

AD 748339

DEVELOPMENT OF CAPABILITIES OF OPTICAL  
DIFFRACTION ANALYSIS FOR QUANTITATIVELY  
COMPARING AND CORRELATING ROCK FABRICS  
AND FABRIC CHANGES

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Principal Investigator

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13. ABSTRACT Fabrics of rock specimens undergoing deformation have been recorded photographically in white light, in ultra-violet illumination after treatment of specimens with fluorescent dye penetrants, and with acetate peels. These fabric pictures have been converted to their two-dimensional Fourier amplitude transforms by optical diffraction. Changes in the transforms reflect spatial changes in the fabrics, and are examined for possible relations to loading curve characteristics.  Transforms have been produced from petrographic thin sections using a modified laboratory microscope and partially coherent light; this technique promises wider application of optical diffraction analysis in petrofabric studies. An extensive collection of reference inputs and their transforms has been prepared. Improvements have been effected in all basic processing operations, e.g. holographic subtraction, rock specimen preparation, deformation experimentation, and calibration of optical power output.  Experimental results show changes in crack width and frequency, with loading, with results obtained in the project's first year. This suggests some possibilities for <u>in situ</u> optical monitoring of microfracturing in active excavations.			

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Maps of Fourier Transforms			5	1		
Fourier transforms Obtained with Laboratory Microscope			10	2		
Slide Comparator			10	0		
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## TECHNICAL REPORT SUMMARY

The purposes of this project are (1) to compare and correlate fabrics of genetically related rocks, utilizing optical diffraction analysis and (2) to contribute to the understanding of the mechanics of rock deformation by quantifying fabric changes and relating these to other deformation parameters. This report covers the first half-year of the second year's work of a three year study.

The data on fabrics of rock slices undergoing deformation in the laboratory have been recorded on photographic film in white and ultra-violet light and on acetate peels. These data have been used as inputs in the optical diffraction system.

Outputs from the optical lab have consisted of transforms, maps of transforms and filtered reconstructed images. Examples of some of these results are given in Figures 1-5.

An increase in concentration of low spatial frequencies is accounted for by widening of fractures, usually in tension. An increase in concentration of high spatial frequencies is accounted for by the generation of new fractures, commonly in compression as well as in tension.

So far, acetate peels have yielded results of high quality and with great versatility. Third-part loading of rock slices cemented to aluminum bars has been a most reliable, experimental approach.

Experimental work with oriented slices has shown systematic differences in development of fabric and transform patterns on slices of different orientation.

The mercury vapor-microscope system for optical diffraction analysis has yielded useful results, indicating possibilities for wider use in petrofabric studies.

All of the results achieved so far are entirely consistent with the aims of the project and the program of which it is a constituent. Personnel and facilities are adequate for the tasks ahead. The direction of the work to follow will follow the general direction of the original plans when the project was undertaken.

# 1. Introduction

## Purposes and Objectives of the Project

This report covers the first half of the second year's work of a three-year study, the purposes of which are: (a) to develop capabilities of optical diffraction analysis to compare and correlate suites of genetically related rock fabrics and (b) to contribute to the understanding of the mechanics of rock deformation by quantifying fabric changes and relating these to other deformation parameters. The special need for quantification of fabric parameters is needed in rock mechanics if the continuing collection of many kinds of data is to be meaningful. The optical analytical techniques being developed are applicable to other fields, such as resource studies using remote sensing, analysis of contour maps, and the like. This work should contribute to more effective design of structures in rock and of safer and more efficient excavation techniques.

The component objectives of the study are as follows: (a) to develop quantitative methods using optical diffraction in order to compare and correlate fabrics of a deformation series so that changes in fabric can be related to deformation curves and other quantitative deformation data; (b) to identify and characterize through spatial frequency analysis the critical fracture parameters associated with failure; (c) to develop a system of standardized fabric patterns and reference transforms with which fabric inputs can be correlated quantitatively; (d) to develop an index of deformation in terms of fabric change, from one input to the next, and to relate this index to deformation history; (e) to develop an index of fabric heterogeneity for different directions in a single specimen, to be compared with anisotropy measures based on directional differences in physical behavior in the same specimen; and (f) to compare fabrics in experimentally deformed rocks with those in several selected equivalent rocks that failed under field conditions.

