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The influence of neo-tectonics on river patterns in Bangladesh; a preliminary study based on Landsat MSS imagery

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Abstract

Bangladesh is part of the active foredeep depression south of the Himalayan collision zone, bordering the Indian plate. Seismic activity is common both in the mountain chain and in the Ganga plain reaching into the basin of the Bay of Bengal and forming the counterpart of the uplifted Himalayan chain. Erosion, sedimentation, river migration and transport within the Jamuna (Brahmaputra) river system are therefore not only controlled by processes on the Earth's surface, but are also the result of a balance between fast and continuing deposition versus geological subsidence and uplift. An attempt is made to correlate the behaviour of the Jamuna river to neo-tectonic movements, as interpreted from Landsat MSS imagery using available literature. From the imagery, covering the period 1976 to 1987, supervised and unsupervised classifications of bands 5 and 7 were made. The 1978 and 1986 images revealed the most useful classifications and yielded pronounced differences in colour variation for visual interpretations of geological lineaments and terrain units. The Jamuna riverbed can be divided into compartments, limited by faults.

Introduction

Various studies on the morphology and riverbed changes of the braiding Jamuna river, the N–S oriented lower reach of the Brahmaputra river in Bangladesh, have been carried out (Masselink 1989, Mosselman et al. 1995). These studies aimed at modelling river hydraulics, focusing on four phenomena: 1) diffluence, splitting (bifurcation) of channels, 2) confluence, flowing together of two or more channels, 3) ratio of channel curvature to channel width, and 4) migration of curves. These river characteristics have proved useful in describing the behaviour of meandering systems; in the case of braiding systems however, there is still no good and realistic, applicable geometric model to represent nature. This is also true for the Jamuna, a large sand-bed river that is responding to extreme seasonal fluctuations in discharge, and that is burdened by a large bedload, with little interference by man. G. Klaassen (pers. comm.) comes to the conclusion that hydraulic laws may explain only part of the Jamuna braiding. Rivers such as the Jamuna, with high discharges and sediment loads but with low gradients, tend to be affected by minor changes in slope resulting from tilting and block-faulting. Kar (1994) and Mohindra et al. (1992) mention tectonic control on fluviatile sedimentation patterns in the Thar desert and Gandak area in India. Local patterns within the river bed are often explained by the dynamics of sediments and water alone, and tectonic influence is often mentioned in explaining large-scale migration of the Jamuna (e.g. Coleman 1969, Thorne et al. 1993). The present study suggests that small-scale patterns may locally also correlate with fault lines.

The Jamuna river is located in one of the most active foredeep depressions of the world, the Himalayan collision zone. The seismic activity and subsidence in this zone are not restricted to the Himalayan chain; the Ganga (= Ganges) foredeep basin extending into the Bay of Bengal is the direct counterpart of uplift in the Himalayan belt (Morgan & McIntire 1959). Geologically the land surface of the major part of Bangladesh is the result of a balance between fast and continuing deposition versus subsidence. Simply stated: the problem of non-understanding the complex braiding mechanism of the Jamuna is tackled freshly when it is regarded as partly reacting to vertical earth movements mainly caused by (neo) tectonics and compaction. In general, the magnitudes of these processes, however, differ considerably with compaction being a factor 10 or more slower than tectonic movements (Selby 1985, p. 583). The Jamuna river is the expression of a balance between: volumes of water, suspension and bedload, erosion, accretion and so forth, and vertical neo-tectonic movements. These movements may lead to tilting, uplift or subsidence of the substratum within various geological compartments or blocks, limited by fault planes. Specific questions in this preliminary survey on the basis of literature and Landsat images are:

- can lineaments indicative of faults be recognized?
- can blocks limited by lineaments be delineated?
- can recent movements on these lineaments influence sedimentation and erosion?
- can relationships be formulated between these movements and river activity?

To answer these questions, information on geology and Landsat MSS image interpretations have been combined into a working hypothesis.

