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Geomorphological, Fractal Dimension and b – value mapping in Northeast India

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ABSTRACT
Satellite based geomorphological mapping is an essential tool for natural hazard estimation in Northeast India. The geomorphological mapping of the study region (26 – 27 ^{0} N, 91 – 95 ^{0} E) was carried out with the help of IRS – 1D LISS – III imagery of March 5, 2003 on 1:250, 000 scales by visible interpretation technique. The individual satellite imagery has been studied and compared with the Survey of India (SOI) topographical sheets on 1:50, 000 scale to demarcate geomorphic features. The geomorphological maps of the study region refers to, (i) flood plain, (ii) younger alluvial plain, (iii) older alluvial plain, (iv) upper piedmont, (v) lower piedmont, (vi) valley fill area, (vii) structural hills of Tertiary group, (viii) structural hills of Shillong group, (ix) denudational hills of Tertiary group, (x) denudational hills of Shillong group, (xi) denudational hills of Gneissic group and (xii) pediment surface. The statistical characteristics of seismicity and drainage parameters, fractal dimension and b – values are mapped in the study region. The maps revealed that the fractal dimension of drainage parameters are comparable with the seismogenic structures and are very appropriate for earthquake risk evaluation.

INTRODUCTION

The synoptic coverage and highly precision of remotely sensed data coupled with the marked cost-effectiveness and time-efficiency of the data acquisition and analysis procedures have made satellite-based geomorphological mapping an extremely effective tool for management of natural hazard in recent times (Rao 1978; Bhattacharya 1980; Srinivasan 1988). Application of these satellite based geomorphological, fractal dimension of drainage parametres and earthquakes mapping in areas like the NE india is more significant and meaningful because the preexisting earthquakes database is extremely sketchy, unreliable and outdated and less accessible.

The Gutenberg & Richter (1954) relation for frequency vs. magnitude is a power law involving magnitude. The estimated coefficient of the Gutenberg and Richter relation, 'b', known as the statistical 'b – value', varies mostly from 0.70 to 1.30, depending on the tectonics of a region. A higher b – value means that the higher magnitude earthquakes are relatively in small fraction of the total earthquakes occur in a region and a lower b – value implies the larger fraction of earthquakes occur at higher magnitudes. Furthermore, the b – value varies preceding major earthquakes (Mogi 1962).

The earthquake phenomenon possesses fractal structure with respect to space, time and magnitude. The two-point spatial correlation function for earthquake epicentres displays a power law structure (Kagan & Knopoff 1980). The earthquakes are represented by self-similar mathematical construct, the 'fractal', and the scaling parameter is known as the fractal dimension, 'D' (Mandelbrot 1982).

Furthermore, the natural drainage systems analysis provides clues to the distribution and attitude of the underlying rock formations and geological structures; such as fractures, faults, folds, etc. (Thornbury 1954). In this study region dendritic drainage systems marked the presence of joints and fractures in the massive rocks. The spatial distribution of the natural drainage systems can be characterised as fractals (Pal 2006). The fractal dimension of drainage frequency (D_f) and drainage density (D_d) correlate with the fractal dimension of earthquakes. More precisely, the fractal dimension of the drainage density (D_d) is closely related to the fractal dimension of the seismicity. This is indirect evidence that the background seismicity of a region can be evaluated from the drainage density (Pal 2007).

The variability of the fractal dimension in different zones may be related to the geological heterogenity. Fractal dimension gives vital information about the stability of a region. A change in fractal dimension corresponds to the dynamic evoluation of the states of the system (Kagan & Knopoff 1980; Hirata 1989; Ogata 1988).

Hence, in this present work an attempt has been made to estimate as well as to correlate the fractal dimension mapping of seismicity and b – value mapping with the fractal dimension mapping of the geomorphological parameter, the drainage systems.

METHODOLOGY AND DATABASE

Satellite remote sensing has been used for geomorphological and natural drainage systems mapping (figs. 1A , 1B, 1C & 1D) and the distinct structural features on satellite images (Fig.2) in the study region based on visible interpretation of IRS LISS – III imagery of 5th March, 2003 on 1:250,000 scale bearing Path – 110, 111, 112, 113 and Row – 53. The individual satellite imagery has been studied and compared with the SOI topographical sheets on 1: 50, 000 scale to identify the said parameters. The drainage frequency [$D_f = \frac{\sum N}{A}$] is defined as the total number of stream segments per unit area (Numbers / Km^2). The drainage density [$D_d = \frac{\sum L}{A}$] is defined as the total length of stream segments per unit area (Km / Km^2). The drainage systems can be represented as a growing tree. The number of branches at each node (including the root) is constant as the tree grows. The growth of a tree is symbolized by the addition of fresh branches at each node.

The earthquake data has been adopted for the period 1964 to 1993 from the International Seismological Catalogue (ISC) of magnitudes $m_b \geq 4.0$. The earthquakes epicentre map is shown in Fig. 3. In order to spatially map of the computed drainage frequency and density, b – value, and the fractal dimension of D_f, D_d and seismicity the study area was grided at 1 degree spacing with an overlapping of 0 . 5 degree respectively.

In this work, the fractal dimensions (D) are estimated using the correlation dimension by Grassberger & Procaccia (1983), measures the spacing of a set of points, which in this case are the earthquake epicentres and cordinates of the computed drainage frequency and density. The correlation integral technique gives the correlation dimension and it is represented as, $D = \lim_{r \to 0} \log(C_r) / \log(r)$, where C_r is the correlation function. The correlation function measures the spacing or clustering of a set of points and is given by the relation, $C(r) = \frac{2}{N(N-1)} N(R<r)$, where $N(R<r)$ is the number of pairs (X_i , X_j) with a smaller distance than r. The correlation integral is related to the standard correlation function as given by Kagan & Knopoff (1980), $C(r) \sim r^{D_2}$, where D_2 is the fractal dimension, more strictly, the correlation dimension (Grassberger and Procaccia, 1983). Here, D is used instead of D_2 for representing the fractal dimension.

The b – value is calculated by the maximum likelihood method (Aki 1965), which is based on the theoritical considerations and is the most accepted method of b – value estimate. According to Kanamori & Anderson (1975) the moment of the earthquake relates to its magnitude and hence, the fractal dimension of regional or world wide seismic activity is simply twice time of the b – value.

According to Smith (1988) the minimum number of points required for a reliable calculation of correlation dimension in two-dimensional case (in the present study epicentres of earthquakes and drainage frequency / drainage density) is 42. In this study the number of earthquakes in each degree grid varies between 32 to 78 per grid. Furthermore, the drainage frequency and density has been evaluated by dividing the each degree grid into 144 numbers of grid. Hence, the condition for reliable calculations has been satisfied here much more in case of drainage frequency and density than that of earthquakes.

