*TB MED 288

DEPARTMENT OF THE ARMY TECHNICAL BULLETIN

MEDICAL PROBLEMS OF MAN AT HIGH TERRESTRIAL ELEVATIONS

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SECTION I
INTRODUCTION AND DEFINITIONS

1. Purpose. This bulletin is designed to provide information to Medical Department personnel regarding the incidence, pathogenesis, clinical description, treatment, and prevention of the adverse effects of short-term exposure to high terrestrial elevations.

2. General. Many problems related to a soldier's health and performance increase with elevations over 2400 meters. The factor of prime medical importance distinguishing these areas of high terrestial *elevation* from lower lands is reduced *partial pressure of oxygen.* In addition, other circumstances associated with high terrestrial elevation may present hazards by themselves or in conjunction with reduced partial pressure of oxygen, and in a manner sometimes not evident to the uninitiated. Therefore, exposure of unacclimatized troops to high terrestrial elevations should be preceded by a thorough orientation of the commander, his staff, and all personnel. Some people experience great apprehension when moved to new and strange environments. High mountains are particularly forbidding. The barrenness, harshness, and climatic violence may all contribute to a generalized anxiety. This can add to the severity of acute mountain sickness. In a sense the symptoms of acute mountain sickness may be regarded as contagious, since the apprehensive individual, observing illness in others, may himself suffer an intensification of his own symptoms. A well-planned pre-exposure briefing for both officers and men will markedly reduce the fear of the unfamiliar by stressing the individuality of response to high elevations and the self-limiting nature of acute mountain sickness. Sketched in brief, here are the factors which make for a forbidding environment. These are to some extent amplified in appendix A.

3. Factors Other Than Hypoxia. *a.* At high elevations the average temperatures are lower, diurnal variations are greater, and severe *cold* is not unusual (conditions conducive to cold injury). The decrease in temperature with altitude approximates 2 degrees Celsius (°C) for every thousand feet.

b. Solar radiation increases considerably. In addition, the reflected radiation, or albedo, is greatly increased by snow cover, creating a very real problem of sunburn and snow blindness (para 31 through 35).

c. Winds may be strong and increase the danger of cold injury; weather changes abruptly, and is frequently unfavorable; storms can be very intense, with significant added hazard from lightning.

d. Terrain is often rugged, decreasing the efficiency of movement, communication, and transportation, and increasing the hazards of injury.

e. A frequent scarcity of natural resources of *food, fuel, shelter,* and *water* impose added difficulties, and personal hygiene is more difficult to maintain. Of these the most critical may be that of water (para 36 and 37).

f. Where personnel are separated or few in number, *solitude* is an adverse factor.

g. Sterilization and food preparation are made more difficult because of the reduced boiling point of water.

h. Combustion engines operate at reduced efficiencies unless they are especially designed or adjusted for the specific altitude. The production of *carbon monoxide* by motors and stoves compounds the adverse effects of the low oxygen pressure. Dichlormethane commonly used in pressurized spray cans is metabolized in the body to carbon monoxide. This too can add to the hazard.

i. The use of any drug which reduces ventilation is dangerous. Barbiturate, opiates or any hypnotic drug can have its LD 50 markedly changed. Drugs which can cause methhemoglobin formation also must be considered with caution.

j. There are few medically redeeming features of high terrestrial elevations. Among these is the fact that insect vectors of disease are lessened, fewer bacteria are present due to the low humidity and food preservation may be facilitated if freezing temperatures prevail.

4. The Atmosphere. *a. Pressure Equivalents.* In terms of pressure one standard atmosphere is equal to 1013.2 millibars, 29.92 inches or 760 millimeters of mercury (mm Hg). Atmospheric pressure at sea level approximates one standard atmosphere, i.e., 760 mm Hg. Except for vapor content the composition of the atmosphere is constant throughout the range of terrestrial elevations. Its pressure, however, decreases with altitude such that at 5500 meters it is approximately one-half atmosphere (380 mm Hg) and at 10,700 meters it is about one-fourth atmosphere (190 mm Hg). For a specific altitude the barometric pressure varies somewhat with the seasons and also with latitude, being highest at the equator and lowest at the poles.

b. Partial Pressures.

(1) *Definition and computations.* The pressure exerted by each component of a gas mixture is termed the *gas tension* or *partial pressure* (P). This is simply a way of stating that the total pressure of a gas mixture is the sum of the partial pressures of the

*For conversion of feet into meters, or meters into feet, see appendix B.

components. The partial pressure of each component is given by the basic formula—

$$P = \frac{\text{gas } \%}{100} \text{ X Total Pressure}$$

(For present purposes "Total Pressure" = Barometric Pressure.) The atmosphere is a mixture of gases which, when absolutely dry (zero humidity), is comprised of 20.94 percent oxygen, 79.02 precent nitrogen and inert gases, and 0.04 percent carbon dioxide. This composition (dry) is constant over the earth's surface and to all elevations with which this bulletin is concerned. Only the moisture content is variable and dependent upon a number of factors. However, at very low temperatures the moisture content becomes negligible, and even at 20-25° C will amount at most to 2 to 2.5 percent by volume. If the gas analysis yields the composition of "dry" air and a correction for moisture content is imperative (as in alveolar air analyses), the above equation becomes—

$$P = \frac{\text{Dry gas } \%}{100} \text{ X (Barom. Press. — Vapor Press.)}$$

At body temperature (37° C) the vapor pressure is 47 mm Hg regardless of barometric pressure. Being solely a function of temperature, it will be higher in fever. Thus at 39° C the alveolar vapor tension will be 50 mm Hg.

(2) *Applications.* Since barometric pressure decreases as a function of altitude the partial pressures of its constituents will also decrease proportionately. Thus, the oxygen partial pressure at sea level (neglecting moisture content) will range from 155 to 161 mm Hg, depending upon the fluctuations of the barometer. At an elevation of 5500 meters the barometric pressure is approximately one half that at sea level. The oxygen partial pressure will therefore also be one-half (.2094 X 380 = 80 mm Hg). Of necessity the alveolar oxygen partial pressure will also be reduced, but because the increase in ventilation rate induced by the hypoxic environment varies from subject to subject the extent of the reduction cannot be accurately predicted and must be measured.

(3) *Gas exchange.* The partial pressure of a gas, rather than amount, governs its entrance into liquids. The exchange of gases between living organisms and the environment is thus dependent upon environmental partial pressures. For mammals this would be the gradients between alveolar air and blood, and between blood and tissues.

