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A Reinterpretation of two Chertbreccias from the Proterozoic Basins of India

VIVEK S. KALE[1] and SHILPA PATIL PILLAI[2*]
Department of Geology, University of Pune, Pune – 411 007
[1]Kalyani Global Engineering Pvt. Ltd., Industry House, Mundhwa, Pune - 411 036
[2] Sinhgad College of Science, Pune - 411 0041
[*]**Email:** geoshilpa24@gmail.com

Abstract: Several horizons of a unique lithotype called "chertbreccia" are interbedded within the Proterozoic platform sediments of the Peninsular India. These cherty rocks with brecciated texture appearing as blocky masses were earlier diversely interpreted as being products of disparate processes such as fault-zone breccias, collapse breccias, and so on. Two of these horizons, one from the Kaladgi Basin (Dharwar Craton) and the other from the Dhar Forest Inlier of the Vindhyanchal Basin (Bundelkhand - Aravalli Craton) are compared in context of their geological setting, field relations and petrological constitution. A model of the mode of development of these peculiar rocks is reconstructed, taking into account their characters and limitations of previous interpretations. They are interpreted as transported debris deposits of syntectonogenic material released during the episodic activity of the growth faults of the Kaladgi and Vindhyanchal Basins that was diagenetically silicified.

Keywords: Proterozoic, Chertbreccias, Kaladgi Basin, Vindhyanchal Basin, India.

INTRODUCTION

Many earlier authors have noted, with fascination, the occurrence of brecciated cherts /cherty conglomerates / hornstones / hornstone breccias from the Proterozoic platform sequences of the Indian Peninsular shield (e.g.: Blanford, 1869; Foote, 1876; Pascoe, 1959; Krishnan, 1982). Adjectives ranging from 'peculiar' to 'exotic' were used to describe these rocks but most authors did not offer a plausible explanation for their genesis. The description of this rock by these names has added to a general confusion in its appropriate recognition. The AGI Glossary advocates (Bates and Jackson, 1980, p: 297) that the term 'hornstone' be abandoned. To avoid this confusion, we have used only the name "Chertbreccia" in the following discussion; except where other terms have precedence based on formal stratigraphic nomenclature.

The chertbreccia is a drab, dirty brown coloured rock containing brecciated fragments of one or more intrabasinal rocks that have undergone severe chertification; floating in cherty matrix. It occurs interbedded within the sediments deposited in the supracrustal Proterozoic basins, in near-shore, tidal and subtidal environments (Radhakrishna, 1987; Singh, 1985, Kale and Phansalkar, 1991). The temporal distribution of such Proterozoic chertbreccias from India is not well constrained. Some of the better known horizons of this rock in India are listed in Table 1 and their localities are depicted in Fig. 1 with some other comparable occurrences.

Table 1. Major chertbreccia formations from the Proterozoic sediments of Peninsular India

Formation	Group	Supergroup	Age
Malhera Breccia (Bijawar Hornstone)	Bijawar	Vindhyan	Palaeoproterozoic
Tirohan Breccia (Tirohan Hornstone)	Semri	Vindhyan	Mesoproterozoic
Medhikhera Chertbreccia	Kishangad= (Semri)	Vindhyan	Mesoproterozoic
Susnai Breccia (Ghurma shale/breccia)	Kaimur	Vindhyan	Mesoproterozoic
Mahakut Chertbreccia	Bagalkot	Kaladgi	Mesoproterozoic
Niralkeri Chertbreccia	Bagalkot	Kaladgi	Mesoproterozoic
Seriska Breccia	Ajabgarh	Delhi	Mesoproterozoic

Amongst these, the Mahakut Chertbreccia from the Kaladgi Basin occurring as large and small disjoint patches throughout the exposures of the Bagalkot Group, is the most widely distributed chertbreccia. The Mehdikhera Chertbreccia from the Dhar Forest Inlier of the Vindhyanchal Basin with a calculated stratigraphic thickness of about 1000 m (Kale, 1985a) is arguably the thickest of these

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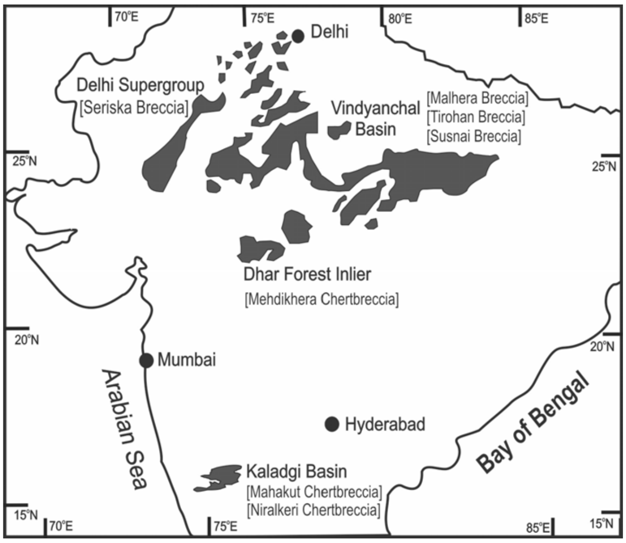

Fig.1. Locations of the major chertbreccia occurrences from the Proterozoic deposits of India listed in Table 1.

horizons. These two chertbreccias are described below and the possible mode of their genesis is discussed.

GEOLOGICAL FRAMEWORK

Kaladgi Basin

The sedimentary succession of this ovoid basin situated on the northern fringes of Dharwar craton has been divided into the Bagalkot Group and the younger Badami Group separated by an erosional and angular unconformity (Table 2). Recent geochronological studies (Padmakumari et al. 1998; Balesh Kumar et al. 1999) have indicated that the Bagalkot Group was deposited around 1800± 100 Ma, supporting a previous suggestion of their Late Palaeo-proterozoic age based on stromatolite studies by Sharma et al. (1998). The Badami Group has been estimated to be of Neoproterozoic age based on trace fossil occurrences (Kulkarni and Borkar, 1997b).

Structurally, the Bagalkot Group displays variable deformation throughout the basin. It is severely deformed in the axial zone of the basin and moderately deformed along the basin margins (Fig. 2). The axial zone displays high density of inherent (E-W to NW-SE trending faults) as well as superimposed deformation (NNW-SSE to NE-SW trending transverse faults and mesoscopic tight isoclinal folds) structures. The sediments exposed along the basin margins display gentle, homoclinal dips.

The two chertbreccia horizons (Mahakut and Niralkeri) are found in profusion in this deformed sector of the basin and are folded along with the other lithotypes of this Group (Fig. 2). The Niralkeri Chertbreccia is similar to the Mahakut Chertbreccia in every aspect (appearance, occurrence and composition) but differs in stratigraphic position (see Table 2). As compared to the Mahakut, the Niralkari Chertbreccia is several magnitudes smaller in lateral extent and thickness.

Table 2. Lithostratigraphy of the Bagalkot Group of the Kaladgi Basin (*after* Kale et al. 1999; Patil Pillai, 2005)

		Subgroup	Formation	Member
	Cretaceous – Tertiary Deccan Traps (basalts, infra and inter-trappean beds)			
~ ~ ~ *Nonconformity* ~ ~ ~				
KALADGI SUPERROUP	*Neoproterozoic* Badami Group			
	~ ~ ~ *Angular Unconformity* ~ ~ ~			
	Mesoproterozoic Bagalkot Group	Simikeri	Lakshanhatti Dolomite	
			Niralkeri Chertbreccia	
			Arlikatti Argillite	
			Muchkundi Quartzite	Tulsigeri Quartzite Bevinmatti Conglomerate
		~ ~ ~ *Disconformity* ~ ~ ~		
		Lokapur	Petlur Carbonate	Chikshellikeri Limestone Chitrabhanukot Dolomite
			Mahakut Chertbreccia	
			Yadhalli Argillite	Yargatti Calc. shale Jalikatti Phyllite Manoli Ferruginous shale
			Saundatti Quartzite	Timmapur Quartzite Almatti Quartzite Salgundi Quartzite
~ ~ ~ *Noncoformity* ~ ~ ~				
	Archaean – Palaeoproterozoic Basement Complex of the Dharwar Craton Granites, metavolcanics, metasediments			

