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Contract N8onr-578
Project NR 084-284

Studies of Obsidian as a Material for Use in Making
Astronomical Mirrors

REPORT TO ASTRONOMERS' COMMITTEE

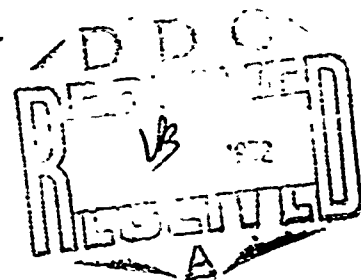
with

Photographs and Tables

Contractor

Fund for Astrophysical Research, Inc.

Submitted in support of application
for one year's extension of contract
and additional funds



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REPORT TO ASTRONOMERS' COMMITTEE

Contract N8onr-578
Project NR 084-284

Studies of Obsidian as a Material for Use in Making Astronomical Mirrors.

AIM OF THE PROJECT *

The aim of this project is to determine the extent to which obsidian can be used for making large mirrors for astronomical and other optical applications.

REQUIREMENTS OF A MATERIAL TO BE USED FOR MAKING OPTICAL MIRRORS

A satisfactory material for use in making large mirrors must have the following properties:

1. Freedom from many bubbles or inclusions.
2. Ability to take a high polish with usual optical techniques.
3. Low intensity of light scattered from the polished surface.
4. Ability to hold firmly an aluminum coating, or some other coating to which aluminum will stick.
5. Low thermal expansion, and uniform expansion throughout the material.
6. High thermal conductivity (to equalize temperature differences).
7. Homogeneous composition.
8. Good annealing.
9. Availability in sizes at least 20 inches in diameter, and preferably considerably larger, at low cost.

A surface free from defects is naturally desirable. A limited number of bubbles or inclusions will do little harm beyond slightly reducing the light reflected by the mirror. Many small defects will, however,

(* The first few pages of this report are paraphrased or copied from the Combined First and Second Periodic Status Reports, so that the present report will be complete in itself.)

have a serious effect on performance, since when aluminized they will combine to scatter a significant percentage of total light out of the beam, and the result will be diminished contrast in the image of any extended object. Ability to take a high polish is necessary for the same reason. Since aluminum is still the most generally useful coating for optical mirrors, it is important that the material used be able to hold aluminum, or an intermediate layer, firmly. Astronomical mirrors are inevitably exposed to sharp temperature changes, and it is therefore important that they be made of a substance which has low thermal expansion and high thermal conductivity. These two properties combine to determine the response of optical figure to a change in temperature; thus a high coefficient of expansion is offset to some degree by a high coefficient of conductivity, and vice versa. Homogeneous composition is important, since if the composition varies through the material, thermal expansion will also vary, with the result that if the mirror has a perfect figure at one temperature, this will not be the case at a different temperature, even if the mirror has attained thermal equilibrium. Good annealing of the material is essential, since internal strains will gradually destroy a perfect optical figure. Any material must be readily obtainable in the form of discs considerably larger than 20 inches in diameter, if it is to be useful for making mirrors, since no difficulty is encountered in obtaining glass discs of moderate size.

BACKGROUND OF THE PRESENT PROJECT

Glass is ordinarily employed for making astronomical mirrors and for most mirrors in other optical applications. Until about

twenty years ago, ordinary well-annealed glass was employed, but in recent years the use of Pyrex has become almost universal, because of its lower coefficient of expansion. Since the recent war, suitable glass of this type has become extremely expensive, both in the United States and in England, and is difficult to obtain in large sizes. A different material with suitable properties, if readily available at moderate cost, would be extremely useful. The suggestion that obsidian might be used for large telescope mirrors was made more than thirty years ago by Dr. F. E. Wright, but until recently no serious attempts have been made to investigate its optical usefulness.

Obsidian is a glassy rhyolitic lava, generally regarded as a magma which failed to crystallize when it cooled. Most specimens contain inclusions (microcliths) in the form of minute crystals, but in many cases these do not appear to project above the polished surface of a polished mirror more than a small fraction of a wave length of light. The coefficient of expansion of several samples of obsidian, measured in the past, is about 4.6×10^{-6} , which is somewhat greater than that of Pyrex.

