ENVIRONMENT AND SOCIETY IN THE MANASLU-GANESH REGION OF THE CENTRAL NEPAL HIMALAYA

A Final Report of the

1987 Manaslu-Ganesh Expedition

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Cover Photograph: Mass wasting and mustard fields on hillslopes west of Trisuli Bazar, 1987. Photo by R.A. Marston

This report is dedicated to the memory of Barry W. Prather, our geological colleague in the early Khumbu Himal studies

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1. INTRODUCTION

R.A. Marston, M.M. Miller, J. Heath

The relationship between environment and society is an everyday concern in mountain communities of the Himalaya and the subject of ongoing debate among Himalayan scientists. The broad patterns of geology, climate, vegetation, landforms and soils in the Himalaya are just beginning to be understood at the same time that human modification of the physical environment continues at an accelerating rate and enlarging scale. Whether or not science can keep up with the environmental and socioeconomic impacts of mountain development pressures is one question, but no one will argue against the notion that new practical understanding of specific problems in mountain science should be applied to decision-making regarding resource development whenever possible.

The purpose of the 1987 Manaslu-Ganesh Expedition was to conduct geological, geomorphological, hydrological, and resource management studies in the Manaslu-Ganesh Himal, on the Nepal-Tibet border. Preliminary results of this work were presented in Kathmandu upon returning from the expedition in November, 1987. One set of presentations was made to a group of scientists visiting the International Centre for Integrated Mountain Development (ICIMOD) from eleven different countries. A second set of presentations was made to a multidisciplinary group of scientists at Tribhuvan University assembled by the National Council of Science and Technology. The following topics were covered: global climatic trends as reflected by glaciological variations in the Himalayas and other great mountain ranges of the world; Himalayan hydrological potential and the importance of sediment budget studies as applied to hydropower projects in Nepal; fracture-controlled mass wastage and implications for land management and mountain development; regional structural and metamorphic geology and the economic mineral potential in the Manaslu-Ganesh Himal; and a land use systems analysis with an emphasis on the need for environmental impact statements prior to development in the Nepal Himalaya. This volume represents the culmination of two years of data analysis and writing since the conclusion of the 1987 expedition. Portions of this final report also include findings from the 1984 Langtang Himal Expedition.

The spectacular physical and cultural landscapes of the Nepal Himalaya have attracted a large number of Western scientists, but their findings have not always been couched in terms pertinent to the economic development of Nepal. In fact, the Nepal National Council for Science and Technology has expressed concern that research findings are often not even made available to scientists and government officials in Nepal. Therefore, one of the objectives of this report is to discuss the implications of our findings to the potential for development, that is, progressive change for the better. Four factors affect economic development: people (number, growth, distribution), environment (especially resources and hazards), culture (how society is organized through its economic, political, and religious systems), and history (affects the relative ease of initiating economic change). Some key demographic data help illustrate the disparity in material well being between Nepal and the rest of the world that must be considered when planning for economic development (Table 1.1).

TABLE 1.1. 1987 demographic data for Nepal, south Asia, United States, and the world.

Statistic	Nepal	South Asia	United States	World
Population (millions)	17.8	1,112	244	5,026
Crude Birth Rate	42	36	16	28
Crude Death Rate	17	13	9	10
Natural Increase (annual percent)	2.5	2.3	0.7	1.8
Population Doubling Time (years, at current rate)	28	30	102	40
Population Projected to 2000 (millions)	24.4	1,448	268	6,158
Population Projected to 2020 (millions)	37.4	1,998	297	7,992
Infant Mortality Rate (deaths/1000 live births)	112	110	10.5	81
Total Fertility Rate (average #children born to a woman during her life)	6.1	4.8	1.8	3.6
Percent of Population Under 15/Over 65	41/3	40/4	22/12	33/6
Life Expectancy at Birth (years)	52	54	75	63
Percent Urban Population	7	25	74	43
Population with Access to Safe Drinking Water Supply (Percent in 1983)	15	50	90	?
Per Capita GNP (1985 US$)	160	250	16,400	2,880

Source: Getis, A., Getis, J., and Fellman, J. 1988 (2nd ed.). Introduction to Geography. Wm. C. Brown: Dubuque, IO, app. (reprint of "1987 World Population Data Sheet" of Population Reference Bureau, Inc.).

The 1987 expedition was composed of two doctors, an expedition journalist, and 16 scientists (geologists, geographers, and meteorologists) from six countries: United States, Australia, Nepal, Great Britain, Norway, and Canada. The expedition arrived in Kathmandu on October 7. The first few days were spent making final logistical arrangements, complicated by the simultaneous demonstrations in Lhasa, Tibet, and the intent of the expedition to work in a restricted area near the Nepal-Tibet border. A 40-day period, October 11-November 19, was spent in the field in a traverse of the southern flanks of the Manaslu and Ganesh Himals. The routes taken by the 1984 Langtang Expedition and the 1987 Manaslu-Ganesh Expedition are shown in Figure 1.1. The 1987 expedition began at the trailhead at Gurkha, 100 kilometers northwest of Kathmandu. The group initially travelled west through the town of Chepe to the Marsyandi River. The route then followed the Marsyandi River north through the town of Tarkughat. The group left the river at Philesangu and followed a ridge toward Bara Pokhri into the Manaslu Himal. An elevation of 4700 meters was reached before unseasonally heavy snows stopped progress. The expedition then travelled east through the towns of Tanje, Barpak, Laprak, and Kholabenesi, and across the Buri Gandaki gorge into the Ganesh Himal. The route then continued through Kasigaon, Khading, Tibling, and Linju. The expedition split into two groups for the purpose of conducting extended studies in the upper Manjet Khola and near Laba. The expedition was reunited in Burong and then returned to the roadhead at Trisuli Bazar. The mountains in the area of our research commonly attain heights of 6000 to over 8000 meters. In 40 days approximately 300 kilometers of trail were negotiated without ever seeing another western party in the field. This research area represents some of the least known sectors of Nepal in terms of physical and human geography. A more detailed description of the route is presented in Table 7.1.

ACKNOWLEDGEMENTS

Assisting in the liaison with the Nepal government and providing other help and advice scientifically and logistically were: Dr. Bidhur Upadhyay, Head of the Department of Meteorology, Tribhuvan University; Professor Suresh Chalise, Dean of Science at Tribhuvan University and currently a consultant to ICIMOD; Shailesh Chandra Singh, Executive Director of the National Council of Science and Technology in Nepal; Dr. Allen Bassett, geologist; Dr. David Wilson, Mission Director of U.S. A.I.D. in Nepal; Lew McFarlane, Charge d'Affairs in the American Embassy in Kathmandu; and Major Robyn Marston and Dr. Lute Jerstad of Mountain Travel Nepal.

Support for the expedition was provided by the Foundation for Glacier and Environmental Research, Pacific Science Center, Seattle, Wa.; the University of Idaho via the Glaciological Institute and American-Nepal Education Foundation, and with field course arrangements through the College of Mines; and the Wyoming Water Research Center and College of Arts and Sciences at the University of Wyoming. Some of the basic costs were shared by each expedition member. Survey equipment, glaciological, meteorological and hydrological instruments, maps, remote sensing imagery, etc., were provided by the Nepal Department of Mines and Geology, Tribhuvan University, the University of Idaho, the University of Wyoming, Foundation for Glacier and Environmental Research, and Texas A&M University. Cartography and typing of the report were contributed by Linda Marston and Debbie McFaul, respectively, of the University of Wyoming. The report was printed at the University of Wyoming using funds from the Foundation for Glacier and Environmental Research. Appreciation is accorded to the anonymous reviewers of the text.

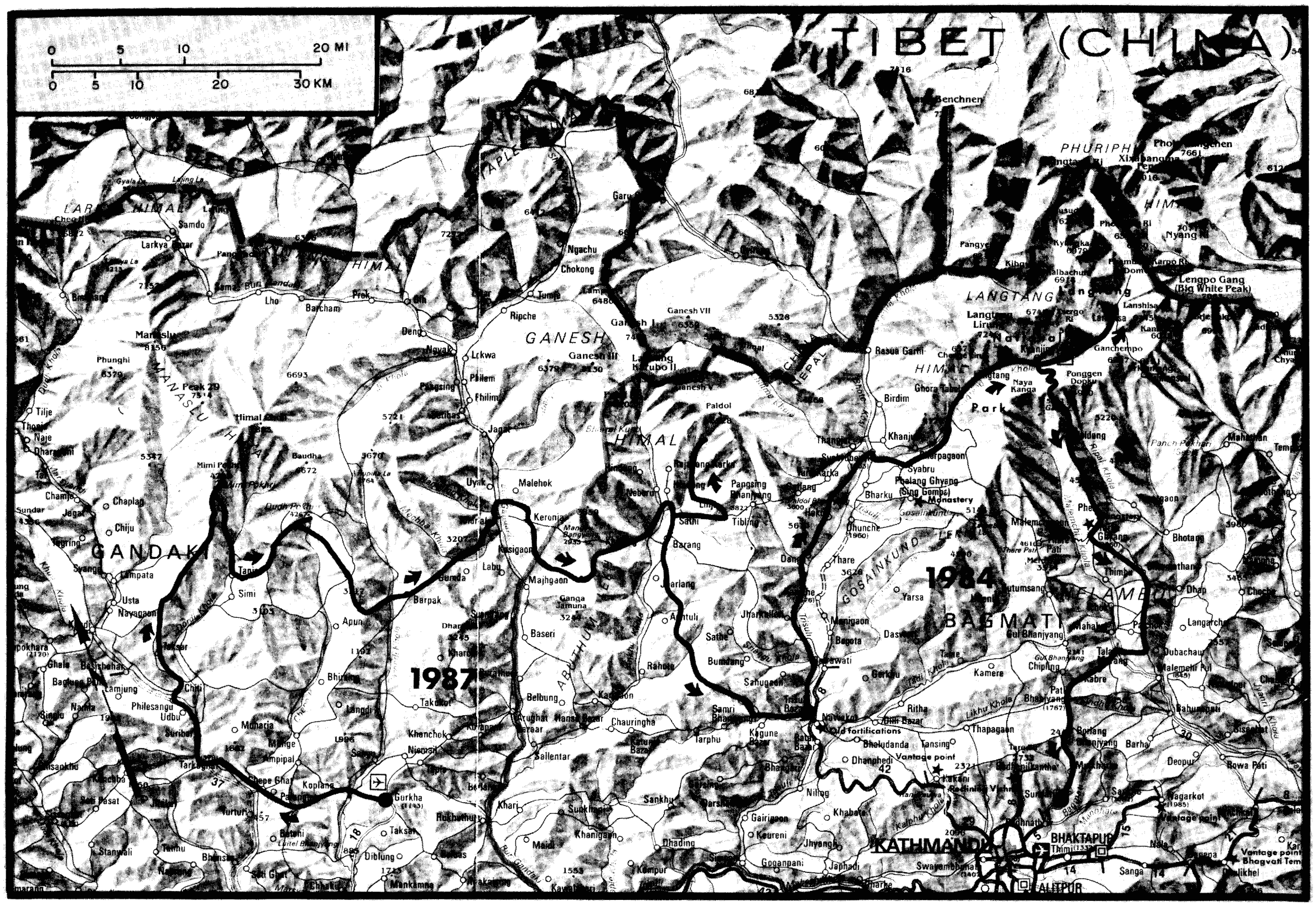

Figure 1.1. Routes taken by the 1987 Manaslu-Ganesh Expedition and the 1984 Langtang-Jugal Expedition.

PROJECT LEADERS

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2. WEATHER BEHAVIOR DURING THE MANASLU-GANESH EXPEDITION

A. H. Thompson and L.P. Devkota

A regular and consistent set of meteorological observations was made during the Manaslu-Ganesh Himal International Geological Expedition of 12 October to 19 November 1987. This chapter describes the observations, together with the conditions and limitations in taking them. Material is also presented on the general trend of meteorological events during the expedition. Finally, a discussion of the significant and severe storm of 17-19 October 1987 is presented. Briefly, except for the three days of the storm and the 20th (following the storm), the events were those of a large-scale fair-weather situation between the ending of the summer monsoon and the beginning of the winter monsoon. On this relatively stagnant large-scale situation were superimposed the much more significant (to members of the expedition) local and diurnal events characteristic of the terrain and time of year. During the period up to the end of October, there were several days with sufficient instability and moisture to result in rain showers (snow at higher elevations) of short duration. These showers were not of sufficient duration or intensity to be considered as specific synoptic-scale storms, though some weak synoptic event obviously increased the instability.

DAILY OBSERVATIONS

The specific meteorological elements observed included only those made by visual means (and often subjectively), with a sling psychrometer, or with a hand-held anemometer. The most severe limitation is probably that the data were obtained while the members of the expedition were mostly moving from one camp to another of the 32 campsites occupied by the observers during the 40 days of expedition.

Observations were made every three hours, beginning each day at 0000 UTC, which is shortly before sunrise in Nepal in October and November. The last observation of the day was made either at 1200 UTC (shortly after sunset) or at 1500 UTC. The late observation was made only if the camp was occupied for more than one night. Late night and early morning observations were not taken as it was felt that uninterrupted sleep was more important. Occasionally, observations were made at intervals differing from three hours.

A sample sheet of the weather log is shown as Table 2.1. The observations were made by an experienced observer using methods and notation as close to official procedure as was reasonable under the circumstances. Temperature as read from the sling psychrometer was noted in both Fahrenheit and Celsius scales. All other units are metric. Visibility was estimated. If the observation site was in a location where terrain limited the distance that one could see, the visibility was often estimated based on the clarity of the air. Thus, many of the cases where visibility was indicated as "UNL" or was not even noted, the value was based on what the observer would expect if there had been no terrain obstruction. Present and past weather and cloud information were determined subjectively. The ten-element "W" code and the ten-element cloud code were used, rather than the more complex "ww" code and the "C_L, C_M, C_H" codes of the World Meteorological Organization. Wind direction was estimated, while speed was determined from a hand-held anemometer. Precipitation amount was estimated. Snow was experienced at the camp above 4000 meters elevation on 29-31 October; the depth of accumulation was less than 2 centimeters. Snow pellets or soft hail was observed while on the trail on a

TABLE 2.1. Sample sheet from meteorological log book (19 October 1987).

Camp No. 7 ("Rain Camp" Date 19 October 1987 Elevation 12,000 feet

TIME (UTC)	0015	0300	0600	0900	1200	1350	1500
DRY BULB (°C.)	2.2	3.9	5.0	5.0	4.0	2.7	
WET BULB (°C.)	2.2	3.6	4.2	4.4	3.8	2.2	
VISIBILITY (m)	1000	1000	600	200	200	UNL	
PRES. WEA.	rain	rain	rain	rain	rain	rain	
PAST WEA.	rain	rain	rain	rain	rain	ptcy	
AMT. CLDS.	8/8	8/8	8/8	8/8	8/8	7/8	
HT. CLDS. (m)	100	150	100	100	100	?	
LOW CLDS.	st	st	st	st	st	st	
MID. CLDS.	ns	ns	ns	ns	ns	ns	
HIGH CLDS.	---	---	---	---	---	---	
CLD. DIR.	SE	E	E	---	SE	---	
WIND DIR.	SE	E	E	SE	SE	---	
WIND SP. (m/s)	6	7	10	8	7	---	
MAX. TEMP. (°C.)	10.6	---	---	---	---	---	
MIN. TEMP. (°C.)	---	---	---	---	---	---	
AMT. PPT. (cm)	3	---	4	---	8	---	
AMT. SNOW (cm)	0	---	0	---	0	---	
RADIATION	0	---	0	---	0	---	
DUR'N SUN	0	---	0	---	0	---	

REMARKS: 0000 = RW AND GUSTY WINDS DURING NIGHT; 0300 = SNOW LEVEL ABOUT 150 METERS ABOVE CAMP; 0600 = SAME AS 0300; ALSO SAME AS 0300 AT 0900, 1200; 1350 = STARS VISIBLE ABOVE WEST HORIZON

NOTE: The difference between UTC and Nepal local time is 5 h 45 m. Thus, 0000 UTC = 0545 Nepal local; 0300 UTC = 0845 Nepal local, etc.

couple of occasions at high elevations. The camp occupied during the storm of 17-19 October was just below the snow line. Duration of sunshine estimates were strongly affected by local terrain. Observation sites were nearly always in the shadow of a mountain at either or both sunrise and sunset. A thermograph, maximum and minimum thermometers, and a recording radiometer were installed if a campsite was to be occupied for more than one night. Because of the difficulties encountered in reaching desired sites, recorded data are available for only a few days.

Altitudes of the campsites are noted in most cases. These were determined either from an altimeter set at standard altitude or from the terrain maps. Neither method can be considered as truly accurate, since the maps lack strict vertical control and no information for adjusting the altimeter reading was available. Further, in nearly all cases it was not possible to determine the exact location of a site on the map. Indicated altitude would be too low (lower than actual altitude) because of the warm tropical air. This error could be as much as 10 percent of the indicated altitude.

DIURNAL AND LOCAL EFFECTS

During most of the days of the expedition, the weather was characterized by fair-weather conditions typical of relatively high atmospheric pressures. The result was that the atmospheric behavior observed during the expedition was dominated by diurnal and local effects. The mountainous terrain played a major role in determining the diurnal and local effects. Just as important was the location (with respect to the terrain) of the campsites and other observation points. One time the site might be on a ridge; several hours or a day later it might be 500 meters lower and half-way down the side wall of a 1000-meter-deep canyon, or perhaps significantly higher. Recording instruments were actuated at only two campsites (Camp 7, the "Rain Camp" and Camp 26, where extensive stream gaging was carried out).

Observation sites nearly always were on a steeply sloping area; the direction of slope might have any orientation, while the actual surface might be anything from bedrock to dense forest. Many of the campsites were on cultivated, harvested artificial terraces. No sites were selected with meteorological exposure in mind. Most sites were fairly high on the slope or very near the ridge line; relatively few were at the bottom of narrow canyons and only a couple near the floor of broad valleys. Thus comparison of observations from day to day is difficult, and there is no point in attempting to determine interdiurnal trends of any element. However, many of the classical diurnal and local meteorological effects described in the literature (Barry 1981, Geiger 1950, Munn 1966, and Oke 1978, among many available references) were readily observed. A few comments are made about observed behavior seen in trends of temperature, clouds and wind.

Temperature

Characteristic classical diurnal changes were quite evident, with maxima in the early afternoon and minima about sunrise. The most rapid change with time usually occurred near sunset when the temperature was decreasing. The time of most rapid decrease and the time of minimum temperature were more closely related to actual sunset and sunrise times, rather than astronomical times; in the mountainous terrain, these times could differ up to several hours because of screening effects of the mountains.

Clouds

While the cloud behavior patterns showed significant variations from day to day, these variations generally fell within the likely range of typical diurnal cloud behavior. Fog and/or stratus during the early morning was common in the lower valleys. As the stratus dissipated, cumulus began to form some 1000 to 2000 meters above the valley floor, the cloud base varying from day to day depending on the actual moisture content and temperature of the air. On most days, the clouds built to the cumulus congestus stage during the afternoon, then began to dissipate an hour or two before sunset. The cumulus were over the valleys and also over or frequently resting on the ridges. The nights usually were clear. There were a few days with cirrus, the result of synoptic disturbances passing some distance away, usually at this time of year to the north. The cumulus growth was suppressed by what appeared to be a stable layer some 4000 to 5000 meters above sea level. (The radiosonde equipment at Kathmandu was inoperative during the period of the expedition, so there is no quantitative verification of this structure of the atmosphere.) On a few days, the air was dry enough that no clouds formed within view of the observation sites. On other days, especially in October, showers of rain (snow or snow pellets at higher altitudes) developed.

What was observed from the various sites again was dependent on the location of the site. The fog and stratus were down valley and below, while the daytime cumulus might also have its base below the observation site. On several days, clouds were on the ridges and the observation site was in the cloud (fog), with even occasional light drizzle or light showers. Some of the higher observation sites were above the cloud tops, and, unless there was a view well down valley, no clouds were observed. On a couple of occasions, snow plumes were observed blowing off the highest peaks.

Winds

The atmospheric motions near the surface were predominantly local and diurnal motions on all days except during the storm of 17-19 October. This means that the winds observed at the various observation sites were essentially part of the typical slope circulations and mountain and valley wind systems characteristic of mountainous terrain when under the influence of weak synoptic-scale horizontal pressure gradients. See, for example, Atkinson (1981), Barry (1981) and Defant (1951).

Because of the locations of most observation sites on the side walls of valleys and canyons and the generally dry, clear meteorological conditions, the slope circulations were by far the most frequently experienced. These consisted of upslope winds during the hours when the slopes were sunlit, and downslope winds at other times, plus the usual short transition time, usually only 10 or 20 minutes, as the direction shifted. On most days, the daytime upvalley and nocturnal downvalley winds were evident in the motions and behavior of the low clouds. On a significant number of the days, the upvalley wind would dominate the upslope wind in the midday hours and the surface wind would be nearly parallel to the contours of the slope. These observations match closely the model of Defant (1951) of the diurnal behavior of winds in mountainous terrain, at least from shortly before sunrise to several hours after sunset. The little evidence obtained suggests that Defant's model was matched also during the late night and early morning hours. However, the expedition policy of uninterrupted sleep meant that no formal observations were made during those hours.

An interesting and illustrative example of slope winds and their rapid shift in direction near sunrise was observed at the village of Yarsa, located nearly half way up the south-facing slope of an ENE-WSW trending unnamed tributary to the Buri Gandaki Khola. Shortly before actual sunrise, smoke from the early morning fires of the village was observed. It was staying at the level of the housetops and drifting distinctly downslope (Figure 2.1), parallel to the ground surface. This drift continued for about another 15 minutes or so

Figure 2.1. The village of Yarsa approximately 15 minutes before rising sunlight struck the village, with smoke drifting downslope. Photo by A.H. Thompson on 8 November 1987.

until the rays of the rising sun struck the slope and the village. Within another 10 minutes the smoke drift had reversed as the slope wind reversed, and was moving up the slope above the village and at the same time starting to diffuse vertically as the few meters of air immediately above the slope were warmed by the sun (Figure 2.2). The rapidity of the shift from downslope to upslope was quite striking (see Thompson 1967).

THE STORM OF 17-19 OCTOBER, 1987

An unusually strong storm, for the season, affected activities of the expedition. The heavy rains and strong winds of 18-19 October 1987 prevented travel on those dates and resulted in the expedition remaining four nights instead of two in what came to be called the "rain camp." The expedition porters were unable to advance above about 4500 meters following the storm because of the deep and lingering snowfall. Destinations could not be reached, backtracking was required, and a general slow-down occurred. Some expedition objectives were dropped and others were redefined.

As a precursor to these events, a tropical cyclone developed some 600-800 kilometers east of Madras, India, on 14 October. It moved westward, reaching the coast in the early hours of the morning of the 16th. While weak as tropical cyclones go, the system retained its identify while moving across India. The system center reached the west coast (near Bombay) early on the 17th, then turned northward and northeastward, then eastward, but remaining south of the Himalaya. The lowest central pressure, approximately 100 kilopascals (750 millimeters of mercury), was attained some 600 kilometers northeast of Bombay. The system lost its identity as it reached Bangladesh on the morning of the 20th. The path of the system center is shown in Figure 2.3. Table 2.2 gives the time and central sea level pressure for each position in the figure.

Other than light rain showers the night of 17-18 October, the first indications of the approaching storm noted by expedition members were significantly increasing amounts of cirrus, cirrostratus and mixed altostratus/altocumulus advancing from the southwest the morning of the 18th. At the same time, the valley below was filled with stratocumulus. The winds at the surface did not show a significant increase during the daylight hours of the 18th, though strong winds several hundred meters above the elevation of the "rain camp" were indicated both by the cloud movement and more significantly by the development to the northeast, near the base of the Manaslu Himal, of a distinct wave motion in the clouds. This wave motion was first evident about two hours before sunset. Some 30 minutes before sunset the wave action was very prominent, as shown in Figure 2.4, as viewed from the "rain camp" toward the base of Himal Chuli. The clouds continued to thicken and lower and the first precipitation began about two hours after dark.

While the values of central pressure of the disturbance do not imply a particularly heavy rainfall, the wind flow (streamline) charts did a highly effective job of transferring moisture-laden air from the Indian Ocean across northern India and up the slopes of the Himalaya, and dropping copious amounts of rain and snow over Nepal and Tibet during an approximately 48-hour period. The heaviest rains at the "rain camp" lasted about 30 hours, beginning near 1500 UTC on the 18th; during this time the rain was nearly continuous and often heavy in intensity. An estimated 20 centimeters fell. The heaviest rainfall rate occurred in the last 6 hours of rainfall.

The nature of the flow pattern at the height of the storm is well illustrated by mapping of the lower and upper troposphere wind flow. Figure 2.5 shows the pattern of wind flow near 85 kilopascals and near 30 kilopascals (about 9000 meters above sea level), both for 0000 UTC on 19 October, thus just before the heaviest rain at the "rain camp."

Figure 2.2. The village of Yarsa approximately 15 minutes after sunlight struck the village, with smoke now rising upslope. Photo by A.H. Thompson on 8 November 1987.

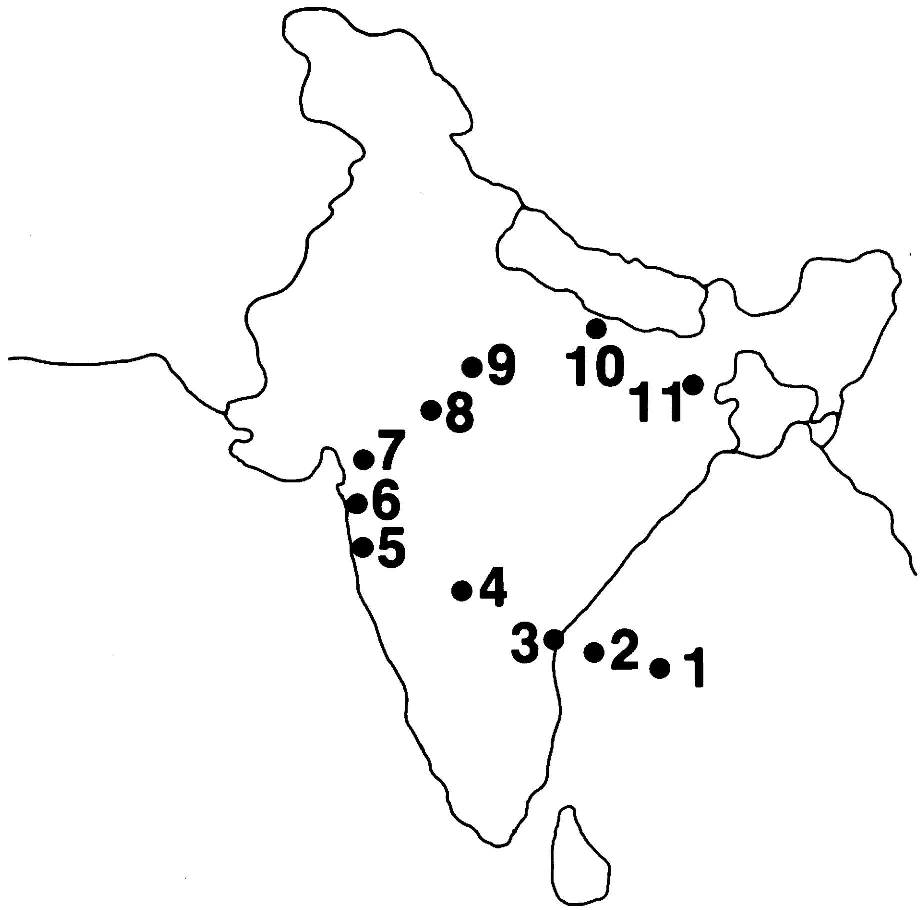

Figure 2.3. Track of the sea level center of the tropical cyclone over the Bay of bengal and India from 14 October to 20 October 1987. Refer to Table 2.1.

TABLE 2.2. Central pressures of the tropical cyclone, 14-20 October 1987.

Position Number*	Date	Time (UTC)	Central Pressure (kPa)
1	14 Oct.	1800	< 100.4
2	15 Oct.	1800	< 100.2
3	16 Oct.	0000	< 100.2
4	16 Oct.	1200	< 100.2
5	17 Oct.	0000	< 100.4
6	17 Oct.	1200	< 100.2
7	18 Oct.	0000	< 100.4
8	18 Oct.	1200	< 100.0
9	19 Oct.	0000	< 100.2
10	19 Oct.	1200	< 100.2
11	20 Oct.	0000	< 100.6

*For locations, refer to Figure 2.3

Figure 2.4. Wave clouds on the flanks of Himal Chuli as seen looking northeast from the "Rain Camp," at approximately 2300 UTC on 18 October 1987. Photo by A.H. Thompson

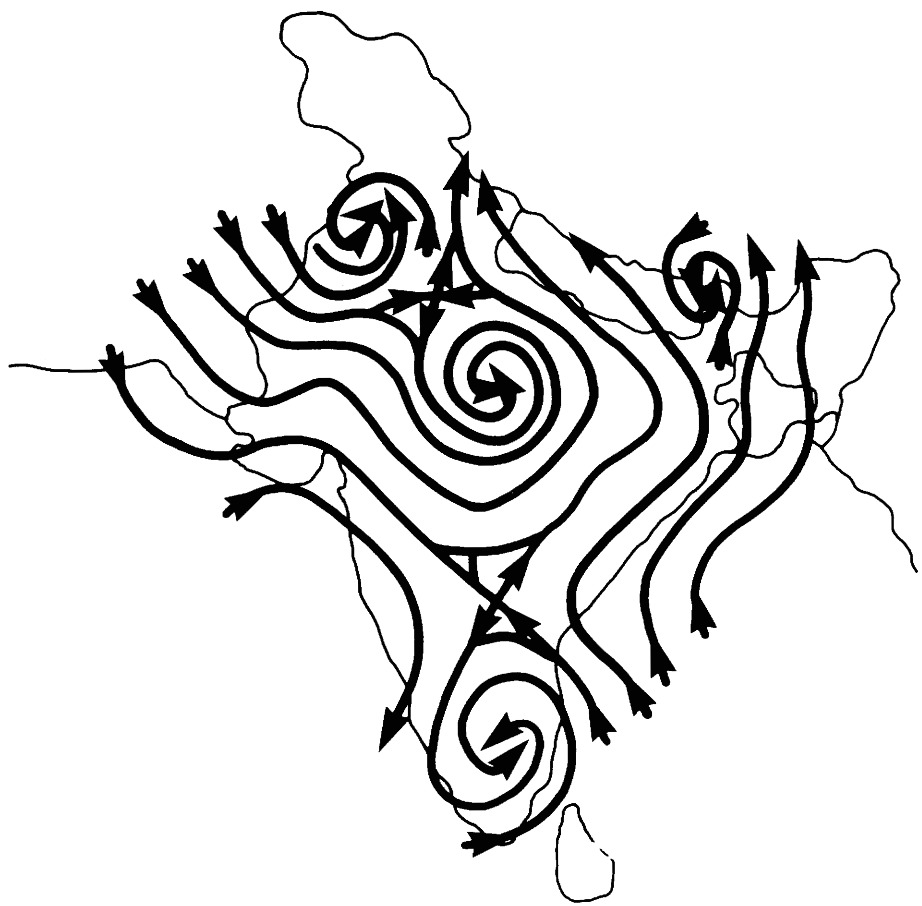

Figure 2.5a. Streamlines of air flow over India and Nepal at 85 kPa (approximately 1500 meters altitude) at 0000 UTC on 19 October 1987.

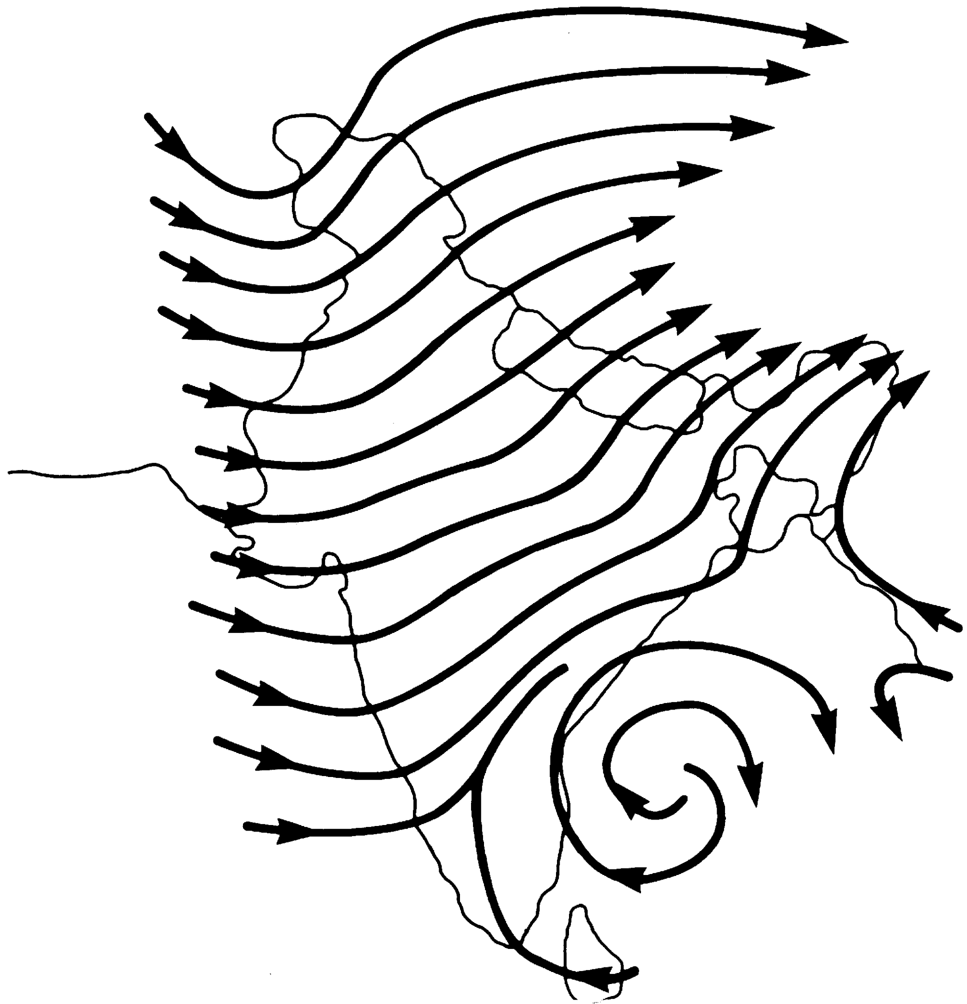

Figure 2.5b. Streamlines of air flow over India and Nepal at 30 kPa (approximately 9000 meters altitude) at 0000 UTC on 19 October 1987.

The lower layers are characterized by south-southeast flow over Nepal; this flow veers with height to south-southwest and southwest in the upper tropospheric layers. Thus at all levels in the troposphere there is a significant wind component normal to the axis of the Himalaya, resulting in general strong orographic lifting of the moist air from the Indian Ocean and the consequent heavy precipitation over Nepal. The snow line was near 4000 meters and heavy snowfall extended well into Tibet, with disastrous consequences for some people in Tibet and northern Nepal.

A map of rainfall isohyets over Nepal for the 48-hour period ending at 0300 UTC, 20 October is presented in Figure 2.6. The circled data are actual 48-hour precipitation at the measuring stations. Kathmandu, for example, reported 155 millimeters of rain, a near-record 48-hour precipitation for October. An east-west axis of maximum rainfall extended from eastern to central Nepal. The isohyets have been given a north-south orientation along the eastern half of the Nepal-Tibet border to account for the high estimated value at the "rain camp," near 28.3°N. Latitude, 84.7°E. Longitude (the estimated value is not used in the analysis since it is not an actual measurement). Further justification for the high values along the border northeast of Kathmandu includes the deep snows reported unofficially by climbers in the vicinity of Mt. Everest, resulting in several disasters. The uncertainty of the analysis along the Nepal-Tibet border is indicated by the dashed isohyets.

A graph of temperature variation with altitude is presented in Figure 2.7. Each line on the graphic represented the 0000 UTC temperature variation. To avoid seasonal effects, an eight days period is considered, except for line (e). Mean value of the temperature is taken for the same altitude. For comparison, environmental lapse rate of the standard atmosphere is drawn as a dashed line on the graph. It can be seen that along the southern slope of the high Himalayas variation of temperature with altitude, in which temporal effect is neglected, almost follows the environmental lapse rate of the standard atmosphere in pattern. Note how the storm of 17-19 October occurred during the time represented by line (a), when temperatures were warmest. More work remains to be done on the synoptic meteorology of this severe storm.

