Mem. Fac. Sci. Shimane Univ.,
24, pp. 71–88 Dec. 20, 1990

Stratigraphy and Geologic Structures of the Churia (Siwalik) Group in the Tinau Khola-Binai Khola Area, West Central Nepal

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(Received September 5, 1990)

The Churia (Siwalik) Group of West Central Nepal, reported in previous papers (Tokuoka *et al.*, 1986, 1988)is traceable stratigraphically and structurally to the present study area. The group is divided into the Arung Khola, Binai Khola, Chitwan and Deorali Formations in ascending order, has a total thickness of 4,000 to 6,000 m and ranges in age from about 15 Ma to the Pleistocene. The group as a whole, is comprised of a coarsening-upward sequence, reflecting the rise of the Himalayas. The Churia group is separated from the Midland Group by the Main Boundary Thrust in the north and from the Alluvial deposits in the Gangetic Plain by the Frontal Churia Thrust in the south. The Central Churia Thrust divides the Siwalik (Churia) Hills into North and South Belts. A geologic map, columnar sections and route-maps are shown in detail in 10 appendix-figures. The results of paleocurrent analysis and sandstone petrography are also discussed in the present paper.

Introduction

The Siwalik Group of Nepal is composed of sediments which have been transported from the Himalayas and deposited at their southern frontal areas during the Neogene Period. In Nepal the Siwalik Group is exposed in the southern frontal hills of the Himalaya, known as the Churia Hills, and the name Churia Group has accordingly been given to them. The Churia Group of the Arung Khola-Binai Khola area was studied by TOKUOKA *et al.* (1986 and 1988), and the present study area is a western extension of the previous areas (Fig. 1). The project team for the "*Geotraverse of the Nepal Himalayas*"

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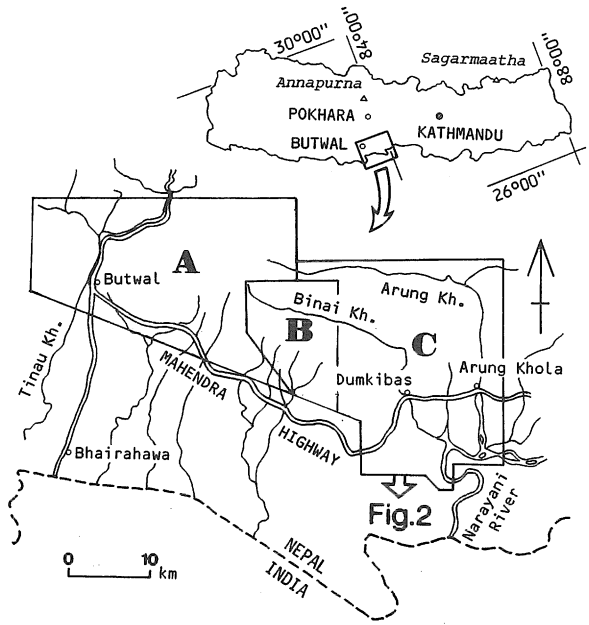


Fig. 1. Index Map. (A: study area, B: TOKUOKA *et al.*, 1988, C: TOKUOKA *et al.*, 1986)

was organized in 1988 by the senior author. This project is the successor of the former project "*Study on the Crustal Movement in the Nepal Himalayas*", which was conducted by Prof. Koshiro KIZAKI of the University of Ryukyus. The main purpose of the present study is to extend our survey area westward from the Binai Khola area up to the Tinau Khola area, where an important fossil of hominoid, *Sivapithecus* (*Ramapithecus*) *punjabicus* was reported by MUNTHE *et al.* (1983) with some paleomagnetic data, and to establish consequently the stratigraphy of the Churia (Siwalik) Group in Nepal, and finally to correlate it with the Siwalik Group of the Potwar Plateau in Pakistan where the standard stratigraphy of the Siwalik group was established on the basis of paleomagnetic studies (OPDYKE *et al.*, 1982; JOHNSON, N. M. *et al.*, 1982; TAUXE and OPDYKE, 1982). The data obtained in the field-work of about 240 man-days in 1988 and in that of about 210 man-days in 1989 are described in the present paper with the route-maps (mostly 1/5,000 in original scale) in the appendices. Sedimentologic, paleontologic and paleomagnetic studies will be reported separately in the future.

Acknowledgements: We are much indebted to Dr. M. P. SHARMA of Tribhuvan University for his support and encouragement. We are also grateful to Mr. TATER, Deputy Director General of the Division of Mines and Geology, His Majesty's Government of Nepal. Drs. B. N. UPRETI and M. R. DHITAL of Tribhuvan University supported our work in various aspects and gave us useful suggestions. Mr. SHARJAHAN, graduate student of Shimane University (Oil & Petrolium Co. Ltd. Bangladesh) joined

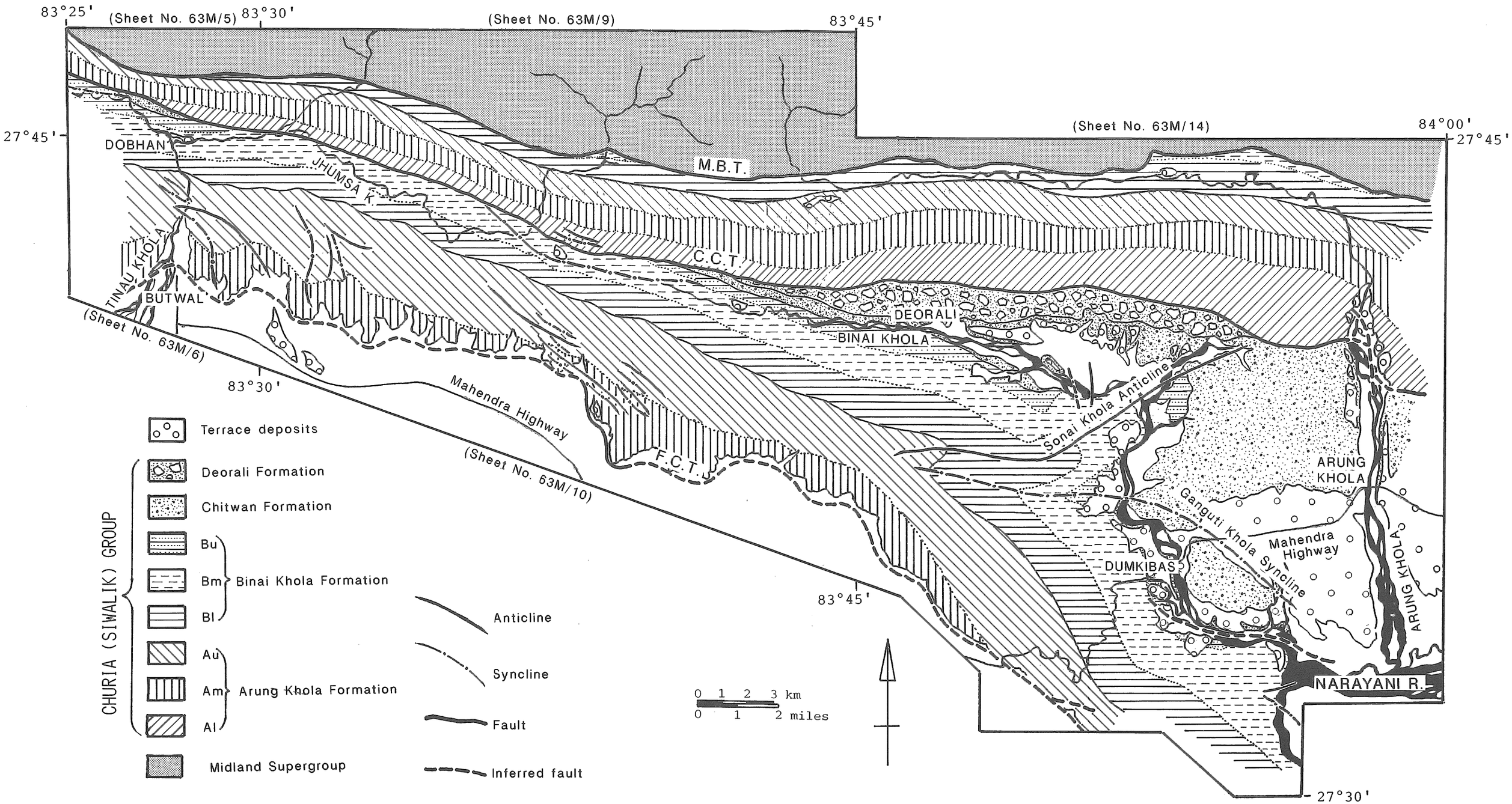


Fig. 2. Generalized geologic map of the Arung Khola-Tinau Khola area surveyed since 1986.

us in the field in 1989. We express our great thanks to them. This study was supported financially by *a Grant-In-Aid, Japan Oversea Research Fund of the Ministry of Science and Culture, Government of Japan,* to which our sincere thanks are also expressed.

