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# THE HIGH MOUNTAIN ENVIRONMENT PROJECT ST. ELIAS MOUNTAINS, YUKON AND ALASKA 1967 – 1971

BY

MELVIN G. MARCUS

FINAL REPORT
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## Abstract

This Final Report summarizes research accomplished by the High Mountain Environment Project of the Arctic Institute of North America under Army Research Office—Durham, Grant DAHC04-67-C0047. Field investigations were conducted in the Chitistone Pass region and on Mt. Logan during the period April 1967 through May 1971.

A historical and philosophical background of the project is presented as are environmental descriptions of the research areas. Work accomplished by the program is described under four headings: (1) Climatology and Meteorology, (2) Botany and Plant Geography, (3) Periglacial Hydrology and Geomorphology, and (4) Glaciology. Relationships between environmental processes are covered in the Conclusions section. Abstracts of published research papers and presentations are provided as is a listing of remaining research in progress.

# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# INTRODUCTION AND BACKGROUND

The Arctic Institute of North America, with support from the Army Research Office - Durham, conducted studies of high mountain environments in Alaska and the Yukon Territory, Canada, during 1966 through 1970. This research evolved from Arctic Institute experience in the Icefield Ranges of the St. Elias Mountains, where the Icefield Ranges Research Project has conducted multidisciplinary and interdisciplinary studies of alpine environments since 1961. It had been postulated that within the St. Elias Mountains and the neighboring Wrangell and Chugach Mountains, regions could be identified which would be analogous to other mountain environments and which would provide a field laboratory for studies of processes and elements within a high mountain region.

In May 1966, the Army Research Office awarded Grant No. DA-ARC-D-31-124-G836 to the Arctic Institute of North America to conduct a reconnaissance and examine the area in the general vicinity of the Chitina River Valley, Skolai and Chitistone Passes, Mt. Bona, and Mt. Logan. The objective of the 1966 program was to select areas that might serve as sites for environmental, physiological, and operational research. The reconnaissance was performed by Robert C. Faylor, Barry C. Bishop, Walter A. Wood, and Philip P. Upton. Results are reported in A Reconnaissance of a High Mountain Region (Faylor, Wood, and Bishop, 1967).

On the basis of this preliminary investigation, suitable sites were identified for research into (1) elements and operative environmental processes in a high mountain region, (2) problems of high

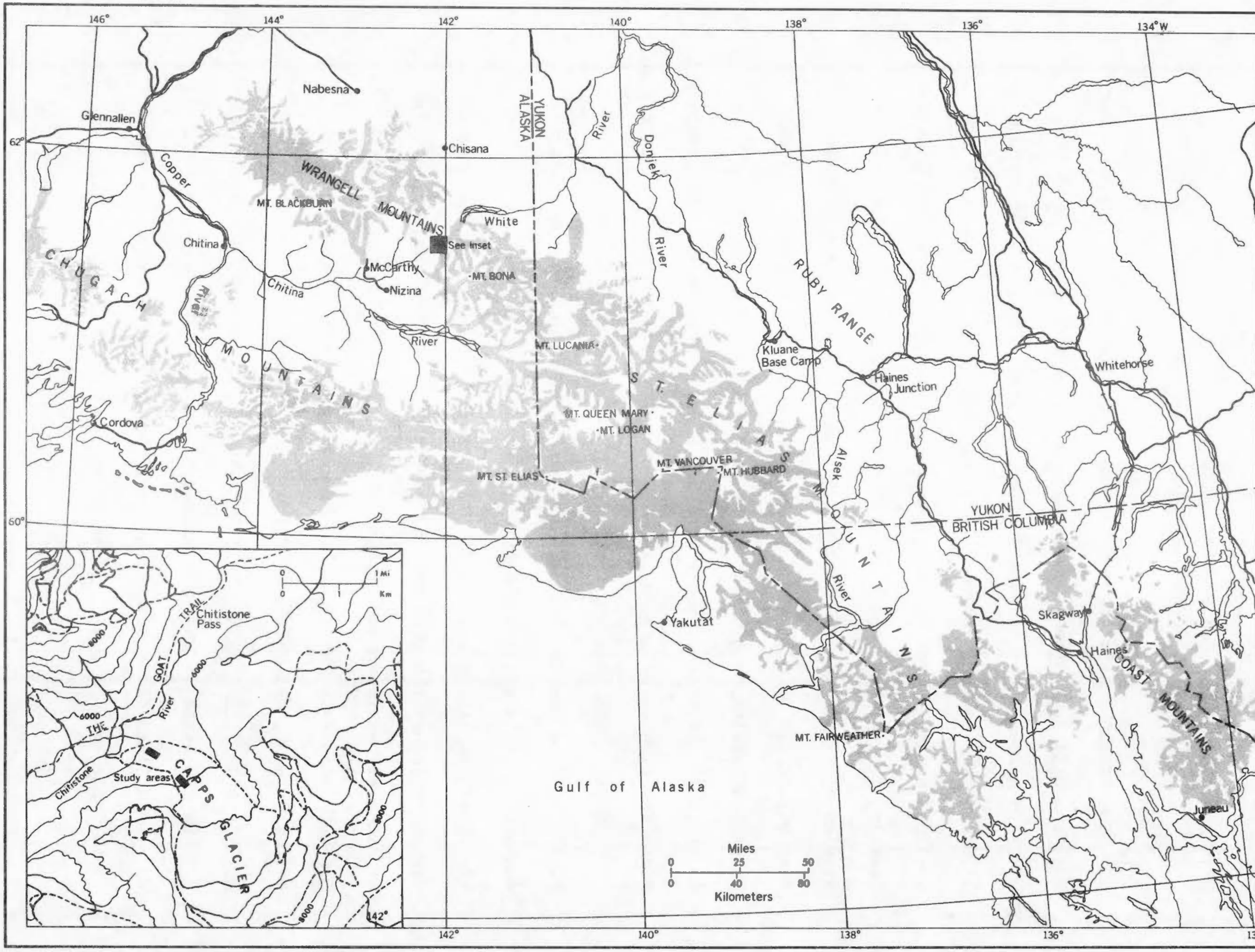



Figure 1. Location of study area.

altitude physiology, and (3) logistical and operational problems in mountain environments. Proposals were subsequently submitted for support of research in these three problem areas. This background discussion is focused on number (1) above -- the environmental research program -- the primary subject of this Final Report.

The Army Research Office in 1967 awarded Grant DAHC04-67-C-0047 to the Arctic Institute in support of environmental studies in the Chitistone/Skolai Pass region, Alaska and on Mt. Logan, Yukon. Subsequent contract extensions permitted field research to be accomplished for three more summer seasons, 1968-1970. The objectives of the program, outlined in the reconnaissance report and in annual proposals, were to study the elements and operative environmental processes in the high mountain region, focusing particular attention on three alpine site types. These are: (1) a high mountain area characterized by permanent snow cover and rugged glacier terrain; (2) a high mountain pass characterized by long-term, seasonal snow cover and exposed ground and vegetation during the short summer season; and (3) a deeply incised gorge and river fed by meltwater from higher snow fields and glaciers. The representative sites chosen for study were respectively: Mt. Logan in the St. Elias Mountains, the Chitistone/Skolai Pass area of Alaska, and the lower reaches of the Chitistone River (Figures 1, 2, 5). Additional research was also accomplished along a continental slope transect from Lake Kluane, Yukon (786 m) to the Mt. Logan plateau (c. 5,500 m).

Although the Mt. Logan and Chitistone areas are separated geographically, the combination of the two sites allowed investigations of environments ranging from forested mountain valleys through the full spectrum of alpine zones, which culminate in permanently glacierized summits. For convenience the research in the two areas is subdivided under the headings Chitistone Phase and Mt. Logan Phase.

## Chitistone Phase

Chitistone research extended over a zone from the Chitistone Glacier to the north side of the Skolai Valley, between the Russell and Frederika Glaciers (Figure 5). The Chitistone program consisted of a number of sub-programs which focused on special aspects of the environment. Studies were undertaken in climatology, geomorphology, glaciology, meteorology, and botany. This research was, in turn, related to the overall physical geography of the area. Through a physical geographic approach, it was possible to identify and analyze the interactions and interrelationships of the individual elements and processes operating within the mountain environment. Also, it should be noted that both the individual programs and the larger physical geography program were executed at a number of scales, ranging from intensive micro-level investigations to regional studies.

Chitistone Pass operations were conducted from May through August, 1967, 1968, and 1969, by a research team from the Department of Geography, the University of Michigan. Dr. Melvin G. Marcus acted as principal investigator; Dr. Thomas R. Detwyler was co-investigator in 1967 and 1968. Specific research has been described in (1) a series of semi-annual reports to the Army Research Office — Durham; (2) papers presented at the Symposium on Natural and Physiological Environment of the St. Elias Mountains, Alaska and the Yukon, Ann Arbor, Michigan, April 22-24, 1971; and (3) a series of published reports and presented papers (see Research and Results section, pp. 43 - 70).

## Mount Logan Phase

Environmental research on Mt. Logan was accomplished during the summer seasons of 1968, 1969, and 1970. A reconnaissance was conducted in 1967. Throughout the period, emphasis was placed upon climatological and glaciological research at the meso-scale. In 1970, however, the program was expanded to include full energy flux investigations at the 5,360 m high research station, as well as at Lake Kluane and Divide stations along the continental slope transect. Studies of DDT concentrations in the snow, winter climate, and infrared thermal patterns were also conducted in the St. Elias Mountains during the last year of the project.

The Mt. Logan Phase was conducted in cooperation with the Mt. Logan Physiology Project, a study of human responses to high altitude, stress environments. Thus, not only were the environmental studies useful for their own sake, but also they provided base data for related research.

## Summary

This Final Report is not intended to provide detailed results of the various scientific endeavors of the High Mountain Environment Project. Rather this report describes the research area, discusses methodologies employed, and provides an overall view of the scientific work that was accomplished. Insofar as research has been completed, abstracts and bibliographic references are provided. Some research, particularly that accomplished in recent field seasons, is still in process and will be forthcoming within the next six to nine months. These have been included in the bibliography and the papers will be forwarded to the Army Research Office - Durham as they appear. Also, it is planned that a collection of papers from the High Mountain Environment Project will be published by the American Geographical Society as a forthcoming volume of Icefield Ranges Research Scientific Results.

## THE HIGH MOUNTAIN STUDY AREA

The High Mountain Environment Project was conducted in the St. Elias Mountains of Yukon and Alaska and the Wrangell Mountains, Alaska (Figure 1). The St. Elias Mountains, which lie in the southwestern part of the Yukon Territory of Canada and the adjacent part of Alaska, are the highest coastal mountain range in the world. The range lies between latitude 59°N and 62°N, and longitude 137°W and 142°W. It consists of a series of north-west trending, heavily glaciated ranges, extending in a shallow arc for 500 km between the Pacific Ocean and the continental interior (Bostock, 1948; Wood, 1967). The area is one of the world's most heavily glacierized outside of Greenland and Antarctica, its valley glaciers flowing up to 150 km from its core in the Icefield Ranges. Sixteen peaks over 4,600 meters in elevation dominate the region.

The boundary between the Wrangell and the St. Elias Mountains is located roughly along the Chitistone and White River watersheds. Largely volcanic in origin, the Wrangells extend some 150 kilometers north-northwest to the Copper River (Wahrhaftig, 1965). More classically alpine than the dramatically glacierized St. Elias Mountains, they nevertheless boast several massive glaciers and peaks higher than 4,500 m. Mount Blackburn and Mount Sanford are notable among them.

### Mount Logan Study Area

Mount Logan lies in the heart of the St. Elias Mountains (Figure 1). At 6050 meters elevation, it is the highest peak in Canada and the second highest in North America. The Logan massif, one of the world's largest, extends roughly 32 kilometers from east to west, and is 14 km wide (Figure 2). Its rock and ice walls rise 3,600 - 4,300 m on all sides from the valley glaciers to a high summit plateau at 5,200 - 5,500 m (Figure 3). The plateau is some 15 km in length, and from it rise the several smooth, rolling summits of Mt. Logan. There are nine major summits on the mountain: three above 5,800 m, four above 5,500 m, and two above 5,200 m. Most of the area above the summit plateau is perpetually covered with a thick mantle of snow and ice; only the steepest precipices and steep, windblown ridges and summits expose bedrock.

The summit plateau holds several large icefields, separated by the ridges connecting the summits. All the glaciers are located on the north (leeward) side of the main summit ridgeline, and since the dry-snow line occurs at about 4,250 meters at latitude 60°N (Benson, 1968), all are classified as high-polar glaciers (Ahlmann, 1948; Sharp, 1956). From the plateau, they cascade down high icefalls onto the upper tributaries of the Logan Glacier -- draining westward to the Chitina-Copper River system.

Mt. Logan station (Figure 4) is located on a broad glacier field, some 20 $km^2$ in area near the center of the plateau (60°36'N, 140°30'W) at 5,360 m. It lies leeward of the summit ridge, presenting a down-glacier view only to the northeast. Wind is, however, an active agent at the station site, where drifting snow and sastrugi typify an ever-changing surface. The summer climate of Mount Logan station is characterized by below-freezing temperatures throughout the season. Insolation

Figure 2. MASSIF of MOUNT LOGAN, YUKON TERR.

