No. 156 HIGH ALTITUDE SITES AND IR ASTRONOMY, II

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ABSTRACT

This paper supplements *LPL Comm.* No. 142 in four areas: (a) The Polar plains and plateaus are moderately accessible in summertime and, because of their very low surface temperatures in winter, would appear to present special opportunities for IR observations. Upon closer examination this is only partly confirmed: very strong inversions build up in winter by radiative cooling over near-level areas, and these are in no way indicative of the warmer and more humid air above. The South Pole, because of its greater elevation, has less humidity in both the surface and upper atmosphere but has no transportation during the 6 months' winter, when astronomical observations requiring dark skies must be made. (b) Polar or Sub-Polar stations on isolated peaks will project above the inversion layer and would appear more suitable. Mount Wrangell (14,000 ft), intermittently used in the 1950's in cosmic-ray research; the Arctic Station on Mt. Logan (17,600 ft); and high mountains in the Antarctic, are briefly reviewed. Manning any of these stations *in winter* appears to present almost insurmountable problems, and the water-vapor contents would not be drastically less than for middle-latitude stations. Furthermore, the planets could, at best, be observed only near the horizon. (c) For the mid-latitudes in the Northern Hemisphere, additional reports are made on two potential sites, White Mountain (37°6 N) and Mt. Shasta (41°4 N), California; and one new IR observatory site, Mt. Lemmon (32°4 N), Arizona. A first approximation of the relative merits of these and other Northern sites is shown in Fig. 32 (using H_2O and *altitude* as coordinates, with *cloudiness* sketched out broadly); but *orographic effects, image quality,* and *sky noise* require on-site studies; and even then logistics and local supporting or adverse interests may be decisive. Mt. Lemmon is in a dry and shielded area (low wind velocities) and can thus make major contributions to IR astronomy. White Mountain is more exposed, more remote, and has stronger orographic effects; but the H_2O content is small, and intensive exploration and use of the summit appears highly justified. Such a program is now scheduled by the University of California. Other comparative studies of sites are scheduled under NASA sponsorship. (d) For the Southern Hemisphere, two promising regions are examined, the lower Western Andes (up to 16,000 ft) between 16° and 29°S in N. Chile and S. Peru, shielded from the moisture of the Amazon Basin and the Atlantic, and facing the Atacama Desert; and the Eastern Andes W of Mendoza and San Juan, Argentina, around 32°S, shielded from the Pacific. Some meteorological data for both regions are available from observatory sites and are collected here. The best sites, W of the Andes in Chile, roughly agree with the best sites in the N. Hemisphere having similar elevations. In summary, the mid-latitudes in the two hemispheres contain the most promising IR observatory sites, but no absolute statements are possible, as is seen from the discussions accompanying Fig. 32. For amounts of water vapor below about 0.2 mm, aircraft or balloons must be used.

Observers at high altitude must be aware of the medical results on high-altitude sickness. We are therefore pleased to be able to publish in *LPL Comm.* No. 157 an invited paper by a world authority on this subject. The importance of prior acclimatization for a few days at a base camp at around 9,000 ft, stressed in Paper I, is confirmed and documented; as is the importance to visiting scientists of the presence of medical assistance on a site well above 14,000 ft. Prof. Rennie's "Conclusions" deserve very careful consideration prior to doing any astronomical work well above 14,000 ft, even if pressurized rooms are used for living and sleeping quarters. An economic solution of the pressurization problem is described by Mr. F. de Wiess in Appendix II.

1. The Polar Regions — Low-Altitude Sites

(a) The Arctic — Because of the very low surface temperatures recorded in the Arctic in winter, one may inquire whether accessible sites would have special merit for IR astronomy. For instance, College, Alaska, is located just below the Arctic Circle (148°W, 65°N, 1,000 ft elev.). The Geophysical Institute of Alaska is located there. The region is shielded from the Pacific by the very high McKinley range, and it is open to the very cold flows from the Pole. The question is whether the low winter surface temperatures are at all indicative of a correspondingly low total H_2O content, or are due to Arctic air beneath warmer and more humid air.

Table 1 lists for four elevations the 5 and 25 percentiles of the dew points above College, Alaska, for the month of January, as derived from AFCRL *Atlas* (Gringorten *et al.,* 1966). Especially for the most significant 5 percentiles, an *inversion* of the water-vapor distribution is clearly marked, with the total amount of precipitable water in the vertical column found to be 0.9 mm. The corresponding amounts for other stations are: Mt. Lemmon (Ariz.) 1.0 mm, Mt. Agassiz (Ariz.) 0.6 mm, and Mt. Shasta (Calif.) 0.35 mm (Paper I, Table 1). Actually, the mountain sites may, at night, be even better, owing to subsidence (I, p. 126).

TABLE 1

"DEW" POINTS ABOVE COLLEGE, ALASKA, AND SHASTA IN JANUARY

P(MB)	ELEV.	5%	25%
970 (Al.)	Surface	−45° C	−31° C
850	1.5 km	−35	−27
700	3.0 km	−41	−33
500	5.5 km	−51	−46
592 (Sh.)	4.3 km	−38	−32

This result is consistent with a report by 6 Russian scientists (Vasil'chenko *et al.,* 1968) who tested the area of extremely low temperature near Yakutsk, Siberia, 63°N (the "North Pole of Cold"), using IR and microwave spectroscopic equipment. Though the temperatures at the time of the observations were −60°C, the vertical column contained as much as 0.5 mm precip. H_2O, as determined from the 1.38 and 1.87 μ H_2O bands. Earlier, about 1940, Prof. Gerhard Herzberg had a similar experience in Saskatoon, Sask., Canada. He found (Herzberg, 1970):

> "The results on the solar spectrum were very disappointing. Spectra taken at times when the outside temperature was −40°C had almost the same intensity of the H_2O lines as spectra taken under more normal conditions. In other words, low temperature of the observing station is no guarantee of low water-vapour concentration through the atmosphere. My feeling is, therefore, that there is no great advantage to be gained from going to Arctic stations for infrared astronomy. The important thing of course is to be as high as possible."

Thus, there are *no special advantages using low altitude sites in the Arctic.* Isolated mountain peaks no less than 10,000 ft (3 km) high, well above the inversion layer, may be of interest.

(b) The Antarctic — The Antarctic is a large icecap surrounded by oceans, whereas the Arctic is an ocean surrounded by land masses. The oceans being more nearly isothermal during the year than the land masses, the summer heat flow into the Antarctic is much less than the summer heat flow into the Arctic. This, with the elevation difference, causes the Antarctic temperatures to be some 25°C lower. The monthly mean temperatures at the South Pole range from −25° to −62° C; those of the Arctic basin, from 0° to −35° C (Rubin, 1962).

The South Pole itself is 9,186 ft (2,800 m) above sea level, with an annual mean temperature of −51° C. It is the site of a permanent Station, Amundsen-Scott, operated by the U.S.A. The mean monthly temperatures are shown in Fig. 1 (Rubin,

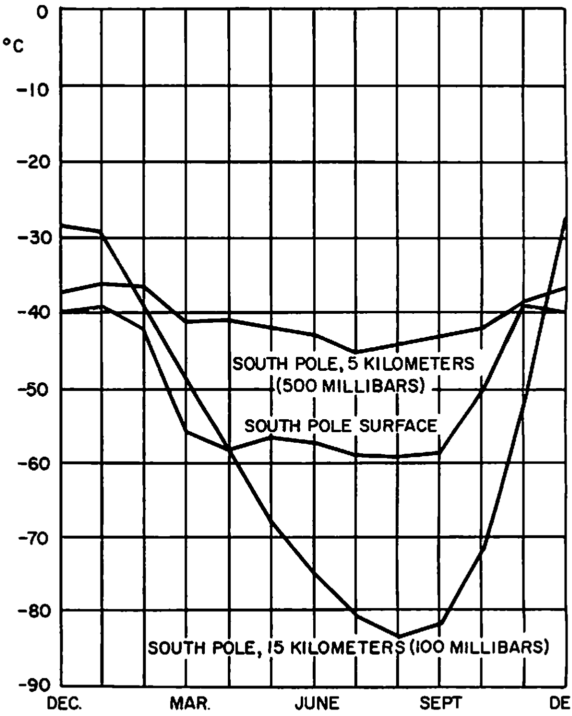


Fig. 1 Mean monthly temperatures at Amundsen-Scott Station, South Pole (Rubin, 1962).

Table 2

Mean Measured Temperatures and Relative Humidities for Six Pressure Levels, South Pole

P(mb)	April 1965			May 1965			June 1965			July 1965			Aug 1965			Sept 1965			Winter 1965		
Srf.	678*	-56.1	--	682*	-57.4	--	676*	-53.0	52	678*	-65.3	--	678*	-57.5	54	675*	-63.7	--	678*	-58.8	53
650	3089	-39.7	37	3129	-40.3	36	3072	-39.6	61	3089	-44.3	28	3090	-42.1	45	3049	-45.1	46	3086	-41.8	42
600	3636	-36.1	49	3671	-37.8	49	3617	-37.7	67	3622	-39.6	43	3628	-39.9	54	3586	-40.3	59	3622	-38.5	53
550	4233	-38.0	50	4261	-40.7	50	4208	-40.1	67	4209	-41.6	41	4216	-41.6	59	4173	-42.4	52	4217	-40.7	53
500	4889	-41.5	50	4912	-44.1	44	4860	-43.8	73	4855	-44.8	38	4862	-44.9	47	4816	-45.5	47	4844	-44.1	49
450	5589	-46.0	22	5600	-48.4	--	5551	-48.1	--	5542	-49.3	--	5549	-49.4	22	5504	-49.5	--	5554	-48.4	22

The three columns for each month give: computed altitude in meters, recorded temperature in °C, and derived % relative humidity, respectively. The surface elevation is 2800 meters; the quantity with *, the surface pressure in mb.

op. cit. p. 91). The Station was activated during the International Geophysical Year and has been described in detail, among others, by P. A. Siple (1957, 1958).

Dr. Siple's descriptions and illustrations leave no illusions about making astronomical observations from the South Pole. At the end of the first winter at the Station, September 17, 1957, he recorded an outside temperature of −102° F = −74°.5 C, saw a person leaving a 100-meter vapor trail (ice fog), photographed a person who had been "observing" for 4 hours (a picture that defies description; *op. cit.*, p. 445).

The author has had the benefit of discussions with Dr. Dietmar Schumacher, who participated in a geological-paleontological expedition to the Antarctic and landed on several mountains between Victoria Land and the Pole; and Mr. Henn Oona, who spent 13 months at the South Pole itself. There are serious obstacles for using the South Polar Station for astronomical observation. A minor one is that the Station moves about ½ meter a day, since it is located on a glacier; it has now moved some distance, of the order of 1 km, from the Pole. The Station itself is buried in the glacier and is covered with some 10 ft of snow. There is no bedrock in the vicinity on which to build a major fixed installation. Snow quakes, lasting several seconds, occur about once a day which may cause changes in leveling. The blowing snow is at times a serious obstacle to survival except underground, but winds rarely exceed 40 mph. Ten to fifteen persons stay at the Station during the winter, which cannot then be reached from the shoreline. One reason is that below −50° C, aircraft break components upon landing; and that landing away from the Base is likely to be fatal. The complete inaccessibility during about 7 months will limit useful astronomical observation which, of course, can only be made (except for daylight sources) during May, June, July, and early August.

The sky in winter is most of the time clear or almost clear (cloud cover < 0.3): 78% of the time in July 1957, 76% August 1957, 67% September 1957. For 1958 the figures are: April 86%, May 71%, June 78%, July 47%, August 60%, September 39% (*Climatological Data for Antarctic Stations,* 1962). The average is 67%. This does not include light ice fogs.

Humidity data are available up to the 450-mb level. In Table 2 we summarize the data for winter of 1965, listed by monthly averages (*Climatological Data for Antarctic Stations,* 1965), and the average for the entire winter. They were all obtained at 0^h GMT. It is noted that the frigid boundary layer is thin; less than 1,000 ft (300 m) above the Station, the temperature is on the average 17° C higher than at the surface. Dr. Siple reports differences of 72° F = 40° C over the lowest 1,400 ft (*op. cit.* p. 449), a condition that incidentally gives rise to unusual optical phenomena. The astronomical "seeing" (image quality) is, however, not as bad as might thus be expected, according to Mr. Oona who made visual observations of stars with a 6-inch telescope during the South Polar winter, away from the buildings.

If the vertical water-vapor distribution over the South Pole had the normal scale height of 1.6 km, the mean temperature of −59°C and R.H. of 53% (Table 2) would signify a total precip. H_2O of only 0.011 mm. Actually, with the distribution given in Table 2, and with the 1.6 km scale height applying above 450 mb, the amount is 0.14 mm, *13 × larger,* though still low for an average wintertime vapor content (Paper I, Table 1, p. 125).

Compared to observation from aircraft at ambient +20°C through an atmosphere at −55° to −66°C and total amounts of water vapor down to 0.006 mm (as the author experienced during 30 flights on NASA's CV-990) or Lear Jet observations with 0.002 mm (F. Low), IR observations from the South Polar Station at ambient −60° or −70°C, both through an atmosphere at −36° to −40°C (Table 2) are at a double disadvantage. Yet, if the 7-month complete isolation is accepted, special programs of IR observations (such as an IR survey S of −20° or thermal variations on Jupiter) would be possible, assuming that the image quality is acceptable and that the programs will allow the observer to withdraw underground at frequent intervals, and that he can produce his own liquid helium, repair his electronics, etc.

2. *The Polar Regions — High-Altitude Sites*

Only above *isolated peaks* projecting well above the inversion layer, will near-normal water-vapor gradients occur and a reasonable balance exist between the difficulties of operation and scientific returns. IR Astronomy has parallel interests with Cosmic-Ray Physics in the establishment of high-altitude sites. The criteria are not identical, however, since IR Astronomy is interested not in the overlying air mass, but in the water vapor; and cosmic-ray observations can presumably be more readily automated and therefore be installed on very high mountains.

A very remarkable and courageous effort was made in 1947 by Prof. Marcel Schein and colleagues of the University of Chicago on Mt. McKinley (summit, 20,269 ft), occupying Delani Pass (19,000 ft), with the camp supplied by air drops. In 1952 Prof. Serge A. Korff of Columbia University made a survey of Alaskan peaks jointly with Dr. Terris Moore, President of the University of Alaska (who piloted the light plane), and landed on many peaks considered previously inaccessible (Korff, 1952). They found that Mt. McKinley presented "considerable atmospheric turbulence" and is accessible by air only about "one day per week"; it has "the most adverse flying conditions of any region that we considered." Mt. Wrangell offers about two good flying days a week, with numerous levels, up to 14,000 ft, to permit landing. A ground party from Gulkana would require about one week to reach the summit. "Five trips by air, requiring less than a full day, will enable a ton of equipment and supplies to be delivered" (Korff, 1952).

Drs. Korff and Moore established a cosmic-ray station on Mt. Wrangell (62° N, 144° W, 14,006 ft = 4,270 m) in 1953 (Korff, 1953). The author learned from Dr. Keith Mather, Director of the Geophysical Institute, University of Alaska, that the station has not been used since 1967 but could be reoccupied if an important program would justify this. In the 1950's some three dozen landings by helicopter or aircraft on skis were successfully accomplished during summer months. Unfortunately, no half-way station exists at the 9,-10,000 ft level (Paper I, Sec. 3), the only settlements being Copper Center, 43 air miles away, at 1,100 ft, and the FAA Post at Gulkana, 30 miles farther North, referred to above. Dr. Mather points out that Mt. Wrangell is a mildly active volcano with natural heating available just under the snow, and used to heat a shelter still existing.

If an Alaskan site near the 9,-12,000 ft level could be found with more than 40-50% clear weather in winter, it could probably be occupied for extended periods without great risks, and make a special contribution to IR Astronomy. (The annual mean daytime sky cover is around 70% for most of Alaska.)

The Arctic Station on Mt. Logan, Canadian Yukon, (60° 36′ N, 140° 30′ W, 17,600 ft = 5,360 m) was established in 1967 by the Arctic Institute of North America. In the following *Communication*, Prof. I. Drummond Rennie, M.D., describes the experience gained on Mt. Logan since 1967 and integrates this experience with that obtained by him and others in the Altiplano of S. America, Nepal, and elsewhere. A topographic map of the region is shown in Fig. 2, with the Station position marked with a cross. Fig. 3, taken by Mr. R. Turner of LPL, shows the plateau of the Station at the right, as seen from the NE, with Mt. Logan at the left. The lower reaches of the St. Elias Range contain the most extensive glacier field in North America outside the Arctic proper. Since the dynamics of glacier flow is so analogous to that of enormous lava flows as observed on the Moon's Mare Imbrium, one view is reproduced in Fig. 4.

Dr. Melvin G. Marcus, Chairman, Department of Geography, University of Michigan, one of the leading members of the Arctic Institute, sent the author two reports on meteorological observations on Mt. Logan carried out by his group in 1968 and 1969. The observing periods were July 2-August 2, 1968, and June 28-July 28, 1969. Table 3 quotes from his report (with J. R. La Belle) in *Arctic and Alpine Research* (Vol. 2, No. 2, pp. 103–114, 1970).

Table 3

Climatological Summary, Mt. Logan, Yukon

Climatic Factor	July 2-August 2, 1968	June 28-July 28, 1969
Mean daily temperature (°C)	-17.2	-17.4
Mean maximum daily temperature	-10.8	-11.2
Mean minimum daily temperature	-22.2	-23.9
Extreme maximum daily temperature	- 3.4	- 3.6
Extreme minimum daily temperature	-28.3	-26.6
Mean cloudiness	0.60	0.49
Mean wind velocity (m sec^{-1})	3.4	2.6
Maximum wind velocity (m sec^{-1})	23.7	8.9
Mean relative humidity (%)	-	73.0
Maximum relative humidity (%)	100.0	100.0
Minimum relative humidity (%)	22.0	23.0
Mean pressure (mb)	528.6	511.5

With the mean 1969 temperature of $-17\overset{\circ}{.}4$C and mean relative humidity of 73%, the mean precip. H_2O is found to be 1.8 mm if the scale height is 1.6

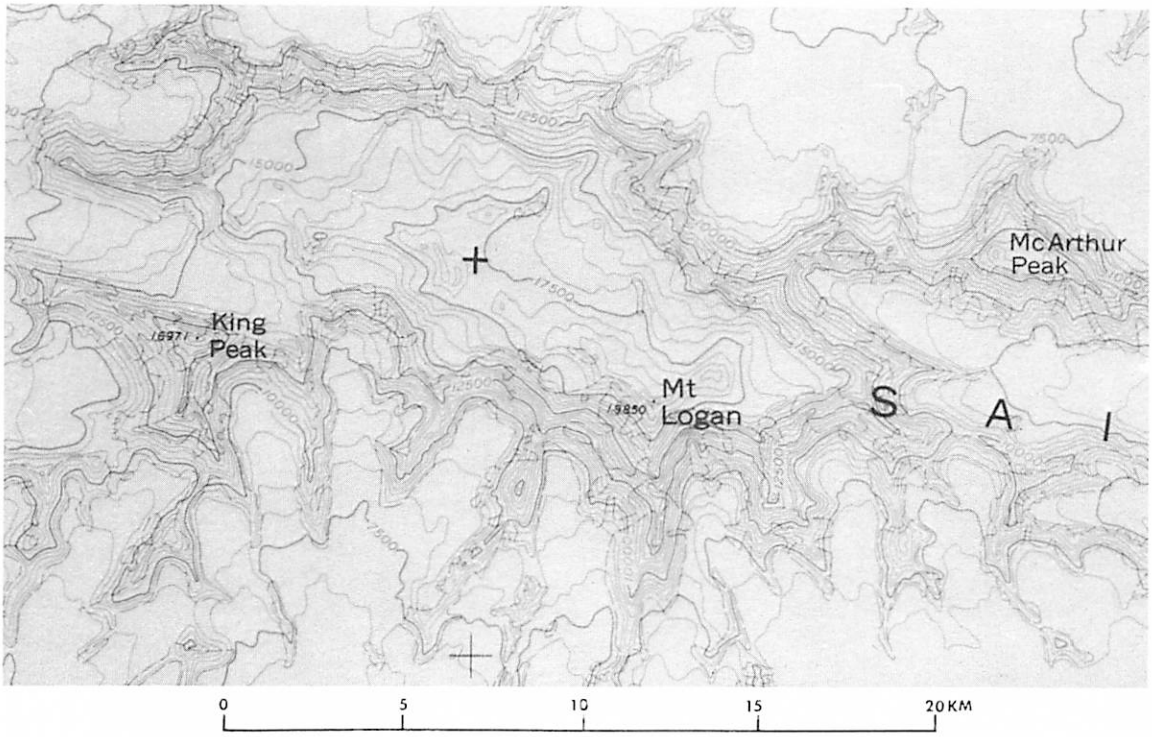


Fig. 2 Section of topographic map near Mt. Logan. Contour interval 500 ft.

Fig. 3 Mt. Logan, Canadian Yukon, looking SW from 12,500 ft. Station located near reflection from ice at right. (R. Turner)

Fig. 4 Coalescing glaciers, St. Elias Range, Canadian Yukon, taken from 11,000 ft by R. Turner.

km. (This value is uncertain; it could be both larger in the Arctic summer and smaller, due to evaporation of the glacier.) Since combining average humidities and temperatures cannot give reliable moisture contents, we use alternatively, the *mean humidities at night* when the sun does not strike the snow, measured to be often around 90%, with the *mean nightly minimum temperature* −23°C, and find 1.1 mm, probably a better value; and probably more appropriate than the median value of 0.5 mm found in Paper I (p. 135) on the assumption that free-air conditions pertain (Mt. Logan is not an isolated peak). Direct H_2O measures on the sun are needed. The percentage of cloudiness (60% in 1968, 49% in 1969) is not much below that of Alaska. The day-by-day breakdown is shown in Fig. 5 (*op. cit.* Fig. 5); together with the barometric pressure (well correlated).

It is concluded that the water vapor above the Mt. Logan Station *in summer* is similar to Mauna Kea year-round or Mt. Lemmon in winter (cf. Fig. 32, below); but the cloudiness is greater and there is no true darkness for astronomical observation (except for daylight sources).