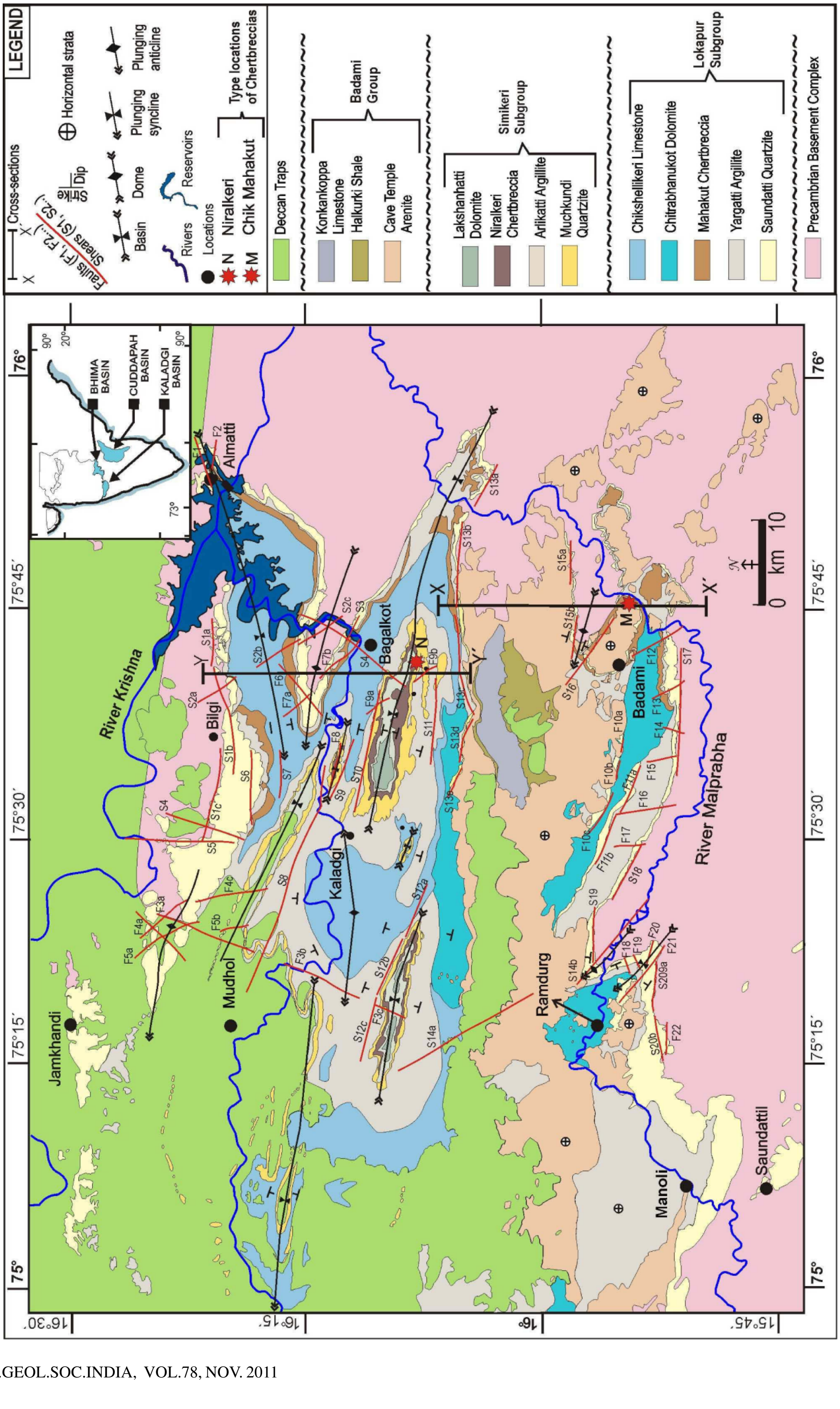

Fig.2. Stratigraphic map of the Kaladgi Basin showing the distribution of the chertbreccia horizons (modified after GSI, 1981 and Patil Pillai 2005). Section lines XX′ (Fig. 3a) and YY′ (Fig. 3b) are shown for reference.

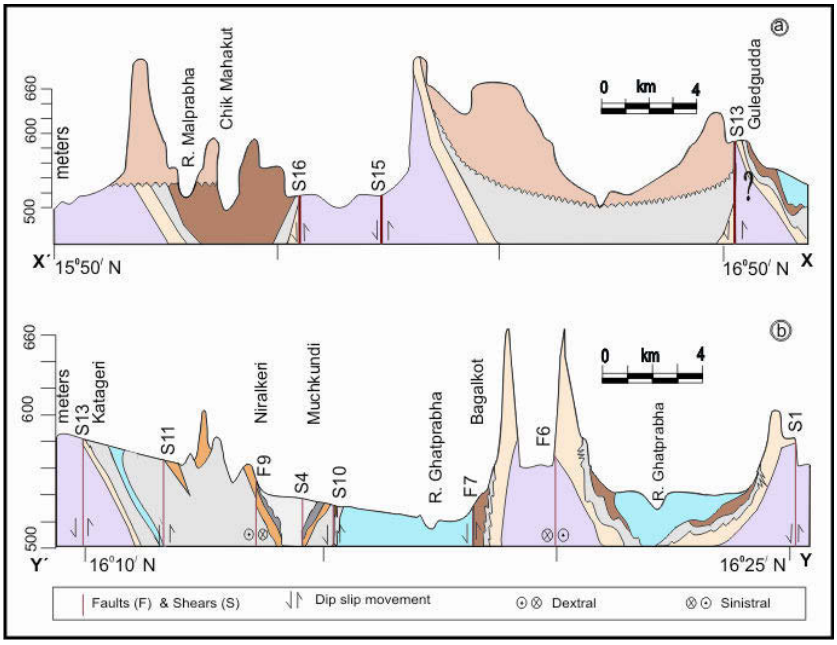

Fig.3. (a) N-S geological cross-section (refer XX´ in Fig.2), across Guledgudda-Chik Mahakut tract depicting the relations between various lithounits (*after* Patil Pillai, 2005). Note the thickness and extent of the Mahakut Chertbreccia at its type locality Chik Mahakut in the southern part of the section. **(b)** N-S geological cross-section (refer YY´ in Fig 2) across Bagalkot-Niralkeri-Katageri tract depicting the structural and stratigraphic relations between various lithounits (*after* Patil Pillai, 2005). Note the lensoid nature of Niralkeri Chertbreccia in its type locality Niralkeri in the northern parts of the Kaladgi Basin. The cross-sections have been vertically exaggerated to display the complex folding patterns in the central sector of the basin.

The Mahakut Chertbreccia has a maximum exposed thickness of 150-200 m along the eastern fringe of the basin around the towns of Bagalkot and Badami (see Figs. 2 and 3a). In these parts, and along the northern margin of the basin, it occurs interbedded within or overlying the siliciclastic Saundatti Quartzite and Yadhalli Argillites, and is often overlain by the Chitrabhanukot Dolomite (Fig. 3b). In the southern exposures of Lokapur Subgroup between Saundatti and Badami, the Mahakut Chertbreccia and the Yadhalli Argillite display a mutually exclusive development (Kale et al., 1996). In the western parts (around Manoli and Yargatti), the Yadhalli Argillites are widespread but thin out eastwards. It is observed that as the dominance of argillites decreases eastwards, the chertbreccia deposits become more profuse and thicker (around Badami).

Dhar Forest Inlier

This Precambrian inlier, located in the Narmada valley of central India contains the southernmost exposures of the Vindhyanchal Basin (Pascoe, 1959; Krishnan, 1982). This inlier with its intricate fault system is a part of the Narmada-Son Structure that stretches across central India (Murthy and Mishra, 1981; Kaila et al. 1985, 1989; Kale, 1986; Mahadevan, 1994) with ENE-WSW to E-W trends (Fig. 4, inset map). The Narmada–Son structure is an array of long deep crustal faults that have been active episodically from Late Archaean to Recent times (Kaila et al. 1985; Naqvi and Rogers, 1987). It has controlled the geometry and evolution of the southern margin of the Vindhyanchal Basin throughout its middle and late Proterozoic history (Valdiya, 1982; Acharyya 2003).

The stratigraphic classification of the Precambrian rocks exposed in the Dhar Forest Inlier (Table 3) and outlined in the geological map (Fig. 4) is based on Ghosh et al. (1981), Soni et al. (1987), Kale (1985a, 1987, 1989) and Pillai (1997).

The eastern exposures of the Dhar Forest Inlier around Neemawar-Joga-Dhanababa area display complex folding and faulting of the Kishangad Group, comparable to the decollement structures (Fig. 5a). Around Jagatpura in the west, the sediments of this Group are overturned along a NNW-SSE trending Choral Fault (Fig. 5b). Around Modri and in the type exposures around Kishangad (Kale, 1989), they display uniform homoclinal dips of 30°-35° towards south, but the dolomite often display mesoscopic and macroscopic folding and crenulations.

