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Provenance, tectonics and palaeoenvironment of Mesoproterozoic Saundatti Quartzite Member of Kaladgi Basin, India: a petrographic view.

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Abstract

The Kaladgi basin, one of the important Proterozoic Sedimentary basins of Peninsular India, exposes a thick sequence of Proterozoic succession composed of a variety of lithologies with predominance of arenaceous rocks interbedded with carbonate sediments at different stratigraphic levels. The present work focuses mainly on understanding the sedimentological nature and diagenetic character of the lower part of the Lokapur Sub-group rocks that are exposed in and around Savadatti Town, Belagavi District of Karnataka. These rocks are mainly composed of arenite sequences of varying grain size. The clastic succession comprises of sandstones with minor conglomeratic facies at the lower part of the sequence. An attempt was made to identify the petrographic character of the sandstones to understand the provenance and depositional environments. Our study suggests that the coarse clastic conglomerates are essentially of polymictic type and the sandstones are sub-mature to mature (mineralogically), medium to coarse grained and can be categorized mainly into lithic/feldspathic and quartz arenites. Minor occurrence of feldspars as the framework constituent also suggests that the rocks have undergone considerable transport. However, with their variable degree of alteration (from fresh to partially to completely altered grains) associated with textural maturity and nature of quartz point towards the possibility of derivation of these sediments from two different sources. Palaeocurrent data that indicate a NW palaeoslope suggest the derivation of sediments from a variety of granitic and gneissic crystalline complexes occurring along the basin margin. The maturity of the sandstones (quartz arenites) is attributed to the recycling and re-working of the older sediments. Analysis of textural parameters of these rocks point towards deposition under beach environments. The lack in preservation of much amount of feldspar in these sandstones indicates a remote source and relatively dry-arid climate of the source area.

Keywords: Proterozoic, Saundatti Quartzite Member, Petrography, Kaladgi Basin, Lithic Arenites, Diagenesis

Introduction

The Kaladgi is one of the major Proterozoic basins (Purana) in northern Karnataka region of India comprising of thick clastic and non-clastic rock succession known as the Kaladgi Supergroup (Jayaprakash et al., 1987). The succession is divided into Older Bagalkot Group and Younger Badami Group and the two are separated by an angular unconformity (Vishwanathiah, 1968). Rb–Sr isotopic age calculated with respect to CHUR for the shales from Bagalkot Group suggested that their deposition was younger than 1800±100 Ma (Padmakumari et al., 1998 and Sambasiva Rao et al., 1999). Various structural, sedimentological and aspects related to evolution of this basin have been studied by previous workers. However, detailed petrographic work form individual formations from this succession has not been reported. Petrographic work is an integral part of any comprehensive sedimentological study and is of paramount importance for studying provenance, palaeoclimate and tectonics (Basu *et al.*, 1975; Dickinson and Suczek, 1979; Zuffa, 1980; Dickinson, 1985; Ingersoll et al., 1984; Uddin and Lunberg, 1998; Das 2008, ; Das and Sarma, 2009; Bokanda et al., 2018; Chima *et al.*, 2018; Chaudhuri *et al.*, 2018, Chaudhury *et al.*, 2020).

The present study is focused primarily on petrography of Saundatti Quartzite Member of Ramdurg Formation exposed in and around Saundatti town (lt. a15.7522° N, lon. 75.1253° E), Karnataka along the southern margin of Kaladgi basin. The sandstones under investigation do not exhibit wide variation in their composition and texture but the minor changes have been critically studied to identify petrographic changes in relation to changing environmental dynamics. Besides, the analysis of time or environment related changes; a major emphasis of the present study is directed towards provenance studies, recognition of palaeoclimate and the tectonic regime. The most of the Saundatti Quartzite Member is exposed mainly in the hill sections in and around Savadatti town as outliers and extending northward up to Ramdurg. Rocks of this unit include slightly deformed Quartz arenite and conglomerates containing Jasper clasts demarcating the basin boundary of the Bagalkot Group and forming a marker horizon due to its prominent geomorphic expression and topographic character.

Geology of the Study Area

The Kaladgi basin is an epicratonic basin formed due to trough faulting. Presently the basin is exposed in an area of about 8000 km^2 whereas, the estimated maximum area is 20,000 km^2 (Kale 1991). The basin is nearly 200 km long and about 100 km wide (Fig.1). The maximum aggregate stratigraphic thickness is ~4500 m (Jayaprakash et al., 1987; Radhakrishna and Vaidyanadhan, 1994). Metasediments, granitic gneisses and schistose rocks form the basement for these sedimentary deposits. In western and northern parts, the sediments are concealed beneath the lava flows of Deccan traps. At places where the lava flows are removed due to weathering the exposures are seen to occur as inliers within trappean rocks. Stratigraphically, the Kaladgi Supergroup is divided into older Bagalkot Group and younger Badami Group separated by an unconformity (Kale and Phansalkar, 1991). Rock types in this basin include conglomerate, sandstone and shale (argillite) as clastic facies and non clastic facies is represented by limestone and dolomite.

The basal Ramdurg Formation comprises partially metamorphosed beds of sandstones with conglomerate at the base and shale as subordinate constituent. The succession unconformably overlies gneisses, granitoids and, schists of Hungund schist belt of the Archaean basement complex. This formation is classified into three members based upon their lithological character. The Salgundi conglomerate is oldest in the sequence followed by Saundatti quartzite and Manoli argillite members. The detailed stratigraphic column of the area is given in Table 1.

