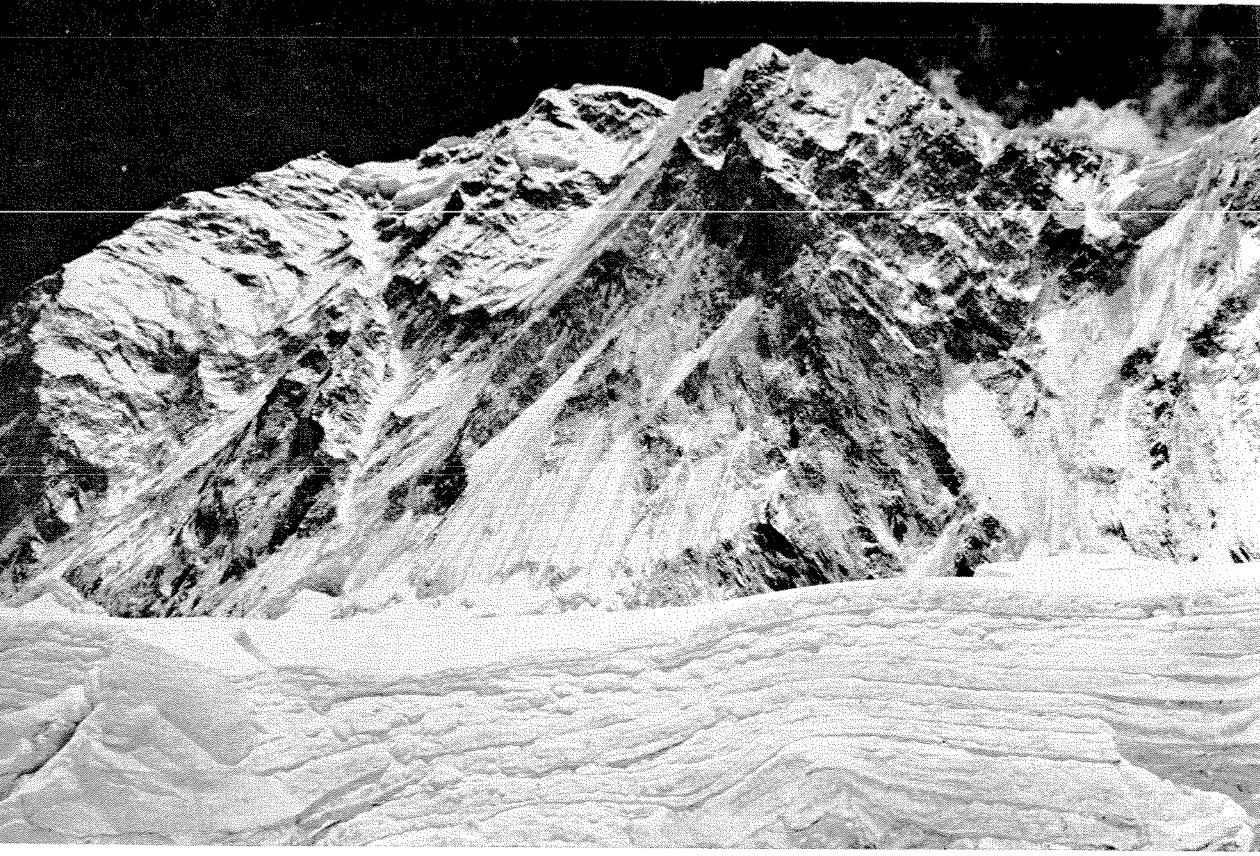


The great North Wall of Nuptse (25,850 ft.) in the Chomolongma Massif, as seen from Camp 1, (20,200 ft.) on the Western Cwm of Mt. Everest. Crevasse wall in foreground reveals nature of accumulation in zone of maximum snowfall on upper Khumbu Glacier. Only upper 60 feet of section visible. Photo by the author, Maynard M. Miller (M^3).

Glacio-Meteorology on Mt. Everest in 1963: The Khumbu Glacier of Chomolongma* in Northeastern Nepal

MAYNARD M. MILLER, *Glaciological Institute, Department of Geology, Michigan State University, East Lansing, Michigan*

Reprinted from WEATHERWISE, Vol. 17, No. 4, August, 1964
Printed in U. S. A.

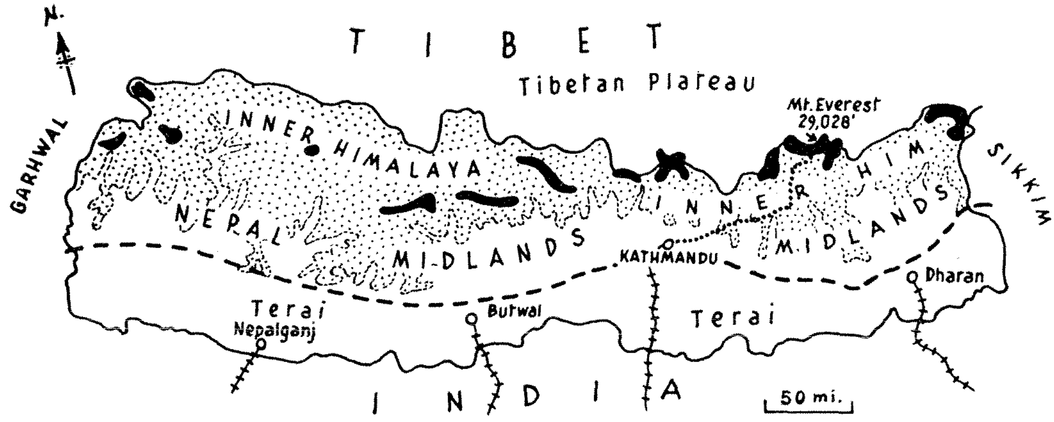


FIG. 1 MAP OF NEPAL
SHOWING LAND ABOVE 7000 FT. NORTH OF MAHABHARAT CHAIN

ABOVE 23,000 ft. · ABOVE 7,000 ft. · APPROACH MARCH ROUTE · ROAD · MAHABHARAT MTS.