A considerable number of small mirrors were made at the California Academy of Sciences for use in military instruments during the recent war. These were entirely satisfactory. A 5-inch flat mirror made by Mr. Fred B. Ferson was examined and found to be quite satisfactory as regards figure and capable of taking an aluminum coating which did not appear to scatter much more light than a similar coating on glass.

On the basis of the above facts, it was felt worth while to investigate further the possibilities that obsidian could be used

for making relatively large mirrors, in cases where glass might not be readily available.

PLAN OF THE INVESTIGATION

The investigation has been planned with the aim of determining, with the minimum feasible expenditure of time and funds, the physical and optical properties of obsidian from several sources, and in the process gaining some information as to the probable cost of obtaining satisfactory discs of obsidian of various sizes.

An effort is being made to obtain small samples of obsidian from as many locations as possible where the material is reasonably free from cracks and inclusions. Test mirrors 3 inches in diameter are being made from all promising samples, and whenever possible two or more from each deposit, selected at intervals separated by a considerable distance from one another and with descriptions and photographs to identify the spot. These 3-inch mirrors are being examined microscopically to determine the frequency of bubbles, crystals, and other inclusions in the surface. Thin sections of the same material are being examined microscopically. The mirrors are being aluminized over a portion of their surface, and the percentage of light scattered by the resulting mirror is being measured. In all cases where the results of these tests are promising, an attempt is being made to obtain larger samples, for making 6-inch to 10-inch mirrors, which will be tested for figure over a wide range of temperatures. If tests of these mirrors show good results, still larger blocks will be obtained, if possible. Finally, several mirrors with diameters of approximately 18, 26 and 30 inches will be made from the best material available from any source, and will be tested

critically for permanence of figure at various temperatures, and for scattered light.

Arrangements are being made to determine the physical and chemical properties of as many as possible of the most interesting samples of obsidian. The cost of making such measurements is, however, considerable, and so the number must necessarily be limited. The following properties will be investigated:

1. Density
2. Index of Refraction
3. Strain
4. Optical density
5. Thermal Expansion
6. Thermal Conductivity
7. Specific Heat
8. Chemical Composition

It is to be hoped that certain of these laboratory measurements of physical properties will make it possible to select samples of obsidian which are suitable for making large mirrors, by predicting to a considerable degree the optical performance that can be expected from a particular sample. Such a basis for selecting material would be important from an economic point of view.

In order to avoid repetition, the details of the program will be described under the various headings of the next section, in which the results to date are summarized.

ACTIVITIES TO DATE

I. Collection of Samples of Obsidian

The most effective procedure for collecting obsidian would undoubtedly be to arrange for a geologist and an assistant to visit a considerable number of the most promising deposits of obsidian in the United States, Mexico, and Iceland. With a

truck and hoisting gear they could not only make examinations of the deposits on a uniform basis, but could in a relatively short time accumulate representative samples of the material for study. Such a field investigation would, however, require appreciably more funds than are available under the present contract.

Accordingly, it has been necessary to depend largely on the willingness of individuals, with a great variety of interests and background, to supply information regarding deposits of obsidian and to obtain samples with the minimum of cost. In spite of the fact that this procedure is not as satisfactory as a survey conducted by one small group for this specific purpose, the results to date are very significant. We are particularly indebted to Dr. G. Dallas Hanna, of the California Academy of Sciences, who has spent much time and effort, without any remuneration, in acquiring samples of obsidian from northern California, southern Oregon, and from Nevada. He has made available to us his pioneering experience in the use of obsidian for mirrors in military instruments. Several other individuals, as indicated below, have been extremely helpful in providing samples from a wide variety of sources. These sources are divided into two groups, on the basis of the quality of samples examined up to the present time:

A. Sources which are Extremely Promising:

1. Iceland. Material of very high quality has been received from Mr. Egill Arnason, in Reykjavik, as a result of arrangements made by Dr. Asg. Thorsteinsson, Chairman of the National Research Council of Iceland. Two 3-inch mirrors made from the only sample received so far, are excellent as regards surface structure. We hope to receive several larger samples in the

near future. Large cliffs of black obsidian occur near My Vatn, and it seems likely that this will turn out to be an important source of obsidian of high quality.

