Geomorphology and tectonics of Kota–Pawalgarh Duns, Central Kumaun Sub-Himalaya

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Interpretation of IRS LISS III satellite data and analysis of digital terrain models in GIS, together with field studies have made it possible to delineate and map geomorphic and tectonic features in Kota–Pawalgarh Duns within the Kumaun Sub-Himalaya. The present study highlights the disposition and characteristics of major geomorphic units within the Duns. The Duns are made up of sediments deposited in different small piedmont fans having modified shapes and distinct surfaces formed in response to various longitudinal and transverse faults. The geomorphic evidences have enabled us to understand the active tectonic activities in the area.

Keywords: Duns, geomorphology, neotectonics, Sub-Himalaya.

QUATERNARY tectonic movements along longitudinal faults/thrusts in the Sub-Himalaya have caused development of intermontane synclinal valleys of varied dimensions, popularly known as 'Duns/Doons'[1–3], e.g. Soan and Pinjor Duns in Punjab, Dehra Dun in Garhwal, Kota–Pawalgarh Duns in Kumaun and Rapti–Dang Duns in Nepal. These are filled with post-Siwalik debris flow and fluvial deposits called 'Dun Gravels' by Medlicott[4]. The dimensions of Duns seem to be tectonically controlled[5,6], whereas the disposition and evolution of landforms therein have been a result of various tectonic, climatic and depositional processes[1–3,6–8].

Among all Duns, Dehra Dun has been extensively studied over the past few years. Using modern tools and methods of investigations like remote sensing data, Geographical Information System (GIS) and Optically Simulated Luminescence (OSL) dating of sediments and lithofacies analysis, valuable information on its chronological, geomorphic, sedimentological and tectonic evolution has been provided[2,3,7–9]. Recently, Malik and Nakata[6], and Malik and Mathew[10] have provided information on the tectonic activities and geomorphology of the Pinjore Dun. The published literature, however, lacks detailed information on various geological aspects of other Duns. The present communication, therefore, provides baseline information on the types and disposition of various landforms and active tectonics of Kota and Pawalgarh Duns.

Preliminary information regarding broad geomorphic surfaces and tectonic set up of the piedmont zone has been provided by Nakata[1]. He identified five levels of surfaces within the Kota Dun, correlated them with the surfaces exposed elsewhere in the piedmont zone, beyond the Dun, and provided a regional geomorphological map of the region. Nakata[1] was the first to recognize the Himalayan Frontal Thrust (HFT), called Himalayan Front Tectonic Line by him, and proposed that between rivers Baur and Kosi, southern Kumaun, it diverges into four parallel branches that are tectonically active as manifested by such features as escarpments, entrenched streams and river terraces. Karunakaran and Ranga Rao[11] have provided the regional geological map of the Himalayan foothills. Valdiya *et al.*[12] and Valdiya[13] have dealt with the nature and activities along the HFT (called Himalayan Frontal Fault by them) and other faults passing through the region, and regarded them to be neotectonically active. They have also observed that the HFT to the west of river Kosi is laterally offset along a few transverse faults. However, such information on faults of the area east of river Kosi is not available so far. Moreover, there is no information available on the processes of sedimentation in the Kota–Pawalgarh Duns.

In the present work, digital LISS III imagery of 4 March 2004 from IRS P6 satellite and stereopair B&W aerial photographs on 1 : 40,000 scale of 2 October 1973 have been used for delineation and mapping of various tectono-geomorphic features. The satellite data were georeferenced and, subsequently, various image-enhancement techniques such as contrast stretching, filtering, band ratioing, colour composite, etc. were applied on it. Aerial photographs were viewed under the Zoom Stereoscope and information was transferred onto the base map prepared from toposheets. This map was then digitized to put into the GIS. Digital Terrain Models (DTMs) like Digital Elevation Model (DEM), slope, slope aspect and 2D cross-sections were prepared in GIS, using contour and point heights from topographic sheets. These were analysed in conjunction with the digitally processed satellite data and the information from aerial photographs to delineate various features present in the area. To get the 3D views of the area from different angles, the imagery was draped over the DEM. Subsequently, accuracy of the maps was verified during extensive field-work and interpretations of geomorphic and tectonic set up of the area were made through synthesis of information from remote sensing data and field observations.

