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A PHOTOGRAMETRIC STUDY ON ACTIVE FAULTS IN THE NEPAL HIMALAYAS

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ABSTRACT

Active faults in the Nepal Himalayas are identified by means of interpretation of vertical aerial photographs. They are mainly distributed along the major tectonic lines as well as older geological faults and are classified into four groups; the Main Central Active Fault system, the active faults in the Lower Hamalayas, the Main Boundary Active Fault system and active faults along the Himalayan Front Fault.

The mode of active faulting is closely related to the strikes of the faults. Along the NW-SE and NE-SW trending faults, lateral displacement with northward drop is prevailing, and right-lateral movement along the former and left-lateral movement along the latter is a rule in the sense of displacements. On the other hand, dip-slip faulting is observed mainly along the E-W trending faults belonging to the Main Boundary Active Fault system. However, apparent displacement along the faults is mostly of northward drop. It is considered that active faulting along the major tectonic lines except the Himalayan Front Fault does not favor the upheaval of the Himalayan ranges during the late Quaternary period.

INTRODUCTION

The Nepal Himalayas are located in the central part of the Himalayan ranges and extend in WNW-ESE approximately for 800km. The Himalayas are considered to be one of the typical examples of continent-continent collision(Dewey and Bird, 1970), and geology and structure of the ranges have been gradually given light based on new information in the last decades since the openning of the kingdom of Nepal. It is generally believed that the ranges are tectonically young and have been rapidly uplifted during the recent geological period, although this widely accepted idea has not been adequately supported from the view point of Quaternary tectonics based on concrete evidences.

In this paper, the author presents the results of interpretation of aerial photographs for active faults in the Nepal Himalayas in order to discuss characteristics of the crustal movements in the recent geological period. Active faults meant in this paper are faults which have repeatedly moved during the recent geological period and have high possibilities of recurrent displacements associated with earthquakes in future.

Active faults were identified by means of interpretation of vertical aerial photographs of 1:40,000 - 1:60,000 scale throughout Nepal excepting the border areas and the northeastern part of the country. The method used here more or less follows that applied by Matsuda *et al.* (1977). Brief field studies have been carried out on several faults to confirm their recent activities.

Topographical lineaments recognized on aerial photographs,have been examined in detail in order to find out geomorphic expression of faulting. Topographical features in young mountain ranges like the Himalayas are considered to have been formed during the Quaternary period. Therefore, lineaments along which topographical features are dislocated can be called active faults. Geomorphic surfaces such as river terraces, alluvial fans and surfaces with low relief, and continuous geomorphic lines such as stream courses, ridges and terrace edges are good references to detect recent faulting from their displacement(The Research Group for Active Faults of Japan, 1980). The mode and sense of faulting are to be deduced; as a result, the present condition of stress field under which the recent crustal deformation has been taking place,may be clarified in this paper. Active faults here are named after geological faults in the case that their locations coincide with each other and in other cases they are to be named after locatities they extend.

DISTRIBUTION OF ACTIVE FAULTS

Geologically two major faults have long been recognized throughout the Himalayan ranges(Gansser,1964). One of them is the Main Boundary Fault and the other the Main Central Thrust, both forming topographical boundaries among the Sub-Himalayas,Lower Himalayas and Higher Himalayas. There is another topographically important fault which is called the Himalayan Front Fault.It fringes the southern margin of the Sub-Himalayan Siwalik foot-hills(Nakata,1975).

Active faults newly found in the Nepal Himalayas are mapped in Fig.1. They may be classified into four groups, i.e. active faults along the above mentioned three major faults and those in the Lower Himalayas. The Main Central Thrust is, geologically, a thrust with sineous traces on the earth surface. However, active faults which occur roughly along the Main Central Thrust in northwest Nepal, are rather straight, forming a fault system with *en echelon* arrangement. This fact suggests that the active faults are not thrusts but high angle faults on the earth surface. Therefore the author proposes to term this active fault system the Main Central Active Fault system. The active faults along the Main Boundary Fault can not be traced throughout the whole length of the Fault, but appear in places forming fault systems with inactive sections lying in between. Each fault system extend for a length of approximately 100km respectively.Geologically, the Main Boundary Fault is also considered to be a thrust and has a sineous course on the surface in general. However, traces of the active faults are rather straight in places, and suggest high angle faulting near the surface. The active fault system along the Main Boundary Fault may be called the Main Boundary Active Fault system as a whole. The southern margin of the Sub-Himalayas in Nepal is rather indented in comparison with that in India. Active faults along the Himalayan Front Fault are mainly observed in east Nepal. They do not seem to be long continuous faults but group of short fault traces trending several directions. Active faults in the Lower Himalayas are not densely or evenly distributed. They seem to extend along geological faults and have rather straight fault traces which imply high angle faulting. Strikes of many active faults are in accordance with the general trend of the Himalayan ranges, but some of them are transverse to it.

Active Faults of the Main Central Active Fault System

This fault system trends NW-SE approximately for 170km roughly along the trace of the Main Central Thrust in the northwestern Nepal Himalayas. Active faults of the fault system include the Darma fault, the Talphi fault, the Tibrikot fault and the Dhauragiri Southwest fault. Forming southwestward-convex arc as a whole, those faults are arranged *en echelon*.

The Darma fault (1) trends NWN-SES for about 15km and follows roughly the course of the Darma thrust on the Main Central Thrust (Ando and Ohta, 1973). Divertions of stream courses and ridges imply that dextral displacement has taken place along the straight trace of the fault although geological evidence of the fault suggests a low angle thrusting dipping northeastwards.

