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Observations Made at a High-Altitude High-Latitude Manned Facility

INTRODUCTION

From 1963 to 1965 the Arctic Aeromedical Laboratory, a facility of the U.S. Air Force Systems Command's Aerospace Medical Division, conducted an active research and development program in conjunction with the Geophysical Institute of the University of Alaska and the U.S. Army Arctic Test Center which resulted in the establishment and operation of a small field station at 4 160 meters (13 650 feet) near the summit of Mount Wrangell, Alaska. Mount Wrangell, located at 62° N, 144° W, is a minimally active vol-

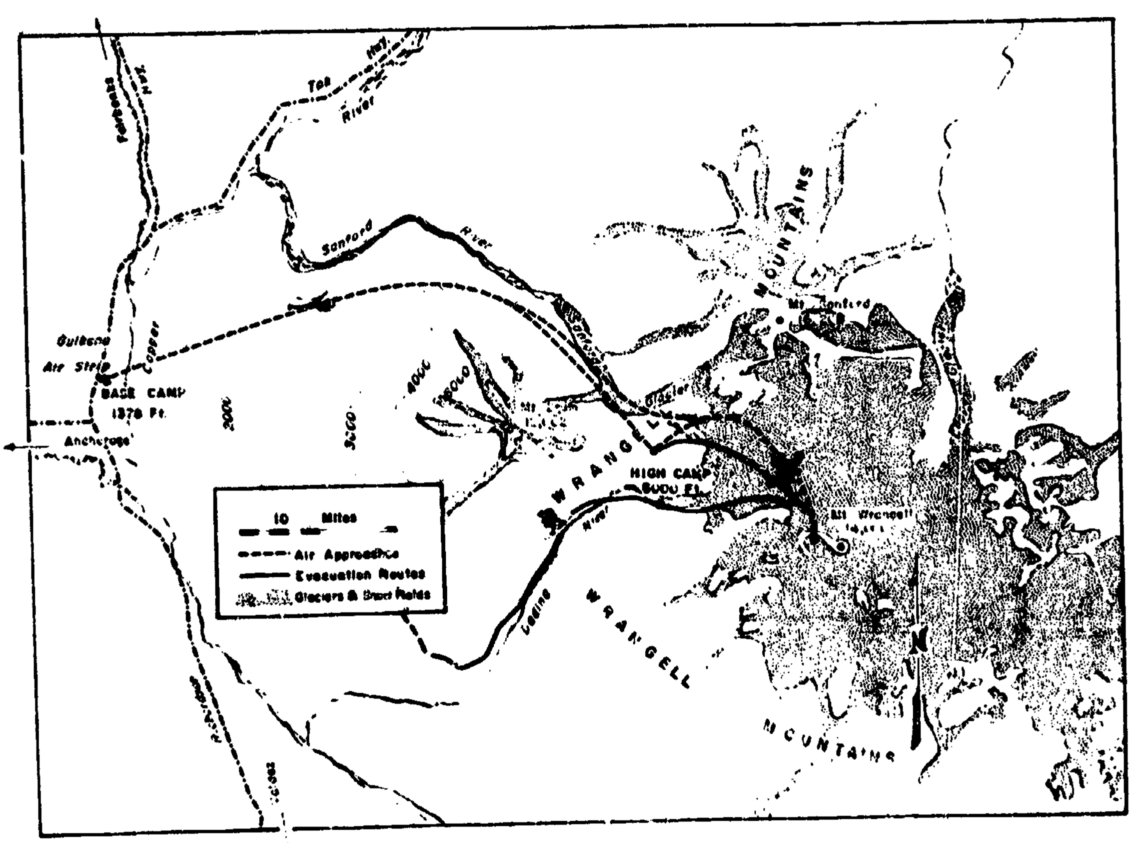

FIGURE 1.—Contour map of Mount Wrangell area showing location of base camp, temporary high camp site, summit, and connecting air route.

cano with a large, relatively flat, plateaulike top which measures about 5 by 3.5 kilometers (figs. 1, 2, and 3). It is covered with a perennial snow and icefield at an altitude high enough to be approximately at the dry-snow line. The icefield is essentially unbroken except for a small crater, which produces modest amounts of steam and hydrogen sulfide, and for several ridges, some of which are kept ice free by the presence of volcanic heat. In the summer of 1964, a specially insulated, prefabricated shelter measuring 16 by 24 feet was assembled on the largest of these ice-free ridges (figs. 4 and 5). The structure was designed to trap and hold heat from the underlying warm ground. Since its erection the structure has remained comfortably warm without the use of supplemental heat regardless of outside temperatures. This building was utilized for several weeks as the living quarters for a working party in the late summer of 1964 and served as the laboratory work and support area for several research and work teams who used the facility in the spring and summer of 1965 (figs. 6 and 7). The present paper reports on certain psychophysiological responses observed in station personnel and on selected temperature and barometric pressure measurements made during this period.

Sincere thanks are expressed to Dr. C. S. Benson for his suggestions concerning the feasibility of using trapped volcanic heat; to D. L. Chauvin, the supervising construction engineer; and his fine team of Geophysical

