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Provenance, tectonic setting and palaeoclimate of the Ridge Sandstone of Jumara Dome, Kachchh, Gujarat

ZUHI KHAN* AND A.H.M. AHMAD

Department of Geology, Aligarh Muslim University, Aligarh 202002, India.
**Corresponding author: zuhikhan9@gmail.com*

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ABSTRACT

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This study deals with petrography, provenance, tectonic setting and palaeoclimate of the Ridge Sandstone Member encountered in the Jumara Dome, Kachchh, Gujarat. The sandstones in this member are medium to coarse grained, poorly to moderately sorted and sub angular to sub rounded. Framework grains are sand–sized to silt–sized particles of mainly detrital origin. Among the main detrital framework grains, quartz constitutes 55.42–96.09%, feldspar 4.9–27.76%, and lithic fragments 0–3.73%. These sandstones have been classified as sub–arkose to arkose in composition and were deposited in continental block provenance with stable craton in rifted continental margin basin setting in a humid climate with the source material from either the Aravalli or Nagar Parker massif.

Key–words—Provenance, Tectonic setting, Palaeoclimate, Petrography, Ridge Sandstone Member, Jumara Dome, Kachchh Basin.

जुमरा डोम, कच्छ, गुजरात में रिज बलुआपत्थर का उद्गम–क्षेत्र, विवर्तनिक विन्यास एवं पुराजलवायु

जुही खान और ए.एच.एम. अहमद

सारांश

इस अध्ययन का सरोकार जुमरा डोम, कच्छ, गुजरात में समागमित रिज बलुआ पत्थर सदस्य का शैलचित्रण, उद्गम क्षेत्र, विवर्तनिक विन्यास और पुराजलवायु से है। इस सदस्य में बलुआपत्थर मध्यम से मोटे दानेदार, अल्प से मध्यम छंटे हुए तथा उपकोणीय से उपगोलित हैं। खासतौर से अपरदी उद्गम के ढाँचा दाने–बालू आकारी से गाद–आकारी कण हैं। मुख्य अपरदी ढांचे दानों में क्वार्ट्ज 55.42-96.09% फेल्डस्पर 4.9-27.76% और शिलीय खंडज 0-3.73% संघटित है। संघटन में ये बलुआ पत्थर उप– आर्कोज के रूप में वर्गीकृत हैं तथा अरावली अथवा पार्कर गिरिपिंड से प्राप्त स्रोत पदार्थ के साथ आर्द्र जलवायु में विदर महाद्वीपीय उपांत द्रोणी विन्यास में स्थायी क्रेटान के संग महाद्वीपीय खंड उद्गम–क्षेत्र में निक्षेपित हो गए थे।

सूचक शब्द—उद्गम–क्षेत्र, विवर्तनिक विन्यास और पुराजलवायु, शैल चित्रण, रिज बलुआपत्थर सदस्य, जुमरा डोम, कच्छ द्रोणी।

INTRODUCTION

SANDSTONE provenance studies have shown that different tectonic settings contain evolutionary trends in their detritus and exhibit specific compositional ranges during re–depositing (Dickinson & Suczek, 1979; Dickinson *et al.*, 1983). Each provenance type contributes distinctive detritus preferentially to associate sedimentary basins in each case. Thus, clastic detrital components preserve detailed information on the provenance and pattern in which the sediments were transported, especially after modification of the original detritus by the interaction of physical and chemical processes such as weathering, erosion, transportation and palaeoclimate. The chemical composition of siliciclastic sedimentary rock is controlled by several factors from source to sink including source rock composition, physical and chemical weathering, erosion, transport, deposition and burial diagenesis (Johnsson, 1993). Clastic sedimentary rocks also contain important information for interpreting both the compositional tectonic setting and evolution of the continental crust that can be

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linked to the depositional environment (Raymond, 1995; Cingolani *et al.*, 2003; Jafarzadeh & Hosseini–Barzi, 2008; Banerjee & Banerjee, 2010). Petrographic studies have shown that siliciclastic rocks can be used to identify the source area (provenance) as well as related geological processes responsible for deposition (Basu *et al.*, 1975; Dickinson *et al.*, 1983; Johnson, 1991).

The main purpose of this paper is to interpret the sandstone petrography so as to characterize the detrital sediments of the Ridge Sandstone of Jumara Dome and to infer its provenance, tectonic setting and palaeoclimate condition. This will serve as a foundation in developing a depositional model of the Ridge Sandstone of Jumara Dome of the Kachchh Basin, Gujarat.

GEOLOGICAL BACKGROUND

The sedimentary basin of Kachchh occupies the entire district of Kachchh in Gujarat State of western India close to its western border with Pakistan between latitude 22°30' and 24°30' N and longitude 68° and 72°E. The Kachchh is a pericratonic rift situated on the southern edge of the Indus shelf at right angle to the Southern Indus fossil rift, evolved within the mid–proterozoic Aravalli Delhi Fold Belt (Biswas, 2005) in the Triassic and formed the Kachchh Basin which was inundated by the sea no later than the Early Mid Jurassic (Fursich *et al.*, 2001). The marine sedimentation prevailed throughout the Jurassic and was terminated by Mid Cretaceous times (Fursich, 1998). These consist of near shore coarse grained siliciclastics to offshore argillaceous silt and carbonates of a storm dominated ramp to carbonates deposited well below storm wave base. Lithostratigraphically the sediments have been grouped into Khavda, Patcham, Chari, Katrol and Umia formations (Waagen, 1873; Pandey *et al.*, 1984; Fursich *et al.*, 1994). The Jurassic sedimentary sequence in the Kachchh Basin outcrops in three east–west trending fault–bounded anticlinal ranges and in an isolated area in Wagad (Fig. 1). The southern and middle ranges

