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Recent Tectonics in the Nepal Himalayas: A Synthesis

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ABSTRACT

Geodetic surveys were carried out across the Main Central Thrust (MCT) at Dana (Kali Gandaki valley), and the Main Boundary Thrust (MBT) near Kerabari (SW of Pokhara) to obtain quantitative data on the tectonic movements along these boundary thrusts. The results have revealed that the MCT is no longer active, although the surveyed area near the MCT showed a 6 mm tilting to the south in four years. At the same time the surveyed points moved 3-4 cm to the west, indicating that the maximum compressive strain around the MCT in the area surveyed is acting along the NE-SW direction instead of the commonly assumed N-S direction. The measurements across the MBT, on the other hand, showed that the MBT is still quite active with an upliftment of 3 mm in four years. A northward tilt of the area just to the south of the MBT was also recorded.

The study of river terraces in the Pokhara area indicated that the overlap of the older Ghachok Terrace by the younger Pokhara Terrace was due to tectonic movements and that the whole area between Pokhara and the upper reaches of the Seti River (north of Pokhara) has tilted to the south since the deposition of the Ghachok Formation or before. The study of river terraces along the Kali Gandaki valley showed that different parts of its N-S section were uplifted at different rates and the most upheaved sections of the terraces were found around Dana (near the MCT) and in the Mahabharat and Siwalik zones since the late Quaternary. The significance of the active faults in the understanding of Recent tectonics in the Nepal Himalayas is also discussed.

INTRODUCTION

Based on geologic and geomorphic evidences, the recent upheaval of the Himalayas has been well recognized (Hagen 1968; Gansser 1983). However, very few quantitative measurements are available on this movement. Thus, a Japanese research team carried out geologic, geomorphic and geodetic surveys during the 1980s in order to understand the upheaval process in the Nepal Himalayas. Some of the results of these surveys were published elsewhere (Nakata 1986; Yamanaka 1982; Iwata et al. 1984). This paper primarily presents a synthesis of the survey results as well as some additional data.

GEODETIC SURVEY ACROSS THE BOUNDARY THRUSTS

Geodetic surveys were carried out across the two boundary thrusts in the central Nepal Himalayas (Omura et al. 1988). The first was across the Main Central Thrust (MCT) at Dana village, which lies about 50 km northwest of Pokhara. The second was across the Main Boundary Thrust (MBT) near Kerabari village about 60 km southwest of Pokhara (Fig.1).

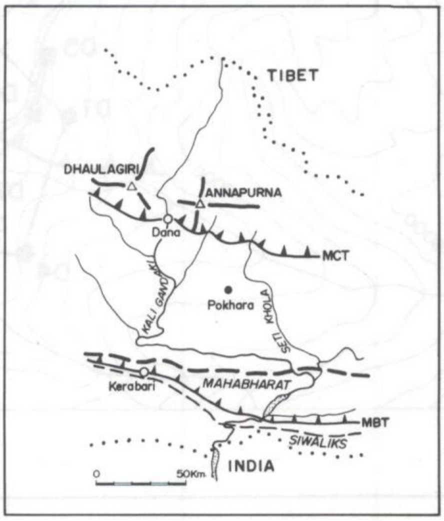

Fig.1 Geodetic survey locations: Dana and Kerabari

For the geodetic surveys, stainless steel shafts of 180 mm long and 16 mm in diameter with cross mark on its head were used to fix the location of each station. Geodimeter model 6, 6BL (AGA) and theodolite WILD T2 were used for measuring distance and angles. An automatic geodetic level N1002 and staff with invar tape of 3 m (Carl Zeiss JENA) were employed for the levelling surveys.

GEODETIC MEASUREMENTS ACROSS THE MCT

In 1980, quadrilateral baseline and levelling stations crossing the MCT (Upper MCT, Arita 1983) were established at Dana along the Kali Gandaki river (Fig. 2), where the MCT marks the base of the Central Crystallines or the Tibetan Slab (Le Fort 1975). The points were resurveyed after four years in 1984.

Remeasurement of the survey points showed that points D1 and D2 forming the quadrilateral baseline shifted 3-4 cm to the west with respect to D4 with the assumption that the position and the orientation of D4 relative to D3 were fixed (Fig. 2). This movement indicates that the maximum compressive strain lies along the NE-SW direction on the horizontal plane which is significantly different from the N - S compressive direction conventionally deduced from the folding axis and roughly E-W trending thrust faults. It is not yet clear why such a change of compressive direction has been observed in the Kali Gandaki area (Fig. 3a).