The Talphi fault (2) extends NW-SE for 10km around Talphi to the east of Jumla(Fig.2). The

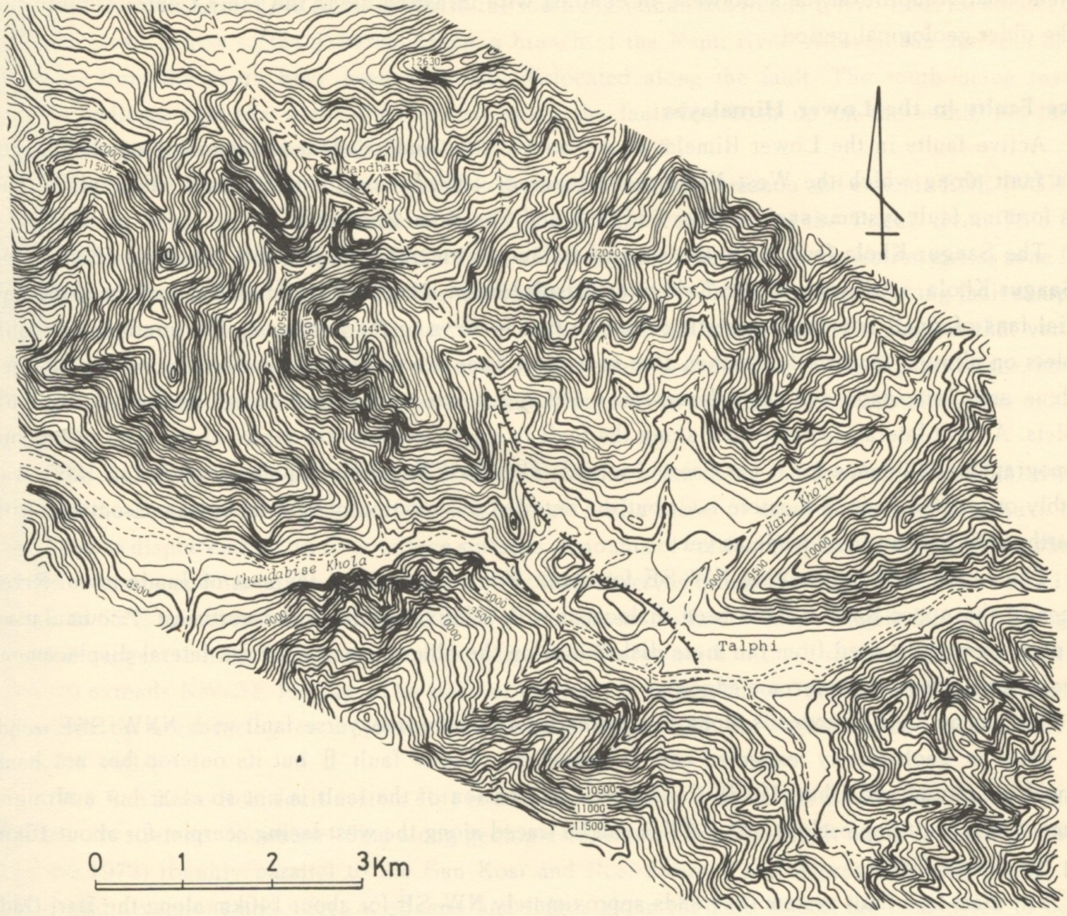

Fig. 2 Trace of the Talphi fault (2)

apparent relative displacement along the fault is up on the southwest and down on the northeast against general height distribution of the mountains. The fault trace is marked by the northeast-facing straight escarpment across several levels of fluvial terraces and hills. The height of fault escarpment on the higher terrace is estimated about 40 m. Dislocated terraces form isolated mounds associated with fault depressions and sag ponds along the fault trace. The youngest activity along the fault is evidenced on the lowest fan surface as a low scarplet less than 5m high. No distinct lateral displacement is so far detected on aerial photographs.

The Tibrikot fault (3) appears along the course of the Thuli Bheri, a branch of the Bheri river and strikes WNW-ESE for about 20km. The trace of the fault is straight and the relative displacement along the fault is up on the southwest and is dextral, judging from breaks in mountain slope and offset of streams and ridges. Young alluvial fans formed by small tributaries around the confluences have also been dislocated in the same mode and sense.

Truncating high mountain tract to the southwest of the Dhauragiri Himal, the Dhauragiri Southwest fault (4) can be traced straightly NW-SE for about 20km. Displacement is marked by fault depressions, ponds, saddles and breaks in slope, and offset of streams and ridges, suggesting that vertical separation is up on the southwest and horizontal separation right-lateral.

Thus displacements on the Main Central Active Fault system are summarized as right-lateral and apparent relative uplift on the southwest, in contrast with thrusting along the Main Central Thrurt during the older geological period.

Active Faults in the Lower Himalayas

Active faults in the Lower Himalayas are mainly short independent faults including the Sangur Khola fault along which the West Nepal Earthquake of 1980 is considered to have taken place, and faults forming fault systems such as Bari Gad fault and Sun Kosi-Rosi fault.

The Sangur Khola fault (5) to the west of Bajaura town trends in NW-SE for about 18km along the Sangur Khola, a tributary of the Kali river. Displacement seem to have faulted mountain slope and alluvial fans of small branchs, suggesting dip-slip that is down to the northeast. The south-facing fault scarplets on alluvial fans are lower than 10m in height. They are arranged *en echelon* around the villages of Tiune and Sutarigaon and fault depressions and sag ponds were found along the feet of the fault scarplets. A right-lateral displacement along the fault is suggested from the strike of the fault traces but no topographical evidence for it has been observed. The West Nepal Earthquake occurred in 1980, was probably originated from this active fault but the detailed observation of surface breaks associated with the earthquake has not been made as yet.

The Jumla fault (6) trending NW-SE for about 5km is situated to the east of Jumla town. River terraces of the upper Karnali have been dislocated with relative uplift on the northeast. Accumulative fault displacement is sited from the more dislocation on the older terraces. A right-lateral displacement is recorded on offset of the terrace edges.

The Samae fault (7) extends along the northern part of the transverse fault with NNW-SSE trend. This fault is geologically expected and is named the Samae fault II but its outcrop has not been observed yet (Ando and Ohta, 1973). Geomorphic expression of the fault is not so clear but a straight lineament with fault depressions and saddles can be traced along the west-facing scarplet for about 10km along the Gobre Gad.