General Geology of the Churia Group

The Churia (Siwalik) group is bounded on the north by the Main Boundary Thrust (M.B.T.) and the Lesser Himalaya, and on the south by the Frontal Churia Thrust (F.C.T.), which is part of the Himalayan Frontal Thrust, and the Ganga Plain. The Churia Group has been studied precisely in the Arung Khola-Binai Khola area by Tokuoka *et al.* (1986), and subordinately in the Binai Khola area by Tokuoka *et al.* (1988). The adjoining western area up to the Tinau Khola, is described in the present paper. The Churia group is divided lithostratigraphically into the Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation in ascending order, that is, in the order of A, B, C and D Formations in their capital letters. The A and B Formations are subdivided into three members respectively. These are, from bottom to top, the Al, Am, Au, Bl, Bm and Bu Members. The group is divided into North and South Belts which are separated by the Central Churia Thrust (C.C.T.). A generalized geologic map of the study areas is shown in Fig. 2. These areas are divided geographically into eastern, central and western areas and their lithologic characteristics are shown in Fig. 3, in which a correlation with the Siwalik Group of the Potwar Plateau, Pakistan, based on paleomagnetic polarity stratigraphy, is also shown. The Churia Group is composed entirely of fluvial sediments ranging from in age the Miocene (15 Ma) to the Pleistocene. In the North Belt the strata up to the Bl Member are exposed, whereas the strata down to the Am Member are exposed in the South Belt. The Churia Group sediments show steeply inclined homoclinal structures in the North Belt, whereas they show gently dipping and folded structures in the South Belt. The Churia Group is characterized by various sedimentary structures, including cross-statification, flute casts, mud-cracks, and sedimentary dykes. Freshwater molluscs are found throughout the area in the Au to Bm members. Vertebrate fossils have been found in the Au to Bm members in the western area.

Stratigraphy

We have surveyed the area included in the Survey of India 1 inch : 1 mile sheet maps, Nos. 63M/5, 6, 9 and 10. The survey routes are collectively shown in Fig. 4. The geologic map and columnar sections along the main routes are shown in App. Figs. 1 and 2 respectively. The route-maps are shown in App. Figs. 3 to 10. The stratigraphic and structural divisions of the Churia Group discussed in previous papers (Tokuoka *et al.,* 1986, 1988) are applicable to the present area. The Churia Group is

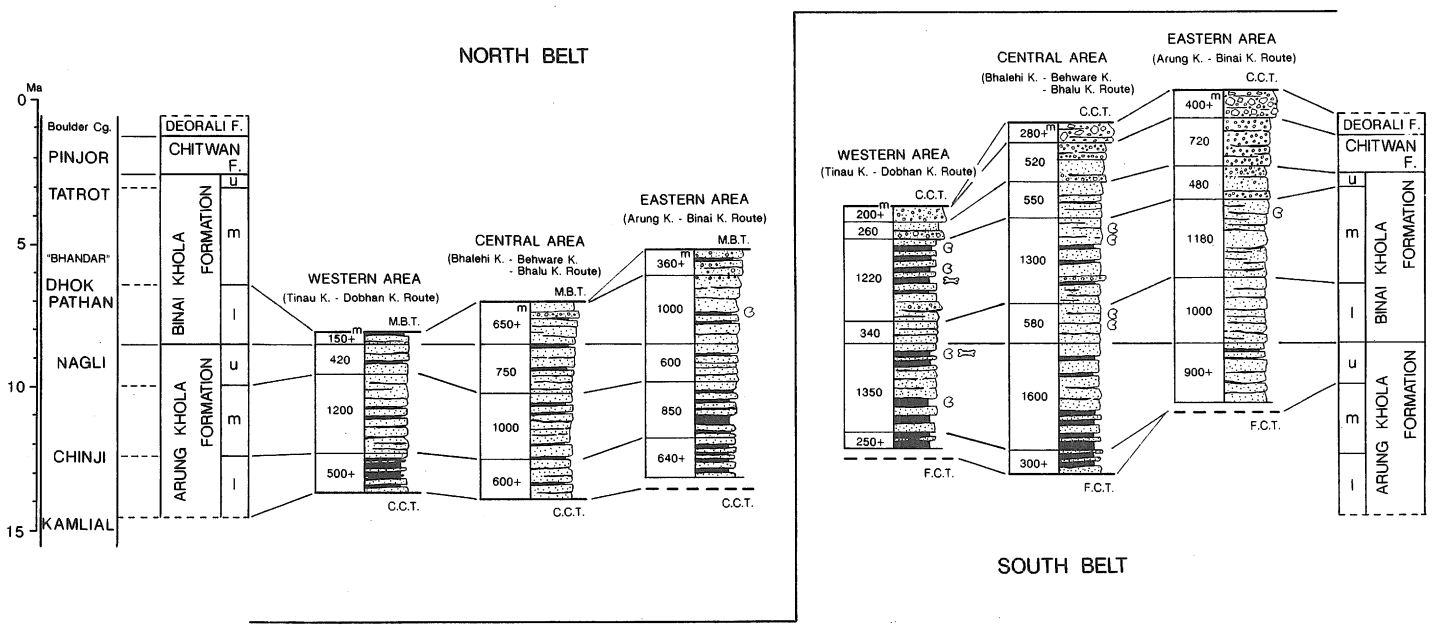


Fig. 3. Generalized columnar sections of the Churia Group of the Arung Khola-Tinau Khola Area and their correlations.

divided into North and South Belts which are separated from each other by the Central Churia Thrust (C.C.T.). The correlation between the Arung Khola-Binai Khola area (Eastern area) reported by TOKUOKA *et al.* (1986 and 1988) and the present area (Central and Western areas) is shown in Fig. 3. In the recently surveyed Central and Western areas the members Al to Bm are exposed in the North Belt, whereas the strata from the Am Member to the D Formation are exposed in the South Belt. Lithologic and other characteristic features of the Churia Group along the main surveyed routes are briefly described in below. Detailed columnar sections are collectively shown in App. Fig. 2.

A. NORTH BELT

1. The Lower Member of the Arung Khola Formation (Al)

The Al Member is exposed in the upper stream of the Tinau Khola (Camp site C-2 shown in Fig. 4) and along the Jhumsa Khola (the area between C-10 and C-11; Plate I, Fig. 1). It is also well-exposed in the upper streams of the Kharehe Khola and Bhalu Khola. It consists of alternating beds of calcareous sandstone and variegated mudstone, attaining a thickness of more than 500 m.

At the Bhalu Khola sole markings are frequently observed, showing a western supply, and fossil leaves are frequently found. At the Kharehe Khola a couple of tightly folded synclines and anticlines exist and plants fossils are frequently found. Ripple-marks and mud cracks are observed on sandstone layers. Along the Jhumsa Khola the Al Member has been crushed extensively in the vicinity of the C.C.T. Along the Tinau Khola variegated mudstones are developed extensively. Plant remains are frequently found in black mudstones.

2. The Middle Member of the Arung Khola Formation (Am)

The Am Member is exposed along the Jhumsa Khola and the Tinau Khola. This member is more rich in sandstones than the Al Member. It has a thickness of about 1,000–1,200 m and is characterized by sole markings and ripple-drift cross laminations.

3. The Upper Member of the Arung Khola Formation (Au)

The Au Member outcrops mainly along the Jhumsa Khola and 109 Nala of the Bosheni Khola. It is composed primarily of sandstone-dominated alternations with mudstone, and is 420–750 m in thickness. Molluscs have been found in mudstones along the Suka Khola, a tributary of the Jhumsa Khola (F52).

4. The Lower Member of the Binai Khola Formation (Bl)

The Bl Member exposed in the northern part of the surveyed area and is in the footwall of the M.B.T., and is well exposed along the Bosheni Khola, Gotadi Khola (a tributary of the Jhumsa Khola), Aridung Khola and Tinau Khola. It is composed mostly of thick-bedded sandstones with mudstone intercalations, though conglomerates are sometimes intercalated in the upper sequences. It has a thickness of more than 650 m. At the 109 Nala of the Bosheni Khola sandstone-dominated alternations dip steeply to the south and are overturned. At the Galti Khola, a tributary of the Gotadi Khola, sandstone-dominated alternations are overturned and molluscan fossils are found in two

horizons (F54 and 55).

