# Site Survey for the Inter-American Observatory in Chile

After three years of investigation, astronomers selected Cerro Tololo, a mountain in the Andes.

Jurgen Stock

Some of the most interesting of all celestial objects are found in the southern sky. The region containing the center of our own Milky Way star system, and the nearest neighboring galaxies, the Magellanic Clouds, probably are the best examples. The need for southern observatories available primarily to astronomers from the Northern Hemisphere has always been felt, and a number of southern stations have already been built. The Boyden Observatory near Bloemfontein, South Africa, as an effort of the Harvard astronomers, and the Radcliffe Observatory near Pretoria, South Africa, as an effort of British astronomers, may be cited here as examples.

During the last decade, three major astronomical organizations made plans for southern observatories for astronomers from the north and began activities in various parts of the world. In contrast to previous efforts, they started out with extensive surveys, searching for the most suitable sites. In fact, among the three organizations a worldwide or, better, a Southern Hemisphere-wide survey was conducted. In 1956 the European Southern Observatory (ESO), an organization of astronomers from Belgium, France, Germany, Holland, and Sweden, started a site survey in South Africa and maintained it, with some interruptions, into 1963. At about the same time Yale and Columbia universities were investigating sites in Australia, Argentina, and Chile. In 1959 the universities of Chicago and Texas began a site survey in Chile, with funds provided by the Air Force Cambridge Research Command. This project was taken over in 1961 by the Kitt Peak National Observatory.

The site survey in Chile profited considerably from experience gained by the previous surveys, in particular the survey conducted by ESO in South Africa and the survey made by the University of Michigan in the southwestern United States which led to the election of Kitt Peak. For nearly a year, as director of the survey in Chile, I was in close contact with the ESO expedition in South Africa, and the equipment we used was developed largely on the basis of the experience gained by the astronomers in South Africa.

One may wonder why it is so difficult to find good sites for astronomical observatories. It is evident that astronomers need a clear sky, and not too long ago they considered this to be the principal criterion for a good site. However, new types of equipment and new methods of research have changed the situation: The astronomer requires more from the atmosphere than the mere absence of clouds. Even a cloud-free atmosphere can seriously interfere with astronomical observations. Interference occurs when particular types of turbulent currents are present in the air. It is this turbulence, rather than the telescope, that sets the limits of the astronomers' investigations.

Atmospheric turbulence, like clouds or any other meteorological phenomenon, varies from one place to another and hence requires local study. Furthermore, the turbulence affecting astronomical observations is not readily evident in any other way, and sophisticated astronomical equipment is therefore required for detection. Also, the relationship of such turbulence to other meteorological phenomena is not yet well understood. This situation is the principal reason for the long duration of surveys for sites for astronomical observatories, particularly for those which are to have large telescopes.

## Optical Effects and Air Turbulence

Owing to the wave nature of light, even the most perfect telescopes do not form point-like images. The optical image of a point source of light—such as a star—consists of a diffuse nucleus surrounded by concentric and equidistant rings. The dimension of this "diffraction pattern" is inversely proportional to the aperture of the telescope. This diffraction pattern evidently affects the resolving power of telescopes. A telescope of 4-inch (10-centimeter) aperture is theoretically capable of resolving details of the order of one second of arc, while the 200-inch Hale Telescope at Mount Palomar should be capable of resolving details of the order of a few hundredths of a second of arc. Practical experience, however, gives a rather different picture. With small telescopes of good optical quality the theoretical resolution is obtained, but with large telescopes even details of the order of one second of arc cannot be resolved with great frequency.

In small telescopes—those with apertures smaller than about 6 inches—the diffraction pattern can practically always be observed. At times it may appear very clearly resolved and contrasty, at others it may appear washed out. On occasion, particularly when observed near the horizon, the images of stars may appear nebulous without any internal structure. Usually when the diffraction pattern is not sharply resolved, its structure also changes rapidly—often in small fractions of a second of time—and it is these rapid variations that assure the observer that it is not the telescope causing the disturbances. Also, the pronounced deterioration of the images with increasing distance from the zenith clearly shows that the origin of the image defects is in the atmosphere.

In addition to these image distortions, an erratic motion of stellar images is also observed in small telescopes. The images seem to jump and bounce around several times a second. The amplitudes and frequencies of the jumps also increase with distance from the zenith, again attesting to an atmospheric origin. Under good or excellent atmospheric conditions, the image motion may be imperceptible. Under poor conditions, deflections of more than 5 seconds of arc can be observed, even near the zenith.

