

THE MOUNTAIN WORLD

1958/59

ENGLISH VERSION EDITED BY
MALCOLM BARNES

London

GEORGE ALLEN & UNWIN LTD
RUSKIN HOUSE * MUSEUM STREET

EIGHT MONTHS OF GLACIER AND SOIL RESEARCH IN THE EVEREST REGION

By Fritz Müller

The offer of the opportunity to work in the Himalayas first came to me, paradoxically, on the wide plains of the Canadian Arctic. In May 1955 on returning from a dog-sledge journey to the Eskimo village of Tuktoyaktuk, I was met by the missionary, Father LeMeur, who handed me a telegram. The Swiss Foundation for Alpine Research in Zürich invited me to join the scientific team of the Swiss Mount Everest Expedition 1956.

However, behind this superficial coincidence there lies a real relationship between the Arctic and the Himalayas in the scope of my work. On several Arctic expeditions I had been given the opportunity to study frost phenomena under the dominating influence of the long, cold winters and the short, relatively warm summers. In a sub-tropical high mountain area such as the Himalayas, it is mainly the alternation of extremely cold nights and intensively hot days which determines the temperature regime. The chance to follow up my work in the Arctic by studying frost phenomena and glacial factors under very different conditions was sufficient temptation for me to accept the offer of the Foundation.

The initiators and organisers of this third Swiss expedition to Mount Everest were most eager that, parallel with the further opening up of the Chomolungma¹ by the mountaineers, the scientific work already started in this region should be brought to a first conclusion. Professor Lombard had, in 1952, analysed the geological structure between Cho Oyu and Mount Everest. Dr. Hagen, after his visit to the Khumbu Glacier in the late autumn of 1954, fitted these results into the broad framework of the geology of Nepal. In 1955 the Austrian mountain survey expert, Erwin Schneider, made a terrestrial photogrammetric survey of the mountain valleys to the south and west of Everest. The first work had already been done on the flora and fauna, the botany in 1952 by Zimmermann, and the zoology in 1954 by the "Yeti Expedition" under John Jackson.

There were still gaps in the petrographic fixation of the Everest-Lhotse stratigraphy, and—most urgently needing attention—exact records of the weather

¹ The local name for the whole massif of which the highest peak is Mount Everest.

N.B. The spelling of geographical names throughout this paper is according to the Quarter Inch map of the Survey of India (edition 1932), or as collected by the author. Several variations of many names are in current usage. The difficulty can only be overcome by international agreement.

factors, especially during the monsoon period, and precise data on the behaviour of the glaciers were lacking. In conjunction with these latter measurements a full account of the present glacial situation and an analysis of former glaciations was essential. This would correlate with the work done by Dr. Heuberger in the autumn of 1954 in the Cho Oyu area. Furthermore there would be the opportunity to continue my own special research on frozen ground.

For such a programme of work short period measurements, sporadic recordings and hasty notes would have little value. It was necessary to prepare for a campaign of longer duration than that of the mountaineers; the monsoon period and at least the whole of the autumn would have to be included in my observations.

I am greatly indebted to the Swiss Foundation for Alpine Research for their wholehearted support of this programme and for their energetic assistance in the realisation of it. The government of the Canton Zürich made a major contribution to the financing of the expedition's scientific programme by a generous donation, for which I would here like to express my sincere thanks. In obtaining the necessary scientific instruments I received much help. The "Versuchsanstalt für Wasserbau und Erdbau" of the Swiss Institute of Technology put at my disposal a soil- and snow-"rammsonde", as well as an equipment for determining the water equivalent of snow and firn. W.H. Ward of the Building Research Institute, London, lent me his well proved ice-boring equipment. The Central Meteorological Station in Zürich equipped me with a double set of meteorological instruments, including a long-lead thermograph. The firm of Wild in Heerbrugg loaned to me one of their excellent T₂-theodolites, as well as the latest design plane-table equipment. To all these I am very grateful. My especial thanks are due to Professor Haefeli who, during a three-day discussion at the Jungfrauoch, reviewed my whole glaciological programme and gave much very useful advice.

I must also thank my mountaineer comrades of the Swiss Mount Everest Expedition 1956, above all their leader Albert Eggler. For me it is beyond question that the working together of alpinists and scientists in the Himalayas is profitable for both. The equipment and provisions of the mountaineers—both on such an expedition per force greatly over-supplied—formed the basis for my longer stay.

The approach to the Khumbu Glacier

Amongst the 360 loads of expedition material, which were carried in a three weeks' march from Jaynagar (India) through the foothills of Nepal to the base of Mount Everest, were twelve containing my special equipment. The beautiful

days of the approach march through the red-splashed rhododendron forests gave me time to accustom myself to the new forms and dimensions of the landscape.

One looked in vain for sound evidence of earlier glaciation until the first main mountain chain was reached. Only at Phaphlu did I see the first distinguishable moraine-like remnants, at Taksindhu the first erratic blocks were noted, and here, on the slopes below this beautifully situated monastery, was an extensive terrace system of uncertain origin. Descending into the Dudh Kosi valley which drains directly south from Mount Everest I was amazed by the numerous quarternary deposits none of which could be irrefutably identified as remnants of the main-valley glaciation. Had they been washed away by large masses of water or did they lie buried beneath later debris? The same question comes to the mind of the observer who looks up-valley from the immense moraine on which the idyllic monastery of Thyangboche (4000 m.) stands. From both sides the terminal moraines of the tributary glaciers extend like huge bastions into the main valley, pushing from side to side the Imjya Khola which in this section of the valley flows bedded on its own deposits. But where is the present main valley glacier, the Khumbu? We came upon it first at 4900 m., in a valley which was far too wide for it. Like the Po in its embankments, the Khumbu sits bedded-up in a cradle formed by its own debris, its surface covered over with rock rubble.

