Tectonics and Geodynamics of a Narrow Continental Rift: Barmer Basin, Rajasthan, India

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Abstract

The Barmer petroliferous basin in W Rajasthan (India) is ~ 50 km wide and ~ 200 km long trending NNW. The Barmer basin experienced a two-phase (NW–SE followed by NE–SW) extension during Early Cretaceous and Late Cretaceous-Paleocene times. It consists of fluvial to shallow marine sediments deposited between Jurassic to Miocene, with some distinct hiatus in between. Late Proterozoic Malani igneous suite/Malani rhyolite is the basement rock. The western margin rift shoulder consists of Malani basement isostatic flexural uplifts, while the eastern margin comprises thick sedimentary cover and is fault-bound. The objective is to understand the rift kinematics, structural inheritance and the type of deformation from field based studies. We carried out structural field studies along the rift margins that helped in deciphering the two-phase (NW–SE followed by NE–SW) extension through brittle shear tectonics. Cross-cutting relation among the NW and NE fault planes connotes the relative timing of the two extension phases. Other key observations from field studies are (1) presence of mega-scale transfer zones along the N margin of the basin, (2) NW trending rift faults inherited the pre-existing structures, (3) variation in strike and cross-cutting nature of fault planes in eastern and western rift margins. Paleostress analysis further interprets the stress regime and relative timing of the tectonic events. Thus, the analysis helps in deciphering the rift evolution and the type of extensions related to tectonic inheritance.

Keywords

Rift basin • Brittle shear • Tectonics • Structural inheritance • Paleostress

1 Introduction

The Barmer rift basin is a major hydrocarbon producing basin in Rajasthan, western India. Three sedimentary basins—Jaisalmer, Barmer and Bikaner-Nagaur—crop out in western Rajasthan (Biswas et al., 2022; Bladon et al., 2015; Dasgupta & Mukherjee, 2017), India. The former two basins consist of thick Mesozoic and Tertiary sediments. The Barmer failed narrow-rift basin is ~ 200 km long along the NNW and is ~50 km wide (Bladon et al., 2015; Dasgupta & Mukherjee, 2017). It is separated from the Jaisalmer basin at north by the NE trending Devikot-Fatehgarh structural high.

The entire area of western Rajasthan is covered by the Thar Desert with few outcrops. Google Earth Pro satellite images were used to identify the exposures in and around the Barmer basin (Dasgupta & Mukherjee, 2017, 2019). The field-based structural study was done along the Barmer rift margins (see Fig. 1, L1–L7) to understand: (1) fracture trends and type of movements, (2) the effect of structural inheritance and (3) relative timing of the rifting events from paleostress analyses.

2 Tectonic and Geological Settings

The Barmer intracontinental rift basin developed over Late Proterozoic basement rock—Malani igneous suite/rhyolites (MIS) (Biswas et al., 2022; Dasgupta & Mukherjee, 2017). The basin experienced two distinct phases of extension, i.e. NW–SE followed by NE–SW (Bladon et al., 2015; Dasgupta & Mukherjee, 2017).