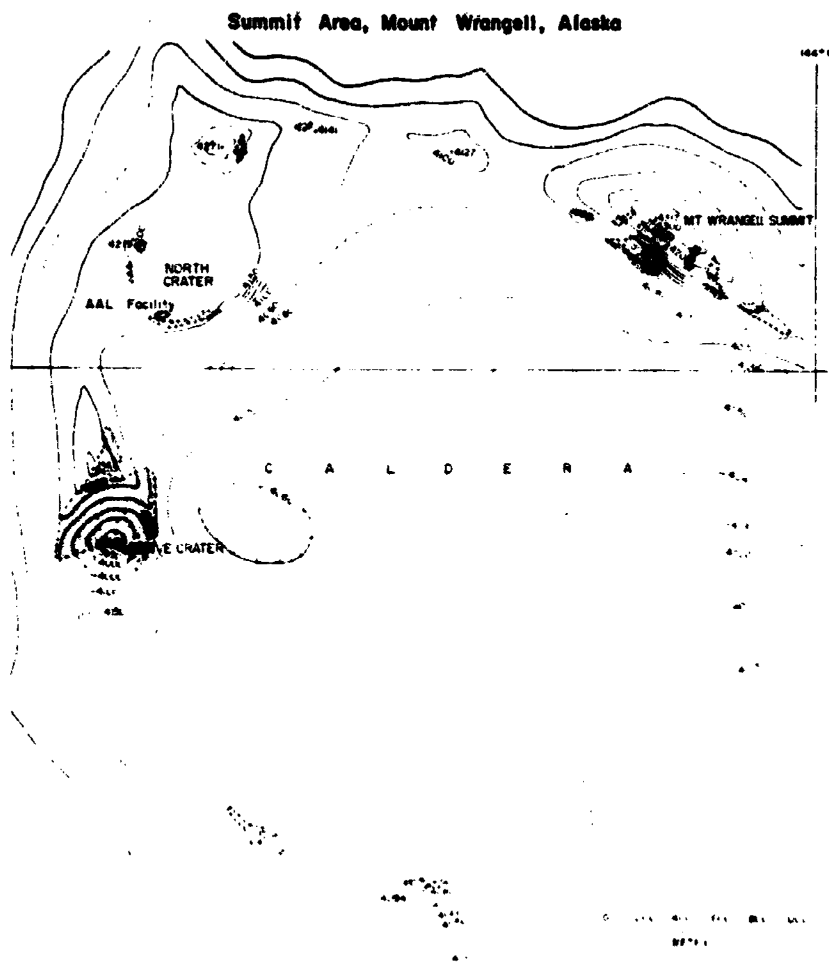

FIGURE 2.—Contour map of summit area, Mount Wrangell, Alaska.

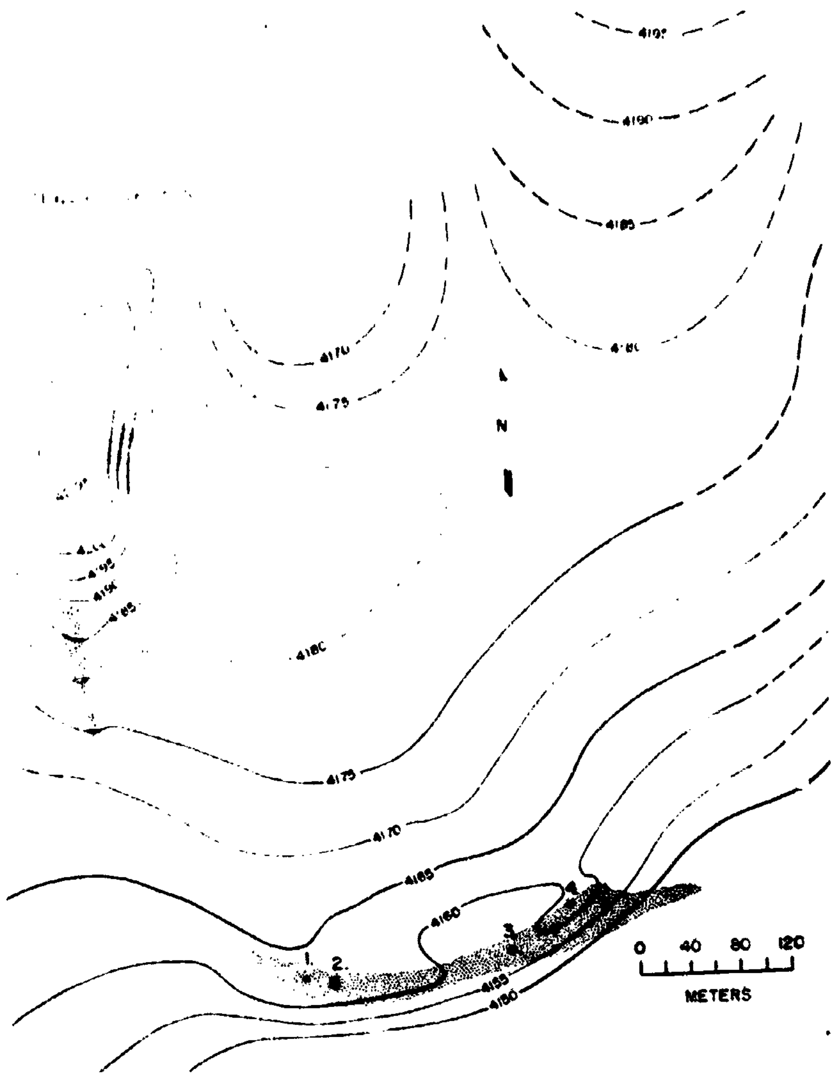

FIGURE 3.—Contour map of research facility area on Mount Wrangell.
1. Storage and generator building.
2. Main building.
3 and 4. Huts from 1953–54 (of possible use in emergency).

Institute personnel; to Dr. C. J. Eagen, Capt. J. Ray, J. Schuman, and the others of the Arctic Aeromedical Laboratory staff who participated both as subjects and observers; and to the outstanding airlift support provided by the U.S. Army Arctic Test Center, the U.S. Air Force Alaskan Air Command, and J. Wilson, owner of the Wilson Air Service in Gulkana, Alaska.

ADAPTATION OF PERSONNEL

A total of 37 different individuals participated in the establishment and initial operation of the facility and in the follow-on research program. Of this number, 28 individuals, varying in age from 20 to 53 years, remained on location for more than 1 day and are included in the analysis. Their average stay