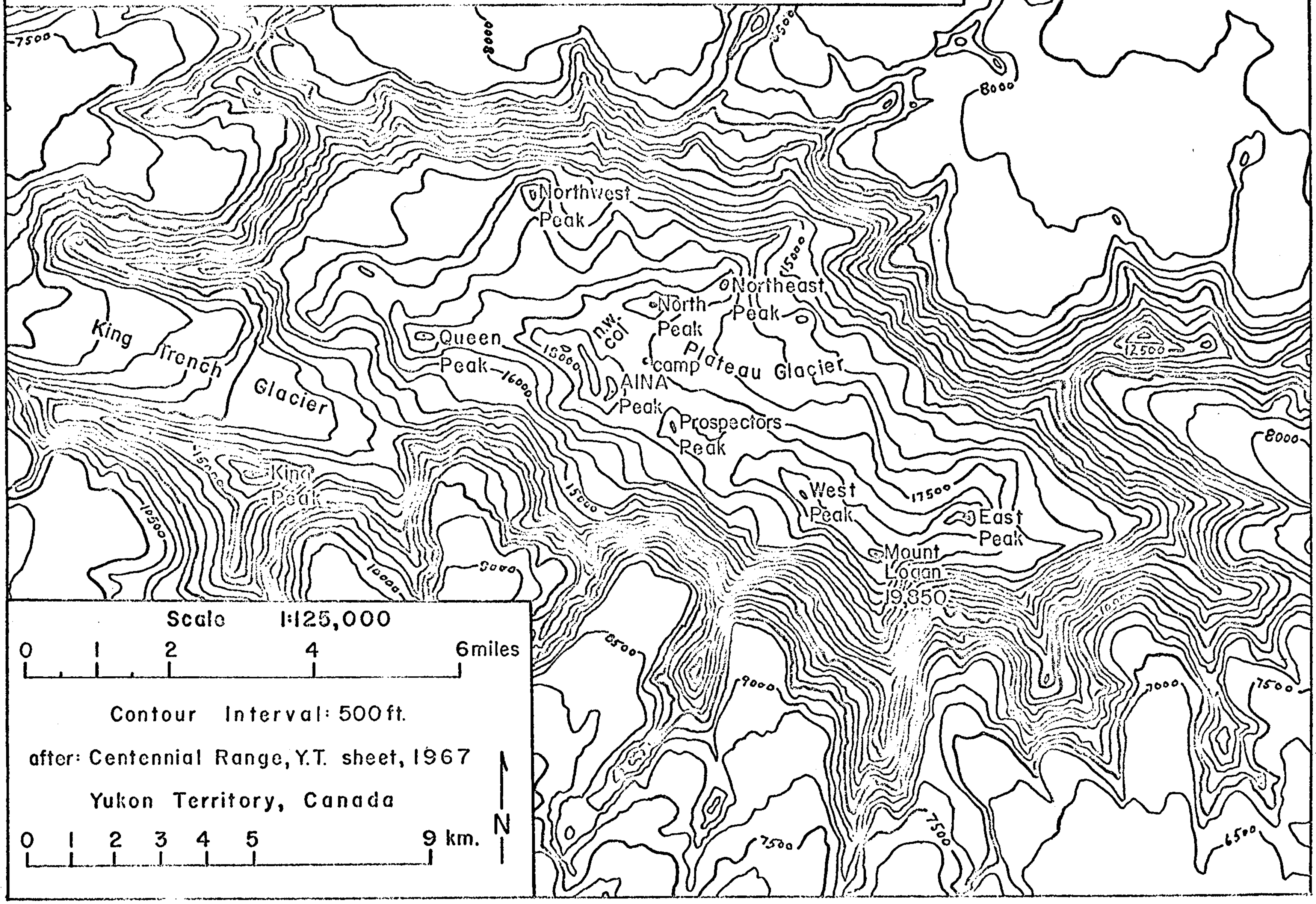


Fig. 3. Mt. Logan, 6050 meters, seen from the northwest. Note summit plateau at 5200 - 5500 meters, with gently rolling summits rising above it. Photo by Joseph C. LaBelle.

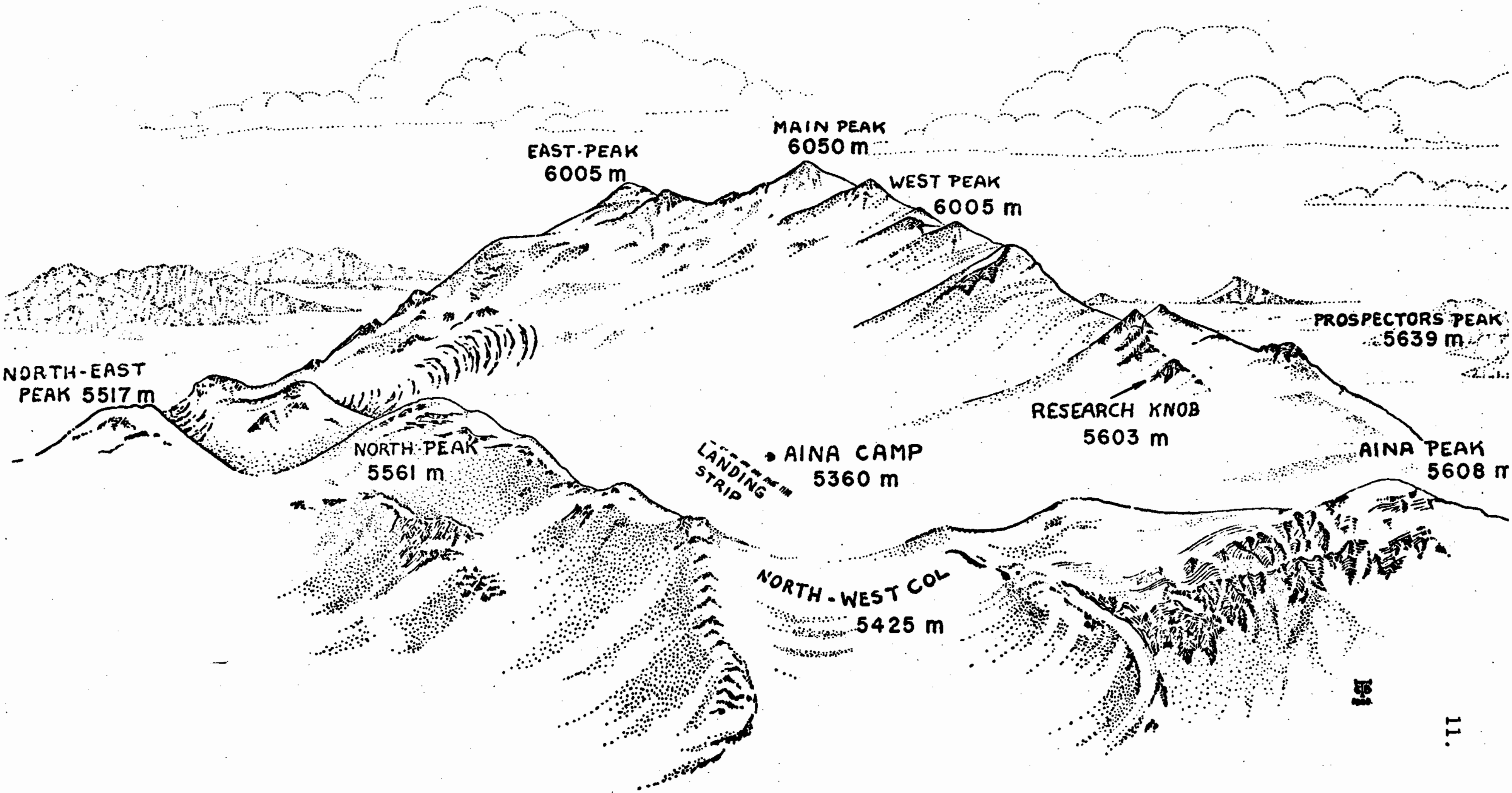



Fig. 4. Mt. Logan Plateau Area

values are high primarily due to altitude, but wind velocities are surprisingly low. Table I summarizes the summer record for 1968-1970.

## Chitistone Study Area

The Chitistone study area, located near the boundary of the St. Elias and Wrangell Mountains physiographic provinces, is roughly skewed-T in shape. The base of the T is represented by the northeast-southwest trending Chitistone valley, taken from Chitistone Pass to the Glacier Creek confluence zone. Summit ridges to either side of the valley define the area's lateral extent. The Skolai valley and Russell Glacier terminus zone represent the cross-bar.

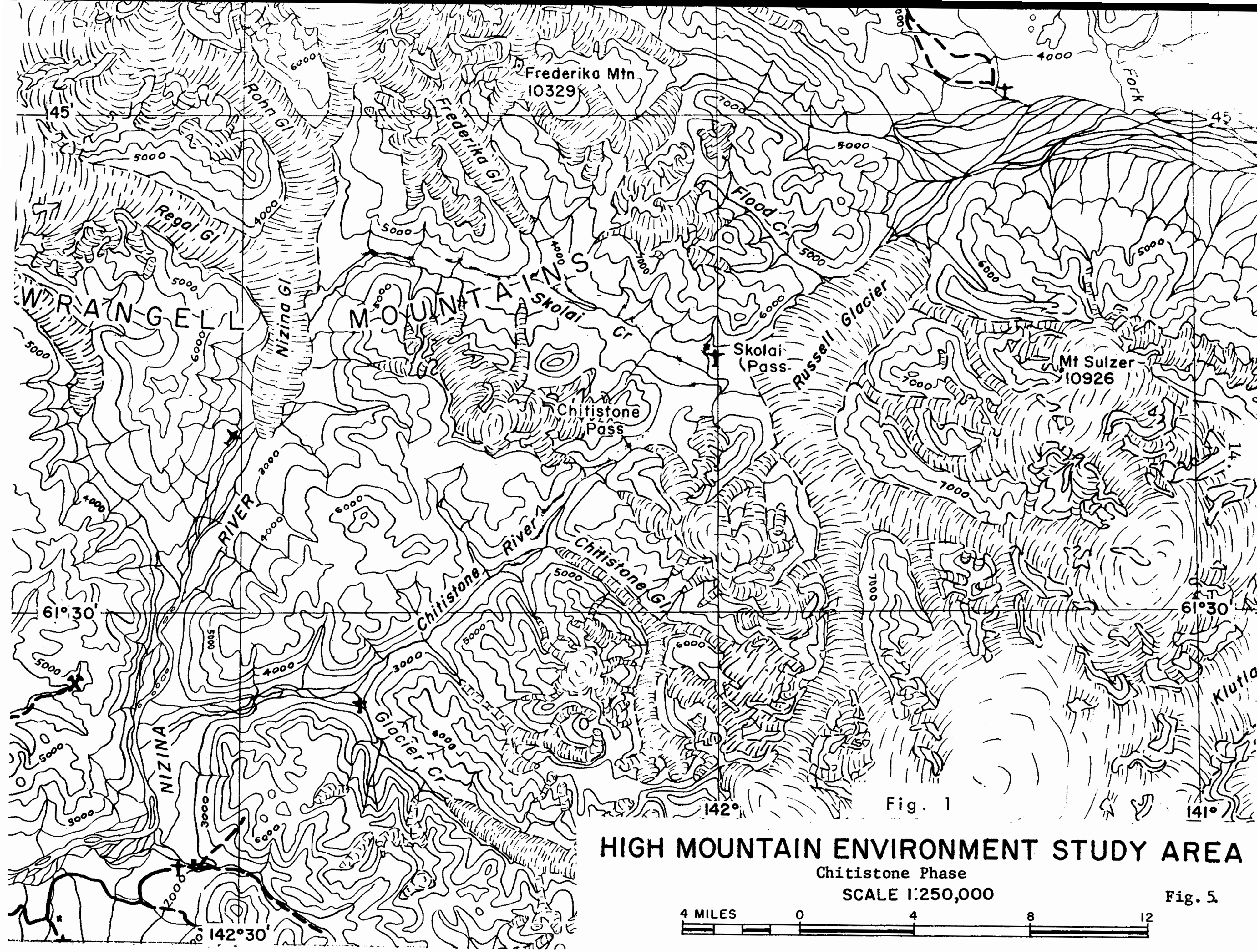
An outstanding aspect of this environment is the great diversity of terrain, vegetation, climate, and other environmental elements which occurs over short distances. This is illustrated by the aerial photograph of the immediate Chitistone Pass zone (Figure 6) and also is exemplified by a listing of the major landform types identified and mapped in the area: (1) glaciers, (2) moraines, (3) valley bottom alluvium, (4) alluvial fans and aprons, (5) stream terraces, (6) structural benches, (7) structural bench escarpments, (8) complexes of escarpments, talus, and steep, unstable slopes, (9) valley walls trimmed by Neo-glacial glacierization, (10) rock glaciers, (11) areas of mass movement deposition, (12) areas of residual periglacial material, and (13) standing water. Regional relief is great, ranging steeply from 900 m at the Chitistone River outwash to over 2,700 m on nearby summits.

TABLE I

CLIMATOLOGICAL SUMMARY, MT. LOGAN YUKON, 1968-1970

| Climatic Factor | July 2- Aug. 2, 1968 | June 28- July 28, 1969 | June 24- July 23, 1970 |
|---|---|---|---|
| Mean daily temperature (°C) | -17.2 | -17.4 | -19.9 |
| Mean maximum daily temperature (°C) | -10.8 | -11.2 | -15.1 |
| Mean minimum daily temperature (°C) | -22.2 | -23.9 | -25.4 |
| Extreme maximum daily temperature (°C) | - 3.4 | - 3.6 | - 6.9 |
| Extreme minimum daily temperature (°C) | -28.3 | -26.6 | -34.2 |
| Mean daily radiation (ly) | 802.4 | 744.2 | 678.4 |
| Extreme maximum daily radiation (ly) | 945.2 | 998.4 | 811.0 |
| Extreme minimum daily radiation (ly) | 550.5 | 566.4 | 507.0 |
| Mean insolation index ($Q_s/Q_e$) | 0.88 | 0.78 | 0.70 |
| Mean cloudiness (tenths) | 6.0 | 4.9 | 6.6 |
| Mean wind velocity (m $sec^{-1}$) | 3.4 | 2.6 | 3.9 |
| Maximum wind velocity (m $sec^{-1}$) | 23.7 | 8.9 | 23.2 |
| Mean relative humidity (%) | -- | 73.0 | 86.9 |
| Maximum relative humidity (%) | 100.0 | 100.0 | 100.0 |
| Minimum relative humidity (%) | 22.0 | 23.0 | 27.0 |
| Mean pressure (mb)[a] | 528.6 | 511.5 | 505.6 |
| Extreme maximum pressure (mb)[a] | 537.5 | 521.9 | 513.0 |
| Extreme minimum pressure (mb)[a] | 517.0 | 494.8 | 494.6 |

[a] Barometric pressure data are correct relative to each other for each year. Absolute pressure values are subject to a constant calibration error for each year. Absolute values for the three years should not be compared.




HIGH MOUNTAIN ENVIRONMENT STUDY AREA

Chitistone Phase

SCALE 1:250,000

4 MILES 0 4 8 12

Fig. 5.