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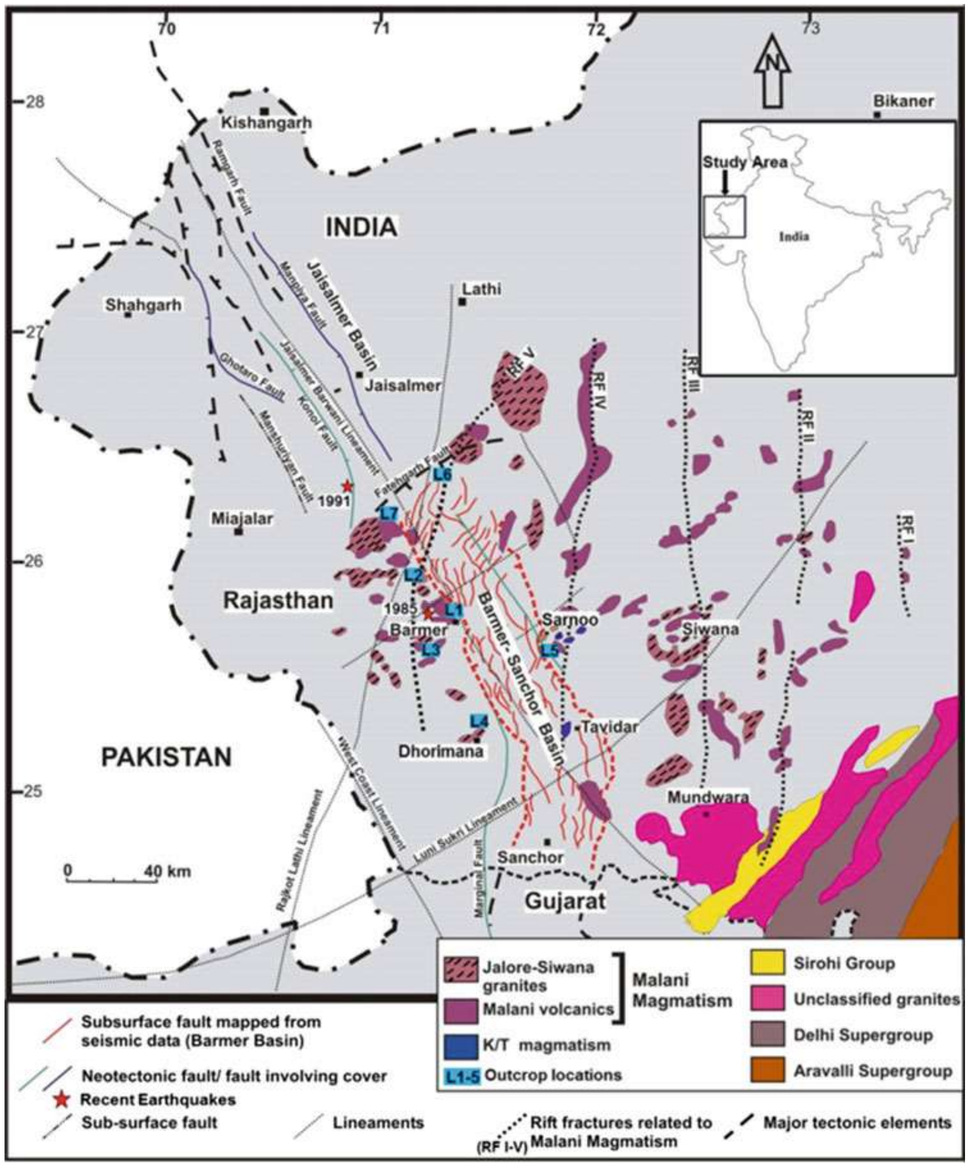

Fig. 1 Tectonic map of western Rajasthan showing Barmer basin with different fault trends and field outcrop locations (L1–L7)

The rift geometry is deciphered from the Bouguer gravity anomaly and seismic (2D and 3D) data-driven maps (Bladon et al., 2015; Dasgupta & Mukherjee, 2017). The basin deepens towards S and SE. The sedimentation in the Barmer rift was discontinuous resulting in distinct hiatuses during Mid-Late Jurassic to Early Cretaceous, in Late Cretaceous, and in Late Tertiary time (Dasgupta & Mukherjee, 2017). Sediments linked to a first phase of rifting of Aptian–Albian age are exposed near Sarnoo in eastern rift shoulder. The Paleocene-Eocene deposits, linked to a second phase of rifting, are the major hydrocarbon producing reservoirs of the basin (Bladon et al., 2015). Pre-cursor of Deccan volcanism is documented at places in the eastern margin (Dasgupta & Mukherjee, 2017). The MIS is exposed along the western basin margin in and around Barmer, towards south near Dhorimana.

3 Results and Deductions

Numerous ~ NW, ~ NNW, ~ NE and ~ E trending brittle shear faults were identified from the structural field work (L1–L7 locations). We further identified: (1) ~ NE trending mega-scale transfer zones along the Fatehgarh fault trend, N margin of the basin, (2) crosscutting fault planes—in E and W margins: NE faults cut by NW faults and NE faults cuts the ~ E trending faults, (3) The pre-existing fractures of MIS and cross faults of first phase of rifting govern the second and main ~ NW trending rift faults.

Around 500 fault slip data were collected from outcrops [L1–L5]. T-Tecto studio X5 and Win-Tensor (v.5.9.2) software (Delvaux & Sperner, 2003; Žalohar & Vrabec, 2007) were used for paleostress analyses which resulted in