5. High Terrestrial Elevations. *a. Hypoxia.* In simplest terms hypoxia refers to a subnormal availability of oxygen to the tissues. Atmospheric or environmental hypoxia occurs when the partial pressure of oxygen is inspired air is less than that which obtains at or near sea level. Ultimately, environmental hypoxia evokes a physiologically subnormal oxygenation of tissues (tissue hypoxia). Although tissue hypoxia may result from any of several causes (anemia, carboxy hemoglobin, tissue poisoning circulatory stagnation, or low oxygen partial pressure in the inspired air) present concern is with the latter, sometimes referred to as hypoxic hypoxia. No defining limits have been set for this term. Practically, however, hypoxia is inconsequential for physiologically fit males below an effective altitude of 2000 meters, but increases at a progressively greater rate from minimal to severe as elevation increases. In the lungs the inspired air (and its oxygen content) is diluted with water vapor and carbon dioxide. At body temperature of 37° C the vapor pressure is 47 mm Hg. The necessary saturation of tracheal and alveolar gases with water vapor increasingly displaces other gases as elevation rises and barometric pressure falls. At 4300 meters, for example, barometric pressure approximates 447 mm Hg, dry air oxygen is 94 mm Hg (447 X 0.21) and inspired tracheal gas oxygen is 84 mm Hg (400 X 0.21). Alveolar gases are: water vapor is 47 mm Hg; nitrogen is 316 mm Hg (400 X 0.79); carbon dioxide is 32 mm Hg (reduced from sea level value of 40 mm Hg) by hyperventilation); and oxygen is 52 mm Hg (447-47-316-32).

b. Symptoms. In general, shortness of breath on mild exertion occurs above 3000 meters; night vision is markedly reduced at 3700 meters; visual perception and fine coordinated movements (such as handwriting) and judgment become impaired at 4900 meters, and unconsciousness will be likely in new arrivals above 7000 meters, but partially acclimatized individuals can tolerate an additional several thousand feet before becoming incapacitated.

6. Pathophysiology of Hypoxia. *a.* The primary consequence of breathing air with a reduced oxygen partial pressure is hypoxemia, by which is meant a reduction in the quantity of oxygen in arterial blood. The degree of tissue hypoxia is determined in part by feedback mechanisms which regulate respiratory and cardiovascular compensatory responses, and in part by oxyhemoglobin dissociation characteristics, which are dependent upon pH, temperature, and the nonlinear relationship between pressure and saturation (quantity).

b. Respiratory regulation is both reflexly and chemically mediated in the presence of a decrease in inspired oxygen (0_2). Reflexly augmented drive to the respiratory center originates in specialized oxygen-sensitive receptors—the carotid and aortic bodies or glomi. The increased tidal volume and respiratory rate produce an increased alveolar ventilation and thus maintain a higher alveolar O_2 tension that would otherwise be obtained. However, the increased ventilation by itself will concurrently decrease the alveolar carbon dioxide tension (hypocapnia) and hence arterial carbon dioxide tension with a resultant respiratory alkalosis. Respiratory alkalosis reduces the sensitivity of the medullary respiratory centers to the excitatory drive from the chemoreceptors, so that (as a first approximation) the resultant augmentation of ventilation may be looked upon as the algebraic sum of chemoreceptor reflex stimulation and hypocapnic (alkalotic) depression. If the alveolar CO_2 tension could be maintained during hypoxic exposure, the chemoreceptor drive would be even more effective in countering the prevailing hypoxia. Thus, the interplay between chemoreceptor sensitivity to oxygen on the one hand, and respiratory center sensitivity to hydrogen ion concentration on the other, appears to be the major determinant of the resultant ventilation rate in the presence of any given degree of hypoxia.

c. Corresponding adjustments occur in the cardiovascular system. With moderate hypoxia, systemic organs may remain adequately functional due to temporary increases in cardiac output or redistribution of blood flow. Within the lung, an increase in pulmonary artery pressure improves apical perfusion and ventilation/perfusion relationships. With severe hypoxia, metabolically active tissues or key organ functions may be dangerously impaired.

d. Second order adjustments (metabolic, spinal fluid, and renal) tend to reduce the respiratory alkalosis via compensatory excretion of bicarbonate ions. Ventilation is observed to increase progressively over a period of days, and the arterial CO_2 tension to fall further during the same interval. The respiratory center adjusts to the reduced hydrogen ion concentration and the chemoreceptor drive gradually becomes more effective. After an initial period of adjustment, termed acclimatization, many individuals are able to reside satisfactorily at substantially high altitudes, and there is evidence that in some respects functional capabilities (especially that of striated muscle) may be improved. Certain medical or surgical conditions may develop at high terrestrial elevations that will require appropriate treatment if the individual is to continue to perform successfully at altitude (e.g., asthma, small pneumothorax, minor atelectasis, blood loss, excessive polycythemia). If these conditions become chronic or cannot be controlled, removal of the patient to a lower elevation may be required. Likewise, the presence of certain medical conditions, especially cardiac and pulmonary insufficiency from any cause, even when they are under control at the lower elevation, will preclude moving the patient to a higher elevation.

e. Interaction of altitude and sickling type hemoglobinopathies. Of the several types of hemoglobin which cause erythrocytic sickling hemoglobin S is by far the most common and serves as a paradigm case. The gene for hemoglobin S is carried by 8 to 11 percent of Americans of Negroid descent and by a lesser percentage of Caucasians of Mediterranean descent. The numbers of sickling hemoglobin S containing erythrocytes increase as they are exposed to decreasing partial pressures of oxygen. Individuals who are homozygous for hemoglobin S (sickle cell disease) show the devastating effects of the continuous, aggressive illness under normal circumstances at sea level and under no circumstances should these individuals be brought to altitude without continuous supplemental oxygen. Individuals who are heterozygous for hemoglobin S (sickle cell trait) are asymptomatic and lead a normal life without increased morbidity of increased mortality under usual circumstances. There are several reports of individuals with sickle cell trait who have had vascular occlusive phenomena or hemolytic phenomena at altitudes ranging from 1500 to 4500 meters. Conditions which would tend to lower blood oxygen tensions or encourage intravascular pooling at altitude would tend to encourage *in vivo* sickling even in individuals with trait. Bringing individuals with trait to altitudes of 2000 or 2500 meters and above carries a small but definite risk. Other conditions, such as extreme exercise, might serve to aggravate the risk. Current statistics do not allow for quantitation of this risk. *In vitro* studies of erythrocytes from individuals with sickle cell trait have shown sickling only under extreme hypoxic conditions.

SECTION II
ACCLIMATIZATION

7. General. Acclimatization has been the subject of much study in recent years, despite which many aspects continue to be poorly understood. It consists of an intricate complex of physiological compensatory adjustments which progress with duration of exposure. These involve essentially all organs and systems, among which the most conspicuous are respiratory, cardiovascular, and renal systems. Less obvious are those of the central nervious and endocrine systems. Transient body fluid shifts, hematopoiesis and erythrocythemia, increased tissue vascularization are observed. There are probably cellular adjustments involved in the storage and release of energy, about which little is presently known. Further intimate discussion of the physiology of acclimatization is beyond the scope and purpose of this bulletin. Of more immediate importance is recognition of the consequences of absence of acclimatization, specifically the deficits in physical, mental and behavioral performance which may ensue to endanger life and mission.

8. Description. A person is said to be acclimatized to high elevations when he can live and perform physically and psychologically at the elevation in reasonable comfort and with reasonable effectiveness. The acclimatization process begins upon arrival at the higher elevation. If the change in elevation is large and abrupt, a proportion of the exposed population will suffer the symptoms of acute mountain sickness (para 13 through 21). The greater the change in elevation, the greater will be the proportion of the group succumbing thereto, and the intensity of the symptoms. Disappearance of symptoms, which occurs in 4 to 7 days, does not indicate complete acclimatization. The processes of adjustment continue for months or years, as evidenced particularly by the progressive improvement in physical and mental performance and emotional stability.