IN May 1962 the "all decisive, unpredictable weather" again thwarted the second major effort of the Indian expedition to reach the summit of Mt. Everest. Similarly, meteorological conditions severely affected the British attempts in 1921, 1922, 1924, 1933 and 1938, and that of the Swiss in 1952. In the spring of 1963, in spite of a series of severe storms and attendant setbacks, the weather looked on the efforts of the American Mt. Everest Expedition with favor, allowing us to put six men on the summit.

Because of the severity of the conditions encountered, all members of the 20-man expedition, led by Norman G. Dyhrenfurth of Santa Monica, California, knew humility in the success. So too had the successful British expedition of 1953 and the Swiss in 1956, because any team on this great peak is acutely aware of the thin line of demarcation between survival and non-survival . . . the line drawn by the elements of the atmosphere which we call "weather." On Mt. Everest the prevailing westerly gales and hypoxia from reduced atmospheric pressure completely control man's hopes, his failures, and his successes.

* The native Tibetan name for 29,028-foot Mt. Everest is Chomolongma, "Goddess Mother of the World." In the geological sense this denotes the composite triumvirate of peaks . . . Everest, Lhotse, and Nuptse, and includes the upper Khumbu Glacier. In the meteorological sense, it has also been translated as "Mother Goddess of the Winds."

The American expedition in the late winter and spring of 1963 provided an opportunity for at least some observations of this region of hostile weather and related studies of what technically may be considered the world's highest glacier . . . the Khumbu, born from the wind-whipped snows between 23,000 and 29,000 feet (fig. 1). These observations were carried out in connection with the expedition's glaciological research program, supported primarily by the National Geographic Society of Washington, D. C. Subsidiary aid was provided by the Army Quartermaster Corps, the Research Fund of the Explorers' Club, and a number of other agencies to whom gratitude is also expressed even though it is impossible to mention them all in this brief article.

Although previous expeditions to Mt. Everest, even those as early as the 1920's and 1930's, maintained basic daily observations on the climate of this region, most of these data are from the Tibetan side of the mountain and far too sporadic to provide more than the most provisional of comparisons. The observations of the Swiss in 1952 and 1956, of the British in 1953, and of the Indians in 1960 and 1962, give some basis for comparison with our data. At this juncture, however, only a few preliminary remarks of general interest are warranted about this highest and probably most unique glacial climate on earth.

Our expedition's field schedule, controlled so inexorably by weather, made it impossible to spend more than two months on this high glacier and Mt. Everest. Generally, before April high winds and great cold make it impossible to climb above 26,000 feet, and after the first of June the monsoon storms usually descend to preclude activity of even the most foolhardy. In the few weeks available, however, with an exceptional break in the weather conditions, we were able to gather some information on the glacio-meteorological character of this sector of the high Himalaya. We were also able to obtain some new facts about existing Himalayan glaciers in this region of the Mahalangur Himal and about the prime atmospheric processes operating upon them. We also learned, as had these earlier expeditions, something about the formidable problems which one must face in field work at the highest elevations on earth, and what has to be done to be effective in a situation where exceptional time and energy are expended on the basic problem of survival.

Assisting in the glaciological program was Barry W. Prather who, since 1958, has been associated with me on the Juneau Icefield Research Program in Alaska. In 1959 we had been together on another high-altitude research expedition when we lived for three months above 14,000 feet near the summit of Mt. Rainier. Within three weeks of our return from Mt. Everest, in July of 1963, Prather and I were back in Alaska, returning from this latest project only in October. The recency of our field activity will, I hope, explain the provisional nature of these present comments.

The expedition's radiation measurement program, under the eye of Mr. Barry Bishop of the National Geographic Society, will also be mentioned. This program continued basic measurements which he had made during the 1960–61 expedition led by Sir Edmund Hillary to the Mingbo Valley in the Everest region.

The geological-glaciological research team of the 1963 American Mt. Everest Expedition. Left to right: Barry W. Prather, Sherpa Kancha of Namche Bazal, and Maynard M. Miller.

The General Expedition Plan and Support

Along with the mountaineering objectives, the expedition carried out selected field studies in high-altitude physiology, under Dr. Will Siri of the Donner Laboratory of the University of California. An individual psychological research study was conducted by Dr. James Lester of the Institute of Personality Assessment and Research at Berkeley, California, and a program of group sociopsychological study was carried out by Dr. Richard Emerson of the University of Cincinnati. These programs were supported respectively by the Atomic Energy Commission, the Office of Naval Research, and the National Science Foundation.

My task as geologist and glaciologist was to assess the physical environment, in some measure perhaps as a framework for our considerations of the activities of man at high altitude. We, therefore, concentrated our glaciological and meteorological program along selected lines compatible with the expedition's overall aims. In effect, the expedition provided a unique field laboratory for all of these scientific purposes.

The Khumbu Glacier's activity in recent decades has been typical of high glaciers in the eastern Himalaya. The glacier averages less than one mile in width (fig. 2), but has