To explain the peculiarities of the Khumbu Glacier I anticipate here one of the main results of my work: the Everest-Cho Oyu Chain is far more arid than so far presumed; the glacier movements are small; the water discharge is slight; the debris is transported away only slowly.

This result is as important for the understanding of the pleistocene and post-pleistocene shaping of the High Himalayas, as a knowledge of the structural geology is for the understanding of the valley pattern and the drainage system. In the Everest region the valley trend is determined by two systems of anticline and syncline, one of which strikes parallel to and the other at right angles with the main mountain chain.

The pre-monsoon period

Simultaneously with the climbing expedition I established my camp on the 7th April 1956 on the Khumbu Glacier. The construction of the *Weather Station* (5400 m.) near to the Base Camp was begun immediately. A Stevenson screen was erected using bamboo poles and box wood, and painted white against direct radiation. On the 12th April regular recording was started. The following measurements were carried out three times a day: Station temperature, including the diurnal maximum and minimum, air-humidity and amount of cloud cover;

momentary and average wind speed every 6 or 12 hours; in addition height, direction and speed of cloud movement were checked whenever possible. Very careful attention was given to the measurement of precipitation, as it is most important to obtain accurate results, but also most difficult because of the interference of numerous local disturbances. Aside from two unavoidable breaks due to an accident, this programme was carried through continuously up to the 25th November, 1956, that is including the whole of the monsoon period.

At the same time it was essential to commence measurements as soon as possible on the glacier, which since the beginning of April had been rapidly denuded of snow. Using a hand ice-drill 30 holes, each of 5 m. depth, were bored, into which 6 m. long bamboo poles were stuck for measuring the *ablation* and *accumulation* of the very irregular glacier surface in the vicinity of the Base Camp. Nine of these measuring stakes were so arranged as to give a *cross-profile* of the glacier, by which the *surface speed* was determined every 14 days throughout the 7½ months.

Thanks to the fact that two of my Sherpas had accompanied Erwin Schneider in the previous year on his photogrammetric survey, it was possible to tie in all my glacier measurements in the Khumbu region with his grid of fix-points.

Meanwhile the mountaineers had forced a passage through the infamous Khumbu Icefall. As soon as the Base Camp measurements were under way, I moved with my small group up to Camp I. Here at 5800 m., on a narrow ledge, I set up three stakes to give a profile across the icefall and determined a base line from which their movement could be measured. The same procedure was carried out for the traction zone (6100 m.) immediately above the icefall and for the pressure zone (6500 m.) between the Lhotse Glacier and the main basin of the Western Cwm. Thus three cross-profiles for the measurement of surface speed were established in the accumulation zone. The surveying of these movable points offered considerable difficulties. This firn basin enclosed by 2000 m. high rock walls is inaccessible in its outer parts because of stone and ice falls, whilst the intensive heat of the sun's rays very soon put the theodolite out of adjustment however carefully one had contrived to place it on the glacier.

At six different locations in the Western Cwm the amount of the previous year's firn was determined, and its water equivalent calculated.

To obtain records for comparison with those of the fixed weather station in the Base Camp, simultaneous weather observations were made in the high altitude camps, mainly in Camp III. For many of these valuable measurements I am indebted to the mountaineers who, in spite of the great demands of their own programme, expended time and energy on this work.

After this first investigation of the Western Cwm I descended again at the beginning of May to the ablation region. Below the Base Camp three further cross-profiles were established for the measurement of ablation and surface

movement. In addition a start was made on my research into frost processes in the ground. The surroundings of Lake Gorakshep¹ proved to be a most suitable place for this work.

If I wished to realise my plan to take the final readings on the three profiles in the Western Cwm immediately before the break up of the high camps, I had to hurry. For the mountaineers would by now have reached the 8000 m. region. Therefore on the 19th May my three Sherpas and I moved in one climb from Base Camp to Camp III.

Arriving exhausted in Camp III, I realised that the state of progress of the climbing campaign gave me a week's free time. So taking up the friendly invitation of Hansruedi von Gunten and Dölf Reist to accompany them—they were just preparing to go up for their final attack on the summit—I climbed higher with my three Sherpas, towards a greater mountain experience. Untrammelled by scientific obligations I enjoyed the ascent through the mighty ice bulges of the Lhotse flank to the South Col. Never shall I forget the brief view from 8000 m. out over Tibet.

My five-day digression to the South Col gave me some valuable experiences which I would like to pass on to those who are interested in scientific work in the High Himalayas:

1) In spite of having no real acclimatisation at heights above 5000 m., I went up to 7000 m. and 8000 m. with no trouble at all. It seems that, in an even greater measure than so far thought, the main acclimatisation is acquired between 4000 m. and 6000 m. and a long stay in this region gives the conditioning necessary for going to even greater heights.

2) The equipment available today for use at high altitudes, oxygen apparatus, tents, sleeping bags, clothes, boots, cooking-stoves, etc., is in all respects excellent.

What the achievements of the English on Mount Everest in 1953 indicated, has since been confirmed by a sequence of successful expeditions, as for example Makalu 1955, Kanchenjunga 1955 and our Everest-Lhotse Expedition 1956: Today with proper care even a long stay at great heights is feasible. This outcome of the decades of mountaineering efforts opens up new possibilities for research at high altitudes.

