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FINAL REPORT
(together with report of 6-14-55)

Report on Progress to

June 15, 1954

under

Contract N8conr-578

Studies of Obsidian as a Material for Making Astronomical Mirrors

by

Theodore Dunham, Jr.

July 9, 1954

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Summary of Progress to June 15, 1954

Collection of Samples of Obsidian

1. Iceland

The regions where obsidian is known to occur in large masses were explored in August 1951. On the basis of a request from ONR, the Iceland Defense Force made available for approximately ten days a heavy truck, a jeep and six enlisted men. Dr. T. Sigurgeirsson had made an investigation of the obsidian at Reykjadalir at our request in 1950, and had sent to us several boulders measuring up to 75 cm. Most of this material contained white inclusions 2 to 3 mm in diameter, but the region is one that merits detailed study. Samples received from Hrafninnuhryggur have been of excellent quality. Dr. Sigurgeirsson and Dr. P. Hannesson of the Department of Geology at the University of Iceland guided the expedition in 1951 and provided invaluable advice and information.

The ridge at Hrafninnuhryggur is approximately 70^{meters}/high above the plateau on which it lies. It is about 2.5 km long and 0.4 km wide at the base, composed principally of rhyolite. Numerous dykes are exposed at the top of the ridge, and these contain layers of hard, brilliant obsidian of very high quality, about 40 to 50 cm thick, cracked in most cases into individual chunks ranging up to about 60 cm in size. There are isolated boulders of this same general size lying loose on the ridge and along its base. The talus slopes are covered with gravel and sparse vegetation. The largest boulder seen measured about 80 x 100 x 150 cm., but was not as good in quality as many of those of moderate size. The grass at the base of the ridge is growing in a thin layer of earth, which can easily be removed by hand, revealing a continuous mass of boulders of obsidian beneath, with unfilled space between the individual boulders. The obsidian at Hrafninnuhryggur is, with few exceptions, of extremely high quality. The fractured surface is brilliant and smooth, suggesting that there are few microcrystals. This impression is confirmed by microscopic examination. Approximately 60 samples were collected and taken to the United States for study of physical and optical properties.

The valley at Reykjadalir contains a flat layer of obsidian about one meter thick, covered in most places by boulder clay, but exposed in several small hills which protrude through the clay. This field of obsidian lies between two tributaries of the Markarfljot River. Across the river to the west there is a rhyolite flow, covered with coarse vesicular obsidian. Across the river to the SE there is a dome-shaped hill, Hrafninnusker, on which there are numerous obsidian boulders ranging up to 60 cm in size. No solid formation of obsidian was detected, but may well exist close to the surface. Several boulders were rolled down the slope of Hrafninnusket to the edge of the river, and were picked up in the truck which was driven along the gravel river bed, under a permanent snow slope through a tunnel large enough to admit the truck. Considerable difficulty was encountered in climbing back onto the slope where the camp was located, due to the heavy load

and soft sandy gravel on the bank, but this was finally accomplished. The layer of obsidian on the floor of the valley is about 2 x 3 km in extent. Its structure was studied at the various outcrops above the layer of boulder clay and ash from Hekla, and by cutting holes through the layer of obsidian, with the aid of crowbars and some dynamite, at six places. The thickness of the obsidian is close to 100 cm at all places where it was measured. There is considerable striation, particularly at the upper and lower parts of the layer. Small white inclusions, ranging between 1 and 3 mm in diameter, occur in moderate concentration in all of the obsidian on the floor of the valley. This may render the obsidian from this location unsuitable for optical applications, but further exploration will be required to determine whether there are regions on the floor of the valley where the material is of higher quality. The obsidian is cracked into chunks, which are in some cases at least 100 cm in maximum dimension. The material from Hrafninnusker has a much lower concentration of inclusions, and appears to be well suited to use for mirrors up to at least 60 cm diameter, and larger pieces could almost surely be found with moderate excavation. About 72 samples of obsidian were obtained at Reykjadalir and the surrounding regions, the largest of which is being used to make a mirror 475 mm in diameter.