DISCUSSION

How do our experiences and observations relate to the land use of the Himalaya and the problems of both local residents and of visitors? The relatively common events cause no real problems, but only minor adjustment of daily activity, if any adjustment is required. The unusual event occurring in the weather is another matter.

Heavy flooding and high rivers can mean washed-out bridges. The local resident may have to delay travel to a nearby village or a major community for buying, trading or visiting; the trekker or mountain climber may have to reroute his path, perhaps with sufficient delay that he cannot achieve or has to curtail or modify his goals or objectives. Flash flooding may result in washing out of sections of roadways and trails, as well as terrace walls in areas where terrace agriculture is practiced. Unusually heavy snowfall at lower-than-usual altitudes frequently is life-threatening when it occurs; in this October tropical cyclone event lives were lost and others threatened.

A severe local storm warning system would be of value. It would be very expensive and require personnel not readily available at this time. Also, even the best of such systems is little more than a means of reporting events as they occur. It would appear that such a system should be a long-term goal. Details of how it should be designed are probably not appropriate for this report; there is an adequate literature on design and utilization

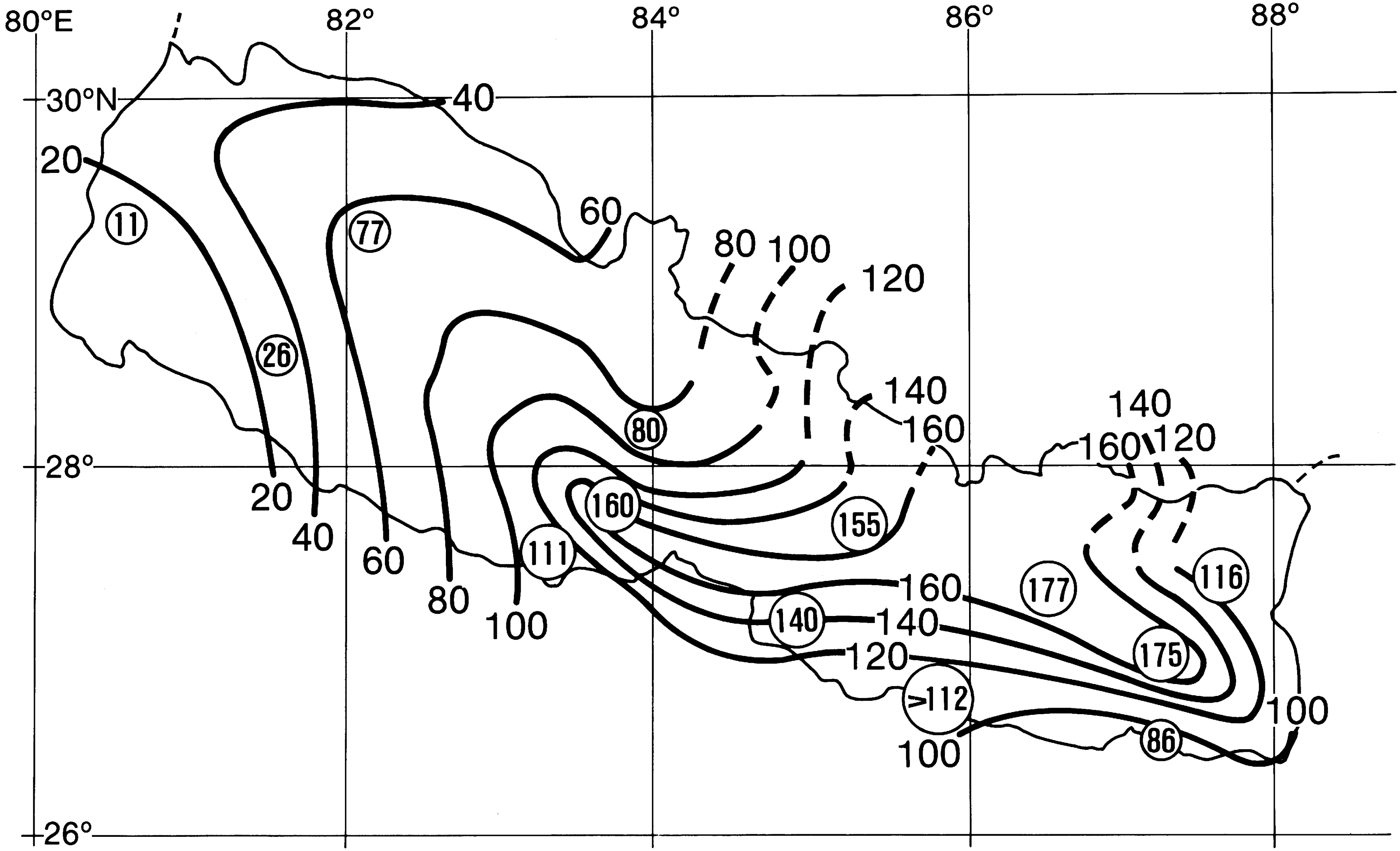

Figure 2.6. Isohyets over Nepal for the 48-hour period ending at 0300 UTC on 20 October 1987.

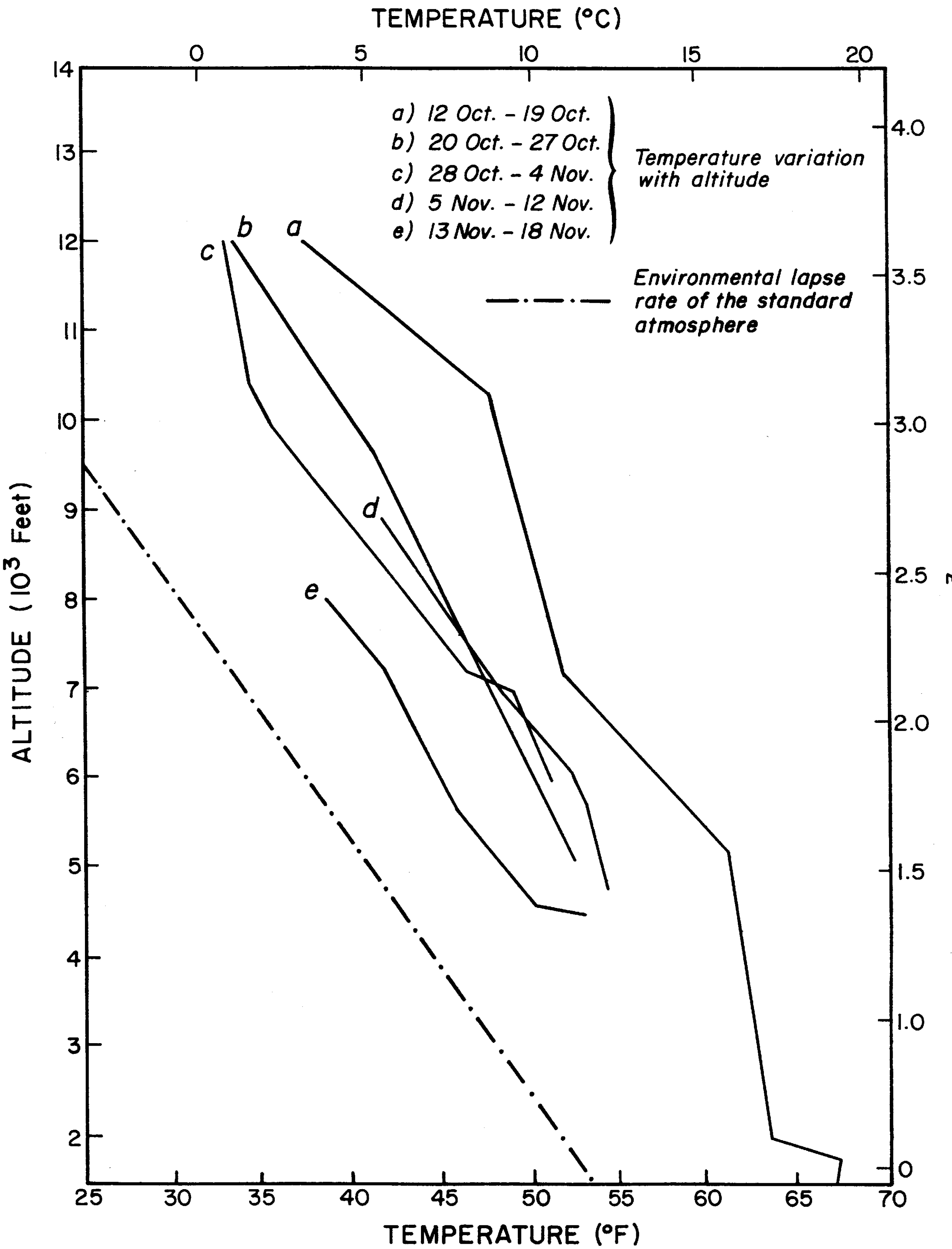

Figure 2.7. Temperature variation with altitude for selected dates.

of such systems, though most are concerned with areas of little land relief.

More feasible at this time might be a more elaborate procedure for dissemination of the forecasts (and weather observations) now available and which will be available in the near future. At the time of the Manaslu-Ganesh Expedition, we received general weather information by radio a couple of times a day from Kathmandu and from India. The parts of the forecasts referring to the mountain areas were brief. It seems feasible to provide for somewhat expanded forecast detail for the mountain regions and to transmit the information somewhat more frequently both to travelers and especially to the local residents. Portable radios are readily available, and an appropriate broadcasting schedule can be established and publicized. In some villages and in the cases of some travelers (especially climbing expeditions) two-way radio communication is or will be available. This would allow also the return of on-site weather observations if an appropriate procedure for obtaining and transmitting such data is developed.

A few words on forecasting accuracy are in order. The type of storm which would result in significant problems related to mountain resource management is the rare storm; this is also by far the most difficult to forecast. For example, in the case of the October tropical cyclone, significant rains were indeed forecast, but that the precipitation would approach or even exceed records for the season would ordinarily not be forecasted. There has, however, been significant improvement in the ability to forecast the unusually strong local or severe quasi-local storm.

The information potentially available from the geostationary meteorological satellite system should be of significant value in severe local storm forecasting and in turn in the relation between such storms and land use problems or mountain resource management in the Himalaya. Techniques for applying satellite data have been developed for other parts of the world, including some mountainous areas. The immediate problem may be attaining the satellite-derived data in Nepal in a timely fashion.

CONCLUSIONS

The severe post-monsoon storm of 17-19 October 1987 resulted from a tropical cyclone which originated in the Bay of Bengal, then crossed the Indian Peninsula before recurving to the north and northeast, south of the Himalaya. The resulting snowfall severely limited the ability of expedition team members to perform planned field work at the higher elevations. Access to elevations above 4500 meters was limited, and in the ensuing days, deep snow prevented making some of the expedition's desired observations. In all other respects, meteorological events proved to be little or no hindrance to the carrying out of desired objectives.

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3. GEOLOGY AND MINERALIZATION IN THE MANASLU-GANESH HIMAL

L.D. Miller, S.L. Garwin, W.W. Featherstone, J.A. Ziegler,
R.M. Johnston, V. Singh, and A.M. Bassett

During the 1987 Manaslu-Ganesh Expedition, two traverses through previously unmapped regions were completed near the Dordi and Chepa Kholas in the Manaslu Himal (Figure 3.1). A third traverse was conducted in the vicinity of the Chumar Ruby deposit in the Ganesh Himal, 30 Kilometers northwest of Trisuli Bazar. Our traverses took us from lower greenschist grade rocks below the Main Central Thrust (MCT), up into sillimanite bearing gneisses above the MCT. The lithologies in the study area consist of a 9500+ meter thick section of rocks from the Lesser Himalaya and the Central Crystalline Zone. This chapter will concentrate on the aspects of our study pertaining to economic and structural geology.

MINERALIZATION - MANASLU AND GANESH HIMAL

During the 1987 Manaslu-Ganesh Expedition two mineralized areas were encountered. Both mineralized sectors occur within a cream white, sugary textured dolomite unit. The carbonate unit has been named the Malekhu limestone by Stocklin (1980) and the GU (Ghanpokhra-Udi) dolomite by Colchen et al. (1980). This carbonate unit is within the Midland series as described by Colchen et al. (1980) which correlates to the Nawakot complex of Stocklin (1980). In the Manaslu Himal an occurrence was observed above the village of Taksar. The mineralization consists of a green mica (fuchsite ?) and an unidentified hard grey metallic mineral (specularite?) which occurs as disseminations in the dolomite and in quartz veins as coarse grained blebs with muscovite.

The second mineralized sector is in the Ganesh Himal, approximately 1.2 kilometers south of Mandra Danda peak near the town of Laba. Minor copper mineralization (cpy) occurs near a black schist-carbonate contact and is readily apparent due to the ubiquitous malachite, azurite and acanthite staining. Also in this area is a ruby - sapphire occurrence in the GU carbonate which is known as the Chumar deposit and is the primary focus of this report. Another similar, but smaller gem occurrence named the Shongla deposit is located less than 0.5 kilometers east of the Chumar.

CHUMAR DEPOSIT

General Geology

The GU dolomite, which is the host to the Chumar ruby deposit, consists of pod-like bodies which vary from 100 to 600 meters long and are up to 200 meters thick (Figure 3.2). Black carbonaceous phyllitic schists containing up to 15 percent pyrite comprise the stratigraphic and structural footwall of the Chumar deposit. Pyrite grains occur as disseminations and as foliation parallel bands. Individual grains are up to 2 millimeters in diameter. The hanging wall is made up of pyritic black schists on the east end, grading into quartzose schists on the west end.

Overlying the stratigraphic hanging wall of the deposit is a section greater than 9OO meters thick of garnet-biotite-schists and gneisses. Based upon the stratigraphic position of the deposit as well as the structural characteristics, it appears that the Chumar ruby-sapphire deposit and the mineralized dolomite unit is located below the MCT (Figure 3.3). This notion is also supported by

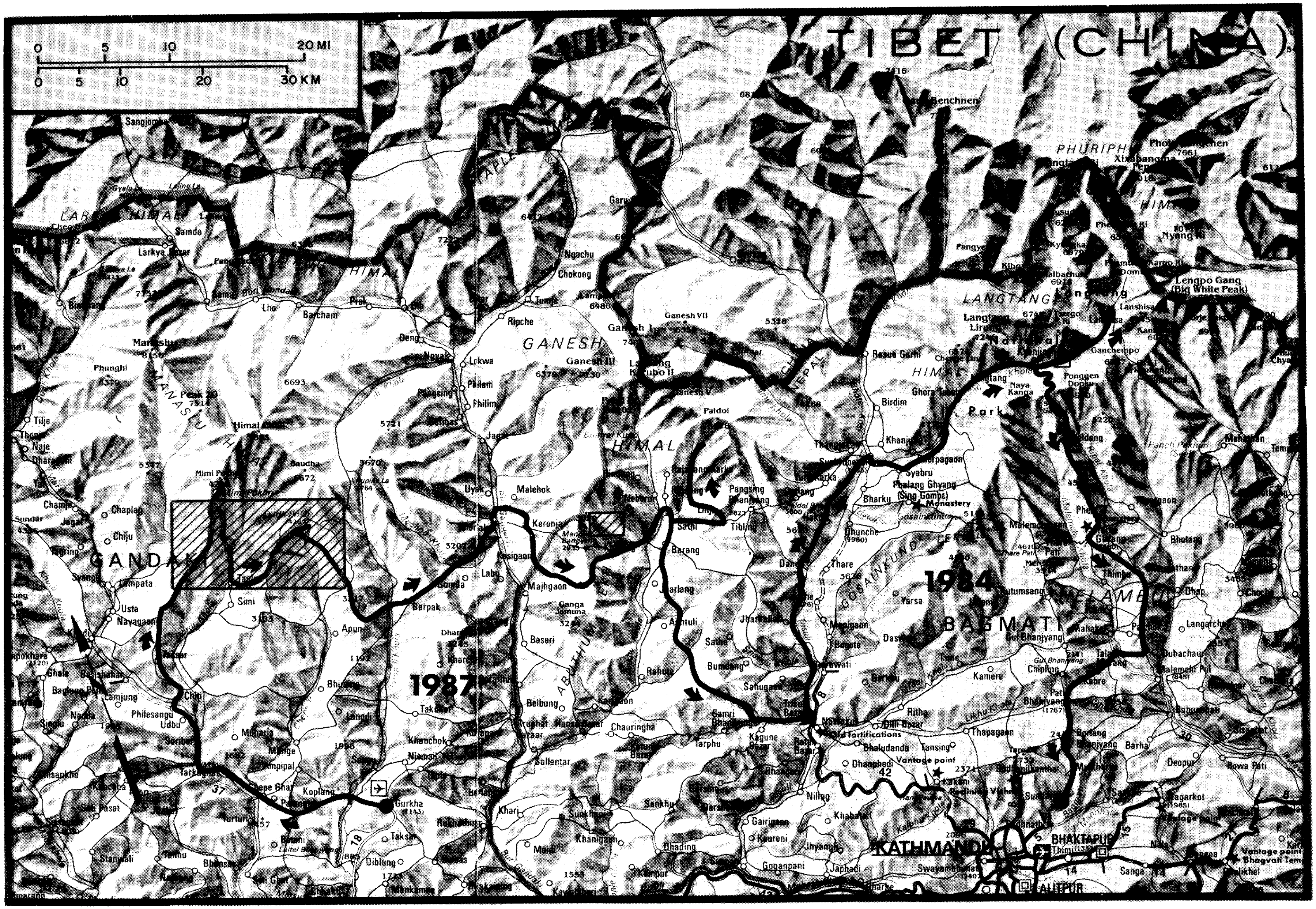

Figure 3.1. Traverse map of the Manaslu-Ganesh Expedition showing area in the Manaslu Himal and the Chumar area in the Ganesh Himal which was mapped during the 1987 expedition.

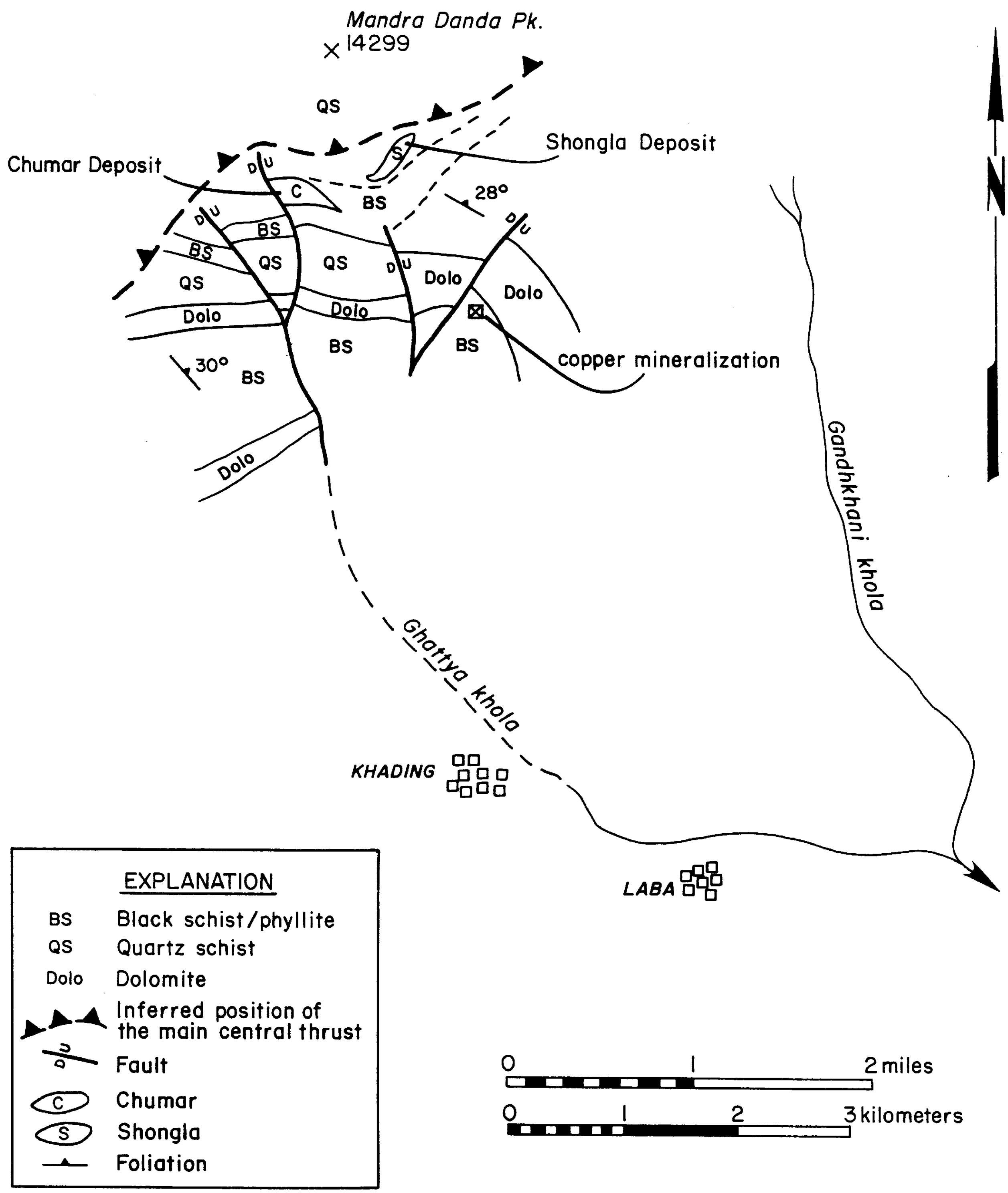

Figure 3.2. Geologic map of the Chumar gem deposit. Refer to Figure 3.1 for general location.

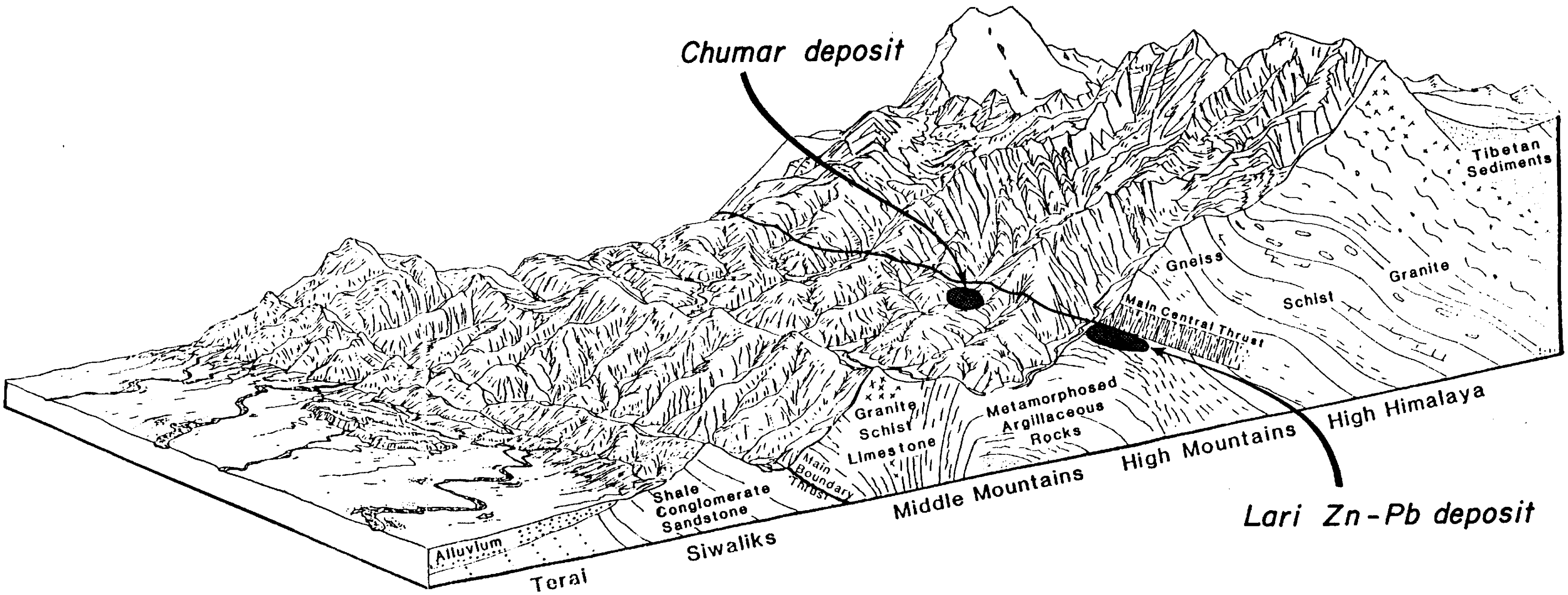

Figure 3.3. General geologic setting of the Chumar deposit and its position with respect to the Lari deposit and the Main Central Thrust. After HMG/WESC (1987).

interpretations of the position of the carbonate unit by various other workers; Stocklin (1980), Colchen and others (1980), and Bassett (1985).

Mineralization

The economic mineralization of the Chumar deposit consists of ruby and sapphire. These minerals are also known as corundum and have a chemical composition of aluminum oxide. Other minerals include phlogophite, fuchsite, muscovite, dolomite/ankerite, calcite, kyanite, nepheline and minor quartz. Also of interest is the occurrence of trace amounts of sphalerite, pyrite, and chalcopyrite. These minerals are present as fine grained disseminations and small blebs (less than one percent).

The ruby-sapphire rich zones occur in seams which vary from 5-40 centimeters thick and parallel the compositional layering. The precious stones account for less than two percent of the total minerals within a given seam. The seams are spaced between 2.5 meters and 7 meters apart and are separated by barren white dolomite. The seams vary in economic importance. The richest pods are up to 10 meters long by 2 meters thick. Geometrically the pods are irregular and discontinuous due to the curvilinear nature of the folds which host the ore. In a general sense the pods conform to the overall geometry of the stratigraphy, they strike east-west and dip moderately to the north.

Structure of the Dolomite

In order to understand the geometry of the ore bearing zone the structure must be delineated first. This was accomplished by studying the structures within the dolomite as well as the bounding units.

At least three phases of folding have been identified in the Chumar deposit. The first phase (fl) can only be inferred from our structural studies in adjoining areas and by the fact that phase two folds (f2) deform an earlier schistosity. The axes of f1 folds are oriented 115° azimuth, 28° NE.

The second phase of folding is isoclinal and recumbent. Fold axes are curvilinear, plunging moderately NE, the axial planes are oriented 100° azimuth, 25° NE. The third phase (f3) is overturned to reclined and has an associated crenulation cleavage developed in the more micaceous sectors. F3 fold axes plunge moderately to the east.

There are three distinct post mineralization joint sets in the Chumar deposit. Set #1 = 280° azimuth, 85° NE; set #2 = 335° azimuth, 9O°; set #3 = 025° azimuth, 90°. The joint sets are not important in light of the structural control on mineralization, yet they will be important for mining and construction operations.

The geometry of the Chumar deposit is lensoid. The eastern edge pinches out into a sea of black schist. The western side, which attains a thickness of l5O meters, is cut off by a high angle fault which is oriented 340° to 010° azimuth, 70-85° E. Along the western side of the deposit numerous fractures are present which are oriented 330-340° azimuth, 60-70° NE and are spaced from 10-50 centimeters apart. Minor limonite staining can be found coating the fracture surfaces.

Field evidence supports the notion that the ruby-sapphire mineralization is intimately associated with the fuchsite. The fuchsite is not folded by f2, however, it is located in the hinge regions of the f2 folds. Based upon this relationship we believe that the mineralization was synchronous with the f2 folding event. f3 followed, which resulted in small crenulations developing in the fuchsite and possibly resulting in some of the crack-seal textures in the sapphires.

Structure of The Bounding Units

Three major folding events have deformed the rocks in the study area. Phase one folds (f1) consist of curvilinear recumbent isoclinal folds and have a fabric which is the result of the transposition of the compositional layering into axial surfaces of f1 folds. The second phase folds (f2) are the most common in the study area. f2 folds are parallel to similar in style, and have an associated penetrative cleavage which dips 20 degrees NE. The asymmetries of the folds support a north over south sense of displacement. The third phase of folding (f3) is localized near the MCT. The geometry of these structures are reclined, open to tight buckle folds with an associated crenulation cleavage. f3 fold axes are curvilinear and the axial surfaces dip 40-70 degrees E-NE.

Mesoscopic ductile shear zones were observed along the limbs of f2 folds, parallel to the f2 axial surfaces. There is a consistent north over south sense of movement along the shear zones with displacement from 10 - 50 centimeters.

A N-NE trending penetrative mineral lineation occurs which is defined by elongate quartz grains as well as kyanite and sillimanite crystals. This orientation is coincident with the movement direction along the shear zones, and is similar to that described by LeFort (1975), for the direction of thrusting.

An interesting aspect of the dolomite hosted ruby deposits in the area, and the dolomite hosted Lari Zn-Pb deposit to the east is the localization of the mineralization to the footwall of the MCT. The MCT has been mapped throughout Nepal as a tectonic boundary based upon structural discontinuities and sharp changes in metamorphic grade (LeFort 1975, Stocklin 1980). The MCT has also been called upon as a mechanism for the inverse metamorphism which occurs along the length of the Nepal Himalaya. In the Manaslu-Ganesh sector the MCT is not a discrete break which can be easily identified, rather it is a zone based upon the following criteria:

1) local steepening in dip of the structurally overlying crystalline schists and gneisses from the lower grade rocks below,

2) contrasting stratigraphy above and below this boundary,

3) localized retrogression of garnet porphyroblasts and the abundance of chlorite, quartz and actinolite veins,

4) the first appearance of kyanite locally in the eastern part of the study area, and

5) a geomorphic change from the underlying steep ridge or cliff to the overlying recessive slope or flat ridge top.

Throughout most of the study area the MCT was not exposed due to the dense forest cover. There is little doubt that the MCT is a major structural, metamorphic and lithologic boundary. However, some major problems still remain. For example what relationship, if any, does the MCT have to the inverse metamorphism? Furthermore, the MCT acted as a major fluid conduit, yet what role did the fluid migration have in the mineralization of the dolomite?

Ore Genesis

As a working hypothesis, a favorable model for ore formation is one in which the mineralizing fluids were transported along a major plumbing conduit such as the MCT. An alternative explanation is suggested by one of the authors, A.M. Bassett, where he calls upon metamorphism of the dolomite without the addition of any other components. In other words all of the necessary ingredients to form the rubies and sapphires were derived from the dolomite. More work is needed on the pH, fO2, and pCO2 conditions of the fluids before a specific model can be applied.

EXPLORATION POTENTIAL

Perhaps of greater interest than the Chumar deposit alone is the potential for undiscovered gem and base metal deposits along the stratigraphic unit which lies between the Chumar deposit on the west and the Lari deposit some 20 kilometers to the east. Minor sphalerite (zinc sulfide), pyrite (iron sulfide), and chalcopyrite (copper sulfide) mineralization was found in the dolomites which host the Chumar deposit. Given the fact that precious stone and base metal deposits have been found within the GU carbonate unit, and given the large strike length of this unit, detailed geologic mapping and prospecting in the region may yield more deposits. With the completion of the road to the Lari Zn-Pb mine, other deposits which might have been previously sub-economic may become economic due to enhanced accessibility. Finally, throughout our traverses we found scatterings of mineralization within the stratigraphically highest carbonate unit of the Midlands or Nawakot formations, making it another attractive mineral exploration target within the Manaslu and Ganesh Himal. In summary some possible exploration criteria include:

1) mineralization lies spatially close to, or just below the MCT,

2) structural controls on mineralization include localization of the ore minerals to fold hinges,

3) mineralization is confined to a buff white crystalline dolomite unit which is easily identified in the field.

GOLD VEIN DEPOSITS

Although gold vein mineralization was not observed on our expedition the similarities of the geological environments in certain parts of the Himalayas to known gold producing areas raise some interesting questions regarding gold mineralization. The most obvious are; is there a possibility for gold mineralization and if so where would one look? By analogy to other gold vein deposits within metamorphic and orogenic terranes, the mixed packages of sedimentary and volcanic rocks near the metamorphic boundaries (where pressures and temperatures change), and in major structures such as shear zones or faults, are favorable exploration sites (Sawkins, 1984). In Nepal these areas include the Lesser Himalaya and the Siwaliks in the western sectors of the country (Figure 3.4). Little information has been published on the occurrence of gold in Nepal, however gold has been documented in panned concentrates by Talalov (1972), in the Kali Gandaki drainage (Bowman 1933) and the Nepal Dept. of Mines is presently pursuing a study on gold in Nepal. The intent here is by no means to suggest that gold deposits are waiting to be found. Rather, the lack of previous gold exploration combined with the geological environment in Nepal warrant exploration on the reconnaissance level.

SUMMARY AND CONCLUSIONS

Two areas of mineralization were investigated in the Manaslu and Ganesh Himal during the 1987 Manaslu-Ganesh Expedition. The first occurrence was located in the Manaslu Himal and consisted of minor specularite (iron oxide) mineralization within a carbonate unit. The most significant deposit visited in the area was the Chumar ruby deposit located in the Ganesh Himal. The Chumar ruby deposit is within the same lithologic or rock unit as the Lari Zn-Pb mine some 20 kilometers to the east. The implications of this are such that geologic mapping and prospecting along this horizon may yield previously undiscovered deposits of gems and/or base metals. With the completion of the road to the Lari Mine, previously sub-economic deposits may become

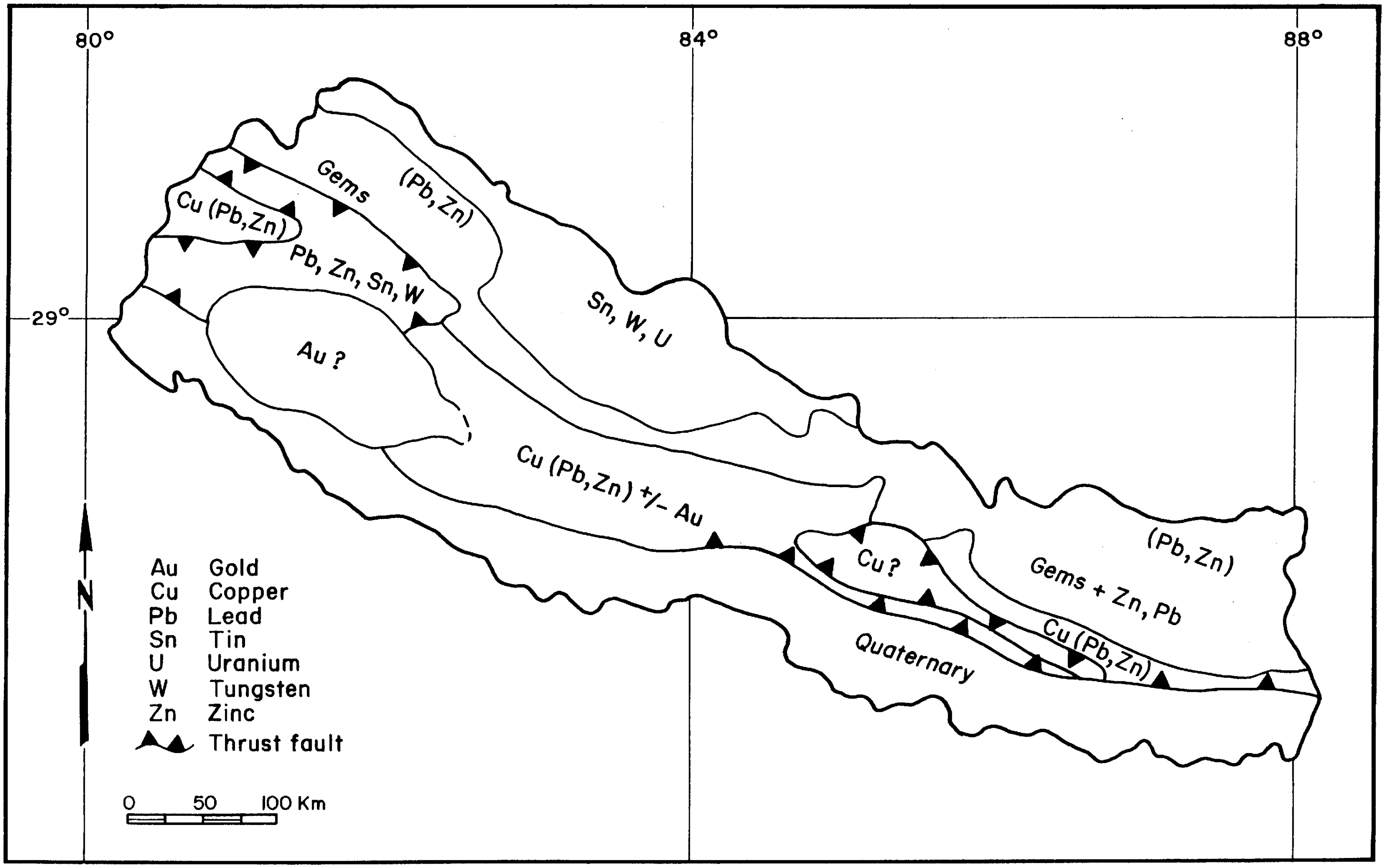

Figure 3.4. Mineral potential map of Nepal. After HMG/UNDP (1981).

more attractive due to the enhanced accessibility from the road. Even if a major deposit is not unearthed, the smaller deposits may support cottage industries such as has been developed by Himalayan Gems in Kathmandu. Such industry would provide local work. Of course, before such a project is undertaken the local political climate must be investigated.

