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Special Report 78

NOTES ON HIGH ELEVATION RESEARCH

WITH SELECTED BIBLIOGRAPHY

by

Donald Alford

AUGUST 1965

U.S. ARMY MATERIEL COMMAND
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

This is the first report of U. S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) High Elevation Project. The purpose of this paper is to point out a general research area which has been largely ignored in the past, to survey the literature dealing with that area, and to attempt to show, broadly, what are felt to be reasonable preliminary approaches.

This report was written by Donald Alford, Geologist, Materials Research Branch, Research Division, James Bender, Chief.

USA CRREL is an Army Materiel Command laboratory.

DA Task IV014501B52A31

CONTENTS

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GENERAL STATEMENT

The ability to operate efficiently under a given environmental condition is a prerequisite for the success of any military operation. Efficient operation presupposes an intimate knowledge of the magnitude of significant environmental features and their effect on men and material. While a great deal of information is presently available on this subject dealing with such diverse environments as polar, desert and tropical we presently have only limited knowledge of the environment from 14,000 to 18,000 feet and only superficial knowledge of the high alpine environment which exists above 18,000 feet on the earth's surface. That the question of operating in this environment is not wholly academic was demonstrated by the activities of the Indian and Chinese armies at elevations up to 21,000 ft in the Himalayas in 1962. Based upon the assumption that it may become necessary in the future to conduct research into this mountain environment, certain preliminary studies were made in early 1963 by USA CRREL. It is the purpose of this paper to record some of the initial findings.

For the most part, the paper represents the results of an extensive literature survey conducted by the writer during 1963 and some of the conclusions which were drawn at that time. This survey was made in order to define as concisely as possible the problems which might be encountered at extreme elevations, to learn the extent of our present knowledge of the various parameters which might affect military operations, and to provide a basic fund of knowledge on which further planning could be based. A statement of those problems which appear initially to be of the greatest interest both scientifically and militarily is combined with an outline of previous work. It should be emphasized that the principal conclusion to be drawn from the literature is that very little quantitative research has been done in regions of extreme elevation. Scientific work in the past has been performed as a secondary objective by expeditions whose main concern was the ascent of high mountains. This paper is primarily concerned with the valley floors, mountain passes, and immediately adjacent slopes, since these are most pertinent from the standpoint of military operations.

The literature search has led to two conclusions: (1) Very little research can be conducted on an expeditionary basis, and (2) Previous workers have had to spend so much time simply combatting the environment that they were able to make little if any significant contribution to our understanding of it.

A general plan for a high-elevation research program is outlined in Appendix A, but no attempt is made to suggest definite research projects in a high-elevation environment. The field is far too broad for any one person to devise pertinent experiments in all fields which should be investigated. The actual design of research projects should be left to those who are competent in the various disciplines. Many of the specific problem areas are self evident; many others probably will not become apparent until initial studies have been completed. All are associated in some way with the decreased atmospheric pressure or the topography.

While the statements contained in the following sections should apply generally to regions of extreme elevations, they are derived primarily from the literature dealing with the Central Asian mountain systems.

GENERAL RESEARCH AREAS

Radiation

One-half of the total weight of the atmosphere is below 18,000 ft. As the atmosphere acts as a filter to the solar radiation passing through it, radiation intensity and composition vary with changes in elevation. This would not be particularly critical in an area where only a few isolated peaks rise above 18,000 ft but in the Himalayas and the Tibetan Plain, where nearly 80% of the total land surface averages near this height, this becomes a factor of some importance.

The early explorers in the Himalayas carried only black bulb thermometers to record the radiation intensity; these did not analyze the entire spectrum of radiation but provided a good indication of the radiational temperatures. Workman (1908) measured a black bulb temperature of 219F at 10,000 ft in the Karakoram and in 1909 the Duke of Abruzzi (de Filippi, 1912) measured a temperature of 152.6F at 16,000 ft in the same range. Pugh (1954) recorded a temperature of 156F on the Khumbu glacier at the foot of Mt. Everest. Sissenwine and Court (1951) report that an intensity of 0.0285 cal cm^{-2} sec^{-1} has been recorded at an elevation of 19,800 ft in Chile. Voloshina (1961) measured an intensity of 0.0290 cal cm^{-2} sec^{-1} at 17,590 ft on Mt. Elbrus in the Caucasus Mountains. This compares with 0.0175 cal cm^{-2} sec^{-1} at Site 2 in Greenland (Gerdel, 1956) and 0.0221 cal cm^{-2} sec^{-1} at sea level when the sun is directly overhead (Sissenwine and Court, 1951). At an intensity of approximately 0.0300 cal cm^{-2} sec^{-1}, the composition of the radiation is estimated to be 50% "infrared" (above 7000 A) and 6% "ultraviolet" (below 4000 A). The remaining 44% is in the visible spectrum. In the Himalayas, the problem is further complicated because much of the surface, being composed primarily of snow and ice, has an albedo of from .50 to .85, so that the total energy received by an absorptive body exposed to both incident and reflected radiation in this environment would undoubtedly be very high. Senn (1934) states..."the experience of climbers in the Himalayas has been that at great heights one can hardly bear the intense solar radiation even when experiencing fierce cold blasts of wind many degrees below the freezing point."

From the standpoint of logistics and equipment design, the intense radiation at extreme elevations is a very critical parameter. Army clothing is not currently designed for the extreme ranges of temperature that occur where radiation is the chief environmental heat source. Clothing and equipment must be developed which is functional through an environmental temperature range of 100F.

Physical and mechanical properties of ice and snow

It is assumed in the absence of any quantitative data that any unusual aspects of snow mechanics at extreme elevations would be intimately linked to the low atmospheric pressure and the extreme incident radiation. Apparently no studies of the properties of snow have been performed in the Himalayas or Andes, but the literature is filled with qualitative descriptions of snow conditions at all elevations. They are not, however, all in agreement. One school of opinion seems to be that the snow is of very low density immediately after deposition and that, except for the top few centimeters exposed to solar radiation, it remains in this state much longer than is normally found at lower elevations. Snow which has crusted sufficiently to support the weight of a pack-carrying man before the sun strikes it softens by late morning to the point where the only practical means of locomotion is a swimming motion (for example: Wiessner, 1956; Schatz, 1960). On the other hand, the Duke of Abruzzi's expedition to the Karakoram in 1909 apparently found new snow being converted to névé in one day. During the period 5-10 July 1906, Filippi (1912) found that in spite of almost uninterrupted precipitation, the end result was a net loss of 1 ft of snow at 16,000 ft. Bell (personal communication) describes "honey-comb" ice formations which he estimated to be

nearly 80% void space. Many persons have spoken of the "rubbery" ice to be found at high elevations.

All aspects of the snow cover and its metamorphosis present interesting possibilities for basic reasearch. From the military standpoint, any form of surface transportation will involve an understanding of the mechanics of the snow and ice. This problem alone could justify the entire research program since any mountain operation will be confronted with snow conditions which at present are only imperfectly understood.

Geology

For the most part, the geological work done to date in the Himalayas has been primarily of a reconnaissance nature. The geological survey organizations of India and Pakistan have not encouraged their geologists to work in the mountains and, consequently, most of the studies have been made by European geologists who have visited the area with climbing expeditions. Apparently little of a geophysical or geochemical nature has been published to date.

Weathering phenomena. The actual processes of weathering above 15,000 ft are still only partially understood. It is generally believed that they are primarily physical although Glasovskaia (1952) reports that bacteria have been found on rocks from 16,000 ft in the central Tien Shan, and Swan (1961) found primitive plants above 20,000 ft in the vicinity of Mt. Everest. The initial assumption is that frost wedging plays an important role in this process, but not enough is known about the presence of free water to draw any definite conclusions. Certainly the large diurnal temperature fluctuations are important.

Mass transport. There are apparently four types of mass transport in the Himalayas: wind, glacial streams, glaciers, and mud flows. The extreme aridity of the region suggests that a great deal of material may collect in unstable positions on the valley walls and therefore be extremely susceptible to gravity transport. A knowledge of this factor would be important in the movement of men and equipment through such areas.

Frozen ground studies. There are no direct references to frozen ground studies in the Himalayan literature. Swan (1961) reports a summer temperature which varies between 39F and 44F at a depth of 6 in. at 16,000 ft. It seems reasonable to assume that much of the subsurface material is below the freezing point but the presence of ice is conjectural.

Glacier mass budget studies. According to the American Geographical Society, only 2% of the Himalayan glaciers have been mapped with any degree of accuracy. The Karakoram Himalayas alone represent the largest single glacier complex outside of the polar regions. Some of the largest valley glaciers in the world (up to 45 miles long) are found there, in an area where the nearest weather recording stations report less than 3 in. of rain per year. This apparent contradiction may be explained by an increase in precipitation with increasing elevation but no studies have been made to establish this hypothesis. A great deal of work has been done on the Himalayan glaciers, but the papers, with the exception of only a few, are of an exploratory or descriptive nature. A knowledge of the dynamics of these glaciers would be quite important from a military standpoint since, in many cases, they provide the only practical surface passage into the range. From an economic standpoint they are perhaps even more important since they are the sources of all the major rivers of India and Pakistan. As a case in point, the entire investment in the Indus basin development program, estimated at one billion dollars, is dependent upon the regime of glaciers which, according to the best available data on the subject, are getting less than 3 in. of water a year in some areas.

