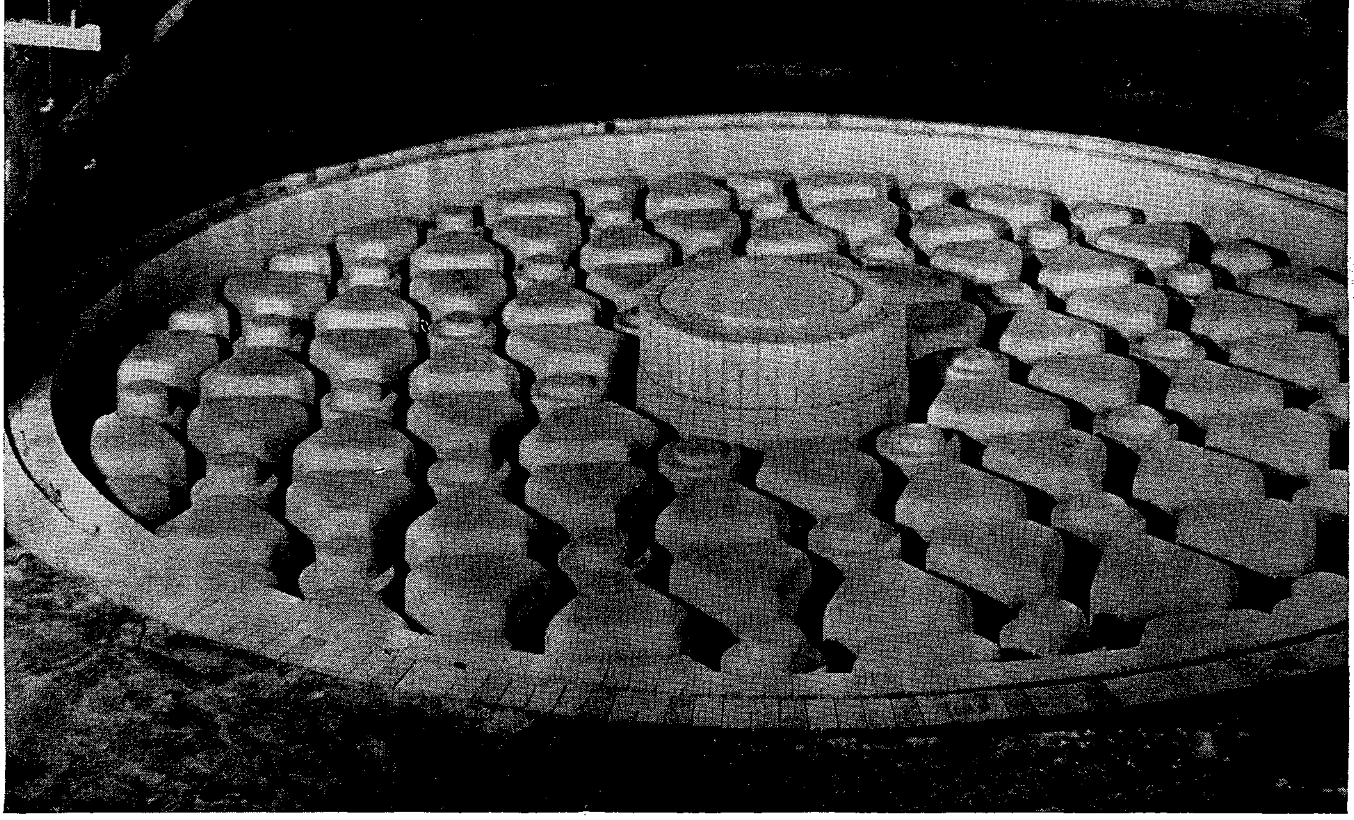


Mold for the 200-inch disk, showing cores for center hole, support holes, and triangular openings between ribs. Corning Glass Works photograph.