The contour interval of 0.10 in case of the fractal dimension for earthquakes and 0.05 in case for the fractal dimension of drainage frequency / drainage density and for the b – value mapping has been selected on the basis of error estimation. The sampling error is estimated by using the sampling distribution theory. Hence, for these contour maps the error is found to vary between 0.05 and 0.03 respectively.

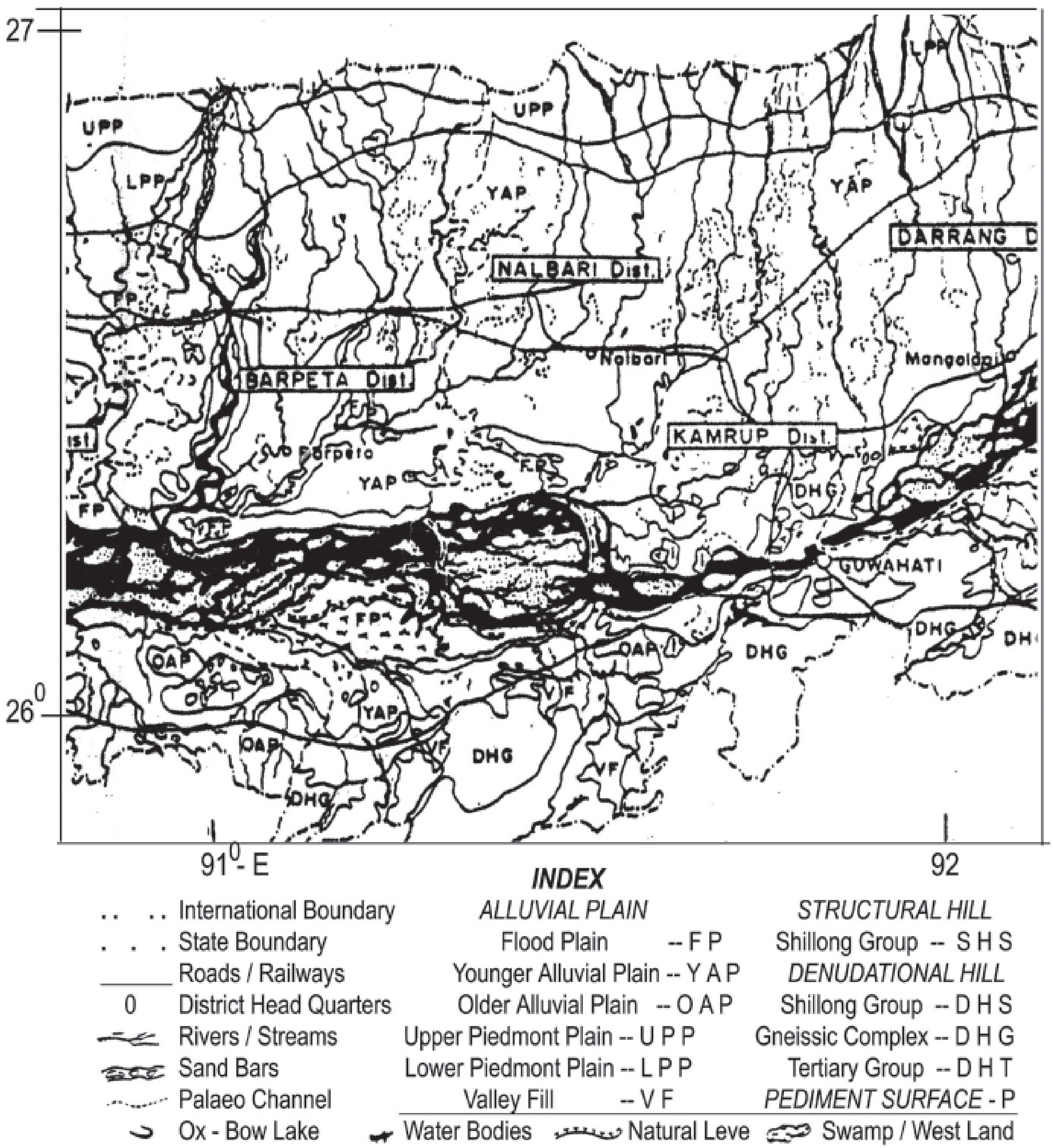

Figure 1A. Geomorphic features in the study region.