Another geologically interesting region, yet one not covered by this expedition, includes the metamorphosed sedimentary rocks of the Lesser Himalaya and the Siwalik hills in *western* Nepal. Similar geological environments in other parts of the world have yielded significant amounts of gold from vein deposits. At this point in time there is no proof that economic gold deposits exist in Nepal; however, in order to prove or disprove the hypothesis mineral exploration is needed.

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4. GEOMORPHIC ESTIMATES OF BANKFULL DISCHARGE IN THE MANASLU-GANESH HIMAL

R.A. Marston and J. Kleinman

It is widely recognized that runoff originating in the Himalaya of Nepal is a tremendous potential resource for hydropower and irrigation development. This same runoff, however, is also a hazard in the form of devastating floods that occur during the monsoon months of July through September, and in the form of glacial lake outburst floods (HMG/WESC 1987). Understanding and predicting floods has been hampered by the lack of adequate hydrologic data on rivers needed to perform resource inventories or hazard analyses. Only 72 ("priority A") gaging stations have been maintained in Nepal with continuous records dating back to the 1960's or 1970's. A hydrograph for one of these stations is shown in Figure 4.1.

The magnitude of floods is exacerbated in the Himalaya of Nepal by the tremendous relief. The world's highest mountains and deepest gorges provide the setting for some of the world's most erosive rivers (Figure 4.2). The damage from floods takes several forms. First, floods destroy foot bridges that often provide the only link between remote mountain villages. Second, irrigation diversions are demolished on a regular basis. Third, peak flows trigger mass wasting by undercutting steep, stream-adjacent slopes (Figure 4.3). Fourth, floodplain agricultural land is damaged by erosion and sedimentation associated with flood events. International conflict between Nepal on the one hand and India and Bangladesh on the other hand has resulted from devastating floods and related sediment discharge and channel instability in the Ganges River Plain. Mountain subsistence farmers in the source areas of the Ganges Drainage have been blamed by lowland farmers in India and Bangladesh for accelerating the problems because of deforestation and other poor land management practices (Ives and Messerli, 1989).

RESEARCH DESIGN

The objective of this study was to determine if the potential for monsoon-related floods could be estimated from a combination of terrain analysis techniques. First, field methods were utilized to evaluate bankfull discharge at selected stream crossings along the 1987 Manaslu-Ganesh Expedition route. Second, the estimates of bankfull discharge were related to upstream characteristics of the drainage basin. It was anticipated that these methods would provide some predictive power to aid in water resource planning.

The study concentrates on the high mountain physiographic region of central Nepal. The bedrock is structurally competent, composed of gneiss and schist, weathering to coarse textured soils. The higher valleys were glaciated and have experienced significant post-glacial downcutting. Data were collected at 11 stream crossings where access allowed channel measurements. The area of drainage basins above these 11 sites ranged over three orders of magnitude, from 15.9 to 3930 square kilometers. Channels affected by glacial lake outbursts were avoided in this study. The study sites are situated within the Marsyandi-Buri Gandaki-Trisuli River drainages, headwater sub-basins of the Ganges River system (Figure 4.4).

Bankfull discharge is a useful indicator of the overall potential for monsoon-related floods. The stage where water fills the channel to the top of its banks marks the condition of incipient flooding. It is recognized by the topographic break between the channel and floodplain alluvium (Figure 4.5a-b). In a gorge, bankfull discharge is

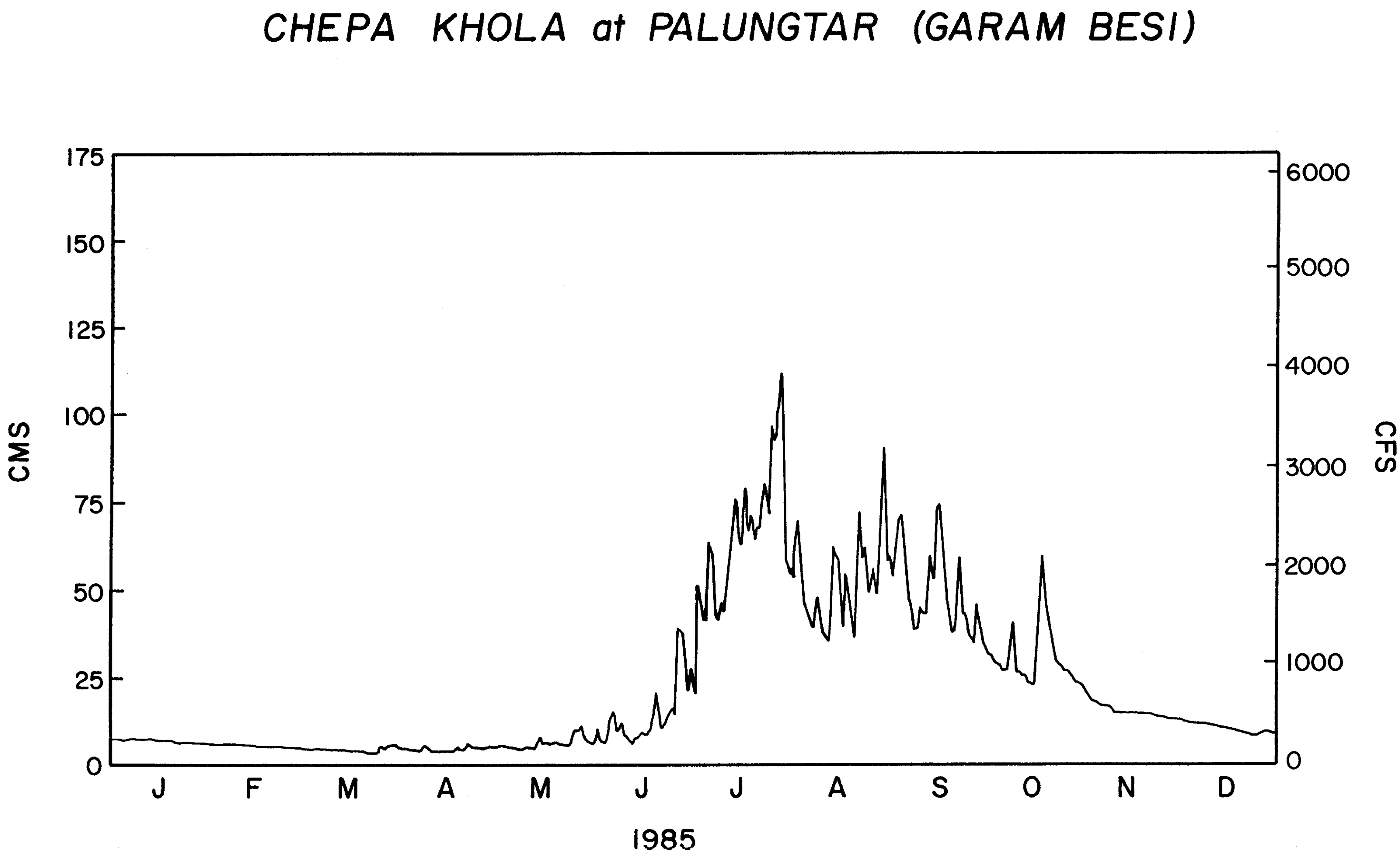

Figure 4.1. Typical annual hydrograph for streams in the Middle Mountains of the Manaslu-Ganesh Himal. Note the strong seasonal effect of the monsoon and the spikes caused by individual storm events.

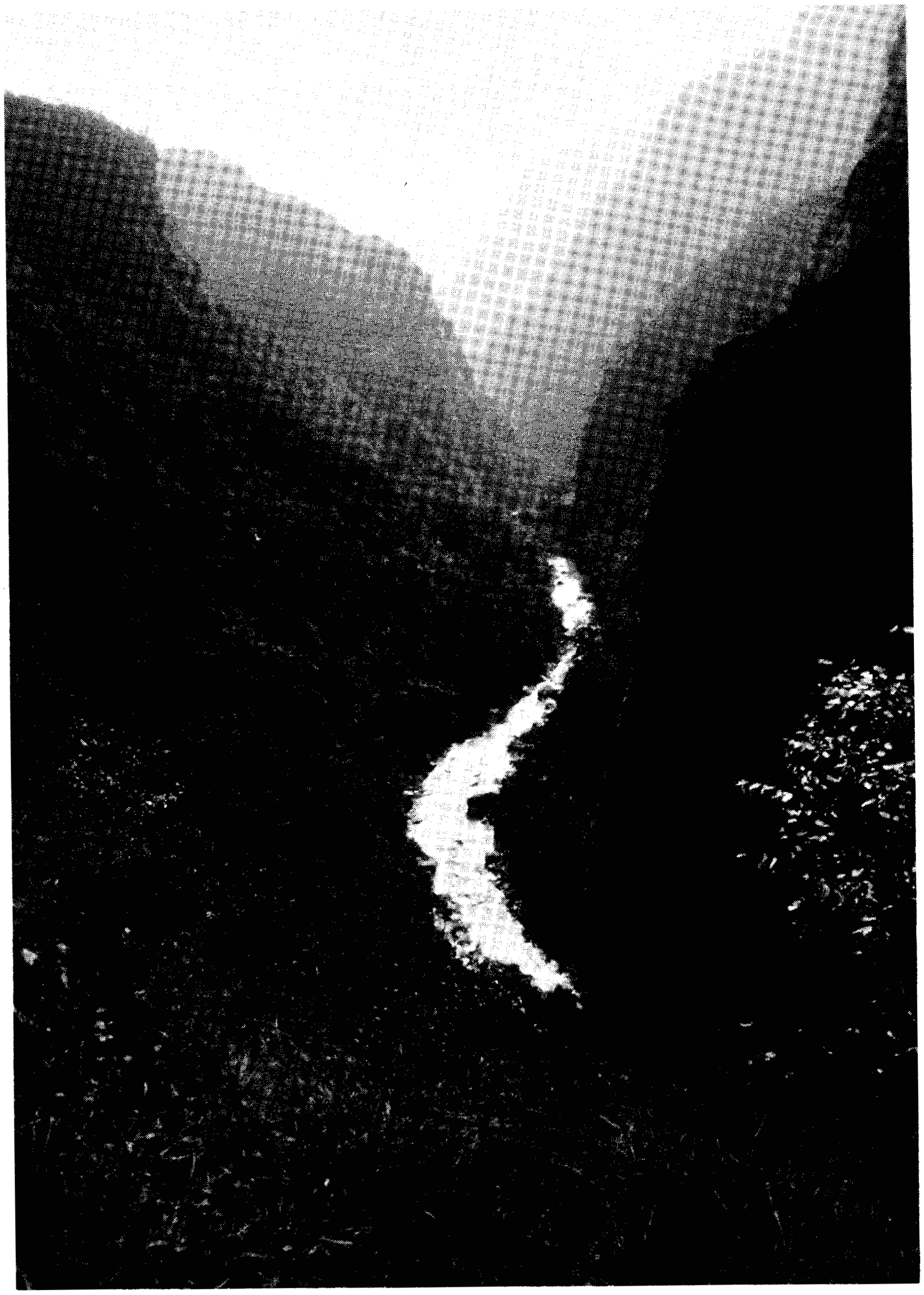

Figure 4.2. Buri Gandaki Gorge and River looking downvalley near Kholabenesi. Photo by R.A. Marston.

Figure 4.3. Stream adjacent mass wasting triggered by monsoon peak flows and related channel aggradation, near Talamarang, Helambu District. Photo by R.A. Marston.

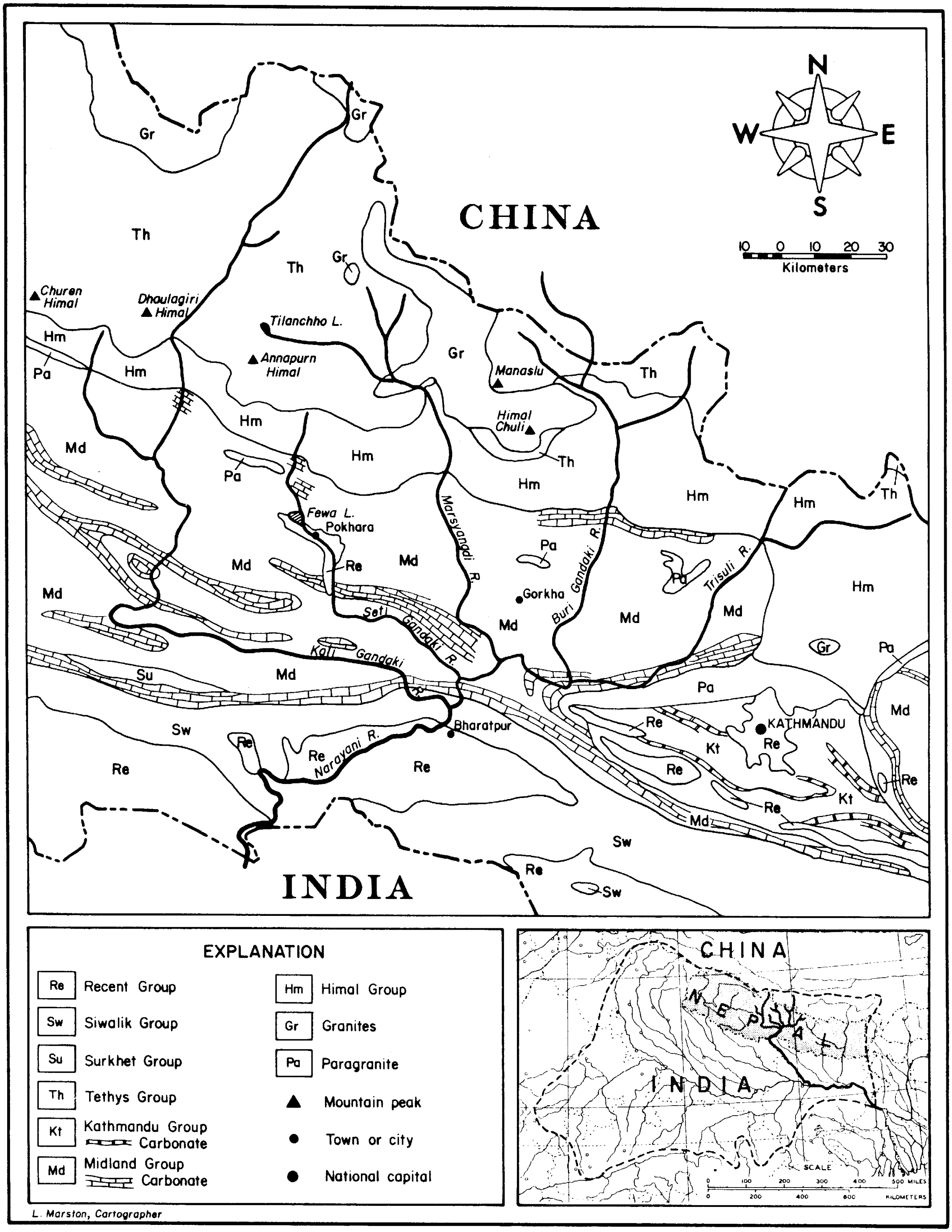

Figure 4.4. Geology and major drainages of the central Nepal Himalaya.

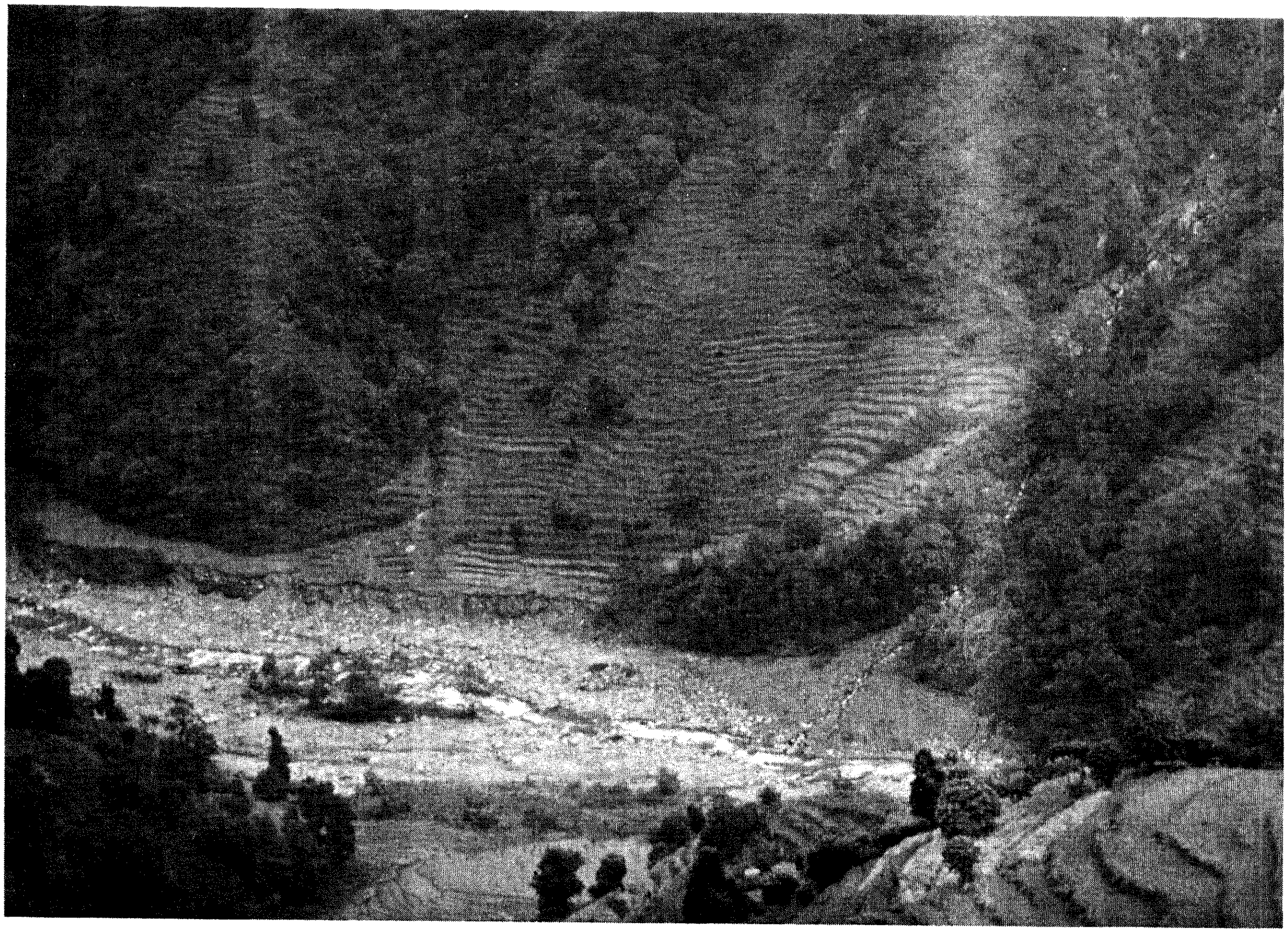

Figure 4.5a. Bankfull discharge is identified by a distinct topographic break between the channel and floodplain alluvium, where a floodplain exists. This is a view of the Dorandi Khola from the village of Ghoachok. Photo by R.A. Marston.

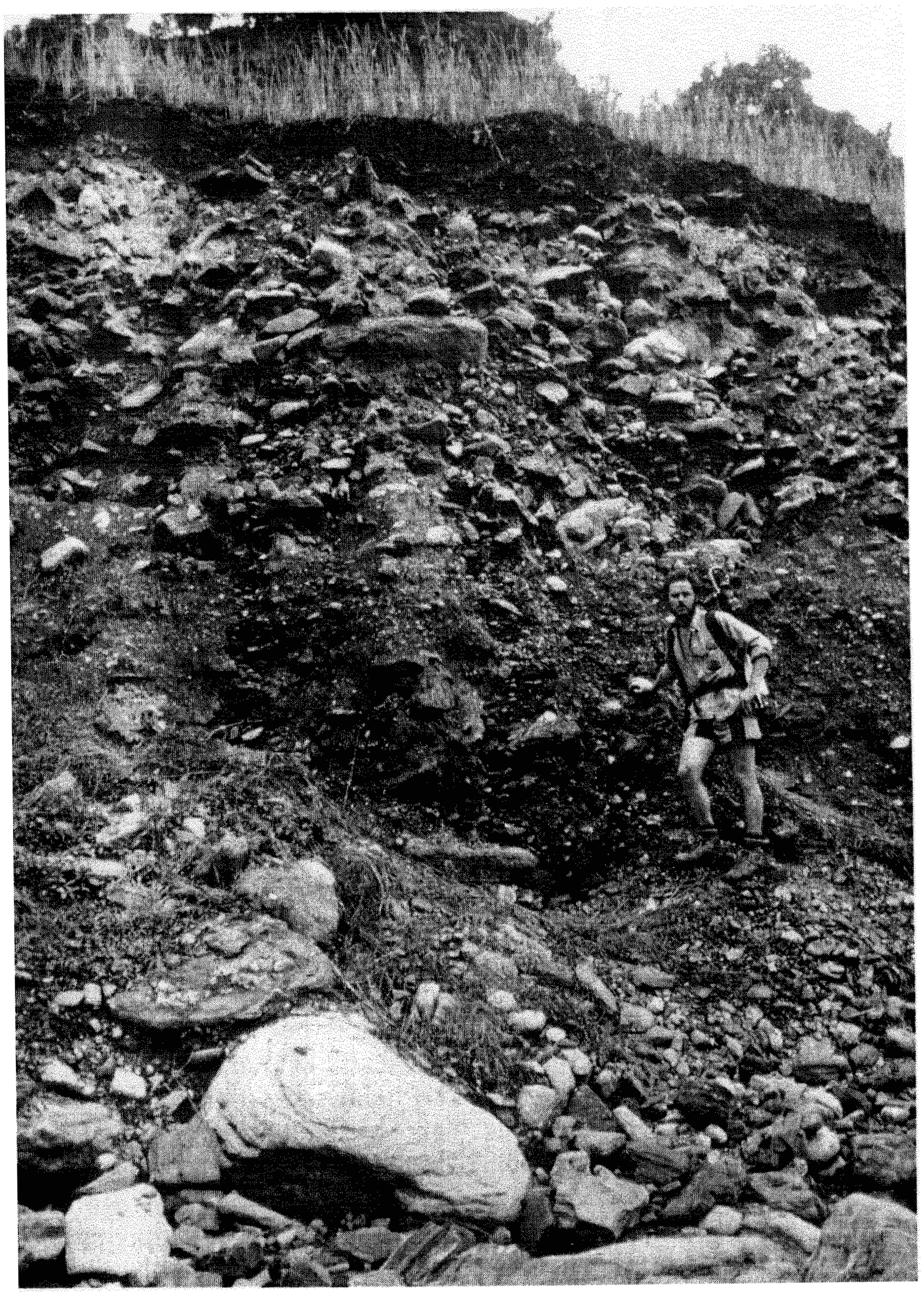

Figure 4.5b. Difference between bankfull stage and low flow when photo was taken. View is of far bank seen in Figure 4.5a. Unsorted and unimbricated colluvial deposits overlie stratified alluvium. Photo by R.A. Marston.

recognized by a scour line or break in vegetation (Figure 4.6). Williams (1978) has reviewed the various definitions of bankfull discharge and the methods used to measure it. Based on his recommendations for the conditions encountered in the Manaslu-Ganesh Himal, and following the strategy of Dalrymple and Benson (1967), the Manning equation was used to estimate bankfull discharge:

$$Q_{bf} = \frac{A(R^{0.667})(S^{0.5})}{n},$$

Q_{bf} = bankfull discharge, in cubic meters per second,

R = hydraulic radius at bankfull stage, in meters = A/P

S = slope of the energy gradient at bankfull stage, expressed as a decimal fraction,

n = Manning's roughness coefficient at bankfull stage,

A = channel cross-section area, in square meters = (channel width, W) x (channel depth, D), and

P = 2D + W, in meters.

Direct measurements were acquired of channel width, depth, and gradient at the bankfull stage. Manning's n was estimated by three techniques:

1) component method (Cowan 1956),

2) particle size relationship (Bray 1979), and

3) regime equation for high gradient streams (Jarrett 1984).

The first method is considered to be appropriate for channels with a hydraulic radius smaller than 5 meters, a condition that was met at each study site. The particle size relationship that was utilized can be expressed as:

$$n = 0.113\ (d_{75})^{0.5}/D^{0.33}$$

where n and D are as above, and
d_{75} = particle size more coarse than 75 percent of the sample.

Particle size was sampled at 20 points along each of three transects at each stream crossing, where possible, for use in the Bray (1979) relationship. The Jarrett (1984) regime equation for high gradient streams is:

$$n = (0.39)(S^{0.38})(R^{-0.16}),$$

where S and R are as above. This equation has been validated for the range of S and R encountered in the present study.

Indian topographic survey maps at a scale of 1:63,360 were used to measure characteristics of the drainage basin upstream of each study site. Measurements were made of basin area (A), basin perimeter (BP), and basin elongation (BE) as defined by Schumm 1956. To calculate basin elongation, basin length (BL) had to be measured; the method of Potter (1961) was utilized. Measurements were also made of basin relief along the axis used to measure basin length (BR), relief ratio (RR), and maximum basin relief (XBR). In addition, mean basin slope (MBS) was measured by the simplified contour-length method described by Williams and Berndt (1976). No morphometric measurements were made of the drainage network because of the vagaries of delineating the network in the Himalaya by either remotely sensed imagery or contour crenulations.

Land cover measurements were made from multispectral images acquired by the SPOT satellite in October and December 1986. These dates were selected to provide optimum conditions for using soil moisture contrast to enhance vegetation patterns since the soil would be wet but not saturated. In addition, snow cover will be minimal at this time. Color positive transparencies of the images were purchased at a scale of 1:400,000 and

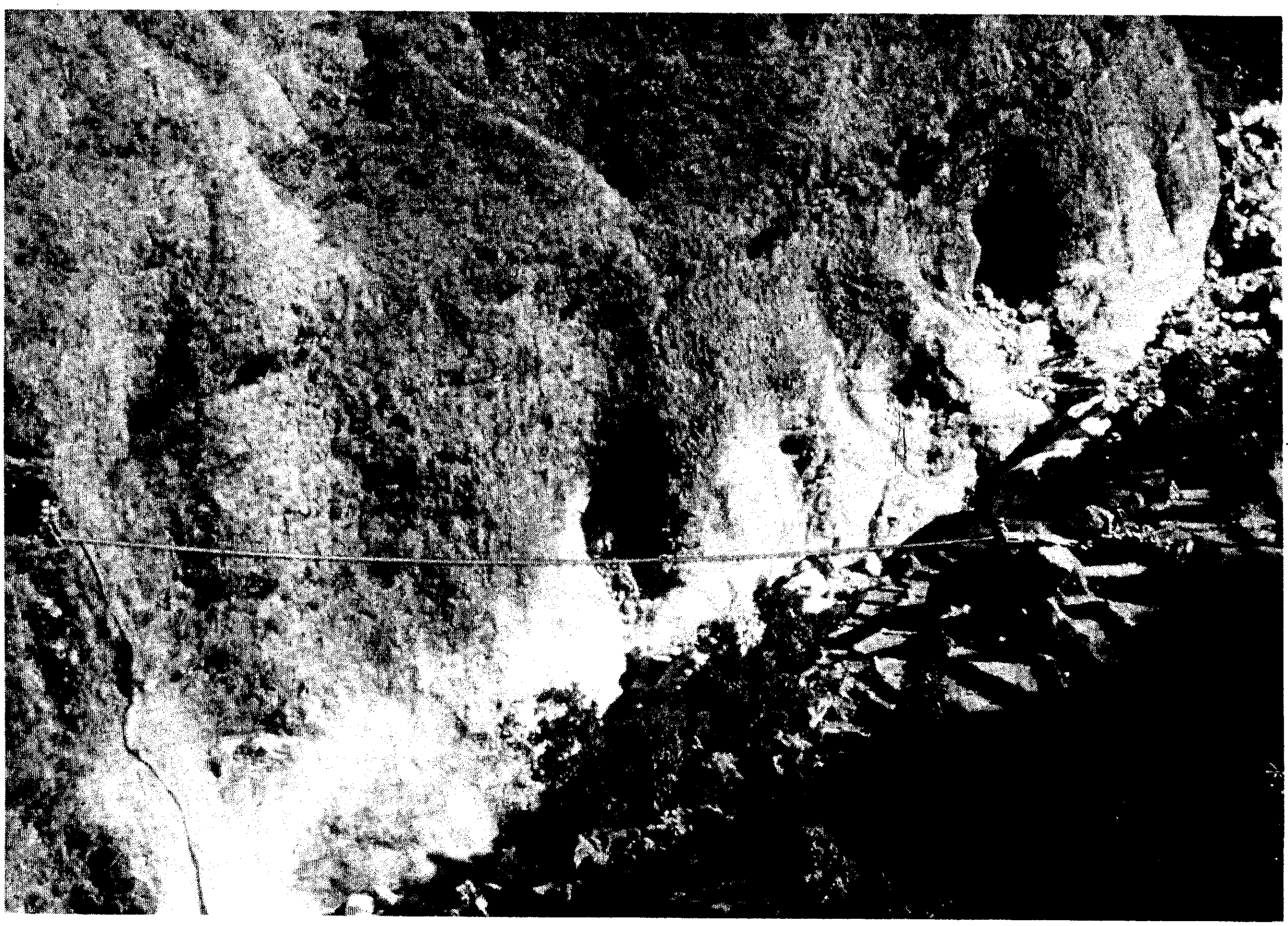

Figure 4.6. Flood-produced vegetation scour line in the gorge of a tributary to Ankhu Khola. Note the team member midway on the suspension bridge for scale. Photo by R.A. Marston.

then photoenlarged to 1:150,000 to improve mapping capabilities. The images are multispectral composites of three bands: green (0.50 to 0.59 microns), red (0.61 to 0.68 microns), and near-infrared (0.79 to 0.89 microns). A ground resolution of 20 meters has been claimed by the distributors of color composite SPOT imagery. The percent forest cover in each drainage basin (FOR) was measured manually from the imagery, using ground truth data from the field expedition and maps published by Nelson et al. (1980).

RESULTS

Field data collected for calculations of bankfull discharge are listed in Table 4.1. A correlation matrix of Manning's n values is presented in Table 4.2. The lack of correlation between the methods suggests that the methods are not measuring the same roughness features. Indeed, it is difficult to use the Cowan (1956) without counting the same features more than once. The Bray (1979) method emphasizes particle roughness without addressing form roughness. In the end, the Jarrett (1984) regime equation was used because it was specifically developed for steep mountain streams.

The estimates of bankfull discharge, using the Jarrett (1984) values of roughness, ranged from 69.3 to 1864 cubic meters per second. Watershed characteristics of the 11 drainage basins are presented in Table 4.3. The first regression equation developed from these data simply relates bankfull discharge to basin area.

$$Q_{bf} = 11.5(A)^{.618},$$

with $r^2 = 0.843$, significant at $p < 0.001$. A more interesting exercise involves estimating bankfull discharge per unit area as a function of other watershed characteristics to gain understanding of the area-yield controls on the peakedness of the hydrograph. Several morphometric variables could not be used because of spurious correlations with basin area (e.g., relief ratio, basin perimeter, mean basin slope). The equation developed from stepwise regression is as follows, with independent variables listed in the order they entered the equation:

$$Q_{bf}/A = 1.38(FOR)^{-.714}(BE)^{.656}$$

with $r^2 = 0.217$, significant at $p < 0.377$. Thus, neither morphometric variables (other than area) nor percent forest cover explain a significant portion of the variation in bankfull discharge. If one ignores the spurious correlation between area and mean basin slope ($r = -.708$) and includes mean basin slope in the regression above, then the coefficient of determination increases to 0.930, but clearly this is not tenable.

Estimates of Q_{bf}/A derived from this equation were compared to values derived from breaks in the stage-discharge rating curve for each of 11 other sites which had gaging stations with more than 10 years of data. A comparison between the two estimates provides some indication of the predictive power of the relationship. The coefficient of determination in this relationship was 0.90. At the Chepa Khola gaging station, where 21 years of gaging records were available, bankfull discharge was estimated to be 243 cubic meters per second. The recurrence interval of this bankfull discharge is 2.00 years (Figure 4.7). Recall that the mean annual flood using annual series data has a recurrence interval of 2.33 years. Williams (1978) analyzed data from 36 stations in the United States to show that the recurrence interval of bankfull discharge averaged 1.5 years as Leopold et al. (1964) proposed, but recurrence intervals could range from 1.01 to 32 years.

CONCLUSIONS

This project has demonstrated that it is possible to use geomorphic measurements of bankfull discharge to estimate the hazard of

TABLE 4.1. Data from field surveys used to estimate bankfull discharge.

Stream	W(m)	D(m)	S(df)	(n1)	(n2)	(n3)	Qbf(cms)
1. Unnamed stream	20.1	.914	.01	.054	.064	.053	30.9
2. Marsyandi Khola at Tarkughat	50.3	5.49	.02	.073	.078	.057	1,860
3. Upper Dorandi Khola	41.1	1.83	.04	.083	.070	.087	243
4. Namyung Khola at Kholabenesi	24.4	2.13	.07	.093	.096	.106	194
5. Buri Gandaki at Kholabenesi	36.6	5.49	.05	.053	.061	.082	1,433
6. Ghattya Khola	13.1	2.13	.08	.101	.079	.115	93.9
7. Gandhkhani Khola	13.1	2.44	.08	.088	.082	.112	119
8. Unnamed stream	21.3	2.44	.08	.078	.068	.110	212
9. Manjor Khola	25.9	3.66	.05	.083	.078	.087	491
10. Durgun Khola	7.32	3.05	.03	.065	.063	.078	69.3
11. Upper Manju Khola	13.7	1.83	.04	.073	.059	.089	72.2

n1 = Manning's n as calculated by Cowan (1956) method
n2 = Manning's n as calculated by Bray (1979) method
n3 = Manning's n as calculated by Jarrett (1984) method, used to calculate Q_{bf}
All values (other than S) reported to three significant digits

TABLE 4.2. Correlation matrix for methods of calculating Manning's n.

	n1	n2	n3
n1	1.000		
n2	.751	1.000	
n3	.426	.747	1.000

Refer to Table 4.1 for definition of n1, n2, n3

TABLE 4.3. Characteristics of drainage basins upstream of the 11 stream sites.

Basin	A (sq.km.)	BP (km)	BL (km)	BE (df)	BR (km)	RR (df)	XMR (m)	MBS (df)	FOR %
1.	30.3	24.1	5.86	1.06	.731	.125	1,280	.214	65
2.	3,240	298	79.4	.809	5.21	.0656	7,498	.100	40
3.	118	59.4	15.9	.771	3.72	.234	4,938	.399	20
4.	54.5	33.3	13.3	.626	3.54	.266	3,536	.710	15
5.	3,930	235	74.3	.952	4.51	.0607	7,071	.0870	35
6.	16.8	15.9	4.44	1.04	1.49	.336	2,255	.480	10
7.	30.9	22.2	7.29	.860	1.68	.230	2,591	.532	20
8.	131	50.7	18.1	.714	5.64	.312	5,639	.597	50
9.	144	49.1	13.3	1.02	4.11	.309	4,420	.498	60
10.	35.4	23.8	8.56	.784	1.68	.196	2,042	.386	40
11.	15.9	15.8	4.44	1.01	1.40	.315	2,774	.567	30

See Table 4.1 for names of basins.