The measurements along the 3 km long levelling line from points D5 to D9 along the Kali Gandaki river indicate a significant tilting of 6 mm to the south within a period of four years (Fig. 3b). This tilting of

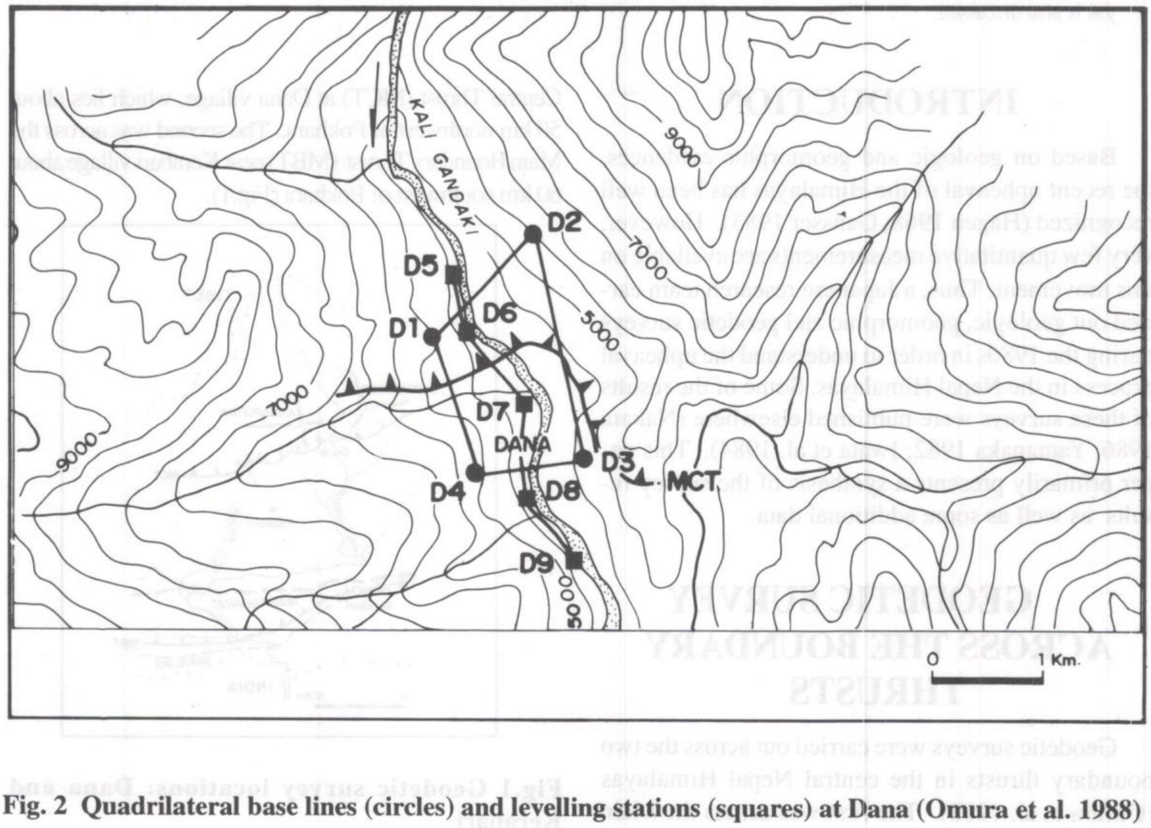

Fig. 2 Quadrilateral base lines (circles) and levelling stations (squares) at Dana (Omura et al. 1988)