The *Antarctic Continent* has numerous peaks that presumably project above the inversion layer. The highest point is the Vinson Massif (16,860 ft = 5,140 m) in Ellsworth Land; numerous peaks, 8,-14,000 ft, exist between 70° and 85° S, 160°-170° E (Victoria Land). Several of these peaks, up to 12,000 ft, were visited by Dr. Schumacher during the Polar summer, using aircraft on skis. He reports that the atmosphere is clear approximately ⅔ of the summertime and that clouds usually stay below 10,-12,000 ft. Presumably, in winter the clouds are lower. The mountain tops are usually bare rock or only thinly covered with snow, because precipitation is very light and the wind blows the snow away. The normal wind velocity was around 15 mph, though

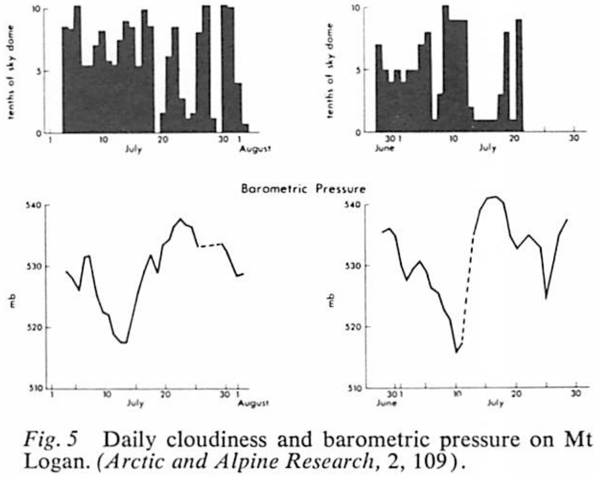


Fig. 5 Daily cloudiness and barometric pressure on Mt. Logan. (*Arctic and Alpine Research*, 2, 109).

winds up to 70 mph were experienced, and much higher winds are known to occur (the "Roaring Forties" extend to the Antarctic). Dr. Schumacher considers these mountains *inaccessible* during the Polar winter, not merely because of the flying hazards, but because *aircraft are dismantled for the winter* and shipped, e.g., to New Zealand. While servicing one of these peaks from New Zealand, during the daily brief twilight hours might at times be feasible, the dangers of maintaining a manned station on one of these peaks for even limited periods in winter would seem too great. Also, construction costs would be at least 2 orders of magnitude above normal.

3. *Mid-Latitudes — Northern Hemisphere*

In Paper I (Table 1) a dozen Northern sites were marked as meriting further studies. We are here presenting additional data on three selected sites, two in California, just above 14,000 ft; and one in Arizona, at 9,200 ft. The first two are in the 0.5 mm H_2O class, requiring transportation by turbo-helicopter, and potentially the best in the U.S.A. The Arizona site, with 1.4 mm H_2O (25%, 9 months) but, of course, better in winter, is readily accessible and is now designated as an IR Observatory, with its initial development underway. In this Section we assemble the supplementary information for these sites. The Mauna Kea Observatory (1.1 mm H_2O) completed earlier in 1970, is a good site year-round.

(a) *White Mountain, California* — In Paper I (p. 136) reference was made to the paper by O'Connor, Welch, and Tayeb of the Space Sciences Laboratory of the University of California (Berkeley), "Progress Report on the Evaluation of the Barcroft Area, Eastern California, as Infrared Telescope Site." Prof. Nello Pace, Director of the White Mountain Research Station of the University of California, called my attention to the additional facilities of the Station (Fig. 6). Personnel transportation is by

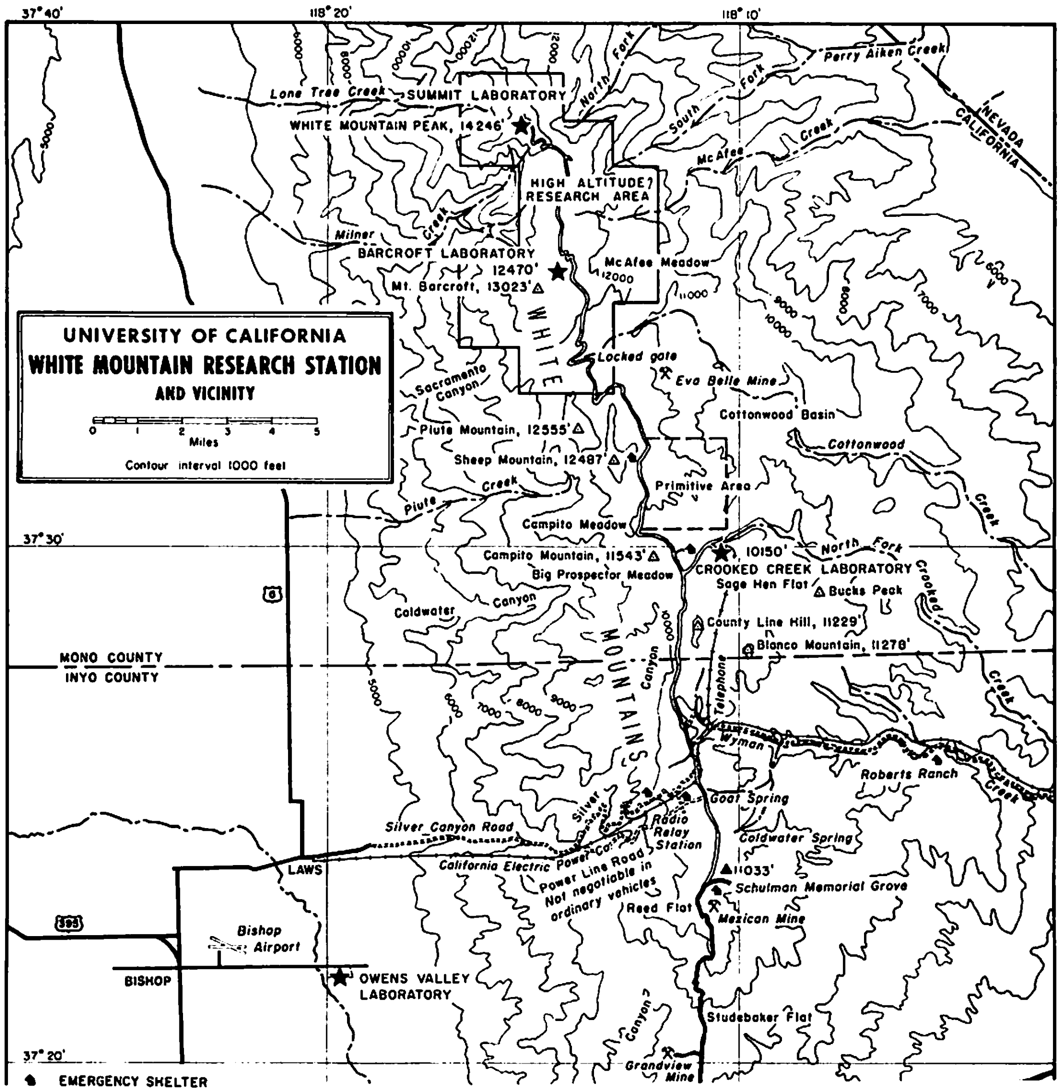


Fig. 6 Map of facilities of White Mountain Research Station, University of California.

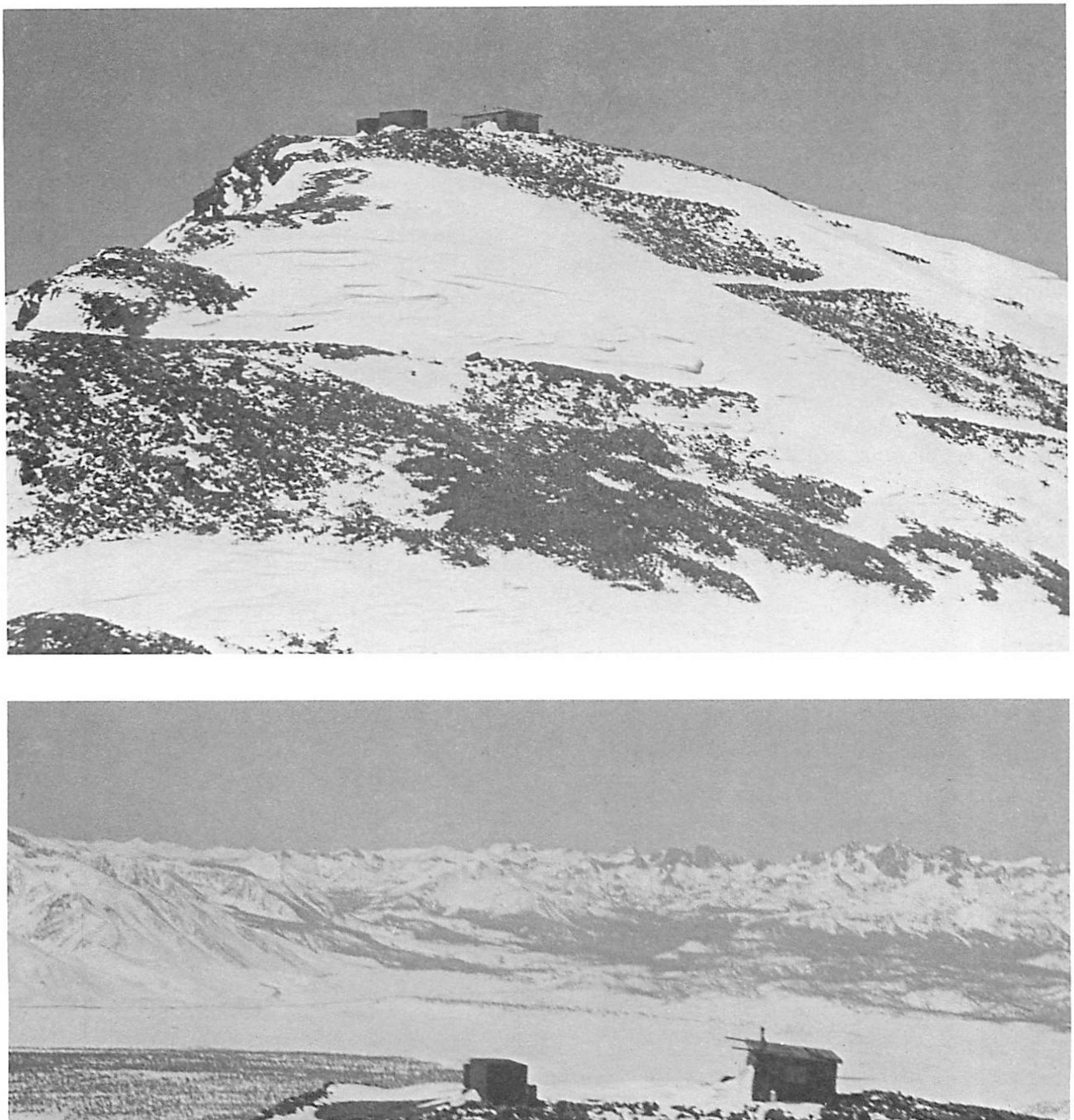


Fig. 7 Two photographs of White Mountain Research Station, University of California, taken mid-winter (courtesy Dr. Nello Pace, Director). Lower view shows Sierra Nevada in background, heavily snow covered.

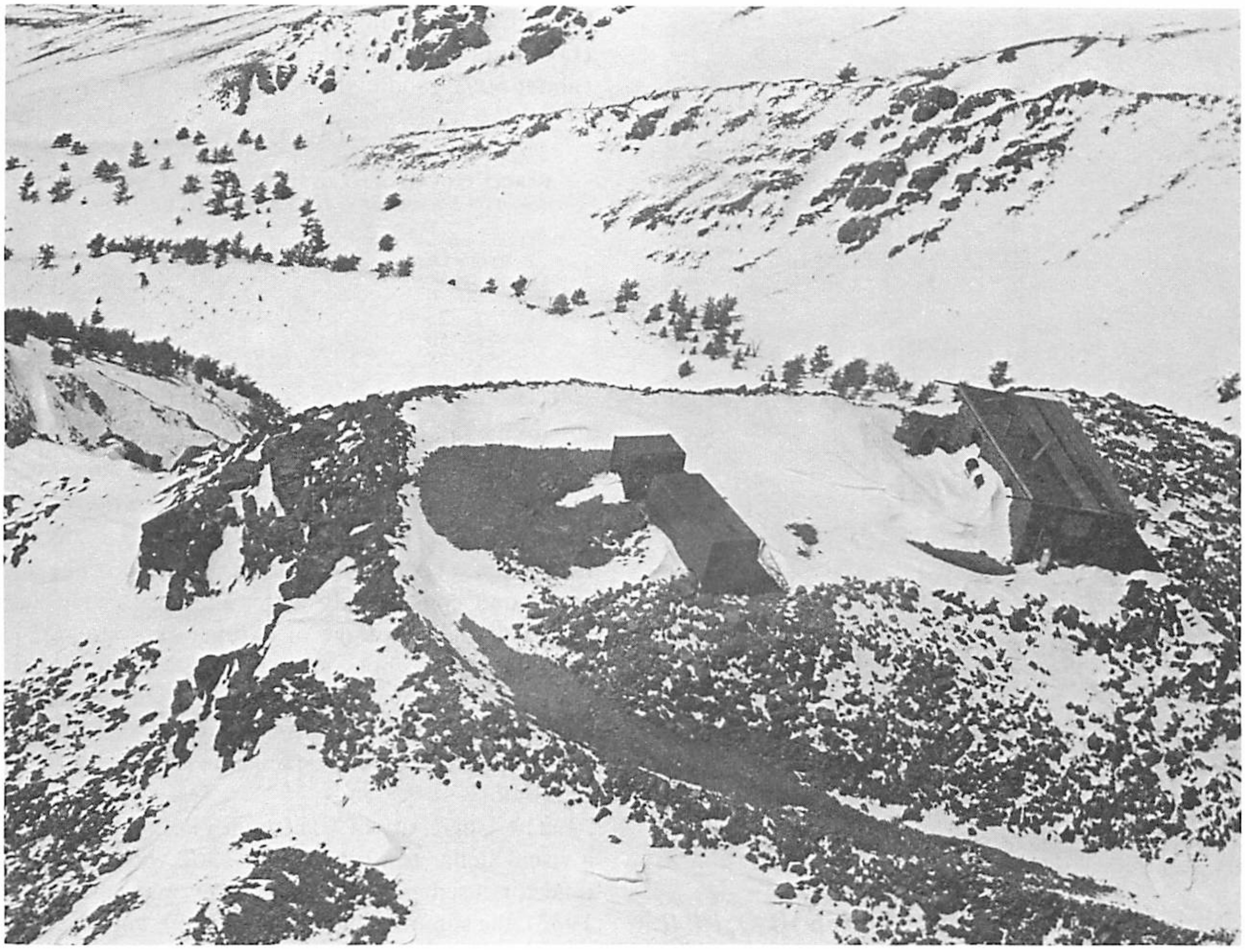


Fig. 8 Additional aerial view of White Mountain Summit Laboratory, mid-winter, (courtesy Dr. Nello Pace). Note bristlecone pines close to summit.

supercharged helicopter from the Station facility at the Bishop Airport, the connecting road being unusually long for the aerial distance and used only for construction items and heavy supplies. (This mode of transportation is not without danger, two non-fatal crashes having occurred on the mountain.) Four photographs of the summit and its shelter are reproduced in Fig. 7-9. It is seen that the winter snow cover is light. The Barcroft Laboratory is occupied on a year-round basis, as is the Crooked Creek Laboratory. A reproduction of the scale 1:62,500 topographic map of Barcroft and the White Mountain summit is found in Fig. 10.

For the *Barcroft Laboratory* 15 years of meteorological data are available (Pace *et al.,* 1968), summarized in Table 4; and more recent astronomical data are found in Table 5 and in the text. The coldest nights of each of the 15 years are scattered, remarkably, over 7 months: Oct., Nov., Apr., each 1; Jan., 2; Dec. 3; Feb. and Mar., each 3½. Coldest nights below −30°C occurred on Mar. 6, 1956; Nov. 17, 1958; Jan 4, 1960; Mar. 10, 1964 (record); Dec. 13, 1967, indicating that a heavy snow load on the continent is not a precondition (though March is statistically probably the best month).

If the mean daily minimum temperature for *January,* −13°4 C (Table 4) is combined with the mean relative humidity at 8 A.M., 65.0%, one finds the absolute humidity of about 1.04 g/m^3. The daytime radio-sonde data by O'Connor *et al.* (1969) indicate the average scale height to be only 0.8 km, which, if valid also at night, puts the mean sunrise H_2O at *0.84 mm.* The median of 30 surface (daytime) *solar* measures, *February-March* 1968, is also 0.84 mm (O'Connor *et al.,* 1969, Table 16). For April and May 1968 the median from 32 solar measures, all but 8 between 7 and 12 A.M., was 1.2 mm. Twenty-two surface relative humidity measures, made on *clear days* at 8 A.M., Dec. 1967-Feb. 1968, yielded the medians: temperature −12°5 C,

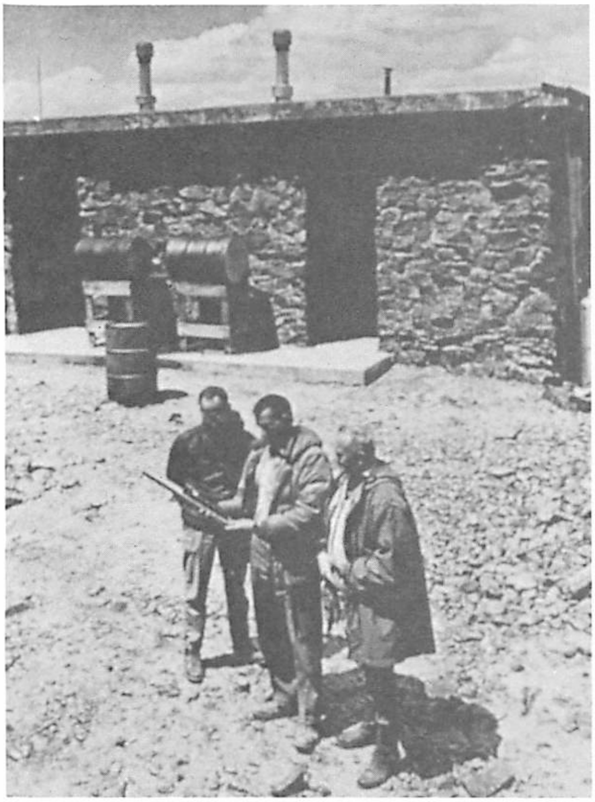


Fig. 9 Close-up view of White Mountain Summit Laboratory, summertime.

relative humidity 36% and 0.40 mm H_2O (if $H = 0.8$ km). The lowest T recorded was $-30°C$ (R.H. = 40%), quite exceptional (cf. Table 4); here the mean $H = 0.8$ km probably did not apply so that the computed H_2O, 0.11 mm, will be a lower limit. The next lowest values were $-24°C$ (R.H. = 61%) and 0.32 mm. The distribution of cloud cover for both day and night, recorded by all-sky cameras (O'Connor *et al.,* Table 2), is quoted in Table 5 (about 50% good nights).

TABLE 5

PERCENTAGE CLOUD COVER, BARCROFT LABORATORY FOR ENTIRE SKY, JULY 1967–MARCH 1968

% CLOUD COVER	DAY	NIGHT
0	12	30
1– 25	23	19
26– 50	18	9
51– 75	24	14
76–100	21	25

White Mountain (Barcroft) was included in an important study supported by ONR, extending over about 14 months, 1948–1949, of the *coronographic quality* of the sky in comparison with Sacramento Peak, New Mexico, and Climax, Colorado. The site was found considerably better than the other sites (some 4^h daily average of excellent coronographic quality), but was not chosen for development apparently because of its remoteness. (The author is indebted to Dr. N. Pace for a copy of the report.) This program led to the establishment of the Barcroft Laboratory.

The University of California (Berkeley) started a visual stellar test program in 1962 with a 10-inch reflector, used near Barcroft (July and early Aug. 1962), the summit (mid-August 1962), and Crooked Creek (late August and Sept. 1962). The principal observer was Mr. E. Simpson. He found the image quality best at Crooked Creek, almost as good as at the Lick Observatory. His tests on the summit, for one week, were hampered by very strong west winds.

With NFF support the Barcroft site was used

Table 4

MONTH SUMMARY, BARCROFT LABORATORY, 1953-1967

(extracted from Pace et al, 1968)

Quantity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	15 yr Mean
AV MAX TEMP °F	22.8	22.8	23.4	28.7	34.9	45.0	53.7	52.8	47.1	39.9	31.0	25.9	35.7
AV MIN TEMP °F	7.8	7.0	6.7	11.6	18.6	28.7	36.5	35.9	30.5	24.1	15.9	10.7	19.5
LO MIN TEMP °F	-25	-21	-35	-15	-15	2	14	17	4	-20	-28	-26	-35
AV MEAN TEMP °F	15.3	14.9	15.0	20.2	26.7	36.8	45.1	44.4	38.8	32.0	23.5	18.3	27.6
AV 8 AM R.H. %	65.0	66.7	66.0	62.3	57.9	49.3	45.5	46.4	47.0	47.0	56.7	57.9	55.6
AV SNOWFALL in.	20.2	16.9	17.8	21.5	26.2	8.2	2.1	0.9	5.9	11.3	14.9	18.1	164.0
AV SNOW DEPTH in.	14.3	20.3	22.3	22.3	18.6	5.8	0.4	0	0.2	1.3	4.9	9.6	10.0
HI SNOW DEPTH in.	81	79	80	96	91	46	15	3	6	28	33	93	96
AV DAYS PRECIP	9.5	8.7	10.4	9.5	9.9	5.2	4.9	4.3	3.8	4.0	7.5	6.8	84.5
AV MAX WIND knots	28.3	29.6	26.9	24.0	22.3	18.6	16.2	16.4	18.3	20.3	24.3	25.6	22.6
HI MAX WIND knots	N 82	(2)70	NW 65	W 72	W 56	W 44	S 46	SW 46	NE 44	W 70	N 58	W 68·	N 82
MAX WIND DIR													
N %	17	23	18	10	12	7	3	2	7	14	16	17	12
NE %	4	5	4	6	8	4	4	4	6	5	6	9	5
E %	3	1	3	3	7	5	11	9	7	8	2	1	5
SE %	0	1	2	3	5	11	17	11	8	5	3	1	6
S %	3	3	4	5	8	12	24	24	14	6	6	4	9
SW %	12	10	17	17	17	21	20	22	21	11	21	15	17
W %	48	47	40	49	38	35	20	27	34	44	34	42	38
NW %	13	10	14	8	5	5	1	1	3	7	13	13	8