The stratigraphic position of the Mehdikhera Chertbreccia has been controversial, and diverse origins have been attributed to it by previous authors. Bose (1884), Fermor (1904) and more recently Roy Chowdhury and Sastri (1954) considered this horizon to be partly of fault or collapse origin, and placed it above the Mandhata Group, delinked from the dolomites that were classified as 'Archaeans'. Blanford (1869), Ghosh et al. (1981), and Soni (1984) grouped the dolomites and chertbreccias together as probable Bijawar equivalents, unconformably underlying the Mandhata Group. A re-evaluation of the lithological and structural characters of this (Kishangad) Group and the Riphean stromatolitic assemblages from the associated dolomitic horizons (Raha and Sastry, 1982; Sisodiya and Athavale, 1985) has led to the revision of its traditional correlation with the early Proterozoic Bijawar Group and it

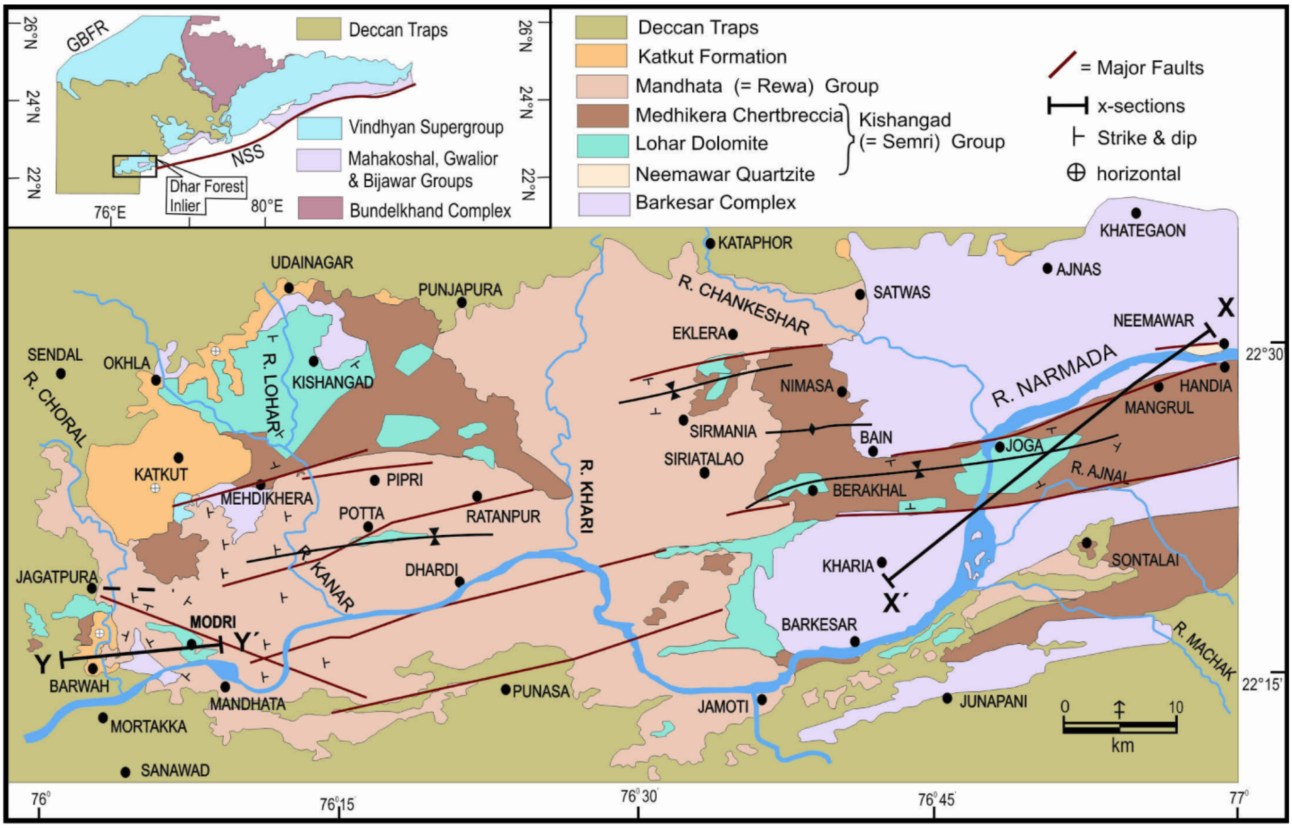

Fig.4. Geological map of the Dhar Forest Inlier (*after* Kale, 1989). Inset shows the location of the Dhar Forest Inlier along the southernmost margin of the Vindhyanchal Basin. The Lohar Dolomite and Mehdikhera Chertbreccia are depicted in this map, while other formations from the Kishangad Group are too small to show independently on this scale. Locations of the section lines XX´ and YY´ of Figs 5a and 5b respectively are depicted.

Table 3. Precambrian Lithostratigraphy of the Dhar Forest Inlier (*after* Kale, 1987, 1989)

	Formation	Structure / Metamorphism	Correlation and Age
Mandhata	• Ratanpur Sandstone • Dhardi Shale • Kanar Sandstone • Jamoti Shale	Gentle, wide amplitude open folds and faults. Unmetamorphosed	*Neoproterozoic* Rewa Group
~ *Angular and erosional unconformity*~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
Kishangad Group	• **Mehdikhera Chert breccia** • Lohar Dolomite • Mangrol Traps • Neemawar Quartzite	Plunging open folds, faulting and intense brecciation, Profuse silicification	*Mesoproterozic* Semri Group
~ *Angular and erosional unconformity*~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~			
	Khategaon Granite	Intrusive granites and syenites	
Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ *Intrusive Contact* Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ Λ			
Barkesar Complex	Barwah Metamorphics	Isoclinal folds, Greenschist facies	Mahakoshal / Bijawar Group
– – – – – – – – – – – – – – – ? ? ? ? ? ? ? ? *Contact not clear* ? ? ? ? ? ? ? ? – – – – – – – – – – – – – – – –			
	Basement Gneiss	Gneissic granites	*Archaean* Basement Complex

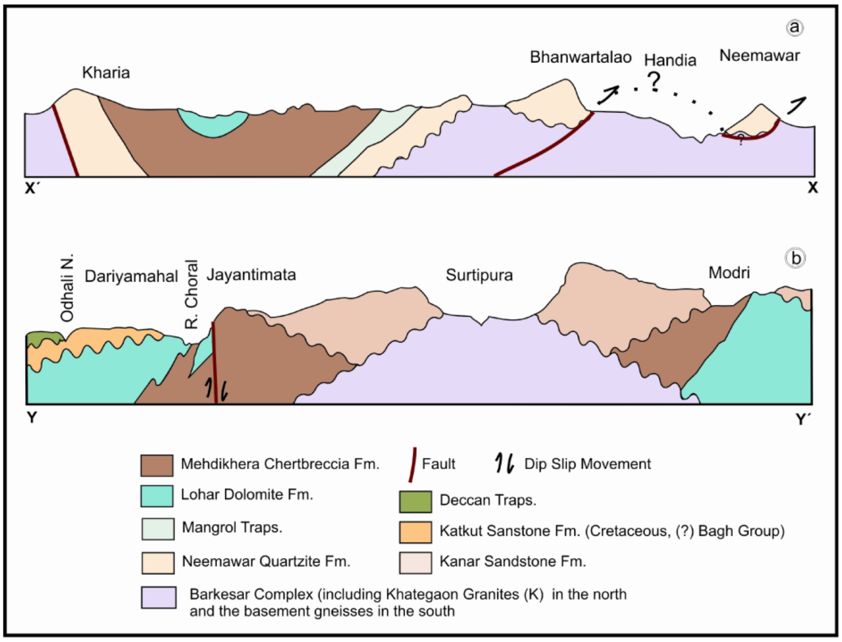

Fig.5. Schematic cross section of the Kishangad Group: **(a)** across Handia-Joga-Berakhal tract depicting the structural and stratigraphic relations between various litho-units. The location of the section line is shown in Fig.4 as XX'. **(b)** across the southwestern exposures between Barwah and Modri across River Choral The location of the section line is shown in Fig.4 as YY' (*after* Kale, 1985b).

is now recognised as the local equivalent of the Semri Group of the Vindhyan Supergroup (Kale, 1985b, 1987). This Mesoproterozoic age is further supported by the age of underlying Khategaon Granite dated as 1856±68 Ma (Bandyopadhyay et al. 1990).

The Mehdikhera Chertbreccia occurs interbedded within the Kishangad Group (see Fig. 4). In a syncline south of Neemawar, the Neemawar Quartzites are followed by exposures of altered metabasalts, which are followed upward by the formless and barren exposures of chertbreccia. The contact between the chertbreccia and the underlying quartzites as well as metabasalts is often concealed below soil cover. This chertbreccia is succeeded by the Lohar Dolomite, which hosts giant columnar stromatolitic colonies (Balasundaram and Mahadevan, 1972). However, the widest and thickest accumulations of the Mehdikhera Chertbreccia and Lohar Dolomite are observed further north-westwards (Fig. 4), in the Lohar and Kanar river valleys around Kishangad (see: Fig 3 of Kale, 1989). Here, both these lithologies display a sharp contact with each other, but faulted relations with the Kanar Group. In the upstream sectors of both the rivers, they are overlain by the Katkut Sandstone and Deccan Traps. In this sector, the chertbreccia completely lacks stratification; but rests upon the Lohar Dolomite (unlike the section around Neemawar – Joga; Figs. 5a, b). Kale, (1985a) had pointed out that with the presence of frequent faults in this region; there is every chance of the chertbreccia being mistaken for fault breccias. It is only through dedicated mapping that the exposures of the chertbreccia can be appropriately recognised, based on:

- Their conformable interbedded relations with the dolomites and quartzites; as against the cross-cutting relations of the fault breccias;
- The development of 'bald low-hill' topography on them, while most fault breccias are encountered along linear stream channels; and
- Their widespread, unstratified and unfoliated nature in contrast to the streaky linearity observed for the fault zone breccias.

