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PRELIMINARY REPORT ON GEOLOGIC FEATURES OF SHEY-PHOKSUMDO NATIONAL PARK, DOLPA, NEPAL

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INTRODUCTION

This report briefly describes both the geologic setting of Shey-Phoksumdo National Park in the Dolpa region of Nepal and several outstanding geologic features in the southern part of the Park. These geologic features are readily visible and understandable to Park visitors; thus this information should enhance the visitors' appreciation of the Park.

Shey-Phoksumdo National Park covers about 3,555 square kilometers in the western high mountain region of the Kingdom of Nepal (Fig. 1). Elevations in the Park range from about 2,200 meters at its lowest point in the Suli Gad valley to 6,883 meters at the summit of Kanjiroba South peak. The Park includes the Kanjiroba, Kagmara, Jagdula and Patrasi mountain ranges as well as world-renowned Phoksumdo Tal (also known as Ringmo Lake) and Shey monastery or gomba. Figure 2 shows the places referred to in this report.

This report consists of four sections, including this first introduction section.The second section discusses the regional geologic setting of Nepal in general and of the Park in particular. The third section briefly describes several geologic features that are well displayed in the southern part of the Park, which is the part with currently unrestricted access. The fourth section is a selected bibliography listing several reports of interest to readers who wish more information on the geology of the Himalayas, of Nepal, and of Dolpa.

REGIONAL GEOLOGIC SETTING

The geologic features of Shey-Phoksumdo National Park result from the continental-scale plate-tectonic collision of the Indian subcontinent with the Eurasian continent.These two major plates of the earth's crust were separated up until about 40 to 50 million years ago; at that time the northward moving Indian plate reached the relatively stationary Asian plate. Since then the Indian plate has continued to drive into and perhaps under the Eurasian, causing large-scale crustal uplift and deformation. The Tibetan plateau, the Greater Himalaya mountains, and the two sharp boundaries between the Gangetic plain and and the Himalayan foothills and between those foothills and the Lesser Himalayas are the major products of the processes operating in this continuing collision. At the present time, the ongoing crustal uplift is estimated to increase the height of the Greater Himalayas by as much as one centimeter per year. Figure 3 illustrates this evolution.

Three major geologic faults, or cracks in the earth's crust, define the tectonic collision zone in Nepal and adjacent countries. The northernmost break is the "Indus-Tsangpo line"; it follows those rivers on the Tibetan plateau and is the boundary between the Eurasian and the Indian plates. (It is not shown on figure 1, but is only about 30 to 50 kilometers north of the northern edge of the map.) The southernmost break is the "main boundary thrust" (MBT on Fig. 1); it is at the northern limit of the Gangetic plain and adjacent foothills and is where the Indian plate is now being overridden by the Himalayas. The main boundary thrust is one of the earthquake-generating zones in the region. Between these two faults is the "main central thrust" (MCT on Fig. 1); the surface trace of this fault extends the length of Nepal and beyond to both the east and west. It separates an upper sequence of highly metamorphosed sedimentary rocks (the "central crystalline zone" and "lesser Himalayan crystallines" of figure 1) from an underlying sequence of slightly metamorphosed and unmetamorphosed sedimentary rocks (the "lesser Himalayan sediments" of figure 1). The main boundary thrust is the major earthquake-generating zone in the region.

Deformation and metamorphism of the Indian plate rocks have been most intense along the main central thrust and in the central crystalline zone. The recrystallization of the original sedimentary rocks is complete in much of the zone; only metamorphic minerals are present and the rocks are dominantly slate, phyllite, schist, and gneiss. The metamorphism and deformation have resulted in well developed layering and mineral orientations, which are parallel and are inclined, or dip, generally to the north. This strong and uniform inclination contrasts with the orientation of the layering below and above the zone, where much more variation in the dip of the layering and bedding is present. Thus, as one approaches the main central thrust and the central crystalline zone from either the north or the south,.one sees a gradual change in both the mineralogy of the rocks and in the attitude of the layering.

Some sections of the central crystalline zone contain faults that dip northward parallel to the layering in the rocks. In such places, distinctly different rock units are now adjacent. In most places, however, the stresses imposed within the colliding plates have been absorbed in plastic-like, ductile, deformation of the metamorphic rocks that is concentrated in ductile-shear zones.

In more detail, the geology of most of Shey-Phoksumdo National Park is quite well known as a result of the field investigations by Fuchs (1967, 1974, 1977) and by Fuchs and Frank (1970). Some of the information in these reports was used by Stoecklin (1980) and HMG (His Majesty's Govrnment of the Kingdom of Nepal) Survey Department (1985) in the preparation of the source material for figures 1 and 4 of this report. At the present time there is no geologic map of the Park; until one is compiled there will continue to be minor discrepancies among the available maps.

