Sedimentary Facies and Depositional Environment of Early Triassic Pachmarhi Formation, Satpura Gondwana Basin, Central India, Madhya Pradesh

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Abstract- Permo-Cretaceous, intracratonic Satpura Gondwana succession unconformably overlies the Precambrian Basement. The lowermost Talchir unit of Satpura succession comprises of glacio-marine and glacio-fluvial deposits. However, the succeeding the successions largely represent a variety of fluvial depositional systems with some records of fluvio-deltaic and fluvio-lacustrine sedimentation under a variety of climatic conditions including cold, warm, arid, subhumid and semiarid. The approximately 5 km thick succession comprises of Talchir, Baraker, Motur, Bijori, Pachmarhi, Denwa, Bagra and Jabalpur formations. The present study is confined to Early Triassic Pachmarhi Formation. On the basis of lithological characters six lithofacies were identified and their lateral trends at the measured section were studied: (1) Planar cross-bedded sandstone (Sp) facies, (2) Trough cross-bedded sandstone (St) facies, (3) Horizontally bedded to gentally inclined sandstone (Sh) facies, (4) Massive to faintly cross-bedded sandstone (Sm) facies; (5) Pebbly sandstone (Pb-S) facies, (6) Small scale ripple fine grained sandstone (Sr) facies were recognized in Pachmarhi Formation. Lithofacies characters and multistory sandstone bodies which are parallel to depositing streams is product of longitudinal bars and locally diagonal/transverse bars of low sinuosity braided streams. It is suggested that Pachmarhi sandstones are deposited in a braided river system under warm, humid to subhumid climatic conditions.

Index Terms- Facies analysis, Depositional environment, Pachmarhi Formation, Satpura basin, Madhya Pradesh.

I. Introduction

The post-Permian Gondwana succession of Satpura basin, central India is characterised by an alternation of sandstones, conglomerate and shales. Compared to post-Permian (Upper Gondwana) sequence, the Late Paleozoic (Lower Gondwana) sequences including the coal measures have been studied in great detail in terms of sedimentological studies (Casshyap and Kumar, 1987; Casshyap and Srivastava, 1988; Casshyap and Tewari, 1984, 1988; Casshyap et al., 1993; Tewari, 1995; Tewari and Casshyap, 1996). Traditionally, Mesozoic Gondwana succession crop out in east central part of Satpura basin comprises the Pachmarhi, Denwa and Bagra formations considered to represent a long term record of alluvial deposition in Satpura basin (Casshyap and Tewari, 1988; Casshyap et al., 1993; Khan, 1997). This paper presents a detailed account of Pachmarhi Formation exposed in east-central part of Satpura basin.

The Triassic succession in the east-central part of the Satpura basin comprises the Pachmarhi and the overlying Denwa Formations. The Pachmarhi Formation attains an average thickness of about 750 m with a maximum of about 900 m. It is dominantly arenaceous, comprising pebbly, gritty to very coarse and coarse to medium grained occurring as channel shaped multistory bodies of 5-20 m thick. The sandstone are profusely cross-bedded with interbeds of horizontal bedded sandstone. Pachmarhi Sandstones occur as laterally coalescing, channel shaped multistory sand bodies of 5-20 m thick. The channel bodies are commonly characterized by 1-2 m thick interbeds of conglomerate or massive pebbly sandstone with an uneven erosional base. Pebbles are present almost throughout the sedimentary unit. The pebbles of mostly quartzose composition and are subrounded to subangular.