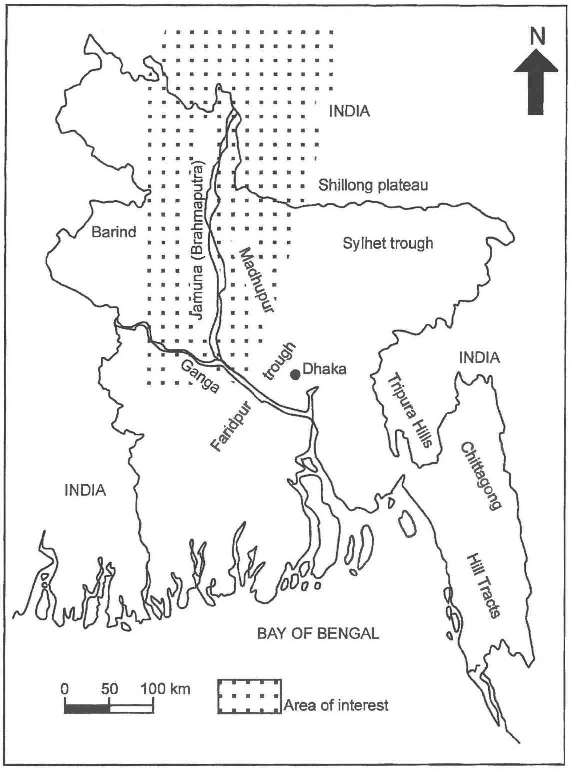

Figure 1. Map of Bangladesh showing main physiographic regions and the location of the area of interest shown in Figure 2.

General geology

The geology of Bangladesh and surroundings recognizes four major areas (e.g. Khan 1991, Reimann 1993, Figure 1):

- the fold-belt of Chittagong–Tripura,
- the Shillong plateau,
- the Sylhet trough,
- the low plains of Barind, Madhupur and the Ganga delta.

The crustal depression north of the Bay of Bengal extends in a northwestern direction from a bend in the river Ganga near Dhaka (Figure 1). The course of the old Brahmaputra, east of its present course, coincides with a regional depression of the top of the Precambrian. Khan (1991) discusses several fault directions at the regional scale; the Holocene direction corresponds to the mainly NW–SE lineament direction recognized on the satellite images in the alluvial tract of the Jamuna.

Available images and method of image classification

For a complete coverage of the Jamuna river, two Landsat Multispectral Scanner (MSS) images were needed, a northern and a southern set. Of each set the spectral bands 5 and 7 at a pixel resolution of 79 by 79 m were used (courtesy: Delft Hydraulics and the Dutch National Air and Space Laboratory NLR). The images were acquired on different dates in the dry season, during the first three months of the year. Images acquired in 1973 and in the period 1976–1980 were used. All of the data were geocoded and used in digital form; however, some large colour prints (60–80 cm, scale 1 : 250 000) were also included for visual interpretation. These prints, previously used by Masselink (1989), show simple classifications of the northern and southern images consisting of four categories. The following prints were available: 1977 north and south, 1978 south, and 1984, 1986, and 1987, north and south. The first step in the processing of the images was to combine the two available spectral bands 5 and 7 into one colour-composite with maximum con-