Avalanche studies. Many observers have commented on the avalanches of the Himalayas (Roch, 1954; de Filippi, 1912; Mason, 1955) but again no quantitative studies have been made. Mason states that the avalanche danger exists at all seasons in the high mountains and ... "most European climbers are surprised... by the distance traveled by Himalayan avalanches, and a much larger margin of safety is required in siting camps where these are likely to occur" (1955). Roch (1954) states that the slopes are so steep in the Everest region that avalanches falling from them attain sufficient velocity to completely cross the valley floors. In addition to snow avalanches, hanging glaciers periodically discharge large masses of ice into the valleys. de Filippi (1912) reports that, in one period of unusually warm weather, ice avalanches fell almost continuously for 24 hours from a peak adjacent to the Baltoro glacier. Mason (1955) states that, in many parts of the Himalayas, the only safe time to travel is at night when the low temperatures have consolidated the snow. The significant effect this would have on troop movements, bivouacs and tactics cannot be overstressed.

Hydrology

The streams of the Himalayas originate at glacier termini and so can be expected to have both a diurnal and annual maximum and minimum volume of flow. The maximum level reached by these streams and the periodicity should be studied since the trafficability of some valley floors will depend almost wholly on this factor at certain times.

Occurrence of free water. The highest elevation at which water naturally occurs in its liquid state should be determined. Pugh (1954) states that at extreme elevations an individual must have between 5 and 7 pints of water a day to replace loss through respiration. It seems quite probable that there is an upper limit to the occurrence of unfrozen water, above which all water would have to be produced from melted snow.

Meteorology

All meteorological data found in the literature pertaining to the Himalayas were of three classes: (1) Readings taken by non-meteorologists in the higher mountains during summer mountaineering expeditions, (2) Data from stations in the foothills to the south of the range and, (3) Balloon soundings. There is no reliable information on winter conditions in the entire range. The following are, for the most part, qualitative statements taken from the various expedition accounts.

The extreme variability of the weather at high altitudes in mountainous regions is well known. Because of their massiveness and height, the Himalayas probably exhibit this factor to a greater degree than any other mountain range. The primary problems facing anyone in the area are much the same as those experienced in the polar regions: violent blizzards, high winds, and intense cold. The prevailing wind at high altitudes throughout the Himalayas and Tibet is westerly and strong, often blowing at gale force. It may at times be so strong at altitudes over 20,000 ft that it is impossible to advance against it or even to stand in one place. Climbers on the northeast ridge of Everest have estimated gusts at well over 100 mph. At altitudes down to 16,000 ft or less in exposed places the wind may be strong enough to destroy a tent (Mason, 1955). Temperatures of -20F are not uncommon during the summer above 18,000 ft and a temperature range of 70F has been measured between two adjacent points in the sun and shade respectively (Wager, 1934).

The Himalayas lie within the influence of the monsoon, which generally reaches them in late May or early June and ends in September. Since the monsoon occurs during the Himalayan summer, the regime of the glaciers there can be expected to be somewhat different than in the areas where they have been more extensively

studied, since maximum precipitation will occur during the period of maximum ablation in those parts of the range most strongly affected by the monsoon. No exact measurements of precipitation above 15,000 ft have been found although there are numerous references to snow accumulation of 1 to 2 ft overnight in the vicinity of 16,000 ft (see for example: Houston and Bates, 1954).

Nutritional requirements

Arctic explorers have found that a high concentration of fats in their diet helps them to combat the cold. In the Himalayas, however, many climbers have found that they are unable to eat even slightly fatty food, because the body cannot make use of this food without a plentiful oxygen supply. Current issue as well as experimental army rations should be tested to determine their suitability at extreme elevations.

Artificially created environments

The only attempt which has been made to date in this direction is the design and testing of portable oxygen equipment. While this would probably not be feasible for a military operation, the possibility of creating pressurized living environments should not be dismissed without some thought.

Transport

Today the Himalayas are probably the most inaccessible area on the earth to any form of motorized transport.

In 1850 the principal modes of transport in the high mountains of Asia were yaks (an animal indigenous to the region (Mason, 1955)) and porters. In 1960 (personal communication, W. Unsoeld, 1961) exactly the same means were being used by travelers in the mountains. In over 100 years, in spite of the gradual encroachment of more modern transportation in the foothills, no progress has been made in the mountains. The problems are manifold. Most of the passes are snow-covered 12 months of the year and the only approach is generally over a glacier. The valley bottoms below the glacier termini are usually very narrow and contain glacial streams while the valley walls are generally steep and of solid rock. Only a very few of the streams have been bridged and most of these bridges cannot be crossed by anything heavier than a man on foot since they consist only of willows woven together. Because of the extreme aridity of the region the disintegration products of the mountains accumulate at steep angles of repose and then come down to the valley floors in great mud flows during the wet season.

As far as can be learned, only one successful aircraft landing has been accomplished in the higher mountains (Eiselin, 1961). Many of the passes are above the service ceiling of loaded helicopters and the high velocity and extreme turbulence of wind in the narrow valleys make the maneuvering of any type of aircraft quite difficult.

In such a region a highly mechanized army would actually be operating at a disadvantage compared to one which relied upon less sophisticated techniques. In order to overcome this disadvantage, it is necessary to determine the reaction of engineering materials to the environment and to devise techniques to make the movement of large groups of men and equipment possible.

Conclusion

The Himalayas have been studied extensively for over 100 years but the primary emphasis has been upon exploration, with only sporadic attempts to understand and analyze the environment. For this reason our knowledge of their geography, if not complete, is extensive while our quantitative knowledge of the physical

environment is negligible and is based almost solely on extrapolation from parameters measured at lower elevations.

In this paper, the Himalayas have been purposely stressed to the exclusion of the Andes. This literature survey was based on the premise that a knowledge of the Himalayas is necessary and that we are interested not only in basic research in a region of extreme elevation but also in very specific information concerning the geography, geology, climatology, and glaciology of the Himalayas. If it is at all possible, this research should be accomplished there. In many ways the Andes are probably an adequate analogue of the Himalayas but, on the basis of the available information, this cannot be ascertained. Those problems caused solely by the effects of extreme elevation could be studied in the Andes; those which result specifically from conditions in the Himalayas probably could not.

Even a complete understanding of the factors discussed above will not lead immediately to a solution of possible problems, but without some knowledge of the magnitude of these parameters it is unrealistic to attempt practical solutions of any problems involving operations in this area. In the final analysis, the clearest and most definitive solutions will undoubtedly come out of laboratory research using artificially controlled environments, but some knowledge of the actual conditions should be gained before investing in sophisticated laboratory instrumentation. Every laboratory experiment must be based on certain assumptions and at the present time we do not have sufficient information to do more than guess at what these assumptions should be. Laboratory research and field research form a continuous cycle, neither is valid or complete without the other; each contributes to the success of the other by providing a cross check on the validity of observed phenomena. There is a proper sequence in these matters however, and in this case it would seem more realistic to proceed from the general to the specific, from actual field conditions to an artificial laboratory environment, rather than the opposite.

RESEARCH SITES

Introduction

The following pages briefly describe those areas in the Andes of South America and the Himalayas of northern India which might lend themselves to the requirements of a high elevation research program. Description of the individual areas is by no means complete but it is believed that all possible field research areas have been covered. Two criteria were used as a basis for this selection: (1) the presence of glaciers, and (2) a wide range of relatively accessible elevations. A combination of these two factors is not as common as might be assumed.

Since the decreasing atmospheric pressure and associated decrease in suspended water vapor is responsible, either directly or indirectly, for most of the characteristic phenomena of a high alpine environment, and since a majority of both lie below 18,000 ft, this elevation is arbitrarily selected as a midpoint of the research. Research should extend above and below this line for several thousand feet so that findings at the lower levels can be correlated with previous work at lower elevations and higher latitudes and conditions at the upper limits will approach extremes for that particular environment. Secondly, in order that the maximum amount of work can be done in one area, a wide variety of surficial compositions, cover, and topographic features should be present. This would enable scientists from a number of different disciplines to work together from a single base. Isolated mountain peaks such as volcanoes, no matter how high above sea level, cannot be considered representative of a mountain range because

they do not possess sufficient bulk to have a pronounced effect on their environment. The region should have extensive snow fields and glaciers and at the same time have exposed rock and soil at its upper limits. The area should be relatively accessible. However, the relativeness of the accessibility should be stressed since the areas discussed here are probably among the most inaccessible regions on the earth. Therefore, the final decision should not be too heavily influenced by this factor. The primary consideration should be the type of research to be done and the suitability of a given area for that research. Logistical considerations should be secondary and should not be allowed to dictate research procedures.