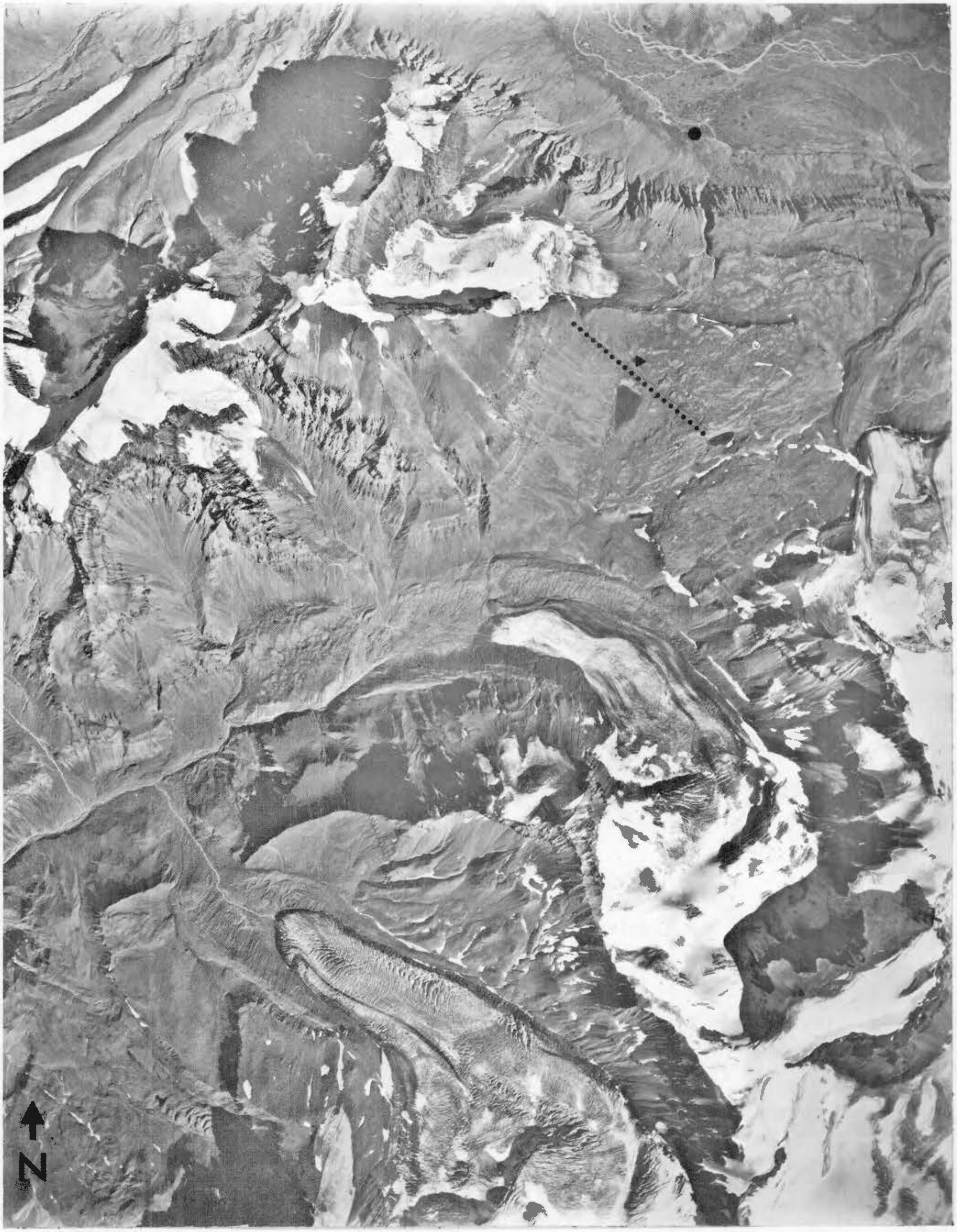



Figure 6. Aerial photo of Chitistone Pass area (U.S.G.S.; 15 August, 1957). Scale: 1/39,000.

▲ = Research station
● = Skolai landing strip
••• = Environmental transect

The main research camp (Figure 7) was at the summit of Chitistone Pass (1,774 m; 61°36'14"N, 142°03'35"W). When not snow-covered, the pass area is characterized by a discontinuous cover of alpine meadow and tundra. The terrain is marked by alpine streams, patterned ground, talus slopes, snow and avalanche debris deposits, and other mass wasting and periglacial features. The ground is permanently frozen except for the surface layer, which thaws to a depth of 1 m or less during the summer.

Chitistone Pass is located in a transitional zone between sub-arctic marine and continental climatic regimes. The relative strength of marine or continental air masses and associated flow significantly influences the summer climate -- which is strikingly different from year-to-year. This, in turn, leads to important annual variations in other environmental conditions such as soil moisture, runoff, snow and active layer permafrost melt, growing season, and mass-wasting. Chitistone weather data is summarized in Table II.

## Logistics

Equipment and supplies for the High Mountain Environment Project were transported locally by air. A supercharged, ski-wheeled Helio-Courier, capable of landing and taking off at the 5,360 m research camp, was utilized on Mount Logan. Scientific personnel were normally flown to the 3,100 m level in King Trench west of the main massif. The research team then climbed slowly to the plateau to allow sufficient time for acclimatization. Once the campsite was occupied, materials were transported directly from Kluane Lake Base Camp. The party was evacuated by air at the end of each season.

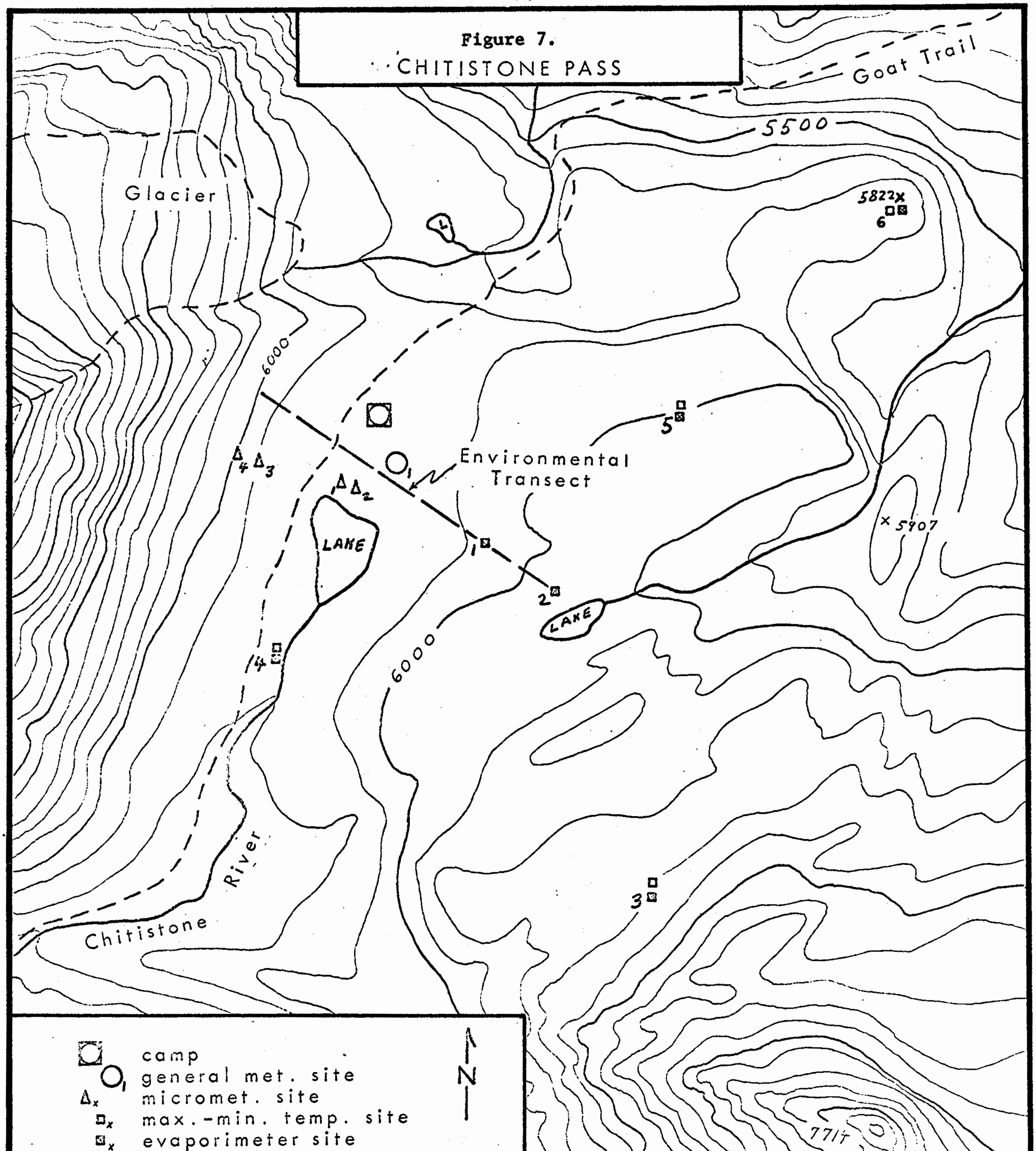


Figure 7.
CHITISTONE PASS
Goat Trail
5500
Glacier
5822x
6
6000
5
Environmental
Transect
1
LAKE
2
LAKE
4
x 5907
6000
3
River
Chitistone
7717
camp
general met. site
micromet. site
max.-min. temp. site
evaporimeter site
Scale: 1 inch to 1/4 mile
Contour Interval: 100 ft.
after: McCarthy Sheet C-3 Quad.
N

In 1967 and 1968, Mt. Logan personnel lived in a wooden frame and plywood cabin constructed on the site. By 1969 the cabin was buried under 10 m of snow, was beginning to collapse, and could be used only for storage. Metal-framed Versadome structures provided shelter and research facilities in 1969 and 1970 (Figure 8). Local travel was usually on creeper-equipped snowshoes, although skis or high altitude climbing boots were occasionally used. Although the party was acclimatized, high altitude and cold temperatures were debilitating and a low per capita workload was obtained compared to that of research stations at lower elevations.

Most Chitistone Phase operations were based at Gulkana Airfield near Glenallen, Alaska. Most equipment and supplies were shipped north in January or February so that they could be landed by a ski-equipped aircraft while sufficient snow was still in the Pass. After mid-May, it was necessary to either air-drop materials to the camp or utilize a 250 m gravel strip near the Skolai River. Since the strip was 450 m below and north of Chitistone Pass, supplies had to be backpacked to the station. A small tote-goat type vehicle proved unsatisfactory over this terrain. All travel in the research region was on foot.

Both the Logan and Chitistone stations maintained regular radio communications with Kluane base camp. Contacts were made at a minimum of every three hours in association with the weather reporting program.

TABLE II

CLIMATIC SUMMARY, CHITISTONE PASS, ALASKA, 1967-1969

| Climatic Factor | June 9- Aug. 18, 1967 | May 31- Aug. 16, 1968 | May 25- Aug. 14, 1969 |
|---|---|---|---|
| Mean daily temperature (°C) | 5.2 | 4.7 | 4.4 |
| Mean maximum daily temperature (°C) | 6.0 | 9.2 | 7.9 |
| Mean minimum daily temperature (°C) | 1.8 | 1.5 | 1.1 |
| Extreme maximum daily temperature (°C) | 15.0 | 16.6 | 20.6 |
| Extreme minimum daily temperature (°C) | - 1.5 | - 6.2 | -10.0 |
| Precipitation (cm. of snow) | 3.3 | 53.7 | 24.1 |
| Precipitation (cm. of rain) | 13.3 | 11.0 | 28.3 |
| Mean daily radiation (lys) | 409.0 | 463.5 | 430.4 |
| Extreme maximum daily radiation (lys) | 681.6 | 691.1 | 657.6 |
| Extreme minimum daily radiation (lys) | 93.1 | 164.4 | 148.8 |
| Mean insolation index ($Q_s/Q_e$) | 0.456 | 0.507 | 0.447 |
| Mean cloudiness (tenths) | 7.5 | 6.9 | 7.2 |
| Mean wind velocity (m $sec^{-1}$) | 3.1 | 2.5 | 3.4 |
| Maximum wind velocity (m $sec^{-1}$) | 15.8 | 9.5 | 11.3 |
| Mean relative humidity (%) | 84.9 | 76.5 | 79.3 |
| Maximum relative humidity (%) | 100.0 | 100.0 | 100.0 |
| Minimum relative humidity (%) | 33.0 | 36.0 | 33.0 |
| Mean pressure (mb)[a] | -- | 819.1 | 834.8 |
| Extreme maximum pressure (mb)[a] | -- | 828.9 | 847.5 |
| Extreme minimum pressure (mb)[a] | -- | 800.2 | 817.6 |

[a]Barometric pressure data are correct relative to each other for each year. Absolute pressure values are subject to a constant calibration error for each year. Absolute values for the three years should not be compared.

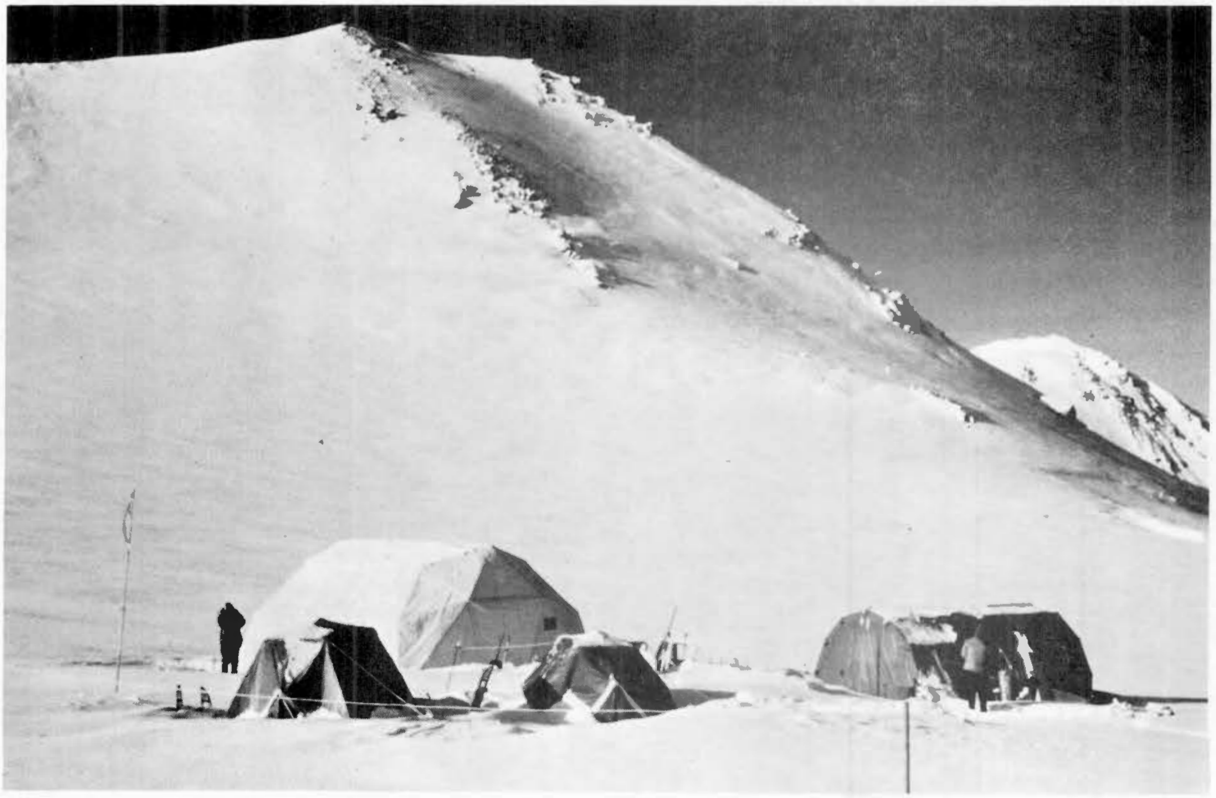


Fig. 8. Mt. Logan Research, 1969. The white versa-dome houses the environmental and physiological research facilities. Photo by Joseph LaBelle.

