The Palaeobotanist 64(2015): 117–128
0031–0174/2015

Tectono–sedimentary and climatic setup for Dhosa Sandstone Member (Chari Formation) of Ler dome, Kachchh, western India

ASMA A. GHAZNAVI[1*], M. MASROOR ALAM[2] AND A.H.M. AHMAD[1]

[1]*Department of Geology, Aligarh Muslim University, Aligarh 202 002, India.*
[2]*Department of Civil Engineering, ZH College of Engineering and Technology, Aligarh Muslim University, Aligarh,202 002, India.*
[*]*Corresponding author: ghaznavi.asma@gmail.com*

(Received 10 September, 2015; revised version accepted 13 October, 2015)

ABSTRACT

Ghaznavi AA, Alam MM & Ahmad AHM 2015. Tectono–sedimentary and climatic setup for Dhosa Sandstone Member (Chari Formation) of Ler dome, Kachchh, western India. The Palaeobotanist 64(2): 117–128.

The Ler Dome situated in the south of Bhuj District, Kachchh, holds a well exposed Dhosa Sandstone Member which is a unit of Chari Formation. Petrographical studies of the sandstones exposed in the river section near Ler Village were carried out to analyse the petrofacies, tectono–provenance and palaeoclimate. The Dhosa Sandstones are composed dominantly of monocrystalline and variable amount of polycrystalline quartz, potassium and plagioclase feldspars with meta–sedimentary rock fragments. The identified petrofacies suggest a hybrid continental block–cum–recycled provenance comprising granite–gneiss with metamorphic supra crustals, exposed in the craton interior. The source rocks were exposed in the early stage of thermal doming prior to incipient rifting and drifting associated with Gondwanaland breakup. Sediments underwent short transportation under moderate relief condition and humid–semi humid to temperate climate, complying with the climatic setup of this region during the Jurassic times.

Key–words—Tectono–provenance, Palaeoclimate, Dhosa Sandstone Member, Chari Formation, Kachchh.

लेर गुंबद, कच्छ, पश्चिमी भारत के धोसा बलुआपत्थर सदस्य (चरी शैलसमूह) हेतु विवर्तन–अवसादी एवं जलवायवी व्यवस्थापन

आस्मा ए. गज़नवी, एम.मसरूर आलम एवं ए.एच.एम. अहमद

सारांश

जिला भुज, कच्छ के दक्षिण में स्थित लेर गुबंद, सुअनावरित धोसा बलुआपत्थर सदस्य है जो कि चरी शैलसमूह की इकाई है। लेर गाँव के नज़दीक नदी खंड अभिव्यक्त करते हुए बलुआपत्थरों के शैलविज्ञान संबंधी अध्ययन शैलसंलक्षणियों, विवर्तन–उद्गम क्षेत्र एवं पुराजलवायु विश्लेषित करने को किए गए थे। धोसा बलुआपत्थर मेटा–अवसादी शैल खंडजों सहित प्रमुखता से मोनोक्रिटेलाइन तथा बहुक्रिस्टलीय क़्वार्टज, पोटेशियम एवं प्लेजिओक्लेस फैल्डस्पर्स की परिवर्तनीय मात्रा सन्निहित हैं। पहचानी गई शैलसंलक्षणियाँ क्रेटान अंतस्थ में अनावरित, कायांतरित अधि भूपर्पटियों सहित ग्रेनाइट–नाइस सन्निहित संकर महादवीपीय खंड–सह–पुनर्चक्रित उद्गम क्षेत्र सुझाती हैं। स्रोत शैल गोंडवानाभूमि विघटन से संबद्ध प्रारंभिक अनुपाट हो रहे एवं अपवाही से पूर्व तापीय गुबंद की प्रारंभिक अवस्था में अनावरित हो गए थे। जुरैसिक काल के दरम्यान इस क्षेत्र के जलवायवी व्यवस्थापन के अनुवर्ती मध्यम राहत दशा और आर्द्र–अर्ध आर्द्र से शीतोष्ण जलवायु के अधीन अवसादों का थोड़ा परिवहन (अभिगमन) हुआ।

सूचक शब्द—विवर्तन–उद्गम क्षेत्र, पुराजलवायु, धोसा बलुआपत्थर सदस्य, चरी शैलसमूह, कच्छ।

INTRODUCTION

THE Mesozoic Kachchh Basin is situated on the western margin of the Indian Plate (Biswas, 1987). It is formed by rifting of South Africa–Madagascar and India during fragmentation of Gondwanaland (Biswas, 1991). The basin is bordered by Nagarparkar massif in the north, Radhanpur–Barmer arch in the east and Kathiawar uplift in the south. The configuration of the basin was controlled by primeval fault pattern in the basement rocks (Biswas, 1977). Mesozoic sediments ranging in age from Bajocian to Albian (Rajnath, 1932; Singh *et al.*, 1982; Fursich *et al.*, 2001) lay unconformably on the Precambrian basement (Bardhan & Datta, 1987). The Jurassic outcrops primarily occur in three