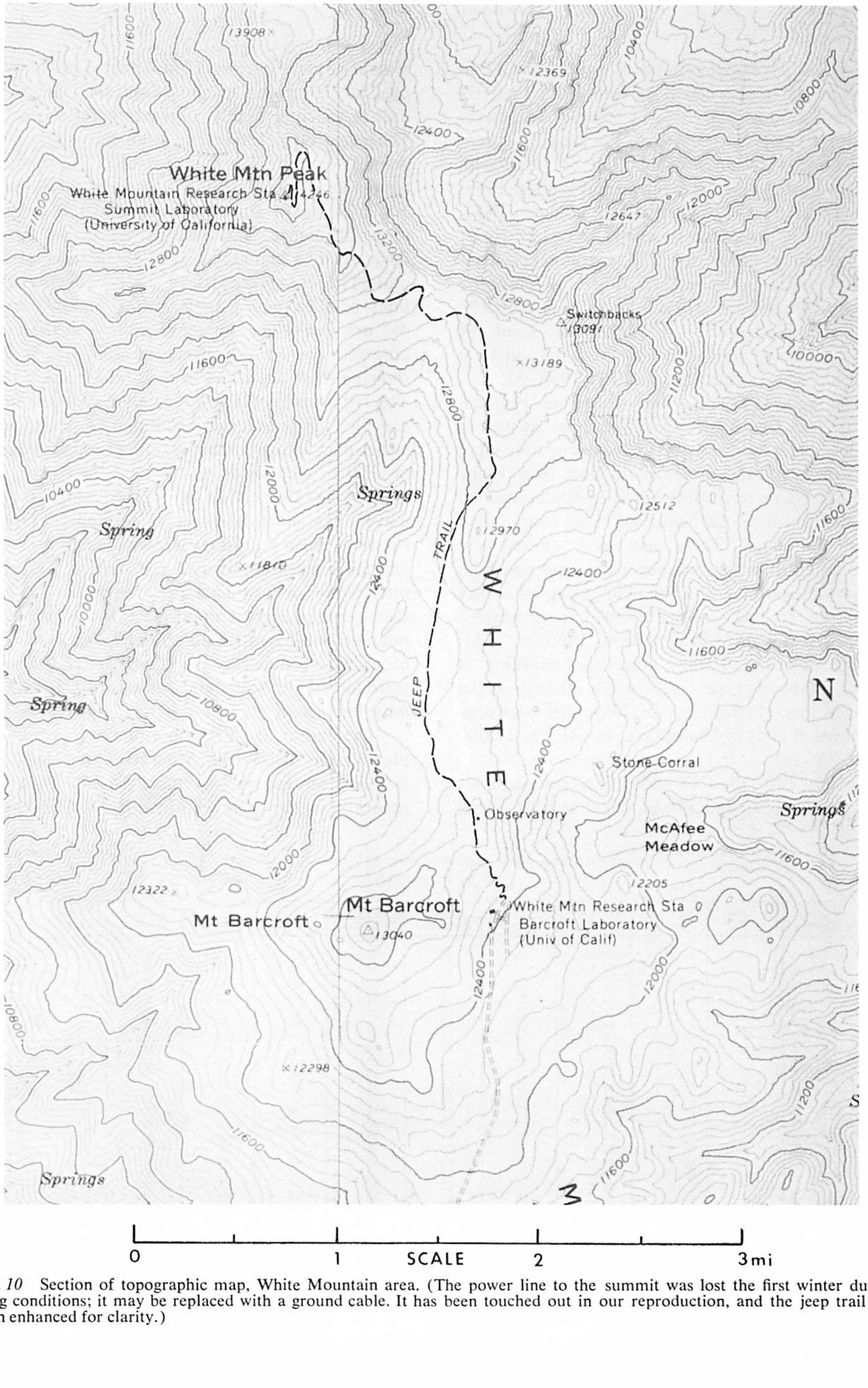


Fig. 10 Section of topographic map, White Mountain area. (The power line to the summit was lost the first winter due to icing conditions; it may be replaced with a ground cable. It has been touched out in our reproduction, and the jeep trail has been enhanced for clarity.)

also by Drs. B. Murray and J. Westphal of CIT in the 10 μ region, at a new *observatory* (cf. Fig. 10) housing a 20-inch (50.8 cm) telescope. The elevation was 12,800 ft = 3,900 m. They used it extensively during the *summer and fall of 1962,* with several important results (Murray and Wildey, 1963; Westphal *et al.,* 1963; Murray and Wildey, *1964*). Because of its remoteness (when reached by road) and the winter snows, the CIT astronomers abandoned the site in November 1962 and moved a 24-inch telescope to Crooked Creek Lab. (10,150 ft, cf. Fig. 6) by mid-1963. This site, E of the mountain range, was found less satisfactory at 10 μ (more sky noise) and was used only 1963–64.

The author has had the benefit of personal reports from Drs. Murray and Westphal, as well as of seeing a film they took in 1962 showing time-lapse photography of the atmospheric flow over White Mountain with a west wind, based on observed cloud formation on the west flank and cloud evaporation on the east flank. These *orographic effects* were found quite prominent whenever the wind was from the west, the normal direction. The strong 10 μ "sky noise" observed was also attributed to orographic effects (Westphal, Murray, Martz, 1963, p. 753). On the other hand, they considered working at the 12,800-ft level quite acceptable (though at the expected loss of efficiency; Dr. Westphal later continued his studies at Chacaltaya, Bolivia, at 17,600 ft = 5,350 m).

In July 1962 the CIT expedition obtained a set of meteorological and astronomical test data that remain of great interest. I am indebted to Dr. Westphal for permission to quote from the original records of which he kindly supplied photostatic copies. The meteorological data and a summary of the astronomical data are found in Table 6. The minimum temperatures agree with the average for Barcroft, 300 ft below, in Table 4, but the daytime temperatures are higher. This essentially accounts for the lower relative humidities, only ⅔ of those at Barcroft. The seeing records (17 sheets) cover observations of stars and planets during nightly runs of 4-7 hrs. each. The Jupiter satellites, on the nights observed, could nearly always be seen as clear discs, showing their diameters in the correct proportions. The last column of Table 6 combines the maximum observed image excursions and blur (a photometric, rather than an astrometric quantity), taken from the original 17 data sheets.

The best IR location on White Mountain is probably the *summit* and the best period probably *December-May,* when the airflow is less dominantly oceanic and more often continental (or Arctic); and more often along, rather than across, the crest (Table 4). Because of the great importance to discover optimum ground-based IR sites, *the IR tests at the summit,* now scheduled by the University of California astronomers to start mid-January 1971, *will be most important.*

The author had the opportunity to inspect and photograph the White Mountain area from the NASA Lear Jet on November 16-17, 1970. The general topography is seen in Fig. 11. Figs. 12–16

Table 6

Atmospheric Data, Summer 1962, White Mountain Station #1 (12,800 ft)

(Courtesy Dr. Westphal, CIT)

Morning Date	Clouds %	Wind mph	Max. 1-hr. Wind	Temperature (°F)					Rel. Humidity	Stellar Seeing
				8 a.m. PST	24-hr. Max.	24-hr. Min.	Wet Bulb	Dew Pt.		
June 29	0	SE 8	SE 11	54	60	30	39	24	30%	1"
30	0	S 6	SE 10	52	60	32	38	24	32	1
July 1	0	SE 6	SE 13	56	64	34	42	30	36	1-2
2	<5	SE 6	SE 15	52	64	32	38	24	32	~1-2
3	0	SE 8	SE 14	54	62	30	37	22	26	2
4	0	S 19	SW 14	48	63	30	34	18	28	1½
5	0	SE 8	SE 10	54	56	28	40	27	34	1-2
6	0	N 2	NE 8	56	60	30	41	27	32	1-2 A B
7	0	E 8	E 12	55	61	32	40	26	32	1-2 A
8	0	SE 10	S 15	58	62	35	42	28	30.7	1½-3 A
9	<5	E 12	E 20	50	60	31	35	18	26	2-3
10	0	SE 10	SE 15	56	62	35	41	27	32	~2 A
11	10-20	SE 10	SE 12	58	62	40	47	38	50	1½-2 A
12	60-90	SE 4	SE 8	46	59	32	35	23	39	
13	~5	SE 6	SE 15	54	64	39	42	32	42.7	2-3
14	5-10	SW 0	NE 10	57	65	41	42	29	33	2-3
15	0	SW 8	SW 14	56	68	34	42	30	34	2-3
16	0	SE 6	SW 12	58	64	36	43	30	34	1-3
17	0	S 10	SW 10	58	61	36	42	28	32	2-3
18	0	S 12	SW 16	58	62	35	42	28	32	2-3
19	0	SE 6	SE 11	58	68	36	42	28	32	1-4 A
20	0	S 7	SE 12	60	70	40	43	28	28	2-4 A
Aver.	--	--	--	54.9	62.6	34.0	40.3	26.8	33.1	--

A: Jupiter satellites clear discs; B: Saturn satellites <½".

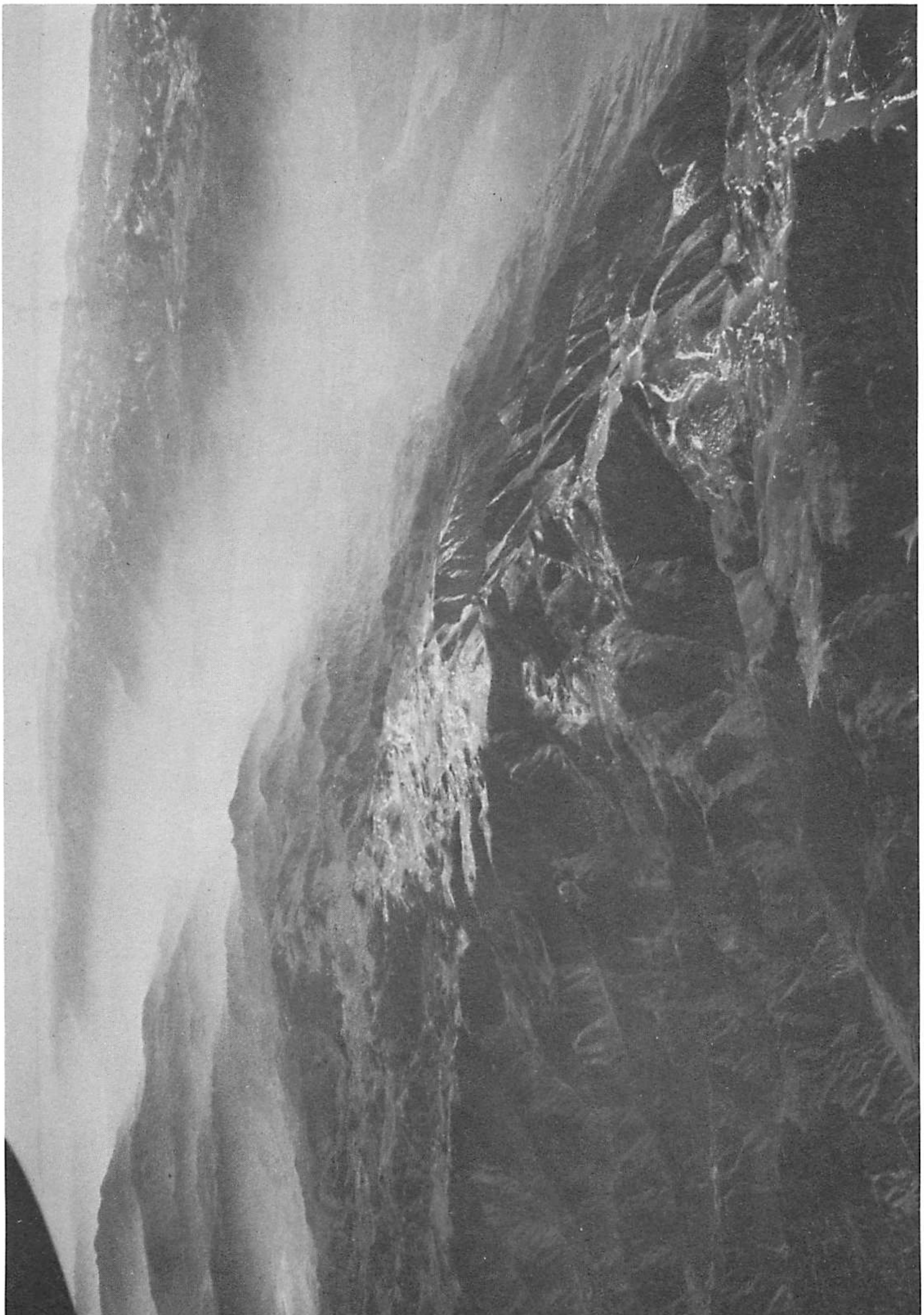


Fig. 11 White Mountain, seen from N, 41,000 ft, Nov. 17, 1970. Owens Valley (under haze) beyond; Mt. Whitney area of Sierra Nevada, 100 miles away, ⅓ from right; Mt. Piños, 230 miles away, NW of Los Angeles, behind defect. Haze below 5,000 ft over entire region.

Fig. 12 White Mountain summit area, Nov. 16, 1970, from W. Note light snow cover and approach from right; Nevada in background. Barcroft Lab. just off margin at right.

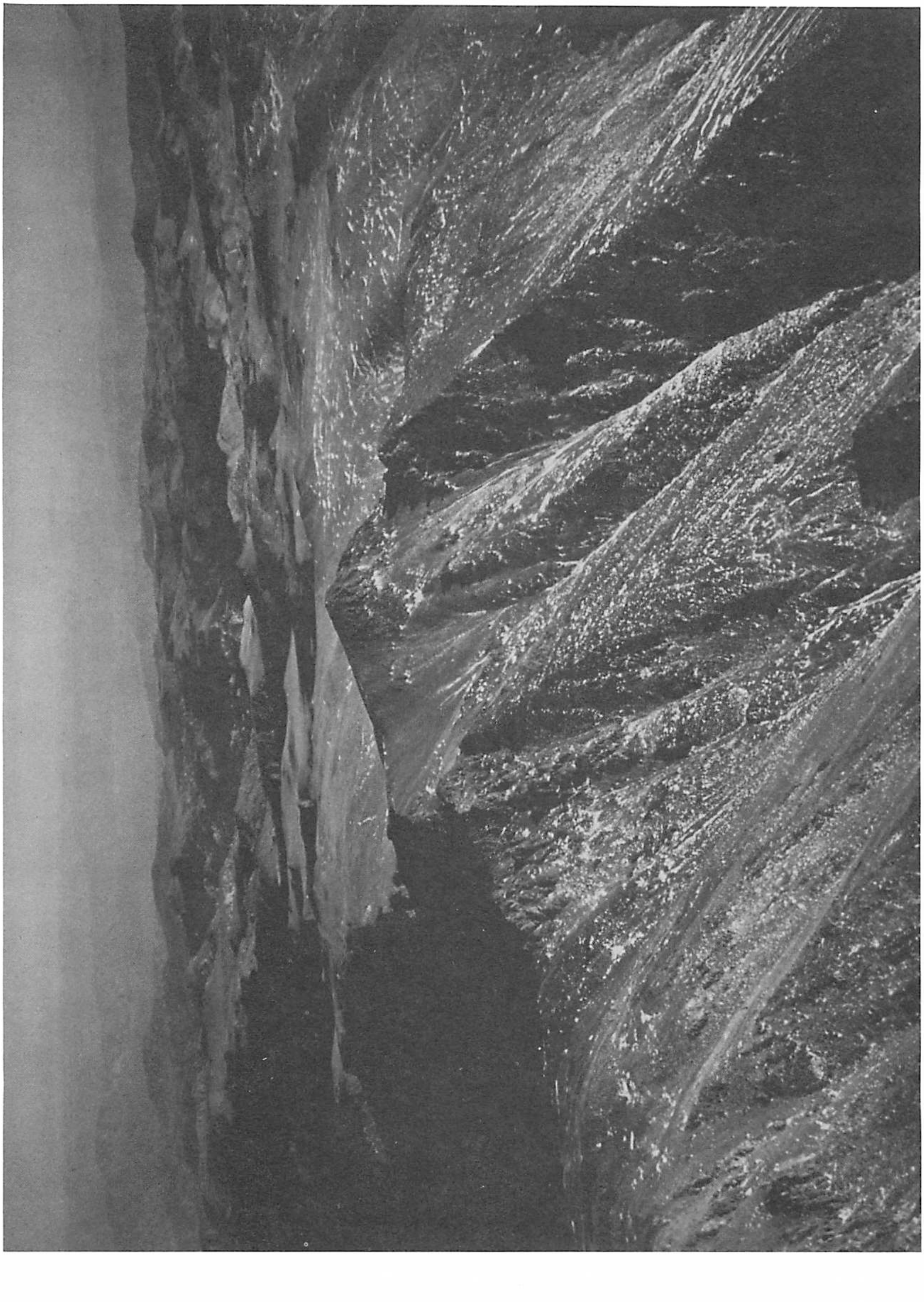


Fig. 13 As Fig. 12, from NW; surface approach from behind summit. Helicopter landing possible on "saddle" 1 inch left of summit. Crest to plateau at lower left (13,900 ft, cf. Fig. 10), impassible. "Saddle" is about 180 ft below summit.

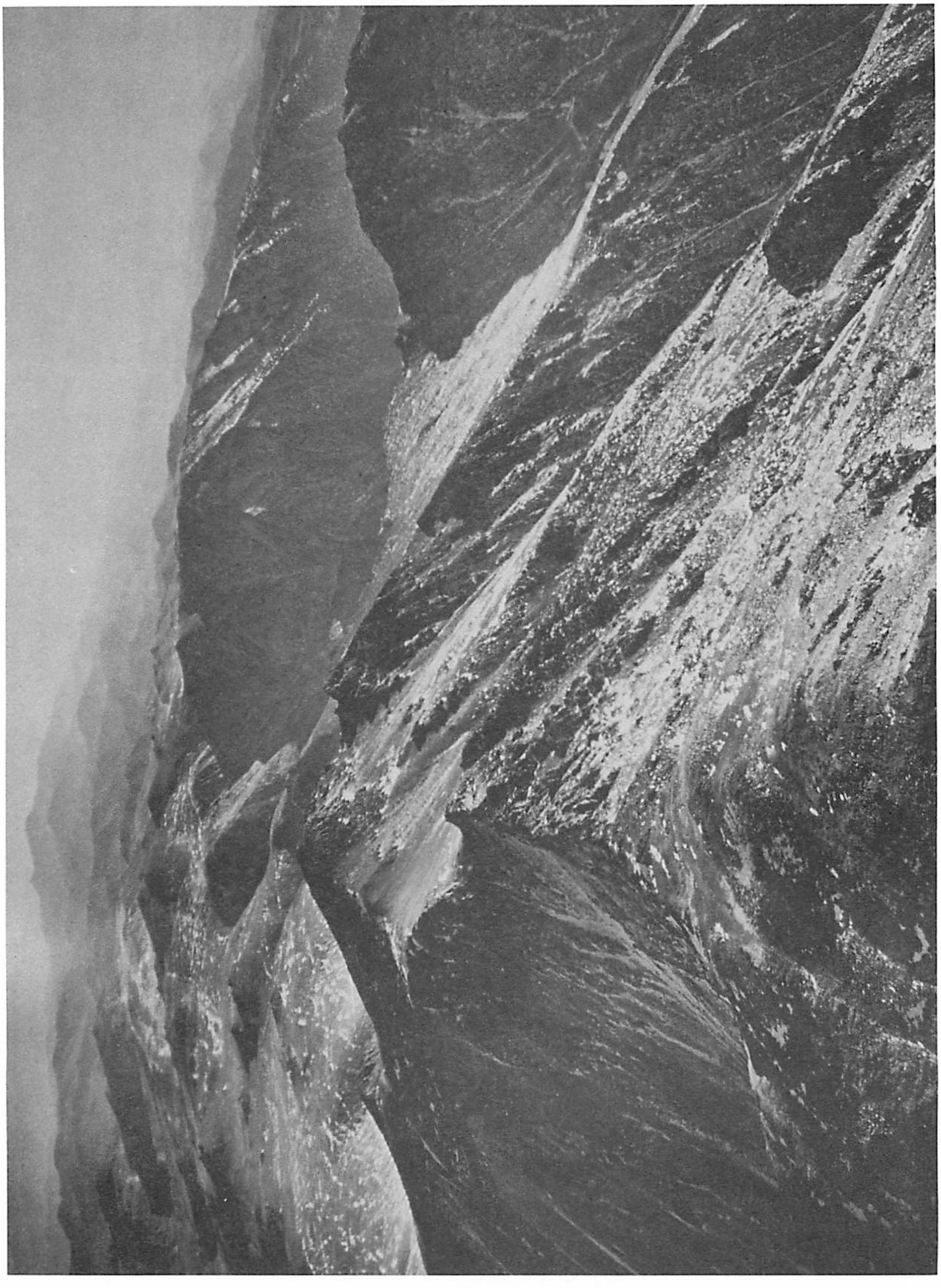


Fig. 14 Summit area from N. (cf. Fig. 11). "Saddle" at 14,050 ft shown with snow patches. Foreground plateau inaccessible from summit. Barcroft area at left, middle background.

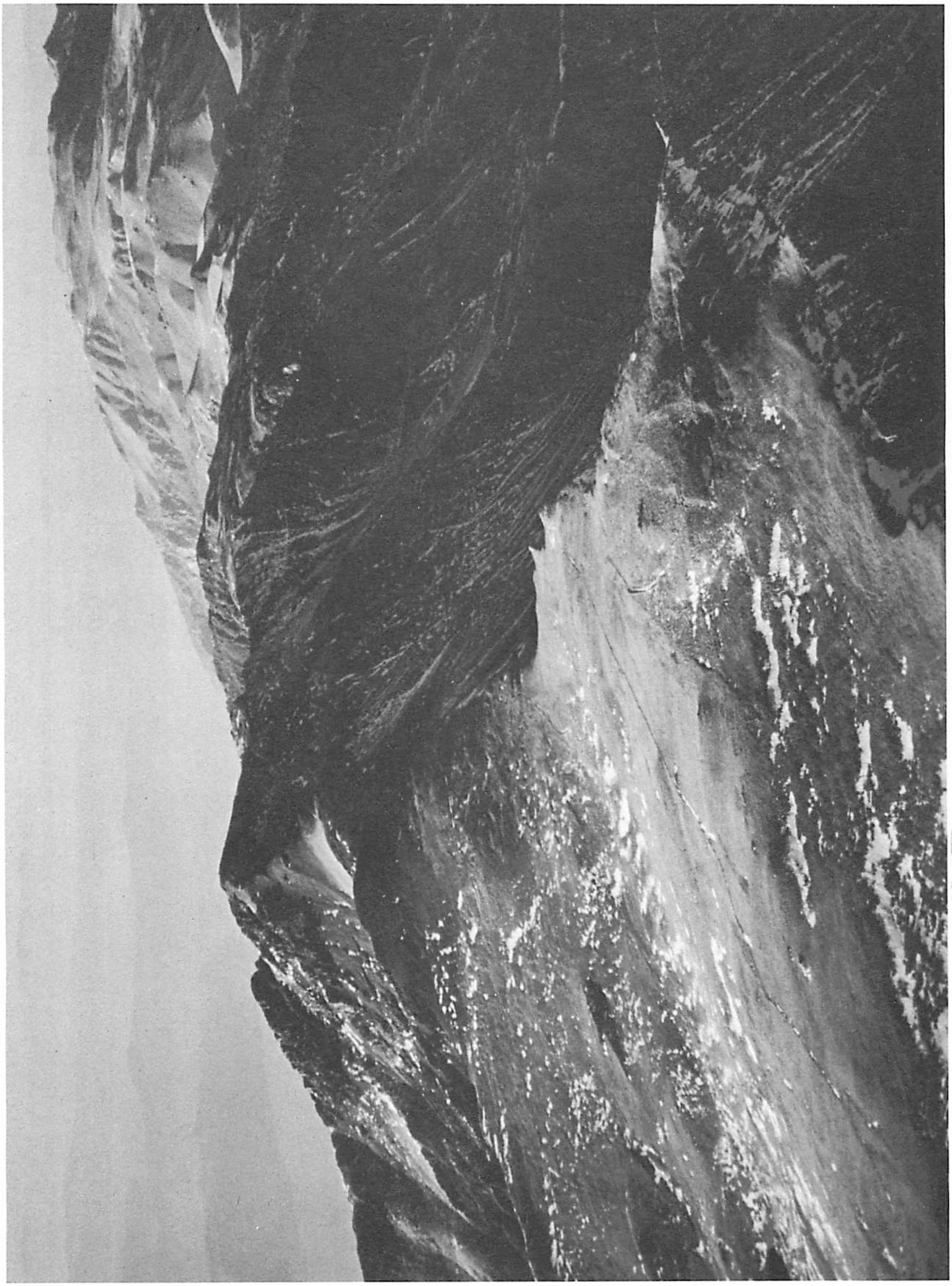


Fig. 15 Summit area from S. Approach road visible (cf. Fig. 10). Extensive development possible on foreground plateau (summit 13,189 ft). Also suitable take-off point for small cable car to summit (1200 ft rise, dist. 1 mile).

