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STUDIES OF OBSIDIAN AS A MATERIAL FOR USE IN MAKING ASTRONOMICAL MIRRORS

FINAL REPORT together with report of 7-9-54

~~Periodic Status Report No. 9~~

June 16, 1954 to June 15, 1955

Contractor

FUND FOR ASTROPHYSICAL RESEARCH

Incorporated

71 Broadway

New York 6, N.Y.

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Studies of Obsidian as a Material for Making Astronomical Mirrors

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9th Periodic Status Report

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During this period no further samples of obsidian have been collected in the field. The principal effort has been concentrated on grinding and accurately figuring mirrors for testing, including one from the largest single piece of obsidian that is available, so that the performance of the material under normal operating conditions in a telescope can be evaluated. Measurements of the thermal properties of obsidian have been made, and measurements of other physical properties are being completed.

OBSIDIAN MIRRORS

The following mirrors have been figured, or are in the process of being figured, at the present time:

A. 12" Parabolic Mirror (Glass Mountain)

This mirror was ground and figured for the Sandia Corporation by the Ferson Optical Company. It was made from the butt end of one of the boulders obtained from Glass Mountain. The material contains many cavities, about 0.5 to 1.0 mm in diameter, and for this reason, although the mirror has been accurately figured, it scatters light to a serious extent. The individual piece of obsidian from which it was made probably includes impure obsidian at one side of the boulder. It is obviously greatly inferior to material in other parts of the boulder, which produced excellent mirrors.

B. 12" Spherical Mirror (Obsidian from Hrafntinnuhryggur , Iceland).

The material is of extremely high quality. The mirror has been figured accurately spherical (30 feet radius) by the Ferson Optical Co., and will be tested at intervals, several months apart, over a period of years to test the permanence of figure of obsidian from this source in Iceland.

C. 13" Parabolic Mirror (Obsidian from Hrafntinnuhryggur, Iceland).

This mirror, made from the same boulder as the preceding mirror, has been figured accurately parabolic with a focal length of approximately 45", so that it can be installed in a small telescope and tested under astronomical conditions, with exposure to variations in temperature.

D. 19" Spherical Mirror (Obsidian from Reykjadalir, Iceland).

The slab from which this mirror was made is the largest that could be cut from any of the boulders obtained in Iceland. It was found on the dome (Hrafntinnusker) just south from the valley at Reykjadalir. When the surface of the disc was polished it was seen to contain a very considerable number of white inclusions, about 2 mm in diameter, so that the mirror would inevitably scatter a considerable amount of light. For this reason figuring was not carried beyond the preliminary stages. Nevertheless, the deviations from a perfect sphere are not large, and the mirror will provide additional information about the permanence of figure of obsidian mirrors.

E. 31" Parabolic Mirror (Obsidian from Glass Mountain, California).

This is the largest mirror that is being made under the present project. The disc shows slight banding, but only a few small inclusions. It was cut from the same boulder that provided the disc for the 31-inch mirror that was made by the Ferson Optical Co. for Johns Hopkins University under an ONR contract

The mirror is being figured parabolic with a focal length of 105". An 8" convex hyperbolic obsidian mirror will be figured, so that the two mirrors can be mounted together as a Cassegrain system in a coude telescope. This will give an opportunity for the first time to test the performance of obsidian mirrors of considerable size in a telescope under operating conditions.

The figuring of the mirror is being done by Fred B. Ferson and Peter Lenart at the Ferson Optical Company. At the present time the surface is well polished and shows few defects of any kind. The figure is very closely parabolic, but work will be continued until deviations from the ideal curve do not exceed one-quarter wavelength of green light (0.000,005 inch).

Testing has been carried as far as is feasible with the knife-edge test alone. In order to facilitate accurate and reproducible testing of individual zones, a metal diaphragm has been made at the Institute of Optics, at the University of Rochester. This contains 20 pairs of circular apertures, each 1.0" in diameter. The centers of the openings corresponding to zones with radii that increase by steps of 0.75". Even and odd pairs of openings in the series lie along diameters at right angles to one another, so as to avoid overlapping of the apertures for adjacent zones (Fig. 1).

Zonal measurements are being made in two ways: (1) with an illuminated pinhole and knife-edge mounted together as a unit, at the center of curvature, and (2) with the pinhole at the long focus and the knife-edge at the short focus of an ellipsoid.