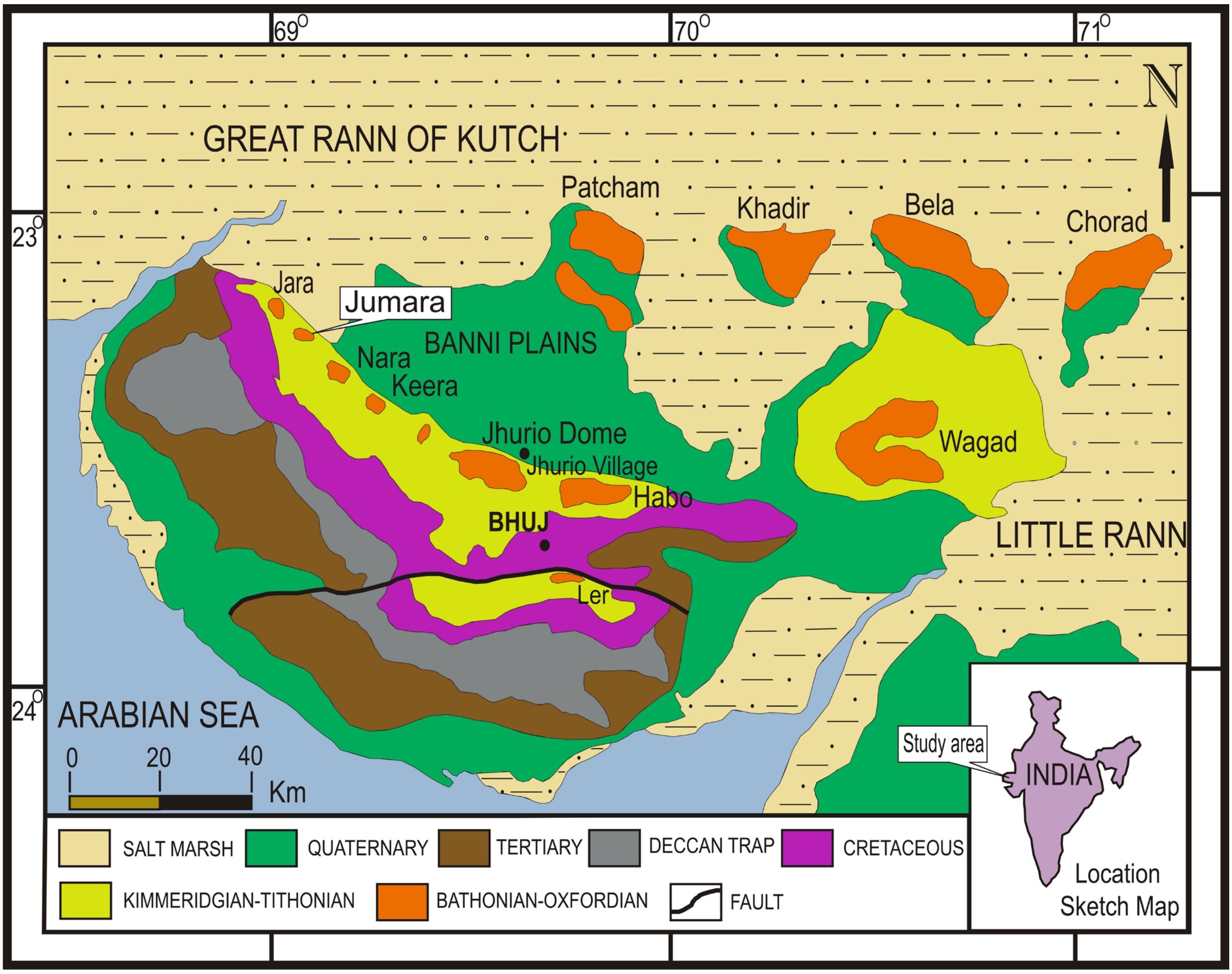


Fig. 1—Geological map of Kachchh Basin (after Biswas, 1977).

Table 1—Lithostratigraphic framework of the Jurassic and Lower Cretaceous rocks of Kachchh Mainland (Fursich *et al.*, 2001).

Age	**Kachchh Mainland**	
Albian–Aptian	Umia Formation	Bhuj Member
		Ukra Member
Neocomian		Ghuneri Member
Tithonian		Umia Member
Tithonian– Kimmeridgion	Katrol Formation	
Late Early Oxfordian	Chari Formation	Dhosa Oolite Member
Early Oxfordian		Dhosa Sandstone Member Gypsiferous Shale Member Athleta Sandstone Member
Callovian		Ridge Sandstone Member Shelly Shale/Keera Golden Oolite Member
Bathonian	Patcham Formation	Spongy Limestone Member Purple Sandstone/Echinodermal Packstone Member Jumara Coralline Limestone Member

to the S and N of Bhuj in western Kachchh include many irregular elliptical quaquaversal units which in the middle range are termed "domes" (Rajnath, 1932) together formed the Kachchh mainland. The mainland exposures consist of Jara, Jumara, Nara, Keera, Jhura and Habo domes and Fakirwari, Walakhawas and Ler areas. The 4 isolated landmasses, viz. pachchhm (earlier spelt as patcham), khadir, bela, chorar are surrounded by vast plains which remain submerged under water during monsoon and hence have been described as "island". The Kachchh Mainland, the 4 "islands" and the isolated area of wagad are the 6 "uplifts" (Biswas, 1991). The domal structures are formed due to Deccan Trap Volcanism. Erosion of younger sediments on and adjacent to the domes has exposed the Jurassic rocks.

Jumara Dome is a wide dome, lies in the western part of E–W trending anticlinal hill range along the northern margin of the mainland Kachchh and located about 80 km NW of Bhuj, the district headquarter of the Kachchh region. The small village of Jumara is situated on the southern edge of the dome. Only the lowermost part of its steeply dipping northern flank is seen, the rest is covered by sediments of the Rann. The remaining flanks dip more gently and the southern flank exposes almost a complete section from the Middle Bathonian to the Oxfordian rocks and beyond. The most widely accepted classification of the Jurassic rocks of Kachchh divides these rocks into Patcham, Chari, Katrol, and Umia formations in ascending order (Table 1). However, in the Jumara Dome only the first 3 formations are exposed and the Chari Formation is the thickest and best developed in this dome, exposing a total thickness of about 245 m. Jumara Dome is the type area of Jumara Formation an alternate name for the Chari Formation coined by Biswas, in a later proposed lithostratigraphy classification of the Jurassic rocks of Kachchh.

In the Kachchh mainland at Jumara Dome mixed carbonate siliciclastic succession represented by the Jhurio and Patcham formations and siliciclastic dominating Chari Formation (Bathonian to Oxfordian) are exposed (Fig. 1). The lower part of Jumara Dome is represented by 16 m thick Jumara Coral Limestone Member (JCL) of the Jhurio Formation followed upward with a sharp contact by about 22 m thick Echinoderm Packstone Member (EP) comprising brownish ferruginous sandy resistant beds. Above this 10 m thick Sponge Limestone Member is followed by 10 m Grey Shale Member, 32 m thick Ridge Sandstone Member overlain by 15 m thick Gypsiferous Shale Member and on the top of the sequence 14 m thick Dhosa Oolite Member of Chari Formation is present.

METHODOLOGY

A total of twenty representative sandstones samples were collected systematically from outcrops within Jumara Dome (Fig. 1). Thin section petrographic studies were carried out from the collected samples to identify the mineralogical composition and to apply modal analysis. At least 300 grains per thin section were counted for each sample using the methods of Dickinson and Suczek (1979) and Dickinson *et al.*, (1983). In Gazzi–Dickinson methodology crystals larger than 0.0625 mm within lithic fragments were counted as monocrystalline grain. Modal analysis from point counting of the framework grains is listed in (Table 2). For Petrofacies analysis, the detrital modes were recalculated to 100 percent by summing up Total quartz (Qt), Monocrystalline quartz (Qm), Polycrystalline quartz (Qp), Total feldspar (F), Total unstable lithic fragments (L), Volcanic lithic fragments (Lv), Sedimentary lithic fragments (Ls), Total lithic fragments (Lt=L+Qp) framework constituents following Dickinson, (1985) (Table 3).