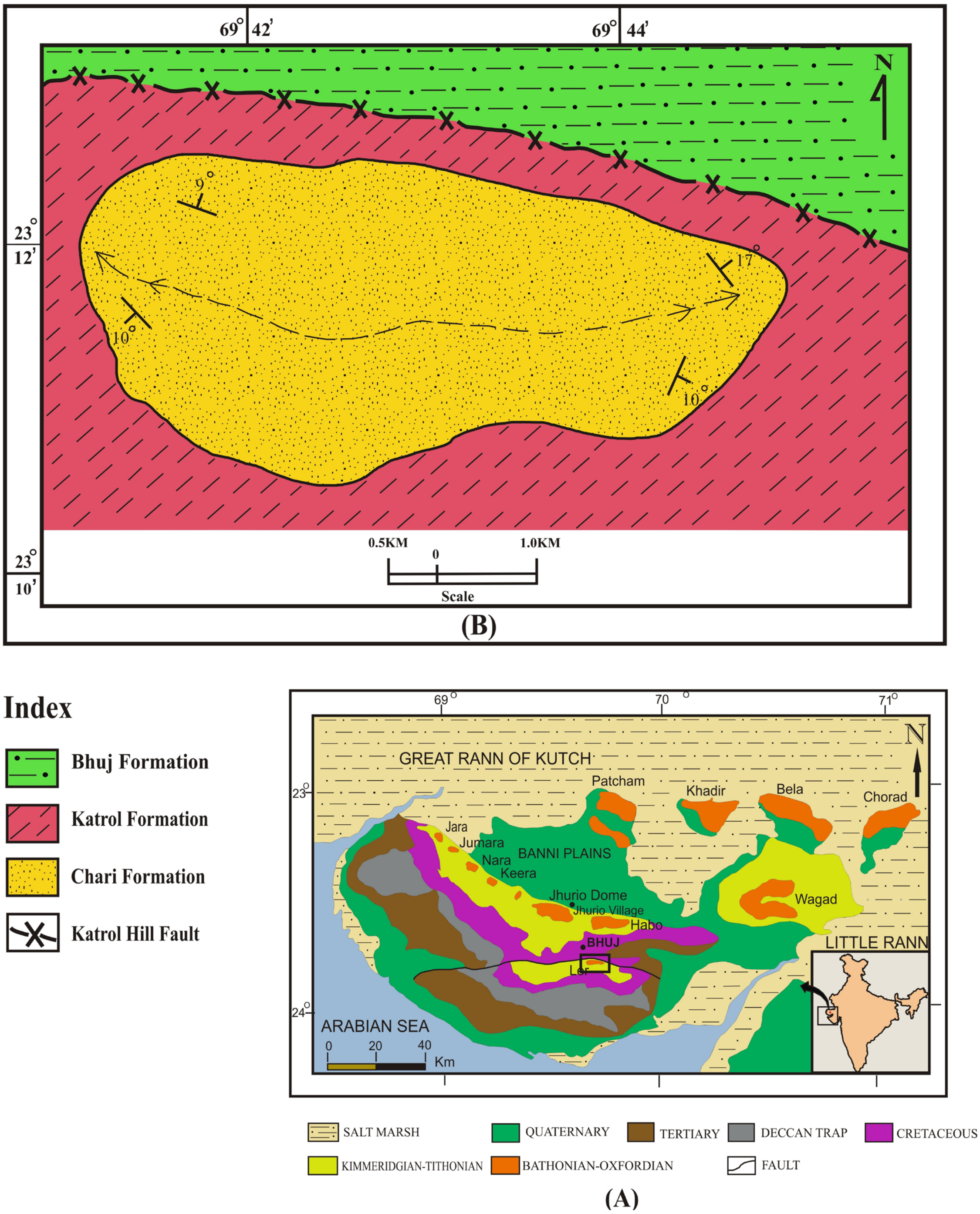


Fig. 1A—Geological map of the Kachchh Basin (modified after Fursich *et al.*, 2001). B—Ler Hill.

areas: the Kachchh mainland covering the central part of the basin, the island belt between the salt marshes of Great Rann of Kachchh, and the Wagad uplift near its eastern boundary.

The Kachchh Basin was the first to form during Early Jurassic, followed by two other basins, i.e. Cambay Basin in Early Cretaceous and Narmada Basin in Late Cretaceous in the aftermath of rifting and drifting of India from Africa–Madagascar, along three intersecting geo–fractures (Biswas 1987). The sea had flooded the basin during marine transgression by Late Bajocian (Singh *et al.*, 1982). The marine transgression persisted throughout the Jurassic and terminated by Early–Cretaceous (Singh *et al.*, 1982; Pandey *et al.*, 2009). The basin is filled by shallow–water to basinal siliciclastic sediments (sandy to clayey–silty) deposited on an inclined ramp surface. They represent coastal and estuarine environments, sub tidal bar complexes, as well as storm–affected shallow shelf deposits and thin offshore deposits (Fursich *et al.*, 1991). In the Bathonian and Lower Callovian, carbonate–siliciclastic sediments were deposited as storm dominated shallow shelf deposits (Fursich *et al.*, 1991).

Jurassic rocks in Kachchh region are exposed in three east–west trending anticlinal ridges. The most noticeable among them is the middle ridge which forms a part of Kachchh mainland. They comprise many irregular elliptical quaquaversal units which are referred to as domes (Rajnath, 1932). In the north of Bhuj District they extend from Jara Dome to Habo Dome from west to east including Jumara, Nara (Kaiya), Keera and Jhurio domes (Fig. 1A). The Ler Dome lying to the south of Bhuj is a small but well exposed outcrop of Jurassic rocks.

Jurassic rocks of Kachchh have been divided into four formations by Stolizcka's unpublished scheme (first used by Waagen, 1873–75), viz. Patcham, Chari, Katrol and Umia in ascending order.

The present area of study, i.e. Ler Dome (Fig. 1B), is situated about 10 km southeast of Bhuj and only Chari and Katrol formations are exposed in the dome. In the Late Bathonian Raimalro Limestone Member (Sponge Limestone Member of Patcham Formation) carbonates occur in considerable quantity. Sediments overlying Chari Formation are fine sand and silt bearing bio–turbated marls with thin intercalations of laminated packstones and grainstones. The top of Raimalro Limestone Member marks a distinct facies change from carbonate rich to siliciclastic rich over entire Kachchh sub–basin. This transition to the Chari Formation is gradual in some areas and sharp in others. Dhosa oolite, the topmost member of Chari Formation is followed by Katrol Formation which bears Kimmeridgian aged ammonites. Although a considerable amount of work has been carried out on the stratigraphy, mega–and micro–fauna (Singh, 1989; Fursich *et al.*, 1991, 2001; Dubey & Chaterjee, 1997), little work has been done on the sedimentological aspects, especially the petrographic analysis.

Petrographic studies help to establish relationship between composition of sandstone and tectonic setting apart from source rocks by incorporating detrital framework

Age	Formation	Member
Albian–Aptian	Umia Formation	Bhuj Member
		Ukra Member
Neocomian		Ghuneri Member
Tithonian		Umia Member
Tithonian–Kimmeridgian	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 Member
		Golden Oolite Member
Bathonian	Patcham Formation	Sponge Limestone Member
Bathonian–Bajocian	Jhurio Formation	–

Fig. 2A—Lithostratigraphy of Dhosa Sandstone Member of Chari Formation of the Jurassic and Lower Cretaceous age rocks of Kachchh Mainland (Fursich *et al.*, 1991, 1992, 2001).

Fig. 2B—Field photograph showing Dhosa Sandstone Member at river section, Ler.

modes (Dickinson, 1970; Uddin & Lundberg, 1998). The petrographic data can be further used to reconstruct palaeogeography, depositional systems and to describe the crust which is no longer exposed. Petrofacies can be defined as sandstones having similar composition in terms of detrital parameters such as Qt–F–L, Qm–F–Lt, Qp–Lv–Ls and Qm–P–K percentages and the ratio of different grain types (Dickinson & Rich, 1972). Sandstone petrofacies of various ages on a regional scale have been useful in interpreting geotectonic evolution of a sedimentological province (Dickinson *et al.*, 1983; Cox & Lowe, 1995). Modification of composition by recycling and transport (Franzinelli & Potter, 1983), palaeoclimate (Basu, 1985), depositional environment (Davis & Ethridge, 1975) and post depositional processes like weathering, long transport, syndepositional abrasion and diagenetic modifications also take place (Akhtar & Ahmad, 1991; Espejo & Gamundi, 1994). In the present study, sandstone samples have been studied for evaluation of their petrofacies and effect of various factors controlling the petrofacies evolution.

