Delineation of an active fault using DTM in the western Gangetic Plain

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Integrated studies of satellite images using digital image processing techniques of image data, DTM and field work to check the geomorphic expressions have helped in inferring an active fault in a gently sloping and apparently featureless region of the Gangetic Plain near Muzaffarnagar (named Muzaffarnagar Normal Fault) with a throw of about 6–9 m.

Keywords: DTM, Ganga, Gangetic Plain, Normal fault, Yamuna.

The study area is located in the western part of the Gangetic Plain and bounded by the Ganga and Yamuna mountain-fed rivers, flowing along major fault systems in the east and west (Figure 1) respectively, and continues from about Roorkee in the north to 20 km south of Muzaffarnagar. The Ganga–Yamuna Interfluve slopes southward gently and is drained by alluvial streams Kali, Hindan and Krishni following the regional slopes.

The Ganga and Yamuna fault systems with initial N–S strike which later change to E–W strike in the southern parts and a number of transverse faults like Meerut and Aligarh faults, south of the study area, have been identified. However, no transverse fault was recognized from the study area, north of the Meerut Fault. Recognition of faults by earlier workers was mainly based on major changes in direction of streams, changes in sinuosity, changes in direction of slopes of the interflaves and mapping of soil-geomorphic units from studies of satellite images. Thus, identification of faults was mainly based on indirect features since rapid erosion/deposition and reworking of deposits by rivers modify direct evidences of faults and are commonly not obvious in the interfluvial regions.

In the present study, we prepared a Digital Elevation Model (DEM) from spot heights of the area and draped the IRS 1D LISS-III image on it. The DTM thus obtained was rotated in three dimensions and vertical exaggeration (150 times) was adjusted so that we enhance the topographic aspects of the area, which suggests the presence of an active fault. Geomorphic expression of the fault was checked in the field.

The available datasets for the study area are: IRS 1D, LISS III image (Path-96 Row-50, resolution 23.5 m) acquired on October 1995 and the digitized spot heights from the 1:50,000 scale Survey of India topographic maps.

For preparing the DTM, spot heights given in the Survey of India topographic maps on scale 1:50,000 were manually digitized. Also, a separate base theme was prepared by digitizing minor drainages, roads, canal networks and cities saved for further analysis, display and georeferencing of spectral images. The DEM at a ground resolution of 100 m was prepared using the ERDAS Imagine Version 8.5 software package from digitized spot-height data. Next, the IRS-1D LISS-III image (Path-96 Row-50, resolution 23.5 m) acquired on October 1995 was enhanced by linear stretching and histogram equalization. Then the image was georeferenced/rectified using the base map. Both the elevation and image data were brought to a common coordinate system (Projection – Polyconic, Sphereid – Everest and Datum – Everest), so that they can be interfaced with other spatial data from the same area.

Several three-dimensional perspective views with varied combinations of setting were generated (Figure 2), using the ‘Image Drape’ option available in ERDAS Imagine. However, the best view was obtained with the specifications given in Table 1.

In addition, three topographic profiles were drawn across the fault (Figure 3) and several field traverses along metallled and unmetalled roads were taken across the inferred fault.

The study of geomorphic expressions using DTMs and longitudinal profiles suggests that an east–west striking normal fault passes through the city of Muzaffarnagar (named here Muzaffarnagar Fault). Evidences for the same are:

(i) The region north of the Muzaffarnagar Fault is gently sloped, almost featureless with river floodplains that are narrow and incised into the older plain. However, the area south of the fault is highly undulating on a regional scale and river channels are significantly broader (Figures 1 and 2).

(ii) Field traverses across the fault indicate that both upthrown and downthrown blocks away from the fault are apparently flat locally and the region close to the fault is gently to moderately sloping.

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Figure 2. Perspective view of study area obtained by draping FCC (LISS III) over the DEM. Location of Muzaffarnagar Fault and incision by the inland streams, e.g. Krishni, Hindan and Kali are fairly prominent.

Figure 3. Topographic profiles drawn across the Muzaffarnagar Fault. Slope breaks in profiles are considered to indicate location of the Muzaffarnagar Fault.

(iii) Comparison of topographic sheet 53G/10 (1961) with IRS satellite image (1995) shows that the rivers Kali, Hindan and Krishni are engaged in active headward erosion. For example, the Kali river showed increase in incised channel by about 4 km during the period 1961–95.

(iv) Topographic profiles across the fault at three places, derived from the DEM, suggest that there is a significant break in slope across the fault and the southern side of the fault has gone down relative to the northern side by 6–9 m.

The Ganga–Yamuna structural block was uplifted during about 2.5 ka BP. Thus the time of activity of the Muzaffarnagar Fault is less than or equal to 2.5 ka. According to Nakata, active faults have shown activity since 125,000 years BP; the Muzaffarnagar Fault is an active fault.

A subsurface basement ridge (Aravalli Ridge) plunging NNE was identified based on geophysical studies and this feature dies out before Doeband is reached. It suggests the presence of a probable fault with throw to the north. However, in the present case, it is just the opposite, as the northern part is the upthrown block and the southern block is the downthrown block.