2. Glass Mountain, Siskiyou County, California. This region has been examined by Dr. Hanna, who regards it as the most promising source about which he has definite information. Boulders of two types are exposed on the surface: (1) grey banded obsidian, from which a very satisfactory 10" mirror has been made under this contract, and (2) black obsidian. Two boulders of the grey obsidian have been selected by Dr. Hanna and Mr. Chesterman, of the California State Division of Mines, and will be moved to San Francisco in the near future for sawing into discs, probably 24" to 30" in diameter. Unless more promising discs of similar size can be obtained from other localities, one or more of these discs will be ground and polished as mirrors for testing.

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Fig. 1
Obsidian Boulders from which Samples Nos. 16 (left) and 17 (right) were chipped. Glass Mountain, Siskiyou County, California.

3. Washoe County, Nevada. One sample of very black obsidian of extremely high quality, has been received from Mr. Carl Wells of Roseville, California, through the kindness of Mr. Ferson. Two very excellent 2" test mirrors have been made from this sample. The source of this material is being investigated, in the hope that larger samples can be obtained.
4. Lane County, Oregon. Several samples of dense black obsidian from this region have been obtained through Ward's Natural Science Establishment. 3-inch test mirrors are being made from these samples, which appear excellent. Larger samples will be obtained as soon as snow conditions permit, if the preliminary tests are satisfactory.

B. Sources which are Moderately Promising:

1. St. Helena, Napa County, California. Dense obsidian of excellent quality occurs here. The 5" flat mirror loaned by Mr. Ferson was made from this obsidian. But no pieces larger than about 13" are exposed on the surface, so that some excavation would be required to obtain larger pieces. In view of the accessibility of this site to San Francisco, it should be investigated further.
2. Valle Grande, N.M. Several excellent samples of dense black obsidian from this region have been provided by Prof. E.S. Larsen of Harvard. An attempt is being made to interest some members of the staff of the laboratory at Los Alamos (which is nearby) in collecting samples 10" to 18" in diameter, and in determining what facilities would be re-

quired to obtain larger samples. Information is also being requested from the U. S. Geological Survey, which has recently had an expedition in this region.

3. Richland, Washington. Mr. John Holeman states that large pieces of obsidian occur in this vicinity. They contain a moderate number of pumice inclusions, but these can probably be avoided in cutting. One sample sent to Ferson and examined in Rochester has more inclusions than most obsidian so far tested. Larger chunks can be obtained in the spring.

4. Michoacan State, Mexico. Mr. Juan B. Garcia, in Niles, California, knows of a deposit where boulders weighing up to several tons can be obtained on the surface. A sample has been examined grossly. It is very black and appears to be reasonably homogeneous, with few streaks or inclusions. Mirrors and sections are being made. It would probably be expensive to obtain large pieces from this site, and that would be justified only if small samples showed the material to be superior to that from the U.S.A. and Iceland.

5. Isle of Lipari. A sample made available by Prof. Larsen is much more transparent than most obsidian. Quite apart from its usefulness for making mirrors, this material should be of great interest because it can be tested for internal strain, and may give an indication as to the strain of other deposits.

C. Sources which are not Promising (but which warrant further study):

1. Lake County, California. Dr. Hanna and Mr. Chesterman

visited the large deposit at Clear Lake in June, 1948. Pieces of obsidian up to 24" and more in size have been piled up at the quarry, where some of this material is being broken up into gravel. Examination shows, however, that most of the material has so many inclusions that its usefulness is doubtful.

2. Millard Co., Utah. A sample from Ward's Natural Science Establishment is black, but contains numerous fine streaks of light material. Its usefulness is doubtful, but other samples will have to be examined before any definite conclusion can be reached.
3. Yellowstone Park. All reports agree in indicating that this deposit has many bubbles and is probably not suitable for optical use. It was visited by Ferson in the summer of 1948.
4. Mororatio, Mexico. One sample has been supplied by Ward's N.S.E. It is black, with a dull surface on fracture. It appears uniform, without inclusions or bubbles visible with a 10X magnifier. Test mirrors and sections are being made. Other sources in Mexico will be investigated.

The collection of small specimens from many sources will be continued. Little cost is involved, since most people are glad to contribute samples for a non-commercial study, such as this. The polishing of 3-inch test mirrors, and the examination of polished surfaces and sections is also easy and inexpensive. Much can be learned about a deposit from such examinations, without the more expensive measurements of physical properties.

