a) and moderately sorted. Most of the sandstone is tightly packed; some grains clearly show pressure solution contacts. Primary porosity is very low, however, some elongated secondary fractures are observable. Low porosity is due to compaction, tight packing and presence of quartz and calcite cementation.

Quartz and feldspar are among the most common mineral constituents. Other minerals include micas, heavy minerals, clays and cements. Also various types of lithic fragments are present. The mineral constituents and rock fragments are described as under:

3.2. Composition

Quartz is among the most abundant framework grains, which include both mono- and poly-crystalline grains. Monocrystalline quartz (Plate 2b) grains are very common, as compare to the polycrystalline grains, which show both undulose and nonundulose extinction. Polycrystalline quartz show two or more crystals per grain having straight to undulose extinction (Plate 2c). Replacement of quartz grains by calcite is a common phenomenon, which has caused corroded boundaries of the quartz grains. Complete to partial replacement of the quartz grains by calcite is common; sometimes, leaving behind relics of original quartz grains may be observed. Quartz grains also show mineral inclusions of zircon, rutile, tourmaline and opaque minerals.

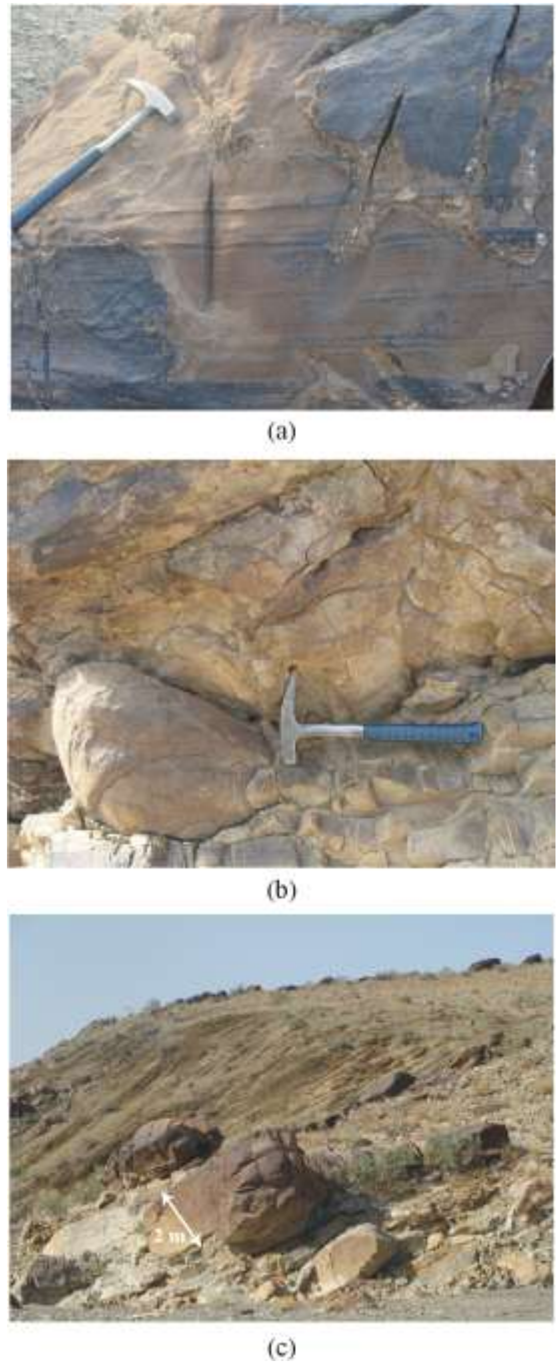


Plate 1. Field photographs of the Loralai Formation of the Feroz-e-Kan section showing: (a) thick bedded sandstone with well-developed parallel lamination; (b) erosive base of the sandstone bed with very large flute-like feature at the base of sandstone bed; (c) distant view of the sandstone succession displaying lenticular channel morphology.

Feldspar includes both K-feldspar and plagioclase. Plagioclase is more common than the K-feldspar. K-feldspar includes perthite (Plate 2d) and orthoclase. Plagioclase grains show characteristic albite twining (Plate 2e). Feldspar grains commonly have cloudy appearance and generally altered to calcite. Study of feldspars under the Scanning Electron Microscope show that the detrital K-feldspar and plagioclase grains have been subject to varying degree of replacement by albite; authigenic albite appears as blocky euhedral crystals, ranging in size from 20 to 100 µm, grown parallel to the cleavage planes of the parent grains as overgrowths (Plate 2f).