FIELD RELATIONS

The most striking feature of chert-breccia is the absence of stratification (Fig. 6a). Disjoint strings of small linear ridges, which extend parallel to the strike of the associated sedimentary horizons of dolomites and minor quartzitic sandstones and shales are the only indicators of the orientation of the Mehdikhera Chertbreccia (Fig. 6d). This obscurity of stratification or bedding planes is also noticed in the Niralkeri Chertbreccia and most of the exposures of the Mahakut Chertbreccia. The exposure of the latter along the northern limb of the anticline north of Bagalkot; however does display crude banding (Fig. 6c). This banding is marked by a sequential predominance of clasts of dolomites, shales and quartzites from north to south. The bands grade into one another upward in the sequence and are individually 5-10 m wide. Comparable banding has not been noticed at any other exposure of the chertbreccia, either in the others parts of the Kaladgi Basin or in the Dhar Forest Inlier.

The interrelations between the chertbreccias and the adjoining rocks are confusing due to the massive unstratified nature of the former. The rubble released due to its weathering further adds to this confusion, by masking its contacts. Blanford's comments (1869, p. 260) for the exposures in the Dhar Forest Inlier that "the breccia and the limestones are perfectly distinct and do not pass into each other, yet they are most strangely mixed together", captures the root of this problem. In the Kaladgi Basin also, Foote, (1876, p.75-76) recorded that the cherty breccia beds "by their peculiar mode of weathering into disconnected

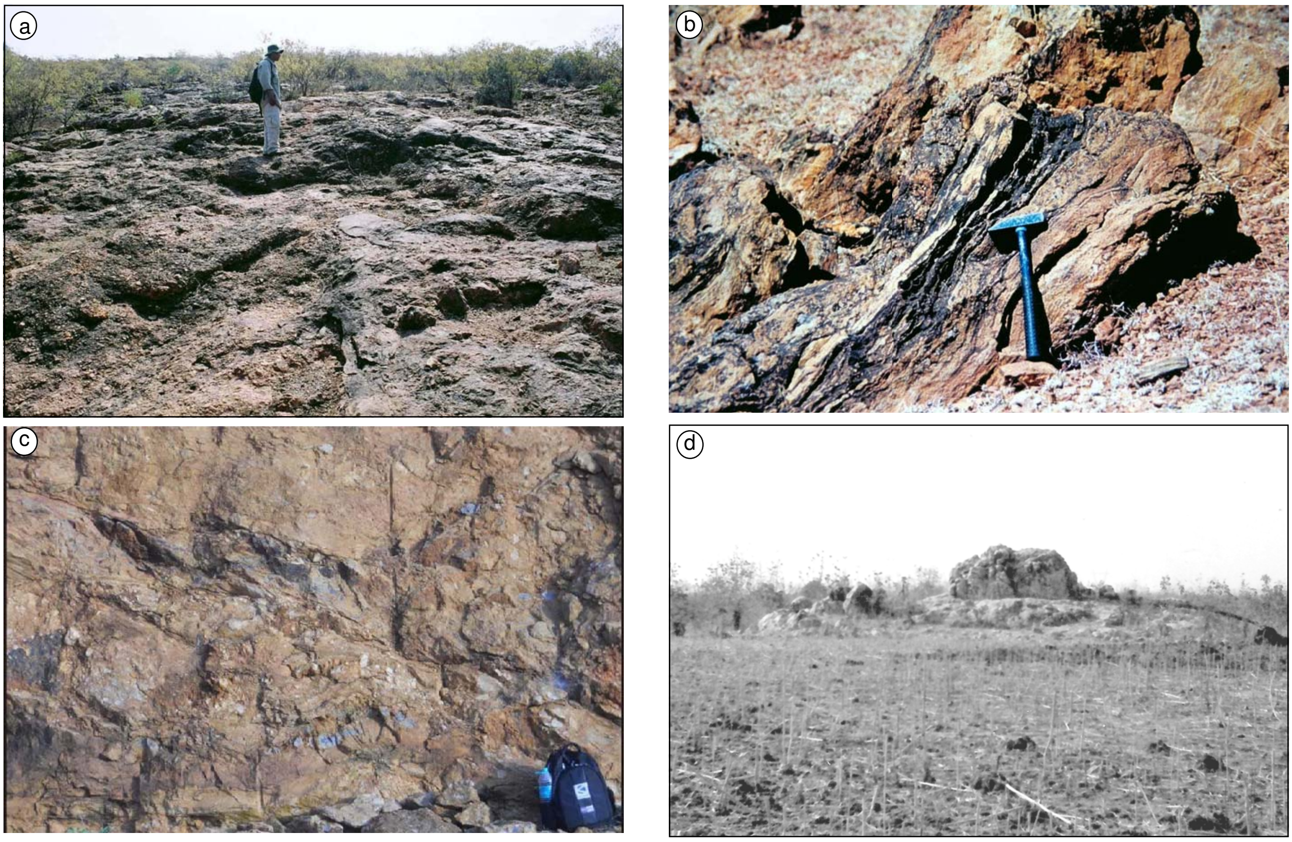

Fig.6. Field photographs of Mahakut Chertbreccia **(a)** showing bald, low-hill topography without any distinct stratification, **(b)** showing crude banding. The hammer used for scale is 30 cm in length. **(c)** Crude banding marked by alternating dominance of quartzitic and dolomitic clasts. **(d)** Mehdikhera Chertbreccia occurring as disjoint, isolated, tor-like exposures within the Kishangad Group.

fragmentary masses with much small debris, obscure the relations of the under and overlying rocks". This obscure nature of the contact of the chertbreccia with the associated sediments, in conjunction with their constitution as a coarse, angular and disoriented admixture in a cherty matrix led to their interpretation by Bose (1989), Roy Chowdhury and Sastri (1954) as a fault-zone or as collapse breccias.

In the late 1970's and 1980's they were recognised as being mappable stratigraphic horizons by Viswanathiah (1979), Ghosh et al. (1981), and Jayaprakash et al. (1987). The remote sensing data (aerial photographs and multispectral satellite images) has added clarity to the "spatial distribution of chertbreccias and their mutual relations with the associated lithologies" (Kale, 1996; Kale et al. 1999).

That these rocks occur conformably interbedded with the other shallow marine sediments hosted in the Vindhyanchal and Kaladgi Basins is unambiguous. They may occur as massive beds, thin seams or as interfingered lenses within the quartzites and dolomitic horizons. In both the areas, the thicker chertbreccia beds also display intercalated horizons of dolomitic limestones. It is significant to note the observation (Kale et al. 1996) along the southern fringes of the Kaladgi Basin, where the suite of arenites-argillites-carbonates is exposed in a monoclinally dipping succession along with the chertbreccias. Here it appears that the argillite development and chertbreccia proliferation appear to be mutually exclusive in space. Thicker exposures of argillites are encountered in the western side where chertbreccia development is absent or limited to thin intercalations; while in the east, argillites thin out and chertbreccia beds are prominent. It is perhaps relevant in this context that in the Dhar Forest Inlier, where the proliferation of chertbreccia is ubiquitous, the Kishangad Group has negligible argillaceous beds.

In both the basins, the geological maps (Figs. 2 and 4) and cross-sections (Figs. 3a and 3b; 5a and 5b) are used to demonstrate that the chertbreccia horizons have been folded and faulted along with the associated lithologies. Therefore it can be concluded that the formation and lithification of this lithology predates any deformation suffered by the sequences in which they occur. Their inherent characters cannot be assigned to such superimposed deformation.

CHARACTERISTICS OF CHERTBRECCIAS

The petrological characters of the Mahakut and Mehdikhera Chertbreccias are remarkably similar to each other. Without prior knowledge, it is not easy to discern, whether a particular specimen or thin section is of chertbreccia from Kaladgi Basin or from Dhar Forest Inlier. The prolific regional development in the Dhar Forest Inlier as against relatively restrictive development in the Kaladgi Basin, dominance of dolomitic clasts in the Mehdikhera as against the admixture in the Mahakut, and the relatively more obvious banded nature of the latter are the only exceptional traits that separate these two. Hence the petrological characters of both of them are described together below.