5. The Middle Member of the Binai Khola Formation (Bm)

The Bm Member is exposed in a narrow strip along the M.B.T. in the most northern part of the surveyed area, along the Gotadi Khola and Shishi Khola, where it lies in the footwall of the M.B.T. This member consists of pebble-bearing, massive sandstones and has a thickness of more than several tens of metre.

B. SOUTH BELT

1. The Middle Member of the Arung Khola Formation (Am)

The Am Member is exposed in the most southern part of the surveyed area. It is separated from alluvial deposits to the south by the F.C.T. Good outcrops are exposed along the Kharehe Khola, Trisuli Khola and the lower sections of the Tinau Khola. It is composed of alternating beds of sandstone and mudstone, in which variegated mudstones are sometimes intercalated. The strata near the F.C.T. are disturbed. Its total thickness exceeds 250 m.

2. The Upper Member of the Arung Khola Formation (Au)

The Au Member is exposed extensively north of the Am Member, with good outcrops observed along the Kharehe Khola, Trisuli Khola and Tinau Khola. It consists of rhythmically alternating beds of sandstone and mudstone between 1 to 2 m thick. Variegated mudstones are sometimes intercalated. Sandstones are often calcareous and those of *pepper-and-salt* type are observed in the upper sequences. The Au member is 1,350–1,600 m thick. At the Kharehe Khola alternating beds of sandstone and mudstone form a splendid gorge. Excellent exposures of this member (Plate I, Fig. 2) are observed along the Tinau Khola where abundant trace fossils (Plate V, Fig. 3) and plant remains are found. Molluscan fossils have been discovered at 3 localities (F8903k, F66, F65). *Sivapithecus* (*Ramapithecus*) *punjabicus* has been discovered overlying the F65 molluscan bed (Plate I, Figs. 3 and 4) by MUNTHE *et al.* (1983).

3. The Lower Member of the Binai Khola Formation (Bl)

The Bl Member is distributed extensively in an E-W trend and outcrops well along the Beware Khola (TOKUOKA *et al.*, 1988), Kharehe Khola, Jhumsa Khola and Tinau Khola. It is composed of alternating sequences of thick-bedded *pepper-and-salt* type sandstone, fine-grained sandstone, and mudstone. It has a thickness of 340–580 m. Along the Kharehe Khola molluscan fossils have been found in 4 horizons (F62, 61, 59, 58). Molluscan fossils are also found in two horizons (F73, 74) along the Jhumsa Khola, where excellent exposures are continuously observable and several sole markings are found. Along the Tinau Khola sandstone dominated alternations are exposed well and some plant remains are found in thin-bedded mudstones.

4. The Middle Member of the Binai Khola Formation (Bm)

The Bm Member outcrops in the upper Binai Khola, Behare Khola (a tributary of the Binai Khola), Kharehe Khola, Jhumsa Khola and Tinau Khola. A tight syncline is observed within the Bm Member in the area between the Jhumsa Khola and the

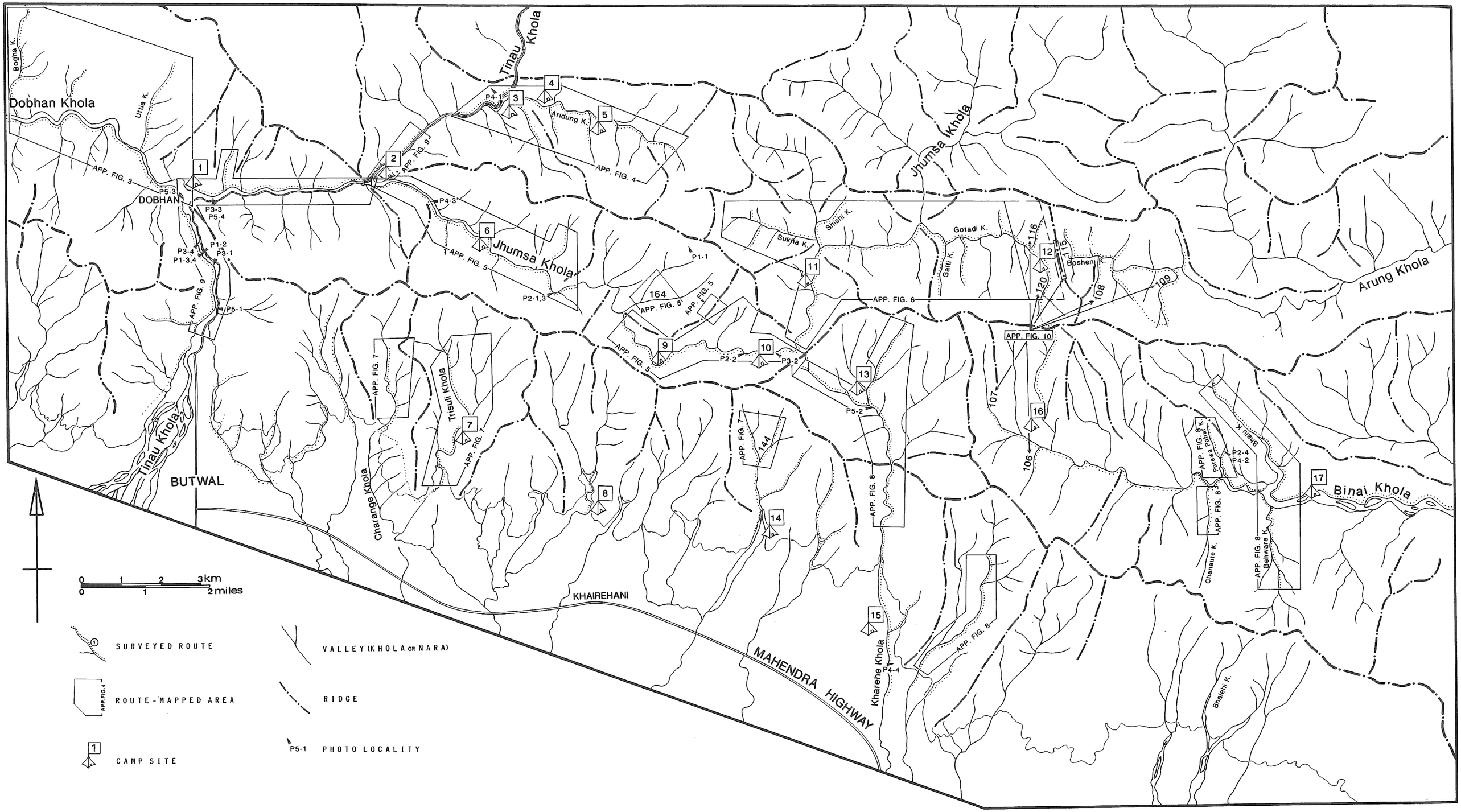


Fig. 4. Locality Map and surveyed routes.

Kharehe Khola. The Bm Member is composed mainly of thick-bedded, massive, *pepper-and-salt* sandstones which are intercalated with thin mudstones (Plate II, Figs. 1 and 3). Pebble conglomerates are sometimes intercalated with the sandstones (Plate II, Fig. 2). It has a thickness of 1,330 m. Molluscan fossils have been found frequently in this member, and bones of mammals are sometimes discovered in the western area (Plate V, Fig. 4). Mammal bones have been discovered in basal, granule-bearing sequences of the thick-bedded sandstones.

5. The Upper Member of the Binai Khola Formation (Bu)

The Bu Member is well exposed along the Binai Khola and Dhoban Khola. It consists mainly of massive sandstones intercalated with 5 to 10 m thick conglomerates. Its total thickness is 260 to 520 m. No molluscan fossils have been found in the Bu Member.

6. The Chitwan Formation (C)

The Chitwan Formation is exposed in a narrow strip along the upper Binai Khola, and along the Dhoban Khola. It is composed of semi-consolidated alternations of conglomerate, sandstone and mudstone. Conglomerates are clast-supported. Clasts are rounded, pebble to sometimes cobble in size, and consist mostly of quartzites and rarely of calcareous and quartzose sandstones. Individual conglomerate attains sometimes a thickness of more than 10 or 20 m. The total thickness of the formation is 500 m.