In telescopes of much larger aperture —more than 40 inches—the atmosphere

The author is director of the Cerro Tololo Inter-American Observatory, Casilla 63-D, La Serena, Chile.

practically never permits the resolution of the diffraction pattern. The images are always disklike, although at times they may possess a rather small nucleus only a few tenths of a second of arc in size. Such small images, however, are of rare occurrence. In fact, images with diameters of the order of 1 second of arc are better than average at many observatories. Under very poor conditions, images readily grow to 10 or 20 seconds of arc, and images as large as 1 minute of arc have been reported. When the conditions are this poor, the size of the image is usually also extremely variable, and its structure can undergo rapid changes, often reminding the observer of boiling water. For fractions of a second the image may appear to be broken up into several pieces. For still larger apertures, greater than 60 inches, these internal motions in the image are less pronounced. More frequently, the images vary rapidly in diameter and often seem to pulsate.

A significant characteristic of large-telescope images is that they show only minor erratic motions of the image as a whole, in contrast to small telescopes, which usually show more image motion than image distortion. In telescopes of intermediate aperture, both effects are generally observed. Thus atmospheric turbulence seems to produce two distinct effects: image *distortion*, including increase in size, and image *motion*. The first effect grows with increasing telescope aperture, while the second decreases with telescope size.

The entire complex of phenomena just described can be understood quite well on the basis of a simple theory of the optical properties of atmospheric turbulence elements. Thus it seems reasonable to refer to these phenomena by a single term, and astronomers have come to general agreement on the word "seeing." The term "seeing," to be more specific, includes any erratic deflection of a ray of light on its passage through the atmosphere.

## A Simplified Theory of "Seeing"

A homogeneously stratified atmosphere—that is, one whose temperature, pressure, and density can be described strictly as a function of elevation above ground—does not affect the structure of an image formed by a telescope, except that short spectra (atmospheric dispersion) may be observed near the horizon. The existence of turbulence, however, causes deviations from homogeneity. In turbulent regions of the air, turbulence elements or "cells" with characteristics different from those of their surroundings are formed. It is their different density that determines their optical property. Turbulent air cells are likely to have a large variety of sizes and shapes. Also, density may differ from one cell to another.

A first understanding of the optical effects of atmospheric turbulence may be obtained by considering turbulence elements as spherical cells of a uniform internal density different from that of the surrounding air. It is not necessary to assume uniform size or equal density among all cells.

Let us first consider the effect of a single cell on the image formed by a telescope with an aperture larger than the cell. In this particular case it is assumed that the density of the cell is greater than the density of the surrounding air. In a first approximation the cell acts like a weak positive lens, affecting, however, only part of the beam of light entering the telescope. Thus part of the light forms the original undisturbed image, while the part passing through the cell produces an out-of-focus image superimposed on the in-focus image. On the whole, a washed-out image less contrasty than the normal undisturbed image is obtained. The next step is to consider the combined effect of several or many small cells. More light will be taken from the original image, and several out-of-focus images of possibly different diameters will be superimposed on it. Thus the image appears more washed-out than in the case of a single disturbing cell.

Finally, considering that the turbulent cells are in motion and that they form and dissipate rapidly, one can understand the rapidly changing appearance of the images.

When the turbulence cell is much larger than the aperture of the telescope, the cell acts primarily like a prism, causing a deflection of the entire beam entering the telescope. This effect is consequently observed as a motion of the entire image. As the cell passes through the beam the amount of deflection, and even its direction, changes. The total effect of many large cells passing through the beam results in an erratic motion of the image.

It can also be readily understood that in the case of cells comparable in size to the telescope aperture both the defocusing effect and the motion effect will occur, with the result that the image is simultaneously distorted and jumping.

This simple theory readily explains qualitatively the characteristic difference in the appearance of astronomical seeing in small and large telescopes. Evidently the size of the turbulence cells relative to the size of the telescope aperture plays the important role. We also gain an insight into the structure of the turbulent atmosphere. The largest optically effective turbulence cells are evidently smaller than the apertures of the largest telescopes, as indicated by the absence of appreciable image motion in the latter. By similar reasoning we can deduce that the smallest optically effective air cells are of sizes of the order of a few centimeters. Other methods indicate the presence of turbulence cells of very large size. However, the difference between the density of these cells and that of their surroundings seems to be too small to make them optically effective.