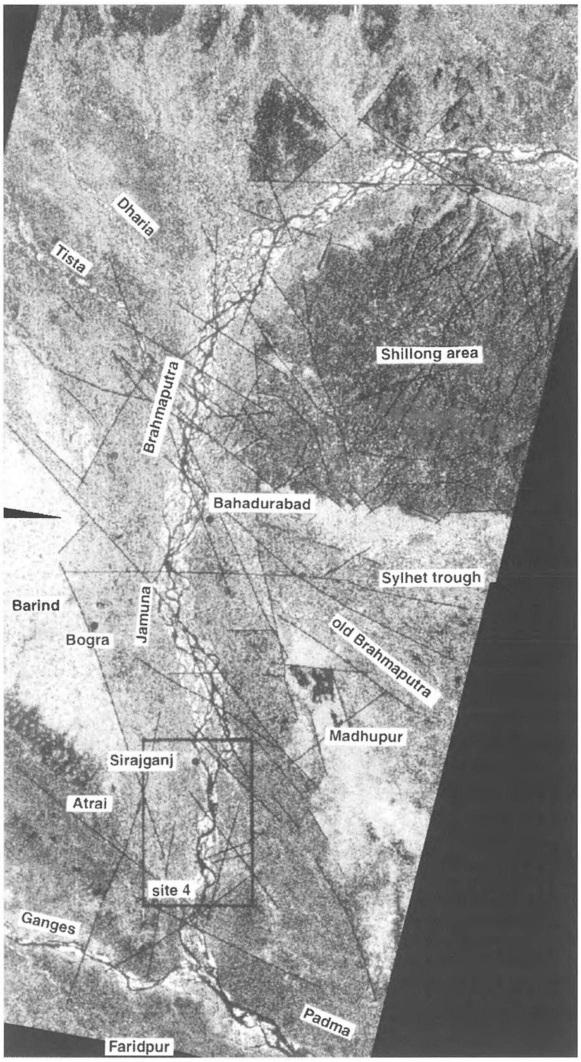

Figure 2. Classified 1978 Landsat MSS image of the area of interest, covering the course of the Jamuna. Interpreted lineaments are indicated. Window area indicates site 4, as shown in Figure 3. North to the top. Image size is ca. 320 km in N–S direction and between 160 and 100 km in E–W west direction. Colours are explained in the text. (For full colour reproduction of this figure, see Appendix at the end of this issue.)

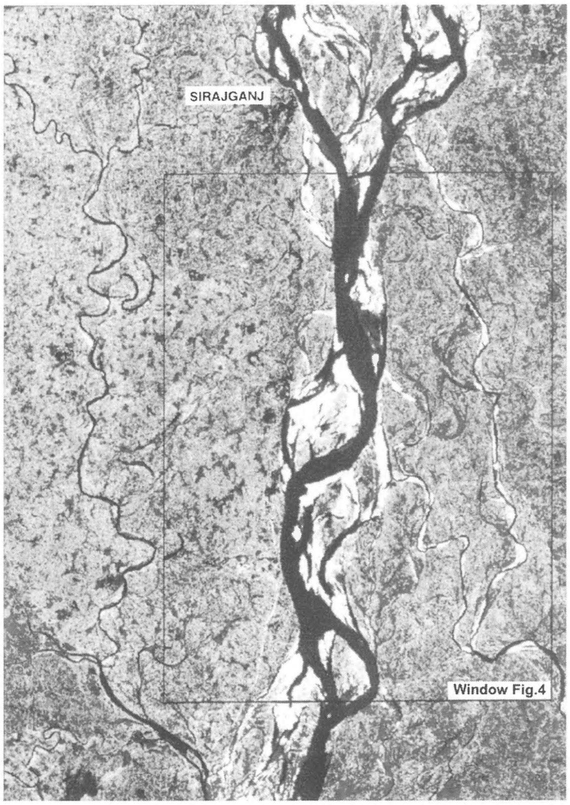

Figure 3. This fragment of the classified Landsat MSS image of 1978 has a colour scheme that approaches natural colours and proved to be most useful in the recognition of geological lineaments. The fragment covers test site no. 4 south of Sirajganj as indicated in Figure 2. Window area is seen in Figure 4. North to the top; image size is ca. 50 km in N–S and 34 km in E–W direction. (For full colour reproduction of this figure, see Appendix at the end of this issue.)

trast and approaching natural colours. During a multi-spectral classification of land-cover units the spectral reflection values of the pixels were analysed. In the spectral image, each pixel has a digital number (DN) or a spectral reflection value ranging from 0 (black) to 255 (white). These reflection values are grouped into clusters or categories. Because vegetation, especially trees, has the largest reflection in the infrared range, the colour green was assigned to band 7. Therefore, dense vegetation is related to green in the image. Red was assigned to band 5 with the result that the composed image has colours from red via orange to yellow and green (the colour white was assigned later to improve contrast). Below, a concise summary interpretation is given of the most distinct patterns (cf. Figures 2, 3).