II., Microscopic Examination of Structure

Thin sections (0.03 mm) of several samples have been ground and mounted by Mr. George W. Robinson, Jr., at Harvard. These have been examined by Professor Harold L. Alling, at the University of Rochester. The samples from Washoe Co., Nevada (No. 10) and the sample (No. 7) supplied by Hanna from a river bed in Nevada (location unknown) show the smallest number of inclusions, and other microscopic defects. The material from Siskiyou Co. and St. Helena, California shows some banding and a considerable number of microlites, but few bubbles or cracks. The most frequent length of microlites in obsidian from Valle Grande, N.M. is about 15 microns. Examination of the polished surfaces gives results similar to those obtained from the thin sections. These studies will be extended to all available samples, and will be put on a quantitative basis. The Engineering Department at the University of Rochester has made available a very good metallurgical microscope, with photographic attachment for this purpose.



Fig. 3

Photomicrograph of Surface of 5-inch Flat Mirror, made from Obsidian from St. Helena, California. 500X Magnification.

III. Optical Grinding and Polishing

All of the optical work has been done by Mr. Fred B. Ferson, of the Ferson Optical Co., Biloxi, Mississippi. Mr. Ferson has given this project much personal attention, and is making test mirrors of all sizes at prices considerably below his usual quotations for glass mirrors, as part of his contribution.

The samples were cut with a diamond saw, milled on a lens generator and ground with No. 240 Aloxite, UO-30, UO-14 and UO-8 Garnet, and were then polished on pitch laps with Barnesite, followed by fine rouge for figuring. All samples were as easily worked as fused quartz and Pyrex. Polishing was continued until all pits due to fine grinding were eliminated. Crystal formations in the matrix exhibited no effect on either polishing or figuring operations, as far as could be seen with 10X magnification.

Distortion of the surface due to the heat generated by fast polishing with a heavily weighted tool was as follows for 3-inch mirrors: Quartz-1/2 fringe; obsidian-1 fringe; Pyrex- 6 fringes. This unexpected observation must be investigated. It is unlikely that it is due to a greater heat conductivity for obsidian. It has been suggested that hysteresis may be less for obsidian than for Pyrex. The observations apply to obsidian from Siskiyou Co., Cal., Washoe Co., Nevada, Lake Co., Oregon, and Iceland.

Samples of Lake Co., Oregon obsidian have been heated to about 200°C and plunged into cold water without fractur-

ing. The material seems to break less easily when struck with a hammer than fused quartz, Pyrex, or ordinary glass.

IV. Laboratory Tests of Mirrors

1. Optical Figure

A Foucault test set is being constructed for use in making tests of concave obsidian mirrors at various temperatures, both above and below the temperature at which each mirror was figured. These tests will show whether there are inhomogeneities in composition large enough to distort the figure, after equilibrium has been attained, at a high or low temperature.

Plans are being made for constructing a small insulated oven with a double glass window, in which 3-inch mirrors of obsidian can be heated uniformly to about 100°C , or cooled to about -76°C , while being examined for figure on an interferometer at Bausch and Lomb. These tests will also show whether inhomogeneities are sufficient to alter the figure when a mirror is in equilibrium at a temperature very different from that at which it was figured.

2. Scattered Light

Equipment is being set up for making quantitative measures of the percentage of light that is scattered out of the beam by aluminized obsidian mirrors. A model of this equipment is almost ready for testing. These measurements are particularly important, because the reduction of contrast by a mirror can be one of its worst defects. Additional measures of scattered light will probably be

made by measuring the apparent brightness of the sky close to the sun, reflected in obsidian mirrors, and comparing the observed value with that obtained for the sky without a mirror. A sky photometer developed by Dr. John Evans at the Harvard High Altitude Observatory at Climax, Colorado, can probably be used for this purpose. Qualitative laboratory tests indicate that aluminized obsidian mirrors do not scatter much more light than aluminized Pyrex mirrors.