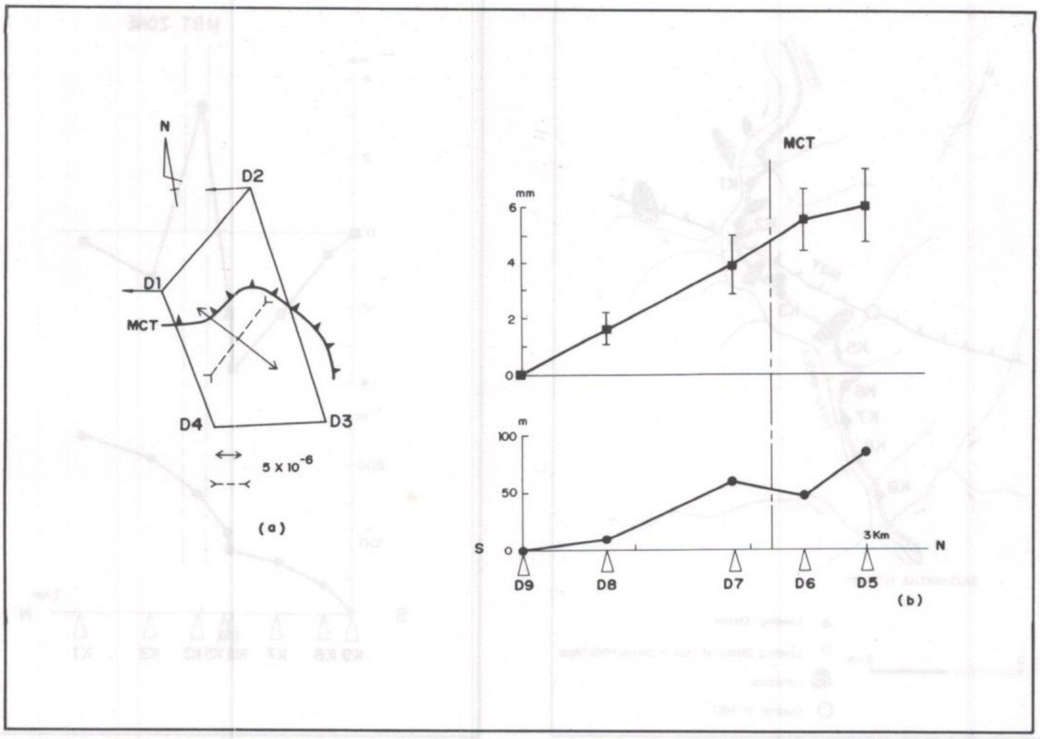

Fig. 3 Results of the geodetic survey at Dana a): The NE-SW maximum stress direction and displacement of D1 and D2 points b): The relative variation of the levelling stations from 1980 to 1984 (Omura et al. 1988)

the levelling line without any sharp vertical dislocation across the MCT clearly indicates that the MCT (at least the Upper MCT) is no longer active.

GEODETIC MEASUREMENTS ACROSS THE MBT

In 1980, eight levelling stations were fixed along the Siddhartha Highway. After four years this 5 km long levelling line crossing the MBT was resurveyed. The bench marks fixed by the Department of Survey, HMG/Nepal were also found along the road but were not suitable for use in the survey (Fig. 4).

The geodetic measurements around Kerabari showed that the levelling point K3 located just to the south of the MBT within a shear zone, was upheaved by 3 mm in four years (Fig. 8). On the other hand, the segment between K6 and K9, which lies just to the south of the MBT, indicates a tilting to the north (Fig. 5).

RIVER TERRACES AND UPHEAVAL HISTORY

RIVER TERRACES OF THE POKHARA VALLEY

The Pokhara Valley has two main terraces, viz. the Ghachok Terrace and the Pokhara Terrace (Yamanaka et al. 1982), whose interrelation is very significant to the interpretation of upheaval history in this part of the Nepal Himalayas.

Ghachok Terrace

The Ghachok Terrace is a filltop terrace made up of the Ghachok Formation, which corresponds to the "Gaunda-Konglomerat" (Hormann 1974) and Terrace I (Sharma 1978). As one goes to the north of Pokhara, upstream along the Seti River, the height

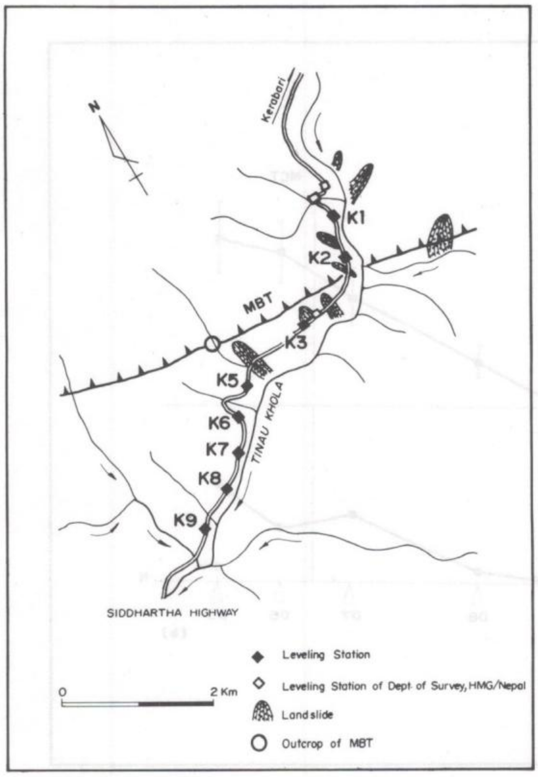

Fig. 4 Position of levelling stations near Kerabari (Omura et al. 1988)