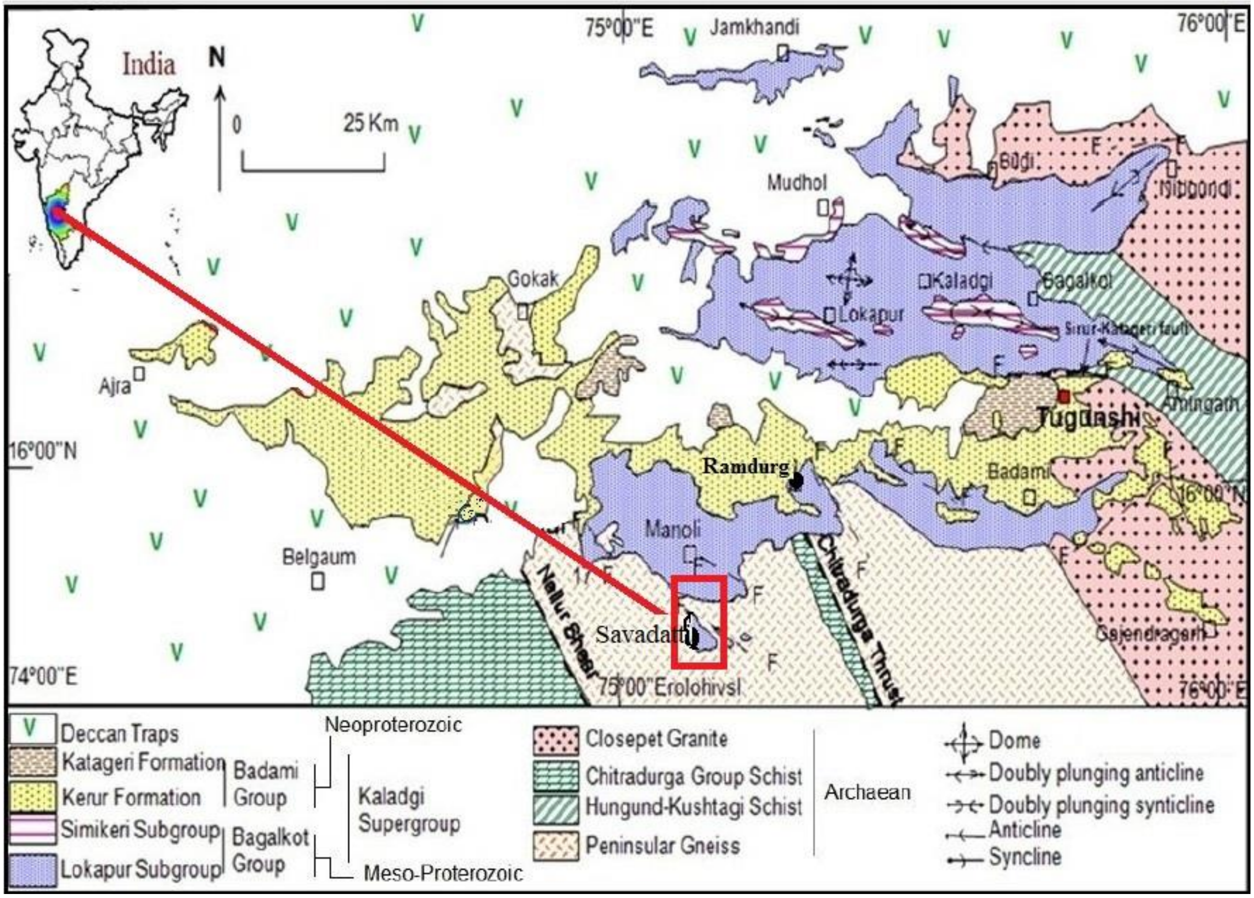

Figure 1: Geological Map of the study area (after Jayaprakash et.al., 1987; Dey et al., 2009)

Table 1: Generalized Stratigraphic succession of Kaladgi Supergroup. (Jayaprakash et al., 1987)

	Group	Subgroup	Formation
KaladgiSupergroup	Badami Group		Katageri
			Kerur
	Angular Unconformity		
	Bagalkot Group	Simikeri Subgroup	Hosakatti
			Arilkatti
			Kundargi
		Disconformity	
		Lokapur Subgroup	Yadhalli
			Muddapur
			Yendigeri
			Yargatti
			Ramdurg
Erosional unconformity			
Archean: Granitoids, gneisses, metasediments			

Field Observations

The outcrops exposed around Savadatti, Hooli and Ramdurg representing the Saundatti quartzite member are selected for the present study. The rocks exposed here directly overly the basement of Precambrian gneissic complex. The Saundatti quartzite beds are gently dipping towards east and display a variety of well-preserved primary sedimentary depositional structures represented by imbrications, ripple marks and cross-bedding. Thickly bedded planar parallel bedding is characteristic bedding observed in these rocks (Figure 2b). Thickness of beds varies from 30 to 50 cm. The bedding plane is smooth, parallel and sharp planar. Further examination of bedding plane revealed presence of ripple marks (Figure 2c). These are wave formed symmetrical ripples with straight and bifurcating crests. Ripple index was estimated at 3-5, having more rounded troughs and flattened crests. A tangential cross-stratification structure was better exposed at a stream cut section (figure 2d). The co-set thickness as measured is around 40cm with a set thickness of 20cm. The cross laminae are 5-10 cm thick. The palaeocurrent analyses of the cross-bedding structures suggest northwesterly (310^0) direction of the sediment transport.