V. Physical and Chemical Properties in Obsidian

1. Density. This will be measured at the University of Rochester on all available samples, without cost.
2. Index of Refraction. This can also probably be measured at the University of Rochester, without cost.
3. Strain. It is most important to have information about strain in obsidian, as an indication of the permanence of figure that can be expected. However, the opacity of the material renders it difficult to pass a beam through a path long enough for measuring strain, unless the strain is very great. It is possible that the material may be sufficiently transparent in the infrared to permit using the method employed by Mendenhall, Ingersoll and Johnson, J.O.S.A., 15, 285, 1927.
4. Optical Density. Samples of obsidian vary greatly in "blackness". Thin plates will be polished so that the absorption curve can be plotted throughout the spectrum, from 2,200A to 20,000A, with a Beckman spectrophotometer at the University of Rochester. (No cost except polishing

the test plates at Ferson Optical Co.)

5. Thermal Expansion. This is most important, since it is one of the factors which influences the figure of a mirror when it is suddenly exposed to a change in temperature. Extensive correspondence is in progress, in an attempt to find a laboratory where thermal expansion can be measured at a cost low enough to permit making such measures on a considerable number of the specimens of obsidian. The lowest price so far quoted is \$28.00 per sample if five samples are run together (N.Y. Testing Laboratory). Dr. E. D. Tillyer at the American Optical Co. has offered to measure the difference in expansion in three coordinates.
6. Thermal Conductivity. This is as important as thermal expansion. The least expensive measurement quoted to date is \$50.00 (J.L.Finck Laboratories).
7. Specific Heat. This is also important, although it may vary less than some of the other properties. A single measurement by the Finck Laboratories costs \$50.00.
8. Chemical Composition. Most obsidian contains about 72-76% silica, although a few samples are reported with as low as 53% silica. Alumina runs 10-20%, iron oxides 1-5%, Mg, Ca, Na and K oxides total 7-14% and water 0.1-6%. It will be useful to have chemical analyses made on at least some of the more interesting samples, in order to determine what relation, if any, exists between chemical composition and good optical properties. However, the N.Y. Testing Laboratory charges \$40.00 per sample for such analyses, when five samples are submitted together.

On the basis of the lowest estimates of cost to date, the expenditure for a complete study of one specimen will cost about \$158.00. Unfortunately, the Bureau of Standards cannot probably make the tests because of their policy which avoids competition with private laboratories. The more expensive tests will be postponed somewhat, so that they can apply to those specimens which are known to have the greatest interest from an optical point of view.

THE OUTLOOK FOR USEFULNESS OF OBSIDIAN IN THE OPTICAL FIELD

The aim of this project is to find out (1) whether obsidian is a satisfactory material for making optical mirrors of considerable size and (2) whether the cost of obtaining suitable material is less than the cost of glass (approximately \$3.75 per pound) by a sufficient amount to justify its use. It is hoped that the technical part of the program will supply the answer to the first part of this question, and that actual costs encountered in obtaining raw material from various sources, for discs up to about 30" in diameter, will settle the second part of the question to a considerable extent. If experience shows that an appreciably higher degree of uncertainty is involved in using an apparently good disc of obsidian, on which expensive optical work must be done, than when glass is used, then the cost of the material must be correspondingly less. Taking all factors into account, it seems at the moment reasonable to suppose that if obsidian is to be used for large mirrors the total cost of acquiring the raw material, transporting it and cutting and edging a disc, should not exceed approximately 1/4 of the cost of a comparable disc of glass. In other words, if the cost of a disc of obsidian, from a source known to have produced other satisfactory optical mirrors, does not

exceed about \$1.00 per pound, the material may well be extremely useful. If the cost of an edged disc exceeds \$1.50 per pound, it will probably not be useful.

There is a question whether, if interest in obsidian should increase, the price at the source might rise to a level where its use would no longer represent a saving. Since the indications are that several sources of good obsidian can probably be located without much difficulty, if the material is optically acceptable, and since the amount of obsidian in one deposit is ordinarily tremendous in comparison with the relatively moderate demand that may be expected, it seems unlikely that the price of obsidian will ever greatly exceed the actual cost of selection, removal, cutting and transportation.