Most of the Park is underlain by unmetamorphosed sedimentary rocks that were laid down along the northern margin of India before it collided with the southern margin of Eurasia. These rocks are referred to as the Tethyan sedimentary rock sequence (Fig. 4); they belong to the Tibetan sedimentary zone (Fig. 1). These sedimentary rocks are intruded along the Nepal-Tibet border by granitic rocks that are about 20 to 25 million years old (Fig. 3). In the southernmost part of the Park, between Phoksumdo Tal and the southern Park boundary, the sedimentary rocks have been thickened and metamorphosed in the central crystalline zone with the intensity of deformation and metamorphism increasing to the south, towards the main central thrust.

The differences between the geology of the northern and southern parts of the Park have a strong influence on the type of scenery and the outcrops encountered along the trails. Visitors to the part of the Park north of Phoksumdo Tal will see high peaks, uplands, and broad valleys formed in the folded and locally faulted limestone, shale, siltstone, and sandstone of the Tethyan (Tibetan) sequence. These rocks in general dip towards the center of a regionally extensive downfold known as the Dolpo syncline (Fuchs, 1977). Figure 5 summarizes this Cambrian(?) through Jurassic age sedimentary section. Figure 6 illustrates the style and scale of folding that is present. Visitors in the eastern part of the park on the route to Tarap will be in rocks like those north of Phoksumdo Tal.

GEOLOGIC FEATURES IN THE SOUTH-CENTRAL PART OF THE PARK

Visitors to the part of the Park south of Phoksumdo Tal will see steep-sided valleys cut in both the rocks that are transitional from the Tethyan sequence to the metamorphic rocks of the central crystalline zone and the high-grade metamorphic rocks of that zone as well. Visitors to the western part near Jagdula Khola will be in high-grade metamorphic rocks.

At the present time, most visitors traverse the southern part of the Park. They arrive from the west by way of Kagmara La and Dorjam Khola, from the south up the Suli Gad, or from the east over the passes from Tarap. Almost all visitors go to Phoksumdo Tal. The following are descriptions of geologic features from this general southern area; they are well displayed on and along the trail from Dunai up the Suli Gad to Sumdawa and on up to Phoksumdo Tal (Fig. 7).

Suli Gad Valley

The valley of the Suli Gad trends north-south and is narrow, straight, very steep sided, and a maximum of about 3,600 meters deep. The river drops steeply for about 1,900 meters over the map distance of about 7.5 kilometers between the Park headquarters at Sumdawa and the confluence with the Bheri River a few kilometers west of Dunai. The valley cuts at a right angle across the strike of a great thickness of metamorphic rocks that are hard and resistant to erosion. The valley does not seem to follow a fault or other zone of weakness in the rocks. From these relations it is inferred that the course of the Suli Gad was established several tens of millions of years ago before the major uplift of this part of the Himalayas and that it has maintained its course by cutting down through the rocks as the Himalayas were being uplifted.

Metamorphic rocks of the main central thrust zone

The trail from Dunai up the east side of the Suli Gad traverses excellent exposures of the high-grade metamorphic rocks of the central crystalline zone. South of the Park entrance station at Anke (C on figure 7), the trail from Rohageon (A on figure 7) crosses interlayered metamorphic units consisting of (a)very light gray biotite-quartz-feldspar gneiss that before metamorphism may have originally been granitic rock, (b) light-gray and dark-gray quartz-rich quartzite, (c) very coarse-grained medium- to light-gray kyanite-biotite-quartz-feldspar schist, (d) garnet-biotite-quartz-feldspar schist, (e) biotite-quartz-feldspar gneiss, and (f) minor amounts of feldspar-rich augen gneiss and migmatite (near B on figure 7). Some of the gneiss units are very uniformly layered. These rocks belong to the amphibolite metamorphic facies and were formed under medium- to high-pressure (5- to 6-kilobars, corresponding to depths of about 20 to 25 kilometers) and medium temperature conditions (500- to 600-degrees Celsius). Studies elsewhere in the Himalayas indicate that this regional metamorphism occurred between 40 and 15 million years ago.