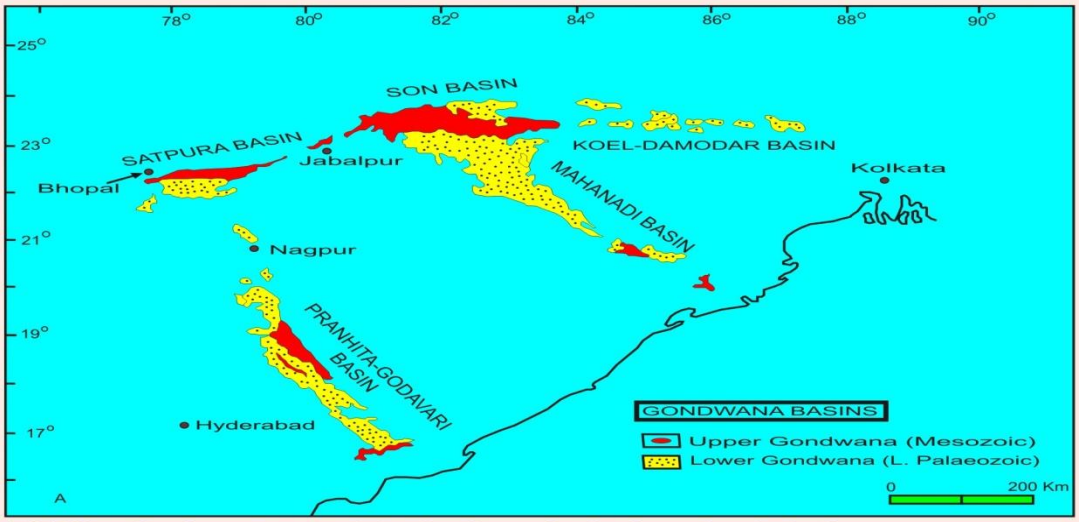
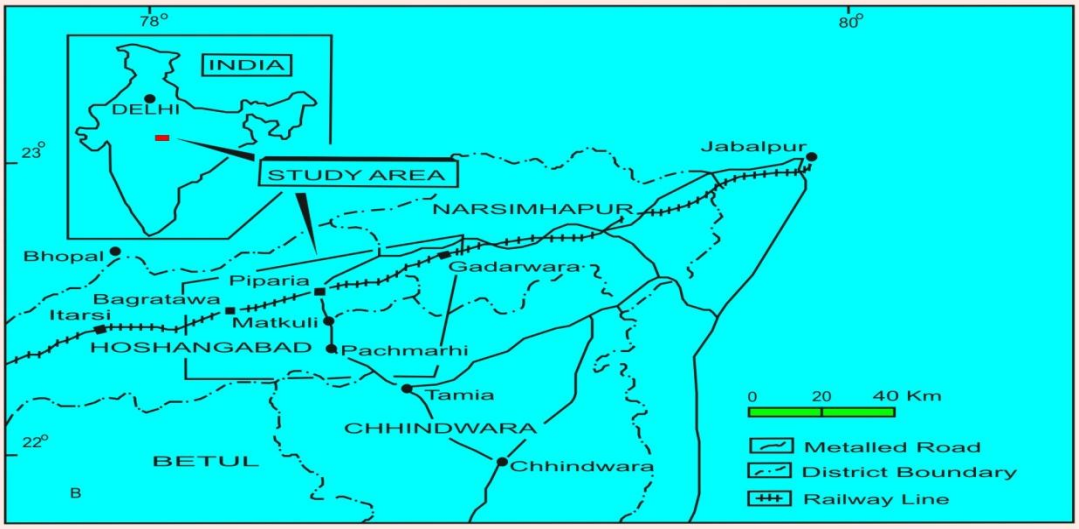


Fig.1 (A) Map showing outcrops of the Gondwana basins in peninsular India.



(B) Map showing location and rail, road access to study area in central India; inset shows position of Satpura Gondwana basin.

II. GEOLOGICAL SETTING

The Gondwana basins of Peninsular India are intracratonic in nature surrounded by Precambrian terrains (Fig.1). They are disposed along ENE-WSW trending Narmada-Son-Damodar valley, NNW-SSE trending Pranhita Godavari valley, NW-SE trending Mahanadi valley and E-W trending Satpura basin (Fig.1A). There is general consensus that these basins originated under a bulk extensional regime due to failure of attenuated crust along pre-existing zones of weakness imparted by Precambrian structural grains (Chaterji and Ghosh, 1970; Naqvi et al., 1974; Mitra, 1994; Biswas, 1999; Acharyya, 2000). The Gondwana deposits heralded the sedimentation in peninsular India after a long hiatus since the Proterozoic. The Satpura basin of central India is the western most Indian Gondwana basin and outcrops along ENE-WSW trending Narmada-Son Damodar Valley (Fig.1A). The basin is rhomb shaped, approximately 200 km long and 60 km wide. The Satpura basin was created as pull-apart basin due to extension related to strike-slip movement along the Son-Narmada Lineament (Chakraborty, et al., 2003; Chakraborty and Ghosh, 2005).

The bulk of Satpura succession was deposited in a mega half graben bounded by basin margin fault controlled subsidence regimes with intervening tectonically static periods. Also, the subsidence rate varied across the basin resulting in an asymmetric basin fill with the thickness increasing towards the north (Chakraborty and Ghosh, 2005). The Satpura basin contains rocks of Permian to Cretaceous age and therefore comprises the longest stratigaraphic range of Indian Gondwana basins. Interistingly, the term Gondwana was introduced by Meddlicott (1872) while he was working in the Satpura basin, after the ancient kingdom of Dravidian Gonds, one of the principal aboriginal tribes who still inhabited the Satpura area. The Gondwana sequence, known as Upper Gondwana, occurs in the central and northern parts of the Satpura basin. These comprise the Pachmarhi, Denwa and Bagra Formations (Table-1).