Fig. 16 Summit from W, like Fig. 12 but closer (light-colored wedge, 2 inches from right margin, also shown on Fig. 15, is sulphur, not snow).

show closer views of the summit area and the plateaus both to the south (in which the jeep road is built) and to the north. Hardly any snow had yet accumulated on White Mountain, whereas Mt. Shasta on the same date was heavily covered down to 9,000 ft. Additional photography is found in Appendix I.

(The White Mountain region is unique in being the habitat of the Bristlecone Pine, the oldest-known living things on Earth, with trees having measured ages up to 4,600 years (Ferguson, 1968). These great ages were discovered by Prof. E. Schulman of the University of Arizona in the 1950's; Fig. 6 indicates the location of the Schulman Memorial Grove.)

(b) *Mt. Shasta* — The possible interest of Mt. Shasta for IR astronomy was noted in *LPL Comm.* No. 142. Through the cooperation of the NASA-Ames staff, it was possible to use a technical flight of the CV-990 on June 19, 1970, for aerial photographic stereo coverage of Mt. Shasta and the measurement of atmospheric water vapor. A similar flight of the NASA Lear Jet on July 7, 1970, made possible securing near-level aspects of the mountain and some further H_2O measures.

The June 19 stereo coverage was obtained by the NASA staff on 70-mm color film in two traverses, at 22,000 ft and 16,000 ft, respectively (summit 14,162 ft). NASA provided the author with a 5-inch-wide paper copy in color of the entire record taken, a beautiful and very informative document. Stereo views could be obtained by selecting suitable pairs along the two traverses. The water-vapor measurements were made by Dr. Peter Kuhn of ESSA, Boulder, Colorado, using a special Barnes radiometer in the 6.3 μ region. He obtained the total precipitable water vapor in the vertical column above the aircraft. The author is much indebted to both NASA-Ames and Dr. Kuhn for making these important records available.

On the July 7 flight with the Lear Jet the author made H_2O measures in the solar beam with Dr. Low's meter and took near-horizontal photography of the summit area to supplement the stereo coverage. A hand-held camera and Kodachrome II film were used. The author had also the opportunity to see a fine series of color slides obtained by Mr. John Arvesen of NASA-Ames during his ascent of Mt. Shasta late September 1970. These slides and Mr. Arvesen's verbal advice made clear that access to Mt. Shasta is difficult compared to White Mountain. For this and other reasons, detailed in Sec. 3*c,* the illustrations initially selected for reproduction in Sec. 3*b* were mostly withdrawn in spite of their interest. Figs. 19*a-d,* below, were selected from Mr. Arvesen's collection for reproduction.

The photographs retained may be studied with the aid of the 15′ Shasta Quadrangle of the Geological Survey (in color), reproduced as a half tone (with some loss of detail) on p. 161.

With the latitude of Mt. Shasta (41°.4 N), the approach to the summit must be from the South. The broad Everett Memorial Highway provides access, at its terminus, Panther Meadow, 7,500 ft elevation. Fig. 17 shows an overall view of the mountain, from

Fig. 17 Mt. Shasta seen from SW, showing Shastina at left and Everett Memorial Highway at base (July 7, 1970).

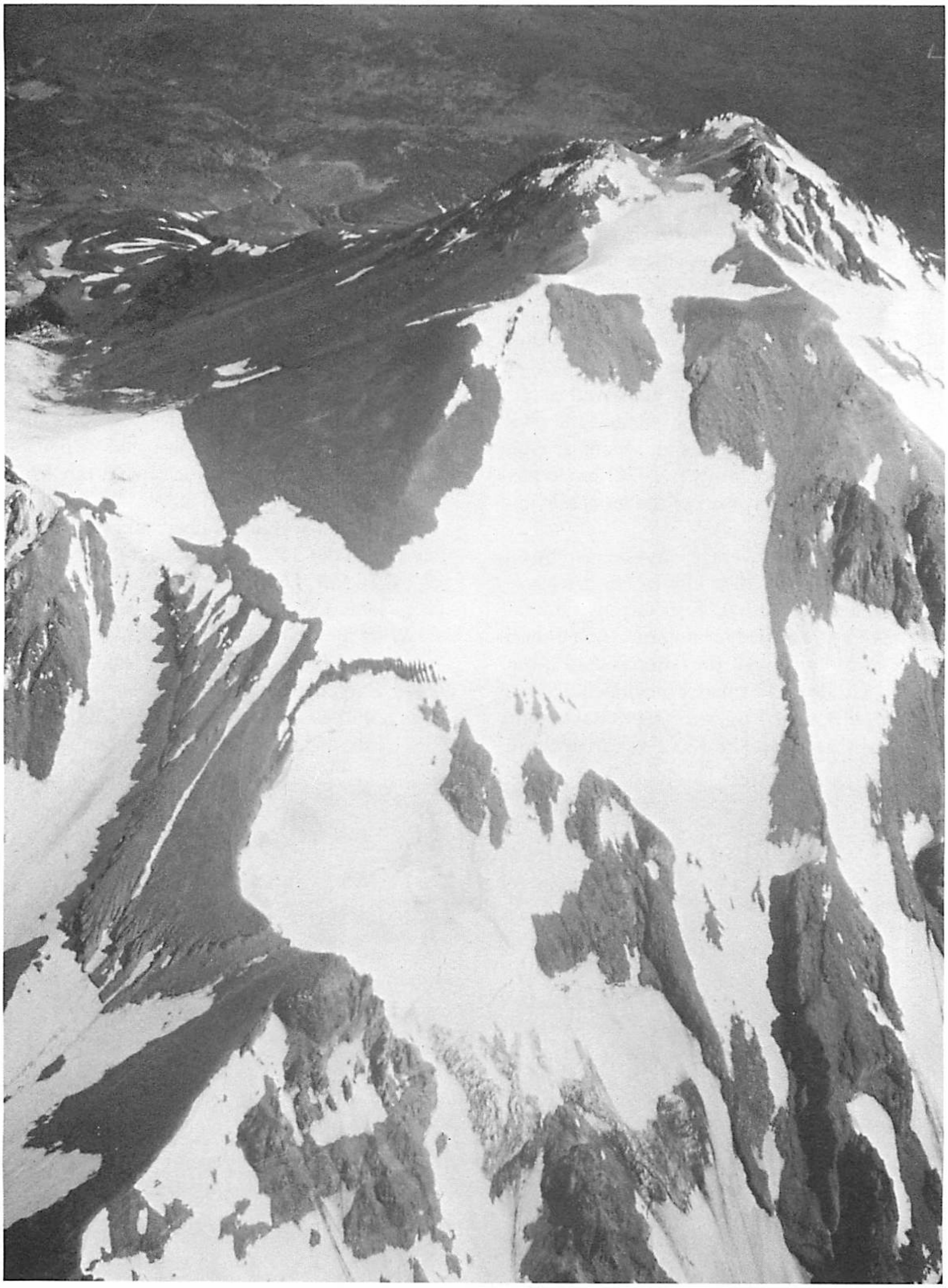


Fig. 18 South slopes, from Red Banks and Thumb Rock (both lower left) to summit (July 7).

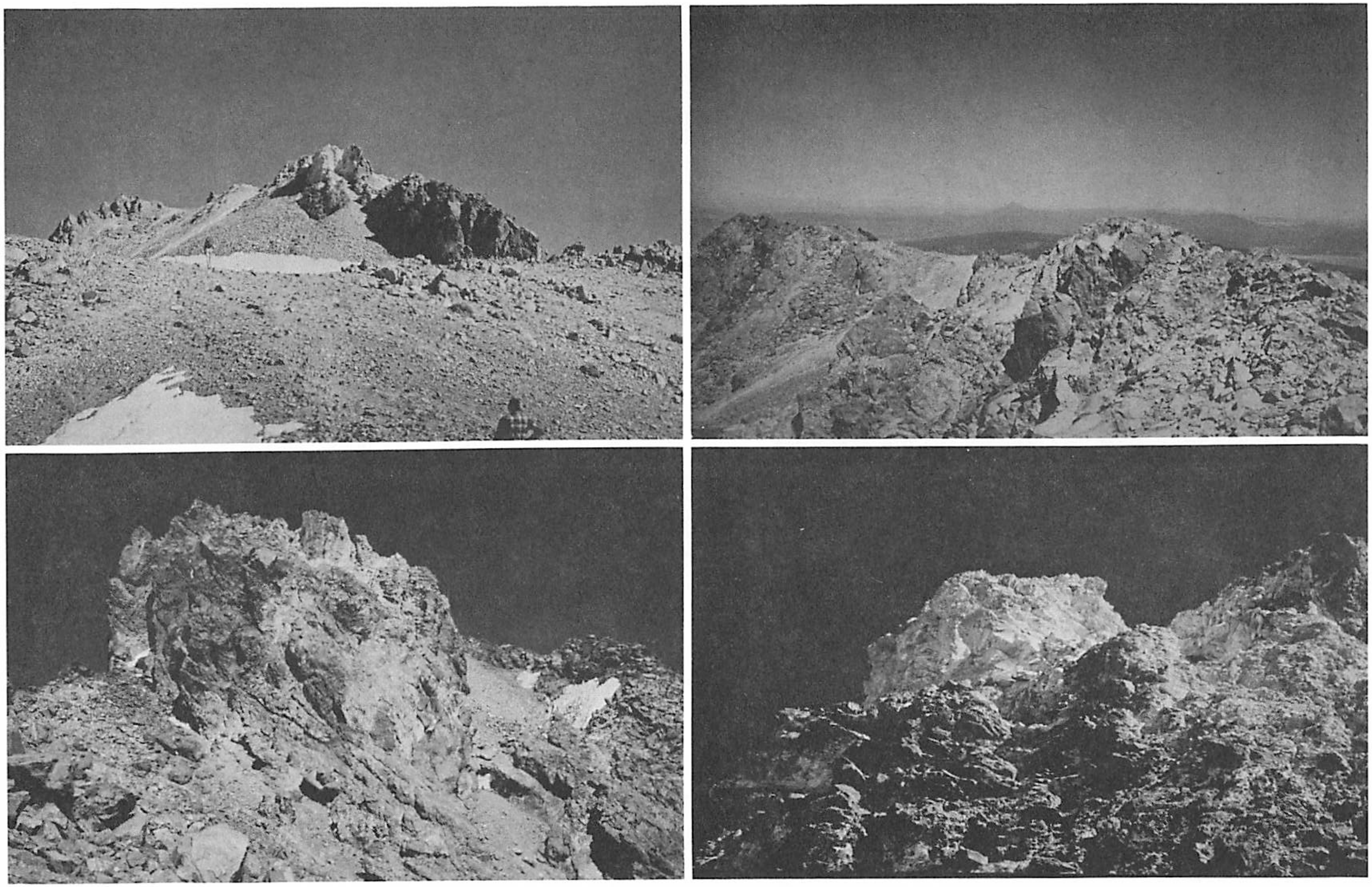


Fig. 19 Four views of Mt. Shasta summit: *Upper left,* view of main (E) ridge and saddle seen from south; *upper right,* northern extension of main ridge, looking north; *lower views,* portions of main (E) ridge (courtesy Mr. J. Arvesen, NASA-Ames).

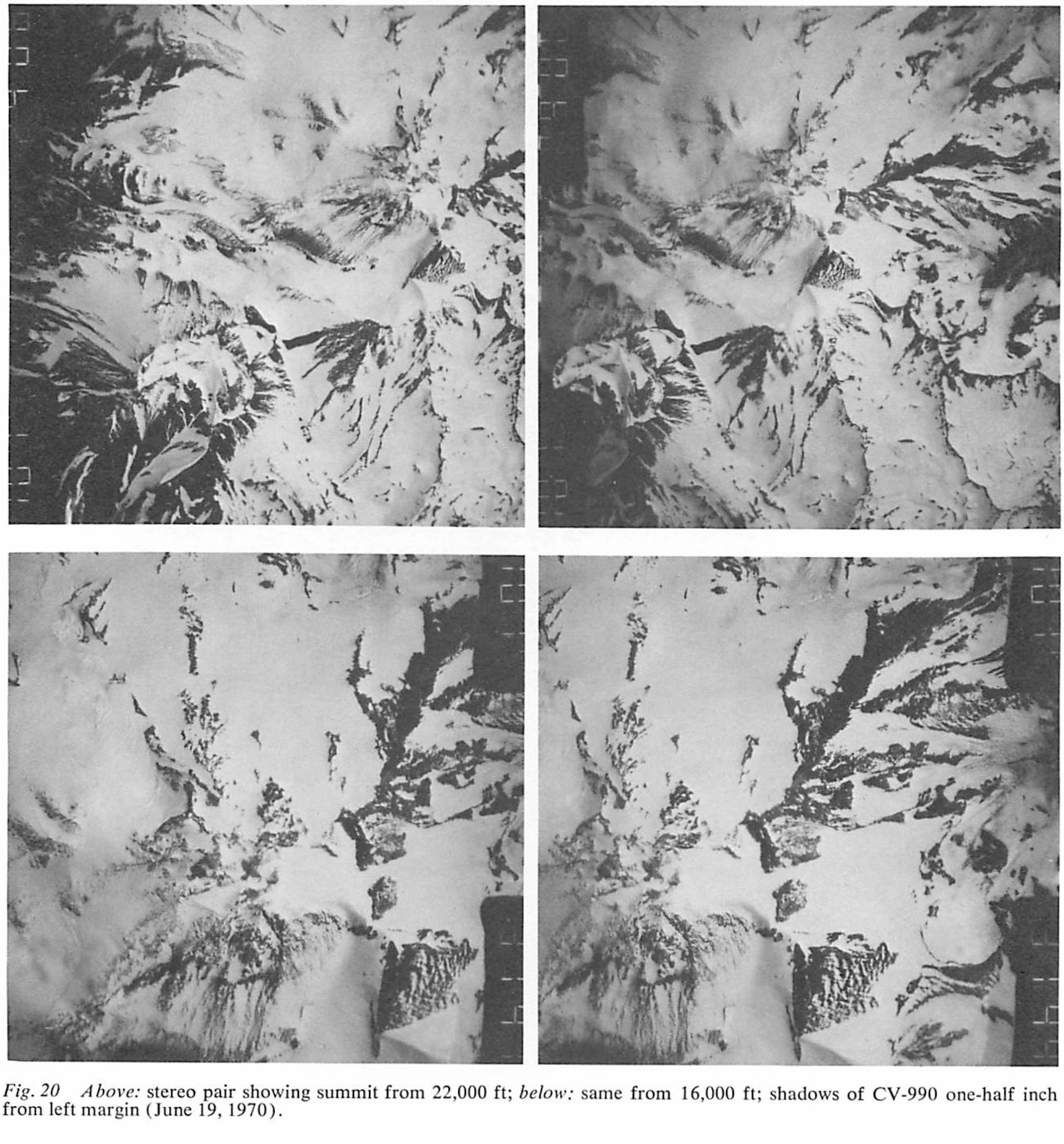
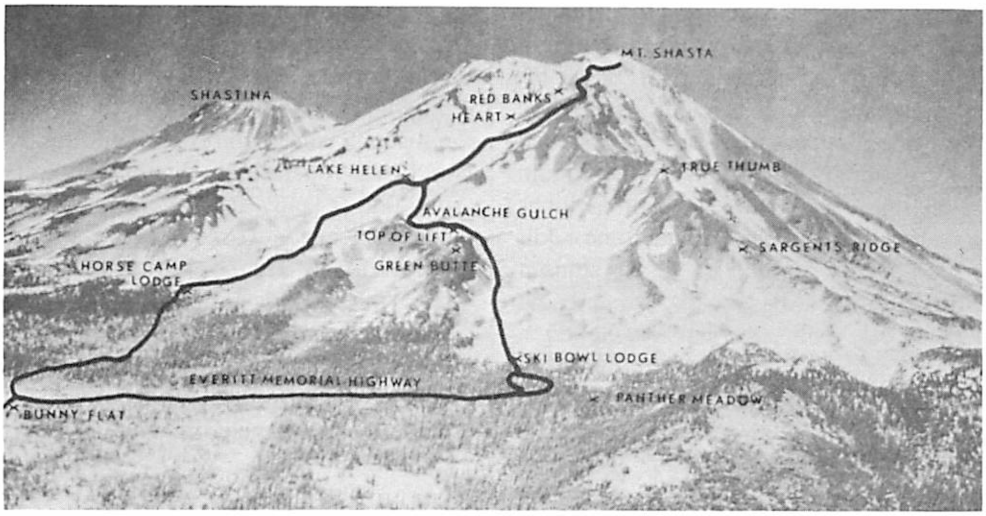


Fig. 20 *Above:* stereo pair showing summit from 22,000 ft; *below:* same from 16,000 ft; shadows of CV-990 one-half inch from left margin (June 19, 1970).

the SW. The snow level is down to 8,-9,000 ft, typical for early July; early September, little snow remains on the South slopes.

The region from about 13,000 ft to the summit is shown in Fig. 18. The serrated, harp-shaped rock formation is Red Banks, rose in color when exposed, with fascinating formations resembling Bryce Canyon; Thumb Rock, a prominent sculptured extension is below it. The summit is also shown, consisting of a main (E) ridge, a saddle, and a lower (W) ridge.

Close-up views of the summit (East ridge) are reproduced in Fig. 19. If an IR observatory were



HORSE CAMP ROUTE

This route, the most popular, begins at Bunny Flat where parking is provided. From here it is 2-1/2 miles to the Sierra Club Lodge at Horse Camp. It is best to spend the night here for an early start in the morning. There is no charge for use of this lodge. Water is available. Bring your own cooking utensils, food, and sleeping bag. Please leave the lodge ship-shape for the next group. Plan to start the climb at 3:00 a.m. Follow the route shown on the photo. You will have plenty of time to reach the summit and return before nightfall. A strong climber can reach the summit in four hours, but don't be surprised if it requires eight hours or more.

SKI BOWL – HELEN LAKE ROUTE

When the chair lift at the Mt. Shasta Ski Bowl is in operation (November to late May)* it may be used to reach a 9,200-foot elevation, which allows you to make a base camp at Helen Lake. A sandy bench 500 feet above the lake is an excellent campsite. From here, the summit may be reached in 3 to 5 hours. Follow the route marked on the photo. Under no circumstances should you attempt to climb the fingers or chimney of the Red Banks without crampons.

*Not in summer as stated on p. 158.

Fig. 21 National Forest diagram showing recommended trails to Mt. Shasta summit.

to be built on Mt. Shasta, the Northern part of the main (E) ridge would probably be the best site.

Fig. 20 shows two stereo views of the summit area obtained on June 19, one from 22,000 ft and one from 16,000 ft. Finally, in Fig. 21 we reproduce part of a National Forest map-pamphlet showing the two recommended trails for ascending Mt. Shasta. Parts of the ascent are difficult because of loose rocks.

Water-vapor measures above Mt. Shasta were made on both NASA flights, June 19 and July 7, 1970. On the first flight Dr. Peter M. Kuhn of ESSA Research Laboratories, Boulder, Colorado, obtained 0.25 mm in the vertical column above 15,000 ft and 0.018 mm above 30,000 ft. This gradient corresponds to a scale height of 5,500 ft = 1.65 km, in good accord with the 1.6 km value adopted in *LPL Comm.* No. 142 for the upper troposphere (and in Fig. 32, below). The noise-level error was 10% for the first value, 20% for the second. Reduced to the summit, 14,162 ft, the H_2O content would be 0.3 mm.

On July 7 the author derived 0.3-0.4 mm equivalent absorption above Mt. Shasta from measures made on the Lear Jet, corresponding to about 0.7 mm abundance. Finally, on July 8 he made a measure at 38° 45′ N, 122° 40′ W, elev. 1,480 ft, 12:52 PST. The zenith amount was 4.0 mm. Reduced to the summit of Mt. Shasta allowing for the latitudes and altitude difference, an estimated 0.4 mm is found.

(c) *Comparison, White Mountain vs. Shasta* — According to Paper I, Table 1, the 25 percentile of precipitable water for the 9 non-summer months for White Mountain is 0.54 mm, for Mt. Shasta 0.49. These numbers refer to the free atmosphere from which there may be appreciable deviations caused by existing orographic (uplift) and surface (evaporation) effects. A direct comparison between the summits has not yet been made. The orographic effects are probably larger on White Mountain than on

Shasta (a mountain range vs. a peak). Other factors tend to favor White Mountain: (1) the precipitation is only 1/6 of that in the Mt. Shasta area (Paper I); (2) White Mountain is within a scientific preserve (Univ. of California), whereas Mt. Shasta is assumed to be purely recreational; (3) the White Mountain Research Station has developed excellent facilities for living up to the 12,500-ft level, and some additional shelters up to the summit level (the summit house itself, of natural rock, has 4 beds, hot and cold water, a stove, etc.); and also has developed a remarkably efficient transportation system by turbo-helicopter, serving all desired points from the base station at Bishop. This system could immediately support a modest astronomical program, though in the long run it should probably be replaced by ordinary aircraft; (4) a jeep road to White Mountain exists for heavier construction in summer and fall; by comparison, Mt. Shasta, with its steep slopes and loose rock left by glaciers, is almost inaccessible; (5) White Mountain is 4° farther south.