Going north from Anke to Sumdawa the trail first traverses more of these high-grade metamorphic rocks of the central crystalline zone and then traverse the beginning of the gradual transition to the unmetamorphosed rocks of the overlying Tethyan (Tibetan) sequence to the north. For most of this distance the rocks are very uniform fine- to medium-grained, light-gray in color, massive-appearing garnet(?)-biotite-quartz-feldspar gneiss (near D on figure 7). There are some interlayered thin units of marble and quartzite and the entire sequence of rocks is intruded by narrow (20 centimeter) cross-cutting dikes of quartz-feldspar aplite, pegmatite and biotite granite(?). These uniform and massive rocks do not extend all the way to Sumdawa; well layered and lineated biotite-quartz-feldspar schist, kyanite-biotite-quartz-feldspar schist, and gray marble in layers up to 30 centimeters thick are present in increasing amounts northward (near E on figure 7). This change is the first evidence of the transition from the main central thrust metamorphic zone to the Tibetan sequence. The layering in the metamorphic rocks generally dips uniformly to the north at about 50 to 60 degrees between Anke and Sumdawa, but steepens to 70 to 80 degrees about midway to Sumdawa and then flatten locally to 20 to 40 degrees near Sumdawa (F on figure 7). At Sumdawa platy biotite-quartz-feldspar schist and massive semischist are of lower metamorphic grade.

Transition from the metamorphic rocks of the main central thrust zone to the sedimentary rocks of the Tibetan sequence

About one-half kilometer south of Sumdawa (F on figure 7) the massive semischist is of a lower metamorphic grade, probably greenschist facies, indicating formation at pressures of 3- to 5-kilobars pressure and a temperature of 200- to 400-degrees Celsius. At the confluence of the Suli Gad and Dorjam Khola at Sumdawa some original sedimentary bedding is present in the slightly metamorphosed feldspar-rich sandstones that are the dominant rocks. These rocks contain some aligned metamorphic minerals and other structural features indicating their similarity to the higher grade rocks to the south. A short distance further up the Suli Gad original bedding is very obvious and the rocks are mostly feldspar-rich sandstone with some interbedded mudstone and shale (near G on figure 7). The climb up to Phoksumdo Tal is in these rocks; they locally contain some fossil debris and small-scale structures that formed at the time the rocks were deposited. The origin of this sedimentary rock unit is unclear; it does not appear to belong with the well bedded limestones of the Tibetan sequence that are in the nearby high cliffs; neither does it have the composition of the rocks from which the central crystalline zone metamorphic zone rocks to the south must have formed.

The spectacular Phoksumdo waterfall (H on figure 7) occurs where the outlet to the lake passes over some resistant-to-erosion cliffs of rock unit just described. Not far above the waterfall are large masses of broken rock that belong to the series of debris flows or rockslides that are described below.

Debris deposits in the Suli Gad valley south of Sumdawa and at Phoksumdo Lake

Two types of large-volume debris deposits occur along the trail in the areas of the transitional rock unit and the Tethyan (Tibetan) sequence. A thick, well cemented waterlaid debris flow several tens of meters thick consisting of poorly sorted sand- to boulder-size angular and semirounded fragments occurs where the prominent tributary joins the Suli Gad from the east, a few hundred meters south of Sumdawa (F on figure 7). The debris appears to have flowed down the tributary valley after the Suli Gad had down almost to its present position. The flow debris probably dammed the Suli Gad temporarily, but the river has since cut its way down through the debris and has carried much of it away.

The second type of debris deposit occurs at the south end of Phoksumdo Tal, including the vicinity of Ringmo village (I on figure 7). Very large volumes, probably ten's of cubic kilometers, of sandstone occur as fragments of broken rock as much as a few tens of meters long west of the village. Even greater volumes of broken limestone occur at the village, at the lake outlet, and on the hillside east of the village in the area immediately south of Ringmo Gomba. The limestone blocks contain some fossil material and are derived from the Dhaulagiri Limestone unit of Cambrian(?) to Ordovician age that occurs in the high peaks on both sides of the lake. These debris deposits have not been studied in detail, but it appears that three or more separate units are present, each the product of a separate large-scale rockfall, landslide, or debris flow event that carried material for several kilometers downslope from their sources. The source of the material on the hillside south of the gomba can be seen in the cliffs above. The hummocky topography between the base of those cliffs and the valley floor is typical of landslide deposits (near J on figure 7).

Folds and faults in the Tethyan (Tibetan) sequence

Limestones of the Tibetan sequence exposed in the cliffs east of Phoksumdo Tal and on Kanchen Ruwa peak (elevation 6,612 meters) west of the lake exhibit large-scale folds that contrast strongly with the regular north dipping structures present in the central crystalline zone to the south. These folds, and the folds on the north side of Dingla Dhuri peak (elevation 6,375 meters; near K on figure 7), have amplitudes and wavelengths of greater than one kilometer. The folds are part of the large regional fold system adjacent to the Dolpo syncline mentioned above as a prominent feature of the northern part of the Park (Fig. 6). These folds dislay a higher structural level of the same deformation that produced the uniform northerly dips in the central crystalline zone. At the north end of Phoksumdo Tal are Devonian-age limestones that overlie the Dhaulagiri Limestone (Fig. 5).