Rochester, N.Y.
December 7, 1948

Theodore Dunham, Jr.
Principal Investigator

Table I

Samples of Obsidian

No.	Origin	Sent by	Dimensions (mm)	Black- ness	Fracture Surface	Mirrors	Notes
1	St. Helena, Cal.	Hanna	2 x 11 x 65	8	Smooth	1	
2	" "	"	2 11 65	8	Smooth	2	
3	Siskiyou Co. "	"	35 200 270	5	Smooth	7,8	
4	" "	"	35 200 270	5	Smooth		
5A	St. Helena, "	"	100 125 190	8	Smooth	9,10	
5B	" "	"	20 38 60	8	Smooth		
6	" "	Person	125 (5 IN.)	D. 8	-----	3	5" flat mirror
7	Nevada (river bed)	Hanna	100 100 10	7	Smooth		
8	Valle Grande, N.M.	Larsen	75 100 125	9	Brilliant		
9	" " (H. 19467)	"	75 125 175	8	Smooth		
10	Washoe Co., Nevada	Wells	75 85 75	10	Brilliant	11,12	
11	Lipari Island (H. 20305)	Larsen	12 30 50	2	Smooth		
12	Lake Co., Cal.	Hanna	18 75 175	7	Dull		
13	Siskiyou Co., Cal.	"		8			10" mirror made from this piece
14A	Lake Co., Cal.	"	75 D.	7	Dull		
14B	" "	"	100 100 125	7	Dull		
15	Iceland	Arnason	75 75 100	10	Brilliant	16,17	
16	Siskiyou Co., Cal.	Hanna	15 50 100	5	Smooth		Fig. 1- left boulder
17	" "	"	15 54 135	5	Smooth	13	Fig. 1- rt. boulder

Table I (continued)

No.	Origin	Sent by	Dimensions (mm)	Blackness	Fracture Surface	Mirrors	Notes
18	Siskiyou Co., Cal.	Hanna	250 (10 in.)	D. 6	-----	4	10" concave mirror
19	Lake Co., Oregon	Ward's	110 150 150	8	Smooth		
20	" "	NSE	100 150 150	8	Smooth		
21	" "	"	45 80 105	-	Smooth		Red and black streaks
22	" "	"	38 65 90	-	Smooth		" " "
23	" "	"	20 38 50	-	Brilliant		" " "
24	" "	"	25 38 80	-	Brilliant		" " "
25	Lipari Is.	"	25 50 75	4	Dull		
26	Mororatio, Mexico	"	30 38 50	9	Smooth		
27	" "	"	7 38 32	-	Dull		Brick red
28	Millard Co., Utah	"	20 38 75	8	Smooth		V. fine brown streak
29	Michoacan State, Mexico	Garola	80 80 120	8	Smooth		
30	Richland, Wash.	Holeman	74 mm diam. 18 mm thick	7	-----	14	Many inclusions
31	" "	"	77 mm diam. 19 mm thick	7	-----	15	" "
32	Siskiyou Co., Cal.	Hanna	450 350 350 approx	8			Black boulder (18")
33	" "	"	600 450 450	5			" " (24")
34	" "	"	750 550 550	5			" " (30")

(Note: Nos. 32, 33 and 34 are still on the ground at Glass Mountain, as of Dec. 1, 1948)

Table II
Obsidian Mirrors

No.	Dimensions	Obsidian Sample No.	Origin	Figure	Notes
1	8 x 11 x 65	1	St. Helena, Cal.	Flat	V. good surface
2	2 11 65	2	" " "	Flat	" " "
3	125 mm diam.	6	" " "	Flat	Aluminized (50% area)
4	250 mm diam.	18	Siskiyou Co., Cal.	20-ft Rad.	Aluminized (90% area)
5	50 mm diam.	Pyrex	Corning	Flat	Comparison Mirror
6	50 mm diam.	Pyrex	Corning	Flat	" "
7	50 mm diam.	3	Siskiyou Co., Cal.	Flat	V. good surface
8	50 mm diam.	3	" " "	Flat	" " "
9	50 mm diam.	5A	St. Helena, Cal.	Flat	" " "
10	50 mm diam.	5A	" " "	Flat	" " "
11	50 mm diam.	10	Washoe Co., Nev.	Flat	Excellent surface
12	50 mm diam.	10	" " "	Flat	" "
13	40 mm diam.	17	Siskiyou Co., Cal.	Flat	Few small inclusions
14	74 mm diam.	30	Richland, Wash.	Flat	Many inclusions
15	77 mm diam.	31	" "	Flat	" "
16	67 mm diam.	10	Iceland	Flat	Superb surface
17	67 mm diam.	10	"	Flat	" "