The "Monsoon Home"

The mountaineers had reached their goal: on the 18th May Ernst Reiss and Fritz Luchsinger climbed Lhotse (8501 m.); on two consecutive days (23rd and 24th May) the teams of Ernst Schmied and Jürg Marmet and then Hansruedi von

¹ Gorak = crow; shep = to die.

Gunten and Dölf Reist stood on the summit of Mount Everest (8848 m.). From 25th May onwards the high camps were vacated in quick succession. The mountaineers and their Sherpas hastened down, to the green valley—and home, whereas for my small group there followed a busy reorganisation as we established a more permanent base for our prolonged stay throughout the monsoon. My Sherpas had realised what the retreat from the Western Cwm meant. They staggered down with incredibly heavy loads of “jetsam” from the high camps, through the painful chaos of the Icefall, saying: “Good for monsoon time, Sahib!”

I accompanied the departing mountaineers for two days' march down-valley, while my three Sherpas—Kamin Tsering, Lakpa Gyalbu and Nyma Gyalsen—stayed behind and immediately set to work on the construction of a stone hut for the “Monsoon Home”.

As I said good-bye to my friends on the 1st June in Namche Bazar, exactly on the day expected, the monsoon set in. In fine, steady rain and often completely enveloped in grey mist I once again returned up to the stone and ice desert of the Khumbu Glacier. In thinking back over those first days alone in the monsoon world I remember the words of the Buddhist hermit, which were then as a motto to me: “Now I climb back up the rocky way, I will be alone, at one with myself!”

From Namche Bazar I brought two new friends: Ang Gyalbu, an always-laughing Sherpa with a long pigtail, like Nyma's, and “Popsi”, a little Namche Bazar dog. Both contributed much joy to the life of our camp.

The “Monsoon Home” lay 2½ km. down-glacier from Base Camp, at the junction of the Chakri and Khumbu Glaciers, 5300 m. above sea-level. It was situated on an old moraine on the slopes of Pumori, about 100 m. above the glacier and the idyllic Gorakshep Lake. As we intended to remain throughout the monsoon in this camp and even hoped to stay on into the winter, we made ourselves as comfortable as possible. The Sherpas erected their two tents in a protecting hollow near our stone hut, which served as kitchen and store-room for provisions and firewood. From my tent, which was pitched in the shelter of a huge boulder near the new weather station, I enjoyed an incomparable view over the whole work area, including Mount Everest, Nuptse, Taweche and Pumori. The Sherpa Lakpa Gyalbu, a fully trained Lama, built on a rise behind the tents a small shrine of opalescent white quartzite on which he made daily offerings to the gods of rice, water and sometimes even chocolate and dried fruit. On the rock behind my tent he put up prayer flags which fluttered in the wind. So we established what was probably the highest “settlement” in Nepal, where we lived for the next six months.

Monsoon weather on the Khumbu Glacier

The ablation region of the Khumbu Glacier was during the monsoon period the battlefield for two opposing weather systems. The monsoon winds from the south, from India, brought rolling, heavily-laden clouds. But often they were overpowered by a dry, squally fair-weather wind from the Tibetan north. This Tibet wind possessed many characteristics of a föhn (föhn-wall, warming up in descent, etc.). In the months of June, July and August it brought frequent bright intervals, usually only in the mornings. Later in the day however, through holes in the monsoon cloud-cover, it could be observed that at a height of 6000 m. to 7000 m. the Tibet wind continued with greater persistence. Therefore it would seem to be more than a local, diurnal wind.

About noon practically everyday a gentle, fine rain set in which in the course of the afternoon changed to sleet and snow. Howsoever, the total of precipitation for the whole $4\frac{1}{2}$ months of the monsoon period only amounted to 32,6 cm.; and it is believed that higher up it would be even less.

In the foggy atmosphere of the afternoons, the mist-enshrouded ice pinnacles of the Khumbu Glacier took on a ghostly aspect. The heavy silence, broken only by the periodic rumbling of down thundering avalanches, exaggerated this eerie impression. No wonder that yeti stories continuously haunted the heads of my Sherpas.

Whenever possible observations were made on the situation in the upper air. Such notes are of especial interest because so far very little is known about the jet stream over the high mountains to the south of Tibet. This weather-determining, subtropical jet stream lies in autumn and winter to the south of the main Himalayan ridge and is known to be very strong. In spring these west winds weaken considerably. Throughout the monsoon period even easterly winds predominate on the upper part of Mount Everest. There are indications that during the monsoon the jet stream lies north of the main chain.¹

The distribution of precipitation between Mount Everest and the Ganges

So far there exist no long term weather records for the High Himalayas of Nepal. It is true the Indian Weather Service runs some weather stations in the fore-ranges. But above 2000 m. there are only a few rain gauges. Unfortunately these are not always looked after with the necessary care. To my great

¹ Cf. P. Koteswaram and S. Parthasarathy: "Winds over Mount Everest", *The Indian Journal of Meteorology and Geophysics*, vol. 4, No. 2, April 1953.

A similar opinion was expressed by Prof. H. Flohn in a lecture in the Geography Seminar of the University of Zürich on December 12th, 1957.

disappointment the Sherpa who was responsible for the daily readings of the Namche Bazar rain gauge left his post for several months to go on a trading journey to Tibet, without arranging for a substitute. Hence I am lacking an important set of readings. In contrast, the Chaunrikharka, Aisyalukharka and Okhaldhunga stations were excellently looked after.