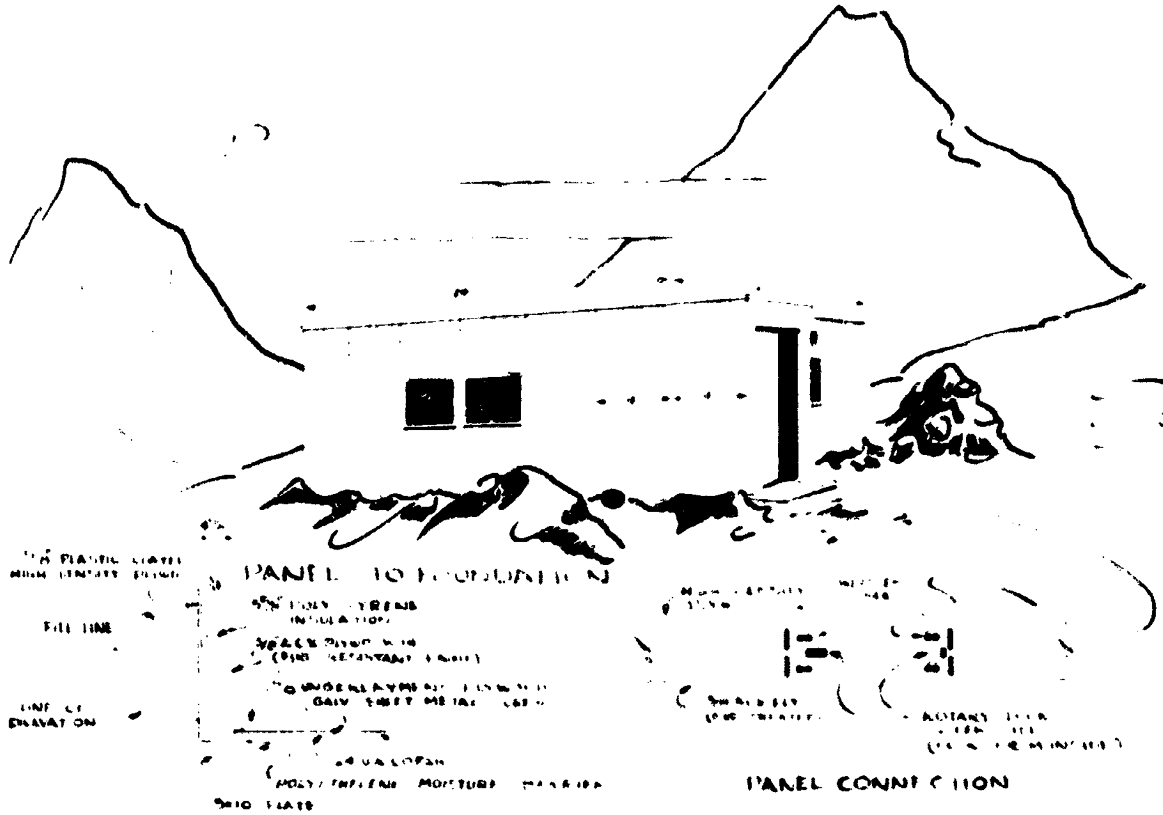

FIGURE 4.—Schematic of laboratory structure.

FIGURE 5.—Aerial view of ice-free ridge with laboratory facility in foreground. Small structures visible at far end of ridge are Jamesway huts erected by Geophysical Institute in 1953–54 to support a cosmic-ray research program.

FIGURE 6.—Mount Wrangell research facility showing laboratory facility on the left, generator hut on the right, and bivouac area in left foreground.

FIGURE 7.—Interior view of laboratory building. Special egress window is open.

was 14 days, so they received a protracted exposure to the combined stress of altitude, cold, and work. Because the remoteness of the site and an aggressive work program placed a premium on maintaining physical fitness, the health and operational effectiveness of all personnel were observed and recorded. These observations are of practical interest inasmuch as they offer substantial evidence that, contrary to popular belief, it is the older, more mature male and not necessarily the young individual who is better able to adapt effectively to the rigors of life in the Arctic at an altitude of 4160 meters.

Physiological Environment

Table 1 summarizes the physiologically significant environment data. Like all high mountains, Mount Wrangell exhibits reduced barometric pressures, low temperatures, high winds, and capricious storms. During the period of this study the barometric pressure as measured at the facility (altitude, 4160 meters) was most frequently observed to be at or about 450 mm Hg, with variations from a high of 457 to a low of 429 mm Hg. Since most of the site activities reported were conducted from July to August 1964 and March to June 1965, the very low temperatures associated with the long arctic night were not observed. Daytime environmental temperatures varied from a high of −5° C on the warmest days to −25° C on the coldest. Nighttime temperatures generally averaged 1° to 6° C colder. High winds and severe storms with blowing snow were common and wind velocities were estimated to be in excess of 75 knots on several occasions.

Participants

The participants were divided into three teams as described in table 2. The construction group, team A, consisted of civilian contract employees from the Geophysical Institute of the University of Alaska. Team B, the research group, was comprised solely of U.S. Air Force personnel. All individuals in teams A and B worked hard at altitude. Team C was a research and support group whose members generally engaged only in light work. It included U.S. Air Force personnel and personnel from the Geophysical Institute as well as one participant from the U.S. Army, one from the University of Hawaii, and one from Oxford University in the United Kingdom.

TABLE 1.—*Environment Characteristics Observed at Mount Wrangell Research Facility*

Characteristic	Value		
	Max	Min	Av
Altitude:			
Meters			4 160
Feet			13 650
Barometric pressure:			
MB	608	572	600
mm Hg	457	429	450
Daytime temperature:			
°C	−5	−25	−18
°F	23	−13	0
Wind, knots	75+	0	10
Length of day, hr	22	12	19

TABLE 2.—*Age Distribution of Participants as a Function of Activity*

Age	Number of subjects with primary activity of—			Total
	Hard work		Light work	
	Team A	Team B	Team C	
20 to 24	1	3	2	6
25 to 29	2	1	4	7
30 to 34	1	0	4	5
35 to 39	2	2	1	5
40 plus	1	1	3	5
Total	7	7	14	28

All participants underwent baseline physical examinations including chest X-ray, 12 lead electrocardiograms, and blood indices. No abnormalities were noted. None of the participants were altitude acclimatized at the time of their ascent to Mount Wrangell. As a matter of fact, only 3 of the 28 had ever lived previously at altitude long enough to acclimatize. For the rest, the present experience was their first.

Only seven individuals, the members of team B, were known to be in excellent physical condition. They had trained daily in cross-country runs, ski reconnaissance patrols, and other types of graded exercise for 5 months prior to ascent. Repeated testing using the method of Johnson et al. (ref. 1) as described by Consolazio, Johnson, and Pecora (ref. 2) classified all of them as highly fit. The rest of the participants made no special effort to train or otherwise improve their fitness. The military members of group C, when tested in the same way, all fell into the lowest category of fitness. Group A was not tested. (The foregoing information was obtained from a personal communication from Dr. C. J. Eagen.)

Quality of the Experience

Nearly everyone spent a substantial number of waking hours in the open. With the exception of a few members of the support groups who slept in the facility structure where the temperature averaged from 23° C (70° F) to 29° C (80° F), all personnel lived in standard four-man mountain tents and slept in arctic sleeping bags placed on air mattresses. Clothing was the standard arctic military issue supplemented by lightweight down-filled parkas and pants. The basic diet, unrestricted with respect to quantity, was the standard military K-ration supplemented, when logistically feasible, by fresh bread, meat, fruits, and vegetables.