White or yellow:	High reflection in bands 5 and 7; e.g. dry, fallow terrain and bare sand bars.
Dark green:	Low reflection in bands 5 and 7; e.g. dense forest, mountainous areas in Shillong area or swamps.
Light green:	Moderate reflection in band 5 and high reflection in band 7; less dense vegetation.
Red:	High reflection in band 5 and moderate to low reflection in band 7; e.g.

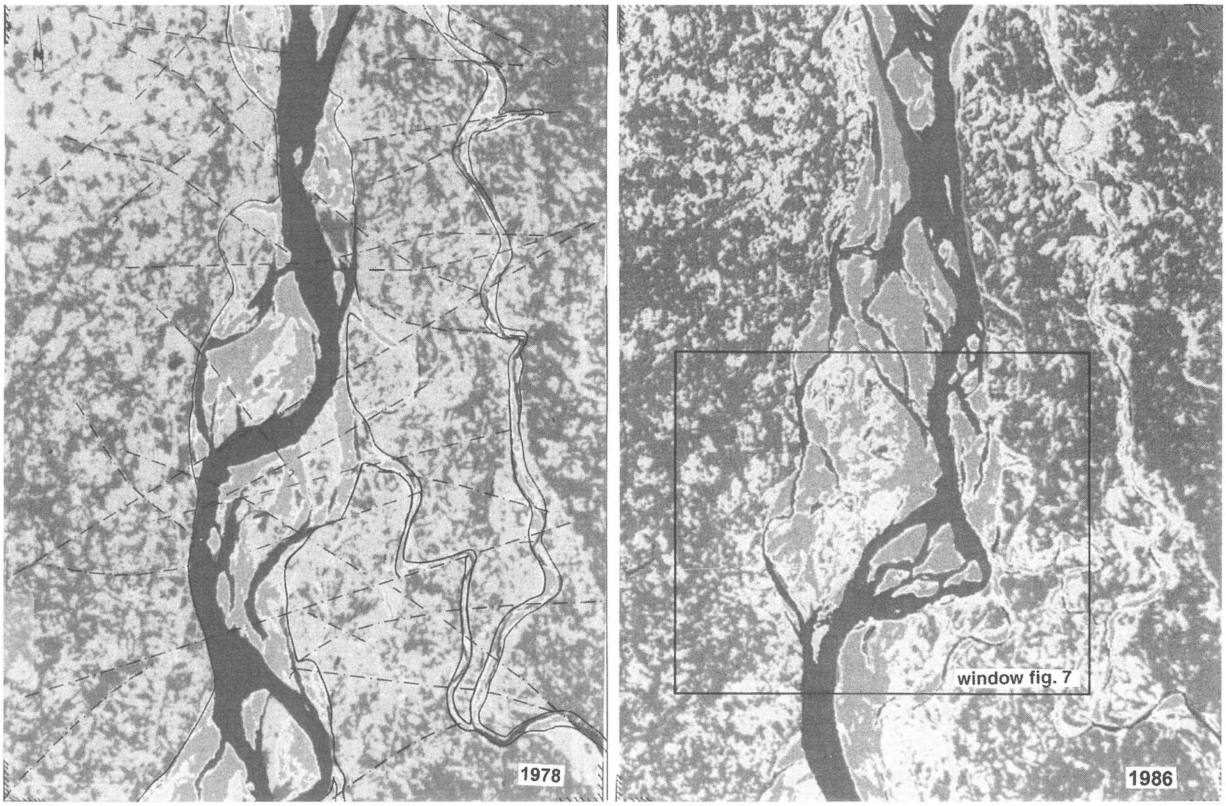

Figure 4. Comparison of 1978 (left) and 1986 (right) classified images showing lateral migration of Jamuna river course. Classification based on simple legend (blue = water, orange = sand bars, green and grey = dry land). Notice the lineament near a major bend in the river (cf. Figure 7). Interpreted lineaments indicative of faulting are shown on the 1978 classification. North to the top; image size is ca. 33 km in N–S, and 24 km in E–W direction. For location see Figure 3. (For full colour reproduction of this figure, see Appendix at the end of this issue)