THE 200-INCH MIRROR

THE PRESENT 200-inch mirror took shape in a New York conference early in 1932. Members of Caltech's Observatory Council, the Corning Glass Works, the Rockefeller General Education Board, and the Carnegie Foundation met to discuss a second attempt at producing a 17-foot disk. The General Electric Company had experimented with fused quartz for more than two years since the International Education Board promised six million dollars for the project, but the work was discontinued owing to slow progress and great cost. The Observatory Council then turned to "Pyrex", a low expansion glass produced at Corning.

In order to gain the necessary rigidity, a 200-inch disk of Pyrex would have to be 30 inches thick and would weigh 40 tons. And if the mirror blank could be cast, there was ahead of the structural engineers the tremendous task of producing a mounting that would carry this weight—almost astronomical itself in dimensions.

In discussing ways of lightening the mirror a suggestion, simple, but radically different from contemporary telescope practice, was made: Design the disk with a thin face supported on a ribbed back. The more the conference considered this construction, the more they were taken with the idea. Not only would it lighten the mirror considerably, but the ribbed back would also provide pockets for a counterbalanced type of support designed by Francis Pease of the Mt. Wilson Observatory staff. Besides, the thinness of the reflecting surface would permit a rapid adjustment to changes in temperature with consequent greatly reduced distortion caused by uneven heating and cooling.

This plan was carried out, and now almost all large telescope mirrors are cast with ribbed backs.

The Observatory Council's program for Corning was to order glass disks of increasing larger size, starting with one of 26-inch diameter. Most of these were to be used as auxiliary equipment in the telescope.

Difficulties were ironed out one by one as they arose. The method of attaching cores to the mold floor in order to produce the ribbed back evolved from cement, to dowel pins, to steel bolts. Cores floating to the top of the molten glass spoiled three pourings. In one case, the casting was rendered usable by fishing

John A. Anderson

Dr. John A. Anderson, executive officer of C.I.T.'s Observatory Council, has served in that capacity throughout the entire development of the Palomar project since 1928. He was active at the Mt. Wilson Observatory from 1916 to 1943, and has done extensive research in the fields of spectroscopy, ruled gratings, and seismometry. The 200-inch mirror was ground, polished, and figured under his direction. A graduate of Valparaiso College, Indiana, in 1900, and holder of the Ph.D. degree from Johns Hopkins University (1907), Anderson was instructor and associate professor of astronomy at the University from 1909 to 1916. During World War I he worked at Caltech on a supersonic anti-submarine project, and has participated in two U. S. Naval eclipse expeditions, one to Spain in 1905 and another to Sumatra in 1926.

Dr. Anderson was awarded the Howard Potts Medal by the Franklin Institute in 1927 and is a member of the American Chemical Society, the A.A.A.S., the National Academy of Sciences, the American Physical Society, the Seismological Society of America, the Geophysicists Union, the Optical Society of America, and the Astronomical Society of the Pacific.

Pouring the 200-inch disk. Glass was ladled into the mold through three such openings. Corning Glass Works photograph.

cores out of the molten surface and grinding solid sections left in the back to the symmetry of the molded pattern.