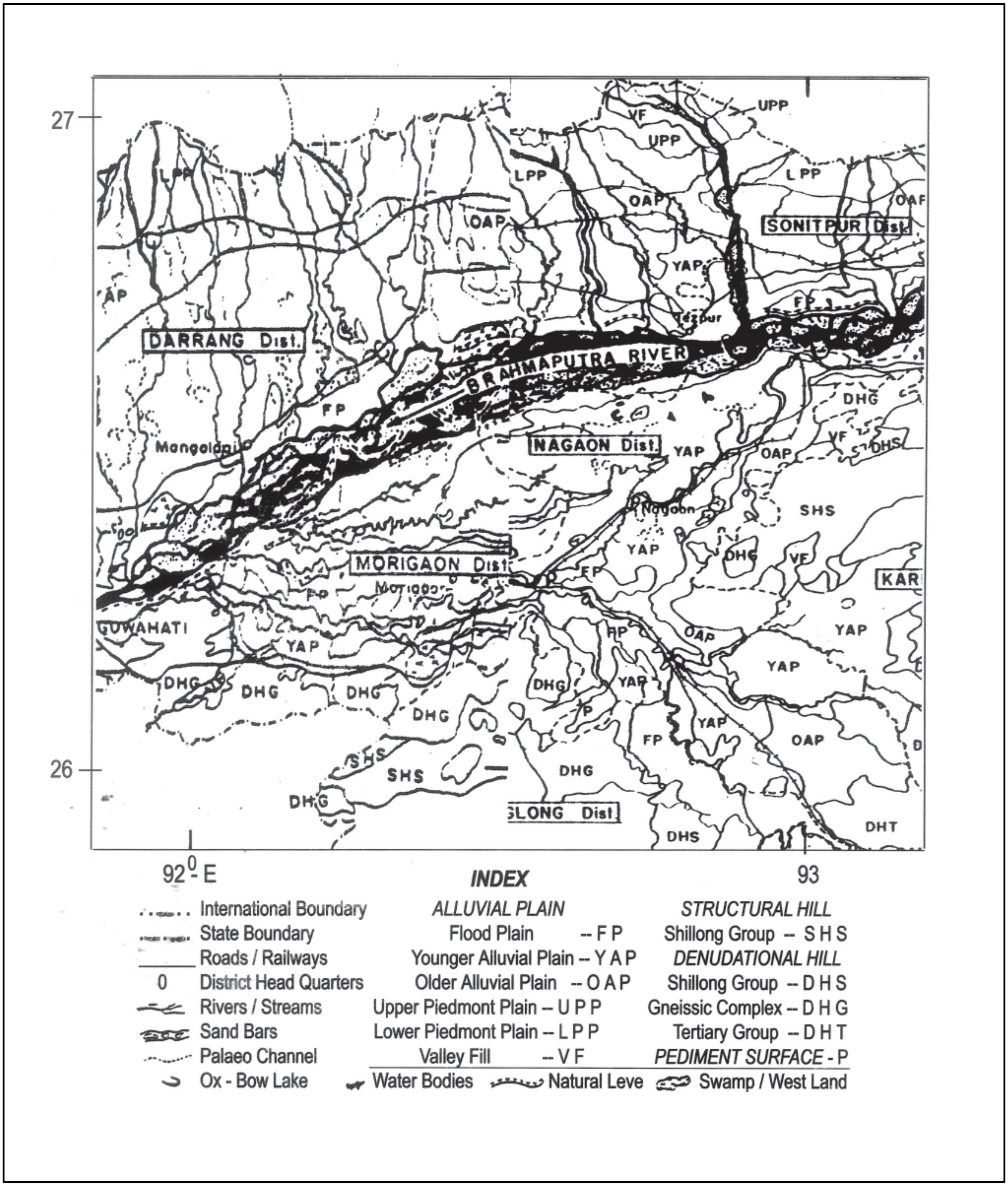

Figure 1B. Geomorphic features in the study region.

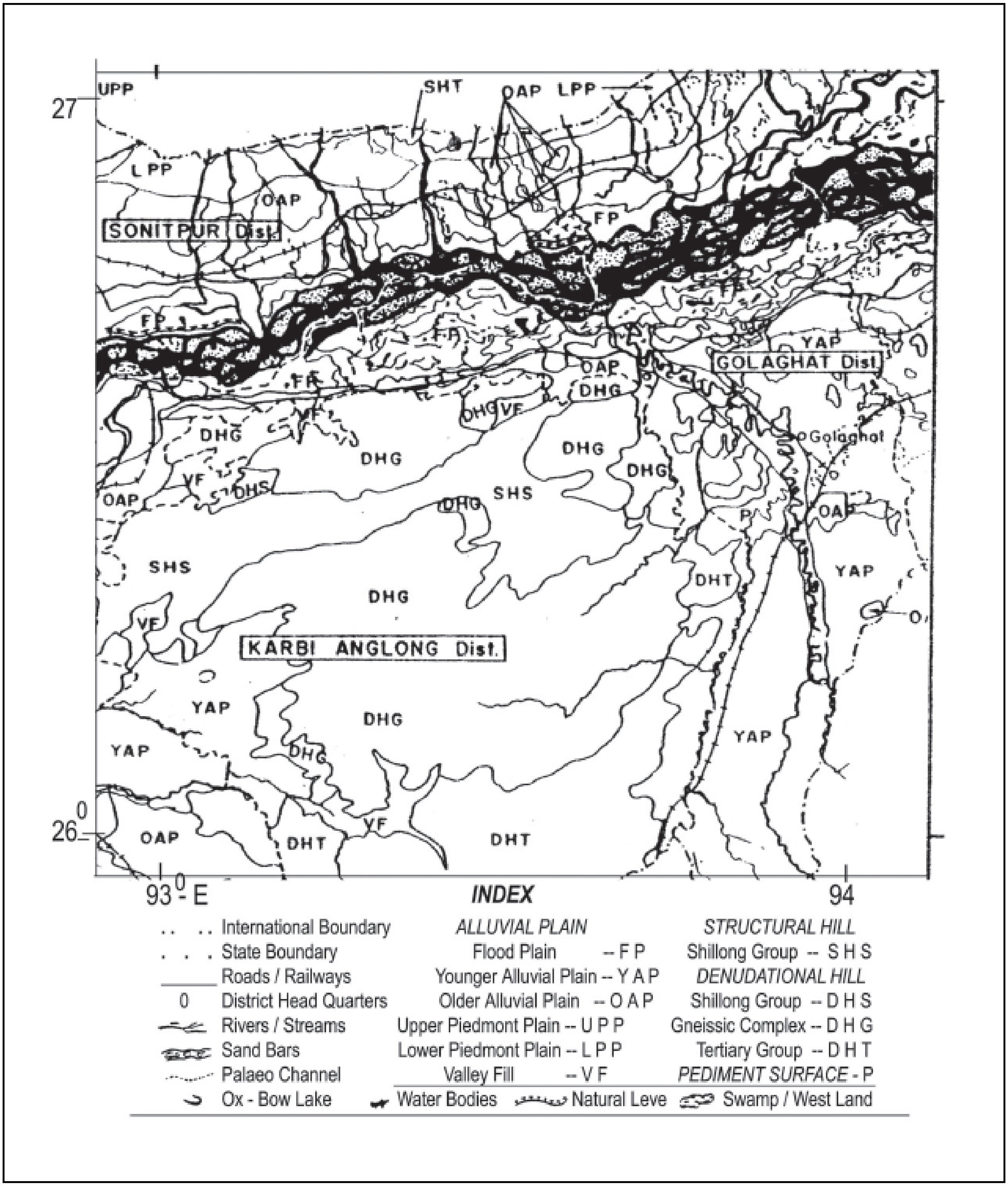

Figure 1C. Geomorphic features in the study region.

