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Quaternary sedimentation in the Indo-Gangetic Basin: A review

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The Indo-Gangetic Basin of molasse developed during the Palaeocene is still an active foreland basin. Recent work by ONGC in connection with hydrocarbon exploration has provided extensive information about basin configuration and various structural elements. The alluvial succession is made up of Paleistocene to Holocene sediments, the youngest Holocene being dominated by thick elongate mega-fans of fluvial sediments. The various lines of evidence show the orogenic belts that divide the Indo-Gangetic basin in neotectonically an active domain.

Introduction

THE Indo-Gangetic Basin comprising very thick sediments of the order of 10 km developed as a result of collision of the Indian and Asian continental plates[1-3]. The intraplate subduction along the Main Central Thrust (MCT) caused the 20-km upliftment of the Great Himalaya, exposing the basement rocks to fast erosion and attendant sediment generation, the 'popping up' of southern Himalayan province, and the subsidence of the northern part of the Indian plate to form the Indo-Gangetic Basin. With continued northward push of the Indian Plate, the southern areas also rose up and contributed sediments. The movements in the mid-Pliocene and subduction of the Peninsular Indian plate bearing a large prism of the Siwalik molasse at its front, took place along the Main Boundary Thrust (MBT). Subsequent folding of the northern edge of the Indian Peninsular plate gave rise to the Siwalik ranges during the early Pleistocene. Subject to cannibalism in the subsequent period, the Siwalik has greatly contributed to the sediment influx into the Basin.

In the Indo Gangetic Basin (Figure 1) paralleling the Himalayan Province, sedimentation started with the shallow marine environment which changed to estuarine-deltaic and finally to fluvial. It was during the mid-Miocene that continental sedimentation, mainly under fluvial environment, started and has continued till the present. The Basin had an uneven configuration characterized by a number of ridges and faults extending from the Peninsular shield. These features largely controlled the dispersal of currents and resultant sedimentation. The Basin had predominently transverse dispersal pattern, controlled by southerly flowing rivers descending from the Himalayan domain.

The present work, dealing mainly with the evolutionary history of the Indo-Gangetic Basin (IGB) is a brief synthesis of the studies carried out by many workers on the most productive geological province of