Methodology

Petrographic study has been made in thin sections prepared from the sandstone samples collected from field outcrops. A total of 50 samples were collected from surface outcrops of Savadatti town and its outskirts which belong to Saundatti quartzite member of lower Kaladgi sequence. In all 25 thin sections were prepared representing entire ~380 m thick section and all were subjected to detailed petrographic analysis with optical microscopy. Around nine hundred points were counted for mineralogical analyses on 16 sandstone samples using conventional point counting method following Dickinson and Suczek (1979) and Dickinson *et al.* (1983). The grain roundness was measured by visual comparison of all the grains used in size measurement with the standard chart of Powers (1953). SEM analyses of selected samples were made to study textural parameters and grain to grain relationship in selected samples. The framework constituents of these rocks are quarts which include monocrystalline (Qm) as well as polycrystalline (Qp) varieties, feldspars and lithic fragments are also seen as part of framework constituents in less amounts. The volumetric percentages of the various framework components as identified and measured under the microscope for use in interpretation of provenance and depositional environments are presented in Table 2. The recalculated data from Table 2 for classification is given in Table 3. Grain size was analyzed by measuring apparent long axes of 100–150 grains per thin section using Digimizer software. Grain size parameters viz., mean size (Mz), standard deviation, skewness and kurtosis were calculated by the standard method of moments (Krumbein *et al*., 1983) as given in Table 4.

Mineralogical classification, framework composition, tectonic setting and provenance were interpreted based on the plotting of modal analysis data in triangular diagram of Folk (1980), James *et al.*, (1986), Dickinson and Suczek (1979), Dickinson *et al.* (1983) and Dickinson (1985). Suttner and Dutta (1986) plot has been used for understanding the Palaeoclimate.

Fig 2a. Gently dipping beds as exposed on the outskirts of Savadatti Town

Fig 2b. Thickly bedded planar parallel beds

Fig 2c. Symmetrical wave ripples preserved on bedding surface,

Fig 2d. Stream cut section exposing trough cross-stratification.

Table 2: Modal analysis of studied samples of Saundatti quartzite member

Sample No.	Sample ID	Quartz		Total	Feldspar	Lithic Fragments
		Monocrystalline	Polycrystalline			
1.	RDG-1	50	8	58	5	9
2.	RDG-2	70	6	76	5	2
3.	HOO-1	20	3	23	0	2
4.	HOO-1B	15	2	17	0	0
5.	HOO-2A	43	2	45	0	14
6.	HOO-2B	44	2	46	0	4
7.	HOO-2C	52	0	52	0	2
8.	HOO-2D	72	0	72	2	11
9.	HOO-3	70	1	71	0	2
10.	SAU-5	48	1	49	0	3
11.	SAU-5B	56	1	57	3	4
12.	SAU-5C	62	2	64	1	4
13.	SAU-6A	55	9	64	1	4
14.	SAU-6B	78	2	80	0	7
15.	SAU-8A	35	4	39	0	7
16.	SAU-7	30	1	31	0	4

Table 3: Recalculated tabulated data from modal analysis

Sample no.	Sample ID	Data for QFR diagram			Data for QmFRt diagram		
		Q	F	Rt	Qmt	F	Rt
1.	RDG-1	82	6	12	78	8	14
2.	RDG-2	91	6	3	91	8	1
3.	HOO-1	92	0	8	91	0	9
4.	HOO-1B	100	0	0	100	0	0
5.	HOO-2A	76	0	24	64	0	36
6.	HOO-2B	92	0	8	92	0	8
7.	HOO-2C	96	0	4	93	0	7
8.	HOO-2D	85	2	13	87	2	11
9.	HOO-3	97	0	3	97	0	3
10.	SAU-5	94	0	6	94	0	6
11.	SAU-5B	90	4	6	93	3	4
12.	SAU-5C	93	1	6	94	1	5
13.	SAU-6A	93	1	6	93	2	5
14.	SAU-6B	92	0	8	88	0	12
15.	SAU-8A	85	0	15	83	0	17
16.	SAU-7	89	0	11	86	0	14

.

Table 4: Detailed textural data of sandstone samples of Saundatti quartzite member.

Sr. no.	Sample Id	Mean Mz	Median	Standard deviation σI		Skewness SkI		Kurtosis KG	
1.	HOO-1B	0.91	0.81	0.54	MWs	0.48	Fine Skewed	0.41	Leptokurtic
2.	HOO-2A	1.66	1.30	0.56	MWs	-0.36	Very Coarse Skewed	-0.72	Platykurtic
3.	HOO-2C	1.82	1.82	0.31	Very Ws	-0.075	Near symmetrical	0.30	Platykurtic
4.	HOO-2D	1.56	1.56	0.42	Ws	-0.31	Very Coarse Skewed	0.76	Platykurtic
5.	HOO-3	1.23	1.19	0.35	Ws	0.11	Near symmetrical	0.13	Platykurtic
6.	KDG-1A	1.54	1.59	0.43	Ws	-0.41	Very Coarse Skewed	-0.73	Very platykurtic
7.	RDG-2	1.02	0.98	0.61	MWs	-0.22	Coarse Skewed	-0.16	Very platykurtic
8.	SAU-1	1.60	1.51	0.51	MWs	-0.34	Coarse Skewed	-0.67	Very platykurtic
9.	SAU-2	2.06	2.05	0.29	Very Ws	0.01	Near symmetrical	-0.20	Very platykurtic
10.	SAU-5	1.49	1.44	0.47	Ws	0.31	Fine Skewed	-0.09	Very platykurtic
11.	SAU-5C	1.15	1.16	0.33	Very Ws	-0.02	Near symmetrical	0.23	platykurtic
12.	SAU-6A	1.11	1.07	0.36	Very Ws	0.36	Very Coarse Skewed	-0.54	Very platykurtic
13.	SAU-6B	1.37	1.38	0.34	Very Ws	0.08	Near symmetrical	-0.038	Very platykurtic
14.	SAU-8A	0.99	0.99	0.55	M Ws	-0.21	Coarse Skewed	0.46	platykurtic
15.	SAU-8B	1.24	1.87	0.54	M Ws	0.24	Coarse Skewed	-0.87	Very platykurtic