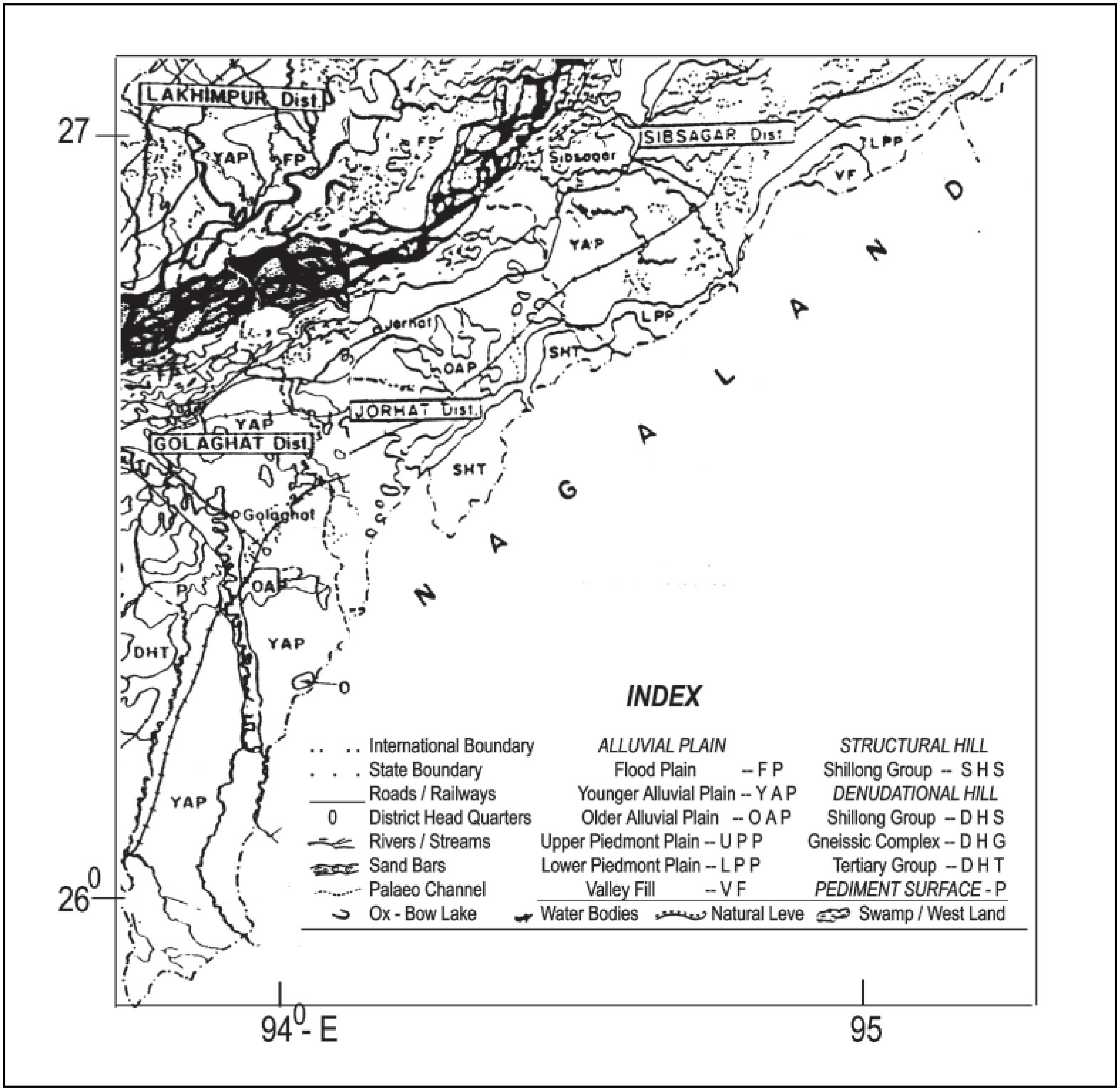

Figure 1D. Geomorphic features in the study region.

STUDY REGION

The present study covers from latitudes 26 ^{0} to 27 ^{0} N and longitudes 91 ^{0} to 95 ^{0} E of the Northeast India. However to study the seismicity patterns, as well as to correlate with the fractal mapping of natural drainage systems the surrounding regions have also been incoroporated. The relief of most of the hills in the study region varies from 130 meters to 1610 meters above mean sea level. Geologically, the study area comprises oldest to youngest rock types: Precambrian gneissic complex, the Shillong group, older and younger alluvium. The topography of this region reveals a criss-cross pattern of faults cutting the ancient rocks of the basement (Fig. 2). The earthquakes in the Himalayan arc are referred to collision tectonics and are associated with the known regional thrusts, the Main Boundary Thrust (MBT)

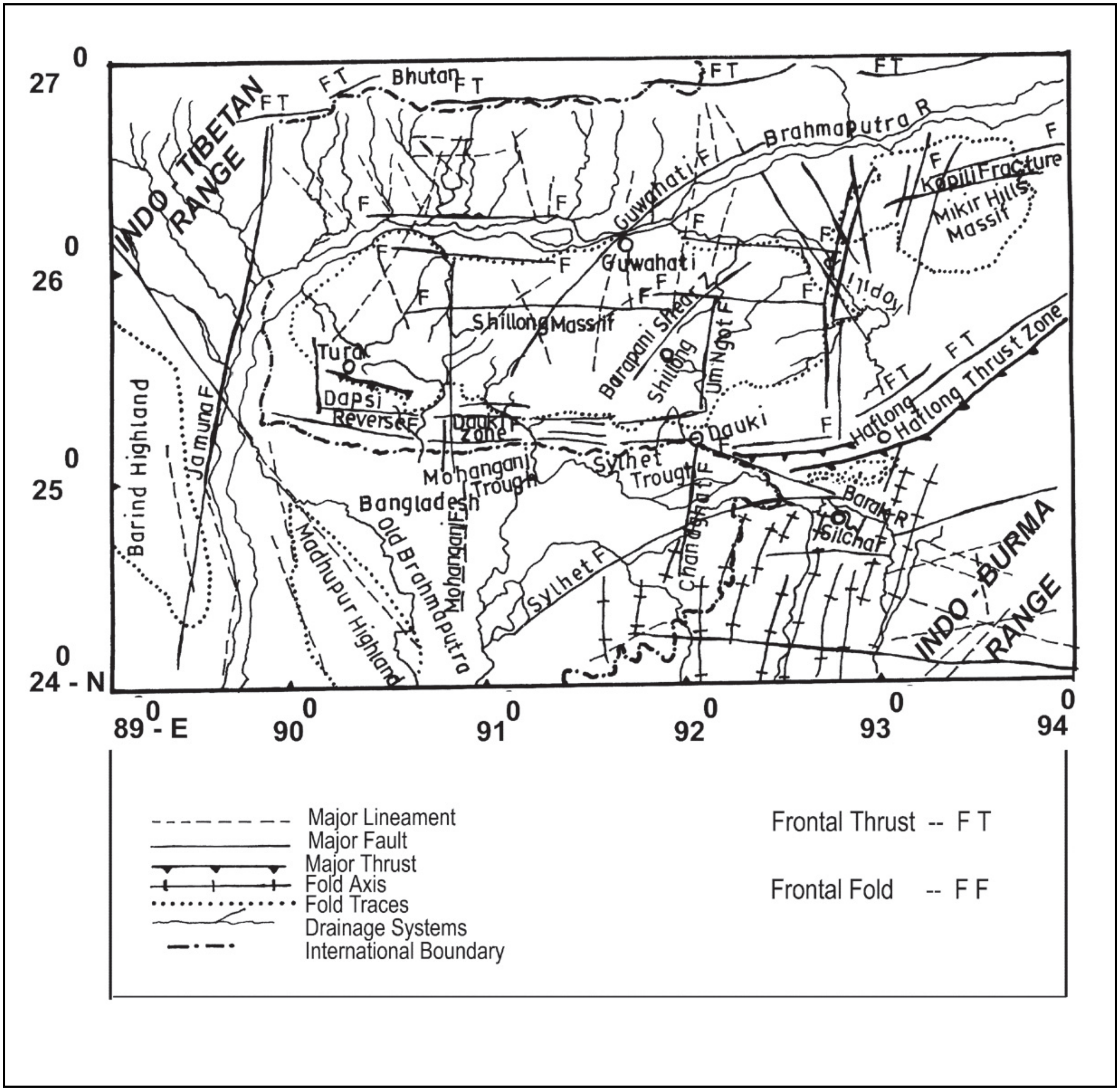

Figure 2. Structural features on satellite images in the study region.