## Background

The feasibility of characterizing two dimensional displays through their Fourier amplitude transforms has been well established. Likewise, the study of such displays by spatial filtering has also been shown to be practical. Beyond the analysis of single displays or inputs are the comparison and analysis of sets of inputs, such as photographs and photomicrographs of suites of like rock specimens that have been deformed under progressively higher loads.

In the attempt to explain rationally the complex mechanical behavior of rocks, increasing attention has been given to identifying relationships between fabric and mechanical behavior. Many fabric studies performed to date have yielded results achieved only after very tedious work. Some analytical fabric studies include a subjective element that renders impractical the pooling of results based on work by different operators. We are concerned with developing means to characterize deformation fabrics more objectively and efficiently.

The experimental techniques required to produce deformation suites of rocks for this study consist of standard uniaxial loading, and cantilever and third-part loading of rock slices cemented to aluminum beams. Biaxial and triaxial loading will come in more advanced stages of the work.

The optical diffraction method used in this project is based on work in 1873 by Abbe. With the appearance of the laser in 1960, it became practical to use this method for optical data processing. The basic technique used is spectral analysis of the input's spatial frequency content by optical diffraction. The input is a reduced transparency that functions as a diffraction grating with unknown spatial properties. The source of illumination has precisely known spectral properties, i.e., it radiates coherent monochromatic light. The resulting diffraction pattern is the two-dimensional Fourier amplitude transform of the input image. This transform is a graph of the distribution of orientations and spacings of the elements in the input.

With additional optics the input image can be reconstructed from the light rays that form the diffraction pattern. A filtered, reconstructed image can be formed by blocking out some of the light rays in the plane of the transform. Such filtering can be used to suppress dominant alignments in the input so that obscure features can be detected more easily, and to aid in analyzing complicated distributions by systematically removing different components of the input.

Through their diffraction patterns, orientation fabrics in rocks can be described, regardless of scale, in terms of spacings, directions, elongations, and symmetries. It is also possible to subtract one input from another to show the net change from one to the other. This is done by a holographic technique that can be accomplished with slight modifications of the optical system used for the operations described above.

Series of fabric inputs from deformation experiments plus series of artificial inputs have provided the main kinds of input data operated on so far.

## 2. Methods of Investigation

Optical diffraction analysis has been explained in our earlier reports and in papers by the principal investigator and by others, cited in Appendix B. A Conductron LaserScan C120 System constitutes the core of our optical diffraction capability. The optical diffraction technique is used to analyze changes in rock fabric produced by experimental deformation. High quality photographs and acetate peels are used to record the fabric at successively higher loads or strains. For photography, specimens are illuminated in white light, and in ultraviolet light after treatment with fluorescent dye penetrants. Transparencies of specimens and peels are used as inputs for optical analysis, such as is illustrated in Figures 1-5 and discussed in Section 5 of this report.

Effective analysis requires concern for registration, image quality, and scale factors. Adequate registration and image quality are necessary to achieve consistent, comparable, and sufficiently informative results. The scales at which rock deformation data are recorded depend on both the size features being studied and the dynamic range of the optical analysis system.

Without strong comparability between sets of related inputs, the analysis of fabrics of a deformation series by optical diffraction becomes qualitative, and supporting techniques such as transform mapping and analytical techniques such as holographic subtraction become ineffective.

In addition to photographs of rocks undergoing deformation and peels taken therefrom we have also been investigating the use of thin sections of experimentally and naturally deformed rocks.

Our rock deformation experiments have been limited to uniaxial deformation of cylinders and cantilever and third-part loading of thin rock slices cemented to 10-1/8 x 2 x 1/4" aluminum beams. During the past six months we have worked with rock slices. During deformation we have photographed specimens to record changes in the two-dimensional fabric of the rock. Among the changes we seek to map are microfracture growth, variation in patterns of microfractures, changes in grain shape and/or orientation, development of twinning, changes in reflectance, and so forth.