(Mz-mean size, σI-standard deviation, SkI-skewness, KG-kurtosis, Ws- Well sorted, MWs- Moderately well Sorted)

Petrography

Petrographic analyses of sandstones were carried out for mineralogical composition, diagenesis and classification. The analyzed sandstone samples revealed that these sandstones from Saundatti quartzite member are medium to coarse grained, sub-angular to sub-rounded, moderate to moderately well sorted. Long grain contacts dominate while sutured and concavo-convex contacts are also observed in these rocks (Table 5; Figure 3a, 3b) with subordinate amount of matrix. Mineralogical constituents of this member thus identified are primary detrital constituents which include variety of quartz and feldspars, lithic fragments, matrix and cement. Quartz is the most abundant grain type and it is identified based on number of distinctive features like undulose extinction, strained nature of crystal shape. Sandstone were classified using Folk (1980) scheme (Figure 4). The rocks belonging to Saundatti quartzite member are mainly sublitharenites with subordinate amounts of quartz arenites and have average framework composition of $Q_{90.43}\, F_{1.25}\, R_{8.32}$. The framework grains are mainly quartz, and less frequently rock fragments, feldspars and heavy minerals. Framework constituents make up the dominant part of the rock and detrital material making up matrix is subordinate.

Quartz is the most abundant framework grain in these sandstones constituting an average 90.43% of the rock volume. The quartz grains are commonly subangular to sub-rounded in shape (Figure 3a). Most of these quartz grain show multiple deformation features (Figure 3b, 6a). Among quartz grains, monocrystalline quartz (Qm) is dominant (94.78%) over polycrystalline quartz (Qp) of 5.22%. Most of the Qm grains show undulatory extinction (Figure 5a). Some of these grains contain mineral inclusions (Fig 5b). Long and sutured contacts are common (Figure 5a, 5c) and are caused by compaction and pressure solution. Few sections also display concavo-convex contacts due to increased compaction. Some of these grains show corroded margins (Figure 5c) while some quartz grains show syntaxial overgrowths (Figure 5d). Heavy minerals (viz. zircon, sphene, and tourmaline) occur as accessories. Quartz grains which show two or more units under cross nicols but look like a single gram under polarized light are called as polycrystalline quartz (Conolly, 1965). Among these, composite quartz and pressure quartz are the two main varieties identified in these rocks. Grains of composite quartz are identified by the presence of two or more internal quartz grains. They show a single grain outline under polarized light while the internal units are distinctly visible under cross-nicols (Figure 5d). Pressure quartz is identified by the presence of internal elongated units of different optical orientation which gives it a mosaic like appearance. The grains show extreme undulose extinction (Figure 5e). The internal boundaries are smooth and units show both unit and undulose extinction.

Feldspar grains are present only in few thin sections (Table 2). They are subangular and devoid of inclusions. Both K-feldspar and plagioclase are present in sandstones. Plagioclase feldspar is characterized by lamellar twinning (Figure 5f) while the orthoclase is untwined and shows cloudy appearance. Few grains of feldspar are altered indicating restricted chemical weathering in these rocks. Absence of feldspars in most of the thin sections indicates an extensive alteration with enhanced chemical weathering and/or recycling.

Lithic or rock fragments are the pieces of disintegrated source rock and are of immense importance in provenance study along with tectonic setting of the source area. Rock fragments are recorded in majority of samples from Saundatti quartzite member (Table 2). These include chert and metamorphic rock fragments (Figure 5g & h). They range from 0 to 24 % with an average of 8.31%. Volcanic rock fragments are absent in the Saundatti quartzite member. Generally, these lithic fragments are subrounded however, few rounded-clasts are also observed.

Heavy minerals form a minor constituent of these sandstones that include sub rounded grains of zircon, sphene, chloritoids, tourmaline (Figure 6 a,b,c,d). Grains of heavy minerals are very fine and show moderate abrasion. The assemblage is suggestive of mixed sedimentary and metamorphic source. Siliceous cement is predominant. Cementing material occurs as pore fillings of silica, clay and iron oxide (Figure 7a). Kaolinite and chlorite are the main Clay mineral species observed in the sandstones. Kaolinite dominates over chlorite in terms of abundance. Samples as observed under SEM show kaolinite occupying the intergranular spaces between framework grains (Figure 7b). Kaolinite is present in variety of forms which include vermiform (Figure 7c),book shaped, well crystallized and blocky forms (Figure 7d). Predominance of kaolinite with little or no illite indicate the sedimentary origin under continental conditions (Lonnie, 1982; Tsuzuki and Kawabe, 1983, Amer *et al*., 1989).