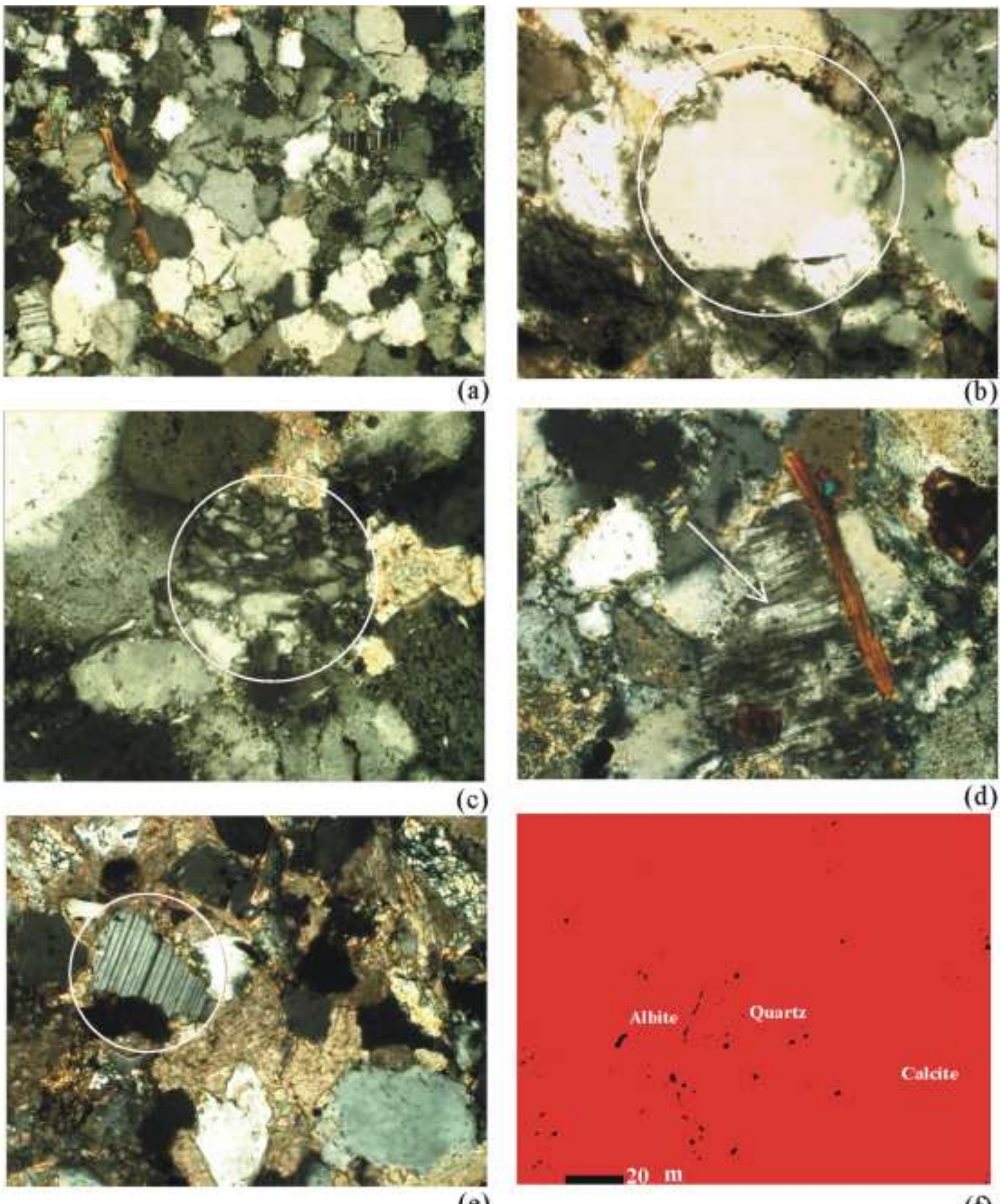


Plate 2. Photomicrographs of sandstone of the Loralai Formation: (a) showing highly quartzose nature of the sample, 10x10, XPL; (b) monocrystalline quartz grain (circled),10x10, XPL; (c) polycrystalline quartz grain (circled), 10x10, XPL; (d) perthite grain (arrow) in the centre, 10x25, XPL; (e) plagioclase feldspar (circled) surrounded by quartz and lithic fragments set in spary calcite cement, 10x40, XPL; (f) back-scattered SEM image showing quartz and authigenic euhedral albite, bar scale shows 20 µm.

Micas are also commonly present, which include muscovite and biotite (Plate 3a). Biotite is pleochroic and varies from yellowish brown to dark brown, while muscovite is colorless to pale green under plain polarized light. Alteration of biotite flakes into chlorite is very common, which may be partial to complete. Mica flakes mostly appear to have been deformed and disrupted between the quartz grains due to compaction.

The heavy minerals include zircon, tourmaline, rutile, staurolite and anatase (Plate 3b, c, d and e). Zircons are present as very small crystals and easily identifiable because of its high relief and high order interference colour. Zircon and tourmaline are the most abundant among heavy minerals in the studied thin sections.