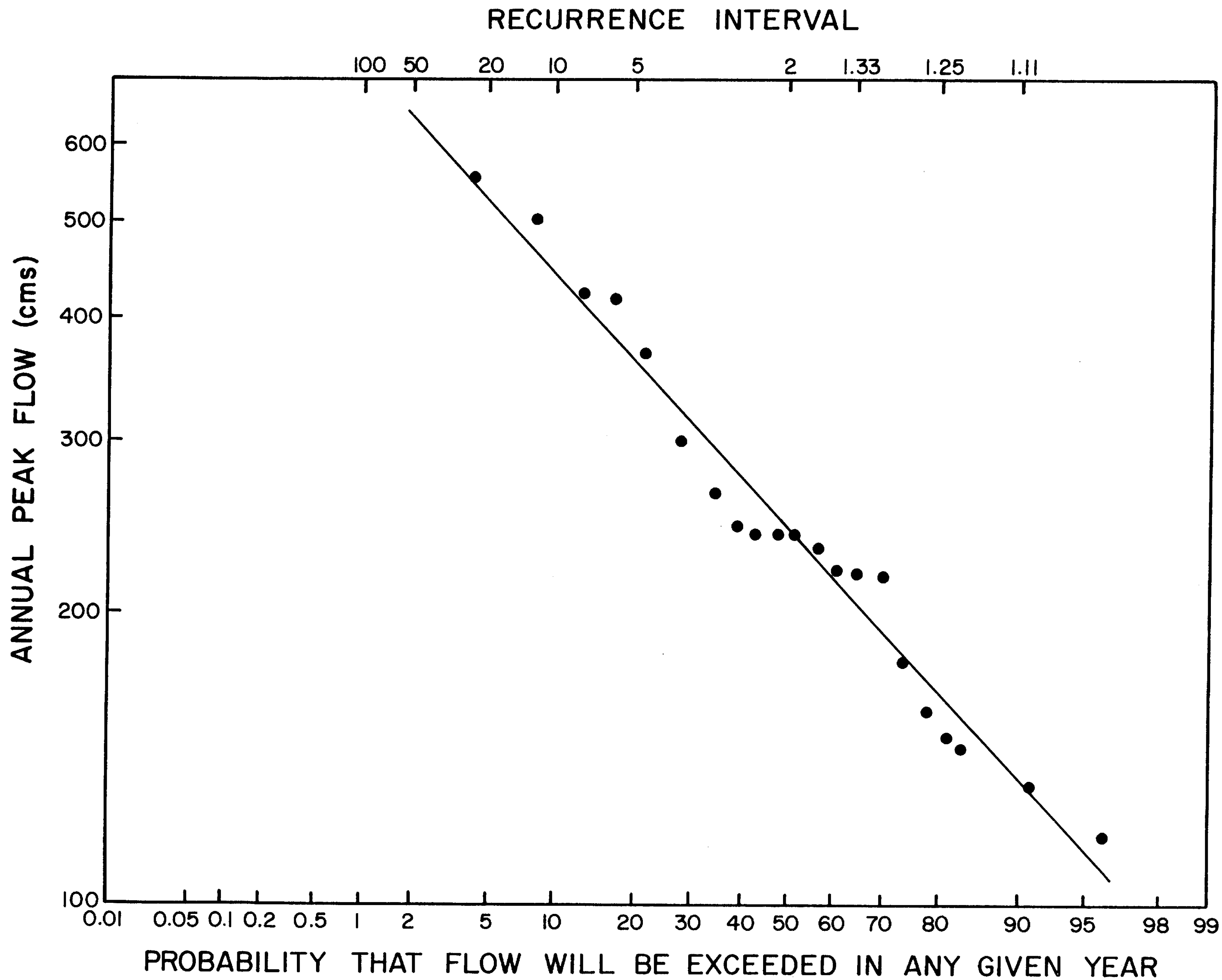

Figure 4.7. Frequency of annual peak flows for the Chepa Khola at Palungtar (Garam Besi).

flooding at ungaged sites from monsoon rainstorm events. Moreover, it has been shown that bankfull discharge can be estimated with a high degrees of precision using characteristics of the watershed derived from topographic maps and remotely sensed imagery. The finding that percent forest cover was not the best single predictor of bankfull discharge may lead one to conclude that deforestation is not contributing to the flood hazard, a conclusion reached by Ives and Messerli (1989). This conclusion must be tempered by recalling that measurements of the variable FOR in this study are from 1986 imagery alone; the **change** in forest cover over time is not taken into account. Nevertheless, it is fair to assert that geomorphic variables, not forest cover, exert the dominant control on peak flows. Findings from this study can be used to guide planning for projects that are affected by flood hazards in the central Nepal Himalaya, including irrigation, hydropower, and footbridge construction.

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5. MASS WASTING IN THE MANASLU-GANESH AND LANGTANG-JUGAL HIMALS

R.A. Marston and M.M. Miller

The geomorphic development of hillslopes in the middle mountain, high mountain, and high Himalaya physiographic regions of central Nepal has been dominated by ancient and modern mass wasting coupled with dramatic incision by major rivers. In fact, it is hard to travel through these regions without being impressed by the extent of mass wasting. Considerable debate rages among Himalayan scientists over the relative effect of human activities on the magnitude and frequency of mass wasting. Excellent summaries of this debate are provided by Carson (1985), Ives and Messerli (1989), and Bruijnzeel and Bremmer (in press). Very few engineering studies of slope stability have been reported, primarily because of the difficulty in acquiring adequate field data of the detail needed. In any case, engineering slope stability analyses often do not lead to a general understanding of controls on mass wasting because of the difficulty in extrapolating from one field site to the next without an equivalent amount of detailed field data. Thus, we find ourselves still at a stage where inventories of mass wasting are useful.

The consequences of mass wasting in the Himalaya are well documented. One set of consequences involves the loss of productive land for forestry, cultivation, or range use. This dimension of the mass wasting hazard is acknowledged by mountain villagers as a serious problem, but in many cases, supernatural causes are blamed. Johnson et al. (1982) have described the range in response of mountain villages to mass wasting events, including preventive maintenance and repair for reuse at a lower land use intensity. A second consequence of mass wasting involves the sedimentation impact on stream channels (Figure 4.3). In some cases, temporary dams are created across channels which cause catastrophic flooding upon failure in the manner described by Costa and Schuster (1988). Damage to hydropower and irrigation projects is a major impact of this sedimentation (HMG/WESC 1987). Mass wasting, and the channel shifting and flooding related to it, are considered by some to be another manifestation of the destruction of life support systems on the Ganges River Plain by the actions of subsistence mountain farmers (Ives and Messerli 1989).

The objective of this study was to evaluate the spatial distribution of mass wasting in the central Nepal Himalaya. An attempt was made to formulate some judgments on the origin and rates of mass wasting. On this later point, it is dangerous to try isolating triggering mechanisms. The processes that trigger mass wasting operate on different time scales. Contrast the long-term effect of progressive weathering along the soil-bedrock contact with the seasonal effect of fluctuating water tables and the sporadic effect of earthquakes. Moreover, it is indeed difficult to identify the triggering mechanism of mass wasting events from hundreds or thousands of years ago. As an alternative, it is more useful to focus on the intrinsic and more static elements of those landscapes prone to mass wasting.

RESEARCH DESIGN

Mass wasting scars were mapped in the field during the 1984 Langtang-Jugal Himal Expedition (traverse of 240 kilometers) and the 1987 Manaslu-Ganesh Himal Expedition (traverse of 300 kilometers). Each mass wasting scar was mapped within the "viewshed" as long as the location and degree of vegetation disturbance could be evaluated. The surveys included portions of the middle mountain, high mountain and high Himalaya physiographic regions as described in HMG/WESC (1987) (Figures 3.3, 5.1a-c). The middle mountain and high mountain physiographic regions are divided by the Main Central Thrust (MCT). The MCT is a major lithologic, metamorphic, and structural discontinuity (see Chapter 3 in this volume). Below the MCT are found low grade, argillaceous and calcareous metasediments. Above the MCT are found high grade arenaceous metasediments, but with an inverse metamorphic gradient. The MCT is the only indisputable thrust fault within the Himalaya (Schelling 1987). In the field, kyanite is often found immediately above the MCT, an aid to mapping.

Several site characteristics were recorded for a total of 272 mass wasting scars. Slope aspect was recorded, but slope gradient could not be measured accurately from a distance or from topographic maps. The lithologic-structural setting of each scar was noted, using direct observation where the scar could be inspected. Otherwise, reference was made to the 1:200,000 scale French geologic map (Colchen et al. 1980) of the Annapurna-Manaslu-Ganesh region or the 1:1,000,000 scale map produced by the Nepal Department of Mines and Geology (1980). In terms of the origin of the scar, a simple classification as "natural" or "human-caused" was used, following the simple criteria of Laban (1979). If the scar was located in a forest or was undercut by a river, it was placed in the natural class. If the scar was located in cleared or cultivated land, or could be attributed to road construction, it was classed as human-caused. This classification has some inherent ambiguity as it is possible to have a natural mass wasting event in disturbed areas, thereby overstating the extent of human-caused mass triggers. Meteorological variables were ignored in this study; Caine and Mool (1982) have noted this isn't a limiting factor. Poor seismicity records prevented analysis of this variable as a control on the spatial distribution of mass wasting.

The 1:63,360 Indian Topographic Survey maps were consulted to analyze rates of mass wasting. This hard to acquire map series was published in the early to mid 1960s, but is based on 1:80,000 aerial photos from 1957-1958. The mass wasting scars are mapped, affording a baseline for calculating rates. One must assume, however, that the mapping is comprehensive and accurate. Unfortunately, historical aerial photos are not readily available for the study area to allow our own direct measurements.

REGIONAL ANALYSIS OF MASS WASTING

Middle Mountain Physiographic Region of the Manaslu-Ganesh Himal

The middle mountain physiographic region of the Manaslu-Ganesh Himal is situated below the MCT, so the bedrock is dominated by phyllites, quartzites, and garnet mica schist (Figure 5.1a). The combination of these lithologic units with the hot-wet climate and dense vegetation has led to deep weathering and a rounding of slope breaks by soil creep. Slope gradients range up to 30 degrees. Stream undercutting is locally important as a trigger to debris slides along major rivers (e.g., Marsyandi, Buri Gandaki).

High Mountain Physiographic Region of the Manaslu-Ganesh Himal

The high mountain physiographic region of the Manaslu-Ganesh Himal is underlain by a medium- to coarse-textured augen gneiss (Figure 5.1b). This lithology is structurally more competent, providing the framework for the prevailing cuestaform topography. The cuestas dip to the north, leading some to speculate that the topography is the surface expression of thrust sheets. Slope breaks are sharp between the dip slope and scarp slopes. Irrigation drainage from the dip slopes is sometimes discharged onto the scarp slope, triggering debris slides. The angle of dip

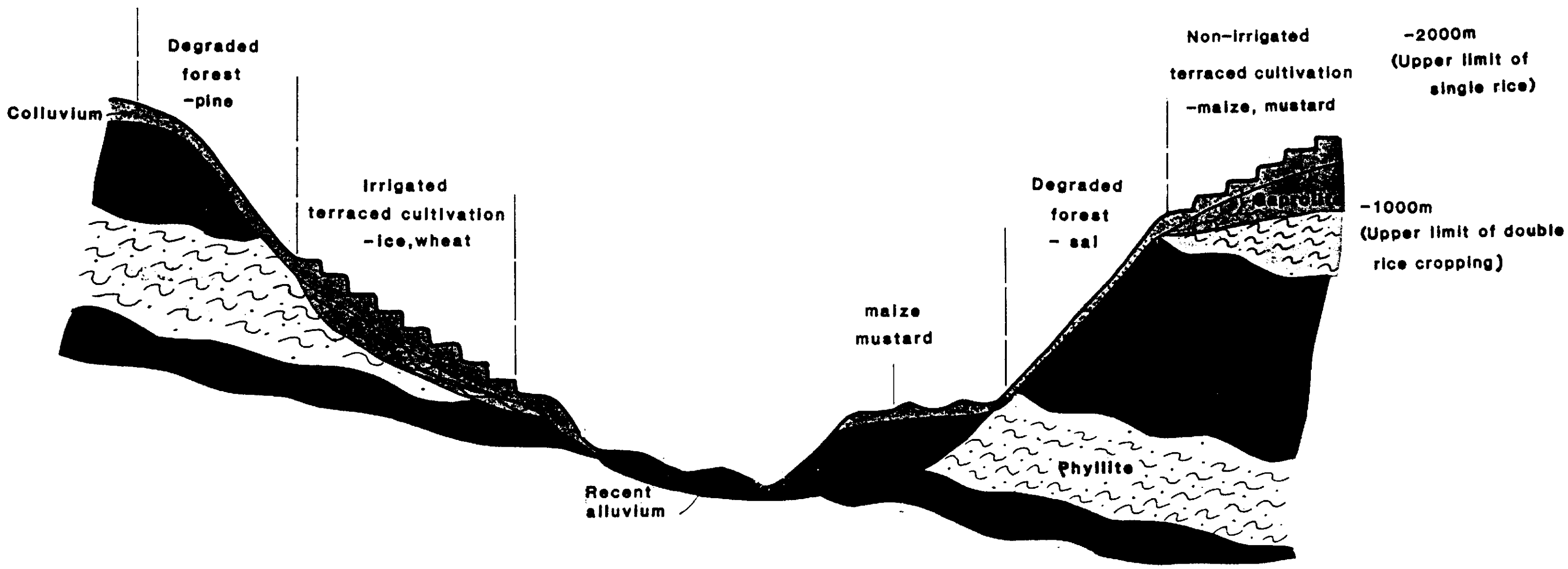

Figure 5.1a. Geology, topography, and land use in the middle mountain physiographic region (HMG/WESC 1987).

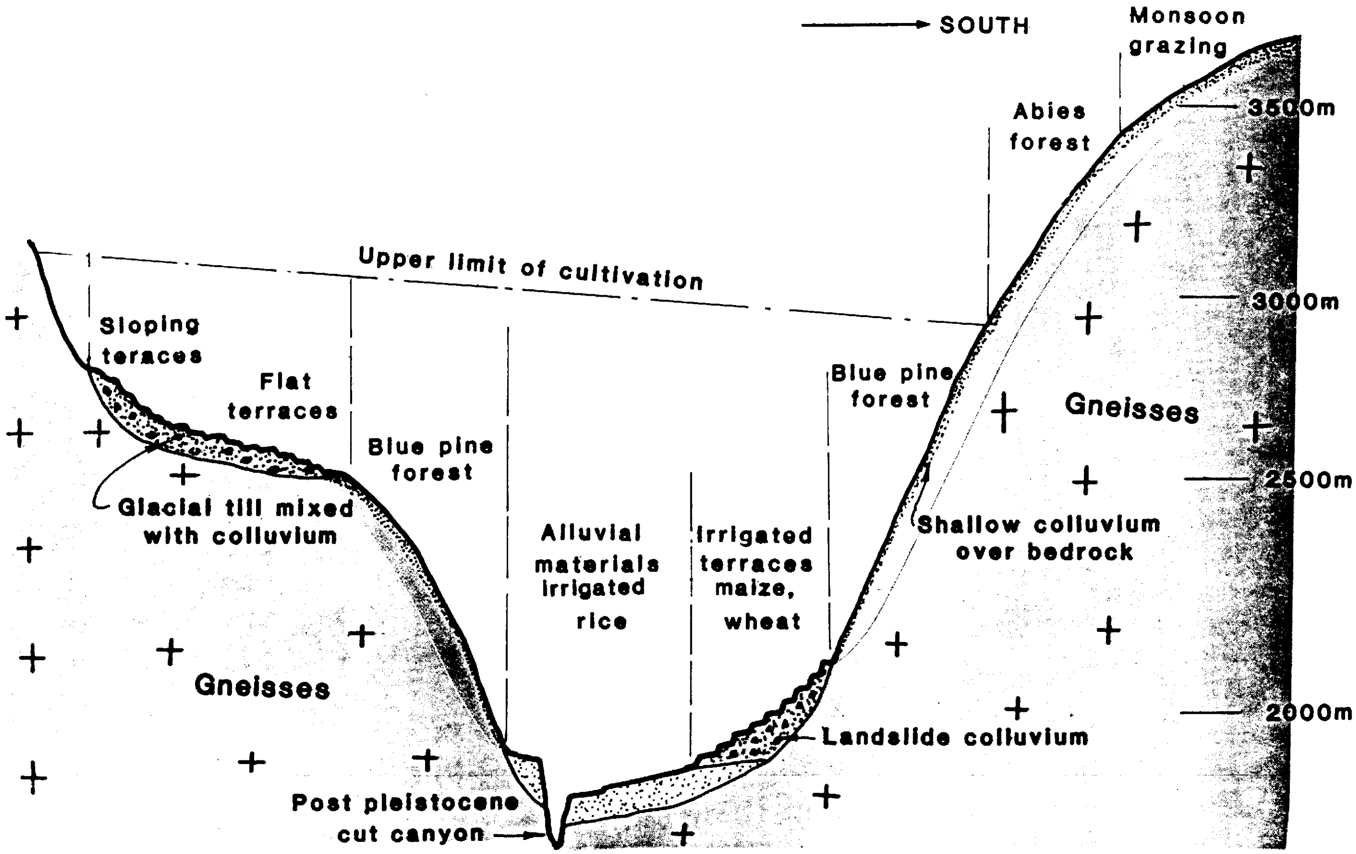

Figure 5.1b. Geology, topography, and land use in the high mountain physiographic region (HMG/WESC 1987).

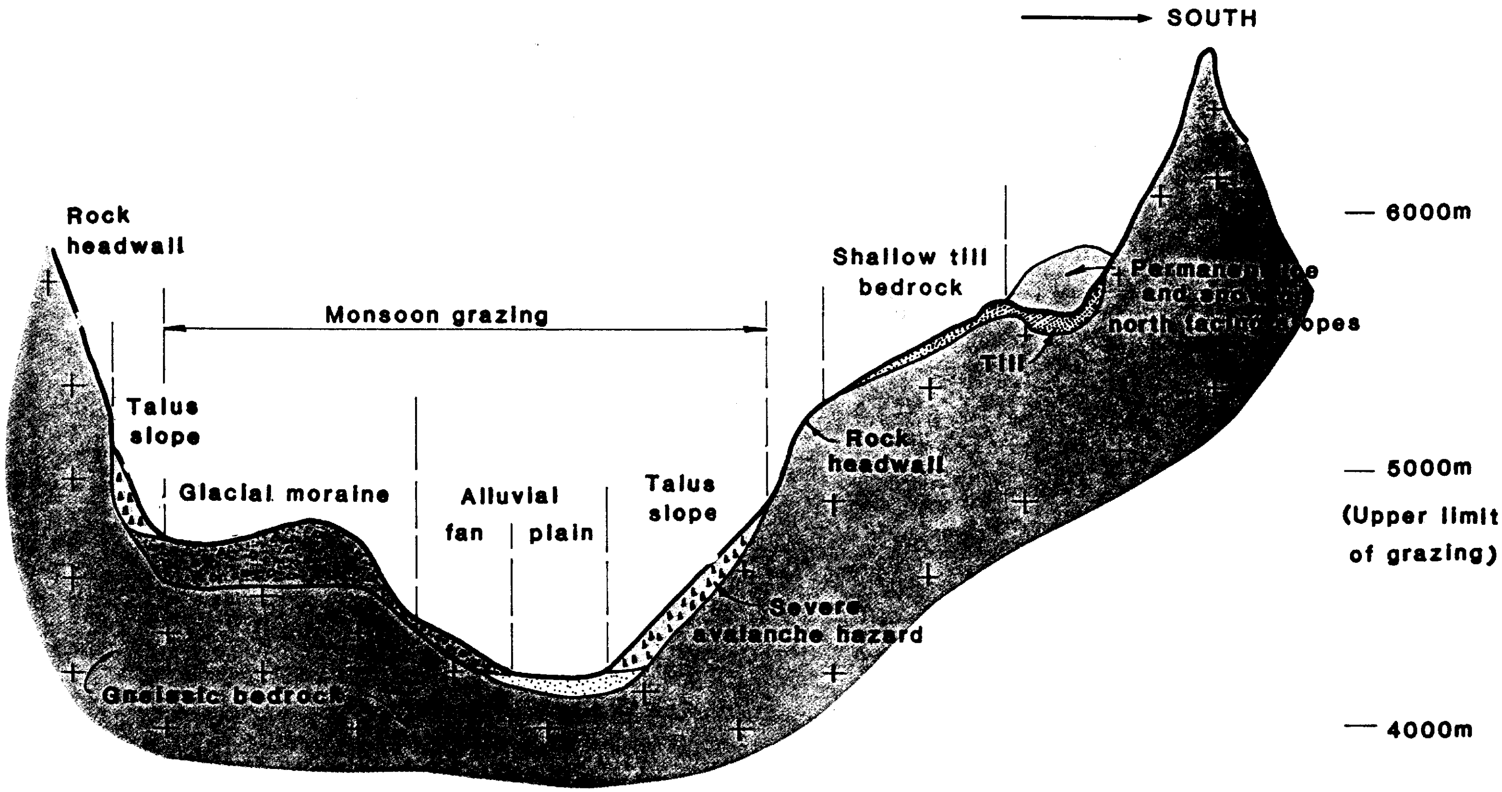

Figure 5.1c. Geology, topography, and land use in the high Himalaya physiographic region (HMG/WESC 1987).

increases as one moves from south to north. At higher elevations, the dip slopes become excessively steep and soils are more shallow, with abundant evidence of ancient and modern debris slides.

Middle Mountain and High Mountain Physiographic Regions of the Langtang-Jugal Himal

The middle mountain and high mountain physiographic regions of the Langtang-Jugal Himal are mantled with loess probably derived from the Tibetan Plateau. Deep-seated slides and slumps are the dominant form of mass wasting in undisturbed situations. Deforestation and poor control of terrace drainage (as discussed above) are more important here in triggering mass wasting than in the Manaslu-Ganesh Himal (Figure 5.2).

High Himalaya Physiographic Region of the Manaslu-Ganesh and Langtang-Jugal Himals

In the high Himalaya physiographic region of the Manaslu-Ganesh and Langtang-Jugal Himals, frost action generates huge talus cones and felsenmeer, especially along fractures (Figure 5.1c). Slopes at elevations above 3000 meters have been oversteepened by glaciation. It is common to find near vertical slopes with local relief in excess of 2000 meters. A sheeting structure was identified in gneissic and granitic bedrock which may contribute to massive block slides. What may be the largest slide in the world in crystalline rock has been reported by Heuberger et al. (1984) in Langtang. An estimated mass of 10 cubic kilometers was displaced along a fault plane. The sliding surface generated fused crystals. Quaternary age glaciers in Langtang have removed or buried 60 to 75 percent of the deposits from this event.

STATISTICAL ANALYSIS OF MASS WASTING SCARS

The chi-square statistical procedure was used to test several hypotheses regarding the spatial distribution of the 272 mass wasting scars. In each test, the division between classes was normalized by the percent of the study area sampled that occurred in each class, a key procedure that was not followed in all past studies. The first hypothesis could be stated as follows:

H_o: No difference exists between slope aspect in terms of the frequency of mass wasting.

Figure 5.3 illustrates the difference between the observed frequency of mass wasting and the expected frequency of mass wasting (i.e., the frequency if mass wasting was equally distributed between slopes of different aspect). The data reveal that mass wasting on south-facing aspects was more frequent than expected. This aspect is on the windward side of summer monsoon storms and receives the most direct solar insolation. Therefore, soils may be subject to numerous wet-dry cycles which can contribute to mass wasting. In addition, abandoned land on south-facing slopes is not as quick to revegetate. The calculated chi-square value was 71.78, greater than the critical chi-square value of 24.32 for seven degrees of freedom (i.e., eight different slope aspects) at $p < 0.001$. Therefore, we reject the first hypothesis and conclude that mass wasting does vary with slope aspect.

The second hypothesis regarding the spatial distribution of mass wasting can be stated as follows:

H_o: No difference exists between lithologic-structural units in terms of the frequency of mass wasting.

Figure 5.4 illustrates that mass wasting is more frequent than expected below the MCT and less frequent than expected above the MCT.

Figure 5.2. Debris slide near Tarke Ghayang, Helambu District, caused by discharge of irrigation drainage from terraced fields onto a scarp slope in the loess mantled slopes of cuestas. Photo by R.A. Marston.

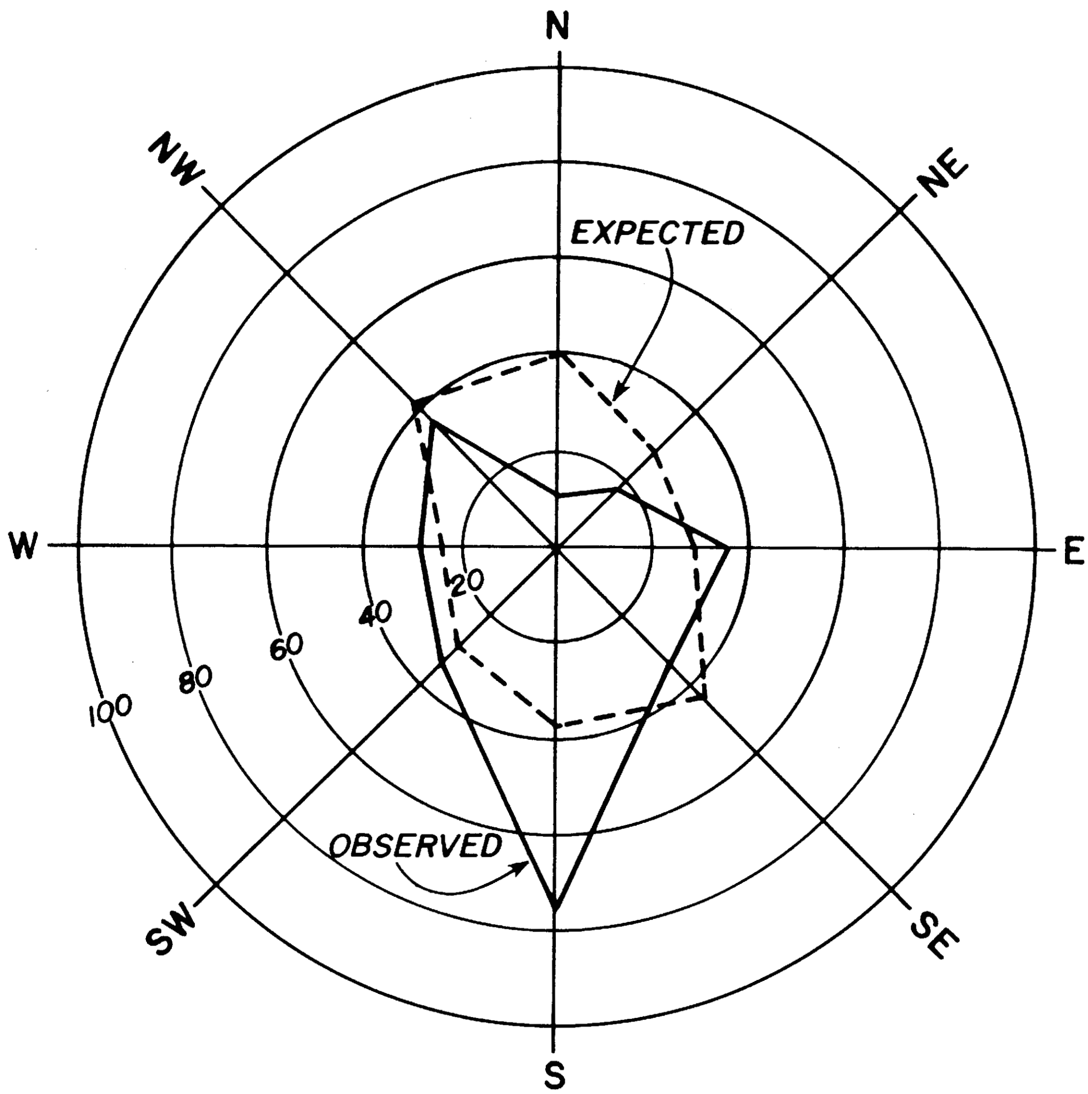

Figure 5.3. Observed and expected frequency of mass wasting by slope aspect.

The deeply weathered gneiss above the MCT appears to be more susceptible to piping and gullying than to mass wasting, confirming the findings of Brunsden et al. (1981) from studies in eastern Nepal. The calculated chi-square value was 39.06, greater than the critical chi-square value of 10.83 for one degree of freedom at $p < 0.001$. Therefore, we reject the second hypothesis and conclude that mass wasting does vary with position above and below the MCT. No significant difference could be found between the phyllites, shales, and schists below the MCT.

The third hypothesis can be stated as follows:

H_o: No difference exists between disturbed and undisturbed landscapes in terms of the frequency of mass wasting.

Figure 5.5 illustrates that mass wasting is more frequent than expected in undisturbed areas and less frequent than expected in disturbed areas. The calculated chi-square value was 10.99, greater than the critical chi-square value of 10.83 for one degree of freedom at $p < 0.001$. Therefore, we reject the third hypothesis and conclude that mass wasting does vary with the degree of disturbance, but opposite to the trend often reported for other regions of the world. Does this finding mean the vegetation is unimportant? It is necessary to distinguish between shallow and deep-seated forms of mass wasting. On unvegetated slopes, mass wasting is smaller and more shallow. Larger, deeper slides occur independent of vegetation cover. Moreover, human activities do account for a disproportionate share of mass wasting in some settings, poor road construction and trail disruption of slopes being the most notable. Clearcutting or poor drainage from terraced fields onto loess-derived soils or steep slopes with shallow soils (especially in the cuestaform topography of the high Himalaya) also leads to accelerated mass wasting. Nevertheless, these data help refute the assumption that human activities greatly increase sediment production from mountain regions of Nepal. This notion can be attributed to studies of the effect of clearcutting around the Pacific Rim, revealed by the review of Sidle et al. (1985). They found that long-term rates of mass wasting in clearcuts were 7.8 times greater than in forested areas. Also, mass wasting from individual storm events were 17.1 times more frequent in clearcuts than in forested terrain. Our observations were that terraces can serve to stabilize slopes, especially with "kari" type terraces that include a bund to control downslope water movement.

Comparison of our field maps with the Indian Topographic Survey maps reveals that the largest mass wasting scars have expanded in the last three decades. In forested areas, the density of mass wasting has exhibited a 100 percent increase. Regardless of the causal factors involved in trigerring mass wasting, one must consider the role that climate change may have played in this expansion (see Chapter 8). In disturbed areas, a great increase in road-related mass wasting is also most evident. There is no doubt that slopes in the Manaslu-Ganesh and Langtang-Jugal Himals are evolving very rapidly, as observed by Thouret (1981).

CONCLUSIONS

This study has identified a few of the key terrain and land use variables that can explain the spatial distribution of mass wasting scars in the central Nepal Himalaya. Some indication has been provided of just how dominant mass wasting is as a modern geomorphic process in the evolution of hillslopes in the region. The study demonstrates that human activities **do not** account for a disproportionate share of mass wasting, contrary to a large number of references in the scientific literature and in the media linking deforestation with mass wasting. Deforestation is occurring, although the style and extent varies from one region of Nepal to the next. At the same time, devastating mass

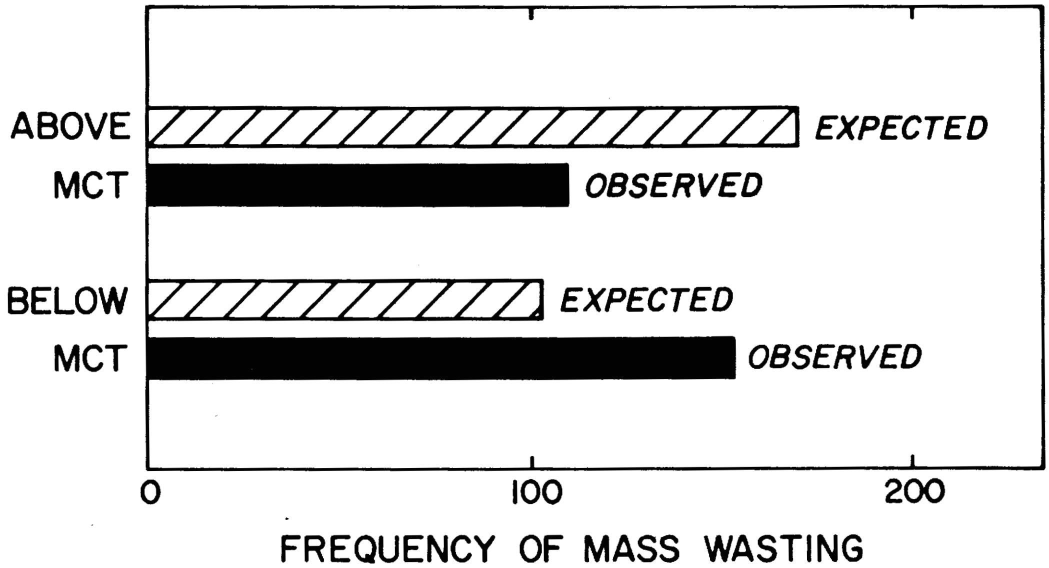

Figure 5.4. Observed and expected frequency of mass wasting by lithologic-structural unit.

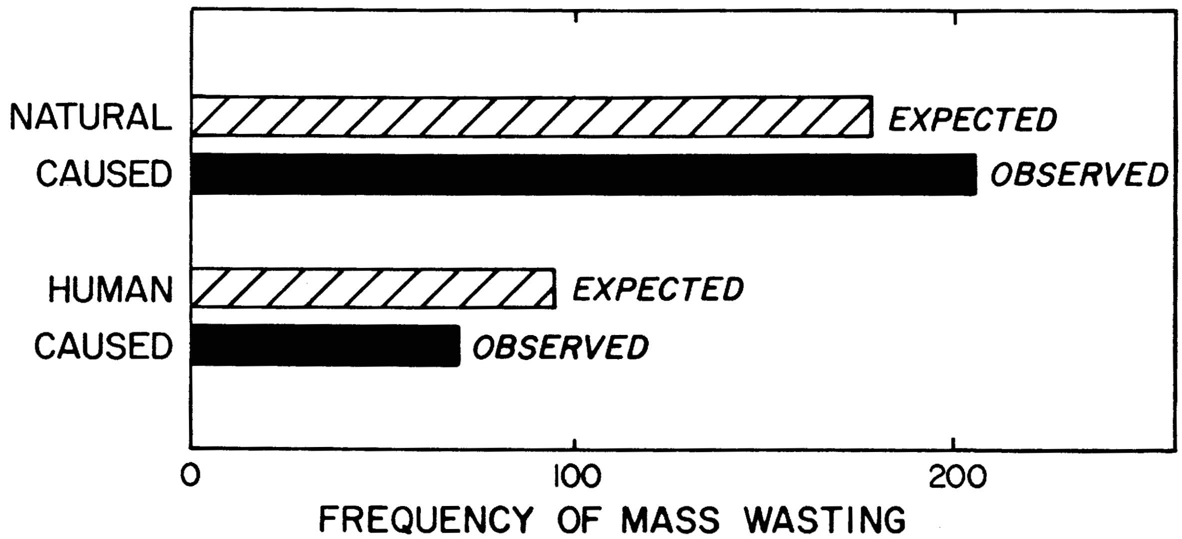

Figure 5.5. Observed and expected frequency of mass wasting by degree of landscape disturbance.

wasting is occurring, but the great leap in logic linking these two phenomena cannot be supported by the data in this study area.

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6. SEDIMENT PRODUCTION IN A SMALL SUBALPINE WATERSHED OF THE MANASLU HIMAL

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B. Kaltenborn, D. Fredericks, J. McConnell, and G. Miller

Much of the attention regarding sediment production in subalpine watersheds has been focused on the spectacular influence of mass wasting, with less attention paid to the processes of land surface erosion (sheetwash, rills, gullies) and sediment storage in interfluvial areas. This emphasis may be justified in undisturbed forested watersheds of the temperate regions of the earth where land surface erosion is rare (Price 1981, Sidle et al. 1985). In the Nepal Himalaya, however, the environmental conditions of tremendous local relief, long duration monsoon rainstorms, and land degradation can combine to produce surface runoff on hillslopes with concomitant erosion, transport and deposition. The complex links between land use and land surface erosion in the Himalaya have been outlined conceptually by Rieger (1981)(Figure 6.1), but quantitative data describing these links are very sparse and in general disagreement (Carson 1985). Consequently, tolerable rates of soil loss have not been established in subalpine regions of the Nepal Himalaya, hindering effective land management. In addition, incorrect estimates of sediment production in the past affect existing and proposed water development projects such as reservoirs, run-of-the-river hydropower projects, irrigation headworks, and river control projects (HMS/WESC 1987). Finally, overstating the importance of sediment production may contribute to regional misunderstandings between Nepal and the lowland countries of India and Bangladesh who suffer from the impacts of aggrading stream channels (Ives and Messerli 1989). An analysis of denudation rates for large watersheds compiled from stream sediment data sheds little light on the upland sources of sediment. Our state of knowledge regarding sediment production in the Himalaya is summarized by Ives and Messerli (1989, p. 98-99):

> TheHimalaya-Brahmaputra-Ganges-Indus system is one of the world's most dynamic mountain-building and sediment transfer systems, processes that have continued unabated over recent geologic time and will likely continue into the future. These processes, the endogenous tectonic-isostatic activity and the exogenous, climatic-weathering-hydrological ones, have created an unstable landscape of the utmost complexity. Given the massive scale of relief,...and the enormous variations in climate, vegetation, and topography, and the variability of major geomorphic events in time and space, the present data base is completely inadequate for determination of actual rates of activity of the various processes affecting the land surface. Thus, determination of the impacts of human intervention, including deforestation, land-use changes, and manipulation of water flow, and their differentiation from the natural processes as a proportion of the total rate of change, is not possible.