9. Altitude Limitations. The limiting altitude to which complete human acclimatization is possible appears to be approximately 5500 meters, i.e., where the ambient barometric pressure is about 1/2 of a standard atmosphere. The members of one Himalayan expedition spent five months at 5700 meters, at the end of which time they found themselves in considerably worse condition than their newly arrived cohorts. The extent to which dietary and nutritional factors may have contributed is unknown. More telling, perhaps, is the fact that no mining camps have been established above 5300 meters in South America or elsewhere. Native miners find it necessary to retreat from the higher mining sites to a lower elevation for rest and sleep at the end of each work day.

10. Work Capacity. Immediately upon arrival at high terrestrial elevations only moderate physical work can be performed because of extreme breathlessness and (within a few hours) headache, nausea, weakness, and dizziness. Thus, the expectation that freshly deployed, unacclimatized troops can go immediately into action (combat or other) is at best likely to be frustrated, and at worst could end in disaster if such a unit were confronted by an acclimatized enemy (as did happen to Indian forces in the early phases of the China-India border dispute of 1962). Even after several months of residence at 4000—4300 meters, the maximum *rate* of work, or energy expenditure (measured ergometrically) remains at 70 percent to 80 percent of the sea level maximum, and may never reach sea level values even after years of continuous stay. The deficit is, of course, greater at higher elevations, as is the time to equivalent acclimatization.

11. Behavioral Deficits. More difficult to quantify are the behavioral deficits encountered in unacclimatized personnel.

a. On the basis of field operations and some controlled laboratory studies, one may find the following:

(1) Increased errors in performing simple mental arithmetic.

(2) Psychomotor retardation.

(3) Decreased ability for sustained concentration.

(4) Deterioration in immediate recall and difficulty with simple coding tasks.

(5) Decreased vigilance, increased irritability in some individuals.

(6) Impairment of night vision and some constriction in peripheral vision.

b. Self-evaluation is impaired (in the same manner as that observed in the inebriated subject), a condition which is without respect for rank. During the first few days at altitude, the leadership will be hard pressed to maintain a coordinated, operational unit. The variability among the group in degree of breathlessness and heart pounding will disrupt the unity of a column of men, and a leader may be sorely taxed to keep the unit moving up a slope. The roughness of the terrain and the harshness and variability of the weather add greatly to the difficulties of unacclimatized personnel performing at high elevations. Although strong motivation may succeed in overcoming some of the physical handicaps imposed by the environment, the total impact may still result in errors of judgment by individual soldiers and officers alike.

12. Deployment. Since there exists no means of temporally telescoping the processes of acclimatization, and since the absence of acclimatization in new arrivals at high elevations essentially precludes the successful execution of a complicated mission, the optimum means for troop deployment poses a serious problem. Troops rapidly transported to high terrestrial elevations from much lower ones cannot be committed immediately to patrolling operations, entrenchment, combat or other physically taxing duty without predictable casualties. Present state of knowledge therefore dictates a deployment which makes for some degree of acclimatization prior to mission committment. Three possibilities appear practical:

a. Stationing troops for four or more days at high elevation sites (2000 meters or higher) prior to rapid, direct movement to combat areas.

b. Staged movement of sea level troops, with 2 days acclimatizing stops at a series of intermediate altitudes, such as 2000 meters, 3000 meters and then 4300 meters.

c. Alternately, (if logistically feasible) troops might be moved directly to the higher elevation with allowance made for their illness and relative inactivity for the first week of residence.

d. A combination of staging plus the administration of acetazolamide can be used (para 21).

e. Finally, acetazolamide alone can be used prophylactically without staging.

SECTION III
ACUTE MOUNTAIN SICKNESS

13. Definition. Acute mountain sickness is a usually self-limited syndrome of unacclimatized persons typically manifest several hours after arrival at high terrestrial elevations, and characterized by lassitude, headache, insomnia, gastro-intestinal symptoms, and depression.

14. Occurrence. The condition has been known almost from antiquity and from the earliest reports of mountain travel in all locations. It occurs whenever man ascends to altitudes of over approximately 2400 meters. Incidence and severity increase with altitude and when transport to high terrestrial elevation is rapid. There are few accurate figures as to the expected incidence at different altitudes and the extent of the disability to be expected in a disciplined group. Travelers and explorers have been incapacitated and their activities delayed. Unofficial reports of the Indian experience in the Himalayas, and modest US experience, indicate that substantial disability and ineffectiveness can occur in from 50 to 80 percent of troops rapidly brought to altitudes in excess of 4000 meters. At lower altitudes (e.g. 3000 meters), or where ascent to altitude is gradual, the lessened severity of the disorder will permit a majority of troops to carry out assignments with moderate effectiveness, although with some discomfort. The syndrome may be confused with voluntary hyperventilation. Infrequently coma or acute pulmonary edema occur. For emphasis and clarity in presentation, the occurrence of high altitude pulmonary edema will be considered as a separate disorder although this separation may be regarded as entirely an arbitrary one.

15. Etiology. Although acute mountain sickness is caused by abrupt transition of an unacclimatized individual to high elevations, the immediate cause is unknown. It is theorized that the hypoxia induces disturbances in water balance, either directly or by the mechamism of the respiratory alkalosis which is produced. Compression of the brain due to fluid and electrolyte shifts from extracellular to intracellular compartments (which has been reported to occur) may explain much of the syndrome. Resistance to the disorder may be increased by staging of ascent in a gradual fashion. Individual predispositions may exist and severity may vary greatly from one experience to another. Susceptibility may return after only a week at lower levels.

16. Morbid Anatomy. The condition is rarely fatal and few fatal cases have been examined. Apart from the presence of pulmonary edema, edema and hyaline thrombi have been described in the brain and kidney.

17. Clinical Description. The new arrival at moderately high terrestrial elevations (3000 — 4600 meters) commonly feels well for the first few hours; a feeling of exhilaration or well-being is not unusual. There may be an initial awareness of breathlessness upon exertion and a need for frequent pauses to rest. Respiratory irregularities can occur, particularly during sleep; and individuals who become aware of these changes may exhibit some apprehension.

a. The true onset of clinical symptoms begins about 4 to 12 hours after arrival at the higher altitude, with feelings of malaise, lethargy, nausea, and headache. Headache is the most distressing symptom and may be quite severe. It may be steady, "pressing," or pulsating. A variety of associated central nervous system symptoms may occur, including lassitude, lightheadedness, dizziness, and an apparent lack of concentration. Even when headache is not present there is almost always some loss of appetite and decrease in tolerance for food. Fatty foods are particularly unappetizing. At these and higher elevations, nausea, even without food ingestion, occurs and leads to diminution in food intake. Vomiting may occur and contribute further to a tendency to dehydration. Despite fatigue, there is insomnia. If the individual becomes aware of his respiratory irregularity, fear and even panic may supervene on awakening from periods of sleep. Mucous membrane congestion and bleeding may occur but are not commonly encountered. Twilight vision impairment is generally attributed to the effect of hypoxia at high elevation. Chest pain and muscle cramps may be noted, increasing breathlessness and fatigue of respiratory muscles can occur. Although resting pulse rate is ordinarily higher than sea level values, it may decline in those more seriously ill.