Fig. 9. Microclimatology instruments on Mt. Logan plateau. View to east. Photo by Thomas R. Stengle.

Fig. 10. One-year temperature and pressure recorder installed by CRREL at 5600 m. on Mt. Logan. The view is south across the Seward Glacier basin to Mt. St. Elias, 5489 m. Photo by Joseph LaBelle.

Fig. 11. Rime accumulation on totalizing anemometer, 5600 m., Mt. Logan. Rime and frost growth seriously impair observation at unmanned sites in this environment. Photo by Joseph LaBelle.

# THE PROGRAM

The principal objectives of the High Mountain Environment Project were to gain an integrated understanding of processes and elements of an alpine landscape. The overall program had as its aims to (1) quantitatively investigate individual processes and subsystems within the environment, (2) search for relationships between the environmental subsystems and (3) attempt to develop models and explanations which may be generally applicable to the physical geography of a high mountain region. Thus the research design required that specialized investigations of individual processes precede the integration and application of gathered information to the broader environmental questions.

It is, therefore, useful to review briefly the spectrum of research conducted in the Chitistone area and on Mt. Logan. No attempt is made to present a detailed accounting of the scientific results. These are enumerated in the abstracts and bibliography. Instead, this section provides an account of scientific operations in the various sub-programs and describes the integration of the materials.

## Climatology and Meteorology

Climatological studies were undertaken at both the regional and micro scales. Regional (or meso-scale measurements) were taken in conjunction with the larger Icefield Ranges Research Project meteorology program. Since 1963 the project has maintained weather stations at all its research camps, thus providing data which could be utilized by both climatologists and investigators in related fields. The results of this program are included in reports and articles by Havens (1964, 1968); Havens and Saarela (1964); Marcus (1965a, 1965b); Marcus, Rens, and Taylor (1966); and Taylor-Barge (1969);

The St. Elias weather stations are characterized by diverse environmental conditions. In terms of topographical position, the stations trace the skeleton of a transmountain profile from moist Pacific slopes to semi-arid continental interior. Mt. Logan is the highest station in the network; Chitistone provides a climatic benchmark northwest of the transect. Government operated stations -- such as Yakutat and Gulkana in Alaska and Burwash Landing and Whitehorse in the Yukon -- may be viewed as low elevation anchors for the alpine network.

Weather observations were taken at three-hour intervals, except where research programs required more frequent readings. Elements measured included: temperature, three-hour temperature maxima and minima, amount and type of precipitation, dew point, relative humidity, wind direction and velocity, sky condition, clouds, pressure, and other meteorological variables. Temperature, relative humidity, and insolation were continuously recorded on automatic instruments. Standard meteorological shelters were used; screens were not mechanically ventilated. In addition to Project use, data for the several stations were transmitted by radio and teletype relay to Canadian and Alaskan weather stations, where they were utilized in area forecasting.

Although the weather observation program has been an integral and significant part of the High Mountain Research Project, more important have been concurrent climatological research programs which focus on process-oriented problems of the alpine environment. This research falls in two categories -- that which concentrates directly on problems of climatology and meteorology and that which focuses on other (but climate-related) facets of the landscape. A brief review of topics and research philosophy is presented here.

Mountain climatology is beset by what might be called "problems of scale". The rapid changes in primary and secondary climatic controls and processes which occur over short distances place serious constraints on analysis. The observations made at any given station cannot, by any stretch of the imagination, be considered representative of more than a very small locality. Thus, at microscales, we may learn something about local climatic processes, but we have difficulty in defining the distribution of these processes in broader spatial terms. At the other end of the scale, we identify major energy, mass, and momentum systems but have difficulty predicting their distortion in localized zones of the boundary layer. For mesoscales -- at which most standard weather observations are made -- no standard linkages exist which allow extension upwards or downwards in the scale.

The objectives of much of the climatic research in the High Mountain Environment Project have been to attack these "problems of scale" by attempting to identify and define the operative climatic processes and their distributions at all three scale levels. Thus, out of the research which has been initiated, methodologies are being developed whereby extrapolations and connections can be made from micro-scales through macro-scales and vice versa. In this sense, the development of observational networks was necessary in order to identify basic parameters which could be used to test hypotheses or to develop new ones.

Among the first climatic investigations in the Icefield Ranges (and previous to the High Mountain Environment Project) was that by Havens (1968), which delineated the relationship between radiation, cloudiness, and sunshine hours as these factors related to variations in site and altitude. For the summer of 1963, Havens drew further comparisons between these processes in the St. Elias region and their behavior in Greenland and Axel Heiberg Island. Brazel (1968) continued radiation observations at the Divide site, and extended radiation and sunshine hour measurements through the summer of 1964. Radiation and energy flux investigations over the Seward Glacier snowpack were accomplished in July, 1965 (Lougeay, 1969). The latter two studies involved data collection previous to the High Mountain Environment Project; however, analysis was in association with that Project's climatology program.

The first view of the broad scale climatology of the region was given in Taylor-Barge's (1969) treatment of the summer transmountain climatology for 1963 through 1965. Her study identified some of the linkages existing between locally observed weather at the Project stations and the principal synoptic situations occurring over the North Pacific and northwestern North America. Of particular importance was her identification of distortions imposed upon air masses and fronts by the mountain barrier. At comparable scales, spatial characteristics of temperature and wind have been respectively interpreted by Marcus (1965) and Benjey (1970b). Benjey (1970a) and Kolberg and Brazel (1969) have summarized recent regional climatic data, while Marcus and LaBelle (1970, 1971) have related the high-elevation Logan weather to other areas of the St. Elias mountains. Variations in precipitation and snow accumulation have been treated in High Mountain Environment Project associated papers by Keeler (1969) and Marcus and Ragle (1970).

Results of several of the climatic investigations are still in preparation, although portions of the work have been presented (Brazel, 1968, 1970, 1971; Aufdemberge, 1971; Kolberg, 1971; Outcalt, 1971). Most ambitious among these are major studies by Brazel, Kolberg, and Aufdemberge. Brazel's work entails the delineation of microclimatic and mesoclimatic processes throughout the Chitistone Pass-Skolai Valley area and an attempt to establish linkages between these two scales. Included in his work are the measurement and calculation of energy and moisture balances along a five-station microclimatology profile. Kolberg's work takes advantage of the full Project records for all stations and is concerned with the broad scale interaction between major air mass systems and the mountain barrier. Aufdemberge focuses on microclimatic variations over the

Capps Glacier surface and Chitistone Pass tundra, two neighboring sites of the same elevation. First draft manuscripts have been completed for each of these Ph.D. dissertations.

In 1970, an effort was made to provide a comprehensive climatic baseline through the development of a three-station energy flux network extending from Lake Kluane (786 m) to Divide (2,650 m) and Mt. Logan (5,360 m). Marcus has just completed data analysis for this summer program, while Benjey has extended the Lake Kluane observations through the winter season to May 1971.

The work of the many individual investigators is now converging so that more general models are being drawn to explain and interpret alpine climates. It is clear that many generally accepted models used to explain mountain climatology -- particularly those relating to lapse rates, valley winds, altitude-precipitation relationships, and wind shear -- do not necessarily work. Forthcoming papers (see Papers in Preparation Section) will help clarify this situation and provide new insights into research design for mountain areas.

## Botany and Plant Geography

Botanical studies in the Chitistone Pass – upper Skolai River area were focused on (1) the taxonomy of the alpine plants and (2) investigation of vegetation-environmental relations. Knowledge of the kinds and characteristics of the plants, gained in the taxonomic study, is necessary for describing variations in the plant cover and for understanding why those variations exist.

As background information to these studies, note that botanical research in high mountain areas of North America has provided little information concerning the actual nature of the plant cover. Most efforts have been concentrated at extreme ends of the scale, ranging from broad, continental consideration of alpine-arctic plant distributions (e.g., Hultén, 1937) to detailed study of the effects of an alpine snowbank on the vegetation immediately surrounding it (Billings and Bliss, 1959). Few workers (e.g., Johnson and Billings, 1962; Drury, 1962) have investigated the relations between plant distributions and parameters of the physical environment within an intermediate area such as a portion of a mountain range, a mountain massif, or drainage system.

The distribution of plants within a given climatic region is determined by a combination of factors, such as surficial material, moisture, temperature, insolation, geomorphic processes, and biotic factors. In Chitistone Pass, as in other alpine and arctic areas, adaptation to the dynamic environment probably is more important than competition with other organisms. In the Chitistone Pass-Glacier Creek region, steep environmental gradients are common; great relief exists over short distances; slope, exposure, and microclimate are highly variable; and geomorphic activity is differentially distributed. Many variations in the vegetation coincide with these variations of environment, suggesting causes of the vegetational patterns. From knowledge of environment-vegetation relations, one can with some confidence (1) predict site conditions based on vegetational analysis, or (2) predict vegetation on the basis of known environments. Directed toward these goals, two investigators (Richard Scott and Thomas Detwyler) conducted related biogeographic studies in the Chitistone Pass region.

In 1967 and 1968, Scott studied the systematics and ecology of the alpine flora. Plant collections totaled over 3,000 specimens including approximately 301 taxa of vascular plants, 132 bryophytes, 52 lichens, 79 fleshy fungi, and 9 liverworts. All plants were collected in triplicate. Identification of these plants has been accomplished (Scott, 1968 and forthcoming). A full discussion of the significance of these taxonomic facts, together with a phytosociological analysis of alpine vegetation, should be completed in 1971. For example, ecological investigations of vegetation on the Fredrika Glacier moraines and outwash deposits show a close similarity to the successional sequences elaborated by William S. Cooper's classical studies at Glacier Bay, Alaska.

The broad phytogeographic implications of this taxonomic work are important. The flora of the St. Elias and Wrangell Mountains is phytogeographically important because the area (1) lies between two refugia, or areas that were unglaciated during the Pleistocene--the Yukon Valley and central Alaska; (2) has many localities that are only recently deglaciated and hence subjected to invasion by plants; and (3) provides a north-south pathway for migration of alpine and arctic species. The affinities of the alpine flora illuminate the processes of plant migration, evolution, and speciation in a region where heretofore almost nothing has been known about the geography and taxonomy of the alpine flora.

Thomas Detwyler studied the relations between vegetation and physical environment in the Chitistone Pass area during 1967 and 1968. Marked variations in the plant cover coincide with variations in the duration of snow cover and with inter-related geomorphic features such as stream courses, mud boils and stripes, solifluction lobes, stone stripes and polygons, wash slopes, moraines, and bedrock knobs. Similar though less apparent correlations between vegetation and microclimate were investigated by Brazel and Scott (in preparation). Understanding of these intimate plant-environment relations allows prediction of some environmental conditions based on the presence of certain indicator plant assemblages. For example, a certain type of moss-lichen turf indicates sites which are clear of snow relatively early each spring. These studies illuminate the distribution of vegetation types with respect to (1) duration of snow cover (1971), and (2) the distributions of soils and geomorphic features (see next Section concerning geomorphological investigations).

## Periglacial Geomorphology

The periglacial and alpine landscape of the Chitistone region is notable for the variety and intensity of geomorphic and hydrologic processes which affect it. Lower slopes of the Lake Kluane-Divide transect are similarly diverse. Because of these complexities, the major objectives of research in geomorphology were: (1) to quantitatively determine the effects over time of some major geomorphic processes such as physical weathering, movement of material down slope surfaces by sheet wash and freezing and thawing, creep, erosion, transport, deposition by streams and deposition of debris by snow avalanches; and (2) to formulate more reliable generalizations about geomorphologic patterns and zonation in high mountain environments. A wide spectrum of processes were measured in an attempt to obtain a comprehensive view of the landscape dynamics of the Chitistone area. There exists only one other <u>integrated</u> study of geomorphic processes and rates in a high latitude mountain environment, that by Rapp (1960) in Scandinavia.

The investigations were conducted at three scales. The first involved a basic inventory of landform types throughout the Chitistone and Skolai Valley regions utilizing aerial photographs, topographical maps and field checks. A map of fourteen major landform classes was produced (Detwyler and Redente, 1971, in press). This map has provided the basis for interpretation of vegetation distributions, hydrology and environmental zonation throughout the mountain area. At the same scale, basic chronologies were determined for three glaciers adjacent to Chitistone Pass and four glaciers adjacent to the lower Chitistone Valley (Figures 12 and 13). With the exception of the now stagnant Chitistone Glacier (which shows signs of previous surging), the glaciers reflect three brief equilibrium and retreat periods since the Little Ice Age. Thus the periglacial features (described later in this section) can be related to a time scale.

At an intermediate scale, investigations of ice-cored moraines constituted a principal focus of the Chitistone field program. Moraines abandoned by glaciers at their former ice margins are prominent features of recently deglaciated alpine environments.

Varying in height from less than a meter to several tens of meters, lateral and recessional moraines form a significant element of the alpine landscape. A multitude of workers have investigated moraines, but most have focused attention on the moraine as a historical indicator for the reconstruction of glacier flow patterns and chronology. Surprisingly little research has been concentrated on moraine mechanics, wastage, and morphology in alpine regions. As a result, it has only recently become apparent that ice-cored moraines are a common feature in deglaciated terrain. Although a few workers have specifically recognized and studied ice-cored moraines (e.g., Goldthwait, 1951; Hoppe, 1952; Bishop, 1957; Østrem, 1959, 1963, 1964, 1965; and Boulton, 1967), detailed information concerning their characteristics and their relationships with the mountain environment remains sparse.

Ice-cored moraines are prominent features in the Chitistone Pass-Glacier Creek area and not only represent a local landform type but also exert an influence on hydrology. The latter is reflected in the diversion of streams and the production of meltwater from buried ice. During the 1967 field season, Stuart Loomis conducted a general reconnaissance of ice-cored moraines with detailed transects studied at four glacier sites. On the basis of this reconnaissance and in association with work on the Kaskawulsh Glacier medial moraine (Loomis, 1970a, 1970b), an intensive two-year research program was designed, focusing particularly on the lateral and terminal ice-cored moraines of the Capps Glacier (Figure 4). Four other moraines were investigated in less detail. The results of these studies for the

Fig. 12. Chitistone Pass, Alaska (August, 1968), viewed from the east. Dodge and Snag Glaciers descend left and right of the Pass, respectively. Broad structural benches form the north-facing escarpment which drops to the Skolai River Valley (lower right).

Fig. 13. Lower Chitistone River Valley viewed to southwest. The debris-covered, stagnant terminal zone of the Chitistone Glacier is in the lower left corner.

first time identify and describe the morphological, structural and textural characteristics which distinguish ice-cored moraines from ice-free moraines (Loomis, 1971 and forthcoming).

Additionally, measurements were made of energy fluxes flowing across the atmosphere/till and the till/ice-core interfaces, relating these fluxes to the insulating properties of the moraine cover. On the basis of these observations, it became possible -- within a spatial and temporal framework -- to define moraine location in terms of retreating glacier margins, aspect and exposure of moraine surfaces, angle of slope, site elevation, and time of year. Thus Loomis has presented a model which explains the mode of origin and operative processes for ice-cored moraines. His assessment of their temporal properties indicates a greater persistence than has been expected -- a significant factor in the understanding of alpine, and possibly continental glaciated landscapes.