Table 2—Percentage of detrital minerals in the Ridge Sandstone Member of Jumara Dome, Kachchh, Gujarat.

Sample No.	**Monocrystalline quartz**	**Polycrystalline quartz**		**Feldspar**		**Mica**		**Chert**	**Rock Fragments**	**Heavies**
	Common quartz	**Recrystallized metamorphic quartz**	**Stretched metamorphic quartz**	**Plagioclase**	**Microcline**	**Biotite**	**Muscovite**			
R–1	68.58	3.26	3.06	9.20	4.21	0.77	6.13	2.11	1.53	1.15
R–2	64.12	3.08	3.82	9.37	11.71	1.23	2.34	2.84	0.62	0.87
R–3	64.56	0.89	3.29	9.87	11.89	2.15	3.04	3.42	0.38	0.51
R–4	61.28	2.49	3.73	8.17	12.79	1.24	3.91	1.95	3.73	0.71
R–5	61.11	0.00	7.14	6.89	11.11	1.32	6.61	2.91	2.38	0.53
R–6	69.16	1.27	4.69	8.50	9.52	0.89	2.28	2.54	0.51	0.64
R–7	75.30	0.00	7.29	4.86	6.68	0.81	2.84	1.01	1.21	0.00
R–8	66.86	1.16	4.36	9.30	13.66	0.29	1.46	2.33	0.00	0.58
R–9	76.16	0.15	0.87	5.96	6.68	0.44	6.98	1.02	1.31	0.43
R–10	73.83	1.52	3.03	6.34	5.10	1.24	7.02	1.65	0.00	0.27
R–11	77.34	0.00	3.20	5.42	4.68	0.99	4.19	1.23	1.72	1.23
R–12	81.25	0.00	2.78	0.69	4.87	0.69	3.47	0.69	2.78	2.78
R–13	72.34	1.99	6.09	2.80	7.29	1.60	3.60	0.99	2.70	0.60
R–14	71.02	1.23	1.11	4.81	13.69	0.12	5.06	0.49	1.98	0.49
R–15	54.74	3.16	11.58	4.21	17.89	0.00	5.26	2.11	0.00	1.05
R–16	76.15	0.30	3.58	4.89	7.11	0.30	4.74	0.59	0.30	1.77
R–17	63.08	1.20	4.96	6.32	8.72	1.20	12.13	0.85	0.17	1.36
R–18	76.33	0.66	1.86	5.85	8.25	0.27	3.86	1.06	1.46	0.40
R–19	64.86	1.69	0.68	7.09	9.12	2.70	11.15	1.35	0.68	0.68
R–20	70.10	2.03	3.55	4.22	8.45	0.00	7.26	1.52	2.36	0.51
Average	**69.41**	**1.30**	**4.05**	**6.24**	**9.17**	**0.91**	**5.17**	**1.63**	**1.29**	**0.83**

Table 3—Percentage of framework modes of the Ridge Sandstone Member of Jumara Dome, Kachchh, Gujarat (Based on classification of Dickinson, 1985).

Qt=Total Quartz; Qm=Monocrystalline Quartz; Qp=Polycrystalline Quartz; F=Total Feldspar grains; P=Plagioclase grains; K= K–Feldspar grains; L=Total unstable lithic fragments; Lv=Volcanic/metavolcanic lithic fragments; Ls= Sedimentary/Metasedimentary fragments; Lt= (L+Qp).

S. No.	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
R–1	83.75	14.58	1.67	74.58	14.58	10.83	84.62	0.00	15.38	83.64	11.21	5.14
R–2	77.29	22.06	0.65	67.10	22.06	10.84	94.05	0.00	5.95	75.25	11.00	13.75
R–3	76.51	23.09	0.40	68.46	23.09	8.46	95.24	0.00	4.76	74.78	11.44	13.78
R–4	73.77	22.26	3.96	65.09	22.26	12.64	68.66	0.00	31.34	74.51	9.94	15.55
R–5	77.75	19.65	2.60	66.76	19.65	13.58	80.85	0.00	19.15	77.26	8.70	14.05
R–6	80.74	18.73	0.53	71.90	18.73	9.37	94.37	0.00	5.63	79.33	9.75	10.92
R–7	86.76	11.97	1.26	78.15	11.97	9.87	87.23	0.00	12.77	86.71	5.59	7.69
R–8	76.49	23.51	0.00	68.45	23.51	8.04	100.00	0.00	0.00	74.43	10.36	15.21
R–9	84.86	13.72	1.42	82.65	13.72	3.63	60.87	0.00	39.13	85.76	6.71	7.53
R–10	87.50	12.50	0.00	80.72	12.50	6.78	100.00	0.00	0.00	86.59	7.43	5.98
R–11	87.37	10.79	1.84	82.63	10.79	6.58	72.00	0.00	28.00	88.45	6.20	5.35
R–12	91.04	5.97	2.99	87.31	5.97	6.72	55.56	0.00	44.44	93.60	0.80	5.60
R–13	86.43	10.71	2.86	76.78	10.71	12.51	77.12	0.00	22.88	87.76	3.39	8.85
R–14	78.30	19.61	2.09	75.29	19.61	5.10	58.97	0.00	41.03	79.34	5.37	15.29
R–15	76.40	23.60	0.00	58.43	23.60	17.98	100.00	0.00	0.00	71.23	5.48	23.29
R–16	86.80	12.88	0.32	81.72	12.88	5.41	94.12	0.00	5.88	86.39	5.55	8.07
R–17	82.16	17.64	0.20	73.95	17.64	8.42	97.62	0.00	2.38	80.74	8.10	11.16
R–18	83.70	14.76	1.53	79.94	14.76	5.29	71.05	0.00	28.95	84.41	6.47	9.12
R–19	80.24	18.97	0.79	75.89	18.97	5.14	84.62	0.00	15.38	80.00	8.75	11.25
R–20	83.70	13.74	2.56	76.01	13.74	10.26	75.00	0.00	25.00	84.69	5.10	10.20
Average	**82.08**	**16.54**	**1.38**	**74.59**	**16.54**	**8.87**	**82.60**	**0.00**	**17.40**	**81.74**	**7.37**	**10.89**

PETROGRAPHY

Framework Grains

Framework grains are sand–sized to silt–sized particles of mainly detrital origin that support one another at their points of contact. The study of framework grains of Ridge Sandstone Member of Jumara Dome reveals that the most common detrital grains are quartz, feldspars and rock fragments. Mica and non–opaque heavy minerals are found as minor accessories.