In the first case the displacements of the knife-edge for various zones are

$$(\Delta \text{ K.E}) \text{ central curvature} = \frac{r^2}{2R}$$

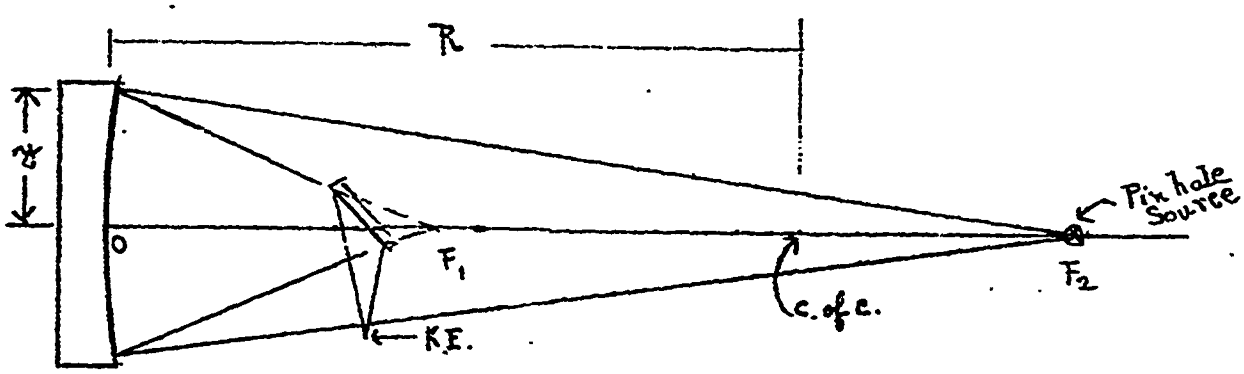
where $\underline{r}$ is the radius of an individual zone and $\underline{R}$ is the radius of curvature at the vertex of the mirror.

In the second case, the displacements of the knife-edge are:

$$(\Delta \text{ K.E.})_{\text{ellipsoid}} = \frac{r^2}{R} \cdot \frac{OF_1^{\,2}}{R^2} \cdot \frac{b^2}{a^2} = \frac{r^2}{R} \cdot \frac{OF_1^{\,2}}{R^2} \cdot \frac{(OF_2 - OF_1)^2}{(OF_2 + OF_1)^2}$$

a and b are the semi-major and semi-minor axes, OF_1 is the distance from the vertex (0) to the shorter focus (F_1) of the ellipsoid and OF_2 is the distance from the vertex to the longer focus (F_2).

The test in which the figure of the paraboloid is compared with that of an ellipsoid has definite advantages as compared with the test at the center of curvature because the desired curve agrees more closely with an ellipsoid than with a sphere. Displacements of the knife-edge for each zone are smaller, in the ratio $\frac{b^2}{a^2}$. The displacements are still further reduced in the ratio $\frac{OF_1^{\,2}}{R^2}$ because the knife-edge is closer to the mirror, but this of course does not add to the sensitivity of the test.



The displacements of the knife-edge for a perfect paraboloid, 31" in diameter with 210" radius of curvature, are shown in Table I, for the two methods of testing.

Table I.

Knife-Edge Setting

Zone No.	Radius of Zone	Test at Center of Curvature	Test at Near Focus of Ellipsoid
1	1.25"	0.0037"	0.0019"
2	2.00	.0096	.0048
3	2.75	.0180	.0090
4	3.50	.0292	.0146
5	4.25	.0430	.0215
6	5.00	.0596	.0298
7	5.75	.0787	.0394
8	6.50	.1006	.0503
9	7.25	.1252	.0626
10	8.00	.1524	.0762
11	8.75	.1823	.0912
12	9.50	.2149	.1075
13	10.25	.2502	.1251
14	11.00	.2831	.1441
15	11.75	.3287	.1644
16	12.50	.3720	.1860
17	13.25	.4180	.2090
18	14.00	.4667	.2333
19	14.75	.5180	.2590
20	15.50	.5720	.2860

In the case of the test at the center of curvature, the calculated displacements are based on the pinhole and knife-edge moving together as a unit. But when testing at the short focus of an ellipsoid, with the source at the long focus, the source of course remains fixed in position.

It seems likely that the test at the short focus of an ellipsoid has marked advantages, as compared with testing at the center of curvature, because as the ellipsoid becomes longer the .tuations approaches a null test. The merits of this test will be investigated because of its general interest for optical work, quite apart from the present application to an obsidian mirror.

Thermal Properties of Obsidian

The coefficient of thermal expansion has been measured on samples of obsidian by Professor Kathryn A. McCarthy at Tufts College, using the equipment described by Ballard, McCarthy and MacLeod (J.O.S.A., 41, 871, 1951). The coefficient of thermal conductivity has been measured by Professor Lewis A. Combes, at Tufts, using the interferometric equipment developed by Combes, MacLeod and Ballard (J.O.S.A. 44, 345A, 1954).

