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RESEARCH ARTICLE

PETROGRAPHY AND MAJOR ELEMENT GEOCHEMISTRY OF HABO FORMATION SEDIMENTS, KACHCHH, WESTERN INDIA: CLUES FOR PROVENANCE

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ABSTRACT

The Habo Dome is one of the most important exposures of Bathonian to Kimmergian sediments among the Kachchh Mainland exposures. The study area is represented by sandstones, shale and limestone, the deposits of shallow marine to fluvio-deltaic environment that was strongly influenced by the fluctuation of relative sea level. Detrital mineralogy and major element chemistry of sandstones and shales of this Jurassic succession in the pericratonic Kachchh Basin have been used to investigate paleoweathering and tectono-provenance. The studied sandstones were derived from a predominantly felsic provenance comprising granites and granite-gneisses with noticeble proportions from basic rocks of the Aravalli range and Nagarparkar massif. The Petrofacies analysis reveals that these sandstones belong to the continental block, recycled orogen and rifted continental margin tectonic regime. The A-CN-K ternary plot and CIA, PIA, ICW and ICV indices suggest that the source rocks of these clastics suffered severe chemical weathering under humid climate. Tectonic setting discrimination diagrams based on major elements suggest a quartz rich igneous provenance in a passive continental margin. The petrography and geochemical interpretation duplicate each other and suggest humid climate and low relief highlands during Jurassic.

INTRODUCTION

The mineralogical and geochemical compositions of terrigenous sedimentary rocks are resultant of the cumulative interplay of several variables such as provenance, weathering conditions, transportation, diagenesis, climate and tectonism (Bhatia and Crook, 1986; Roser and Korsch, 1986; Cullers and Podkovyrov, 2000; Taylor and Mclennan, 1985; Mclennan and Taylor, 1991; Fedo *et al*., 1997; Cox *et al*., 1995; Nesbitt *et al*., 1996). Thus clastic petrochemistry can in turn may be effectively used to interpret source rocks, tectonic setting, paleoweathering condition and paleoclimate (Bhatia, 1983; Condie, 1993; Mclennan *et al*., 1993). The present work is the first account of petrographic characters, mineral composition and geochemistry of Middle to Upper Jurassic sediments of Habo Dome, Kachchh Basin. The main objectives of this study are to identify the source rock character and to evaluate the relative role of tectonics and climate in controlling the sediment composition.

Geological Setting

The Mesozoic rocks in the Kachchh Basin range from Middle Jurassic to Lower Cretaceous and are exposed extensively in the Kachchh Mainland, Wagad, the Islands of Pachchham, Bela and Khadir and Chorar (Fig 1). The basin formed due to rifting and counter clockwise rotation of the Indian plate during the late Triassic/early Jurassic period (Biswas, 1987).

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This Mesozoic succession developed due to repeated marine incursions during the Middle Jurassic to Early Cretaceous time and followed by major tectonic movements and Deccan flood volcanism during Late Cretaceous. The Mainland outcrops records a continuous succession from Bajocian to Albian and exposed in the form of a prominent ridge extending for about 193 Km from Jawahar Nagar in the East to Jara in the West. Middle Jurassic sediments of the Kachchh Basin are predominantly siliciclastic in nature comprising conglomerates, sandstones and silty clays. Carbonates and mixed- carbonates–siliciclastic rocks in the Kachchh Basin are largely confined to the Bajocian and Early Callovian ages and represent storm dominated shallow shelf environments (Fursich *et al*., 1991). Ahmad and Majid (2010) suggested that the Habo Formation was deposited in shallow marine to fluvio-deltaic environment which was strongly influenced by fluctuation in relative sea level. These fluctuations resulted in various types of key stratigraphic surfaces, mainly transgressive and regressive.

METHODOLOGY

The study is based on measurement of stratigraphic sections and collection of representative sandstone samples (Fig 2). Out of collected samples, sixty sandstone samples were cut into thin sections for petrographic study .Framework grains varying from 200-250 per thin sections were counted. Classification and tabulation of grain type was done following the traditional methods (Ingersoll *et al*., 1984). In order to reconstruct the original detrital composition of the sandstones, the effects of the diagenesis were taken into consideration as far as possible during the counting. For petrofacies analysis the detrital modes were recalculated to 100 % by summing of Qt, Qm, Qp, F, P, K, L, Lt, Lv, Ls framework constituents following Dickinson (1985). Kanjilal (1978) classified Habo Formation in to Five Members on the basis of the lithological variations (Table 1). Thirty samples of sandstones/shales were chosen for geochemical analysis. The samples were analyzed for their major elements by XRF at NIO, Goa. First we chipped the samples and then powdered them in pulverizer into 200 mesh size. Ultimately sample was taken after quatering and coning process. Pressed discs made from a 2:3 ratio mixtures of powdered sample and binder were analyzed by XRF. Major elements data of the studied sandstones and shales are given in Table 2.

Petrography

The studied sandstones of Habo Formation are soft, friable, hard to compact, massive, current bedded and cemented with carbonate and ferruginous cement. Common sedimentary structures include large scale planar and trough cross-bedding. Ripple marks occasionally occur in these sandstone. The sandstones is fine, medium to coarse grained and moderately well sorted. The detrital grains are subangular to subrounded and of low to medium sphericity. The sandstones are generally characterized as quartzarenites and subarkose. The average composition of these sandstones is Q=93 %, F=5% and L=2%.The petrographic characters of the sandstones are also attested by its geochemical classification diagrams (Pettijohn

Table 1. Middle Jurassic stratigraphic succession of Habo Hill

Formation	Member	Lithology	Age
		Gypsiferous shale and sandstone	Middle Kimmeridgian
		Disconformity	
	Lodai	Alternating beds of Limestone and shale (limestone yellowish to light brown; shale grayish green to yellowish)	Oxfordian
Habo	Rudramata	Yellowish shale overlain by ferruginous sandstone	
	Jhikadi	Ferruginous and calcareous sandstone with beds of shale and discontinuous conglomerate and coral bed on top sandstone exhibits cross-bedding and ripple marks	Callovian
	Dharang	Yellowish to grayish yellow limestone and yellowish shale	
	Black limestone	Black to greenish grey limestone	Bathonian
		Base not exposed	