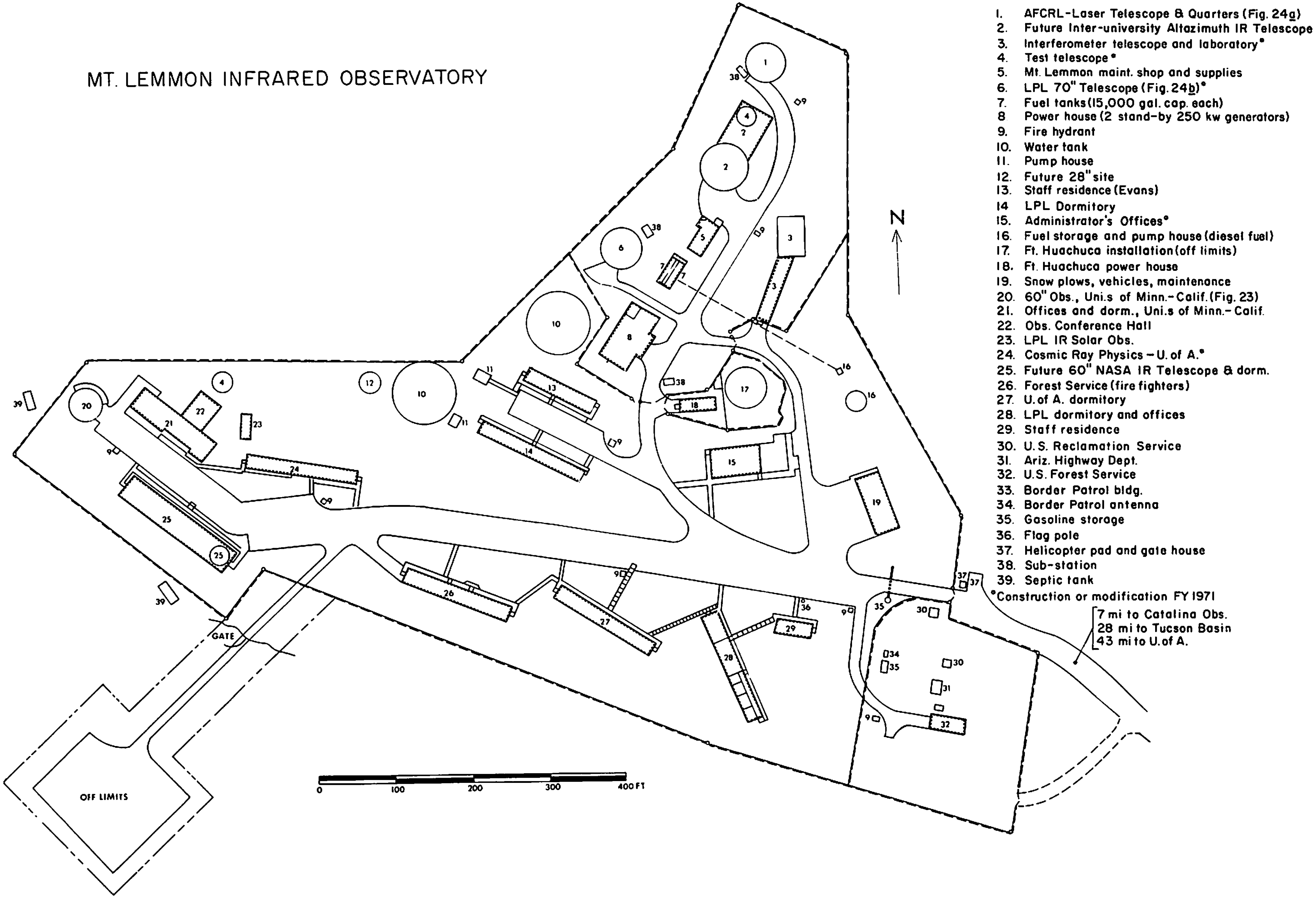
The White Mountain range, 80-100 miles NS, causes a major *mountain wave* when the wind is from the west, as is often the case (Table 4). In fact, the high altitude record for soar planes (45,000 ft = 13.7 km) was obtained there. During the late fall and winter the storm track often passes from the San Francisco Bay area eastward. In mid-winter and early spring, northerly winds occur more frequently (Table 4) and then the cold continental air will enter the White Mountain region. There does not appear to be a single typical pattern during this period. *An incisive study of the White Mountain climatology and its annual cycles would be important to future astronomical applications.* It is conceivable that White Mountain would prove optimum in winter and spring, and Mt. Shasta in summer and possibly fall.

If the 1971 U. of Calif. H_2O tests prove White Mountain to be the prime site during winter and spring, this would fully justify its further astronomical development. Initially, transportation by high-altitude helicopter would probably be the only practical solution (including for coolants and electronic components). Larger construction items could be transported by road in summer and fall. The road from the summit to the 13,000-ft plateau can probably be kept open because of the light snowfall. This would allow the use of a safer landing area than the summit (cf. Fig. 36, below) and possibly allow the use of small aircraft. Ultimately, a small cable car could supplement this road.

The altitude problem is serious, particularly for scientists commuting with a university near sea level. At Barcroft (12,470 ft) most visitors still react well, but the additional 2,000 ft to the summit is very noticeable and requires remedial steps for continued and safe operations. Simple quarters pressurized to 9,000 ft (only 2 psi over-pressure) are indicated. This concept is worked out by Mr. F. de Wiess in Appendix II. The scientific operations need not be done in pressurized space as long as the observers spend most of their time in the pressurized living room (partially-automated and ultimately *remote-control* observations are assumed). Appendix I contains supplementary data on the White Mountain site.

(d) *Mt. Lemmon, Arizona* — As a result of consultations between the Department of Defense, the U.S. Forest Service, and the University of Arizona (Nov. 1969-Oct. 1970), the 20-acre Mt. Lemmon summit area has been designated as the "Mt. Lemmon Infrared Observatory." It is the property of the U.S. Forest Service, under an indefinite Permit to the University of Arizona (signed Oct. 26, 1970), managed by a small group of Universities and the Air Force Cambridge Research Laboratories which on February 2, 1970 formed, in anticipation of a transfer of the Base by late 1970, a Users Group (Paper I, p. 136). The assignment of Mt. Lemmon to IR Astronomy was endorsed by the Infrared Panel of the National Academy of Sciences during its meeting in Tucson on January 30, 1970, with two draft resolutions: "1) National IR facilities are urgently needed. 2) An excellent site has become available as a result of the decommissioning of the Mt. Lemmon Radar Station by the Air Force. This site and facilities should be made available, under the control of an appropriate management organization, for IR telescopes in existence and under construction." The Users Group is an open Consortium.

A map of the Mt. Lemmon Infrared Observatory, giving present assignments to existing buildings and some structures yet to be erected, is given in Fig. 22. It incorporates the wishes of the U.S. Forest Service for the eventual transfer of the four telescopes on Site II of the Catalina Observatory to Mt. Lemmon. The map is readily interpreted with the aid of the photographs reproduced in Paper I. Fig. 23 shows the Minnesota telescope and dome, installed within a few weeks from the issuance of the Permit. Fig. 24*a* gives a design drawing of the AFCRL installation in Building No. 1, with the living quarters and piers largely installed at this writing, and with the 32-ft



1. AFCRL-Laser Telescope & Quarters (Fig. 24a)
2. Future Inter-university Altazimuth IR Telescope
3. Interferometer telescope and laboratory*
4. Test telescope*
5. Mt. Lemmon maint. shop and supplies
6. LPL 70" Telescope (Fig. 24b)*
7. Fuel tanks (15,000 gal. cap. each)
8 Power house (2 stand-by 250 kw generators)
9. Fire hydrant
10. Water tank
11. Pump house
12. Future 28" site
13. Staff residence (Evans)
14 LPL Dormitory
15. Administrator's Offices*
16. Fuel storage and pump house (diesel fuel)
17. Ft. Huachuca installation (off limits)
18. Ft. Huachuca power house
19. Snow plows, vehicles, maintenance
20. 60" Obs., Uni.s of Minn.-Calif. (Fig. 23)
21. Offices and dorm., Uni.s of Minn.-Calif.
22. Obs. Conference Hall
23. LPL IR Solar Obs.
24. Cosmic Ray Physics – U. of A.*
25. Future 60" NASA IR Telescope & dorm.
26. Forest Service (fire fighters)
27. U. of A. dormitory
28. LPL dormitory and offices
29. Staff residence
30. U.S. Reclamation Service
31. Ariz. Highway Dept.
32. U.S. Forest Service
33. Border Patrol bldg.
34. Border Patrol antenna
35. Gasoline storage
36. Flag pole
37. Helicopter pad and gate house
38. Sub-station
39. Septic tank

*Construction or modification FY 1971

7 mi to Catalina Obs.
28 mi to Tucson Basin
43 mi to U. of A.

Fig. 22 Map of Mt. Lemmon Infrared Observatory, with current building assignments.

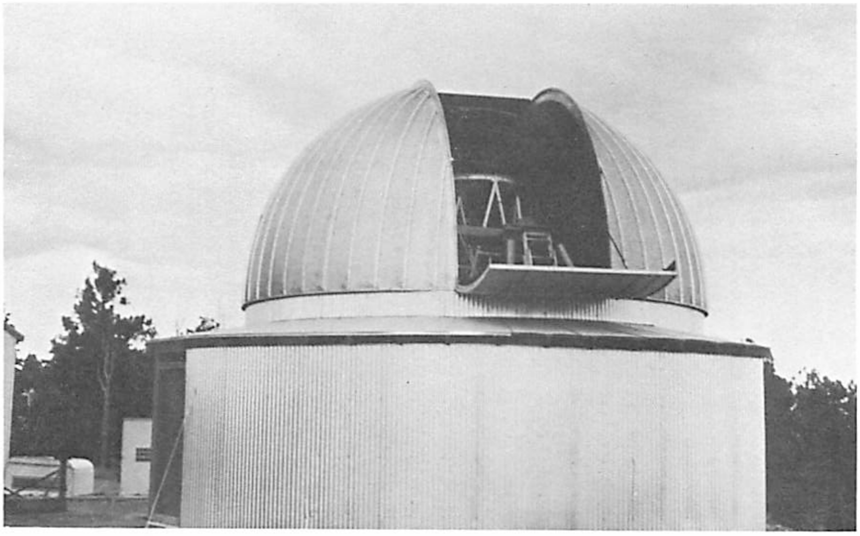


Fig. 23 Views of 60-inch telescope and dome of the University of Minnesota-University of California (San Diego) on Mt. Lemmon (Bldg. 20).

dome expected to arrive early in 1971 (the telescope will be moved from the Catalina Observatory, Site II). Fig. 24*b* shows the plans for the LPL 70-inch telescope, with construction scheduled to begin in 1971. The design of the fixed focus interferometer telescope (Bldg. 3) follows that shown in Paper I, pp. 148–149.

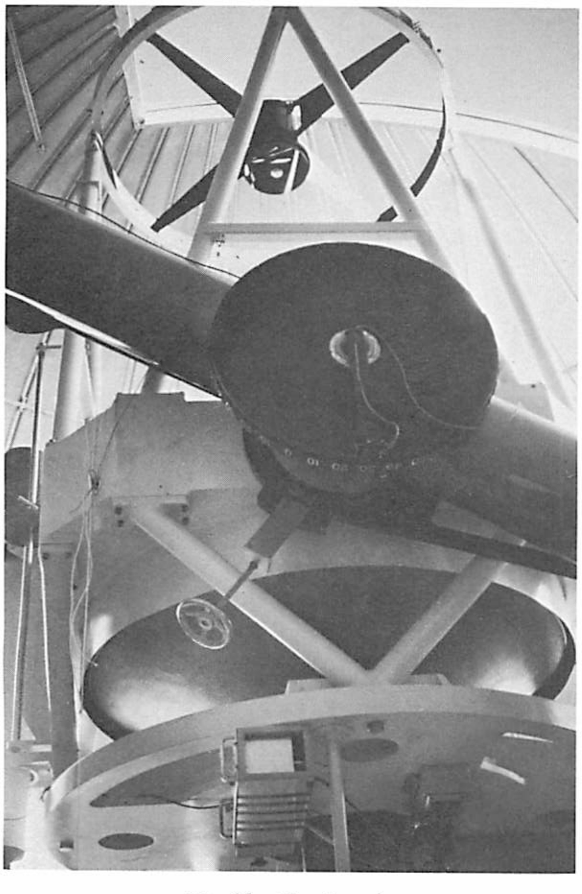


Fig. 23 Continued.

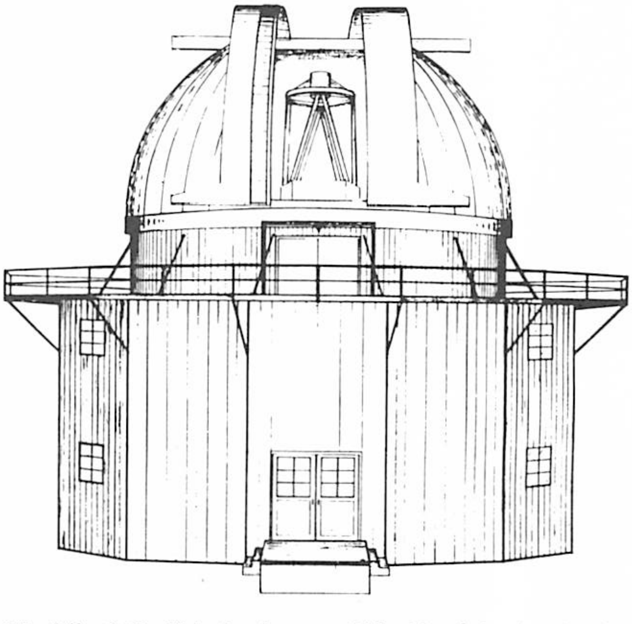


Fig. 24b LPL 70-inch telescope, Bldg. No. 6 (under development).

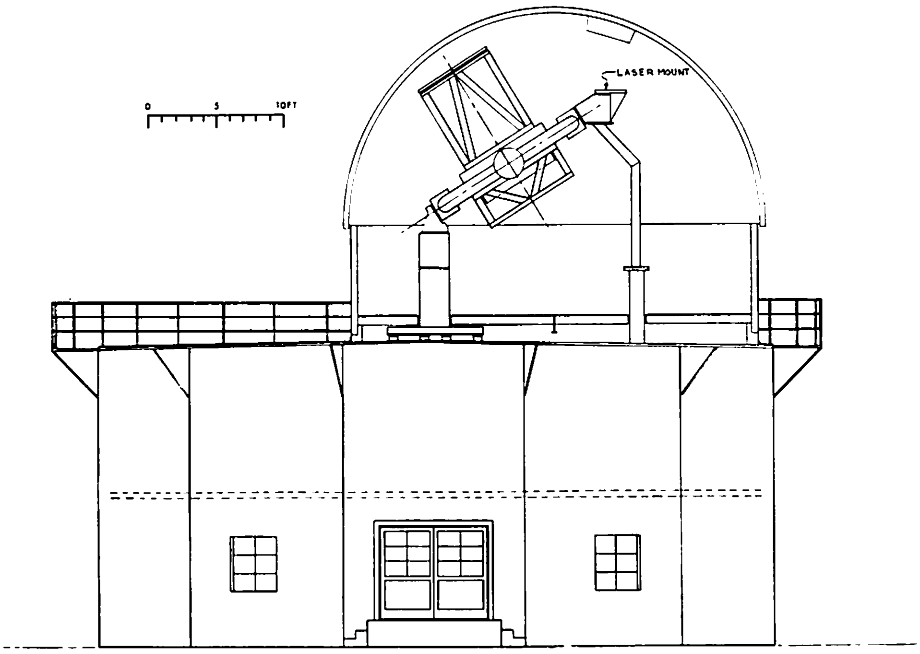


Fig. 24a AFCRL lunar-laser installation, Bldg. No. 1 (under construction). Living quarters on ground floor.

With the assistance of Mrs. Mildred Gholson of the Institute of Atmospheric Physics, we are able to show in Fig. 25 the frequency curve of dew points for the month of January, based on the years 1965–1970, and taken from the radio-sonde data obtained at the nearby Tucson International Airport, daily at 4 A.M. local time, valid for the summit level of Mt. Lemmon (these data are superior to the earlier radio-sonde data, which could not register low humidities; cf. Paper I, p. 147). The curve of Fig. 25*b*, computed from Fig. 25*a*, agrees well with the curve "Le" (Paper I, p. 135), based on the Gringorten *Atlas* data. The bimodal distribution in Fig. 25*b* shows, basically, the "good- and bad-weather" fractions, as does the Mauna Kea curve in Paper I. The 25% value for H_2O in January is about 1.1 mm, in accord with Paper I (Table 1, and p. 126, line 12), with values ~ 0.5 mm occurring occasionally.

Continuous temperature and relative humidity records for Mt. Lemmon were started by Mr. E. A. Whitaker in October 1970; he makes weekly calibrations of the scales. On most weekly records there are 2-3 days, or substantial fractions of these, during which the relative humidity falls to very low values. Seven weeks of continuous records of *T* and *R.H.* for Mt. Lemmon and the Catalina Observatory, held to be quite representative of late Fall conditions, are

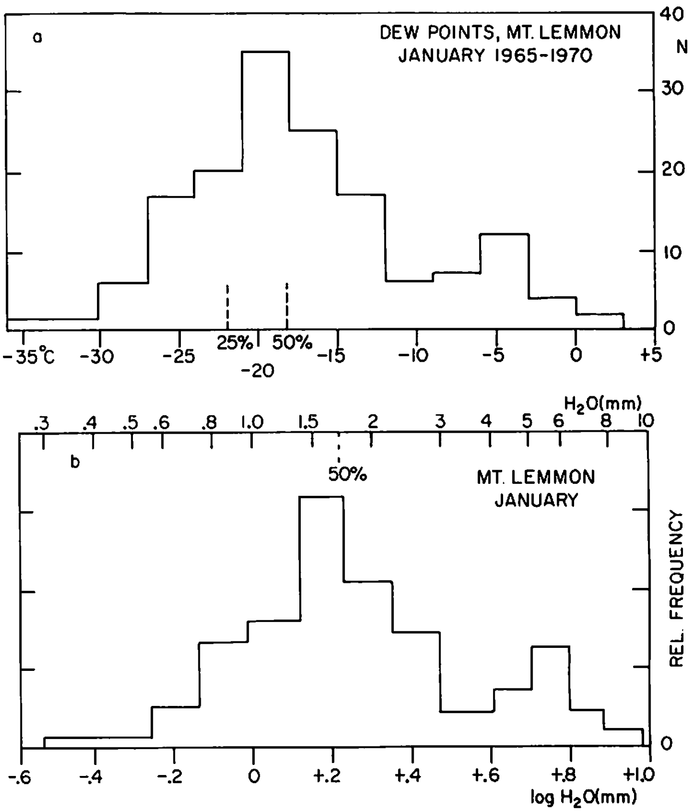


Fig. 25 Frequency curves of dew points and precip. H_2O for Mt. Lemmon summit for January, based on radio-sonde data, Tucson International Airport, 1965–1970.

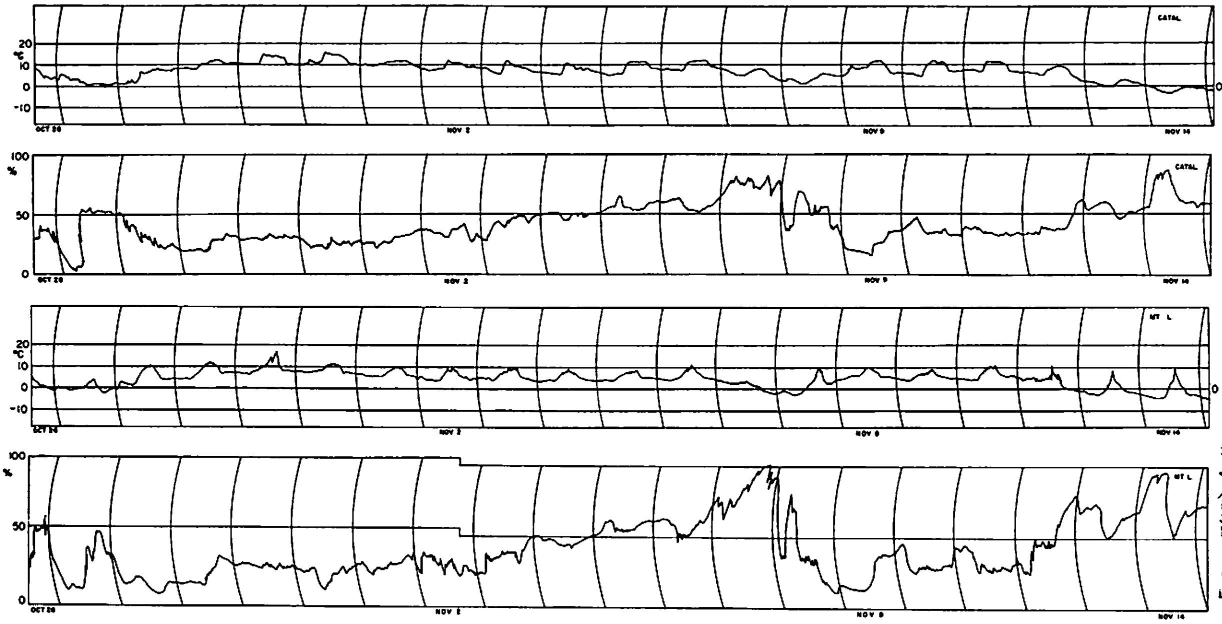


Fig a 47(156) duplicate was made

Fig. 26 Thermo-hydrograph records for Catalina Observatory (8,250 ft) *above* and Mt. Lemmon (9,180 ft), calibrated by Mr. E. A. Whitaker: *a*, Oct. 26-Nov. 14, 1970. (Housing of Mt. Lemmon instrument not satisfactory at first; peaks in *T*.)

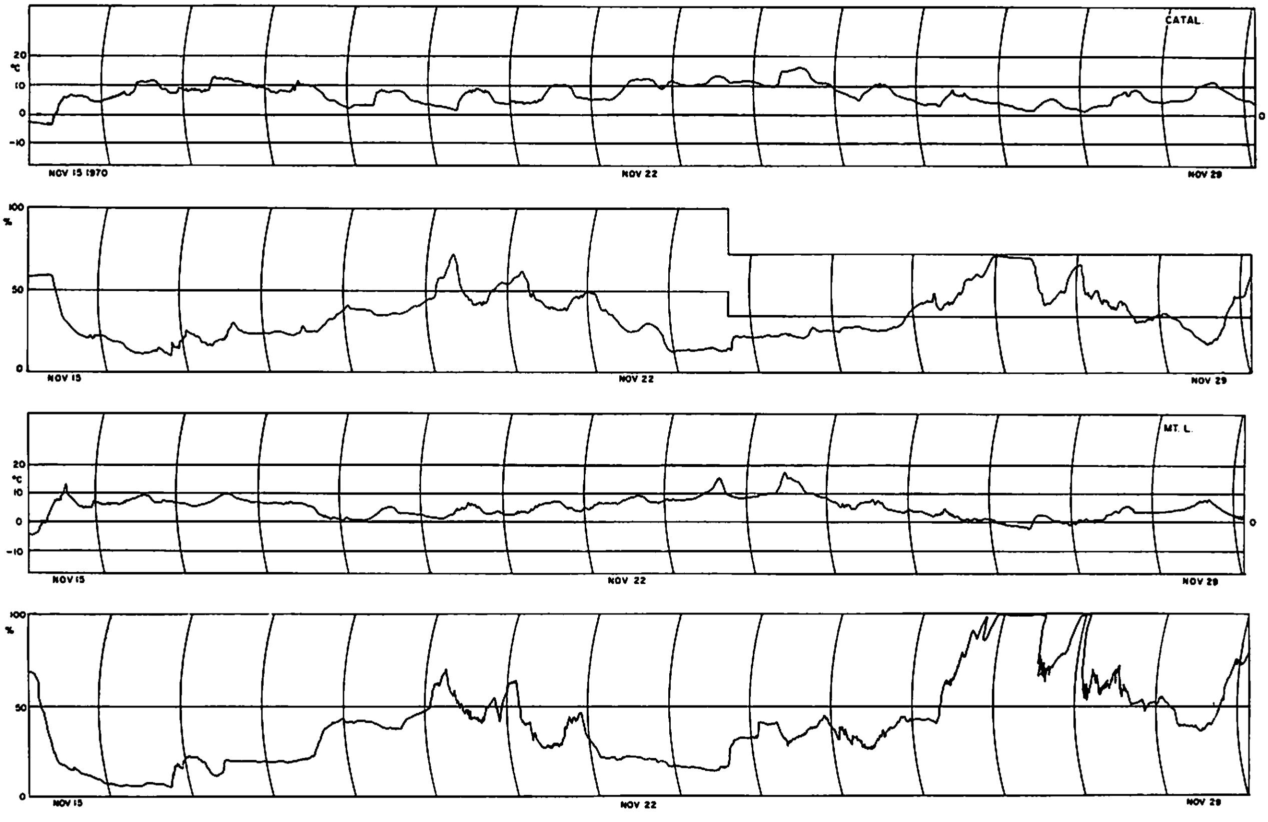


Fig. 26 Continued: b, Nov. 15-Nov. 29, 1970.