Transportation between base camp and the summit was accomplished by aircraft, the total ascent usually taking less than an hour. Immediately on arriving, participants undertook a full work schedule. In the case of the construction crew, team A, the initial task was to excavate a foundation for the laboratory building and also unload incoming materials as they arrived. For example, six men working almost continuously were able to excavate and move an estimated 4.6 cu m (cu yd) of volcanic ash and sand weighing about 7250 kilograms (8 British tons) in the first 15 hours on location, in addition to unloading several tons of supplies and materials from incoming aircraft. They continued their heavy work at a lesser rate for the next 4 days until all major assembly activities had been completed. Similarly, the seven men in the physically fit team B worked hard from the onset; they set up a bivouac area on their first day and initiated a preplanned program of ski patrols, climbing activities, and calisthenics on the following day. By way of contrast, most members of group A engaged in a comparatively undemanding work regimen; they limited their activity to setting up and operating research equipment and conducting general station-keeping tasks.

The close presence of a volcanic crater intermittently venting modest quantities of visible steam and small amounts of hydrogen sulfide gas, which was also the source of occasional tremors as masses of snow and ice on the crater rim would melt, loosen, and audibly tumble to the bottom of the cone, continually reminded each participant that he was indeed living on the edge of a volcano. Although the probability of a substantial unheralded eruption was judged to be negligible, the possibility of such an event could not be completely discounted (ref. 3). Thus, the participants were subjected to a unique whole-body stress based not only on a physiologically demanding environment but also on a series of psychological loads which included the problems of small-group living in a location remote from outside help, where work and exercise schedules had to be tailored to fit the immediate weather, and a quiet volcano exerting its own background effect.

Observations

For the first several hours after arrival at 13 650 feet, nearly all subjects reported a transient sense of elation. Within 4 to 24 hours slightly more than one-half of the individuals were affected by symptoms of altitude sickness occurring in varying degrees of severity: Headache, shortness of breath, general weakness, loss of appetite, nausea, and sometimes vomiting. However, only a few were disabled enough to restrict job performance.

A rating scale of from 1 to 4 is used to assess the operational effectiveness of each of the 28 individual participants, the assessment being based on general work performance rather than on the degree of symptomatology. (See table 3.) A subject is judged fully effective and

TABLE 3.—*Classification of Operational Effectiveness*

Classification	Degree of effectiveness
1	Fully effective.
2	Marginally effective.
3	Temporarily ineffective.
4	Ineffective.

rated as 1 if no symptoms were reported, if activity was not consciously limited by dyspnea or weakness, and if assigned tasks were performed appropriately. A rating of 2 suggests marginal effectiveness and indicates that the subject had overt signs and symptoms of acute altitude disease perhaps for as long as several days, but the capacity to work, exercise, and perform general duties as assigned was not noticeably compromised. Group 3 is composed of subjects probably best described as temporarily ineffective because they required intermittent bedrest for time periods ranging from hours to days. Although these subjects were not a major burden since they could take care of their personal needs, they were physically unable to perform part of their assigned duties in a predictable manner. However, all recovered in place and became effective within a week. Subjects rated as 4 are termed ineffective because they were so severely incapacitated by nausea, vomiting, headache, and weakness that immediate evacuation to base camp was clearly indicated.

Tables 4 and 5 show the variation in operational effectiveness of the Wrangell subjects. On inspection it is evident that the maintenance of operational effectiveness is somewhat proportional to age with young men under 25 years of age being most vulnerable to significant impairment and failure, while similarly exposed men in their thirties and forties remained comparatively effective. As a matter of fact, the data might even be interpreted as suggesting that it is the combination of youth and hard work that is most likely to cause disability, while in the more mature subjects physical work at altitude seems therapeutic.

TABLE 4.—*Operational Effectiveness at 4150 Meters Shown as a Function of Age*

Age	Number of subjects for effectiveness rating—				Total
	1	2	3	4	
20 to 24	1		3	2	6
25 to 29	2	1	3	1	7
30 to 34	1	4			5
35 to 39	5				5
40 +	3	1	1		5
Total	12	6	7	3	28

Effective Performance at Altitude

Thresholds for Altitude Tolerance

It is believed that the observed decreases in operational effectiveness were primarily related to acute altitude sickness in most instances. Altitude sickness derives from hypoxia which in turn is a function of the decreased partial pressure of oxygen found at altitude. Table 6 presents a spectrum of operationally applicable hypoxic thresholds as a function of altitude. The performance of athletes such as long-distance runners is reduced by 5 to 7 percent at 2134 meters (7000 feet) (ref. 4). Psychomotor function is impaired by acute exposure to altitudes above 3048 meters (10 000 feet), and for this reason military fliers are required to breathe supplementary oxygen when that altitude is exceeded during flight. However, given time, complete acclimatization appears possible in most healthy individuals up to an altitude of 4752 meters (15 000 feet). Above that altitude, sometimes termed the "threshold of incomplete compensation," men born at sea level fail in substantial numbers to adapt successfully to prolonged exposures. The maximum threshold for permanent residence is very well defined at 5334 meters (17 500 feet) (ref. 5). The Mount Wrangell field station strategically located at 4150 meters (13 615 feet) is thus within the range that should be fully compensable for most

TABLE 5.—*Operational Effectiveness at 4160 Meters as a Function of Age*

Age	Fitness	Number of subjects for effectiveness rating [a]				Total
		1	2	3	4	
20 to 24	Fit			(1)	(2)	2(4)
	Less fit					
	Unknown	(1)		2		
25 to 29	Fit			(1)		4(3)
	Less fit	1		2		
	Unknown	(1)	1		(1)	
30 to 34	Fit					4(1)
	Less fit		2			
	Unknown	(1)	2			
35 to 39	Fit	(2)				1(4)
	Less fit					
	Unknown	1(2)				
40+ [b]	Fit	(1)				3(2)
	Less fit					
	Unknown	1(1)	1	1		
Total subjects		3(9)	6(0)	5(2)	0(3)	14(14)

[a] Numbers in parentheses indicate subjects who engaged in hard labor; others refer to subjects engaged in light work.

[b] 4 of the 5 subjects in the 40+ group were younger than 44; the fifth was a hard-working, 53-year-old member of team A.

healthy people but is nevertheless high enough to provide a severe degree of hypoxic stress.