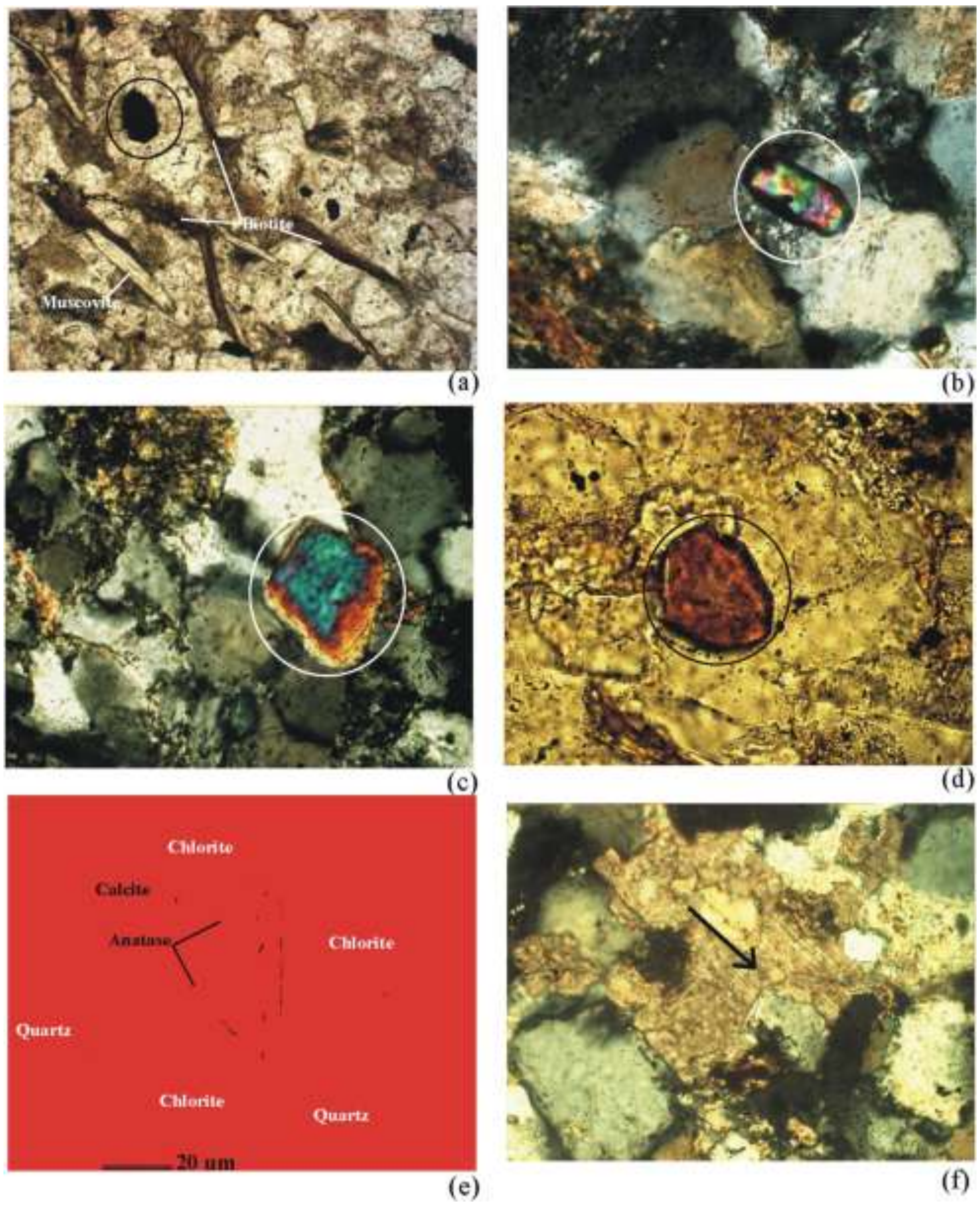


Plate 3. Photomicrographs of sandstone of the Lor Formation showing: (a) muscovite and biotite grains and opaque minerals (circled),10x10, PPL; (b) zircon grain (circled), 10x40, XPL; (c) tourmaline grain (circled), 10x40, XPL; (d) staurolite grain (circled), 10x40, PPL; (e) back- scattered image showing anatase crystals surrounded by chlorite, 20 um; (f) extensive replacement of quartz by spary calcite cement leaving behind the relics of quartz (arrow), 10x25, XPL.

The most common cementing material is calcite, along with lesser proportion of quartz and clay minerals. Calcite cement is mainly in the form of sparry calcite (Plate 3f). Quartz cement exists in the form of quartz overgrowths, which is evident in most of the thin sections (Plate 4a), however, two samples have very high amount of quartz cement, and this may be due to high compaction of quartz grains, which may not have allowed calcite cement to penetrate. The calcite cement seems to be secondary, as it has replaced quartz cement samples that are loosely packed and corrosion of the quartz grain is common. Quartz overgrowths are recognized from development of euhedral forms around detrital grains; in some cases perfect euhedral crystals have been developed. Clays are also present as thin authigenic veneers around most of the quartz grains. Study of samples under Scanning Electron Microscope revealed that clays are mostly chlorite (Plate 3e).

Various types of rock fragments were identified including mostly, metamorphic and igneous varieties, which collectively represent the second most abundant component. The metamorphic fragments include gneiss and schist (Plate 4b). Igneous fragments include mostly granitic and very rarely mafic volcanic rocks of basaltic composition. Chert fragments are recognizable and distinguished by its very fine grained texture.

3.3. Modal analysis

Selected samples 8 in number were point counted using a James Swift Digital point counter, installed on Olympus polarizing microscope at the Department of Earth Sciences, Aarhus University, Denmark. 300 points were counted in each thin section (Tables 2, 3 and 4) using the Gazzi-Dickinson method (Gazzi, 1966; Dickinson, 1970) and petrographic groups of Zuffa (1987, 1985 and1980) and Ingersoll et al. (1984). Identification of grains was achieved with confidence of almost all grains, therefore, 300 counts per thin section yielded statistically reliable values for all parameters (Tables 3 and 4), (Zuffa, 1987, 1985 and 1980; Ingersoll et al., 1984). Point counts of detrital grains such as quartz, feldspar and lithic fragments were recalculated to get their percentages (Table 4) and then plotted on various triangular diagrams (Figs. 3, 4 and 5). A test of comparison between the percentages of components for 300 and 600 point counts, in one thin section, indicates that the percentages obtained for the components in each count are classified in the same order. Components selected for point counting include quartz, feldspar, lithic fragments, micas, carbonate cement and matrix, which are defined in Table 2, their results and percentages are shown in Table 4. In order to avoid multiple counting of large clasts, point counts were set 0.3 mm and traverses 2 mm apart.


(a)

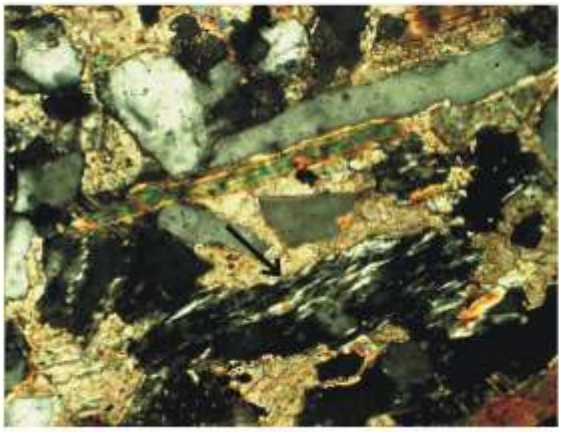

(b)

Plate 4. Photomicrographs of sandstone of the Loralai Formation showing: (a) quartz over-growth (circled), 10x25, XPL; (b) gneiss and schist fragments (arrow) surrounded by quartz and muscovite, 10x25, XPL.