and the Main Central Thrust (MCT) [Ni & Barajangi, 1984). The earthquakes in the study region are mostly confined within the depth range of 20 to 40 km (Fig. 3). The earthquakes in the Shillong plateau and Assam valley area (bounded by the MBT to the North and by the Dauki fault to the South) are reverse faulting and strike slip faulting. Microearthquake investigation, however, revealed transverse tectonics in the Arunachal Himalaya (Kayal & De 1991). To the east of Shillong plateau lies the Mikir massif, which is separated from the Shillong massif by NW – SE Kopili lineament and both the Mikir hills area as well as the Shillong plateau are in equally active (Nandy 1980). The earthquakes in the Burmese arc, on the other hand, are referred to subduction tectonics; normal, thrust and strike-slip faulting (Mukhopadhyay 1992).

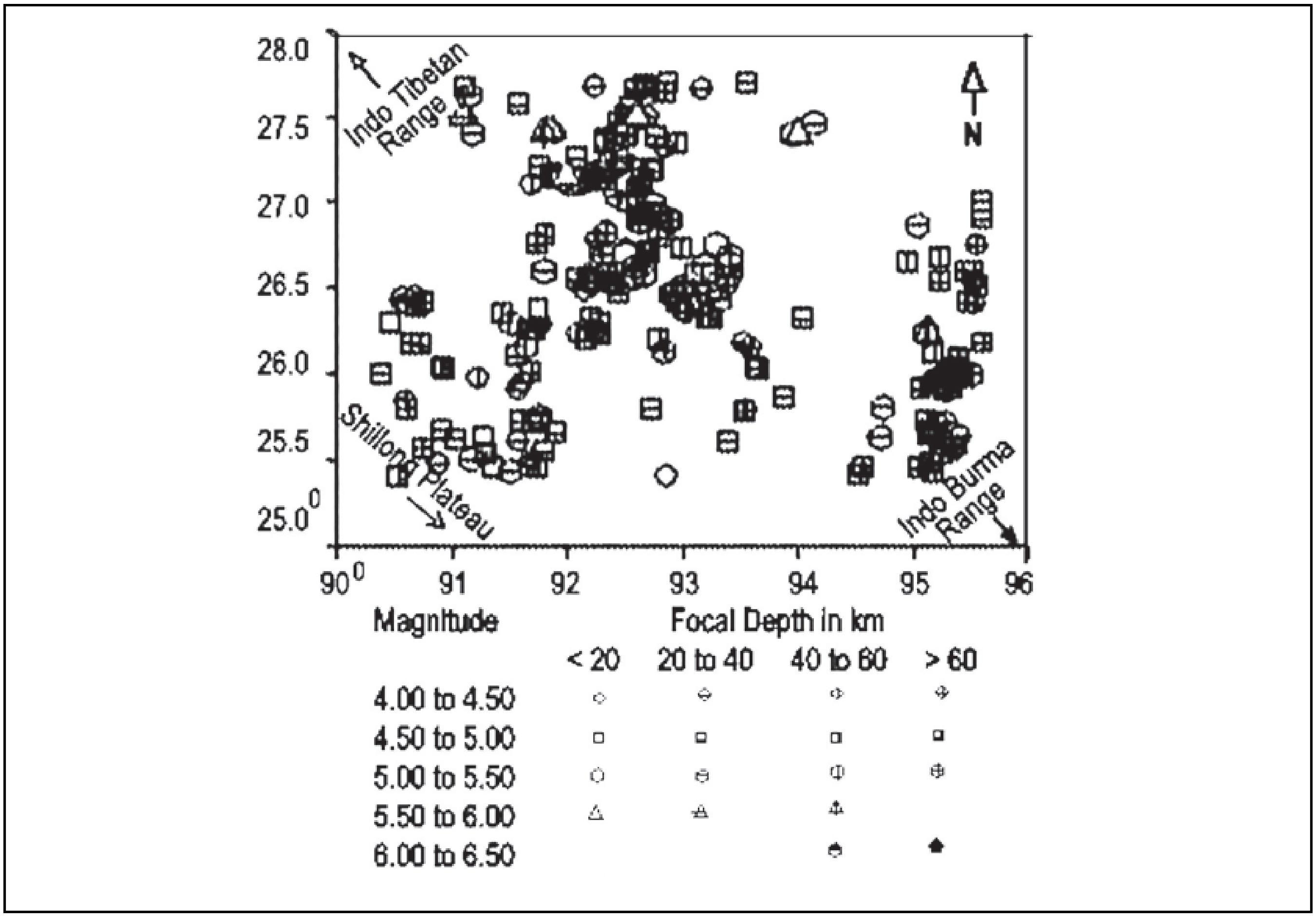

Figure 3. Map showing the epicentres of the earthquakes.