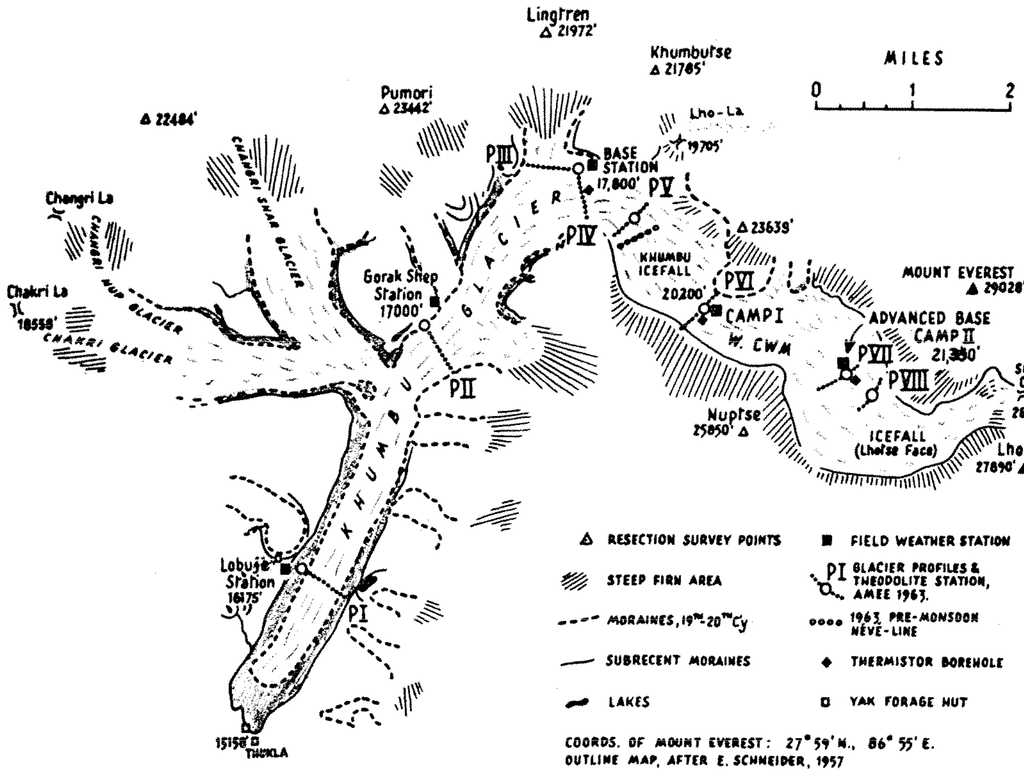
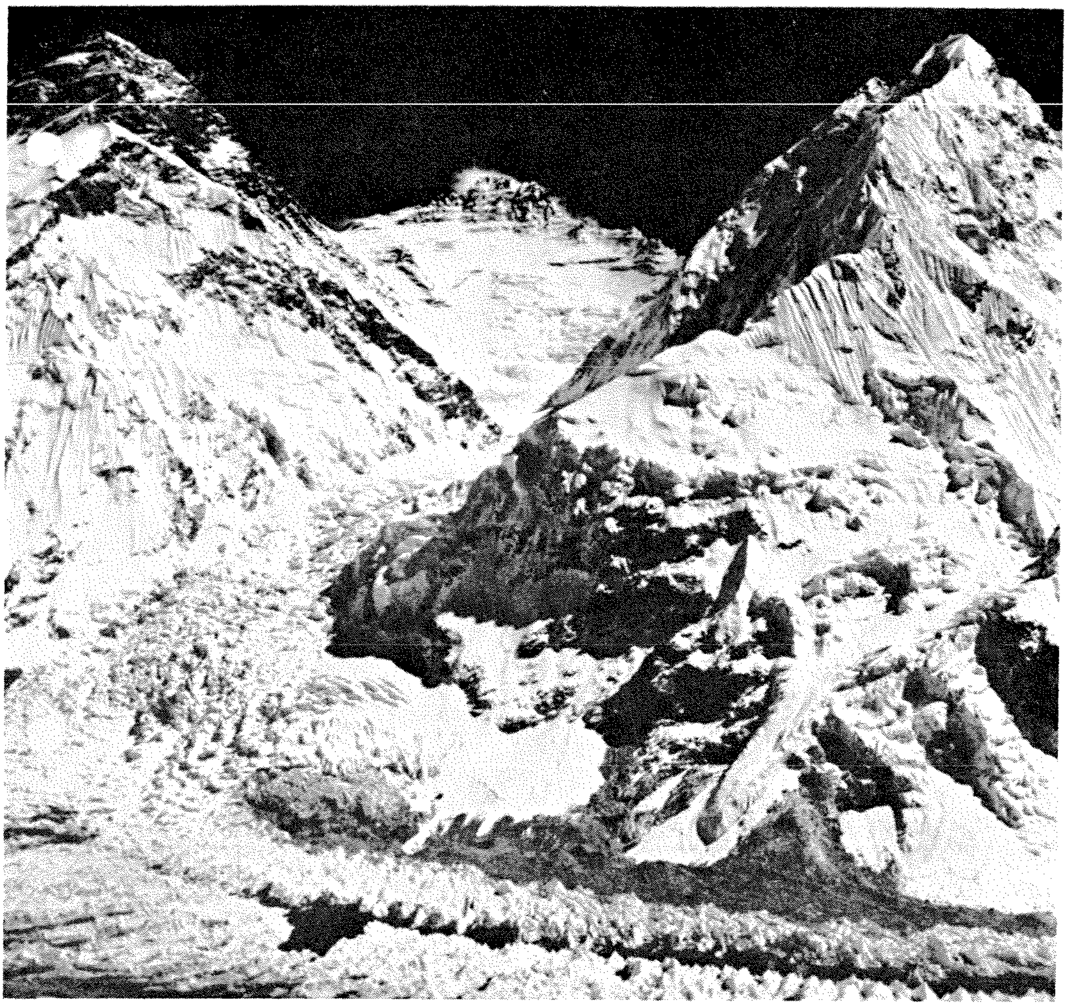


FIG. 2. THE KHUMBU GLACIER SYSTEM,
Northeastern Nepal, 1963.

one of the widest elevation ranges of any glacier system in the world. Avalanche snow and wind-drift nourish it from within 2000 feet of the summits of Everest and Lhotse, i.e., just under 27,000 feet, from which level the glacier descends down to about 15,000 feet in a distance of some 12 miles. For this reason, the factors controlling its fluctuations have significance in terms of regional, if not worldwide, climatic change. Our original plan was to work both above and below the mean upper limit of the snow-line on the main ice mass, extending from 15,000 to 23,000 feet, a plan which we were fortunately able to carry out. Special attention was paid to the accretion zone in the Western Cwm while based at the high glacier camps during the course of the expedition's several ascents.

Expeditionary Meteorological Equipment

Since all scientific equipment used on the expedition had to be transported nearly 200 miles across rugged terrain on the backs of porters, much thought had to be given to weight and portability. This ruled out the transport of any elaborate equipment and, hence, only basic instrumentation was employed. This included items purchased from leading firms as well as that loaned to the program by the National Geographic Society, the Eppley Co., the Wallace and Tiernan Co., the Hamilton Watch Co., and the Foundation for Glacier Research, Seattle, Washington. Science Associates of Princeton, New Jersey, very kindly donated certain critical items, and the J. L. Darling Co., Tacoma, Washington, donated waterproof weather-observing sheets and record books.