The theory just presented also permits prediction of the dependence of seeing effects on distance from the zenith. Utilizing the theory of the superposition of random errors, we can deduce that the seeing effects should be proportional to the square root of the total air mass between the star and the observer. This result has been confirmed by observations.

## Causes of "Seeing"

It is well known that seeing differs from night to night and also from place to place. Some observatories are renowned for their good seeing, while others suffer from persistently poor seeing. Apparently there are sites that are more suitable for astronomical work than others. Unfortunately, very few of the causes of seeing are known. So far they can only be related, in some instances, to other more easily observable meteorological phenomena. A systematic study of the "physics of seeing" has recently been started by C. R. Lynds at the Kitt Peak National Observatory in Arizona. It will certainly be some years before the mechanisms involved are well understood. Results to date show, in agreement with previous work by I. S. Bowen at the Mount Wilson Observatory, that part of the seeing effects have their origin close to the ground. However, it is also known that optically effective turbulence exists at high altitudes. This latter effect deserves particular attention, since it cannot be avoided by placing the telescope well above ground.

From theoretical considerations as well as from practical experiments, it is clear that zones where air masses of different temperatures are being mixed are the primary sources of seeing effects. Such mixing is produced very effectively during daytime by the ground, heated by sunlight. During the night this mechanism becomes ineffective, and it subsides altogether when the temperature of the ground falls below that of the air close to it. However, an effective mechanism which produces seeing does exist at nighttime. It is related to a phenomenon that meteorologists call "temperature inversion."

Under normal circumstances, the temperature of the air decreases with increasing elevation, in a predictable manner. However, under certain conditions a layer of cold air can form over the ground. This condition, although it deviates considerably from the normal state of equilibrium, is very stable, because the cold air on the ground is heavier than the warm air above it, and hence it has no tendency to change the distribution. The transition zone between the cold and the warm layers of air is turbulent.

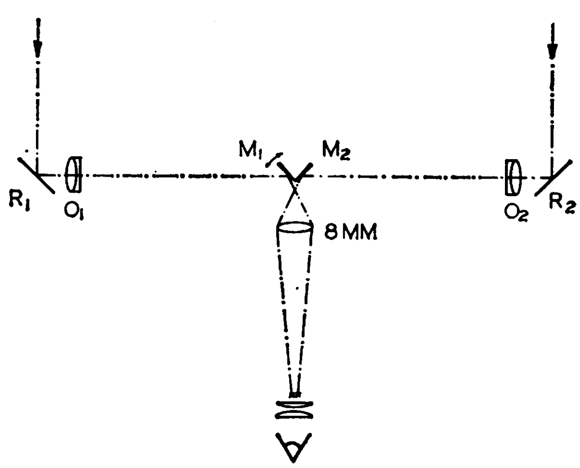
There are various processes that cause such temperature inversions. One of particular interest occurs in arid mountainous regions. During clear and dry weather periods, the surface cools off effectively overnight. Owing to the absence of clouds and the scarcity of water vapor, little of the energy radiated by the ground is reflected or retained by the atmosphere. Since air does not radiate very well, it stays at nearly constant temperature during the night. The air close to the ground, however, is cooled by contact with the cold surface. Thus a layer of cold air is formed over the ground. Its thickness increases during the night and may reach as much as 100 meters over a plain. Its thickness depends on the surface cover, the moisture in the air, the length of the night, and so forth. The effect is greatly enhanced in mountainous areas. The air cooled on the slopes of the mountains flows downhill almost like water and fills the valleys with lakes and pools of cold air. Cold breezes coming down through ravines are often strikingly noticeable. In mountain ranges of sufficient heights, more than 1000 meters of cold air may build up above the valley floors. This effect can easily be studied by placing temperature-recording equipment at various elevations. In particular, the maximum elevation reached by the temperature inversion during the course of the night can readily be determined.