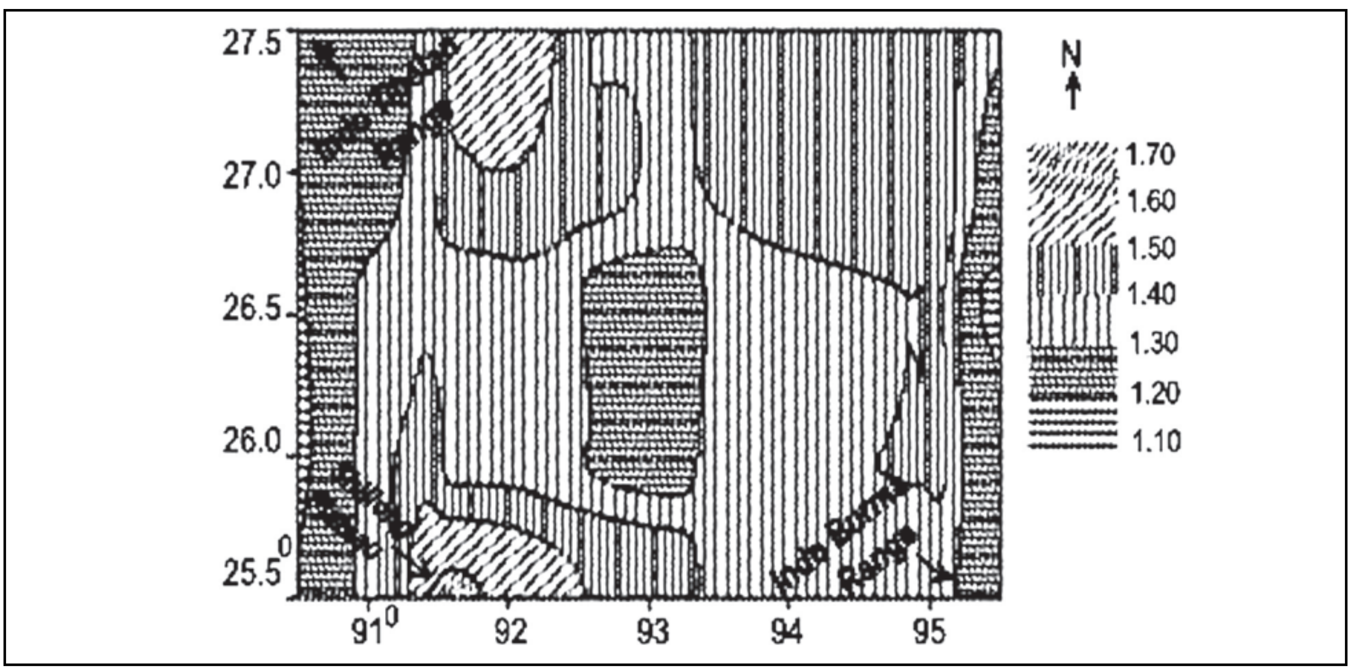

Figure 4. Map showing the contours of fractal dimension (D) of earthquakes in the study region with 1 degree grid.

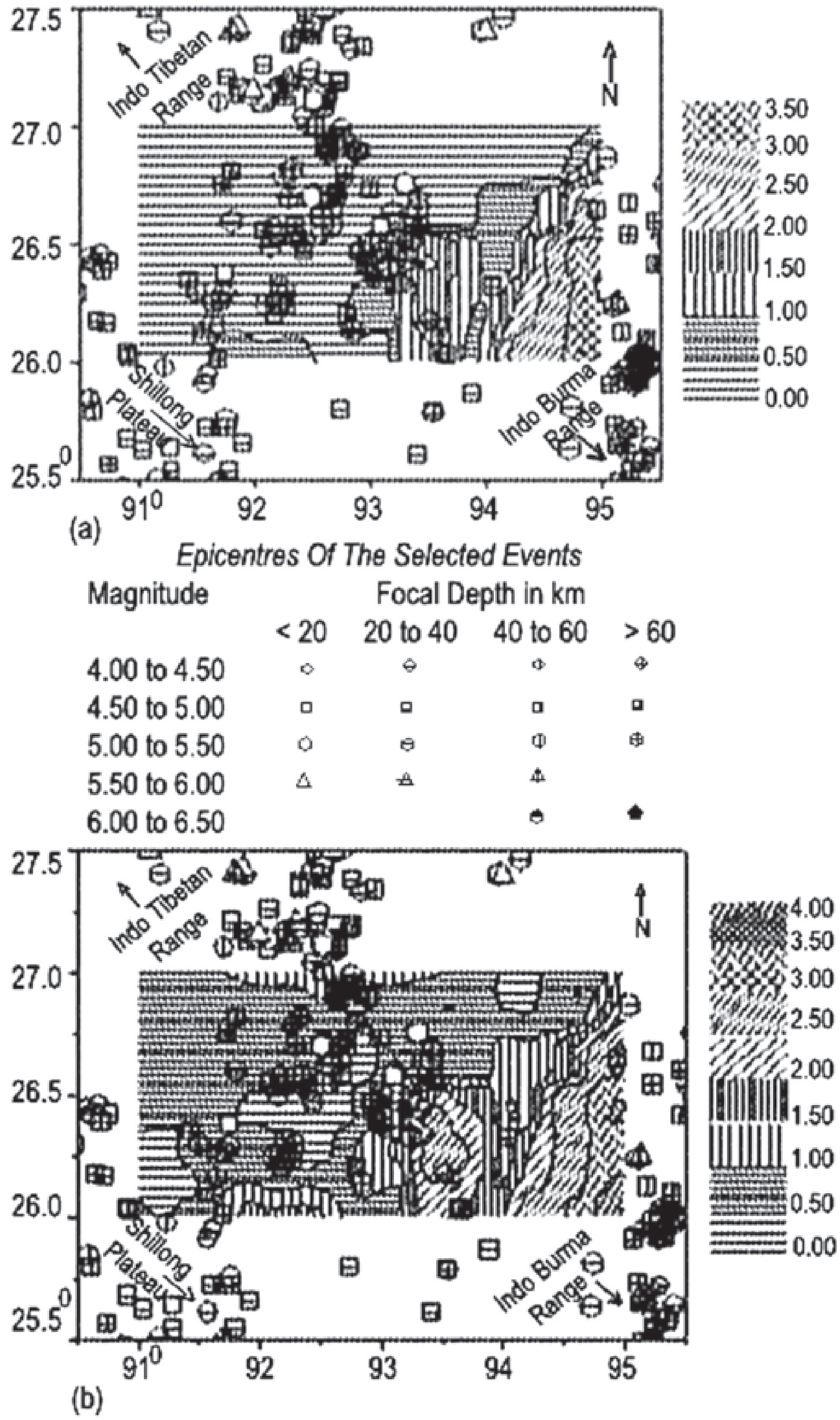

Figure 5. Map showing the contours of (a) drainage frequency and (b) drainage density in the study region with 1 degree grid. The epicentres for the earthquakes also shown.

RESULTS AND DISCUSSION

Contour maps were prepared separately for drainage frequency and drainage density and also the epicentre of the selected events were plotted to correlate with the drainage parameters as shown in Fig.5. Using the aforesaid methodology the fractal dimension, D values are estimated using the correlation dimension and the maps are prepared for drainage frequency and density (figs. 7 and 8) and also for the earthquakes (Fig.4). The b – value map (Fig.6) clearly depict the spatial variation of earthquakes in the study region. The variations in the fractal dimension of earthquakes (Fig. 4) are comparable with the fractal dimension of drainage frequency and density (figs.7 and 8). It must be mentioned here that in figs. 7 and 8, the fractal dimension of drainage frequency and drainage density has been estimated with respect to the cordinates of the evaluated drainage frequency and density that best fits with the statistical median values of drainage frequency and drainage density, and the maximum values respectively. Furthermore, according to Kanamori & Anderson (1975) the fractal dimension of seismic activity is simply twice times the b – value. It is also obvious that this condition is almost satisfying for the fractal contour maps of drainage frequency and drainage density (Fig. 7 and Fig. 8) and earthquakes (Fig.4). Hence, it can be said that the fractal dimension mappings of earthquakes, drainage frequency and density and b – value maps are comparable.