ACKNOWLEDGEMENTS

This report was improved as a result of helpful technical reviews by D.G. Howell, M.J. Bergin, and M.J. Terman.

Perhaps I should explain the origin of this report. I was in Nepal In October and November, 1990, trekking from Pokhara to Jumla and studying the geology *en route*. While in Shey-Phoksumdo National Park I came in contact with the Park Warden, Nima Wangchu Sherpa, as a result of the interest of our trek leader, the late Hugh Swift. Nima Wangchu was in the process of putting together a management plan for the park and needed some geologic input. He was most interested in the description of features that visitors might be able to see, understand, and relate to the overall park environment. I had spent several days in the part of the park that is open to westerners and I had been observing and taking notes, mainly (but not exclusively) concerning the metamorphic rocks of the central crystalline zone above the main central thrust. I told Nima Wangchu I would help. Interestingly, much of the information I've used comes from studies done in the region by my 1959-1960 classmate at the University of Vienna, Gerhard Fuchs. My studies were funded personally and by the Suli Gad Foundation. I also wish to thank Hugh Swift for his advice and guidance in my contacts with the Park personnel, with officials of the Kingdom of Nepal Remote Sensing Laboratory in Kathmandu, and with other scientists working in the region.

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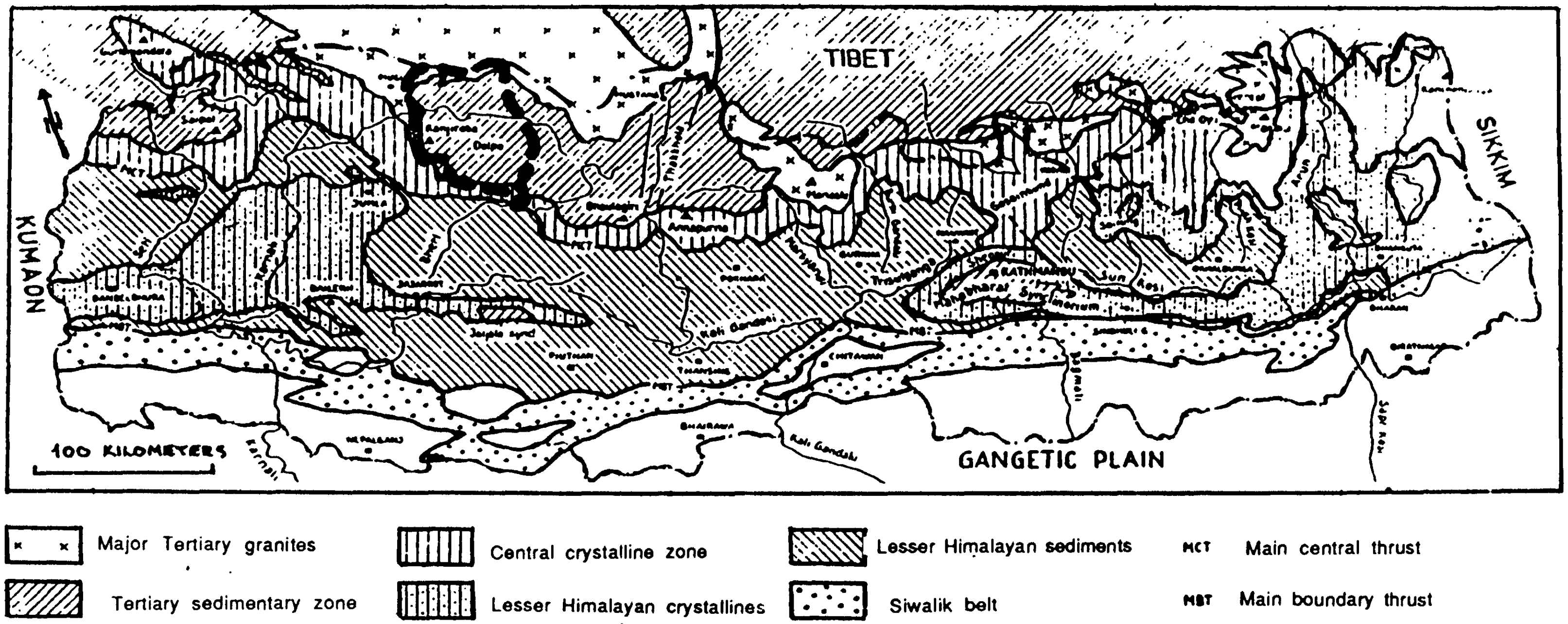

Figure 1. Geological zonation of Nepal Himalaya. After Hagen (1969) with amendments from Bordet (1961), Fuchs and Frank (1970), Hashimoto et al. (1973), Remy (1975) and others. Modified from Stoecklin (1980) by the addition of the approximate boundary of Shey-Phoksumdo National Park, shown as a heavy dashed line.