FIELD CHARACTERS

The exposures of chertbreccias display rugged topography with stray linear ridges. The slopes of these ridges are covered by subangular talus, while its peaks are lined by tor-like blocks. In the planar tracts, smooth surfaces of exfoliation joints are lined with blocky and gravely material, making it difficult to recognize insitu blocks.

The obscure stratification of this rock makes it difficult to recognise its orientation. The extensive (more than 2 - 3 km wide) exposure of the Mehdikhera Chertbreccia occurring south of Kishangad is a typical case where one may not be able to discern any stratification or attitude of bedding of these rocks across several 100s of meters. Associated and interbedded sedimentary beds and lensoid intercalations serve as the only reliable clues of the bounding surfaces of the chertbreccia beds. Superimposed joint-patterns have further obliterated the evidence of stratification in vast tracts of exposures of the Mehdikhera Chertbreccias. Several traverses in both the chertbreccias, along and across the strike, failed to reveal any bedform features or patterns of the grain-size variation of the clasts. As mentioned earlier, the northern limb of the anticlinal fold, north of Bagalkot (see Figs. 2, 3b and 6c) is the only exposure, where crude banding can be recognised in the chertbreccia. They are therefore recognised as "massively bedded" (*sensu* Pettijohn, 1977, p. 104) or "very thickly bedded" (*sensu* Tucker, 1982, p. 48) deposits, devoid of internal stratification or partings.

These rocks display a wide range of colours and a patchy texture in the field. Pink, yellowish-brown, white and pale grey shades are the most common. Weathered surfaces display varieties of earthy and reddish brown shades. The fresh rock is hard to break and splinters along concoidal fractures. Strong cohesion exists between the framework clasts and the matrix making it impossible to disaggregate the clasts, indicating a significant degree of compositional homogenisation between the two, an observation that is reaffirmed in the thin sections.

MEGASCOPIC CHARACTERS

This rock displays a matrix-supported rudaceous texture (Fig 7a). The lithic clasts are arranged in a haphazard manner, but at places may display a localised, patchy continuum of folded laminae, boudinaged or fractured patterns. The framework component is very poorly sorted and the clasts range in size from coarse sand to very large boulders. These clasts are angular to subangular in shapes (Fig. 7b).

In hand specimens, it is often possible to recognise the source rock of the lithic clasts, due to their internal inherited characters such as banding or layering, stromatolitic laminations, current bedding etc. Occasionally, these clasts also display inherited deformation. As mentioned earlier, no lateral or vertical gradations are discernible in the

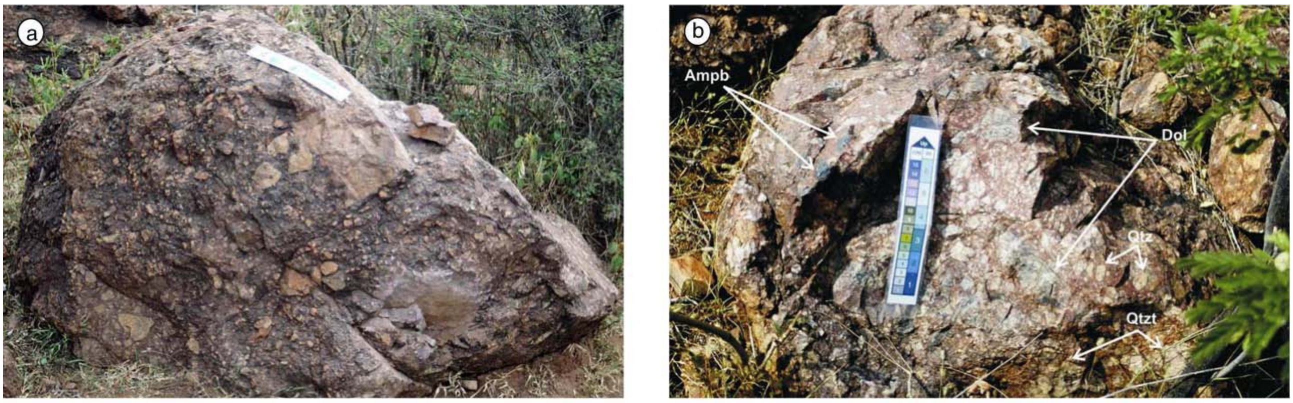

Fig.7. (a) Field photograph of Mahakut Chertbreccia showing matrix supported rudaceous texture and clast size variation. The white scale on the exposure is 20 cm in length. **(b)** Field exposure of Mehdikhera Chertbreccia near Potta, showing fragments of amphibolites (Ampb), dolomites (Dol) and quartzites (Qtzt).

chertbreccias, in sorting or packing characters, though different specimens/exposures display divergent grain sizes, sorting and packing.

The matrix is supported by cryptocrystalline, hard cherty material mixed up with fine clastic particles. They are devoid of any laminations in most cases, though at places, colloform and parallel laminations can be seen. Jaspedious and novaculite varieties randomly interspersed with very fine grained, sacchroidal cherty silica and banded chalcedony impart the diverse colours to the rock. The outlines of the framework clasts are usually very sharp, but the relatively fine clasts locally seem to merge with the cherty matrix and may display peripheral corrosion, or embayment of chert along the cracks in them.

Several attempts, using direct and indirect methods of measurements (e.g.: overlays/photographs/etc.) failed to reveal any consistent pattern in the clasts: matrix proportions of this rock as the wide variations in the clast sizes impose severe limitations on the accuracy of these measurements. The clasts vary between 15% and 67% of the measured surface areas.

FRAMEWORK CLAST COMPONENTS

Field exposures, hand-specimens and thin sections were studied to identify the parentage of the framework clasts. It has been observed that lithic fragments are the dominant constituents of the framework clasts. Quartz, feldspar and chert clasts are generally smaller in size, and often display relatively higher degree of rounding than the lithic clasts. While no accurate measurements are possible, the mono-mineralic clasts account for less than 5% of the framework in the Mahakut Chertbreccia. The proportion is slightly higher (~7-10%) in the Mehdikhera Chertbreccia, with quartz (chiefly the polycrystalline type) alone accounting for around 5%. The matrix is about 43%.

The lithic clasts can be attributed to intrabasinal as well as extrabasinal sources. The intrabasinal clasts are around 10 to 15 times more abundant than the extrabasinal clasts. In sequence of decreasing frequency, the intrabasinal clasts include:

1. Quartzitic sandstones,
2. Dolomites (both stromatolitic and non-stromatolitic varieties),
3. Siltstones and shales,
4. Ferruginous sandstones and
5. Polymictic conglomerates.

This lithic clast assemblage is identical to the sediments associated with these chertbreccias in the Bagalkot and Kishangad Groups. In the Mahakut Chertbreccia, fragments from the underlying Precambrian basement, constituted of granites and gneissic, quartz-mica and hornblende schists, sericitic quartzites and amphibolites are present (Fig. 7b). In the Mehdikhera Chertbreccia fragments of granitoids, siliceous and ferruginous phyllites, quartz-sericite schists and deformed, flattened, schistose conglomerate constitute the extrabasinal clasts that are comparable to the rocks of the Barkesar Complex. This admixture of intra- and extra-formational clasts in the chertbreccias, and their angularity does impart "fault breccia" like appearance to this rock, as has been interpreted by some earlier authors.

The outlines of these framework clasts are sharp and distinct in hand-specimens as well as in thin sections when seen in plane polarised light. Overgrowths are rare and restricted to the quartz grains. Undeformed clasts are blended with the intrabasinal clasts, which display inherited deformational features. This indicates that these intrabasinal clasts were derived from the associated sediments after partial deformation of the latter. The angular, unsorted blending indicates that the removal from their individual sources involved brittle fragmentation (=brecciation) and that they were accumulated very close to their source, without suffering even partial or peripheral rounding.

MICROSCOPIC CHARACTERS

The loosely packed, angular, gravely nature of the chertbreccias is evident in thin sections when viewed under plane polarised light, however, this effect is obliterated in crossed polars, where the rock displays a composition of very fine-grained, microcrystalline quartz (Fig. 8a and b). Both, the matrix and the framework clasts are observed to be entirely constituted of this. The intergranular spaces are dominantly composed of microquartz, which is relatively fine than that comprising the framework clasts. Sometimes opaque oxides and chalcedonic type fibrous crypto-crystalline chert is encountered along the intergranular spaces (Fig. 8c). Though iron oxides (mainly reddish brown limonite type) is distinctly a later precipitation along cracks and pores, at times hematite and magnetite segregations are found lining the relict bedding planes in the framework clasts (Fig. 8c). The inherited disturbance structures of the component clasts are also observed in thin sections (Fig. 8d). Barring these, the rocks are thoroughly chertified, leaving behind only the pseudomorphs of the framework clasts, embedded in the cherty matrix.