Quartz is the most abundant constituent ranging from 54.74% to 81.25% of the total rock components with an average 69.41%, predominantly occurring as monocrystalline either with undulatory or non–undulatory extinction. The contact boundaries of the monocrystalline quartz are dominantly long, concavo–convex, point contacts and sutured contacts are also found. Polycrystalline quartz constitutes 0.68% to 14.84% of the total rock component with an average 5.35%. Polycrystalline quartz occurs in the form of recrystallised metamorphic and stretched metamorphic polycrystalline quartz. Polycrystalline quartz grains are composed of two or more crystals (Pl. 1.1). Crystal boundary of polycrystalline quartz is often obscured due to recrystallization, but extinction characteristics generally indicate the polycrystalline nature. Inclusions in quartz grains include biotite, zircon and tourmaline, but these are very rare. A few quartz grains have numerous vacules as indicated by their cloudy appearance.

Feldspars are the important constituent among the detrital framework grains of Ridge Sandstone. Point count data indicate that feldspars constitute 4.9% to 27.76% with an average 15.41% of the total rock components. Feldspars are present in the form of potassium (K) and plagioclase feldspar. Potassium feldspar has been found as microcline (Pl. 1.2). Microcline was recognized by its typical crosshatch twinning. Alteration and leaching of feldspar grains is observed along the cleavage plains and grain boundaries. The feldspar grains are generally subsequent with mostly sub rounded to rounded outlines. Some angular to sub angular grains also occur.

Mica constitutes 1.46% to 14.83% of the detrital components with an average 6.08%. Muscovite is found to be more abundant than biotite (Pl. 1.3). Mica generally occurs along partings, laminae or bedding planes and frequently shows bending due to compaction. Muscovites are colourless under plane polarized light and show high birefringence with variegated colour under cross nicols. Biotites are brown and strongly pleochroic under plane light.

Lithic fragments are found to be the next abundant to mica among the detrital components. The range of total lithic fragment is 0% to 3.73% with an average 1.29%. Both sedimentary and metamorphic lithic fragments occur in the studied sandstones. Lithic sedimentary grains are found to be more abundant than the lithic metamorphic grains. Very few or traces of lithic volcanic grains are found. The sedimentary rock fragments include siltstone and chert (Pl. 1.4). Metamorphic rock fragments include phyllite (Pl. 1.6) and schist.

Detrital heavy minerals are found 0% to 2.87% of the total rock constituents with an average 0.83% as insignificant detrital grains. Heavy minerals include garnet, zircon (Pl. 1.5), tourmaline, epidote, rutile, etc. and some black opaque grains.

Classification of Sandstones

Classification of sandstones is mainly governed by some general criteria like mineralogical composition, texture, types of cement/matrix, existing structure and/or combination of two or more factors mentioned. Several schools of thoughts have been postulated regarding the genetic and descriptive classification of sandstones and subsequently modified by a number of leading workers (Dott, 1964; Folk, 1968, 1980; McBride, 1963; Pettijohn *et al.*, 1972). Among these, Folk's (1980) scheme is used in the present study.

The classification model is basically a composition triangle based on major detrital framework compositions (quartz, feldspar and lithic fragments) and divides the rocks on the relative abundance of these components. According to this classification scheme, the Ridge Sandstone Member of Jumara Dome has been classified as subarkose to arkose in nature (Fig. 2).

Provenance

The provenance of clastic rocks has been determined by several petrographical techniques, including investigation of the undulosity and polycrystallinity of quartz grains (Basu *et al.*, 1975; Young, 1976), feldspar types (Pittman, 1970), rock fragments (Pettijohn *et al.*, 1987) and heavy mineral types (Morton, 1985; Asiedu *et al.*, 2000). The existence of number of detrital grains in the sandstone samples indicate important clues to provenance, and particular characteristics of many detrital grains (roundness, alteration, etc.) may also indicate certain provenance categories (Folk, 1968; Blatt *et al.*, 1980; Pettijohn, 1975; Scholle, 1979). For example, shale, sandstone, siltstone fragments, secondary deformed quartz, chert, rounded and altered feldspars, are direct indication of sedimentary provenance; whereas slate, phyllite, quartzite fragments, muscovite, chlorite, highly altered feldspars are important indicators of low rank metamorphic provenance and schist, gneiss fragments, muscovite, biotite, chlorite, meta quartzite, etc are indicators of medium to high rank metamorphic provenance and on the other hand igneous provenance is indicated by the presence of volcanic rock fragments, various types of fresh feldspar grains, biotite, muscovite, hornblende, augite, olivine, etc.

The grains identified during the point counting of sandstone include non–undulatory monocrystalline quartz, undulatory monocrystalline quartz, polycrystalline quartz with 2–3 sub grains, polycrystalline quartz with >3 sub grains. The relative percentages of the four types of quartz were plotted on the provenance–discrimination diagram of Basu *et al.*, (1975). Girty *et al.* (1988) have also recommended this diagram for the discrimination of quartz grains derived from plutonic and meta sedimentary rocks.

The Basu *et al.*, (1975) plot suggests that the quartz grains of the Ridge Sandstone were derived from plutonic and middle and upper metamorphic source (Fig. 3). The abundance of non–undulatory over undulatory quartz in Ridge Sandstone suggests plutonic and volcanic source rock (Basu, 1985). The dominance of monocrystalline quartz grain indicates that the sediments were derived from a granitic source (Basu *et al.*, 1975). The relatively higher proportion of monocrystalline

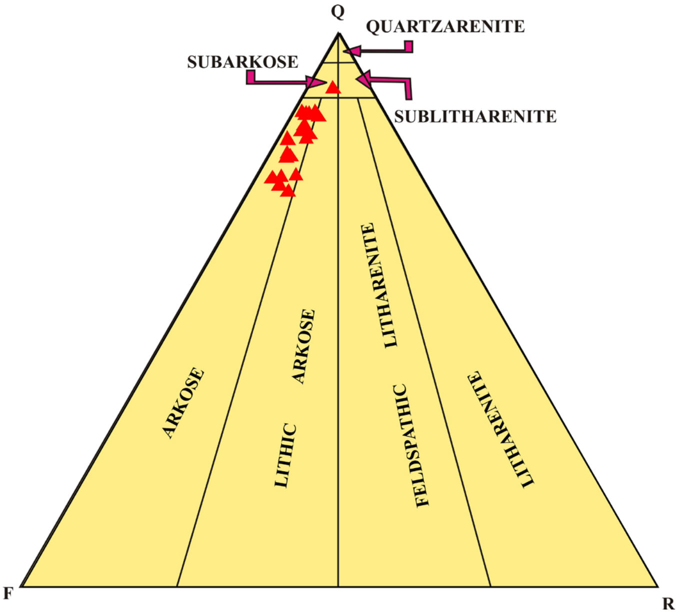


Fig. 2—Modal data plot of quartz–feldspar–lithic fragments (Q–F–L) and triangular classification on the Folk (1980) diagram of Ridge Sandstone Member samples from the Jumara Dome.