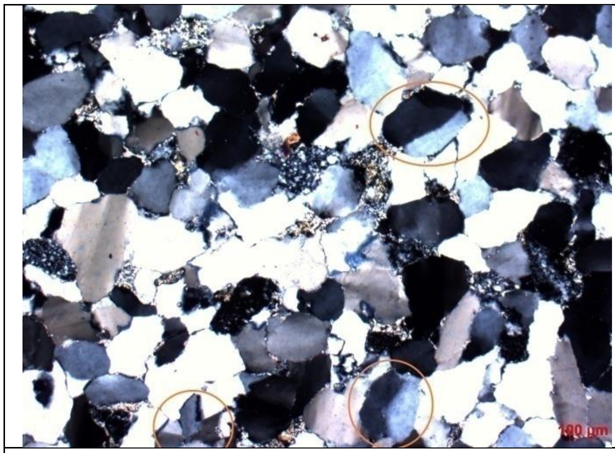

Figure 5a: Grains of monocrystalline quartz exhibiting undulose extinction, also note long and sutured grain contacts

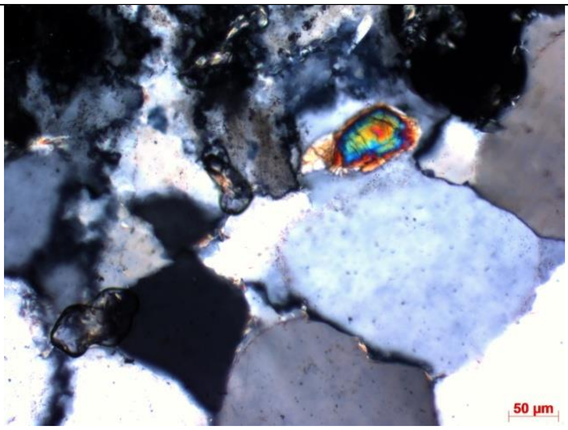

Figure 5b: Zoning observed in crystal of zircon

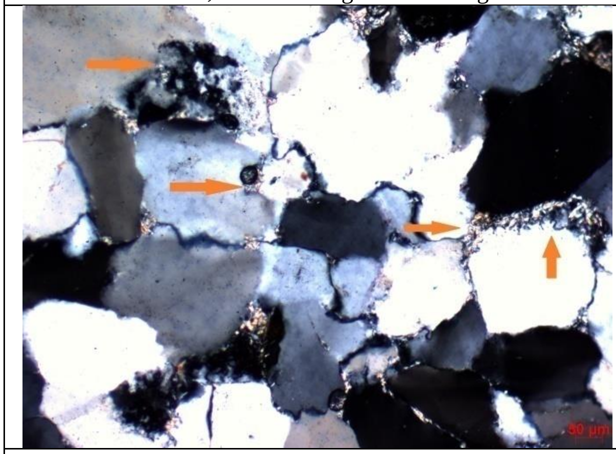

Figure 5c: Corroded grain boundaries filled by clay minerals precipitated secondary minerals

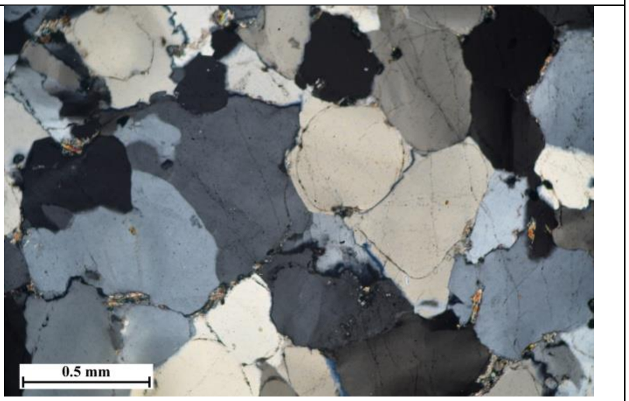

Figure 5d: Quartz overgrowth around detrital grains. Original grain boundaries can also be seen