It is obvious that all the problems of the mid-alpine zone between 10,000 and 15,000 ft have not yet been solved. However, a great deal of work has been done in this zone, notably in the Alps, and this elevation range does not present the extremes encountered above 18,000 ft. Also, with the exception of those ranges in the higher latitudes which are subject to very heavy precipitation, there is generally no permanent snow cover. They are cold regions only in a seasonal sense. For this reason, it is felt that the Rocky Mountains of the United States and Canada, the Sierras of California, and the Coast Ranges of Oregon, Washington, and British Columbia are inappropriate for this type of research. Several mountain ranges in Alaska and the Yukon, notably those centering on Mt. McKinley, Mt. Logan and Mt. St. Elias, fall within the desired elevation range and have an abundance of permanent snow and glaciers. However, these mountains are not a desirable location for high elevation research. The highest summits lie between 60° and 63° N latitude, where the vertical environmental range is overshadowed by the strong influence of the circumpolar environment. It would probably be difficult to separate effects wholly related to elevation from those associated with high latitudes. Secondly, the relief in the mountains of Alaska and the Yukon is generally extreme, in many places exceeding 10,000 ft from the cirque basins to the mountain summits. Since most of the valleys are relatively low much of the work would have to be done on or near the summits. This would mean that more technical mountaineering skills would be needed by those studying in the area. This would probably have the effect of reducing the overall level of the research which could be done.

The above is not meant to indicate that valid high elevation research cannot be conducted in those areas mentioned. However, as a first approximation, they all leave something to be desired. The most desirable areas, from the standpoint of research alone, are to be found in the Himalayas and the Andes.

The Himalayas

The word "Himalaya" is derived from a Sanskrit word meaning "the abode of snow." The range extends in an east-southeast direction from the eastern edge of Afghanistan at 35° N latitude to the Brahmaputra River at 25° N latitude, a distance of over 1800 miles, and averages between 100 and 150 miles wide. The average elevation of the crest of the range is 20,000 to 22,000 ft with individual massifs rising to between 27,000 and 29,000 ft. The principal passes vary from 14,000 to 19,000 ft and the snow line lies between 15,000 and 19,000 ft, depending upon precipitation, which decreases from a high of 90-120 in. in the east to a low of 20-30 in. in the west. Most of the precipitation falls during the monsoon, which comes during the summer months. To the south of the range the land drops rapidly to the plain of the Ganges river; here one may go from near sea level to the crest of the range at 22,000 ft in a distance of 100 miles. North of the Himalayas lies the Tibetan Plateau, an area of approximately 500,000 square miles which averages 13,000-15,000 ft in elevation and extends north for 500 miles.

Floral zones on the south side of the range progress through jungles, rain forests and stunted alpine growth to the near sterility of the mountains above 15,000 ft. The Tibetan Plateau is covered primarily with grasslands.

The selection of a research site in the Himalayas is complicated primarily by the isolation of the range and the lack of detailed geographical data. Most of the individual areas have been visited by Europeans only once or twice to climb the major peaks of the range, and generally these expeditions have not produced accurate topographic maps. There seem to be only two areas of relative accessibility which have been visited repeatedly and which are well mapped. These are (1) the Central Karakoram in northern Pakistan and (2) the complex centering on Mt. Everest in northeastern Nepal. The major glaciers of the former lie within 40-50 miles of the town of Skardu, which has an airport capable of handling C-47 and C-130 aircraft; the latter is probably the most heavily visited region of the entire Himalayas and has in the past been the scene of a fairly extensive research effort. Sir Edmund Hillary and a party of physiologists spent the winter of 1960-61 near the village of Thyanboche at an elevation of over 19,000 ft. Either of these areas would be quite suitable for the type of research which is contemplated. A brief description of the geography of the mountain system of Central Asia is given in Appendix B.

The Andes

In common with all mountainous areas, the Andes of South America are a region of extreme contrast and variability, both laterally and vertically. They extend along the entire western coast of South America from Venezuela at 10° N latitude to Tierra del Fuego at 55° S, a distance of over 4000 miles, with an average width of between 100 and 200 miles. Between 8° and 35° S latitude, the highest crest of the range rarely drops below 5000 meters (16,500 ft).

The predominating impression one gains of the Andes from the literature is one of aridity. In *spite* of its height and great extent it is not a heavily glacierized range. According to von Klebelsberg (1949) there are 12,000 km^2 covered by glaciers in the Andes. Assuming that the entire range has a total surface area of between 1.2×10^6 and 1.5×10^6 km^2, approximately 1% is covered by glaciers or permanent snow fields. This compares with 4.5% in Switzerland and 28% in the Karakoram Himalayas (Lliboutry, 1956). Of the 12,000 km^2 covered by glaciers, at least 90% is in the Patagonian Andes, which comprise only about 10% of the total surface area of the range. The remaining glaciers are concentrated in two areas: the Central Chilean Andes between 32° and 34°S latitude and the Cordillera Blanca and Cordillera Huayhuash between 8° 30' and 10° 30'S latitude in northern Peru.

The Andes of Central Chile. This portion of the Andes lies approximately west of Santiago de Chile between 32° and 34°S latitude. According to the Encyclopedia Britannica (p. 991), "Northward from latitude 39S to latitude 30S, the character of the Andes is greatly simplified. It consists of a double line of crests, the westernmost of which carries the Argentine-Chile boundary. The high valleys between the crests are at an altitude of from 10,000 to 13,000 feet. The passes to the east and west in the northern part are between 13,000 and 15,000 feet in altitude. South of latitude 31S, they are somewhat lower. Isolated summits rise from 5,000 to 7,000 feet above the high valleys and between 32 and 34 S. latitude include three of the highest peaks of the Andes: Aconcagua (23,080 ft), Mercedario (21,870 ft) and Tupungato (21,550 ft). The snow line is quite low in this region, lying at 6500 ft. at 37 S. latitude and rising to approximately 14,000 ft at 30S." According to Lliboutry (1956) there are 1,350 km^3 of permanent snow and glaciers

between 32° and 34° S which comprise 4.5% of the total surface area. This is a very low figure in terms of the ruggedness and average elevation of the region and is probably explained by the low precipitation.

Precipitation is a very seasonal phenomenon here, occurring only during the southern winter. During this time, between 120 and 140 centimeters of water is deposited at the elevation of the highest peaks. This figure decreases with decreasing elevation (Lliboutry, 1956). Corte (personal communication) estimates that at least one-half of this is returned to the atmosphere by evaporation. The formation of the glaciers here is not directly related to the initial distribution of precipitation but rather is a function of the snow which is blown from the ridges and summits by the prevailing west wind. For this reason, almost all of the glaciers in this region are found in cirques lying to the east of and several thousand feet below the main crest. None of the glaciers appear to reach the summits and for the most part these higher locations are free of snow. In general, the average upper limit of permanent snow is near 17,000 feet in the north and 15,000 feet in the south. Glaciers have a narrow vertical range, extending only through 2000-3000 feet.

The eastern side of the range is largely undeveloped and consequently relatively inaccessible. On the western, or Chilean, side, there are a few mines and these are connected with the coast by road. All of these roads, however, approach the range at right angles to its major axis and, consequently, do not simplify the problem of north-south movement within the mountains. There is a trans-Andean highway between Santiago and Mendoza, Argentina, which passes within 15 km of Aconcagua but it adds little to the general accessibility.

The Peruvian Cordilleras. The Cordillera Blanca lies between 8° 30' and 10° 10'S latitude, 62 miles east of the Pacific Ocean in northern Peru. It is bordered on the west by the Santa Valley, on the southeast by the Cordillera Huayhuash, and is in the northern portion of a vast, high-level (13,000-15,000 ft) plain which extends southward to northern Bolivia. The range is 180 km long, 20-30 km wide and consists of an elevated upland lying at approximately 13,000 ft, above which the main range rises to between 19,000 and 22,000 ft. The highest peak in the range is the Nevado Huascaran, 22,334 ft. The Santa Valley immediately adjacent to the foot of this peak is 8500 ft.

Precipitation occurs in the range at all times of the year but most comes during the months October-April when the mountains are continuously blanketed by clouds. During the southern winter, there are long stretches of good weather interspersed with snow storms at the higher elevations. No figures on annual precipitation in the mountains were found. Records are available for towns to the west of the range but these lie in the rain shadow of the mountains, which receive most of their moisture from the east, and so are probably not representative. The snow line is between 16,000 and 17,000 ft.

Lliboutry (1956) estimates that the total surface area of snow and ice in the Cordilleras Blanca and Huayhuash is 1000 km^2. This agrees well with a planimetric measurement of Kinzl and Schneider's (1950) map of the Cordillera Blanca which gave a figure of 650 km^2 for that range alone. Assuming the total surface area of the range to be 4000 km^2, 12-16% is covered by permanent snow fields or glaciers. The majority of this consists of large accumulation areas reaching to the summits of the highest peaks with very short glaciers (the longest is 6 km long in the vicinity of Huascaran) extending down to between 14,500 and 14,000 ft. The elevation of the valley floors in the range itself is between 13,000 and 15,000 ft, so that the glacial termini are quite accessible; most of them have trails leading directly to them.

The Cordillera Blanca is probably the most accessible of all the world's major mountain massifs. The Santa Valley is connected with Lima by an all-weather road. Above the village of Yungay the summit of Huascaran is within 10 km of this road and the glacier termini are in most cases closer. The Santa Valley is one of the most heavily populated sections of Peru, the principal occupation of the inhabitants being agriculture. The range itself is cut on the average of every 5 km by glacial valleys running at right angles to the major axis and this effectively breaks it up into separate blocks 20 x 5 km in area. Apparently the only part of the range which cannot be reached in a maximum of 2 days from Lima (disregarding acclimatisation time) is the extreme northeast corner. A plentiful supply of mules and horses together with trained mountain porters has been developed in the towns of the Santa Valley because of the large number of expeditions which have visited this area in the past.