RESEARCH DESIGN

The objective of this study was to calculate rates of land surface erosion and volumes of sediment stored in a small subalpine watershed of the Manaslu Himal. The study catchment has a total area of 3.07 hectares was located below Camp 7 ("Rain Camp") for the 1987 expedition (Figure 6.2). The elevation of this catchment ranged from 3566 meters at the outlet to 3658 meters at Camp 7. The rolling terrain is covered with a variety of deciduous shrubs and small trees, dominated by rhododendron. The soil texture

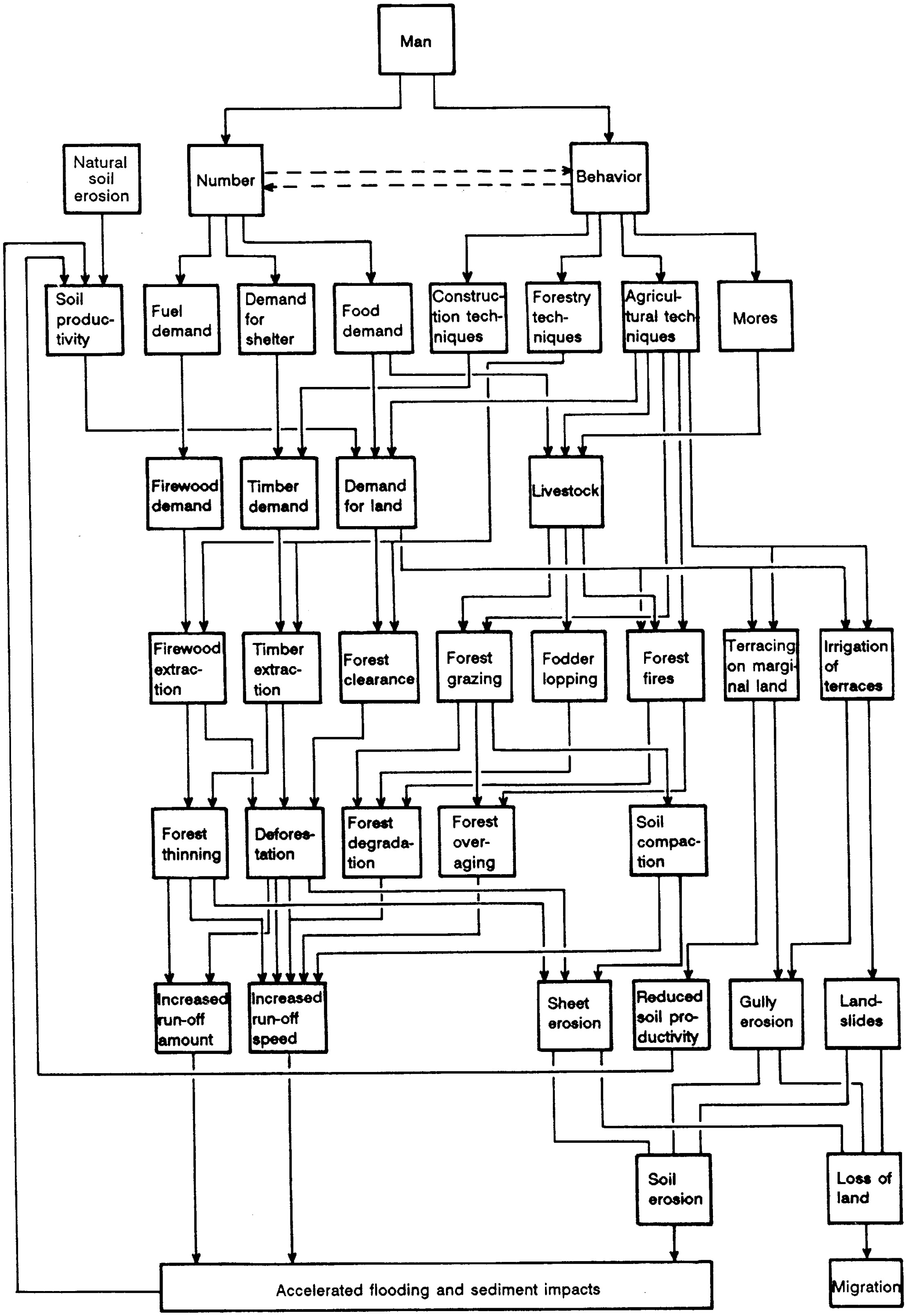


Figure 6.1. Human intervention in sediment production from the Nepal Himalaya. Source: Rieger 1981, p. 354.

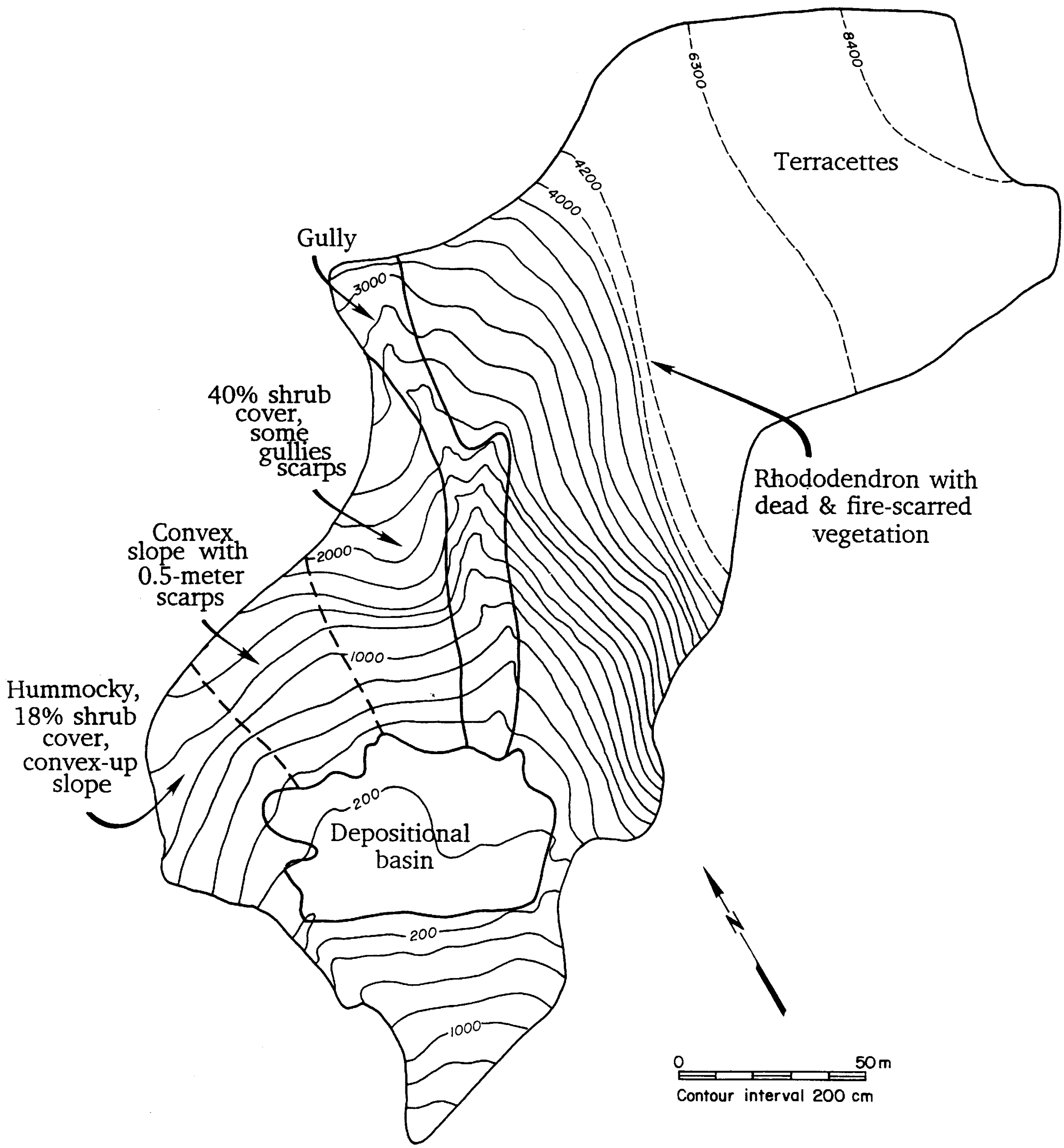


Figure 6.2. Topographic sketch map of the study watershed.

on the hillslopes is predominantly sandy where soil can be found. A prominent gully originates on the north perimeter of the watershed and empties into a depositional basin near the outlet of the watershed. This grass-covered basin has an area of 0.28 hectares and serves as seasonal pastureland for livestock. We have speculated that this basin may have formed as a nivation hollow during glacial periods. A poorly developed drainage system is present at the western end of the basin, but the surface deposits in the basin do not exhibit evidence of mobility. Small alluvial fans protrude into the basin, further indication of stability of the deposits. Numerous fire scars were evident on the hillslope vegetation. The assumption was made that the sand layer was deposited in the basin after a fire in the watershed which destroyed the protective vegetation.

A topographic map of the watershed was compiled by levelling and the watershed was divided into several geomorphic units (Figures 6.2-6.3). A detailed survey of the gully was undertaken for the purpose of calculating the volume excavated by erosion. The gully was divided into 22 reaches, with calculations of mean width, mean depth, and length for each (Figure 6.4). A total of 89 soil pits were dug in the depositional basin. Throughout the basin, a layer of uniform sand was found above clay which had been subject to gleyification by a seasonally fluctuating water table. The thickness of the sand layer was recorded in each pit for the purpose of calculating the total volume of sand deposited in the basin. In pit #69, a layer of charcoal was discovered between the sand and clay and was sampled for radiocarbon dating.

RESULTS

An isopleth map of thickness of the sand layer was compiled. The area between successive 10-centimeter isopleths was measured, yielding a total volume of sand in the depositional basin of 1050 cubic meters. The volume of the gully was calculated to be 959 cubic meters. If no material was exported from the basin, then the difference of 91 cubic meters had to be derived from sheetwash and rill erosion on the hillslopes. The sediment yield coming from the portion of the watershed outside of the depositional basin is 376 cubic meters per hectare (37,600 cubic meters per square kilometer).

The charcoal sample taken from pit #69 yielded a ^{14}C date of 127 +/-0.9 years B.P. The sample was processed by the Radiocarbon Dating Laboratory at Washington State University and is based on the Libby half-life (5570 +/- 30 years) for radiocarbon, with a zero age date of 1950. Thus, the charcoal would have been produced in 1823. The sediment production cited above can be now be restated as a time rate of 2.29 $m^3/ha/y$ (229 $m^3/km^2/y$), or a denudation rate of 229 mm/1000 years. Expressed in units of mass, the sediment yield would be 5.72 tonnes/ha/y (572 tonnes/km^2/y). These would be considered low rates of sediment yield and denudation when compared to data for degraded land elsewhere in the middle and high mountain physiographic provinces of Nepal and lower than rates for large tropical rivers elsewhere in the world (Carson 1985, HMG/WESC 1987, Ives and Messerli 1989). Sediment yield generally declines as watershed area increases because of the increased role of sediment storage. Moreover, it is likely that the rate calculated in this study, averaged over 164 years, does not represent the actual timing of sediment delivery to the depositional basin. The sediment production may have been compressed into just a few years. Also, some of the sediment may have been exported.

CONCLUSIONS

This cursory examination of a small subalpine watershed disturbed by fire demonstrates that sediment can be mobilized by fire, but the time rates of sediment yield are difficult to state with precision. Moreover, a significant portion of the sediment derived

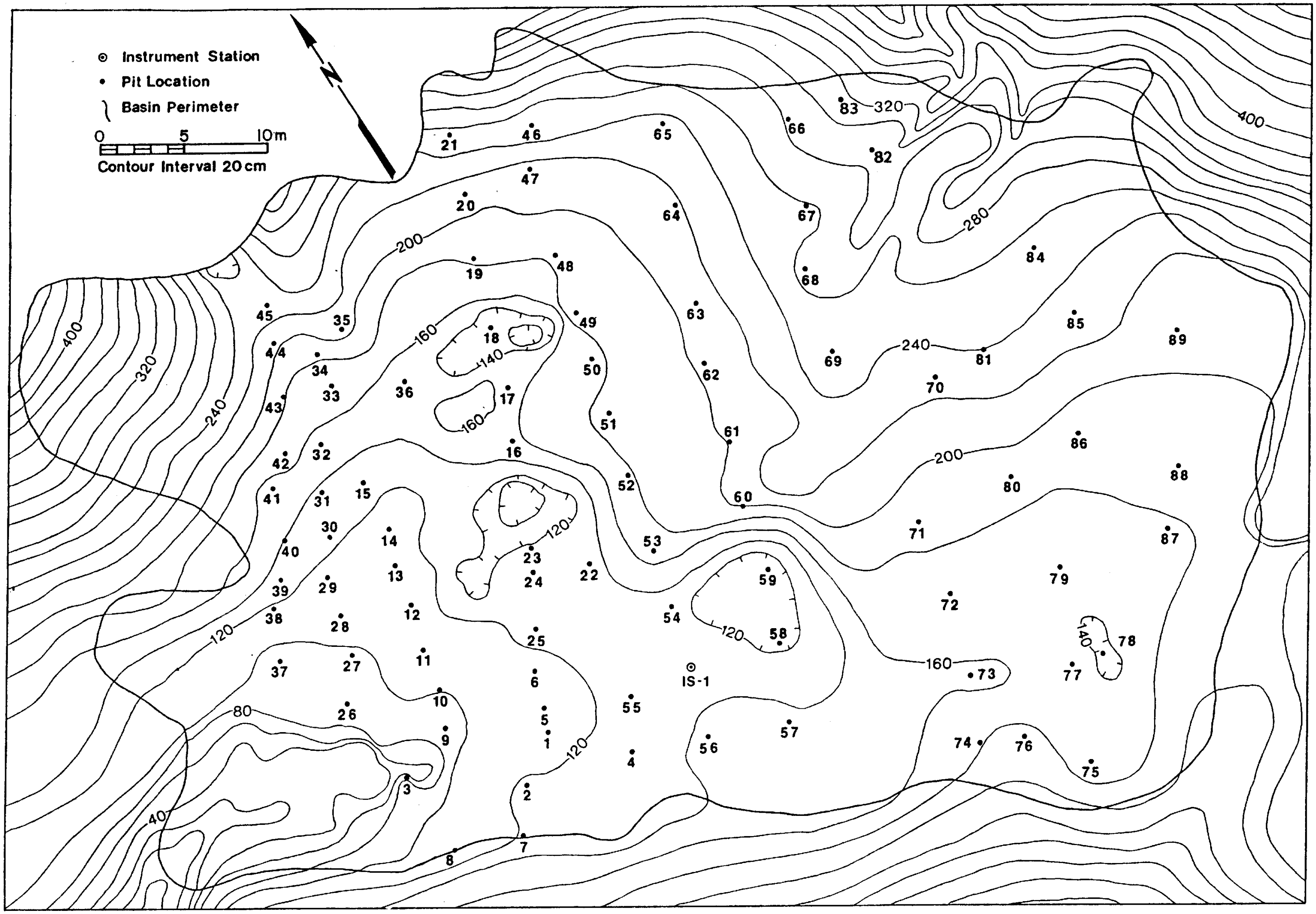
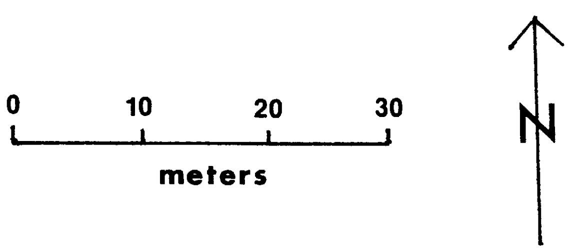


Figure 6.3. Topographic and geomorphic map of the depositional basin. The location of soil pits is also shown.

Reach	Length (m)	Mean W (m)	Mean D (m)	Vol. (m^3)
1-2	5.88	3.32	0.38	7.42
2-3	6.31	3.83	0.52	12.57
3-4	3.72	3.51	0.70	9.14
4-5	6.10	3.42	0.99	20.65
5-6	3.96	2.80	0.88	9.76
6-7	5.18	3.57	0.75	13.87
7-8	5.94	3.92	0.73	17.00
8-9	6.25	4.37	0.73	19.94
9-10	8.38	5.90	1.17	57.85
10-11	8.53	7.30	1.74	108.35
11-12	14.48	7.13	1.87	193.06
12-13	2.74	3.92	1.16	12.46
13-14	5.94	5.48	1.40	45.57
14-15	7.47	5.79	1.45	62.71
15-16	9.45	3.66	0.94	32.51
16-17	11.89	4.75	1.67	94.32
17-19	3.66	17.83	0.85	55.47
19-20	13.56	6.71	1.08	98.27
20-21	13.26	6.24	0.78	64.54
12-22	20.12	1.41	0.83	23.55

TOTAL VOLUME OF THE GULLY = 959.01 m^3



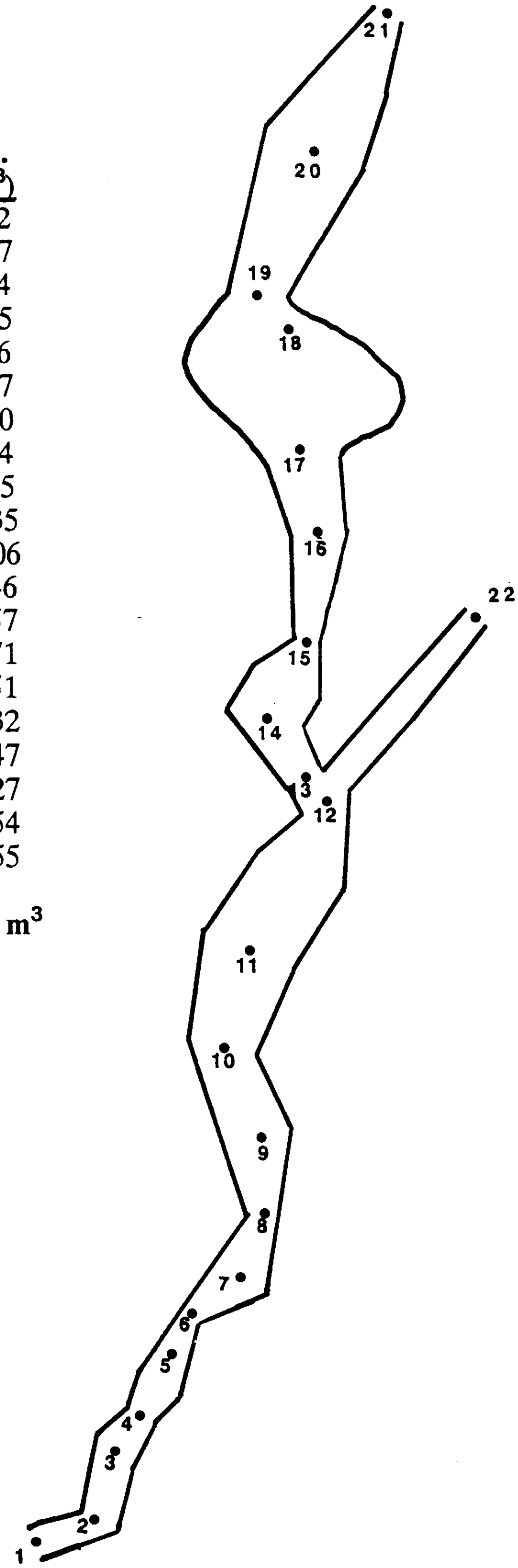


Figure 6.4. Gully survey data.

from hillslopes can be stored in meso-scale topographic depressions without reaching channel systems. Each watershed will respond differently to environmental change, whether by natural processes or induced by humans. Additional studies of sediment budgets are needed in geographically distinct watersheds in order to better characterize the natural and human controls on soil loss.

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7. GLACIAL RESPONSE TO CLIMATE CHANGE AND EPEIROGENY IN THE NEPALESE HIMALAYA

M.M. Miller and R.A. Marston

The extent of Pleistocene and modern glaciation in the Manaslu and Ganesh Himals involves questions of teleconnection. Regionally, this concerns the comparison of ancient and existing glacier-climate patterns along the 3000 kilometer length of the Himalayan chain (Figure 7.1). On a world basis, it relates contemporaneous fluctuations of ice masses in other great ranges on other continents. Globally, comparisons can be made with counterparts in the western hemisphere, including the Alaska-Canada Boundary Ranges Miller 1951).

In this consideration, our premises are as follows:

1) Himalayan Pleistocene glaciation limits (Ostrem 1966) reflect world-wide cooling prior to the Holocene,

2) climatic fluctuations of the Quaternary were attended by changes in atmospheric circulation across southern Asia, and

3) the effect of recent epeirogeny on glaciation in the Himalaya should be considered, with evidence sought to demonstrate it.

To address these questions, reconnaissance field observations will be discussed relating to 250 kilometers of the Himalaya in Nepal, between Manaslu, the world's eighth highest peak at 8156 meters, and Mount Everest, the highest at 8848 meters (Figure 7.1).

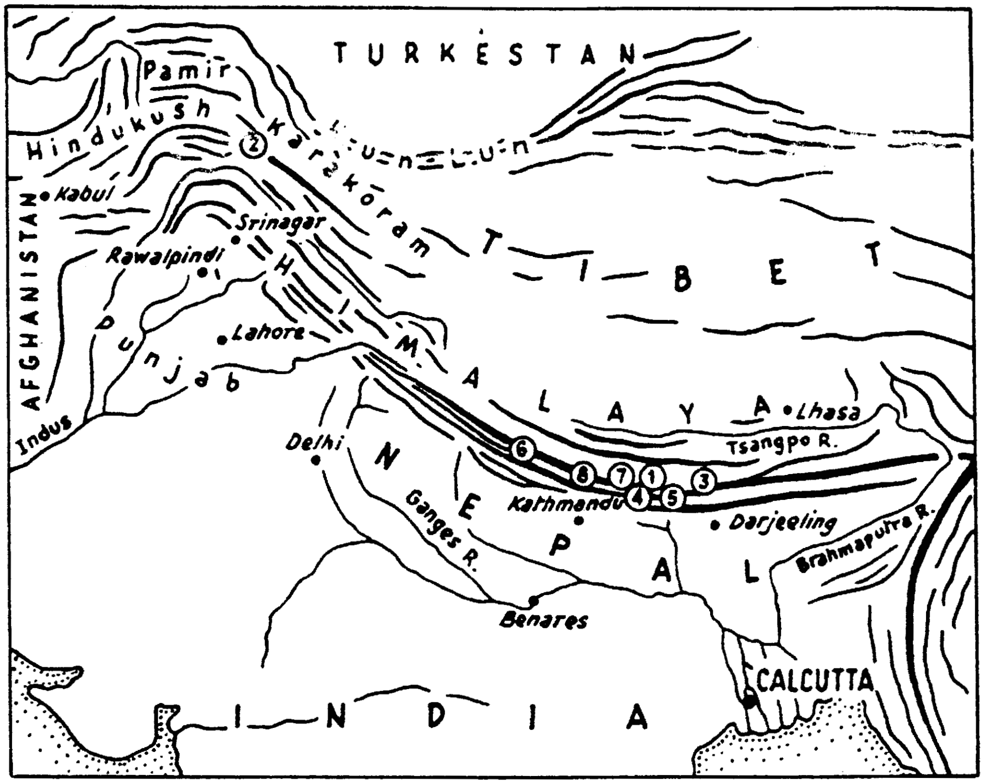
Other aims of this report are to assess the character of both ancient and modern glaciers on the southern flank of the Manaslu and Ganesh Himals, and to compare this with the Langtang and Khumbu districts lying to the east. This may assist in assessment of future changes in existing ice masses in headwater areas of trans-Himalayan rivers.

Political restrictions on the Tibetan border in 1987 prevented us from entering areas north of these ranges, so we concentrated on the southern flank of the Manaslu and Ganesh Himals. Plans also were altered because of a 100-year October snowstorm above 3960 meters. This precluded some of the planned high-elevation glaciological studies, especially mass balance measurements. Therefore, we invoke relevant records from our Langtang and Khumbu investigations of 1984 and 1963.

The glaciomorphic areas visited in 1987 are noted in Table 7.1, listing camp locations, elevations, routes travelled, and key physiographic and climatic notes. Reference is also made to the maps in Figures 1.1 and 7.2, showing areas of traverse in 1984 and 1987. The latter map focusses in sectors where we accomplished reconnaissance glacial geology in the Manaslu and adjoining Gorkha Himals. To the east, our route extended to the Buri Gandaki canyon and on to the road head in the Trisuli Gandaki valley (Figure 1.1). Described next are features encountered in the western part of the 1987 traverse.

THE MANASLU GROUP--MAIN GLACIAL FEATURES

Cirque-headed valleys and bold moraines characterize headwaters of the Dordi Khola and Chepa Khola drainages (Figure 7.2). Here evidences of former glaciation are most pronounced in the vicinity of Camp 8 (3900 meters), above Camp 9 (2840 meters) south of Manaslu, and in the Gorkha Himal in trail areas from Camp 12 (3660 m) to Camp 13 (4150 m) and Camp 14 (3260 m). There was



THE GREAT HIMALAYAN AND KARAKORAM TECTONIC ARCS
with Position of the Worlds Eight Highest Peaks

①	Mount Everest (Chomolonga)	29,028 ft.
②	K2 (Godwin-Austen)	28,253 ft.
③	Kanchenjunga	28,168 ft.
④	Lhotse	27,890 ft.
⑤	Makalu	27,790 ft.
⑥	Dhaulagiri	26,811 ft.
⑦	Cho Oyu	26,750 ft.
⑧	Manaslu	26,638 ft.

Figure 7.1. Great Himalayan and Karakoram tectonic areas.

TABLE 7.1. Location and terrain character for 31 camps during 1987 expedition.

Camp No.	Date	Location	Elev. (m)	Terrain Character
1	11 Oct	3 kms W. of Gorkha	500	Afforested ridges; broad, irrigated rice fields; maize, mustard, bananas
2	12 Oct	Chepe	610	Irrigated terraces, single rice crop per year, monkeys seen on trail
3	13 Oct	Phalenksangu	720	Marsyandi Khola; sal forests; heavily used trekker route (Annapurna circuit), leeches
4	14 Oct	Taksar	1620	Ridge route west of Chhangdi Khola; maize and wheat terraces, ridgetop camp, leeches, guest lectures at school (grades 1-7)
5	15 Oct	N. of Sandha	2230	Blue pine, rain forest, leech area, potatoe terraces, leeches, hot & humid
6	16 Oct	Bara Pokhri	3050	Open Abies forest; relict nivation basin containing small lake; goat and sheep grazing area; kyanite schist, MCT zone, religious pilgrimage site in July-August for festival
7	17-20 Oct	Rain camp	3860	Gneiss and schist outcrops, relict nivation hollows, stable felsenmeer; timberline with deciduous shrubs (incl. rhododendron); old burn area; monsoon grazing area for goats and sheep
8	21-24 Oct	Meme Pokhri approach	3900-5030	Gneissic outcrops, timberline, talus and felsenmeer, bold lateral moraines to 3430 meters, upper limit to monsoon grazing, C-1 to C-4 shallow cirque area on S. facing slopes, transient snowline at 4000 meters
9	25 Oct	W. of Dordi Khola Valley	2840	Dense Abies forest, canyon topography, mass wasting scars
10	26 Oct	Tanje Valley	1590	Open ridge on slopes above Dordi Khola, barley and millet terraces, some potatoes

TABLE 7.1. Continued.

Camp No.	Date	Location	Elev. (m)	Terrain Character
11	27 Oct	E. of Dordi Khola	3080	Open forest, sheep and goat grazing, relict nivation hollows, stabilized talus and felsenmeer, large burned-out cedar stumps; terracettes from comination of solifluction, livestock, action of needle ice on terracette scarps, sheetwash important
12	28 Oct	Burn camp	3660	E. side of Dudh Pokhri ridge, timberline burn area, grass slopes, monsoon grazing area, stable felsenmeer, lower edge of C-1 cirques, more terracettes
13	29-30 Oct	Dudh Pokhri approach	4150	Access to C-1 through C-3 cirque floor levels, large Pleistocene lateral moraine, large block felsenmeer, rhododendron forest on moraines, 6 bold recessional moraines above 4000 meters
14	31 Oct	Sheep camp	3260	Heavily glaciated, terminal moraine at 2900-3200 meters at lower edge of cirque
15	1 Nov	W. of Chayachak	2600	Mixed grassland and cedar forest below 3000 meters, transitional to oak-rhododendron forest, mass wasting scars
16	2 Nov	Barpak	1920	Open grass slopes
17	3 Nov	Laprak	2200	Sparse forest area
18	4 Nov	Karlak	1680	Barley and wheat cultivation, irrigated terraces, single season rice
19	5 Nov	E. wall of Buri Gandaki gorge	1590	Oversteepened slopes, dense forest, mass wasting scars
20	6 Nov	Kasigaon	1890	Convex slopes above gorge, oversteepened with minimal cultivation, some barley and single season rice
21	7 Nov	Yarsa	1520	Open grass slopes, afforested gullies; maize, wheat, single season rice on steep terraces

TABLE 7.1. Continued.

Camp No.	Date	Location	Elev. (m)	Terrain Character
22	8 Nov	Bamboo camp	2750	Abies and bamboo forest zone
23	9 Nov	NE of Khading	1980	terraced ridges, open slopes, mass wasting scars, barley and wheat cultivation
24	10 Nov	Tir (N. of Burang)	1830	Above Ankhu Khola near junction with Manjor Khola; maize, wheat, single season rice terraces
25	11 Nov	N. of Sherthung & Tibling	2070	On Linju Khola; potatoes, barley, single season rice
26	12-13 Nov	Hot spring camp	2680-	Upper Manjor Khola, monsoon grazing area, cedar and Abies forest, burn area, potatoes at 3000 meters, winter wheat, glaciated above 3660 meters
27	14 Nov	Near Linju	2800	Steep open slopes, afforested gullies, blue pine; maize, mustard, single crop rice fields
28	15 Nov	Burang	1680	Open broad slopes, wide terraces of single crop rice, maize and mustard
29	16 Nov	S. of Agathali	1560	Ridge area, cultivated terraces of maize, potatoes, mustard, mass wasting scars
30	17 Nov	Kimdang	1470	Terraced valley sides, mass wasting scars; barley, potatoes, maize, rice crops
31	18 Nov	Trisuli Bazaar	540	Two-season rice terraces, flood-water scars, mass wasting scars

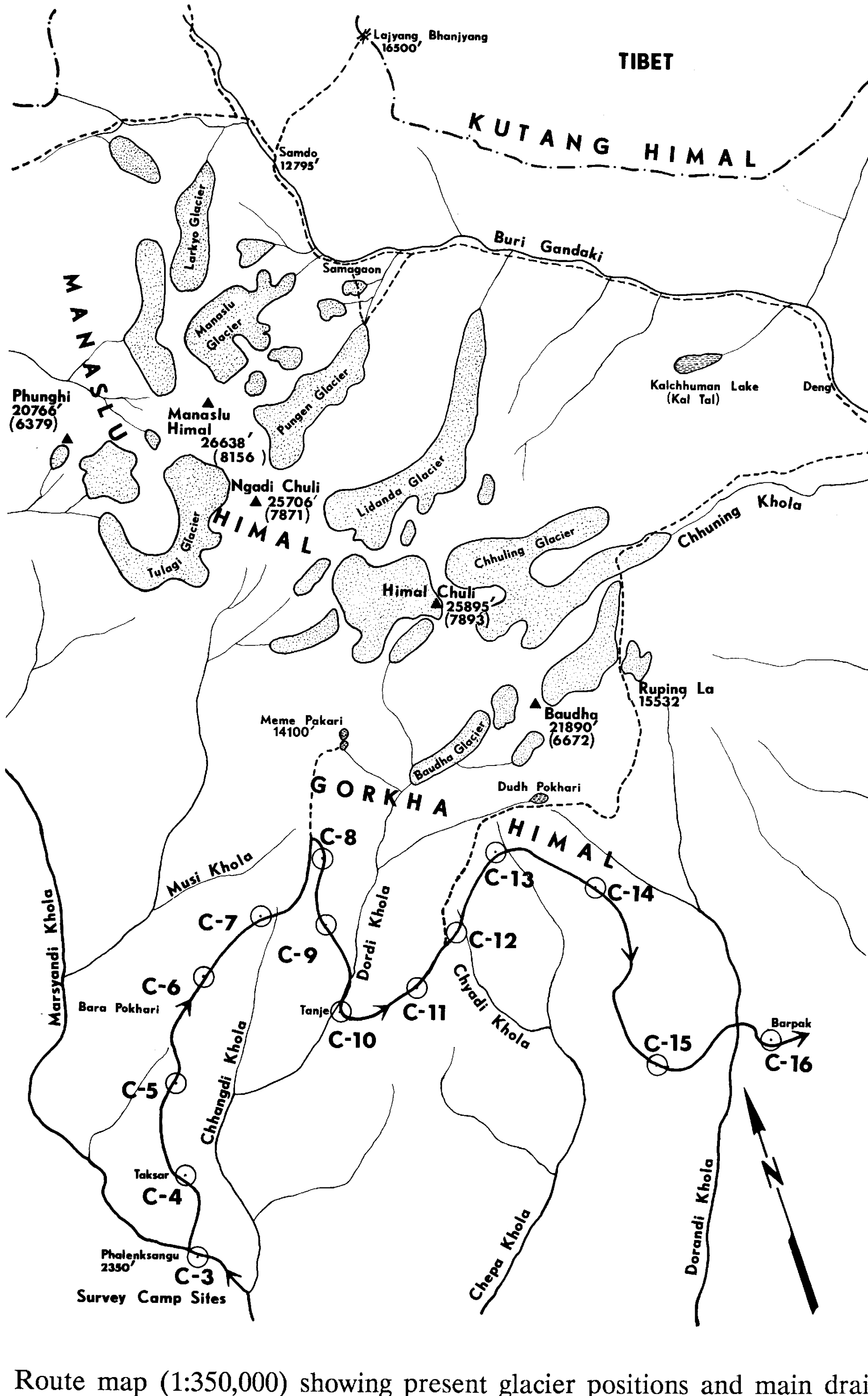


Figure 7.2. Route map (1:350,000) showing present glacier positions and main drainage network in the Manaslu and Gorkha Himals.

a local Pleistocene ice center near the Meme Pokhari lakes, which we approached along the lower half of the great south-trending ridge of Himal Chuli (7893 meters) and Baudha Peak (6672 meters).

The most extensive former glaciation originated near Dudh Pokhari Lake (Figure 7.2), south of which the mountain scarp is riven with multiple cirque depressions, each having been a source of local Pleistocene ice. Here spectacular lateral moraines, 60 or more meters high, plunge boldly down valley along the base of the mountain wall. Modest dissection of these, and ground moraines on the cirque floors, connotes that they represent very late Pleistocene fluctuations. Some may even relate to readvances in the early Holocene, 9000 to 10,000 years BP.

The map in Figure 7.2 also indicates the extent of existing high-level ice, all of which stems from healthy neves at or above 6100 meters. Most of these glaciers are substantially nourished by ice avalanches, making glaciological field work dangerous in those areas. Some of the south and west-trending termini, as on Tulagi and Baudha Glaciers, are active down to 2900 meters, though their lower sections are extremely ablated and debris-covered. On the Tibetan side, Manaslu, Pungen and other north-trending glaciers have large nourishment neves with strongly positive mass balances; and active termini down to 3660 to 4270 meters. In general, the north-facing glaciers are the healthiest.