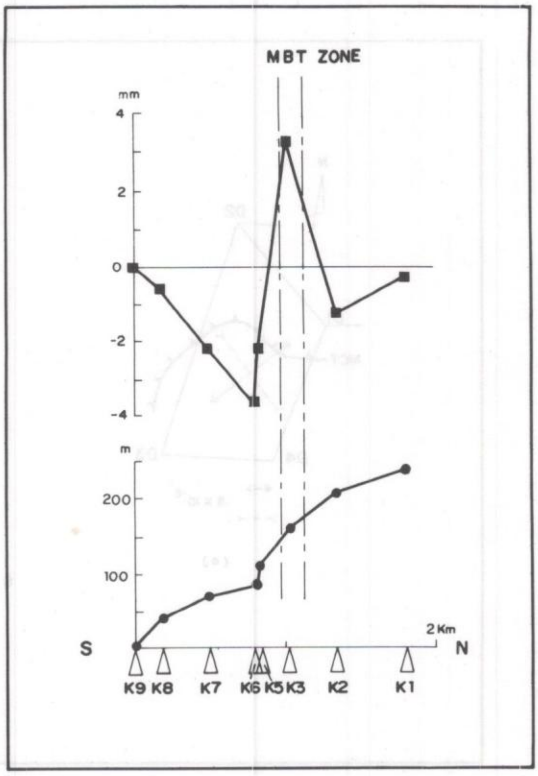

Fig. 5 Level variation across the MBT near Kerabari from 1980 to 1984 (Omura et al. 1988)

difference between Ghachok Terrace and Pokhara Terrace gradually increases. Downstream, the height difference between the two terraces gradually decreases and finally the Pokhara Terrace crosses the Ghachok Terrace and overlies it (Fig. 6).

Pokhara Terrace

The Pokhara Terrace, which corresponds to the "Pokhara-Fläche" (Hormann 1974) and Terrace II (Sharma 1978) is an accumulation terrace built up by gravels of the Pokhara Formation. The occurrence of Pokhara Terrace is widespread in the main part of the Pokhara valley (Fig. 6) whereas its occurrence along the Seti river (north of Pokhara) is limited (Fig. 6). Its relative height above the present Seti River bed is more or less uniform (52 to 96 m) unlike the pronounced variation in case of the Ghachok Terrace. The organic remains from the Pokhara Terrace gave radiocarbon dates from 1,100 to 600 yr B.P. indicating that the Pokhara Terrace was deposited during that period.

Tilting of Terraces

The relative height difference between the Ghachok and Pokhara Terraces diminishes gradually from north to south, and just to the south of Pokhara, the Pokhara Terrace crosses and overlaps the Ghachok Terrace. Hormann (1974) attributed the tilting of the older Ghachok Terrace and overlap by the newly formed Pokhara Terrace to tectonic movements.

The lithofacies of the Ghachok and Pokhara formations are similar and both are composed mainly of gravels, though the former is more consolidated and better cemented than the latter. Therefore it can be inferred that the gradient and other conditions of the Seti River during the deposition of both the formations

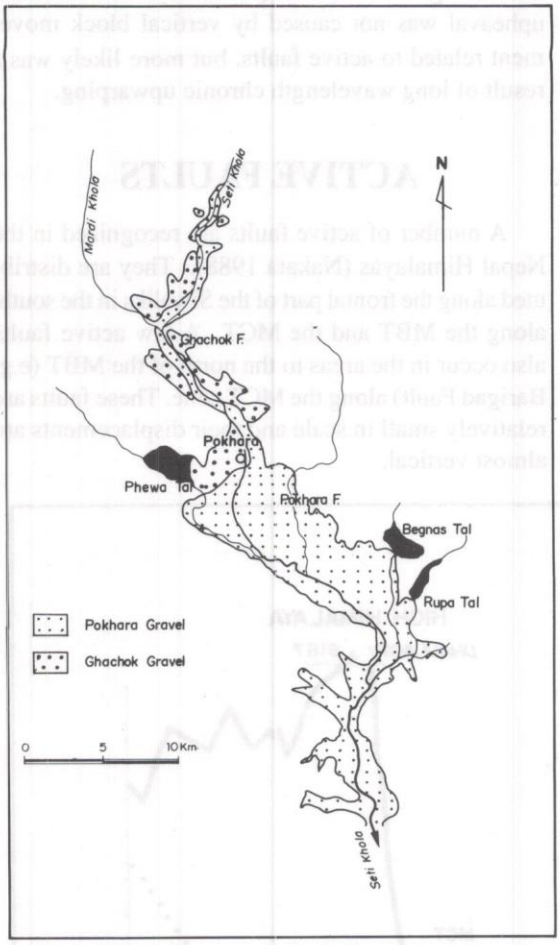

Fig. 6 Distribution of the Ghachok and Pokhara Gravel Beds in the Pokhara Valley (Yamanaka et al. 1982)

essentially remained similar and the whole area between Pokhara and the upper reaches of the Seti River tilted to the south since the deposition of the Ghachok Formation or before (Fig. 7). The above observation indicating the southward tilting of the area can be well supported by the geodetic measurements at Dana.