The Khumbu Glacier and the Chomolongma Massif: Mt. Everest (29,028 ft.) at left; Lhotse (27,890 ft.) center; and Nuptse (25,850 ft.) at right. Photo by N. G. Dyhrenfurth, American Mt. Everest Expedition.

The instrumentation included: 4 Stevenson Screens; a dozen max./min. thermometers; 16 pocket thermometers with spare tubes; 4 sling psychrometers with spares; 2 Campbell-Stokes Sunshine Recorders; a Belfort Pyrheliograph (Actinograph); 3 Terrestrial Radiation Thermometers; 2 marine chronometers; 4 precision aneroid barometers, 2 of them calibrated to 30,000 feet, 3 sets of wind vanes; 3 cup generator anemometers and remote indicators; 3 hand anemometers; 2 micro-meteorology anemometers and accessory recorders for continuous operation; five 55-foot englacial thermistor cables; a set of Wheatstone Bridges and selector switches; 24 dial thermometers for ice temperatures; 2 bore-hole thermometers and miscellaneous charts; ice calibration sheets, and so forth. In addition there were several battery-operated psychrometers, thermographs, and thermo-hygrographs. For the radiation measurements, an Eppley hemispheric Radiometer was used with inter-changeable filters for breakdown of the solar spectrum. An Eppley pyranometer (and normal incidence radiometer) for direct solar radiation was employed. Accompanying these units were 2 portable battery-operated recording potentiometers.

Climatic Contrasts during the Approach March

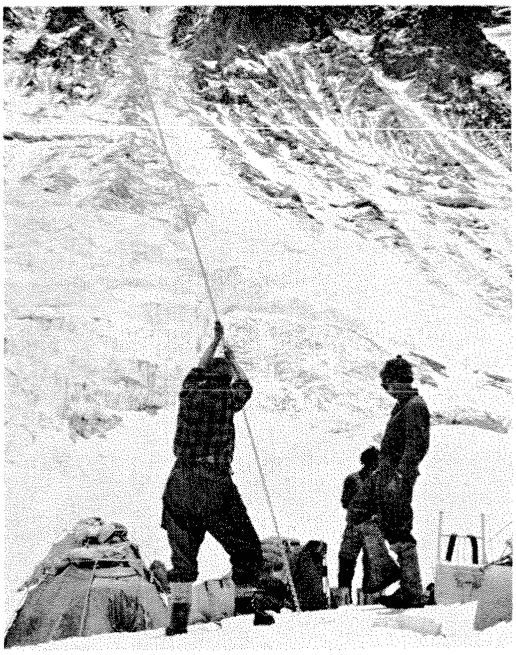
For generations the Himalaya has cast its mysterious spell on natural scientists as well as mountaineers, because many of the characteristics of these remote highlands are so unique compared to other regions on earth. In early February, as we flew northward from India across the gently sloping Terai of Southern Nepal, and then walked from Kathmandu to the crest of the inner Himalaya on the border of Tibet, we could see how Nepal, with its great variations in surface morphology and tremendous relief, contains prototypes of all the climatic zones found in the world (fig. 1). Because of this and the fact that most of Nepal lies south of the axis of the main high range, it has unparalleled variety of vegetation and weather.

The region traversed during the 180-mile approach march from Kathmandu lay between latitudes 26°40′N. and 28°N. (figs. *1 and 2*). This corresponds roughly to that of the Libyan Desert in North Africa. The latitudinal equivalent in North America is Florida and northern Mexico. In fact, portions of Central Mexico are morphologically and climatologically strikingly similar to the inner valley region of Nepal. Were much lower elevations involved, the main Himalayan chain would be thought of as tropical to sub-tropical. But because of the tremendous differences in elevation, plus the seasonal alternation of dry and rainy months, extreme climatic contrasts occur. This means that the Khumbu Glacier lies but 100 miles from the steaming tropical jungles of the Ganges plain, and yet on Mt. Everest we encountered polar glacial climatic conditions. In further contrast, less than 30 miles to the north was the dry non-glacial desert, characterizing much of the high Tibetan plateau.

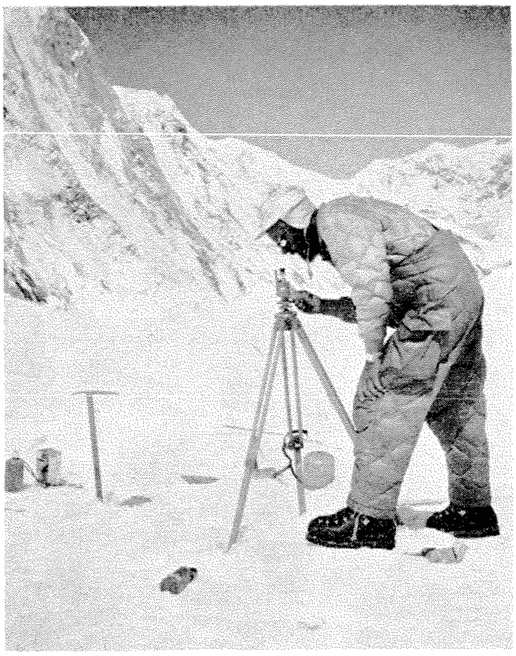
When we arrived in Nepal, the Nepali Midlands were still gripped by the winter dry season, with only a few negligible thunderstorms having occurred in the preceding weeks. Here the dry season begins in October and lasts through May. With 909 porters carrying our 29 tons of equipment, we began our approach march from the village of Banepa on February 20th. It was 16 days by trail to Namche Bazar, and most of them pleasantly dry and warm. The only important precipitation we experienced before reaching the mountains were two late-winter cloudbursts on March 4–5th in the Dudh Kosi valley, and on March 9th and 10th in the Imja Khola valley. Fresh snow from the effects of these storms at the 13,000-foot level lay knee-deep at Thangboche Monastery which we reached in the second week of March. This was the only significant snowfall in the Tibetan border province of Solu Khumbu during the entire winter of 1962–63.