3.4. Classification and provenance

Using the classification scheme of Pettijohn et al. (1987), we plotted our re-calculated parameters on the Q-F-L triangular diagram (Fig. 3a). It may be observed that all the samples fall into the field of sub-lithic arenite. However, only one sample plot on the border of sub-lithic arenite with sub-arkose (Fig. 3a).

3.5. Detrital modes

Point counting methods are employed primarily to determine statistical parameters and modal composition of rock samples (Ingersoll et al., 1984) using Dickinson et al. (1983) procedures. We also recalculated and plotted our data on the Q-F-L, Qt-F-L, Qm-F-Lt and Qp-Lvm-Lsm triangular diagrams (Pettijohn et al., 1987; Dickinson, 1985; Suczek and Ingersoll; 1985; Dickenson et al., 1983; Dickinson and Suczek, 1979; Ingersoll and Suczek; 1979). The Qt-F-L and Qm-F-Lt triangular plots (Figs. 3b and 4a) (after Dickinson, 1985; Dickinson et al., 1983) indicate that six out of eight samples plot in the Quartzose Recycled Orogen and two samples within the field of Craton Interior.

Table 2. Classification of detrital grain types (after Graham et al., 1976; Ingersoll and Suczek, 1979).

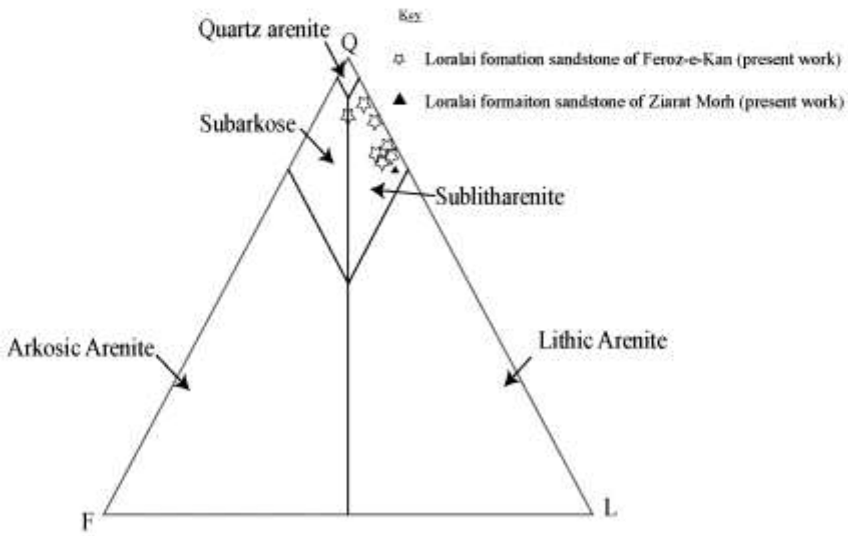
Sums	**Symbols**	**Grain Types**
Q = Qm + Qp Qt= Qm + Qp + C	Qt+Q	Total quartzose grains + chert
	Qm	Monocrystalline quartz grains
	Qp	Polycrystalline quartz grains
	C	Chert grains
F = P+ K	F	Total feldspar grains
	P	Plagioclase grains
	K	K-feldspar grains
Lt = Lvm+ Lsm+ Lm+Lv+Ls+Lm	Lt	Total lithic fragments
	Lv	Volcanic lithic fragments
	Ls	Sedimentary lithic fragments
	Lm	Metamorphic lithic fragments
	Lvm	Volcanic and metavolcanic lithic fregments
	Lsm	Sedimentary and metasedimentary lithic fregments

Table 3. Point counting data of sandstones of the measured sections of the Loralai Formation, using the Gazzi-Dickinson method (Gazzi, 1966; Dickinson, 1970). (Qm) monocrystalline quartz; (Qp) polycrystalline quartz; (K) Potash feldspar; (P) plagioclase; (M) mica; (A) accessory minerals; (C) chert; (Cf) carbonate fragment; (Ls) sedimentary lithic fragment; (Lm) metamorphic lithic fragment; (Lv) volcanic lithic fragment.

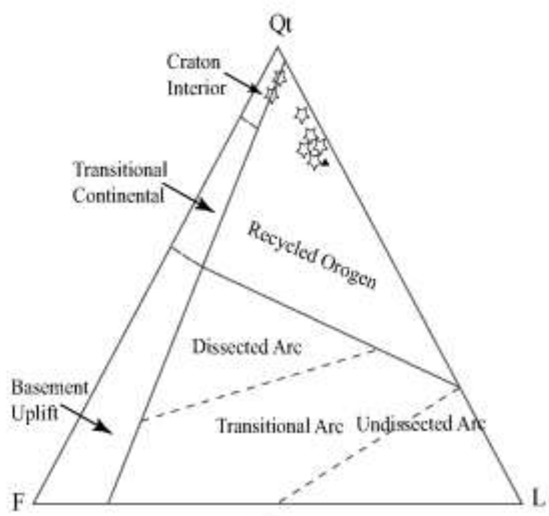
S. #	**Sample No.**	**Qm**	**Qp**	**Qt**	**K**	**P**	**M**	**A**	**C**	**Cf**	**Ls**	**Lm**	**Lv**	**Cement**
1	FROZ-14	253	6.0	259	0.0	7.0	9.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0
2	FROZ-15	216	3.0	219	1.0	8.0	6.0	0.0	0.0	0.0	0.0	58.0	0.0	8.0
3	FROZ-16	159	9.0	168	0.0	13.0	9.0	7.0	0.0	0.0	0.0	13.0	0.0	90.0
4	FROZ-19	220	10.0	230	0.0	6.0	1.0	7.0	0.0	0.0	0.0	36.0	0.0	20.0
5	FROZ-21	201	9.0	210	3.0	11.0	9.0	5.0	0.0	0.0	0.0	44.0	0.0	18.0
6	FROZ-23	361	18.0	379	0.0	9.0	19.0	12.0	0.0	0.0	0.0	77.0	1.0	103.0
7	FROZ-24	188	18.0	208	0.0	4.0	12.0	3.0	2.0	4..	0.0	43.0	0.0	26.0
8	ZRTMR-2	126	30.0	156	3.0	3.0	9.0	28.0	0.0	0.0	0.0	48.0	0.0	53.0