Table 1 Paleostress analyses results as obtained from fault slip data

Area	No	Sense of Slip	Dominant Rock Type	No. of Fault Slip data	σ1 (trend/plunge, in °)	σ2 (trend/plunge, in °)	σ3 (trend/plunge, in °)	Stress Ratio (unitless)	Stress Regime (unitless)		SHMax (T-Tecto, in °)
								D	R′	**Inference**	
W Margin—Barmer	1	Normal	MIS	12	105/24	291/66	22/0	0.7	1.27	**S1**—Pure Strike Slip	105
W Margin—Barmer	2	Reverse	MIS	9	110/0	200/85	32/5	0.2	1.5	**S1**—Strike Slip to Transpressive	113
W Margin—Dhorimana	7	Normal	MIS	19	82/35	273/55	172/8	0.2	1.45	**S1**—Pure Strike Slip	68
W Margin—Dhorimana	8	Normal (Dyke Parallel)	MIS	22	75/1	264/89	162/0	1	1.5	**S1**—Strike Slip to Transtensive	87
E Margin—Sarnoo	13	Normal	Sandstone	7	283/55	65/29	163/15	1	0.85	**S1**—Extensive to Transtensive	80
E Margin—Sarnoo	14	Normal	Sandstone	6	96/17	303/71	180/11	0.5	1.7	**S1**—Pure Strike Slip	90
W Margin—Barmer	3	Normal	MIS	8	353/84	229/3	138/4	0.5	0.5	**S2**—Pure Extensive	55
E Margin—Sarnoo	15	Normal	Sandstone	30	138/80	234/1	144/0	0.3	0.56	**S2**—Pure Extensive	63
E Margin—Sarnoo	16	Normal	Sandstone	22	160/61	255/2	346/29	0.2	0.62	**S2**—Pure Extensive	60
W Margin—Barmer	4	Normal	MIS	6	27/28	210/62	113/3	0.5	1.34	**S3**—Pure Strike Slip	26
W Margin—Dhorimana	9	Normal	MIS	12	163/69	37/31	302/18	0.3	1.5	**S3**—Pure Strike Slip	15
E Margin—Sarnoo	17	Normal	Sandstone	12	60/46	168/16	271/39	0.7	0.86	**S3**—Extensive to Transtensive	0
E Margin—Sarnoo	18	Normal	Sandstone	7	239/70	9/13	102/13	0.5	0.63	**S3**—Extensive to Transtensive	15

(continued)

Table 1 (continued)

Area	No	Sense of Slip	Dominant Rock Type	No. of Fault Slip data	σ1 (trend/plunge, in °)	σ2 (trend/plunge, in °)	σ3 (trend/plunge, in °)	Stress Ratio (unitless)	Stress Regime (unitless)		SHMax (T-Tecto, in °)
								D	R′	**Inference**	
W Margin—Barmer	5	Normal	MIS	25	194/77	348/11	79/5	0.4	0.5	**S4a**—Pure Extensive	170
W Margin—Barmer	6	Normal	MIS	10	132/44	277/40	24/20	0.4	0.82	**S4a**—Extensive to Transtensive	113
W Margin—Dhorimana	10	Normal	MIS	10	117/40	347/37	230/31	0.4	0.85	**S4a**—Extensive to Transtensive	136
E Margin—Sarnoo	19	Normal	Sandstone	26	32/61	136/8	230/27	0.2	0.66	**S4a**—Pure Extensive	160
E Margin—Sarnoo	20	Normal	Sandstone	14	267/77	153/5	62/12	0	0.64	**S4a**—Extensive	120
W Margin—Dhorimana	11	Normal	MIS	22	7/30	181/60	90/0	0.6	1.41	**S4b**—Pure Strike Slip	177
W Margin—Dhorimana	12	Reverse	MIS	7	303/11	193/60	39/27	0.4	2.11	**S4b**—Transpressive to Compressive	129
E Margin—Sarnoo	21	Normal	Sandstone	9	126/7	311/83	43/0	0.7	1.52	**S4b**—Strike Slip to Transtensive	129
E Margin—Sarnoo	22	Reverse	Sandstone	6	172/0	262/39	99/49	0.1	2.3	**S4b**—Compressive to Transpressive	183

four stress regimes (S1–S4) based upon the stress ratio and maximum horizontal stress direction (SHMax). These stress regimes are as follows. S1—strike slip regime, initiation of oblique extension in Early Cretaceous (SHMax ∼ E), S2—Extensional regime in Early Cretaceous resulting in the first phase of synrift deposition during Albian-Aptian (SHMax ∼ NE), S3—strike slip to transtensive regime in Mid-Late Cretaceous (SHMax ∼ N to NNE). S1–S3 are linked to Madagascar separation from West Indian plate. S4 stress regime is sub-divided into two parts, i.e. S4a—extensive to transtensive linked to 2nd and main rift phase of rifting (SHMax ∼ SE), and S4b—strike slip transpressive to compressive regime likely linked to progressive phase of Barmer rifting in Early Tertiary (SHMax ∼ SSE). Stress regime S4 is coeval with the Seychelles–India separation and northward drift of Indian plate (Dasgupta & Mukherjee, 2017) (Table 1).

4 Conclusion

We were able to establish the following: (1) relative timing of the faults from crosscutting nature identified in the field, (2) transfer zones in N margin identified from remote sensing and field observations, (3) four main paleostress regimes obtained from the analyses, S1-S3 indicates stress rotation from ∼ E to NNE during Cretaceous and (4) structural inheritance plays a key role in rift fault propagation.

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