Neotectonically controlled catchment capture: An example from the Banas and Chambal drainage basins, Rajasthan

S. Sinha-Roy

Birla Institute of Scientific Research, Statue Circle, Jaipur 302 001, India

The Banas drainage basin in central Rajasthan is asymmetric in nature with respect to the 6th order Hortonian Banas river channel. The minimum distance of the channel from the watershed in the SE segment of the Banas catchment, adjoining the Mej river sub-basin of the Chambal catchment, is only 7 km. This feature is interpreted as having been caused by 25–30 km migration of the Banas watershed from its initial position along the Vindhyan hills to the present position, due to superposition of the Mej river system and its headward erosion in the Banas system in response to neotectonism. A part of the Banas catchment has been captured in this process by the Chambal river system. Since the Mej river system is very active, it is likely to pirate and behead a large segment of the Banas river in the future.

STREAM capture or river piracy has been a popular concept of geomorphologists for generation[1,2]. One stream may erode into the drainage basin of another stream, either by chance or aided by structural features, and either progressively or abruptly divert or capture the tributaries. The trunk stream that is deprived of a part of its catchment with the divide leaping to a new regional position, gets beheaded. Slowly or abruptly migrating divide and catchment capture are part of the regional adjustments among drainage systems that result from progressive changes in response to structural features and neotectonic activities, as a landscape evolves by fluvial erosion.

The Banas drainage basin of central Rajasthan covers ca. 46,570 sq km area[3]. The Banas river originates from the Aravalli range, north of Udaipur, traverses ca. 510 km through the Bhilwara pediplain and across the Vindhyan plateau and joins the Chambal river, SE of Khandar. The Banas catchment is highly asymmetric in nature in the sense that the main channel does not bisect the watershed. In its middle reaches, the average width of the basin on the left bank is ca. 100 km, while that on the right bank is 30 km. Notably, between Kachola and Devli the minimum width of the catchment is 7 km near Jahazpur (Figure 1). The adjacent drainage basin is that of the Mej river which is a part of the Chambal drainage basin. This feature of basinal asymmetry needs an explanation. It is proposed to demonstrate here that this feature is caused by divide migration, drainage network adjustments and catchment capture due to neotectonism. For this purpose an area comprising the narrowest part of the Banas basin on the right bank was chosen for study (Figure 1).

e-mail: ssinharoy@yahoo.com

The study area comprises the Precambrian rock sequences, namely Mangalwar Complex, Hindoli Group, Jahazpur Group and Vindhyan Supergroup[4] (Figure 1). The Mangalwar sequence of migmatites and gneisses, and the Hindoli sequence of metagraywacke and metavolcanics constitute the basement rocks[5]. Ca. 2.5 Ga-old Berach granite pluton occurs in the western part of the area. The Jahazpur sequence comprising quartzite, dolomite and BIF, occurs as infolded cover sequence on the Hindoli Group above a folded unconformity[6]. Limestone, shale and sandstone of the Bhander Group of the Upper Vindhyans represent the Vindhyan Supergroup.

The basement rocks and the Jahazpur cover sequence show structures of multiple deformation producing regional schistosity, crenulation cleavage and at least four generations of folds[7]. The Vindhyan rocks show highly appressed to open non-cylindrical folds with the axial traces, being roughly parallel to and the fold tightness increasing toward the Great Boundary Fault (GBF) that separates the Vindhyan rocks and the pre-Vindhyan rocks[8]. Clearly, the GBF has been active in post-Vindhyan times. The GBF, running NE–SW in the study area, separates the Hindoli Group and the Vindhyan rocks and marks the approximate limit of the Vindhyan plateau. It shows several splays, especially into the Vindhyan sequence. The GBF is considered a reverse fault[9] and a hinge-fault with the hinge located between Bundi and Chittorgarh[10]. The average throw of the fault has been estimated at 500 m (ref. 11). Some workers believe that the GBF was initiated as a Vindhyan basin-margin normal fault and that its present reverse nature was acquired later during basin inversion[12]. A complex kinematics of the GBF has been suggested[13] which relates the reactivation of the GBF to indentation tectonics caused by westward push of the Mangalwar–Hindoli terrain by the Bundelkhand massif. The GBF is a reverse fault with nearly orthogonal slip in Chittorgarh sector, while it is an oblique reverse fault with left-lateral slip component in the NE sector, including the study area. This fault geometry is linked with Tertiary and Quaternary deformation of the NW Indian shield in response to Indian plate movement[13]. Neotectonic features have been reported along and adjacent to the GBF[12,13].