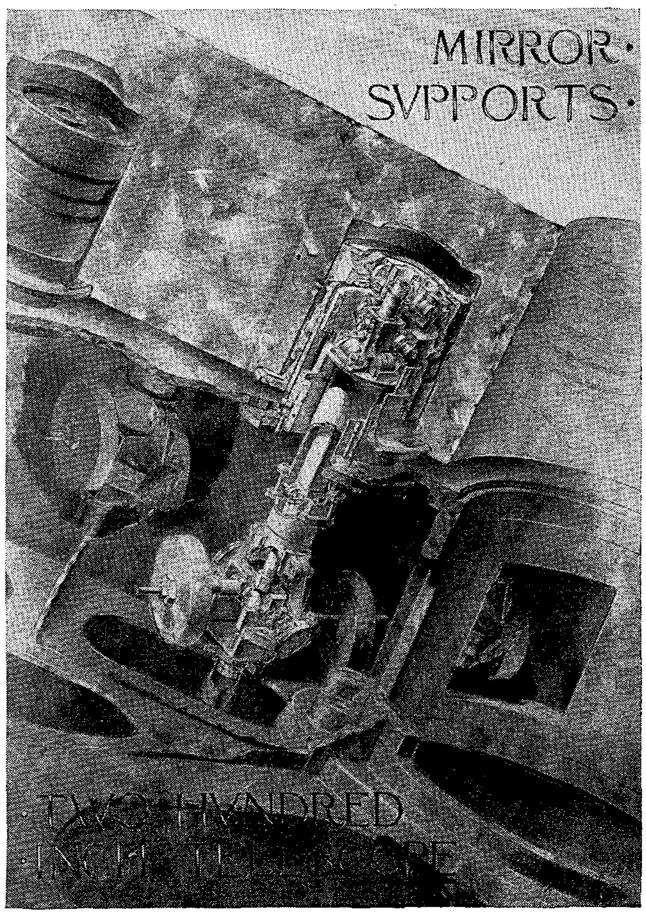
This trouble with cores was chiefly caused by the tremendous heat needed. Starting with the third mirror, one 60 inches in diameter, a furnace over the mold was required, as the molten glass had been found to solidify before filling all of the channels between the cores.

Everything was in readiness in February 1934 for the pouring of the 200-inch. Cores, 114 in all, had been bolted into place, and the brick furnace was keeping a heat of 2400° F concentrated over the mold. Pouring commenced, was half completed, when a core appeared on the surface of the glass lake inside the furnace. Three altogether rose, their retaining bolts having burned through in the great heat, but workers were able to break them into smaller pieces. The pourers finished their work, but Corning engineers had already made up their minds to try again.

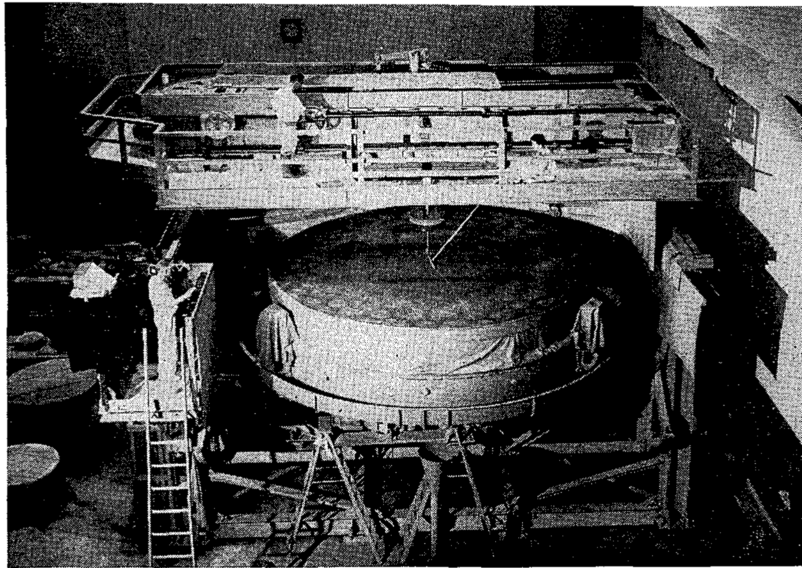
The first disk was an excellent subject for experimentation. Corning cooled it at ten times the calculated rate, and on checking, found internal strains of exactly ten times those desired. With their calculations verified, the glass men drilled out the pieces of core and reheated the disk until the face became smooth again.