The Kota Dun extends for a length of about 21 km in NW–SE direction between rivers Kosi in the west and Baur in the east, within Central Kumaun Sub-Himalaya (Figures 1–3). Average width of the Dun is ~5 km and it covers an area of ~107 sq. km. In the north, it is bounded by ~650 to ~1700 m high Siwalik mountains made up of Upper Tertiary rocks of the Lower Siwalik Subgroup. To the north of the Siwalik mountains, up to ~2600 m high Lesser Himalayan mountains comprising Krol Belt are exposed. The Neoproterozoic–Lower Cambrian rocks of Lesser Himalaya are thrust over the Siwalik rocks along the Main Boundary Thrust (MBT)[14,15]. The southern boundary

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of the Dun is marked by ~ 440 to ~700 m high low-relief hills, composed of Upper Tertiary to Pliestocene conglomerates, sandstones and mudstones of the Upper Siwalik Subgroup. To the south of the Kota Dun, and at a lower altitude, the Pawalgarh Dun is developed within the Upper Siwalik. Covering an area of about 27 sq. km, the length of the Pawalgarh Dun varies from about 9.5 km in the south to about 350 m in the north and has a maximum width of about 5.5 km. Southern limit of the Pawalgarh Dun is marked by three small, isolated, frontal hills and, therefore, the Dun Gravels extend southward through corridors and superimpose on the alluvium of the Ganga Plain. Moreover, the frontal hills of Kota–Pawalgarh Duns generally have a few metres thick cover of Dun Gravels over the Upper Siwalik conglomerates. At places, such as along the left bank of Dabka river, only the Dun Gravels are exposed in the hills and the underlying Siwalik rocks are concealed below, so that the hill appears to be a mound of gravels only.

The frontal hills, separating the Duns from the Ganga Plain in the south, rise abruptly as they have been uplifted and moved southward over the alluvium of Ganga Plain along the HFT[1,12,13]. The active nature of the HFT is manifest by the near-vertical scarp along the southern face of the frontal hills all through the Gaibua–Kaladhungi stretch (inset, Figures 3 and 4). Between rivers Kosi and Dabka, the HFT is geomorphically expressed by ~3 m high NW–SE trending scarp within the Ganga Plain alluvium. The uplift of Dun Gravels up to 13 m in the Dabka Valley and entrenchment of small streams in frontal hills also indicate movements along the HFT. Moreover, it is laterally offset by a few transverse, strike slip faults. The scarp of one such fault can be seen along the right bank of the Kusum Raula stream. This fault passes through the remarkably straight, roughly N–S trending channel of Kusum Raula stream, north of Chunakhan, and has caused a sudden deflection of this stream as also dextrally offset the scarp of HFT (inset, Figure 3). Another similar fault passes through river Dabka, causing a knee-bend turn of its course from E–W to almost N–S (Figure 2).

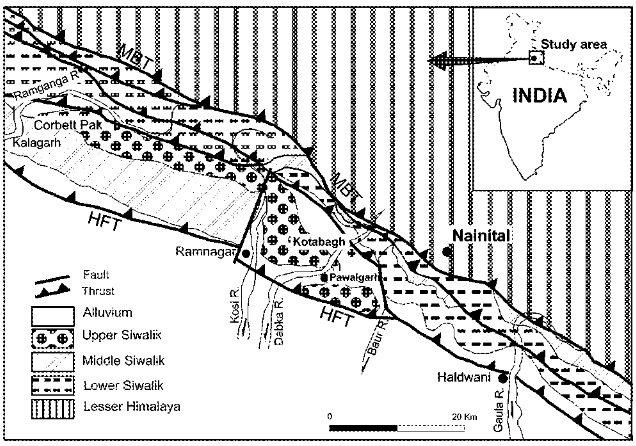

Figure 1. Regional geological map showing location of the area (modified after Karunakaran and Ranga Rao[11], and Valdiya *et al.*[12]).