Table 4. Recalculated percentages of various parameters used in triangular plots for composition and provenance (after Graham et al., 1976; Ingersoll and Suczek, 1979; Dickinson and Suczek, 1979) of sandstone of the Loralai Formation.

	Q-F-L			Qt-F-L			Qm-F-Lt			Qm-P-K			Lm-Lv-Ls			Qp-Lvm-Lsm		
Sample No.	**Q**	**F**	**L**	**Qt**	**F**	**L**	**Qm**	**F**	**Lt**	**Qm**	**P**	**K**	**Lm**	**Lv**	**Ls**	**Qp**	**Lvm**	**Lsm**
FROZ-14	89	2	9	89	2	9	87	2	11	97	3	0	0	100	0	19	0	81
FROZ-15	77	3	20	77	3	20	76	3	21	96	4	0	0	100	0	5	0	95
FROZ-16	86	7	7	91	4	5	82	7	11	92	0	8	0	100	0	41	0	59
FROZ-19	85	2	13	85	2	13	81	2	17	97	0	3	0	100	0	22	0	78
FROZ-21	78	6	16	78	6	16	75	5	20	93	5	2	0	100	0	17	0	83
FROZ-23	79	2	19	79	2	19	76	2	22	98	2	0	13	86	1	17	0	83
FROZ-24	78	2	20	78	2	20	71	2	27	98	2	0	11	89	0	25	0	75
ZRTMR-2	74	3	23	74	3	23	60	3	37	95	3	2	0	100	0	38	0	62



(a)



(b)

Fig. 3(a). Q-F-L plot of sandstone samples of the Loralai Formation (after Pettijohn et al., 1987).
Fig. 3(b). Qt-F-L compositional diagram (after Dickinson and Suczek, 1979) of sandstone of the Loralai formation.

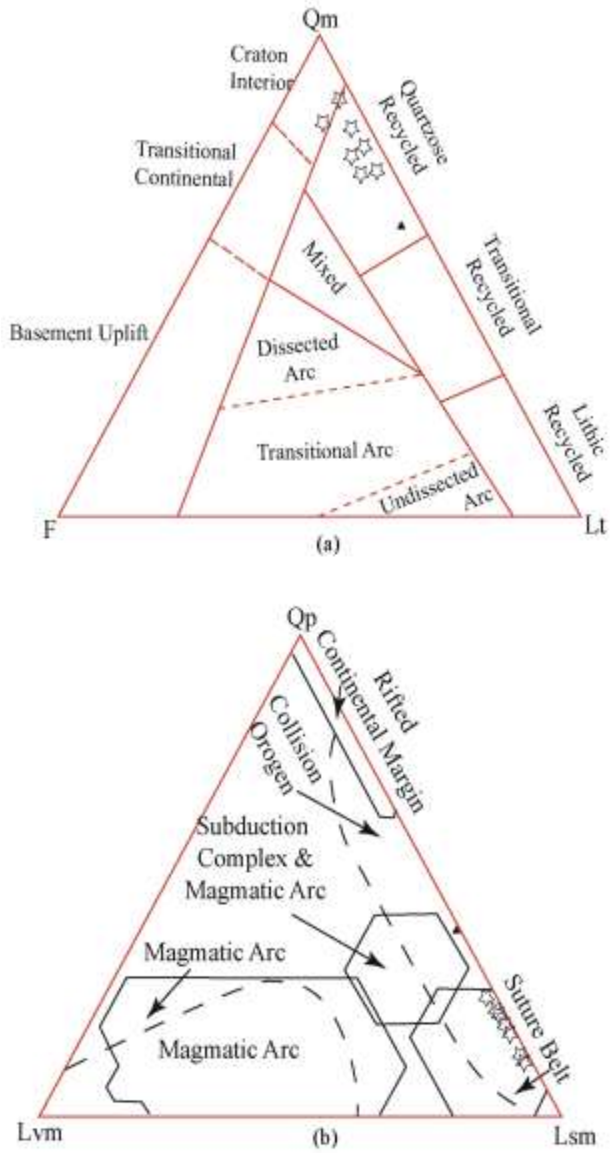


Fig. 4(a). Qm-F-Lt compositional diagram (after Dickinson et al., 1983; Dickinson, 1985) of the sandstone samples of the Loralai formation.

Fig. 4(b). Qp-Lvm-Lsm compositional diagram of sandstone samples of the Loralai formation; dashed-lined fields are from Dickinson and Suczek, (1979) and solid lined fields are from Ingersoll and Suczek, (1979). Symbols as in Figure 3a.