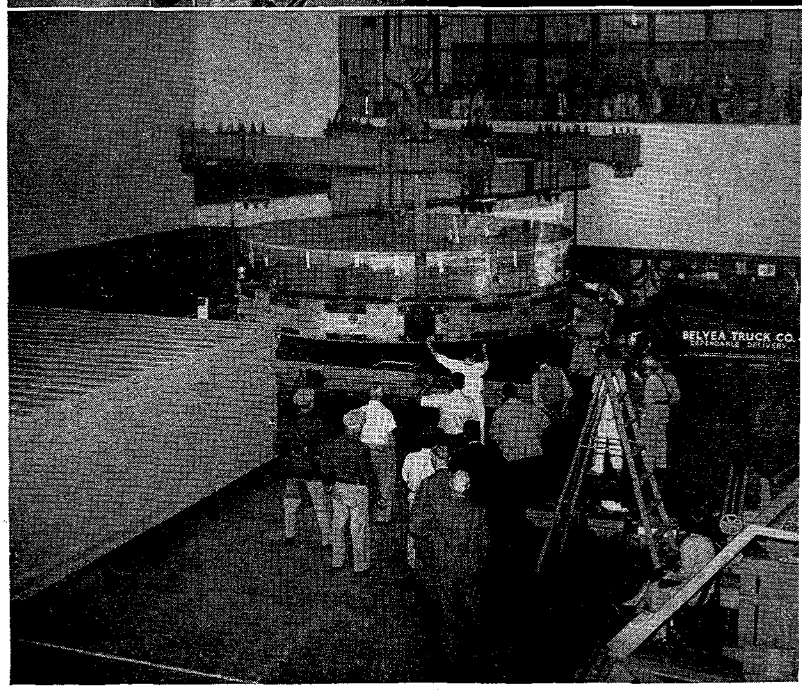
In December another disk was poured without a hitch. The mold had cores held in place by bolts of chrome nickel steel and cooled by an air circulating system. The disk was placed in the annealer to "soak" for two months at constant temperature, and then cool for eight more.

The next summer, with three months of cooling at the rate of one and one-half degrees Fahrenheit per day left, the nearby Chemung river flooded. The annealer was on the second floor of the laboratory, but the electrical equipment was on the ground floor. For a day and a half Corning men slaved to build a protecting dike, but in the end the current was shut off. Three days the great disk bled its heat away until the electrical equipment could be moved to the second floor. It was finally hooked up and



There are 36 supports identical to the ones shown here. Each is made up of over 1000 parts, comprising a series of gimbals and compound levers designed so that each support carries its share of the glass above it, no matter what inclination the mirror has to gravity. Drawing by R. W. Porter.





UPPER: Polishing the 200-inch mirror in the optical shop. The man at right on the bridge stirs the rouge-and-water compound and keeps it at the point of contact between the tool and the mirror.

***LOWER:* Loading the 200-inch mirror *in the optical shop.* This photograph shows the shop's observation gallery at the south end. To the left is the box which was placed over the mirror on its trip to Palomar Mountain.**

the annealing continued for the last three months.

No strains appeared when the annealer was opened. Across the country the disk was sent, arriving in Pasadena on Easter morning, 1936.

In the optical shop at Caltech the mirror was placed face down on an especially designed machine where its lower surface was ground smooth. Next came the face. After it was entirely trued up, 36 holes for the mirror supports were ground out.

Then came the grinding of a spherical surface, followed by polishing. These operations, as well as the original truing-up, were conducted on a turntable held high above the shop floor on a heavy iron frame. Underneath were motors and driving linkages which not only rotated the mirror but also tilted it to a vertical position for testing. Above the turntable was a heavy horizontal beam, called the bridge, which moved back and forth on wheels. This bridge supported a carriage, also on wheels, which held a vertical shaft for the grinding tool. In operation the disk on its table was rotated about once every 80 seconds, the tool turned faster and was moved over the surface by the bridge and carriage. The motors driving these parts were linked together so that the tool could be made to trace any kind of a pattern desired and hence distribute the grinding evenly over the whole surface of the disk.

For grinding and polishing, tools of 12 to 200 inches in diameter were constructed. These were faced with Pyrex blocks, used uncovered for grinding, and surfaced with a special pitch for polishing. Thirty-one tons of grinding and polishing compounds were used, ranging from carborundum to a very fine grade of rouge.