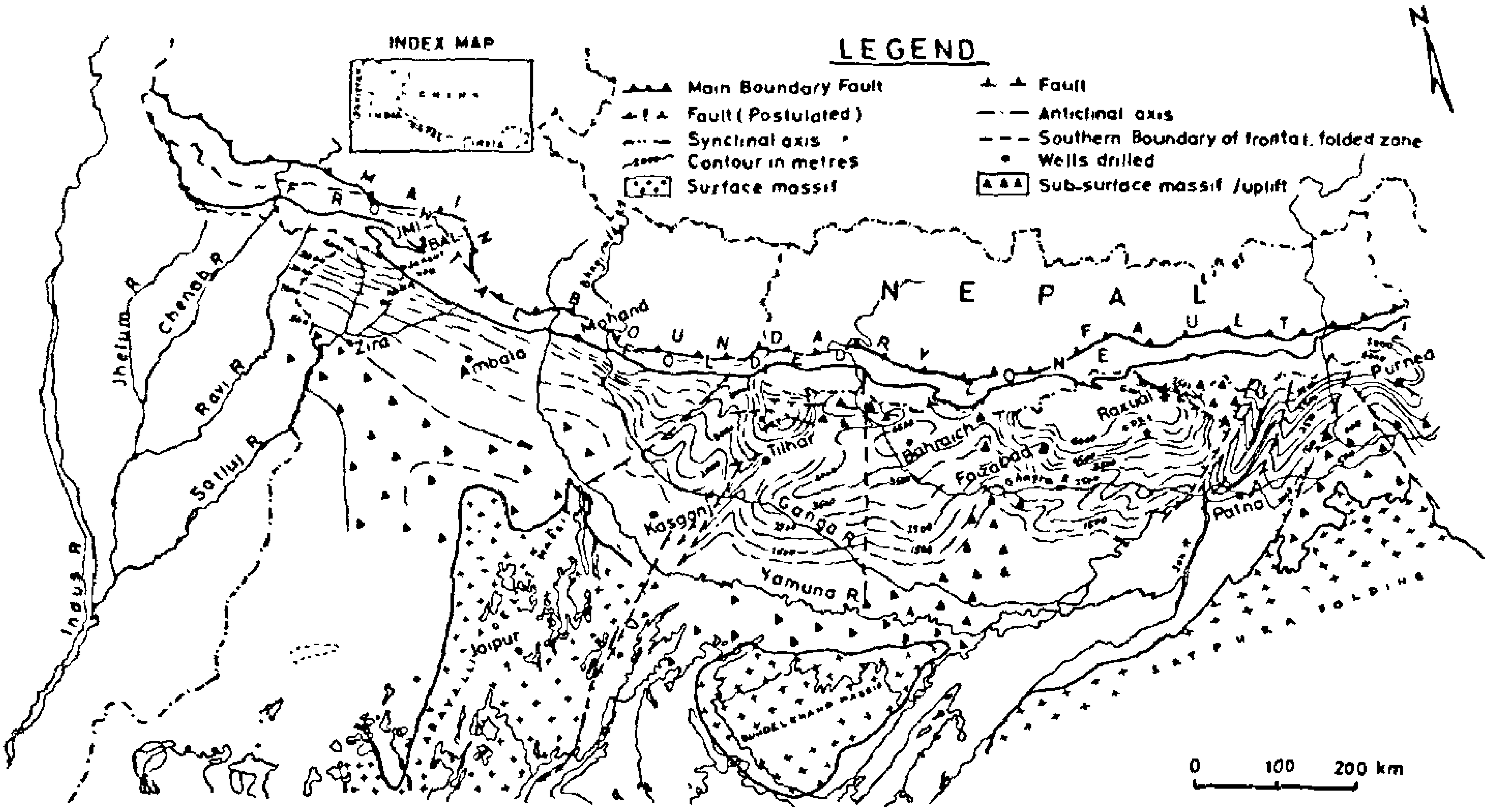

Figure 1. Basement configuration of the Indo-Gangetic Plains (IGP). (After Raiverman *et al.*[15]).

the Quaternary origin that supports one-third of the population of India.

Geological setting

The Himalayan Frontal Fault (HFF) delimits the Indo-Gangetic Plains from the Siwalik folded belt[4]. The southern boundary with the Peninsular India is probably a normal fault[5].

Rapid sedimentation is taking place in the Indo-Gangetic Plains (IGP) and along the foothills. Along the Siwalik border, sediments are accumulating in the form of mega fans and as channel deposits in the intramontane valleys known as 'Duns'[6]. The E-W running weak zones control the courses of main rivers and pattern of sedimentation in plains. During the later part of the Pleistocene, in response to lowering of the sea-level, small river systems developed within the alluvial plains, which cut their valleys deep and frequently shifted laterally, as a result of neotectonic movements.[7].

Basin configuration and subsurface structures

Recent geophysical studies in connection with oil exploration have unravelled subsurface geology and topography[8-10]. The basement slopes northward with corresponding increase in thickness of sediments toward the Himalayan foothills. Beneath the undeformed sediments of the IGB, the extensions of the Siwalik of foreland thrust belt have been encountered in wells drilled by the ONGC. The drilling also encountered basement crystallines, the Vindhyans and the coal-bearing Gondwanas, suggesting that the basement of the IGP actually represents the northern prolongation of the Peninsular Shield (Figures 2, 3).

The floor of the IGB is uneven and dissected by a number of ridges and faults. The northern boundary of Ganga basin is faulted (HFF) against the outer Himalaya. The IGB is divisible into a number of first-order units from east to west[11] (Figure 4). A brief account of these units is given in the following pages.

Purnia–Kishanganj Basin

Lying to the east of the Munger-Saharsa Ridge and demarcated in the west by the northern extension of the basement high, the Rajmahal-Garo gap is a basin of small extent. It is probably a half graben[5], having a maximum depth of 4000 m in the vicinity of the foothills.

Munger-Saharsa Ridge

The Munger-Saharsa Ridge probably represents the NNE-projecting Satpura folded belt of the Chota Nagpur plateau. It forms the eastern boundary of the Ganga Foredeep, separating it from the Bengal Fan