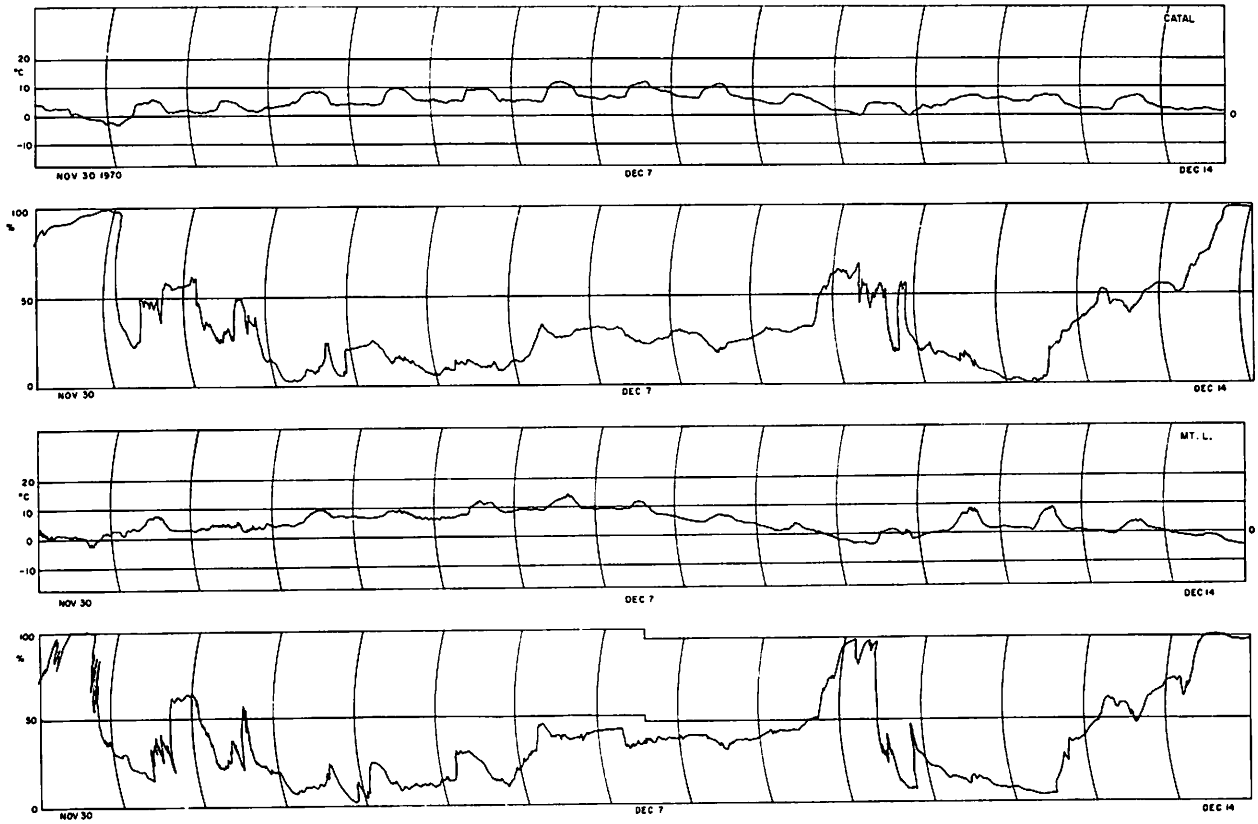


Fig. 26 Continued: c, Nov. 30-Dec. 14, 1970.

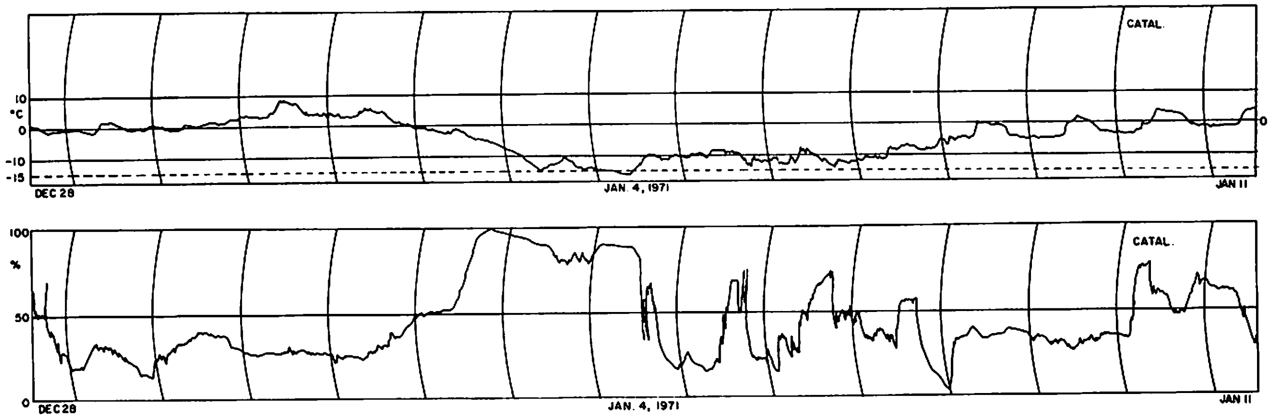


Fig. 26 Continued: d, Dec. 28-Jan. 11, 1971. (Catalina records only; snow in Mt. Lemmon housing disturbed R.H.)

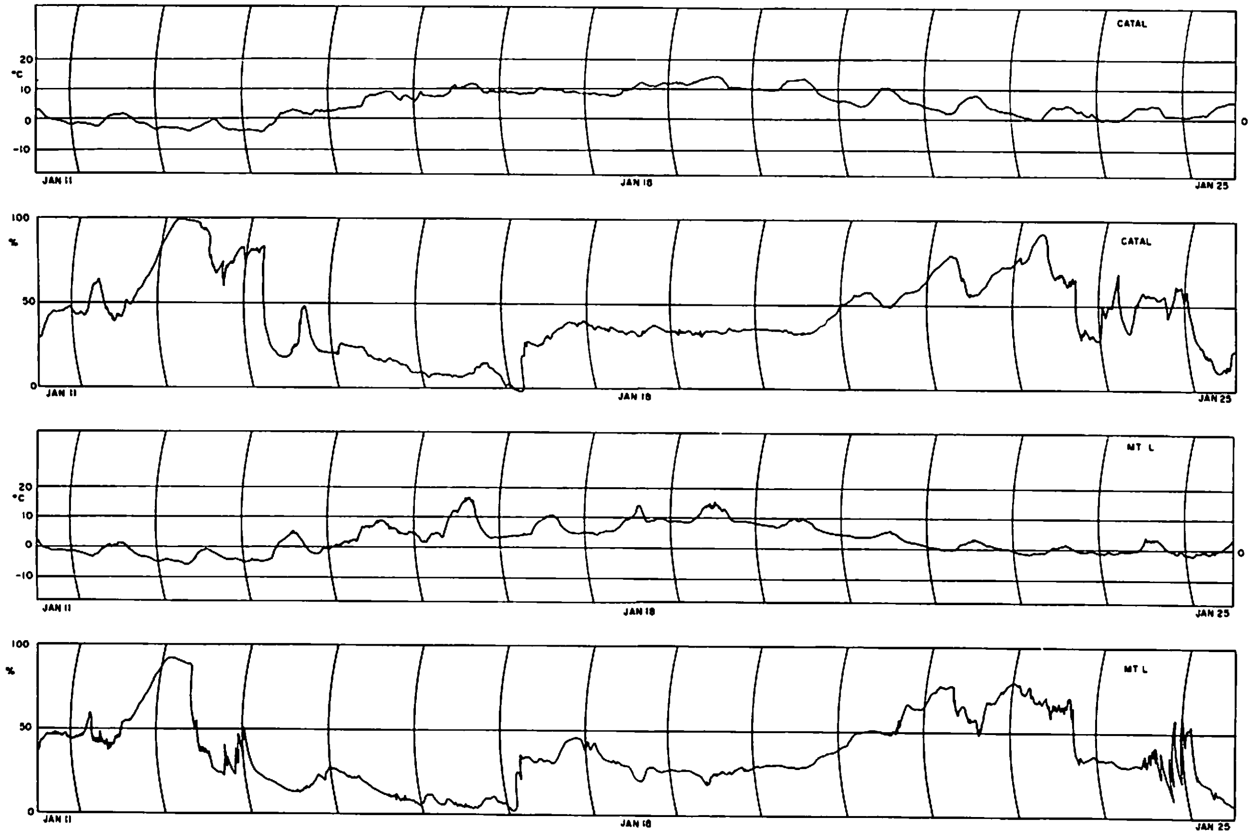


Fig. 26 Continued: e, Jan. 11-Jan. 25, 1971.

reproduced in Fig. 26*a-c*. This matter will be pursued, partly with the aid of radio-sonde observations of *T* and *R.H.* being made daily at 4 A.M. and 4 P.M. from the nearby Weather Bureau Station at the Tucson International Airport (cf. Fig. 25). The small daily temperature ranges favor good image quality. Mr. Whitaker regards the temperatures to be accurate to about 1°C; the 0 and 100% humidity values to be very close (based on sling psychrometer calibrations), with the intermediate scale possibly not strictly linear. The 8-20% *R.H.* values should be reliable. Occasionally, as on Dec. 10, the relative humidity was substantially higher on Mt. Lemmon than at the Catalina Observatory, apparently due to cloud formation at the higher level. The Catalina instruments are mounted on the balcony of the 61-inch dome (N, shadow side) about 20 ft above the ground; the Mt. Lemmon instruments are more exposed, about 30 ft above the ground, on tower No. 6 (Fig. 22). Often mild temperature inversions occur near the 7,000-ft level which are just discernible in our temperature records. (These inversions are beneficial since they confine the valley haze.) The median *R.H.* is about 35%. In the proofs we added Fig. 26*d, e*, representing winter conditions.

The transportation problem to the summit of Mt. Lemmon, especially the final rise of 800 ft from the Ski Bowl (pp. 137, 138, Kingler Spr.*) is in winter not trivial but manageable, with an experienced driver available for the final rise, using 4-wheel-drive vehicles or a snowmobile.

(e) Other sites, not discussed here, include Mauna Kea and its major new facilities; and Mt. Agassiz, Arizona, on which some decisions are pending.

4. *Mid-Latitudes — Southern Hemisphere*

Of the three continents in the middle latitudes only South America appears to offer superior sites for IR astronomical observations. The highest mountain in Australia is Mt. Kosciusko (7,328 ft = 2,230 m., 36°4 S). Mt. Cook, 12,349 ft = 3,764 m, 43°6 S, in New Zealand, has a maritime climate. In S. Africa the highest mountains are just over 10,000 ft, between 28°8-30°6 S, in Basutoland.

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*Misspelled on Topographic Map; should be "Kinglet" (named by Mr. Randolph Jenks after the golden-crowned kinglet, Regulus satrapa).

In S. America there is the unbroken series of peaks in the High Andes, with numerous lesser peaks on either side, many of which are accessible through mining operations. The author examined the Antofagasta area and on Southward, to Santiago, mostly from the air, in March 1959, during a journey that led to the establishment of the 60-inch telescope of the present Inter-American Observatory (continued under AURA sponsorship after the transfer from the Univ. of Chicago, August 1960). The author has further discussed the low-humidity requirements with Dr. Jurgen Stock of the University of Chile (who conducted the site-test under the auspices of the U. of Chicago and later AURA, since May 1959); with Dr. Franz Mayer, geologist, long-time resident of N. Chile; and other scientists.

For extremes in low precipitation and humidity, the region of the central Andes is unmatched in the Southern Hemisphere. The moisture of the Amazon Basin cannot penetrate because of the high Cordillera Oriental, N and E of Lake Titicaca. Antofagasta, central to the Western area, is readily accessible by air, with jeep roads leading to altitudes of 14,-16,000 ft. Also, there are two narrow-gauge diesel railroads out of Antofagasta, one NE to Bolivia and one SE to Argentina. The first runs one passenger train per week (7^h to Calama, a town with an airport, at 7,831 ft = 2,390 m; and 10^h more to Oyahue at 13,000 ft, which alternatively can be reached from Calama by automobile in 3½ hours). Just S of Oyahue, on the border, there exists an active volcanic crater (19,265 ft = 5,870 m) reachable by road and aerial cableway (for sulphur ore) to within 300 ft of the summit. The region N of Calama, to beyond 21°S, is shown in Fig. 27. Near the 21° parallel several sulphur mines exist, with a narrow-gauge railroad leading to 15,500 ft and an aerial cableway for ore to 18,000 ft.

One very promising area for IR observation would appear to be near San José del Abra, 2½-3 hours by automobile N of Chuquicamata, which in turn is just N of the Calama airport. Chuquicamata, at about 9,000 ft, would be a suitable headquarters for an IR observatory at 14,000 ft near San José del Abra (21° 58′ S, 68° 45′ W), a mining area that has some small buildings, as well as a narrow-gauge railroad. Seven miles SE of Calama Airport is located the Mt. Montezuma Observatory of the Smithsonian Astrophysical Observatory (SAO) (Fig. 27), to which reference is made below.

As is well known, the "green" and "desert" parts of Chile divide near 30° S (Elqui River). The European Southern Observatory is in the southern part of dry Chile, on La Silla (29° 15′ S, 70° 44′ W), elev. 8,000 ft or 2,444 m. Fig. 28*a* shows the percentage of photometric nights (6 hrs. or more, completely clear) through the seasons (Blaauw, 1970); 28*b*, the relative humidities *during the photometric nights;* and 28*c*, maximum and minimum temperatures (both averaged for three years, Muller, 1969). If we combine the average relative humidity for the driest month, August, 22% (for the 46% photometric nights), with the average *minimum* temperature, −4°C, we shall get about a 25-percentile value of the humidity. Adopting a scale height of 1.6 km (in analogy with California), the 25% August precip. H_2O on La Silla at night would be 1.3 mm. The 9 months' 25-percentile value for the 8,000-ft level in the Northern Hemisphere clear belt is 1.6 mm (Fig. 32); for the driest month, January, about 1.3 mm. Hence, from this limited material, there appears to be *no appreciable differences between the humidities in the dry belts of the two hemispheres* (there may, however, be some difference in the fractional cloud covers).

A similar result is derived from the published records of the Smithsonian Solar Observatory at Mt. Montezuma (Fig. 27; 22° 34′ S, 68° 52′ W, 8,895 ft = 2,711 m). Fig. 29 is based on a compilation for the years 1929 and 1930 (Smithsonian Institution, *Annals of the Astrophysical Observatory,* Vol. 5, 1932). Fig. 29*a* shows the monthly averages of clear or nearly-clear days (solid line) and the total number of days on which at least some solar observations were possible. Fig. 29*b* shows the monthly average temperatures measured at 8 A.M.; and Fig. 29*c* the precip. H_2O in mm for unit air mass (the original records show the values for 2.0 air masses, both in Table 4 and Fig. 8). The average August value is the lowest, at 1.6 mm; though, of course, occasionally much lower readings were obtained, not unlike those shown in Fig. 25 for Mt. Lemmon.

Other interesting areas (low humidity, accessibility) are (1) the (rather inaccessible) mountainous region of Northwest Argentina; (2) the more accessible region W of Mendoza and San Juan, Argentina, in which the Yale Columbia Station is located; and (3) the very accessible region just N and E of Arequipa, Peru (Fig. 30; the 14,000-ft level is reached both by railroad and automobile) with Arequipa having a good airport 8,461 ft = 2,580 m). The Smithsonian Station is located 2 km N of Characato, and has collected meteorological data which, for the period 1961–1965, were generously summarized by SAO. The seasonal maximum

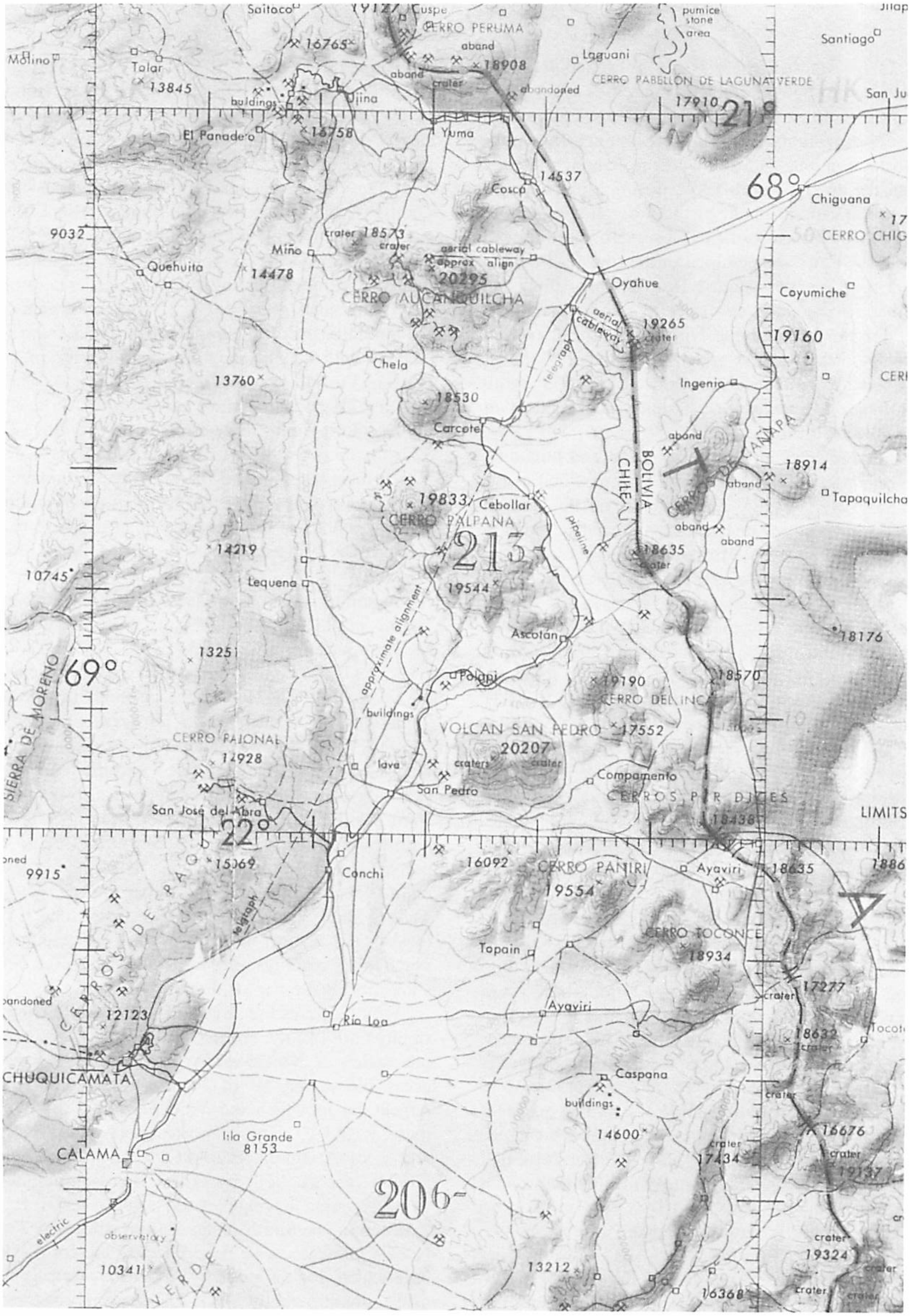

Fig. 27 Map of Andes, NE of Antofagasta, Chile. *(World Aeronautical Chart)*

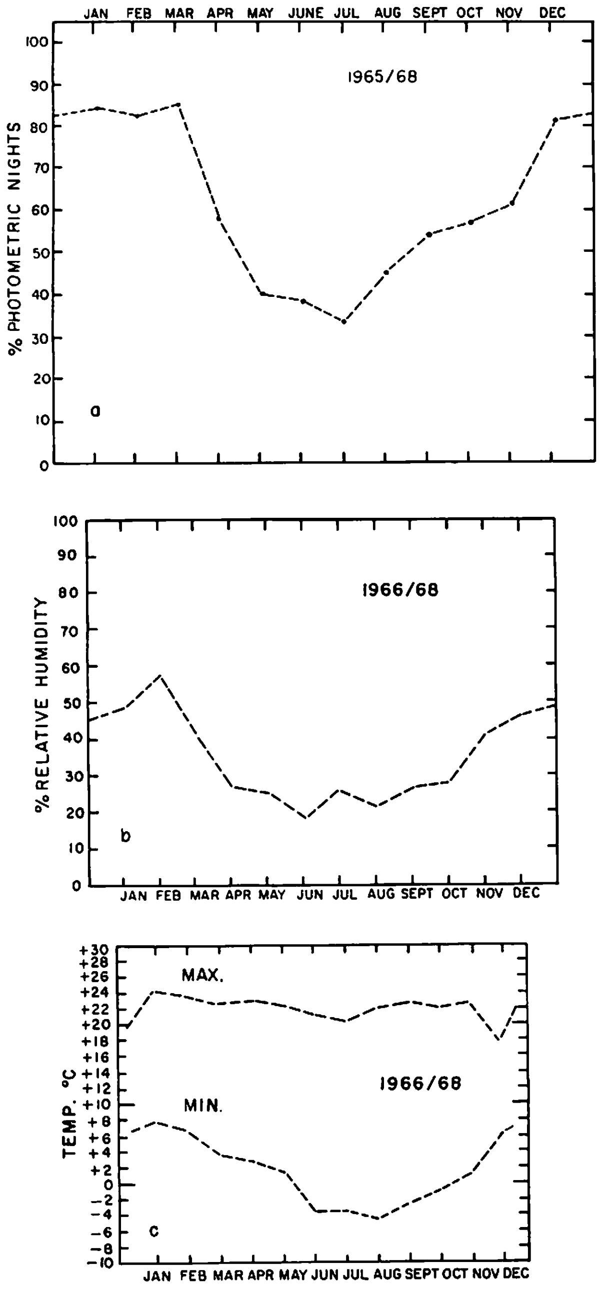

Fig. 28a Percentage of photometric nights, European Southern Observatory, La Silla, Chile, 1965–68; *b*, Relative humidity in %, 1966–68 (Site S), photometric nights only; *c*, Maximum and minimum temperatures, 1966–68 (Site S).

temperatures vary only 1 °C. The mean maximum is found to be 22°C; the mean minimum, +6°C. The La Silla values obtained at nearly the same altitude are 22°C and +1°C.