RIVER TERRACES OF THE KALI GANDAKI VALLEY

During the field investigation, the relative height difference between the terrace surfaces and the Kali Gandaki River bed was studied mainly based on the field observations (Yamanaka and Iwata 1982; Iwata 1988). However, some inaccessible areas were studied with the help of airphotos and topographic maps.

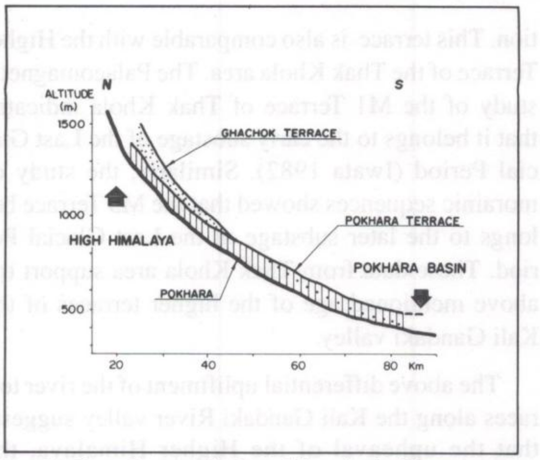

Fig. 7 Overlap of the Ghachok Terrace by Pokhara Terrace

Since river terraces were initially the flood plain of a river, the amount and extent of vertical movements in an area can be determined using measurements of vertical displacement of their terraces along a longitudinal profile provided that the present river bed has not changed significantly from that one existing during the time of the terrace formation. Figure 8 shows the present longitudinal profile of the Kali Gandaki River from Narayanghat in the south to Mustang in the north crossing the Siwaliks, the Mahabharat Range, the Midland and the Higher Himalaya, along with the topographic profile and the relative height of the highest river terraces. It is interesting to note that the relative height between the terrace surfaces and the present river bed increases from the Siwaliks in the south to the Higher Himalaya in the north. The longitudinal profile also shows that the most upheaved part of the Himalayas is located around Dana near the MCT (Higher Himalaya) and the second most upheaved part lies in the Mahabharat-Siwalik zone near the MBT (Fig. 8).

The age of deposition of the higher level terrace is estimated to be around 120,000 to 200,000 yr B.P. corresponding to the Last Interglacial Period. The terrace is remarkably dissected and the presence of red lateritic soil on the weathered surface of the terrace indicates a warm climate at the time its deposition. This terrace is also comparable with the Higher Terrace of the Thak Khola area. The Palaeomagnetic study of the M1 Terrace of Thak Khola indicated that it belongs to the early substage of the Last Glacial Period (Iwata 1982). Similarly, the study of morainic sequences showed that the M3 Terrace belongs to the later substage of the Last Glacial Period. These data from Thak Khola area support the above mentioned age of the higher terraces of the Kali Gandaki valley.

The above differential upliftment of the river terraces along the Kali Gandaki River valley suggests that the upheaval of the Higher Himalaya, the Mahabharat Range and the Siwaliks, must have been continuing since the late Quaternary. However, this upheaval was not caused by vertical block movement related to active faults, but more likely was a result of long wavelength chronic upwarping.

ACTIVE FAULTS

A number of active faults are recognized in the Nepal Himalayas (Nakata 1988). They are distributed along the frontal part of the Siwaliks in the south, along the MBT and the MCT. A few active faults also occur in the areas to the north of the MBT (e.g. Barigad Fault) along the MCT zone. These faults are relatively small in scale and their displacements are almost vertical.