STRATIGRAPHY

The Chari Formation has been distinguished by Fursich *et al.* (2001) into three members (Fig. 2A), viz. upper Gypsiferous Shale Member (Late Callovian) consisting of argillaceous silt with abundant secondary gypsum. The unit coarsens into Dhosa Sandstone and is followed by Dhosa Oolite Member, an excellent lithologic marker horizon of Callovian–Oxfordian age (Fursich *et al.*, 1992; Singh, 1989) at the top. The boundary between these two members is based on arbitrary presence or absence of ferruginous ooids and is diachronous in nature.

The river section exposures of Dhosa Sandstone Member (Upper Callovian–Lower Oxfordian) (Fig. 2B) is about 47 m in thickness. The member epitomize faintly coarsening upward sequence predominantly composed of silty clays, fine sandy silt and sandstone. The thin, ripple–laminated sand units mostly occur at the base and towards the top (Ahmad & Bhat, 2006). With the aid of sedimentary and biostratinomic evidences, the depositional environment for Dhosa Sandstone Member has been interpreted in terms of the transgressive–

Table 1—Key for petrographic and other parameters used in this study (modified from Trop & Ridgway, 1997).

Symbol	**Definition**
Qm	Monocrystalline quartz
Qpq	Polycrystalline quartz
C	Chert
P	Plagioclase feldspar
K	Potassium feldspar
Lsi	Siliceous shale fragments
Lsm	Shale fragments
Lst	Siltstone fragments
Lsa	Argillite fragments
Lsc	Carbonate rock fragments; extrabasinal limestone only
Lmq	Quartz–mica tectonite fragments; foliated
Lmc	Metamorphic chert fragments; foliated, micaceous
Lmm	Mica schist fragments
Lv	Volcanic rock fragments; aphanitic
Recalculated components	
Qt	Total quartzose grains (=Qm+Qpq+C)
F	Total feldspar grains (=P+K)
L	Total unstable lithic fragments (=Lsi+Lsm+Lst+Lsa+Lsc+Lmq+Lmc+Lmm+Lv)
Lm	Metamorphic lithic grains (=Lmq+Lmc+Lmm)
Lv	Volcanic lithic grains (=Lv)
Ls	Sedimentary lithic grains (=Lsi+Lsm+Lst+Lsa+Lsc)
Qp	Total polycrystalline quartzose grains (=Qpq+C)
Lvm	Volcanic and metavolcanic grains (=Lv)
Lsm	Sedimentary, metasedimentary and metamorphic grains (=Lm+Ls)
Lt	Total lithic grains (=Qp+Lm+Lv+Ls)
Percentages	
QtFL%Qt	=100Qt/(Qt+F+L)
QtFL%F	=100F/(Qt+F+L)
QtFL%L	=100L/(Qt+F+L)
QmFLt%Qm	=100Qm/(Qm+F+Lt)
QmFLt%F	=100F/(Qm+F+Lt)
QmFLt%Lt	=100Lt/(Qm+F+Lt)
QmPK%P	=100P/(Qm+P+K)
QmPK%K	=100K/(Qm+P+K)
QpLvmLsm%Qp	=100Qp/(Qp+Lvm+Lsm)
QpLvmLsm%Lvm	=100Lvm/(Qp+Lvm+Lsm)
QpLvmLsm%Lsm	=100Lsm/(Qp+Lvm+Lsm)
LmLvLs%Lm	=100Lm/(Lm+Lv+Ls)
LmLvLs%Lv	=100Lv/(Lm+Lv+Ls)
LmLvLs%Ls	=100Ls/(Lm+Lv+Ls)

regressive cycles (Fursich *et al.*, 1991). The peak transgression was reached in the Oxfordian. It was followed by regression in the overlying Kimmeridgian Katrol Formation. Presence of some intercalated carbonate layers within sandstone body (Fursich *et al.*, 1991) also suggest transgressive environment aiding calcareous deposition.

METHODOLOGY

More than forty five samples were collected from the exposure of Dhosa Sandstone Member at the river section near Ler Village to represent the complete 47 m thick section. Thirty three samples were cut into standard petrographic thin sections. They were etched and stained for calcium and potassium feldspar and pore spaces. 300–350 points of framework grains were counted per thin section by Ghazzi–Dickinson method (e.g. Dickinson, 1970; Ingersoll *et al.*, 1984).

The volume percent of different constituent grains i.e. quartz (Q), feldspar (F) and rock fragments (R), were calculated and plotted on the Folk's (1980) diagram. Key for the description of raw and recalculated parameters used in the present study is defined in Table 1.

Following the classic method for petrofacies analysis defined by Dickinson (1985), counts for total quartzose grains (Qt), monocrystalline quartz (Qm), polycrystalline quartz (Qp), total feldspar content including both plagioclase and K–feldspars (F), plagioclase feldspar (P), potassium feldspar (K), volcanic lithics (Lv), meta–sedimentary lithics (Ls), total lithics, i.e. sum of polycrystalline quartzose grains, metamorphic, sedimentary and lithic fragments (Lt) and total unstable lithic fragments (L) were performed and recalculated to 100%. Average and standard deviation of these "operational values" were computed in order to express variation in the data.

PETROGRAPHY

The sandstones are of medium grain size, angular to sub rounded, poorly to moderately sorted. The major cement is calcite cement (Pl. 1.1) suggesting good content of calcium carbonate deposited by pore waters. Few sandstones show presence of matrix (Pl. 1.2). Texturally these sandstones are submature to immature.

The sandstones consist of abundant quartz grains ranging from 86.03% to 96.25% of the total volume with an average of 90.50% (Table 2). Both mono–as well as polycrystalline quartz are found with the dominance of monocrystalline variety (86.06%). The monocrystalline quartz exhibits non–undulose extinction. In the polycrystalline variety, extinction in grains reveals the presence of two or more crystals which may otherwise be obscured due to re–crystallization and fusion of grain boundaries, but still showing undulosity. In the given sandstones polycrystalline quartz occur both as recrystallized as well as stretched metamorphic quartz. However, the former predominate over the latter (Pl. 1.3).

Feldspar (7.07%) is next in abundance to quartz which includes mostly potassium rich varieties, i.e. microcline (Pl. 1.4) and orthoclase. Plagioclase feldspars are also present in appreciable quantity(2.42%). In addition to these, micas in form of small laths of muscovite (Pl. 1.5), and specks of biotite are also present. In the sandstones, lithic fragments comprise of mainly meta–sedimentary lithics, averaging 2.62%. The common lithic grains include schist, phyllite, chert (Pl. 1.6) and siltstone. Zircon (Pl. 1.7), epidote and tourmaline (Pl. 1.8) are the common heavy minerals apart from dominating opaques.

The Dhosa Sandstone Member can be categorized mainly as subarkose, based on Folk's diagram (1980) for classification of sandstone. However, some of the samples fall in the quartzarenite field (Fig. 3).

PETROFACIES AND TECTONO–PROVENANCE

The petrographic data were generated and the petrofacies were plotted on corresponding standard ternary diagrams, viz. Qt–F–L, Qm–F–Lt, Qp–Lv–Ls and Qm–P–K specified by Dickinson (1985). These diagrams identify three major tectonic provenances, viz. continental block provenance, recycled orogen provenance and magmatic arc provenance. These individual provenances are further divided into subfields depending upon enrichment of quartz, polycrystalline quartz, metamorphic and volcanic lithics respectively.