Figure 2. Map of northern west-central Nepal with names of most places referred to in the text. Modified from Mandala Maps 1:800,000-scale Nepal trekking routes map. Approximate boundary of Shey-Phoksumdo National Park shown as heavy dashed line.

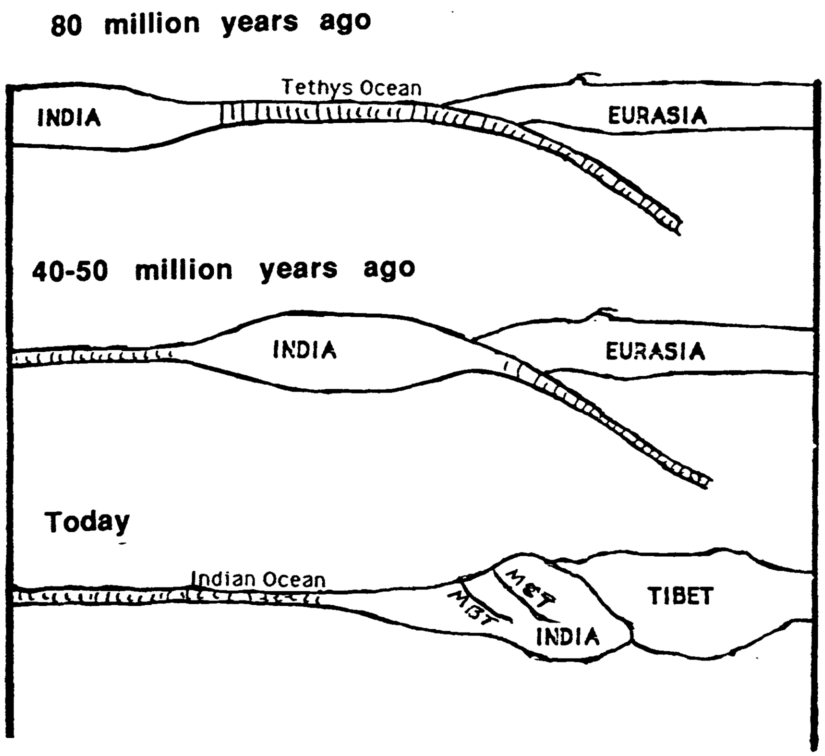

Figure 3. Diagrammatic profiles showing the evolution of the Eurasian-Indian-tectonic-plate-collision events. Modified from Howell (1989). MBT = Main boundary thrust; MCT = Main central thrust.