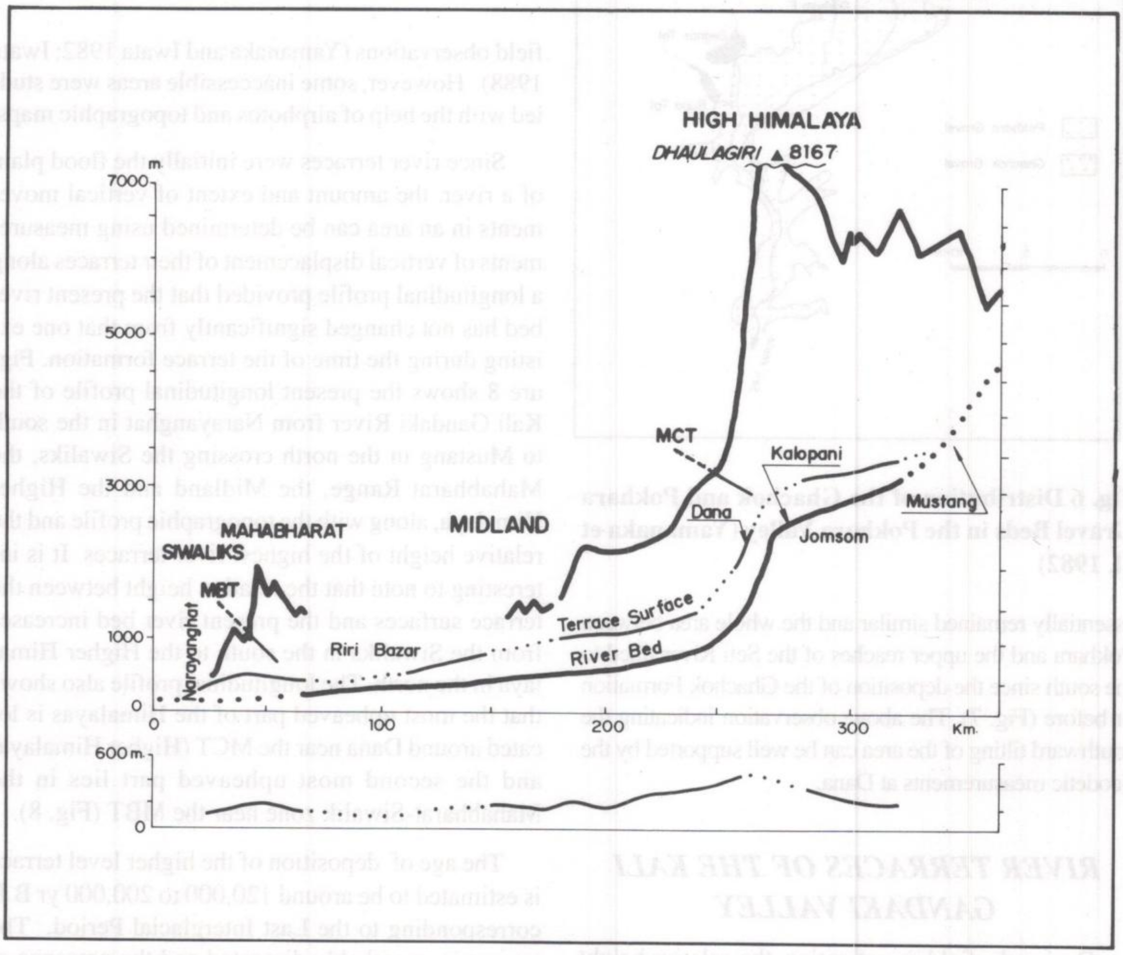

Fig. 8 Variation of surface altitude of the higher terrace and variation of relative height of the terrace surface above river bed along the Kali Gandaki River (Iwata 1988)

ACTIVE FAULTS IN THE SIWALIKS

Active faults act like living fossils of earthquakes. They keep record of repeating earthquake events. There is always a probability that an active fault may become reactivated in the future and produce earthquakes. Earthquakes frequently occur in Nepal and medium to large damaging earthquakes occur every several years. They are invariably related to movements along active faults. The reactivation of these faults dislocate terraces and river fans indicating recent crustal movements.

Nakata (1988) mapped a number of active faults along the southern slopes of the Siwalik hills. In southeastern Nepal, the flat surface of alluvial terraces and fans are clearly tilted to the north towards upstream instead of a gentle downstream slope as is expected normally. Also, nearly vertical fault scarps are found at the southern edge of these tilted fans and terraces indicating that they were uplifted and tilted to the north by the active faults. The vertical dislocations along these active faults are found to be as large as 100 m or more.

At the Sahere Khola near Dharan Bazar in southeastern Nepal, an active fault was studied in detail and its age of faulting was determined by radiocarbon dating of the humus soil covering the gravels of a terrace. The soil bed is about 50 cm thick and is found to be folded by a fault movement. The 14C age of the lower part of the bed was found to be 1000 yr B.P., while the upper part was approximately 300 yr B.P. It can be interpreted that during this period the sediments were deposited under a calm environment without much disturbances. After the last deposition of the sediment (around 300 yr B.P.) the fault became active and the displacement along the fault dragged and folded the sediment layers. In the same area near the Main Frontal Thrust (MFT), Nakata (1988) recognized a fault scarp in the lowest terrace produced by a most recent earthquake. The total vertical displacement along the fault was 33m and the rate of displacement was calculated at 1.8 m per 1,000 yr considering the age of the higher terrace as 18,000 yr B.P. (i.e. the Last Glacial Epoch). He thus estimated that the earthquake associated with the active fault has a return period of about 2,500 yr.