The sediment fill (Dun Gravel) of Kota Dun rests unconformably over the Upper Siwalik conglomerates in the southern part and Lower and Middle Siwalik rocks in the northern part (Figure 5). The sediments are deposited in four distinct piedmont fans of varying dimensions that are subsequently modified in shape (Figure 2). These fans have been named, after major settlements located on them, from east to west as Dechauri, Kotabagh, Patkot and Chopra. The fan surfaces have laterally been coalesced. The Pawalgarh Dun, on the other hand, is occupied by the Pawalgarh Fan where the sediments are deposited over Upper Siwalik conglomerates. All these fans originate in the north and, in general, slope southwards.

The Dechauri Fan is the easternmost fan of the Kota Dun. The Baur river, flowing in a remarkably straight, entrenched channel, roughly marks the eastern boundary of the Dechauri Fan as well as the Kota Dun. The fan covers an area of about 25 sq. km and its surface slopes in SW to SE direction on an average 4.2° in the proximal and 1.3° in the distal part. The sediment fill is composed mainly of sheet to channelized clast-supported gravels, matrix-supported gravels and sand horizons. The gravels are dominated by well rounded to subrounded, pebble-boulder sized clasts of Krol dolomite, Lower Siwalik silty mudstone, Blaini quartzite, slate and diamictite, and Middle Siwalik sandstone, in order of abundance. On the left bank of the Baur river, the sediment fill rests over mudstones and sandstones of Lower Siwalik, whereas on the right bank it rests on the Upper Siwalik conglomerates. The thickness of the sediment fill is ~120 m in the proximal part.

Within the Dechauri Fan, five levels of terraces (BT_1–BT_5) are seen along the right and two levels (BT_1–BT_2) along the left bank of Baur river, above its active channel (BT_0) (Figure 6). The average elevation differences between successive terraces on the left bank are about 1, 4, 5, 53 and 62 m respectively, whereas on the right bank these are of the order of about 1 and 110 m respectively. The right bank of the Baur river represents an uplifted block as also evidenced by abandoned channels incised within BT_2 and BT_1 surfaces on the right bank of Baur, upstream and downstream of Roorkee–Degaon Bridge respectively (Figure 7). Presence of abandoned, incised channels on the right bank indicates sudden uplift of the terrace and eastward shift of the river. These features along with active landslides, triangular facets and near-vertical cliffs along the valley walls downstream of Chilkiya, indicate the presence of an active N–S trending fault passing through the Baur river (referred hereafter as the Baur Fault). The Upper Siwalik conglomerates coming in juxtaposition with the Lower Siwalik mudstones, uplifting of right bank sediments and, consequently, the eastward shifting of the river channel are attributable to movements along this fault (Figure 8).