Effect of Age

The effect of aging on changing the responsiveness of man to physical stress usually takes the form of a gradual and progressive loss of physiological reserves. It becomes evident in the third or fourth decade of life to a degree sufficient to compromise performance in those physical activities which require both reasonably long-term, high-energy outputs and quick reaction times. By analogy, it would seem that the most fundamental of the physiological stresses—namely, exposure to high terrestrial altitudes with its reduction in inspired oxygen—should be tolerated better by the young adult than by an older person. This viewpoint is probably accepted a priori by most individuals and has support in the literature. For example, it has been reported that at 4000 meters (13 120 feet), younger subjects acclimatize better and sooner (ref. 6) and at 2896 meters (9500 feet) older people are more severely affected by symptoms of altitude sickness than is the average fit young man (ref. 7).

Insofar as the 28 subjects in this study represent a reasonable sample of the general American population of military age, the data in table 4 indicated that probably the reverse is true; namely, a man in his late twenties, thirties, and early forties performs more effectively at altitude than does a younger person. This is not an anomalous finding but has been substantiated to some degree by the observations of others. Mountaineers have long appreciated the fact that it is the person in his thirties, and not necessarily the very fit young man in his late teens or early twenties, who makes the best high-altitude climber. Nevison (ref. 8), in reporting on the Hidden Peak expedition in the Himalayas in 1958, observed that it was the two oldest members of the party who were able to make the highest ascent. Hellriegel, medical director of the Cuero del

TABLE 6. *Operationally Significant Reaction Thresholds to Altitude Showing Critical Location of Mount Wrangell*

Threshold	Altitude		Atmospheric pressure, mm Hg	Po_2,[a] mm Hg	PAo_2,[b] mm Hg
	Meters	Feet			
Normal function	0	0	760	159	102
Significant reaction	3048	10 000	523	110	61
Mount Wrangell:					
Average	4160	13 650	450	94	51
Max			457	95	52
Min			429	90	46
Incomplete compensation	4572	15 000	429	90	46
Highest permanent residence	5334	17 500	387	81	43
Acute exposure, lethal	6706	22 000	321	67	30

[a] Po_2, partial pressure of atmospheric oxygen.
[b] PAo_2, partial pressure of alveolar oxygen.

Pasco Corp., which conducts mining operations in the high mountains of South America, has noted, in a personal communication, that the degree of disability suffered by miners recruited from the lowlands and newly arrived at altitudes of 3658 to 4663 meters (12 000 to 15 300 feet) appears to be age specific and closely parallels the Wrangell experience as presented in table 4. Bowerman (ref. 9) stated that among track athletes training at 2133 meters (7000 feet), the more youthful the competitor, the less adjustment in 15 to 20 days. McFarland, in a study of more than 200 men varying from 18 to 70 years of age who were acutely exposed for 2 hours to a 4267-meter (14 000-foot) altitude in a low-pressure chamber (ref. 10), found heart rates of older men to be slower than those of the younger. In addition, the older subjects appeared to have fewer complaints and were less susceptible to fainting and collapse. Folk (ref. 11), using Mosso's original data, showed that young men aged 18 to 19 years exposed for 3 days to 4559 meters (14 957 feet) at the Regina Margherita Hut in the Italian Alps had substantially higher heart rates than did older men between 22 to 50 years, but that the older men had higher respiratory rates. Hall et al. (ref. 12), in evaluating the effectiveness of potassium chloride to modify altitude sickness, transported 20 Indian Army soldiers varying in age from 18 to 30 years from a sea-level location to 5782 meters (17 000 feet) within a 24-hour period. None had a history of previous altitude acclimatization. All subjects suffered to some degree from acute altitude sickness during the 4 days at altitude, and it was concluded that the drug was ineffective. However, when Hall's original data are evaluated in terms of the degree of disability as determined by incapacitation requiring bedrest (see table 7), an age effect is uncovered which shows that men over 20 years of age apparently are less affected than are younger men. Luft (ref. 13), in a series of low-pressure-chamber studies, found a remarkable age-related difference in tolerance to acute exposures of 7500 meters (24 600 feet) with men between the ages of 25 and 40 years having a time of useful consciousness about 2 minutes longer than the average time of 6 minutes 8 seconds recorded for subjects between the ages of 20 and 25 years. Finally, the observation that high-altitude pulmonary edema, an uncommon but serious complication of acute sickness, seems to have a higher incidence in young people is not inconsistent with the general thesis that performance at altitude improves with age (ref. 14).

There is no convincing explanation for the age-related altitude effect. In the case of

TABLE 7.—*Estimated Effectiveness of 20 Indian Army Soldiers Exposed for 5 Days to 5782 Meters in the Himalayas*

[Estimates based on a review of Hall's original data to determine length of time subjects in each age category were confined to bed because of illness]

Age	Number of subjects requiring—			
	No bed	Bed <1 day	Bed >1 day	Total
20	0	4	1	5
20 to 24	3	2	5	10
25 to 30	2	2	1	5
Total	5	8	7	20

mountaineers, part of the answer may be found in previous training and motivation. The older man is presumably willing to accept the discomfort and anxiety associated with exposure and work at altitude secure in the knowledge, based on the firsthand experience of the past, that the situation is tolerable. On the other hand, one cannot completely discount the possibility that the older mountaineer does better because his acclimatization processes, having been previously exercised, are more effectively mobilized and thus minimize the severity of altitude sickness. The observation of Pugh (ref. 7), when he was referring to successive ascents to altitude, is very much to the point because he notes that most of the people he knows who have personal experience would say they had less trouble the second time. He said he would certainly claim for himself that he had less trouble, although his ceiling is lower now that he is getting older. Perhaps this phenomenon can be considered evidence of a biological memory which, once established, promotes successful patterns of acclimatization to subsequent exposures. Considerations of previous training and exposure, important though they may be to mountaineers, are not believed to be important factors in the present study, since only 3 of the 28 subjects had previously lived at altitude. However, it is interesting that one of these, a 33-year-old member of team A, volunteered the information that his second exposure, which followed his first by about 9 months, was much more tolerable.

The possibility of a relationship between maturity and the qualities that promote operational effectiveness cannot be discounted. Maturity in a physiological sense occurs at about age 20 in males and age 21 in women (ref. 15). With respect to altitude tolerance, the Wrangell data suggest that males have a critical point (perhaps a kind of "setpoint") at about age 25 which tends to divide the ineffectives from the more effective. The observations of Luft and the analysis of Hall's data as presented in table 7 seem consistent with such a conclusion. Although the temporal coincidence observed between physiological maturity and setpoint age cannot be considered cause and effect, evidence of a setpoint phenomenon in females of an appropriate age would tend to be confirmatory. Unfortunately, few references are to be found on this matter. Harris et al. (ref. 16) observed that girls of college age when compared with men experienced less shortness of breath, chest tightness, and so forth, at 4300 meters (14 110 feet) and Ravenhill (ref. 17) in referring to altitude sickness felt that women suffer less than men.