The plots in Fig. 31, arranged by month, show the averages of the SAO observations. Fig. 31*a* shows the fractional cloud cover, with the 50-percentile (or median) values listed in Table 7. It is seen that the months April through November have a satisfactory observing record, just the opposite phase of La Silla, Fig. 28, but in accord with Mt. Montezuma, Fig. 29. Fig. 31*b* shows the seasonal run of relative humidity, with the medians listed in Table 7; the months of June, July, and August are the driest, with just below 40% relative humidities, in phase with, but larger than, those on La Silla shown in Fig. 28. The temperatures are so uniform throughout the year that they are not shown graphically but summarized in Table 7.

Table 7

Meteorological Data, SAO, Arequipa, Peru

Month (1961-1965)	Cloud Cover 50 Percentiles	Humidity 50 Percentiles	Temperature°C Max.	Min.	Wind Vel. (mph) 0-2.5	2.5-7.5	>7.5
January	0.91	0.73	21.6	7.5	95	3.7	1.3
February	0.91	0.76	21.6	8.0	97	2.5	0.7
March	0.75	0.72	22.5	7.4	97	2.6	0.6
April	0.39	0.64	22.0	6.1	97	3.1	0.3
May	0.17	0.48	22.6	5.9	98	2.0	0.0
June	0.09	0.39	22.1	4.6	97	2.0	0.7
July	0.11	0.39	22.2	4.5	97	3.3	0.0
August	0.11	0.38	22.3	5.0	95	4.3	1.0
September	0.27	0.45	22.4	5.5	95	4.2	0.4
October	0.33	0.45	22.9	5.6	93	6.4	0.3
November	0.43	0.51	22.7	5.4	87	12.5	0.3
December	0.86	0.63	22.1	6.5	89	10.0	1.0

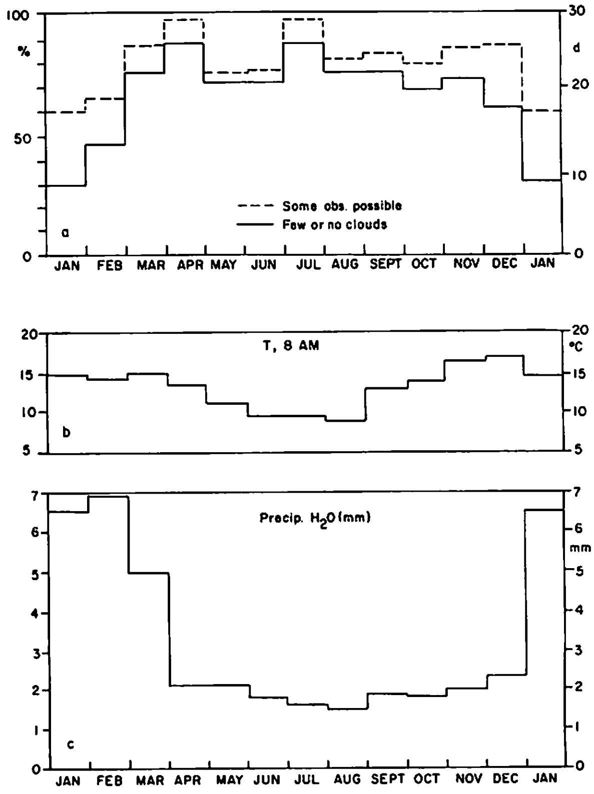

Fig. 29 Data for Mt. Montezuma, Chile, Smithsonian Astrophysical Observatory station, averaged for 1929 and 1930: *a* Fraction of daytime cloud cover; *b* Temperatures in °C at 8 A.M.; *c*, Average precipitable H_2O in mm, unit air mass.

Fig. 30 Map of Andes, NE of Arequipa, Peru. *(World Aeronautical Chart)*

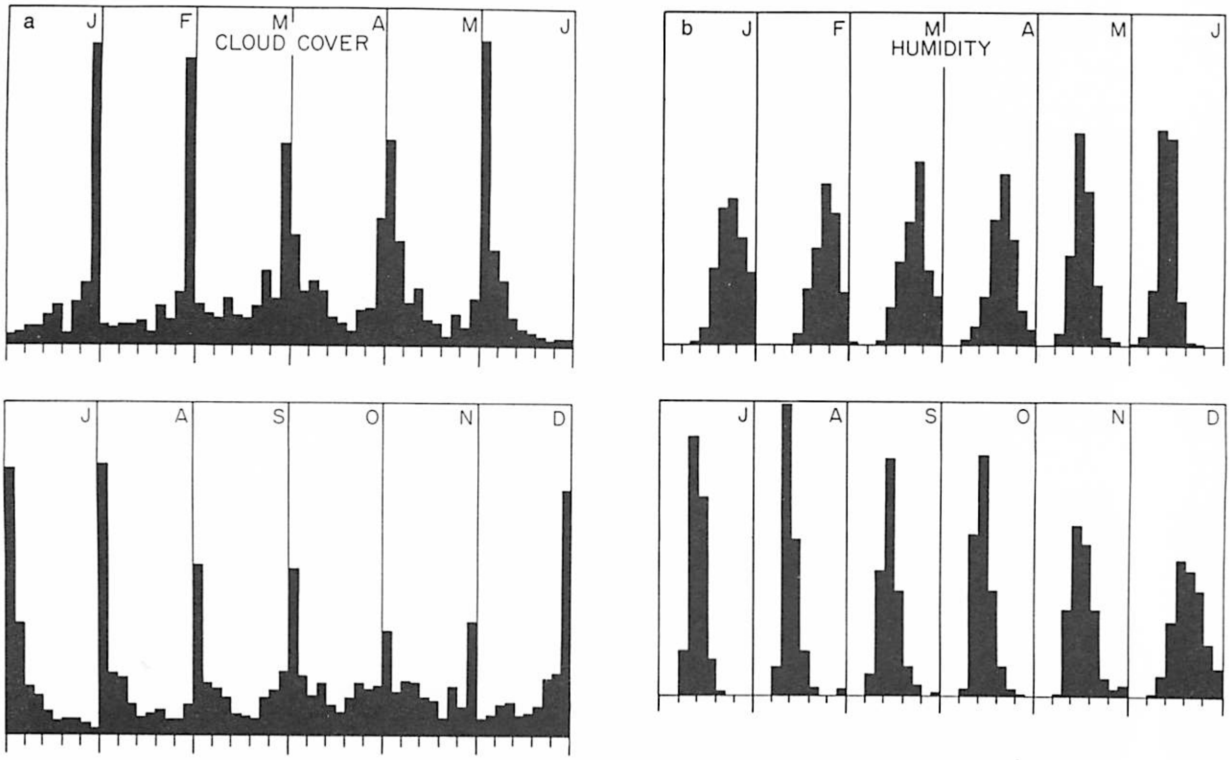

Fig. 31 Relative humidity and cloud cover, by months, 1961–1965, for Arequipa, Peru, Smithsonian Astrophysical Observatory Station.

If one adopts the 39% R.H. for the three driest months and applies it to their mean temperature, 13°5 C, the estimated 50 percentile of the precip. H_2O would at 8,000 ft be 4.6 mm (if $H = 2.1$ km). For 14,000 ft this would correspond to about 1.9 precip. H_2O, values not as favorable as found at the same altitudes on Mt. Montezuma and La Silla.

Meteorological data were obtained Nov. 28, 1960-June 20, 1962 at the Yale Columbia Station (69° 25′ W, 31° 48′ S, 8,030 ft). The data are contained in a Report by Dr. J. Schilt to the National Science Foundation and kindly made available by Dr. A. J. Wesselink, Executive Director. The driest 3 months of this period were December 1960, January 1961, and June 1962, with average R.H. values of 20, 24, and 31%, and average 24^{h} temperatures of 20°0, 19°0, and 5°3 C (the values given for June 1961 are 68% and 25°0 C, a period of several hurricanes). Taking straight averages* of the three dry months, 25% R.H. and 14°8 C, one finds 6.7 mm precip. H_2O for their average conditions. The author is indebted also to Dr. J. Sahade, Director of the La Plata Observatory for supplying him with a listing of average R.H. and rainfall data for all Western Argentina.

It will still be of special interest to obtain integrated H_2O measures for La Silla, Mt. Montezuma, and high sites near Antofagasta (Fig. 27) for direct comparison with the IR stations in the Northern Hemisphere (Fig. 32).

5. Rule for Judging IR Quality of Night

At an observatory engaged in IR stellar planetary spectroscopy shortward of 5 microns the variations of the atmospheric water-vapor content from night to night, or even during a night, are of prime concern to the astronomer. He needs to estimate whether it is justified to devote a given night to such work or release the telescope to other programs. The author, often faced with this decision in the late 1940's and early 1950's at the McDonald Observatory, came upon a rule of thumb that still has its utility: add the relative humidity in % to the temperature in °F (both readily available in an observatory). *If the sum is more than 80, the night is useless for IR work; if less than 60, good; if less than 40, very good, etc.* The explanation for the rule is found in Table 8. If H is 2 km, the three parts of the Table correspond to 4, 2, and 1 mm precip. H_2O; if H is 0.8 km, the values are 1.6, 0.8, and 0.4 mm precip. H_2O. (This shows the need of caution when comparing sites with different H.) The rule works better than might be concluded from Table 8 because the average *R.H.* for the *entire* overlying atmosphere is rarely much less than 10% (or over 60%, when clear).

TABLE 8

SUM RULE FOR IR QUALITY

g/m^3	°F	R. H. %	SUM
2.0	20	67	87
	30	44	74
	40	31	71
	50	21	71
	60	15	75
	70	11	81
1.0	5	62	67
	15	41	56
	25	27	52
	35	18	53
	45	13	58
	50	11	61
	55	9	64
0.5	− 5	48	43
	0	39	39
	10	25	35
	20	17	37
	30	11	41

6. Conclusions

The criteria for optimizing ground-based IR-microwave programs are: (a) lowest attainable water-vapor content; (b) lowest useful altitude of observatory (up to 9,000 ft comfortable, 9,-14,000 ft workable with lower base, 14,-20,000 ft requiring pressurized quarters and reliable personnel evacuation); (c) good image quality (small, sensitive detectors usable); (d) lowest fractional cloud cover; (e) proximity to equator (planets, maximum sky cover); (f) proximity to home institution, availability of support facilities; (g) good transportation (for staff, coolants, replacement components; rapid access to observatory when conditions suddenly become excellent; rapid evacuation when a major storm approaches; high-altitude sites experience extremes unknown at lower altitudes); (h) for the higher altitudes, adequate survival measures for staff (altitude sickness, power failures, breakdown of transportation; cf. *Comm.* 157). In addition, some discussion has focused on the "sky noise" recorded primarily in the 8-14 μ window, the only large IR window accessible from sea level; there is evidence that the "sky noise" varies with the region, the Arizona obser-

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*The relationship of 50 percentiles in precip. H_2O and dew points (°C) is illustrated by Fig. 25.

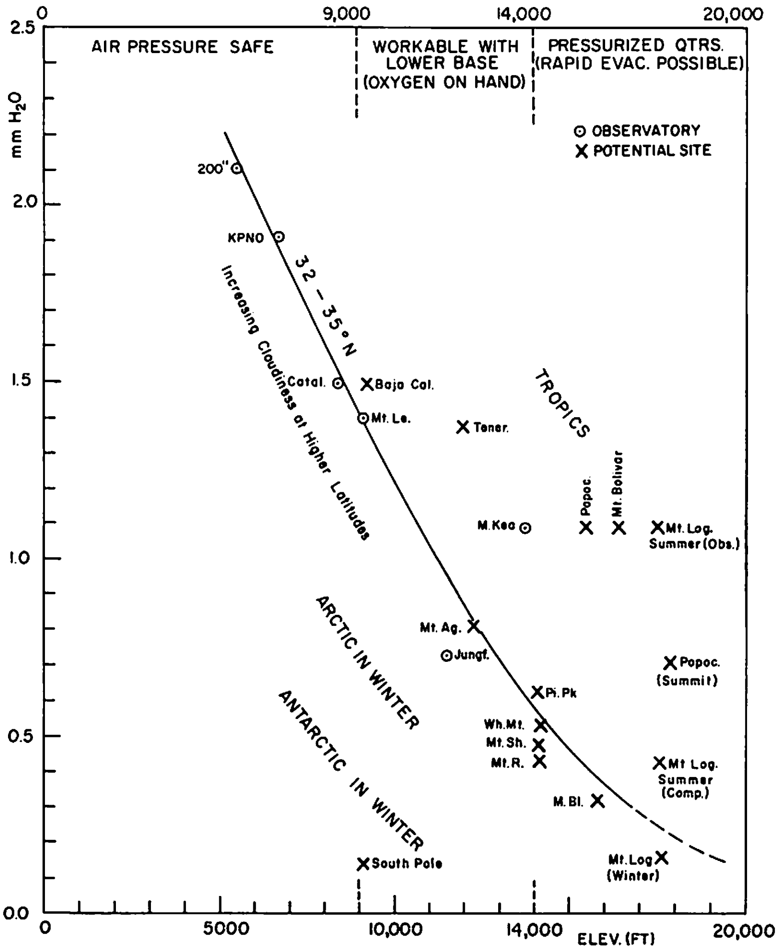

Fig. 32 Precip. water vapor in vertical column above observatory site vs. elevation, 25 percentile values for nine dry months of year, Northern Hemisphere, based on free-air values (Paper I, Table 1, last column).

vatories having less than other Northern Stations tested. (For stars the only troublesome part of the sky noise is that small residue that the observer does not succeed in compensating for, cf. Paper I, p. 126; for extended objects the problem is more complex and detector arrays have to be used to allow correction.)

Criteria (a) and (b) may be shown graphically. This is done in Fig. 32 for the 9-months, 25-percentile, humidity conditions taken from Paper I, Table 1 (p. 125). For sites in the dry and "clear" belt (32°-35°N), the relationship, apart from local orographic effects, is essentially one of *altitude vs. water-vapor* (with $H = 2.1$ km in the lower part, $H = 1.6$ km in the higher part, consistent with the results in Paper I). Surveys are still needed to ascertain *image quality, orographic effects,* and *cloud-cover* data. Equatorward, one must go higher to reach the same H_2O level; poleward (but excluding the poles themselves), lower, but at the price of *increased cloudiness,* say, from 30% to 70-80%. Also, one violates criterion (e) and possibly (f). The summer Arctic does not belong in a plot excluding the summer for the middle latitudes; it has some apparent aspects of the tropics. A 10,-12,000 ft isolated mountain in Alaska could be considered, in addition to sites in the "clear" belt, in spite of the frequent terrible weather and severe evacuation problems; also, the air-mass effect on planets would be serious. The South Pole is so exceptional as to require separate discussion; it is not well suited to observations of planets, but could be used for some surveys, as indicated in Sec. 1. The Southern Hemisphere has its own dry zone, with several high-altitude sites in Bolivia, Chile, and Argentina accessible; and those in N. Chile especially promising. The H_2O data available show the clear and dry belts in the two hemispheres to be rather alike.

IR observations requiring moisture levels below 0.2 mm, must be made from aircraft or balloons, especially for the planets and other equatorial objects. The existence of such facilities will incidentally put a ceiling on the justifiable efforts on isolated high mountains, as discussed in Paper I.

Addendum — After this Paper had been completed, the volume *Polar Research* (National Academy of Sciences, 1970) became available. Chapter 8 deals with "Polar Astronomy." In it the low surface temperature at the South Pole is used to compute the total atmospheric water content, a procedure that is not valid, as discussed in the above text. The author endorses most of the other comments made, especially Recommendation No. 1 (seeing tests).

Acknowledgments — This paper derives its information from many sources and has benefited from helpful comments from several colleagues in other disciplines. Prof. Serge A. Korff of New York University called my attention to his series of important papers on High Altitude Laboratories (1950, 1952, 1953, 1954), directed toward finding suitable stations for cosmic-ray research. These reports contain no data on atmospheric water vapor but list coordinates, altitudes, temperatures, snow conditions, and living facilities of the numerous stations included. Of special importance to this paper are his references to the Mount Wrangell Observatory, established by him and the University of Alaska in 1953.

I am indebted also to Prof. Nello Pace, Director of the White Mountain Research Station, University of California at Berkeley, for supplementary information on the facilities on White Mountain under his direction. White Mountain would appear to offer great opportunities to IR Astronomy. I am further indebted to the staff of the Smithsonian Astrophysical Observatory for condensing the 5-year meteorological records of their Arequipa station, 1961–1965, on which our Fig. 31 is based.

Special thanks are due to Mr. Robert Cameron of NASA-Ames for arranging with NASA for the two flights to the Mt. Shasta area referred to in the text, the principal results of which are published in this paper, and to Mr. John Arvesen for a discussion of the summit area and for the photographs reproduced in Fig. 19. My thanks are also due to Mr. Ralph Turner for his observations of the St. Elias Range, Canadian Yukon; to Prof. Melvin G. Marcus for the report on Mt. Logan quoted in the text; and especially to Prof. I. Drummond Rennie who arranged for Mr. Turner's flight and who agreed to contribute the paper on the Mt. Logan Arctic Station that follows. Dr. D. P. Cruikshank called my attention to the Russian observations in Yakutsk, Siberia, area. Mrs. F. Larson assisted ably with the search for relevant publications of the Polar regions; Mrs. M. Matthews, with the compilation of Fig. 32 and Table 7. The planetary research program is supported by NASA, Grant NGL 03-002-002.

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APPENDIX I
ADDITIONAL DATA, WHITE MOUNTAIN, CALIFORNIA

On December 4, 1970, the author had the opportunity to meet with the director of the White Mountain Research Station, Dr. Nello Pace, and astronomers and physicists potentially interested in IR and microwave programs conducted from White Mountain. The next day he had the privilege of being Dr. Pace's guest on a trip to the Bishop, Barcroft, Summit and plateau facilities, and experience the unmatched delights of helicopter trips over peaks and saddles, and through impassible canyons. The incredible efficiency of helicopter transportation (better by at least two orders of magnitude over traditional methods), with the astronomer saving his energies for his own tasks, was most impressive.

The author's visit to White Mountain occurred just after ten days of continuous precipitation in Northern and Central California, with 10 ft of snow having accumulated, e.g., at the Donner Pass. Yet, the snow cover on the summit of White Mountain was inappreciable, as may be seen from the photographs shown below. It did, however, cause the entire area to be covered with a layer of excess moisture.

The author made water-vapor measures with two instruments: (a) the Low device measuring the total vapor absorption in the solar beam; (b) a sling psychrometer. The measures are collected in Table 9. In order to reduce the integrated values (which are *equivalent* absorptions) to abundances, the mean vapor pressure must be estimated. We adopt $\bar{p}$ (mean) $= p$ (elevation + 1 km), entered in column 6. The approximate abundances are found from the entries of the 5th column by division by $\bar{p}$, and are given in the 7th column. These values define a scale height between Bishop and the Summit of 2.3-2.4 km; with the aid of the surface relative humidities, scale heights can be computed for each of the three

TABLE 9
SURFACE H_2O MEASURES, DEC. 5, 1970

LOCATION	EL (FT)	EL (M)	PST	EQUIV. H_2O (Z)	p (mb)	ABUND. H_2O (Z)	T°C		R.H.
							D	W	
Bishop Ap.	4110	1252	11:24	5.4	772	7.0	+9.2	+4.7	0.52
Barcroft	12470	3881	12:18	1.5	550	2.7	−1.7	−5.6	0.41
Summit	14250	4344	13:58	1.05	517	2.0	−5.8	−7.8*	0.64*
			14:01	1.0		1.9			
SE Plateau	13189	4020	14:36	1.1	539	2.0			

* Upper limit (operation strenuous)

Fig. 33 Barcroft Laboratory, Univ. of California White Mountain Research Station (cf. Fig. 10): *a*, Facing west, with Mt. Barcroft in background; *b*, Close-up view, facing NW. Observatory location behind and to right of hilltop at right (foundation left only).

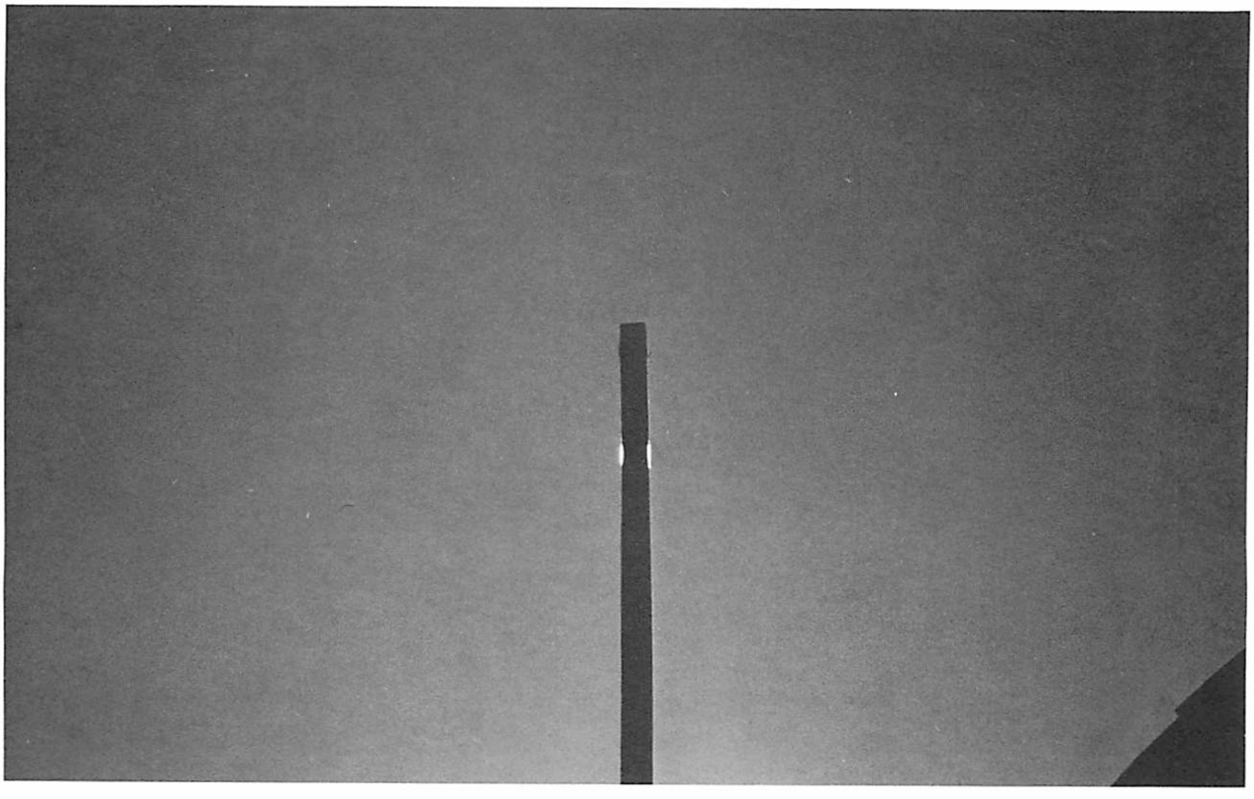

Fig. 33 Continued: c, Helicopter landing area; *d,* Occulted sun, showing perfect sky conditions. (Note diffraction of type observed by Surveyor on Moon horizon after sunset.)