Table 2: Major Chemical Analysis of Habo Dome Formation Sediments

Sample number	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5
D 29	75.90	0.68	10.08	7.24	0.89	0.01	1.73	0.62	2.81	0.05
D 25	58.98	0.32	2.79	1.70	0.29	0.11	34.77	0.21	0.76	0.08
D 13	61.92	1.29	21.80	8.54	1.86	0.04	1.68	0.32	2.38	0.16
D 12	61.95	1.29	21.86	8.51	1.84	0.04	1.69	0.30	2.36	0.17
D 11	59.78	1.04	17.99	9.49	1.78	0.09	7.00	0.40	1.96	0.46
D 6	67.19	0.31	4.01	1.49	0.37	0.13	24.87	0.40	1.16	0.06
D 8	59.05	0.29	2.86	4.10	0.62	0.11	31.39	0.18	0.47	0.94
D 20	90.63	0.71	5.29	1.24	0.19	0.01	0.27	0.10	1.52	0.04
R 6	61.55	1.44	27.29	6.17	0.80	0.01	0.24	0.22	2.07	0.21
R 5	63.70	1.44	26.06	5.12	0.84	0.04	0.28	0.20	2.14	0.17
R 4	62.72	1.48	27.48	4.34	0.97	0.02	0.23	0.50	2.12	0.13
R 3	62.39	1.52	28.64	3.87	0.81	0.01	0.20	0.33	2.07	0.16
R 2	62.64	1.53	29.11	2.89	0.89	0.01	0.20	0.49	2.07	0.17
R 1	60.41	1.47	27.44	7.13	0.85	0.03	0.19	0.29	2.02	0.16
L 3	84.60	0.07	1.00	1.38	0.14	0.01	12.40	0.01	0.36	0.04
L 1	78.14	0.30	2.68	0.54	0.31	0.00	17.27	0.06	0.65	0.04
L 5	73.47	1.18	20.11	2.11	0.58	0.01	0.20	0.22	2.04	0.07
L 4	41.82	0.65	14.35	0.77	0.95	0.00	40.04	0.09	1.27	0.06
L 8	79.44	0.75	13.21	3.30	0.23	0.02	0.18	0.13	2.68	0.06
L 6	73.96	1.29	20.15	1.16	0.59	0.01	0.24	0.16	2.38	0.06
J 14 A	73.73	0.60	9.03	6.77	0.88	0.02	5.86	0.48	2.57	0.06
J 14	73.57	0.65	8.02	7.57	0.81	0.02	6.69	0.42	2.19	0.05
J 12	69.90	0.66	6.01	3.26	0.43	0.05	16.79	0.41	2.45	0.05
J 10	69.96	0.81	9.86	8.15	0.98	0.03	7.46	0.54	2.14	0.07
J 8	75.41	0.96	10.38	8.84	0.97	0.02	0.41	0.57	2.39	0.05
J 7	78.62	0.90	5.35	4.49	0.40	0.02	7.71	0.42	2.05	0.04
J 1	37.86	0.23	4.07	3.02	0.58	0.09	51.70	0.35	1.64	0.45
J 1.1.1	66.54	0.44	7.09	8.59	0.83	0.05	13.19	0.49	2.71	0.06

Table 3.Percentages of framework modes of the sandstones of Habo Dome Formation, Kachchh, Gujarat, (Based on classification of Dickinson, 1985)

	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
Dharang Member												
Range	90-99	0-8	0-5	82-97	0-8	0-12	0-100	0	0-50	94-97	0-4	0-6
Average	94	4	2	90	4	6	73	0	27	95	2	3
Jhikadi Member												
Range	88-96	2-10	0-5	82-93	2-10	2-11	0-100	0	0	73-96	1-4	2-10
Average	92	6	2	87	6	7	100	0	0	92	2	6

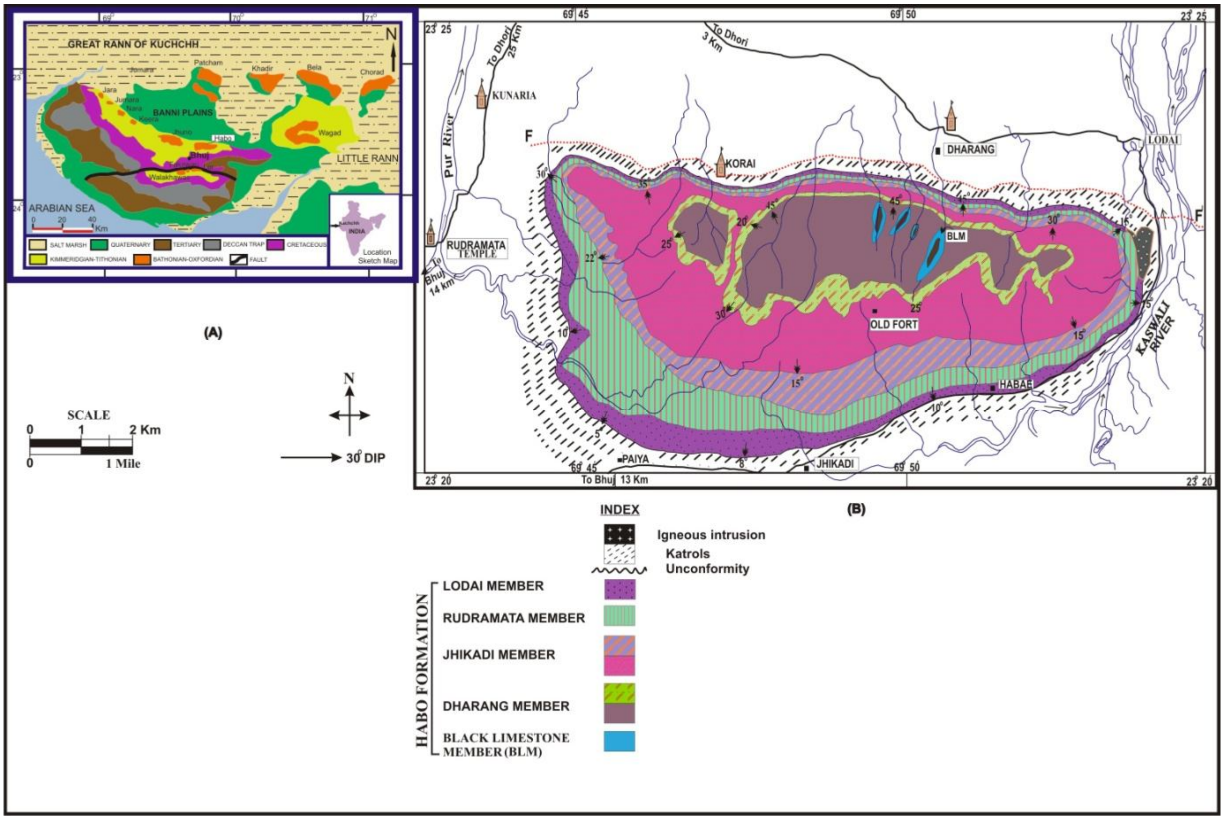


Figure 1. (A) Geological map of Kachchh basin. (B) Geological map of Habo Dome.

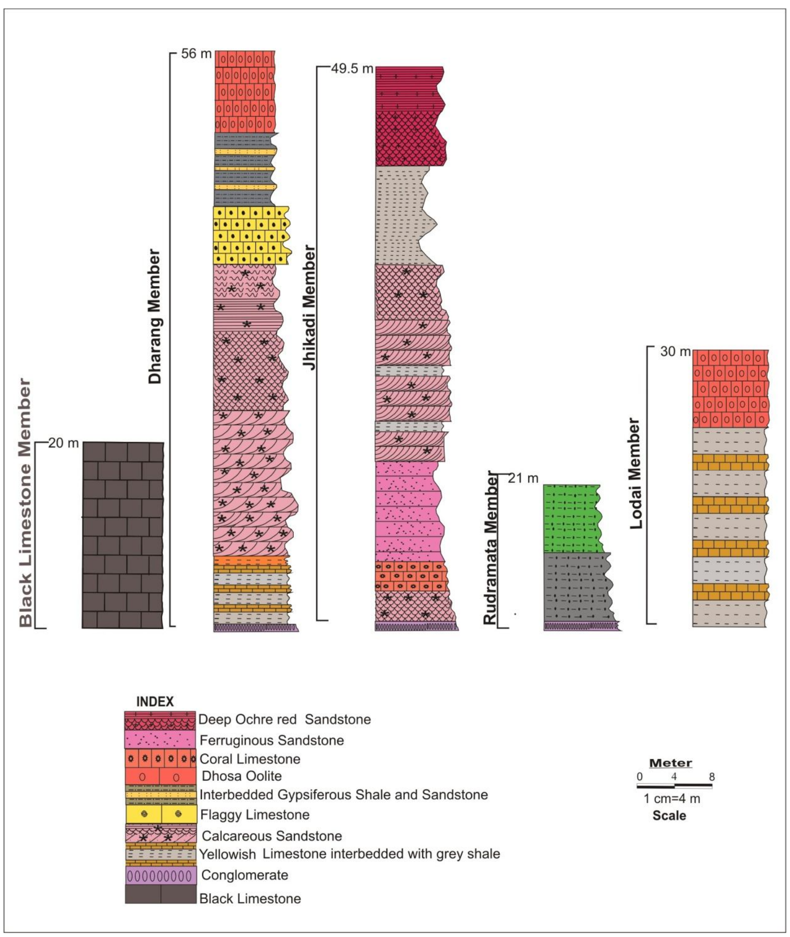


Figure 2. Measured sections from Habo Dome.