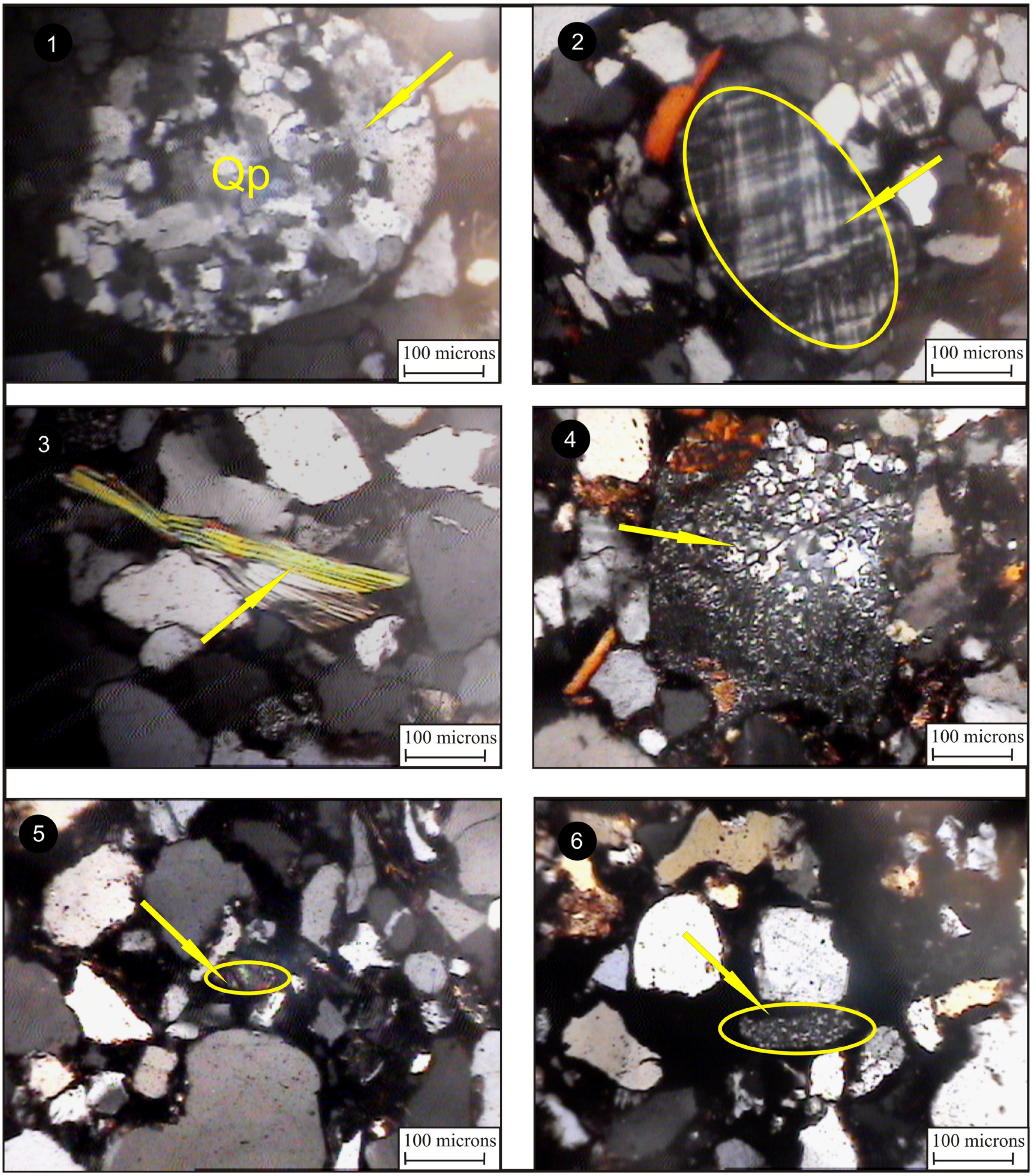


PLATE 1

Photomicrograph of selected Ridge Sandstone Member illustrating:

1. Polycrystalline quartz grain.
2. Crosshatch twinning of microcline.
3. Bent flexible muscovite flake, thus postdating mechanical compaction.
4. Chert grain.
5. Rounded grain of zircon.
6. Phyllite grain.

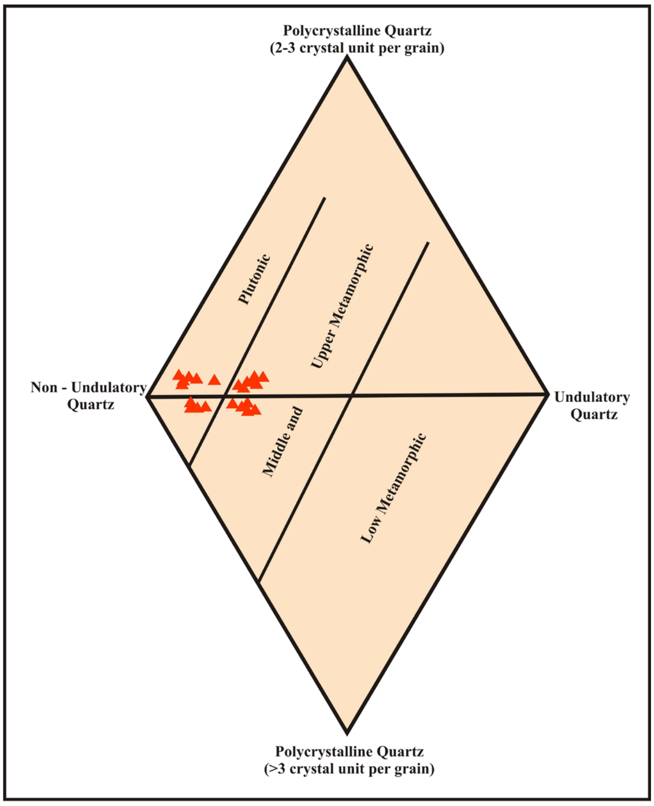


Fig. 3—Ternary plot of detrital quartz types of the Ridge Sandstone Member of Jumara Dome (after Basu *et al.*, 1975).