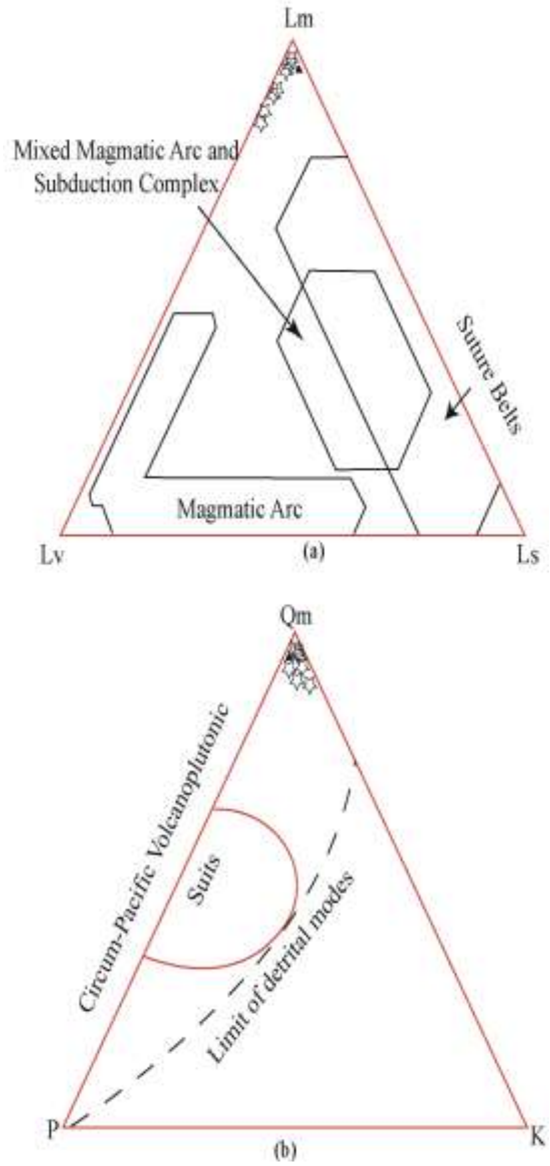


Fig. 5(a). Lm-Lv-Ls compositional diagram (after Ingersoll and Suczek, 1979; Suczek and Ingersoll, 1985) of sandstone samples of the Loralai formation.

Fig. 5(b). Qm-P-K compositional diagram (after Dickinson and Suczek, 1979) of sandstone samples of the Loralai formation. Symbols as in Figure 3a.

The Qp-Lv-Lm triangular diagram (Fig. 4b) was introduced by Graham et al. (1976) as a useful indicator of provenance, followed by Ingersoll and Suczek (1979). They used two types of triangular plots to show lithic components, which are more indicative of provenance and tectonic setting. The same plots are hereby designated in order to avoid the confusion of terminology of Qp- Lvm-Lsm (after Ingersoll and Suczek, 1979) with the Lm-Lv-Ls plot (after Graham et al., 1976). Both Qp-Lvm-Lsm and Lm-Lv-Ls plots are useful to differentiate sandstones derived from Suture Belts, Magmatic Arcs and Rifted Continental Basins (Ingersoll and Suczek, 1979; Dickinson and Suczek, 1979). Plot of Qp-Lvm-Lsm diagram (Fig. 4b, Table 4), indicates that seven out of eight samples fall within the fields of Suture Belt and only one in the Collision Orogen. The Lm-Lv-Ls triangular plot (Fig. 5a, after Ingersoll and Suczek, 1979, Suczek and Ingersoll, 1985) differentiates metamorphic lithic grains from the sedimentary and volcanic lithic grains. These plots indicate that the lithic fragments have mainly been derived from the igneous and metamorphic source rocks; however metamorphic rock fragments are the dominant (Fig. 5a). The Qm-P-K (Fig. 5b) plots indicate detrital modes of the mineral grains alone and polycrystalline fragments. The Qm-P-K triangular plot illustrates that quartz and feldspar grains were derived mainly from granitic rocks with minor contributions from volcanic and metamorphic rocks. The Qm pole of the triangle reflects increasing maturity or stability for detritus derived from the cratonic blocks or recycled through derivative orogenic terrains (Dickinson and Suczek, 1979). The plot clusters near the Qm pole of the Qm-P-K, indicating that sandstone were recycled and highly mature.

3.6. Provenance

Sandstone petrography of the Loralai Formation reveals the types of quartz grains, which are indicative of metamorphic and plutonic source terrain. The high proportion of monocrystalline quartz of nonundulose as well as undulose nature (42-84%), indicates derivation from a plutonic igneous source (Blatt, 1967). The suit of heavy minerals, including tourmaline, staurolite, rutile and zircon, also support contribution from the acidic igneous source (Gallala et al., 2009).

Petrographic data of lithic fragments also indicate that a metasedimentary terrain may have been an additional source (Graham et al., 1976). On the basis of our sandstone petrography and plots of detrital modes on different compositional diagrams it may be concluded that sandstones of the Jurassic Loralai Formation was fed from Craton Interior, however, later on it was recycled to reach at the destination. The north westward paleocurrents by flute marks also indicate that detritus was derived from the Indian Craton, located to the east and southeast of the study area.

3.7. Comparison with other formations of the area

We compared the compositional diagrams of sandstone of the Loralai Formation with the Late Cretaceous Pab and Mughal Kot formations of the Kirthar-Sulaiman Fold-Thrust Belt, (Kassi et al., 1991; Sultan and Gipson, 1995; Sarwar, 2001; Umar, 2008) indicate that they have similar characters. Modal analysis of the Pab and Mughal Kot formations of the eastern parts of the Sulaiman Fold-Thrust Belt, indicate that they are highly quartzose and their Q-F-L plots (Kassi et al., 1991; Sultan and Gipson, 1995) indicate that they fall mostly in the fields of quartz arenite and sub-arkose. Samples of the Pab and Mughal Kot formations of the Spera Ragha areas Sulaiman Fold- Thrust Belt (Sarwar, 2001) are classified as quartz arenite and sub-lithic arenite (Fig. 6a). However, sandstones of the Pab and the Mughal Kot formations of the Kirthar Belt (Umar, 2008) however, fall into the field of sub-lithic arenite and quartz arenite fields. The sub-arkose natures of the samples of the eastern, Sulaiman Fold-thrust Belt (Sultan and Gipson, 1995) indicate lesser degree of maturity due to its proximity with the source terrain.