The Bari Gad fault system (8) trends approximately NW-SE for about 140km along the Bari Gad, Nishi Khola, Thulo Khola, Rukum Khola and Sani Bheri rivers. This fault system coincides with the Bari Gad fault which subdivides the Midland metasediment zone into two parts, northern one with large scale folded strutures and the southern one with complicated folded structures. This fault system is composed of short but sharp straight fault traces along which fault scarplets, elongated fault depressions and offset of streams and ridges are observed intermittently in places. The apparent relatve displacement deduced from these fault features is right-lateral and up on the south, suggesting the high angle fault plane. Fault outcrops observed in the field have strike of N40° - 70° W and dip of 60° - 80° NE (Sako *et al.*, 1973) and support the interpretation of aerial photograph. Fault activities during the recent geological period have been well observed in the middle course of this fault system. Topographical expression along the faults dies out on the right bank of the Kali Gandaki river, but it is likely that the activity along the Gandaki fault to the south is connected with that along the system. Active faulting in this area is marked by a series of north-facing scarplets on the mountain flanks as well as on the river terraces of the Gandaki.

The Dhorpatan fault (9) is an active fault trending NNW-SSE for about 17km, bifurcating from the Bari Gad fault system. Fault saddles and reverse scarplets observed along the straight trace of the fault seem to be the result of recent fault activities. The most recent activity is recorded as a north-facing scarplet on the recent alluvial fan on the right bank the Uttar Ganga. The relative displacement along this fault is up on the southwest; as a result, the Uttar Ganga forms a narrow valley in the upthrown block on the west and a wide braided course in the down-thrown block on the east. Lateral displacement is expected to be observed but is not clearly recognized along this fault.

The Jhimruk Khola fault (10) is located to the south of Piuthan and trends WNW-ESE for about 15km along the lower course of the Jhimruk Khola, a branch of the Rapti river. Alluvial fan surfaces of the tributaries from the south have been vertically dislocated along the fault. The south-facing reverse scarplets indicate that the vertical movement along the fault has been up on the south. No lateral displacement is detected from fault features.

The Kalphu Khola fault (11) is located to the northwest of Kathmandu and extends ENE-WSW for approximately 10km on the right bank of the Kalphu Khola, a tributary of the Trisuli river. This fault follows the eastern part of the Kalphu-Dhanr fault which separates the Sheopuri injection gneiss zone from the Kathmandu basin(Arita *et al.*, 1973). The dip of the fault is 40° - 50° north. North-facing fault scarplets truncating mountain slopes and the higher river terrace observed along the fault, suggest that vertical displacement is up on the south. The amount of displacement is about 30m on the higher terrace, but the lower terrace and flood plain have not been dislocated. There is no evidence of horizontal movement along the fault.

The Kulikhani fault (12) trends NNW-SSE for about 10km along the course of Kulikhani river, a branch of the Bagmati river. The fault trace is straight and a series of north-facing scarplets have been formed due to displacements on river terrace surfaces. Amounts of vertical displacements are about 15m on the higher terrace and 3m on the lowest terrace. The fault observed around Kitinigaon has strike of N10°W and dip of 60°E associated with shattered zone of 5m across. No lateral displacement is found along the fault, and suggest that the fault is a normal dip-slip fault. To the north of the Kulikhani fault, the Chitlang fault (13) extends NW-SE for 7km. The trace of the fault is rather sineous and vertical displacement is recognized by north-facing escarpments on mountain slopes and the higher terrace in the elevated pre-cyclic valley.

The Sun Kosi-Rosi fault system (14) is a rather extensive fault in the Lower Himalayas trending NW-SE. It stretches for about 40km along geologically-known Sun Kosi fault and Rosi fault II (Ishida and Ohta,1973) roughly parallel to the Sun Kosi and Rosi rivers. Fault depressions, sag ponds, fault saddles and diversions and offset of streams and ridges along the fault traces, are considered to be the results of fault activities during the recent geological period. Vertical displacement is up on the southwest and lateral displacemet is dextral. The accumulation of lateral displacements is suggested by the larger offset on the longer stream.

The active faults in the Lower Himalayas are recognized mainly along the geological faults trending roughly NW-SE. Common characteristics of the displacements along the active faults are considered to be vertical displacement with the north side faulted relatively down, making a striking contrast with the present height distribution of the range.

Active Faults of the Main Boundary Active Fault System.

The Main Boundary Fault has been known as the most important tectonic feature with the highest activity throughout the Himalayas. However, it has not yet been mapped in detail from the view point of active faults in the Nepal Himalayas. Active faults along the Main Boundary Fault may be called the Main Boundary Active Fault system.

This active fault system is not continuously traced topographically through the whole length of the geological Main Boundary Fault, but is recognized as chains of active faults for around 100km interrupted by inactive sections. The active faults of the Main Boundary Active Fault system include the Rangun Khola fault, the Surkhet-Gorahi fault, the Arung Khola fault, the Hetaura fault, the Udaipur fault and the Sapt Kosi-Mechi fault from the west to the east.

The Rangun Khola fault (15) is situated in the western corner of Nepal and extends for 80km along the Main Boundary Fault between the Kali and Karnali rivers. The trace of this fault is rather sineous in the western part but rather straight in the eastern part. Fault scarps are north-facing, and fault depressions, and sag ponds are common along the fault. Consequent streams on the steep Lower Himalayan slopes are disturbed by reverse scarplets transversely formed on the mountain flank. A series of fluvial terraces have been vertically dislocated on the left bank of the Rangun Khola along the fault trace (Fig.3). The sense of vertical faulting generally observed in this area is up on the south and down on the north. The fault trace bifurcates on the right bank of the Khola and the displacement mainly occurs on the southern bifurcation to the west. It is also striking that elongated linear ridges extending along the fault trace in this place appear to be pressure ridges. It is assumed from the mode of the horizontal extension of fault that the fault plane along which recent activities have been taking place is northward dipping in the west and is rather vertical in the east. Along the Thuli Khola in the east, common displacement on the fault is dip-slip with northward drop. On the right bank of the Karnali river, a young alluvial fan is dislocated along the fault ; as a result, a low reverse scarplet has been formed. In the section between the Karnali river and Surkhet town the Main Boundary Fault is inactive and many tensional fractures are observed on the surface with low relief on the Lower Himalayan ridge.