## Field Equipment

The temperature-inversion mechanism explains part of the seeing effects observed, and hence astronomers are able to select sites where such obvious effects do not occur. However, actual seeing observations have to be made on the spot to test the quality of any new site. In previous years a variety of gadgets for the measurement of seeing have been developed and attached to existing telescopes at established observatories. Our interest, however, is centered on the discovery of new and possibly better sites. From the discussion in the preceding section, we can conclude that the best astronomical observing sites are probably found not along the highways but on isolated mountain tops or on far-away islands. Therefore, small and readily portable equipment is needed for seeing tests. A number of instruments for seeing tests in the field have been developed, but I shall confine my description to those used in the site survey in Chile.

The theoretical considerations presented previously suggest the use of a small-aperture telescope to observe the erratic motion of the image of a star. With a sufficiently small aperture most of the seeing effects can be expected to be image motion. In practice, however, this simple method is not sufficient, because any erratic motions of the telescope due to the handling of the instrument or to wind can produce an image motion similar to the motion caused by the seeing. The observer has no means of distinguishing between the two sources of the motion of the image. Fortunately, this difficulty can be overcome.

Let us consider the effect of a large turbulent air cell on two small telescopes mounted side by side and pointing at the same star. If the separation of the telescopes is small compared to the size of the cell, the images in the two telescopes will show identical motions due to seeing. When the two telescopes are rigidly joined, instrument vibrations also cause common motion of the two images. Thus, if by some optical means the two images are brought into the same eyepiece, but kept just a little separated, one can observe a "double-



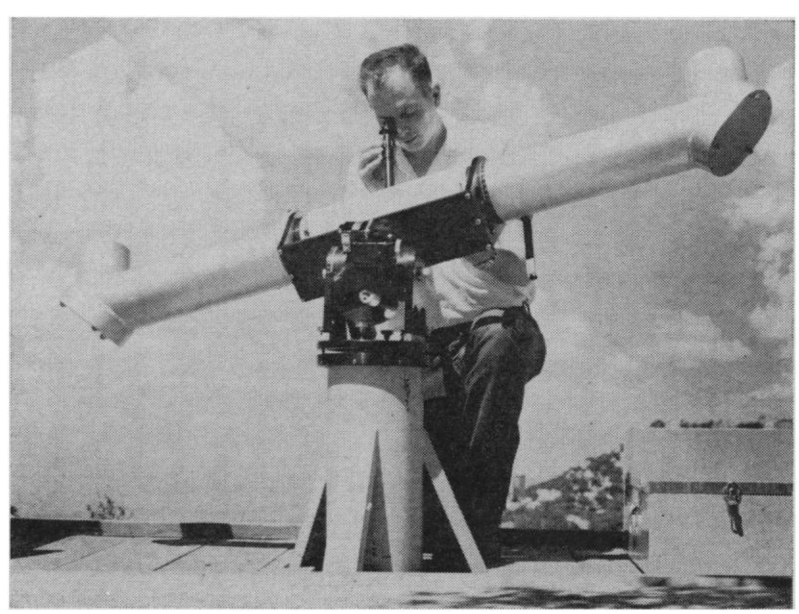



Fig. 1 (above). Optical system of a double-beam telescope. *R*, reflector; *O*, objective; *M*, mirror. Fig. 2 (right). Double-beam telescope for seeing tests.

star" of constant separation, though not necessarily in a fixed position in the field.

The situation becomes different when the separation of the telescopes is increased while their rigid combination is maintained. Vibrations still do not affect the relative position of the two images. However, since the two telescopes are now looking through different parts of the turbulent area, the deflections are different in the two beams, and consequently changes in the relative position of the two images can be observed. This relative image motion increases with increasing separation of the two beams, until it surpasses the size of the largest optically effective turbulence element. Then the seeing causes independent erratic motions of the two images, and the relative motion has reached its maximum. A "double-beam" telescope of fixed separation has been developed for the site survey in Chile. Its optical layout is shown in Fig. 1; Fig. 2 shows an instrument set up for use.

## First Phase of the Site Survey

In the first stage of the survey, the plan was to establish the future observatory in the vicinity of Santiago, and in April 1959 I was entrusted with the responsibility of organizing a short test program on a number of sites within a 70-kilometer radius of Santiago. A minimum elevation of 2000 meters was required in order to avoid a known and almost permanent temperature inversion in that area. Apart from that condition, only possibilities of access were taken into consideration when the first sites—Alto del Toro, Cerro Colorado, and Cerro Robles, shown on the map in Fig. 3—were selected.