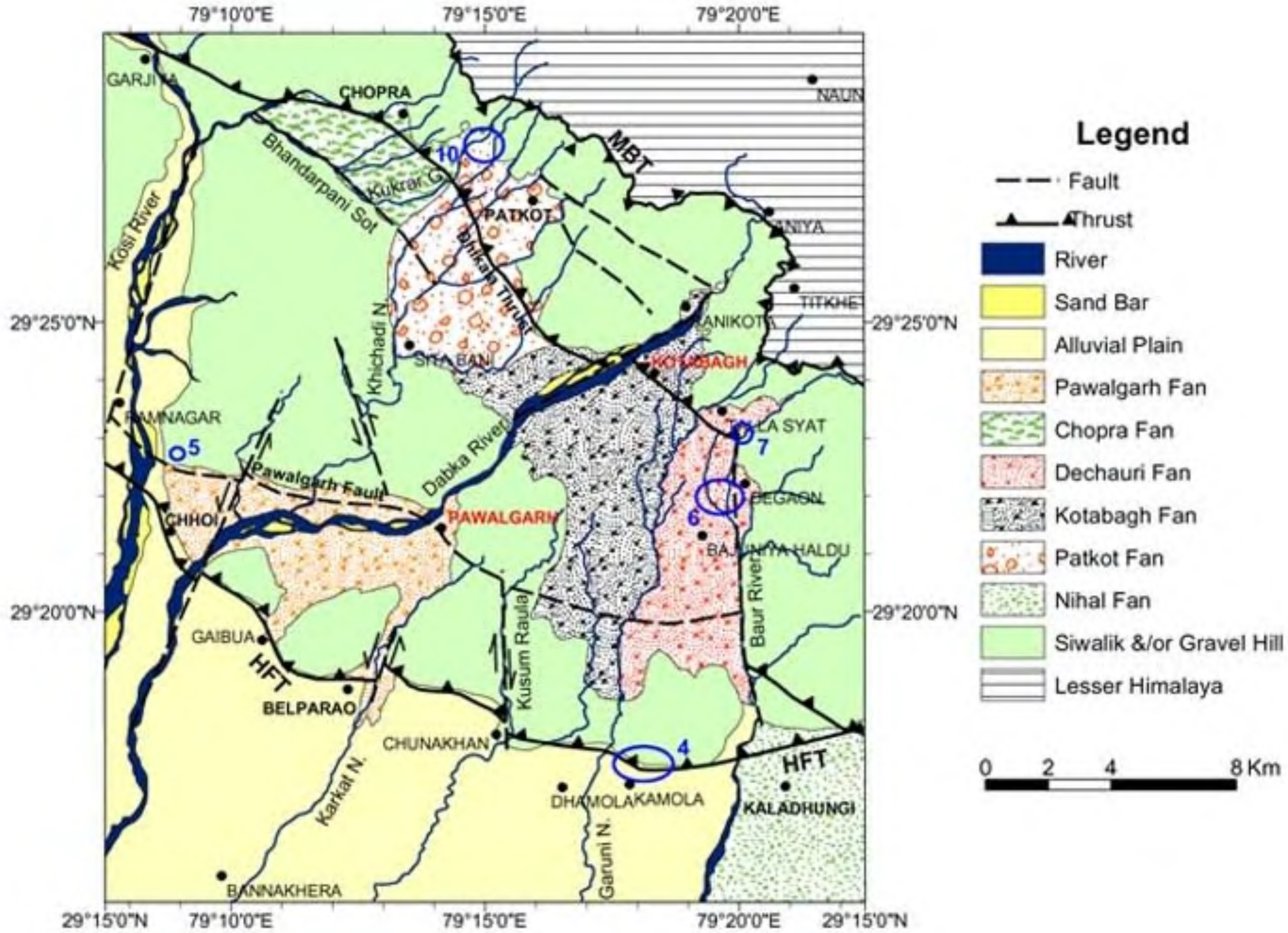

Figure 2. Tectonogeomorphic map of the Kota and Pawalgarh Duns. Areas shown in blue ellipses marked with numbers indicate locations of the corresponding figures (photographs).

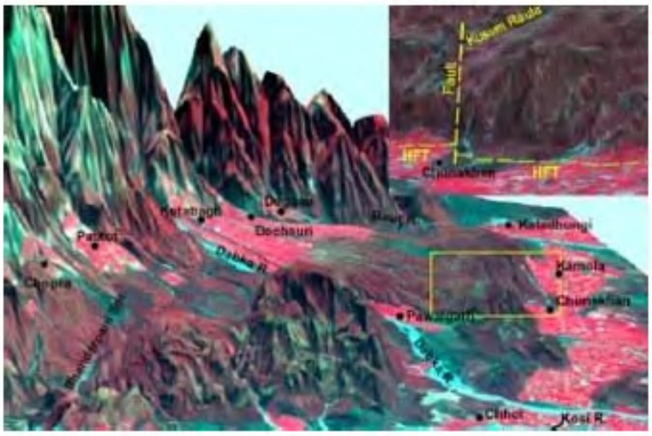

Figure 3. 3D perspective view of Kota–Pawalgarh Duns obtained by draping IRS P6 LISS III Band 2, 3, 4 FCC over DEM (viewing east from north of Ramnagar). (Inset) 3D perspective view of the area marked within the yellow rectangle (viewing north from the south of Chunakhan); the scarp of fault passing through Kusum Raula stream and offset of HFT along it can be seen.