My own records at 5300 m. together with those of the nine Indian weather stations, which all lie more or less in a straight line between Everest and the Ganges, give a most interesting precipitation profile for the south slope of the eastern Himalayas. The total precipitation at the "Monsoon Home" (5300 m.) for the observation period 12th April to 26th November 1956 amounted to 39 cm. Since this time span included the whole of the monsoon, and since the winter precipitation in the eastern Himalayas is probably small, this value may nearly count as the total for the year. This result shows very clearly the unexpectedly great aridity of the Everest region. Corresponding with the 39 cm. at 5300 m., the Chaunrikharka station (3000 m.), the next south of Mount Everest, already showed a total precipitation of as much as 166 cm., for the same period. In the southernmost foothill chain (Chisapani Bazar, 300 m.) it reached 199 cm. and at Sirha (80 m.), the first station which lies entirely in the Ganges plain, 225 cm.

From statistical calculations the Indian Weather Service reported the precipitation for the Sun Kosi catchment area, to which the ten stations of my profile belong, as normal $\pm 17\%$ for the year 1956. This is very fortunate for my recordings.

Precise and long term weather observations in the High Himalayas are not only of meteorological importance, they also form the essential foundation for the various branches of scientific investigation which are now reaching into this highest region. Without a good knowledge of weather conditions and climate only a very limited interpretation of glaciological and glacialmorphological findings is feasible. Therefore it is to be hoped that further such measurements on a still broader base can be put into operation as soon as possible.

The Khumbu Glacier : a) Surface speed

On the Khumbu Glacier, which is nourished from the huge, high situated firn basin of the Western Cwm, the firn line runs through the icefall and is therefore very irregular. It lies on the average 5600 m. above sea level. In contrast the firn basin of the Chakri Glacier has an unhimalayan character being a broad, flat, open depression, lacking the steep enclosing walls except on the south. Its firn line is a little under 5500 m. above sea level.

There is remarkably little gradient in the ablation zone of the Khumbu Glacier, except for the brief upper section which is the lower part of the icefall.

From Base Camp to the terminal area, in a distance of about 9 km., the difference in height is only 400 m. In contrast the accumulation zone has a drop of many thousands of meters.

A total of eight cross-profiles had been established for the determination of surface speeds, seven on the Khumbu and one on the Chakri Glacier (map p. 192/193). The periodic measurements of these showed that the ice movements were astonishingly small. Preliminary calculations from the readings on the main profile, situated immediately below the icefall, give speeds of more than 50 m. a year at only a few points. Though the final results are not available yet, still it is possible to say now with safety that the old estimates of speed for the region of the Khumbu Icefall of 700 m. a year are far too high.

At the Lobuje, the lowest, profile two of the five measuring stakes even showed a slight backward movement.

The fact that the glaciers of the Everest region do not move at record speeds is in good accordance with the previously mentioned discovery that the climate of this part of the Himalayas has far less precipitation than so far thought.

b) Morphology of the Ablation Area

Slow ice movement and little precipitation explain *the vast quantities of debris* in the lower ablation zone, as there is a correspondingly slow removal of the great masses of rock waste accruing from the very active weathering processes.

In its lowest section the Khumbu Glacier is banked up on accumulated debris and its surface is protected by a thick layer of almost consolidated material. Whereas in the next section up-glacier, in the zone of the ice pinnacles, the ablation is much stronger (up to 12 m. per year) and the thinning of the glacier consequently much greater. This process together with the lack of gradient throughout the lower ablation zone is encouraging the development of huge masses of *dead ice* in the lower part of the glacier. Probably the slight recession of two stakes in the Lobuje profile may be due to a backward gravitation of dead ice.

This situation in the terminal region of the Khumbu Glacier explains why the present glacier stream, the Lobuje Chubung¹, does not drain from the tongue through the end moraine, but leaves the glacier just below the alp Lobuje, where it bubbles out from about halfway up the lateral moraine.

By reason of the slow movement of the ice more time is available for the morphological development of the glacier surface in the ablation zone. On the one hand fantastic *ice pinnacles* are formed, reaching heights of up to 26 m., whilst

¹ Chubung = bubbling, boiling.

on the other hand huge *ablation lakes*, mainly of oval shape, develop. Several hundred of these lakes were counted, the largest of them having dimensions of 200 m. by 150 m. with a depth of up to 20 m.; the main axis is normally at right angles to the line of glacier movement.

The outstanding characteristic of the Khumbu Glacier below the icefall—its highly complex surface morphology—is the product of many interrelated factors, the initial forms being moulded by differential ablation. The towering ice pinnacles and lake-filled hollows are a climax result of such different rates of melting. The variety in quantity and quality of debris cover is a main cause of differentiation. The early history of the ice also has an important influence, for—as with many of the Everest region glaciers—the Khumbu Glacier is mainly nourished by avalanches from the surrounding, precipitous mountain flanks rather than by the normal sedimentation of snow. The icefall is an additional disturbance contributing to the very irregular glacier surface.

An attempt was made to investigate some of the factors which lead to the remarkable differences in rates of melting in the ablation area. A series of controlled experiments was carried out on the effects of patches of debris of different thicknesses and petrographic composition, and of varying coarseness. Temperatures were recorded at various points. For these morphometric measurements two instruments were especially useful, a long-lead thermograph and Stantel thermistors. I had fifty of the latter at my disposal. Thermistors are resistance thermometers having an absolute accuracy of $1/5^{\circ}$ C. and an even greater relative accuracy. They are most suitable for expedition use.

There is a practical value in the morphometric studies of these glacier surface features. For the ablation lakes mentioned above often empty themselves sub- and intraglacially in a very short time. Sometimes the sudden breakout of one such lake will start a chain reaction for a whole string of lower lakes. The discharged water, increasing in volume from lake to lake, can cause completely unexpected floods in the valleys below, even in fine weather.