7. The Deorali Formation (D)

The Deorali Formation is exposed only in the eastern extremity of the study area, along the upper Binai Khola, and is cut by the C.C.T. to the north. It consists primarily of weakly consolidated, ill-sorted, subangular to rounded, cobble to boulder conglomerates, along with some sandstones and rarely mudstones. Conglomerates are mostly matrix-supported. The Deorali Formation is differentiated from the underlying Chitwan Formation by the presence of many clasts which were derived secondarily from the Churia Group (especially from the Arung Khola Formation). The Deorali Formation outcrops well along the Bhalu Khola (Plate II, Fig. 4) and the Parewa Pahar Khola of the upper Binai Khola where we have observed a thrust contact between the underlying Deorali Formation and the overlying Arung Khola Formation (Plate IV, Fig. 2).

Geologic Structures

The Churia Hills are divided tectonically into the North and South Belts which are separated by the Central Churia Thrust (C.C.T.). In the North Belt the Churia Group strata below and including the Bm Member are present, the beds striking E-W and, dipping 40° to 70° to the north. The Churia Group is separated from the Midland Group to the north by the Main Boundary Thrust. In the South Belt only the Am Formation through the Deorali Formation are exposed, the beds striking WNW-ESE

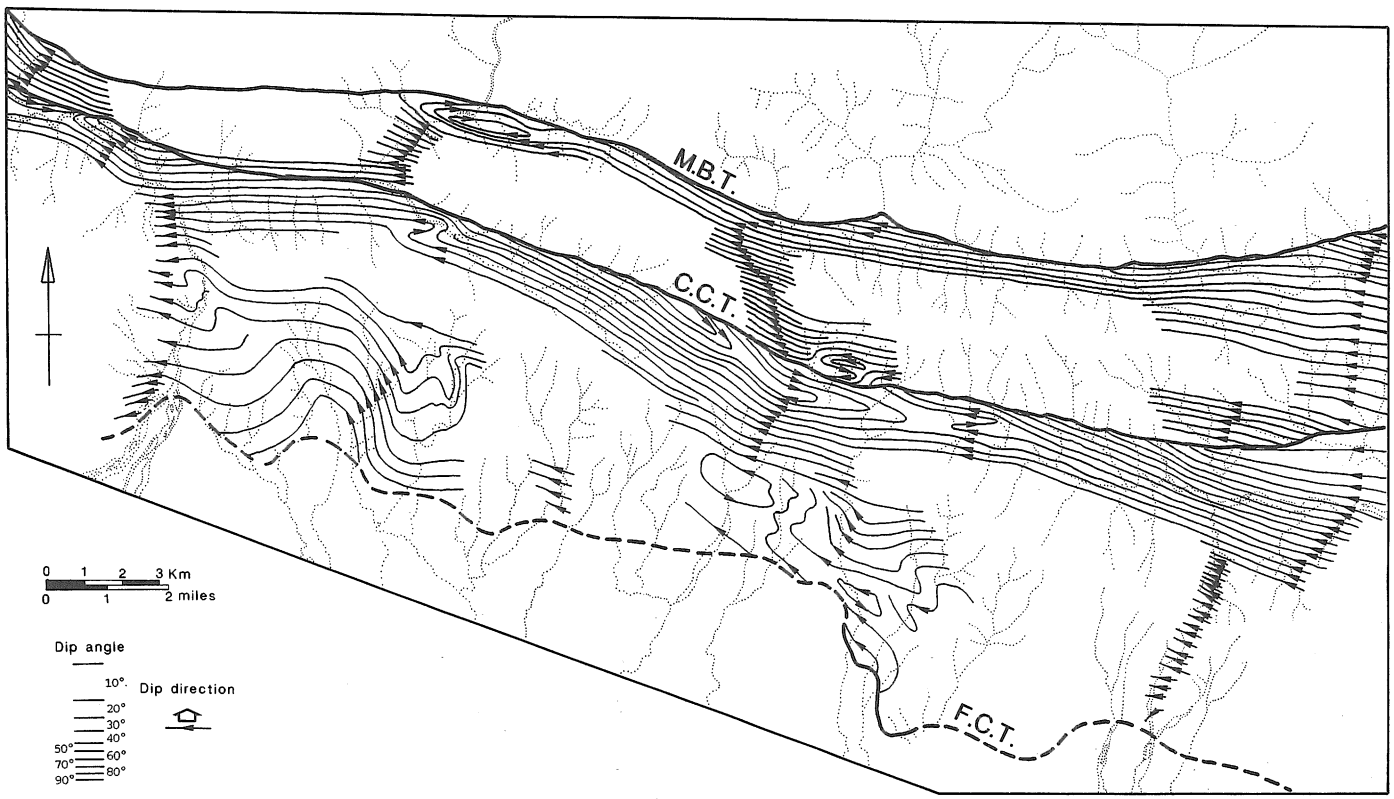


Fig. 5. Strike-line map of the Churia Group. M.B.T.: Main Boundary Thrust, C.C.T.: Central Churia Thrust, F.C.T.: Frontal Churia Thrust.

and, dipping 50° to 80° to the northeast. The Churia Group sediments of the South Belt are separated from the alluvial deposits of Gangetic Plain to the south by the Frontal Churia Thrust (F.C.T.). A strike-line map of the Churia Group is shown in Fig. 5. The strata in the North Belt dip steeply northward and some folded structures exist along M.B.T. and C.C.T. In the South Belt, the strata dip steeply northward in its northern half, and tightly folded structures exist along C.C.T. (Plate V, Fig. 2), whereas in its southern half the strata dip rather gently and have open-fold structures (Plate V, Fig. 1).

The Main Boundary Thrust (M.B.T.) is the boundary between the Lesser Himalaya and the Sub-Himalaya. It can be traced throughout the surveyed area as a lithological break with a geomorphologic expression. Along the Jhumsa Khola (App. Fig. 6) the M.B.T. is exposed, the footwall, pebble-bearing sandy alternations of the Bm Member in high-angle fault contact with the hangingwall, quartzose sandstones of the Midland Group. Along the Aridung Khola the Midland Group has been thrust over the Bl Member although the M.B.T. is not exposed (App. Fig. 4). Along the Tinau Khola and the Dhoban Khola the strata near the M.B.T. are highly disturbed and a high-angle fault is believed to separate the Churia and Midland Groups (Plate IV. Fig. 1). The M.B.T. is believed to become a low-angle thrust at greater depth.

The Central Churia Thrust (C.C.T.) was named in the Arung Khola area by TOKUOKA *et al.* (1986), where the Al Member in the North Belt is thrust onto the Deorali Formation in the South Belt, although the thrust plane is not exposed there. As a geomorphological feature the C.C.T. can be traced laterally for the long distances, indicating its active nature. It is one of the most important thrust systems in the Siwalik Belt of the Frontal Himalayas (Sub-Himalayas). In the present study area the C.C.T. trend WNW-ESE. An excellent exposure of the thrust plane can be observed along the Parewa Pahar Khola (App. Fig. 8; Plate IV, Fig. 2), which was reported by TOKUOKA *et al.* (1988). The Deorali Formation, consisting of conglomerates with 5 to 50 cm thick beds, has been thrust by the Al Member with alternating beds of sandstone and mudstone. The latter has been crushed extensively within about 200 m of the C.C.T. TOKUOKA *et al.* (1988) reported the existence of basaltic fragments in fault gauge and these were believed by them to have been squeezed out from deeper levels along the thrust plane. However, this theory is now rejected as it has become apparent that some in the conglomerates of the Deorali Formation. The C.C.T. is also observed in the area near the junction of the Tinau Khola and the Jhumsa Khola, where the Al Member of the hanging wall is separated from Bm Member of the footwall by a high angle fault (App. Fig. 9).

The Frontal Churia Thrust (F.C.T.) was named in the Arung Khola area by TOKUOKA *et al.* (1986). It can be traced throughout the surveyed area as a geomorphological feature. As shown in the geologic map (App. Fig. 1) an exposure of the F.C.T. can be observed at the Kharehe Khola where the disturbed alternations of the Am Member has been thrust onto the alluvial gravel deposits of the Gangetic plain (Plate IV, Fig. 3).