The Surkhet-Gorahi fault (16) can be traced continuously along the northern margin of the longitudinal depressions in the Siwaliks for approximately 120km between Surkhet and Gorahi. The most common fault feature in this sections is a fault depression with steep north-facing scarplet to the south. This type of fault depression is bounded by fault on one side and can be termed fault angle depression. Therefore it seems to be different from the similar depression bounded by reverse faults on both sides observed along the Main Boundary Fault to the north of Dehra Dun in India (Nakata,1972). The apparent

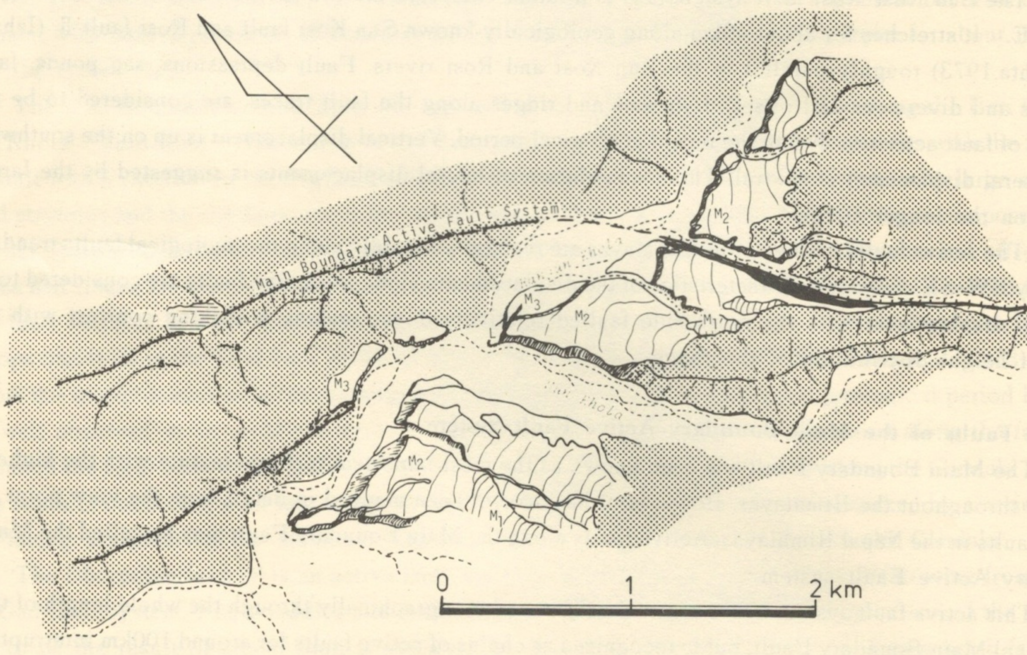

Fig. 3 Trace of the Rangun Khola fault (15) around the Rangun Khola. Thick black line is a pressure ridge.

relative displacement along the fault is dip-slip that is down to the north. In this area the trace forms a southwestward-convex arc maintaining a northwesterly regional trend, which indicates the fault being north-dipping. Although it is yet to be confirmed in the field, nomal dip-slip faulting seems to be prevailing also in this area as deduced from relative subsidence of the Lower Himalayas along the Main Boundary Active Fault system. However, an evidence for upheaval of the Lower Himalayas along the fault system is observed on the displacement of river terrace of the Bheri river on its right bank. In this place,the fault is rather straight associated with an elongated narrow ridge and dislocates the northern block up relatively to the southern one (Fig.4). The hill-side ridges are commonly observed along the fault trace to the south. Lateral component of fault displacement is not so commonly recognized but to the east of Bijauri where fault trace strikes rather north-south, a right-lateral displacement is examined from offset of terrace edges. The most recent evidence of faulting is found as fault scarplets on alluvial terrace surfaces slightly higher than the present river bed. The trace of this fault dies out to the east where the Siwalik hills directly contact the Lower Himalayan slope.

The Arung Khola fault (17) can be traced for about 60km in the direction of approximately E-W. To the north of Butwal, this fault roughly traces the course of Dobhan Khola dislocating mountain slopes and fluvial fans. The fault trace is rather straight and dip-slip movement suggested by diplacement of fan surfaces around Kachal is down on the north as commonly observed along the Main Boundary Active Fault system. Judging from its straight strand, the dip of the fault plane is considered to be steep, and the fault observed at the outcrop along the Tinau Khola strikes N75°E and dips nearly vertical or even southward. This fact shows that the Main Boundary Fault is not always northward dipping thrust near the surface. The fault trace is not topographically clear along the Tinau Khola. In the eastern part, the fault can be traced rather continuously and north-facing fault scarplets are generally recognized on fan surfaces of the small tributaries of the Arung Khola.

The Hitaura fault (18) is an active fault with low certainity. The fault trends E-W for 40km along the Churling Khola, a tributary of the Narayani river and the Bagmati river. The fault is recognized as weak lineaments with reverse scarplets in places. The straight trace of this fault is also suggesting that the Main Boundary Fault is steeply dipping near the surface in this section.

The Udaipur fault (19) is sineous and trends approximately WNW-ESE for 85km. The trace of fault is continuously recognized as north-facing scarplets with fault depression to the north on the mountain slopes and fluvial terrace surfaces. The fault trace in the east forms small southward-convex arcs where the mountain slopes are projecting southward, and suggests the northward dipping fault plane. This coincides with that of the geological Main Baundary Fault (Itihara *et al.*,1972) but the sense of dip-slip along the fault appears to be contrary. There is no evidence of strike-slip along the fault. The trace of the western part of this fault is trending NW-SE and is rather straight, and a fault outcrop of the Main Boundary Fault found on tributary of the Kakaru Khola to the north of Katari, shows that dip of the fault is 80°SE-vertical.