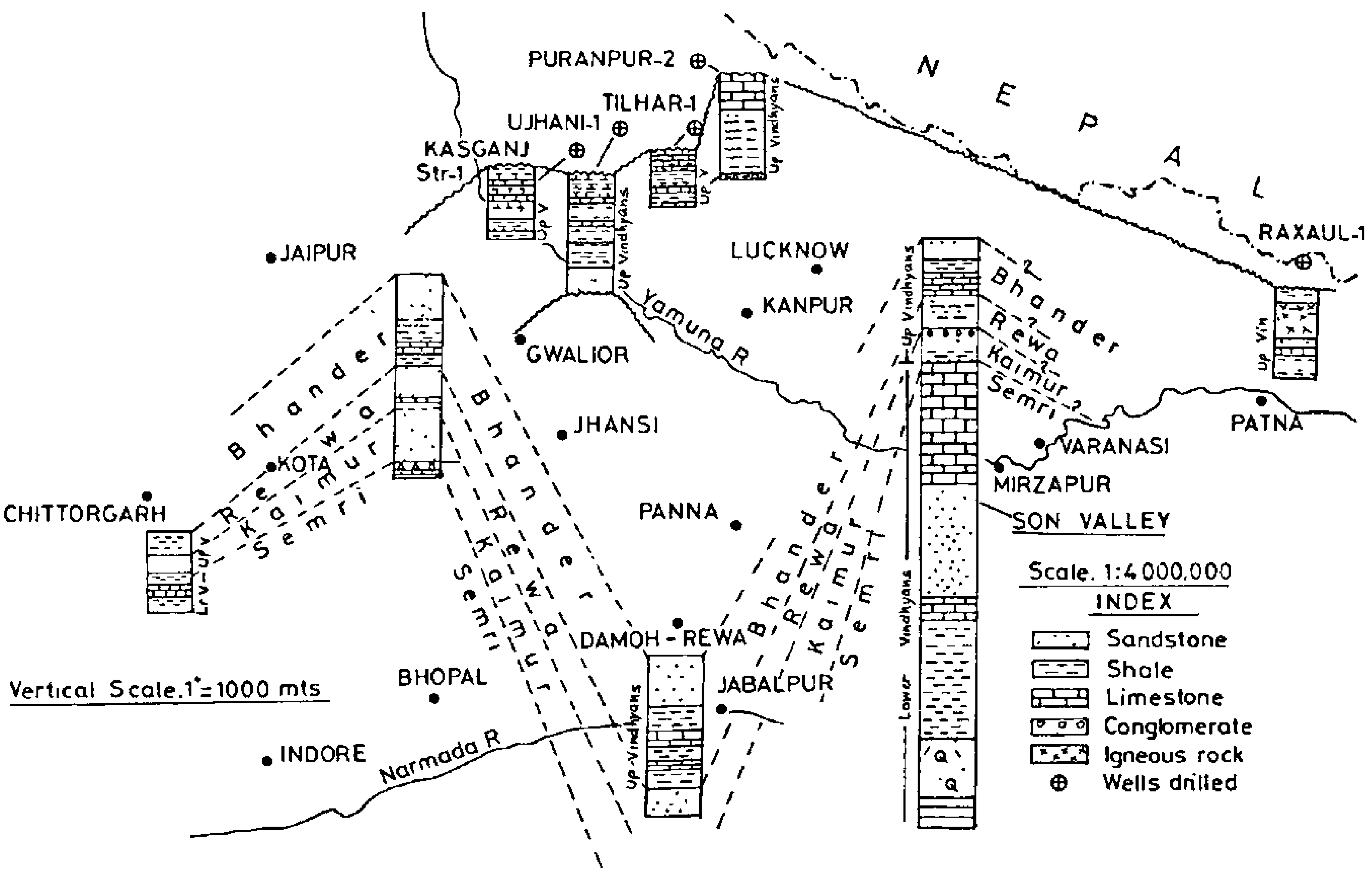

Figure 2. Subsurface lithology and correlation of the Vindhyan Supergroup and equivalents in the Ganga Basin. (After Srivastava *et al.*).

(Figure 5). The shallow nature of the basement is indicated by magnetic and seismic surveys (Figure 6). The Neogene sediments directly overlying the basement sedimentary cover over the Ridge hardly exceeds 3000 m.

East Uttar Pradesh Shelf

The East Uttar Pradesh Shelf is bounded by the Munger-Saharsa Ridge in the east and the Faizabad Ridge to the west. (Figure 5). The shelf extends to the North and merges with Gandak Depression. The basement is probably the continuation of Satpura orogen and is overlain by the Vindhyans (Figure 6).

Gandak Depression

The Gandak Depression exhibits sedimentary thickness more than 6000 m. The basement is similar to that of the East U.P. Shelf. A well drilled by the ONGC at northeastern margin near Raxaul encountered pre-Neogene unconformity at a depth of 4128 m below a thin sequence of uncertain stratigraphic affinity, followed by the Vindhyans (Figure 3). However, Raiverman *et al.* (see ref. 15) considered this undesignated sequence to be of Palaeocene age. The Purnea well drilled within this depression encountered the Gondwana sediments between the Tertiary and the crystalline basement.

West Uttar Pradesh Shelf

This sector of the IGB has been extensively studied. The shelf is subdivided into two parts by the Moradabad Fault[5]. East of the Moradabad Fault, the Vindhyan sequence overlies the Aravalli basement, and west of it the Neogene sequence directly overlies the basement made up of the Delhi Supergroup. Various second-order structures recognized on this shelf have a pronounced NW-SE trend.

Faizabad Ridge

Geophysical data suggest that the Faizabad Ridge is the northeastward extension of the Archaean Bundelkhand massif. It seems that the Neogene sediments directly overlie the basement, for the Vindhyan sediments are missing.