The elevation difference between successive terraces on both banks of river Baur is unequal. As such, the BT_2 on the left bank lies at almost the same elevation from the present channel (BT_0), the BT_5 lies on the right bank. Further, on the right bank there are elevation differences within BT_4 and BT_5 terraces, so that BT_4 and BT_5 at villages Dechauri and Syat respectively, lie at an altitude 30 to 40 m above the same surfaces in the south, e.g. at villages Khuruliya and Patliya respectively (Figure 9). Moreover, a small stream called Roorkee Nala, is entrenched up to 3 m with vertical walls into the BT_4 near Dechauri Forest Rest House. Also, the gravels within the BT_4 near the same locality are tilted about 25° towards SW. These features indicate continued uplift of the northern part of the fan along a NW–SE trending fault/thrust passing south of Dechauri Forest Rest House, as also observed and perceived by Nakata[1]. This fault also marks the boundary between Lower Siwalik and Upper Siwalik buried under the Dun Gravel[1], and extends further westward just south of villages Kotabagh and Chopra. It seems to be the eastward extension of Sarpduli–Dhikala Thrust[12] and to the east of Baur river it is concealed under the alluvium of Nihal Fan, ultimately converging with HFT to the north-east of Kaladhungi[1,12,13] (Figure 2). The uplift of sediments on the right bank of Baur is attributed to movements along this fault (hereafter referred as Dhikala Thrust). In the area, the Baur Fault has dextrally offset it, indicating a relatively younger age for the former. The Baur Fault, thus, is an oblique fault. Consequently, the right bank of Baur is uplifted as well as pushed northward.

To the west of Dechauri Fan, the gravels of Kotabagh Fan are exposed. The Kotabagh Fan, covering an area of about 40 sq. km, is the largest fan of Kota Dun. The fan surface slopes in WSW to SE direction on an average 3.4° in the proximal and 1.5° in the distal part. Sedimentological characters of the fill are similar to those of the Dechauri Fan, except that the clast population of gravels is deficient in clasts of Krol dolomite and rich in clasts of Blaini quartzite. The gravels generally rest on the Upper Siwalik conglomerates, but in the extreme proximal part the Middle Siwalik sandstones underlie the nearly 100 m thick gravel succession. In the west Dabka river with almost straight channel, drains through the Kotabagh Fan. It is entrenched into the fan with tens of metres high vertical cliff along valley walls and triangular facets along the right bank. Beyond the southern margin of Kota Dun, the channel of Dabka suddenly becomes narrow and steep.

Figure 4. Upper Siwalik Hills with a thick cover of dun gravels are uplifted abruptly against the Ganga Plain along the HFT to the north of village Kamola.

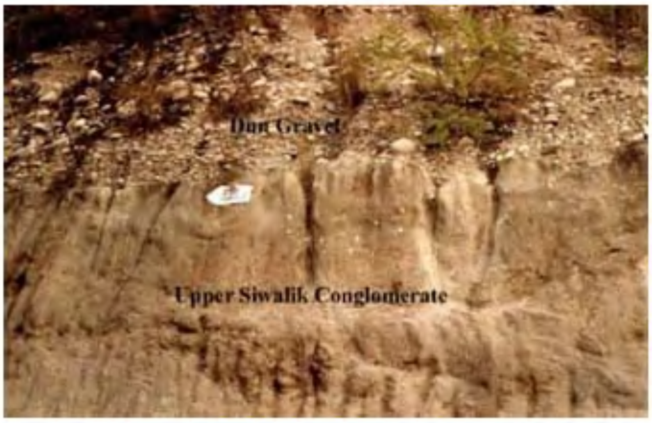

Figure 5. Dun Gravels unconformably rest over the Upper Siwalik conglomerates as could be seen along the left bank of river Kosi, east of Ramnagar.