2. Australia and New Guinea

The occurrence of obsidian in Australia was discussed with Prof. Alan Voisey of the University of Armidale, while he was at Antioch College in Ohio in May, 1953. During a visit to Australia in June, 1953, further information was obtained from Dr. N.H. Fisher, of the Bureau of Mineral Resources at Canberra. It appears that the only promising regions are in southeastern Queensland and northeastern New South Wales, where there are Lower Tertiary rocks, probably including obsidian, but the age suggests that it may be badly devitrified. Red and black obsidian occurs at The Gap, in the Townsville-Bowen district of Queensland, but it is of Permian origin and probably devitrified.

There are indications that obsidian of good quality may occur in New Guinea, where the flows are much more recent than in Australia. On Fergusson Island, in the D'Entrecasteaux Group, there are deposits near Garia Crater and perhaps in the Iamelene area, on the west side of the island. Also near Talasea, New Britain, and on Lou Island, south of Manus I. At these places the natives have used obsidian for making spear heads. It is known to occur banded, and also without bands. Requests for samples are being made to the District Commissioner on Manus Island. We are indebted to Dr. Fisher for this important information.

3. New Zealand

It seems clear that the most promising known deposits of obsidian are on Mayor Island in the Bay of Plenty, about 21 miles off the east coast of the North Island. This conclusion is based on correspondence with Prof. A.R. Lillie at the Auckland University College, Prof. C.A. Cotton at Victoria University College, Prof. R.A. Allan at Canterbury University College, and Dr. J. Healy at the Geological Survey Office at Rotorua. A three-day expedition to Mayor Island was organized in June, 1953, with the active cooperation of Prof. Lillie. He and two graduate students in the Department of Geology at Auckland accompanied the writer to Tauranga, where a 35-foot launch was hired. Camp was established in a small cabin used by fishermen at the head of Opo Bay, which is the only possible anchorage.

Mayor Island is about 3 x 4 km in size, with a central volcanic

crater about 1.5 km in diameter. The walls rise to about 400 meters elevation on the west side, but are only about 75 meters high on the SE side, where access is possible by scaling a loose slope from the beach.

Obsidian occurs on Mayor Island in several continuous layers, ranging between 1 and 2 meters in thickness, in the nearly vertical cliffs of lava, about 100 to 150 meters high, which rise out of the sea on the East and North sides of the island. These layers of brilliant obsidian, as seen in the sunlight from the boat, were most impressive. It is the only occurrence of massive obsidian in situ that has been encountered so far in the course of the present study, with the exception of the deposit at Reykjadalir in Iceland, and the outcrops on the ridge at Hrafftinnuhryggur. There are several of these bands of obsidian. Some extend for about 2 km. They are nearly horizontal, but slope gradually, and in one place there are three bands of obsidian at different levels, representing the lower parts of successive flows of lava. At Ottawa Bay a layer of obsidian in the lava comes down close to sea level, and at the northern end of the bay it forms the roof of a cave about 10 meters wide and 10 meters deep. On the beach are loose boulders that have obviously fallen from this layer. They range up to more than 100 cm in size. There is obsidian also in the cliffs on both of the headlands at the entrance to Opo Bay, but the structure is more complex. About 30 samples were collected from the beaches and from the crater. These were divided between our colleagues in New Zealand and our own collection. Much of the obsidian is of good quality, with very few inclusions, and for the most part without cracks. Some has a greenish tinge. There is little that is quite as brilliant on the fractured surface as the material at Hrafftinnuhryggur in Iceland, which still remains the very best so far encountered. But it is possible that chunks of obsidian of very considerable size could be obtained from the massive layers in the lava cliffs, and this might easily prove to be definitely useful for optical purposes. The island is the property of one of the Maori tribes, and permission for any exploration must be obtained from the chief who has an office in Auckland.