The Qt–F–L petrofacies plots help to deduce the stability and maturity of detrital modes which in turn replicate the relief of the provenance and rigour of transport mechanism. The Qm–F–Lt petrofacies stress on the identification of source rocks and its exposure.

The Qt–F–L petrofacies suggest craton interior continental block provenance (Fig. 4A). The high percentage of Qt (90.50%) and moderate amount of feldspars (6.88%) shows high to moderate maturity, suggesting moderate relief and short transportation.

In the Qm–F–Lt petrofacies data plot gets concentrated in the mid of F and Lt leg near the apex suggesting a good contribution of quartzose recycled orogen provenance (Fig. 4B) which may be attributed to presence of basement rocks covered with supracrustals as is the case with recycled orogens (Dickinson, 1985) which is indicated by presence of meta–sedimentary lithics in studied sandstones.

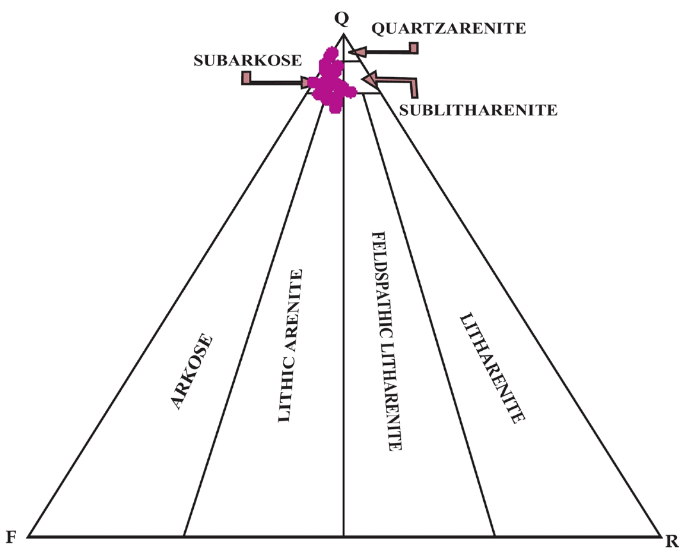


Fig. 3—Triangular classification plot of sandstone (Folk, 1980) for Dhosa Sandstone Member.

Sample No.	Q%	F%	R%	Qt %	F%	L%	Qm%	F%	Lt%	Qp%	Lv%	Ls%	Qm%	P%	K%
D1(A)	93.00	5.90	1.10	93.08	5.84	1.09	87.23	5.90	6.86	86.21	0.00	13.79	93.66	1.25	5.08
D1(B)	95.51	4.49	0.00	95.51	4.49	0.00	86.96	4.49	8.55	100.00	0.00	0.00	95.09	1.11	3.80
D2(A)	96.08	3.92	0.00	96.08	3.92	0.00	92.47	3.92	3.61	100.00	0.00	0.00	95.93	0.89	3.18
D2(B)	96.25	3.75	0.00	96.25	3.75	0.00	88.48	3.75	7.77	100.00	0.00	0.00	95.93	1.11	2.96
D3(A)	93.57	4.21	2.21	93.71	4.12	2.17	90.36	4.21	5.43	71.03	0.00	28.97	95.54	1.51	2.95
D3(B)	91.45	6.34	2.21	91.63	6.20	2.16	87.46	6.34	6.19	73.68	0.00	26.32	93.24	0.63	6.13
D4(A)	92.71	6.65	0.64	92.76	6.61	0.64	91.05	6.65	2.30	78.26	0.00	21.74	93.19	2.75	4.06
D4(B)	90.21	8.20	1.59	90.36	8.07	1.56	86.77	8.20	5.03	76.00	0.00	24.00	91.36	1.11	7.52
D5(B)	87.97	10.02	2.00	88.21	9.83	1.97	85.52	10.02	4.45	68.97	0.00	31.03	89.51	4.20	6.29
D6	90.99	7.01	2.00	91.17	6.87	1.96	84.98	7.01	8.01	80.00	0.00	20.00	92.38	2.72	4.90
D7	93.92	6.08	0.00	93.92	6.08	0.00	92.93	6.08	0.99	100.00	0.00	0.00	93.86	2.51	3.63
D8	90.57	6.44	2.99	90.85	6.25	2.90	86.67	6.44	6.90	69.77	0.00	30.23	93.09	1.48	5.43
D9	90.07	7.58	2.35	90.29	7.41	2.30	82.48	7.58	9.93	80.85	0.00	19.15	91.58	3.92	4.50
D10	88.67	8.90	2.43	88.94	8.69	2.37	86.89	8.90	4.21	63.41	0.00	36.59	90.71	2.53	6.76
D11	89.98	8.88	1.13	90.09	8.79	1.12	80.53	8.88	10.59	90.32	0.00	9.68	90.06	2.54	7.40
D12	91.31	6.76	1.93	91.48	6.63	1.89	83.78	6.76	9.46	83.05	0.00	16.95	92.54	2.56	4.90
D13	88.44	6.36	5.19	89.01	6.05	4.94	84.03	6.36	9.61	64.91	0.00	35.09	92.96	2.30	4.74
D14	92.37	5.24	2.40	92.54	5.12	2.34	85.93	5.24	8.83	78.67	0.00	21.33	94.25	2.46	3.28
D15	87.19	7.72	5.08	87.81	7.35	4.84	81.54	7.72	10.73	67.86	0.00	32.14	91.35	2.32	6.33
L1	90.34	9.66	0.00	90.34	9.66	0.00	87.21	9.66	3.13	100.00	0.00	0.00	90.03	3.23	6.74
L2	86.94	9.24	3.82	87.42	8.90	3.68	83.76	9.24	7.01	64.71	0.00	35.29	90.07	3.77	6.16
L8	86.27	7.99	5.74	87.02	7.56	5.43	81.97	7.99	10.04	63.64	0.00	36.36	91.12	2.96	5.92
L10	89.06	5.85	5.09	89.59	5.57	4.85	86.04	5.85	8.11	61.43	0.00	38.57	93.63	2.46	3.90
L12	85.19	8.80	6.01	86.03	8.30	5.67	79.40	8.80	11.80	66.27	0.00	33.73	90.02	4.38	5.60
SII–3	89.07	8.15	2.78	89.37	7.93	2.70	85.93	8.15	5.93	68.09	0.00	31.91	91.34	2.56	6.10
SII–6	88.25	8.65	3.10	88.61	8.39	3.01	86.62	8.65	4.73	60.42	0.00	39.58	90.92	3.42	5.65
SII–7	89.49	5.59	4.92	89.98	5.33	4.68	86.95	5.59	7.46	60.27	0.00	39.73	93.96	1.83	4.21
SII–8	87.95	9.04	3.01	88.30	8.78	2.93	85.88	9.04	5.08	62.79	0.00	37.21	90.48	2.78	6.75
SII–9	89.58	8.47	1.95	89.78	8.31	1.92	87.62	8.47	3.91	66.67	0.00	33.33	91.19	3.05	5.76
SII–12	86.95	7.83	5.22	87.59	7.44	4.96	84.07	7.83	8.09	60.78	0.00	39.22	91.48	2.56	5.97
SII–15	89.97	6.07	3.96	90.36	5.84	3.81	87.86	6.07	6.07	60.53	0.00	39.47	93.54	1.69	4.78
LII–2	88.99	8.70	2.32	89.24	8.50	2.27	86.96	8.70	4.35	65.22	0.00	34.78	90.91	3.33	5.76
LII–5	88.39	4.78	6.83	89.13	4.48	6.39	83.61	4.78	11.61	62.96	0.00	37.04	94.59	2.01	3.40
Mean	90.20	7.07	2.73	90.50	6.88	2.62	86.06	7.07	6.87	74.45	0.00	25.55	92.41	2.42	5.17
Std. Dev.	2.77	1.75	1.93	2.58	1.71	1.82	3.08	1.75	2.77	13.50	0.00	13.50	1.86	0.96	1.31