Probably the following story from my Khumbu sojourn can be ascribed to the breakout of one, or maybe many of the large glacier surface lakes: At the

Plate 42: Two visitors—Lama Ngawang Gurmin and his novice—with my three Sherpas Ang Gyalbu, Lakpa Gyalbu and Nyma Gyalsen on the way to our work on the south flank of Pumori (7145 m.).

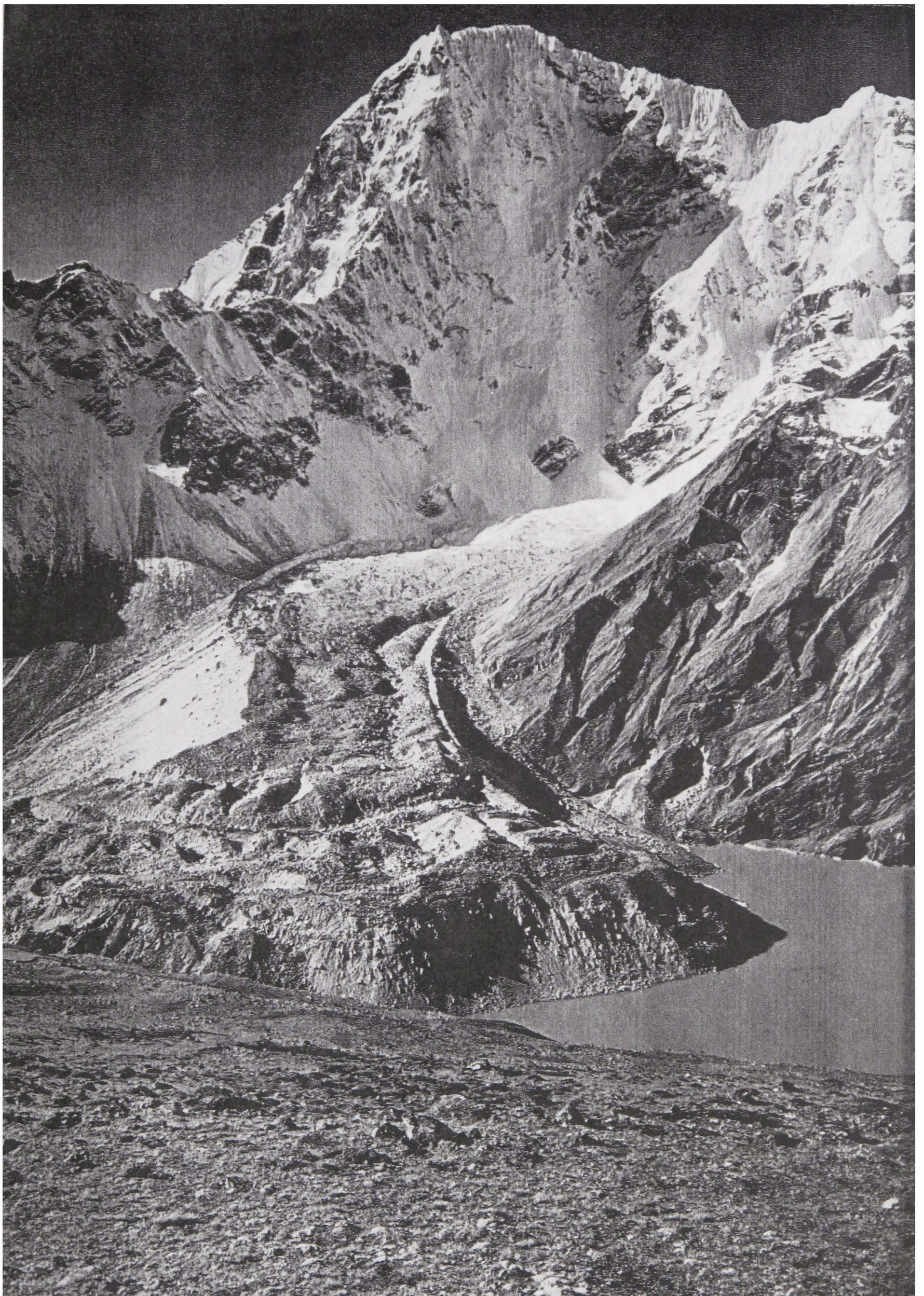
Plate 43: Peculiar ice-blister in the labyrinth of the Khumbu Glacier. Such ice formations sometimes grow in a few nights in the many dammed lakes of this extremely irregular surface.

Plate 44: Ice pinnacles of up to 26 m. in height characterise the middle section of the Khumbu Glacier. These pyramids are the result of differential ablation, and reflect the chaotic break-down of the glacier in the icefall.













beginning of July a flood wave swept down-valley from the Imjya Khola basin, carrying away five tsampa mills. Thereupon the men from the villages of Pangboche, Thyangboche and Khumjung banded themselves together to throw out of the country the Sahib up on the Khumbu Glacier, who was obviously responsible for arousing the wrath of the gods. For the fact that my work was not brought to an untimely and unhappy end, I am indebted to the deep friendship of the Tawas¹ of Thyangboche, especially the Zawi Lama², who pacified the excited people and deterred them from their purpose.

But still more serious is the danger which menaces the valleys on the south side of the High Himalayas from the many glacier-dammed lakes. Numerous side glaciers, which are especially strongly developed in the fore-ranges, block the outlets of the main valleys with their debris-covered tongues and their moraines. The resulting lakes are particularly dangerous when the dam consists of dead ice. In the event of an outbreak of the lake in the Chola Khola valley (plate 46) at the end of the monsoon period, a flood wave would plunge down-valley which might possibly result in a catastrophe similar to the one which occurred in the summer of 1956 in middle Nepal, when in the Indrawati valley it was said some 40,000 Nepali were made homeless in a few days, and many were drowned in the

¹ Buddhist monks who are bound by stronger vows than the ordinary Lamas.