Figure 6. Five levels of terrace development within the Dechauri Fan along the right bank of Baur river (photograph taken from village Degaon, looking west).

Figure 7. Movements along Baur Fault have led to the development of terraces and left the channel abandoned along the right bank of Baur river, east of village Syat.

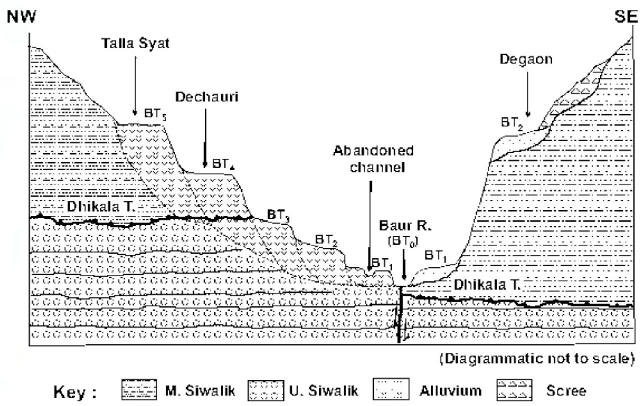

Figure 8. Lower Siwalik rocks, north of Kota Dun are thrust over the Upper Siwalik conglomerates and the entire sequence with overlying dun gravel is further offset along the oblique Baur Fault.

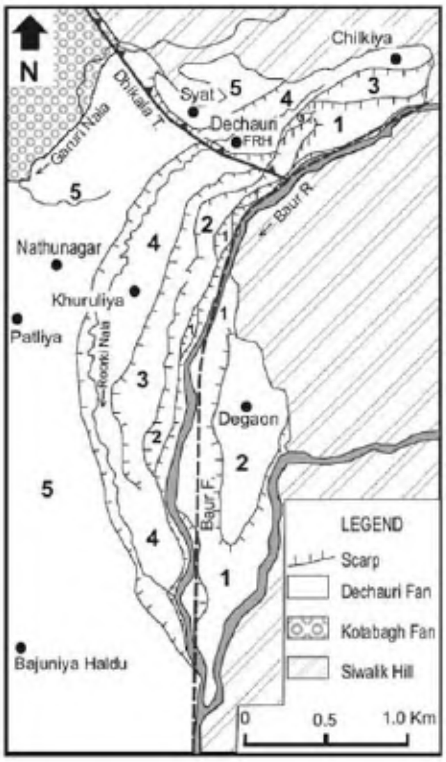

Figure 9. Map showing distribution of terraces along the Baur river. Numbers indicate altitudinal position of corresponding terraces from present level of the river channel (1 = BT_1, 2 = BT_2 and so on).

Figure 10. All streams like the Kukrar Gad are entrenched into the dun gravel and underlying Siwalik rocks in response to tectonic uplift of fan sediments (photograph taken from village Amgadi on the right bank of Kukrar Gad stream).

Three levels of terraces (DT_1–DT_3) above the active channel (DT_0) are seen along both banks of Dabka river. The elevation difference between successive terraces on both banks is unequal and as such the DT_3 on the left bank, on which the Kotabagh is located, is about 10 m above the level of DT_3 on the right bank. It indicates that while the entire Kotabagh Fan is uplifting along an E–W trending fault passing south of the fan, the left bank of Dabka is uplifting relative to the right bank along a NE–SW trending transverse fault passing through the Dabka river. The narrowing and steeping of the channel of Dabka beyond the southern margin of the Kota Dun, and abrupt rise of Siwalik Hills north of Pawalgarh Dun are also attributed to the E–W trending fault causing uplift of the entire Kotabagh Fan. This fault passes through Pawalgarh as also visualized by Nakata[1] (referred hereafter as the Pawalgarh Fault). It is traceable up to Ramnagar in the west and appears to have branched-off from the HFT. In the east it could be traced up to Baur river, where it is geomorphically expressed by southward tilting of the distal part of the Dechauri Fan surface, e.g. to the south of Bajuniya Haldu, and abrupt swing in south-flowing streams. Moreover, the fan surface (DT_3) in the north, just south of Kotabagh market, is suddenly uplifted by about 2 m along the Dhikala Thrust.