The Recent upheaval of the Siwalik hills also perhaps resulted from the vertical displacements caused by active faults in the area. Evidence for this can be found in the Tangting Khola in southeastern Nepal, where the 1,600 m high Siwalik ridge has preserved a thick, coarse alluvial gravel bed whose flat surface undoubtedly represents a river deposit. The gravel bed is undisturbed and occupies the top of the hill 200 m above the present river bed. Despite the significant height difference from the present river bed, the terrace plain must have formed quite recently, as the surface of the gravel bed is veneered only by a very thin soil layer and is slightly weathered. The southern side of the terrace clearly shows a fault scarp which suggests upliftment along an active fault. The undeformed and flat gravel bed, unaffected by horizontal stress and resting over the thrust-bound folded Siwaliks, quite clearly indicates that the recent upheaval of the Siwaliks was due to vertical movement along active faults.

All of the active faults that dislocate terrace surfaces along the southern edge of the Siwalik hills have downthrow to the south and the terraces are tilted to the north. The dislocation is normally small and ranges between 10 and 50 m except in some cases where it reaches over 100 m.

MOVEMENT ALONG THE MAIN BOUNDARY THRUST (MBT)

As discussed above, the geodetic measurements have clearly shown that the MBT is quite active today. The movement along the MBT is also manifest in geomorphic features like pressure ridges. Nakata et al. (1984) identified a 20 to 35 m high linear ridge between Surkhet and Ghorahi in western Nepal just to the south of the MBT. This narrow ridge runs parallel to the MBT and has formed in the Recent sediments rather than in the country rock. The river gravels forming the terraces in the area is thrown into these peculiar ridges. The southward movement of the hanging wall along the MBT has pushed the sediments and resulted into these low-lying narrow ridges. The ^{14}C age of the humus soil from the alluvial gravel in the ridge was found to be 1400 yr B.P., which indicates that the ridge was formed by the movement along the MBT and does not represent an old geomorphic feature formed by other processes. The mechanism of the formation of the ridge by the movement along the MBT is shown in Figure 9.

ACTIVE FAULTS WITH DOWNTHROW TOWARDS THE NORTH

Active Faults along the MBT

A series of active faults along the MBT throughout southern Nepal were identified by Nakata (1984, 1988). All these active faults have downthrow to the north in contrast to the MBT, which is a thrust fault with an uplifting northern block (Fig. 10). These active faults have very small amount of downthrow (35 m at most).

Barigad Fault

The Barigad Fault is an active fault in the Lesser Himalaya which is formed by the rejuvenation of an old fault. It extends in a NW-SE direction for about 140 km along the present course of the Barigad Khola. The tectonic landform that have developed along the fault are fault scarps, small grabens, saddles and stream offsets. The Barigad Fault shows right lateral movement and downthrow to the north-east. The vertical displacement is as much as 20 m and the horizontal displacement shown by landform offsets is as much as 240 m.

ACTIVE FAULTS ALONG MCT ZONE

Talphi Fault

Another example of an active fault with downthrow to the north is the Talphi Fault, lying 15 km west of Jumla along the MCT zone in western Nepal. The maximum uplift of the terraces was found to be 48 m (southern block). The age of the terrace is not precisely known, but it possibly belong to the late Quaternary.

A fault with downthrow to the north was also identified in the southern part of the Dhaulagiri massif with the help of airphoto studies. The fault trace

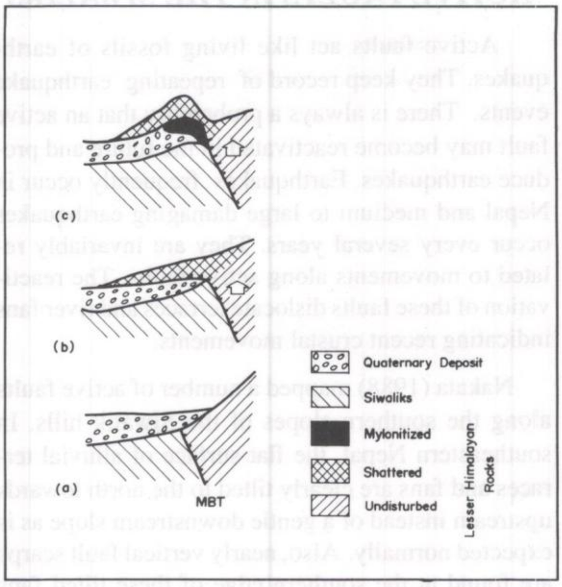

Fig. 9 Development process of the pressure ridge (Nakata et al. 1988)

is about 20 km long, extends in a NW-SE direction and cuts through the glacial and periglacial morphology such as the moraine hills, cirques, and ridges formed since the Last Glacial Stage. The downthrow to the north is clearly exhibited by the fresh but low fault scarps facing north.