Within the larger clasts, the individual laminations sometimes display differing grain-sizes (Fig. 8c) of the microquartz. This may have some reflection on the original

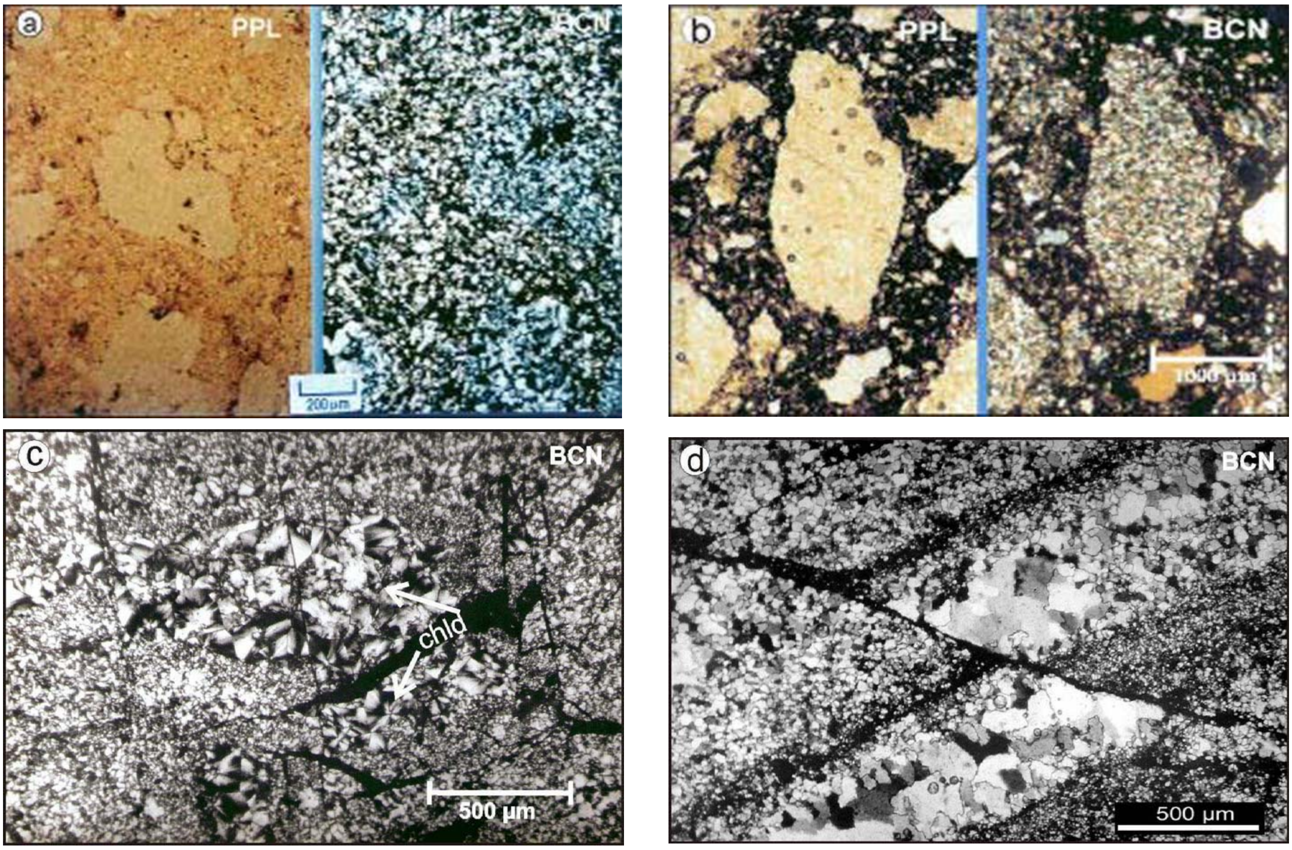

Fig.8. (a) Photomicrograph of Mahakut Chertbreccia. Note the irregular and subangular nature of the framework clasts, which have sharp outlines against the matrix. The clasts and matrix display complete chertification in BCN. **(b, c and d)** Photomicrographs of Mehdikhera Chertbreccia **(b)** displaying similar characters but with ferruginous cement. **(c)** showing pervasive chertification and development of chalcedonic chert occupying interstitial voids. **(d)** showing iron oxides along bedding planes. Note the microfault displacing laminations in this fragment and grain size variation in the original fragment is retained even after chertification.

constitutions of the individual laminations. Coarsening in the grain size of the microquartz, towards the centre of such laminations and a relative fining towards the interlaminar boundaries is commonly observed.

Direct precipitation in cavities and voids yields the chalcedonic type of chert, while the microquartz variety is produced during replacement by silica (Folk and Weaver, 1952, p.506; Adams et al., 1984, p. 85). Replacive silicification thus appears to be the dominant cause of the siliceous constitution of the chertbreccias. The evidences mentioned above and the obvious diversity of the ancestry of the clast grains show that these are not disrupted deposits of chert. Rather an existing accumulation of assorted debris that was subsequently replaced pervasively by the siliceous material. The point to point replacement of the original material produced the pseudomorph clasts and the cherty matrix. The remnant solidifying fluids, entrapped at the interparticulate spaces may have produced the patchy, intergranular chalcedonic chert.

SYNTHESIS

Chertification is obviously a superimposed character, post-dating the accumulation of the debris but predating the deformation of the Bagalkot and Kishangad Groups, and hence the silicification therefore may be provisionally treated as a diagenetic phenomenon. The debris have been derived from both intrabasinal and extrabasinal rock sources. The interbedded nature of this debris within the intrabasinal (source) sediments indicates close links between the processes, which yielded debris and the depositional system itself, which gave the enveloping sediments. The retention of the clasts angularity also supports this, by severely restricting the distance of transport of debris. The interbedded and intercalated relations between the allied sediments and the chertbreccias indicate that the process of the debris accumulation did not severely alter the broad depositional framework of these systems, which reset itself rapidly following the event of debris deposition. Hence, to better constraint the process(es), which yielded the chertbreccias, the associated sediments are briefly described below.

ENVELOPING SEDIMENTS

In the Mahakut Chertbreccia, quartzitic sandstones, shales (both siliceous and ferruginous), thin bedded chert layers and cherty dolomites are interlayered. These thin horizons are often the only clue to the orientation of chertbreccia beds. In the Dhar Forest Inlier, the quartzitic sandstones and thin conglomeratic bands are most frequently observed intercalated within the mass of chertbreccias, with minor shale and siltstone bands and the dolomites. The chertbreccias themselves may occur as lenses interbedded within the other sediments.

In both, the Kaladgi Basin and the Dhar Forest Inlier, more so in the former, the main bulks of the chertbreccias are most frequently found straddling the siliciclastic-carbonate transitions. As a result, the chertbreccia horizons are more closely associated with the dolomites, which are conformably juxtaposed laterally as well as atop the former.

DOLOMITES

The Chitrabhanukot and the Lohar Dolomite Formations are represented by thinly, bedded, crystalline calc-arenite grainstones. The alternate laminations are discernible due to differences in grain sizes or alternation of pure and siliceous dolomitic laminae. Alizarin Red Stain-test (Adams et al. 1984) showed that these rocks are 'clacite dolomites' or 'dolomites' (Tucker, 1988, p. 140). The stromatolitic varieties display bioherms comprising alternate cherty and dolomitic laminations. Sparry, unimodal, non-planar textures are commonly observed in thin sections. Some coarse grained layers display planar-s type idiotopic textures, while the stromatolitic varieties generally display fine-grained xenotopic textures of Sibley and Gregg (1987). Stringers and lenses of lithoclasts, predominantly of quartz, testify to episodic influx of clastic material into this carbonate facies.

The stromatolitic forms from the Chitrabhanukot Dolomite and Lohar Dolomite are attributed to *Kussiella – Colonnella - Conophyton* assemblages of early Riphean age (Raha and Sastry, 1982; Kumar, 1984; Sisodiya and Athavale, 1985; Kale, 1989, 1990, Sharma et al. 1998, 1999). The stromatolitic forms testify to protected, carbonate tidal flat environments (Logan et al. 1964; Kale, 1989). The preservation of ripple marks overprinted on the stromatolitic laminations (Fig. 9a) and on the bedding laminations suggests that they were occasionally subjected to wave action of the water column. Intraformational breccias (Fig. 9b), load structures and convolute bedding within these dolomites indicates that the basin-floor was occasionally disturbed, interrupting their depositional sequence, possibly permitting subaerial exposure.

ARGILLITES

Thinly bedded siltstones and shales are more frequently encountered in the Bagalkot Group than the Kishangad Group. Siliceous and ferruginous varieties of mudflat deposits are encountered, characterised by flaser and lenticular bedding. Slump folds and contorted bedding commonly observed in them; testify to events of synsedimentation instability of the basin floor (Patil-Pillai and Kale, 1999, 2008; Patil Pillai, 2005).