To the west of Dabka river, the Dun surface is covered by dense multistoried forest and thus remains inaccessible for the major part. The western part of Kotabagh Fan, and the Patkot and Chopra fans occupy the western part of the Dun. The Patkot Fan, having a total surface area of 28 sq. km, lies to the west of Kotabagh Fan. The Chopra Fan, covering an area of about 14 sq. km, is the westernmost and smallest fan of the Dun. Both these fans, in general, are steeply westward sloping; the Patkot Fan slopes in SSE to SW direction on an average 4.6° in the proximal and 2.1° in the distal part. The Chopra Fan slopes in SW to NW direction on an average 5.5° in the proximal and 2.0° in the distal part. In the proximal part, the thicknesses of the sediment fill of Patkot and Chopra fans, resting on Lower Siwalik mudstones and sandstones, and Middle Siwalik sandstones are of the order of 30 and 50 m respectively. In the south, the sediment fill of these fans rests on the Upper Siwalik conglomerates. The boundary between the Lower Siwalik and Upper Siwalik below the sediment fill is marked by the Dhikala Thrust, passing south of villages Chopra and Patkot, and geomorphologically expressed by steep gradients of fan surfaces along its trace. The gravels of Patkot and Chopra fans are compositionally similar. These are mostly disorganized matrix-supported, generally wedge-like gravels and consist of angular to surrounded clasts of Blaini quartzite and slate, Krol dolomite, Blaini diamictite and dolomite, and Middle and Lower Siwalik sandstone and mudstone in order of abundance.

The southern extension of the Chopra Fan is abruptly terminated against the upper Siwalik hill along the left bank of Bhandarpani Sot stream that flows westward in a remarkably straight channel having one terrace along the left bank, about 1.5–2 m above the present level of the channel. All streams initially flow southwestward on the Chopra Fan and then join the Bhandarpani Sot with a sharp knee-bend turn. These features are related to an active NW–SE trending fault passing through the Bhandarpani Sot. The Upper Siwalik Hills are located on the upthrown block of this fault that extends eastward into the Patkot Fan causing uplift and thus slope aspect reversal in its distal part. Moreover, all the smaller streams on fans, such as Kukrar Gad, Jam Gadhera, Masani Gad and Chahal Sot are entrenched into the gravels or even into the underlying Siwalik rocks and sometimes have paired terraces (Figure 10). Gullies developed along the banks of these streams are presently lengthening through headward erosion. All these features are developed in response to the *en block* uplift of this part of the Dun along the Pawalgarh Fault.

The Pawalgarh Dun lying between HFT in the south and Pawalgarh Fault in the north is composed of sediments deposited in Pawalgarh Fan. The fan covers an area of about 27 sq. km and gently slopes SE to W. However, the slope angle of the fan surface is slightly steeper to the north of Dabka (~1.2° in proximal and ~1° in the distal part) than that to the south (~1° in proximal and <1° in the distal part). Thickness of the sediment fill of Pawalgarh Dun in the proximal part is of the order of 50–60 m. The sediment fill rests on Upper Siwalik conglomerates and consists of clast to matrix-supported gravels, sand and mud. The clast population of gravels is more or less similar to that in Kotabagh Fan, except that it also consists of angular to sub-rounded granule–boulder clasts of Upper Siwalik conglomerate. Within the Pawalgarh Fan, two levels of terraces are seen along the left bank of Dabka river, above the active channel, indicating a right lateral shift of the channel in response to uplift of the fan surface along the HFT in the south. The Dabka river, during its course within the Pawalgarh Dun is characterized by up to 1.25 km long and 300 m wide channel bars, indicating reduction in carrying capacity in response to gentle gradient of the surface, probably because of its uplift along the HFT in the south.