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The source of samples so far for our deformation experiments is the U. S. Bureau of Mines "ARPA suite". These are out from one foot cubes of St. Cloud Gray Granodiorite, Westerly Granite, Barre Granodiorite, Dresser basalt, Sioux Quartzite, Berea Sandstone, Tennessee marble and Salem Limestone. This report presents results with the St. Cloud Gray Granodiorite (Charcoal granite) and Barre Granite. Samples taken from these cubes are all oriented.

### 3. Important Technical Developments

#### Spatial Filtering

Our capability for frequency filtering is now almost on a par with our directional filtering capability. Very good results have been obtained with frequency filters recorded on glass plates and mounted in the X-Y- $\theta$  gate which also acts as a holographic plate holder/repositioner (Figure 9). Equipment has been ordered which will allow direct exposure of Kodak high resolution glass plates using the Hasselblad camera. This will save much time and, obviously, increase the final resolution of the filters because of a reduction of photographic steps.

All spatial filters on hand have been catalogued and filed and can be used with good versatility in conjunction with previously prepared transform scaling curves.

#### Mapping Transforms

Early in the year the procedures for producing maps of transforms were refined so that maps could be produced more rapidly. In late April an order was placed for a dual trace strip chart recorder, delivery of which is due immediately. Acquisition of this instrument should greatly reduce the time required for the production of transform maps and will also permit the monitoring of laser power output as a transform is being mapped.

In order to calibrate maps of transforms in absolute terms, we have constructed a new meter for our laser power sensing head. This meter has given consistent reproducible readings down to 0.01 mw. Because the light in portions of most transforms falls below this power level, we have arranged for modification of the new meter so that readings can be obtained in three ranges, 0.1 - 0.01 ms, 0.01 - 0.001 mw and 0.001 - 0.0001 mw, via a selector switch. Parts necessary for this modification have recently arrived and the meter will be available for testing and calibration shortly.

#### Optical Processing of Thin Sections

Extensive experimentation with a mercury vapor light source and various microscope optics has been conducted in order to devise a system for the optical diffraction analysis of thin sections. Such a system would also be capable of processing photographic inputs with little additional investment in equipment.

These experiments have led to the conclusion that an auxiliary focusable and removable lens between the microscope ocular and objective would allow convenient viewing of the diffraction pattern with a wide range of objectives. This lens would allow a quick change from diffraction pattern to reconstructed input simply by removing it. A petrographic microscope with a focusable Bertrand lens should work. The ability to view a reconstructed input is just a short step from spatial filtering.

A Zeiss Universal microscope has been used to observe diffraction patterns generated by thin sections and inputs have been recorded on photographic film. The microscope has been modified by the addition of a pinhole and interference filter in the light path to obtain a point source of light of partial coherence. Patterns observed to date have been consistent with respect to both directional and frequency parameters. Theoretical considerations indicate that this method will work on most thin sections of good quality; in the worst cases the transform will be somewhat smeared and in such cases photographs of the thin sections can be used instead as inputs.

Equipment needed to photograph diffraction patterns and inputs for detailed analysis has been made available by a manufacturer on an approval basis and this work will be undertaken immediately.

### Holographic Subtractions

A schematic diagram of our arrangement of optical components for the production of image plane holograms is shown in Figure 6. With the addition of a lens, a stop and a camera back the image hologram can be used as a filter and a difference image recorded (Figure 7). Figure 8 shows the actual optical setup used. Both input and holographic plate are mounted in adjustable gates; the latter holder is shown in Figure 9. The mirrors and beam splitters are mounted in adjustable holders on movable rack and pinion slides (Figure 10).

In order to minimize shrinkage problems the emulsions on the plates are destressed before exposure. This is done by placing the plates in a high humidity atmosphere (but not high enough for water to condense on the plates) overnight. The plate holder is positioned so that the plane of the holographic plate is perpendicular to the bisector of the angle between the signal and reference beams. After exposure the plate is soaked in a hardening bath prior to development in order to minimize degradation of the emulsion surface. After development and fixing the

plate is dried in a series of alcohol baths for quick uniform drying, thus avoiding a migrating drying boundary and restressing. The alcohol baths also help return the emulsion to its original dimensions (Pennington & Harper, 1970).