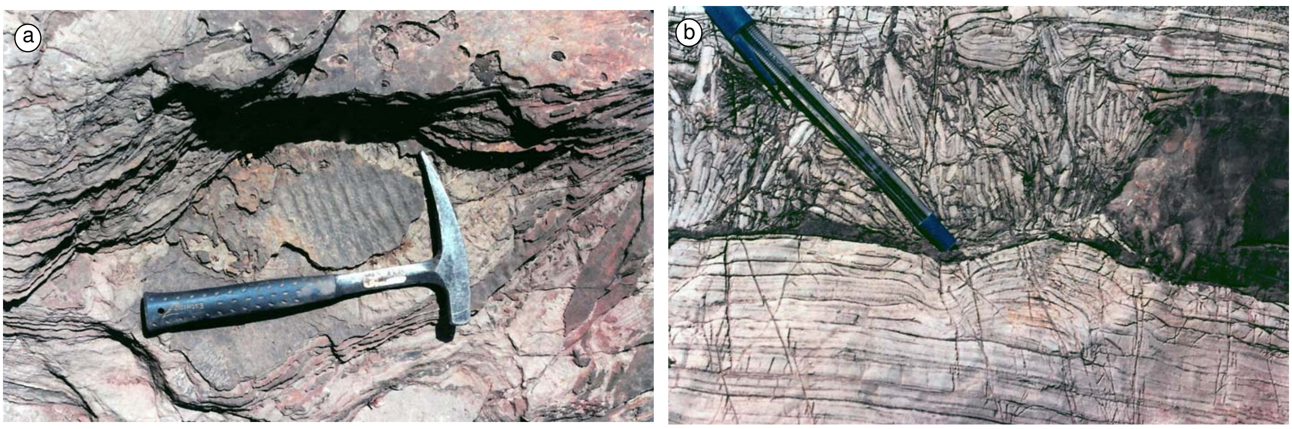

Fig.9. (a) Parallel ripple marks preserved on the laminations of the stromatolites from Lohar Dolomite, near Joga. The hammer used for scale is 28 cm in length. **(b)** Intraformational breccias in Lohar Dolomites, Kishangad Group. The pen used for scale is 15 cm in length.

SANDSTONES/ QUARTZITES

The thickly bedded and tabular current-bedded quartz arenites are thoroughly polygonised and recrystallised into glassy quartzitic sandstones, in the Bagalkot as well as the Kishangad Groups. The relict outlines of the clastic grains testify to their subrounded to rounded nature and a unimodal well sorted texture. At places they show disrupted bedding, indicating penecontemporaneous deformation. Cherty, nodular concretions are occasionally encountered within the quartzitic sandstones, some of which are replaced by botryoidal iron oxides. Horizons of this rock intercalated within the chertbreccias display upward fining and are often floored by thin conglomeratic layers.

CONGLOMERATES

Polymictic, extraformational conglomerates generally occur as thin layers interbedded within the arenaceous beds or as a 25 m thick bed at the base of the Bagalkot Group. Internal graded bedding and sometimes rhythmic upward fining is commonly observed within these rudites. The relatively finer rudites display faint tabular cross-bedding and channel-fill structures.

DEPOSITIONAL ENVIRONMENTS OF THE SEQUENCE

The Bagalkot and Semri Groups (represented in the Dhar Forest Inlier by the Kishangad Group) constitute the earliest deposits in the Kaladgi and the Vindhyanchal basins respectively (Jayaprakash et al. 1987; Soni et al. 1987). Their overall constitution is comparable to "Assemblage I" of Condie (1982) which is recorded from stable continental margins or intracratonic basins. They contain all features of a typical transgressive suite deposited in the early phases of basin evolution on an uneven eroded basement. The rudites and quartz-arenites are shoreline deposits while the argillites and carbonates represent the tidal flat facies in these two basins.

Generally passivity of this depositional system, without high energy inputs (excepting for the deposition of basal rudites) is evidenced by thick argillite and carbonate accumulations. Within this low to moderate energy, stable shelf system, the chertbreccias have been deposited and chertified. The clast coarseness in the chertbreccias suggests considerably higher energy transporting currents than the enveloping sediments. This energy contrast and the blending of the intra and extra-basinal clasts have been major hurdles for the 'sedimentary' interpretations of the chertbreccias. Further, the fact that the "passive-margin" sedimentation framework persisted before, during and after the accumulation of the chertbreccias is seen from the mutual inter-relations between them and the associated sediments. The considerable thickness of the chertbreccias is contradictive of their being storm-deposits.

DISCUSSION

The various similarities in the constitution and occurrence modes of the Mahakut and Mehdikhera Chertbreccias far outweigh the nominal differences between them. Their genesis must have therefore been through identical processes. Comparisons with the published descriptions of the other Proterozoic chertbreccias from India by other authors indicate close petrological similarities with them as well. Of the diverse genetic models, proposed to explain the chertbreccias by earlier authors, the more popular interpretations were:

- Fault breccia
- Collapse breccia
- Purely rudaceous (breccia) sediments.
- Pedogenic, silicified deposits and
- Disturbed brecciated chert-beds.

The heterogeneity and angularity of the framework clasts in association with the lack of stratification were used to interpret these rocks as pedogenic or cataclastic deposits (e.g.: Foote 1876, in part; Fermor, 1909, p.272-277; Ghosh et al. 1981). The close association of faults with the exposures of the Mehdikhera Chertbreccias was considered as an additional evidence of it being a fault breccia by Bose (1884, p. 12-13). However, conformable, interbedded relationships of the chertbreccias within the Bagalkot and Kishangad Groups show that neither of these processes could have been independently responsible for them. The loose sorting and coarse nature of the chertbreccia framework; as well as the 'boudinage-like disruption of some of the clasts observed in them could be attributed to emergent cracking as in case of pedogenic deposits. However, the thickness as well as the extrabasinal clasts in them would not be explained by this mode of origin. Further, the 'disconformable relation' between the strata below and above a pedogenic horizon is absent in the relationships observed between the chertbreccia and the dolomites.

A collapse origin was attributed to them, presuming a shrinkage of the carbonates either during dolomitisation or through subsequent dissolution (e.g.: Foote, 1876, p.75-76; Chakrabarti, 1980). The interbedded relations and the fact that chertbreccias dominantly occurs abutting against underlying dolomites in the Kaladgi Basin and the Dhar

Forest Inlier deters such an interpretation. Further, the occurrence of chertbreccia lenses intercalated within the Saundatti Quartzites (e.g.: at Ramdurg and east of Saundatti), which are separated from the carbonates by a stratigraphic thickness of over 100 m cannot be explained by the collapse model. One would also expect overburden rocks to collapse into the underlying lithologies in such a situation, while often the carbonates rest upon the chertbreccias in both the basins. Most of the field relations of the rocks strongly indicate its sedimentary nature, conformable within the associated transgressive sediments, as has been recognised by many recent authors (Ghosh et al. 1981; Sisodiya and Athavale, 1985; Jayaprakash et al. 1987 etc.).The presence of diverse framework clasts in these rocks indicates that their interpretation as brecciated chert-beds is untenable as well. In a chert bed that suffers brecciation, the clasts would be homogeneous and not heterogenous.

Texturally, the chertbreccias display close similarities with the tillites. In fact, the admixture of intra and extra-basinal clasts observed in the chertbreccias would be expected in diamictites. However, the poor documentation of the Proterozoic glacial events in the Indian Peninsula (e.g.: Radhakrishna, 1987), absence of any evidence of glacial erosion in the basement of Bagalkot and Kishangad Groups and the warm water environments of the sediments in the Kaladgi and Vindhyanchal Basins as testified to by glauconitic sediments, evaporites and stromatolites from these successions (see: Raha and Sastry, 1982; Singh, 1980a, 1985) stand against such an interpretation. It is therefore unlikely that these rocks are diamictites / tillites that were deposited through any process associated with glaciation.

Taking into consideration the textural characters, these rocks have a lot of similarities with (alluvial or submarine) fan gravels. They could be compared with the disorganised gravel facies (A1-1) of deep marine sediments (Pickering et al. 1989, p.43). However, they lack the spatial (lobate) geometry of the fan deposits, and do not show the lateral facies changes associated with fan deposits (e.g.: Stow, 1981; Bouma et al., 1985a; Neef et al., 1985) in the Kaladgi Basin and in the Dhar Forest Inlier. The associated sediments display a typical shallow marine, near-shore shelf affiliation, as mentioned earlier. Therefore, although the chertbreccias cannot be fan deposits *sensu stricto*, it is likely that the transportation and dumping of this debris may have resulted through comparable processes.