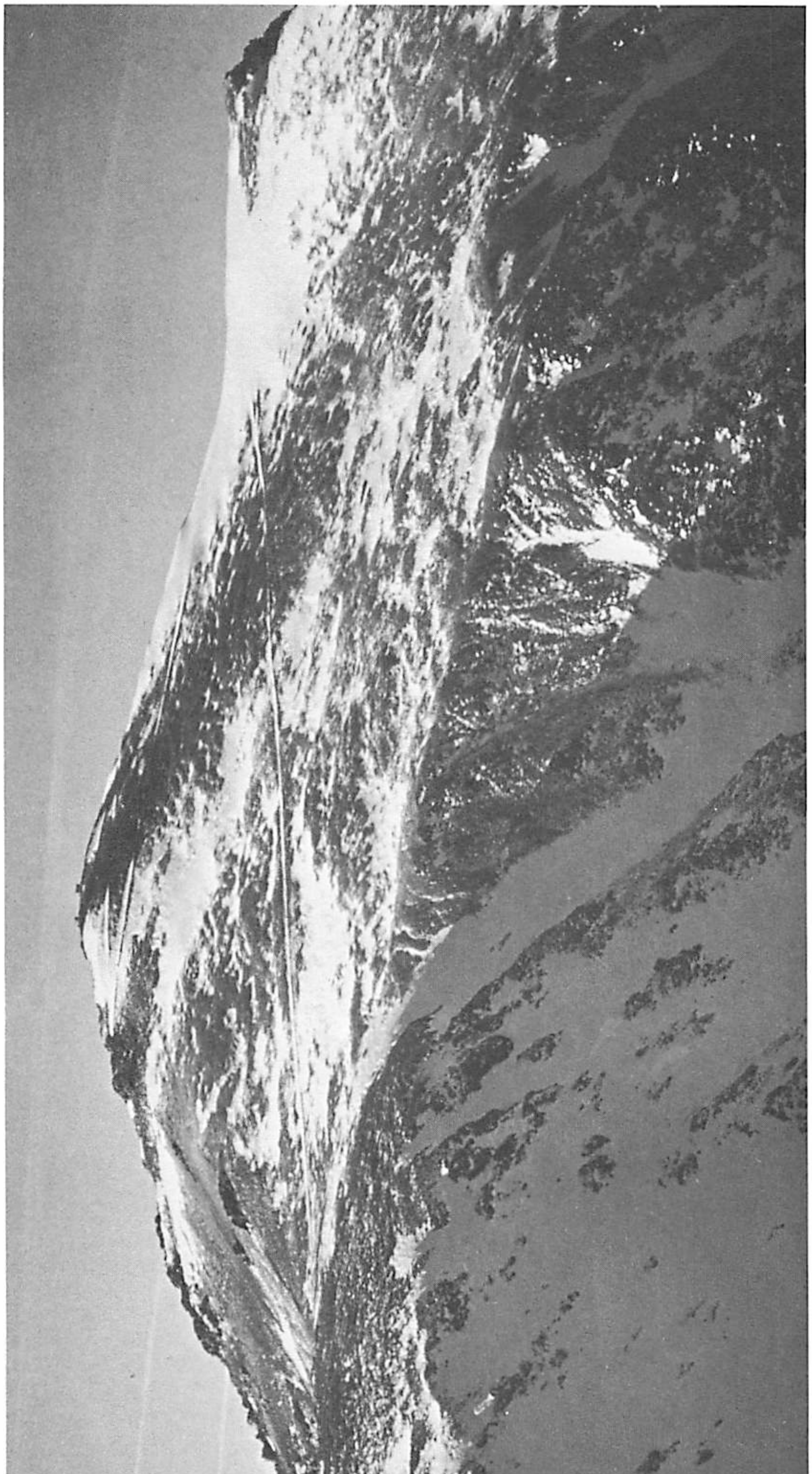

Fig. 34 Continued: b, View of summit from 13,200 ft, facing WNW, showing jeep road from lower left. Helicopter saddle covered with snow, at right. Contrails from Bay Area near horizon.

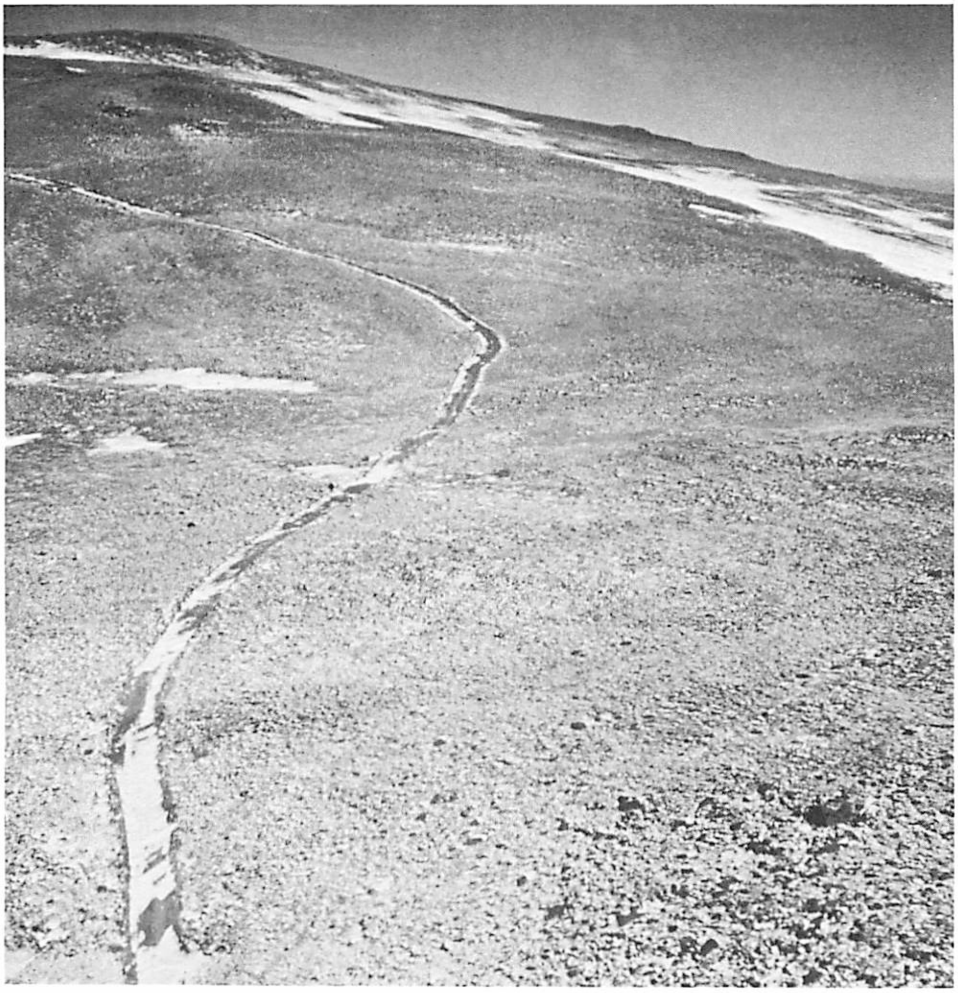

Fig. 34 Approach to White Mountain Summit: *a,* Jeep road to summit across plateau.

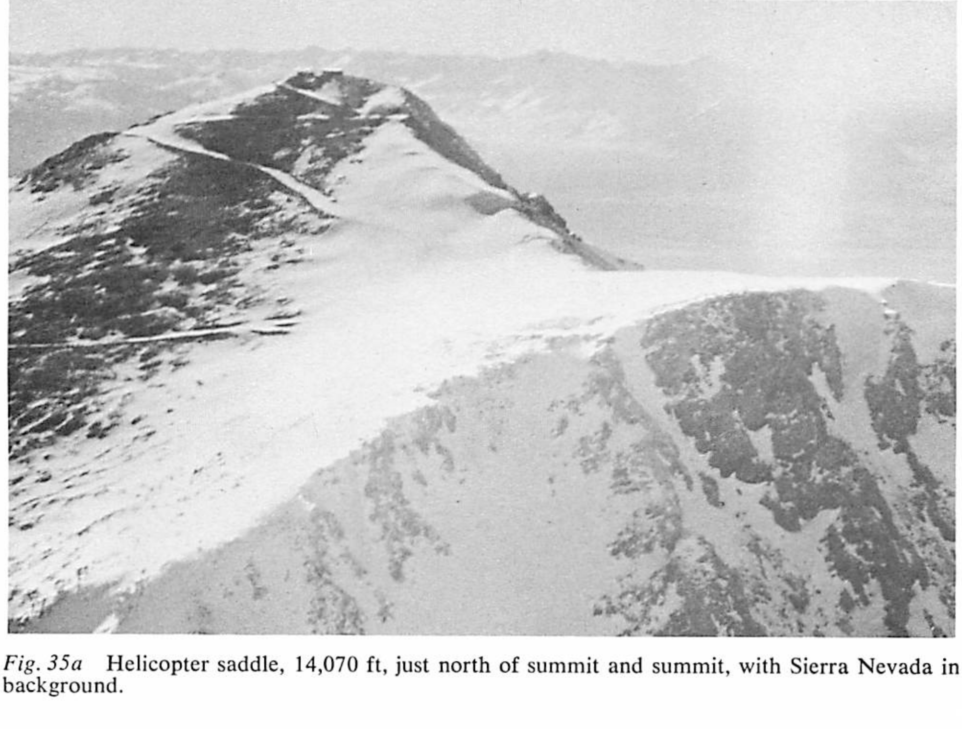

Fig. 35a Helicopter saddle, 14,070 ft, just north of summit and summit, with Sierra Nevada in background.

Fig. 35 Continued: b, Close-up of saddle, with contrails in background; *c,* Landing on saddle, Dr. Blume ascends summit.

Fig. 36 White Mountain Summit: *a,* View from helicopter, with jeep road partly covered with snow.

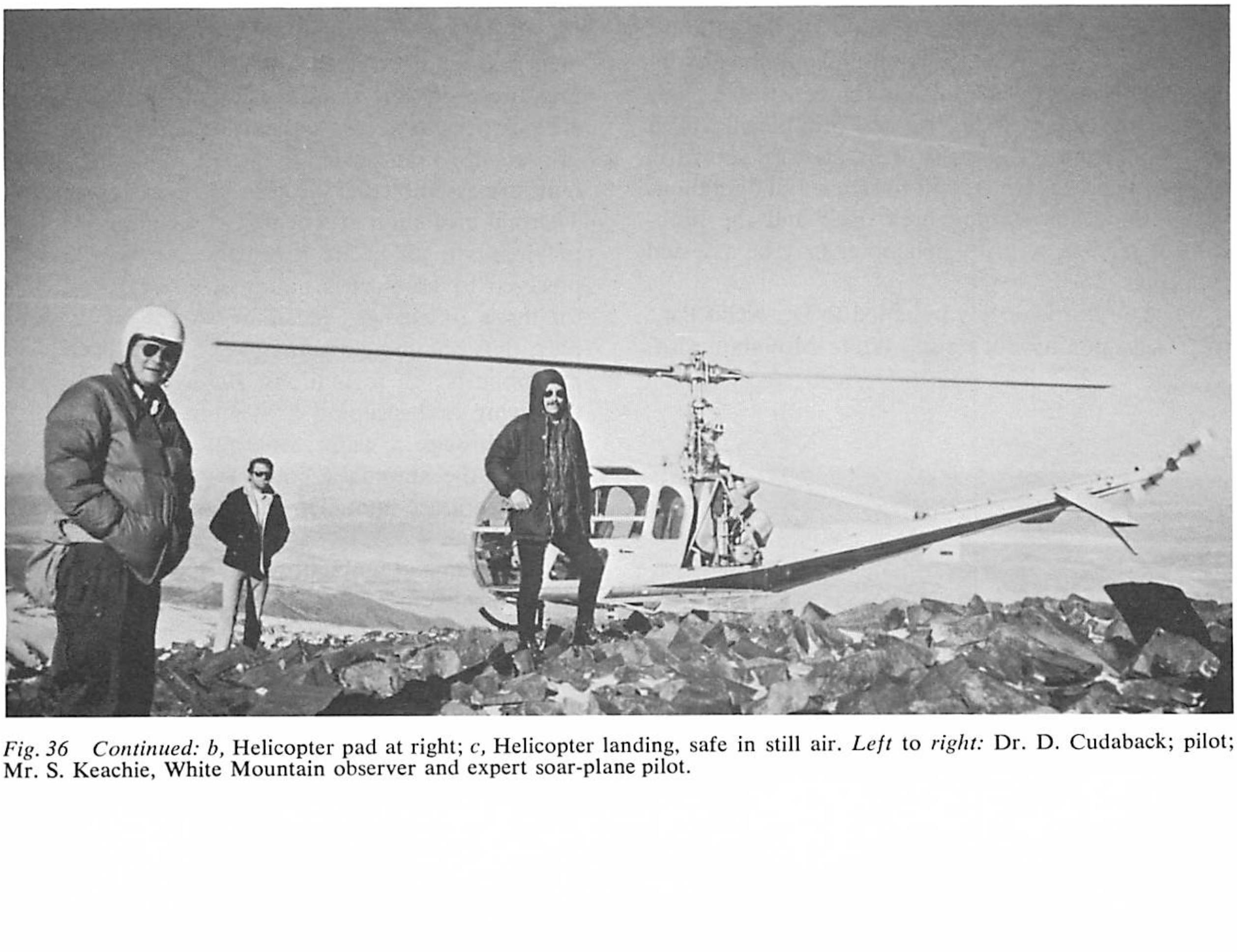

Fig. 36 Continued: b, Helicopter pad at right; *c,* Helicopter landing, safe in still air. *Left* to *right:* Dr. D. Cudaback; pilot; Mr. S. Keachie, White Mountain observer and expert soar-plane pilot.

stations separately: Bishop 1.65 km, Barcroft 1.4 km, and Summit 1.0 km (+). This indicates that there was an orographic effect, the moisture content over the summit being about 1.8× larger than that of the free air over Bishop at the same level. This orographic effect could be due in part to daytime evaporation in the powerful sunlight.

Some of the photographs taken from the helicopter flight on December 5, 1970, are herewith reproduced. Figs. 33*a* and *b* show two views of the setting of the Barcroft Laboratory. The Quonset hut at the center of Fig. 33*b*, having about ten rooms, is the comfortable headquarters of the Laboratory. Meteorological instruments are in the weather shelter, in front. The helicopter pad is covered with a steel mat (Fig. 33*c*). The area is sheltered and allows safe landing operations except during storms. The exquisite coronographic qualities of the sky at Barcroft are attested by Fig. 33*d*, which shows the sun covered up by a pole only a few minutes of arc greater in diameter (excellent coronographic conditions occur on the average about 4^h per day).

The jeep road to the summit, crossing the plateau, SE of the summit, is shown in Fig. 34*a*. The approach is a very gradual one, safe in summer and fall; and, because on the summit area the snowfall is light, the road could be opened almost at any time of the year. Nevertheless, because of the altitude, scientific operations on the summit would be enormously facilitated by the installation of a small cable car, slightly over a mile long and dropping 1,200 ft to the plateau at 13,000 ft. This plateau, shown in Figs. 34*a* and 15, lends itself to safe aerial operations year-round. The summit area itself and the problems of landing on it by helicopter may be assessed from Figs. 35-36.

The author is deeply indebted to Dr. Nello Pace for his hospitality during his White Mountain visit.

APPENDIX II

STAFF QUARTERS FOR HIGH ALTITUDE OBSERVATORY

by FERDINAND A. DE WIESS

The dangers to the health of personnel and the reduction in their capabilities due to prolonged exposure to the environment at 14,500 ft altitude may be avoided by providing living and sleeping quarters having an artificial atmosphere of controlled temperature, humidity, and pressure. In accordance with Professor I. D. Rennie (cf. *LPL Comm.* No. 157) an air pressure of 10.5 psi, representing an elevation of about 9,000 ft, appears indicated for this purpose as being sufficiently high not to cause discomfort to normally healthy individuals, even after long periods of stay, yet being low enough to produce acclimatization to altitude, reducing thereby the effects of exposure to the lower ambient pressure at 14,500 ft. As the pressure difference between these altitudes of 9,000 and 14,500 ft is in the order of only 2 psi, the construction and maintenance of such living quarters poses no serious economical or technical problems.

Figs. 37 and 38 show a possible design of such quarters, capable of providing comfortable accommodations for occupants. The basic structure is formed from three prefabricated steel tanks, as used for storage under pressure by the chemical industry. Steel frames are welded to the shell to support the pressure-proof doors and porthole-like windows. An air lock permits access and exit with a minimum loss of pressure. Transported to the site in sections, these units are assembled at location by means of welding. Thermal insulation is provided by bonding sheets of polyfoam to all inside surfaces. A rotary blower, powered by an electric motor of 2½ HP, provides for three air changes per hour for the whole complex, thus obtaining a value in excess of those given by public health regulations. Before being fed into the living and sleeping areas, the compressed air passes through a water evaporator and a heat exchanger, the automatic controls of which maintain the temperature-humidity relation within the human comfort zone.

A building at ambient pressure houses these service units, together with a standby generator powered by a gasoline engine, a water heater, and provides general storage.

An enclosed entrance permits protected traffic between this area and the living compound, and prevents obstruction of the air lock by snow or ice formation.

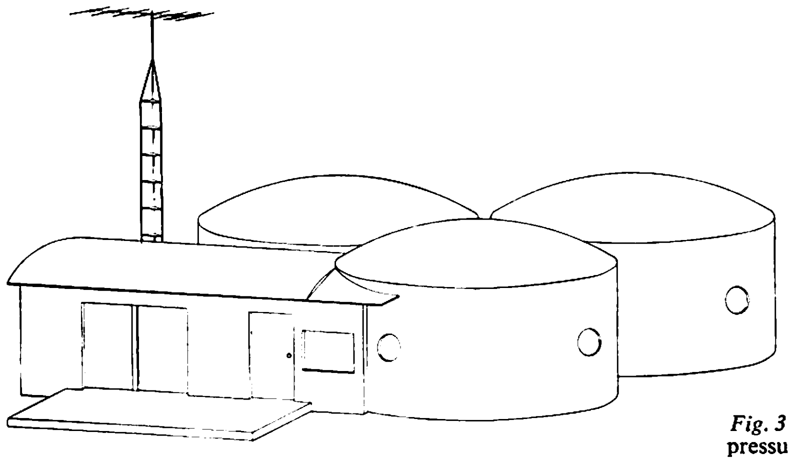

Fig. 37 Possible design of pressurized living quarters for observers on high mountain.

A preliminary estimate indicates an overall cost for the construction and implementation of this design of roughly $31,000, with a breakdown as follows:

Pressure tanks, 10 ft high by 16 ft dia., air lock doors and windows, foundation, insulation, construction	$17,700
Service building and entrance	3,000
Blower 300 cu ft/min 2.5 psig, motor 2½ HP, standby generator and gasoline engine, controls, battery	2,000
Heater, humidifier, ducting and valves, plumbing, sewer, electrical wiring, and installation	3,500
Furniture and appliances	800
Contingency	4,000
Total	$31,000

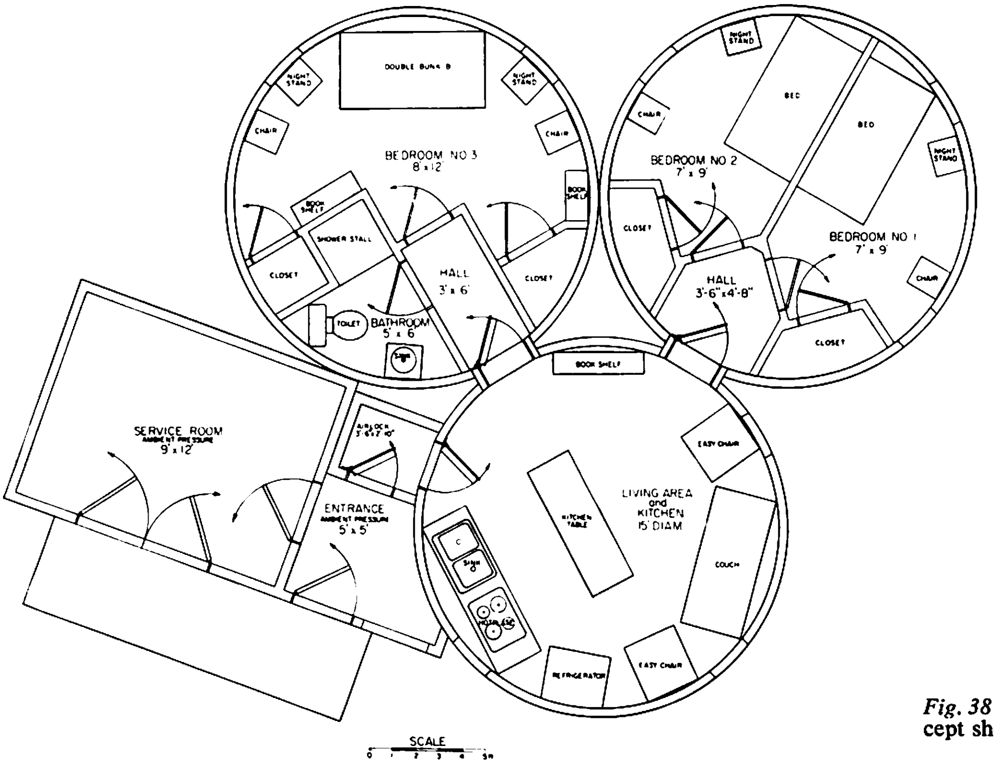

Fig. 38 Floor plan of concept shown in Fig. 37.