Another important tectonic zone in the study area is a segment of the Banas Dislocation Zone (BDZ) which is a deep-crustal regional fault and a ductile shear zone in eastern Rajasthan[14]. The BDZ, which separates the Hindoli–Jahazpur ensemble and the Mangalwar Complex has been very well imaged in Deep Seismic Reflection profiles as ca. 20 km wide NW-dipping reflector[15,16]. It

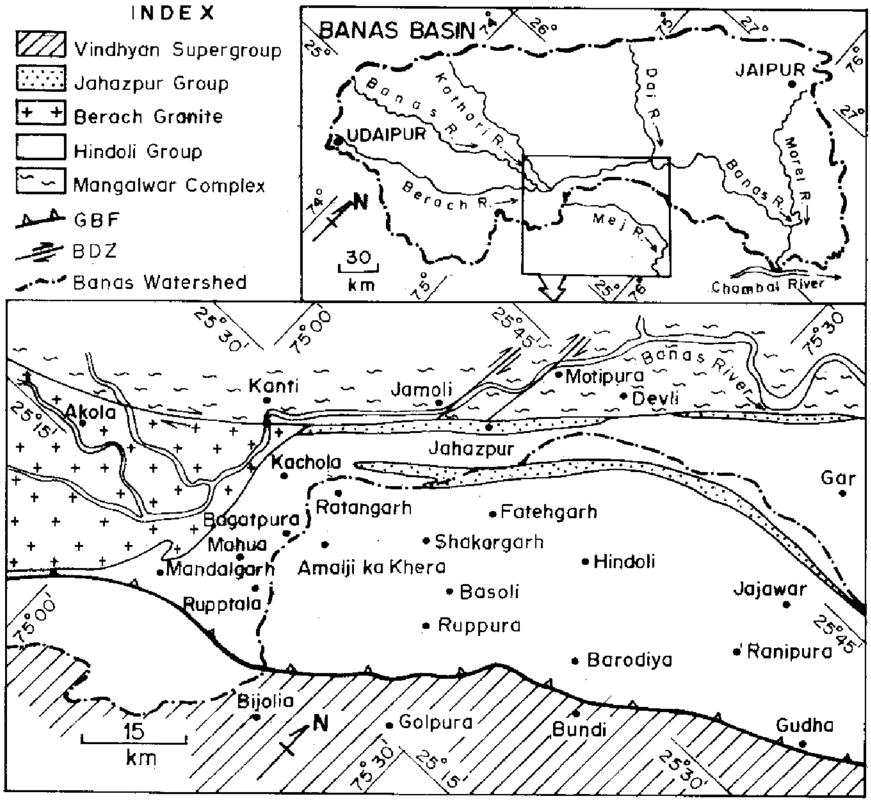

Figure 1. The Banas drainage basin (inset) and the generalized geology of the study area (modified after ref. 4). Principal localities mentioned in the text are shown. GBF, Great Boundary Fault; BDZ, Banas Dislocation Zone.

has an oblique thrust fault geometry with right-lateral slip component in the study area.