To the east of the Sapt Kosi river short faults can be traced intermittently along the Main Boundary Fault for 80km and they may be collectively named the Sapt Kosi-Mechi fault (20). To the east of Dharan the fault strands roughly E-W for 10km and north-facing reverse escarpment associated with fault depressions on the mountain slopes is of common characteristic along the fault traces. The same type of fault feature can be traced for 20km to the west of the Kankai river. However, in the area close to the Indian border, clear evidences of faulting in the recent geological period have been recorded as fault escarpments on the river terraces of the Goyang Khola, Bering Khola and Timai Khola. Amount of vertical displacement on the younger terrace is over 40m. Along the conjugate faults trending NW-SE and NE-SW, horizontal displacements of the faults are also marked by offsets of terrace edges and small streams (Fig.5). Right-lateral diplacement is a rule on the NW-SE trending faults and left-lateral on the NE-SW trending

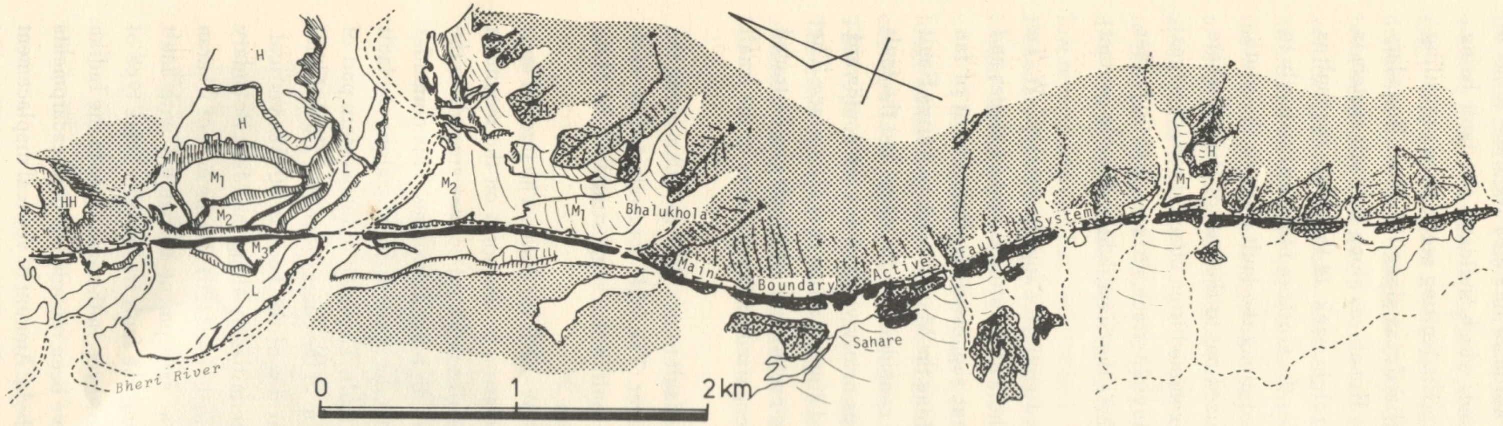

Fig. 4 Fault features along the Surkhet–Gorai fault (16) near the Bheri river. Thick black lines are pressure ridges.

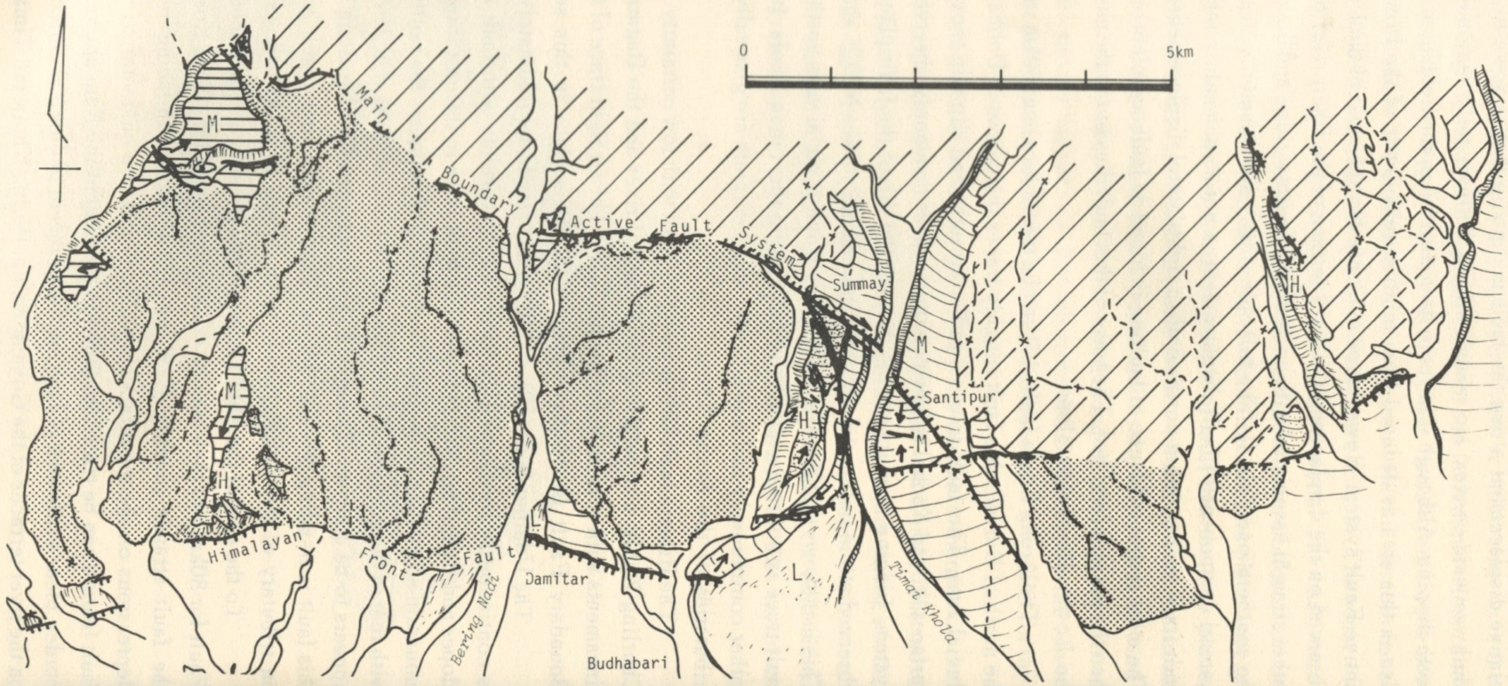

Fig. 5 Fault displacements of river terraces by active faults of the Main Boundary Fault system and the Himalayan Front