From the very beginning great emphasis was laid on the seeing conditions. Double-beam telescopes were not available at first, but image motion could be measured successfully with single-beam telescopes on calm nights or when the wind was low. Besides the seeing observations, a variety of meteorological data were collected by the observers, all of whom were from the staff of the National Observatory of the University of Chile.

None of the sites selected for testing was located on an existing road, and the nearest roads were at distances from 2 to 5 kilometers. Thus equipment, supplies, and, at times, the observers, had to be transported by mules. This means of transportation became the very basis of the survey during its later phases when increasingly inaccessible sites were investigated.

The observations we gathered during the first months of the expedition indicated that, in general, these sites ranked among those of the best observatory sites known at that time. Also, the isolated peaks in the coastal mountain range appeared to have an advantage over sites in the "foothills" of the high Andes Cordillera. Thus one of the sites in the high mountain range was abandoned, and an alternate site, Cerro Tabaco, in the lower coastal range was added to the program.

During this early work, as we became more and more familiar with the climate of Chile, we began to believe that considerably better observing conditions might be found in more northerly parts of the country. Also, the growing interest of North American astronomers in the Chile project pointed to the possibility that the Chile observing station might at a later date develop into a large observatory. These two facts justified dropping the restriction—imposed for economy reasons—to test only in the vicinity of Santiago and extending the search to the more promising northern half of the country. Therefore, after several months of investigations in the central valley of Santiago de Chile, a new phase of the site survey was initiated by a reconnaissance extending 500 kilometers to the north.

## Second Phase of the Survey

When we started on our first trip to the north, intending to select new sites for seeing and meteorological observations, we had to take a number of factors into account. From available cloud statistics, we could anticipate a gain of about ten clear nights per year for every degree of latitude toward the north, for cloud occurrence decreases rapidly with decreasing latitude. On the other hand, for more accurate and efficient observations of the Magellanic Clouds in the far southern sky, the observatory should not be located too far north.

These considerations made it undesirable to go farther north than about 27° south latitude. On our inspection tour, which was made during the end of the winter in 1959, we were greatly impressed by the rather sudden change


Fig. 3. Map of Chile showing the sites investigated. Triangles, sites tested; circles and dots, cities.

in climate and vegetation near 30°S. As we reached the Elqui Valley, which is located almost exactly at 30°S, we came into the exceptionally clear weather that persists there nearly all the time. We also found that the air was remarkably clear, even at rather low elevations. North of this area there still is a fair amount of vegetation, not unlike that on the lower mountain ranges and desert areas of southern Arizona. Continuing farther to the north, we very soon ran into absolute desert—the lower end of the great Atacama Desert, one of the driest regions on earth. Thus, this latitude (30°S) seemed to be a good compromise between the increasing number of clear nights and the decreasing altitudes of southernmost sky regions.

We decided, therefore, to set up a test station in the Elqui Valley area, and the small town of Vicuña seemed to be best suited as headquarters for exploration of the region. We did not have much choice of a mountain site where seeing and meteorological studies were to be carried out. Limitations of funds, instrumentation, and personnel forced us to choose Cerro Guamayuca, the site closest to town and most accessible.

The observations carried out over the next month indicated that on every count this site had considerable advantage over any of the sites near Santiago. The seeing was better, there were more

Fig. 4. Summit of Cerro Tololo (2200 m).

clear nights, and the wind speeds were lower. Because of the success of this operation we decided to look for the best possible site in this part of the country, no matter where located, since we hoped to find sites with conditions better than those at any astronomical site known so far. Some experience indicated that we might find better sites in that area where we would avoid some particular local phenomena connected with the nearness of higher mountains or the deep valley coming up from the ocean. Just at that time, new equipment for making seeing observations, namely two double-beam telescopes, arrived in Chile.

Two steps had to be taken for such an extended exploration. First, sites that looked suitable on the basis of experience and knowledge already gained had to be found. Second, since these sites were almost certain to be far away from highways or roads, a supply and transport organization had to be set up to make it possible to work at these more remote sites. During a 2-month period we visited almost every site that appeared suitable on the basis of either selection on a map or inspection from an airplane. No consideration was given to accessibility, but availability of water was considered an important factor.

In April 1960, three sites in addition to Guamayuca were selected from the group of mountains that had been visited. These were Cerro Tololo, Cerro Morado, and Cerro Blanco (see Fig. 3). Guamayuca proved to be inferior to the new sites and was dropped from the program.