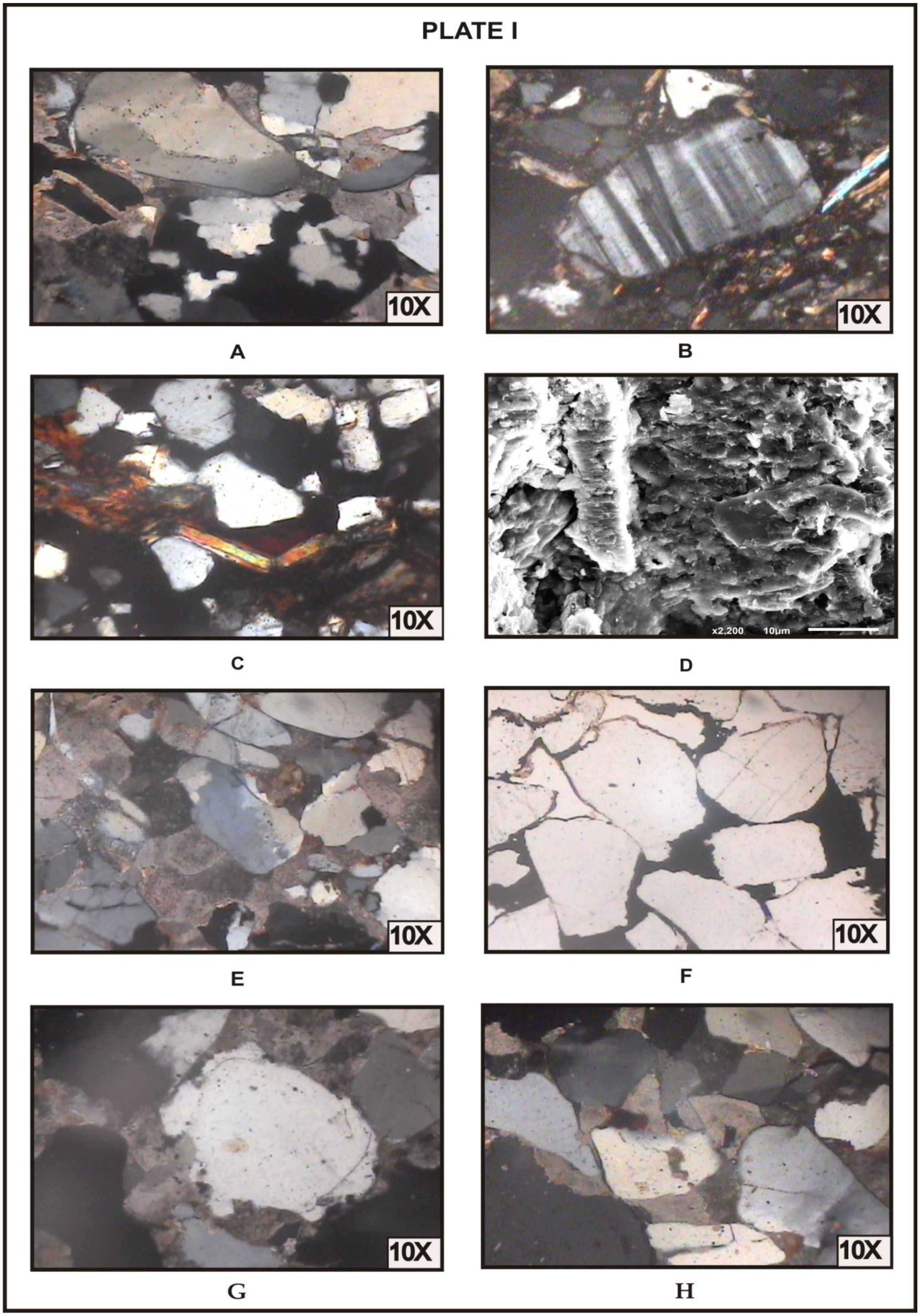
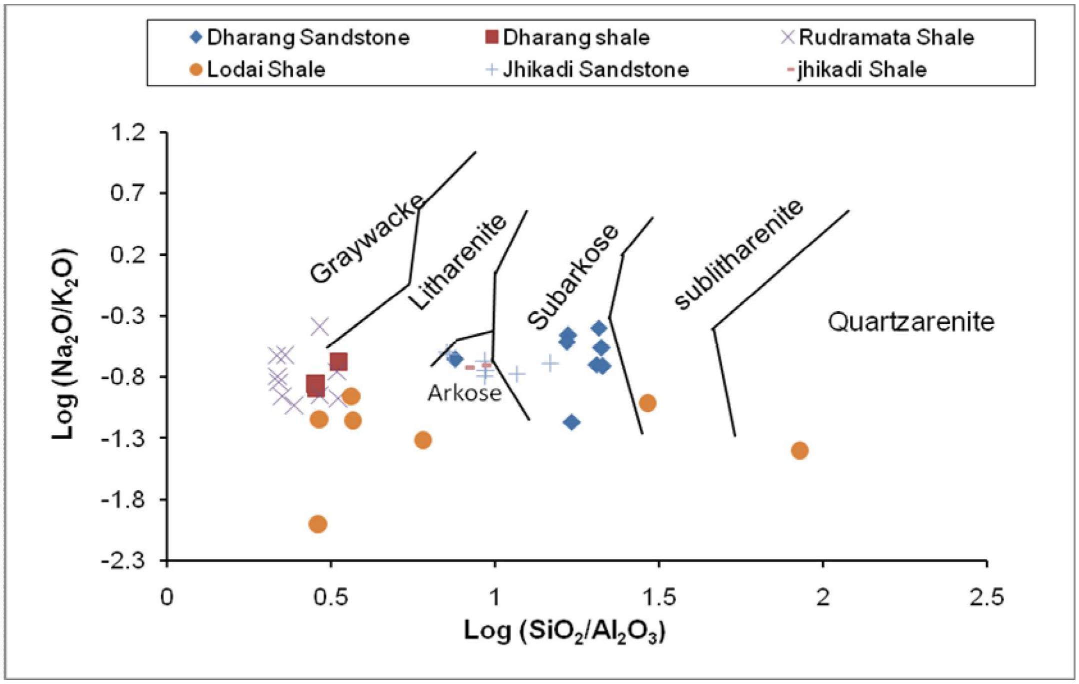
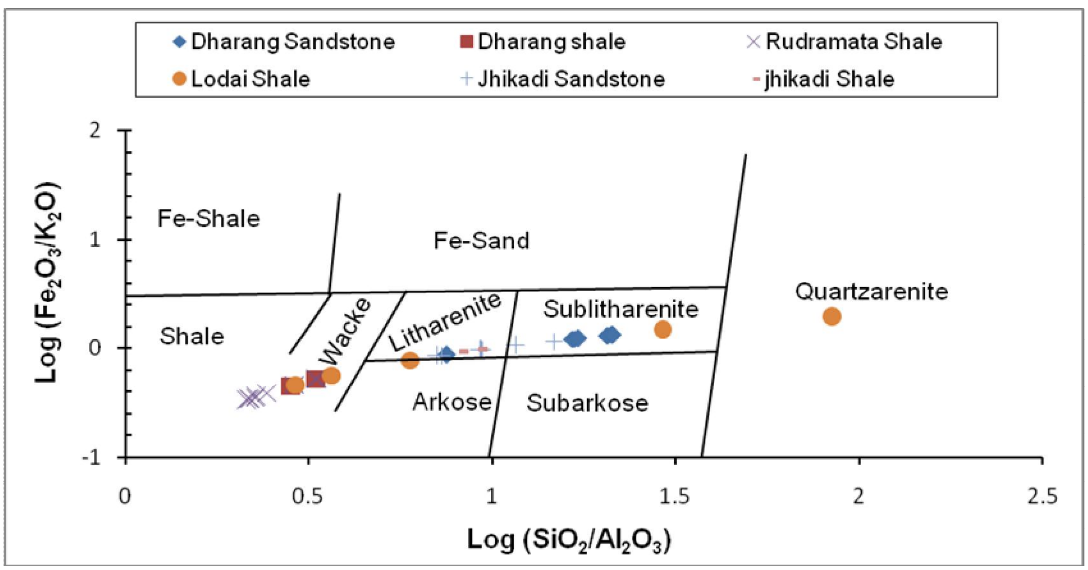