Sawing of Boulders into Slabs

All of the large Iceland boulders were sent to Barre, Vermont, where the most promising were sawed into slabs about 2½" to 3" thick with the wire sawing technique that is regularly employed for sawing granite, at the plant of Anderson-Friberg & Co. A 1/4" three-strand saw is employed, operating at 5,000 feet/minute between 5-foot sheaves which descend onto the work at a rate that can be about 1 foot/hour for obsidian. The saw provides a width of 20 feet, between which a number of boulders can be mounted for simultaneous cutting. A smooth cut surface results. The cost will probably be appreciably less than the cost of sawing boulders in California in 1949, where a steel blade, with iron spheres as abrasive, was used. There is obviously an application for a portable wire saw that can be used to cut slabs of obsidian from boulders in the field. This would greatly simplify transportation and reduce cost. Studies have been made and are being continued on this problem.

A steel biscuit-cutting tool, with carborundum abrasive, was used at Barre to cut two of the obsidian slabs, 12" and 13" in diameter, into circular discs. This technique is extremely satisfactory, and can be applied to larger slabs, to prepare them for optical grinding.

C. Obsidian Mirrors

A 31" concave mirror has been made from obsidian sawed from one of the boulders collected under this project in 1949 at Glass Mountain, California. The disc was turned over to Dr. John Strong at Johns Hopkins University, for use under an ONR project, in an infrared spectrometer. The disc was figured for Johns Hopkins by Mr. Fred B. Ferson of the Ferson Optical Co. in Biloxi, Mississippi in 1950. The optical work was carried out in the same way as for pyrex glass, and there was little detectable difference in the working quality of the two materials. The obsidian is somewhat harder. There appears to be a tendency for a partly figured mirror to regain its equilibrium figure more quickly after the heating effect of polishing than is the case with pyrex glass, which suggests that thermal conduction may be higher than for pyrex. This will be settled in the near future by laboratory tests. The polish on the face of this mirror is excellent. There are only a few defects, due for the most part to very small inclusions, between 1 and 2 mm in diameter in most cases. These are probably not more numerous than on glass mirrors. The mirror has been in operation since 1952, and appears to be holding its figure satisfactorily. Arrangements have been made to test the figure at intervals of about five years, so as to determine whether any change occurs, presumably due to residual strain in the obsidian. Since polarized light cannot be used to test for strain, the permanence of figure appears to be the most practical test.

A 20" concave mirror was made in 1952 by the John H. Ransom Co. in Los Angeles for the U.S. Naval Air Missile Test Center at Point Mugu, California. This mirror was made from another slab from one of the boulders collected under this project at Glass Mountain, California in 1949. It has been agreed that Mr. Ransom will furnish us with a full report describing the experience encountered in grinding and figuring the mirror. On the basis of limited reports no difficulty was encountered and an excellent polish resulted. The principal reason for using obsidian for this mirror and for the 31" at Johns Hopkins was availability. Waiting for a pyrex disc from Corning would have required about six to twelve months in each case. And the cost would have been about six times as much.

Three obsidian discs are being ground and figured as mirrors by the Ferson Optical Co. (now at Ocean Springs, Mississippi). One is a 13" disc from Hrafninnuhryggur, Iceland; one is a 19" disc from Hrafninnusker, Iceland; and one is a 32" disc from Glass Mountain, California. These discs are being figured as ellipsoids with $f/3.5$ focal ratio, so that they can be used with spherical convex secondary mirrors as Cassegrain telescopes. They will provide an excellent test of the properties of obsidian under actual operating conditions over a period of time. It is hoped that this work can be completed in October, 1954.