The Banas river is a 6th order Hortonian stream whose major 5th order tributaries are Berach on the right bank and Kothari, Mashi, Dai and Morel on the left bank (Figure 1). The Mej river is a 5th order tributary of the Chambal river. The Banas drainage pattern is variable, being controlled by the rock types and major structures. The pattern is generally dendritic in the Mangalwar gneissic terrain, but in the folded sedimentary belts such as the Vindhyan Supergroup, the pattern is parallel and contorted. The Mej river network is fault-trellis to dendritic. The Banas river course follows the BDZ for a long distance showing low-amplitude sinuosity (e.g. west of Jahazpur, north-east of Devli), being controlled by BDZ splays. The Mej river has a remarkably straight course in its upper reaches, which appears to have been caused by the Hindoli structural grain and controlled by a recent fault (see later in the article). At Gudha, the Mej river takes an abrupt right angle southward turn following a fault zone across the GBF, cuts through the Vindhyan range and enters the Vindhyan plateau where it meets the Chambal river. Clearly, the Mej river is antecedent.

Largely faults and lithologic contrasts control the Banas watershed configuration in the study area. It cuts across the Vindhyan plateau and the GBF ca. 15 km to the east of Mandalgarh and the Hindoli stratigraphy up to 10 km east of Kachola. In this stretch the watershed is controlled by a cross fault which displaces the GBF. Beyond this stretch it takes a right-angle turn and runs almost NE–SW subparallel to the Banas channel, 12–7 km away, being controlled by the alignment of competent quartzite and dolomite ridge uplifted along a fault and the BDZ. The average elevation of the watershed is 450 m, the highest elevation being 603 m in the area ca. 20 km south of Mandalgarh. It is dissected and has a subdued topography at many places where the elevation is less than 300 m. The dissection of the watershed is prominent at the head of the Mej river and its tributaries, which indicates that the Mej drainage system is actively eroding headward into the Banas watershed. This is corroborated by the difference in the drainage density (D) and drainage frequency of the Banas network of the south bank in the study area and those of the Mej network adjacent to it. D and F values for the Banas and the Mej are 0.08, 0.11 and 0.18, 0.45, respectively. Since D and F parameters are indicators of the degree of drainage network development through fluvial erosion, clearly, the Mej drainage system is more active than the Banas system in this part of its catchment.