Concerning the Cordillera Blanca, Kinzl (1950) writes, "The Cordillera Blanca are the highest and perhaps most beautiful alps of the tropical zone and also boast the greatest number of glaciers. They far exceed the glaciated (sic) mountains of Africa and of New Guinea, the ranges of the Himalaya lying outside the tropics. Even considered as part of the South American Andes, the Cordillera Blanca stand alone. Although Aconcagua, the only peak in the New World reaching up to 7000 meters, exceeds them in height, it is much less heavily glaciated. The mountain chains of Patagonia, on the other hand, though carrying much larger ice fields, are not nearly so high. Apart from this, the Cordillera Blanca is to this day the most easily accessible mountain range with ice peaks more than 6,000 meters high." Liiboutry (1956), who has made an extensive study of the glaciers of the Andes, says, "...But it is in Peru where the glaciers assume their greatest extent. The Cordillera Blanca, between 8° 45' and 9° 15'S. latitude and the Cordillera Huayhuash between 10° 10' and 10° 30'S. latitude have together 1000 km^2 of ice. Their splendid granite summits with hanging glaciers, tremendous cornices and fluted névé remind one of the Himalaya."

The Cordillera Huayhuash is a short (30 km long) range lying to the southeast of the Cordillera Blanca and is in almost all respects identical to it. The foot of the range can be reached in one day over the Pan-American highway from Lima. It is quite a bit more glacierized than the Cordillera Blanca, having nearly 40% of its total surface area covered by permanent snow fields and glaciers. The average elevation of the crest of the main ridge is approximately 6000 meters. According to Kinzl (1955), "...glaciers of this group are similar to those of the eastern Alps with the largest covering approximately 12 km^2" and, "Within the region of the main peaks, these glaciers, also as regards their outer forms, remind us more of Alpine regions than other mountainous regions of Peru. At the foot of the steep head walls leading up to the peaks we find comparatively flat firn basins, which develop into long, narrow tongues farther down the valleys."

Both of these ranges in Peru seem to be ideally suited to high elevation research and if it should prove to be impossible to work in the Himalayas, they would certainly be an acceptable substitute.

Conclusion

It is hoped that this section will stimulate further thought on the problems associated with a high elevation research program. It is based on the assumption that the Army is concerned with cold environments which are not associated with the polar and sub-polar regions and that the presence of permanent snow fields is a good indicator of such an environment.

The question of the similarity of the Andean and Himalayan environments is a moot point and probably will remain so until some basic investigations have been completed. Grossly, of course, they are alike in many ways. Just how pervasive this superficial similarity is should certainly be one of the overall goals of a high elevation research program.

SUPPORT REQUIREMENTS FOR HIGH ELEVATION RESEARCH

Introduction

The problems to be faced by scientists working in a high altitude environment will in many ways be similar to those encountered in the polar regions but, initially at least, there will be important exceptions. The purpose of this short section is to outline support problems which will probably occur and how these problems have been dealt with in the past in the mountains.

Oxygen

Each person seems to adjust to increasing elevation at a different rate and so no hard and fast rules can be applied to everyone going into the mountains. Certain problems, however, do occur with a high degree of regularity. One is the possibility of a pulmonary breakdown. This is brought about in a number of ways including pulmonary edema, pulmonary embolism and bacterial infections such as pneumonia. All three of these are rather serious at sea level but at elevations above 15,000 ft they are generally fatal if left untreated. For this reason, it is essential that therapeutic oxygen be constantly available at all research sites. This oxygen can be carried in a variety of cylinder sizes; the 800-liter cylinder which weighs 11½ lb fully charged and the 1400-liter cylinder weighing 21 lb are easily portable. These cylinders can be equipped with either an "open circuit" or a "closed circuit" face mask, the former being connected with the atmosphere and the latter being designed to re-use its oxygen supply. For therapeutic purposes, the "closed circuit" is probably most desirable.

Clothing

In many respects, clothing designed specifically for an arctic environment is not suitable for high elevations. There are a number of reasons for this. At high elevations the daily sensible temperature range is often as great as the annual, and consequently, an individual can not dress for one narrow temperature range on any given day. In fact, it is quite likely that the diurnal sensible temperature range will approach 100F. Clothing must provide protection from -30 to +120F in winds ranging from 0 to over 70 mph.

The danger of frostbite is much more imminent at the higher elevations. The hyperventilation which occurs consumes a large amount of body heat, thus leaving the extremities with a lower reserve. There are two ways in which this problem can be approached. One is to prevent the loss of heat through the lungs by devising some method to heat the air which is taken into them or by slowing the breathing rate by the use of oxygen. The other is to provide more protection for the extremities. While the use of oxygen is probably more effective, it is more expensive and involves many complications.

All the clothing required by the field worker during the day must be carried with him. Because of this, weight must be considered as well as the amount of protection provided. The total weight of clothing required during any one day should not exceed 20 lb, and it should be so designed that no more than half of this need be carried at any one time.

Boots. Any footgear used must meet a number of minimum requirements. It must be rugged enough to survive a field season without noticeable deterioration. It must be completely waterproof. It must be designed to give maximum protection from the cold either alone or when used with crampons. It should have a cleated sole (vibram montagna) to increase its range of usefulness without the use of crampons. The best boot presently available is probably the "Lowa" type high altitude boot which is available commercially in the United States.

Parkas and jackets. The jacket must give protection down to at least -20F without the addition of a large quantity of clothing beneath it and yet be easily portable when it is not needed. It should be both wind and water-proof. The only jackets found which meet all of the above specifications are the down jackets developed specifically for a high elevation environment. The Gerry "Himalayan" jacket is a good example. A lighter, wind and water-proof parka should probably be included for temperatures above freezing on windy days. These two items together should not weigh over 3 lb.

Pants. Pants should be made of a warm durable material such as gabardine whipcord with double thickness at points of extreme wear. They should be provided with some device to draw them tight at the ankles and should have roomy pockets which may be closed to keep out snow. A pair of wind pants, made of a tightly woven nylon for wind and water protection, should also be available. A pair of gaiters should be used to close the gap between pants and boots.

Miscellaneous. The remaining clothing, such as shirts, socks, and underwear need not be out of the ordinary. Each person going to the field should be equipped with at least two pairs of down mittens together with several pairs of lined leather gloves with silk inner liners. Hats should be designed to give maximum protection against the intense radiation as well as the cold.

The following is a list of commercially available clothing items representing the minimum weight combined with the maximum protection.

Down parka	2.5 lb
Gabardine pants	2.0
Wind pants	.5
Long underwear	1.0
Boots	6.5
Wool shirt	1.2
Socks (4 pr)	1.5
Mittens	.5
Gloves	.3
Hat	.2
	16.2 lb

Of the above list, at least 10 lb would be worn 90% of the time leaving only 6 lb to be carried during warm parts of the day. It is essential that the weight of the clothing be kept to a minimum so that it in itself does not become a problem to be dealt with in the field.

Tents

The central research site in any area should be of rigid construction to promote comfort and increase the efficiency of the operation. It is to be expected, however, that much of the research done in the field will be wide-ranging in character, and this will introduce the necessity of portable camps. For these, tents will probably be best. At least two different models should be included: sleeping tents and work tents. The sleeping tents should be lightweight and windproof but only the floor need be completely waterproof since they will be used on

snow at elevations where rain will be extremely rare if not non-existent. They should be double walled for warmth and should be equipped with spreader wands to restrict flapping in high winds. If possible they should be compartmentalized so that equipment may be stored separate from the location of the sleeping bags. The material from which they are made must be the sort that "breathes." This is one of the principal problems with the Army two-man mountain tent and for this reason it is completely undesirable under any but emergency conditions. The larger tent should be large enough so that four or five people can cook, eat and work in it with no crowding. It should have a waterproof floor with an opening in it for cooking. Neither of these tents should weigh over 15 lb since most of the time they will probably be backpacked to the research site.

Sleeping bags

The type of area chosen for a research project will determine, to a large extent, the type of sleeping bag to be used. In a semi-permanent camp below the snow line, the standard Army issue sleeping bag will probably be more than adequate. In camps above the snow line it will not meet all the requirements. In order to be easily carried, the bag should not weigh more than 5 lb. At the same time it should give protection down to -20F. For maximum comfort, the bag should be used with a foam pad $1\frac{1}{2}$-2 in. thick and should be equipped with a waterproof cover and carrying case. The bag should be filled with down and not a mixture of down and feathers.

Cooking equipment

This is not an item which requires a great deal of specialized equipment but in one way, at least, it will differ from that used in the polar regions. Since water boils at a lower temperature because of the decreased atmospheric pressure, it is essential that some type of pressure cooker be included in the cooking paraphernalia.

Packboards

A properly designed rucksack or packboard can make a great deal of difference in the ease with which a load is carried. The ideal packboard should weigh about 1 lb so as to contribute a very small percentage of the total load and should be designed to distribute the load rather than concentrate it all on the shoulders. Such a packboard is manufactured commercially by the Kelty Company and is far superior to any other packboard currently in use. Its only drawback is that it will not take large, awkwardly shaped loads. For this purpose, several Army plywood packboards should be taken along.