The DTM obtained by draping the Landsat image over DEM obtained from TOPSAR investigations has been used to locate active faults in the foothills regions of the Andes in Nevada and California, USA, where the throws were > 40 m. However, in the present case we have used DTM obtained by draping LISS-III data over DEM obtained from spot heights manually digitized from the Survey of India topographic maps (scale 1 : 50,000). We were able to locate an active fault with a much smaller throw of 6–9 m.

Combined use of studying the satellite images using digital image processing techniques, DTM of the regions and extensive field work to check the geomorphic expressions were extremely useful in inferring an active fault in a gently sloping region of the Gangetic Plains. Such studies should prove valuable in locating active faults and enhancing our understanding of seismic hazards in other nearly flat, monotonous regions.

Table 1. Specifications for the best view

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun position</td>
<td>Northwest</td>
</tr>
<tr>
<td>Vertical exaggeration</td>
<td>150 times</td>
</tr>
<tr>
<td>Viewing height</td>
<td>773 m</td>
</tr>
<tr>
<td>Viewing direction</td>
<td>North to South</td>
</tr>
<tr>
<td>Viewing distance from DEM</td>
<td>39.75 km</td>
</tr>
<tr>
<td>Level of details for DEM and</td>
<td>64 and 100% respectively</td>
</tr>
<tr>
<td>for image</td>
<td></td>
</tr>
<tr>
<td>Position of the viewing point</td>
<td>Long. 77°54'24&quot;E</td>
</tr>
<tr>
<td></td>
<td>Lat. 29°18'11&quot;N</td>
</tr>
</tbody>
</table>

Sexual isolation between two sibling species of Drosophila: D. ananassae and D. pallidosa

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Sexual isolation, a form of pre-mating reproductive barriers, is one of the elementary causes of speciation. In the present study, investigations on sexual isolation between two sympatric sibling species, namely Drosophila ananassae and D. pallidosa have been undertaken by employing four different choice conditions (multiple-, female-, male- and no-choice). Mating success was scored by direct observation in Elens–Wattiaux mating chamber. In all the four choice conditions, homogamic matings were more frequent than heterogamic ones, which indicates preferential mating between males and females of the same species. The values of isolation estimate in all the four techniques are close to zero, suggesting the presence of strong sexual isolation between these two sibling species. In female choice method, where the sex ratio was 1 female : 2 males, males of the two species differ in their mating success. Similarly, in male-choice method with sex ratio 1 male : 2 females, females of the two species differ in their mating success. However, in multiple- and no-choice methods where the sex ratio was 1:1 (equal number of males and females), no difference was found in mating success of the two types of males and females. From these results, it is concluded that there is strong ethological isolation between D. ananassae and D. pallidosa, which is not affected by different experimental conditions. However, mating propensity is influenced by sex ratio in these two sibling species.

**Keywords:** Drosophila, experimental conditions, mating propensity, sexual isolation, sibling species.

UNDERSTANDING the mechanisms of speciation is one of the prime targets for evolutionary biologists. Reproductive isolation can be broadly categorized into two forms: pre-mating and post-mating. Pre-mating isolation is the interaction between individuals of pure species while post-mating isolation is a phenomenon of developmental defects. In sympatric species, prezygotic isolation has evolved faster than postzygotic isolation, whereas in allopatric species, prezygotic and postzygotic isolation evolved at the same rate. Sexual selection and isolation are stronger in sympatric populations than in allopatric ones in the semi-species group of Drosophila paulistorum. Sexual isolation is a form of pre-mating barriers to gene exchange, where opposite sexes of different populations fail to mate due to behavioural incompatibility. Genes controlling sexual behaviour are likely to control species-specific differences in courtship and are involved in reproductive isolation of closely related species of Drosophila. Different patterns of sexual isolation exist in interspecific and intraspecific populations of Drosophila. Investigations on sexual isolation between those sympatric species where post-mating isolation is absent, have a great potential to unravel the mechanisms of speciation.

D. ananassae and D. pallidosa are an excellent species pair for such studies. They belong to the D. ananassae complex of the ananassae species subgroup of the melanogaster species group. D. ananassae is a cosmopolitan and circumtropical species, but D. pallidosa is endemic to the islands of the South Pacific Ocean. In spite of their sympatric distribution, post-mating reproductive barriers, such as hybrid sterility or hybrid inviability do not exist between them. In addition, clear morphological differences are observed only in body colouration and number of rows in the sex-comb. It suggests that the phylogenetic separation in D. ananassae and D. pallidosa must have been a recent event in speciation of the melanogaster group. Sexual isolation has been considered to be crucial in maintaining the integrity of the gene pool of the two species, despite their sympatric habitat and absence of post-mating isolation. In the laboratory, strong sexual isolation between the two species has been confirmed by employing male- and no-choice techniques. These previous studies were insufficient to clarify mating success difference under different choice techniques and sex ratio. Different choice conditions are multiple-, male-, female- and no-choice. In the experiment employing multiple-choice technique, males and females of the two types closely correspond to natural conditions. In no-choice experiments, one type of male is placed with one type of female and it does not represent a choice situation. In male-choice experiments,