Physical Fitness

Fitness refers to the efficiency with which physical work can be performed. A highly fit person requires less energy to perform a physical task than does someone in poor condition. Presumably the fit person, because of training, has not only greater skill and dexterity but also more efficient metabolic processes and should be better able to tolerate altitude. Our data on fitness are inadequate since the status of less than one-half of the subjects is defined. In even those the applicability of the fitness test used is open to question. Table 5 presents the available evidence which compares operational effectiveness as a function of fitness and age. In this connection, Dr. C. J. Eagen, resident scientist for the Wrangell effort, found no significant differences between the fit and less fit as a result of their exposure in his report on body weight changes in teams B and C (ref. 18).

Cold Exposure

The possibility that living and working in subfreezing temperatures may affect altitude adaptation deserves consideration. Exposure to cold induces a diuresis with loss of fluids and electrolytes to cause a reduction in plasma volume and hemoconcentration. However, cold also causes a general peripheral vasoconstriction which not only serves to insulate against heat loss but also reduces the size of the vascular bed and thus adjusts one to the reduced blood volume. The extent to which such physiological changes altered the adaptability of our subjects is not known. However, since no pertinent evidence implicating age as a factor in cold tolerance has been found in the literature, it is assumed that the impact of cold, if any, should fall equally on all participants.

Day-Night Cycle

The long summer day is one of the most striking characteristics of the Earth's polar regions. At the latitude of Mount Wrangell there is little or no darkness for the best part of several weeks before and after the summer solstice. Although a long day of this kind has a potential for disturbing the inborn circadian cycle and thus affecting health and efficiency, it was not an important factor in this study. Each of the subjects had been at the same or at higher latitudes for weeks to years before moving to the summit and had already adopted his activities to the usual 24-hour day independent of the hours of daylight. There was no essential change in work and sleep schedules at the laboratory station.

Psychological Factors

Of all the variables that influence behavior in a practical situation, only a few can ever be incorporated in any series of laboratory tests. At best then, laboratory experiments only approximate real life and incorporate a potential for error since important interactions may not be observed. The Wrangell location is not a structured laboratory setting. The knowledge that unpredictable, potentially destructive, unrestrainable natural forces are underfoot and operative provides an emotional test bed that cannot be duplicated in any laboratory and may represent a reasonable terrestrial approximation to the kind of psychological stress implicit in an extraterrestrial location.

Reactions to stress include fear, anxiety, depression, tremors, speech disturbances, increased muscle tension, altered cognition which can impair performance, and physiological changes related to autonomic nervous-system stimulation. Because stress reactions may also mimic the symptoms of altitude sickness, the degree to which the Wrangell subjects were stressed by location, independent of altitude, cannot be accurately determined. That such a stress was operative and caused the evacuation of at least one subject is quite clear. The subject, a motivated, physically fit, 21-year-old man, had been an unofficial leader during the months of preascent training; he had consistently tried to improve his own performance and had urged the rest of the group to do the same. Several days before ascent he underwent an obvious change in mood and became depressed and anxious. He was allowed to ascend with his group. His first action upon arrival at the summit was to walk to the laboratory building, spread out his sleeping bag, lie down, and immediately complain of headache, weakness, nausea, and anorexia. He resisted all offers of assistance and refused to be encouraged until he was evacuated a day and a half later. He recovered quickly on returning to base camp.

In spite of this instance, the general performance of most subjects exceeded expectations. Living in isolated togetherness, the subjects maintained good individual and group discipline, remained strongly motivated to perform well, and were responsive to broad general guidance from base camp. There was no evidence of the so-called "breakaway" phenomenon that has been reported in certain long-term underwater habitation studies which feature a strong control and command function from the surface (ref. 19), perhaps because our groups had the primary responsibility of scheduling their own activities on location so that they could take advantage of weather and events so as best to accomplish their established objectives in the time which had been allotted.

Summary of Adaptation Data

The Wrangell data strongly suggest that altitude tolerance in males when measured in terms of the effective performance of physical labor, reconnaissance ski patrolling, and general responsiveness to a disciplined group regimen is related to age. Others have made observations consistent with such a conclusion at altitudes as low as 2133 meters (7000 feet) (ref. 9) and as high as 7500 meters (24 600 feet) (ref. 13). An age effect has been observed in people of different ethnic origins; for example, European and American Caucasian mountaineers (refs. 7 and 8), Indian soldiers, and Latin American miners. The effect seems to be essentially independent of cold, of prior altitude acclimatization, and possibly of physical fitness. Psychological stresses enhanced by the essential autonomic nervous instability of the young are undoubtedly important.

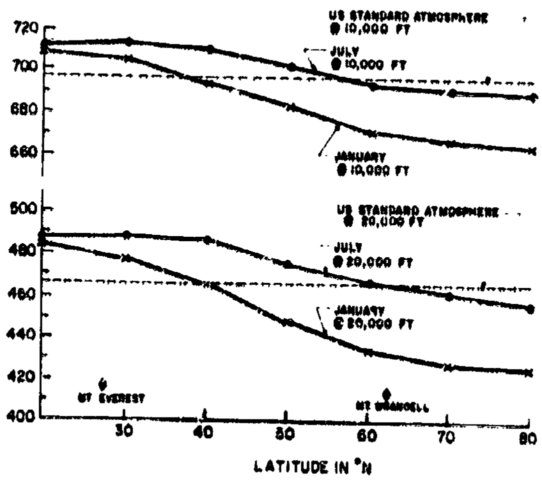

FIGURE 8.—Variation in barometric pressure as a function of altitude, latitude, and season compared with U.S. standard atmosphere (ref. 21). Latitudes of Mount Wrangell and Mount Everest are shown.

ENVIRONMENTAL VARIABILITY

Barometric Pressure

Changes in barometric pressure with pressures ranging from 572 to 608 millibars have been observed on Mount Wrangell. While part of this variability is attributable to local meteorological conditions, by far the major influence is seasonal as shown in figures 8 and 9. Pressure changes of this magnitude, particularly at altitude, are physiologically significant. For example, a subject at the Wrangell station who is at a tapeline altitude of 4160 meters (13 650 feet) and therefore assumes that he is at a pressure altitude of 604 millibars may, in the worst case, be exposed to a pressure altitude of only 572 millibars. Thus, from a physiological viewpoint, he is really exposed to an altitude of 4572 meters (15 000 feet). The effect of barometric pressure changes primarily related to latitude becomes evident if the situation at 4160 meters (13 650 feet) on Mount Wrangell is compared with that at the same tapeline altitude at 28° N on Mount Everest. In the worst case, calculated on the basis of the data extrapolated from figure 8, an Everest subject would be at a pressure altitude of 606 millibars or 4136 meters (13 570 feet) and, by comparison, would enjoy a substantial physiological advantage.