Standard mountaineering equipment

Any group attempting research in the mountains should be equipped with a normal complement of mountaineering equipment whether or not its use is planned. This should include: (1) at least 1000 feet of $\frac{1}{2}$-in. goldline nylon rope in 150-ft lengths, (2) ice axes (3) crampons, (4) 200-300 willow wands, (5) karabiners, (6) assorted pitons, (7) expansion bolts, drills and hangers, (8) ice screws, (9) skis and climbers, (10) basket stretcher.

Each person in the research group should be competent in the use of the above, either through training before departure or on-the-spot training before the start of the research, and each person should be familiar with the techniques of mountain rescue and first aid.

Medical support

Because of the nature of the country in which the research will be conducted, it would be desirable to have a doctor accompany the field party each season. This

person could be a physiologist, and could contribute to the total research effort in addition to his duties as a physician. The group should also be completely equipped with medical supplies so as to be as self-sufficient as possible.

Acclimatisation

It is not possible to determine beforehand the extent of any individual's reaction to increasing elevation but it can be assumed that the average person, coming from sea level, will definitely have his efficiency impaired by the time he reaches 10,000 ft. This problem can be overcome by the use of a planned acclimatisation program, lasting from 1 to 2 weeks. During this time, the group should move upwards gradually, preferably walking, and going higher each day than the planned sleeping elevation. In the Andes, it would be quite simple to go from 8000 to 16,000 ft in one day, but this would probably not be in the best interests of the party.

Conclusion

The efficiency of the research party will be governed by the comfort with which they are able to live and work at the research sites. Their health and safety will, to a large extent, depend upon the degree to which their equipment is adapted to the environment. For this reason the equipment used in the field should be specifically designed for and tested in such an environment. Compromises in the quality of the personal and support equipment of the group can only result, at best, in a loss of efficiency.

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APPENDIX A. PROPOSED HIGH ELEVATION RESEARCH PROGRAM

General Statement

To successfully fulfill its mission, the Army must develop an increased capability for operation in unique terrestrial environments. One such environment, concerning which we have only superficial knowledge, is that found in the earth's major mountain ranges. This appendix outlines a research program designed to analyse that environment.

Objectives

The primary objective of a study of the physical properties of the materials existing in a high elevation environment and the processes contributing to those properties is to better equip the U. S. Army to fulfill its mission in the event it is called upon to operate, or advise allies who are operating, in mountainous terrain. In order to accomplish this, certain definite research goals must be established to furnish guidelines for a systematic approach to the problems and their solution. While it can be expected that the ultimate goals will be modified as our knowledge of them increases, it is possible at this time to state the general research objectives of a program of high elevation research. These are:

1. To determine the physical properties of snow, ice and frozen ground as they exist in the mountains and the processes contributing to their formation.
2. To study the slope stability of materials such as snow, soil and rock in order to better understand such phenomena as avalanches, mud flows, rock slides and other gravity-induced movements.
3. To analyse the variation in the hydrologic regimen of streams originating from glaciers and snow fields in order to gain a better understanding of the significance of these variations on troop movement and water supply.
4. To determine the means of transport, deposition, distribution and importance of the products of both physical and chemical weathering so that the nature of the relationship between topography and surficial composition may be established.
5. To investigate the value of biotic communities as indicators in the analysis of an environment.
6. To determine the significant differences between the high elevation environment and that found in the polar regions.
7. To establish engineering criteria for the optimum utilization of materials existing in the high elevation environment.
8. To determine the similarities and differences between an arctic high elevation environment and an equatorial high elevation environment and to examine the validity of the "geographic analogue concept" as it is applied to mountainous areas.
9. To establish criteria on which to base solutions of problems pertaining to troop movement, construction, water supply, sanitation, performance of equipment, and tactics.
10. To measure the relative importance of the macroclimate and the microclimate as controlling factors in the high elevation environment.

11. To develop an Army in-house capability in the field of high elevation research and to establish a pool of experience and specialists to be called upon in the event of an emergency.

Justification

Mountains represent an extension of the polar environment into temperate latitudes. However, because of certain modifying factors, the analogy is not completely valid and it is difficult to base solutions to problems encountered in one environment on experience gained in the other. This entire program is based on the assumption that the U. S. Army requires a more complete knowledge of the high elevation environment in order to meet present or anticipated commitments and that this knowledge can only be gained through a comprehensive research program.

Historically, mountains have played a significant role in military operations. Within the framework of the limited war concept, they assume an increased importance today. Mountainous areas constitute ideal operational bases for small, mobile forces and, at the same time, to a large extent negate the sophisticated equipment designed to function in a less extreme environment. In order to succeed, military operations conducted in mountainous regions must be based on an understanding of the alpine environment and must be designed to take advantage of the peculiarities of that environment.

Procedures.

This research program should be conducted on three levels: (1) Field research for a period of five years at a site to be selected in order to determine the variations within an individual area and to establish a "type" area for the basis of comparison; (2) Field research in a variety of superficially differing high elevation environments for the purpose of determining the extent of regional variation; and (3) Controlled laboratory experiments designed to analyze in depth the significant problems as determined by (1) and (2). While the three phases of the research program will be so designed as to be complementary from the research standpoint, they must be regarded as separate entities for the purposes of execution. The first will require the establishment of, or the use of, a currently existing, semi-permanent year-around facility with power, living quarters and laboratory space. The second will require self-contained, portable camps which can be shifted from area to area. These will be largely based on equipment and techniques developed as a result of expeditionary mountaineering. The facilities for the successful prosecution of the third are already in existence at this laboratory.

APPENDIX B. A BRIEF GEOGRAPHY OF THE MOUNTAIN SYSTEMS OF CENTRAL ASIA.

Introduction

Extending east from Afghanistan and north from Pakistan and India is the greatest mountain complex on the surface of the earth. This complex consists of the Himalayan, Karakoram, Hindu Kush, Pamir, Alay, Tien Shan, Kun Lun, and Nan Shan mountain ranges and the Tibetan Plateau. Considered as a unit, these mountain ranges cover an area of over 1,000,000 square miles, in which the average elevation exceeds 13,000 ft (Fig. B1) and, in large sections, approaches 20,000 ft. It has been estimated that much of the Tibetan Plateau has an average elevation higher than that of the main range of the Himalayas, in spite of the fact that its highest elevations do not exceed 24,000 ft. In spite of its proximity to the equator, the region has been referred to as "the third pole" and within it are found the largest number of glaciers outside the circumpolar portions of the earth.

Hindu Kush

The Hindu Kush is a mountain system situated largely in northeastern Afghanistan and the state of Chitral in Pakistan. The eastern end of this system is bounded by the Karumbar and Ishkoman rivers. The northern boundary, stemming from the base of the Sarykol range of the Pamirs where it joins with the Tagh-dumbush Pamir, curves southwestward along the Pyandzh-Pamir river (sometimes called the Oxus) for about 400 miles and then fans out into several outlier ranges of decreasing elevations. The western extremities of the Hindu Kush cover most of central Afghanistan. The southern boundary fades out in the plains of Pakistan.

The Hindu Kush is not as formidable a barrier as some of the other mountain systems of Central Asia. The Encyclopedia Brittanica (1953) provides a general description of the geography of the range with particular attention to the passes of importance.

"For the first 100 miles, the Hindu Kush is a comparatively wide, flat-backed range with small alkes on the crest, and possessing no considerable peaks. It is crossed by many passes, varying in height from 12,500 ft. to 17,500 ft., the lowest and the easiest being the group about Baroghil. As the Hindu Kush gradually recedes from the Ab-i-Panja and turns southwestwards, it gains in altitude, and prominent peaks rise to more than 24,000 feet above sea-level. The main central water-divide is not the line of its highest peaks, which line is farther south, where Tirich Mir dominates Chitral from a southern spur. For some 40 or 50 miles of this south-westerly bend, the crest is intersected by many passes, of which the most important is the Dorah group which rise to some 15,000 feet and which are practical links between the Oxus and Chitral basins.

"From the Dorah to the Khawak group of passes (11,000 and 12,000 feet in altitude), the water-divide overlooks Kafiristan and Badakshan. Here, its exact position uncertain, it lies amidst a wild inaccessible region of snow-bound crests, and is nowhere less than 15,000 feet above sea-level. The Khawak, at the head of the Panjshir river, leading straight from Badakshan to Charikar and the city of Kabul, is now an excellent route, and is available for traffic throughout the year. From the Khawak to the head of the Ghorband (a river which meets the Panjshir near Charikar), the Hindu Kush is intersected by passes at many intervals, e.g., the Kaoshan (the 'Hindu Kush' pass par excellence), 14,340 feet; the Chahardar (13,900 feet) on the Afghanistan high road to Turkistan; and the Shibar (9,800 feet). Here is the southern extremity of the Hindu Kush, for here commences the Koh-i-Baba system into which the Hindu Kush is merged."