Table 2—Modal composition based on Folk (1980) and detrital petrofacies modes based on Dickinson (1985) of the Dhosa Sandstone Member at Ler. **According to Folk (1980):** Q: total quartz, F: total feldspar, R: total rock fragments. **According to Dickinson (1985):** Qt: total quartzose grain, F: total feldspar, L: lithic, Qm: monocrystalline quartz, Lt: total lithics, Qp: polycrystalline quartz, Lv: volcanic lithics, Ls: meta–sedimentary lithics, P: plagioclase feldspar, K: potassium feldspar.

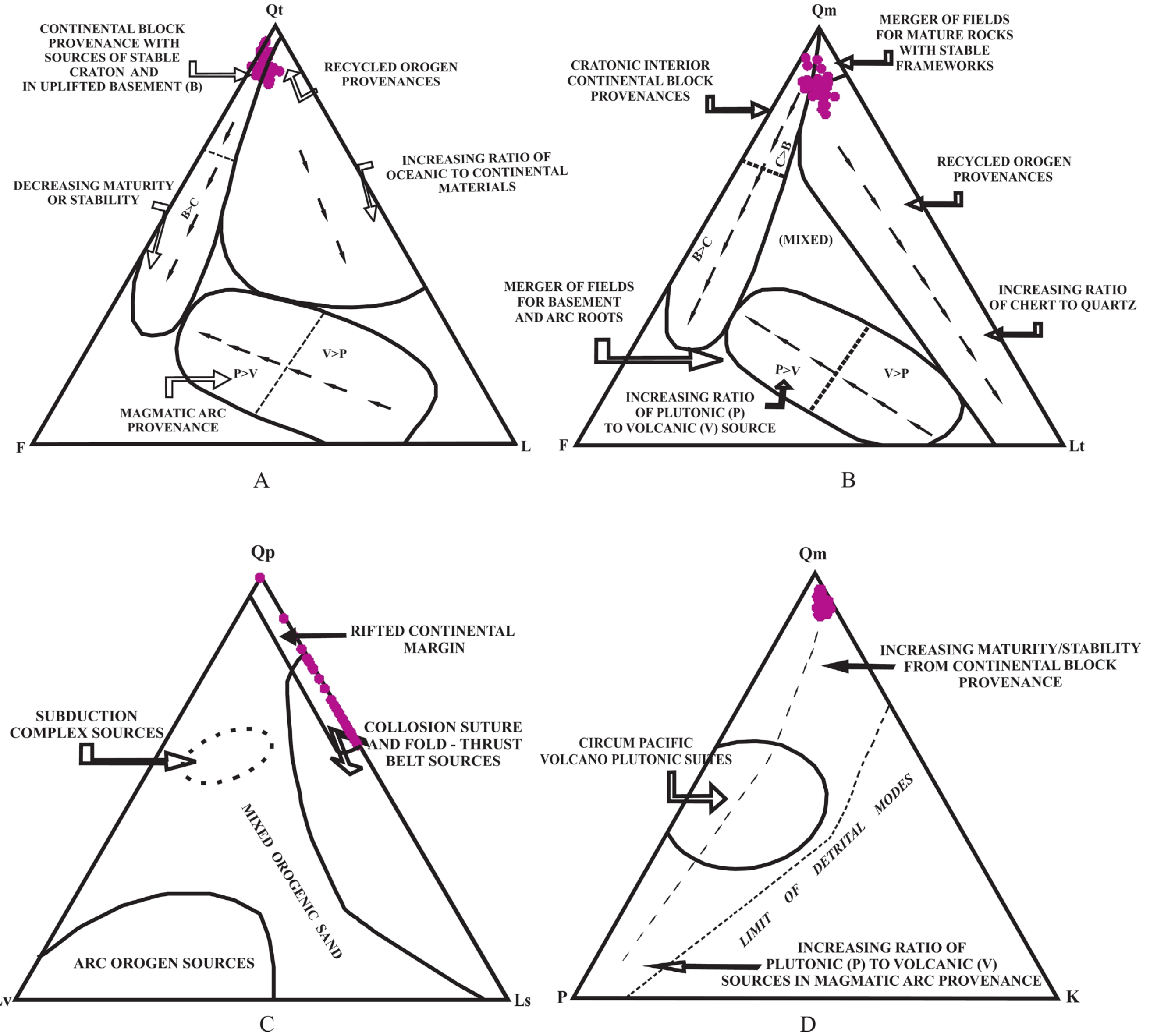


Fig. 4—Tectono–provenance discriminating diagrams (Dickinson, 1985) for the Dhosa Sandstone Member. C is modified after Dickinson, (1985); Dickinson & Suczek (1979) and Ingersoll & Suczek (1979).

Polycrystalline quartzose grains as well as lithic fragments consisting of both metamorphic and sedimentary lithic grains are plotted in the Qp–Lv–Ls diagram. The samples are completely devoid of volcanic lithic grains, hence, the data plot entirely on the Qp–Ls leg pointing to a rifted–continental margin type of tectono–province with some plots in collision suture zone (Fig. 4C).

The Qm–P–K plot takes into account Qm as monocrystalline quartz, P as plagioclase feldspar and K as the sum of microcline and orthoclase. The data samples suggest maturity of continental block provenance (Fig. 4D). But, the presence of plagioclase and general absence of volcanic lithics suggest the granitic source of plagioclase rather than volcanic.