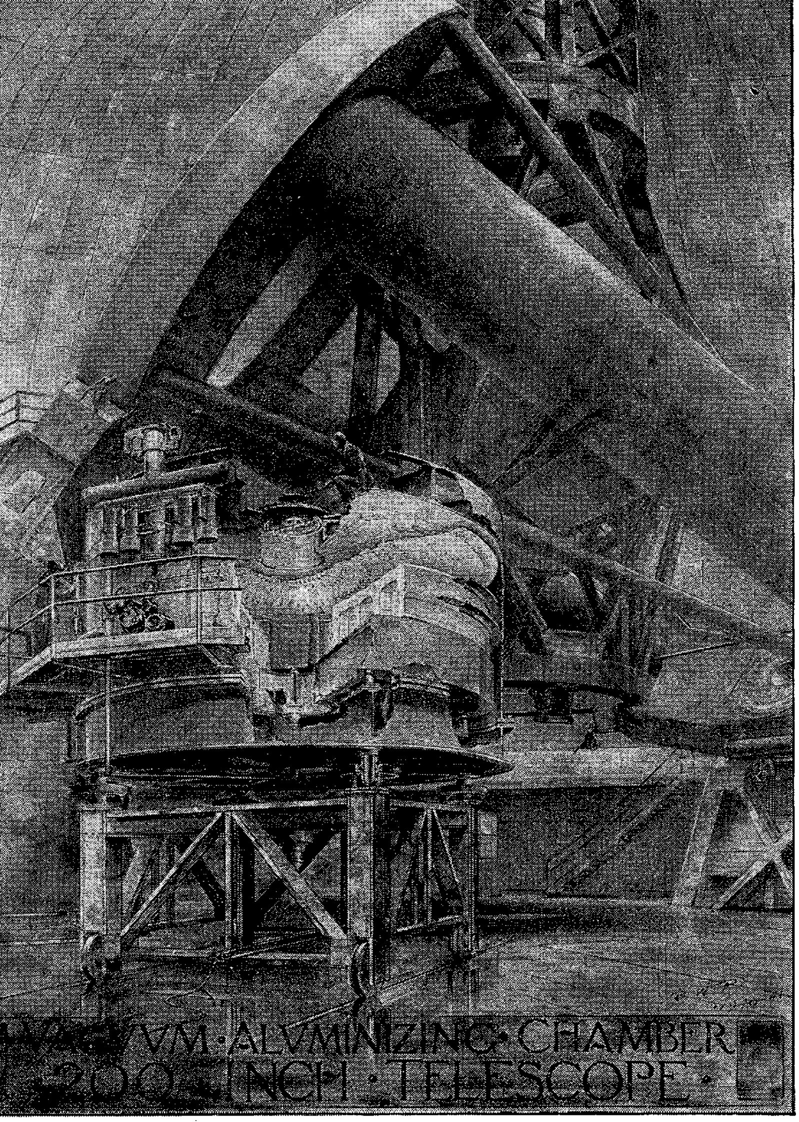
For rough polishing the 200-inch tool was used, with 1964 glass blocks surfaced with a compound concocted of resin, paraffin, and cylinder oil. Each pad was divided by channels into squares roughly one inch on a side, so that the 200-inch lap finally became a mosaic of 8000 facets with innumerable little canals for the polishing compound to run through.

In 1942, with polishing well under way, optical requirements for war work closed in, and the mirror was covered and left on its grinding machine. The crew spent three and a half years making mirrors, prisms, and other optical devices for the armed forces. In December 1945 polishing of the disk was resumed.

The work slowed down from 1946 to 1947. More and more time was spent in testing, and less and less in polishing. On October 3, 1947, the polishing was declared finished. By all of the routine tests used from the beginning, the mirror's parabolic surface was accurate to within two one-millionths of an inch—one-tenth of a wave length of light. Dr. John A. Anderson and his staff devised new testing methods. These new methods confirmed the accuracy of previous ones. The mirror was ready; and five and a quarter tons lighter than when it entered the optical shop.