One additional project was accomplished at the intermediate scale. This was Lougeay's (1971 and forthcoming) study of infrared temperatures in the alpine environment. Working a variety of environmental surfaces, he has demonstrated that field determination of thermal infrared temperatures is a relatively inexpensive and effective means of thermal mapping. Also, he has demonstrated that field radiometer techniques can be useful in predicting the applicability of more sophisticated airborne remote sensing for alpine areas.

At a local scale, and beginning early in the field season of 1967, a permanent profile was established across the Chitistone Pass, about 500 m below (south of) the low point in the pass (Figures 6, 7, and 15). The profile was re-occupied in 1968 and 1969. The profile is 1,070 meters long and crosses a wide variety of landforms that are characteristic of the pass area. This profile served two important purposes: (1) it provided a base for the remeasurement of features that change through time; and (2) it provided a common base for studying the integration of landscape elements. The following processes and phenomena have been measured and described along the transect:

Topography and physical description -- A detailed topographic profile was surveyed, and the physical environment along the profile described. Measurements of drainage, slope, soils, and rock particle sizes were recorded.

Snow ablation -- Weekly measurements of snow depth were determined every 20 meters along the profiles in each field season. Remeasurements of snow depth indicate rates of snow ablation in the pass relative to slope and aspect and -- together with periodic, panorama photographs -- quantitatively record the seasonal retreat of snow in the pass. Vertical snow density profiles were periodically plotted at one point along the transect in order to establish water equivalent values of snow storage and ablation. These data have been particularly important in explaining plant geography, soil moisture, runoff, and other interacting elements.

Depth to frozen ground -- At the same 20-meter intervals, measurements were made of the depth to frozen ground in the soil.

Fig. 14. Capps Glacier to southeast, August, 1968. Note large ice-cored lateral moraine system.

Fig. 15. Chitistone Pass viewed to southeast, July, 1968. The environmental transect crosses the left-hand side of the photograph.

Vegetation -- To allow the construction of a detailed vegetation profile, the presence or absence of 23 primary plant species was recorded in continuous 1 x 2 plots along the transect.

Microclimatology -- The permanent transect parallels and is close to the microclimatology profile. This permitted an extrapolation and integration of climatological data with other transect measurements.

Also at the microscale, investigations were focused on a small area in the pass. Features were mapped by plane table and alidade in an area of approximately 90 x 120 m, which includes a first-order drainage basin. Bedrock outcrops, boulder fields, wash slopes, mud stripes and polygons, rock polygons, and lines of drainage were differentiated and are shown on a topographic base map (Detwyler, forthcoming). Vegetation, which was mapped according to plant cover classes and floristically sampled, is similarly represented. Mapping was repeated annually to assess changes over time.

## Glaciology and Hydrology

The overlap between glaciologic, hydrologic, and geomorphic studies in the high mountain area is considerable. Thus, much of the work already discussed (e.g., ice-cored moraines and snow profiles) is also pertinent to this section and vice versa. Additionally, the glaciology program is closely related to the climatological research.

Research into snow properties and accumulation was conducted at Divide station and on the slopes and plateau of Mt. Logan. These were an extension of snow studies conducted in other zones of the Icefield Ranges (Grew and Mellor, 1966; Marcus and Ragle, 1970) and continued the Mt. Logan snow profiles initiated by a cooperating research group from CRREL (Alford and Keeler, 1968; Keeler, 1969). The Logan snow studies have been accomplished by LaBelle and/or Marcus and are described in a series of articles (see Abstracts). A special facet of the 1970 snow studies was determination of DDT and other contaminant quantities in the Plateau snowpack (Stengle, et. al., 1971). The 1967-70 work provides the first high latitude/high altitude record of alpine precipitation trends.

Among the results it should be noted that snow accumulation is less at high altitudes than has been suggested, that aeolian processes are a significant primary control of snow distribution and that snow-producing weather phenomena are highly variable with altitude. It has been concluded, in fact, that precipitation trend reversals occur altitudinally along the St. Elias profile; i.e., high precipitation at low altitudes is reciprocated by low precipitation at high altitudes, and conversely. Several climatological causes have been suggested by Marcus and Ragle (1970) and Wahl and Marcus (1971).

Ablation zone studies were accomplished primarily by the microclimatological teams; however, supraglacial streams, an important and unstudied facet of ablation, were investigated in detail. Ewing (1970) initiated this work on the ablation zone of the Kaskawulsh Glacier where she described and classified supraglacial stream patterns and their morphology. Dozier (1970) studied the seasonal development of two supraglacial channels on the Capps Glacier, particularly emphasizing questions of channel adjustment. They found that supraglacial streams obey the general principles applicable to streams flowing over other kinds of surfaces. They are, however, particularly sensitive to climatic conditions, grow and deteriorate rapidly, and are the only streams that can enlarge by melting their channels. Also the movement of the glaciers on which they are located affects their distribution and configuration.

The discharge of proglacial streams depends, in part, upon the rates at which supraglacial streams carry ablation zone runoff to the termini. Snow melt over glacierized surfaces also provides a significant seasonal input to proglacial streams. Barnett (1971) has related the discharge of the Slims River, a proglacial stream of the Kaskawulsh Glacier, to these and other factors. Thus the behavior and distribution of water have been traced from the frozen high altitude zones on Mt. Logan to the valley floor at continental Lake Kluane.

## CONCLUSIONS

The High Mountain Environment Project has been an effort to describe and interpret the phenomena and processes present in an alpine landscape. The approach has been interdisciplinary, bringing to bear on key problems the expertise of subdisciplines among the earth and biological sciences. Since mountainous areas are usually investigated in terms of isolated niches and zones, it was important to break this pattern by viewing the full spectrum of the alpine environment. Thus research ranged from the forested lowlands to the perennially glacier covered summits, and from marine exposures to continental precipitation shadows. Finally, processes and phenomena were viewed at a number of scales to optimize understanding of their behavior and spatial distributions.

Because of the tremendous environmental diversity involved, such an integrated effort is difficult. Therefore, and not unexpectedly, the program has evolved through three research and production stages:

(1) Initial specialized research. During the early stage of the project, basic inventories of landscape phenomena and studies of specific physical and biological processes were undertaken. This was significant not only because it provided basic data for later research, but also because it permitted investigators to work within the familiar framework of their own disciplines. A high percentage of publications to date has been in this category.

(2) Intermediate stage of interdisciplinary cooperation. Interdisciplinary research is often undertaken but seldom achieved. Most

efforts achieve only multi-disciplinary results; that is, collections of papers focused on the same landscape region but isolated from each other. One reason for this is that scientific experts seldom have an opportunity to share each others' research activities or background. The High Mountain Environment Project provided a four-month opportunity each summer for investigators to interact in a field research and problem-solving situation. This stimulus led to eventual recognition of the contributions that different disciplines could make to each others' mutual benefit. Thus the field workers began to draw on each others' knowledge and methodologies to achieve a clearer understanding of the interacting processes of the mountain environment. Later research and papers reflect the move in this direction, as is exemplified by the cross-disciplinary work involving botany and climatology, geomorphology and plant geography, glaciology and hydrology and other more complex combinations.

(3) Environmental Integration. The integration into a meaningful whole of all the processes and elements of the mountain environment is extremely difficult. The very complexities of the landscape militates against such an effort, yet in the long run such an integration is one of our most important needs. The environment, after all, is not made up of isolated actions and events, but rather of interdependent elements responding to a variety of interacting processes. Environmental integration under the High Mountain Environment Project is just beginning to emerge, particularly in the dissertations by Brazel and Loomis and the environmental summaries being prepared by Detwyler and

Marcus. These will be treated in a forthcoming volume of the Icefield Ranges Research Project Scientific Results published by the American Geographical Society and the Arctic Institute of North America.

Finally, investigations accomplished by the High Mountain Environment Project have stimulated new ideas regarding research design and execution. This is particularly important at the meso-scale level where environmental field measurement is time consuming and expensive. New techniques have been initially tested for remote sensing and physical modeling. Broader implications of these and other techniques utilizing new research approaches are being discussed and developed.

# RESEARCH RESULTS

This section presents abstracts of papers published or presented based on the High Mountain Environment Project. Those marked by an asterisk indicate partial support or field participation in the Project. Additionally, a bibliography of work in progress and to be completed in 1971 is provided.

Aufdemberge, Theodore

1971 : Comparative energy flux over glacier and tundra surfaces, Chitistone Pass, Alaska. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971. Also in Icefield Ranges Research Project Scientific Results (in press).

Abstract

Empirical studies were carried out comparing the energy balances of two thermally different surfaces, glacier ice and alpine tundra, found at the same elevation and having similar exposure to insolation and major weather systems. Two ideal sites for this study were found in the Chitistone Pass region of Alaska.

Two micro-meterological stations were established, one in the ablation zone of Capps Glacier and the other at Chitistone Pass. Temperatures were taken at four levels, psychrometric data at two levels, The radiation fluxes were determined by two Eppley 180° pyranometers and two Beckman-Whitley thermal radiometers, one hemispheric and one net exchange model. These stations were manned for ten 24 hour periods during a variety of weather conditions between June 30 and August 4, 1969. The data collected was put on IBM cards and processed by the University of Michigan Computer Center. The energy balance was calculated using a variation of the aerodynamic equation suggested by Streten and Wendler (1968).

The ten day daily means for each component of the energy balance for both stations were calculated and compared. This study shows a measurable difference in the energy balance of the two sites with the glacier site receiving 2.7 times more energy than the pass. The temperature data were also different. The pass had a higher mean temperature, higher mean maximum, lower mean minimum temperature, so therefore had a greater temperature range than the glacier.

The temperature field of the Capps Glacier and its adjacent valley was determined using nine thermographs set out in two transects of the glacier, one running from the recessional moraine to the accumulation zone, the other from one valley wall, across the glacier's ablation zone, and up the opposite side of the valley. The thermographs indicate that the air over the glacier had lower mean temperatures and lower temperature ranges than did the adjacent earth parts of the valley.

These studies indicate that the presence of a glacier has a noticeable moderating effect on the micro-climate and energy balance

of a mountain region during the summer months when there is a marked difference in the thermal properties of the surface material making up high latitude mountains.

Barnett, Albert

1971 : Relationship of Slims River discharge to climatic and glaciological factors. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971.

Abstract

During the summer of 1970, hydrological studies were conducted concerning the seasonal flow characteristics of the Slims River in the Icefield Ranges of the St. Elias Mountains of the Yukon Territory. Stretching some fourteen miles over a valley composed of glacial silt, this meltwater stream flows north from the terminus of the Kaskawulsh Glacier into Kluane Lake, the largest lake in the Yukon Territory.

The purpose of this study was to determine the factors causing diurnal and seasonal variation in discharge. In order to accomplish this objective, discharge measurements of the river were taken during a period which displayed different climatological conditions. In order to gain insight into diurnal variations, a series of measurements were taken within sampled twenty-four hour periods; seasonal changes were compiled continuously by stage recorder. Discharge measurements of tributary streams were also taken to determine what percentage of the Slims' discharge was composed of Kaskawalsh glacial meltwater.

Climatological data for the area of study were also gathered. Daily measurements of temperature, wind direction and velocity, cloud cover and type, precipitation, pressure, humidity, incoming shortwave radiation and snow accumulation were compiled. Through the analysis of the above data, one may derive the various factors influencing the diurnal and seasonal variations in discharge.

Continuous stage and periodic discharge measurements began on 30 June 1970 and terminated on 15 August 1970. Three distinct periods of discharge measurements were noted.

The first two periods were characterized by a gradual increase of stage and discharge, each followed by a decline. The increases in discharges were associated with increased insolation and subsequent snow and glacial runoff. The discharge reduction following the first period is accredited to the invasion of a cold air mass. A massive decline in discharge out of the second period -- creating the third flow period -- was due to a major shift of meltwater at the glacier's terminus from the Slims River to the Kaskawulsh River. This shift left the Slims River with less than 1/4th of its previous discharge.

The 24 hour observation revealed that peak discharge occurred between 12 and 1 a.m. and low around 2 p.m. Given normal conditions the greatest ablation occurs when solar energy is most abundant, which generally occurs between the hours of 1 and 2 p.m. mean solar time. The difference in peak discharge readings and peak ablation rest within a time lag created by the distance (14 miles) between the gauging station and the ablating zone of the glacier.

Benjey, William
1970 a: Climatological Observations in St. Elias Mountains, Yukon and Alaska May-August, 1969. The Arctic Institute of North America Research Paper 59.

Abstract

This report presents and summarizes climatological observations made at the following stations of the High Mountain Environment Project, the Arctic Institute of North America: Chitistone Pass (Alaska), Divide (Yukon), Lake Kluane (Yukon), and Logan (Yukon). Observational records for May, June, July, and August include temperature, precipitation, wind direction and speed, relative humidity, cloud cover, and short wave radiation.

Benjey, William *
1970b: Upper-air wind patterns in the St. Elias Mountains, Summer 1965. Icefield Ranges Research Project Scientific Results 2: 3-16.

Abstract

In the summer of 1965 pilot balloons were used to investigate the upper-air wind patterns over three stations in the heavily glacierized St. Elias Mountains. Observed wind patterns are compared with the streamline directions on 500-mb and 700-mb upper-air charts and with pilot balloon data from the United States and Canadian weather services. Large differences are noted, casting doubt on the accuracy of the charts in such a high mountain region. Topographic influences on winds over each station are examined. Comparison of the results of the study with some models of airflow as affected by mountainous topography (particularly the mountain and valley wind model) reveals that the models fail to account adequately for the winds observed.

Brazel, Anthony J.
1968 : Microclimatological and mesoclimatological studies of Chitistone Pass, Alaska, 1967-1968. Paper presented at the Nineteenth Alaska Science Conference, Whitehorse, Yukon, August 28-30 1968. Mimeo.

Abstract

Climatological studies have been conducted in the Chitistone Pass area of Alaska during the period May-August, 1967 and 1968 as part of the Arctic Institute of North America's High Mountain Environment Project. Principal objectives of the program are:

(1) To sample microclimatic and mesoclimatic elements throughout the Pass region;
(2) To investigate in detail energy fluxes and components as they vary spatially according to such environmental variables as slope, orientation, aspect, elevation, and surface cover; and
(3) To look for linkages between climatic variables at both scales of measurements.

Micrometeorological studies were conducted along a 0.5 km transect of four stations with flux components measured from 50 cm below the surface to 3 m above the surface. A standard weather station was operated at the main camp, and at nine sites in the Pass region, temperature, evaporation and precipitation records were maintained on a daily basis. Additional radiation and temperature measurements were taken in coordination with associated geomorphic studies.