faults. Along the active fault truncating the course of the Timai Khola in the direction of NW-SE, the Lower Himalayas have been dislocated southerly and the Siwalik hills have become narrower. Vertical displacement along the fault is scissoring, up on the southwest near its northern end and up on the northeast near its southern end, suggesting right-lateral dislocation. This fault may be connected with a short fault trace in the plain near Kakarbita on the bank of the Mechi river.

Active Faults of the Himalayan Front Fault

Active faults of the Himalayan Front Fault are distributed as short fault traces along the southern margin of the Siwalik-hills. In the west, between the Karnali and Bobai rivers(21), sineous trace of the fault is recognized for about 20km by a series of fault scarplets dislocating alluvial fan surfaces. Deformed fan surfaces have been upwarped along the fault; as a result, buldges have been formed. This type of fault feature is commonly observed along the reverse faults in the Japanese islands. Short fault traces intermittently fringe the Siwalik front in places in central Nepal. It seems that the Himalayan Front Fault is active for over 100km to the south of Kathmandu(22). River terraces and fans of small rivers from the Siwalik hills have been displaced along the faults vertically up on the north in places. However the fault trace is not continuous but intermittent, probably due to erosion after the displacement in many places. Along the fault trending E-W, pure dip-slip movements have been recorded. On the other hand left-lateral slip is observed along the NW-SE striking fault on the right bank of the Bagmati river. This fault is also active to the east of Dharan(23). A series of alluvial fans and river terraces have been vertically as well as laterally dislocated in this section. Pure dip-slip on the E-W trending fault, right-lateral slip on the NW-SE fault and left-lateral slip on the NE-SW fault are the rule of displacements deduced from topographical expression of faulting. Displacements seem to have been accumulated along the faults, for the larger displacement is observed on the higher terrace.

In the eastern corner of the Siwalik hills in Nepal, the trace of Himalayan Front Fault crosses the Main Boundary Active Fault system (Fig.5). The former seems to have acted later than the latter, judging from the relation between two faults. Vertical displacement along the Himalayan Front Fault is commonly prevailing.

DISCUSSION OF CHARACTERISTICS OF THE ACTIVE FAULTS IN THE NEPAL HIMALAYAS

Density of Distribution of Active Faults

The active faults are not evenly distributed throughout the Nepal Himalayas but show linear concentrations along the major tectonic lines and older geological faults (Fig.6). The active faults forming the Main Central Active Fault system appear in west Nepal where the Main Central Thrust extends roughly NW-SE with rather smooth trace. However, geomorphic evidences of recent activities along the Thrust has not yet been found in central and west Nepal where the Thrust forms sineous traces. In the Higher Himalayas, active faults with high certainity have not been observed so far, although many short gravity faults seem to exist on the steep mountain slopes and ridges. The active faults in the Lower Himalayas appear somewhat concentrated along the geological faults in west-central and east-central Nepal, while wide portion of the Lower Himalayas have not experienced active faulting. It is interesting to note that recent displacements along the Main Boundary Fault seems to have been active in the sections where displacements along the active faults in the Himalayas have not been taking place, making up each other for the lack or weakness of faulting. As a whole total amounts of active faulting in each section seem

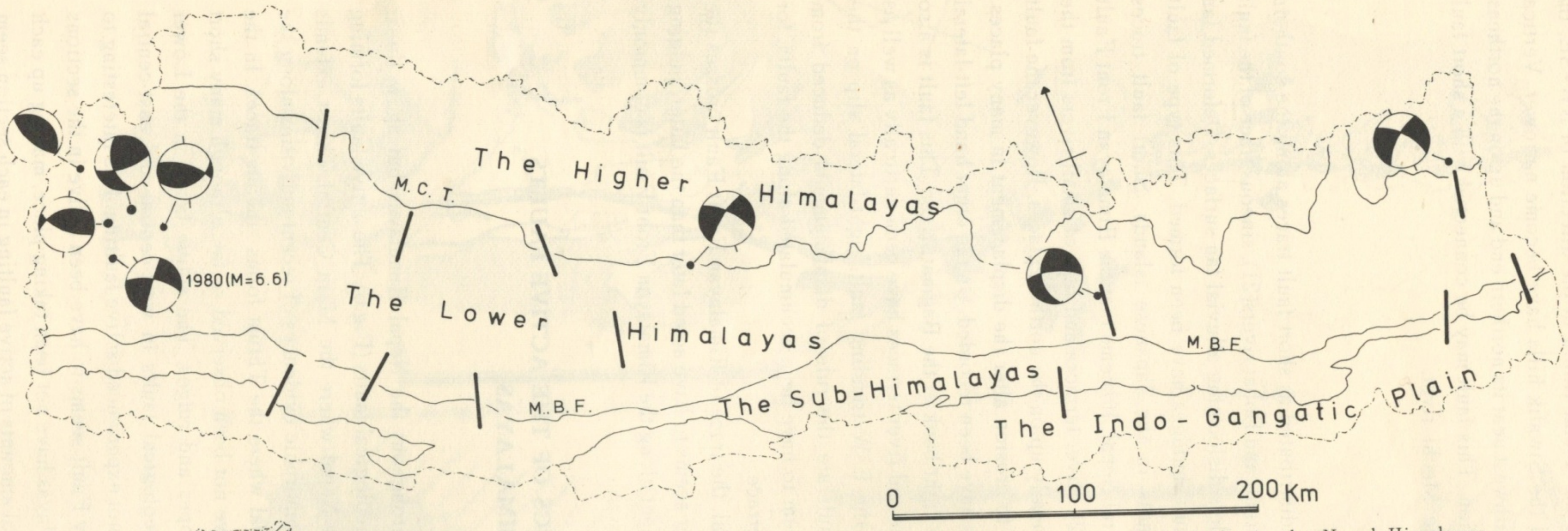

Fig. 6 Characteristics of distribution of the active faults in the Nepal Himalayas.