The lower valley sections of glaciers which flow toward the northeast have experienced the most excessive down-wasting. Their terminal sectors are choked by angular rock fragments and finer debris completely covering the ice. On Chhuling Glacier, deactivation of the terminal section has allowed thick vegetation to grow on its outer moraines. Here the ice has thinned and in places become dormant. Multiple moraines at the snout indicate that there was vigorous Neoglacial activity, followed by accentuated ablation, especially in the past 40 to 50 years. A heavy concentration of supraglacial debris covering the lower glacier is due to intensive mass wastage by rock falls off oversteepened cliffs in the upper reaches. This is a common characteristic of low-reaching glaciers in the Himalaya today. Significance of the widespread down-wasting of these lower termini will be considered again at the end of this chapter, and in Chapter 8.

FELSENMEER, NIVATION HOLLOWS AND ABANDONED CIRQUES

On the Himal Chuli ridge, near Camp 6 (3050 meters), Bara Pokhri Lake lies in a ridge-top depression which is considered a relict nivation hollow (Figure 7.2). In late-glacial and early Holocene time it would have contained perennial snow, a view strengthened by the former glaciation limits found at comparable elevations on the mountain front to the east. Other ancient nivation hollows occur at and above 3350 meters. One is the 3660 meter ridge-crest catchment basin filled by solifluction debris and recent sheetwash alluvium described in Chapter 6. In the area of that basin today, and at comparable elevations throughout the traverse, active solifluction terraces and related vegetation tussocks abound. This demonstrates that soil creep is still a dominant mass wastage process in the Himalaya.

In the Camp 6 to Camp 8 sectors there was particularly strong solifluction development, and slopes characterized by large Pleistocene felsenmeer and vegetation-stabilized talus. Mature lichen crusts on the rock blocks connote at least early Holocene if not late Pleistocene age. Timberline felsenmeer also abound in the Meme Pokhari sector above Camp 8. Also here there are bold Pleistocene moraines on south-facing slopes. Because of the precipitous terrain, these old moraines are close to the present glacial position, although some extend down to 3350 meters.

Between Camp locations 7 and 14 (Figure 7.2; Table 7.1), there is an array of shallow ice-abandoned cirques. These are not as well-formed as classic cirques in high mid-latitude mountain regions, indicating more recent development. The approximate mean floor elevations are diagrammatically shown in Figure 7.3. Lower cirque levels are chronologically older. The top level may not be the highest or the youngest in the region. It was simply the uppermost observed in this sector.

Numbering of cirque levels is arbitrary, as it is not known how this sequence may relate to a continuum at higher elevations in other south-facing areas. Undoubtedly, higher cirques occur. In this connection, it is of interest that the lowest abandoned cirques we have seen in south-facing slopes in the Khumbu Himal lie at about 4570 meters. This circumstance, however, may relate to greater Quaternary uplift in the eastern Himalaya region. This subject will be explored further at the end of the chapter.

At this time it should be noted that our observations were conditioned by the terrain circumstances encountered on this particular traverse. Therefore, we do not consider them fully representative nor details as complete as we would like. Extreme variations in relief and difficulties in getting back-up aerial photography are problems in Himalayan field work. We are confident, however, that the connection with phases of former glaciation is valid.

In the broad mountain front depressions which we identify as cirques, down-valley bedrock thresholds were also recognized, albeit some incompletely formed. In situations where tandem sequences were found there were cyclopean steps and headwalls. With more shallow cirques on steep slopes, estimates of mean floor elevations were often difficult and required special care. Again, however, the amphitheater character was not well developed, compared to those we have studied in the Boundary Range of Alaska-Canada (Miller 1961).

Where glaciated rock benches were structurally controlled by north-dipping metamorphic strata, we used caution to prevent misinterpretation of threshold characteristics and to calculate elevation differentials between cirque floors. As best we can determine, in the south Manaslu sector mean floor-elevation differentials average 130 meters, with a range of between 80 and 200 meters. This is about half the mean differential we have found on cirque-incised maritime flanks of the Alaska-Canada Boundary Ranges. It is also half that reported from the mountains of Norway, where well-developed tandem cirques likewise occur (Ljunger 1948). Both in Alaska and Norway the differential is represented by a surprisingly consistent 240-meter floor-level spacing. The fact that the Himalayan differential appears to be half this amount may argue for epeirogenic uplift during the Pleistocene. This is a tantalizing comparison, worth exploring in more detail.

Also in Alaska, the pattern includes nine separate levels. The lower five are ice-abandoned, and all are ascribed to phases of Pleistocene glaciation (Miller 1964a, 1976). If the Himalaya reveal more cirque levels than that, it could further support the uplift concept. This too could be addressed in more detailed studies.

In cirque analyses, questions always turn on what glacial stages the indicated phases represent; or to what extent are they a consequence of multiple stages? In this region, strong lichen cover, coupled with weak surface weathering on glacially overidden bedrock, and generally azonal soil development, all suggest the final overprint of glacial erosion to be late Wisconsinan. Also, the described immature development of these basins suggests that they experienced greatest evolution during and/or after mid-Wisconsinan (Wurm) time. This significantly contrasts to an early Wisconsinan or pre-Sangamonian (Riis-Wurm) initiation, as

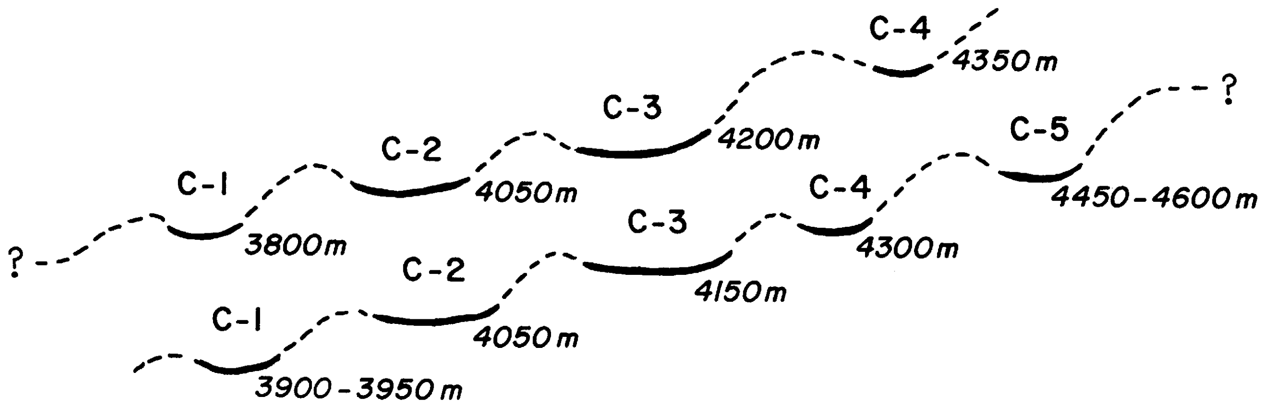


Figure 7.3a. The array of cirque levels in two different locations between Camps 7 and 14. Not drawn to scale.

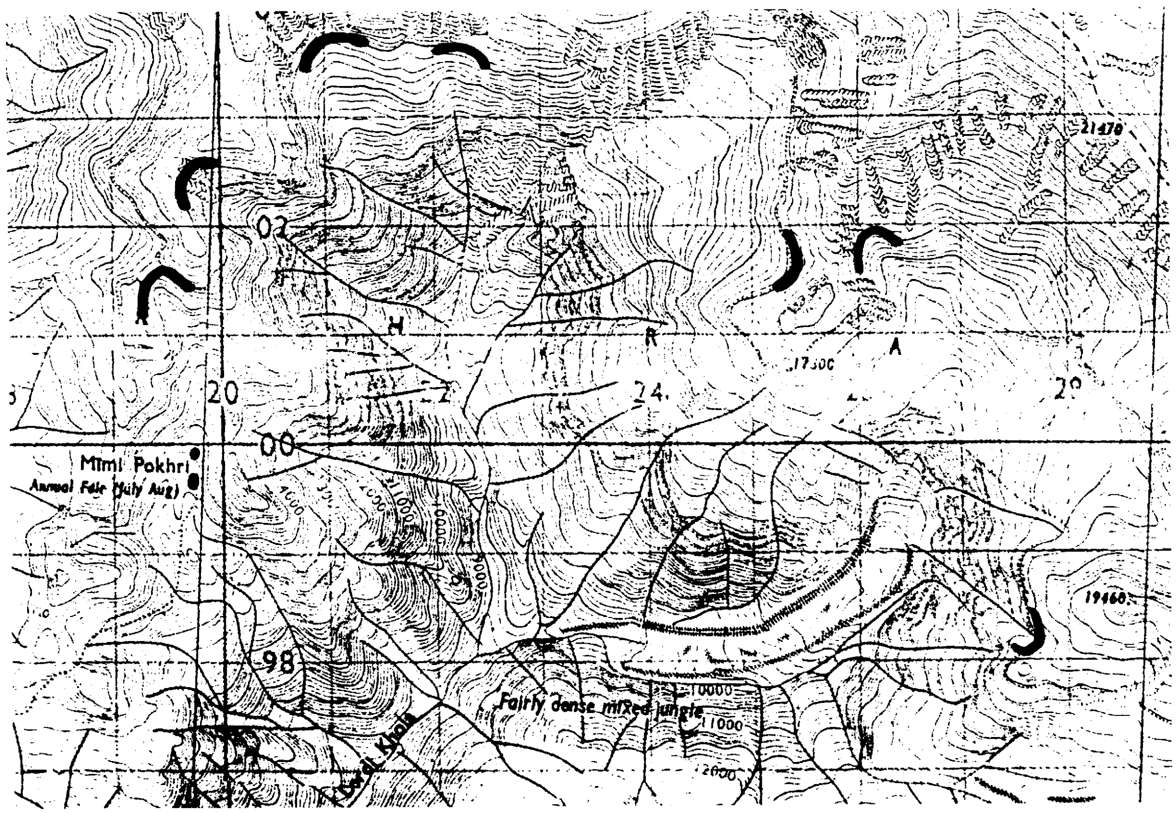


Figure 7.3b. Portion of 1:63,360 scale map from Indian Topographic Survey showing cirque development in the vicinity of Meme (also spelled Mimi) Pokhri. Only the highest level cirques are marked in this figure.

was probable in the better developed Alaskan counterparts. This inference is debatable, but it is mentioned in interest of stimulating further ideas.

Regardless of chronology, indisputable glacial erosion is shown by deep grooves and glacial striae on glacial pavements in gneissic bedrock in the Camp 8 and Camp 12 sectors. These occur at 3510 to 3750 meters. Additional evidence in the Camp 13 area was provided by an abandoned multiple cirque of the C-3 system at and above 4210 meters. The highest clearly identified cirque in this area was a very shallow one at the C-5 level, or about 4570 meters. Without permanent ice, this cirque floor was covered with snow, a situation to be expected so close to the 1987 late autumn transient snowline. Later in the expedition, we observed prominent cirques at 4570 meters on westerly exposures at the head of Manjor Khola valley in the eastern Ganesh Himal. Instead of a five-fold sequence, we could delineate only three. The lower cirques had floor elevations of 4620 and 4460 meters.

Overall, the distribution pattern of cirque basins in this more easterly part of the transect was similar to that south of Manaslu and Himal Chuli. This supports the interpretation that in this region the best developed Pleistocene cirques are at the C-2 and C-3 levels. These also represent mean Pleistocene snowlines (equilibrium lines) for those glaciation phases. Supporting this contention was a large multiple cirque comprising the basin in which we located Camp 13 (Table 7.1). Here a C-3 basin was inset in the upper segment of a larger C-2 cirque. From a glacier which formerly descended out of this C-2 zone, a set of downward trending lateral moraines was deposited, partly on the floor of the larger basin. These terminate in an oversteepened frontal moraine below 3660 meters. This moraine was essentially unweathered and lacked post-glacial dissection. These criteria and absence of moraines outside of the basin lead to the conclusion that this moraine system is the oldest in this sector and that it was deposited in the late Pleistocene. Noteworthy too were extensive felsenmeer containing huge blocks of fragmental rock on slopes and ridges between these cirque depressions.

The most striking proof of low-level Pleistocene glacier thresholds in the southern Manaslu group was at Camp 14, southeast of Dudh Pokhari (Table 7.1). Here, in a large basin at the C-l level, with mixed cedar and grassland cover at 2900 meters to 3260 meters, there are particularly well-formed terminal moraines. To show the geographic context of this location and its variety of glacial features, we followed a sheep herder trail from Camp 13 along the crests of another set of steeply sloping lateral moraines. For several kilometers these extended downward to the east, passing below an adjoining area of ice-abandoned cirques at C-3 to C-5 elevations. Former glaciers from these, tandem fashion, nourished a wide shelving zone below. On its eastern edge this broad bench merges with the above-noted C-l basin. For map reference, this south-facing basin is east of the highest tributary of the Chepa Khola (Figure 7.2). Timberline reaches up to its lower edge which offers a broad opening four kilometers across.

The complex of late-Pleistocene terminal moraines in and below this prominent basin is well-delineated and hardly dissected. The outer terminal moraine parallels contours between 2900 and 3050 meters. It represents the lowest elevation former ice limit encountered on the southern flanks of the Gorkha and Manaslu Himals.

The ice which produced these lowest moraines was derived from C-1 to C-4 levels estimated at close to 4300 meters. Time prevented exploring these source areas which, of course, no longer contain ice, but a cursory assessment of the headwall sector of the main tributary valley indicated the presence of higher cirques. Below the main C-1 threshold, several subdued moraines suggest they were recessionals. Dominating the terrain are bold push moraines with intervening surfaces covered by ablation till.

On the lower edge of this main basin, exposed on the side of a shallow stream gully, a buried 10-centimeter organic silt horizon was sampled. The bottom of this gully was incised into hardened till and mixed colluvium on till. Dating of this sample by the Radiocarbon Dating Laboratory at Washington State University (WSU no.3863, 9-9-88) gives 1800 +/- 65 years BP. Overlying the organic deposit was a diamicton with mud-flow character. From this, presumably early Neoglacial conditions were wetter than present, probably causing local remobilization of some glacially-derived material.

MANASLU AND GANESH HIMALS--MODERN GLACIER POSITIONS

Locations of existing glaciers in the Manaslu Himal are shown in Figure 7.2. Most are extremely steep and heavily crevassed, especially Manaslu Glacier to the north, which descends precipitously through a spectacular icefall into an iceberg-filled proglacial lake. Glaciers which cascade off of Himal Chuli and Ngadi Chuli (Peak 29) are likewise healthy. These are all riven with crevasses, implying rapid flow. Positive regimes are also indicated in the upper reaches of all glaciers above 5490 meters. The western Himal Chuli neves above 6100 meters appear exceptionally healthy through abundant snow accumulation. Baudha Glacier also experiences vigorous discharge via strong longitudinal load stress from continually active avalanches. The severe storm of late October precluded close examination of these ice masses.

Later observation of the Paldol Glacier in the eastern Ganesh group, originating at a comparable 5790 meters, also revealed actively crevassed surface ice, and a terminus slightly readvancing and beginning to override old debris-covered stagnant ice at an elevation of about 4690 meters. The drainage waters from this glacier were milky, suggesting that basal slippage is taking place and that the glacial regime is probably positive. Other high-level glaciers in the Ganesh Himal were difficult for us to access from the south, but from binocular views those parts descending to lower elevation appear to have regimes comparable to the glaciers in the southern and eastern sectors of the Manaslu group. This included severely down-wasted and debris-entrained lower sections. In the Ganesh Himal, too, the largest glaciers and neve areas stem from high and protected north-facing slopes.

Related comments from our 1984 field work follow. These concern the Langtang and Jugal Himals, only 30 kilometers east of the Ganesh group.

GLACIAL CHARACTER OF THE LANGTANG AND JUGAL HIMALS

The western entrance to upper Langtang valley is 15 kilometers east of Syabrubensi (Figure 1.1). Only two kilometers down valley from Ghora Tabela, there is striking evidence of Pleistocene glaciation. Where the valley floor levels off at about 2740 meters, an undulating terminal moraine complex extends down into a hemlock and cedar forest. It exhibits moss-covered knob and kettle terrain. Angular gneissic erratics are thickly overgown with lichen, including abundant <u>Rhyzocarpon geographicum</u> and another similar grey lichen, all beyond dating size. From this we infer the moraine to be late-Wisconsinan, most likely 10,000 to 11,000 years BP. It could, however, be as early as middle Wisconsinan because we did cross over moraine segments in the lower sector where the glacial drift is somewhat obscured by forest litter. The area is certainly one worth further careful study.

As at Camp 14 in the Manaslu group, this is a relatively low elevation for large concentrations of Pleistocene glacial deposits. The explanation may be morphologic, relating to the 25-kilometer upper Langtang Valley, which drains an isolated upland at and above 3660 meters. The upland comprises a large area positioned between the inner Langtang and outer Jugal Himals. It was certainly a major ice center in the Pleistocene. As a source area it is expansive compared to the local center areas identified on the southern flanks of the Manaslu and Ganesh groups.

The upper Langtang Valley is characterized by a dramatic U-shaped form, framed by smooth ice-eroded bedrock cliffs. At the western entrance, the U-profile passes through a distinctive Pleistocene glaciation limit at 3660 meters. This dominating scour-line extends down valley to the knob and kettle moraine. The relatively unweathered nature of the scour zone supports the interpretation of a late-Wisconsinan age for the down-valley moraine.

At the village of Kyanjin another five kilometers up valley, the scour zone rises to over 3960 meters, or about 300 meters higher than the valley floor. Above this clearly identified limit the sheer bedrock surface is weathered, broken and serrated, testimony that it was never eroded by Pleistocene ice. This also supports contention that there are no earlier Pleistocene deposits down-valley from the Ghora Tabela moraine.

There is one more massive yet younger moraine system about four kilometers up valley, being also one kilometer down valley from Kyanjin. Here bold piles of till and fragmental boulders form ridges up to 50 meters high. There is extensive lichen growth on these boulders, too mature for lichenometric dating, but insufficient in development to.be pre-Holocene. Provenance of this moraine can be traced to the Langtang Lirung Glacier, further suggesting that its history post-dates the latest main valley Pleistocene stage. We, therefore, assign it an early Neoglacial age, about 300 years BP to as young as 250 years BP. On order of sequence this supports the late-Wisconsinan age of the Ghora Tabela moraine.

One kilometer farther up valley is the double end moraine of the modern Langtang Lirung Glacier. On these we measured the maximum thalli of Rhyzocarpon geographicum. Based on growth rates in the eastern Alps where similar dry continental conditions exist, we applied a C-factor of 10 nm/100 years (Beschel 1961). Up to 200 measurements were made at each location, with the distribution of thallir sizes plotted in Figure 7.4. From the resulting histograms the respective lichen dates for inner and outer moraines are 360 and 450 years. These fit the global Little Ice Age pattern. As the glacier is only three kilometers long its response to accumulation changes should be fast. The dates suggest that it did quickly reflect global cooling at the height of the Little Ice Age in the 16th and 17th centuries.

Over the last 30 to 40 years, Lirung Glacier has undergone abnormally high ablation and wasting of its terminal area. The ice surface is heavily crevassed and extremely dirty, with entrained debris and surficial detritus up to the main headwall in the source area. Numerous ice avalanches add to the accretion of frost shattered rocks.

Impressive flood deposits are associated with the early Neoglacial moraines just below Kyanjin. These are represented by prominent lag boulders in wide swashes. Presumably they came from breakouts of impounded water in or near Lirung Glacier. Also, on the south side of the main Langtang valley two prominent glacio-fluvial terraces characterize the valley floor. The lower one has degraded into a canyon several hundred meters deep, and is still being cut by the fast-flowing waters of Langtang Khola. Because of their size, these terraces are concluded to be the result of rapid deglaciation of Wisconsinan ice from the upper valley.

At the valley's far eastern end, 10 kilometers northeast of Kyanjin and at 4420 to 4570 meters, bold Neoglacial end moraines 80 meters high again dominate the landscape.

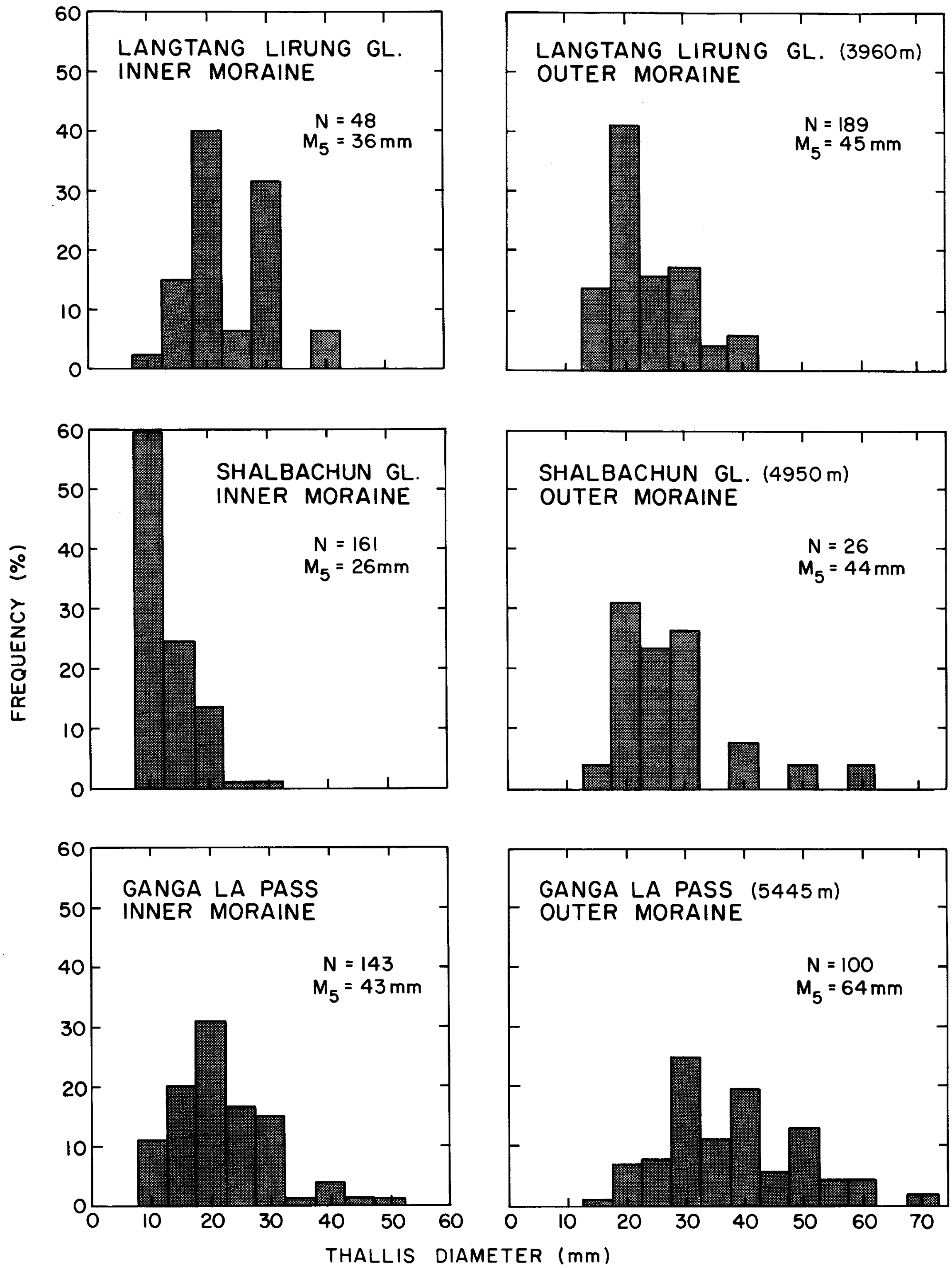


Figure 7.4. Histograms of thalli diameters for <u>Rhyzocarpon geographicum</u> on moraines in the Langtang and Jugal Himals. N = number of lichen thalli sampled; M_5 = mean of largest five diameters, utilized as an index size.

These are in a confluence zone of Langtang, Langshisha and Shalbachan glaciers. They are comparable in form and age to the Lirung Glacier moraines. Each has a heavily crevassed and debris-covered terminus. On Shalbachan Glacier the ice remains in frontal contact with its terminal moraine, which manifests bold inner and outer segments.

For these moraines, another plot of thalli diameters of Rhyzocarpon geographicum is presented (Figure 7.4). Based on growth rates previously discussed for dry continental alpine conditions, we compute dates of 260 years BP for the inner moraine and 440 years BP for the outer. These dates are again in line with ice advances during Little Ice Age time. The degree of vegetation cover is also consistent with Little Ice Age dates in other glacier regions of the world.

From teleconnectional inference, lower sections of the outermost Shalbachan moraine may have developed in the early Neoglacial. This would mean superposition by the Little Ice Age advances. The possibility arises from extremely large bulk of the moraine system and thick vegetation growth found on the moraine pediment. Alternatively, several modest moraines a short distance down valley might be a 3000 BP early Neoglacial counterpart of the 50-meter high Neoglacial moraine system at Kyanjin. Based on aspect, soil development and orientation, however, these are more likely early Holocene recessionals from main valley Pleistocene glaciation. In spite of these unresolved questions, it is certain that Shalbachan and Lirung Glaciers experienced prolonged and intense Neoglacial activity.

Farther to the northeast in the high valley head sector, debris-covered ice is found in the lower six kilometers of Langtang Glacier. This extends from 4420 meters to just below Tilman Col at 5670 meters on the Tibetan border. As with the above, intense down-wasting in this century has occurred, resulting in large segments of stagnant ice. Fresh appearance of the supraglacial rubble suggests that much of it ablated in the last 50 to 60 years. In binocular views we surveyed an upper glacier area subjected to incessant rockfalls from confining oversteepened cliffs, repeating the picture of concentrated supraglacial debris. By insulation this could actually have slowed down the ablation process on lower Langtang Glacier.

The neve areas above the equilibrium line on each of these glaciers appeared to be well-nourished and still healthy. Nearby and just across the border in Tibet we could see the majestic ice massif of Shisha Pangma (Gosainthan) at 8013 meters, with its great mantle of steep glistening ice and domed neves. This is the only 8000-meter peak in Tibet. As it must have been in the Pleistocene, today it is an important high-elevation ice center. This area ,too, is worthy of future geological and glaciologcial investigation. For the record, the current regimen of glaciers in this Tibetan sector, as throughout the upper Langtang valley, is Manaslu and Ganesh Himals.

To recapitulate, low elevation of the late-Pleistocene glacier limit (2740 meters) at the western end of the upper Langtang Valley is worth noting, as is the lack of observed evidence for any earlier glaciation threshold at lower levels to the west. Throughout this high valley there was an early Neoglacial episode of significant ice advance, indicated by terminal moraine complexes on the main valley floor. These were derived from tributary valley glaciers. There are also bold double-phased Little Ice Age moraines at the entrances of these side valleys, with greatly down-wasted ice still in contact with the inner moraines. From the fresh appearance of the ice-contact zones it is concluded that much of the ablation of late-Neoglacial termini has taken place in this century. Down-wasting seems to have been intensified during the past 40 years. Insulating effects from debris mantling has also resulted in large areas of stagnant ice in the far northeastern sector. These observations are pertinent to the interpretation of recent regional climatic trends, discussed in later pages.

South of Kyanjin, the 5180 meter Ganja La Pass crosses the crestal line of the Jugal Himal. On the high west side of this pass a glacier from the summit area of Naya Kanja (ca. 5790 meters) produced a double set of moraines at 5030 meters. The location is just below Ganja La, and in 1984 was close to the orographcial snowline. The cited moraines are within a half kilometer of the glacier's still-active ice front, which has a convex upward profile indicating a currently healthy state. Our lichenometric measurements of maximum thalli diameters of Rhyzocarpon geographicum are plotted in Figure 7.4, using the same method as previously described. The date of ice advance which resulted in the inner moraine is interpreted as 430 years BP. Similarly the outer moraine is dated at 640 years BP.

A 200-year pulsation interval seen here reflects the same interval as between the inner and outer Little Ice Age moraines on the glaciers at 4572 meters in the Langtang Valley, but with the outer moraine some 200 years "older". This makes us suspect that topographic and climatic factors may have given faster growth rates for lichen in the Ganja La sector. Was this by increased solar radiation at the higher altitude, or by more precipitation influence in the monsoon season at this more southerly and ridge-exposed location? Obviously further research is needed. Nonetheless, the Little Ice Age relation remains intact, in that the trend toward global cooling in the last half of Neoglacial time was well underway in the 13th and 14th centuries. So this could be the time of ice readvance suggested by these dates. However, because there are only two noteworthy moraines and they have the same time spacing as those in the Langtang Himal, we suspect there may be an explanation relating to a different C-factor dependent on altitude and relating to a different C-factor dependent on altitude and exposure.

Though our lichen measurements should be amplified by records from other recent moraines in the Himalaya, in broad Little Ice Age resurgence found on glaciers around the world. For some time we have felt that it is characteristic of most high-level glaciers in the Himalaya (Miller 1964b).

In the regional sense, our studies of recent lateral moraines at 5490 meters on glaciers of the Khumbu Himal in the Mount Everest area, provide a picture of related two-phase ice fluctuations. Details of those observations, and a description of the Khumbu Glacier's complex down-valley terminal moraine systems, are presented in the next section. This adds to the glacial history of the middle Himalaya, considered so far.

It is also appropriate to mention that the resurgence of glaciers in the Himalayan Little Ice Age carries the following important inference. As in Alaska and the Andes, glacier recession during the amelioration of the Thermal Maximum (8000 to 3000 years BP) shifted ice fronts some distance up valley from the positions they occupy today. It follows that with the mid-Holocene warming there also must have been an upward and probably northward shift of snowfall maxima to the crestal Himalaya. This set the stage for vigorous Neoglacial readvances.

In the long fugue of Quaternary climatic events, the same principle applies. A southward displacement of accumulation centers was compatible with pronounced cooling of the Pleistocene. This also connotes altered storm-track positions associated with that cooling. This premise is strengthened by the generally accepted northern hemisphere shift of circumpolar vortices to lower latitudes during periods of Quaternary cooling. In further support of this interpretation, a report on additional field observations and a discussion of Pleistocene glaciation in the Mahalangur (Khumbu) Himal follow.

MODERN AND ANCIENT GLACIER POSITIONS IN THE KHUMBU HIMAL

The problem of former glaciation in the Himalaya is intriguing, in view of the wide differences in elevation, character and extent of Pleistocene ice centers. Compounding this is a lack of evidence for any large-magnitude former ice sheets. In fact, in the region north of the Nepalese Himalaya there is no evidence of a discrete Tibetan Pleistocene ice sheet. The situation has an analog in the which throughout the Pleistocene was never glaciated. Similarly, in the northern reaches of the Khumbu Himal the lowest ancient moraines in the Rongbuk and adjoining valleys appear to lie betwen 4570 and 4880 meters, not far from the debris-covered Neoglacial and Little Ice Age termini of the East and West Rongbuk glaciers. To appreciate this more, note is taken of the significant south to north rise in regional orographic snowlines and glacier equilibrium lines (ELA's, as discussed in Chapter 8) from the south-facing Himalayan flank to the Tibetan slope. These, of course, are acutely controlled not only by elevation but by geographic position, topography and precipitation intensity.

South of the Khumbu Himal, in the valley of the Imja Khola and close to today's timberline, a remarkable series of late-Pleistocene lateral moraines reach down to 3960 meters. These are in the Pangboche to Pheriche area, where they line the valley flanks to heights of 100 meters. Being some of the most massive moraines in the Himalaya, they are immense compared to those described so far in this report. They represent bold limits of an extinct but once very active composite glacier system which formerly drained out of the Khumbu and other tributary valleys at the high center of the Mahalangur group.

The latest and highest of these old laterals passes beneath marginal detritus of modern moraines of the Khumbu Glacier, near its present terminus. The earliest segments in this sequence are found six kilometers down valley from the present ice, near Dingboche. They form a massive terminal moraine and outwash complex interfingering with outwash from the Nuptse Glacier and Mingbo valley to the east. Vegetation cover and weathering suggest that these moraines formed in the late Wisconsinan. They may be correlates of the Ghora Tabela moraine complex in the Langtang region. Down valley, six major fluvial terraces reveal a complex history of late Pleistocene deglaciation.

As for the character of the modern Khumbu Glacier, its frontal ice lies behind a mountain of fresh moraine. The inner ridges are probably less than 100 years old, hence far younger than the aforementioned system The glacier snout rests at the head of the broad outwash-filled valley above Pheriche. This is a summer yak pasturing ground at an elevation of about 4270 meters. The glacier's terminal moraine is multiple, with a dozen or more ridges boldly displayed. Its ice contact side is at 4880 meters. The base of the oldest (outer) section is at 4270 meters and from the size and maturity of lichen thalli it is interpreted as early Neoglacial. The situation is comparable to what we have described in the far northeastern group of Langtang glaciers at and above 4420 meters. In the up-valley direction, the modern Khumbu Glacier's terminal moraine area is two kilometers across, emphasizing its massive character and reflecting a healthy glacial regime during the Neoglacial. This represents a truly dominant glacio-climatic interval in this part of the Himalaya. It is noted again that the older moraines down valley are considered to be late Pleistocene in age.

This prompts several questions, which also can be asked concerning the upper and lower moraine complexes in the Langtang valley. Were the massive pre-Holocene moraines in the Khumbu valley part of a long sequence of normal ice retreat from some older down-valley Pleistocene positions, or do they represent a distinctly different glacial intervals.

Does this reflect a zone of former glacier concentration which shifted upward and northward in late Quaternary time?

In seeking an answer two things are clear. The highest parts of the youngest Pleistocene moraines are juxtaposed to present bodies of Neoglacial ice; and the ancient moraine system at Dingboche is separated by 20 kilometers from the southern limit of any possible Pleistocene ice limit in the down-valley area. Arguing against down-valley connection are the deep canyon cutting of the Imja Khola toward Thangboche and a lack of ice erosional or depositional features to the west that could be tied to a Khumbu Glacier provenance. Added to this is the deep entrenchment of the Dudh Kosi in a V-form canyon between Thangboche and Namche Bazaar.

The southernmost evidence of possible glacier-related Pleistocene events in the Solu Khumbu district may be found south of Namche Bazaar, near the village of Khari Khola. Attention is drawn to this because of probable alliance to a glacially-induced process with important environmental implications. This involves glacier bursts or catastrophic hydrological surges with devastating down-valley consequences. Such occurrences are common in the Himalaya, as they are in the Alaskan Boundary Ranges and in the glacierized southern Andes. They are often associated with extreme ablation of lower and intermediate elevation glacier areas producing ice and moraine-dammed lakes (Marcus 1960, Asher et al. 1974). They also can result from simultaneous advance and retreat of adjoining glaciers, causing impounding and conditions for sudden discharge (Nichols and Miller 1952).

The site of this discussion is at 2060 meters on the threshold of a hanging valley above the Dudh Kosi. Here terraces of winter wheat are cultivated in rocky soil. On slopes nearby slabs of metamorphic rock show signs of grooving. Our original view (Miller 1964b) was that this was a glaciated area. The impression was given by an irregular line of boulders and hummocks crossing the terraces, first suspected as an ancient moraine. If these features were, in fact, of glacial origin, the ice which produced them might have come from the hanging valley to the east. Since that original opinion, further information has been incorporated, including oblique aerial photography which we obtained in and that the Dudh Kosi valley has been repeatedly subjected to catastrophic glacially-related floods originating in the glacierized headwaters areas.

In this connection, the hurried schedule of our 1963 Everest expedition precluded enough time for an effective ground investigation of this problem. (This is the old story of conflict between science and mountaineering objectives on major expeditions. The two missions do not merge well unless divided into separate administrative and logistic units.) As a result, our initial impression of some large erratic boulders found as low as 1890 meters was that they may have delimited an old moraine. Now we believe they were flood-water deposited. It is clear that even at the present transport in Himalayan streams. This pertains, regardless of whether or not there is a glacial provenance.

Several kilometers up the Dudh Kosi to the north, near the village of Puiyan (2500 meters) and at the mouth of another side valley, there is further evidence. Here we found a concentration of huge erratic blocks of fragmental rock, their surfaces covered by a deep veneer of lichen and considerations and size and distribution of the blocks suggest torrential glacio-fluvial origin.

A short distance farther up valley, near the Chorten of Chaurikharka at 2530 meters, another massive debris complex occurs. This one curves into a terminal limit on an old fluvial terrace representing a former valley floor. Continuity of this feature has been destroyed by the deep post-glacial notch, through which the Dudh Kosi now thunders 180 meters below. This suggests some antiquity for this deposit. Also we originally considered to be glacial, but now interpret it as mass wastage and flood-related.