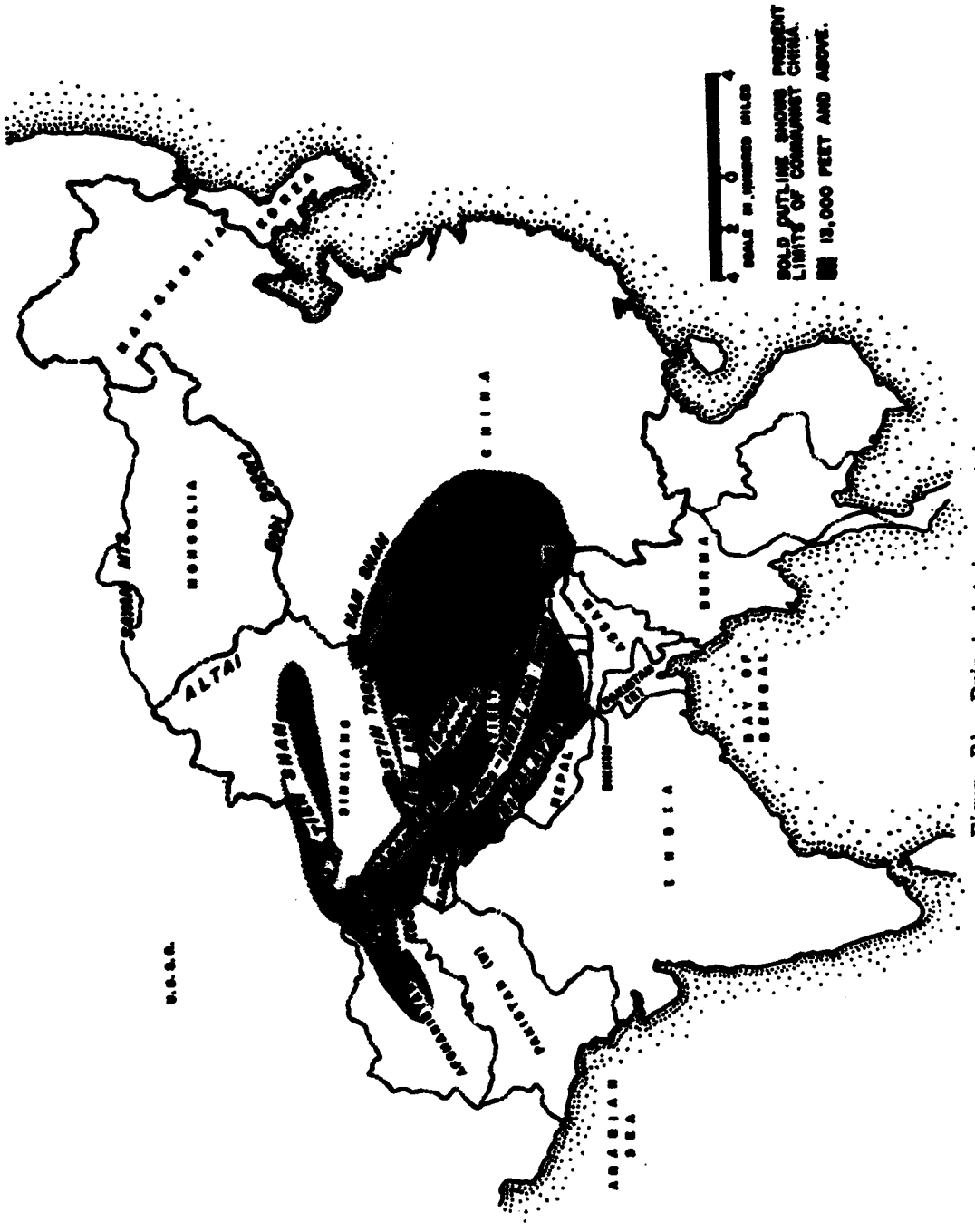

Figure B1. Principal Asian mountain ranges.

The Hindu Kush has a drier climate than the Himalayas. These climatic conditions are reflected in the snow line which C. F. Lewis has estimated as being at about 18,000 ft on the southern slopes, and 15,500 ft on the northern slopes at approximately 36° 30'N, 72° 00'E in both the eastern Hindu Kush and Hindu Raj (Mason, 1929). According to Burrard and Hayden (1933), Lewis has written: "It must be remembered that it is the temperature and the rainfall that govern the height of the snowline,...In the Hindu Kush the average snowline is about 17,000 feet; this is a good deal lower than in the Karakoram. If we omit from consideration the lack of oxygen, a peak of 19,000 feet would correspond to one of 21,000 feet in a range where the snowline is 19,000 feet." Raimund von Klebelsberg (1948) notes that Raymond Furon and Emil Trnkler, in 1927 and 1928, respectively, reported that the snowline in the western Hindu Kush was at 4000 meters on the northern slopes and 4500 meters in the interior.

The Karakoram

The Karakoram is surrounded by the Great Himalaya and the Ladakh ranges on the southeast, the Aghil Range on the northeast, the Pamirs to the northwest and the Hindu Kush to the southwest. The Indus River bounds the southern fringe, the Shyok River flows along the eastern margin, the Shaksgam is on the north in Sinkiang, and the Karumbar and Ishkoman rivers form the western boundary.

The Great Karakoram, a term denoting the main crests of the entire northwest-southeast system, is divided into sections called "mustaghs," meaning "ice-mountains." From northwest to southeast there are the Batura, Hispar, Panmah, Baltoro, Rimo, Siachen, and Saser mustaghs. "North of the Great Karakoram, in Hunza territory, there are two systems of mountains, one on each side of the Hunza river, which may be called the Lupghar group and the Ghujerab mountains respectively. The remaining mountains south of the Great Karakoram had not all been grouped at the time of the Conference, but the main alignments are called the Rakaposhi, Haramosh, Masherbrum, and Saltoro ranges. These are sometimes termed the Lesser Karakoram" (Mason, 1938).

Some of the biggest glaciers outside the polar regions are in the Karakoram. They are much larger than those of the Himalayas, and they rank with the largest glaciers of the Pamirs, the Andes, Alaska and northwestern Canada. Of the 13 separate mountain massifs which are over 8000 meters or 26,000 ft in elevation, three are in the Karakoram; the remainder are in the Himalayas. These three are: K2 (28,250 ft), the second highest known peak in the world; Gasherbrum (26,470 ft); and Broad Peak (26,414 ft). The Karakoram combines extreme ruggedness, great heights, and extensive glacierization to a greater degree than any other mountain system.

"The Karakoram range is on the same latitude as Gibraltar and is, broadly, the section of the Himalayas furthest from the sea. For these reasons, its climate is somewhat different from that of the Himalayan area best known to the public— that of Nepal, where rises Mt. Everest,...The famous monsoon, the humid summer wind, only affects the Karakoram to a small degree, and it arrives with its humidity very much reduced, having to a large extent lost it on the mountain ranges and the plateaus near the sea. The climate is consequently drier, as is seen from the steppe-like and indeed desert landscape prevailing in that area, except in the irrigated districts where the vegetation flourishes and one comes upon oases rich in cereals and fruits" (Desio, 1955).

The Karakoram is an uplifted peneplain, a block-mountain system which has been cut by erosion and scoured by glaciation (Lobeck, 1945). "The southern part is mainly granite and syenite and reaches down to the Indus valley, metamorphic rocks of uncertain age and supposedly Triassic limestones are included. In the region of the high peaks, eruptive, metamorphic and sedimentary rocks are mingled; the last are especially important. On the Karakoram pass (18,290 feet) Liassic

(sic) and Cretaceous rocks have been identified. In the east the Jurassic strata are of continental formation and so is the Tertiary, but there is evidence of a Cretaceous maritime transgression" (Encyclopedia Brittanica, 1953).

Table BI. Snow line elevation in the Karakoram (feet). (Mason, 1929).

	Lat. N	Long. E	North	South
Lesser Karakoram	35°	77°	16,700	16,700
Great Karakoram	35°	78°	18,000	18,500
Aghil	36°	77°	19,000	20,000
Ladakh	34°	78°	18,500	19,000

The Himalayas

The Himalayas are a formidable arc of high mountains which trend northwestward across the northeastern corner of the subcontinent of India. The Hindu Kush and the Karakoram are at their western end, and in the east they grade into the systems of Southeast Asia. (Mason (1955) states that the Ladakh, Aghil, and other ranges at the western end of the Himalayas are properly labeled "trans-Himalayan.") The Himalayan system is north of the Indian plain and is encompassed by the Indus River on the west and by the Tsangpo-Dihang-Brahmaputra River on the east. (The Brahmaputra is known as the Tsangpo in Tibet and as the Dihang in the section where it bends to breach the mountains.) Nanga Parbat, in the northwestern corner of the Himalaya region, has an elevation of 26,620 ft; Mt. Everest in the east-central part dominates all other peaks with an elevation of 29,028 ft; and Namcha Barwa towers in the eastern part at 25,445 ft. Of the 13 mountain massifs known to be over 26,000 ft (8000 m), 10 are in the Himalayas.

All waters derived from Himalayan snows eventually reach either the Arabian Sea or the Bay of Bengal. The western parts are drained by the Indus and its tributaries—the Jhelum, Chenab, Ravi, Sutlej, and Beas rivers. The northern face of the central part drains both to the west and to the east via the Indus, Sutlej, and Tsangpo, whereas the southern slopes are drained eastward by the Ganges system—the Jumna, Bhagarathi, Alaknanda, Kali, Seti, Harnali, Bheri, Gogra, Gandak, and Kosi rivers. The eastern parts of the Himalayas are drained by the Tista, Raidak and Manas tributaries of the Brahmaputra (Burrard and Hayden, 1933).