Preliminary results indicate the significance of using a multipoint system of climate sampling rather than the usual single station method. Also, insights are gained into the variations of weather phenomena and climatic processes which occur over short distances under the influence of changing altitude and topography.

Brazel, Anthony J.

1970 : Surface heat exchange at Chitistone Pass, Alaska. Proceedings of the Association of American Geographers, Volume 2: 26-30.

Abstract:

The heat balance at the tundra interface is examined using summer season microclimatic data from Chitistone Pass, Alaska. Three short-term weather periods were chosen from the summer season of 1968 for analysis of the thermal conditions at the air-vegetation-soil interfaces. A set of thermo-isopleth diagrams display the need to consider a variety of weather events and conditions, rather than only the ideal (clear day) weather situation. Tabulated energy balance results show that for this location, transitional between the marine exposure of the Alaskan coastline and the dry continental interior of the Yukon, insights into the surface energy balance climatology can be gained only when diverse synoptic events are considered. The clear, calm condition is the exception and not the norm for this location.

Brazel, Anthony

1971 : Comparisons of theory and reality of global radiation in a high mountain pass. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April, 1971.

Abstract

Empirical methods for estimating total incoming solar radiation at a location in a high mountain environment were compared with measurements at Chitistone Pass, Alaska. All empirical methods were found somewhat unreliable, especially under cloudy conditions. This evidence strongly supports the contention that sea level cloud classification methods fail at altitude. It is therefore indicated that empirical estimates of the types explored here are extremely site dependent when cloud is involved.

Detwyler, Thomas R.
1971 : Vegetation-snow cover relations in an alpine pass, Alaska. In: Arctic (in press).

Abstract

Duration of snow cover, which is mainly a function of summer temperatures, topography, and depth of accumulation, is a primary determinant of spatial differences in the alpine vegetation at Chitistone Pass, Alaska. Quantitative study of the relations between species occurrence and the dates during 1967 and 1968 on which sites became bare of snow has indicated the tolerances of different plants for varying durations of snow cover. Snow cover affects plants mainly by protecting them from extreme cold and wind, and especially by shortening the growing season where snow lies late. Water supplied by melting snow patches, and various geomorphic processes, apparently are secondary causes of spatial variations in the plant cover. Knowledge of such relations allows the prediction from vegetation of approximate duration of snow cover on a site.

Dozier, J.
1970 : Channel adjustments in supraglacial streams. In: Studies of Morphology and Stream Action on Ablating Ice. Arctic Institute of North America Research Paper 57: 69-109.

Abstract

Planimetric similarities exist between ordinary streams and streams that flow on top of glaciers, even though a supraglacial stream erodes its bed primarily by melting, rather than scouring. In the summer of 1969 two supraglacial streams on Capps Glacier near Chitistone Pass, Wrangell Mountains, Alaska were studied to determine if the principle which hypothetically governs channel adjustment in short reaches of ordinary streams -- minimum variance of factors related to adjustment -- also applies to supraglacial streams. Data show that for supraglacial streams the variances of slope, bed shear, and the Darcy-Weisbach friction factor of a curved reach are usually less than half those of a straight reach of the same stream, thus indicating that in supraglacial streams curved reaches have more uniform channel adjustment than do straight reaches. In both curved and straight reaches these variances are reduced over the course of the summer. Thus curved reaches are closer to equilibrium than are straight reaches, and the particular supraglacial stream studied adjusted toward equilibrium. Fourier analysis of stream direction angles shows a downstream phase shift during the summer and an increase in importance of a higher harmonic at lower discharge late in the season. Processes of channel adjustment in supraglacial streams may be divided into two categories: those of the stream itself, namely thermal erosion in both lateral and downward directions; and processes independent of the stream, such as shearing in the glacier which causes structural variations, movement of the glacier, and differential ablation of the banks above the stream due to difference in exposure.

Ewing, Karen J.*

1970 : Supraglacial streams on the Kaskawulsh Glacier, Yukon Territory. In: Studies of Morphology and Stream Action on Ablating Ice. Arctic Institute of North America Research Paper 57.

Abstract

Two general categories of supraglacial stream channels were identified during 1965 and 1966 on the Kaskawulsh Glacier, Yukon Territory. Annual streams have shallow channels and are recreated each year. Perennial streams have deeper channels which are reused from year to year and show an elongation of stream patterns which closely parallel the ice flow pattern of the glacier. All streams show diurnal fluctuations of discharge, related to high and low sun periods.

Static factors influencing supraglacial stream development and morphology include relief, gradient, structure, and biota. Dynamic processes include glacier flow and climate.

Jackman, Albert

1971 : The history of travel and scientific research in the St. Elias Mountains. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971.

Abstract

This paper discusses the evolution and modernization of modes of travel and sophistication of scientific research that have occurred in the St. Elias Mountains from the early days of exploration and boundary survey mapping up to the present-day methods utilized in the Icefield Ranges Research Project and the High Mountain Environment Project. Emphasis is placed on the role of modern logistical methods, such as light-weight equipment and foods, high-altitude STOL aircraft, and single-sideband radio communications and electronic instrumentation, in enabling sophisticated and highly complex environmental and physiological research to be conducted in remote and high-altitude environments.

Kolberg, Donald W. and Brazel, A.J.
1969 : Climatological Observations in the St. Elias Mountains, Yukon and Alaska, May-August, 1969. The Arctic Institute of North America High Mountain Environment Project Technical Report 3. 166 pp.

Abstract

This report presents and summarizes climatological observations made at the following stations of the High Mountain Environment Project, the Arctic Institute of North America: Chitistone Pass (Alaska), Divide (Yukon), Fox Glacier (Yukon), Gladstone (Yukon), and Lake Kluane (Yukon). Observational records for May, June, July, and August include temperature, precipitation, wind direction and speed, relative humidity, cloud cover, and short wave radiation.

Kolberg, Donald W.
1971 : Regional climatic patterns, St. Elias Mountains. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April, 1971.

Abstract

Generalized surface pressure-patterns over Alaska and the Yukon were determined through a statistical correlation procedure for six summer seasons from 1963 to 1968. Twenty first-order weather stations were selected over the study area. The daily average sea-level pressure at each of these stations was correlated with the average pressure on each successive day through the total period. This procedure isolated map-patterns with the highest correlation and allowed for the determination of patterns occurring most frequently and with the highest degree of persistence.

Three major pressure map-patterns emerged as dominant types. From these, several sub-types were isolated. All map-patterns displayed considerable departures from standard maps determined from seasonal and monthly sea-level pressure averages. Pressure systems delineated by the statistically derived map-patterns showed the greatest variation in tracking and form when compared to "average" maps. Therefore, it is suggested that the climatology of these map-patterns will be useful in analyzing the occurrence of various synoptic weather regimes across the St. Elias Mountains.

LaBelle, Joseph C.
1971a: Characteristics of the Mt. Logan snow cover above 5300 meters. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971. Also in Icefield Ranges Research Project Scientific Results (in press)

Abstract

Studies of snow accumulation in the summit region of Mt. Logan were carried out during the period May 1968 to August 1970. Net accumulation over that period proves to be essentially zero on the steep slopes and tops of the summits, the obstacle-deposit topography of these summits having reached equilibrium with prevailing wind conditions. Transient free surface forms, such as dunes and sastrugi, are the only changes in the surface. These migrate over a hard, highly windpolished, stable snow-ice base, which represents the semi-permanent form of the summits. The tops of rock summits remain free of snow cover because of their near-vertical ends. Snow-dome summits, which have generalized dune shapes, have a shallow snow cover over a gently sloping rock form. This shallow mantle does not change in net thickness over time.

The summit plateau glacier sets in a gently sloping basin on the lee side of the long summit ridge, and accumulates snow from a combination of normal precipitation and heavy wind drifting, in a similar manner to the formation of "Ural" type drift glaciers. Snow drifts form in the "wind shadows" of summits, and also through a funneling effect in the lee of "drift corridors". Drifts shift position and areal extent in response to changing winds.

Wind and topography play controlling roles in accumulation in the summit region. Drifting is so dominant a factor that meaningful correlations between accumulation and such factors as altitude or temperature are extremely difficult to make.

LaBelle, Joseph C.
1971b: Snow studies on Mt. Logan, Yukon, 1968. In: Environmental Studies on Mt. Logan, Yukon Territory, 1968-70, IV. The Arctic Institute of North America High Mountain Environment Project Technical Report 4. (in press).

Abstract

During the summer of 1968, snow studies were carried out on and above the 17000 foot (5200 m.) summit plateau of Mount Logan. Studies were made of snow accumulation, snow properties, and the annual layer, using surface snow and snow-pit data.

Accumulation on the summit plateau for the period 5 July to 2 August was 79.47 cm of snow, equivalent to 11.36 cm of water. Studies of accumulation patterns in the high-mountain environment indicate that topography, as it affects exposure to winds, is the primary factor controlling accumulation. It completely overrides factors such as simple altitude-orographic effects that are principal elements controlling accumulation on relatively flat icecaps, such as Greenland and Antarctica. Flat surfaces catch the greatest amount of accumulation on the mountain, while steep gradients receive and hold much less. Winds, continually blowing across the steep slopes, redistribute the snow there through the mechanisms of blowing snow, sastrugi and snow dunes, which continually migrate over a hard wind-polished basement surface. On summits with exposed rock outcrops, the rocks provide an upper level to which snow is allowed to accumulate, and exchange through alternate accumulation and wind scour deflation is the rule.

Studies of surface snow on the summit plateau show that diurnal temperature variations are effectively damped out at 1.5 meters depth, and temperature waves at 10, 20, and 30 cm depth are presented for the observation period, exhibiting no noticeable time-lag at these depths. Effects of an obstacle on wind-drifted snow are such as to cause higher snow density in front of the obstacle, low density behind it, and an intermediate density on a flat, open surface. It is shown that no correlation can be made between snow density and air temperature or winds on a day-to-day basis, though mean figures over longer periods, such as month-to-month, probably can be correlated.

Studies in snow-pits excavated on the summit plateau, in various cols, and on several summits indicate that density increases linearly with altitude, at a rate between 0.74 - 0.89 $g/cm^3/100$ m. Since this is exactly opposite the relationship found on most icecaps, it suggests an increasing exposure to wind-packing effects with altitude in the mountains. Snow-pit temperature at one-meter depth is found to decrease with altitude at a rate of -3.7$^{o}$C/100 m., far greater than the normal dry adiabatic lapse rate in the atmosphere. This effect may be due to "wind chill" -- increased evaporational cooling with increased exposure to winds. A discontinuity in the curve at about 18000 feet (5480 m) may be due to direct exposure to prevailing winds above that altitude, whereas all pits below that altitude were located on the summit plateau, which is located in a broad, flat basin that may act as a cold air sink during temperature inversions over the snow. This may cause the plateau snow pack to be cooler than the snow on steeper, exposed slopes, where temperature inversions give rise to Katabatic winds that carry away the cold air.

LaBelle, Joseph C.

1971c: Snow accumulation in the summit region, Mt. Logan, Yukon. In: Environmental Studies on Mt. Logan, Yukon Territory, 1968-1970, Part V. Arctic Institute of North America High Mountain Environment Project Tech. Rept. 4.


## Abstract

Studies of snow accumulation in the summit region of Mt. Logan were carried out during the period May 1968 to August 1970. Net accumulation over that period proves to be essentially zero on the steep slopes and tops of the summits, the obstacle-deposit topography of these summits having reached equilibrium with prevailing wind conditions. Transient free surface forms, such as dunes and sastrugi, are the only changes in the surface. These migrate over a hard, highly windpolished, stable snow-ice base, which represents the semi-permanent form of the summits. The tops of rock summits remain free of snow cover because of their near-vertical ends. Snow-dome summits, which have generalized dune shapes, have a shallow snow cover over a gently sloping rock form. This shallow mantle does not change in net thickness over time.

The summit plateau glacier sets in a gently sloping basin on the ice side of the long summit ridge, and accumulates snow from a combination of normal precipitation and heavy wind drifting, in a similar manner to the formation of "Ural" type drift glaciers. Snow drifts form in the "wind shadows" of summits, and also through the funneling effect in the lee of "drift corridors". Drifts shift position and areal extent in response to changing winds.

Wind and topography play controlling roles in accumulation in the summit region. Drifting is so dominant a factor that meaningful correlations between accumulation and such factors as altitude and temperature are extremely difficult to make.

Studies of surface snow properties in 1968 indicate that surface density increases with increasing altitude, at a rate of 74 - 89 kg $m^{-3}$ per 100 meter rise. This is described as due to increasing exposure to wind packing effects at higher altitudes.

Temperatures in the snow pack, below the level of diurnal fluctuations, decrease with altitude at a rate of -3.7°C per 100 meter rise. This large lapse rate may be due to increased evaporation cooling, or "wind chill", due to increased wind exposure at altitude.

Cooler temperatures in the snow pack on the plateau glacier may be due to trapping of cold air, in the high basin in which the glacier sets, during periods of temperature inversion over the snow pack. On open slopes, where relatively warmer temperatures exist, inversions initiate katabatic winds which disperse the cold air.

Loomis, Stuart R. *
1970a: Morphology and ablation processes on glacier ice. Icefield Ranges Research Project Scientific Results Volume 2: 27-32.

## Abstract

Differential ablation on debris-laden glacier ice has long been recognized for its importance in producing ice-cored topographic features. A study of ablation rates on a medial moraine of the Kaskawulsh Glacier is used in conjunction with ice-flow data and an equilibrium hypothesis of mass movement in the debris mantle to explain the morphological form that the moraine assumes.

Loomis, Stuart R.*
1970b: Morphology and structure of an ice-cored medial moraine, Kaskawulsh Glacier, Yukon. In: Studies of Morphology and Stream Action on Ablating Ice, Arctic Institute of North America Research Paper 57: 1-65. Also in: Proceedings of the Association of American Geographers, V. 2: 88-92.

## Abstract

In 1966, during the months of July and early August, as part of the Icefield Ranges Research Project of the Arctic Institute of North America, a research station was operated on the medial moraine at the confluence of the North and Central Arms of the Kaskawulsh Glacier, Yukon, Canada. Included in the programs conducted at the station was an investigation of the morphology and structure of the ice-cored medial moraine.

Ablation stakes spaced at intervals of 15 m were established across the moraine and read daily. At each ablation stake site, samples of till were collected for particle size and thickness analysis. For mapping purposes, 7 topographic profiles were surveyed across the moraine. These transects were supplemented later in the season by large scale aerial photographic stereoscopic coverage.

The marked ridge and hillock topography of the moraine is explained partially in terms of the effect of the ice-cored moraine's energy regime, associated with the local climate. Representative of this energy flux are the differential ablation rates of the ice-core which relate to changing slope and aspect of the moraine and varying depths of moraine mantle. In addition, ice associated features such as crevasses, moulins, meltwater streams, and glacier flow patterns impose strong controls on moraine form and topographic relief.