Plate 1. Photomicrograph showing polycrystalline quartz grains, B- Plagioclase grain C-Mica flake showing bending, D- Kaolinite, E- Carbonate cement, F-Iron cement, G- Silica overgrowth, H- grains showing loose packing.



(A)



(B)

Figure 3. (A, B). Chemical classification of samples Habo Formation based on (a) log SiO_2/ Al_2O_3) vs. log (Na_2O/K_2O) diagram of Pettijohn et al. (1972) and (b) the log (SiO_2/Al_2O_3) vs. log (Fe_2O_3/K_2O) diagram of Herron (1988).

et al., 1972; Herron, 1988) and the studied samples occupy litharenite, subarkose, greywacke, arkose and quartzarenite fields (Fig 3A,B). These sandstones consist of various types of quartz including detrital quartz, recrystallized metamorphic quartz and stretched metamorphic quartz (Plate I A). The total quartz mode which comprise about 93%of the sandstone composition, is itself constituted by of 94% monocrystalline and 6% polycrystalline quartz. K-feldspar is generally common in the studied sandstones and occurs in different stages of alteration, but plagioclase occurs in small amount (Plate IB). Muscovite occurs as tiny as well as large flakes (Plate IC). Chert grains are represented by clear, cloudy and altered varities. Lithic fragments include shale, glauconite, carbonate and metamorphic rock fragments. Alteration of K-feldspar and occurrence of epimatrix and Kaolinite cement (Plate ID) are consistent with temperature and humid climatic setting of Jurassic period. Three varieties of opaques viz. limonite, goethite and magnetite are recorded. These opaque grains are subangular to subrounded. Pink and light pink varieties of garnet are more dominant than colorless varities. Garnet is identified by its isotropic nature but some grains do not show complete isotropism due to inclusion of opaque and zircon minerals. The greenish yellow variety of tourmaline is dominant while green and pink varieties are rare. Pleochroism is an important and most distinguishing feature of tourmaline. Zircon grains are colorless and brown in ordinary light and generally exhibit euhedral crystal outline. They are identified by their high refractive index, straight extinction and high order of polarization color. Rutile occurs as elongated, subrounded grains having deep red and orange colour, dark boundaries, very high refractive index and weak pleochroism. The grains of staurolite are identified by their characteristic color, pleochroism and straight extinction. Epidote grains are pale green in color, weakly pleochroic and subrounded in shape. The grains of biotite are prismatic or subrounded with irregular outlines. Pale brown variety of biotite is common. The Habo Dome Sandstone exhibit carbonate, iron oxide and silica cements (Plate I, E, F, G). The carbonate cement occurs in the form of sparry calcite and microcrystalline calcite cement. The iron oxide occurs as coating around detrital grains as well as in patches. In some thin sections characterized by Fe calcite cement, the corroded quartz grains exhibit calcite cement infilling. This evidence suggests the presence of syndepositional calcite cement, which was later replaced by Fe calcite cement during deep burial. Silica cement occurs in small amount as overgrowth around detrital grain boundaries. Generally the sandstones of the Habo Dome do not show any evidence of intergranular pressure solution. Apparently early carbonate cement may have acted as a buffer between the framework quartz grains and thereby eased grain to grain stress.

Sandstone Petrofacies

Clastic sediments are made up of two type of material; detrital grains which are residues of weathered parent rocks and fine grain sediments, which are composed of clay minerals from weathered unstable minerals. Chemical alteration and mechanical breakdown of source rocks, modification by recycling, transport, mixing, deposition, and diagenesis etc. control the compositional and textural characteristics of detrital grains. Naturally final properties of the sediments essentially bear signature of the parent lithology along with the entire process of modification that the sediment had gone through. Although, detrital modes of sandstones suites primarily reflect the different tectonic setting of provenance terrains, various sedimentological factors also influence sandstone composition, sometime strong relief, climate, transport mechanism, depositional environment and diagenetic changes all can be important secondary factors in determining the detrital composition of sandstones. Hence, it is necessary to synthesize and integrate all the above factors for the interpretations adduced from petrofacies study and in turn for logical identification of tectono provenance. To understand the tectonic setting of Habo Dome, the petrofacies were plotted on standard triangular diagrams: Qt-F-L, Qm-F-Lt and Qm-P-K given by Dickinson (1985) and Qp-Lv-Ls modified after Dickinson (1985) and Ingersoll and Suczek (1979) (Fig 4A,B,C,D). Plot of the recalculated values revealed that most of the samples of the Habo Dome Sandstone fall in the continental block provenance field in the Qt-F-L plot suggesting contribution from craton interior with basement uplift (Table 3).

The Qm-F-Lt plot shows that the samples fall in continental block provenance with little contributions from the recycled orogen provenance. The Qp-Lv-Ls plot, which is based on rock fragments population, reveals that the source lie in rifted continental margin, collision suture and fold thrust belt. In the Qm-P-K diagram, the data lie in the continental block provenance reflecting maturity of sediments and stability of source area.

Source Area Weathering

In the regions of higher temperature and moisture content, weathering is more intense causing destruction of feldspars and other labiles, thereby increasing the compositional maturity by enrichment of more stable quartz. A colder and more arid region may produce less mature sediments .The chemical weathering may be further enhanced due to biochemical reaction in highly vegetated area (Basu, 1981). Bivariant log/log plot of the ratio of polycrystalline quartz to feldspar plus rock fragments (Suttner and Dutta, 1986) has been used for interpreting the paleoclimate of Habo Dome Sandstone. This diagram indicates a humid climate for the region (Fig 5A). The paleoclimate simulations for Jurassic and Lower Cretaceous times show that India as a part of Gondwanaland experienced humid to tropical climate (Thompson and Barron, 1981; Chatterjee and Hotton, 1986; Chandler *et al*., 1992). The precipitation of huge carbonate during Jurassic is also supportive of the fact that the area was witnessing a warm climate similar to found in tropics. A combination of low relief, hot humid climate and ample vegetation can produce quartz rich detritus (Franzinelli and Potter, 1983). Low relief provides prolonged residence time of sediments, thereby increasing the duration of chemical weathering and thus enriching the sediments in stable quartz.