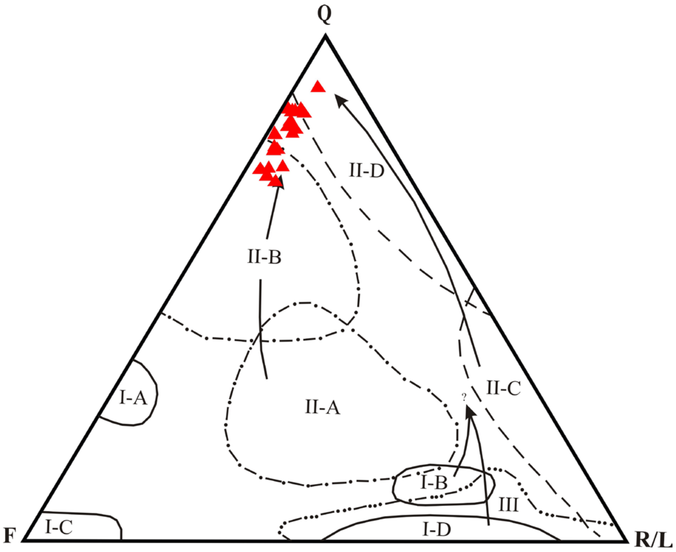


Fig. 4—Postulated idealized evolution model of Ridge sandstone with emphasis on source rocks and climate. Expected petrofacies composition from ideal provenances with different climate and their relationship with primary source rocks by Alam (2002). The modal modified after Cox and Lowe, (1995). Fields–IA, IB, IC, ID are of granite, rhyolite, gabbro, and andesite–basalt respectively after McBirney, (1983), IIA, IIB, IIC and IID are first cycle of Holocene fluvial sands from granite (arid climate), granite (humid climate), metamorphic (arid climate) and metamorphic (humid climate) respectively after Suttner *et al.*, (1981). III represents sediments from magmatic arcs after Marsaglia and Ingersoll, (1992).

quartz may be attributed to the disaggregation of original polycrystalline quartz during high energy/ and or long distance transport from the source area (Dabbagh & Rogers, 1983). The high proportion of alkali feldspar than plagioclase shows dominance of granite and acidic gneisses in the source area. However this feature might also be due to the higher chemical stability of alkali feldspar than plagioclase during transportation (Tucker, 1992). The presence of microcline also favours granitic and pegmatitic sources.

The abundance of quartz and feldspar minerals and their predominance over the lithic fragments in the Ridge Sandstone suggests a primary rather than reworked source for the sandstone (Pettijohn *et al.*, 1987). The presence of polycrystalline quartz that are not elongated or flattened and of equant grains with sutured intercrystalline boundaries, non undulose quartz extinction favours a plutonic igneous granitiod source as the dominant source rock of a humid environment (Pettijohn *et al.*, 1987; Folk, 1974; Blat *et al.*, 1980; Basu, 1985). In addition the presence of monocrystalline quartz with strong undulose extinction, polycrystalline quartz and metamorphic rock fragments suggests contribution from metamorphic sources. The presence of strain free quartz suggests that the source is Plutonic rocks (Basu, 1985). To evaluate the importance of plutonic and metamorphic rocks as Ridge Sandstone source, the compositional framework grain data is deduced by plotting the point count data on Suttner *et al.* (1981) (Fig. 4). This approach also points to both Metamorphic and Plutonic Igneous source rocks for the Ridge Sandstone.

The occurrence of heavy minerals including tourmaline, rutile and zircon indicates origin from igneous (plutonic) source rocks (Friedman & Sanders, 1978) whereas epidote, garnet and staurolite indicate a source in metamorphic rocks (Pettijohn, 1984). Therefore from the types of heavy minerals, the Ridge Sandstone was derived from the metamorphic and plutonic igneous sources. The dominance of the most stable heavy mineral (e.g. Zircon, tourmaline and rutile) indicates intensive chemical weathering of the source rocks and recycling of earlier detrital materials. This in turn indicates a high degree of maturity of sandstone (Carver, 1971; Morton, 1985).

However, quantitative petrography provides information on the nature of the source area. The high proportion of quartz as well as the dominance of K–feldspar over the more chemically unstable plagioclase in the Ridge Sandstone Member of Chari Formation in Jumara Dome suggests that the source area was exposed to long term weathering and that the sediments is at least partly polycyclic. This mineralogy is consistent with their derivation from plutonic rocks (granite and granitic gneisses). Integrated analysis of petrographic