The Pachmarhi Formation comprises recurring sequence of multistorey sandstones bodies which crop out largely in the southern and central parts as lofty hills and plateau (Fig. 2). The Satpura Gondwana basin hosts a ~5 km thick siliciclastic succession (Permian-Cretaceous, Crookshank, 1936) that unconformably lies over the Precambrian basement. The regional strike of the basin-fill strata is NE-SW, and the regional dip (~5°) directed towords north. The Permo-Cretaceous Satpura Gondwana succession has been classified into seven major lithostratigraphic unit that form oldest to youngest are the Talchir, Baraker, Motur, Bijori, Pachmarhi, Denwa and Bagra formations (Fig. 2 & 3, Table 1). Barring the lowermost glacio-marine and glacio-fluvial deposits, the rest of the succession largely comprises a variety of fluvial deposits with some records of fluvio-deltaic and fluvio-lacustrine sediments (Maulik et al., 2000; Ray and Chakraborty, 2002; Ghosh et al., 2004; Chakraborty and Sarkar, 2005; Ghosh et al., 2006; Chakraborty and Ghosh, 2008). In the Satpura Gondwana basin, periods of maximum subsidence are indicated by glaciomarine, fluvio-deltaic and fluvio-lacustrine regimes that prevailed during the Talchir, Barakar and Bijori sedimentation respectively. Following the Bijori sedimentation, accumulation in the Satpura Gondwana basin took place under the alluvial regime indicating a decrease in the rate of subsidence (Chakraborty and Ghosh, 2005).

The available paleogeographic reconstructions suggest that the Satpura basin had migrated from a position of 60°S latitude in Lower Permian to 30°-40°S latitude by Middle Triassic (Scotese, 2001, 2002; Ghosh, 2003; Ghosh et al., 2006) and thus had traversed through different climatic zones during this period.

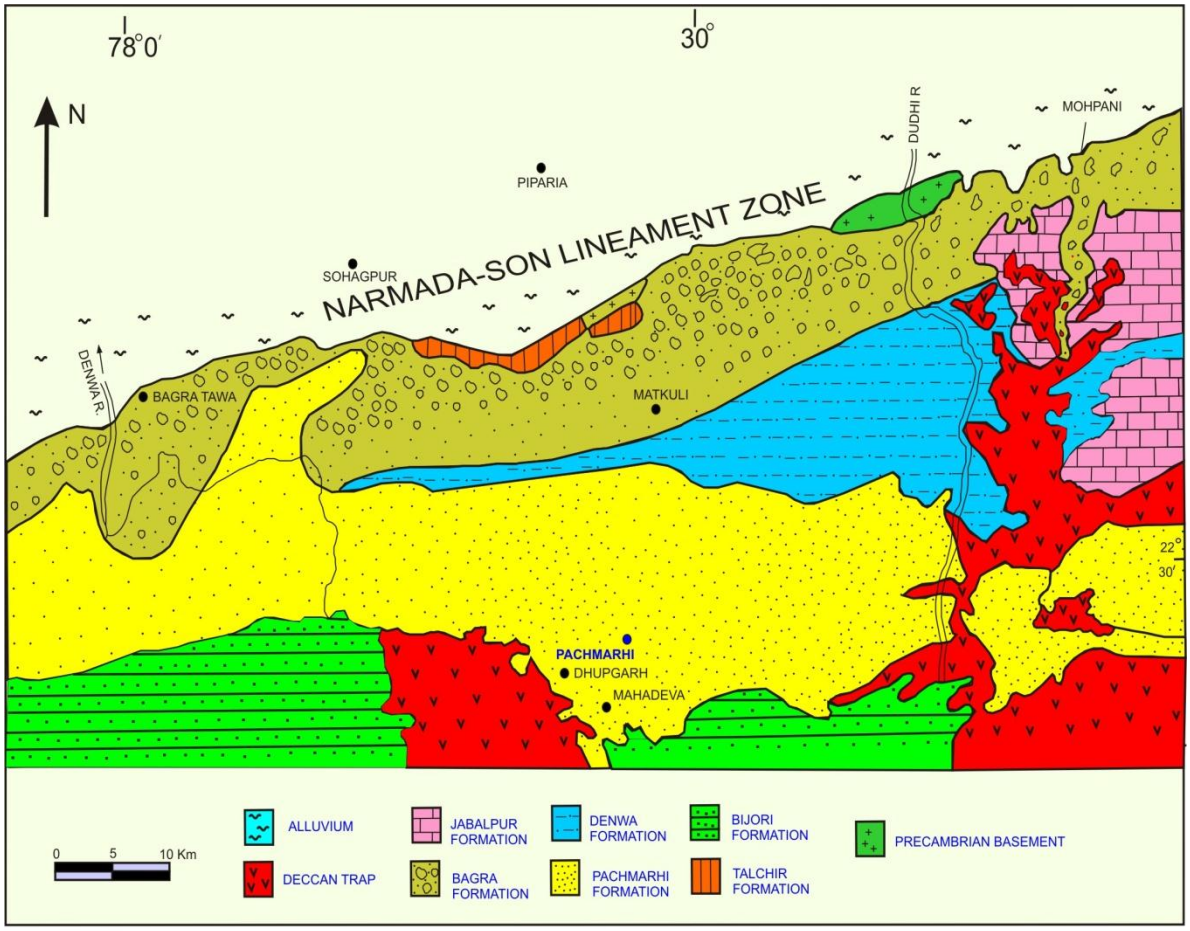


Fig.2 Geologicac map of Satpura Gondwana succession, central India (mainly after Raja Rao, 1983).