² Head Lama of the Thyangboche monastery (plate 49).

Plate 45: View from the Nuptse Towers across the Khumbu Glacier to the eastern facade of the still unclimbed Pumori (7145 m.). The Khumbu Glacier here is composed of two branches: the ice-pinnacled section in the foreground originates from the Western Cwm, whilst the dirt-covered half comes from the much lower Lingtrense basin. Extreme thinning of the glacier has left the precipitously steep lateral moraine (← a →) rising some 70 m. above the present ice surface. With the hanging glacier b of Pumori this most recent shrinkage resulted in a rapid recession from its terminal moraine.

Plate 46: The Taweche Glacier, which is nourished by avalanches from the 1500 m. north flank of Taweche (left, 6540 m.), blocks the end of the Chola Khola valley (coming from the right) and dams a lake which at the end of the monsoon period extends to the foot of Cholatse (right, 6440 m.). After the monsoon the level of the lake drops slowly due to a sub-glacial outlet. Should the dammed waters of a specially rainy monsoon once break through the ice-barrier, in a few hours some 15–20 million m³ of water would be released. The anticipated discharge of 1000 m³ per second would cause widespread devastation.

Plate 47: Folds and cracks resulting respectively from the plastic and rigid behaviour of ice, here found in juxtaposition at the base of one of the Pumori hanging glaciers (ice moves from right to left).

Plate 48: In a tunnel under the above glacier, 110 m. from the entrance and 20 m. beneath the glacier surface. The ice (moving towards the camera) passes over a knob of outcropping aplite, and in so doing is moulded by every detail of the rock's outline. The foreground rocks are covered by water-ice.

floods. In the Sun Kosi valley I came across a small group of emigrating Indrawati people who had lost all their relatives and all their possessions. In the Indus region, 11 of the 13 floods which occurred in the main valley between 1830 and 1930 were due to glacier lakes breaking out of their confines.¹

c) Old Glacier Positions

In the upper and especially in the middle ablation zone the huge, sub-recent moraines, which are comparable with the 1850 moraines in the Alps, rise much higher above the present glacier surface than in the tongue region, where the extraordinarily strong preservation of the ice has maintained its level. Below Lobuje the glacier still completely fills its old moraine frame, indeed it even spills out over it in some places. These light coloured overflows of fresh-looking debris across the dark well-vegetated old moraines, which are clearly visible from a distance, characterise the terminal area of almost all the greater glaciers of the Everest and Cho Oyu region. This last advance which caused the overflows must have reached its maximum at least four or five decades ago, for since then the glacier has shrunk so much in the middle ablation zone as to leave the steep lateral moraines standing 70 m. above the present glacier surface (plate 45).

Huge "Eckfluren" which throughout the area lie at least a hundred meters above the present glacier surface, together with well-vegetated lateral moraines of even greater dimensions than the sub-recent ones, represent the next earlier glacier stand. At that time the Khumbu Glacier fell down over the marked gradient step at Thukla (height difference of 500 m.) and filled up the flat valley section of Pheriche as far as the junction of the Imjya Khola. Here are situated today the classically well developed 120 m. high, terminal moraines of those former Khumbu and Imjya Glaciers, in two huge adjoining crescents. The plains of the former tongue basins, which after the rapid retreat of the ice fronts were temporarily occupied by lakes, now carry the pastures of Pheriche and the fertile barley and potato fields of Dingboche (4300 m.). The latter is probably one of the highest locations in the world of rotation cultivation.

All that can now be observed of a third, even older and more extensive stand of the Everest glaciers are some few isolated remnants and occasionally preserved striae.

Evidences of the situation of the Everest glaciers during pleistocene times are very difficult to trace in the interior mountains. Some indication of the height of the firn line at that time can be obtained from a study of the numerous empty

¹ K. Mason: "Indus floods and Shylok glaciers", *The Himalayan Journal*, No. 1, April 1929.

corries. But the main history of the pleistocene can only be unravelled in the fluvio-glacial deposits of the foothill region.

In due course it should be possible to date at least the two most recent glacier positions. In an interstadial deposit near Gorak Lake I found well-preserved plant remnants which are now undergoing C₁₄ age determination tests. In addition tree-ring analyses are being done on root knobs of juniper (*Juniperus recurva*) which grew on the outside slope of the "1850" moraine above Thukla. On the margins of the lake in the Chola Khola valley I succeeded in obtaining two varve profiles. Furthermore measurements were carried out on *Rhizocarpon geographicum* and other lichens.

Unfortunately there appears to be little possibility of determining precisely the so dominant Pheriche stage. Perhaps that glacier position corresponds with the maximum of the 1600 advance in the Alps, it may however be very much older.

Investigations on the Pumori Glacier

The hanging glacier on the south slope of Pumori, the tongue of which lies at 5500 m. and the highest snow catchment at over 7000 m., offered good opportunities for the study of problems of ice mechanics and glacial erosion.

At the tongue end and in the huge randklufts it was possible to make interesting observations and measurements on glacier movement. The ice walls showed the annual layers clearly separated by dirt bands. Squeezed out folds resulting from plastic deformation could be seen in close proximity with rending cracks due to the rigid reaction of the ice (plate 47).