CONCLUSIONS

The northward downthrow along all the active faults of Lesser Himalaya and the MCT zone is not consistent with the well recognized south-vergent thrust tectonics (e.g. MCT, MBT, MFT) typically associated with the upheaval of the Himalayan range. It is apparent that the Higher Himalaya is sinking and collapsing with respect to the uplifting Siwalik hills.

The geodetic surveys and river terrace tectonics show that the Higher Himalaya has been upheaving without faulting since the late Quaternary or before. The only possible explanation for this upheaving is the long wavelength chronic upwarping in the Himalayas (Iwata 1984). The collapse along the active

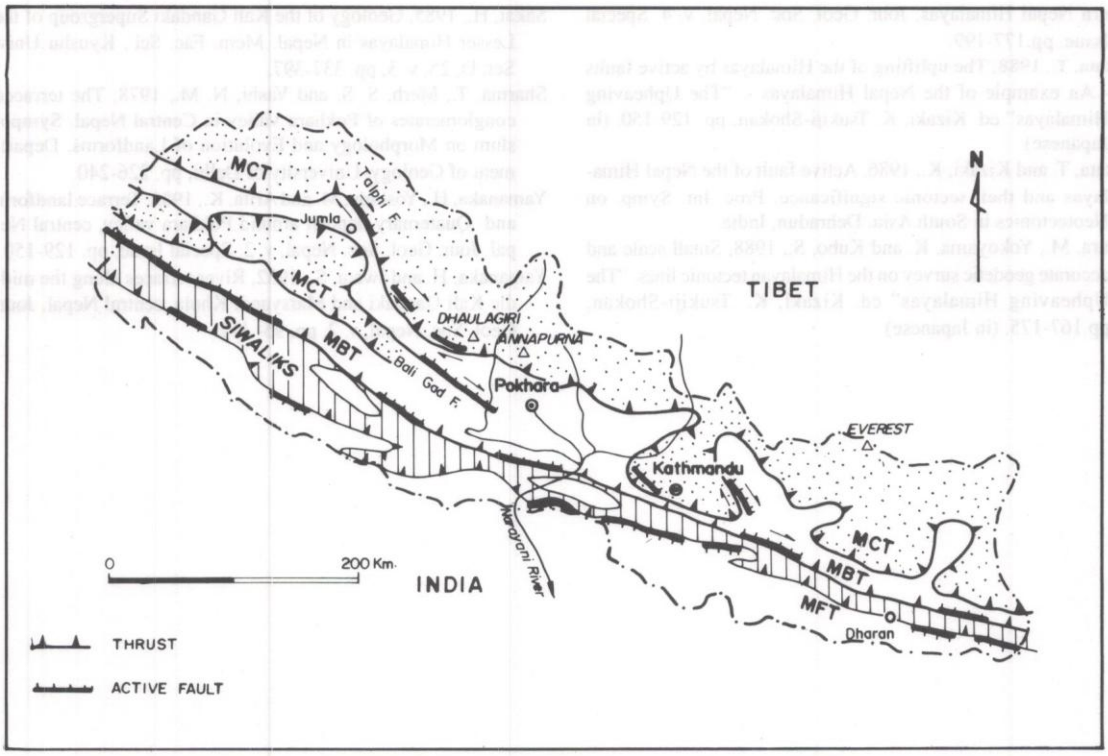

Fig. 10 Distribution of active faults in the Nepal Himalayas (Nakata 1988)

faults has little effect on the process of the mountain building of the Himalayas.

Sakai (1985) illustrated that in west central Nepal, the Midland has block-faulted and depressed in tensional stress field against the frontal belt of the Lesser Himalaya resulting in intense deformation by south-vergent folds and thrusts. The stress field is compressional in the front part along the thrust faults but subsequently a tensional field with thrust planes to compensate a gravity instability, appears on the rear side.

The regional collapse was significant during the middle to late Tertiary and has produced a few grabens in the N-S direction crossing the Himalayas. The occurrence of the active faults might be an indication that a new phase of the collapse is taking place.

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