Comparison of the Qt-F-L plots of sandstone Jurassic Loralai Formation of the study area with those of Late Cretaceous Pab and Mughal Kot formations of Kirthar Fold-Thrust Belt (after Umar, 2008) illustrates comparable detrital modes (Fig. 6b). The Qt-F-L plots of the study area and those carried out by Umar (2008) indicate derivation from the Craton Interior and Recycled orogens (Fig. 6b). Comparison of the Qm-F-Lt plots also indicates comparable detrital modes of the Quartzose Recycled and Craton Interior orogens (Fig. 7a). However, comparison of the composition diagram of Qp-Lv-Ls indicate that sandstone of the Loralai Formation plot within the Collision Orogen and Suture Belt, whereas, the Late Cretaceous Pab and Mughal Kot formations of the Kirthar Fold-Thrust Belt indicate derivation from the Subduction Complex and Arc Orogenic source terrains (Umar, 2008).

Plots of the sandstones of Jurassic Loralai Formation and Late Cretaceous successions in the Quartzose Recycled and Craton Interior orogens (Figs. 6 and 7) indicate derivation from similar source terrain, i.e. material has been derived from the Indian Craton, however, later on recycled to reach at the destination of the study areas. Our study indicates that sandstones of the Loralai, Pab and Mughal Kot formations of Kirthar-Sulaiman Fold-Thrust Belt had a common source terrain (i.e. Indian Craton) through the Jurassic-Cretaceous times.

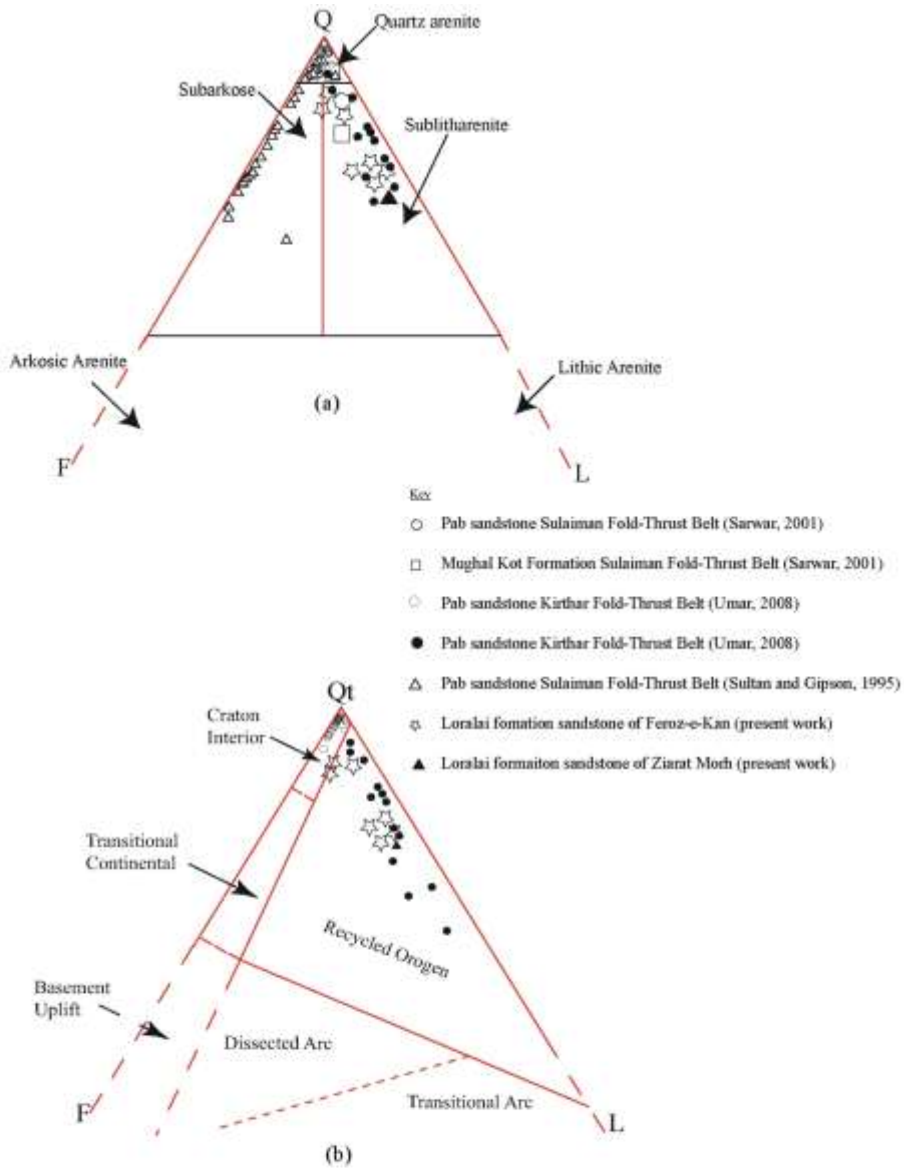
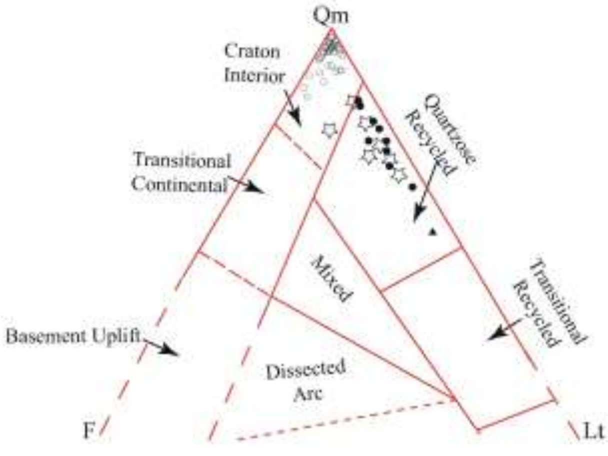
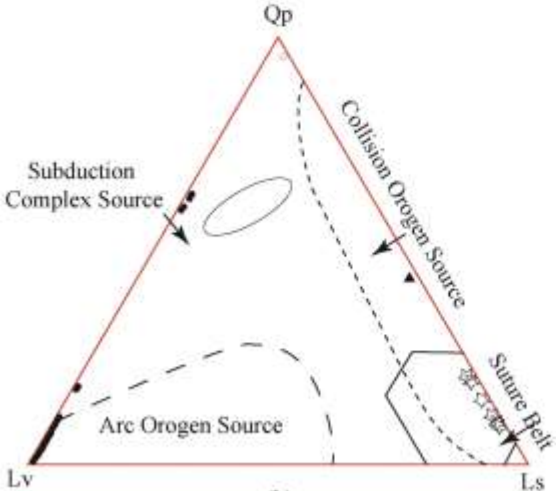