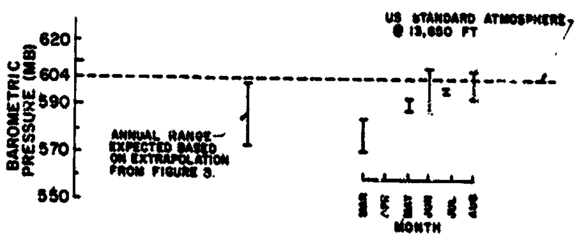

FIGURE 9.—Range of barometric pressures observed at Mount Wrangell by month and annual expected range based on an extrapolation from figure 8. Data from Bingham and Benson (ref. 23) and unpublished Arctic Aeromedical Laboratory observations.

The reasons for the seasonal and latitude barometric pressure effects have been discussed by others (ref. 20). The latitude effect is related to the axial rotation of the Earth which produces an equatorial bulging and polar flattening of the Earth's atmospheric envelope as a function of angular velocity and the Earth's diameter. The seasonal effects are related to the changes in thermal inputs to the atmosphere from solar radiation as a function of the 22° axial inclination of the Earth.

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Air Temperature

The mean average temperature at the Wrangell station is −20° C (ref. 21). Figure 10 shows the temperature lapse rate as a function of season. These readings are free-air temperatures recorded from an aircraft during ascent from the base camp. It is evident that temperatures at the summit have a relatively narrow range when compared with the wide seasonal excursions seen near sea level only a short distance away.

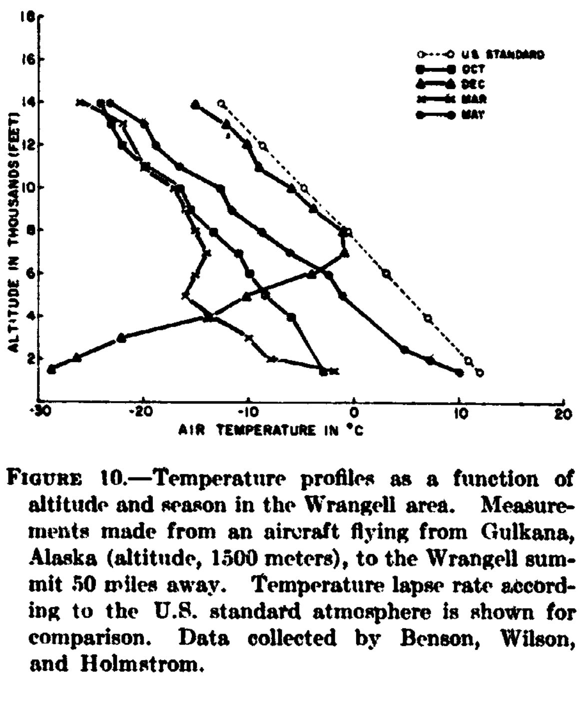

FIGURE 10.—Temperature profiles as a function of altitude and season in the Wrangell area. Measurements made from an aircraft flying from Gulkana, Alaska (altitude, 1500 meters), to the Wrangell summit 50 miles away. Temperature lapse rate according to the U.S. standard atmosphere is shown for comparison. Data collected by Benson, Wilson, and Holmstrom.

Ground Temperature

Mount Wrangell's attractiveness as a location for an arctic altitude station is related in part to the availability of usable ground heat in the region of the ice-free ridge. A reconnaissance study performed in 1961 by Benson (ref. 21) provided the basic data. (See fig. 11.) The ash comprising the main body of the ridge was identified as typical Pacific rim andesites. The thermal gradient in the ridge was found to be 0.30° cm^{-1} down to a depth of 1 meter. Calculations performed in 1963 (ref. 22) showed the heat flux to be sufficient to maintain a 16- by 24- by 8-foot structure with an uninsulated floor and 4-1/2-inch-thick insulated walls and roof at an interior temperature of 20° C in the face of an external temperature of −40° C. Since its erection in 1964 the present structure has, in fact, remained warm, fairly dry, and stably located in its original position. The enormous logistical advantage of being able to draw on an unlimited thermal source for warming an arctic building in a remote location can be best appreciated by those with some experience in the polar regions.

During construction, three dial thermometers reading from 0° to 100° C were mounted in the plywood floor to measure ash temperatures below the building as shown in figure 12. During the period of occupancy substantial temperature variations were seen; they rose on occasion to the boiling point of water (84.7° to 86.4° C, depending on barometric pressure) at rates as high as 4.5° C hr^{-1}. (See fig. 13.) Bingham and Benson (ref. 23) have observed that the temperature rises correlate well with decreases in barometric pressure and explain it on the basis of Elder's steaming ground model. They feel that the temperature effect, although operative in the whole ridge, is accentuated in the ash under the structure probably because the hut, acting as a seal, prevents the free escape of water vapor to the outside.

In addition to the main ice-free ridge, there are other evidences of volcanic heat such as a modest crater, several small, hot areas scattered around the rim of the caldera, and one area of several hundred square meters of red clay formed by the hydrothermal alteration of the rock in the area. The temperature of the clay surface ranges from warm to hot to the touch, with temperatures as high as 86° C having been measured. Blue-green algae tentatively identified as a *Phormidium* have been observed growing on the warm surface. Unfortunately, no systematic biological study of this or any of the other ridges has been undertaken, although such an effort might prove very interesting, particularly if the results could be compared with similar studies from other mountainous areas such as the warm spots on Mount Erebus (altitude 4023 meters (13 200 feet)) at 77° S.