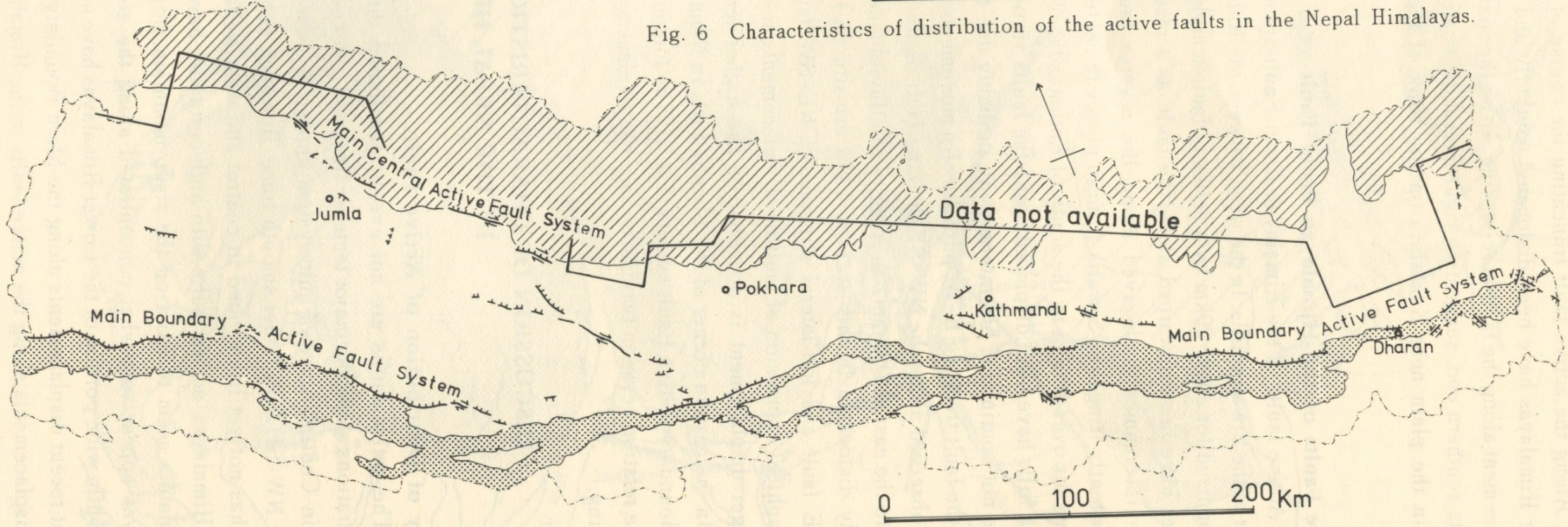

Fig. 7 The direction of tectonic stress in the Nepal Himalayas.
Bar indicates the direction of maximum horizontal principal stress axes deduced from active faults. Fault plane solutions of shallow earthquakes after Fitch (1970) and Rastogi (1974).

to be equalized within the Nepal Himalayas. However, in central Nepal between Kathmandu and Pokhara recent fault activity is found to be weak and it may be attributed to the exceptionally low altitude of the Lower Himalayas in this area.

Strikes of the Active Faults and Mode of Faulting

Strikes of active faults in the Nepal Himalayas varies greatly and seem to be closely related to mode of faulting. The active faults of the Main Central Active Fault system and of the Lower Himalayas are, in general, trending NW-SE-WNW-ESE, oblique to the general trend of the Himalayan Front except for several faults. They are considered to be mostly right-lateral strike-slip faults associated with dip-slip of northward down throw. A few N-S transverse faults appear in the ranges and they seem to be normal faults. The same type of faults have been detected in the Tibetian Plateau (Molnar, 1978). Normal faults in this direction are presumed to extend also along the both sides of Mustang valley, although interpretation of areal photographs has not been done yet. Following the sineous traces with southward-convex arcs of the Main Boundary Fault, active faults appear in the directions of E-W-NW-SE. Locally faults extend rather straight and suggest that they are mostly of dip-slip, probably normal in sense along the high angle fault plane. Apparent displacement along the faults is of northward drop. Normal faulting along Main Boundary Fault has been also recognized in the Kumaon Himalayas in India (Rupke, 1974). The right-lateral displacement is observed along NW-SE directed traces of the fault in places. Short active faults of the Himalayan Front Fault extend roughly in three directions. They are conjugate sets of NW-SE and NE-SW trending faults, and E-W trending fault. Right-lateral and left-lateral slips are observed along the respective conjugate faults and dip-slip on the E-W trending reverse fault.The northward uplift is common along to E-W fault as seen in the Darjeeling Himalayan foot-hills (Nakata, 1982).

Tectoic Stress Field Deduced from Active Faults and ShallowEarthquakes.

Directions of maximum horizontal principal stress axes under which the recent crustal deformations have been taking place are deduced from strike and mode of active faulting (Fig.7). They are generally N-S, transverse to the general trend of the Himalayan ranges as well as parallel to the direction of relative motion between the Indian and Eurasian plates along the Himalayan Front . Fault plane solutions of shallow earthquakes (Fitch, 1970, Rastogi, 1974) show that strike-slip faulting is predominant in the Himalayan ranges, as seen in the West Nepal Earthquake of 1980 which probably occurred along the Sangur Khola fault. The above-mentioned characteristics well coincide with the direction, mode and sense of active faulting. The directions of maximum horizontal principal stress axes are more or less harmonious with that known from the active faults. However, it is still open to debate how the apparent normal faulting along the Main Boundary Active Fault system has been taking place under such stress field.