The estimated fractal dimensions of drainage frequency 1.10 to 1.56 [Fig.8 (a)] and 1.25 to 1.64 [Fig.7(a)]; and drainage density 1.10 to 1.60 [Fig.8 (b)] and 1.30 to 1.60 [Fig.7(b)] are comparable to the fractal dimension of earthquakes 1.10 to 1.70 (Fig.4) and the b – values 0.56 to 0.95 (Fig.6). According to Hirata (1989a), 1.6 is an upper limit for the fractal dimension of the fracture geometry that can be explained by the Griffith energy balance concept. Hence, from the estimated fractal dimensions in the study region it can be said that the faults are spatially distributed and the whole study region is seismically active. The ascending order of the fractal dimension contours (both for the earthquakes and the drainage parametres) towards Shillong plateau, Indo Burma range and Indo Tibetan range indicate the clustering of epicentres in the two-dimensional space may be due to greater stress concentration; which are comparable to the trends of b – value contours.

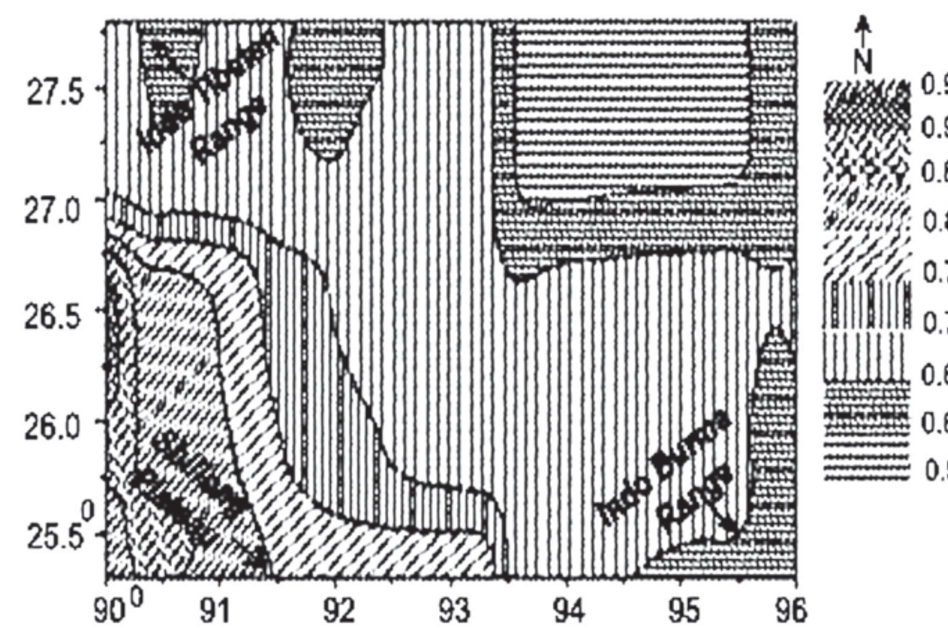

Figure 6. Map showing the contours of b – values for the earthquakes in the study region with 1 degree grid.