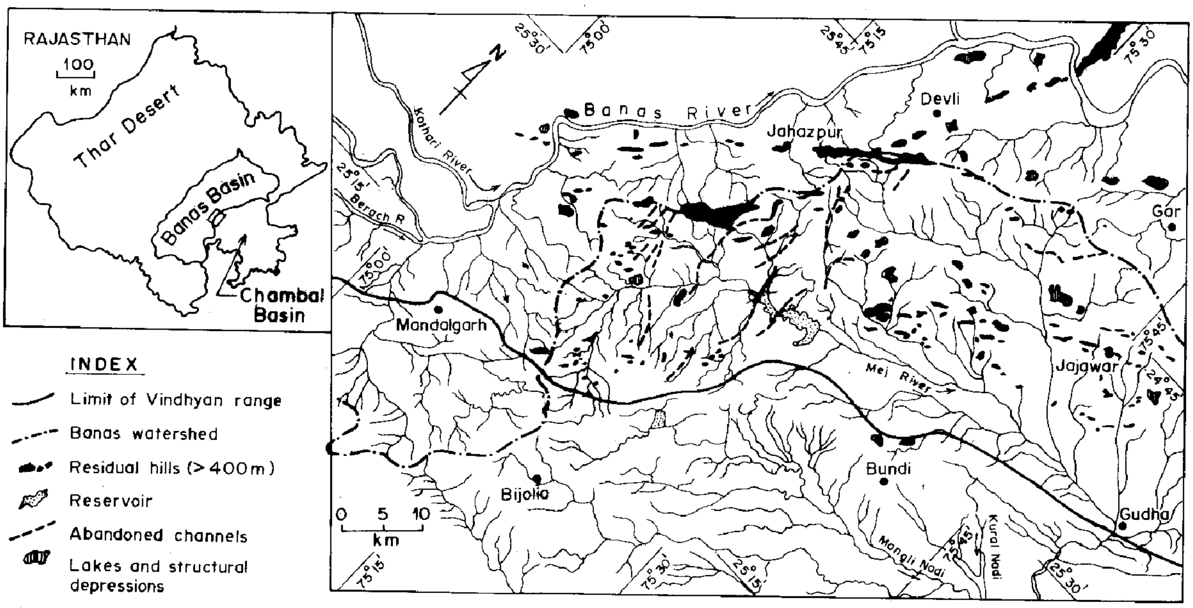

Figure 2. Geomorphological map of the study area. (Inset) Location of Banas and Chambal drainage basins in Rajasthan. Note the zonal distribution of residual hills signifying watershed migration. The palaeochannels in the Mej river basin are athwart and misfit to the Mej drainage network.

Dissected hill range and inselbergs are common in the Mej river basin (Figure 2). Apart from those associated with the Banas basin mentioned above, these features occur as residual hill trails in two tracts, namely Ruptalai-Umar (RU trail), close to the Vindhyan plateau front, and Ratangarh–Fatehgarh–Hindoli–Jajawar (RFHJ trail) at the middle of the Mej river basin. These two trails with elevation ranging from 300 to 400 represent the vestiges of the old watershed of the Banas catchment, which has been captured by the Mej river system.

The existence of a palaeodrainage system in the Mej river basin is indicated by a number of abandoned river channels (Figure 2), identified on IRS-LISS FCC, and through ground check. The general trend of 5–15 km long palaeochannels, occupied by pedogenized fluviatile sediments, is generally N–S, although a few trend NE–SW (e.g. west of Gar). These palaeochannels are generally sinuous and are truncated by the Mej river and its tributaries. It is inferred that these palaeochannels are the relicts of the Banas drainage network that has been superposed and disorganized by the Mej drainage system.

The profile of the study area across the Banas and the Mej rivers (Figure 3) brings out the following features. (1) The Banas and the Mej rivers are in grade with each other, although the latter is a lower order stream than the former. This indicates a high competence and strong erosive power of the Mej river relative to the Banas. (2) The average ground slopes of the catchment of the Banas and the Mej rivers in the study area are variable. This feature is reflected in the difference in gradient of the tributaries on the right bank of the Banas river and those on the left bank of the Mej river. For example, the Unli Nadi, a Banas tributary north of Mandalgarh, has a gradient of 0.54%, while a Mej tributary across the watershed has a gradient of 1.20%. Similarly, a Banas tributary SW of Jahazpur has a gradient of 0.52%, but the gradient of the Mej tributary across the watershed is 1.52%. The hydraulic geometry of evolving river basins suggests that the tributaries of the capturing stream have steeper longitudinal gradients than those of the defeated stream[2]. It is therefore argued that a number of the Banas tributaries have been captured and others are in the process of being captured by the Mej river system.

Many authors have described neotectonic features from Rajasthan[13,17–19]. Post-Vindhyan (Jurassic?) regional uplift of the Aravalli range and formation of various erosion surfaces have been postulated[20]. The exact ages of the two prominent dislocation zones in the study area, namely BDZ and GBF, are uncertain. However, several geomorphic features suggest that these dislocation zones are neotectonically active[5,12,13].

Several longitudinal and transverse normal faults have been recognized in the area (Figure 4). Although these faults have good geomorphic expressions, the geometry of the longitudinal faults, including the fault plane dip and direction is difficult to ascertain. However, at some places (e.g. Shakargarh, Amalji Ka Khera) the displacement of the marker lithological units indicates normal fault geometry, with the fault planes dipping steeply toward south and south-east or are vertical.