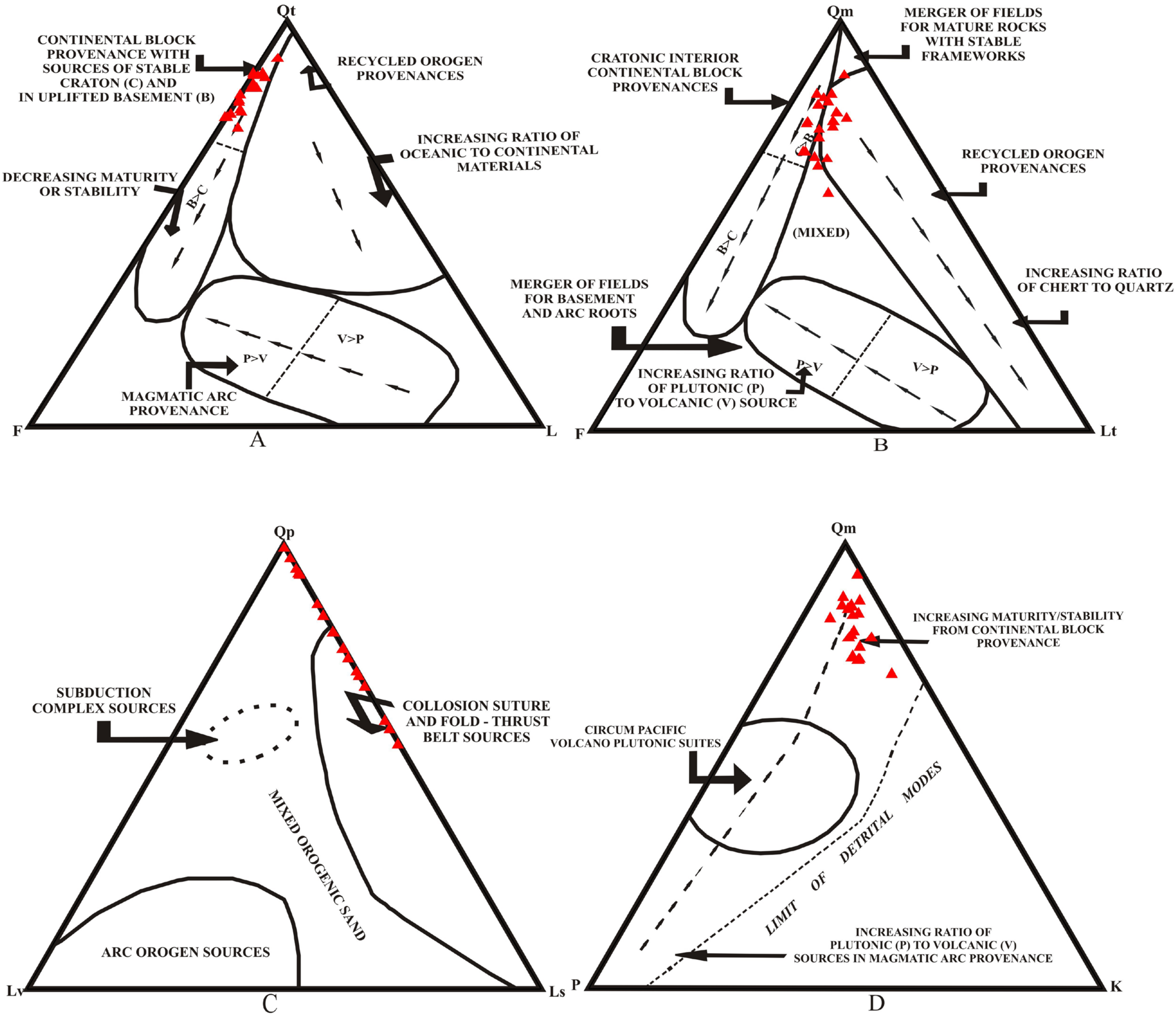


Fig. 5(A)–(D)—Tectono–provenance discrimination diagrams (Dickinson, 1985) for Ridge Sandstone Member of Jumara Dome.

characteristics coupled with palaeocurrent direction of the Ridge Sandstone Member of Jumara Dome of the Kachchh Basin suggests that sand detritus was mostly derived from the weathered parts of the present day, Aravalli range situated to the northeast, east and southeast of the basin and from the Nagar parker massif situated to the north and northwest of the basin (Ahmad *et al.*, 2014; Dubey & Chatterjee, 1997).

Tectonic Setting

Sandstone composition not only reflects the source area but also reflect the tectonic setting and climatic condition (Taylor & McLennan, 1985). The detrital framework modes of sandstone provide information about the tectonic setting of basin of deposition and associated provenance (Dickinson *et al.*, 1983). The character of the provenance, the nature of sedimentary process within the sedimentary basin and the kind of depositional paths that link provenance to basin influence the sandstone composition (Dickinson & Suczek, 1979). So the petrographic data of studied sandstone samples may be used as a tool for determination of provenance and nature of plate tectonics, which we related by source as well as environment of deposition. The tectonic setting of the provenance for the Ridge Sandstone Member of Jumara Dome has been determined using the ternary diagrams Qt–F–L, Qm–F–Lt, Qp–Lv–Ls and Qm–P–K given by Dickinson, (1985). The framework grains used to construct the triangular diagram are listed in Table 3.

Both Qt–F–L and Qm–F–Lt plots show full grain populations, but with different emphasis. In Qt–F–L plot where all quartzose grains are plotted together, the emphasis is on grain stability and thus on weathering, provenance, relief, and transport mechanism as well as source rock, while in Qm–F–Lt where all the lithic fragments are plotted together as Lt, the emphasis is shifted towards the grain size of source rock, because fine grained rocks yield more lithic fragments in the sand size range. The Qp–Lv–Ls and Qm–P–K plots show only partial grain populations, but reveal the character of polycrystalline and monocrystalline components of the framework respectively.

On the Qt–F–L diagram the mean detrital modes of the studied sandstone plot in the continental block provenance with stable craton and uplifted basement source (Fig. 5A). On Qm–F–Lt diagram the plot of the data fall in the continental block provenance with almost equal contribution from recycled orogen provenance and mixed provenance also (Fig. 5B). On Qp–Lv–Ls plot, the sample data fall in the rifted continental margin provenance and some data also fall in collision suture and fold thrust belt (Fig. 5C). The Qm–P–K plot of the data shows that all the sediment contribution is from continental block basement uplift provenance and reflecting maturity of the sediments and stability of the source area (Fig. 5D). The sandstone petrofacies and heavy mineral suites of the Ridge Sandstone indicate multiple rock sources for these sandstones, which are not shown in the triangular plots. The apparent reason for this could be diagenetic alteration and weathering of unstable framework grains, which increased the proportion of quartz grains relative to the original detrital composition.

Palaeoclimate

Although the composition and association of source rocks are controlled by plate tectonics and structural evolution of the area, the process of weathering, production and composition of detritus are determined primarily by climate (Basu, 1985; Suttner & Dutta, 1986; Akhtar & Ahmad, 1991). The palaeoclimate condition can be derived from the study of modal sandstone composition. Bivariant log/log plot of the ratio of polycrystalline quartz to feldspar plus rock fragments (Suttner & Dutta, 1986) has been used for interpreting the palaeoclimate of the Ridge Sandstone. This diagram indicates a humid climate for the region (Fig. 6A). The palaeoclimate simulation for Jurassic and Cretaceous time show that India as a part of Gondwanaland experienced humid to tropical climate (Thompson & Barron, 1981; Chatterjee & Hotton, 1986; Chandler *et al.*, 1992). The precipitation of huge carbonate during Jurassic is also supportive of the fact that the area was witnessing warm climate similar to found in tropics. A combination of low relief, hot humid climate and ample vegetation can produce quartz rich detritus (Franzinelli & Potter, 1983). Low relief provides prolonged residence time of sediments, thereby increasing the duration of chemical weathering and thus the sediments in the stable quartz. The mineralogical data plotted on Weltje *et al.* (1998) diagram fall in the field number 1 which indicates sedimentation in a low relief and temperate sub humid condition (Fig. 6B). Overall study suggest that such strong chemical weathering condition in unconformity with worldwide humid and warm climate during the Jurassic period (Thomson & Barron, 1981). Thus, climate might have been an important factor in the production of compositionally mature quartz rich sandstones. The point count data plotted in the QFR ternary diagram of Suttner *et al.* (1981) indicates igneous and metamorphic source rock in a humid climate (Fig. 4). However, this particular diagram can discriminate only sources of metamorphic and plutonic rocks (humid or arid conditions), and it does not discriminate between different tectonic settings.

DISCUSSION

The Jumara Dome sediments were derived from a variety of source rocks comprising granitic batholiths/ igneous plutons, magmatic–arc granite–gneisses, pegmatite or schist, metaquartzite, quartz vein, etc. The Qt–F–L and Qm–F–Lt plots of Ridge Sandstone suggests that the detritus of the sandstone was derived from the granite–gneisses exhumed in the craton interior as well as low to high grade supracrystals forming recycled orogen shedding quartz debries of the continental affinity into the basin. The sediments were deposited under the rifted basin condition as indicated by plotting of Ridge Sandstone on the Qp–Lv–Ls diagram. The plot of Ridge Sandstone on the Qm–P–K diagram suggests the maturity of the sediments and stability of the source area.