The developed plate must be precisely repositioned. This can be done by observing the fringes with a microscope (Bromley, et.al., 1971). After repositioning the filter (hologram), the final lens is placed behind the filter such that the difference image is of an appropriate scale and, more importantly, such that all desired information is passed by the lens and not lost due to the finite lens aperture's intercepting the diverging beams. The stop is then placed in the focal plane of the lens in order to eliminate the undiffracted portion of the reference beam.

We have produced high quality image holograms of complex inputs and have achieved a degree of subtraction. Both phase and amplitude holograms have been used. The former are produced by bleaching the developed plate prior to drying in the alcohol baths. Our sole remaining major problem in holographic subtraction is lack of adequate isolation from sources of vibration.

#### Reference Transforms

Approximately 250 reference inputs have been prepared from Harper (1950), Jung (1969), Ramsey (1967), J. Rosenfeld (1970), Sander (1970), and Whitten (1966). A low exposure and a high exposure transform have been prepared for each input, giving a total of approximately 500 reference transforms. These series can now be used as references to which inputs and transforms obtained in our research can be compared.

#### Slide Comparator

A slide comparator has been designed (Figure 11) and necessary components have been ordered and most have been received. The comparator will allow us to determine objectively and quickly gross differences in similar transforms and, in some cases, to make quick comparisons of similar inputs. The comparator will effect savings in optical bench time and will permit more efficient profiling of transforms.

## Study of Closed Curves (Contours)

A paper on the optical diffraction analysis of closed curves (contours) has been completed and accepted for publication by Geoforum. Necessary minor revisions and additions have been completed and the abstract and figure captions have been translated into French and German. Publication is expected in November.

## Preparation and Deformation of Rock Slices

An analysis of the effects of the thickness of rock slices on cantilever and third-part loading experiments has shown that tolerances permitting more rapid production of slices are acceptable. Also, experimental and analytical studies of the generation of strain data in beam deformation studies are aimed in part at reliably reducing the amount of strain gage data required.

In cantilever experiments, strain gages on rock slices have been relocated from a position that gives approximately the minimum tensional strain to a position giving approximately the mean tensional strain. The former arrangement was used for Barre Granite slices; the latter was initiated with experiments on St. Cloud Gray Granodiorite (Charcoal granite). Changing to the latter arrangement does not diminish the continuous area of the slice available for fabric analysis.

## Photographic Procedures

To insure consistency of results in visible light photography, illumination from each floodlight is monitored by a light meter to insure balanced illumination in each exposure and consistency from each exposure to the next. Reflected light is measured from an 18% gray reflecting card on top of the specimen for each series of experiments; comparable values are sought for successive tests. Prior to each test series, an exposure is made of a graduated gray scale placed in the position of the specimen; this provides a means for comparing the input transparencies from different experiments. Great care is taken in dark room processing to insure uniformity of results. A 3 x 3 cm square is inked on all slices for photographic registration and to simplify position control of the input on the optical bench.

Photographic recording of specimens treated with fluorescent dye penetrants has been enhanced considerably through the use of a special emulsifier and yellow filter.

#### 4. Technical Problems Encountered

It was found that series of input transparencies from early deformation experiments, although apparently processed photographically under uniform conditions, were not in fact sufficiently uniform for our purposes. Slight variations from one exposure to the next in registration, contrast and darkness introduced enough difference in spatial frequency content to obscure the other spatial frequency contrasts we were seeking. The measures described in Section 3, Photographic Procedures, have successfully countered these problems. Similarly, early difficulty in achieving good results with the fluorescent dye penetrant method have been overcome by the steps described in the last part of the aforementioned section.

The surface grinder we have been looking forward to pressing into service for preparation of some specimens has undergone three phases of renovation and repair by an extremely slow and unresponsive vendor. At long last the work has been completed and the grinder is due to be delivered and installed any day.

We are presently facing the problem of isolating our basic optical system from vibrations to which the holographic subtraction operation is sensitive. We are investigating two commercially available systems for isolating the system from the floor up. This, plus the contemplated move of our laboratory to a room to be used exclusively by our operation will almost certainly improve the situation.

In general, problems reported in the first year's semiannual and annual reports have been solved or adequately mitigated.