For some distance above this river-entrenched defile, indurated remnants of mixed boulders and fines appear in indurated remnants of mixed boulders and fines appear in non-sorted pockets clinging to the afforested wall. Their origin is debatable, but the geomorphic framework again suggests debris-torrent deposition. Some of the deposits hang 50 to 100 meters above the bottom of the gorge, the deposits have antiquity. As often pertains in reconnaissance situations, all of the deposits in this deep reconnaissance situations, all of the deposits in this deep valley deserve more detailed study.

The aforementioned location is 15 kilometers down valley from the Dingboche Pleistocene moraines. Keeping the option open that a nearby glacier could have been involved, attention is drawn to the presence of side canyons such as that of the Kyangshar Khola draining the Kangtega region. More probably, though, a flood water origin would have been from the Bhote Kosi, Kyajo Khola or upper Dudh Kosi drainages northwest and north of Namche Bazaar. These high tributary valleys are not only nearer than the Khumbu valley, but even now have ice and moraine-dammed lakes in their upper reaches.

As for relationship to possible Pleistocene glaciation in the valleys just above Namche Bazaar, the geomorphology indicates that any such glaciation would have been of a greater age than we feel confident in projecting for the Puiyan and Chaurikharka deposits. Part of the argument once more relates to the intensity of subaerial processes in this region of such high relief. These include maximum mass wastage effects shown by the abundant felsenmeers and extreme post-Glacial cutting of glacier-fed streams. For example in the high tributary valleys of the Dudh Kosi fluvial erosion has produced deeply inset V-form defiles. Also there is no indication of smooth-walled ice erosion and clear-cut upper glaciation limits, as so well displayed in the Langtang district. These factors alone indicate that any formative glaciation would have to have been well before even the middle Wisconsinan. In fact, they argue against the locations.

This brings up the question once more as to whether there is really any substantive evidence of early Wisconsinan (Wurm) or pre-Wisconsinan (pre-Wurm) glaciation in this part of the Himalaya. The lower forest moraine below Ghora Tabela in the Langtang district is too recent to give problems one faces in the Himalaya when trying to identify evidence of earlier Quaternary glaciation.

It is reemphasized that throughout the Dudh Kosi Valley the latest sequence of geomorphic events involved largely fluvial processes including lacustrine impounding. This is confirmed by the valley bottom debris-torrent deposits and by dissected layers of hardened gravel and remnants of lake clay. The range of deposits indicates a former environment of ice retreat and melting, and an oscillation of valley-head glaciers which created conditions for ephemeral self-dumping lakes.

The torrential character of some of the deposits also suggests that Jokulhlaups (the Icelandic term for glacier bursts after Thorarinsson 1940) produced them. Spoken history of the Sherpas tells us that even in this century catastrophic floods have occurred at irregular intervals in Solu Khumbu. A major one came out of the Imja Khola in 1977, doing damage for some 35 kilometers down valley. Another in 1985 affected the lower Dudh Kosi (Ives 1988). This latter one originated from breakout of a moraine-dammed lake on Langmoche Glacier, at the head of a high-valley tributary to the Bhote Kosi, which in turn joins the Dudh Kosi just below Namche Bazaar. This flood damaged much farmland in the lower valley, and washed out trails and bridges and even a small hydro-electric development near Namche Bazaar. The damage was severe for an additional 30 kilometers downstream, as far south as Chaurikharka, with further effects down river for 60 kilometers to the confluence of the Sun Kosi.

From many reports elsewhere in the Himalaya it is known that glacier floods are a serious geological hazard. Their causes are to be studied and understood, especially in areas where the results can be devastating to human activity. Their once even larger role in and near areas of former glaciation should also be appreciated. This can help explain the spectacular mudflow and turbidite deposits that we have seen in the foothill areas of the middle and eastern Himalaya. During the 1987 expedition, these deposits were conspicuous on Pliocene-Quaternary terraces which we crossed in stream valley areas between the Trisuli and Marsyandi kholas (Figure 1.1). Particularly striking examples occur in road-cuts near Gorkha and at the road head just south of Phalenksangu (see map in Figure 7.1).

This brings us back to the marked depression of paleoclimatic snowlines and the corollary of lower Pleistocene ice limits, as given by the elevation of ancient cirques and nivation hollows and the lowest terminal moraines we have cited for the great south Himalayan flank. In the Khumbu Himal this depression appears to be notably less than in the middle and western Himalaya. Even if we were to place a 3960 meter older Pleistocene ice limit the oldest Khumbu moraines end, this would not equate to the lowest found in the middle Himalaya, including the 2900 meter forest moraines at Camp 14 in the Manaslu group and the 2740 meter forest moraine below Ghora Tabela in the Langtang group. It is in even larger contrast to the 1220 meter mean glacier thresholds for Pleistocene ice found in the Himalaya of north India and the Karakoram, as documented later in this report.

Further to this consideration, the geography of the southern ice limits implies that maximum early glaciation in the Mahalangur Himal was asymmetrical to the south. With such increased thickening of ice south of the present glacial position, the reconstructed picture of Pleistocene glaciation in the Nepal Himalaya is seen as one of many ice centers, each with its own regime and fluctuation pattern dependent on altitude and geographical position. Each would also be characterized by polythermal conditions. This means that the highest areas were glaciothermally polar, grading through sub-polar to sub-temperate englacial temperatures at intermediate levels, and to temperate (0°C.) geophysical character at the termini of lowest outflow glaciers. The situation would be similar to that in the expanded icefield phase of morphogenetic glaciation in the Alaskan Boundary Range (Miller 1964b). It would also pertain to the situation in isolated sectors of the highest Himalaya today, where topography of the loftiest ridges and peaks control the positions of existing glaciers and ice centers.

From this model, we conclude that during the late-Glacial maximum there was a series of partially connected mountain-valley glaciers. They were far more extensive than today, but with substantial areas of intervening bedrock spurs and broad ridges. This resulted in numerous regional icefields throughout the Himalaya, and myriads of small cirques on flanking slopes. These separate outflow glaciers produced the diverse terminal positions that we have seen. This picture is in contrast to the view of a connected ice-flooded Pleistocene landscape with contiguous ice-sheets.

DISTRIBUTION AND PROVENANCE OF HIMALAYAN LOESS

On low-angled rock surfaces, such as exposed ridges in the foothills areas, numerous deposits of loess occur. These are undoubtedly Pleistocene in age and deflated from arid areas in Tibet. At higher levels in these hills, aeolian dust deposits are in areas of former periglacial conditions. At lower elevations, they are abundant over wide areas on the southern flanks of these ranges. At all elevations, they manifest a significant influence of former continental winds, not characterized by today's climate.

Illustrating this significant change in wind pattern and related Pleistocene climate are other features too, such as the relict felsenmeer also found near the 3660 meter level in the southern part of the Khumbu Himal. These are counterparts of the same features noted in the Langtang and Manaslu areas and, as there, relate to former frost climates. In Solu Khumbu they are also often seen in areas of ridge-top loess. In places this loess is many meters thick, with leached surfaces and some spodosol development and stabilizing grass cover. No loess has been deposited in these areas under the monsoon conditions of post-glacial time.

Westward through the Rolwaling and Jugal Himals, and typified by the Helembu district north of Kathmandu, we have observed equally thick loessial soils into which the centuries old hill country trails are deeply incised. Significant is the fact that farther west loess is absent. It is most notably missing on the south flanks of the Ganesh, Gorkha and Manaslu Himals and in the middle mountain region south of those ranges (Figure 3.3).

Did the Manaslu and Ganesh Himals form a topographic barrier to former southeasterly moving air? Did Quaternary uplift of the Tibetan slab change air mass passage? Or is this a consequence of different tropospheric wave patterns during the Quaternary? Whatever the reason, a more arid periglacial climate with heavy loess deposition once affected the areas east of the Trisuli Gandaki. It is not certain when in the Quaternary the loess deposition occurred, but as already indicated it was not in post-glacial time. This is another problem worthy of special investigation. As for the subsequently milder Holocene, we presume a poleward shift of the annual monsoon across these areas, as well as comparably warmer and wetter winter seasons.

The idea of a drier-colder Pleistocene in the inner Himalaya and a wetter-colder climate to the south melds with the previously mentioned southward shift of the globe-circling circumpolar vortex. This also supports a post-Thermal Maximum return to slightly colder and wetter conditions toward the south, as global cooling developed in Neoglacial time. This model is commensurate with the Pleistocene ice limits and associated glacio-fluvial evidences which have been presented.

REGIONAL CONSIDERATIONS IN THE OTHER HIMALAYA AND KARAKORAM

Concerning more distant sectors of the Himalaya (Figure 7.l), in northern India Heim and Gansser (1939) have reported old moraines as low as 2135 meters in the Kali River valley, and down to 2040 meters on the Alaknanda River. The geological literature of Garhwal, Kashmir and the Karakoram Range of Pakistan produces citations of old glacial limits at even lower elevations. For example Norin (1926) reported ancient glacial thresholds at 975 meters in the Chinal River basin of the Punjab; and Kuhle (1987) reports Pleistocene glaciation in the Nanga Parbat region reaching down to 1000 meters. Others have noted ancient glacial limits in the Karakorams down to 915 to 1220 meters.

There are even long-standing reports of erratic blocks in the Jhelum and Indus River valleys down to a few hundred meters above sea level (Theobold 1880), but these could be catastrophic flood remnants, as we observed in the Jhelum River Basin west of Srinagar in 1987. Also in Kashmir we found undisputed glacial drift and high valley moraines from local Pleistocene glaciation in the Gulmarg hills, with moraine thresholds at about 2286 meters. Likewise Holmes (1989) has reported that ancient glaciers in this part of the northwestern Himalaya extended down to 2150 meters on the Himalayan flank, and to 2600 meters in the Pir Panjal Range. He also found evidences of two pre-Holocene glacial advances in Kashmir, the oldest of which he cites as pre-dating 35,000 years BP.

The generally lower elevation of outermost ancient moraines in the western Himalaya and Karakoram might be interpreted in terms of lower regional snowlines on the great Himalayan flank. The reported variation in levels, as noted in Nepal, seems to confirm that local physiographic factors, as well as geographic location, are prime controls. Viewed in the context of these teleconnectional references, the 2900 meter relict ice limit in the Manaslu-Ganesh group fits the picture of local and limited Pleistocene ice centers. The restricted source areas prescribed by large numbers of shallow cirques on the southern flank of these himals, corroborate the positions of ancient glacier termini in the middle Himalaya. This emphasizes contrast with the Mahalangur Himal, where a broader land mass at high elevation has produced a more extensive platform for Quaternary glaciation.

As for Holocene and modern ice limits in the Himalayan-Karakoram arc, the Neoglacial is also characterized by great diversity. In the Garhwal, Heim and Gansser (1939) report modern glaciers down to 3600 meters. In the Zanskar Himal east of Kashmir they are found as low as 2870 meters (Wadia, 1919). Farther north in the Hunza and Karakoram Ranges, termini of existing ice masses occur at 2140 meters. Even in the Manaslu group modern glaciers reach to 3050 meters, and in the Langtang group to 3500 meters. The exception is the eastern Himalaya where, as we have seen, the Khumbu and other large south-flowing glaciers descend only to about 4420 meters. In the Kanchenjunga Himal, on the border of Sikkim they reach no lower than 3960 meters.

Though we obviously could not observe all of the glaciers in these regions, the ones cited were selected as generally representative. In this framework, the average of the lowest elevation of present glaciers in the western Himalaya and Karakorams is only about 1220 meters higher than the mean lower limit of Pleistocene glacier thresholds in those regions. This suggests that the lowest descent of both modern and ancient ice throughout the whole of this tectonic arc, from Darjeeling to Srinagar (Figure 7.1), was and is in the northwestern Himalaya and Karakoram. The comparison made with the eastern Himalaya becomes especially significant because the more continental climate to the northwest should actually have produced higher snowlines and lesser glaciation.

Because of these seeming ambiguities we now ask whether another significant factor is reflected in the glaciation of the Himalaya, one which is neither geographic or climatic?

CLIMATOLOGICAL PARADOX OR TECTONIC EFFECT?

From the foregoing considerations, the following conclusions are summarized. First, throughout the Himalaya there is a surprising proximity between geographic limits of Pleistocene ice and those of existing glaciers. Second, there appears to be a smaller elevation difference between Pleistocene glacial limits and those of modern glaciers in the eastern Himalaya than in the middle and western Himalaya and Karakoram. Third, vigorous late Holocene-Neoglacial ice advances in the Himalayan Little Ice Age characterize higher elevation areas, with these resurgences being intensive and extensive. Fourth, in most Himalayan glaciers, terminal thinning by intensive ablation and surface lowering of down-valley segments has taken place during this century, with accelerated ablation in recent decades. This has produced heavy concentrations of supraglacial debris in the terminal zones. Excessive rock avalanching from oversteepened cliffs is one of the factors, abetted by steeply dipping bedrock joints and extreme frost action at higher elevations. Fifth, annual accumulation segments in the nourishment zones of glaciers fed from neves at or in excess of 6100 meters are generally positive. As discussed at the end of this report and in Chapter 8, global warming is also coming into focus as a related factor in mass balance considerations.

Because much of the evidence we have assembled to support these conclusions is from reconnaissance studies, further work will modify some interpretations. The propositions are presented, however, as a record of our field studies and as helpful points of departure for future discussion and investigation. In our opinion, they are sufficiently valid to support the idea that pronounced crustal uplift during and since the Pliocene has played a signal role in the development of Himalayan glaciation. We suggest that this can explain unique aspects of that glaciation differing from other mountain regions of the world, as well as adding credence to the teleconnection similarities.

Elaborating on those aspects which are unique, we conclude that local and regional evidences support that epeirogeny, continuing through the Quaternary, has thrust segments of the Himalaya upward into a colder climate than would have resulted from global atmospheric trends alone. Some have inferred an uplift rate as high as 50 centimeters per century. With a most conservatively estimated minimum uplift of only 10 centimeters per century, or 1 meter per thousand years, this would still produce at least 2000 meters of uplift in Quaternary time. Even such a minimal elevation change could have resulted in a superimposed effect leading to accentuated glaciation in the eastern Himalaya. The comparative glaciation picture does support that the greatest uplift has taken place in that region. Furthermore, it is hardly coincidental that the earth's highest mountains are concentrated there.

In summary, the behavior of Himalayan glaciers in Nepal reflects a unique response to the earth's most unusual atmospheric influences. These reconnaissance observations indicate that the main glacial advances took place late in the Quaternary. This contrasts sharply with what has occurred in other of the world's great mountain ranges. Some evidence may be found for an earlier Pleistocene glaciation, but it is likely so close to the present glacial position that it has mostly been destroyed by the increased intensity of late Pleistocene-Holocene climatic events.

This information, when fitted to geological and geomorphological observations in this report, emboldens us to conclude that tectonic forces through epeirogeny have added a significant axillary effect on the secular climatic relationship. We purport that this may explain the seeming paradox of maximum late-Quaternary glaciation, and the lack of evidence for any widespread early Pleistocene glaciation, at least in the eastern Himalaya.

EPILOGUE ON THE "THIRD POLE"

From 3000 years ago to the present, even though the effects are small over such a short period of time, continuing epeirogeny has tended to reinforce reglaciation during the Neoglacial. The world-wide amelioration of the Thermal Maximum, 8000 to 3000 years BP, also had its dynamic influence by producing extensive recession of late-Pleistocene ice. The result today is strong development of post-Glacial notching in down-valley areas, and extensive Holocene glacio-fluvial outwash and terracing. This is pronounced in the proglacial area of existing large valley glaciers, where late-Neoglacial advances laid down Little Ice Age moraines on the earlier valley train deposits. Thus, in recent millenia, parts of this newly-elevated land have continued to experience healthy glacial conditions in spite of its sub-tropical latitude.

The topographic configuration also supports that the greatest epeirogeny affected the high eastern Himalaya. Compared to the Manaslau to Langtang terrains, the Mahalangur Himal is a region of more elevated and broader landmass. This is a form readily seen in ground traverses and air views. It suggests that the crust has risen in a domal fashion, allied to movements by shearing of the major thrust slices. Such a configuration does not characterize the central and western himals, tending to support the idea of less epeirogeny there (see Chapter 3). Also throughout the eastern region, dominantly convex upward slope profiles are the rule, which further supports the epeirogenic role. These are most apparent in the northern areas of middle and eastern Nepal, and notably on walls of the oversteepened and deeply incised canyons of the main trans-Himalayan river systems.

With the above as a postulate and the concept of epeirogeny a given, we are reminded that uplift along the whole Himalayan arc has taken place throughout the Tertiary. This represents a continuum through the last 90 million years, of which the Quaternary is only the most recent episode. In this time frame, differential uplift is to be expected, given the probability of changing orogenic stress as the Indian plate sheared against the Tibetan slab. We hope that future research will provide a more detailed look at the tectono-climate relationship and its influence in specific locales.

Finally, the fact of unusually strong glaciation in the late Pleistocene, followed by major resurgence of ice in the Neoglacial, frames the present glacial position, and its polar character at the highest elevations, in a glaciothermal category as severe as any in the Pleistocene. This is why uppermost levels of the Himalaya have been referred to as "the Third Pole." With current climatic trends, however, this unique characteristic may be changing.

To appreciate the reality of continuing change, it is noted that, as in the Pleistocene, the largest Himalayan glacier systems are polythermal. This means that polar conditions still exist in the highest source areas, but temperate glaciothermal characteristics are found in the lower elevation termini (Miller 1964a). In recent decades this has abetted thinning and excessive ablation of much of the lower ice. It has also fostered Jokulhlaups as a serious environmental hazard. The close interrelationship of each of these processes demands future systematic consideration of glaciothermal and accumulation regimes and allied mass balance trends. Then we can look more critically at the companion issue of global warming. Regarding the Nepal Himalaya, these topics are discussed in Chapter 8, which follows.

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8. COMPARATIVE ACCUMULATION REGIMES ON HIMALAYAN AND ALASKAN NEVES AND THE ISSUE OF GLOBAL WARMING

M.M. Miller

The unseasonable storm of late October, 1989, plagued our field efforts and covered the high glaciers of the central and eastern Himalaya with several meters of new snow. As a result planned mass balance measurements in the Manaslu Himal had to be abandoned. Alternative reference is made to our earlier stratigraphic measurements in the accumulation zone of the Khumbu Glacier in the Mahalangur Himal (Miller 1970). This neve area typifies high-elevation glacier regimes in the Nepalese Himalaya. Because of the region's sub-tropical latitude and high elevation it provides insights into the unique character of the nourishment zones. Coupled with these factors are the polar-temperate thermophysical nature of Himalayan ice and the zonal tropospheric meteorology involved. This includes powerful winds associated with the jet stream (Miller 1964).

The records also provide a framework for discussing the negative regime of termini of these glaciers over the past 30 to 40 years. As shown in the previous chapter this is manifest by increased downwasting of low-level ice. This could be a signal of recent unusual changes in the composition and behavior of the global atmosphere which may have begun to show their effect on Himalayan climate.

Physical character of the Khumbu Glacier's prime neve at 6160 meters is shown in Figure 8.1. This is comparable to the 6100 to 6700 meter neves which in 1987 we found to be main nourishment zones for glaciers on Himal Chuli and Baudha Peak (Figure 7.1) in the Manaslu group. On the original assumption that layers seen in Figure 8.1 were annual, this would have meant that the deepest accessible annual strata at 20-30 meters down would have corresponded to solid precipitation during the years before nuclear testing. This would also have allowed us to check the natural production rate for tritium (T, radioactive hydrogen, mass 3, 18 years average life). The advent of fusion weapons testing in 1954, added amounts of tritium so large as to mask its natural production from solar outbursts. This did, however, give us readily datable horizons in the profile (Miller, Leventhal and Libby 1965).

At this location in the Western Cwm of Mount Everest the glacier stratigraphy was measured and ice samples taken from shaved-back crevasse walls. The stratification was neatly revealed over more or less regular intervals. This 6100 meter elevation is a dominant one for high neves throughout the Nepalese Himalaya. With mean annual temperatures well below -10°C (Miller 1964), the glaciothermal character was found to be polar. At this latitude (28°N.), were it not for the great elevation, the climate would be as tropical as the jungles of the Terai and the northern Gangetic plain 160 kilometers to the south.

The stratigraphic records in Figure 8.2 show that we succeeded in dating the ice strata at this elevation and demonstrate that two identifiable strata are deposited annually, instead of one as previously believed. This semi-annual accumulation pertains to two periods of significant snowfall. One is during the cold and dry winter season of westerly gales at high elevation, when the jet stream sometimes descends to the level of the highest summits. This is usually between December and March. The other is during the less windy but heavier monsoon snowfalls of late May into September.

At the end of May, eight days after the profiles in Figures 8.1 and 8.2 were measured,

Figure 8.1. Exposed crevasse wall in main neve of Khumbu Glacier at 6710 meters. Primary stratification can be identified

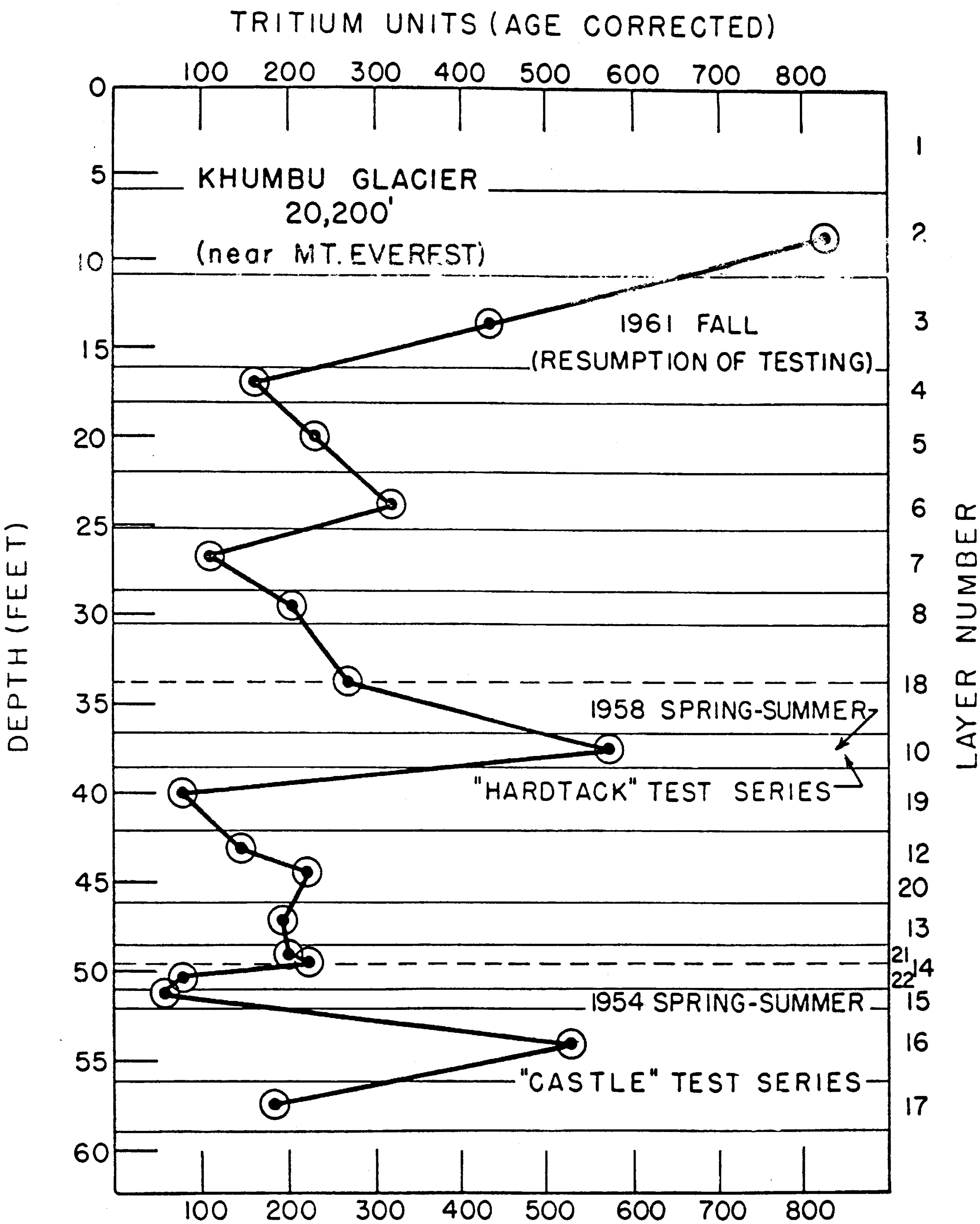

Figure 8.2. Neve stratigraphy on vertical profile at 6710 meters on Khumbu Glacier in May, 1963. Zones of Tritium concentration are shown in relation to nuclear test series of the 1950's and early 1960's.

the monsoon season began, heralding phase two of the accumulation regime. Our profiles represent positive mass balance for the upper Khumbu Glacier during each of the preceding 12 years.

Another significant discovery was that constructive metamorphism of new snow to firn to bubbly glacier ice took place very rapidly, compared to glaciers in temperate latitudes. This process is completed within one year, after which the preceding year's accumulation strata has reached a bulk density of 0.90, in other words, that of bubbly glacier ice. In the Khumbu Glacier profiles this density prevailed through the upper 30 meters of stratigraphic thickness. This rapid metamorphism is attributed primarily to penetrative solar radiation through the annual snowpack, a situation unique to this great altitude and low latitude. The mechanism seems to be subsurface radiation melting and vapor transport followed by refreezing of epigenetic ice on crystal faces to produce the accelerated densification. Similar snow metamorphism, density increase and double-phased annual accumulation patterns undoubtedly affect the comparable elevation neves of the Manaslu, Ganesh and Langtang Himals.

Allied with the two distinct periods of annual snowfall on Himalayan neves is the equally important equilibrium line (ELA, or equilibrium line, annual) which. Normally this refers to the highest elevation reached by the transient snowline on glacier surfaces in a given year. On higher latitude glaciers there is only one ELA because of one yearly accumulation season. In the Himalaya, the two yearly accumulation seasons actually means two ELA's. We refer to these as the ELA-W, for winter; and the ELA-S, for summer. The latter designates altitude of the late-autumn transient snowline on a glacier just before arrival of the first winter snows. It defines the areal limit of retained post- monsoon snowpack for that glacier in the referenced year.

Most citations of Himalayan ELA's, refer to the ELA-W. This is the late-winter (including spring) seasonal neve-line on glaciers, with an equivalent orographic snowline on intervening non-glacierized slopes. As with the ELA-S, the ELA-W notes a maximum height of the transient snowline, but in the time frame of late spring, just prior to advent of the monsoon. As such it delimits areas of the previous year's net retained monsoon accumulation plus the ensuing winter snowpack. Detailed analysis of annual regimes must take into account these semi-annual ELA's, as well as stratigraphic depths of the two accumulation layers. This is a unique situation, again quite different from that in accumulation regions where there no summer monsoon (e.g. Figure 8.3).

To illustrate these measurements on several Himalayan glaciers, the 1963 ELa-W on the Khumbu Glacier rose to 5580 meters. In 1987, on south-facing glaciers of the Manaslu group the ELA-S moved up to about 5490 meters prior to the first winter season snow storm in late October that year (see Chapter 2). In 1984 in the Langtang-Jugal region on north slope glaciers the ELA-S reached 5030 meters before the first winter snows arrived in late November. Sporadic observations like these from occasional expeditions are interesting and give a feeling for the parameters involved, but they do not provide the connected sequence of mass balance statistics needed for meaningful monitoring of trends.

If logistical constraints allow only one equilibrium line to be measured in any year, preference might be given to the ELA-S as more closely representing the year's net retained snowpack for a maximum number of months. The ELA-W can be used alone too, but with the recognized complication that its snowpack includes that of the previous year's monsoon. Sequential satellite imagery can help in annual ELA determinations, though adequate resolution and elevation control in the Himalaya will always be difficult (Miller

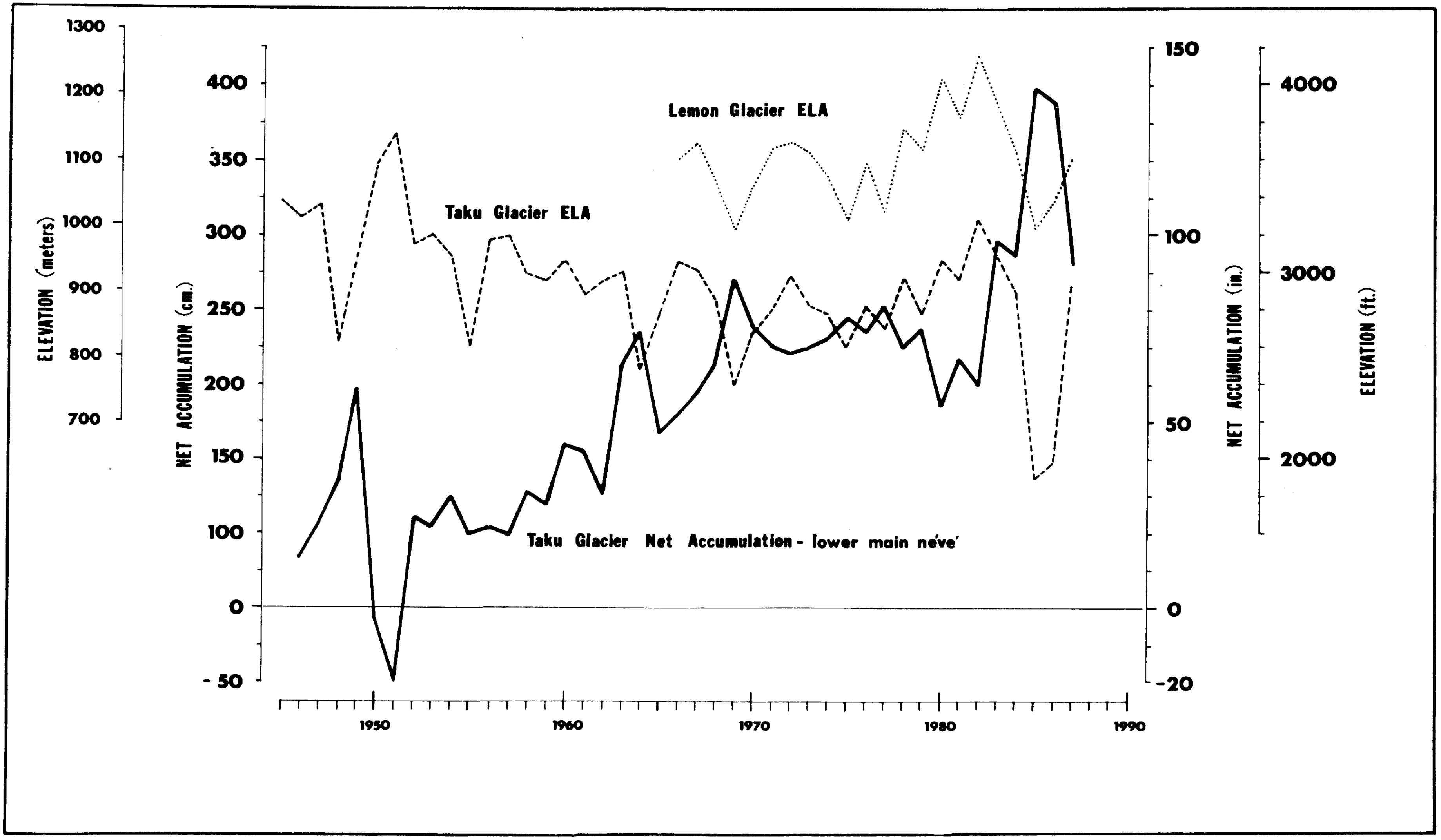

Figure 8.3. Comparative ELA and net accumulation trends on the Taku and Lemon Glaciers, 1946-1987, southeastern Alaska.

1968). To provide effective ground truth, field measurements should be acquired every several years, with appreciation of the two-fold nature of yearly accumulation.

We urge that a continuing satellite imagery assessment be initiated per the foregoing discussion. This could be an appropriate project for our meteorological colleagues at Tribhuvan University in Kathmandu. Such can also be useful for monitoring potential effects of global warming on hydrological trends in the shared Nepal-Tibet watersheds of trans-Himalayan river systems.

TELECONNECTION AND GLOBAL WARMING

At the outset of our 1984 and 1987 studies we had hoped to up-date glacial mass balance trends since the mid-1960's. That was when the first tangible signs of global warming began to be recognized in glacier systems in Alaska (Miller 1985). Recent findings have verified this early indication and have helped to make its teleconnectional aspects more certain (Kleeschulte 1988). Now, more than ever, there is need for systematic records of neve changes on representative Himalayan glaciers. This should require on-going measurements on both southern and northern flanks of these ranges because snowfall trends can be tied to significant lateral shifts in storm tracks (Miller 1985).

There is well-documented evidence of significant increases in atmospheric CO_2, N_2O, methane, CFCs and other trace gases in consequence of industrial processes, deforestation and the burning of fossil fuels for our global civilization's needs. Many scientists are working on this important issue. Recently Pearman, et al. (1986) have documented the rapid increase in CO_2, N_2O and CH_4 since the mid-19th century, through analysis of entrapped air bubbles in deep cores of Antarctic ice. Still, the dynamic relationship of these "greenhouse gases" and climate today and throughout geologic time is poorly understood. It is not even yet known whether increased CO_2 lags or leads global warming. Nevertheless, just since 1958 there has been an 11 percent increase in world-wide atmospheric CO_2 alone, in ppm by volume.

To illustrate how snowfall trends may relate, a 41-year record of continuing accumulation increases on upper neves of Alaska's Juneau Icefield is shown in Figure 8.3. The data cover the 41-year period between 1946 and 1987. As indicated, the increased amounts of winter season snowfall has lowered the ELA as much as 610 meters over these four decades, in spite of progressively warmer summers. The record is from the main accumulation zone of the Taku Glacier which is the primary outflow from this icefield. It is a prototype of large mountain valley glaciers with high source areas but extending to low elevations in coastal Alaska.

Annual ELA's since the 1960's are also shown in Figure 8.3 for the Lemon Glacier, a small cirque-headed glacier at intermediate elevation in the Alaska-Canada Boundary Range. The Lemon Glacier is one that was selected during the IGY in 1958 as part of the world-wide glacier monitoring network. This plot is relevant in typifying that accumulation regimes above the mean ELA of recent years have been positive and increasing on many of Alaska's highest glaciers. That has been coincident with unusual down-wasting and increased ablation effects on most of Alaska's low-level glacier termini. The result has been negative mass balances on a number of the lower and intermediate elevation glaciers during the last four decades. The same seems to be true of glacier regions elsewhere in the high mid-latitudes.

Some of this, of course, can be attributed to natural climatic trends based on solar variability. The apparent periodicities and atmospheric relationships pertaining in the areas of our Alaskan research have been studied in detail, with seemingly natural cycles of 11, 25-30 and 80-90 years revealed in the glacier record (Miller 1985). But the natural trends have been reversing to such an extent in the past 30 to 40 years that the possibility of a superimposed warming effect is real. There is also documentation that sea level in this century has risen over one-third of a meter. This is coincident with records of progressive summer warming in southern Alaska, and is reflected in higher winter temperatures in that region since the early 1960's. Most significantly there has also been a dynamic shift of cyclonic pressure cells in northwestern North America, and inland migration of the spring and autumn Arctic Front with its associated storm winds and precipitation belts (Miller 1985). The question continues--how much of this can be attributed to natural climatic trends?

Evidence is not yet clear for the Himalaya, but based on our field observations this same general pattern appears to have been developing in recent decades. We do need the supplemental neve accumulation data for recent years in the Manaslu and Ganesh Himals, as well as updated measurements in the Khumbu Himal. By relating longer-term paleo-climatic trends, the teleconnectional model seems to pertain. In the future, if validity can be demonstrated through records of on-going accumulation and ELA changes, this could have far reaching impact on available water for use during the dry seasons. Regardless, attention should be given to this problem in Nepal because glacier effects recognized elsewhere could soon, if not already, be pervasive.

The weight of evidence now tilts toward general acceptance that the globe is warming. Governments are beginning to take the issue seriously. According to some computer models, a doubling of current levels of atmospheric carbon dioxide would raise average world temperatures by 3 to 9°F. (2 to 5°C.). This would also substantially raise the zone of maximum snowfall in the Himalaya to even higher levels, probably well above the 6100 meter apparent mean of today. With this would come vastly increased ablation on lower-level glaciers. In practical terms this can be an issue of importance to water management, agriculture practices and hydroelectric development in all Himalayan countries.

Although global warming may not be entirely carbon dioxide-induced, the Greenhouse Effect is a generally accepted condition and one deemed not only to be increasing but to be irreversible. The effort in our Nepal studies to address this has admittedly been incomplete, because of time constraints, logistical limitations, and the reconnaissance nature of our observations. But this makes the mandate for more detailed research even more compelling. Eventually a systematic accrual of on-going glacio-climatic measurements should produce a dependable base-line of useful information.