Although in the Upper Khumbu Valley sporadic afternoon snow showers fell daily in April, it was not until the last few days of May that regional pre-monsoon showers

Barry W. Prather taking reading with double purpose hemispheric radiometer which includes a solarimeter and pyrheliometer at 17,800-ft. camp. Khumbu Icefall in background. Photo by M[3].



Drilling bore-hole for implanting englacial thermistor cables for in-ice temperature readings at Advanced Base Camp (21,500 ft.) on the upper Khumbu Glacier. Photo by M³.



Close-up of geologist employing surveying equipment to establish distances and heights. Note the heavy Arctic clothing, yet the strong solar insolation permits barehanded work.

The meteorological station at the 21,500-ft. camp on the upper Khumbu Glacier. Shown in photo are shelter, portable wind indicator, and Cambell-Stokes sunshine recorder. Photo by M³.

Dr. Maynard M. Miller taking englacial thermistor readings for temperature with portable Wheatstone Bridge on Upper Khumbu Glacier (c. 21,000 ft.). Mt. Everest Expedition photo.

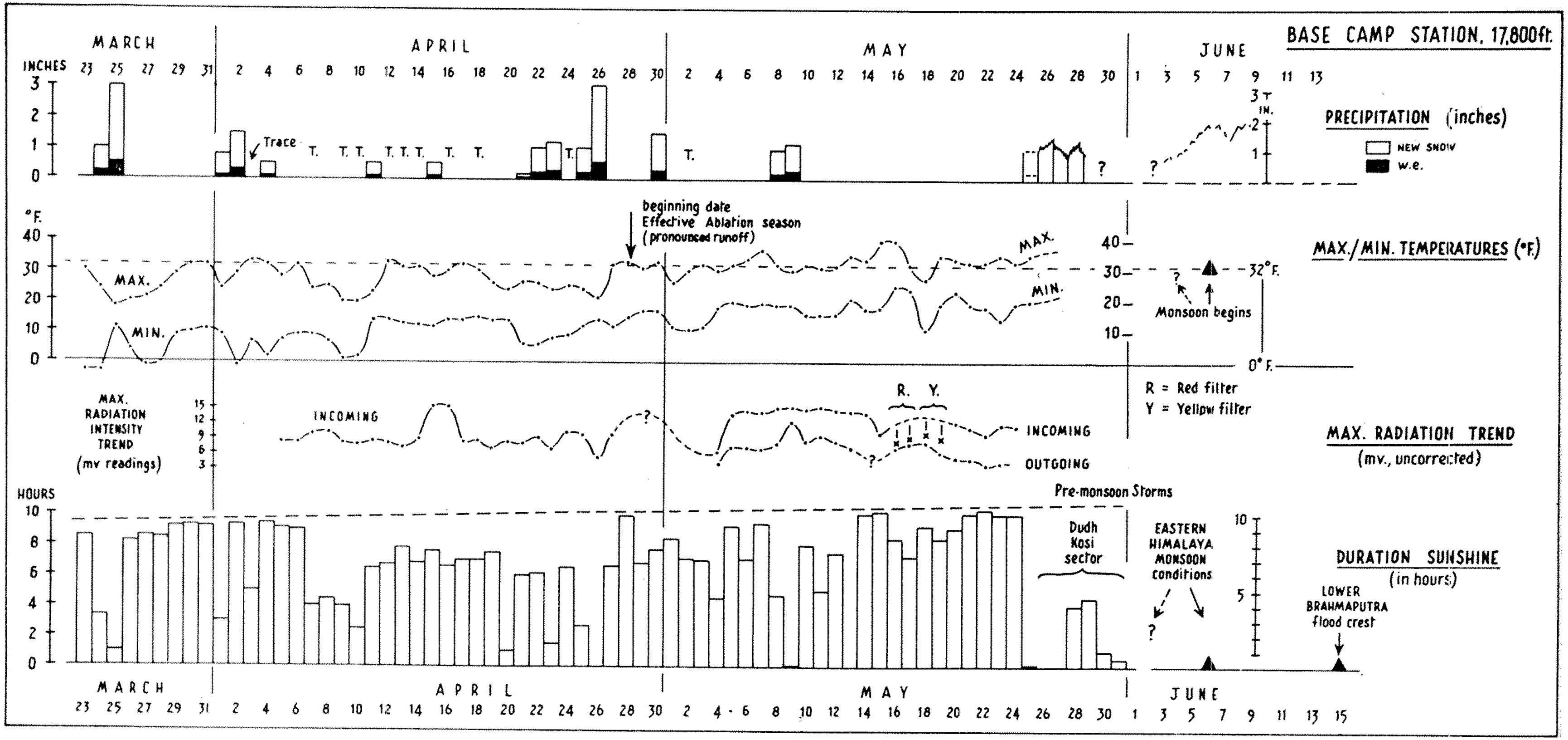


FIG. 3. DAILY TEMPERATURE AND PRECIPITATION RECORD AT BASE CAMP (17,800 ft.) ON THE KHUMBU GLACIER, MT. EVEREST, MARCH–JUNE, 1963.

moved against the peaks to accompany our descent from the heights. This was fortunate, since in some years the drenching monsoon rains strike as early as the middle of May and high in the mountains result in treacherous avalanche snow. Once the torrential monsoon strikes, it usually lasts well into September.

Khumbu Glacier Sites: 15,000 to 23,000 Feet

Base Camp, at 17,800 feet, was established in the third week of March on the north side of the Khumbu Glacier at a point rimmed completely by high ridges and peaks, all over 20,000 feet (fig. 2). The most remarkable rampart was that which topographically follows the Tibetan frontier, only a mile north of our camp. Here the line of great massifs included Pumori (23,441′), Lingtren (20,735′), and Khumbutse (21,785′), extending the prodigious west shoulder of Everest. Above were the gale-whipped summits of the Chomolongma group (Everest, 29,028′; Lhotse, 27,890′; and Nuptse, 25,850′), from the two highest perpetual banners of clouds trailed towards the east.