shallow streams or paddy-fields (small red dots), low terraces occupied by horticulture.

Dark red: Low to moderate reflection in band 5 and low reflection in band 7; e.g. swamps and zones under irrigated agriculture.

Black: Very low reflection of band 5 and 7; e.g. deep clear water or shady areas in mountains of the Shillong area.

The choice of colours is important for the degree of contrast between categories of interest. Several classifications were generated, involving ten to four classes, and different colour tables were tested to trace lineaments more easily. The copies on photo paper of the 1978 image turned out to be appropriate and sufficient for lineament analysis. Four classes were distinquished: water (blue), sandbars (orange) and two types of terrain expression within the dry land (green and grey), mainly based on differences in soil moisture and vegetation cover (Figure 4).

Visual interpretation makes use of pattern, size, relation to relief, textural differences, drainage (e.g. pattern, density), lithology and structure, cover (e.g. surficial material and vegetation) and association with local phenomena (e.g. logical localities for infiltration, seepage, and waterlogging). Linear features of major length can be interpreted on satellite images. They can be termed 'lineament' in case they are topographic features of regional extent that are believed to reflect crustal structure. The reliability of the interpretation of lineaments from satellite images depends much on their extent; if lineaments dissect two or more main terrain units, the reliability of the interpretation is higher. Also, if these lineaments seemingly affect the course of a river, they are more likely to be structurally controlled. A river-channel development in three phases is presented in Figure 5, illustrating how renewed fault activity may lead to increased erosion or sedimentation and how this is reflected in satellite images. Downthrown blocks will tend to fill with sediments, upthrown blocks will tend to gain less sediment or even tend to be eroded (e.g. bank erosion, rapid migration).

Observations and interpretations

At first a physiographical and geomorphological classification was made. Four main units can be distinguished (Figure 2): 1) mountains (Shillong area); 2) alluvial fan systems including thick weathering mantles associated with the Shillong plateau; 3) floodplain of the Jamuna and the Ganga; 4) Barind–Madhupur weathering surfaces and Pleistocene fluvial terraces. With regard to lineaments, the Shillong plateau is characterized by straight valleys corresponding to NW–SE trending lineaments and some NE–SW trending lineaments. The southern boundary of the Shillong plateau is composed of intersecting lineaments that create a 'zig–zag' pattern; this pattern separates the plateau from the adjacent southern fan systems.

Alluvial fan systems and thick weathering mantles are associated with the Shillong plateau. Debris produced by weathering, erosion and denudation on the plateau will eventually accumulate in a peripheral stretch with fans surrounding the plateau. Disappearing channels on the fan surfaces indicate water loss in the permeable debris. Most channels are dry; this is also reflected in the colour associated with the (upper) fan surfaces in the images: white to yellowish colours indicate bare soil associated with limited agricultural activity. Along the southern boundary of the plateau a zone of increasingly reddish patchy appearance and of irregular outer limits occurs on the images, representing an area with better agricultural and irrigation qualities on fine-grained deposits. The southern limit to this zone is irregular and interspersed by ponds, most probably due to overbank deposits of the old Brahmaputra river.