Loomis, Stuart R.

1971 : Structure, morphology, and development of ice-cored moraines. Paper presented at the Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971.

## Abstract

Ice-cored moraines often take on a significant role in the deglaciation sequence in areas subject to alpine and continental scale glaciation. Glacial ice which is insulated from ablation processes by an overlying drift veneer may persist for tens or hundreds or even thousands of years after active glaciation in an area has ceased. This is significant because the buried ice, as it slowly melts at differing rates in time and space, substantially prolongs the effect of glaciation on an area. That is, an ice-cored moraine continues to glacially modify the immediate environment through the hydrologic element created by ice-core meltwater and sediment load added to local streams, and also through an instability effect created by the associated changing topographic slopes and forms of the wasting ice-cored moraine which disrupts the various soil forming processes and the development of an enduring vegetation cover.

In order to better understand this phenomena, the Chitistone Pass area of southeastern Alaska was chosen as the site for an investigation of the structure, morphology, origin and development of ice-cored moraines. The study concentrated on two aspects of the main problem (which was to be able to explain the ways that ice-cored moraines relate to their environment): (a) an investigation of the energy relationships existing between a buried ice-core and the atmosphere, and (b) an investigation of the mass wasting processes causing a shifting and subsequent change in thickness of the insulating drift veneer over the ice-core. A site for intensive instrumentation and observation during the summers of 1968 and 1969 was chosen on an east-west trending ice-cored lateral moraine of the small Capps Glacier. Temperature gradients were recorded throughout the observation period using thermocouple sensors placed at a series of levels extending from the free air through the drift cover and into the ice-core at points having various slope exposures and drift depths. Shortwave radiation and surface albedo at the thermocouple points were measured with an Eppley Pyrheliometer. Drift lithology, particle size and moisture conditions were observed and ablation of the ice-core, where it occurred, was recorded. The moraine was mapped intensively using combined theodolite, plane table and Brunton compass techniques at repeated time periods in order to record possible ice-core movement, changing surface morphology and rates of mass movement.

Results to date show that on a horizontal surface a drift cover approximately one meter thick is sufficient under present Chitistone climatic conditions to prevent ablation of the moraine's ice-core. However, on south-facing slopes substantial ablation of the ice-core occurred with this depth of drift. A cover of one and a half to two meters thickness would be necessary to prevent melting with this slope exposure. On north-facing slopes, though, a drift cover only one-half meter thick prevented ice-core ablation. Erosional thinning of the drift cover does not seem to occur by a steady mass wasting process such as creep but rather occurs sporadically on slopes steepened beyond the angle of particle repose by processes of slumping and debris fall with subsequent removal of water-saturated till on gentler slopes by periodic mudflows (flow-till). Ablation of the buried ice then accelerates to a rate of five to six centimeters per day in those places where the ice-core is exposed by mass wasting erosion. However, this ablation rate is of relatively short duration as flow-till tends to collect in those lower places in the ice created by this accelerated ablation rate and thus reestablishes the important insulating drift cover. Evidence collected from the intensively studied Chitistone Pass site suggests that some of the ice-cores of the moraines abandoned by the ablating but still active glacier mass of Capps Glacier may survive for at least 80 to 100 years before mass wasting of the drift cover exposes the last of the ice-core remnants to final melting.

Lougeay, Ray L.*

1969 : Microclimatological studies over the Seward Glacier snowpack. In: Climatological Investigations in the Icefield Ranges, Summer, 1965. Arctic Institute of North America Research Paper 54: 55-102. Also in: Icefield Ranges Research Project Scientific Results 2 (1970): 3-13.

## Abstract

Microclimatic observations for a ten day period in the summer of 1965 on the Upper Seward Glacier show: (1) wind profiles that closely approximate log-linear curves (as would be expected under the stable conditions characteristic of this study period); (2) temperature profiles with a distinct double inversion pattern during daytime hours; and (3) net radiation the dominant heat source during each day of the study period whereas sensible and latent heat fluxes were almost insignificant due to low wind velocities and slight temperature ranges near 0°C.

Lougeay, Ray
1971 : Infrared temperatures in alpine and periglacial environments. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971. Also in: Icefield Ranges Research Project Scientific Results (in press).

## Abstract

Observations of both actual and thermal infrared radiant temperatures were made over various environmental surfaces in the alpine/periglacial environment. These surfaces included various types of ice-cored moraine, glacial ice, and morainic outwash at the terminal margins of a large valley glacier. Also included were rubble and turf surfaces of a rock glacier, plus talus and bedrock at its margins. These observations were conducted to determine some aspects of the applicability of thermal infrared remote sensing in this environment, and to develop a technique by which a researcher might determine the usefulness of infrared scanning to his study without the financial investment of airborne remote sensing on a trial-and-error basis. Also, an attempt was made to determine the environmental controls upon radiant temperature and to determine changing patterns of radiant temperature relative to the changing meteorologic situation. It was found that infrared radiant temperature was directly linked with incident solar radiation, which is in turn a function of cloud cover and atmospheric transmissivity. When comparing radiant temperatures with the various components of the energy balance over an environmental surface, it was found that trends in radiant temperature closely mirrored trends of net radiation received at the surface, as expected. However, relatively large variations in the trends of other energy balance components (i.e. latent, soil, and sensible heat fluxes) seemed to affect radiant temperature only slightly. The techniques used here seem quite useful in predicting the applicability of airborne infrared remote sensing, and are useful both in predicting the best time of overflight for a given purpose, and indicating the intensity of ground truth needed at that time.

Marcus, Melvin G.
1969a: High mountain environment project, 1968 field season. Arctic, 22: 163.

## Abstract

Under sponsorship of the U.S. Army Research Office, Durham, the Arctic Institute's High Mountain Environment Project continued research activities for the second year in the St. Elias and Wrangell Mountains, Yukon and Alaska. Twenty-three investigators and their assistants maintained a three-phase program from May to August 1968. These studies included: (1) Chitistone Pass - meteorology, meso- and microclimatology, floristic and ecological studies, phenology, thermal investigation of ice-cored moraines, glacial geology and chronology, and mass wasting and weathering processes on fluvial and periglacial features. (2) Mt. Logan - regular meteorological observations, radiation measurements, snow samples for cation content and Oxygen 18 content, snow density and accumulation studies, hard rock geological collection and mapping, and high-altitude human physiological research. (3) Broad scale climatology - all weather stations in the Icefield Ranges Research Project network were integrated into a single operation, and observations from these stations relayed to the Whitehorse Weather Station and the Canadian and United States teletype circuits. Upper air temperature studies were carried out throughout the season by the project's Helio Courier aircraft. A principal objective of the broad scale climatology program is to interpret influences of a major topographic barrier on local weather patterns as well as major air mass migrations and storm tracks in the region.

Marcus, Melvin G.
1969b: Investigations in alpine climatology, Alaska, U.S.A. and Yukon, Canada. Paper presented at Joint United States-Israel Symposium on Geography, Jerusalem, June, 1969 (Proceedings in press).

## Abstract

During the period 1963 through 1968, climatological research has been conducted in the St. Elias Mountains, Alaska, U.S.A., and Yukon, Canada, under the auspices of the Icefield Ranges Research Project of the Arctic Institute of North America. The climatic investigations have been an integral part of a larger program attempting to describe and explain the physical geography of a high mountain region. A network of summer weather stations has been maintained during the six-year research period at sites within and adjacent to the St. Elias Mountains. Also, specific microclimatological and mesoclimatological investigations have been conducted at six mountain locations.

This paper reviews the climatology program, focusing particular attention on three problems of alpine climatology: (1) mountain winds; (2) precipitation patterns; and (3) temperature gradients. It is suggested that, because of the complexity and magnitude of the St. Elias Mountains, generally accepted models for mountain climatology do not always apply in this region.

Marcus, Melvin G.
1971 : Surface and free atmosphere temperature relationships. In: Environment Studies of Mt. Logan, Yukon Territory, 1968-1970, Part III. The Arctic Institute of North America, High Mountain Environment Project Technical Report 4 (in press).

Abstract

An airborne temperature sensing study was conducted during June, July, and August in the St. Elias Mountains in conjunction with environmental studies at Lake Kluane, Divide, and Mt. Logan Station, Yukon.

Temperatures were measured at 150 m levels in the atmosphere on some 30 flights between Lake Kluane (786 m) and Mt. Logan station (5,360 m). Both vertical and horizontal positions were recorded for each measurement. Temperatures were sensed by a shielded thermister suspended from the Arctic Institute's Helio-Courier aircraft. This paper presents and summarizes profile data. Free atmosphere lapse rates are compared to environmental lapse rates measured at the surface and those recorded by balloon ascents at Whitehorse and Yakutat.

Marcus, M.G., Ford, J., and Willingham, J.
1968 : Climatological Observations at Chitistone Pass, June-August 1967. Arctic Institute of North America High Mountain Environment Project Technical Report 1. 39 pp.

Abstract

This report describes the 1967 climatological program of the High Mountain Environment Project, Chitistone Pass phase, the Arctic Institute of North America. Weather data for June, July, and August are presented and summarized. Records include temperature, precipitation, wind direction and speed, relative humidity, cloud cover, and short wave radiation.

Marcus, M.G., Kolberg, D.W., and LaBelle, J.C.
1968 : Summer climatic observations at the 17,000 foot level, Mt. Logan, Yukon. Paper presented at the Nineteenth Alaska Science Conference, Whitehorse, Yukon, August 28-30, 1969. Mimeo.

Abstract

This paper discusses and summarizes climatological research at the station most recently established in the Icefield Ranges Research Project climatological program, as part of the High Mountain Environment Project. This program carries out investigations into the nature and distribution of processes operating in the atmosphere, and across the earth-atmosphere interface, and fall into two categories: those which concentrate directly on problems of meteorology and climatology, and those which integrate climatic processes with other environmental phenomena; that is, those studied in glaciology, hydrology, geomorphology, and ecology.

Discussion is made of the Mt. Logan regional site, station location and operation, summary of observations during the 1968 field season, special operational problems, observational and recording problems, instrumentation, and logistics and station operation.

Marcus, M.G. and LaBelle, J.C.
1970 : Summer climatic observations at the 5,360 meter level, Mt. Logan, Yukon, 1968-1969. Arctic and Alpine Research 2: 103-114.

Abstract

During the summers of 1968 and 1969 a climatological station was operated at the 5,360 m level on Mt. Logan, Yukon Territory. The station was one of several operated in the St. Elias Mountains under the Icefield Ranges Research Project. Measurements were taken of temperature, wind direction and velocity, cloud cover and type, pressure, humidity, incoming shortwave radiation, and snow accumulation. The climatological observations are summarized and discussed, particularly in terms of their relationship to equivalent altitudes in the free atmosphere and lower climatic conditions in the St. Elias Mountains. Logistical and observational problems encountered in the operation of a high altitude station are also reviewed.

Marcus, M.G. and LaBelle, J.C.
1971 : Summer climatic observations at the 17,600 foot level, Mt. Logan, Yukon, 1968-1970. In: Environmental Studies on Mt. Logan Yukon Territory, 1968-1970, II. The Arctic Institute of North America High Mountain Environment Project Technical Report 4 (in press).

Abstract

This report presents basic climatic data for the 1970 field season on Mt. Logan, plus seasonal climatic summaries for the 1968, 1969, and 1970 seasons. Discussion is also made of the Mt. Logan station site, observations and records, observational and recording problems, and instrumentation.

Marcus, M.G. and Ragle, R.H.
1970 : Snow accumulation in the Icefield Ranges, St. Elias Mountains, Yukon. Arctic and Alpine Research, Volume 2, 4: pp. 277-292.

Abstract

Snowpack characteristics in the St. Elias Mountains were examined as part of the Icefield Ranges Project for 1961 to 1965, emphasizing particularly the 1964-1965 glacier balance year, together with reconstructions for 1953 to 1961. Analysis was carried out along a hydrological traverse on the Kaskawulsh, Hubbard, and Seward-Malaspina glaciers, and at a single location through a period of time. The data obtained are summarized in graphs and tables. The relationships between precipitation, elevation, and topography, and effects of continentality and exposure are considered. In neither case are the relationships clearly defined, but it is evident that elevation is a critical factor in the maintenance of continental slope glaciers and spring runoff. Fluctuations in net accumulation are determined and evaluated; a stable period is indicated for the late 1950s, followed by an increase of 200 to 300 mm in the early 1960s and a minimum in 1964-1965 and 1965-1966 of winter nourishment and mass balance. Climatic implications are drawn from the snow accumulation data.

Outcalt, Samuel I.
1971 : Equilibrium temperature modeling: applications and possibilities in alpine climatology. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971. Also in Icefield Ranges Research Project Scientific Results (in press).

Abstract

A diurnal surface climate simulator has been developed at the Geography Department, the University of Michigan as a teaching and research tool. It provides a strategy for the analysis of the effect of variation of individual geographical and meteorological boundary conditions on the surface thermal and energy transfer regime.

Specifically, the thermal contrast between ice-cored and non-ice cored glacier terminus features have been simulated. It is intuitively obvious that as this technique is improved it will provide a powerful analysis strategy for both modern process and historical analysis of arctic and alpine environmental evolution and probable manipulation responses.

Page, M.L.
1971 : A petrographic study of Mt. Logan, Yukon, Canada. Environmental Studies on Mt. Logan, Yukon, Canada, VI. The Arctic Institute of North America, Tech. Rept. 4: 6.1-6.27.

Abstract

The Mount Logan massif is located in the St. Elias Range in the southwestern Yukon. This is a highly glaciated area made up of metamorphic rocks of the amphibolite facies which are intruded by albite quartz diorites, diorites, and quartz diorites. The eastern two-thirds of the massif is composed of highly altered and sheared albite quartz diorite and amphibolite. The plagioclase, from thin section relationships, appears to be primary. All of these rocks have been chloritized through shearing and hydrothermal alteration. In the western portion of the massif unaltered andesine quartz diorites are present. These two distinct quartz diorites may be the result of : (1) two separate intrusions, (2) the fractionation of a parent magma producing sodium rich interstitial fluid, or (3) alteration of an original andesine quartz diorite to an albite epidote quartz diorite. Sometime after emplacement, shearing and alteration occurred and this may be related to Tertiary fault systems that extend through this region into Alaska.

Ragle, Richard H., Marcus, Melvin G., and Houston, Charles S.
1970 : The icefield ranges research project, 1969.
Arctic, 23: pp. 56-61.

Abstract

This report summarizes research activities during the 1969 field season of the Icefield Ranges Research Project and the High Mountain Environment Project. Discussion is made of activities of the IRRP on the Fox Glacier - mass balance studies, moraine features mapping, geological mapping, thermal drilling, englacial temperatures, and surveying; Kaskawulsh Glacier - pit studies and thermal drilling; Steele Glacier - surge movement studies; Archaeological reconnaissance; zoology studies; rock glacier studies and other short-term studies. Also discusses the programs of the HMEP in environmental studies at Chitistone Pass, Alaska - ice-cored moraine studies, channel adjustments of supraglacial streams, reconnaissance of soils in a periglacial environment, local microclimatology, and related environmental studies; and Mt. Logan field research - climatology, ice and snow studies, and high-altitude human physiological research.