b. Retinal and vitreous hemorrhages have been reported as occuring. These effects, which have only recently been recognized, may be frequent in individuals who are transported directly to very high elevations. Most are small, asymtomatic, and without prognostic significance. Scotomata may occur. The cause of these hemorrhages is not known, but is considered to be related to cerebral and retinal vasodilatation.

c. In the few instances in which papilledema has been observed there were also other signs of increased intracranial pressure, due presumably to edema rather than other cause. Although severe forms of cerebral edema are rarely encountered, they are associated with aggravated central nervous system manifestations, stupor, coma and convulsive seizures, and demand immediate attention and removal to a lower altitude.

d. If cough occurs, it should be interpreted as a possible sign of high altitude pulmonary edema, even though it is a dry, mild cough and even if evidence of respiratory infection is also present. Because of the comparative seriousness of high altitude pulmonary edema, it is preferable not to classify cough as a symptom of uncomplicated acute mountain sickness.

e. The symptoms usually develop and increase to a peak intensity by the second day and then gradually subside over the next several days so that the total course may extend to five or seven days. In some instances headache persists until the patient is returned to a lower elevation. With the subsidence of symptoms there is a return of appetite and an augmentation of food intake; however, it is customary for a weight loss to have occurred during the first week and to persist or even increase in amount.

18. Treatment. The treatment of the manifestations in the acute phase is symptomatic and is not very satisfactory. Headache may be resistant or recurrent, and may be somewhat relieved by common analgesics (aspirin, codeine). Fluids and light foods are to be encouraged in small frequent amounts. Antiemetics are rarely required. Phenothiazine tranquilizers, e.g., prochlorperazine, in small dosage (5-10 mg by mouth, 25 mg in a suppository) may be of benefit, especially in the anxious patient. The patient who is distressed by respiratory irregularities (Cheyne-Stokes) is to be reassured. The physician should remind himself that this is an exaggerated physiological response, brought out by the diminished sensitivity of the respiratory center to CO_2, which normally occurs during sleep, and has in itself no adverse prognostic implications. The value of short periods of administration of oxygen is dubious. Longer periods of 30 to 50 percent oxygen (4-12 hours, or during sleep periods) or return to elevations 6100 to 9100 meters lower will alleviate symptoms and provide for more gradual acclimatization. Long periods of oxygen administration in high concentration or return to sea level will delay acclimatization and not protect against the return of symptoms on reascent. For this reason oxygen supplementation or evacuation, if necessary, should be to an intermediate level if return to high altitude duty is considered desirable. With the advent of agents for the prevention or amelioration of acute mountain sickness a more effective therapeutic regimen may be outlined. For problems associated with evacuation of casualties from high elevations, consult FM 31-72.

19. Prognosis. Except in very rare instances, the prognosis is uniformly good, the disorder is selflimited, and the relief afforded by the disappearance or diminution in headache and return of restful sleep and appetite for food will terminate the disability in 3 to 5 days. Persistent severe headache, and the occurrence of papilledema are indicative of a cerebral form of the disease and require evacuation and hospitalization. As noted above, the occurrence of cough, while it may not represent acute pulmonary edema, should be considered as indicative of this possibility.

20. Differential Diagnosis. Voluntary or hysterical hyperventilation can occur, particularly in apprehensive individuals or in misinformed individuals who anticipate and increase their respiratory depth and frequency before entering a lower oxygen environment. Headache may be induced by hyperventilation, although it is not usually severe, and lightheadedness or dizziness may be present. The development of tetany and the presence of a positive Chvostek sign are not expected with the moderate respiratory alkalosis which altitude induces, therefore these will be useful differential signs. The effect of sedation and reassurance and the absence of insomnia and gastrointestinal symptoms will further a rapid diagnosis. ***Migraine*** can be differentiated by a characteristic prior history, the typical hemicranial distribution, if present, and any associated aura. ***Encephalopathies*** of other etiology may have to be considered, including viral, rickettsial, and bacterial infections of the central nervious system. The rarity of papilledema or convulsions should prompt a careful search for other causes. Modest fever may be present with acute mountain sickness, therefore this is not a reliable differential sign of infection, although the leukocyte count and sedimentation rate are not elevated in uncomplicated acute mountain sickness. The headache and malaise associated with respiratory and enteroviral infections or those of the typhoid and typhus group will be distinguishable by the usually more severe constitutional symptoms of these infections. Sinusitis, rarely associated with changes in barometric pressure due to rapid ascent, may elicit point tenderness on examination and be relieved by decongestants and, if infection is present, antibiotics. The differential diagnosis between acute mountain sickness and high altitude pulmonary edema is arbitrary since the latter usually occurs during the same time period or in the course of the occurrence of the former. The presence of cough or (in its absence) the presence of moist rales in the lungs, justifies the consideration of incipient pulmonary edema. The co-existence of a respiratory disorder which would otherwise explain these findings must not be assumed, and all individuals with actual or presumed respiratory infections must be very carefully evaluated.

21. Prevention. *a.* The most effective means of preventing acute mountain sickness still remains a progressive staging of ascent, permitting a scheduled intermediate altitude of about 2400 meters before going above 3000 meters with at least a 1- to 2-day sojourn and repeating this each 600 to 900 meters of further elevation desired. There is suggestive evidence that mild activity reduces the disability of acute mountain sickness, but also fairly substantial evidence that strenuous physical exertion in the first several days increases the likelihood of pulmonary edema. Therefore light activity with frequent rest periods is advised. There is no clear evidence that a high degree of physical fitness or periodic hyperventilation prior to ascent will prevent the symptoms of mountain sickness. The former is desired for its own sake, as is the avoidance of excess prior fatigue, or inadequate sleep, or of ingestion of alcoholic beverages.

b. Symptoms of mountain sickness can be reduced by the administration of 1000 mg of acetazolamide daily for 48 hours prior to ascent to high altitude and for 48 hours after arrival. This has been shown to be effective for ascent to altitudes up to 5300 meters. Combining staging at 1600 meters for four days plus acetazolamide administration at 1000 mg daily as previously mentioned completely eliminated the symptoms of acute mountain sickness for subjects taken from sea level to 4300 meters. However, neither acetazolamide alone or in combination with staging has been found to be of use in normalizing heavy physical work capacity, visual defects or mental incapacities caused by altitude exposure. Previously the diuretic furosemide had been suggested as a treatment for acute mountain sickness. More recent, controlled experiments have refuted this claim. Furosemide confers no benefits and may increase the symptoms of acute mountain disease.