Prima facie, the transportation of the coarse, unsorted rudaceous material would require an extremely high energy transporting medium (Allen, 1985), in contrast to the low energy depositional system within which the chertbreccias occur. However, studies of debris flows, in a fluidised or liquefied state have shown that such flows (without significantly large energy requirements) are capable of transporting large blocks over very gentle basin-floor slopes, without inducing any significant rounding or sorting (Rodine and Johnson, 1976; Tucker, 1988, pp.73-74) and producing unstratified deposits of a structure-less character. Such a mechanism is therefore distinctly conceivable for the constituent debris in the chertbreccias.

Since such debris flows are relatively instantaneous events, they will not significantly alter the sedimentological framework of the depositing system. This will explain the intercalations of the associated lithologies within the chertbreccias and vice versa. Further, the thickness of the debris will not be strictly time dependent, but rather will be a function of the size and strength of the debris flows itself.

Given this mechanism of deposition and transportation, the next character, which needs explanation is the blending of intra- and extra-basinal clasts, particularly the profusion of the former. The shape of the clasts (i.e. their angularity in particular) points to their production through brecciation and fragmentation. The (source) associated sediments, which under and overlie the chertbreccia, as well as the basement rocks should be involved in this cataclastic event. The margins of the Kaladgi Basin are fault-bounded at several places (Jayaprakash et al. 1987; Peshwa et al. 1989, Patil Pillai, 2005). Several intrabasinal faults are subparallel to the basin margins and the basal siliciclastic horizons of this basin are traversed by bedding plane faults (Gokhale and Pujar, 1989). Deep crustal faults along the Narmada-Son Structure are known to have controlled the geometry and evolution of the Vindhyanchal Basin, including its southernmost exposure in the Dhar Forest Inlier (Murthy and Mishra, 1981; Valdiya, 1982; Kale, 1986). Both, the Kaladgi and the Vindhyanchal Basins have been generated in extensional tectonic regimes (Kale, 1990). Growth fault arrays transect the floors of extensional basins (Gibbs, 1984; Coward, 1986; Klein and Hsui, 1987) and it is very likely that the fault systems mentioned above are manifestations of such growth faults. The various evidences of basin floor instability, recorded from the associated sediments are products of the episodic movements along such growth faults (Kale et al. 1998, Patil-Pillai and Kale, 1999, 2008; Patil Pillai, 2005). It is likely, that same movements were responsible for the brecciation and fragmentation of the earlier deposited and abruptly or completely lithified sediments and their basement along the fault-lines.

Banerjee and Singh (1981) had previously speculated upon the possible affiliation of the Tirohan Breccia (Semri Group of Rajasthan), with the penecontemporaneous tectonism along the great boundary fault of Rajasthan, which has been known to have controlled the western margin of the Vindhyanchal Basin (Valdiya, 1982). It is interesting to note that, as many as 68 beds of intraformational breccia have been recorded from the dolomitic limestones of the Semri Group in Rajasthan, which contains intercalated horizons of chertbreccias (Prasad, 1975, p. 39-40). On comparable lines, in the Chikshellikeri Limestone, Kale et al., (1998) have demonstrated that in a sequence of about 500 m more than 72 intraformational limestone breccia horizons are present. Both these occurrences from the carbonates associated conformably with the chertbreccias show that there were multiple events of basin floor instability accompanying the sedimentation in the two basins. While carbonates dominate on the sea-ward side in shallow platform areas; on the land-ward side, where the faults are actually present, such events would produce a disrupted admixture of the earlier lithified sediments as well as their basement.

CONCLUSIONS

The debris constituting the chertbreccias is therefore interpreted to have been produced as a penecontemporaneous tectogenic brecciated admixture, resulting from movements along the growth faults of the Kaladgi and Vindhyanchal Basins, comparable to the tectogenic gravels described by Steidtmann and Schmidtt (1988). Liquefaction of this debris and the initiation of the debris flow in the subaqueous, shallow marine regime may have been caused by the (? seismic) shocks attending the activity of the growth faults (Lowe, 1976; Collinson and Thompson, 1982; p.136). The spatial distribution of this debris draped over the previous sediments (which in part would have also contributed to it) may thus be achieved through a combination of debris flows and plain gravity dispersal, as depicted in Fig.10. Such a model also explains the juxtapositions of the chertbreccias with the faults in both the basins (see Figs. 3a and b; 5a and b). For all practical purposes, this dispersal of the debris may have been achieved swiftly, allowing minimal disturbances to the depositional regime, permitting its rapid resetting (e.g. Lundberg and Dorsey, 1988). This dumped debris, as discussed, would be characterised by poor sorting, loose packing and lack of stratification. It would have sharp limits and in eventual sedimentary accumulation may abut with interfingered, but abrupt contacts with the adjoining rocks, but conformably-within the sequence. Eventual chertification will yield all the characters of the chertbreccias.

There is no doubt that elaborate, particle by particle replacement by siliceous material has yielded the present

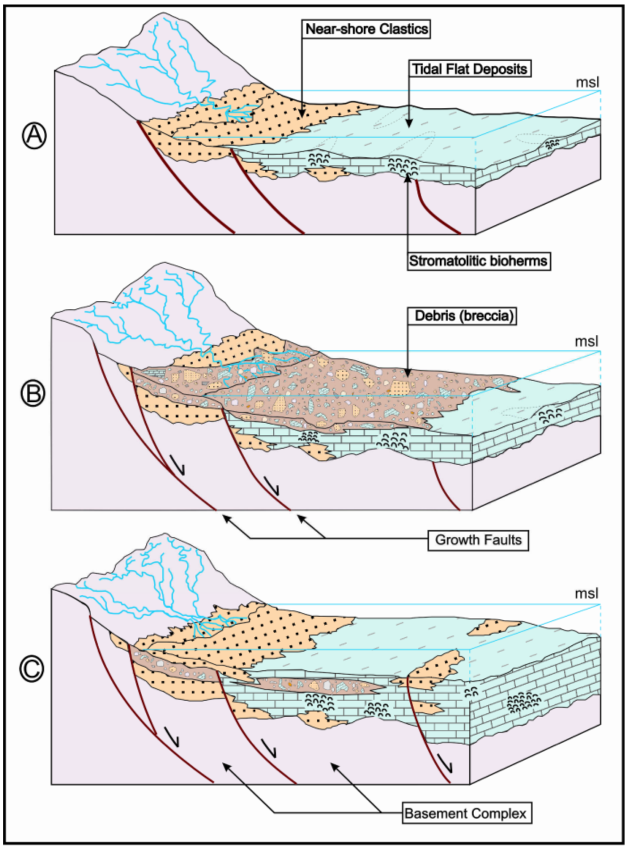

Fig.10. Schematic sketch showing the inferred mode of chertbreccia formation.

composition of the chertbreccias. The higher silica concentrations in the Proterozoic sea-water (Holland, 1984) and the higher geothermal gradients of passive Proterozoic craton margins (Hoffmann and Bowring, 1984) may have assisted this silicification. Current free, restricted environments, proximity of the sediment-water interface and interaction between pore fluids and charged marine/ground waters are known to be conducive to silicification (Knoll, 1985; Pollack, 1987; McBride, 1988).

The close association between the dolomites and the chertbreccias has been pointed out earlier. The inter-replacement of carbonates and silica by each other is known during and after diagenesis (Walker, 1967; Williams et al., 1985). Although the exact process of dolomitisation of lime-carbonates is not very well defined (Hardie, 1987), the broad conditions enabling dolomitisation (e.g.: Chilingar, et al., 1979; Wanless, 1979; Tucker, 1988, p. 148-145) are similar to those aiding silica precipitation.

It is therefore likely that the debris dump and adjoining carbonate deposits were subjected to same diagenetic changes. Because of their closer affinity to Ca, the Mg ions from the interstitial fluids yielded dolomitisation of the lime-carbonates. These fluids were consequently enriched relatively in silica, which was possibly quenched by the chertification of the debris. An inherent predominance of silica could be inferred to be responsible for partial chertification of the dolomitic rocks as well. This mechanism of the replacive silicification of the debris can be conceived to exclude the associated arenaceous and finer siliciclastic sediments to a large extent, because of their significantly lower porosity, than the loosely packed debris. It must be accepted that this mode of chertification, with associated dolomitisation is purely speculative, but allows the formation of the chertbreccias in toto, prior to the cessation of sedimentation and the subsequent deformation of the Bagalkot and the Kishangad Groups. The observed deformation in these beds described earlier conclusively shows that rocks were subjected to a cohesive deformation along with the allied lithologies. This in turn could be possible only if the chertbreccia had been fully lithified and interlocked with the rest of the sequence of the Kishangad and Kaladgi sediments.

This model has several implications on the growth and depositional histories of the Purana (/ Proterozoic) platform sediments in the epicratonic basins. Most significant amongst these being that the chertbreccias provide a strong indicator of synsedimentary deformation attendant to the growth of the basins.

This model has been constructed taking into account the observations from the Mahakut and the Mehdikhera Chertbreccia Formations. It would be interesting to see if this can be extended to other Proterozoic platform sediments as well, by studying those deposits in future.

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