The Himalayas are comprised of several parallel ranges within three principal parallel divisions. The three divisions are (1) the Siwalik foothills rising from the Indian plain to about 3000 ft and characteristically supporting dense forests, (2) the 15,000-ft Lesser Himalayas, with heavily wooded ridges, and (3) the Great Himalayas with a crest line at 22,000 ft.

"Geologically, the Himalayas may be divided into three zones. The northern (Tibetan zone), in which fossiliferous beds of the Paleozoic and Mesozoic age are largely developed--excepting in the northwest, no such rocks are known on the southern flanks. The second (Himalayan zone) comprises most of the Lesser and Great Himalayas, and is composed chiefly of crystalline and metamorphic rocks, together with unfossiliferous sedimentary beds supposed to be of Paleozoic age. The southern (sub-Himalayan zone) consists entirely of Tertiary beds, and especially of the "Upper Tertiaries." The oldest beds which have yielded fossils occur in the Spiti valley and belong to the Cambrian system... The Himalaya grew southwards in a series of stages. A reversed fault was formed at the foot of the chain and upon this fault the beds were pushed forward over the beds deposited at their base, crumpling and folding them in the process, and forming a sub-

Himalayan ridge in front of the main chain. This process was repeated several times and the earthquakes of today in this region can be traced to the fault lines and show that crustal equilibrium has not yet been reached.

"Independently of the enormous variety of topography the vast altitude of the mountains alone is sufficient to cause very great modifications of climate. One-half of the total mass of the atmosphere and three-fourths of the water suspended in it in the form of vapour lie below the average altitude of the Himalayas; and of the residue, one-half of the air and virtually almost all the vapour come within the influence of the highest peaks... The general relations of temperature to altitude as determined by Himalayan observations are as follows: (1) The decrease of temperature with altitude is most rapid in summer. (2) The annual range diminishes with the elevation. (3) The diurnal range increases with the elevation.

"Rainfall is chiefly related to the monsoonal rainfall of India of which the Himalaya catch a large portion. There is more rain, and rain for a longer season, in the east than in the west. The east may have 50 to 80 inches of rain against the southward hill slopes and in certain spots even higher totals are reached, for example, Darjeeling gets 120 inches. The rainfall diminishes westward to 40 inches near the place where the Ganges leaves the mountains and falls to 30 inches towards the emergence of the Indus from the mountains..." (Encyclopedia Brittanica, 1953).

"In the Kumaun Himalaya of the Great Himalayan range, the snowline lies about 3,000 feet lower on those slopes with a southern aspect than on those facing the north. In the Assam-Himalaya the difference is 2,000 feet, and the snowline is low on both slopes. In the Bhutan Himalaya the difference is also 2,000 feet but the snowline is higher on both slopes as this region lies in the 'rain shadow' of the Khasi and Jaintia hills. In the Punjab Himalaya of the same range, the difference is again about 2,000 feet and the snowline is higher still, thanks to the Pir Panjal" (Mason, 1929).

The snowline of Mount Everest is at approximately 5500 meters (18,000 ft) and that of Nanga Parbat somewhat below 16,500 ft (Roch, 1954; Finsterwalder, 1937).

"In April, May and June, the effect of the strong insolation of the Indian plains extends upward: there is a more or less sudden break in the frequent precipitation over the Himalayas, and the weather becomes much warmer. The advent of the monsoon in the first half of June brings moister and still warmer conditions, but precipitation is still less than in cold weather season. In October there is another interval of fine calm weather between the end of the monsoon and the onset of the winter storms" (Pugh, 1954).

Table BII. Important passes across the Himalayas. (Mason, 1936)

From	To	Pass or route	Elevation (ft)
Srinagar	Gilgit	Kamri Pass	13,368
		Burzil Pass	13,775
Srinagar	Leh	Zoji la	11,578
Simla or Kulu	Leh	Baralacha la	16,200
Simla	Shipki	Sutlej valley	ca. 6,000
Tehri	Totling	Bhagirathi valley	ca. 9,400
Garhwal	Totling	Alaknanda valley	ca. 6,000
Almora	Gyanima	Goriganga valley	ca. 6,500
W. Nepal	Laktsang	Karnali valley	ca. 5,000
Central Nepal	Tradom	Kali Gandaki valley	ca. 9,000
E. Nepal	Lhotse and Lhasa	Sun Kosi valley	ca. 8,000
E. Nepal	Lhotse and Lhasa	Arun valley	ca. 8,000
Sikkim	Shigatse and Lhasa	Tista valley	ca. 7,000

APPENDIX B

The Pamirs

"Pamir, the 'Roof of the World' is a part of the 'world of high mountains and desert, in Middle Asia, a region of the greatest contrasts in which in places, snowfields adjoin almost directly broad burning sandy plains'... The Pamir forms an almost rectangular projection between lat. 36° 42' and 39° 52'N. and long. 70° 06' and 76° 50'E. Its northern boundary is the broad green Alayskaya valley, separated by the Alayskiy Khrebet...from the Fergana valley—the so-called flowering paradise of Middle Asia. The southern boundary is near the Hindu Kush; the western and eastern boundaries are respectively the West Tajik and the Tarim depressions" (Poire, 1953).

Poire (1953) and many other Russian geographers recognize three large divisions within the Pamirs, although Sven Hedin, Colonel R. A. Wauhope and others have used different systems (Burrard and Hayden, 1933). The three regions are (1) the Western Pamirs, west of the Zulumart range, (2) the Central Pamirs, and (3) the Eastern Pamirs, east of the Sarykol range. The Zaalay (meaning trans-Alay) range bisects all three of these regional divisions at their northern ends.

The northwestern Pamirs are the most glaciered and the most rugged parts of the group. Directly south of the western end of the Zaalay range are four latitudinal ranges known as Peter I, Darvaz, Vanch and Yazgulem; they are united at their eastern end by the longitudinal Akademiya Nauk range. South of this group, the principal ranges of the western Pamirs are the Rushan, Shugnan, Shakhdara, and Vakhan. Stalin Peak* (24,590 ft) at the junction of the Peter I and Akademiya Nauk ranges is the highest peak in the Soviet Union. Deep gorges, sharp peaks, large glaciers, and great heights are characteristic of the western Pamirs as a whole (Poire, 1953).

The intermediate region of the Central Pamirs is "a high and arid country with wide, gently sloping valleys and rounded or flat fractured mountains whose altitudes are not great for the Pamir, i.e., 5,000 to 5,600 meters (16,000 to 18,000 feet). Their height above the valleys is about 4,000 meters (13,000 feet)" (Poire, 1953).

The Eastern Pamirs are again a region of high, sharp peaks; Kungur I (25,200 ft), Kungur II (25,145 ft), and Muztagh Ata (24,387 ft) are among the highest recorded peaks in the area (Poire, 1953).

Geologically, the Pamirs are comprised of four arcs. The southwest consist of metamorphic and igneous rocks of unknown age. Tue second arc in the central Pamirs is a zone of Upper Paleozoic and Lower Mesozoic sedimentary rocks. The third strip, just south of the Zaalay range, is composed of Lower and Middle Paleozoic sedimentary formations. The fourth arc includes the eastern part of the Zaalay range, the Peter I range and parts of several ranges in Kashgaria; this contains Cretaceous and Tertiary sediments. Folding is still going on in these regions (Poire, 1953).

The months of maximum precipitation vary greatly between the northwest and southeast Pamirs. The west and northwest regions receive most of their precipitation during winter and spring, whereas the east and southeast regions receive theirs during spring and summer. For example, at Khorog, Kalai-Khumba and the Fedchenko glacier two-thirds of the precipitation falls between November and May, while at Murgab, Ishkashim, Sary-Tashe, and Kara-kul (lake), two-thirds falls between May and November.

In the northwest Pamirs, at high altitudes (4200 m) on the Fedchenko glacier, there is an annual precipitation of 820 mm, but in the valleys below (1800-2000 m)

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*Now called "Peak of Communism"

precipitation is four or five times less. The lowest temperatures recorded for the Fedchenko region are near -31.4C, but insolation there is 25-30% higher than at Tashkent; direct and diffused radiation amounts to about 1,507,000 cal cm^{-2} yr^{-1}. Average July and August temperatures at the Fedchenko are about 3.9C with a 15.5C maximum. Eastern Pamirs temperatures sometimes drop to -40C, with extremes of -50C; average July and August temperatures are about 8C with a 20.6C maximum (Finsterwalder, 1932).

Alay Mountains

The Alay Mountains are usually considered to be a geologic extension of the central arc of the Tien Shan. N. T. Mirov (1950), in a modification of L. S. Berg's physiographic classification of the U. S. S. R., also includes the more westerly Zeravshan and Turkestan ranges, along with the main Alay range, within this central arc. The fourth principal range of the Alay system, the Ghissar, is to the south of and parallel to the Zeravshan and Turkestan ranges, but Mirov groups this with the southern arc of the Tien Shan system. The southern arc is primarily a Tertiary phenomenon, whereas the central arc is Upper Paleozoic. The Turkestan, Zeravshan and Alay ranges interlock at a mountain knot called Matcha Junction (39° 35'N, 70° 45'E). Most of the glacierization of these ranges centers around this junction, where the elevations (approximately 6000 m) are the highest in the entire system. However, there are glaciers between approximately 68° and 73° E all along these ranges. The average snowline rises from 3900 m in the west at about 68° 20' E to over 4500 m in the east around 73° 30'E (Klebelsberg, 1948).