## 5. Experimental Results to Date

Table 1 summarizes the number of deformation tests (left side) and the number of inputs and outputs processed optically (right side). The numbers on the right side are larger than those on the left because each test involves the preparation of a series of photographs or peels, each corresponding to a data point on the loading curve.

The results shown in Figures 1-5 are representative of some of those obtained during the first half of the second year of this project.

Specimen strains represented in the loaded specimens shown in the five figures are, respectively, 0.14%, 0.47%, 0.14% (min.), 0.28% (min.), and 0.47%. In Figure 3, the darker background in c) as compared to a) is characteristic only of the prints used in this report, and not of the input transparency used to generate the transform.

The slices shown in these figures were loaded to higher levels than those depicted from equivalent experiments in last February's annual report. The results described in the figure captions are consistent with the apparent trends described in the annual report, (p. 19) for slice (cantilever), cylinder, and prism experiments. The results in Figure 5 suggest that the fluorescent dye penetrant method might be more sensitive to detecting fracture widening than are the methods using white light and acetate peels.

The acetate peel method continues to yield very useful results in a variety of experimental set-ups. Not only is their detail well defined, but they also provide for the easy variation of input scale; it is a simple matter to prepare input transparencies over a wide range of scales from a single peel that records permanently the fabric of a specimen for a particular data point on a loading curve.

Let us consider here the results of detailed comparisons of inputs and transforms from the following experiments on Barre Granite using acetate peels:

- a) Cantilever, weight loaded, tension, duplicate tests on slices from each of three mutually perpendicular directions. (C008-A-2T, C009-A-2T, C017-A-1T, C018-A-1T, C026-A-3T, C027-A-3T; Figure 4 is based on two inputs and their transforms from C008-A-2T).
- b) Cantilever, weight loaded, compression, single tests on slices from each of three mutually perpendicular directions (C010-A-2C, C019-A-1C, C028-A-3C).

TABLE 1

NUMBER OF TESTS

.I. - Regular Illumination  
 U.V. - Ultra-violet illumination  
 .P. - Acetate Peel

OPTICAL DIFFRACTION ANALYSIS  
 No. of Inputs

	BARRE GRANITE		ST. CLOUD		Prepared		Processed		Transforms Prepare	
	TENSION	COMPRESSION	TENSION	COMPRESSION	Barre Granite	St. Cloud	Barre Granite	St. Cloud	Barre Granite	St. Cloud
SLICES Cantilever Weight Loaded	6 6 6	3	4 1 6	3	169	107	44	8	88	16
Micrometer - Loaded		3 3			72	0	0	0	0	0
Third Part Loading		9 6 9		6 9	193	120	40	4	80	8
Column Totals	18	33	11	18						
Rock Type Totals	51		29		434	227	84	12	168	24

- c) Third part load, compression, triplicate tests on slices from three mutually perpendicular directions. (P001-A-2C, P002-A-2C, P003-A-2C, P010-A-1C, P011-A-1C, P012-A-1C, P013-A-2C, P013-A-3C, P014-A-3C, P015-A-3C; Figure 3 is based on two inputs and their transforms from P011-A-1C)

The input transparencies are 1/10 the size of the corresponding specimens. Prints of four inputs and their transforms were selected from the approximately eight data points available from each experiment. The four data points for each test were generally obtained at comparable loads. The same mutually perpendicular orientations of slices, corresponding to three faces of the source cube of rock, have been used in all of these experiments.

The following conclusions have been drawn from these examinations:

- 1) Replicated experiments yield very similar results. In the two exceptional cases (C009-A-2T and P015-A-3C), slightly oblique fractures appearing in the no-load input became accentuated with loading yielding high-load patterns similar to the no-load patterns and different from their corresponding replicates. The transforms, of course, show the spatial frequency counter parts of these relationships, and more.
- 2) In each of the three classes of experiments (a), (b), (c), above, slices of the same orientation (suffix numeral 1, preceding T or C) yield patterns different from those of the other two orientations (suffix numerals 2 and 3). Patterns from one of those orientations (suffix numeral 3) appear in some series to be intermediate between the other two (suffix numerals 2 and 1) but to resemble the former quite closely. It is perhaps significant that the orientation designated by the suffix numeral 1 is parallel to the rift of the Barre Granite.
- 3) Within each class of experiments, the results accord with what one would expect in tension and compression experiments. That is, fractures develop perpendicular to the axis of tension and diagonal fractures (and others) develop in compression.