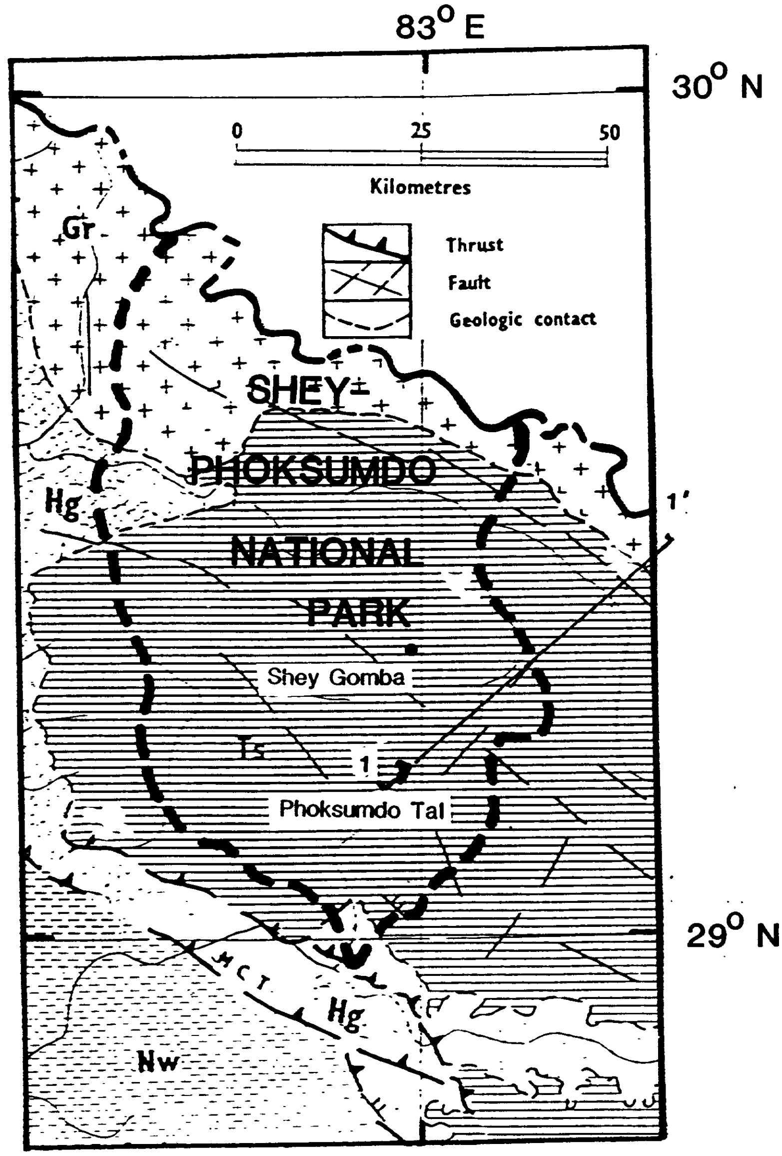

Figure 4. Generalized geologic map of Shey-Phoksumdo National Park. After HMG Survey Department (1985). Symbols are as follows: Nw- Nuwakot Group (Precambrian to Paleozoic).Argillaceous, arenaceous, and calcareous metasedimentary rocks of Lesser Himalayan crystalline zone of figure 1; Hg- Himalayan gneisses (Precambrian and younger(?)) Gneiss, schist, and quartzite of Central crystalline zone of figure 1; Ts- Tethyan sedimentary rocks (Cambrian to Cretaceous) Limestone, shale, and quartz sandstone of Tibetan sedimentary zone of figure 1; Gr- Granite (Tertiary) Granite and related rocks of Major Tertiary granite zone of figure 1; MCT-Main central thrust. Line labeled 1-1' is line of profile shown in figure 6.