There were several holes going in under the glacier, some of which gave entry to tunnels penetrating hundreds of meters beneath the ice. Exploration of these lead to the discovery of a location where it was possible to study by measurements on the spot the question of the behaviour of ice when over-riding a great resistance, which is one of the still unsettled basic problems of glacial erosion. One such tunnel was followed for 110 m. until further passage was blocked by the ice and bedrock meeting. A roche-moutonnée-like aplite knob projected about one metre above its surrounding paragneisses (plate 48). The overlying ice was about 20 m. thick. By chance it was possible to get round the knob and with difficulty drill four holes into the ice behind the rock. Thermistors were frozen into these. As the ice advanced over the outcrop, at the rate of 26 cm. per 14 days, carrying the thermistors with it, the temperature variations were recorded every two weeks. From these data, the related pressures can be calculated by using the Clausius-Klapèyron equation.

Frozen ground at Gorakshep

In the Everest region the optimum height for the development of patterned grounds seems to lie at 5300 m. above sea level. There were in the vicinity of "Monsoon Home" magnificent examples of stone circles, stone nets (miniature as well as large formations), earth hummocks, Rasengirlanden (turf garlands) and stone stripes, in a great diversity of variations. Two fossil ice wedges of about 100 m. long, found in material that was deposited in connection with the "1850" moraines, are of special interest for the further understanding of the climate of earlier glacier phases.

Though by the beginning of April the snow had almost all melted at 5200 m. above sea level, the frozen ground was still too thick for the large rammsonde to penetrate through it. Only on the 17th May did it become possible to determine the thickness and character of the frozen ground, which at that date maintained a depth of 55 cm. to 86 cm. in the vicinity of Lake Gorakshep. Special attention was given to the study of its further disintegration which continued up to the 20th July. The re-freezing started again on the 18th October. Temperature and humidity in the ground were carefully recorded as winter conditions set in.

Solifluction is less important than expected, which is quite obviously explained by the great aridity, and by the non-existence of true permafrost in the periglacial area of Mount Everest. In contrast the effects of *regelation* (= diurnal freezing and thawing) are very great and most patently obvious. Enormous devastations on the slopes of the Pheriche and Lobuje yak pastures are caused by extensive turf ex-foliation resulting from such repeated freezing and thawing.

It is not the ruggedness of the landscape which sets the upper limit of habitation and land-use in the high valleys at the foot of Mount Everest, but the lengthy duration of frozen ground and the extreme activity of frost processes. Potatoes, which according to the stories of old Sherpas came from Darjeeling to the Khumbu valley only 50 years ago, form today the staple food of the people. There is no hope of growing potatoes above the present limit of Dingboche (4300 m.) because of frost, even though there would be many areas of suitable soils higher up. Yak pastures used each year are found as high as

Plate 49: Zawi Lama, the 23 year-old Head Lama of the Thyangboche monastery, with his mother. He is believed to be the reincarnation of his predecessor and is held in great reverence far beyond the borders of the Solu Khumbu.

Plate 50: On the way up to the Nangpa La. Only the Sherpas with their yaks are capable of handling the important trade between India and Tibet over this nearly 5800 m. high glacier pass. Amazingly sure-footed the yaks carry their 60-80 kg. loads over boulder slopes and ice, at extremely high altitudes and in great cold.









5100 m. in the Khumbu valley. For the first time, in the summer of 1956, the yaks from the Thyangboche monastery were on my advice pastured on the old moraine slopes and high flats near Gorakshep (up to 5350 m.). But when the yaks trampled on several of my research projects, I rather regretted my suggestion!

Grey days

Gradually the number of measurement sites to be visited swelled. With each month I became more and more the slave of my own organisation and time-table.

In the 4½ months of the monsoon there were only two brief occasions when I was able to go below the 5000 m. limit. The Sherpas went down to the village (the round trip taking about four days) in turns on the average once every two weeks to fetch potatoes and firewood. I hoped very much that in the time after the monsoon, when in the eastern Himalayas the weather is unsurpassably beautiful, I would have greater freedom of movement. It was planned to visit neighbouring glaciers to compare them with the Khumbu, and at the same time to investigate some of the problems of the old moraines and the area immediately outside them. A series of unfortunate events prevented me from fully realising this programme.

Arthur Dürst, who was sent off from Zürich at the end of July by the Swiss Foundation for Alpine Research to come to assist me on the Khumbu Glacier, never got as far as the "Monsoon Home". The only piece of mail which reached my camp during the 4½ month monsoon period was a telegram with the information that my friend Thuri would be with me at the end of August. When towards the end of September he had not arrived I decided to go to search for him.

But new troubles delayed my departure: Three of my four Sherpas fell ill one after the other. The demands of the long stay at high altitude and the monsoon weather had weakened them. Perhaps too there is some value in our "pills"; carefree and thoughtless the Sherpas had consistently forgotten to swallow their daily vitamin ration. The first victim, the tough Kamin Tsering, lay for two days and two nights in a delirious fever and no longer recognised his surroundings.

Plate 51: A herd of dso-yaks being driven to Tibet for selling. Caravans of normally some dozen animals, but often more than a hundred, move over the Nangpa La in both directions in spring and autumn. During this crossing Sherpas and yaks must spend three nights in the open; should they encounter unexpected bad weather disaster can result.

Plate 52: View over the brown rolling hills of the Tibetan plateau. The lonely pole in the wind-crusted snow marks the almost imperceptible summit of the pass and the many prayer-flags ask for the protection of the gods.

He was in the grip of a severe pneumonia. Luckily before his departure our expedition doctor, Edi Leuthold, had given me extensive instruction on how to treat pneumonia. Penicillin injections and oxygen, which I had carried from Base Camp to the "Monsoon Home" for just such an emergency, quickly helped Kamin over the worst, but at this height his further recovery went very slowly.