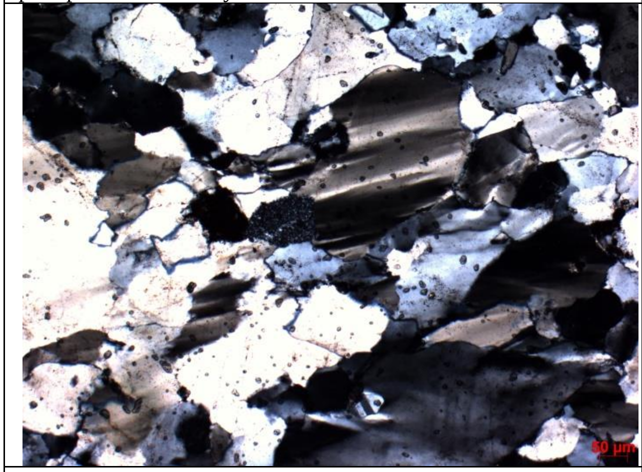

Figure 5e: Extreme undulose extinction shown by pressure quartz

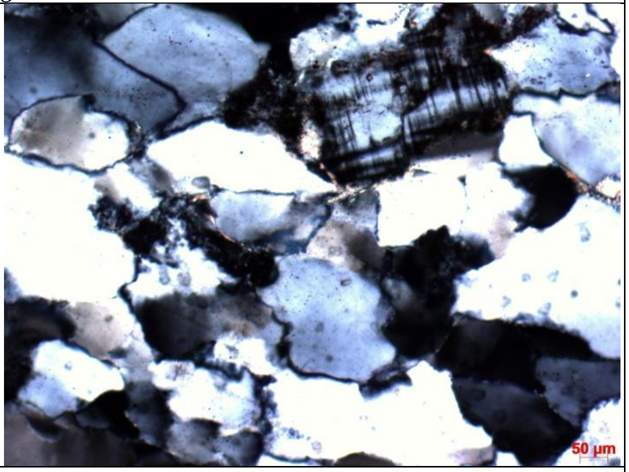

Figure 5f: Grain of plagioclase feldspar showing lamellar twinning

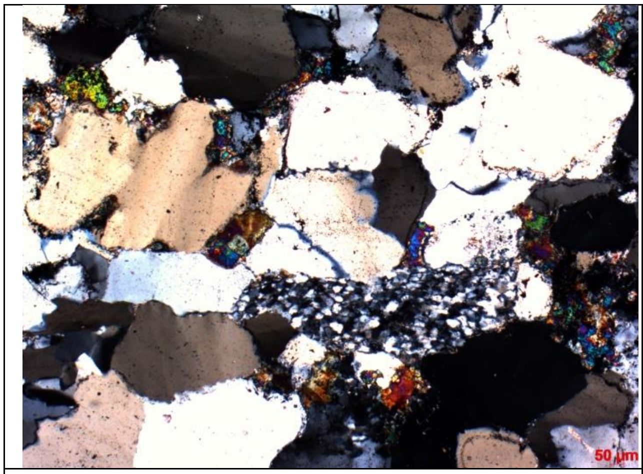

Figure 5g: Metamorphic rock fragment as a part of framework constituent

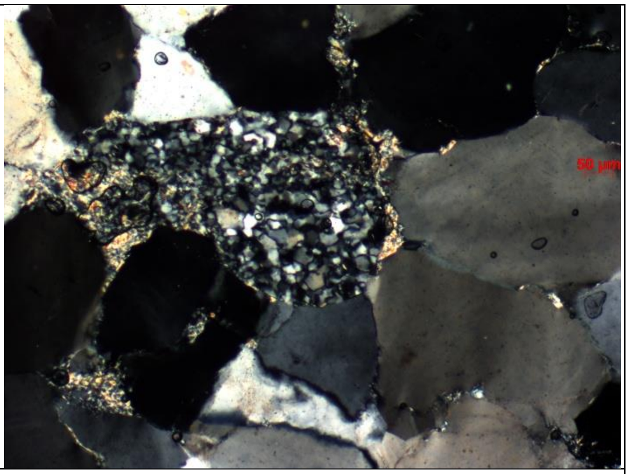

Figure 5h: Metamorphic rock fragment showing alteration

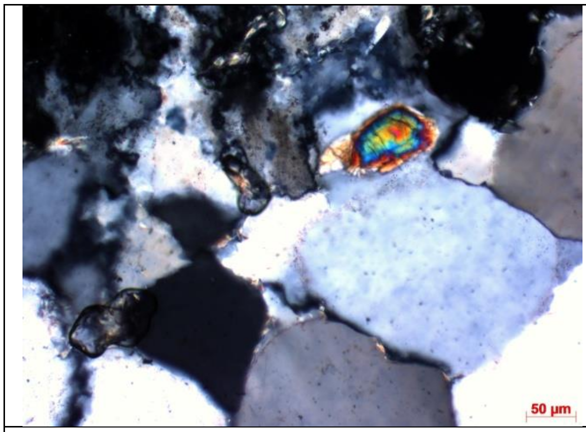

Figure 6a: Zoning observed in crystal of zircon

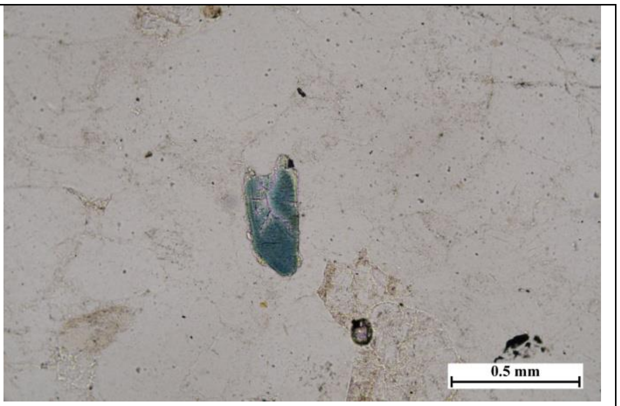

Figure 6b: Pale green, characteristic wedge shaped grain of sphene

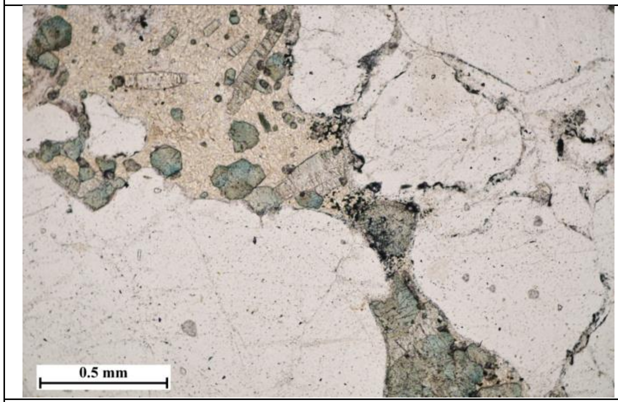

Figure 6c: Distinct greenish to yellow coloured specs of chloritoids, note flowage around quartz grains