The mineralogical data plotted on Waltje *et al*. (1988) diagram and fall in the field number 1 which points to the sedimentation in a low relief and temperate sub-humid conditions (Fig 5B). The diagram of Suttner *et al*. (1981) (Fig 6), however indicates a metamorphic source rock in a humid climate. The Z-T-R index obtained from study ranges from 43 to 67 indicating low to moderate relief in the provenance (Mishra and Tiwari, 2005). Variation of ZTR index also manifests climatic changes in the source area (Tiwari and Yadav, 1993). The intense weathering in the humid climate causes the partial destruction of unstable species like hornblende, epidote, etc. while mainly stable ones like zircon, tourmaline, rutile are transported to the basin. In cold and arid climatic condition most of the unstable to semi unstable minerals are also derived. Thus, the study shows that the climate changed from relatively colder and arid to warmer and humid upwards in the stratigraphic column. The weathering history of sedimentary rocks can be obtained by calculation of Chemical Index of Alteration. [$CIA=Al_2O_3*100/(AL_2O_3+CaO*+Na_2O+K_2O)$] as proposed by Nesbitt and Young (1982) where CaO* corresponds to silicate fractions. Some samples contain higher abundance of CaO which may be due to the presence of calcite as cement. These samples have been excluded from the calculation of all the weathering indices.CIA values of the sandstones and shales of Habo Dome Formation are 53 to 90(average 78) significantly greater than PAAS 70, (Taylor and Mclennan 1985). The high value of CIA indicates that the source rocks underwent moderate to high weathering, possibly under warm and humid conditions. CIW (Chemical Index of Weathering) calculated by the formula [$Al_2O_3/(Al_2O_3+CaO*+Na_2O)*100$] has been considered a better measure of the intensity of chemical weathering over CIA (Condie, 1992) because CIA calculations involve K_2O which is a mobile oxide.

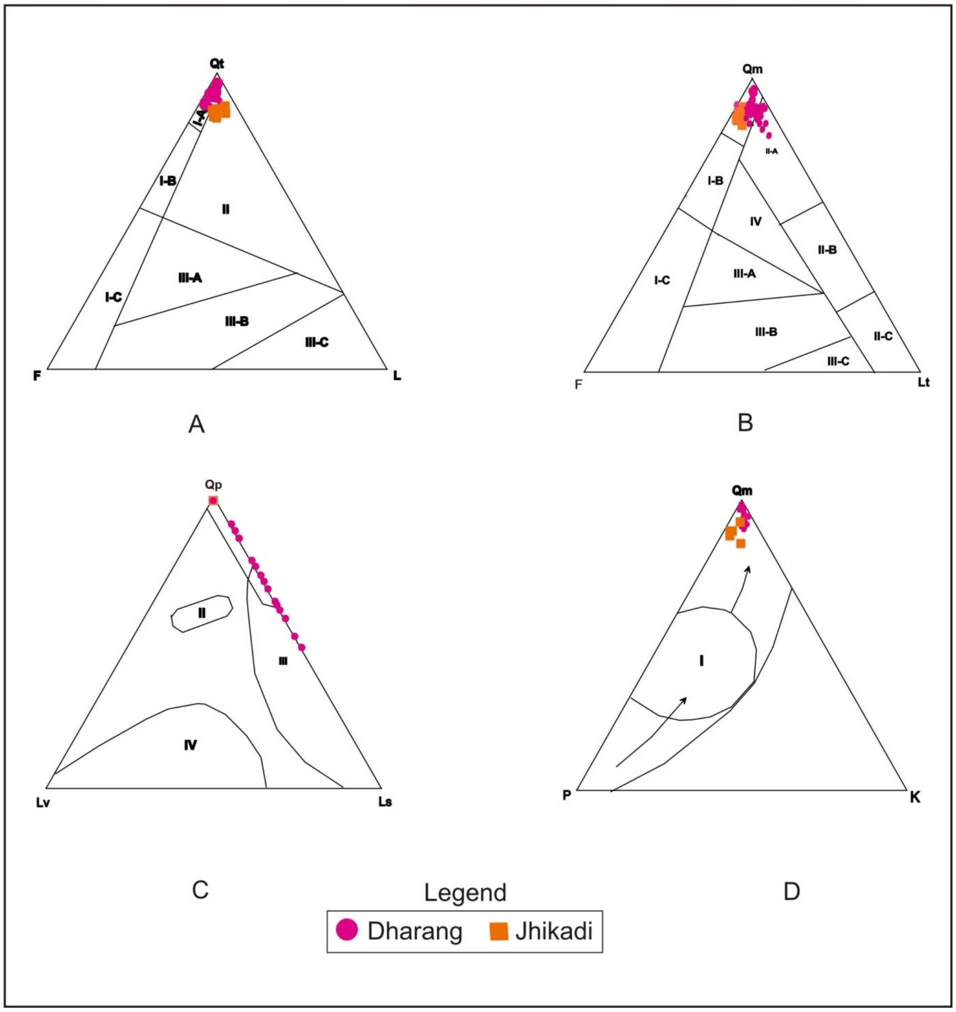
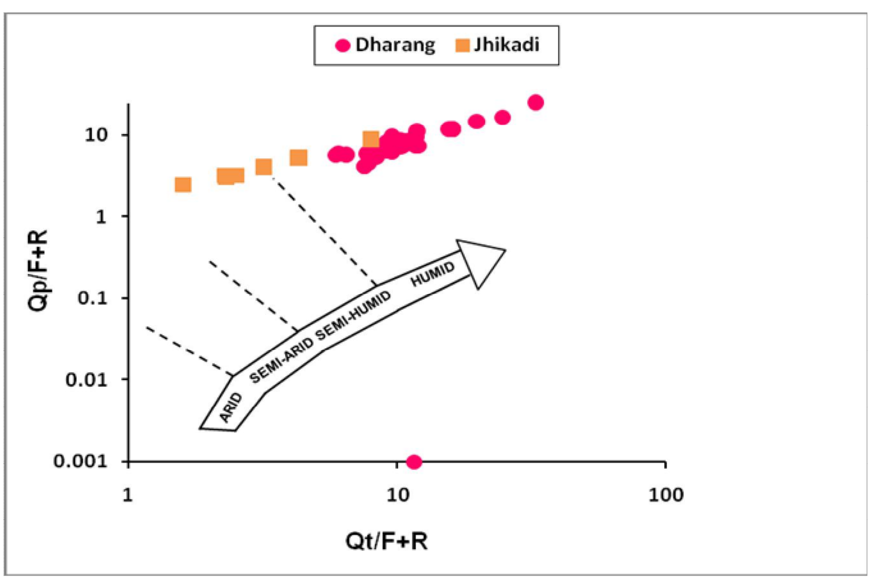
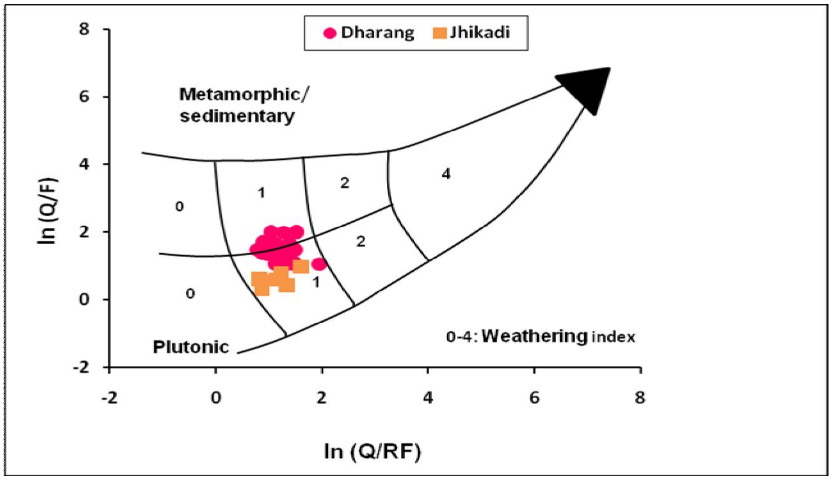


Figure 4 (A, B, C, D). Tectono-provenance discriminating diagrams (Dickinson, 1985) for Habo Dome Sandstone. The provenance field in A and B are continental Block (I): I-A: Craton Interior, I-B: Transitional Continent, I-C: Continent uplift, Recycled Orogen (II): II-A Quartzose, II-B: Transitional, II-C: Lithic Magmatic Arc (III): III-A: Dissected, III-B: Transitional III-C: Undissected and Mixed (IV). In C, I: Rifted continental margin, II: Subduction complex, III: Collision suture and fold thrust belt, IV: Arc Orogen D. Circumpacific volcano plutonic suites, the arrow indicates maturity and stability from continental block provenance.