Sharada Depression

The Sharada Depression forms the northern continuation of the Western Uttar Pradesh Shelf and comprises

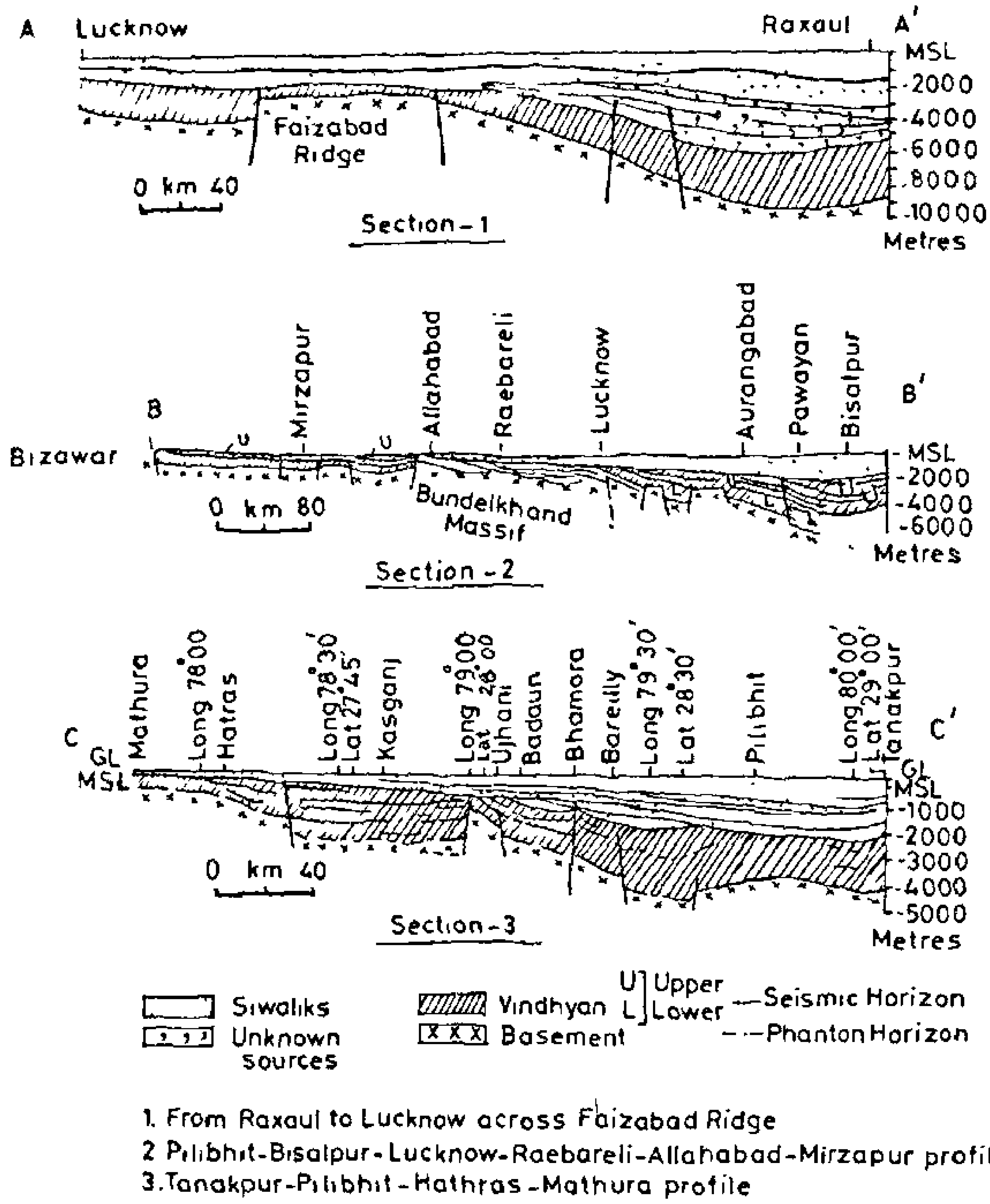

Figure 3. Seismo-geological cross-sections across the IGP.

about 6000 m thick sediments. Vindhyan Supergroup forms the floor of the Tertiary rocks beneath the Quaternary sediments, as revealed by deep structural wells drilled by ONGC at Ujhani, Tilhar and Puranpur[12].

Dudwa Ridge

Trending E-W, and close to the foothills of Nepal on the northern side of the Sharada Depression, is an isolated feature without physical connection with any of subsurface ridges that extends from the shield area.

Delhi–Hardwar Ridge

Forming the NNE extension of Delhi folded belt, it is a shallow structure, as evident from northwest deflection of aeromagnetic contours (Figure 6).