The terminus of the Khumbu Glacier rests at the head of a broad valley of glacial outwash, which today serves as a summer yak pasturing ground for the Sherpas. Its terminal moraine boldly displays a dozen or more fluctuational ridges, indicating a complex glacio-climatic history of this ice mass. The ice-contact side of the moraine is at an elevation of 16,000 feet. The base of its oldest section, and related valley train fan below, is at 14,500 feet.

Base Camp was about seven miles up-glacier from these moraines. The debris-charged ice surface between is a no-man's land of hidden crevasses, treacherous ice ponds, 30- to 60-foot high radiation pinnacles (nieves penitentes), and constantly sliding ablation moraine. At the 16,000 foot camp at Lobuje below a 20,076-ft peak, which we reached on March 16th, our first task was to set up a weather shelter and begin the meteorological observations which were later extended into the upper nourishment zone in the Western Cwm.

Our next task was to establish a base-line on a consolidated moraine ridge one mile above the terminus and to initiate our glacier movement surveys and ice depth measurements by geophysical means. One week later we had moved nearly four miles up-valley to Gorak Shep Camp (17,000′), where a recording thermograph was placed in a windscreen facing north and levelled at four feet above the ground. By the 25th of March instruments for a complete meteorological field station were also installed another two miles up-glacier at the 17,800-foot Base Camp, where continuous records were maintained for the following two months. Here, too, in the days on through April, our glaciological work continued, including daily recording on a thermistor cable installed in a 25-foot bore-hole near the center of the glacier.

At Base Camp we erected Bishop's pyrheliometer and connected recorders for incoming and outgoing radiation. Bishop, committed to pressing tasks high on the mountain, was unable to spend as much time as he had hoped on these measurements. However, the records were kept in operation during most of April and May. Although we had hoped to carry the light-weight actinograph to the South Col, Prather suffered an attack of high-altitude Pulmonary Edema at 24,800 feet, shortly after I had sustained a crushed foot in a rock avalanche while engaged in the gravity survey of the glacier west of Base Camp. To compound the difficulties further, Kancha and Angayle, our leading Sherpa assistants, both became ill from altitude effects and could only give minimal help for the rest of the time in the field. Thus we had to content ourselves with whatever total radiation and spectral measurements could be obtained at the 18,000-foot level.

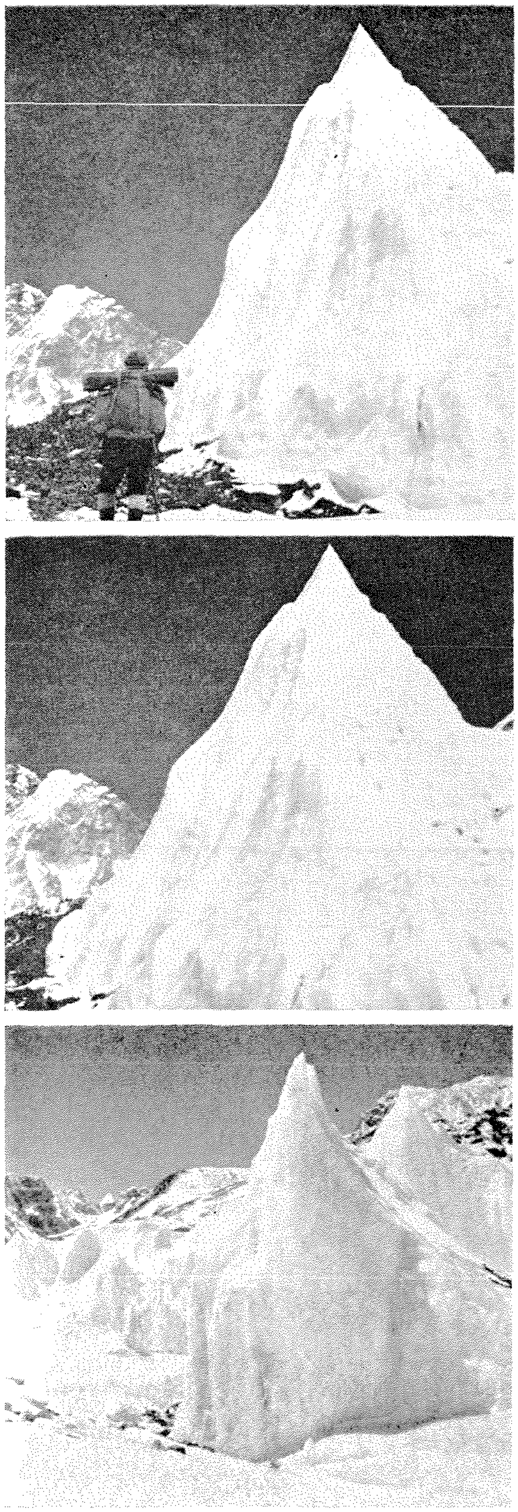
Early in April a meteorological field station was set up at Camp I (20,200′) above the Khumbu Icefall (fig. 2, for all main camp and observation sites). Weather records were kept intermittently here until evacuation of the Cwm at the end of May. At Camp II (21,350′) a screen, a sunshine recorder, and so forth, were also set up and fairly continuous weather readings were made from April 15th through May 25th. At both of these camps in the Western Cwm, systematic measurements of englacial temperatures were also maintained.

Thrice daily throughout the expedition a special report on weather conditions based on analyses of aerological conditions over Kashmir and the western Himalaya was directed to us by All India Radio (AIR), information which gave some clue to the arrival of storm conditions out of the west. In spite of the paucity of Himalayan stations and the inability to receive weather reports from Chinese stations in Tibet, on occasion the reports nevertheless proved quite useful to our field plans. We are grateful to the Indian Meteorological Service and the AIR for their cooperative efforts on our behalf.