D. Physical Properties of Obsidian

1. Internal Structure

a. Gross Structure

Discs about 1 mm thick have been polished from a number of samples, to permit observations to be made on banding and other gross features of internal structure.

b. Microscopic Structure

Sections 0.003" thick have been made for microscopic examination, to determine the type and concentration of crystals of various kinds. This work is still in progress.

c. Spectral Transmission

Polished slabs about 1 mm thick (thinner for the most dense material) have been made and are being measured for spectral transmission with a Beckman spectrometer. There are marked differences between different samples of obsidian.

2. Properties of Polished Surfaces

a. General Properties

Samples 2½" to 3" in diameter have been made from several samples of obsidian, and are now being made from a variety of others, to show the general properties of the polished surfaces, such as frequency of gross defects, including bubbles, inclusions and cracks.

b. Microcrystals

The concentration of microcrystals per cm² is being measured on the polished test mirrors with a microscope provided with vertical illumination. The elevation and depression of the surfaces of the crystals, as compared with the mean level of the mirror will be determined with a microinterferometer at Bausch and Lomb. Present indications are that the level of crystals is not different by more than 1/4 wavelength in most cases.

c. Scattering of Light

The scattering of light at angles other than the angle of reflection is a most important property of any mirror. that is to be used for high quality optical work. Equipment is being constructed at the University of Rochester, under another ONR contract (N6onr-241-13), for measuring the scattering of light throughout the spectrum from various types of mirrors. This employs an extremely sensitive photomultiplier with pulse-counting equipment, which will make it possible to measure the very low level of the scattered radiation. This equipment will be used for measuring the properties of obsidian mirrors.

3. Thermal Properties of Obsidian

a. Coefficient of Thermal Conduction

Measurements will be made on a number of samples during July, 1954 at Tufts College, in the Physics Department, by Prof. Kathryn McCarthy, using the equipment developed by Ballard, McCarthy and MacLeod (J.O.S.A. 41, 871, 1951). Samples measuring 4.5 x 11 x 11 mm have been prepared for this purpose, with angles close to 90°, and with faces ground to 820 grade. Dr. Weeks at the Argonne National Laboratory is also measuring conductivity for us on three samples with very excellent equipment that he has recently developed for operation in a vacuum.

b. Coefficient of Thermal Expansion

Measurements of thermal expansion will also be made at Tufts College, using the device recently described by Combes, MacLeod and Ballard (J.O.S.A. 44, 345A, 1954). This is an interferometric device which also employs samples measuring 4.5 x 11 x 11 mm.

4. Strain

Since optical methods are not easy to apply to a material as dense as obsidian, we are depending on watching for changes in optical figure of obsidian mirrors. The 10" mirror made from California obsidian in 1949 has not as yet changed noticeably in figure. Its radius of curvature is 20 feet, so that minor changes can easily be detected with the knife edge. The mirror has been heated at 100° C for a week to accelerate any changes that would otherwise require a very long time to occur.

E. Summary

Obsidian has been collected from sites in the United States, Iceland and New Zealand. Information about numerous deposits has been accumulated, and valuable contacts have been made with individuals who would help in acquiring further samples if desired.

Mirrors up to 36" in diameter have been made from obsidian. Optical work is much the same as with glass. The performance of obsidian mirrors, made from the best material, appear to be excellent.

For mirrors up to 15" in diameter there are no obvious advantages for obsidian, as compared with glass, but for sizes between 15" and 36" there is an advantage in cost (about 1:6), and there is the obvious advantage of availability without delay if a stockpile is on hand. This has been strikingly illustrated in the case of the requirements of Johns Hopkins and of the U.S. Naval Air Missile Test Center at Point Mugu, California. It seems likely that larger mirrors could be made from obsidian, and that the material could be found, but the cost and difficulty involved are beyond the scope of the present project. Some excavation would have to be done to acquire chunks larger than 36" at any of the sites that have been studied. There is an indication that much larger chunks may be available in Mexico at accessible sites. These sites should be studied.