It is suggested that the provenance consist of a collage comprising basement granitic–gneiss and meta–sedimentary

PLATE 1 →

Microphotograph showing

1. Calcite cement
2. Matrix
3. Recrystallized Quartz
4. Microcline
5. Split end in muscovite flake
6. Chert grain
7. Zircon
8. Tourmaline

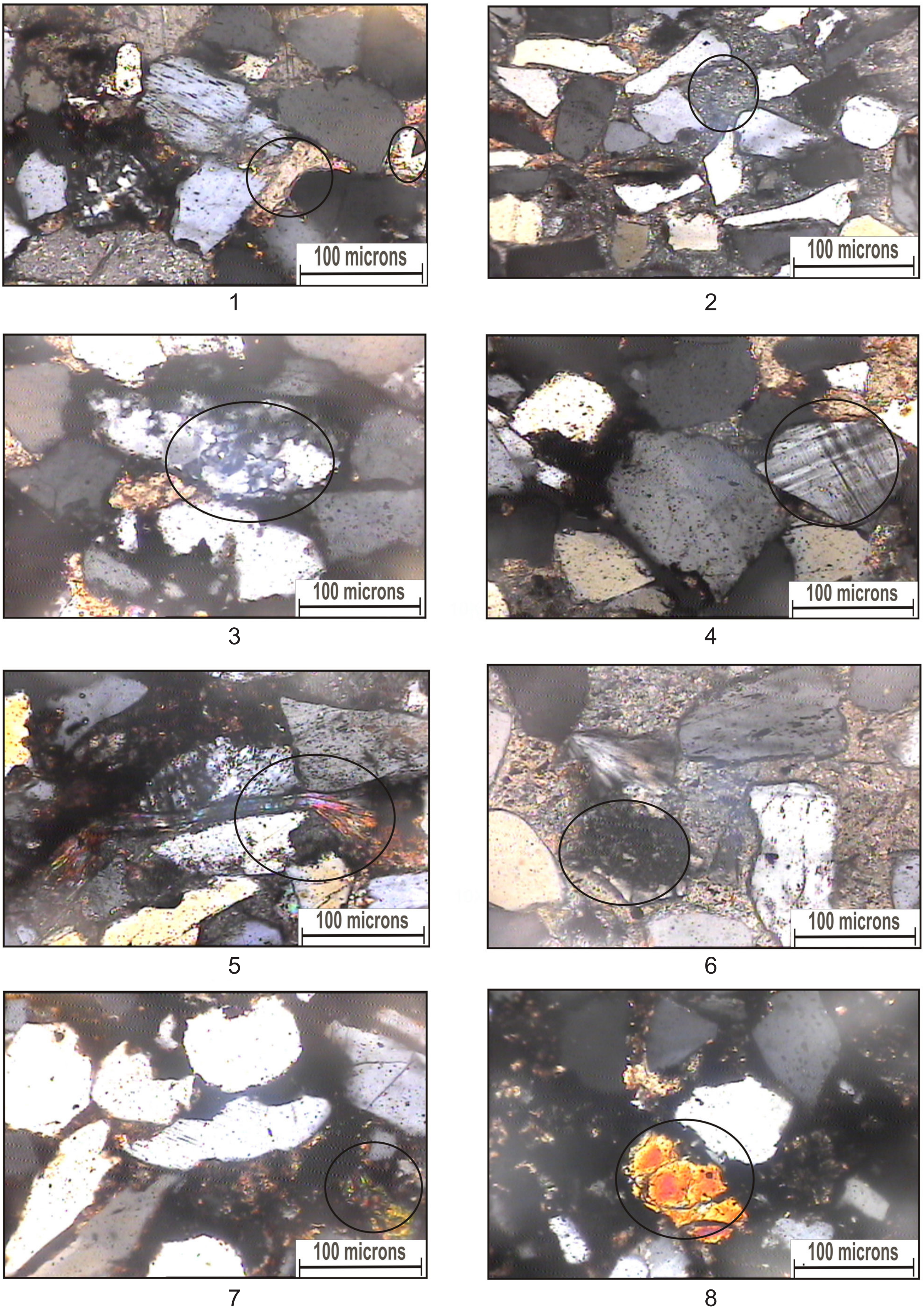

100 microns
1
100 microns
2
100 microns
3
100 microns
4
100 microns
5
100 microns
6
100 microns
7
100 microns
8

PLATE 1

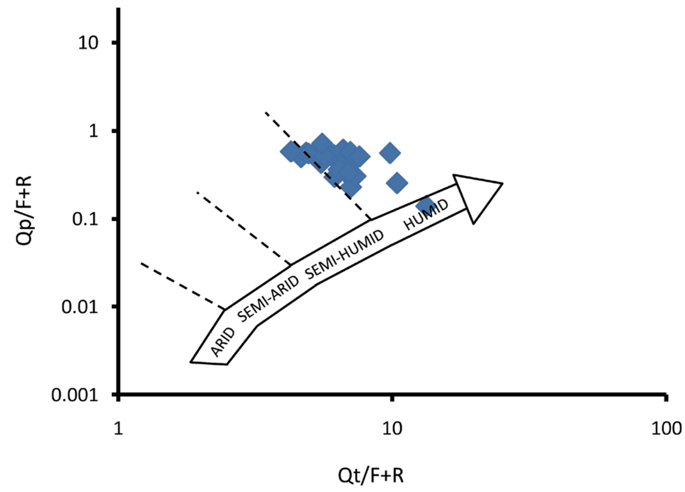


Fig. 5—Plotting of Dhosa sandstones in palaeoclimate discriminant diagram (according to Suttner & Datta, 1986).

supracrustals with minor sedimentary rocks exposed in a divergent tectonic setting.

It seems that the sandstones represent early stage of incipient rifting under tensional tectonic regime when the provenance started shedding detritus for the upcoming basins. The overall tectono–provenance envisaged for the studied rocks are craton interior with granite–gneisses, akin to rocks of Chota Udaipur Plateau with quartzose supracrustals from Aravalli Craton, were subjected to thermal doming and incipient rifting. This condition was in all probability precursor to rifting and drifting of South Africa–Madagascar–India at the end of Triassic and beginning of Jurassic. The little contribution of detritus from sedimentary source rocks may represent intra–basinal rocks, got exposed in response to synsedimentary basinal tectonics (Alberti *et al.*, 2013). As this basin was formed in response to rifting and drifting of Indian Plate from Africa-Madagascar, there is a possibility that earlier exposed sedimentary deposits started shedding sediments.

The average petrofacies recognized are $Qt_{90.5}F_{6.9}L_{2.6}$, $Qm_{86}F_{7}Lt_{7}$, $Qp_{74}Lv_{00}Ls_{26}$, $Qm_{92.5}P_{2.0}K_{5.5}$. Based on the petrofacies it is suggested that the provenance consist of collage comprising basement granitic–gneiss and meta–sedimentary supracrustals with minor sedimentary rocks exposed in a divergent tectonic setting.

PALAEOCLIMATE

There is an intimate relationship between climate and composition of sandstone (Suttner *et al.*, 1981; Franzinelli & Potter, 1983; Mack, 1984; Basu, 1985; Stewart, 1991). The changes in the parent rock composition of sandstone are in fact a result of weathering, specially chemical weathering, which breakdown as well as modifies the primary composition of rocks (Nesbitt & Young, 1982; Velbel & Saad, 1991).