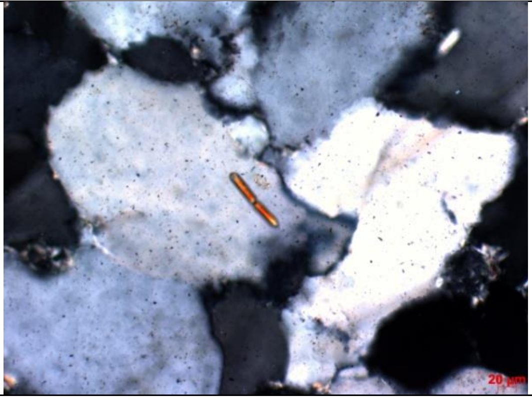

Figure 6d: Slender prismatic habit of tourmaline grain

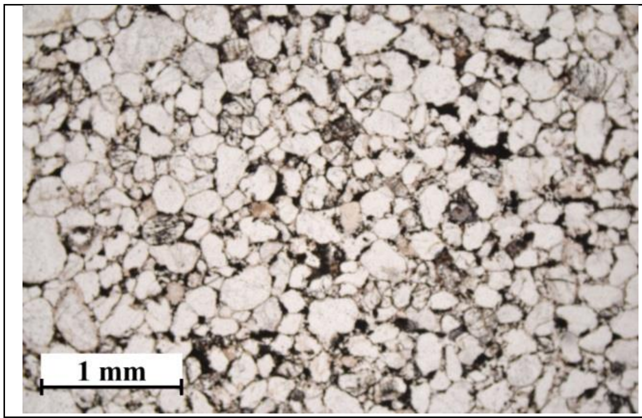

Figure 7a: PPL image of well sorted arenite with brownish ferruginous cement

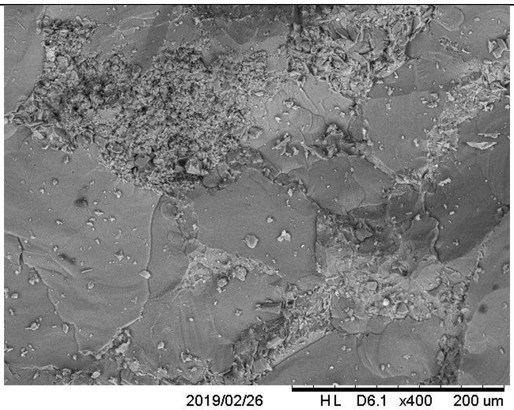

Figure 7b: SEM image showing intergranular spaces occupied by kaolinite

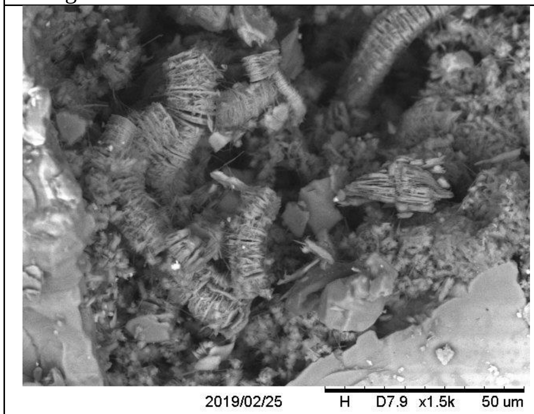

Figure 7c: SEM image of vermiform overgrowth of kaolinite seen in void spaces

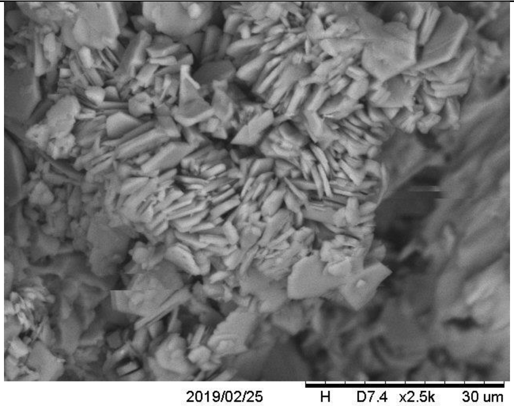

Figure 7d: SEM image showing well developed crystal faces of kaolinite

Tectonic Setting and Provenance

The petrographic study reveals that the studied rocks are characterized by higher proportion of monocrystalline quartz followed by polycrystalline quartz, considerable number of lithic fragments and subordinate feldspar. Much work has been done on the composition of sandstone and its implications on the tectonic setting of a depositional basin. Important amongst these are the works of Crook (1974), Young (1976), Dickinson and Suczek (1979), Mack (1984), Dickinson (1985) Trop and Ridgway (1997). The key relationship between provenance and basins are governed by plate tectonics which ultimately controls the distribution of different types of sandstones (Dickinson and Suczek, 1979).

To interpret the tectonics of the source area, mineral composition of the samples collected from Saundatti quartzite member were plotted on Qt-F-L and Qm-F-Lt ternary diagrams of Dickinson et al. (1983) (Fig 4 c, d). On the QtFL diagram of Dickinson and Suczek (1979), most of the studied samples fall within recycled orogen field and few fall in craton interior field. The framework grain properties like subordinate presence of feldspars, polycrystalline quartz and rock fragments of studied units are consistent with those of sediments deposited in a recycled orogen setup. Such a craton type reflects mature sandstone derived from relatively low lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins (Dickinson et al., 1983). Low percentage of unstable grains, the dominance of monocrystalline quartz and alteration of feldspar grains suggests that the source area underwent a long period of intensive chemical weathering in a warm humid climate (Pettijohn et al., 1987).

It is known that the ratios of feldspar and lithic fragments to polycrystalline quartz or total quartz are sensitive indicator of climatic signature of the sandstones (Young et al., 1975 and Basu, 1985). Following Suttner and Datta (1986) data was plotted in QFR diagram and plotted points indicate a metamorphic source in a sub humid to humid conditions (Fig 4b).