Several Sedimentologic Descriptions

1. SEDIMENTARY SEQUENCES

The Churia Group attains a total thickness of up to 6,000 m and the entire succession is illustrated in the columnar sections in Fig. 3. The Churia Group consists of a coarsening-upward sequence as a whole and is composed of numerous sequences of fluvial origin. The Al and Am Members are mostly composed of alternating beds of quartzose, and partly calcareous, fine-grained sandstone and variegated mudstone. Sandstone beds are generally 0.5 to 3 m thick and show ripple-cross laminations. Thick-bedded sandstones of 3 to 5 m, with planar and trough cross laminations, are sporadically intercalated in the Al and Am Members. The Au Member is lithologically similar to the underlying members, however, sandstone beds become thicker upwards. Its upper sequences are dominated by thick-bedded (2 to 5 m, sometimes to 10 m thick) sandstones. These sandstones are of *pepper-and-salt* type. A typical cross-laminated sequence is shown in Fig. 6. The Bl and Bm Members are characterized by dominant *pepper-and-salt* sandstones. These sandstones are medium- to very coarse-grained, partly pebbly, and beds are several meters to 20 m thick. Trough and planar cross laminations are well developed, and channel and scouring structures with rip-up clasts are often found (Plate III, Fig. 2). Mudstones are mostly bluish gray in color, and occasionally reddish brown. The Bu Member is lithologically similar to the Bm Member but is intercalated with many pebbly sandstone beds. The Chitwan (C)

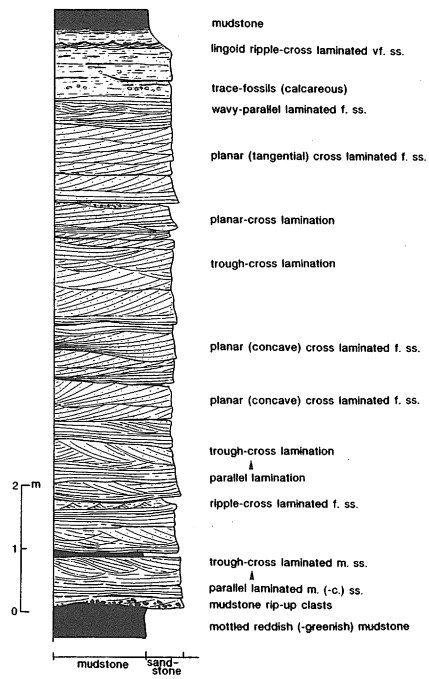


Fig. 6. A typical sedimentary sequence observed in the Au Member, 80 m upstream from point 258, Tinau Khola. (Prepared by TANAKA and HISATOMI).

Formation is composed mostly of clast-supported, pebble to cobble conglomerates, the conglomerate beds between several meters to 10 m thick. Trough-cross laminations and parallel lainations are well developed in them. Mudstones are bluish gray to dark gray in color. A typical sequence is shown in Fig. 7. The Deorali (D) Formation is

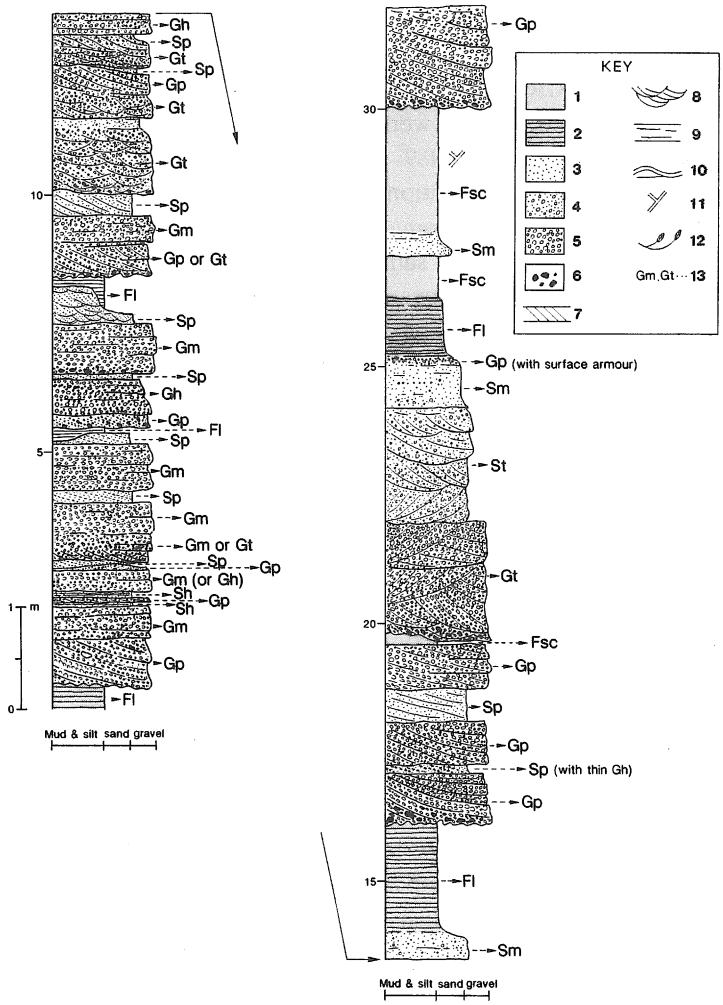


Fig. 7. A typical sedimentary sequence observed in the Chitwan Formation at the 53 Nala, lowersteam of the Binai Khola. The point is located east from the surveyed area and was reported by TOKUOKA *et al.* (1986). 1: mudstone and siltstone, 2: siltstone or very fine-grained sandstone with horizontal lamination, 3: sandstone, 4: pebbly sandstone, 5: conglomerate, 6: mudstone rip-up clasts, 7: planar cross-lamination, 8: trough cross-lamination, 9: horizontal lamination, 10: undulatory bedding, 11: bioturbation, 12: plant fossils, 13: letter code devised by MIALL (1978) for facies nomenclature. (Prepared by TANAKA and HISATOMI).

made up of matrix-supported, cobble to boulder conglomerates and alternating beds of coarse to very coarse sandstones and pebble to cobble conglomerates. The former are considered to be debris-flow deposits and the latter to be stream-flow deposits. These sedimentary sequences indicate a complete development of fluvial fan systems from 15 Ma to the Pleistocene in the Frontal Himalayas which reflect the uplift of the Lesser and Higher Himalayas.

2. SANDSTONE PETROGRAPHY

More than two hundred samples were obtained from sandstones thicker than one meter during the survey of 1988 and 1989. The sampling points are shown in APP Figs. 3 to 10. The major mineral composition of seventy-five samples was analyzed by K. HISATOMI. Fifty samples from the Arung Khola Formation, twenty-four samples from the Binal Khola Formation, and one sample from a gravel in the Deorali Formation were studied. Semiconsolidated Chitwan and Deorali sandstones were not checked. The results are shown in Fig. 8 and Table 1.

Almost all sandstones of the Churia Group are lithic or quartzose arenites. Clay matrix is very rare and calcite cement is rich in many samples. Sandstones are divisible into three groups. Group 1 (Al and Am Members) is characterized by the dominance of quartz and the scarcity of feldspar, and Group 3 (Binai Khola Formation) is characterized by the abundance of rock-fragments and feldspar. Group 2 (Au Member) has an intermediate nature between Groups 1 and 3. Sandstones of Group 1 are dominated by quartz (52 to 90% of the total grains). Among quartz grains, polycrystalline quartz occupies 10 to 20% of the total. Feldspars range between 1.5 to 8% and are mostly K-feldspar. Rock-fragments comprise less than 28%, and mica, especially biotite, is very rare.

Sandstones of Group 2 in the North Belt are characterized by dominant rock-fragments, and some samples are rich in feldspar. On the other hand, in the South Belt, they are relatively poor in rock-fragments and are similar in composition to that of Group 1.

Sandstones of Group 3 are characterized by predominant rock-fragments and micas (25 to 53%). Rock-fragments are composed mainly of gneissose, schistose and granitic rocks. Among them, quartz-mica schist is predominant. Feldspars are common (up to 20%), and are mostly K-feldspars. The content of the heavy minerals (mainly garnet, and subordinately kyanite, staurolite and tourmaline) is much higher in Group 3 (up to 2.4%) than in Groups 1 and 2 (Table 1).

As shown in Fig. 8 there is no essential difference between samples from the North and South Belts, except the following two minor differences: (1) In samples from the Au and Bl Members, samples from the North Belt are richer in rock-fragments and poorer in quartz than those from the South Belt. (2) Some samples from the Au Member in the North Belt are rich in Feldspars, and they are nearly similar to Group 3 sandstones.