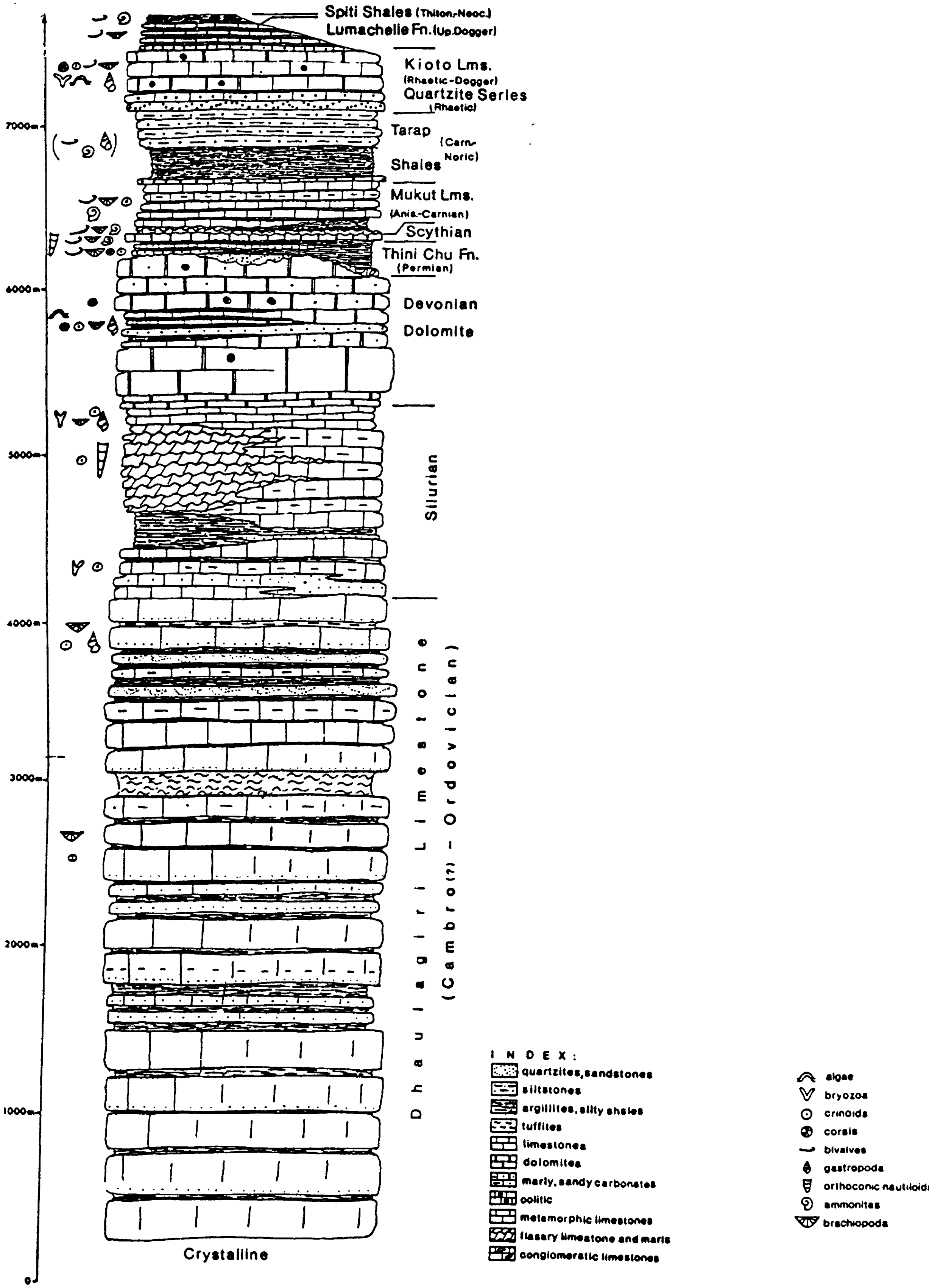

Figure 5. Stratigraphic column of western Dolpo, showing thickness and generalized composition of rock units. From Fuchs (1974). Note scale bar at left.

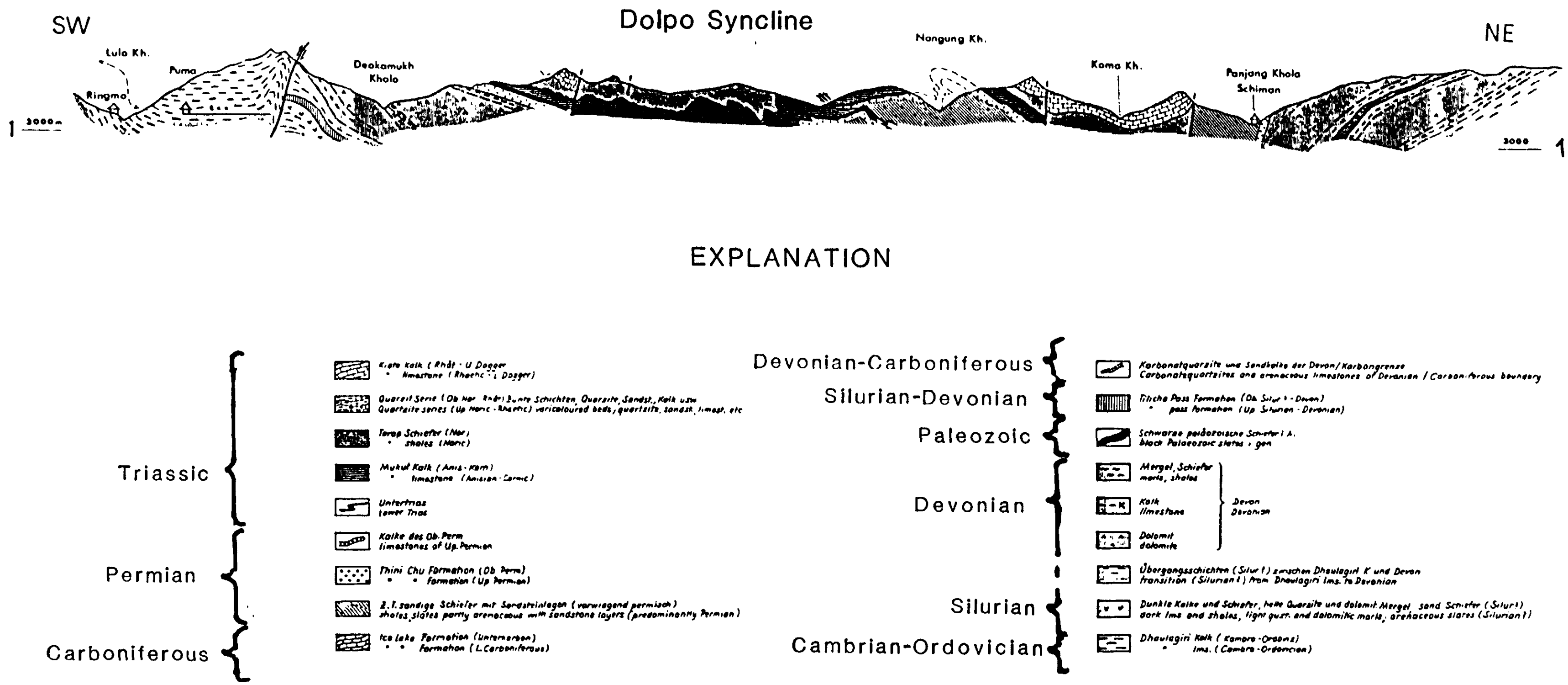

Figure 6. Detailed profile from Phoksumdo Tal (Ringmo) on the southwest to beyond Panjang Khola on the northeast, showing style of folds and rock units. From Fuchs and Frank (1970). Line of profile is shown as 1-1' on figure 4.