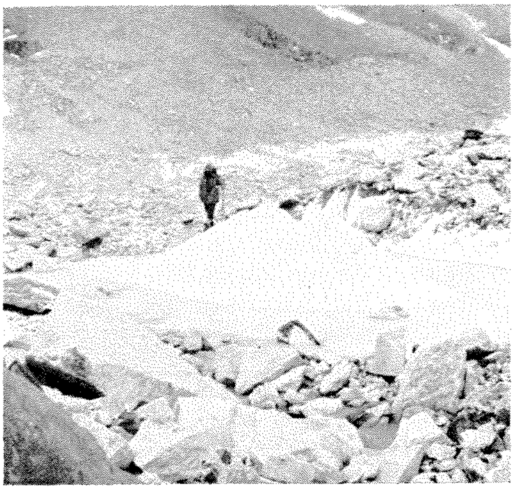
Brief Comments on the Glacio-Meteorological Observations

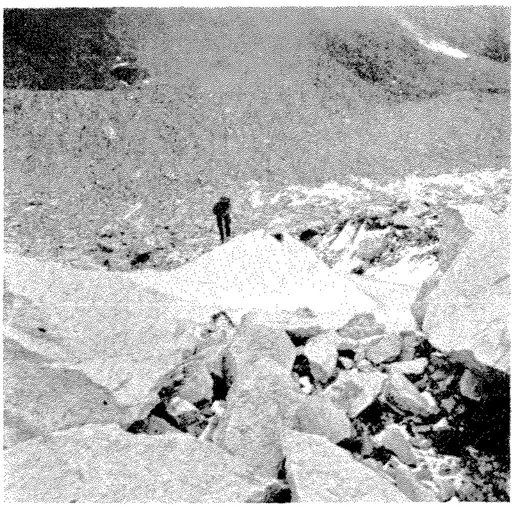
The meteorological observations were carried out from the middle of March until the last week of May. Because of the aforementioned injuries and illness in the team, the program had to be carried out essentially as a reconnaissance. Since our concern was the glacio-physical character of the glacier as a whole, and the gross atmospheric factors affecting its state of health, we concentrated on observations and measurements on ice surface regime and movement and on englacial structures and temperature. The basic meteorological records obtained at the Base and Advance Base Camps and the supplementary data at Gorak Shep and Camp I provide a related climatological profile between 17,000 and 21,350 feet.

The 1963 pre-monsoon transient snow-line (late May névé-line) was found to lie at 18,500 feet. Measurements of net accumulation were made at a number of sites upglacier from this level, with a positive accumulation budget noted at and above 20,000 feet. We found that most of the accumulation in the Cwm is by direct snowfall rather than by avalanche snows, although katabatic winds off the Lhotse face remove much of the snow-cover from the Cwm surface above the 22,500-foot level, and re-deposit it in the middle and lower sections of the Cwm. Over the past decade, the zone of maximum total accumulation appears to be in the lower one-third of the Cwm, i.e., at about 21,000 feet. A thickening of ice along the Pumori-Khumbutse rampart (fig. 2) was observed at this level, suggesting that this elevation zone is regionally representative. Over the past decade the annual net accumulation in this zone



Large radiation pinnacles (nieve penitentes) are 60 feet high on Khumbu Glacier at 17,500-ft. level.





Above: Recent moraines at 18–19,000 ft. on Khumbu Glacier. Center and lower: "Pingo" mound of ice in moraine-mantled glacier near Base Camp at 17,800 ft.

has averaged approximately 3.5 feet, water equivalent. Most accumulation appears to be monsoonal snow deposited in the summer months, June through September.

In the Western Cwm, a stratigraphic thickness of 60 feet retained firn and ice represents the last 17 years of accumulation. Melt samples from each of these strata were obtained for laboratory analysis of the nature and origin of any wind-borne material, such as pollen, spores, salts, and other inorganic particulates. From this it may be possible to say something about the dominant wind directions during periods of heavy seasonal snowfall. Another phase of the study is the measurement of natural Tritium from ice samples believed to represent annual accumulation. Significant variations of this radioactive isotope of hydrogen (H^3) are known to be produced in periodic outbursts of flare activity on the surface of the sun. This phase of the analyses is being carried out by Dr. W. E. Libby at the University of California, Los Angeles.

Our preliminary geophysical results indicate thermophysical conditions in the highest altitude sectors of the Khumbu Glacier representative of subpolar to polar conditions. This means mild to rather severely negative englacial temperatures, indicating that in the Western Cwm ambient and glaciothermal conditions throughout the year are substantially below freezing, with little propagated melt-water being produced. As yet, however, we do not know what effects the monsoon conditions impose at high elevation. Furthermore, subtemperate to temperate glaciothermal conditions, that is progressively warmer, with the glacier throughout being at the freezing point in the terminal zone, appear to exist in the glacier at lower elevations. On the basis of glaciological observations, it is provisionally suggested that during the past fifteen years this glacier, as a whole, has been experiencing a relatively temperate glaciothermal condition, but that the trend has been reverting to colder thermophysical conditions in the past several years.

The overall accumulation/ablation balance points to an equilibrium regime verging on slight down-wasting and terminal area retreat. Even short-term climatic regime changes are being expressed by pulsations in ice movement, such as in the icefall zone (fig.

2), which can make the glacier more difficult to traverse in some years than in others. In 1963 an abnormally difficult set of serac and crevasse conditions seemed to pertain. In fact, to this cause may possibly be attributed the tragedy in the icefall on March 23rd, when John E. Breitenbach was killed by the collapse of an ice wall at 19,000 feet. Significant longer-term changes are also being expressed at lower levels in a similarly oscillating manner. Regionally, this condition appears to prevail on other glaciers in the eastern Himalaya.

The glaciological-climatological relationship is interesting because of the high solar radiation recorded, the low humidity, and the extremely arid conditions experienced during the spring. At present, above 19,000 feet the propagation of melt-water on the glacier surface appears to be negligible, with ablation primarily by evaporation. This, too, is a direct result of the intense radiation. Up to 24,000 feet, slight melting was observed on ice adjacent to bedrock exposures, but this only for one to two hours in the afternoon. The crevasse wall stratigraphy suggests that a decade ago melt-water may have played a larger role, but regime-wise the total melt-water effects observed in this year were nil.