In the hot and humid climate, chemical weathering actually obliterate the labile components of feldspars and lithics (Basu, 1981; James *et al.*, 1981; Suttner *et al.*, 1981; Girty, 1991).

Thin section of Dhosa Sandstone were studied to determine the ratio of total quartz to feldspar + rock fragments (Qt/F+R) and polycrystalline quartz to feldspar + rock fragments (Qp/F+R). They were plotted in the log–log graph palaeoclimate diagram given by Suttner and Datta (1986) which identifies four climates, viz. arid, semi–arid, semi–humid and humid.

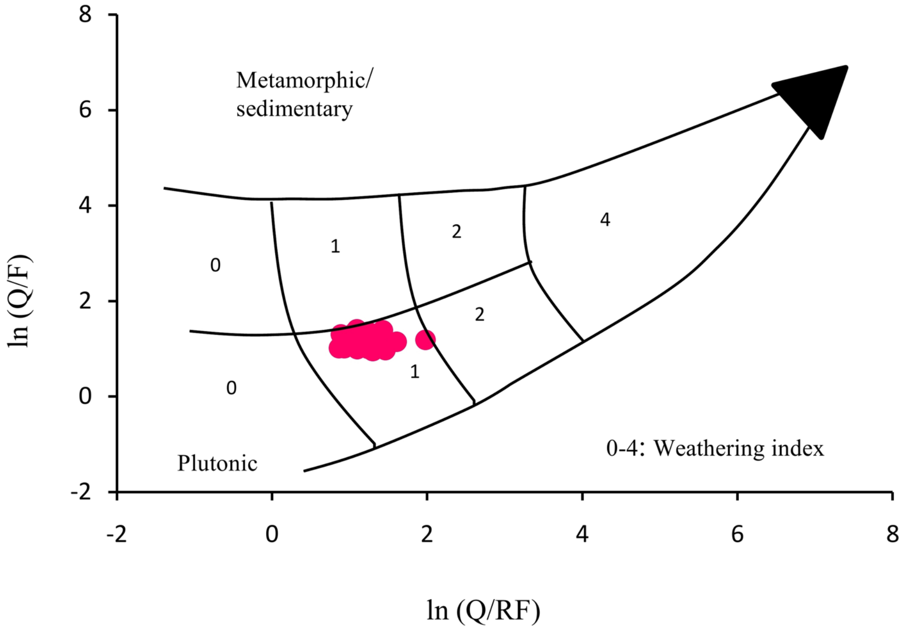
Plot of samples depict a humid to sub–humid palaeoclimate (Fig. 5). Evidences gathered by Thompson and Barron, 1981; Chatterjee and Hotton, 1986; Chandler *et al.*, 1992 for India, as a part of Gondwanaland during Jurassic and Lower Cretaceous, propose a humid to tropical climate.

The residence time of sediments depend largely on the relief conditions. A low relief usually lengthens the residence time of sediments thereby destroying the labile contents and increasing quartz percentage. Presence of hot and humid climate accelerates the process. On plotting the data points on Weltje *et al.*, (1998) diagram, it is seen that nearly all of them are plotted in field number 1 (Fig. 6) which suggests that the sedimentation took place in moderate relief and temperate–sub humid climate. The presence of moderate amount of potash feldspars, plagioclase and rock fragments suggest their survival in this climatic setup in moderate topography.

CONCLUSION

The sandstones of Late Callovian to Oxfordian age exposed in Ler Dome are mostly sub arkoses, deposited in transgressive phase. There are some carbonate deposits intercalated with sandstones and most of the sandstones have calcite cement suggesting good content of calcium carbonate in water. The sandstone petrofacies represent source rocks to be granite–gneiss with some meta–sedimentary supra crustals exposed in topographic highs of moderate relief under humid–temperate climate. The detritus were sequestered from a mix tectono–provenance comprising deep continental interior block and recycled orogen provenance since the plots are lying in between two fields, i.e. continental block and recycled orogen provenance. These tectono–provenance are identified as Chota Udaipur Plateau, a part of Aravalli Craton. The absence of volcanic lithics and texturally immature to submature nature of sandstones indicate short transportation with deposition below wave base in the basin which formed as incipient rifts in response to Gondwanaland fragmentation, at the north western part of the Indian subcontinent.

Acknowledgements—*The authors are greatly thankful to the Chairman, Department of Geology, Aligarh Muslim University, Aligarh for providing necessary facilities in the*



Semi-quantitative weathering index (W=c*r) (Weltje, 1994)		Relief (r) high, mountains 0	moderate, hills 1	low, plain 2
Climate(c) semi-arid mediterranean	0	0	0	0
temperate sub-humid	1	0	1	2
tropical humid	2	0	2	4

Fig. 6—Log–ratio plot after Weltje *et al.,* 1998. Q; quartz, F: feldspar, RF: rock fragments. Fields 1–4 represents semi–quantitative weathering. For the diagram, data point count of rock samples whose volume percent of F and RF is not zero were taken.

department. We also gratefully acknowledge the critical and constructive suggestions offered by two anonymous referees, who improved the original manuscript.

REFERENCES

Ahmad AHM & Bhat GM 2006. Petrofacies, provenance and diagenesis of the Dhosa Sandstone Member (Chari Formation) at Ler, Kachchh sub–basin, western India. Journal of Asian Earth Sciences 27: 857–872.

Akhtar K & Ahmad AHM 1991. Single–cycle cratonic quartzarenites produced by tropical weathering: the Nimar Sandstone (Lower Cretaceous), Narmada Basin, India. Sedimentary Geology 71: 23–32.

Alberti M, Fursich FT & Pandey DK 2013. Deciphering condensed sequences: A case study from Oxfordian (Upper Jurassic) Dhosa Oolite member of the Kachchh Basin, western India. Sedimentology 60: 574–598.

Bardhan S & Datta K 1987. Biostratigraphy of Jurassic Chari Formation: a study in Keera Dome, Kutch, Gujarat. Journal of Geological Society of India 30: 121–131.

Basu A 1981. Weathering before the advent of land plants: evidence from unaltered detrital K–feldspar in Cambrian–Ordovician arenites. Geology 9: 132–133.

Basu A 1985. Influence of climate and relief on composition of sand release at source areas. *In:* Zuffa GG (Editor)—Provenance of Arenites. Reidel, Dordrecht–Boston–Lancaster: 1–18.

Biswas SK 1977. Mesozoic rock stratigraphy of Kutch. Quarternary Journal of Geological Society of India 49: 1–52.

Biswas SK 1987. Regional tectonic framework, structure and evolution of the western marginal basins of India. Tectonophysics 135: 307–327.

Biswas SK 1991. Stratigraphy and sedimentary evolution of the Mesozoic basin of Kutch, western India. *In:* Tandon SK, Pant CC & Casshyap SM (Editors)—Stratigraphy and sedimentary evolution of western India, Gyanodaya Prakashan, Nainital: 74–103.