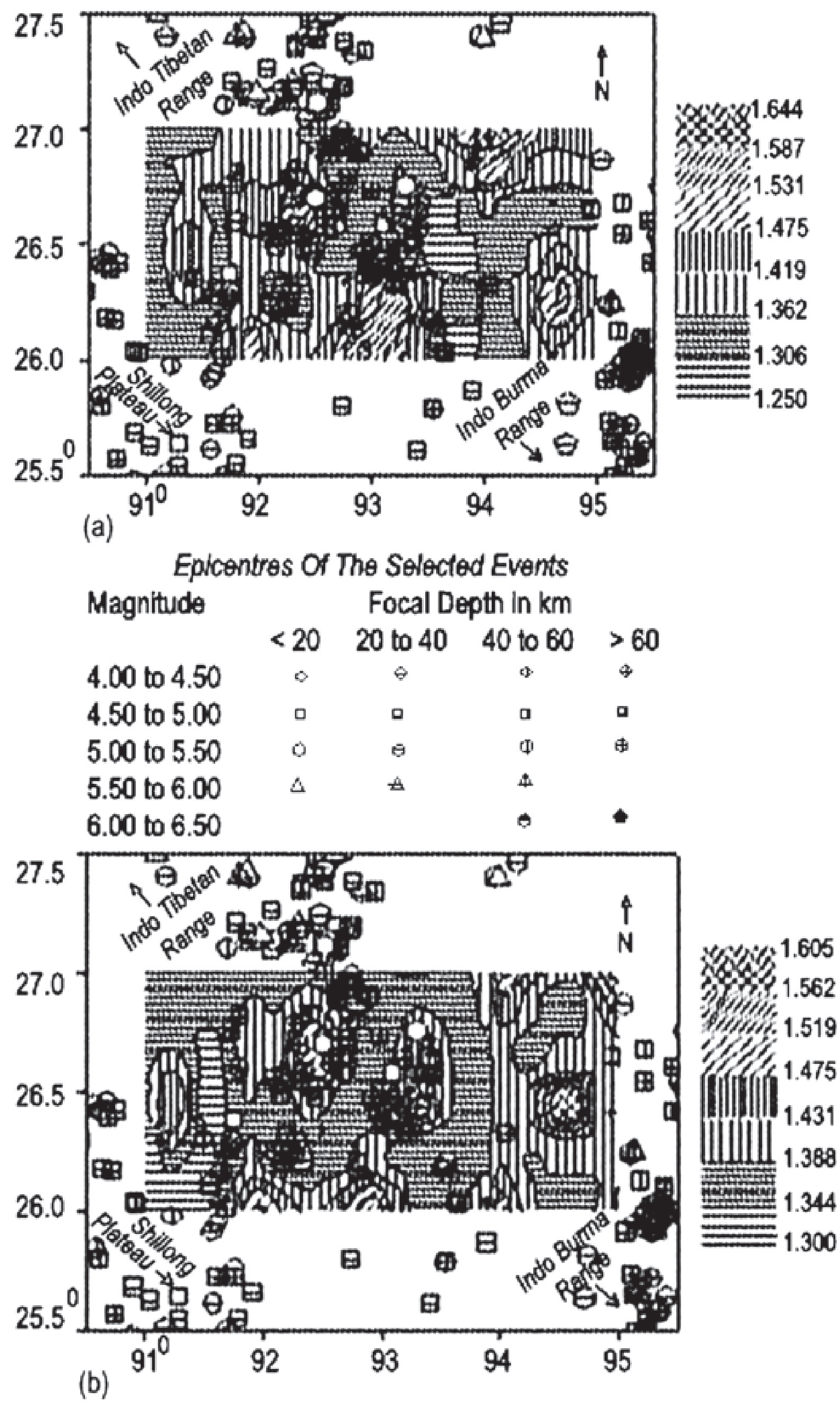

Figure 7. Map showing the contours of fractal dimension (D) in the study region with 1 degree grid : (a) drainage frequency; (b) drainage density, with respect to the statistical median value of the computed drainage frequency and drainage density in each degree grid respectively. The epicentres for the earthquakes also shown.

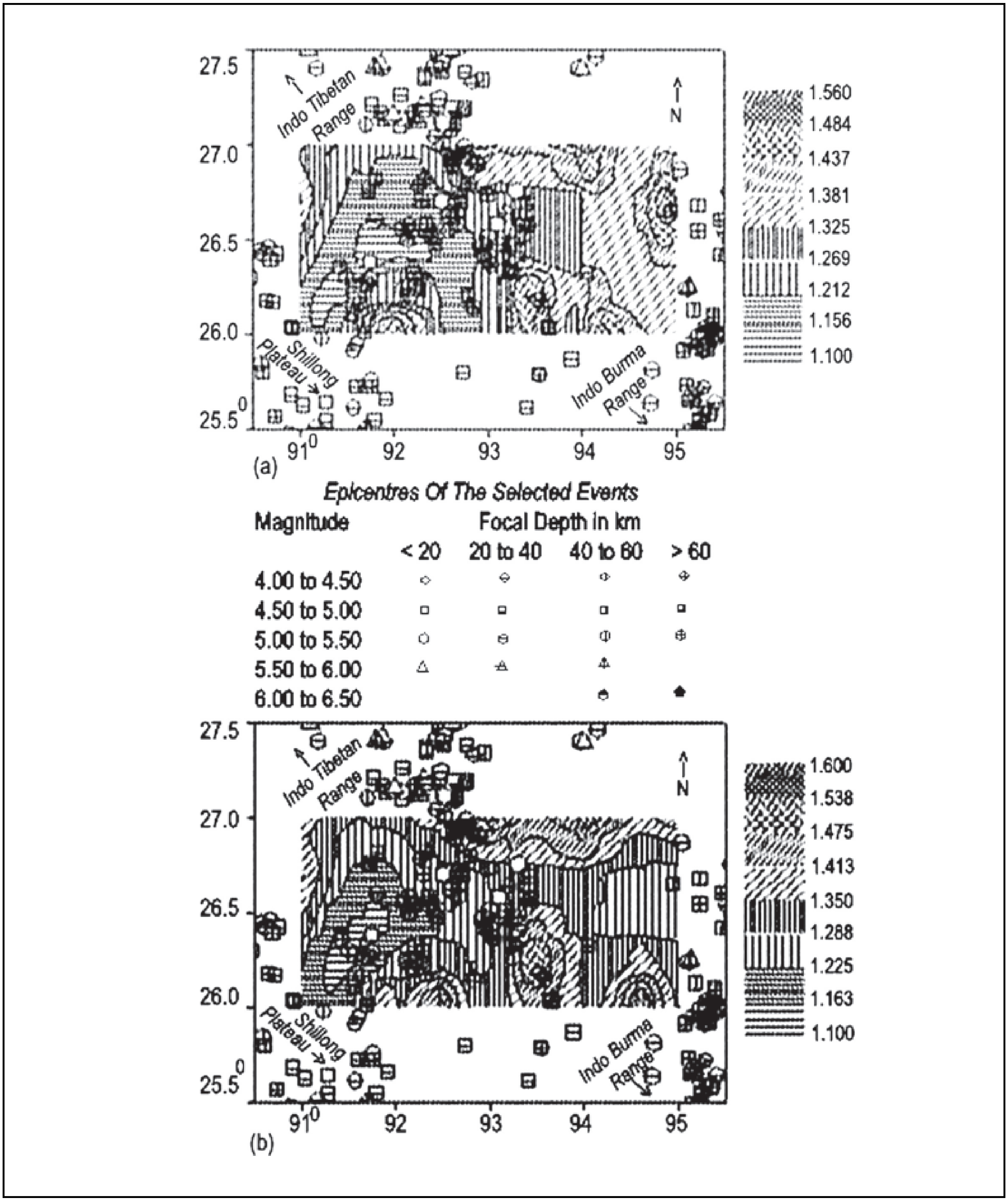

Figure 8. Map showing the contours of fractal dimension (D) in the study region with 1 degree grid : (a) drainage frequency; (b) drainage density, with respect to the maximum value of the computed drainage frequency and drainage density in each degree grid respectively. The epicentres for the earthquakes also shown.

CONCLUSIONS

It may me seen that while the study region as a whole is highly seismic, there are pockets of very high seismicity with other small areas of comparatively less activity.

Bhattacharya, Majumdar & Kayal (2002) studied fractal dimension of this seismically active zone (latitude 24 – 28 ^{0} N and longitude 89 – 98 ^{0} E) using the teleismic ISC data ($M \geq 3.0$) and NGRI / RRL(J) data ($M \geq 4.0$) by correlation integral method with 2 degree and 1 degree grided spacing. They estimated the fractal dimension value as 0.80 to 1.90 and 1.05 to 1.75. Their results are comparable with the estimated fractal dimension of earthquakes with the present study in this region.

Furthermore, in this present study the fractal dimension of earthquakes are comparable to the fractal dimension of drainage parametres (as it is obvious from the trends of the contours of the fractal dimensions of earthquakes, drainage frequency and drainage density, spatial distribution of earthquake epicentres and also from the b – value contours). Hence, the fractal dimension mapping of drainage parametres may be identified as the seismogenic structures in this study region; an inhabitant structural and lithological controlling agents of landform evoluation of the mother earth.

Keeping in view the overall urgency and low cost provided by the funding authority for this work, only few numbers of the recent time of 5th March, 2003 satellite imageries (very costly) have been studied by visible interpretation techniques. Also, the images cover very small area. Hence, this technique utilised for earthquake risk evaluation from the natural drainage parametres may provide a broadly new idea regarding the earthquake hazard estimation.

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