(A)



(B)

Semi-quantitative Weathering index			Physiography (relief) High (mountains) 0	Moderate (hills) 1	Low (plains) 2
Climate (precipitation)	(semi) Arid and Mediterranian	0	0	0	0
	Temperate subhumid	1	0	1	2
	Tropical humid	2	0	2	4

Figure (5A, B). Bivariant log/log plot of the ratio of Qp/F+R against Qt/F+R of the sandstones of Habo Formation, according to Suttner and Dutta, 1986. Log ratio plot after Weltje et al. (1998).Q=Quarz, F=Feldspar, RF=Rock fragements. Fields 1-4 refer to the semi –quantitative weathering indices declined on the basis of relief and climate as indicated in the table (respectively).

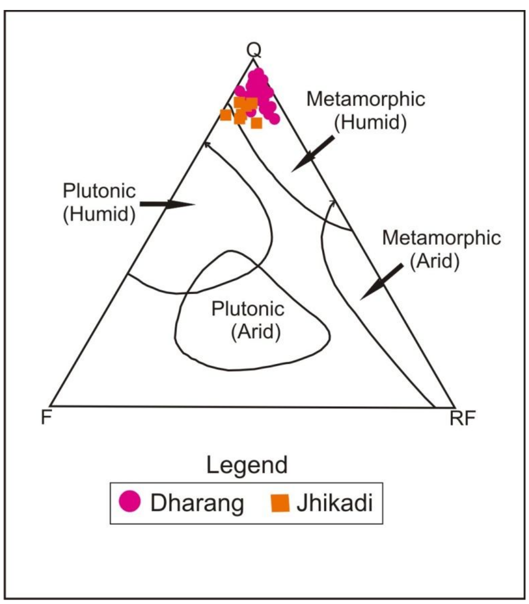


Figure 6. The effect of source rock on the composition of the Habo Dome sandstone.

This limits its applications to sediments in which potassium has been actually leached. The CIW index increases with the degree of depletion of Na and Ca in the sediments relative to Al. CIW values of Habo Dome clastics range from 57 to 97(average 87) which may be interpreted to show high weathering. The chemical weathering can also be indicated by PIA=(Plagioclase Index of Alteration). PIA = (Al_2O_3-K_2O)/(Al_2O_3+CaO*+Na_2O-K_2O)*100 as proposed by Fedo *et al*., (1995). The maximum PIA value is hundred for completely altered material. PIA value for studied sandstones and shale is highly variable and vary from 62 to 96 (average 85) suggesting moderate to intense plagioclase weathering in source area. The ternary A-CN-K plot (Nesbitt and Young, 1984) depicts the clustering of points near the A-K edge, along illite composition indicating high extents of weathering of the source rocks (Fig.7). The source rock composition can be determined by backward projection, parallel to A-CN line of the weathered sample to a point on the feldspar join. This indicates the provenance for the rocks of the Habo Dome Formation to be average granite. The samples of both types cluster at one point indicating their similar extents of chemical weathering with the similar provenance of granitic composition. Overall study suggests that such strong chemical weathering condition is in conformity with worldwide humid and warm climate during the Jurassic period (Thompson and Barron, 1981). This may be result of non-steady-state weathering conditions where active tectonism and uplift allow erosion of all soil horizons and rock surfaces (Nesbitt *et al*., 1997).

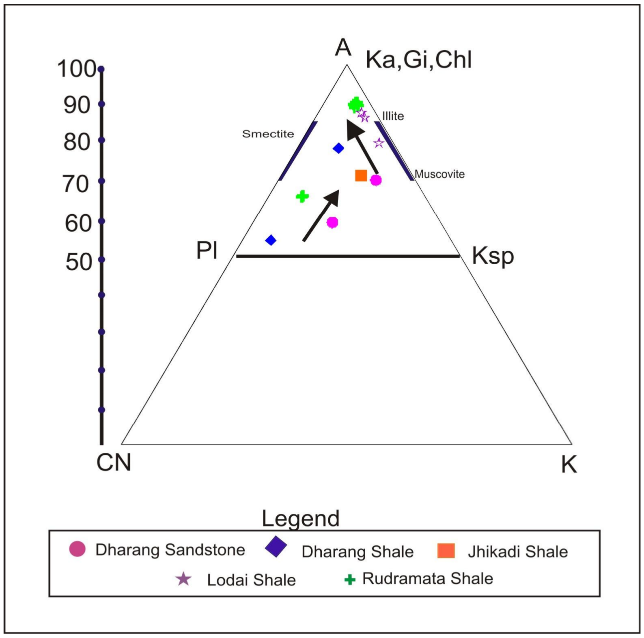


Figure 7. Al_2O_3-(CaO+Na_2O)-K_2O diagram for Habo Formation. Most of the samples plot around UCC and TTG suggesting a low to moderate weathering history for the provenance, Ka, Kaolinite; Gi, Gibbsite; Chl, chlorite; pl, plagioclase; ksp, k-feldspar.

Tectono Provenance

A high percentage of monocrystalline quartz grains, undulatory extinction and crypto-polycrystalline quartz grains are suggestive of metamorphic source rocks. The presence of strain free quartz suggest that their source is plutonic rocks (Basu, 1985). The low percentage of feldspar and rock fragments favors a cratonic source, mature transport regime and long , moderate to high chemical weathering in a humid climate (Chandler *et al.*, 1992). The studied sandstones are quartzarenitic and subarkosic in nature which suggests interplay of pulses of rapid uplift of the source area and quick subsidence of the basin, followed by a period of quiescence within an overall transgressive-regressive cycle in a rift tectonic regime . The first cycle quartz sand may have been supplied from a nearby quartz-rich source area. A unique combination of tropical climate, low relief, low rate of sedimentation and long residence on the beach is considered to produce mature, first cycle quartzarenite (Suttner *et al*., 1981). The studied sandstone composition suggests that during basin unstability, sediments supplied from the source area were quickly buried and more or less retained the original composition except for modification of unstable constituents (lithic fragments, feldspars etc) induced by chemical weathering, which has a greater capacity to alter sandstone composition (Basu 1976, James *et al*., 1981; Franzinelli and Potter, 1983; Suttner and Dutta,1986).