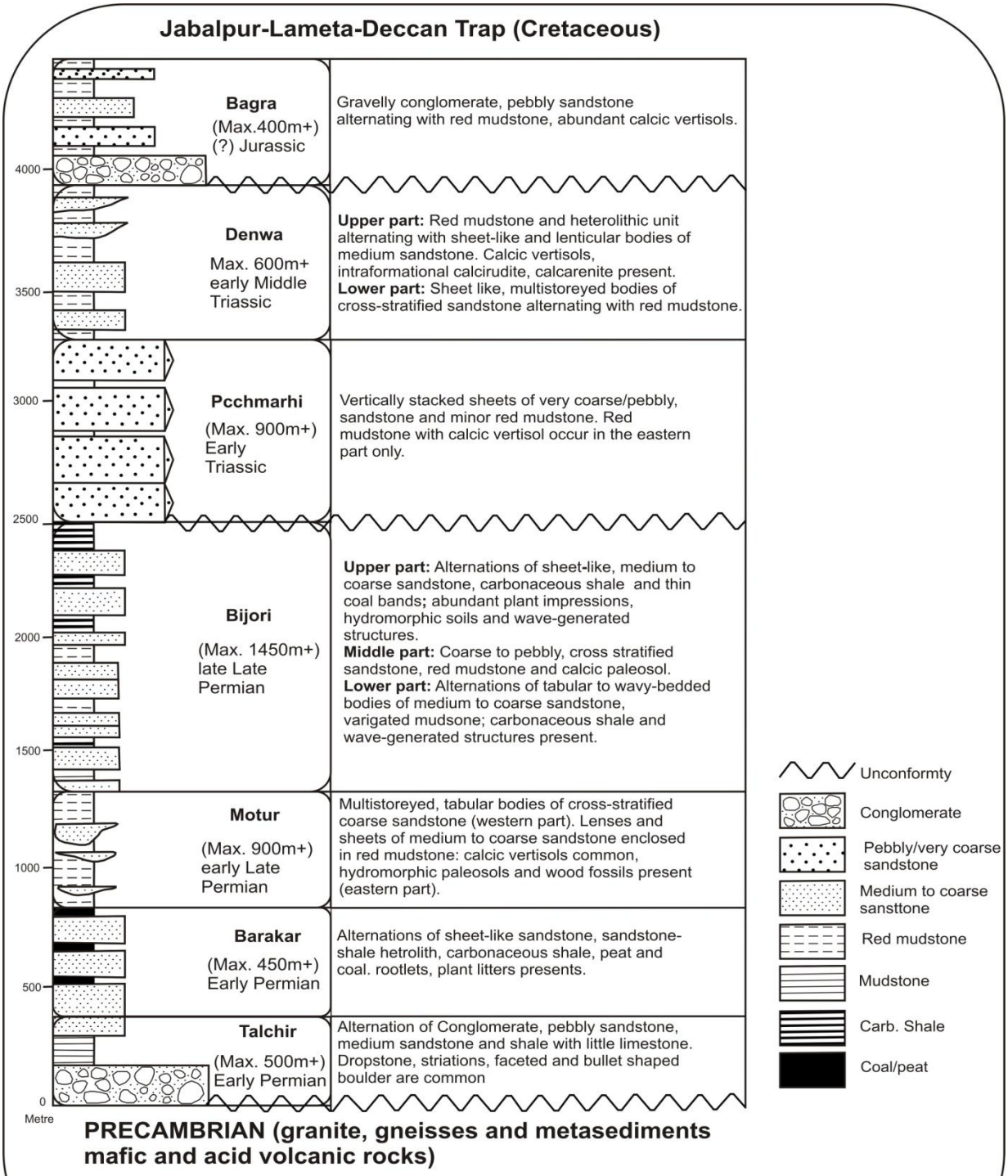


Fig. 3. Generalized lithostratigraphy of the Gondwana succession in the eastern part of Satpura basin (mainly after *Ghosh et al.*, 2012).

Table 1: Stratigraphic succession of Satpura Gondwana Basin (modified after Raja Rao, 1983 and Chakraborty and Ghosh, 2005).