The floodplains of the Jamuna and Ganga rivers cover most of Bangladesh. Outside the active channels and bare sand bars, the main features on the images that relate to the past regime of the Brahmaputra are:

- A zone of waterlogged areas in darkgreen to blackish tones, representing water seepages complementary to the fan infiltration area.
- Innumerable patterns of former fluvial activity, such as abandoned meander curves and dry channels; these can be recognized from the present land-use pattern and the shape of natural, possible marshy vegetation that follows abandoned river patterns. Dark colours, in general, indicate low vegetation in these small sub-units. Good examples can be observed in the Jamuna flood plain (Figure 3) and in the former Brahmaputra course in the Sylhet basin.
- The green colours in the northern part of the northern image on the coalescing fan systems of local minor streams, e.g. Tista and Dharia, coming from the Bhutan mountains, probably indicate natural forest.

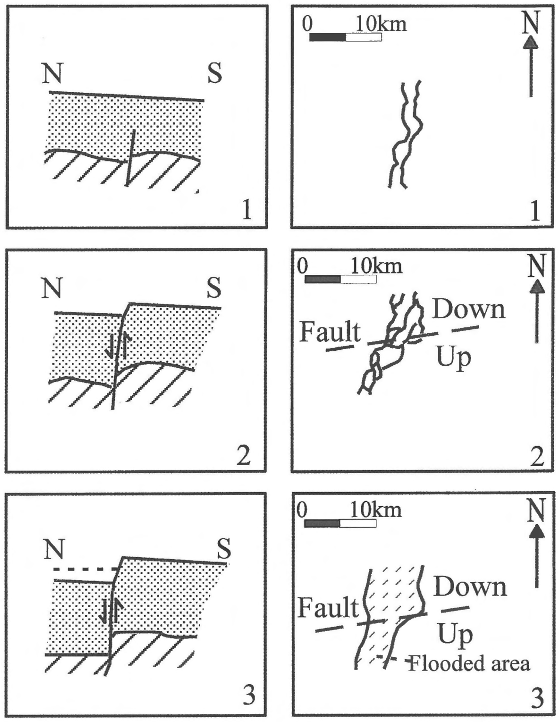

Figure 5. Neo-tectonic activity in three phases in the floodplain of the Jamuna river, and its implication for river behaviour; longitudinal sections on the left, common map or image patterns on the right. Narrow compartments (phase 1) correspond to increased (bank) erosion, and wide compartments (phase 3) to increased sedimentation. Thick lines in the river patterns are braid channels (phase 2) or edges of main channel (phases 1, 3). Scale is approximate.

The Barind and Madhupur weathering surfaces are clearly expressed on the satellite images. They were formed by fluvial action and can be regarded as fluvial terraces. These terraces show the following characteristics on the images:

- rather homogeneous colours, mainly yellowish, whitish and light-green, representing bare and/or dry topsoil,
- the black colours on the plateau east of the Jamuna indicate natural forest.

In this article only parts of the original images and interpretations can be presented. The majority of the lineaments were visually interpreted by examining copies of the colour-composite images and by screen interpretation and digitizing (at better resolution than the figures suggest). In Figure 3, a fragment of the classified image is given. An interpretation of lineaments indicating fault systems, is shown in Figure 4.

Tectonically limited compartments

The Jamuna river is characterized by a series of changes in width along its course. This phenomenon is not always linked to the sediment input provided by tributary river systems. For instance, if we look at confluences where smaller rivers, e.g. the Tista, enter the Jamuna we observe a smaller width downstream (Figure 2). The broader sector directly upstream of the confluence is not merely due to extra sediment input; the widening already begins earlier, outside the reach of tributary rivers.

Another explanation as to the wider and narrower compartments along the Jamuna appears to be the presence of fault blocks. The river behaviour within these compartments or blocks depends on the time of movement along a particular fault as well as on the rate, and direction of the movement. Such faults affect the Quaternary and can influence the river to migrate laterally, to broaden its channel, or to straighten its course. A possible relation of subsurface tectonics and pattern recognition on satellite images was already given in Figure 5. An interpretation of tectonically limited compartments along the Jamuna is given in Figure 6.