Chandler MA, Rind R & Ruedy R 1992. Pangaean climate during the Early Jurassic: GCM simulations and the sedimentary record of palaeoclimate. Geological Society of America Bulletin 104: 543–559.

Chatterjee S & Hotton N 1986. The paleoposition of India. Journal of Southeast Asian Earth Sciences 1: 145–189.

Cox R & Lowe DR1995. A conceptual review of regional–scale controls on the composition of clastic sediment and the co–evolution of continental blocks and their sedimentary cover. Journal of Sedimentary Research A65: 1–12.

Davis DK & Ethridge FC 1975. Sandstone composition and depositional environments: American association of Petroleum Geologist Bulletin 59: 234–264.

Dickinson WR 1970. Interpreting detrital modes of greywacke and arkose. Journal of Sedimentary Petrology 40: 695–707.

Dickinson WR 1985. Interpreting relations from detrital modes of sandstone. *In:* Zuffa GG (Editor)—Provenance of Arenites. Reidel, Dordrecht–Boston–Lancaster: 333–361.

Dickinson WR, Beard LS, Brakenridge GR, Erjavec JL, Ferguson RC, Inman KF, Knepp RA, Lindberg FA & Ryberg PT 1983. Provenance of north American Phanerozoic sandstones in relation to tectonic setting. Geological Society of American Bulletin 94: 222–235.

Dickinson WR & Rich EI 1972. Petrologic intervals and petrofacies in the Great Valley sequence, Sacramento Valley, California. Geological Society of America Bulletin 83: 3007–3024.

Dickinson WR & Suczek CA 1979. Plate tectonics and sandstone compositions. The American Association of Petroleum Geologists Bulletin 63: 2164–2182.

Espejo IS & Gamundi ORL 1994. Source versus Depositional Controls on Sandstone Composition in a Foreland Basin: The Imperial formation (Mid. Carboniferous–Lower Permian), San Rafael Basin, western Argentina. Journal of Sedimentary Research 64: 8–16.

Dubey N & Chatterjee BK 1997. Sandstones of Mesozoic Kachchh Basin: Their Provenance and Basinal Evolution. Indian Journal of Petroleum Geology 6: 55–58.

Folk RL 1980. Petrology of Sedimentary Rocks. Hemphill, Austin, Texas: 182.

Franzinelli E & Potter PE 1983. Petrology, chemistry and texture of modern river sands, Amazon River system. Journal of Geology 91: 23–39.

Fursich FT, Oschmann W, Jaitly AK & Singh IB 1991. Faunal response to transgressive–regressive cycles: examples from the Jurassic of western India. Palaeogeography Palaeoclimatology Palaeoecology 85: 149–159.

Fursich FT, Oschmann W, Singh IB & Jaitly AK 1992. Hardgrounds, reworked concretion levels and condensed horizons in the Jurassic of western India: their significance for basin analysis. Journal of the Geological Society of London 149: 313–331.

Fursich FT, Pandey DK, Callomon JH, Jaitly AK & Singh IB 2001. Marker beds in the Jurassic of the Kachchh Basin, western India: their depositional environment and sequence–stratigraphic significance. Journal of Palaeontological Society of India 46: 173–198.

Girty G 1991. A note on the composition on the plutonic clastic sand produced in different climatic belts. Journal of Sedimentary Petrology 61: 428–433.

Ingersoll RV, Bullard TF, Ford RL, Grimm JP, Pickle JD & Sares SW 1984. The effect of grain size on detrital modes: a test of the Gazzi–Dickinson point counting method. Journal of Sedimentary Petrology 54: 103–116.

Ingersoll RV & Suczek CA 1979. Petrology and provenance of Neogene sand from Nicobar and Bengal Fans, DSDP sites 211 and 218. Journal of Sedimentary Petrology 49: 1217–1218.

James W, Mack G & Suttner L 1981. Relative alteration of microcline and sodic plagioclase in semi arid and humid climates. Journal of Sedimentary Petrology 51: 151–164.

Mack GH 1984. Exception to the relationship between plate tectonics and sandstone composition. Journal of Sedimentary Petrology 54: 212–220.

Nesbitt HW & Young GM 1982. Early Proterozoic climates and plate motion inferred from major element chemistry of Lutites. Nature 299: 715–717.

Pandey DK, Fursich FT & Sha J 2009. Inter–basinal marker intervals–A case study from the Jurassic basins of Kachchh and Jaisalmer, western India. Science China Series D, Earth Sciences 52: 1924–1931.

Rajnath 1932. A contribution to the stratigraphy of Cutch. The Quarterly Journal of the Geological, Mining and Metallurgical Society of India 4: 161–174.

Singh CSP, Jaitly AK & Pandey DK 1982. First report of some Bajocian–Bathonian (Middle Jurassic) ammonoids and the age of the oldest sediments from Kachchh, western India. Newsletter on Stratigraphy 11: 37–40.

Singh IB 1989. Dhosa Oolite–a transgressive condensation Horizon of Oxfordian age in Kachchh, western India. Journal of Geological Society of India 34: 152–160.

Stewart AD 1991. Geochemistry, provenance and climate of the Upper Proterozoic Stoer Group in Scotland. Scottish Journal of Geology 27: 81–95.

Suttner LJ, Basu A & Mack GH 1981. Climate and the origin of quartz arenites: Journal of Sedimentary Petrology 51: 1235–1246.

Suttner LJ & Dutta PK 1986. Alluvial sandstones composition and palaeoclimate, I, framework mineralogy. Journal of Sedimentary Petrology 56: 329–345.

Thompson SL & Barron EJ 1981. Comparison of Cretaceous and present earth albedos: implications for the causes of palaeoclimates. The Journal of Geology 89: 143–168.

Trop JM & Ridgway KD 1997. Petrofacies and provenance of a Late Cretaceous suture zone thrust–top basin, Cantwell basin, central Alaska Range. Journal of Sedimentary Research 67: 469–485.

Uddin A & Lundberg N 1998. Cenozoic history of the Himalayan Bengal system, sand composition in the Bengal Basin, Bangladesh. Geological Society of America Bulletin 110: 497–511.

Velbel MA & Saad MK 1991. Paleoweathering or diagenesis as the principal modifier of sandstone framework composition? A case study from Triassic rift–valley redbeds of eastern North America. *In:* Morton AC, Todd SP & Haughton PDW (Editors)—Developments in Sedimentary Provenance Studies. Geological Society of London, Special Publication 57: 91–99.

Waagen W 1873–75. The Jurassic fauna of Kutch. Memoirs of the Geological Survey of India. Palaeontologia Indica series 9: 1–247.

Weltje GJ, Meijer XD & Doer PL 1998. Stratigraphic inversion of siliciclastic basin fills: A note on the distinction between supply signals resulting from tectonic and climate forcing. Basin Research 10: 129–153.