Panjab Shelf

The Panjab wedge separates the Indus Basin in the west from the Panjab Shelf in the east. As evident in other parts, the shelf becomes deeper towards the Siwalik Hills.[13] The Panjab Shelf consists essentially of several blocks demarcated by down-to-basin faults. There are a number of minor ridges alternating with depressions in the northern part such as the NW-SE trending Adampur and Hoshiarpur ridges flanked by depressions. These subsurface ridges merge together, further northwest and form a prominent depression near Gurdaspur. This depression extends up to Pathankot, where the basement rises by 2 km, probably due to faulting.

A well drilled near Hoshiarpur revealed the presence of Upper, Middle and Lower Siwaliks below the Quaternary riverine sediments. However, the basement could not be met up to a depth of 3439 m. The well drilled near Adampur and Jalandhar revealed basement

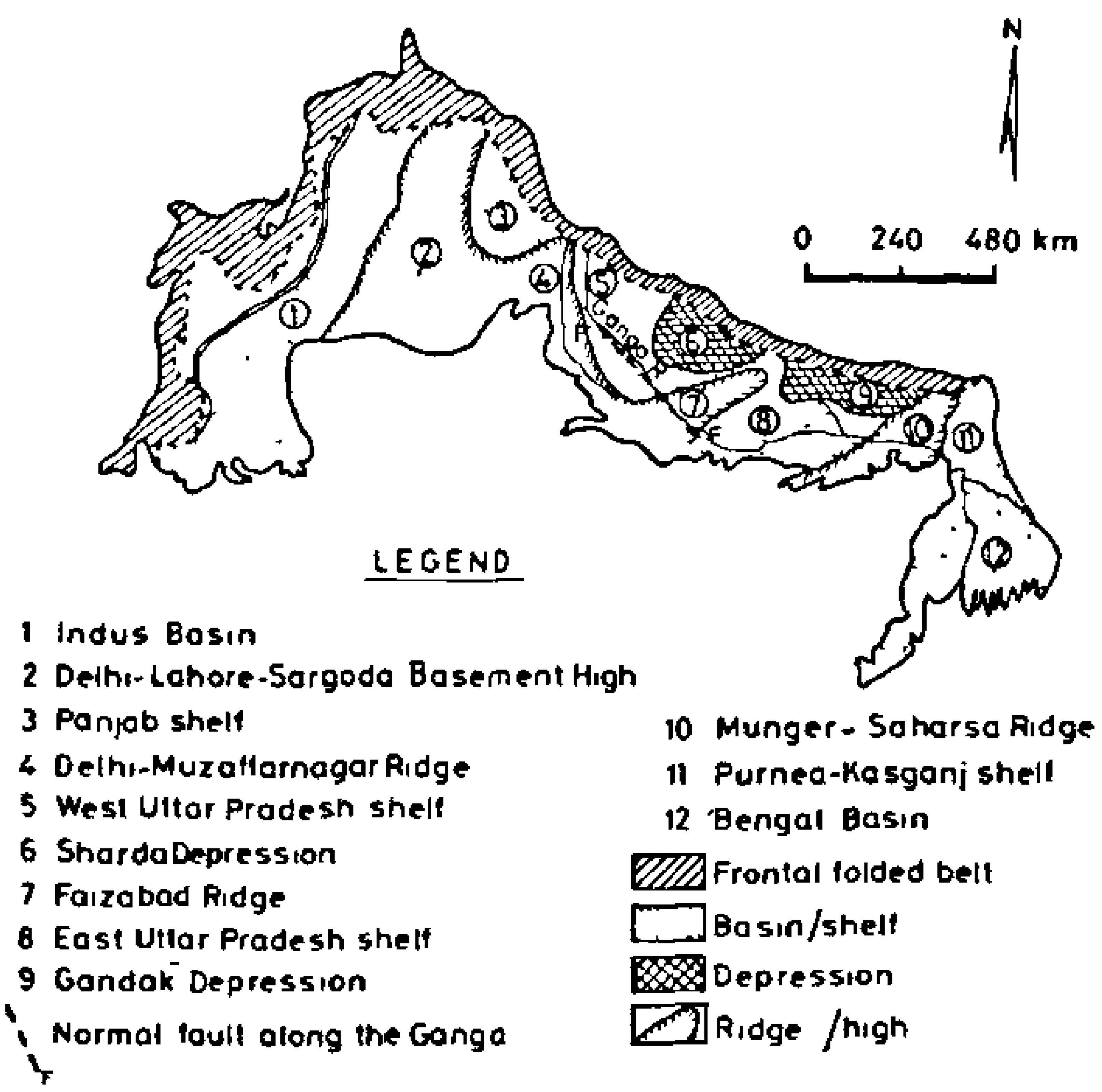

Figure 4. Map of the Indo-Gangetic Basin (IGB) showing major tectonic features. (After Parkash and Kumar[5]).

at the depth fo 2513 m underneath the Lower Siwalik sediments. The Zira (Firozpur) well located near the edge of the Shelf met with granitic basement at the depth of about 700 m below the Upper and Middle Siwalik. Seismic surveys conducted by ONGC[13] have indicated that the basement surface and the overlying sediments below the alluvium in the Panjab Basin slope generally towards the foothills, the maximum depth being 4500 m. The basement is about 2800 m near Jagadhri[14]. A well drilled in the Panjab plains encountered the Siwalik overlying the basement. Significantly, marine sediments are wholly absent. In the northwest, the Basin is fairly wide and deep, but becomes narrower and shallow towards southeast.