The physical properties of obsidian are now being studied on a uniform basis for all sites that have been investigated. These include internal structure, spectral transmission, the frequency of microcrystals in the polished surfaces, and their effect on scattered light, thermal conduction and transmission, and strain.

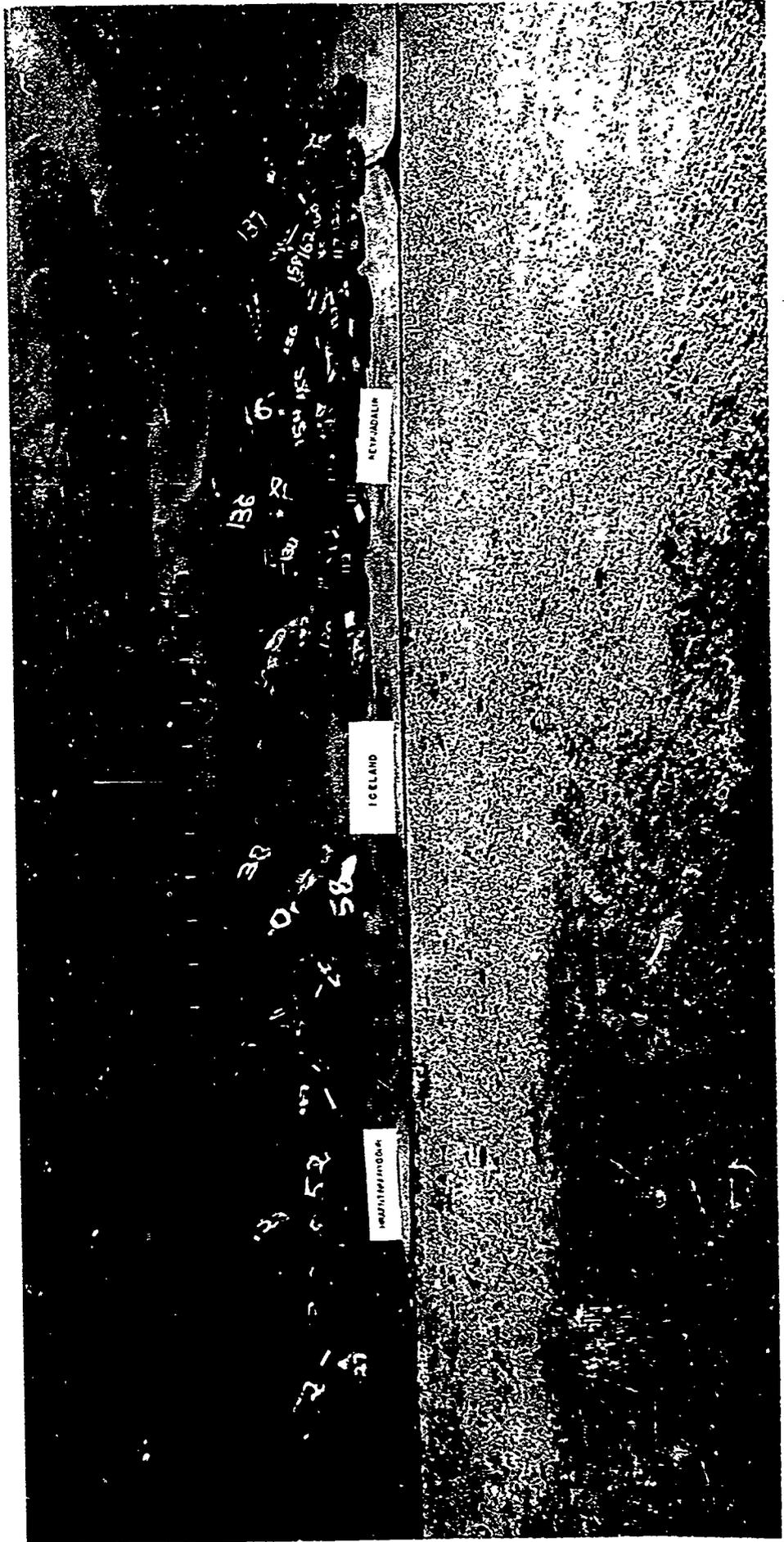
F. Financial Status of the Project

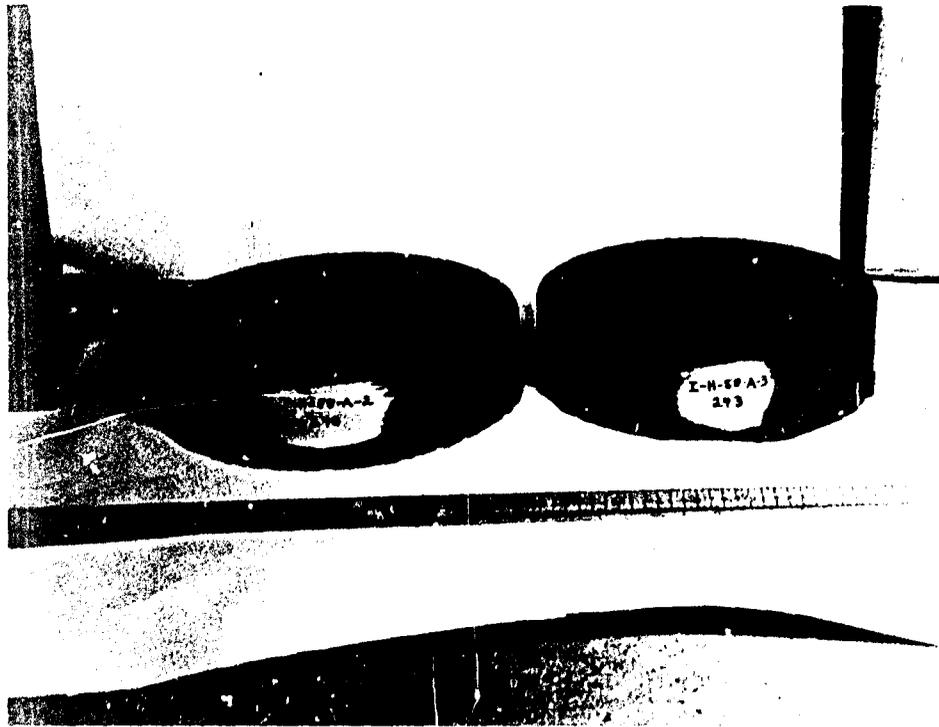
A balance of approximately \$3,100 remains available. The major expenditures have not yet been made, because the largest mirrors are only now being figured, following studies of the most promising sites where obsidian occurs. This amount will probably be adequate to cover completion of the program outlined, since no charges are being made for salaries of staff or for overhead.

It is requested that consideration be given to extending Contract N8onr-578 for six months, or if possible for one year, in order to permit completion of this program. Serious delays have been caused by government work at the Ferson Optical Company and by an interruption of operations last year at the Anderson-Friberg Company, but these difficulties no longer exist, and it is likely that the work can be completed as planned.