	Formation(s)	Thikness	Lithology	Depositional environment and climate	Age
Upper Gondwana	Bagra	Max. 400 m+	Gravelly conglomerate, pebbly sandstone, alternating with pedogenically modified red mudstone, abundant calcic vertisols. Coarser clastics define channel-like bodies, macroform bars and are thoroughly cross-stratified.	High gradient piedmont rivers with braided morphology. Alluvial tracts separated in space by muddy plains. Subordinate mass flow deposits (Casshyap *et al*., 1993). Hot, semi-arid to arid climate.	(?) Jurassic
			Unconformity		
	Denwa	Max. 600 m+	**Upper part:** Red mudstone and heterolithic unit alternating with medium sandstone, sand-mud ratio is 1:9, calcic vertisols and intraformational calcirudite/calcarenite (Ghosh *et al*., 2006). **Lower part:** Sheet-like, multistoreyed, cross-stratified sandstone bodies alternating with red mudstone. Sand-mud ratio is 9:11 (Maulik *et al*., 2000)	Lower part represents braided channel deposits (Maulik *et al*., 2000) and upper part represents an anabranching system. Warm, subhumid to semi-arid climate (Ghosh *et al*., 2006; Ghosh and Sarkar, 2011).	Early Middle Triassic (Early Anisian; Bandyopadhyay and Sengupta, 1999)
	Pachmarhi	Max. 900 m+	Pebbly sandstone. Sandstone bodies define thick laterally extensive sheets that are superimposed upon one another. Thoroughly cross-stratified. Downcurrent dipping macroform stratification common. Sandstone bodies separated by red mudstones with calcic vertisols occur in the eastern part only (Maulik *et al*., 2000)	Braided river deposits (Tewari, 1995; Maulik *et al*., 2000); Predominantly warm, subhumid, climate with semi-arid intervals.	(?) Early Triassic
			Unconformity		
Lower Gondwana	Bijori	Max. 1450 m+	**Upper part:** Alternations of sheet-like, medium to coarse sandstone, carbonaceous shale and thin coal bands; abundant plant impressions**, Middle part:** Coarse to pebbly cross-stratified sandstones, red mudstones and calcic paleosols (Chakraborty and Sarkar, 2005). **Lower part:** Alternations of tabular to wavy-bedded bodies of medium to coarse sandstone, variaegated mudstone; carbonaceous shale and wave generated structures present.	**Lower and upper part:** Lake shorelines, sub-aqueous distributory channel and associated levees, wave and storm-affected delta front and open lacustrine/lower shore face deposits. **Middle part:** Fluvial channels and associated flood plains. Warm, semi-arid climate with seasonal rainfall in the middle part; more humid regimes during lower and upper intervals (Chakraborty and Sarkar, 2005)**.**	Late Late Permian (Early Tatarian; Werneburg and Schneider, 1996)
	Motur	Max. 900 m+	Multistoreyed, cross-stratified, coarse sandstone (mainly in the western part). Red mudstone-dominated succession with embedded lenses and sheets of medium to coarse sandstone; sandstone:mudstone varies from 1:10 to 3:1; calcic vertisols common in the red mudstones, hydromorphic paleosols present at places; silicified wood fossils present (mainly in the eastern part, Ray and Chakraborty, 2002).	Braided, bedload channel deposits. Anastomosed channel deposits.Predominantly semi-arid climate (Ray and Chakraborty, 2002) possibly with intermittent wet periods towards later phase of the sedimentation.	Early Late Permian (Ufimian-Kazanian, Ray and Chakraborthy, 2002)
	Barakar	Max. 450 m+	Alternation of sandstone, sandstone-shale heterolith and carbonaceous shale/peat/coal. Two types of sandstone bodies: (1) coarse sandstone characterized by unidirectional cross-sets, (2) medium sandstone characterized by hummocky cross-stratification, tidal bundles. Sandstone to shale heterolith show flaser, lenticular and wavy bedding. Rootlets, plant litters present. Three major coal seams inter-bedded with sandstones in the upper part of the formation. Contact with the Talchir Formation is gradational (Ghosh *et al*,. 2004).	Tidally influenced delta front deposit, delta top interdistributory deposits, delta top braided channel deposits. Temperate-humid climate (Ghosh *et al*., 2004).	Early Permian (Kungurian, Robinson, 1967)
	Talchir	Max. 500 m+	Alternation of conglomerate, pebbly sandstone, medium sandstone and shale with little limestone. Two types of sandstone bodies: (1) coarse sandstone characterized by unidirectional cross-strata, (2) Medium sandstone characterized by hummocky, swaley, low-angle cross-strata, parallel and wave ripple lamination. Dropstone, striation, faceted and bullet-shaped boulders are common (Chakraborty and Ghosh, 2008).	Deposition in ice-contact fan delta, outwash braidplain delta and avirtually ice-free, non-deltaic open marine condition (shoreface and offshore shelf); cold, arid climate (Chakraborty and Ghosh, 2008).	Early Permian (Sakmarian, Robinson, 1967)
			Unconformity		
Basement			Tonalite gneiss, granite, meta-sediments, mafic and acid volcanic rocks		Precambrian