SECTION IV
HIGH ALTITUDE PULMONARY EDEMA

22. Definition. High altitude pulmonary edema (HAPE) is a form of lung edema, unique in that it occurs solely under conditions of exposure to low partial pressures of oxygen, has been encountered exclusively at high terrestrial elevations, and characteristically occurs in individuals with pre-existing excellent health. It may occur in the absence of other signs of acute mountain sickness. HAPE may be considered as a form or manifestation of acute mountain sickness since it occurs during the period of susceptibility to this disorder. HAPE, as currently recognized, is characterized by high morbidity and some mortality.

23. Background, Distribution, and Incidence. The disorder was characterized and its nature investigated in a relatively few cases reported from 1937 to 1962. Since that time over 500 cases have been reported in soldiers of the Indian Army engaged at altitude in the Himalayan Mountains. The apparent rapid increase in incidence may be ascribed to several factors: improved recognition and reporting, increased numbers of individuals at risk, and the increased frequency of abrupt transportation to elevation. Both incidence and severity increase with altitude. Cases have been reported as low as 2400 meters in the continental United States but only above 3000 meters in South America and Asia. In some reports from South America, children and young adults comprise the majority of cases. Except for acclimatization to altitude, there are no factors known to confer spontaneous resistance or immunity. Predisposing factors are considered to include the following:

a. a history of prior high altitude pulmonary edema;

b. a rapid or abrupt transition from low altitude;

c. strenuous physical exertion;

d. exposure to cold;

e. anxiety;

f. return to high elevation after a short stay (weeks) at sea level following prior prolonged residence at altitude.

The incidence rate has been reported to vary from 10 to 155 per thousand, the latter figure in unacclimated troops at altitudes between 3500 and 5500 meters. The time of onset is characteristically related to the duration of time spent at altitude. Cases are rare on the day of arrival and infrequent after the fourth day. Very few cases have been reported after more than ten days at altitude.

24. Etiology. As in acute mountain sickness, the factor or combination of factors directly responsible for development of acute pulmonary edema at altitude remains undetermined. Left ventricular failure and elevated wedge pressures are not found, but pulmonary hypertension is common.

25. Morbid Anatomy. Necropsy examination has not furnished any characteristics to identify the pulmonary edema of high altitude except for the lack of evidence of other predisposing causes. There is commonly visceral congestion, distension of the right heart and pulmonary blood vessels, marked congestion of alveolar capillaries by red cells, and scattered focal alveolar and intrapleural hemorrhage. Focal areas of atelectasis and secondary pneumonic consolidation may be present. Alveoli show fibrinous exudates and some hyaline membrane formation. Hyaline or fibrinous thrombi are observed in pulmonary capillaries and arterial branches, in the sinusoids of the liver, and in glomerular and peritubular arteries of the kidney. Cerebral edema has been observed in severe cases.

26. Clinical Description. *a.* Characteristically, high altitude pulmonary edema begins with progressive cough and dyspnea. Cyanosis of face and extremities appears or becomes more intense. The initially dry cough becomes productive, and frothy white or pink sputum is present in established cases. Since the majority of individuals have the symptoms of acute mountain sickness, the early pulmonary manifestations may not be primary or striking. Prodromal syndromes may be shown by increasing malaise, dyspnea, repeated clearing of the throat, the development of a dry cough, and increase in the dyspnea at rest or at night. In rapidly progressive cases the onset of respiratory difficulty may be quite sudden, associated with choking feelings and rapid deterioration. Infrequently, central nervous symptoms may occur and dominate the picture, the pulmonary manifestations becoming superimposed on disorders of affect, mentation and consciousness.

b. The striking physical finding in addition to dyspnea and cyanosis is the presence of pulmonary rales. These may be symmetrically located, tend to appear first in the interscapular areas and often include the upper areas of the lung. The cough is typically nonproductive, although small amounts of blood-tinged sputum may occur. Pleural effusion may be a late and complicating feature and may be hemorrhagic. The heart rate is increased but not disproportionately so. Characteristically, the heart is normal in size and there are no evidences of enlargement or failure although in protracted cases distended neck veins, enlarged and tender liver, and peripheral edema have been described. Temperature may be slightly elevated, i.e., about one degree.

c. Hemodynamic studies in recovering cases and in the few cases studied in the acute phases of the disorder have shown normal cardiac output, elevated pulmonary arterial pressures and normal left atrial pressures. Although in convalescent cases pulmonary blood volume has been reported to be elevated, in acute cases studied this was not a consistent finding. Electrocardiograms show evidence of right axis deviation with clockwise rotation and T-wave inversion in the precordial leads, but it is not known whether these are more marked in patients with pulmonary edema then in subjects with a comparable degree of pulmonary arterial hypertension. Chest X-rays show multiple small, irregular pulmonary infiltrates with poorly defined margins occurring in a patchy distribution, typically asymmetrically. They may be unilateral, often occur first in the middle and upper zones, and tend to be more predominate on the right side. The infiltrate may spread and become confluent or extensive. Prominent interlobar septal shadows and pleural effusions may occur. The pulmonary vascular shadows may appear widened. With recovery there is rapid clearing of the radiographic picture.

d. Characteristic of recovery is a complete resolution of both physical and radiographic findings. In individuals recovered from acute pulmonary edema, a greater susceptibility to recurrence has been described together with a heightened response of pulmonary arterial pressure to hypoxia.

e. A presumptive diagnosis of pulmonary edema should be entertained if cough or disproportionate dyspnea at rest develops during the first week of altitude. If the diagnosis of pulmonary edema cannot be established in these cases, they should be regarded as potential cases of high altitude pulmonary edema unless another diagnosis can be substantiated. For purposes of treatment, therefore, cases can be divided into two categories: established and potential.

27. Treatment. The treatment of potential high altitude pulmonary edema should be prompt and vigorous, consisting of rest, warmth, and, in the presence of disproportionate dyspnea, the administration of oxygen in adequate amounts. Patients should be observed closely and if signs develop or symptoms progress they should be treated as established pulmonary edema. For high altitude pulmonary edema in the established phase, oxygen inhalation, up to 100 percent, at flow rates proportionate to ventilation (7-14 L/min) may be indicated. Addition of CO_2 to the oxygen is not recommended. Morphine may be given to reduce anxiety and has been claimed to exert several other directly beneficial actions. Despite morphine's known respiratory depressing effect, Indian experience has not shown this to be a drawback to the use of full dosage in severe cases of pulmonary edema at altitude. Dosages of 15 mg. intravenously have been used with prompt benefit. Atropine 0.6 mg. and aminophyllin 250 mg. intravenously may be useful in improving ventilation, particularly if there is any sign of associated airway compromise. Recent trials recommend the use of furosemide in dosages of 40 mg. intravenously every 12 hours as needed. But this recommendation needs confirmatory study. This rapidly acting potent diuretic has been effective in treating pulmonary edema of other etiologies, particularly that occurring in the course of acute left ventricular failure. A more recent study casts doubt on the value of furosemide. The results mentioned before may have been more due to the corticosteroid, betamethasone, with which the furosemide was administered than the diuretic itself. Certainly the administration of oxygen plus morphine should be considered as the fundamental therapy. The uses of other diuretics (except mercury which is slightly helpful), phlebotomy, or venous tourniquets have not been reported. Digitalis has been used with questionable value. When used with oxygen the cumulative effect appears to be better than either alone, and in no case startling. The cautious employment of intermittent positive pressure breathing may be of value. The careful use of adrenocortical steroids has been advocated, but only in cases with cerebral edema. Antibiotics are not indicated unless required for concurrent infection. Depending upon the ease vs. hazards of evacuation, the use of warmth, rest, morphine and oxygen may be preferable to a hasty evacuation to a lower altitude.