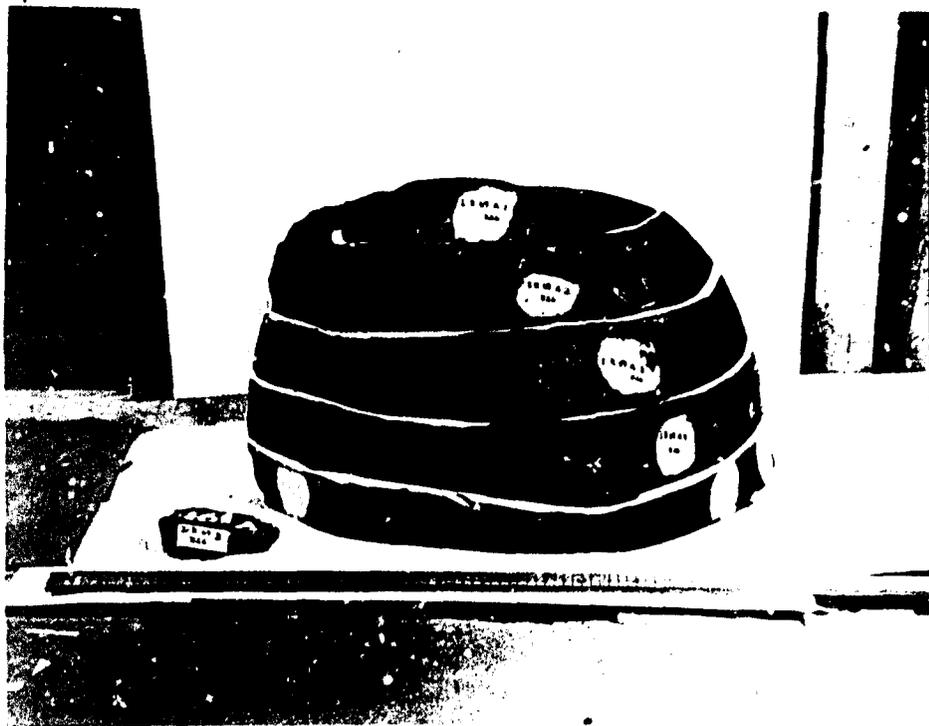
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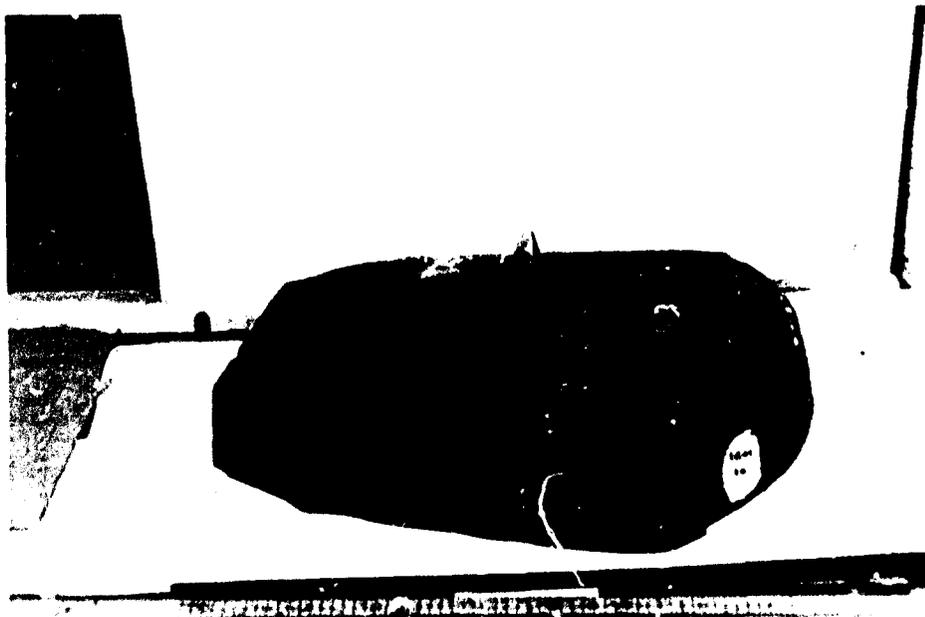