III. SEDIMENTARY FACIES

Facies description of Pachmarhi sandstone is based on varieties and types of lithofacies, their texture, framework, and primary sedimentary structures. On the basis of lithological characters six lithofacies were identified and their lateral trends at the measured section were studied:

(1) Planar cross-bedded sandstone (Sp) facies (Plate - IA)

(2) Trough cross-bedded sandstone (St) facies (Plate - IB)

(3) Horizontally bedded to gentally inclined sandstone (Sh) facies (Plate - IC)

(4) Massive to faintly cross-bedded sandstone (Sm) facies facies (Plate-ID)

(5) Pebbly sandstone (Pb-S) facies (Plate-IE)

(6) Small scale ripple fine grained sandstone (Sr) facies (Plate-IF) were recognized in Pachmarhi Formation.

PLATE -I

(1): Planar Cross-bedded Sandstone Facies (Sp)

This facies is medium to coarse grained and locally contains pebbles dispersed along bedding planes and foresets. The sandstone white to dirty white, and buff to brownish in colour on outcrops. The thickness of each cross-bedded set ranges from 10-40 cm. The upper bounding surfaces of cross bedded sets may exhibits uneven reactivation surfaces, implying erosion of migration bars/sandwaves locally. The planar cross-bedding sets rest on thin lenses of gravels or conglomerate and pass laterally into trough cross-bedded (St)/massive sandstone (Sm).

The deposition of small scale planar cross-bedded (Sp) facies has been attributed to down current migration of linear ripple whereas large scale planar cross-bedding is produced both by linear (two dimensional) mega ripple and sand waves or migration of three dimensional medium subaqueous dunes (Ashley, 1990).

(2): Trough Cross-bedded Sandstone Facies (St)

Trough cross-bedded facies is commonly developed in coarse and medium grained sandstone and occur in large (average set thickness is more than 20 cm) and medium scale (5-10 cm), like planar cross-bedded (sp) facies. Thickness of individual sets is rarely more than 30 cm, and often in some sets grain size and thickness decreases upward, giving an appearance of fining upword character. Most commonly this facies may have been deposited as migrating dunes or lunate bars on top of a gravel facies, in association with planar cross-bedded sand body (Sp facies), or in local depressions of megaripples showing evidence of scour-fill episodes.

(3): Horizontally-bedded to gentally inclined Sandstone Facies (Sh)

This facies is medium to coarse grained and exhibits thinly developed horizontal bedding or lamination to gently inclined bedding at places. The facies is 1 to 2 meters thick or even more at places, extends laterally for a few tens of meters. Stratigraphically, Sh facies is more common in the Pachmarhi section. This facies may be attributed as a product of upper flow regime plane bed at high velocity and low water depth (Reading, 1978; Collinson and Thompson, 1984).

(4): Massive to Faintly Cross-bedded Sandstone Facies (Sm)

The massive sandstone is ferruginous, buff brown to white in colour and commonly medium to course grained. It contains scattered granules and pebbles of 2-45 mm in diameter, predominantly of quartzite. The granules and pebbles are dispersed specially towards the base of sandstone units, but without preferred orientation. The pebbles are subangular to subrounded with a mean size of about 4 centimeters. This facies ranges from 3 to 5 meter in thickness and have an erosional contact with overlying Sp facies. The massive to faintly stratified sandstone facies (Sm) of Pachmarhi sandstone may possibly have been deposited by rapid fallout of sand without time for development of well preserved internal organization within the beds. Braided river most commoly undergo this type of lateral migration as a result of erosion of the outer and deposition on the inner bank channel lag deposits.

(5): Pebbly Sandstone Facies (Pb-S)

The pebbly sandstone facies forms an important part of in the Pachmarhi Formation. It occur as small lens-like sandstone bodies in which clasts of pebble and cobble size are dispersed in some outcrops, varying in size from <1 to 10 cm in diameter. The embedded clasts are mostly subangular to subrounded irrespective of size, rounded pebbles are rare. Locally, clast occurs as clusters of pebbles of quartzite, resembling well sorted lag deposit.

(6): Small scale-ripple Fine Grained Sandstone Facies (Sr)

This facies (Sr) comprising fine to very fine grained sand displays parallel laminatons, ripple lamination and ripple cross lamination. It is white to dirty white in colour. This facies occurs in cosets commonly than in single sets, and overlies large scale Sp and St facies. Occurrence of Sr facies in successive cosets may be attributed to downcurrent migration of small-scale ripples under regular sediment supply (Allen, 1963).

IV. FACIES ASSOCIATION AND INTERPRETATION

Predominance of laterally coalescing and multistoried medium to coarse grained sandstone bodies, with profuse development of large scale planar and trough cross-bedding, presence of conglomerate lenses and unimodal orientation of cross-bedding foresets and paucity of fine clastics are conspicuous depositional feature of Pachmarhi Formation suggesting deposition most likely in extensive braided river plains.