Plotting of Ridge Sandstone data on Qt–F–L tectonic provenance–ternary diagram (Dickinson, 1985) illustrates that the sandstone fall into the craton interior field. Sandstone derived from sources on continental block could theoretically come from two tectonic settings. If a continental block has been affected by faulting associated with rifting, associated sands will probably be quartzofeldspathic, with high ratio of alkali feldspar to plagioclase. If sands are derived from high topographic locations far from the depositional areas, they will tend to be quartz–rich and mineralogically mature. The high proportion of quartz and dominance of K–feldspar in the Ridge Sandstone suggests that the source region was exposed to intense weathering and the sediments were at least partly multicyclic. The study suggests that the Jumara Dome sediments are compositionally mature as they deposited in cratonic environment.

As Kachchh Basin is the earliest rift basin that initiated as a result of north and north east drifting coupled with counter

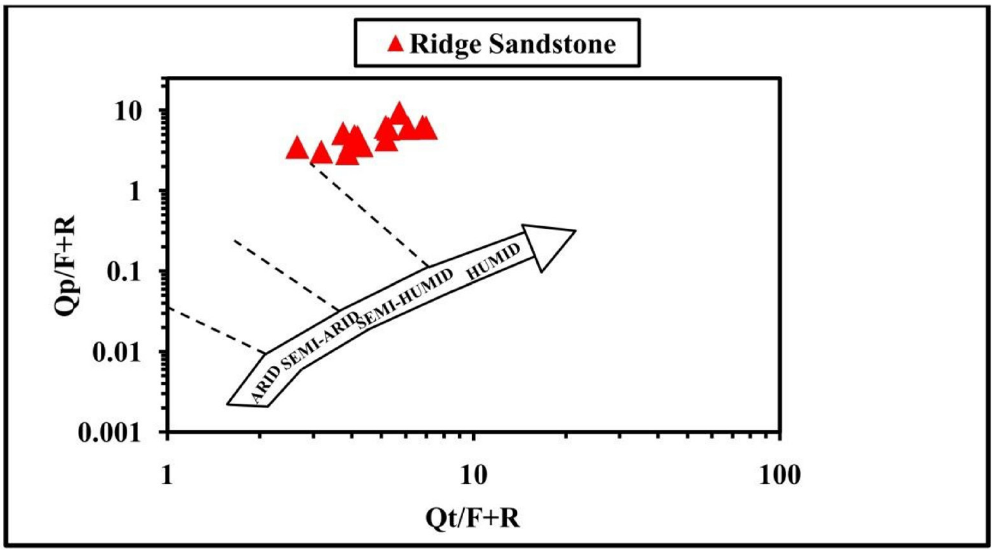
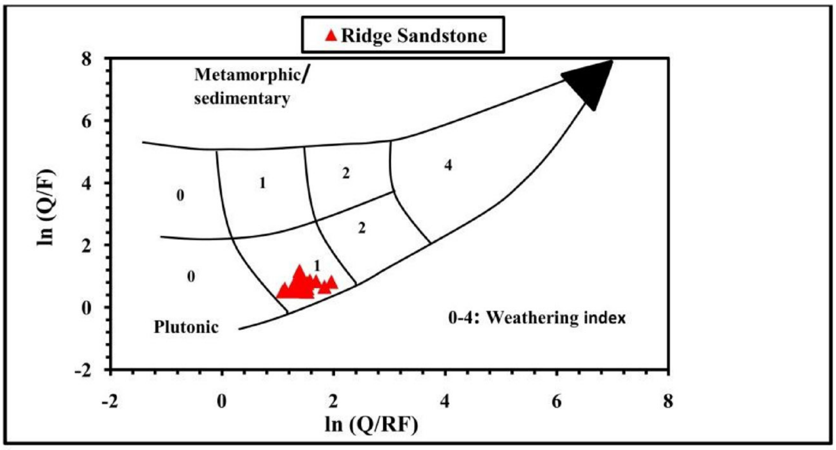


Fig. 6A—Bivariant log/log plot for Jumara Dome Sandstone, Kachchh Basin, according to Suttner and Dutta, (1986).



Semi- quantitative Weathering index			Physiography (relief)		
			High (Mountain) 0	Moderate (Hill) 1	Low (Plains) 2
Climate (Precipitation)	(Semi)Arid and Mediterranean	0	**0**	**0**	**0**
	Temperate sub humid	1	**0**	**1**	**2**
	Tropical humid	2	**0**	**2**	**4**

Fig. 6B—Log ratio plot after Weltje *et al.*, (1998). Q=Quartz, F=Feldspar, RF=Rock fragments. Field 1–4 refer to the semi–quantitative weathering indices declined on the basis of relief and climate as indicated in the table (respectively).

clockwise rotation of the Indian Plate after it detached from the Gondwanaland during Late Triassic/or Early Jurassic (Biswas, 1982; Biswas *et al.*, 1993). The heavy mineral suites like well rounded grains of zircon, tourmaline and rutile were perhaps derived from the Aravalli metasediments. The garnet, epidote and staurolite grains originating from the Aravalli pelitic metasediments which have been described to attain high rank metamorphism at places found in the Ridge Sandstone reflects their sources in the mixed provenance, such as that being believed to represent the eroded and weathered parts of the present day Aravalli range situated to the east and northeast of the basin and the Nagar parkar massif situated to the north and northwest (Dubey & Chatterjee, 1997).

CONCLUSION

1. The sediments of Ridge Sandstone of Jumara Dome are medium to coarse grained, sub–angular to sub–rounded and poorly to moderately sorted. The dominant framework constituent of the Ridge Sandstone Member is quartz, feldspar and rock fragment. The Q–F–R (Folk, 1980) plot suggests that the sandstone is subarkose to arkose in nature.
2. The plot of detrital modes of Ridge Sandstone on Qt–F–L suggests stable craton continental block provenance. Qm–F–Lt diagram indicates continental block, recycled orogen and mixed provenance. The Qp–Lv–Ls plot indicates rifted continental margin source. The Qm–P–K plot indicates maturity of sediments and stability of source region. The petrofacies analysis of the sandstone suggests continental block provenance with source on a stable craton which has been recognized as the Aravalli range situated to the northeast, east and southeast of the basin and from the Nagar parker massif situated to the north and northwest of the basin.
3. Diamond diagram by Basu *et al.* (1975) has shown that the sandstone was derived from plutonic and middle and upper metamorphic source. Suttner *et al.* (1981) plot indicates igneous and metamorphic source and humid climate for Ridge Sandstone. Bivariant log/log plot of the ratio of polycrystalline quartz to feldspar plus rock fragments (Suttner & Dutta, 1986) indicate that the palaeoclimate of the Ridge Sandstone is humid climate.

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