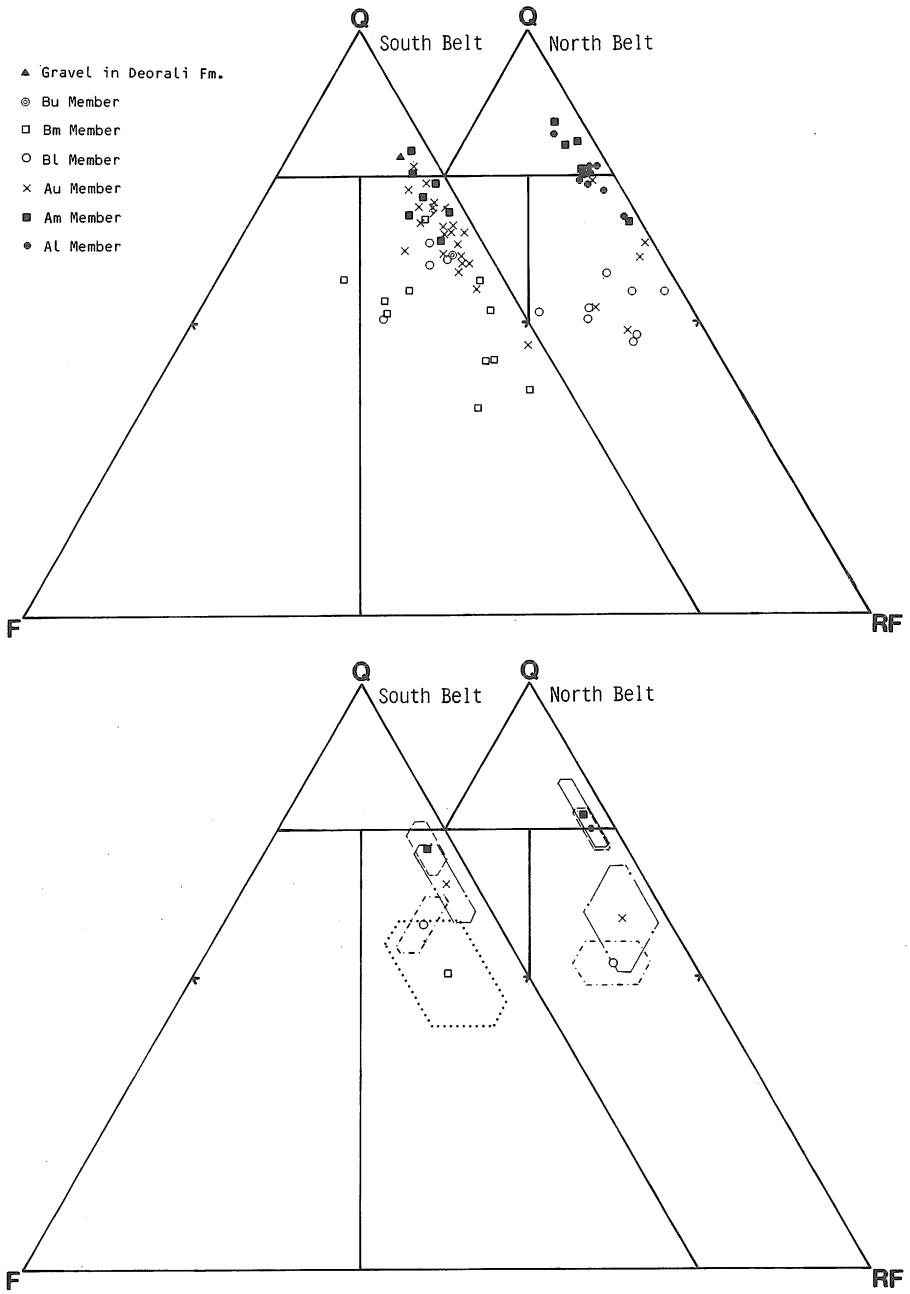


Fig. 8. *upper*: Q (quartz)-F (feldspars)-RF (rock-fragments) diagram of sandstones. *lower*: The average mineral composition and the area of one standard deviation of each member.

Table 1. Compositional properties of sandstones of the Churia Group. The numerals below the name of each member indicates the number of samples.

		MQ	PQ	TQ	PL	KF	TF	RF	MC	HM	OT
North Belt	Bl (8)	35.43	11.91	47.34	1.88	8.8.	10.70	32.61	6.02	0.54	3.96
	Au (5)	41.35	12.61	53.96	0.41	5.36	5.77	29.92	4.96	0.13	5.25
	Am (5)	58.04	14.11	72.15	0.70	2.32	3.02	17.49	0.83	0.23	6.30
	Al (9)	52.91	18.74	71.65	0.57	2.87	3.43	20.32	1.11	0.31	3.43
	Bu (1)	40.64	17.58	58.22	0.00	5.25	5.25	31.51	2.28	0.00	5.79
	Bm (11)	36.76	7.49	45.13	1.71	8.87	10.59	33.57	5.94	0.66	4.12
South Belt	Bl (4)	38.36	10.97	49.33	1.57	8.95	10.53	30.70	4.93	0.72	4.17
	Au (24)	48.97	12.39	61.32	0.65	3.79	4.42	27.56	1.29	0.26	5.09
	Am (7)	51.01	15.67	66.63	0.71	3.36	4.07	22.26	0.76	0.23	6.03

MQ: monocrystalline quartz, PQ: polycrystalline quartz, TQ: total quartz, PL: plagioclase, KF: K-feldspar, TF: total feldspar, RF: rock-fragments, MC: micas, HM: heavy minerals (excluding opaque minerals), OT: others.

The significant stratigraphic changes in the mineral composition of sandstones in the reported area can be summarized as follows: (1) The content of rock-fragments increases upward from the Au Member to the Bm Member. (2) The content of feldspars and that of heavy minerals (especially those of garnet and kayanite) suddenly increases around the boundary between the Arung Khola and the Binai Khola Formations. These features are basically similar to those reported in the Arung Khola-Binai Khola area by TOKUOKA *et al.* (1986) and HISATOMI (1990).

3. PALEOCURRENT ANALYSIS

Paleocurrent data were obtained in the Arung Khola and Binai Khola Formations. These include sole-markings, cross-bedding and ripple-marks and clasts-fabrics of conglomerates (Plate V, Figs. 1 and 4). All data are shown in the route-maps of App. Figs. 3 to 10. The data are also shown in Fig. 9. The Arung Khola Formation is characterized by paleocurrents which flowed from the NE or E, and the B Formation is characterized by two dominant paleocurrents directions, one from the NE or E and the other from the NNW. A paleo-river system flowing from the ENE to WSW can be reasonably assumed from these data. TOKUOKA *et al.* (1988) reported a similar river system in the same formations in the adjoining eastern area where proximal facies are