Glaciers are immediately responsive to atmospheric influences, and so they are the most sensitive indicator of climate change in the natural world. The Himalayan regions contain the largest area of glacial ice in the mid-latitudes. This makes them a prime field laboratory for such study.

Certainly, long-term secular climatic variations based on solar variability will continue. But because of supplemental global warming from man-made causes, we must assume that more rapid than usual change is taking place. The general assessment given in this report corroborates this. Even for the immediate future in the Himalaya, the question is how far will it go? The answer lies in vigorously continuing research, including well-organized and properly funded monitoring of selected glaciers on a regional basis. These investigations could be cooperatively carried out by teams of scientists of Nepal and other interested nations. No matter how this is accomplished, it should involve substantive integration of key disciplines, especially glaciology, high altitude meteorology and hydrology. The multidisciplinary spinoff can also be large, as indicated by the combination of diverse topics dealt with in the chapters of this report. Reconnaissance studies are helpful in paving the way, but for the future they will not be enough to provide the needed practical answers.

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9. LAND MANAGEMENT AND LAND USE PROBLEMS IN THE MANASLU-GANESH HIMAL

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The Hindu Kush-Himalaya Region is currently subject to a wide range of ecological problems and environmental degradation. Scarcity of resources, population pressure, mismanagement of land, changing climatic patterns, cultural diversity and conflicts and significant local variations in perceptions of problems are only a few of the factors that must be addressed in order to achieve a sustainable development of the region. This chapter aims at describing and discussing some of the main issues in land management and land use problems in the Manaslu-Ganesh region in north-central Nepal. It is believed that most of the issues relating to land use, land management and environmental degradation of the Himalayan ecosystem can be found in the Manaslu-Ganesh region. It should be emphasized that this chapter is of a reconnaissance nature. It is based on a mere six weeks in the field, covering a substantial area. This allowed systematic studies only in a few localities, but on the other hand it was possible to obtain an overview of important issues and the opportunity to compare and develop a regional perspective.

ISSUES AND PROBLEMS

It is the authors' belief that this region, as the rest of the Himalaya, is surrounded by vast uncertainties regarding the key variables of man-land interactions. One cannot speak of a single problem and it may be pointless to generalize specific data across a wide region (Thompson and Warburton 1985b). Rather than dwell on these tremendous uncertainties as the major problem, one can examine how a systems approach to the Himalayan man-land interactions may provide needed insight. People are the foremost resource in this region. By applying a systems view the hill farmer can be included as an ecological strategist (and not just a problem creator), social, cultural, economic and physical variables can be examined, and definitions of issues adapted to local conditions can be formulated. The Manaslu-Ganesh region as well as the rest of the Himalayas, will need a conceptual framework for environmental systems in order to "know where to hit it" (Thompson and Warburton 1985a).

Evaluations of land use and land management in the Manaslu-Ganesh region should focus closely on the relationships or linkages between the hill farmer and forestry practices. The steadily increasing population density in mountain areas of Nepal is perhaps the heart of the problem causing forest resource depletion and environmental degradation.

The hill farmer has a series of potential strategies for tackling problems which historically have worked well (Figure 9.1). Today however, there are numerous indications that the adopted strategies are insufficient for solving the problem of resource scarcity, and the hill farming communities are no longer self-sustainable. This will be discussed later in the chapter.

In addition to the general issues mentioned, the field work in the Manaslu-Ganesh Himal uncovered several problems deserving attention. First, many localities are more environmentally sensitive because of combinations of surface slope angles, soils, overuse and natural hazards. Second, there are significant regional differences in food production capacity and an uneven supply (sustainability) through the year. Third, a considerable unutilized human

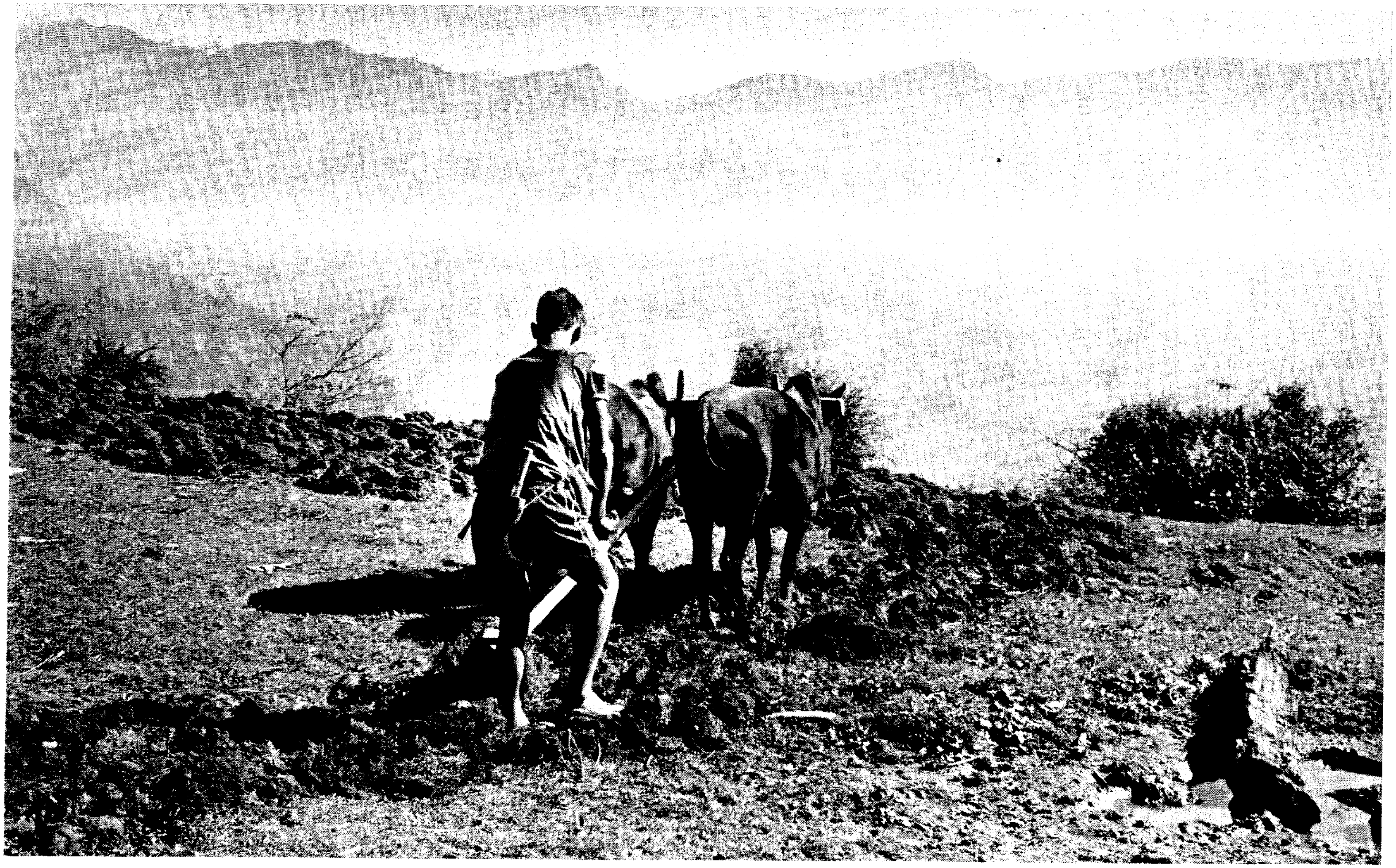

Figure 9.1. The Nepali hill farmer has coped with a changing environment through the centuries. However, traditional strategies, such as the wooden plow, may no longer be adequate to halt the increasing resource scarcity. Photo by B.P. Kaltenborn.

potential exists all across the region in terms of applying or stimulating people who are willing and capable of working to improve the resource base (e.g., through land stabilization and reforestation). Finally, resource depletion cannot be assessed and managed without recognition of the differences in perception of the problem between hill farmers, all levels of administrators, and scientists. Numerous respondents in the interviews called attention to the lack of communication they felt with outside planners, decision-makers and experts.

During the 1987 Manaslu-Ganesh Expedition, several tasks of this investigation emerged:

1) report observations of land use and land management, including qualitative evaluations of the status of resources,

2) identify and evaluate major resource use related problems and possible geo-ecological and socio-economic impacts,

3) specifically point to "bottlenecks", such as social, economic or physical barriers to solving environmental problems, (e.g., the lack of seedlings for reforestation when the manpower and willingness to work are present),

4) indicate and illustrate some important systems (physical-biological, social-cultural, economic) and important linkages between these, and

5) suggest research/mapping needs, possible methodologies, techniques and approaches.

METHODS

Random interviews were carried out with local landowners and farmers in a number of villages during the 1987 Manaslu-Ganesh Expedition, including Phalenksangu, Tanje, Barpak, Kasigaon, Sherthung, and Burang. The interviews were of the unstructured type with open ended questions. The nature of the logistics did not permit a more systematic sampling method. Also the aim of the study was to identify major issues, rather than quantifying key variables. An unstructured approach does not provide much comparability or representation through a sample. Reliability and validity are also harder to cross check and evaluate. However, one can more easily pursue topics that emerge during the interview. Whyte (1977) expresses the differences between the two approaches as: "Structured approaches tend to emphasize the operations of specific components of the system whereas unstructured approaches are more concerned with general relationships within the system as a whole." The data are not intended for quantitative statistical analysis, but as an aid in identifying some major issues and opinions among local people on different administrative levels (independent hill farmer-panchayat leader). Respondents were chosen randomly along the route, and some of our own porters (belonging to areas through which we travelled) were also included. The primary foci of the interviews were demographic variables, socio-economic aspects, perceptions of hazards and environmental degradation as well as quantification of resource utilization. A Nepali scientist and a sherpa served as interpreters during the interviews.

Data collected from secondary sources before and after the expedition include vegetational/ecological zonation, topographical data, socio-economic data, and Landsat imagery (from December 1987) showing ecological variations, land degradation etc. Ground truthing of the secondary data was carried out along the entire route. Significant anomalies were detected through visual recordings of land use, resource categories and environmental degradation. Anomalies were recorded on thematic and topographical maps and with ground level photography. Analyses of these data will allow: a) simple resource inventories (showing land capability) on two or three localities along the route intended for local planning and management purposes; and b) a land-use classification system and land systems map based on the U.S. Forest Service (Wertz and Arnold 1972) Land Systems Inventory methodology.

LAND USE IN THE MANASLU-GANESH REGION

The south facing slopes of the high Himalaya represent the lush side of this mountain range. An ecological gradient from tropical forests up to the alpine and nival level can be drawn, chiefly in a north-south direction. A typical zonation within this field area from low elevations up includes (Dobremez and Joshi 1984): 1) subtropical rainforest; 2) mahabarat hill sal forest; 3) lower subtropical forest; 4) hygrophytic oak forest; 5) oak forest montane level; 6) fir forest, lower subalpine level; 7) rhododendron and birch upper subalpine forest; 8) mesophytic - hygrophytic rhododendron - juniperus lower alpine scrubland; 9) mesophytic - hygrophytic patches and scarcely vegetated upper alpine rocks and screes; and 10) the nival zone (ice, snow, rock).

The history of land use and resource utilization in the central hill region of Nepal gives the impression that the different uses of resources may at one point have been well integrated and balanced relative to each other and to the carrying capacity of the environment. Today, this is clearly not the case for the Manaslu-Ganesh region, and probably not for any other part of Nepal. The rapidly growing population pressure during the last few decades has resulted in markedly increased competition for scarce resources. Areas which formerly used to be self-sustainable are no longer so, landholdings are more fragmented, and both common (forest lands) and private (agricultural lands) resources are being degraded. It is apparent that every village in the field area is more or less dependent on cash income from off-farm labor. It should be emphasized however, that the degree of subsistence appears to vary widely throughout the area.

From a land use perspective, a systems view of the interactions of the farmer with his surrounding environment is necessary to illustrate the linkages causing degradation of the resource base. The farmer and his family constitute agents with demands that are more or less fulfilled from their environmental setting. This constitutes a complex system with environmental resources such as water, soil, forests, plants, and the farmers (and their families) using and managing these resources according to basic needs, preferences, cultural, religious and social beliefs, available technology and skills. The basic activities of the farmers are agricultural production and livestock, but many also engage in off-farm employment to generate a cash income. This main system can be divided into sub-systems: environmental setting systems, economic systems, technological systems and demand systems. The farm unit is often viewed as a system (or systems) due to comparability in demands, resource use, effects on the environment, behavior and economics. Farms also often share services, benefits and risks. Farms can be considered both economic units or systems (production - satisfaction of needs) and environmental systems (interaction with the resource base).

The traditional production system of croplands, forest harvesting and grazing is found throughout the area (Figure 9.2). As in every part of Nepal, the agricultural system follows a clear zonation with species such as potatoes, millet, barley, summer and winter wheat, corn and rice as the most common species according to local climate, elevation, soils and moisture availability. The forest harvesting system is an important component in the hill farmer's life also in this region supplying the basic needs of fuel, fodder, leaf-litter, poles, and construction material. The livestock and grazing system interacts with the agricultural system and the forestry system in a number of ways which will be discussed.

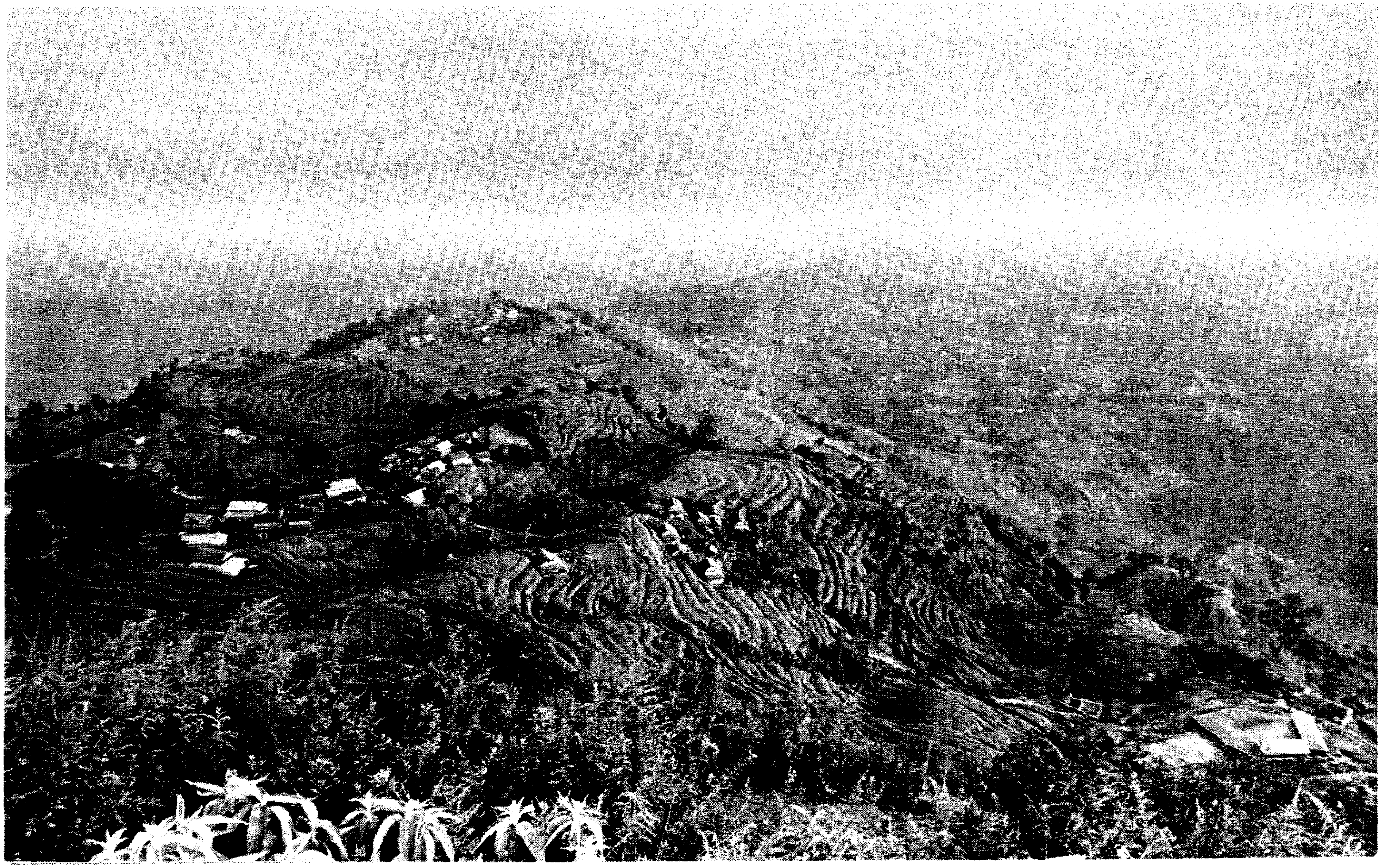

Figure 9.2. Hill farms in Nepal are economic and environmental systems. The typical lowland to highland production gradient is found throughout the Manaslu-Ganesh region. Photo by B.P. Kaltenborn.

All the linkages and components in these systems lead to one profound and fundamental issue: the shortage of productive land. The land-man ratio is usually considered the foremost problem in the entire Hindu Kush-Himalaya region. There is good reason to believe this is the prime concern in the Manaslu-Ganesh region as well. Mahat (1987) reports that the average land holding for a family of 5-6 persons is 0.4 ha. The World Bank (1979) has estimated that the ratio of persons per ha of arable land was 15.76 in the Middle Hills and 3.79 in the Terai. These figures illustrate the uneven demands on land, and the precariousness of doing something about the situation in the high country.

The field work did not permit detailed studies of the land-man ratio locally, but shortage of productive land (and well managed forests) was a recurring theme in the interviews. General observations in this area, indicate that the land-man ratio will only be declining in the future. This is a major issue which cannot be ignored in the development of the region. Resources are finite and there is no reason to believe that the pressure on those resources will decrease. In particular, Nepal can ill afford to convert more forest resources to agricultural areas at any significant scale, even though only 16 percent of the country is under cultivation. The paramount task will, therefore, be improved management of existing use, rather than agricultural extension. This requires use within carrying capacities and in some cases restoring and artificially raising carrying capacities through measures such as fertilization, irrigation and soil stabilization. In this respect, the linkages between the hill farmer and the forest use appear to be extremely important.

Forest Use

Considering that the area covered by this chapter covers a wide range of ecological systems and every forest type present in Nepal, comments must be of a general nature. Substantial investigations are required if the forest use and related problems are to be quantified within this region. Naturally every type of traditional Himalayan forest use was observed throughout the Manaslu-Ganesh region, including fuel, fodder, building materials (Figure 9.3), and leaf-litter. In many cases, it was plain that a resource shortage existed. In most cases however, identification of the problems were contingent upon interviews with locals. It is worth mentioning that although wood shortage seems to be universal in the region, the problem is highly differentiated. This applies particularly to an altitudinal gradient, that is, the scarcity of wood is of greater relative importance or has a greater impact on daily life in the high country than in the lower parts of the valley. Along the same lines, detection of wood scarcity and related problems are often easier in the high regions where ecological margins are narrower and impacts are visually striking. Wood supply was never reported to be satisfactory, and the households continuously adjusted to an increasing scarcity by spending more time on wood gathering. This was observed throughout the region.

Estimates for wood consumption per capita in Nepal vary greatly. Current figures have been shown to vary by a factor of 67 (Thompson and Warburton 1985b)! Based on interviews in the Manaslu-Ganesh region, consumption averages 30 to 40 kilograms per household per day. This amount probably varies substantially through the region and also according to wood accessibility, altitude, local relief, household sizes and farming systems. Regular large-scale, multiple-purpose wood cutting was generally observed up to 2100 meters. In some cases, especially on a few locations in central parts of the region, extensive forest clearing had taken place up to 3000 meters.

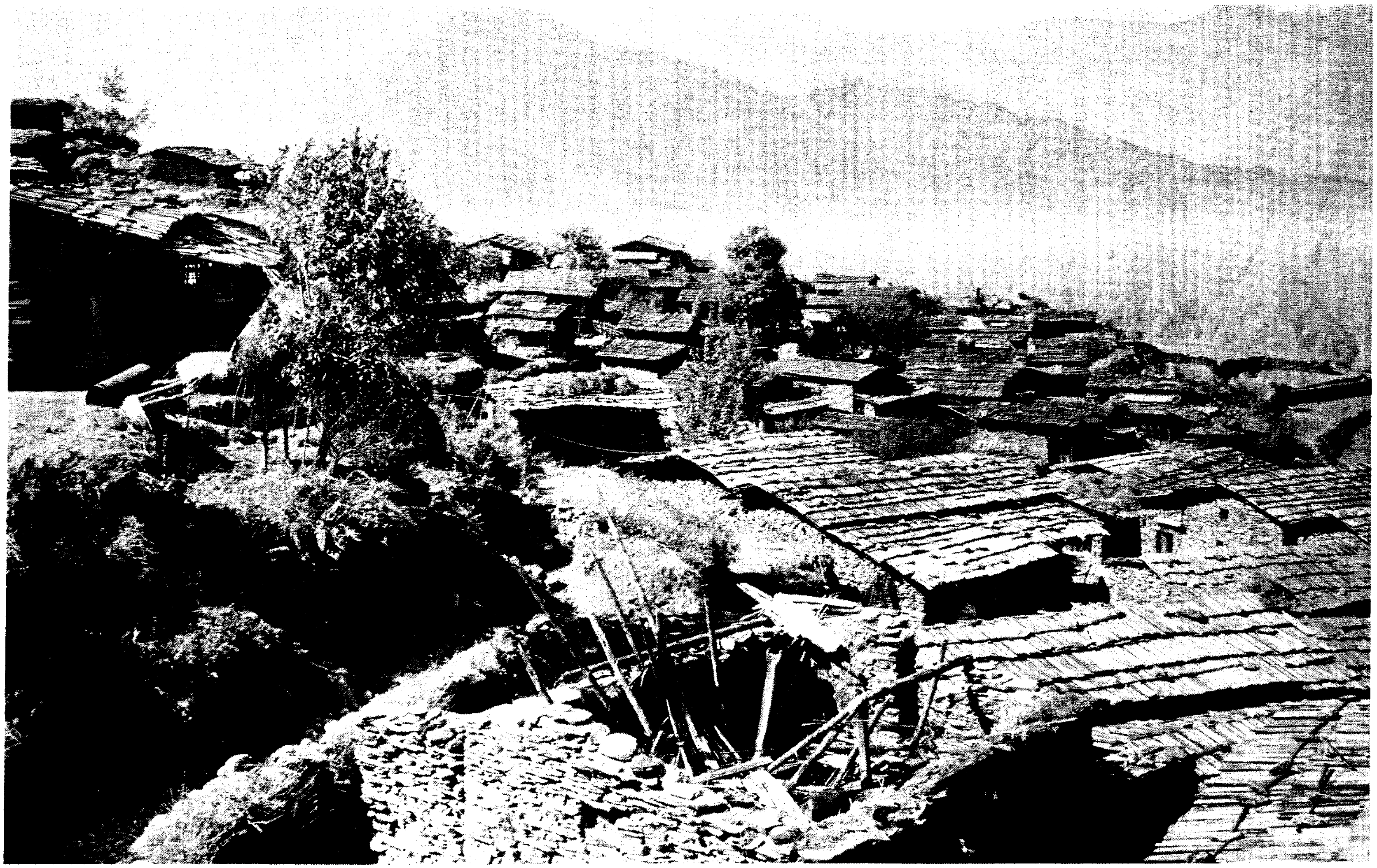

Figure 9.3. Roofing for homes is a common use of wood in the region. Photo by B.P. Kaltenborn.

Grazing Practices and Agricultural Strategies

The grazing systems in the Manaslu - Ganesh region have developed over a long time span. They also interact strongly with forest use and agricultural practices. The western part of the region, especially areas between the Marsyandi Khola and the Dorandi Khola, are characterized by intense use in the higher elevations (temperate to alpine). Beginning at elevations of approximately 2700 meters, the ridges are marked by extensive grazing. Grazing patterns are evident up to 3800 to 4000 meters, as long as vegetation is sufficient for grazing. The forests and shrublands at these elevations are heavily impacted directly and indirectly by grazing practices. Wood is taken for fuel, construction materials for shelters, and fodder and leaf-litter for animals.

Grazing activities are seasonal (May to October) and require shelters for people as well as animals. Especially large shelters were found on the high ridges northwest and northeast of Tanje on the Dordi Khola (Figure 9.4). These shelters were up to 40 square meters in area and three or four buildings were often grouped together. Interviews in the area showed that these were used partly by farmers from lower lying valleys for a small number of animals during the summer, and partly by full-time pastoralists with herds up to several hundred animals (cows, water buffalo, sheep and goats). Foundations of older and seemingly unused shelters were found up to 3800 meters. It must be assumed that these groups of people also have been sedentary. Evaluations of the effects or impacts presently visible from this kind of land use must also take into consideration the fact that the pastoralist may have been more mobile in former times. Thus they may have caused a more intense or more extensive pressure on the land than they do today. These areas are presently subject to heavy grazing and partial reduction of forest cover. The forest and shrublands have been used extensively and are in some cases eradicated for large areas. However, there was no clear detection of irreversible degradational processes such as soil erosion due to loss of vegetational cover. In some localities great amounts of wood (cedars) were being wasted after logging. Only small fractions of the trees had been utilized for construction materials, mainly roof shingles.

Grazing activities complement other agricultural practices for many households. The transhumance in the Manaslu-Ganesh region is part of a production system with some flexibility. The grazing component relieves pressure on lowland resources in the critical summer production phase. Many of the areas described in this region combine the traditional agricultural system of potato, wheat, millet and rice farming with some pastoralism. Both domestic animals and agriculture are necessary parts of a combined cash and subsistence economy. The production system is to some extent flexible in the sense that the grazing component can absorb and yield varying amounts of use and products from grazing depending on lowland needs. In other words, it is probable that a marginal year with a poor output from the agricultural component can to some degree be compensated for with a longer and/or more intense grazing season in the highlands.

The hill people of Nepal have developed a set of adaptations and strategies. The hill farmer's use of the grazing component in the system reflects this ability to utilize and adapt to environmental changes, but the awareness of the ecological limits may at times be inadequate. The grazing areas visited during the field work are subject to significant environmental changes due to human use. Still, they may be within bounds of carrying capacity. Competing or complementing land use practices, however, could in the future threaten this.

Agricultural land extension is another common strategy in land use and development. As in other parts of Nepal, land ownership and boundaries in the Manaslu-Ganesh region are

Figure 9.4. Grazing shelters are found almost up to 4000 meters above sea level. This shelter is located at approximately 3000 meters northwest of the village of Tanje. Photo by B.P. Kaltenborn.

believed to be more or less fixed. Thus when a farmer or his household needs to acquire new land, this will most often happen on steep forested slopes above existing villages. Agricultural land extension was observed on a number of occasions, both in areas with Thamangs and Gurungs. Typically the sites were steep and small, with rocky and poor soils. Observations indicated that new land use occasionally came in conflict with established rights for forest harvesting. It is also the authors' belief that expansion of agricultural land in this region eventually will develop increased conflicts with existing grazing and forestry practices, all of which constitute required parts of the hill farmers's total production system.

RESPONSES TO RESOURCE SCARCITY AND LAND USE PROBLEMS

It is well known that the hill farmer and his household respond to resource scarcity and production problems in a number of ways. Common strategies such as agricultural land extension and land intensification have already been mentioned. Two other important income sources, cottage industries (mainly bamboo crafts) and off-farm employment, should also be included. Both of these were observed and reported in a number of villages in the region. However, we have not quantified the extent or economic importance of these.

Off-farm employment mainly takes place in the form of paid labor in agriculture outside the home village, construction, and in portering on expeditions. In some villages in the eastern part of the region, for instance Sherthung and Tibling, a significant portion of the male population was engaged in road construction and mining operations. These kinds of activities are pursued to create cash-income, but a vicious social-economic circle is created as a result. The men leave their households and their farmland for several months each year in order to buy food. Some of the young women migrate as "camp followers" to the road-building and mining areas with disruptive family impacts. While the work force is depleted, the production capacity of the local farm lands is lowered even more. Keep in mind that insufficient farmland is the main reason for seasonal out-migration in the first place. This spiral increases cash dependency, reduces agricultural and possible pastoral activities, gives the farmer less opportunities for participating in local reforestation schemes and communal village efforts, and probably increases social problems within the individual households. As agricultural output and local self-sufficiency is lowered, the farmer must make even more money on outside labor to purchase food and other goods.

A paramount question regarding adjustment to increasing scarcity is identifying critical thresholds for local agricultural production below which the village cannot continue to exist in its present form. Stated as a question, how much of the local subsistence economy can be converted to cash dependency without eradicating the agricultural output and seriously disrupting the social network? Likewise, how much agricultural land extension or grazing intensification can take place before the forest resources are depleted to a level where they can no longer supply the minimum required amount of wood?

An increasing competition between land uses is occurring, with the result that some land uses will decrease in importance, but not without impacts to the rest of the system. Although the Nepalese traditionally have been competent ecological strategists, adjusting cleverly to resource scarcity, there is reason to believe that some land use problems in the Manaslu-Ganesh region are approaching carrying capacity levels. The linkages between land uses and resource scarcities mark the need for an integrated approach to problem solving.

FROM ISSUES TO ATTEMPTED PROBLEM SOLVING

In summary, major issues and problems to be looked at in the Manaslu-Ganesh region are:

1) a declining natural resource base, particularly forest products and fertile agricultural lands,

2) uneven supply of food products through the year,

3) vulnerable and unstable ecological environment,

4) natural hazards,

5) gaps in perception regarding the status of resources between farmers and administrators,

6) communication problems between local communities and central authorities; who should manage what?

7) a large human potential throughout the hills not being utilized for problem solving (Figure 9.5), and

8) a training problem: how to employ local human resources?

Solving land use problems in the Manaslu-Ganesh region is not a question of finding the right answer. It is the authors' belief that there may be great differences between optimal and feasible solutions. Thus, this is the concept of the art of the possible. Some ideas on possible actions are given below.

Bottlenecks

Lack of communication between the districts and central administrators and scientists, as well as lack of training relevant to land improvement among locals, and lack of material resources are thought to be specific bottlenecks hampering land and production improvement. Frequently initiatives are taken for reforestation schemes on the village level, but poor communication above panchayat levels and lack of technical needs halt further development. Decentralized forest property and management and responsibilities for common forest property at the village or panchayat level are probably not only favorable, but absolutely necessary to steward the forests soundly. Social forestry programs have often come a long way in transcending cultural and perceptual barriers in reforestation schemes. However, operational experiences have on several occasions shown the pitfalls of not adequately understanding local conditions or not securing local cooperation and responsibility for the project (Thompson & Warburton 1985a, 1985b). Such topics should indeed be addressed in the Manaslu-Ganesh region.

Initial Environmental Assessments

Preliminary assessments of resource related problems of more detail are recommended, especially for communities or areas with obvious problems. However, initial assessments are potentially useful for any community or level. The assessments should have a scientific basis in ecology and conceptualize major ecological, social and economic issues pertinent to the chosen region. The initial assessments should attempt to distinguish between perceived and actual problems, and outline a study strategy. Useful methodologies are described in Beanlands and Duinker (1983), Munn (1979) and Walters (1986).

Resource Inventories

In order to identify resource scarcity, user conflicts and acceptable limits for use, one must know the extent and types of resources.

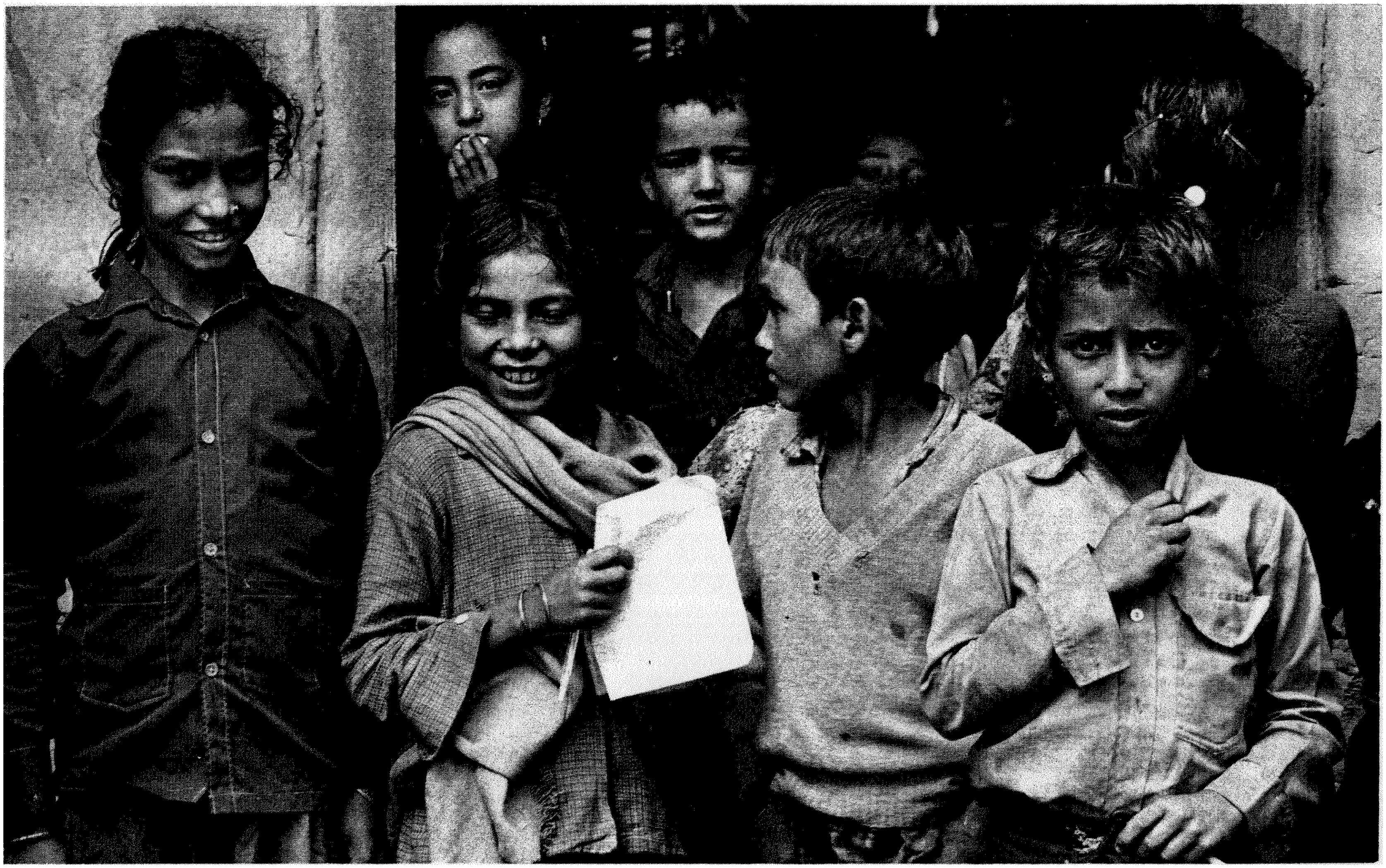

Figure 9.5. It is impossible to separate Nepal's future from Nepal's children. Young generations suffer from lack of basic training and simple technical skills. Photo by B.P. Kaltenborn.

Resource inventories, land capability and land suitability mapping are recommended for areas identified in initial assessments as having a certain problem or conflict level. Natural hazards mapping may in some cases be important, and the socio-cultural aspects of hazards should not be forgotten (Bjonness 1986).

Land Systems Mapping

Land systems maps can be valuable planning and management tools. The maps can be constructed at different scales and for a variety of objectives. Land units are defined based on desired information integrating land uses with land or resource characteristics. The Land Resource Mapping Project sponsored by ICIMOD is an excellent example of this approach to planning. For the Manaslu-Ganesh region (and other parts of Nepal) larger scale maps could be derived using existing information from Landsat imagery, geological maps, ecological maps (Dobremetz et al. 1984), aerial photographs, topographic maps and field resource inventories.

Defining the Degree of Subsistence Economy

A somewhat more theoretical and certainly more difficult task is determining the balance and transformations between cash and subsistence economies. Concepts and suggestions for indicators and methodologies have been developed by Sharif (1986) and others. This issue is thought to be important because it gives some indication of the degree of local economic stability and self-sustainability. Economic stability is closely tied to the extent and quality of the natural resources, and this illustrates the need for resource mapping along with analysis of the degree of self-sustainability.

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