None of the sites in the program had an existing road, even anywhere near its base. They could be reached only by animal transportation, and with such heavy cargo as a telescope, two days were required to reach any of the summits. While the observers were on the mountain, water had to be regularly supplied, again by pack animals. The difficulties of reaching the sites made it advisable for the observers to go up for rather long intervals of time. The weather conditions at the sites were unknown, particularly during the winter, because most weather stations in Chile are located at lower elevations, and no meteorological data are available for the mountains. It was therefore necessary to build shelter huts for the observers, rather than continue to use temporary tents. All this construction made it necessary to acquire our own animal teams and the personnel to maintain them. It took some time to organize this operation.

During this time it became evident that we should think in terms of a larger observatory available to North American astronomers, and that the Association of Universities for Research in Astronomy (AURA, Inc.) would be better able to handle such a large project. The universities of Chicago and Texas began negotiations with AURA in 1960; these negotiations concluded with AURA's taking over the project on 1 May 1961. The Air Force was still willing to provide the basic 60-inch telescope, and the National Science Foundation, AURA's sponsor, was willing to finance the necessary additional facilities, including a road to the site that would finally be chosen. Also, with the increased funds which became available for the expedition when AURA took over, we were able to purchase three four-wheel drive vehicles, which greatly improved the speed of our operations. We were then able to build rough roads to reach the base of the mountains under investigation.

From the Kitt Peak site survey in the United States, there was still available a 16-inch reflector telescope with photoelectric attachments, and we thought it desirable to use this telescope to obtain data from Chile similar to those obtained during the Kitt Peak survey. The access difficulties in Chile, however, made it necessary to reconstruct the telescope and to prepare it for transportation by pack mules. The telescope, packed in 29 boxes, arrived in Chile in July 1961, together with a set of three small generators, tools, and other equipment. At that time Cerro Tololo was considered the most promising site, and preparations had already been made to install the 16-inch reflector there. It took the mule team of nearly 2 dozen animals and just as many men about 3 weeks to haul the parts of the telescope and all additional equipment, as well as the sliding-roof shelter for the telescope, to the mountain. The assembly of the telescope itself had been so well prepared by the Kitt Peak National Observatory shops in Tucson that it took only 4 days, after opening the first box, to have the first look at a star. This telescope has been in regular operation since early in August 1961 and has been used not only for seeing and atmospheric extinction observations, but also for regular astronomical research programs.

The studies of the sites in the Elqui Valley area had shown that Cerro Tololo and Cerro Morado had practically identical conditions. The preference for Cerro Tololo was based mostly on semitheoretical considerations which led us to believe that if there were any difference between the two sites, it would probably be in favor of Cerro Tololo. However, the difference could be so small that it might be impossible to detect with our field instruments. Cerro Blanco was considered inferior because of its much more severe winter weather, although during the summer it was an excellent site.

### Extension Northward

The substantial improvement in conditions that had been found by going from the Santiago area to the Elqui Valley made us wonder whether we could not obtain even better performance by going still farther north. A search for new suitable sites was made early in 1961. The experience gained up to then was extremely helpful in selecting sites that had the necessary topographical structure and location to avoid known sources of local disturbances. A promising site called Cerro Checo was found near the city of Copiapó (see Fig. 3). The preparations for the occupation of this site were extremely difficult, because of its location in an almost absolutely dry area; however, we were fortunate in discovering a water hole at the base of Cerro Checo.

The first few months of observations at Cerro Checo yielded very promising data; however, we had to face two new problems that we had not encountered on Cerro Tololo, namely, strong winds during the winter months and dust. Studies of the origin and location of the dust showed that most of it might be avoided by going eastward and to a higher elevation. To test this idea, a new site called La Peineta (see Fig. 3) located only 21 kilometers east of Cerro Checo and relatively accessible was chosen.

Although winds on La Peineta were practically identical to those on Cerro Checo, on La Peineta we did not encounter the dust and haze we had found on Cerro Checo; thus it became evident that La Peineta was the best choice among the northern sites tested.

### The Final Choice

The last months of the site survey in Chile were spent on comparison of Cerro Tololo and Cerro La Peineta. We had hoped that one site would show clear astronomical advantages over the other, in order to simplify the final decision. However, reality proved otherwise.