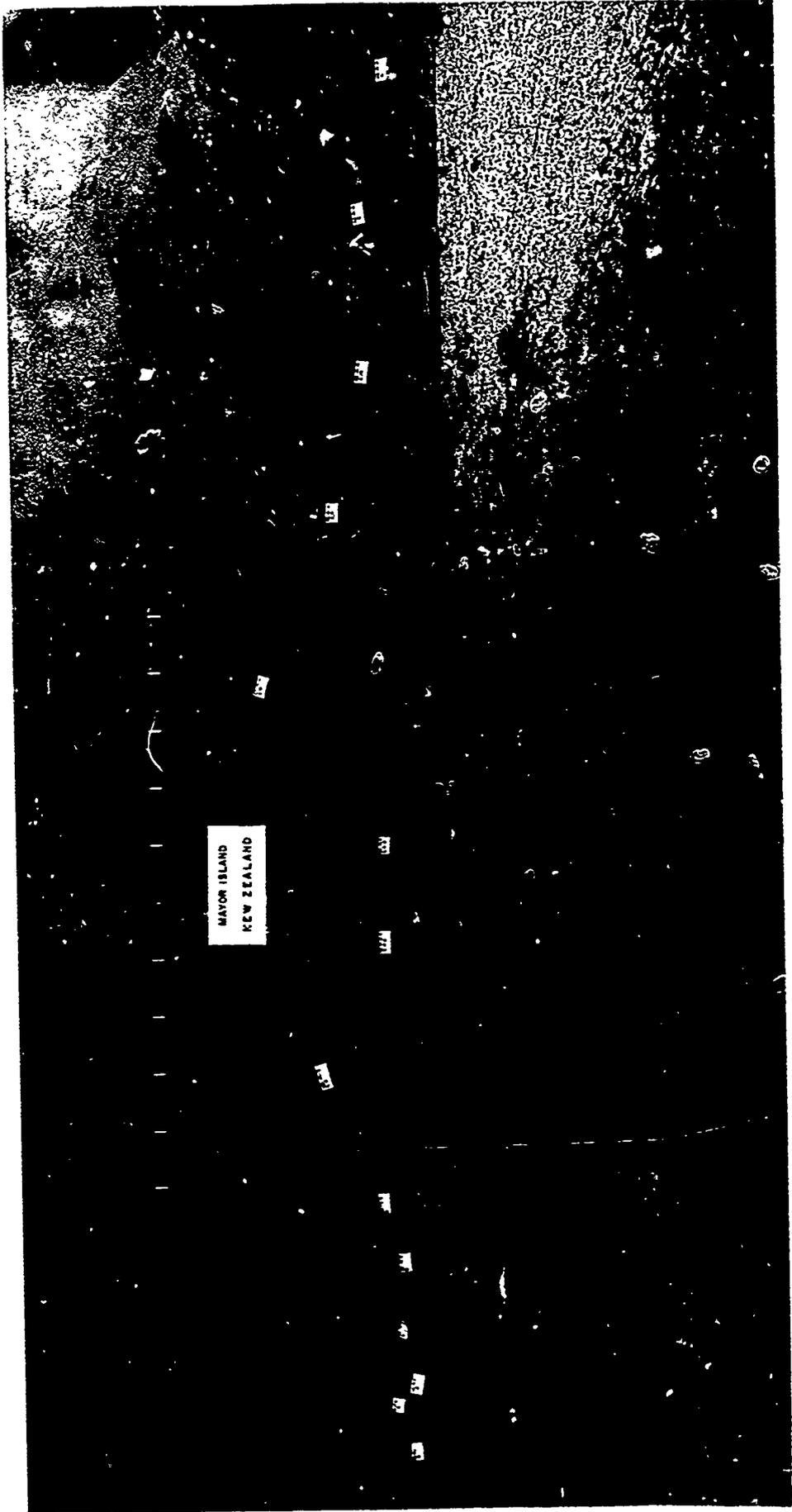
Discs 12" and 13" in diameter cut from Obsidian Boulder
taken from the ridge at Hrafninnuhryggur, Iceland
(Specimen No. 243)



Slabs cut from boulder of obsidian taken from the slopes of Hrafninnusker, Iceland (Reyðjadalir). (Specimen No. 326)



Slab from above boulder, from which a disc and mirror 19^m in diameter is being ground and figured. (Specimen No. 326)



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