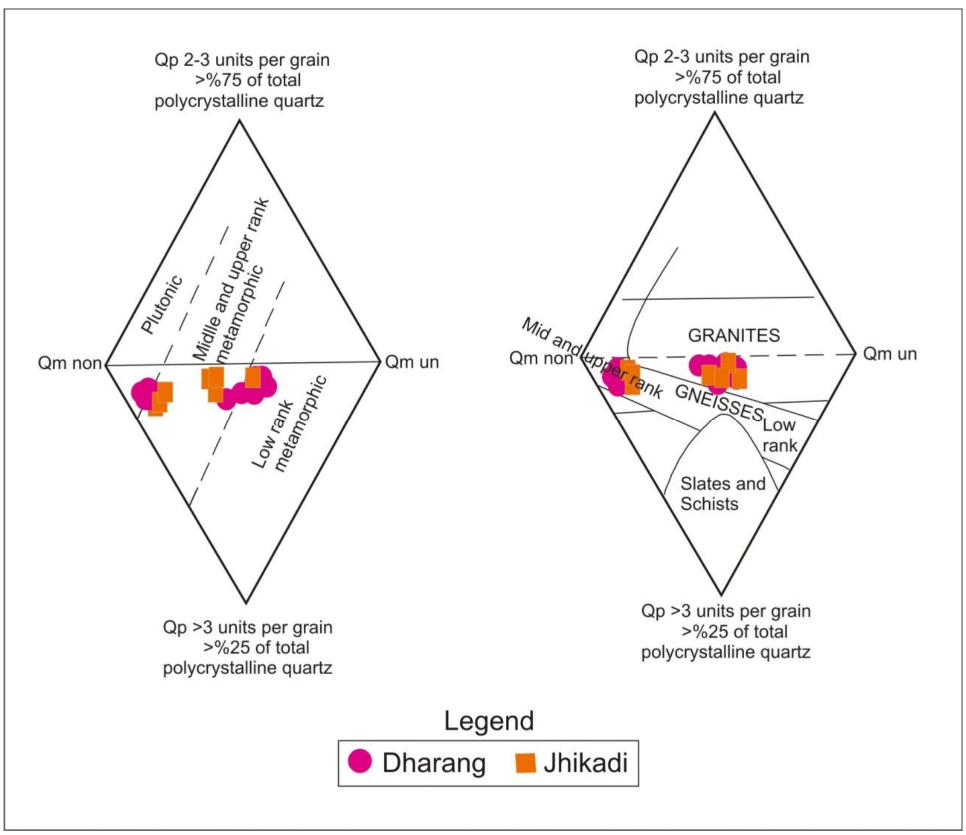


Figure 8.Varietal quartz diamond plot currently used to discriminate sands sourced by different types of crystalline rocks, on the basis of extinction pattern and polycrystalline of quartz grains. Qm non: low-undulosity monocrystalline quartz grains; Qm un = high undulosity monocrystalline quartz grains; Qp 2-3 = coarse-grained polycrystalline quartz grains; Qp >3=fine grained polycrystalline quartz grains. Habo Formation sandstone are compared with provenance fields after Tortosa et al., (1991) and Basu et al., (1975) (diagram b and a, respectively).

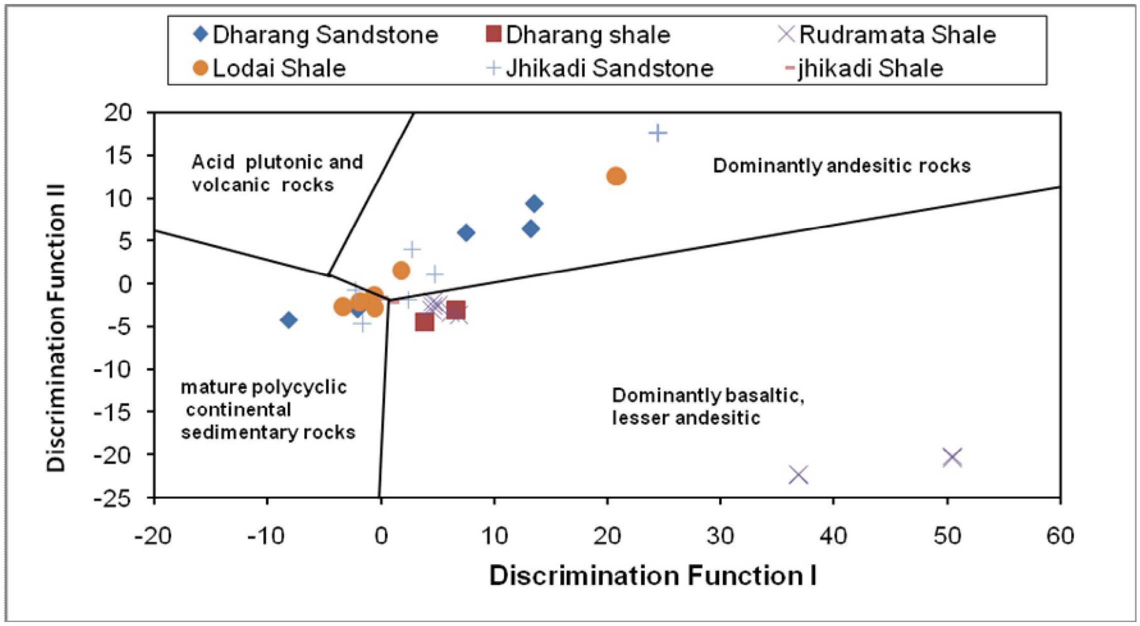


Figure 9. Discrimination Function analysis classification plot of Habo Formation (Roser and Korsch, 1988).

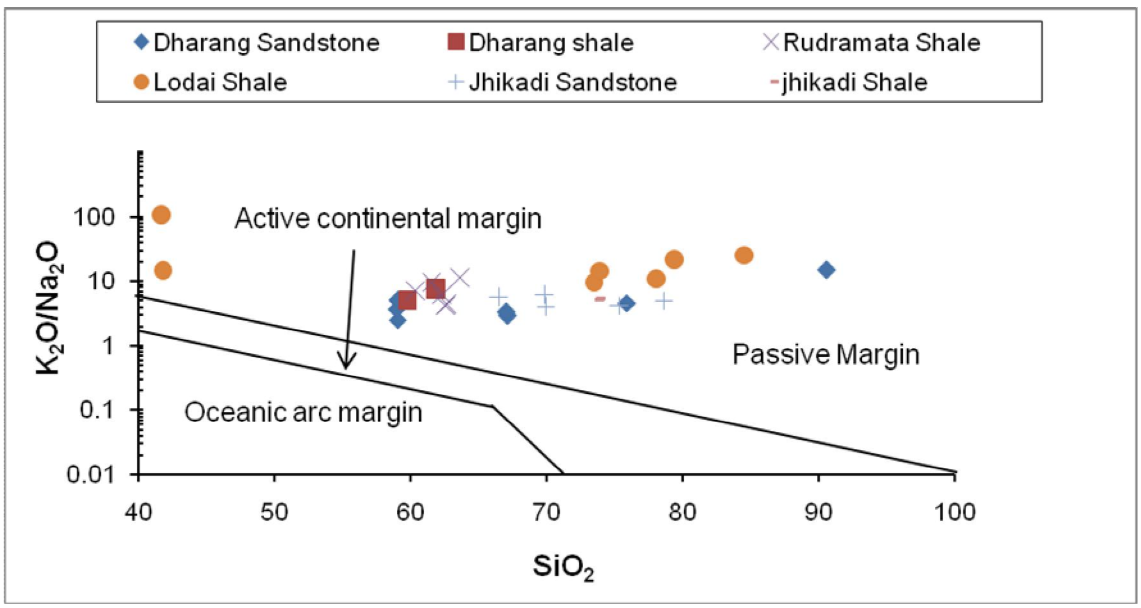


Figure 10. Tectonic discrimination diagram for Habo Formation (Roser and Korsch, 1986).