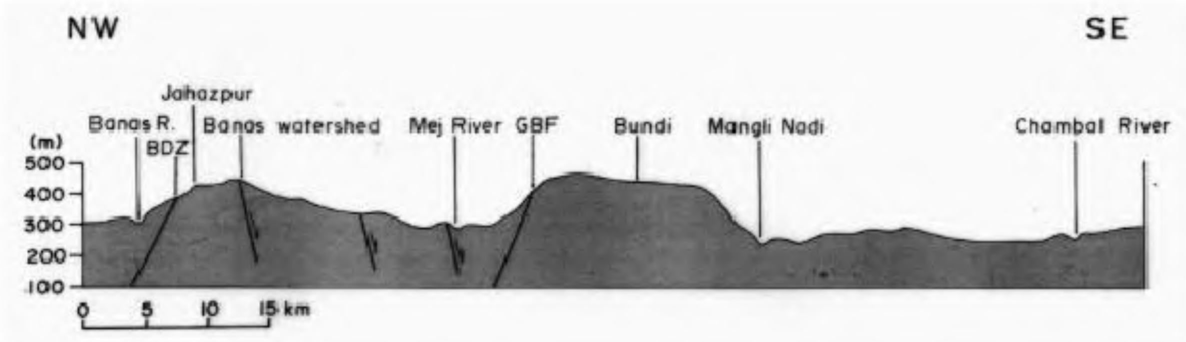

Figure 3. Transverse profile across the study area showing the major dislocations and rivers. Note that the Vindhyan plateau, NW of Bundi from where the Banas watershed migrated toward NW, is at a height similar to that of the present Banas watershed.

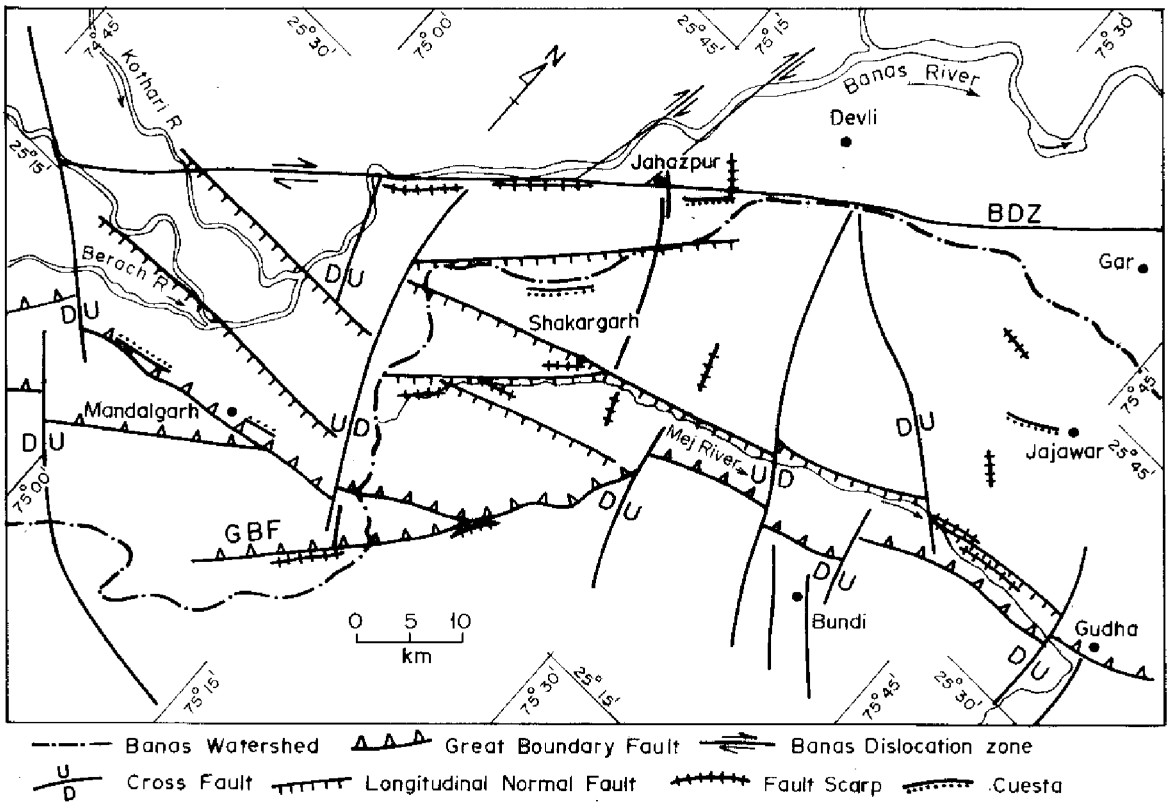

Figure 4. Fault systems and neotectonic features of the study area. Note the horst-graben structures caused by longitudinal and transverse faults, and the fault-controlled course of the Mej river.