November 18, 1947, saw the next high point in the mirror's career. The huge disk in its cell had been lifted off the grinding machine and lowered onto a trailer. At 3:30 in the morning State Highway Patrol officers gave the signal, and the tractor and trailer, convoyed by a spare tractor unit, another truck for spare parts, and innumerable reporters and cameramen, started the 160-mile trip to the Palomar Observatory. Road blocks were set up on some sections of the route, bridges received additional shoring, and the trailer had on one occasion 16 extra wheels mounted in order to distribute its 35-ton weight more evenly over a suspect bridge.

On arrival at the Observatory, the mirror was placed in an aluminizing tank, built as a permanent fixture on the observing floor. In this tank, under conditions of high vacuum, pure aluminum was vaporized off tungsten heating coils and condensed on the polished surface. The even coating thus formed is about two molecules thick—less than one-millionth of an inch. This was the reflecting surface. The glass, into which

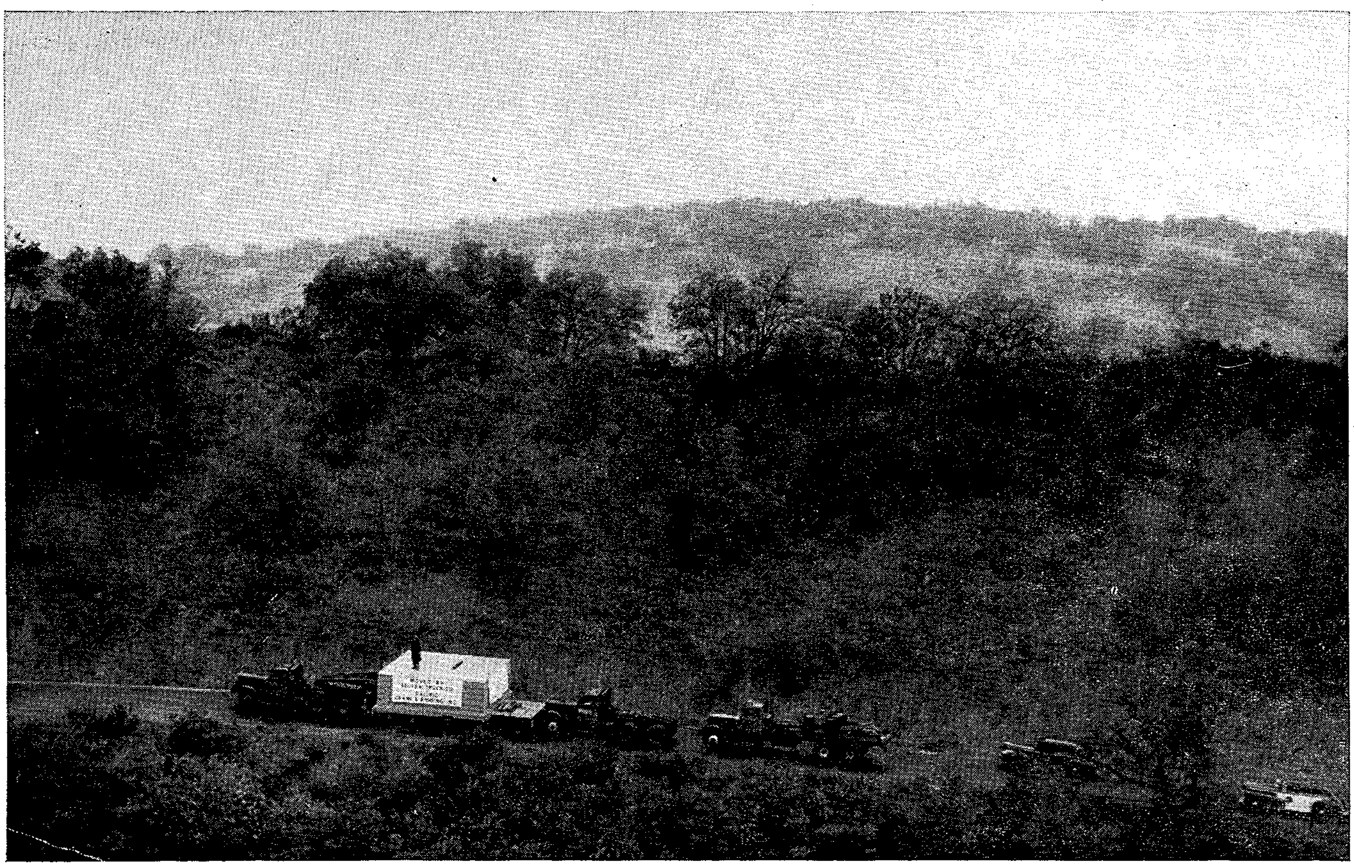


The aluminizing chamber is mounted on rails, so that it may be moved directly underneath the telescope. On the left are vacuum pumps. Pieces of aluminum wire are hung from tungsten coils inside the chamber, and vaporized in vacuum. Their temperature and position has been so computed as to place a layer of aluminum one or two molecules thick evenly over the surface of the 200-inch mirror. Each aluminizing is expected to last for about ten years. Drawing by R. W. Porter.

eleven years of work had gone, became backing for the mirror.

In December 1947 the first stars were seen reflected in the mirror. There was nothing spectacular about the "first look". Dr. Anderson used a small reading glass for an eye piece and peered into the big mirror. Asked what he saw, his noncommital answer was, "Oh, some stars." Marcus Brown, in charge of the optical shop and the actual mechanics of grinding and polishing from the beginning, was also there, as were Dr. Bowen, Dr. Hubble, Bruce Rule, and a few others.