I. DEPOSITIONAL MODEL

Facies analysis in particular, provides evidence for reconstruction of environment of deposition and prevailing hydrodynamic processes during the deposition of Pachmarhi sandstone.

Pachmarhi sedimentation is predominantly arenaceous assemblage consists of recurring sequences of multistory sandstone bodies, which are by and large conglomeratic, pebbly, coarse grained and profusely cross-bedded to horizontally bedded in lower part, exhibiting progressive decrease in thickness and grain size towards top of each recurring sequence (Fig. 4&5). The individual sandstone bodies are commonly elongated or oriented in the direction of depositing streams and locally oriented diagonally/transverselly.

These may well be attributed to longitudinal, diagonal, transeverse sand bars in the channel framework of low sinuosity (bed load) braided streams (Miall, 1977; Walker, 1979). The frequent migrations of these channel bars, common phenomena of braided rivers, have passively resulted in multilateral coalescing sandstone bodies.

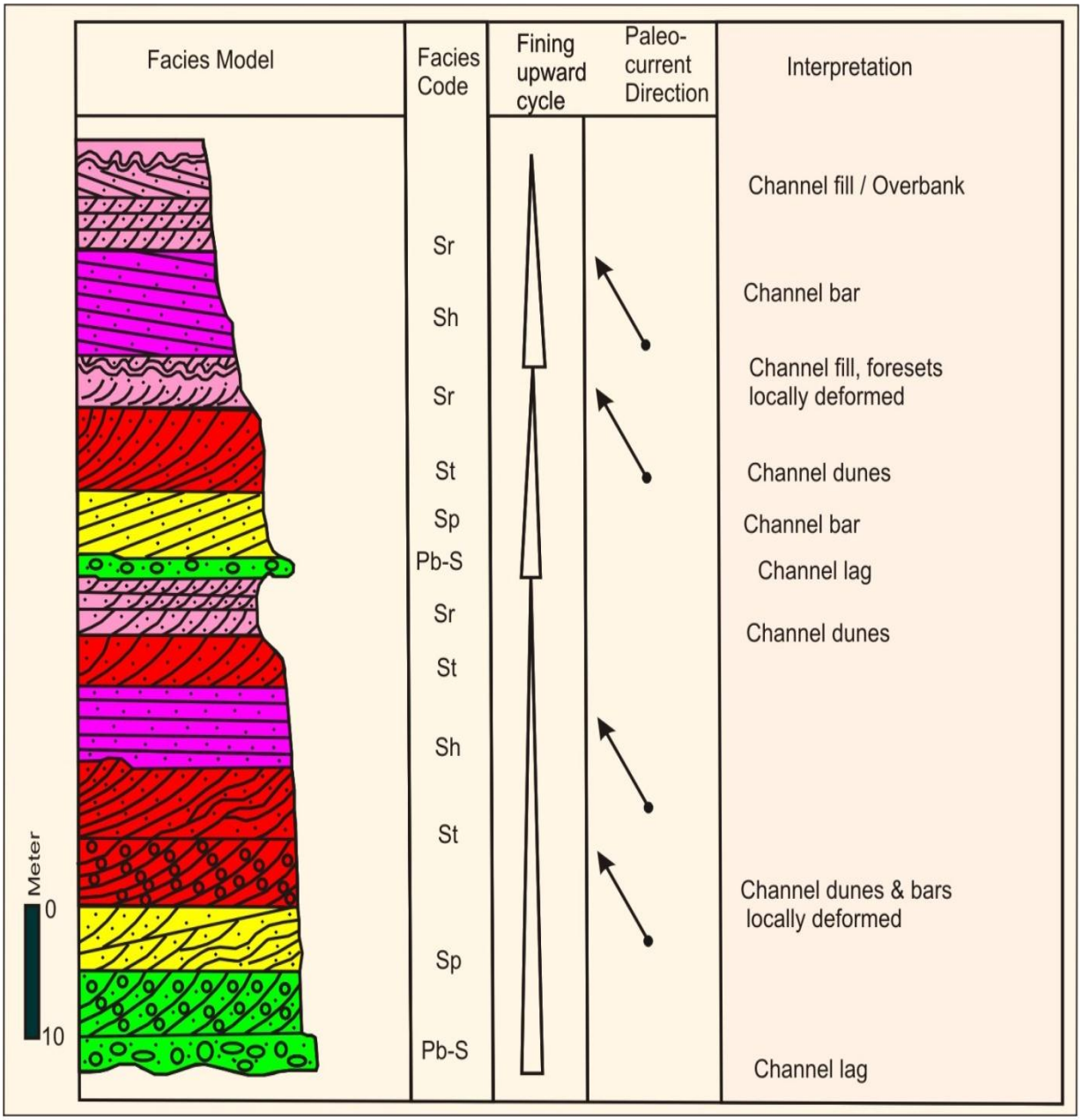


Fig.4. A generalised facies model of Pachmarhi Formation of Satpura Gondwana basin.