28. Prognosis. Some cases undoubtedly recover without diagnosis or treatment. In others, enforced bed rest or descent to a lower altitude will suffice. In cases which are recognized late, or where pulmonary infection supervenes, the prognosis is guarded due to the attendant difficulty of restoring adequate oxygenation. Occasional cases have been described with fulminating course in which hermorrhagic pleural effusions and cerebral edema were present.

29. Differential Diagnosis. Presumptive cases of high altitude pulmonary edema will include a large number of simply respiratory infections with laryngitis, tracheitis or bronchitis, as well as cases of bronchopneumonia and bronchial asthma. Fever and leucocytosis are not prominent in high altitude pulmonary edema. A history of acute exposure to toxic or edema-producing irritants will differentiate this type of condition from HAPE. Pulmonary edema secondary to acute left ventricular failure is unexpected but not unknown in men of military age. The electrocardiogram may assist in the recognition of underlying cause, such as myocardial infarction, myocarditis, arrhythmia, nephritis, or cardiac injury. A normal heart size and the absence of other signs of pre-existing heart disease are thus important to the diagnosis of high altitude pulmonary edema.

30. Prevention. High altitude pulmonary edema can be largely prevented by a program of pre-acclimatization, as indicated under acute mountain sickness. In situations where this is not feasible, measures should be taken to safeguard personnel against the condition, and the importance of these measures stressed to command and troops. The crucial element is to provide 2 or 3 days of relative rest and warmth upon arrival. If this is impossible, physical activity should be restricted to that which is minimal for the accomplishment of the mission, and severe exertion or continued strenuous physical activity avoided. Adequate shelter and protection from the cold is an important preventive measure. As anxiety is considered to play a role, confidence and reassurance among sick and well alike is of value. It is also recommended that individuals who have had a previous attack of pulmonary edema be considered as more likely to have second attacks. Patients with severe mountain sickness, or any incoherence should be kept at rest, given analgesics (including codeine or morphine) and oxygen, and closely observed.

SECTION V
INJURY FROM SOLAR RADIATION

31. General. Sunlight in moderate amounts is not injurious to health, but several harmful effects can be produced by excessive exposure to that portion of the ultraviolet radiation represented by wave lengths in the range 2900 to 3200 Å (1 centimeter = 10^8 Angstroms). Wave lengths shorter than 2900 Å are filtered out by the earth's atmosphere, and those longer than 3200 Å may be considered beneficial to the extent that they (as well as the erythema-producing wavelengths) promote tanning of the skin.

32. High Elevation vs Sea Level Exposure. Exposure to ultraviolet light at high terrestrial elevations may be much greater than at sea level for several reasons:

a. At high elevations there is less filtering of the sun's rays by the earth's atmosphere.

b. Glaciers and snow fields reflect about 75 percent of the incident ultraviolet radiation.

c. Under certain conditions (as in a cirque) reflection can increase the total radiation many fold.

d. Atmospheric scattering or "sky radiation" increases the total radiation at the earth's surface, particularly when high, thin, cirrus clouds are present, i.e., the ultraviolet radiation at the earth's surface may be greater on an overcast than on a cloudless day. In sum, the total ultraviolet radiation impinging upon exposed skin per unit time at high terrestrial elevations will be several times that at sea level; and it strikes from *all* directions, from below as well as from above and sides.

33. Sunburn. Variation in sensitivity to sunlight among individuals is considerable. Blue-eyed redheads and blonds are more susceptible to sunburn than are brunettes; children more than adults.

a. Photosensitization. Agents which increase sensitivity to sunlight are certain drugs: oral antidiabetic agents; phenothiazines; sulfonamides and their derivatives; certain diuretics; thiazides; most tetracyclines, especially demethylchlorotetracycline; barbiturates; bithionol (used in soaps, many first-aid creams and cosmetics); many plants and grasses (fig leaf, certain meadow grasses, buckwheat, wild parsnip, celery, and others); certain dyes used in lipstick; grean soap; coal tar derivatives.

b. Exposure Factors. Excessive exposure to the ultraviolet radiation of 2900 to 3200 Å in sunlight damages the tissues of the superficial skin layers. Short term exposure may produce redness of the skin along with a slight swelling. More prolonged exposure may cause pain and blistering. In severe cases chills, fever, or headache may develop.

c. Protective Effects. Exposure to the erythema producing wavelengths, and to longer wavelengths (3200-4400Å), causes an increase and darkening of pigment in the outermost layers of the skin, giving rise to a sun tan.

d. Prevention. Individuals at altitude must take unusual care to prevent sunburn. Whenever possible, exposure should be gradual to permit natural tanning and thickening of the skin. For some light-skinned individual adequate tanning is impossible.

(1) Protective creams or lotions should be applied liberally and frequently, particularly when excessive sweating and wiping of the neck and face tend to remove the preparation. The nose, cheeks, neck, and ears are most frequently sunburned; the lower surfaces of the nose and chin, which are frequently burned by reflected radiation, should not be neglected.

(2) Many preparations contain screening agents, such as esters of para-aminobenzoic acid, methyl anthranilate, methyl salicylate, or digalloyl trioleate, which filter out ultraviolet radiation of wavelengths from 2900 to 3200 Å. The screening agents usually permit wavelengths above 3200 Å to pass through, allowing tanning but not burning. The most complete protection, however, is provided by addition of an opaque pigment such as titanium dioxide or zinc oxide. The latter preparation is particularly useful in protecting sensitive areas such as the lips and nose. Red veterinary petrolatum (R.V.P.) is also a very effective sun screen.

e. Treatment. If prevention has been neglected or has been inadequate, application of cold, normal saline (0.8 percent) dressings, benzalkonium chloride 1:3000, or 2 percent aluminum acetate may relieve discomfort. Soothing creams may be helpful if swelling is not severe. Steroid preparations, such as 1/2 percent hydrocortisone in ointment or in an aerosol spray, are helpful in reducing inflammation if applied early. Steroid preparations are applied sparingly. Extensive or unusually severe sunburn may have to be treated as a second degree burn. Antibiotics may be required if burns become infected.