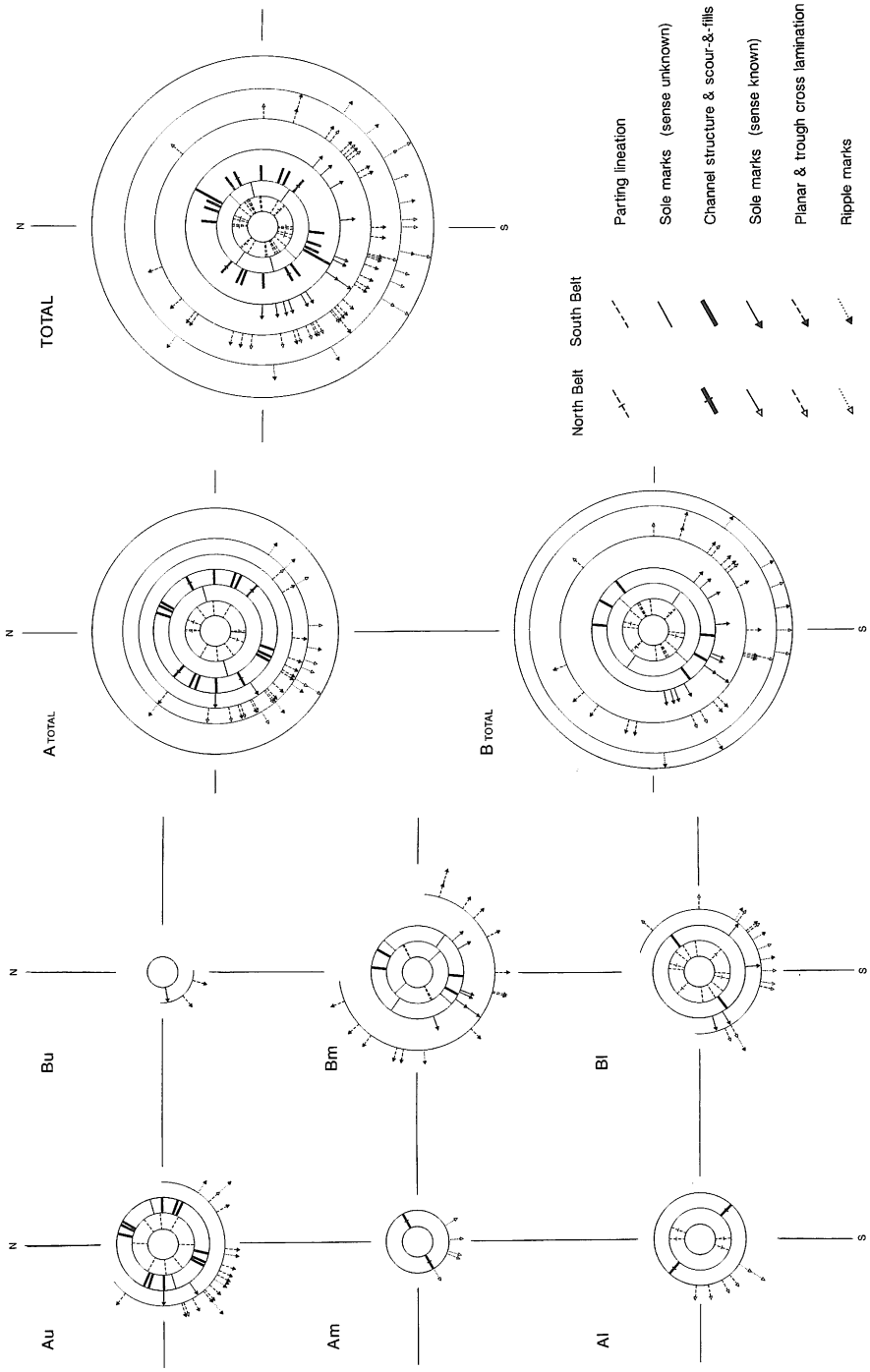


Fig. 9. Current-rose diagrams.

known to be much more developed than the present (western) area. The present area is considered to be a downstream part of the former area.

The above-mentioned sedimentologic analysis suggest the existence of the following paleostream systems, which will be described and discussed in greater detail in a separate paper. A typical meandering stream system was developed during the deposition of the Arung Khola and Binai Khola Formations, which was succeeded during the deposition of the Chitwan Formation by a braided stream system developed on the outer part of an alluvial-fan. Finally during the deposition of the Deorali Formation, the alluvial fan system had prograded southward and debris-flow and stream-flow materials were deposited on the mid-fan area. These stream systems are believed to have been parts of the ancestral Kali-Gandaki River.

Summary and Conclusions

1. Full geologic descriptions of the surveyed area are given in the present paper, along with 10 appendix-figures including a geologic map, columnar sections along the main routes, and each route-map.
2. The Churia Group reported in the previous papers (TOKUOKA *et al.*, 1986 and 1988) can be traced stratigraphically and structurally to the present area. The group has a total thickness of 4,200 to 6,000 m and is comprised of a coasening-upward sequence as a whole. It is bounded by the Main Boundary Thrust in the north and by the Frontal Churia Thrust in the south, and is divided into the North and South Belts separated by the Central Churia Thrust.
3. The horizon containing *Sivapithecus* (*Ramapithecus*) *punjabicus* reported by MUNTHE *et al.* (1983) belongs to the top of the upper Member of the Arung Khola Formation (Au Member). The magnetic polarity zone of Chron 9 was suspected by MUNTHE *et al.* (1983) for this fossil horizon. This is supported by the present study as Chron 9 has been located in the Au Member in the Arung Khola area by TOKUOKA *et al.* (1986).
4. Paleocurrent analysis and sandstone petrography indicate that terrigenous materials have been transported southwards from the Himalayas, probably by the ancestral Kali-Gandaki River.

References

HISATOMI, K., 1990. The sandstone petrography of the Churia (Siwalik) Group in the Arung Khola-Binai Khola area, West Central Nepal. *Bull. Fac. Edu. Wakayama Univ. Nat. Sci.*, **39**, 5–29.

JOHNSON, M. M. K., OPDYKE, N. D., JOHNSON, G. D., LINDSAY, E. H. and TAHIRKHELI, R. A. Kl. K, 1982. Magentic polarity stratigraphy and ages of Siwalik Group rocks of the Potwar Pakistan. *Palaeogeogr. Palaeocli. Palaeoecol.*, **37**, 17–42.

MIALL, A. D., 1978. Lithofacias types and vertical profile models in braided river deposits: a summary. *in* A. D. MIALL, ed., *Fluvial sedimentology,* Can. Soc. Petrol. Geol. Mem. **5**, 597–604.

MUNTHE, J., DONGOL, B., HUTCHISON, J. H., KEAN, W. F., MUNTHE, K. and WEST, R. M., 1983. New fossil discoveries from the Miocene of Nepal include a hominoid. *Nature,* **303**, 331–333.

OPDYKE, N. D., JOHNSON, G. D., LINDSAY, E. H. and TAHIRKHELI, R. A. K., 1982. Paleomagnetism of the Middle Siwalik formations of northern Pakistan and rotation of the Salt Range Decollement. *Paleogeogr. Palaeocli. Palaeoecol.,* **37**, 1–15.

TAUXE, L. and OPDYKE, N. D., 1982. A time framework based on magnetostratigraphy for the Siwalik sediments of the Khaur area, northern Pakistan. *Palaeogeogr. Palaeocli. Palaeoecol.,* **37**, 43–61.

TOKUOKA, T., TAKAYASU, K., YOSHIDA, M. and HISATOMI, K., 1986. The Churia (Siwalik) Group of the Arung Khola Area, West Central Nepal. *Mem. Fac. Sci., Shimane Univ.,* **20**, 135–210.

TOKUOKA, T., TAKEDA, S., YOSHIDA, M. and UPRETI, B. N., 1988. The Churia (Siwalik) Group in the western part of the Arung Khola area, west Central Nepal. *Mem. Fac. Sci. Shimane Univ.,* **22**, 131–140.

Appendices (*in pocket, back of the volume*)

Fig. 1. Geologic map of the Churia Group in the Tinau Khola-Binai Khola area, West Central Nepal

Fig. 2. Columnar sections of the Churia Group in the Tinau Khola-Binai Khola area, West Central Nepal

Figs. 3 to 10. Route-maps of the Churia Group in the Tinau Khola-Binai Khola area, West Central Nepal

Explanation of Plates

Plate I

Fig. 1. A distal view of the Arung Khola Formation at Jhumsa Khola in the North Belt.
Fig. 2. Thick-bedded alternations of sandstone and mudstone in the Upper Member of the Arung Khola Formation in the South Belt at Tinau Khola.
Fig. 3. Alternating beds of calcareous sandstone and mudstone in the Upper Member of the Arung Khola Formation in the South Belt along Tinau Khola.
Fig. 4. A close-up view of Fig. 3. The horizon of fossil hominoid (*Sivapithecus punjabicus* by MUNTHE *et al.*, 1983) from the Upper Member of the Arung Khola Formation at Tinau Khola.

Plate II

Fig. 1. Thick-bedded alternations of sandstone and mudstone in the Binai Khola Formation in the South Belt at Jhumsa Khola.
Fig. 2. A close-up view of pebble-bearing sandstone in the Binai Khola Formation at Jhusma Khola.
Fig. 3. Mudstone dominated alternations of the Binai Khola Formation at Jhumsa Khola.
Fig. 4. Boulder-bearing conglomerate (debris flow deposit) of the Deorali Formation in the South Belt at Bhalu Khola.

Plate III

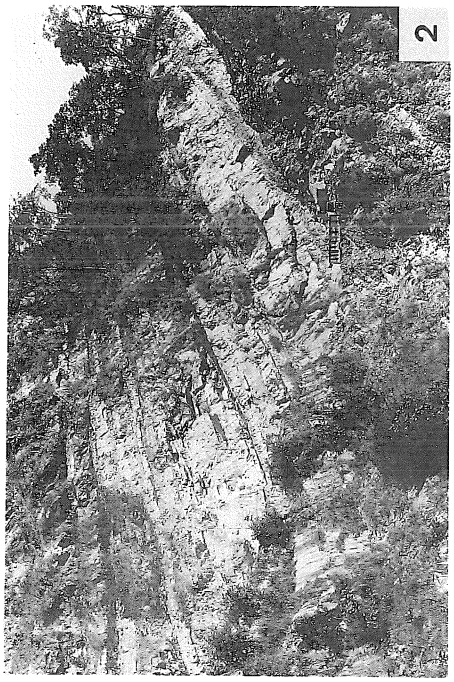
Fig. 1. Ripple-marks on the top of a sandstone bed of the Arung Khola Formation in the South Belt at Tinau Khola.
Fig. 2. A close-up view of pseudo-conglomerate in the Binai Khola Formation in the South Belt at Jhumsa Khola.
Fig. 3. Clastic (sandstone) dykes in the Binai Khola Formation in the South Belt along the Jhumsa Khola.
Fig. 4. Flute marks on the bottom of a sandstone bed in the Arung Khola Formation in the South Belt at Tinau Khola.