Only a most cursory evaluation of our meteorological records has yet been attempted. In figure 3, the maximum/minimum temperature and precipitation trends for Base Camp are noted during the two months in the field. Gross comparison is also made with the total sunshine record and the trends of incoming and outgoing radiation maxima at this 17,800-foot level. Surprisingly, the lowest temperatures encountered at Gorak Shep (17,000′) were as much as 15 degrees F. colder than at Base Camp, suggesting strong katabatic wind effects. The Base Camp minimum temperatures in April are seen to be seldom below zero (F.), rising to maxima of 15° to 20° higher during the warmer afternoons. During May the nighttime minimum temperatures were seldom below 15° F., and the maxima were at or slightly above 32° F. Pronounced increases in daytime temperatures after the 27th of April caused some melt-water to form and produce substantial runoff at and below 18,000 feet. Such was not seen at any time above the 19,000-foot level. During May at the Cwm camps (20,000 to 23,000′), ambient temperatures persisted below 15° F. and at night invariably dropped below zero. During April, temperatures at the Advanced Base Camp in the western Cwm were 10 to 15 degrees colder than at Base.

In mid-morning of May 1st, the day of the first summit assault, temperatures at the South Col (26,200′) registered 18 below zero (F.). The diurnal range at Base Camp on this day was 12° to 26° F., with a mean of 19° F. Because of strong differences in orographical control, lapse rates cannot be considered pertinent in extrapolating temperatures at these higher levels. But it is presumed to have been at least 10° colder than the Col temperature, or about 30° below zero at the time that Jim Whittaker and Nawang Gombu attained the summit (on which day winds gusted to 80 mph while they were above 27,000 feet).

Temperatures were not as low as expected. Comparison of the spring weather record with

Sampling glacier stratigraphy on crevasse wall of upper Khumbu Glacier at 20,200-ft. level. Photo by M[3].

that of previous expeditions on Mt. Everest suggests conditions considerably warmer and drier than in the 1920's. Presumably, the world-wide climatic amelioration of the past half-century has also affected this part of the Himalaya and has been expressed by a regional shift of storm tracks, perhaps to the south. Such is suggested by the unexpectedly low precipitation records for March and April. For example, at Base Camp light snow-showers fell daily, but through them, over the Lho-La, we noted continual blue skies on the Rongbuk side of the Lingtren ridge. This was in the direction of the North Col where the early British expeditions of the 1920's and 1930's recorded violent snow squalls every afternoon during these same months. Related to this seemingly changed condition may be a later arrival of monsoon storms since the early 1950's, in contrast to reports of monsoon arrival during expeditions of 30 to 40 years ago.

The wind was incessant above the 26,000-foot level. Only on May 22nd, the day of the successful double ascents and traverse via the west ridge and Col routes, was there negligible wind. This was one of the few days in the past two months when winds of 50 to 100 mph or more could not be seen trailing a banner of cloud or fine snow particles in a lengthy plume towards the east. It is because of this lull in the wind that our teams had the success that they did. We now know that this lull was the break-off of the prevailing westerly gales, for within 48 hours the pre-monsoon storms had moved up from the Bay of Bengal.

Thus, on May 25th, we evacuated Base Camp. The expedition could do no more. As seen in the chart of figure 3, these storms were followed about the 6th of June by what appeared to be violent monsoon conditions affecting the Everest region. At least the lower Brahmaputra and the Ganges began to flood-crest within the following week, but by then we had completed the long trek out to Kathmandu.

A Climatological Paradox?

In conclusion several interesting facts are noted. The first is that the two very latest expanded positions of the glacier in historic time in the main Khumbu Valley we found not far from the present glacial surface. The corresponding scour zones and associated lateral moraines along the valley walls suggested that these were as vigorous advances as have occurred probably at any time in the past several millenia. Also we found the present glacier resting, in part, on a subglacial mantle of older till, bearing out the strong recent resurgence of the Himalayan Little Ice Age and the probability that during the Thermal Maximum of about 5,000 years ago recession had occurred some distance up-valley from the present glacial position. It follows that perhaps development of a strong upward and northward shift in maximum glacial position in the crestal Himalaya might explain the lack of ice-cut morphological features and moraine-deposits of earlier vintage at or above the latest ice limits. In the long fugue of strictly climatic events, however, a northward shift of centers of accumulation does not seem compatible with climatic theory nor with the storm-track

(*Continued on page 189*)

Ice avalanche off the Lingtren-Khumbutse ridge (c. 22,000 ft.) as seen from Base Camp (17,800 ft.) in April 1963. Photo by M[3].

Glacier *(Continued from page 179)*

trends which are indicated. One is left with the tantalizing geological possibility that pronounced crustal upwarp in very recent geologic time has thrust this part of the Himalaya up into a colder climatic condition than the normal atmospheric trends could produce. None of the geologic facts which we found vitiates this suggestion.

In summary, the Khumbu Glacier reflects the unique character of the highest Himalayan glaciers as a response to what are probably the earth's most unusual atmospheric effects. The cursory review of our observations in this high and dry region, when allied with our geological and geomorphological results to date, seem to bear out the proposition that recent tectonic uplift and a consequent change in climatic relationships on these high slopes has taken place. At least they partially explain the paradox of the extensive glaciation which has developed here late in Pleistocene time, in contrast to early Pleistocene Maxima known to have occurred in formerly-glaciated regions elsewhere. This apparent uplift, corroborated by considerable geomorphic evidence, must be presumed to have been sufficiently rapid to balance out deglaciation effects of the worldwide climatic amelioration of the last 10,000 years. On this theory the upwarp in this sector of the eastern Himalaya also had to be of sufficient magnitude to maintain this newly-elevated land in a glacial condition quite out of phase with the natural climatic trend.

Regardless of the proof upon which our eventual conclusions will rest, the exceptionally depressed position of ancient snow-lines and terminal ice limits in the Everest region, when compared with the present glacial position (as well as that of both ancient and modern glaciers in the far northwestern provinces of the Himalaya), suggests that other than normal climatic changes have occurred in this border region of Nepal and Tibet. The suggestion of a maximum glaciation in recent time also frames the present glacial position and our observations of their subpolar to polar characteristics in a category only slightly less severe than the most expanded conditions of the last Glacial Age.