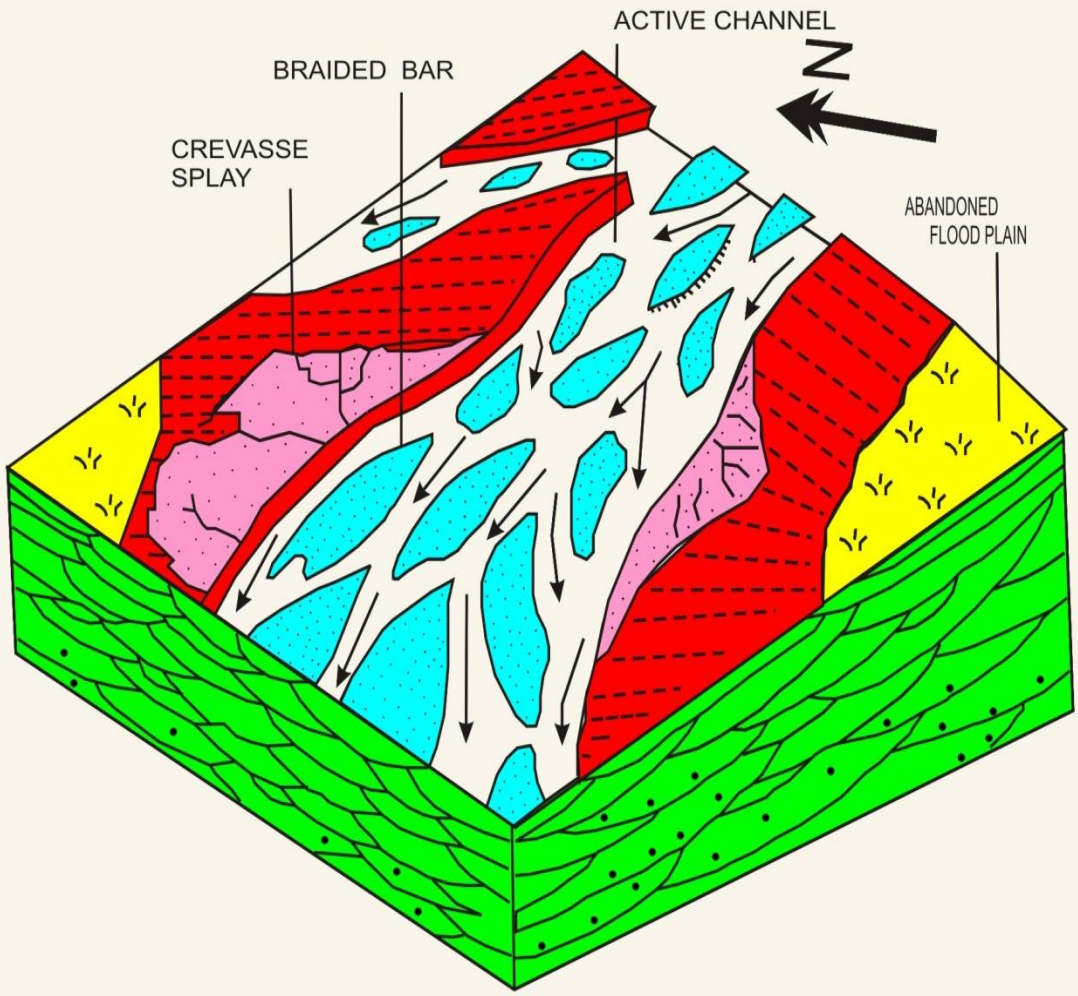


Fig.5. Schematic depositional model of braided river system for the Pachmarhi Formation, Satpura Basin.

V. CONCLUSION

The Pachmarhi Formation comprises recurring sequence of multistory sandstone bodies, which are, by and large, conglomeratic, pebbly coarse grained in lower part, with progressive decrease in thickness, grain size, and scale of cross-bedding in the upper part of each cycle. On the basis of lithological characters overall six lithofacies were recognised in Pachmarhi Formation. Lithofacies characters and multistory sandstone bodies which are parallel to depositing streams is product of longitudinal bars and locally diagonal/transverse bars of low sinuosity braided streams. Generalised facies model provide a basis for reconstructing the depositional environment of Pachmarhi Formation. It is suggested that Pachmarhi sandstones are deposited in a braided river system under warm,

humid to subhumid climatic conditions.

ACKNOWLEDGMENT

The authors would like to thank the Chairman, Department of Geology, Aligarh Muslim University, Aligarh for providing research facilities. This study forms a part UGC major research project No. F 40-305/2011 (SR) sanctioned to Abdullah Khan. We are very grateful for the same.

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