Tien Shan

"As a whole, the Tien Shan represents a mountain system composed of ranges and chains of different ages and located north of the Trans-Alay range and east of the Amu Darya river. However, there is no clear-cut boundary line between the Tien Shan and the Pamir-Alay. The eastern part of the Tien Shan extends beyond the Soviet border where the range separates Sinkiang from Dsungaria" (Mirov, 1951). In its widest acceptance, the Tien Shan system extends from 67° E in the Aral-Caspian depression to 103° E at the great bend of Hwang-ho river (Encyclopedia Britannica, 1953). The principal physical confines of the Tien Shan are the Takla Makan basin on the south, the Lake Balkash basin on the north, the Syr Dar'ya basin in the west, and the Gobi Desert on the east.

The most intensely glacierized region of the Tien Shan centers around Khan Tengri (6989 m, 22,949 ft) at 42° 08'N, 80° 15' E on the U. S. S. R.-Chinese border. This peak was formerly thought to be the highest in the Tien Shan, but in 1943 the Soviets discovered that Pobeda Peak, 10 miles farther south, is 24,406 ft (7444 m) high (Klebelsberg, 1948).

Altay-Sayan Mountains

The Altay and Sayan mountain systems are two very closely related continuations of the upland which begins in the Caucasus, continues through the Pamirs and the Tien Shan and extends to the Arctic. "The Altay region, in west Siberia and Mongolia, is similar in character to the Alps, but covers a much greater area. It extends from the river Irtysh and the Dsungarian depression (46-47 N. lat.) northward to the Siberian railway and to the Sayan mountains. The backbone of the region is the Sailughem mountains... which stretch north-eastward from 49 N. and 86 E. toward the west end of the Sayan mountains (51 60' N. and 89 E.)... The Altai proper (the Ek-tagh, Mongolian Altai, Great Altai or Southern Altai) likewise extend in two twin parallel chains eastward as far as 99 if not farther" (Encyclopedia Britannica, 1954). The Sayan ranges from both the eastern continuation of the Sailughem Range and the border between the plateau of northwestern Mongolia and Siberia (Encyclopedia Britannica, 1954).

The Following environmental notes were extracted from Cressey (1951).

"Both the Altai and the Sayan were folded in the middle and late Paleozoic, then after being worn down to essential peneplains, were again uplifted during the late Tertiary. The central portions of the mountains remain rolling upland above 10,000 feet, comparable to the Pamir and the Tien Shan, with active dissection on the margins.

"The Altai system has a general northwest-southeast trend, which continues far into Mongolia. Several divisions may be distinguished within the Soviet Union. The Tarbagatai Range lies between the Dzungarian Gate and Lake Zaisan on the Irtysh. Between the Irtysh and Ob are the Altai Mountains proper, culminating in Mt. Belukha... East of the Ob lie the eastern Altai, reaching almost to the Yenisei and formed of two north-south ranges, the Salair and the Kuznets-Alatau respectively, west and east of the Kuznets basin.

"Around the Minusinsk basin are the two ranges of the Sayan system. The Eastern Sayan, with elevations up to 11,447 feet, is the main range, extending from Lake Baikal to the Yenisei, with a southern branch known as the Western Sayan.

"The Tanna Tuva occupies the headwaters of the Yenisei, encircled by the Western Sayan and the Tannu Ola. This area was formerly a part of China, but has long been claimed by the U. S. S. R. since it lies within the Yenisei basin. It was unilaterally annexed in 1946.

"Steppe vegetation covers the lower slopes of the Altai-Sayan mountains up to some 3,000 feet, above which there is a splendid forest of Siberian larch, cedar, fir, pine and birch to 6,000 feet or more, followed by alpine meadows to the snow-line around 9,000 feet.

"Winter temperature inversions, combined with the thinness of the Siberian cold air masses, make the highlands a relatively warm island between the cold plains of Siberia and Middle Asia. The Minusinsk basin, which receives cold air drainage from the surrounding mountains, has a January average of -5F., and an extreme low of -65.7F. July temperatures at Minusinsk average 69F. These temperatures are lower than anywhere farther north along the Yenisei river."

Kun Lun Mountains

The Kun Lun mountains are a narrow system of steep ranges, physiographically similar to the Tien Shan, that form the northern border of the Tibetan Plateau. They originate at approximately 76° E and continue eastward to 113° E at their farthest extension. Thus, extending eastward from the base of the Pamirs, they rise from the Takla Makan Desert and skirt the southern edge of the Tsaidam depression until, after 2500 miles, they grade out into the hills of China.

The Astin Tagh, a northeastern offshoot of the Kun Lun, continues eastward as the Nan Shan range, forming the northern wall of the Tsaidam depression.

"Broadly defined, the range of the Kun Lun mountains,... extend for nearly 2500 miles from east to west..., in the west their constituent ranges are folded and squeezed, to some 150-200 miles broad, their summit being correspondingly high (21,500 to 22,000 feet), in the east they spread out to some 600 miles, the ranges being here... flatter and lower.

"Generally speaking, the Nan Shan highlands (12,000 to 14,000 feet) are intersected by wild, stony and partly snow-clad mountains, towering another 4,000 to 7,000 feet above its surface, and arranged in narrow parallel chains. The chains of mountains are from 8 to 17 miles wide, seldom as much as 35, while broad, flat valleys between them attain widths of 20 to 27 miles. The passes are at 12,000 to 14,000 feet, and the peaks reach 18,000 to 20,000 feet in the west, while in the east they are 2,000 feet lower" (Encyclopedia Britannica, 1953).

The Tibetan Plateau

The Tibetan Plateau is bordered on the west by the Pamir-Karakoram system, on the north by the Kun Lun-Nan Shan mountains, on the south by the Great Himalayas and on the east by the many ranges and hills tapering off into China and Southeast Asia.

Cressey (1951) divides the region into seven sub-regions, the two most important of which are (1) the Chang Tang Plateau and (2) "The Land of the Great Canyons" in eastern Tibet, often known as Kam. The following descriptions are taken from Cressey's book:

"The largest part of Tibet lies in the region of Chang Tang, extending from 80 to 92 E., and from 31 to 36 N. This part of the plateau is a series of desert playa basins and massive, but low mountains, all at elevations over 16,000 feet. Scoured by the wind, baked by the sun, and cracked by frost, these desolate uplands have a grandeur of their own but are not a feasible home for man...

"Scores of partly explored mountains trend roughly east and west. The southernmost range is a massive chain, variously known as the Kailas or Nyenchen Tang La, and described by Sven Hedin as the Trans-Himalaya. The average elevation is greater than the Himalaya, as are also the passes, but the peaks are lower. Other important ranges farther north are the Tang La, the Dungbura, and Kokoshili.

"Kam...in Eastern Tibet is a land of great valleys and intervening high ranges, with a general northwest to southeast orientation. It is known to the Tibetans as the Land Of Great Canyons. Here are the Hwang, Yantse, Mekong, Salween, Irrawaddy, and their tributaries. Although the rivers flow at elevations of slightly over a mile, there is so little level land in the valleys that most people live at altitudes between 9,000 and 13,000 feet. Because of the more abundant rainfall, extensive forests cover the lower slopes.

"In southeastern Tibet these rivers plus the Brahmaputra approach within 400 miles of each other, but on leaving the plateau they diverge so that their mouths are 2,000 miles apart. Since each river is in a deep gorge and intervening ridges are sharp crested, travel between India and China is very difficult.

"The easternmost mountains, bordering Szechwan and Yunnan, are known to the Chinese as the Tahsueh Shan, or Great Snowy Mountains. Numerous peaks exceed 20,000 feet and are glacier clad. As an expression of decreasing moisture northward toward the heart of Asia, the snowline rises from 13,500 feet in Yunnan to 18,000 feet in Kansu. The highest peak is Minya Gongkar, southwest of Tatsienlu..."

With regard to the climate that prevails on the Tibetan Plateau, Cressey (1951) states:

"The climate of Tibet is conditioned by its great elevation and by the encircling mountains. High altitudes and thin air join with intense insolation and strong radiation to produce sharp temperature contrasts between day and night as well as from dry winter to the somewhat moist summer. Conditions differ widely, for whereas the vicinity of Lhasa has a mild Cwb climate (Koeppen symbols), the northern plains are a cold desert, EBw, and the windward slopes of the Himalaya have subtropical conditions.

"The difference between temperatures during the day and at night may exceed 80F. In the short summer the thermometer may reach 90F. while in winter, travelers have recorded -40F. The winter cold is intensified by strong winds.

"Most of Tibet is cut off from the summer Indian monsoon by the Himalayan barrier, especially in the west where pressure gradients and winds parallel the mountain front. In the southeast, moisture-bearing winds blow up the valleys of the Brahmaputra, Salween, Mekong, and Yangtse, and bring summer rain to the Tsangpo lowland. Almost none of this moisture crosses the Nyenchen Tang La range".

APPENDIX B

Flint (1957), in a table titled, "World Distribution of Existing Glaciers," states that there are, according to planimetric measurements of the best available maps, approximately 125,083 square kilometers of glaciers in Asia. All but about 683 square kilometers of this ice is in what may be termed Central Asia. Of this, roughly 23,000 square kilometers are found on the Tibetan Plateau.