Since that night, periodic photographs have been taken for the purpose of obtaining test data on how both the mirror and telescope react under working conditions. These tests will continue for some time yet as necessary adjustments are made, auxiliary mirrors installed, and other equipment completed.



Three trucks carring the mirror up Palomar Mountain. In spite of very poor visibility and road conditions, the trip was completed safely seven hours ahead of schedule. Photograph by Edna Sommer.

SHOPS AT CALTECH

WITH the decision made in 1928 to attempt a 200-inch telescope, past experience indicated the necessity of constructing special shops for finishing work on the mirror and development and fabrication of auxiliary apparatus for the project. Following the plan so successful at Yerkes and Mt. Wilson, Dr. Hale planned his third observatory with shops as an integral part of the project. The instrument shop, completed in 1931, and the optical shop, in 1933, were financed with funds from the Rockefeller grants.

INSTRUMENT SHOP

First to be built was the instrument shop, a one-story structure 70 feet by 197 feet, with a mezzanine floor for engineering offices and drafting rooms. The building is lighted by windows on the north and south sides, and through inclined "sawtooth" skylights.

A crane, normally equipped for five-ton capacity, but which can be rigged to carry considerably heavier loads, runs the entire length of the shop. All of the heaviest machinery is located in the central bay, where it is directly accessible by the crane. This location serves a two-fold purpose, permitting the crane to carry work to and from the machines, and also facilitating the dismantling of the machines themselves for overhauling.

Nearly all apparatus for the Palomar project, from the 10-ton gears cut for the telescope's right ascension and declination movements down to the smallest instrument part, has been manufactured here on the Institute campus. In a large woodshop for patternmaking, located in the southwest corner of the instrument shop, patterns for castings ranging in size from the great 14-foot gears just mentioned have been turned out. In most cases, actual casting was the only operation carried on outside the shop.