Fig. 6(a). Comparison of Q-F-L plots of sandstone samples of the Upper Cretaceous Pab and Mughal Kot formations of the Sulaiman Fold-Thrust Belt (Sultan and Gipson, 1995; Sarwar, 2001) and Kirthar Fold-Thrust Belt (Umar, 2008) with the Loralai Formation (present work).

Fig. 6(b). Comparison of Qt-F-L plots of sandstones of the Pab and Mughal Kot Formations of the Kirthar Fold-Thrust Belt (Umar, 2008) with the sandstones of the Loralai Formation (present work). Symbols as in figure 6a.



(a)



(b)

Fig. 7(a). Comparison of the Qm-F-Lt compositional diagram (after Dickinson et al., 1983) of sandstones of the Pab Formation of Kirthar Fold-Thrust Belt (Umar, 2008) with the Loralai Formation (present work).

Fig. 7(b). Comparison of the Qp-Lv-Ls compositional diagram (after Dickinson et al., 1983) of sandstones of the Pab Formation of Kirthar Fold-Thrust Belt (Umar, 2008) with the Loralai Formation (present work). Symbols as in figure 6a.

4. Discussion

Hunting Survey Corporation (1961) mapped and described the Triassic-Jurassic succession of Kirthar-Sulaiman Fold-Thrust Belt; in their description limestone and shale has been mentioned as the main lithology of their Jurassic Loralai Limestone. Sandstone has been reported only from the Anjira Member of the Shirinab Formation; however, it has not been further studied and described. Also sandstone has never been reported from the Loralai limestone. We are first time reporting sandstone succession from the Jurassic Loralai Formation from the Feroz-e-Kan and Ziarat Morh sections of the western Sulaiman Fold-Thrust Belt (Fig. 1). Presence of the sandstone succession may also point to the existence of potential hydrocarbon reservoirs within the Jurassic succession. We propose that exposed sections of the Loralai Formation in other areas may be thoroughly investigated for the presence of similar sandstone successions, in order to get further details of the petrology, provenance and reservoir potential of the succession.

Although tectonism culminated during the Upper Cretaceous times (Powell, 1979), evidence show various phases of transgressions and regressions of Tethys during the Triassic-Jurassic times, a phenomena which may have been related to earlier tectonic activity. The Triassic Wulgai Formation and Jurassic Loralai Formation show a gradual progradational trend from deep marine to shallow marine environments and ultimately emergence, as represented by the disconformity between the Jurassic Loralai Formation an upper Jurassic-Lower Cretaceous Sember Formation (Hunting Survey Corporation, 1961; Kassi and Khan, 1993).

Comparison of the compositional diagrams of sandstone of the Loralai Formation (Figs. 6b and 7) with the Late Cretaceous successions i.e. Pab and Mughal Kot Formations of the Kirthar-Sulaiman Fold-Thrust Belt (Sultan and Gipson, 1995; Sarwar, 2001; Umar, 2008) indicate comparable detrital modes and provenance, which also suggested that detritus had been derived from the common source of Indian Craton from the east and southeast. This is also supported by the paleocurrent trends found within the Jurassic Loralai Formation as well as Pab and Mughal Kot formations. We further add that the Indian Craton remained the source terrain for the sandstone throughout the Jurassic-Cretaceous times.

5. Conclusions

Sandstones of the Jurassic of Loralai Formation, Western Sulaiman Fold-Thrust is hereby first time reported and classified as sub-lithic arenite. Plots of point count data on various compositional triangular diagrams suggest derivation from Quartzose Recycled and Craton Interior orogens. Petrographic data, obtained from sandstone samples of the Loralai Formation, suggest derivation mainly from igneous and metamorphic source terrains. Compositional plots of the Jurassic Loralai Formation are closely comparable with sandstones of the Late Cretaceous Pab and Mughal Kot formations of the Kirthar-Sulaiman Fold-Thrust Belt, which have been derived from the common source terrain of Indian Craton, located to the east and southeast of the study areas. Our study indicates that Indian Craton a source terrain of sandstone throughout the Jurassic-Cretaceous times.

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