Second-order subsurface features

Raiverman *et al.*[15] recognized additional second-order[11] subsurface ridges, depressions and spurs. Among these are the Aravalli Horst, trending in the NE-SW direction from Rupar on the Satluj to Sharada River in the east. At its northern edge, there are a

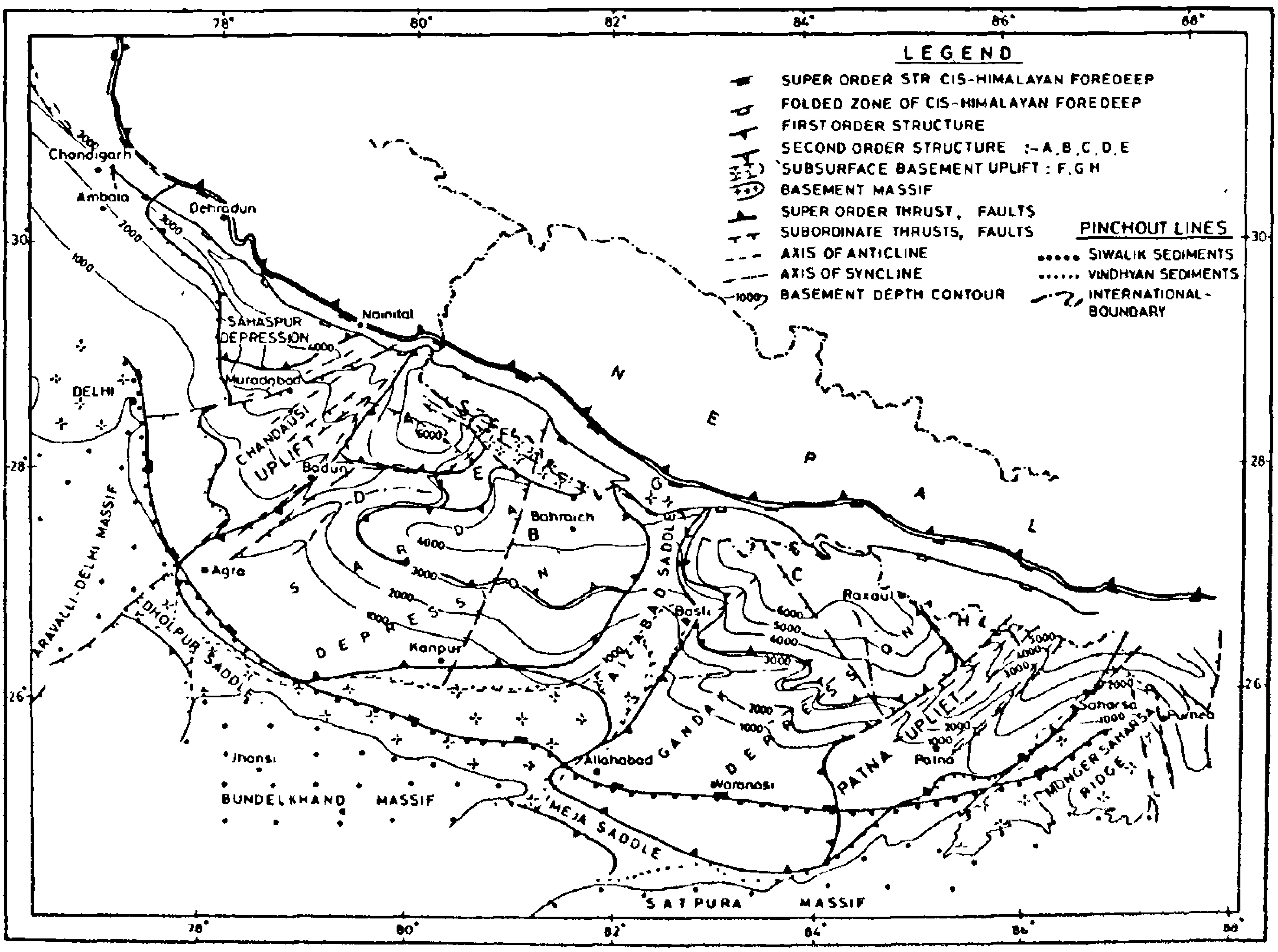

Figure 5. Tectonic map of the IGB. (After the ONGC map).