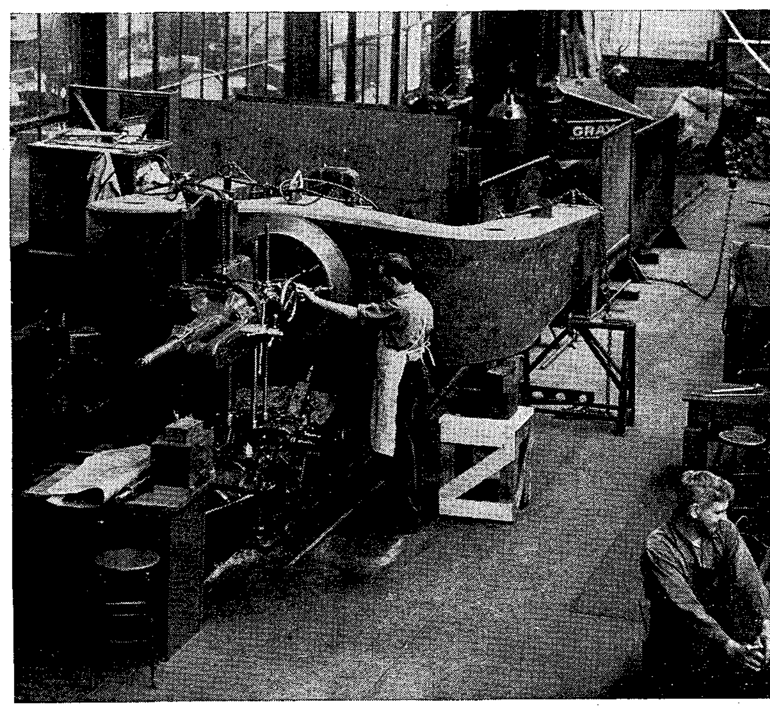
Opposite the pattern shop is the welding department, which also contains several heat-treating furnaces for hardening and annealing. One of the largest jobs done recently in this department was the fabrication of the 5½-ton fork mounting for the 48-inch Schmidt telescope from steel plates.

Since the shop's inception in 1930, its facilities have been used for a wide variety of work. Construction of all control cabinets, desks, and electrical test facilities, adaption of stock electrical parts and instruments to specialized telescope control, and installation and servicing of the short-wave radio formerly used for communication with the Observatory have been part of the shop crew's activities. In addition, all of the machinery for the optical laboratory, varying from the mechanism for grinding a 36-inch mirror to a machine for finishing the 200-inch, has been built in the instrument shop.

During the war when construction on the 200-inch project was suspended, the shop turned to Navy-sponsored work for the Institute. The usual complement of 24 workers was expanded to 70 to carry on rocket and torpedo research and development.

One of the most interesting jobs to be done in the shop was the machining of the three 14-foot gears for the 200-inch telescope right ascension and declination drives. These gears, each weighing ten tons and containing 720 teeth, were cut to an overall tolerance of one ten-thousandth of an inch. To cut the three gears required two and one-half years. And to achieve the degree of precision required, work was carried on inside a specially constructed, air-conditioned room maintained at constant temperature between 74° and 76° F.

The shop building also houses a complete electrical department. Chief electrician is Jerry Dowd, who joined the Mt. Wilson project as a truck driver in 1907, switching to the 200-inch job in 1930 when the shop went into operation. All electric equipment was built under his direction and was wired and tested under the same roof before being installed.



The 48-inch Schmidt telescope fork on the Lucas boring mill in the instrument shop. In this photograph, looking west, the pattern shop is to the left.

OPTICAL SHOP

One of the most important factors that had to be considered in designing the optical shop was its 17-foot scale. Facilities for the grinding and testing of the big mirror were all-important, although the shop would be used only for small auxiliary mirrors and testing after the 200-inch was moved to Palomar.

Completed plans provided for one large room, 52½ feet wide, 165 feet long, and 48 feet from floor to ceiling. The floor is of reinforced concrete divided into sections, each section completely isolated from the walls and adjacent sections to absorb earth disturbances. In turn, each section is floated on three inches of cork for insulation. The walls and roof are similarly of reinforced concrete and lined inside with cork.

For air conditioning a large blower is installed in the attic. This blower has a capacity of 12,000 cubic