The present study has enabled us to identify and map various tectonic and mega-geomorphic features in the area. The sediment input in Duns, at present, is mainly through mass wasting and sheet flow processes; anthropogenic activities further redistribute the sediments. Landforms of Duns have been continuously modified under the influence of tectonic activities along longitudinal as well as transverse faults. The Kota–Pawalgarh Duns are still in a phase of evolution. These are the preliminary results of our ongoing studies focused on understanding the geological evolution of the area and documenting large magnitude, unknown palaeoseismic events of the Himalaya.

1. Nakata, T., *Geomorphic History and Crustal Movements of the Foot-hills of Himalaya*, Institute of Geography, Tohoku University, Sendai, Japan, 1972, p. 177.
2. Singh, A. K., Parkash, B., Mohindra, R., Thomas, J. V. and Singhvi, A. K., Quaternary alluvial fan sedimentation in the Dehradun valley piggyback basin, NW Himalaya: Tectonic and palaeoclimatic implications. *Basin Res.*, 2001, **13**, 449–471.
3. Thakur, V. C. and Pandey, A. K., Late Quaternary tectonic evolution of Dun in fault bend/propagated fold system, Garhwal Sub-Himalaya. *Curr. Sci.*, 2004, **87**, 1567–1576.
4. Medlicott, H. B., On the geological structure and relations of the southern portions of the Himalayan ranges between the Ganges and Ravee. *Mem. Geol. Surv. India*, 1864, **3**, 1–86.
5. Powers, P. M., Lillie, R. J. and Yeats, R. S., Structure and shortening of the Kangra and Dehra Dun reentrants, Sub-Himalaya, India. *Geol. Soc. Am. Bull.*, 1998, **110**, 1010–1027.
6. Malik, J. N. and Nakata, T., Active faults and related Late Quaternary deformation along the northwestern Himalayan Frontal Zone, India. *Ann. Geophys.*, 2003, **46**, 917–936.
7. Philip, G., Landsat Thematic Mapper data analysis for Quaternary tectonics in parts of Doon valley, NW Himalaya, India. *Int. J. Remote Sensing*, 1996, **17**, 143–153.
8. Singh, A. K., Parkash, B. and Manchanda, M. L., Tectonic geomorphology of the Dehradun valley using Digital Terrain Models and Optically Simulated Luminescence dating. *Himalayan Geol.*, 2004, **25**, 59–78.
9. Mohindra, R. and Thakur, V. C., Historic large earthquake-induced soft sediment deformation features in the Sub-Himalayan Doon valley. *Geol. Mag.*, 1998, **135**, 269–281.
10. Malik, J. N. and Mathew, G., Evidence of paleoearthquakes from trench investigations across Pinjore Garden fault in Pinjore Dun, NW Himalaya. *J. Earth Syst. Sci.*, 2005, **114**, 387–400.
11. Karunakaran, C. and Ranga Rao, A., Status of exploration for hydrocarbons in the Himalayan region – contribution to stratigraphy and structure. *Geol. Surv. India Misc. Publ.*, 1976, **41**, 1–66.
12. Valdiya, K. S., Rana, R. S., Sharma, P. K. and Dey, P., Active Himalayan Frontal Fault, Main Boundary Thrust and Ramgarh Thrust in southern Kumaun. *J. Geol. Soc. India*, 1992, **40**, 509–529.
13. Valdiya, K. S., Reactivation of Himalayan Frontal Fault: Implications. *Curr. Sci.*, 2003, **85**, 1031–1040.
14. Auden, J. B., Geology of the Krol Belt. *Rec. Geol. Surv. India*, 1934, **67**, 357–454.
15. Valdiya, K. S., *Geology and Natural Environment of Nainital Hills, Kumaun Himalaya*, Gyanodaya Prakashan, Nainital, 1988, p. 155.

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