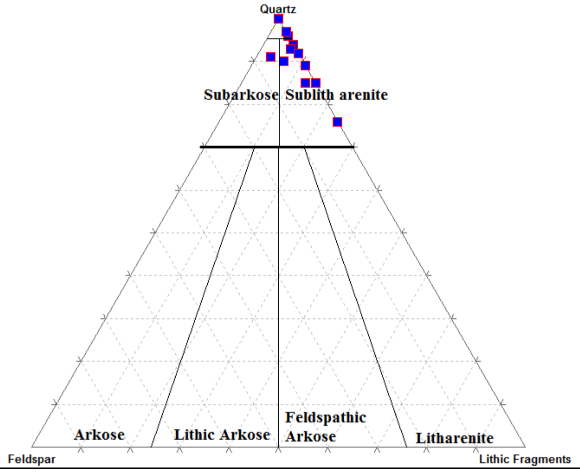

Figure 4a: Classification of studied sample as per Folk (1980) scheme

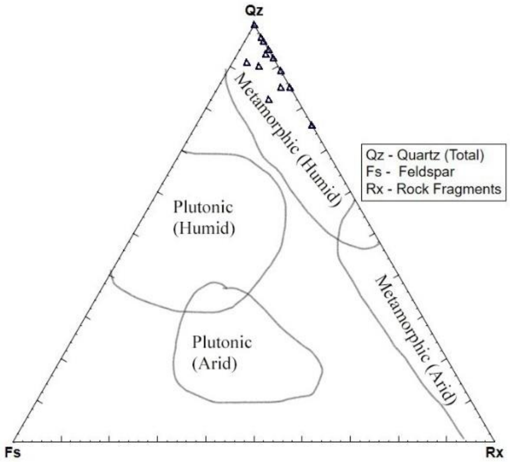

Figure 4b: The effect of source rock on the composition after Suttner et. al. (1981)

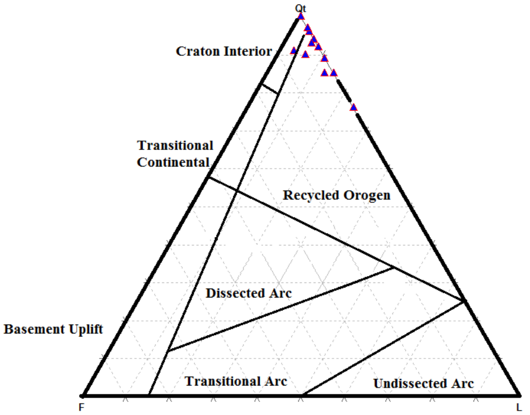

Figure 4c: Tectonic setting discrimination diagram based on Qt-F-L after Dickinson and Suczek (1979)

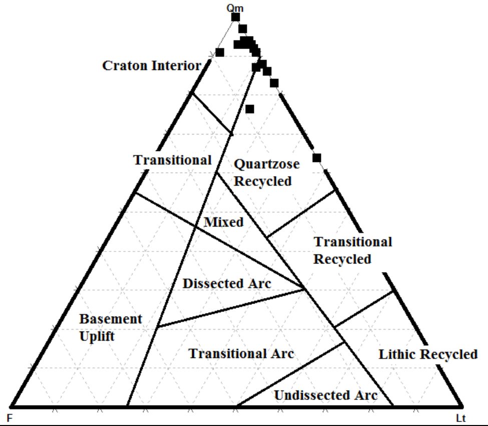

Figure 4d: Qm-F-Lt ternary diagram after Dickinson et. al. (1983)

A high percentage of quartz (90.43%) and textural features such as coarse to fine grain texure, moderate to moderately well sorting and sub-rounded to sub-angular shape and low percentage of feldspars (Table 2, 3) point towards a distant source and extensive transportation and/or reworking of the sediments. The sandstones of Saundatti quartzites member is probably derived from the platform or uplifted basement rocks and has been extensively recycled. Polycrystalline quartz grains with more crystal units indicate metamorphic provenance. Elongated nature of polycrystalline grains and suturing of grain boundaries further suggest metamorphic derivation of sediments of these rocks. The studied samples also show the effect of pressure on some grains before and after deposition. Therefore, the sediments could have possibly been derived from metamorphic source rocks of Dharwarian basement probably peninsular gneissic complex.

Conclusions

Presence of Primary sedimentary structures like asymmetrical ripple marks, cross bedding in the Saundatti quartzite member indicate that it was dominantly formed under the influence of tidal processes. The overall environment of deposition for these sediments thus can be attributed a fluvial i.e., a continental set up. The Sandstones of Saundatti quartzite member are medium to coarse grained, moderately sorted to moderately well sorted. The sand grains are subangular to sub-rounded. The framework constituents of the studied samples are mainly composed of various types of quartz, followed by feldspars and rock fragments. Heavy minerals are seen to be occurring as minor constituents. The provenance is crystalline rocks of Archaean-Dharwar craton.

The sediments of the sandstones were derived from metamorphic and igneous source. Tectonic domain discrimination based on Qt-F-L and Qm-F-Lt plots suggest sediment supply from the recycled orogen and from basement granites exhumed in the craton interior. The cementing material in these sandstones is Silica and iron oxide.

Mechanical compaction was the dominant diagenetic process during the early stage of diagenesis. During mechanical compaction rearrangement of grains took place and long, sutured and concave-convex contacts developed. The climate plots concentrate mainly in the humid zone. However, the composition got further modified during transportation and subsequent sedimentation

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