In the Mej drainage basin, a major nearly E–W trending longitudinal fault runs 70 km from Kachola through Shakargarh up to west of Gudha. This fault bifurcates near Shakargarh and runs south-west up to Bagatpura. Another parallel longitudinal fault emanates in the vicinity of the GBF near Basoli and extends up to Amalji Ka Khera, where it joins with the Mej river fault. This fault system controls the Mej river channel pattern and its major tributaries, producing a trellis drainage pattern. These faults are marked by fault-line scarps with triangular facets, cuestas (Figure 4) and steep gully faces in the river channels. The Mej river has a straight course following a fault trace, and it meanders within a structural valley.

In the Banas basin a set of two E–W trending longitudinal faults controls the courses of the Banas river and its tributaries, and the Kothari river within a neotectonic half-graben structure between Mahua in the SE and Akola in the NW. The present Banas watershed between Kachola in the SW and Biletha in the NE is controlled by a longitudinal fault associated with cuesta.

The transverse faults are generally NW–SE oriented, and they appear to be the youngest neotectonic structures. The area between the major tectonic lines, namely

BDZ and GBF, has been fragmented into several neotectonic blocks by the transverse faults (Figure 4). These blocks are Mandalgarh in SW, Shakargarh in the centre, and Jajawar in the NE. The Mandalgarh block is a horst whose eastern fault-uplifted edge roughly demarcates the Banas watershed. The Shakargarh block, a half-graben, contains a number of small cross-faults marked by dissected fault-line scarps. There are several lakes and structural depressions in this block (Figure 2) that are generally aligned along the longitudinal and transverse faults, suggesting fault-related ponding. Such type of ponding and lake formation seems to be a characteristic feature of neotectonics related to drainage basin evolution[21]. A large upper reach segment of the Mej river system is located in the Shakargarh half-graben where the Mej channel has carved an incised valley along a longitudinal fault. Fluvial terraces at different levels are common in this segment, especially north of Basoli and south of Hindoli. The Jajawar block is a horst whose south-eastward tilting aided by a cross-fault across the GBF and the Vindhyan hills caused the course diversion near Gudha and the antecedence of the Mej river.

The neotectonic reactivation of the GBF is indicated by fault-line scarps at many places (e.g. north of Bundi, south of Mandalgarh, 12 km NW of Bijolia along a GBF splay). Course diversion of several tributaries of the Mej river (e.g. N–S course to nearly E–W course of the tributaries at Ruppura, Barodiya, Nayagaon, etc.) along the GBF traces is a common feature. The BDZ is also neotectonically active, which caused abrupt change in the Banas river course from NW–SE to NE–SW near Kanti, and an almost straight course with several fault-scarps on the banks up to Jahazpur. Between Jamoli and Motipura the course shows Z-shaped loops caused by N–S oriented right-lateral fault splays emanating from the BDZ.

From the foregoing geomorphic and tectonic setting, a model of catchment capture is proposed (Figure 5). The different stages of this feature could not be dated as no Quaternary age-dates of relevant material in the study area are available. In the initial stage, the SE segment of the Banas drainage basin extended up to the Vindhyan hills which formed the watershed between the Banas and the Chambal basins (Figure 5 *a*). In the next