The Sirajganj test site

Special maps have been prepared of the downstream vicinity of the proposed Sirajganj bridge site, based on hard copies of the Landsat 1978 and 1986 classified images (Figure 4). The outlines of channels and pools of the 1986 image are shown in Figure 7. A lineament, already visible in the 1978 images, is now more clearly in evidence. This is one of the best examples of migrating channels, influenced by a fault.

A lineament analysis, limited by the scale of the Landsat images, revealed a number of lineaments present in the test site. It was furthermore observed that (Figure 4):

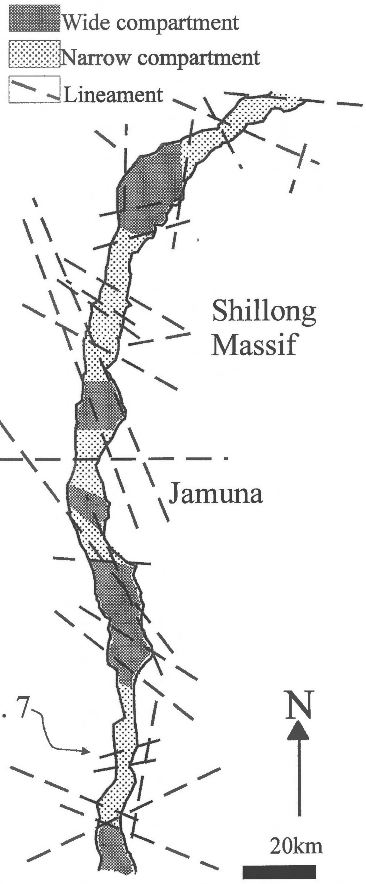

Figure 6. Subdivision of the Jamuna river bed according to main lineaments into fault-limited blocks (cf. Figure 2 for location).

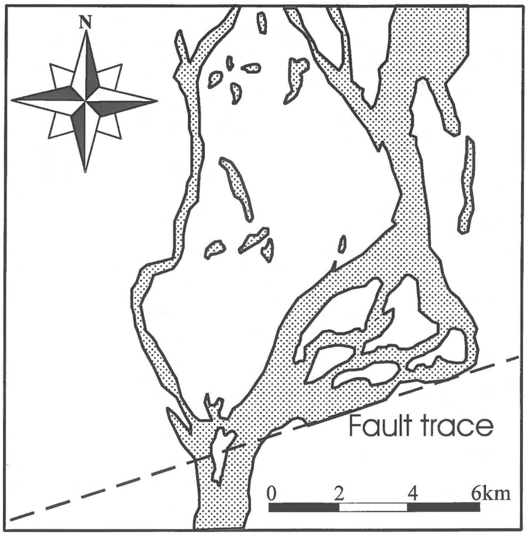

Figure 7. Interpretation of window area of 1986 image of Figure 4, illustrating inhibition of channel migration at a fault. Dotted areas are water-bearing channels (after a drawing by Seijmonsbergen in Mosselman et al. 1995).

- Two directions of lineaments prevail; NW–SE and WSW–ENE.
- Some of the lineaments cannot be traced within the active floodplain of the river; they are obscured by recent fluvial processes.
- The width of the Jamuna downstream of the bridge site (just above the centre of the 1978 image of Figure 3) has widened considerably between 1978 and 1986.
- A major curve migrated downstream and aligns in 1986 perfectly with a fault, already expressed in the 1978 image. On the 1978 image the Jamuna shows little adaptation to this lineament. In 1986 the channel bends through more than 90°.

Summarising, recent fault activity caused an adaptation of the river, especially upstream of the fault, where it may have led to increased sedimentation and widening of the riverbed.

Future research

Future research on the Jamuna river should focus on:

- Assembling drilling data to obtain Tertiary–Quaternary sediment records that can be correlated with geological and geophysical data.
- Field work during periods of low discharge to check on interpreted lineaments, recent tilting, lines of infiltration or ponding, and sudden changes in recent sediment.
- Air-photo interpretation to better understand the features observed on the satellite images.

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