Rate of Displacement along the Active Faults

Many young geomorphic surfaces such as river terraces and alluvial fans have been displaced along the active faults, and the rate of displacement may be obtained from the amounts of displacements and ages of these geomorphic surfaces. Average slip rate of faulting along the southern margin of the Himalayas, i.e. along the Main Boundary Fault and Himalayan Front Fault altogether amounts 3-4mm per year in the Darjeeling Himalayas (Nakata, 1982). Rough estimation of average slip rate along the east Nepal foot-hills near Indian border may be obtained about 2mm a year from the height of fault escarpment (ca. 40m) on river terraces (ca.20,000y.B.P.) (Fig.5). However, no concrete data for estimation of rate of displacement have been collected along the strike-slip faults.

Active Faults and Earthquakes

As already described, the West Nepal Earthquake (1980, M= 6.6) broke out along one of the active faults, and we can predict that future large earthquakes will occur mostly along the mapped active faults in the Nepal Himalayas. Magnitude of earthquakes depends on the dimension (length) of the pre-existing active faults, and so we may presume the magnitude of future earthquakes according to the empirical rule between magnitude and fault length.

In the Lower Himalayas including along the Main Central Thrust, active faults are rather short and intermittent ranging 10-40km. On the other hand, the active faults are long and continuous along the Main Boundary Fault, ranging 40-120km. Therefore, earthquakes predicted in the Lower Himalayas are smaller than those along the Main Boundary Fault. Accodring to empirical rule for intraplate earthquake proposed by Matsuda (1975), i.e. Log L= 0.6M-2.9 where L= length of fault, M= magnitude of earthquake, earthquakes of magnitude ranging 6.5 - 7.5 will occur in the Lower Himalayas and those ranging 7.5 - 8.3 along the Main Boundary Fault in future.

Further Hypothesis

As mentioned above, displacements along the major tectonic lines during the late Quaternary except the Himalayan Front Fault, do not favor the upheaval of the Himalayan ranges or the crustal shortening of large scale (Gansser, 1966; Stocklin, 1980) due to the collision. On the contrary, the ranges have been widely subsiding and dislocated laterally along the active faults with high angle fault plane. It was reported by Qureshy *et al.* (1974) that the positive isostatic gravity anomaly covered the Lower Himalayas. This may indicate isostatical over-compensation of the range; as a result, subsidence might have taken place in the anomaly area. However, it is widely believed that abrupt increase in altitude of the ranges has been attributed to the thrusting along the major tectonic lines under the same stress field in accordance with the comtemporaneous one as deduced from fault plane solution of shallow earthquakes. Judging from height distribution of river terraces along the Kali Gandaki, Iwata and Yamanaka (1982) presume the uplift of the Siwalik hills and the Mahabarat Lekh as well as the Higher Himalayas during the last 100,000 years. This phenomenon also appears not to be harmonized with the mode and sense of displacements along the faults.

A paradox of active faulting as a part of the recent crustal movements of the ranges seems difficult to be properly explained. Nevertheless, the author proposes a hypothetical model for the recent crustal movements of the Nepal Himalayas. The collision of the above mentioned two plates has been taking place at relatively shallow depth (ca 3,000-4,000m) along the Himalayan Front in east Nepal in comparison with central and west Nepal where the two plates contact about over 8,000m beneath the surface (Fig.8). As a result, in the eastern Nepal Himalayas, distinct upheaval movements have occurred along the Himalayan Front as the direct surfacial expression of thusting along the Main Boundary Fault. On the contrary, in the central and western Nepal Himalayas the fault plane of the Main Boundary Fault becomes steeper, dips more or less vertical and even overturns southward near the surface. Along this steeply dipping fault plane of the Main Boundary Fault, vertical displacement seems to have become weak, while the displacement along the strike-slip faults have appeared in the Lower Himalayas. Thrusting along the Main Central Thrust seems to be dormant in the eastern Nepal Himalayas in the recent geological period , while lateral displacement have been taking place along the high angle faults which have newly appeared along the pre-existing Main Central Thrust.

Thus, regional disparities of active faulting may be attributed to differing depth of the continental collision.

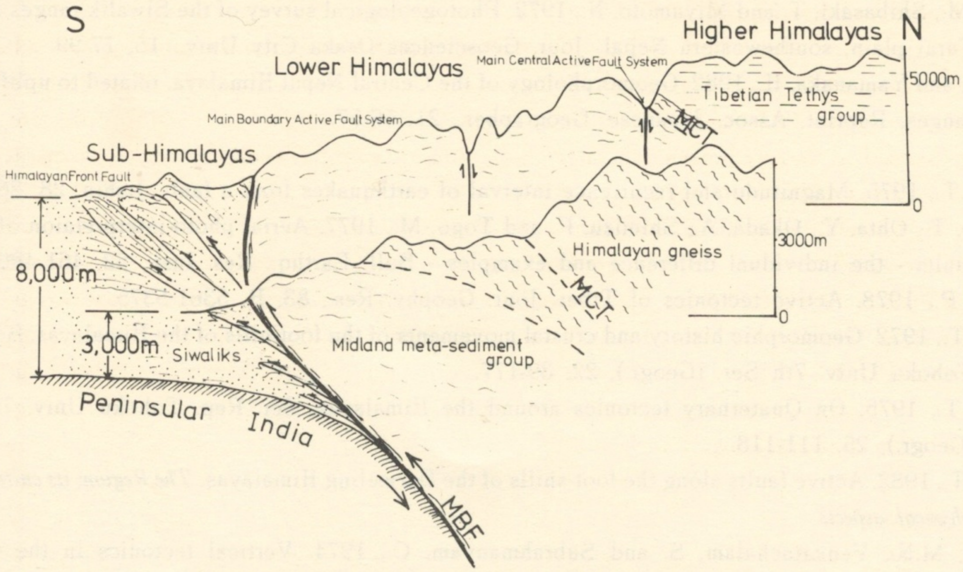

Fig. 8 A hypothetical model for the recent crustal movements of the Nepal Himalayas.
Above : Central and West Nepal
Below : East Nepal

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