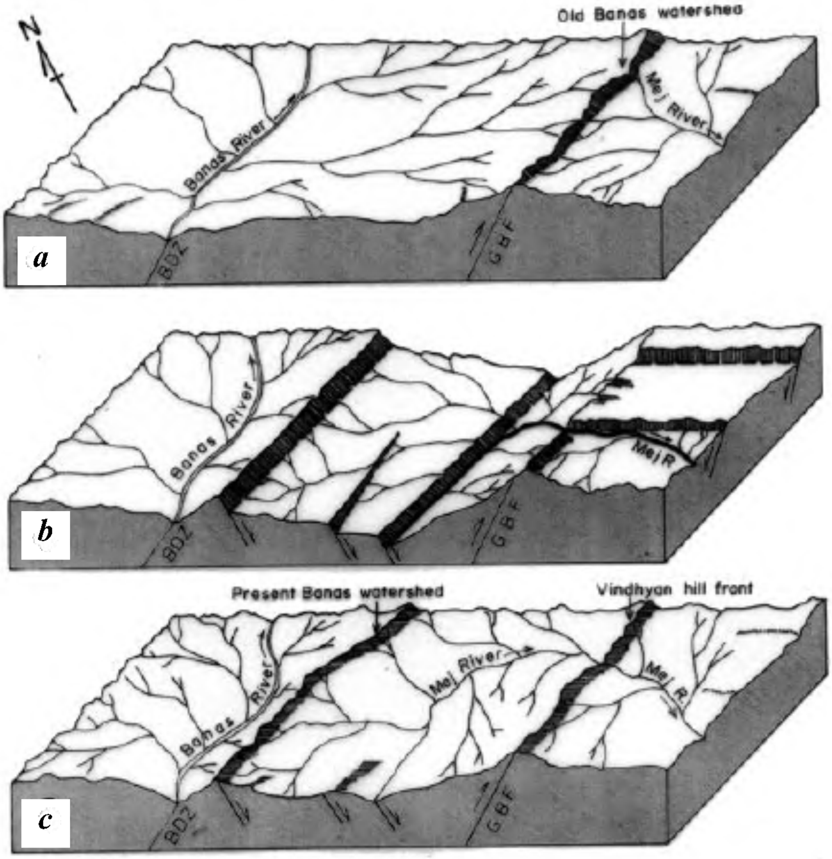

Figure 5. Model showing the stages of capture of a part of the Banas catchment by the Mej drainage system. ***a***, Stage A – Initial disposition of the Banas and the Mej drainage systems, the Banas watershed being located at the Vindhyan plateau edge, marked by the GBF; ***b***, Stage B – Neotectonic movement formed half-graben structure in a part of the Banas right catchment, which was captured by antecedent Mej system and the Banas drainage divide migrated NW; ***c***, Stage C – Present-day disposition of the Banas and the Mej drainage systems.

stage (Figure 5 *b*) neotectonic movements produced the antithetic longitudinal faults in response to reactivation of the GBF. These and the cross-faults divided the area into structural blocks, which show evidence for differential vertical movement. Among these blocks, the most active was the Shakargarh block where longitudinal faulting created grabens and half-grabens. The Banas watershed migrated toward NW to occupy the present-day position at the graben shoulder. The RFHJ residual hill trail gives an approximate location of the intermediate position of the divide, before leaping to the present position. The new Mej river course came into existence at the graben floor. Its drainage network, superposed on that of the Banas, developed due to headward erosion in the left bank whose inward slope was controlled by the tilting of the downthrown block. The main tributaries of the Banas river were captured. The slope of the right bank segment of the Mej river basin was controlled by the rotational movement of the block whose bounding faults were the normal longitudinal fault in the NW and the reactivated reverse GBF in the SE. Eventually, the Mej river cut through the Vindhyan hills at a location where a transverse fault crossed the GBF to form a part of the Chambal drainage system. Thus, a part of the Banas catchment was lost to the Chambal basin (Figure 5 *c*). Judging from the active headward erosion of the present Banas watershed by the Mej river and its tributaries, it is postulated that with only 7 km extension of these channels across the watershed near Jahazpur, the Banas main channel is likely to be captured by the Mej river in the future. The Banas river will then stand beheaded.

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