In the early morning of 1st October, which was to be my blackest day, Lakpa fetched me out of my sleeping bag with the request: "Nyma very sick—Sahib come help, please!" Another case of pneumonia! The next blow fell in the evening when there emerged from out of the mist and flurrying snow seven porters—but without Thuri Sahib! They brought the bad news that Arthur Dürst on his march through the monsoon-infected foothills had become very ill near Seta—half way between Kathmandu and Mount Everest—and had to be carried back.

The Kathmandu porters stood around barefoot in the new snow, their whole bodies shivering. They must be sent back down immediately! I decided that Kamin should go too, well wrapped up in blankets. In his father's house in Namche Bazar (3600 m.) he would recuperate more quickly than in our tents at 5300 m. It was with much regret that I said good-bye to this faithful assistant.

With the passing of each day we hoped for the end of the monsoon. Sherpa Numbi, for whom I had sent to Pangboche, was a worthy substitute for Kamin. He and Lakpa performed super-human tasks. Lakpa proved to be an excellent nurse to Nyma and Angi, who had also become sick. A painful infection of my right eye made the situation critical. If it wasn't going to be possible to continue the measurements without gaps it was senseless to stay on.

Finally, on the 18th October a three-day westerly wind storm set in which swept away the grey clouds and brought to a definite end the long damp monsoon months. With surface speeds of up to 55 km. per hour it tore three of our tents to pieces. The air was bitterly cold. Even at midday the station temperature was as low as $-11,5^{\circ}$ C. However this wind brought us crystal-clear skies and incomparable long distance views. The return of sunshine and warmth immensely improved our conditions. Except for a two day snow storm in early November, the brilliant weather persisted until the beginning of December when I finally left the Solu Khumbu; only the nights at 5300 m. became progressively, uncomfortably cold.

Autumn journeys

At the end of October when the good weather seemed to be well established, I reduced my rotar of duties on the Khumbu Glacier to a minimum and put Lakpa and Ang Gyalbu in charge of the remaining unavoidable measurements.

Lakpa, who at the beginning of our work could not write our numbers nor reckon with fractions, had in the meantime even learnt to read the logarithmic divisions on the scale of the Wheatstone bridge.

Then I set off with Nyma, Numbi and Kamin Tsering—who, now more or less recovered, joined us in Namche Bazar—to the Bhote Kosi valley, and from there with a large yak caravan up the famous pilgrim and trade route to the *Nangpa La*.

Hundreds of Sherpas and yaks go every year, in the pre- and post-monsoon seasons, across this 5800 m. high glacier pass to Tibet. On the way north they transport chakpa¹, ghee², rice, sugar, petrol and many other commodities. Dsoyaks, the much-prized male offspring from crossing cow and yak, which are excellent load carriers, are driven over in herds for sale in Tibet. There the Sherpas barter their wares for salt, the outstandingly important item in the reverse trade, and some raw wool, dried meat and a variety of fancy goods such as hats, embroideries and Chinese teacups.

The Khumbu Sherpas keep a firm control over this trade route. Only those Sherpas who live higher up valley than the bridge in the gorge below Namche Bazar are allowed to trade across the Nangpa La. The Tibetans who also use this pass are only permitted to make one trading trip a season and they may not take their goods below Namche Bazar. Whereas the Khumbu Sherpas make three or more crossings back and forth and sometimes carry their wares the whole way from India to Lhasa. Some rich Namche Bazar Sherpas even own houses in Tibet.

The whistling and calling of the yak drivers, sometimes leading into a monotonous singsong, and the tinkling of the yak bells give to this trade route the atmosphere of a completely different world and time. For those ten days on the way to and from the Nangpa La we lived in the Middle Ages. So must our forefathers have traded across the great Alpine passes centuries ago.

For me this journey to the Nangpa La brought not only a closer contact with the true life of the Sherpa people and a second unforgettable glimpse of Tibet, but also a valuable widening of the knowledge I had gathered on the Khumbu Glacier.

Of similar significance were some superb days which I spent in late November in the Imjya Khola basin, making comparative studies of the glaciers.

On the *march back to Kathmandu*, for which we set out at the beginning of December, I left my porter column of 18 men with all the expedition gear to go alone via Okhaldhunga to “Nepal-dana” (= Kathmandu). Taking with me only the quiet Nyma and Kirken, an utterly tireless, continually chattering and

¹ Air-dried potato slices.

² Butter (packed in petrol cans!).

laughing Sherpa, I followed the course of the Dudh Kosi to the south beyond Aisyalukharka. The purpose of this last digression was to search for remnants of the pleistocene advances of the Everest glaciers in the direct line of their prolongation.

Just before the confluence of the two rivers we cut across to the Sun Kosi and ascended this valley and its upper tributaries in a series of quick marches. On the same day as our porter column, the 12th December, we finally reached Kathmandu.

Looking back on that eight months spent in vicinity of the Chomolungma I realise that in both the details of the work and in the whole experience, many things were very different from what I had anticipated. But compromises, restrictions and renunciations are as much an integral part of a Himalayan expedition as the sudden excitement of unexpected discoveries, and as the evening light on the high peaks, as the tang of wood smoke, as the clarity of the November air, and as the gradually deepening participation in another way of life, enlivened by yeti stories and by the mask dances of the Lamas in Thyangboche.

When, in summarising, I say that my long stay in the Khumbu region was a wonderful experience, as well as scientifically most profitable, I know that this was in a large measure due to the faithful services of my Sherpas and to the goodwill of the Government of Nepal, to both of whom I am very grateful.