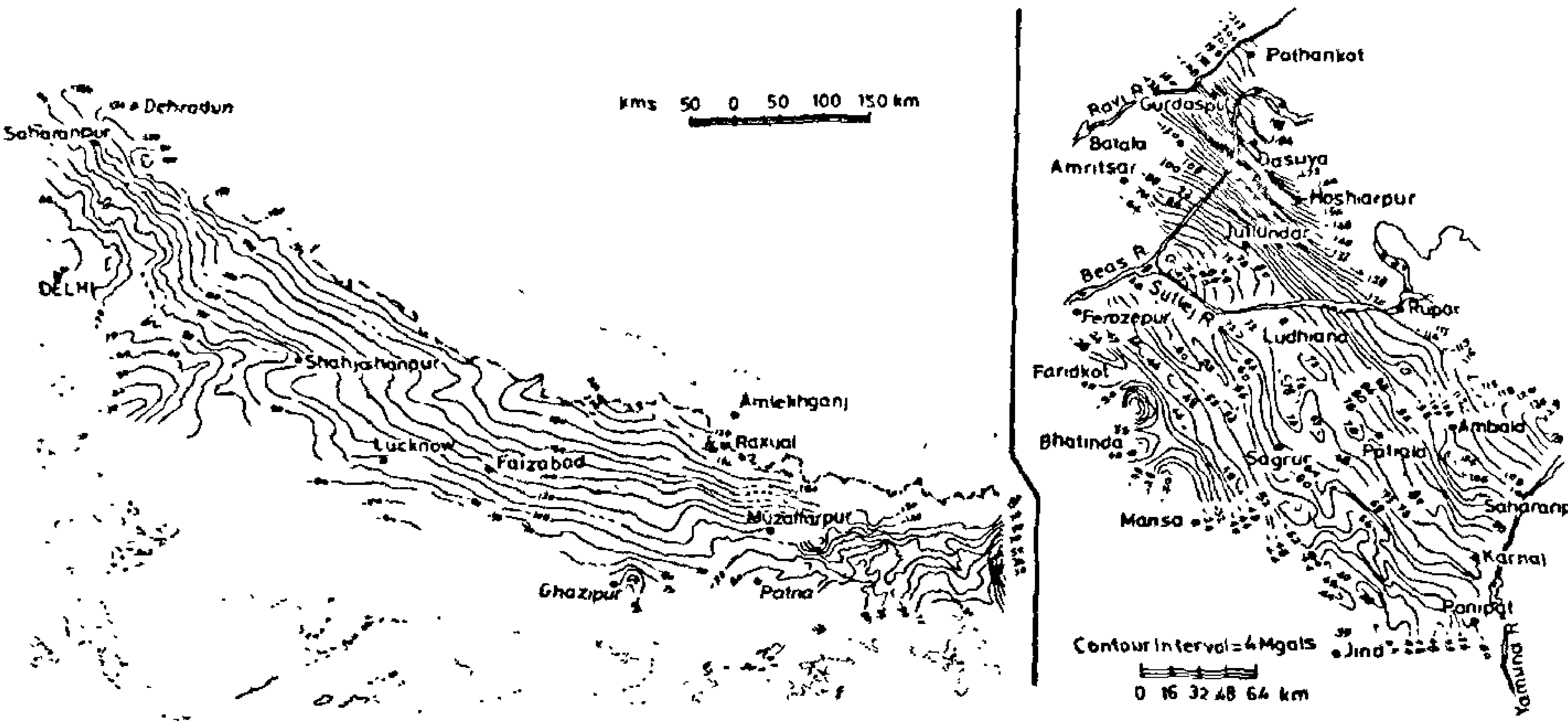

Figure 6. Bouguer gravity anomaly map of the Ganga Basin (left) and Panjab Basin (right). (Raiverman *et al.*[15]).

number of minor ridges alternating with depressions[15]. Then there are many spurs branching off from the Delhi-Sargodha Ridge, the Delhi-Aravalli Horst such as the Chenab spur, Ravi spur, Ambala spur and Kasganj-Tanakpur spur. Smaller depression and sub-basins such as Naushera, Ramnagar, Kangra, Subathu, Dehradun and Ramganga, flank these spurs. However, Parkash and Kumar[5] doubt that such spurs of great relief bounded on both sides by faults, could exist on the basement which has been subjected to denudation for a long time before the beginning of the Cenozoic sedimentation.

Stratigraphy

The Gangetic alluvium is made up of the Pleistocene-Holocene sediments, having an average thickness of 500–1000 m adjacent to the foothills and decreasing thickness southward. Excepting the work of Singh *et al.*[16] no detailed information on the subsurface Quaternary succession of these plains is available. However, the surficial Quaternary sediments of the Indo-Gangetic Plains have been subdivided into Older (Bhangar Alluvium and Younger (Khadar) Alluvium[17]. Subdividing the Pleistocene-to-Recent alluvia of the Birbhum and Murshidabad districts in West Bengal, Bhattacharyya and Banerjee[18] recognize Lateritic Upland, Older Deltaic Plain, Younger Deltaic Plain and Bhagirathi Recent Surface on the basis of morphology and soil characteristics.