Samples from the following locations have been prepared by cutting them to the dimensions shown in Table II, and fine grinding the surfaces:

Iceland	Hrafntinnuhryggur
Iceland	Reykjadalir
California	Glass Mountain
New Zealand	Mayor Island

Table II

Sample No.	Obsidian Specimen No.	Source	Thickness mm	Cross Section mm	Axis Measured
4	225	Iceland-Hraf.	4.50	10.98 x 11.00	a-a*
5	225	Iceland-Hraf.	7.87	10.98 x 11.00	a-a*
6	326	Iceland-Reyk.	4.50	10.98 x 11.00	c-c
7	326	Iceland-Reyk.	4.50	10.98 x 11.00	a-a
8	326	Iceland-Reyk.	4.50	10.98 x 11.00	b-b
9	125	California-Glass Mt.	4.50	10.98 x 11.00	a-a
10	125	California-Glass Mt.	4.50	10.98 x 11.00	c-c
11	341	New Zealand-Mayor Island	4.50	10.98 x 11.00	a-a*
12	341	New Zealand-Mayor Island	4.50	10.98 x 11.00	c-c*

* No visible structure. Axis defined only by dimensions of boulder (a-a, longest dimension; c-c shortest dimension)

Note: When striae are visible, axes are defined as follows:

a-a in plane of striae, in direction of longest dimension of boulder
b-b in plane of striae, in direction of shorter dimension of boulder
c-c perpendicular to plane of striae

Preliminary results for thermal conductivity are as follows:

Table III

Thermal Expansion

Sample		Coefficient of Expansion (C^{o-1})
Obsidian No. 9		5.38×10^{-6}
11	(two orientations)	6.22
11		5.41
7	(two orientations)	5.15
7		5.66
12	(two orientations)	5.31
12		5.15
Corning (7740)		3.14
		3.13
Corning (7160)		2.50
		2.51

The results for thermal conductivity are as follows:

Table IV

Thermal Conductivity

Sample	Direction of Flow, relative to striae	Thermal Conductivity (Cal sec^{-1} cm^{-1} C^{o-1})
4	no striae	2.43×10^{-3}
5	‖	2.55
6	⊥	2.5
7	‖	2.65
9	‖	2.52
10	⊥	2.4
11	‖	2.75
12	⊥	2.58
Corning (7740)		2.5
Fused Silica		2.8

The results indicate that the thermal expansion of obsidian is approximately twice as great as that of Corning 7160 glass, and that thermal conductivity is almost the same for the two materials. This suggests that, on the basis of thermal properties alone, obsidian mirrors up to about 30 inches diameter may be expected to give reasonably satisfactory performance under the conditions to which astronomical telescopes are subjected.

Permanence of Figure of Obsidian Mirrors

Tests of the 10" diameter spherical obsidian mirror (radius 240") that was made in 1949 show no detectable changes in figure. The figure will be watched in the future for as long a time as possible.

Micro-Crystals

A considerable number of samples of obsidian are being ground as thin sections in order to complete the examination of microscopic structure. The variations of level in polished surfaces of a series of obsidian mirrors will be measured with a Zeiss interferometer microscope at Bausch and Lomb, as soon as the group of mirrors has been completed.

Scattering of Light by Obsidian Mirrors

It was stated in the last progress report that scattering of light by obsidian mirrors would be measured quantitatively. This is to be done with sensitive photoelectric equipment that is now nearly ready for use, and every effort will be made to make the measures in time for inclusions in the final report under this contract. It seems clear that reliable measurements of scattering are of great importance in evaluating the usefulness of obsidian.

Publications

A paper entitled " Thermal Conductivity and Thermal Expansion of Obsidian" was read by McCarthy, Combes, Ballard and Dunham at the meeting of the Optical Society of America in New York on April 9th. This describes the preliminary measurements that were in progress at Tufts College. A paper with the same title and by the same authors is in preparation now, and will describe the final results of these measurements. This paper will be presented to the Journal of the Optical Society of America.

Conclusions

On the basis of the data and experience that has been accumulated to date, it seems clear that mirrors up to 30 inches can be made successfully from obsidian, and that the cost for material will ordinarily be about one sixth of the cost for glass discs of good quality. This cost would be greatly reduced if material for a considerable number of mirrors were acquired at one time. On the other hand, obsidian has no obvious advantages as compared with low expansion glass. Accordingly, it will in all probability be used only when cost of material is an important consideration or when the need for a mirror is urgent and the time required for annealing would involve a serious delay. Under emergency conditions, obsidian could serve an extremely useful purpose for Government requirements, in that it could be substituted for glass in many instruments.