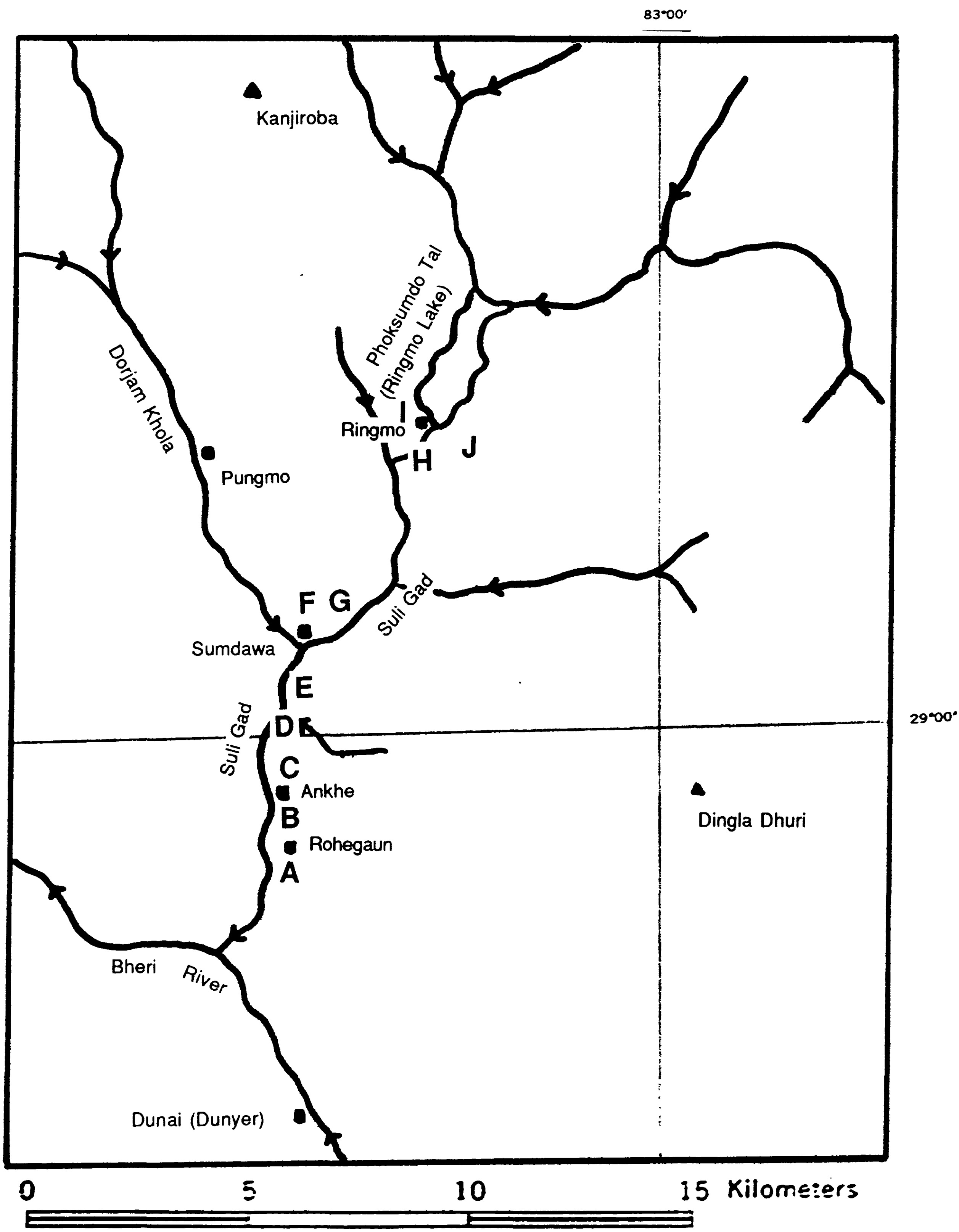

Figure 7. Sketch map of the Suli Gad valley area, showing approximate location of local features A, B, C, etc., discussed in the text. Base map is modified from 1:250,000-scale Mustang and Pokhara AMS sheets.