34. Snowblindness. The surface of the eye (cornea and conjunctiva) absorbs ultraviolet radiation just as does the skin. Excessive exposure can result in snowblindness (photophthalmia). During the actual period of exposure there is no sensation other than brightness to warn the individual. Symptoms may not develop until as much as 8 to 12 hours after exposure. The eyes initially feel simply irritated or dry, but as symptoms progress, the eyes feel as though they are full of sand. Moving or blinking the eyes is extremely painful. Even exposure to light may cause pain. Swelling of eyelids, redness of the eyes, and excessive tearing may occur. A severe case of snowblindness may be completely disabling for several days.

a. Prevention. Snowblindness can be completely prevented by the consistent use of proper goggles or sunglasses. Any lens transmitting less than 10 percent of the erythemal band of sunlight (below 3200 Å) is satisfactory. Glasses should be large and curved sufficiently to block most of the reflected light coming from below and from the sides. Under severe radiation conditions (as on a concave, high-altitude snow field) goggles are safer even though they are less comfortable and tend to steam up. If only sun glasses are available, an ointment should be applied to the eyelids to prevent burning. Spare goggles should be carried, but in an emergency lenses made of cardboard with a thin slit may be used. Sherpa and Balti porters have been known to protect their eyes very effectively by pulling their hair down over their faces. Eye protection is more necessary on a partly cloudy or moderately overcast day than in full sunlight.

b. Treatment. Snowblindness heals spontaneously in a few days; however, the pain may be quite severe if the condition is not treated. Cold compresses to the eyes and a dark environment may give some temporary relief. Early and frequent applications (hourly) of an ophthalmic ointment containing cortisone or some other steroid can provide relief from pain, lessen the inflammatory reaction, and shorten the course of the illness. However, the individual must not rub his eyes. Preparations containing local anesthetic agents should not be employed since they may favor corneal damage.

35. Chapping. Chapping of lips and nostrils, caused by the combination of wind, low humidity, and sunburn, results in cracking and bleeding. It can be both painful and otherwise annoying while eating or laughing. A chapstick or other preventive is an essential part of each man's equipment.

SECTION VI
NUTRITION AND FLUID BALANCE

36. Nutritional Balance. Controlled studies of this subject are few, necessitating reliance predominantly upon anecdotal material from those mountaineering expeditions which include reliable observers. With respect to nutritional problems, one may speak of the period of acute mountain sickness (at whatever elevation) and of intermediate vs very high elevations (3000 — 4600 meters vs 5800 meters and higher). Weight loss during the first days at high elevation is characteristic, predominantly due to a loss of appetite associated with the symptoms of mountain sickness. With the subsidence of symptoms and progressive acclimatization the loss of weight generally stops. One study suggests that a high carbohydrate diet (68 percent CHO, 20 percent fat, 12 percent protein) serves to diminish the intensity of symptoms at intermediate elevations, and in addition improves the physical work capacity of the subjects. Even below 4600 meters newcomers prefer carbohydrates to noncarbohydrate foods. At progressively higher elevations the tolerance for fatty foods decreases rapidly and sugars are in progressively greater demand (usually in the form of beverages). This is apparently not solely a matter of taste. Reduced absorption of fats from the gastrointestinal tract may be an important aspect, as evidence by the observation that fat in the diet leads to greasy stools. Above approximately 5500 meters there is a progressive loss of appetite and a progressive weight loss. At these elevations in particular, the craving for sweetened beverages is high. In one report the subjects consumed as much as 350 gm. of sugar per day. Since, as previously mentioned, complete acclimatization does not occur at these altitudes, it becomes axiomatic that prolonged residence associated with daily hard work means steady deterioration.

37. Fluid Balance. The maintenance of fluid balance is also a problem. It appears that the sense of thirst may also be blunted at very high elevations despite the ever greater threat of dehydration. The hyperventilation caused by the low ambient oxygen pressure and the cool, dry atmosphere brings about a 3- to 4-fold increase in water loss via the lungs. Hard work and overheating increase the sweat rate. *Unless a conscious effort is made to imbibe fluids even in the absence of a sensation of thirst, dehydration becomes a very serious threat.* It has been recommended that a quart of water (or equivalent) be imbibed every 3 hours. In the absence of potable water and in the presence of snow-cover, resort must be had to the melting of snow. This, however, is a time and energy consuming process which the individual suffering severe acute mountain sickness might be unable to undertake. Water, in short, may prove an additional serious supply problem.

SECTION VII
BRIEFINGS AND ADVICE ON PRACTICAL PROBLEMS

38. The Medical Officer. *a.* He is not immune to mountain sickness or high altitude pulmonary edema.

b. Pre-ascent briefings to officers and troops are important.

c. Briefing the commanding officer will include—

(1) Making him aware that he and his staff are susceptible to intellectual malfunctioning and moods.

(2) Institution of cross checking of data and decisions.

d. Difficulties of supply and communications (as well as casualty evacuation), should be anticipated in regard to medical supplies and equipment (such as electrocardiograph and portable X-ray machine).

e. Availability of palatable foods, analgesics, sunburn ointments, and chap sticks.

39. The Commanding Officer. *a.* He, too, may suffer symptoms and consequences.

b. He must exercise careful judgment as between urgency of mission accomplishment and the condition of the troops to carry on. For example, following rapid transport to 14,000 feet (from near sea level), 60 percent of the troops will become ill, and may well become ineffective.

40. The Food Service Personnel. Food service personnel will make available palatable foods such as soup, fruits, sweetened beverages, and candy.

41. The Troops. The troops should be briefed to—

a. Anticipate fear, anxiety, depression, irritability, self-limiting nature of mountain sickness.

b. The cause and duration of symptoms.

42. Supply and Communications. The briefing for personnel involved in supply and communications should stress the following facts:

a. Everything tends to function less well.

b. Supply and evacuation are difficult, hence preparations should be made in anticipation of delays.

43. Required Special Gear.

a. Sun glasses (large curved lenses) or goggles.

b. Ointment to filter out erythema-producing ultraviolet radiation.

c. Chap sticks.

APPENDIX A
NATURAL ENVIRONMENT OF TERRESTRIAL ALTITUDES OVER 3,000 METERS

1. The land surface of our world covers approximately 57,000,000 square miles, of which some 2,700,000 square miles are above 3000 meters. This amounts to nearly 5 percent of the total land mass. Almost half of the surface above 3000 meters is in Antarctica, where a "land surface" which is predominatly below 2000 meters is covered with an ice sheet 1500 or more meters thick. The Central Asian Highlands constitute the largest land mass over 3000 meters, with close to a million square miles above this height. This is about 1.6 percent of the total land area of the world. South America has some 365,000 square miles, which is about 0.6 percent. All the rest of the land above 3000 meters totals only 155,000 square miles (less than 0.3 percent). These figures would normally lead one to suspect that the total amount of land above 3000 meters is of little consequence on a world basis, but the strategic location of the Central Asian Highlands and the very nature of much of today's guerrilla-type warfare make this a region of great military importance.

2. When one discusses the physical environment above 3000 meters, he is immediately cognizant of the unique local situation, with its site factors. The orientation of the sun, the steepness of the slopes, the surface material, the vegetation, and the terrestrial configuration result in microenvironments within rather broad physiographic regions. However, there are many large-scale phenomena which change with some degree of regularity with elevation. One is the decrease in barometric pressure. At 3000 meters, the atmospheric pressure is about 70 percent that of sea level, and at 5700 meters it is 1/2 the sea level pressure.