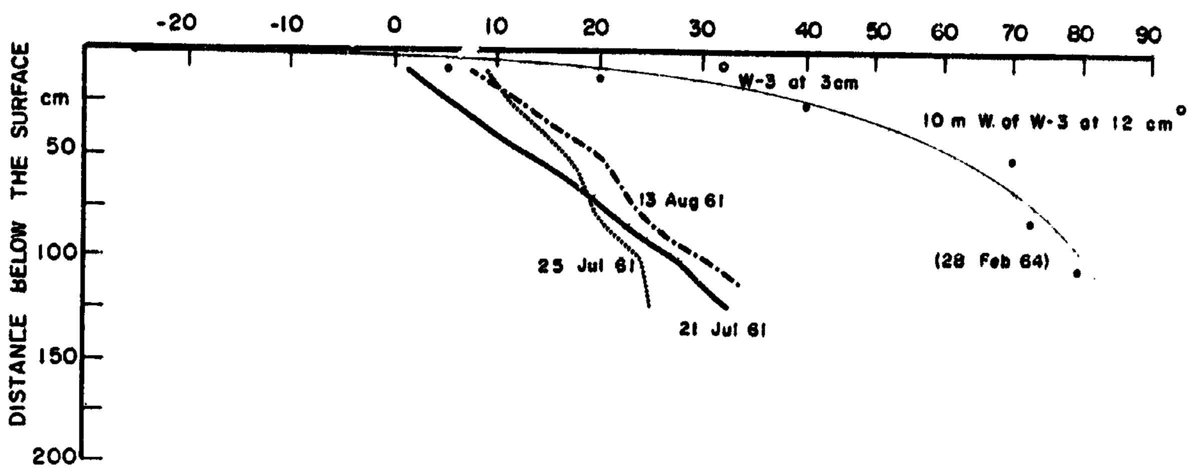

FIGURE 11.—Temperature gradient in ice-free ridge. 1961 data from Benson (ref. 21) 1964 data collected by Bingham and Wilson.

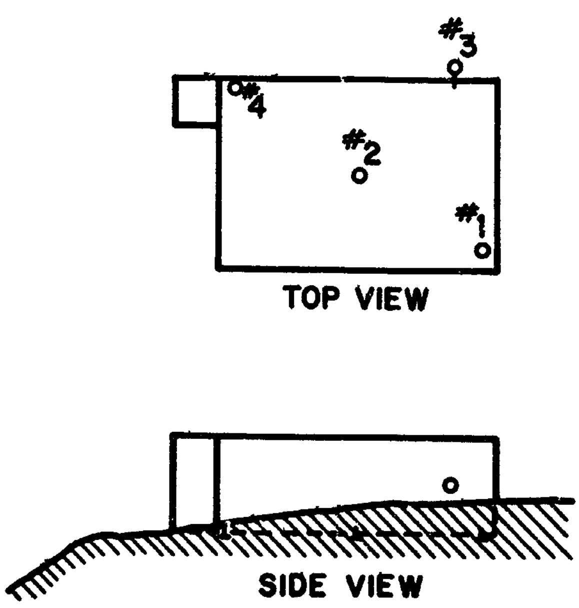

FIGURE 12.—Floor plan showing location of thermocouples used to measure ground-floor temperatures. Thermocouple 3 was located outside, next to wall of hut, and measured free-air temperature.

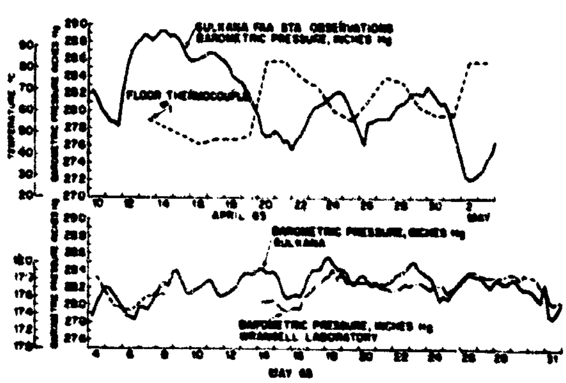

FIGURE 13.—Comparison of barometric pressures. Data collected by personnel from Geophysical Institute, U.S. Army, and U.S. Air Force. (*a*) Comparison of barometric pressures as measured at Gulkana with subfloor ground temperatures at laboratory building. Mount Wrangell pressures were not made during this time. (*b*) Comparison of barometric pressures at Gulkana and at Mount Wrangell showing the close correspondence in direction and extent of changes.

APPLICATION TO EXTRATERRESTRIAL ACTIVITIES

The Wrangell summit is one of the world's unique locations. It has the polar day; temperatures well below freezing; a massive, relatively flat, permanent snow field and icefield; a small volcanic crater; and an ice-free ridge productive of ground heat which can be trapped in useful quantities with a minimum of effort. The yearly ambient temperature range is about half as great as that in the valley lowlands 50 miles away. Barometric pressures are much lower than those ordinarily expected at such an altitude. It is remote yet logistically acceptable.

The establishment of a small facility on the Wrangell summit provided an unusual opportunity to observe several fundamental interactions of man and his environment. In the first of these, the impact of the multiple environmental and psychological stresses on the subjects appeared to have been greater than a simple sum of the parts. Thus, the Wrangell experience accentuated and uncovered a naturally occurring age-specific relationship to altitude tolerance. This is an important observation which relates to the selection and training of planetary pioneers as well as to lunar and planetary station operations. It suggests that a man in his thirties is innately superior to a younger man, a superiority probably related, at least in part, to physiological factors and independent of the processes of self-selection incidental to time. It also provides a model for the broad human response that might be seen should a degradation in the station life-support system result in a modest reduction in internal pressure and oxygen tension. Second, the significance of certain physical phenomena becomes evident only after the environment has been "stressed" by the works of man. Figure 10 shows the ground-temperature gradient as measured February 28, 1964, to be very steep when compared to earlier measurements. It was incidentally observed at the time that a thin surface layer of ash was frozen in the area. However, it was only after the ground-temperature effect under the shelter had been observed and evaluated that the abnormally steep gradient noted in 1964 could be appreciated as a variation having meteorological rather than volcanological significance. Finally, the Wrangell observations focus attention on season and latitude in determining physiologically important atmospheric characteristics in the world's high places, considerations which might also be important should an extraterrestrial location be found which possesses a sensible atmosphere.

From a logistic point of view, the use of ground heat proved to be a major operational asset. The same general principle may well apply in long-term manned extraterrestrial efforts as applies to the utilization of locally available natural resources. Although the Wrangell ridge is only a small thermal island in a vast, lifeless desert of snow on an Arctic mountaintop, when compared with other Arctic mountain sites it represents a preferred location for a manned station because of its usable heat stores. Preferred locations may also exist on otherwise forbidding extraterrestrial bodies. In defining them, the availability of local energy sources such as ground heat may well be an important criterion, in which case the observations already made at Wrangell represent only a beginning.

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