Here I shall present some of the data in order to make it clear why it was difficult to make a decision.

1) *Seeing*. The comparison of seeing data for the two sites showed that La Peineta might have a small advantage over Tololo. Unfortunately, however, during the winter we were unable to get a significant number of seeing observations on La Peineta because wind speeds frequently prevented the use of the double-beam telescope. On the other hand, the low wind speeds on Tololo permitted seeing observations to be made at practically all times, and it was found that Tololo had its best seeing conditions during the winter. The seeing observations available from La Peineta seem to indicate that this is not the case there. On the whole, we expect that on both sites a large telescope would have images smaller than one second of arc most of the time.

2) *Cloudiness*. During the summer, clouds are rare in both areas, but possibly slightly more frequent in the Copiapó area. During the winter, however, there are considerably more clear night hours in the Copiapó area.

3) *Wind*. During the summer, wind velocities are rather low on both sites, but during the winter they are considerably higher on La Peineta than on Tololo.

It is clear that both clouds and excessive wind speeds will prohibit the use of large astronomical equipment. It is not clear, though, above what limit wind speeds should be called "excessive." Many astronomers believe that, for critical observations, the limit is around 50 km/hr average wind velocity; but, this average means that peak velocities in gusts will often be over 65 km/hr. For wind speeds up to 30 km/hr, Tololo has during the winter about 300 more useful hours for astronomical work than does La Peineta. For wind speeds up to 50 km/hr, both sites have about the same number of useful hours. Only if wind speeds considerably higher than 50 km/hr are considered tolerable does the less frequent cloud occurrence on La Peineta produce any advantage. In effect, both sites probably would yield the same number of hours for high-quality astronomical work.

4) *Temperature and Humidity*. Generally, the temperatures on both sites are very favorable for astronomical work. On Cerro Tololo the temperature through the night is practically constant and varies relatively little from the daytime temperature, the difference between the daytime maximum and the nighttime minimum being only 8°C. The situation on La Peineta is very similar.

The relative humidity, on the other hand, shows a very characteristic change with the seasons. The average humidity is moderately high during the summer months and fairly low in the winter months. However, during periods of bad weather, which seldom occur except during the winter, the humidity may rise for short times to saturation.

In November 1962, a group of AURA board members visited Chile with the intention of either making a decision between the two sites or recommending continuation of the survey. The group visited both sites. Some of the members spent a night on each of the two mountains, and visited the nearby towns that might serve as headquarters, the nearest port facilities, and so on. On 23 November 1962, the group unanimously decided to recommend Cerro Tololo (Fig. 4) as the site for the future Inter-American Observatory. This recommendation was approved by the Executive Committee of AURA, Inc., on 1 December 1962, thus marking the end of a 3½-year survey for what is planned to be a large and modern observatory. Its 16-, 36-, and 60-inch telescopes will be available not only to North American astronomers whose research requires observations in the Southern Hemisphere, but also to Latin American astronomers whose telescopes may not be modern nor located in favorable sites.

*A letter from the author, which appears in this issue of* Science, *describes the progress that has been made in the construction of the observatory*—Ed.

**Bibliography**

General information on astronomical seeing, site surveys, and instrumentation may be obtained from J. Stock and G. Keller, in *Telescopes*, G. P. Kuiper and B. M. Middlehurst, Eds. (Univ. of Chicago Press, Chicago, 1960), chapter 9; A. B. Meinel, *ibid*., chapter 10.

A method for testing seeing with a single telescope is described in A. Danjon, *Lunettes et Telescopes* (Revue d'Optique Théorique et Instrumentale, Paris, 1935), chapter 5.

More technical discussions and data are given in A. J. Gardiner, F. Gifford, R. I. Mitchell, H. L. Giclas, H. L. Johnson, A. G. Wilson, *Optical Studies of Atmospheric Turbulence*, Final Report under Contract No. AF19 (604)-953, Lowell Observatory, Flagstaff, Arizona (also issued as Air Force Cambridge Research Center Technical Report 56-261, 1956); G. Keller, W. M. Protheroe, P. E. Barnhart, J. Galli, *Investigations of Stellar Scintillation and the Behavior of Telescopic Images*, Reprint No. 39, Perkins Observatory, Delaware, Ohio (also issued as Final Report, RF Project 635, Air Force Cambridge Research Center).