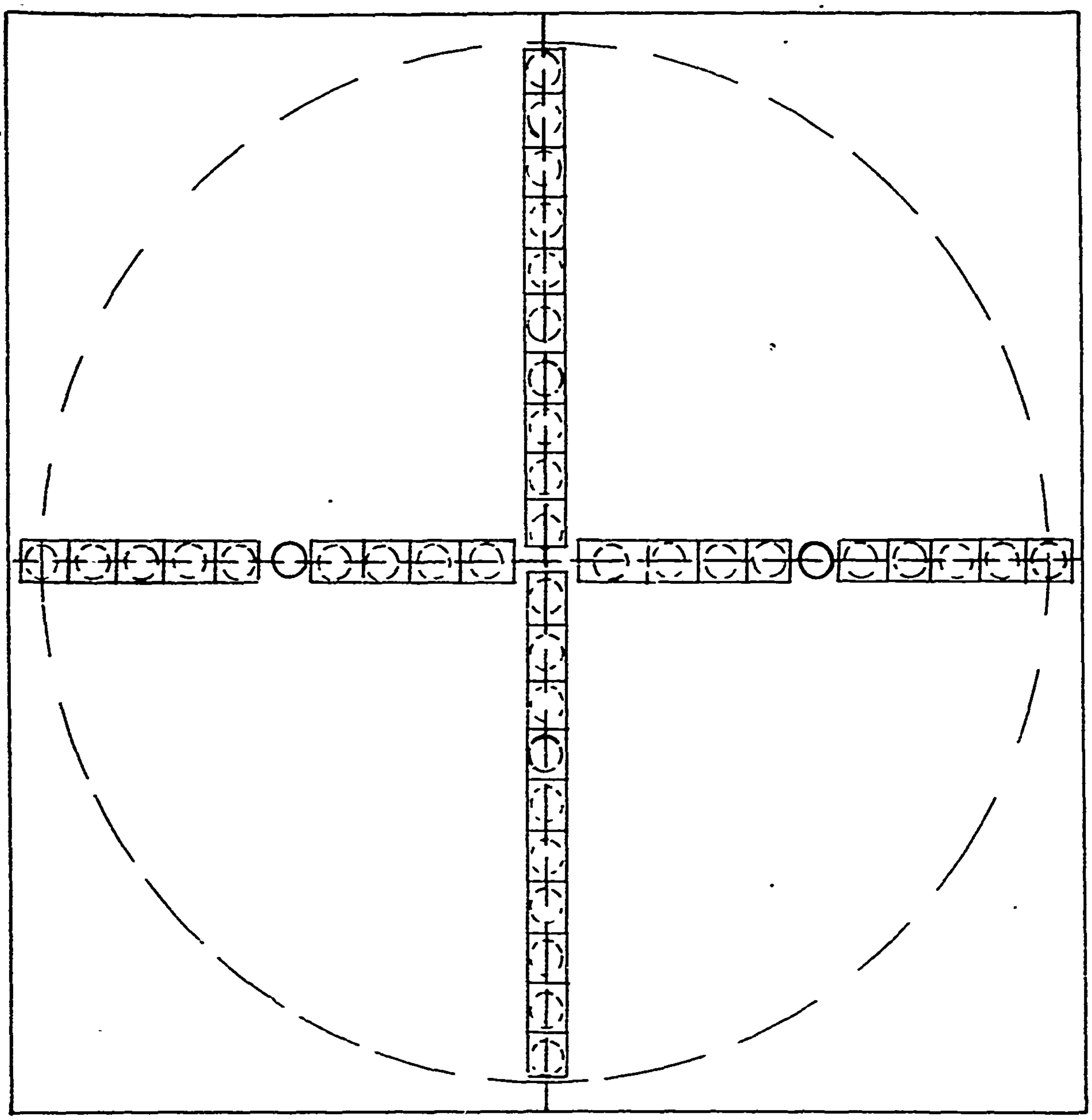
Plans for the Immediate Future

The 31" mirror will be completed as rapidly as possible by the Ferson Optical Company. Until recently, the pressure of other work for the Government has made it impossible to work continuously on the obsidian project there, but this situation is now greatly improved.

The remaining measurements on physical propoerties will be made as quickly as possible. The final report will be completed in the near future.

T.Dunham, Jr.
Principal Investigator

Rochester, New York
June 14, 1955



Diaphragm for Zonal Testing
of 31" diameter Obsidian Mirror

Fig. 1