The sandstone petrofacies and heavy mineral suites of the Habo Dome Formation Sandstone indicate multiple rock sources for these sandstones, which are not reflected in the triangular plots. The apparent reason for this could be diagenetic alteration and weathering of unstable framework grains relative to the original detrital composition. To evaluate the relative importance of plutonic and metamorphic rocks as quartz sources. We plotted polycrystalline quartz versus non-undulatory and undulatory monocrystalline quartz in a double triangular diagram following the technique of Basu *et al.* (1975) and Tortosa *et al.* (1991). The data plot in the plutonic, middle to high to low rank metamorphic fields (Fig 8). This plots yields consistent results that indicate a source area containing plutonic, middle to high and low rank metamorphic rocks, which represents the exposed roots of magmatic arcs or older crystalline basement in the area (Dickinson and Suczek, 1979). The above observations suggest that the sandstones of Habo Dome Formation derived from a variety of source rocks. The most likely regions of these source rocks may be eroded and weathered parts of the Aravalli range situated in the east and north east of the basin and Nagarparkar Massif lying to the north and northwest. Dubey and Chatterjee, (1997) also proposed similar sources for the Jurassic sandstones of Kachchh Basin. Analysis of major elements was used to discriminate the tectonic setting of sandstones studied by Schwab (1975), Bhatia (1983), Roser and Korsch (1986, 1988) and Armstrong-Altrin *et al*. (2004) suggested the use of discriminate function diagram to understand the provenance for the feldspathic terrain. This diagram suggests that the sediments were derived from a mixed provenance (Fig 9).

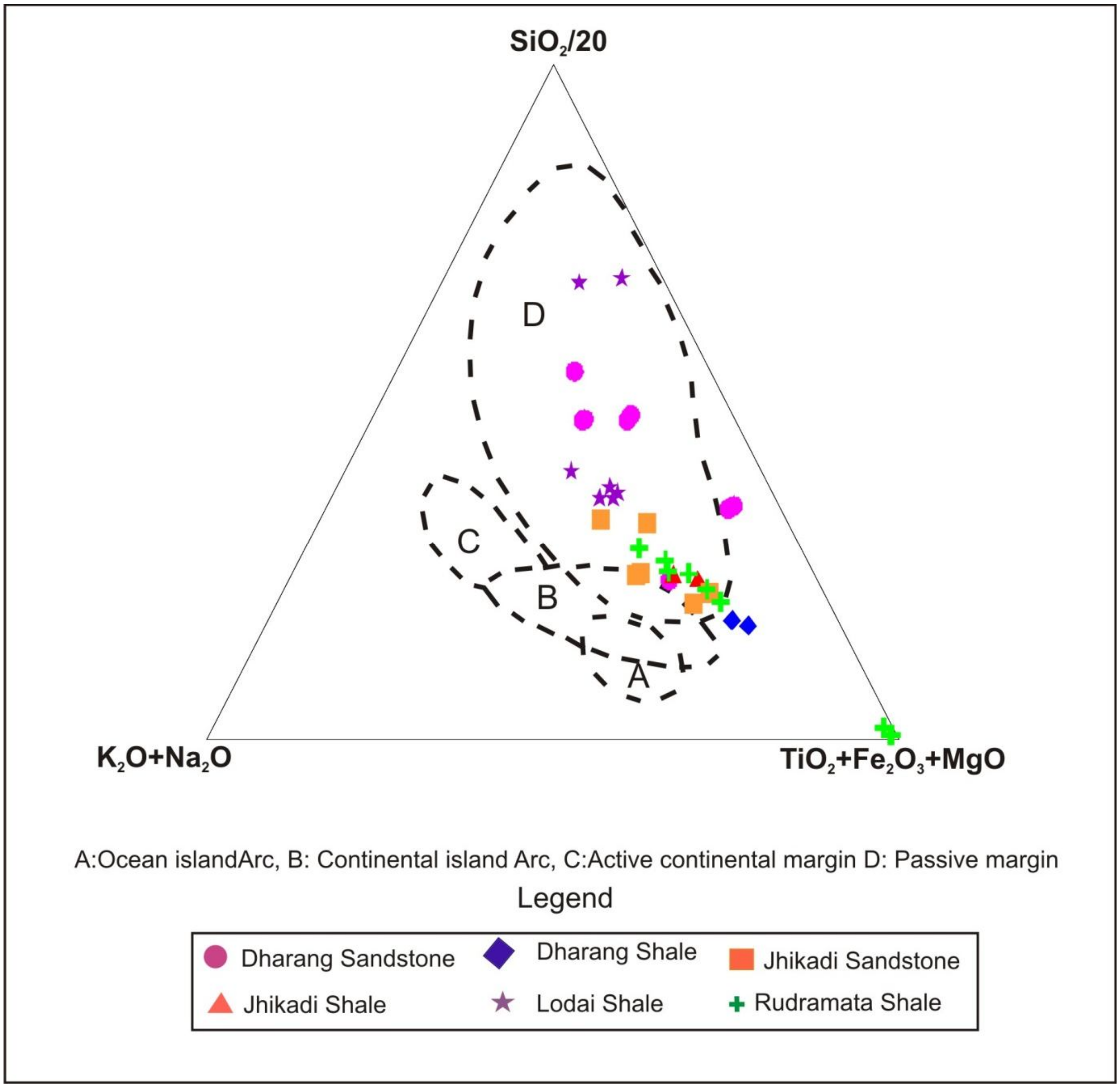


Figure 11. Plot of major element composition of the Habo Formation on the tectonic setting discrimination diagram of Kroonberg (1994).

Samples plot in SiO_2-K_2O/Na_2O diagram (Fig 10) of Roser and Korsch (1986) suggests that the sandstones and shale samples fall in the field of passive tectonic margin. The ternary plot of Kroonenberg (Fig. 11) also favors a passive margin setting. The petrographic and geochemical data collectively suggest that the Habo Dome Formation sediments deposited in a passive margin of stable pericratonic basin. Another method to measure the maturity of rocks and to assess the original composition of sandstone and their relation to tectonic setting is to employ index of compositional variability of by Cox *et al*. (1995). The studied sandstone /shale with ICV >1 are compositionally immature as they possess along with the first cycle sediments deposited in tectonically active settings.

RESULTS AND DISCUSSION

The Habo Dome sediments were derived from a variety of source rocks comprising granitic batholiths/ igneous plutons, magmatic arc granite-gneisses, pegmatite or schist metaquartzite and quartz vein etc. The plots of Habo Dome sandstones on Qt-F-L and Qm-F-Lt diagram suggest that the detritus of the sandstones were derived from the granite-gneisses exhumed in the craton interior and low to high metamorphosed supracrustal forming recycled orogen provenance. The source in rifted continental margin, collision suture and fold thrust belt reflecting maturity of sediments and stability of source area. The petrography and petro chemistry of the studied sediments indicates generation of sediments under humid climate by high degree of chemical weathering. The study further suggests that Habo Dome Sediments are compositionally immature as they possess along with the first cycle sediments deposited in tectonically active settings.

Conclusion

- Major framework mineral modes of the sandstones indicate a predominantly continental block provenance and stable cratonic to fault bounded basement uplift tectonic setting. Relative proportion of various quartz types suggests plutonic source rocks (granites and granitic gneisses for the Habo Dome Formation Sandstone).

- The CIA, ICV and A-CN-K plot imply that the source rocks were subjected to moderate to intense chemical weathering of the rocks.
- Plots involving major oxides in general advocates for passive tectonic setting.
- Integrated analysis of petrographic and geochemical characteristics coupled with paleocurrent direction of Jurassic sandstone of Kachchh Basin suggests that sand detritus was mostly derived from Aravalli range situated north east, east and south east of the basin and Nagar Parkar massif situated north and north west of the basin.

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