Ragle, Richard H., Marcus, Melvin G., and Houston, Charles S.
1971 : Icefield ranges research project, 1970. Arctic
24: 67-72.

Abstract

Discusses and summarizes research activities of the Icefield Ranges Research Project, the High Mountain Environment Project, and the High Altitude Physiology Program, in the Yukon Territory, Canada. Environmental studies were carried out on Fox Glacier -- surveying, englacial temperature measurements; Steele Glacier -- surveying; Kluane Lake -- physical lymnology, raised benches, drowned forest, synoptic and energy balance climatology; Donjek River -- glacial geomorphology, rock glacier studies; Mt. Logan -- synoptic climatology, energy balance climatology, glaciology, thermal studies, DDT studies, high altitude human physiology studies; Divide station -- glaciology, synoptic and energy balance climatology; Donjek Glacier -- thermal studies; and Kluane Range -- large mammal biological study.

Scott, Richard W.

1968 : Vascular Plants of the Chitistone Pass Area, Alaska. The Arctic Institute of North America High Mountain Environment Project Technical Rept. 2. 18 pp.

Abstract

This report is an annotated list of plant species collected from June 1 to August 17, 1967, in the Chitistone Pass region, Alaska (see Figure 1). Knowledge of the kinds of plants present there is requisite to understanding the alpine vegetation of the area, and also contributes to our understanding of the plant geography of the northern North American cordillera. Thus, the collections reported here are part of broader botanical research in progress in the High Mountain Environment Project of the Arctic Institute of North America.

The collections on which this report is based were concentrated in Chitistone Pass and the upper Skolai River Valley, between approximately 4,500 and 8,000 feet elevation. This area is located along the physiographic boundary between the St. Elias Mountains and Wrangell Mountains. When not snow-covered, the area, which is above timberline, is characterized by a discontinuous cover of alpine tundra. The terrain is marked by glaciers, streams, patterned ground features, talus slopes, and other mass wasting and periglacial features. The ground is permanently frozen except for the surface layer, which thaws to a depth of several feet or less during the summer.

This paper enumerates only the vascular plant collections; lists of bryophytes, lichens, and fungi will be presented following the 1968 field season. In this report the species are ordered by family, with alphabetical arrangement of genera and species within each family. Collection numbers, habitat, and general indication of abundance are given for each species. Until the detailed floristic studies in progress can be completed, a discussion of taxonomic status of each species and infraspecific taxon is inappropriate. A complete set of specimens has been deposited in the Herbarium of the University of Michigan.

Scott, Richard
1971 : The effect of snow duration on alpine vegetation in the Chitistone Pass, Wrangell Mountains, Alaska. Paper presented at Symposium on Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971.

Abstract

Chitistone Pass is situated in a high environmental stress zone near the upper limits of vegetation in the Wrangell Mountains. Prolonged duration of snow results in local modifications of the growing season. Snow deposition and subsequent melt patterns vary little from year to year because of the wind-channeling effect of the pass. Time required for snow melt fluctuates in response to prevailing macroclimatic patterns. Recession of snow was mapped throughout the growing season and transects were established along which square meter plots were sampled. Data analysis by ordination and graph clustering indicated a significant correlation between species composition and duration of snow. The trend of change was from high-density, species-rich vegetation in the early snow melt zones to low-density, species-poor aggregation in the latest snow melt zones. A shift in dominance from vascular plants to lichens and bryophytes was noted in the intermediate and later snow melt zones. Slope and exposure changes within the same snow melt zone resulted in minor modifications of vegetation composition. Significant increases in species richness were detected in snow flush vegetation, a response to melt water irrigation.

Stengle, Thomas R., Lichtenberg, James J., and Houston, Charles S.
1971 : Sampling of glacial snow for pesticide analysis, the plateau glacier of Mt. Logan, Yukon Territory, Canada. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April, 1971. Also in Icefield Ranges Research Project Scientific Results (in press).

## Abstract

Recent interest in the impact of man on his environment has led to a number of attempts to determine the presence of pollutants in remote areas of the world. The snow of glaciers is a particularly intriguing subject for such work, since it contains a record of past years as well as the present. It has been shown that there is a clear correlation between the lead concentration in old snow strata and the level of industrial activity. This study has undertaken the measurement in snow of another common pollutant, the insecticide, DDT. This paper reports on our attempt to develop techniques for taking snow samples without contamination in locations where the work had to be done under adverse conditions and with simple equipment. The site chosen for this work was the high plateau glacier (elevation 17,600 ft.) on Mt. Logan, Yukon Territory, Canada. This spot is very remote; the nearest permanent habitation or road is nearly ninety miles away. Due to the short growing season, almost no agriculture is practiced in the Yukon, and massive applications of pesticides are unknown there. Conditions at the sampling site were quite hostile. Most of the work was done at temperatures between 0° and -10° F., and often in the wind.

Precautions were taken to avoid contamination during sample collection. Some problems did develop with equipment and are described. The sampling site was located 1,000 ft. upwind of the main camp to remove it from aircraft and generator exhaust and all trash in the camp was buried rather than burned. The first few samples were discarded in the hope of removing any residual contamination from the auger. During the sampling process the auger was never touched by bare hands or gloves.

A total of 19 samples were taken ranging in depth from 1 to 15 meters below the surface. The DDT analysis was carried out at the WQO Analytical Control Laboratory in Cincinnati, Ohio using a gas chromatographic technique (2). DDT was not detected in any of the samples. The lower limit of detectibility for DDT was 5 nanograms per liter for seven of the samples. Due to interference, apparently from polychlorinated biphenyls (PCB's), 10 to 50 ng/l of DDT could have been present in the remaining twelve samples and not been detected. Efforts to remove the PCB's from the extract to allow for more sensitive

determination of DDT were only partially successful. Thus the results are in part inconclusive. It is suggested that the seven samples showing no PCB contamination were the last ones taken. It appears that the auger had become sufficiently cleaned in the first part of the drilling. Thus it is highly likely that the DDT concentration in all of the samples was less than 5 ng/l.

On the basis of these results it seems that sampling of glacial snow for trace organic pollutants is quite feasible, even when samples must be taken under unfavorable conditions with primitive techniques.

Wahl, Herbert and Marcus, Melvin

1971 : Problems of climatic observation and forecasting in an alpine environment. Paper presented at Symposium on the Natural and Physiological Environment of the St. Elias Mountains, Alaska and Yukon, April 1971. (Manuscript submitted to Atmosphere, May 1971.)

Abstract

During the period 1963-71, the Arctic Institute of North America and the Canadian Meteorological Service have maintained a cooperative weather observation and forecasting program in the St. Elias Mountains, Yukon. Weather data are reported from research stations to Lake Kluane Base Camp on a 3-hour basis, commencing 0000 GMT. Airways code and special reports are telephoned six times a day to the Burwash Landing facility, where they are relayed throughout the teletype system. At 0000 and 1200 GMT, the Whitehorse weather station is contacted directly for an exchange of data and receipt of the forecast.

The Arctic Institute weather network has helped fill an important void in regional weather observation. The St. Elias Mountains exert significant control over climatic patterns and regional forecasts (particularly for general aviation) have profitted from the added information. Several case examples are given of regional synoptic patterns and their relationship to the mountain barrier.

# PUBLICATIONS IN PROCESS

## Doctoral Dissertations

Aufdemberge, Theodore, Department of Geography, The University of Michigan. Comparative energy balance studies of an alpine glacier and tundra surface at the 5,800 ft. level, Chitistone Pass, Alaska.

Benjey, William G., Department of Geography, The University of Michigan. Seasonal variations of the energy budget over tundra, forest, and snow surfaces, St. Elias Mountains, Yukon.

Brazel, Anthony, Department of Geography, The University of Michigan. Micro- and meso-scale processes in climatology of a high mountain pass.

Kolberg, Donald, Department of Geography, The University of Michigan Summer climate patterns in relation to a highland barrier.

Loomis, Stuart, Department of Geography, The University of Michigan. Evolution, morphology and structure of ice-cored moraines in the Wrangell Mountains, Alaska.

Lougeay, Ray L., Department of Geography, State University of New York at Geneseo. Infrared temperatures and thermal sensing in alpine and periglacial environments.

Scott, Richard, Department of Botany, The University of Michigan, Taxonomy and ecology of the Chitistone Region, Alaska.

## Other

Brazel, Anthony, and Scott, Richard. Interrelated investigations of climate, runoff, and phenology at Chitistone Pass, Alaska.

Detwyler, Thomas R. An environmental transect, Chitistone Pass, Alaska.

______________. Mass wasting and periglacial phenomena in the Chitistone Pass, Alaska.

Detwyler, Thomas R., and Redente, Anthony. A landform map and classification for the Chitistone Pass-Skolai Valley area, Alaska.

Loomis, Stuart, and Marcus, Melvin G. Recent glacier chronologies in the Chitistone Valley, Alaska.

Marcus, Melvin G. The summer energy balance at 5,360 m, Mt. Logan, Yukon.

Marcus, Melvin G. Snow studies between 3,300 m - 5,300 m, Mt. Logan, Yukon.

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# APPENDIX A

## FIELD PERSONNEL

Research and field personnel who participated in the High Mountain Environment Project are listed below. In addition, a list of scientists who worked out of the Chitistone, and Mt. Logan field stations, but were separately funded, is provided. These investigators coordinated their research activities with those of the Project, and considerable additional scientific interaction was achieved. The results of their research is not included in this report. Visitors from the Department of Army are listed at the end of this section.

### High Mountain Environment Project

Melvin G. Marcus, Ph.D., Principal Investigator, Department of Geography, The University of Michigan (1966, '67, '68, '69, '70).

Robert Faylor, Director, Washington Office, Arctic Institute of North America (1966, '67, '68, '69, '70).

Philip Upton, Project Pilot, Washington Office, Arctic Institute of North America.

Thomas R. Detwyler, Ph.D., Co-investigator, Department of Geography, The University of Michigan (1967, '68).

Samuel I. Outcalt, Ph.D., Co-investigator, Department of Geography, The University of Michigan (1970).

Barry C. Bishop, Physical Geographer, Department of Geography, The University of Michigan (1966, '67).

Theodore Aufdemberge, Climatologist, Department of Geography, Concordia College (1969).

Albert Barnett, Hydrology assistant, Department of Geography, The University of Michigan (1970).

William Benjey, Climatology, Department of Geography, The University of Michigan (1968, '69, '70).

Anthony Brazel, Climatology, Department of Geography, University of Windsor (1967, '68).

Timothy Brockdorf, Geomorphology assistant, Department of Geography, The University of Michigan (1970).

Philip Cantino, Botany assistant, Department of Botany, The University of Michigan (1968).

Francis Domoy, Geomorphology assistant, Department of Geography, State University of New York at Buffalo (1968).

Jeffrey Dozier, Hydrology, Department of Geography, California State College, Hayward (1969).

Karen Ewing, Glacier Hydrology, Department of Geography, The University of Michigan (1966, '68).

John Ford, Climatology assistant, Department of Geography, The University of Michigan (1967).

Helen Fox, Geomorphology assistant, Department of Environmental Science, Johns Hopkins University (1968).

Donald W. Kolberg, Climatology, Department of Geography, State University of New York at Buffalo (1968).

Joseph LaBelle, Glaciology, Department of Geography, The University of Michigan (1968, '69, '70).

A.J. LaFleur, Glaciology assistant, Department of Geography, University of Massachusetts (1969, '70).

Stuart Loomis, Geomorphology, Department of Geography, University of Minnesota (1967, '68).

Ray Lougeay, Geomorphology, Department of Geography, State University of New York at Geneseo (1967, '68, '70).

Richard Porter, Climatology assistant, Department of Meteorology and Oceanography, The University of Michigan (1969).

Richard Scott, Botany, Department of Botany, The University of Michigan (1967, '68).

Thomas R. Stengle, Ph.D., Water Chemistry and Glaciology, Department of Chemistry, University of Massachusetts (1969, '70).

Marjorie Uren, Climatology assistant, Department of Geography, The University of Michigan (1968, '69).

James Willingham, Climatology assistant, Department of Geophysical Science, The University of Michigan (1967).

Elizabeth Witherill, Glaciology assistant, Department of Geophysical Science, The University of Chicago (1970).

## Researchers Not Funded by the High Mountain Environment Project

Frederick F. Bragdon, MS, Glacial Geology, Department of Geography, University of Maine (1968, '69).

Gerald Holdsworth, Ph.D., Glaciology and Surveying, Institute of Polar Studies, Ohio State University (1968).

Albert Jackman, Ph.D., Military Geography, Department of Geography, Western Michigan University (1967).

Charles Keeler, Ph.D., Glaciology, Cold Regions Research and Engineering Laboratory (1968, '69).

Orson K. Miller, Jr., Mycologist, United States Forest Service (1968, '69).

Barbara M. Murray, Biologist, College, Alaska (1966, '68).

David F. Murray, Ph.D., Botanist, Department of Botany, University of Alaska (1966, '68).

Anthony Redente, MS, Geomorphology, Department of Geography, Western Michigan University (1969).

Will F. Thompson, Ph.D., Physical Geographer, U.S. Army Natick Labs (1969).

## Visitors

William Devereaux, Lt. Col., Arctic Test Center, Fort Greeley (1969).

Charles Markley, Engineer, Arctic Test Center, Fort Greeley (1969).

Edwin M. Rhoads, Col., Commanding Officer, Arctic Test Center, Fort Greeley, Alaska (1969).

William Van Royen, Ph.D., Director, Division of Environmental Sciences, Army Research Office-Durham (1969).

John Todd, Lt. Col., Combat Development Office, U.S. Army-Alaska, Fort Richardson (1970).

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13. ABSTRACT

This report provides the results of field investigations conducted in Chitistone Pass in Alaska and on Mt. Logan in Yukon Territory, Canada. A historical and philosophical background of the project is given, as are environmental descriptions of the research areas. During the program, research was carried out in these areas: (1) climatology and meteorology, (2) botany and plant geography, (3) periglacial hydrology and geomorphology, and (4) glaciology.

Relationships between environmental processes are covered. Abstracts, of published research papers and presentations that derived from the program are included, as is a listing of remaining research reports in progress.

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| 2. Botany and plant geography in high-altitude, cold-weather environments | | | | | | |
| 3. Periglacial hydrology and geomorphology in glacial areas | | | | | | |
| 4. Glaciology in Alaska and Yukon Territory | | | | | | |
| 5. High mountain environmental research | | | | | | |
| 6. Geography of glaciated regions in St. Elias Mountains | | | | | | |



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