Sedimentation in Indo-Gangetic Basin

Recent sedimentation in the frontal folded belt in the Indo-Gangetic Plains is a continuation of the process that started with the beginning of the Siwalik deposition[19]. IGB thus continues to be an active basin of molasse sedimentation. The youngest Holocene scene is dominated by formation of thick prisms of alluvia in the IGP and thin terraces within the mountain valleys in the Siwalik terrain. Vigorous sedimentation on the plains is still taking place in the form of large megafans[5] originating from the exits of gorges of many Himalayan rivers[20]. Megacones are forming adjacent to the HFF along the Siwalik-IGP boundary[4].

The Ganga River megacone has been studied for its soils[21]. The major part of the cone is receiving sediments by a network of braided streams. Gravels are being deposited in the upper part in the vicinity of Hardwar and sands along the remaining course (lower part) of the channel. Away from the active channels the flood plains are receiving silty clays and clays. The Ganga River has meandered over a large portion of the cone, as manifest in the many meandering belts[21]. The alluvial deposits near Rishikesh can be divided into proximal, medial and distal fan facies[22].

The best developed Kosi Fan has been investigated in detail. The Kosi has shifted its course over the face of the fan, sometimes in discrete steps. As a matter of fact it shifted westwards by 167 km between 1738 and 1964. There was slow avulsion during the shifting of the river course[23,24] and the Kosi deposited predominantly coarse sediments in the proximal half of the megafan[8,24,25], and finer sediments in the distal part as well as in intercone areas. There are four district topographic levels: levels 1 and 2 correspond to low stage flow and levels 3 and 4 correspond to high stage discharge during the monsoon[25]. The river shows an ideal down change in channel patterns from gravelly sandy braided, through sandy braided to straight or meandering pattern on the fan.

Spectacular deposition by rivers of the gravel beds in the wide piedmont zone called 'Bhabar' is also taking place all along the foothills of the Siwalik Range. The apron of gravels formed by the coalescence of these fans and various fluvial systems have varied morphology, sedimentary facies and evolutionary history[26-37]

Neotectonics

Shifting courses of rivers

The continued northward drift and pressure of the Indian plate resulted in rise and subsidence of the IGP. Similarly crustal accommodation is taking place through strike-slip movements along the many transcurrent faults of the Indian shield, which extend beneath the alluvial sediments in the IGB[4,38]. The neotectonic movements in the IGP are evident from progressive eastward shift (10–40 km) of the Ganga system since the Mahabharat times (more than 3000 years ago) and the westward shift of the Sindhu system as a consequence of uplift of the subsurface Aravalli tectonic province[38].

Futhermore, the strike-slip movements on the basement faults of the IGB are associated with seismicity which is quite pronounced in the Aravalli belt trending NNE-SSW. The recent shifting and migration of the river systems such as the westward migration of Bihar rivers and the shifting of the confluence of the Ganga and Yamuna at Allahabad are probably related to neotectonic movements in the plains[39]. The surface and subsurface characters of the Ganga River sedimentation pattern and sediment attributes in the Kanpur-Unnao region of the Central Ganga Plain indicate that the Ganga was relatively stable in earlier times as evident from its sinuous course and point-bar activity, which has now turned to straight channel to braided-bar activity due to neotectonic subsidence along the longitudinal section of the river[40]. The Ganga has now adjusted itself to the regional fault extending up to the basement granites. It had accelerated deposition of coarse sand and gravel material in the past. These faults have been rejuvenated in the Recent times, giving rise to escarpments in uplands and tilting of the flood plain.

The Vedic Saraswati River flowing through the districts of Karnal, Hissar, Hanumangarh, Suratgarh and Bhawalpur and ultimately discharging into the Rann of Kachchh was a mighty river having a very large discharge[3]. The wide channels abandoned by the Saraswati are clearly discernible in satellite imageries[41] and are known as the Ghaggar in Haryana, Hakra in Rajasthan and Nara in Sind (Pakistan)[3]. The Saraswati was fed by the Satluj and Yamuna rivers. Uplift of the Aravalli tectonic province caused westward deflection of the Satluj, which swung west at Ropar to join the Sindhu system and Yamuna deviated eastward to join the Ganga. Deprived of the waters of the Himalayan rivers the Saraswati became dry and ultimately disappeared[3]. The Yamuna has continued migrating eastward by 10–40 km in different sectors as revealed by satellite imageries[42]. The orogenic belt that divides the IGB is thus neotectonically an active domain.

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