3. The atmospheric pressure for a given altitude decreases slightly but progressively with distance from the equator.

4. **Standard Atmosphere.** A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by international agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibration, aircraft performance calculations, aircraft and missile design and ballistic tables. The air is assumed to obey the perfect gas law and the hydrostatic equation, which, taken together, relate temperature, pressure, and density variations in the vertical. It is further assumed that the air contains no water vapor, and that the acceleration of gravity does not change with height. The last assumption is tantamount to adopting a particular unit of geopotential height in place of a unit of geometric height for representing the measure of vertical displacement, for the two units are numerically equivalent in both the metric and English systems, as defined in connection with the standard atmosphere.

5. Temperature in the lower troposphere will decrease by approximately 6° C for every 900 meters of increase in altitude. This is oversimplifying the actual circumstances, as lapse rates can vary according to the moisture content of the air mass as well as according to latitude and season. Precipitation within mountainous regions depends to a large degree on the orientation of the mountain range, the prevailing winds, and the amount of moisture being carried in the air mass. When one considers the Himalayas, one must also include the physical qualities of the monsoon circulation. Generally, one can expect an increase in precipitation with elevation up to a certain height. In Central Asia, the maximum occurs below 2000 meters with considerable decrease above 3000 meters. Where the general circulation does not bring in moist air to an elevated region, precipitation usually occurs in the form of afternoon showers. Lee sides of many mountains and high basins are often arid. Winds are influenced by terrain characteristics. Commonly, cold, dry air will drain downslope during the night and increase in wind speed along the valley floors. Within an hour after sunrise, air begins to warm and rise upslope. During maximum heating in late afternoon, the winds usually reach their greatest strength. On the high peaks, winds are consistently strong, but the maximum wind speed ever measured on the Tibetan Plateau was only 39 knots. Storms can be very intense at high elevations, and wind speeds of over 100 knots are estimated by mountaineers. Mt. Washington, N.H., at about 1900 meters elevation, holds the world's record for highest wind speed (195 knots). Higher winds have no doubt occurred at higher elevations but have never been measured. Solar radiation becomes more intense with elevation increase and some of the highest normal incidence radiation measurements have been taken on Mt. Everest, Mauna Loa, and on the Antarctic Plateau. The danger of snow blindness becomes acute at the high elevations where the albedo of the snow surface results in strong reflectivity from the surface. Visibility at high elevations is also much better because much of the dust, smoke, and haze which one finds at lower elevations is absent. Timber- and snow-lines all depend upon latitude, precipitation, slope, orientation, and surface material. In Central

Asia, the climatic snowline lies above 15,000 feet. On the Tibetan Plateau it is between 17,000 feet and 21,000 feet. The general lowering of the snowline from the equator to the poles is interrupted in the "horse latitudes" (between 20° and 25° north and south) where there is less snowfall. In the Andes the snowline between 5° N and 9° S lies at 13,000 feet to 16,500 feet, whereas between 20° and 25° South, it lies at 19,500 feet to 21,000 feet. The one most appropriate word to describe climate in mountains is variability. Situations can change very rapidly in such a complex environment.

6. Except in the plateau regions of Bolivia, Peru, and Tibet, land surfaces above 10,000 feet are mountains. That is, they are parts of the land surface which have been uplifted and strongly dissected by streams of glaciers. Many high stations are so dry that many of their streams do not descend to the sea. The plateaus of South America and Central Asia are often traversed by many ranges of mountains, some of which have only moderate local relief and slope gradients. However, they are rimmed by ranges which stand very high above surrounding basins and, except on the western scarp of the Andes, are very steep and are dissected by deep, steep-walled gorges.

7. The floors of basins of internal drainage at very high levels are mostly ordinary desert alluvial fans and playas (central depositional areas of mud or salt, with ephemeral or fluctuating lakes). The playas may be soft or firm, and if firm are subject to dust storms, often carrying much salt. Alluvial fans above 3,000 feet are likely to be smoothed by frost heave of their surface. Stream channels traversing them are likely to be less deeply incised, and to have gentler banks than those of warmer deserts.

8. The ruggedness of mountain terrain is a function of local (not total) relief. Ranges on high plateaus will not ordinarily have much high cliff, or extensive exposed bedrock. However, their surface has perennial ground frost, and the surface freeze-thaw zone (active zone) is likely to be somewhat unstable and may be very bouldery. Glaciers are not always severely fractured by crevasses, and may even offer good going. They are absent in the drier ranges of the Andean Plateau.

9. The ranges on the eastern margin of the Andean Plateau, and most of those rimming Tibet, are among the highest and most difficult in the world. All of them have been deeply dissected both by glaciers and, below the glacial level, by mountain torrents. In such a complex, terrain problems may be very severe.

10. Timberline may lie well above 10,000 feet, and subalpine forests may be matted and difficult to traverse except on a prepared trail. Because they are steep and cascade down rugged channels, both glaciers and streams are formidable barriers, often forcing the track onto very steep ground. Other terrain problems involve not only ascent and descent of cliffs, icefields, and detritus masses which may or may not be stable, but also present the risk of rockfall, icefall, and avalanches.

11. Because of the variety of environments in such terrain, mechanical solutions to problems of mobility are not helpful; even VTOL aircraft do not work well at high altitudes. Troops should not be introduced to such terrain without an opportunity to become oriented to it, since the variety of terrain generally means that safe routes can be found, but to do so requires considerable understanding of the country. In general, movement in such mountains must be by small units, since defiles are frequent and greatly delay large forces moving together.

APPENDIX B
EQUIVALENT ALTITUDES IN METERS AND FEET

Meters	Feet	Feet	Meters
500	1,640	10,000	3,048
1,000	3,281	11,000	3,353
1,500	4,921	12,000	3,658
2,000	6,562	13,000	3,962
2,500	8,202	14,000	4,267
3,000	9,843	15,000	4,572
3,500	11,483	16,000	4,877
4,000	13,124	17,000	5,182
4,500	14,764	18,000	5,486
5,000	16,405	19,000	5,791
5,500	18,045	20,000	6,096
6,000	19,686	21,000	6,401
6,500	21,326	22,000	6,706
7,000	22,967	23,000	7,010
7,500	24,608	24,000	7,315
8,000	26,248	25,000	7,620
8,500	27,889	26,000	7,925
9,000	29,529	27,000	8,230
9,500	31,170	28,000	8,535
10,000	32,810	29,000	8,840

Note. To convert meters to feet, multiply by 3.281.
To convert feet to meters, multiply by 0.3048.

APPENDIX C
REFERENCES

Although the emphasis of this bulletin has been placed upon hypoxia, other features of high terrestrial elevations may also give rise to pathological states which must be anticipated, e.g., cold injuries, diseases peculiar to particular nations or regions of the world. Treatises on acute mountain sickness and its management are few, as is also the case with HAPE. The references listed below are given in categories:

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4. Medicine, Pathology, Epidemiology Which May be Peculiar to Specific Nations or Regions.

a. DA Pam 550-series (AR 310—3).
Foreign Area Studies (Name of country).

b. Health Data Publication for (Name of country)
Department of Health Data
Division of Biometrics and Information Data Processing
Walter Reed Army Institute of Research
Walter Reed Army Medical Center
Washington, D.C. 20012

5. General. "Medicine for Mountaineering," Edited by James A. Wilkerson. Published by The Mountaineers, Seattle, WA 98111.

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