Plate IV

Fig. 1. Main Boundary Thrust (M.B.T.) along a tributary of the Tinau Khola, south of Kerabari.
Fig. 2. Central Churia Thrust (C.C.T.) along the Balu Khola, a tributary of Binai Khola.
Fig. 3. Frontal Churia Thrust (F.C.T.) along the Karehe Khola.

Plate V

Fig. 1. A folded structure of alternating beds of sandstone and mudstone in the Upper Member of the Arung Khola Formation in the South Belt at Tinau Khola.
Fig. 2. A synclinal fold in the Binai Khola Formation in the South Belt along the upper Jhumsa Khola.
Fig. 3. Trace fossils in the Upper Member of the Arung Khola Formation in the South Belt at Tinau Khola.
Fig. 4. A fossil bone preserved in conglomeratic sandstone of the Binai Khola Formation in the South Belt at Jhumsa Khola.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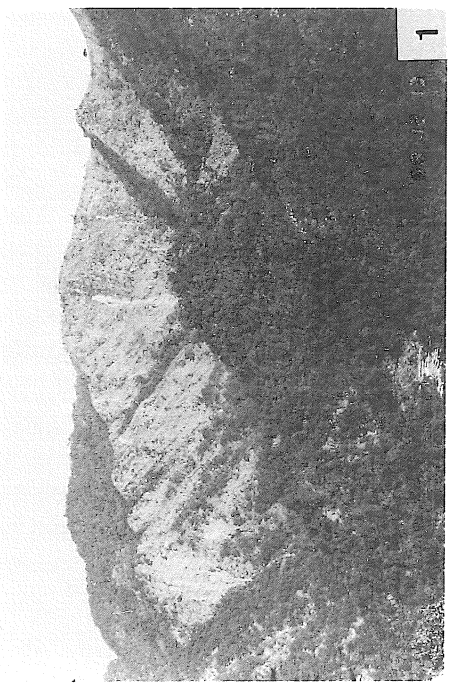
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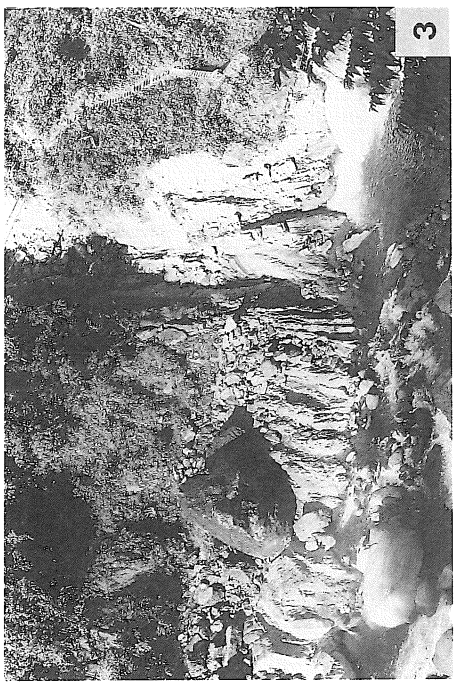
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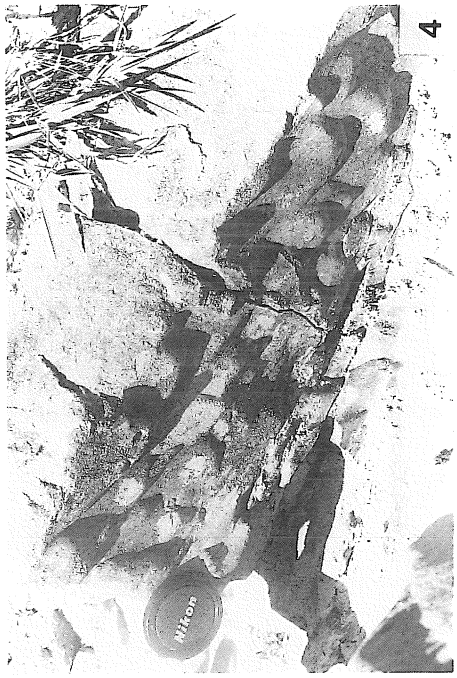

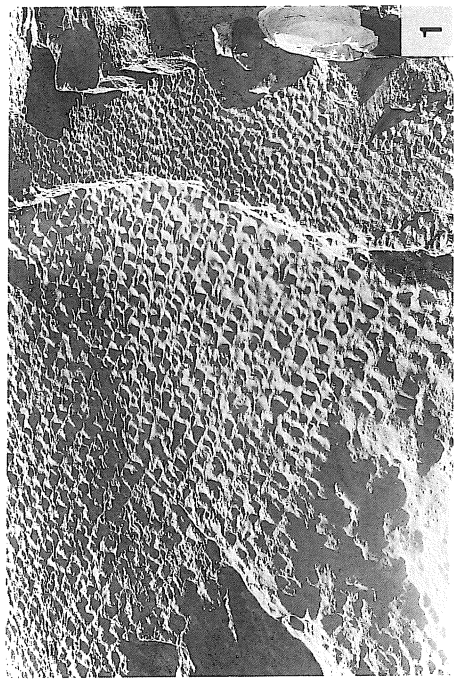

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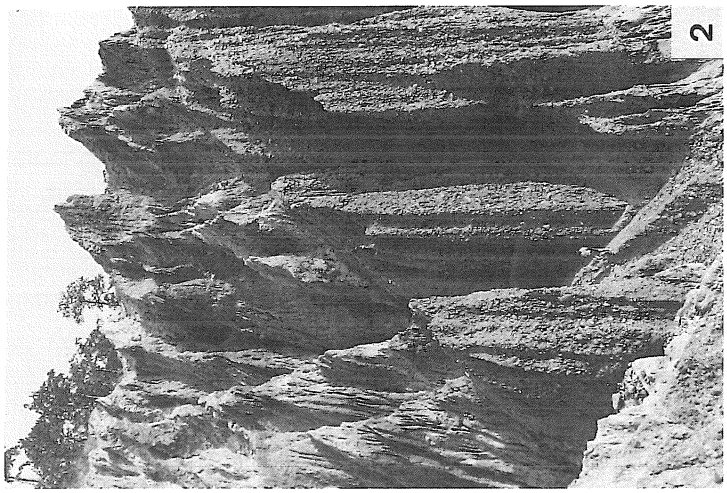
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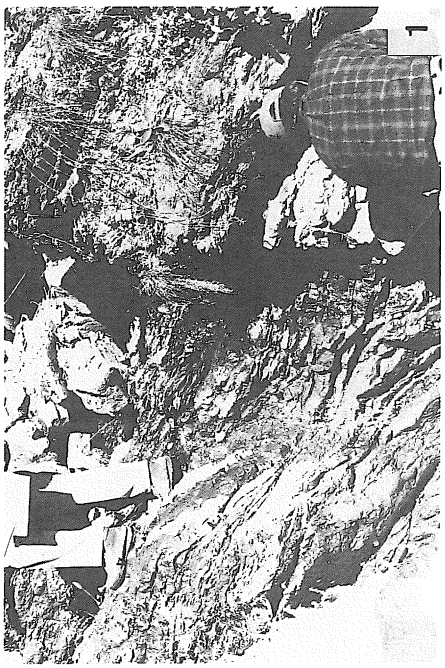
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Mem. Fac. Sci., Shimane Univ., vol. 24, 1990

Stratigraphy and Geologic Structures of the Churia (Siwalik) Group in the Tinau Khola-Binai Khola Area, West Central Nepal

By

T. Tokuoka, K. Takayasu, K. Hisatomi, H. Yamasaki
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and S. M. Ray

APPENDICES (FIGURES 1 to 10)

Fig. 1. Geologic map of the Churia Group in the Tinau Khola-Binai Khola area, West Central Nepal

Fig. 2. Columnar sections of the Churia Group in the Tinau Khola-Binai Khola area, West Central Nepal

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