- 4) In the two compression series, b) and c), the results are mutually consistent, more-so for two orientations (suffix numerals 2 and 3) and less so for the third (suffix numeral 1)
- 5) In a), there appear to be increases with loading in low and high spatial frequencies. In b), there appear to be increases with loading in medium and high spatial frequencies. In c), there appear to be increases with loading in low to high spatial frequencies; in the transforms, diagonal concentrations appear in the low frequency range except in one orientation (suffix numeral 3) where these appear in the high frequency range
- 6) On all of the results described above, the inputs and their transforms give mutually consistent reinterpretations, and the study of each enhances the understanding of the other.

Additional analyses and interpretations of the results of these and other experiments are or will shortly be underway.

In all experiments conducted so far with slices, third-part loading seems to yield more nearly linear and lower hysteresis loading curves than do the cantilever experiments, and the fabrics and their transforms seem to be more easily interpreted.

## 6. Implications for Further Research

The technical results achieved so far indicate that, as before, we are on the right track and that the general direction of the research will follow original plans. We will continue to concentrate on recording more deformation data; this will include use of results from uniaxial deformation of right-circular cylinders and rectangular prisms, in addition to continuing the current work with slices

Late in the year we will begin to obtain data on changes in fabrics of triaxially deformed specimens. This will be done by carrying cylindrical specimens to specified axial and radial loads and photographing medial sections cut along their axes. One specimen will have to be sacrificed for each data point, and the photographs will be made following unloading.

We will begin shortly some pilot experiments leading to the capability of generating transforms in reflected light. Having demonstrated that slight changes in fabric are detectable by our techniques, we will investigate possibilities for in situ optical monitoring of rock fabrics in active excavations.

## 7. Special Comments

Related research projects in which we are involved are providing materials and knowhow of benefit to the conduct of this project, and vice versa. Those projects include a study of the effects of rock alteration, joint fillings, and fracture geometry on mechanical behavior of rocks, especially from block-caving operations. We are also measuring triaxial-acoustic properties of rocks from block-caving areas. Fabric analysis is an important aspect of these studies. We are also studying the transforms of separated particles of different shapes and sizes to determine empirically the effects of different configurations, shapes, spacings, and sample size.

## 8. Concluding Remarks

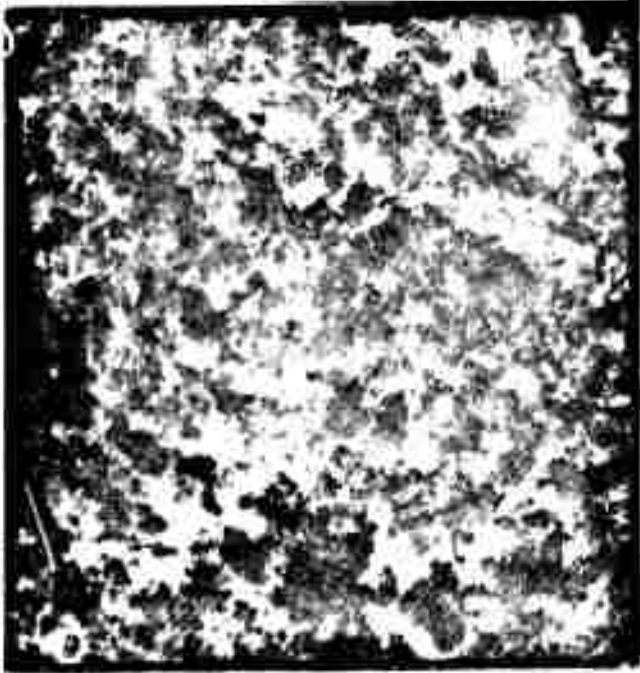
The basic research design appears to be sound. The results achieved so far have been quite encouraging. The technical skill of the projects' personnel and the major items of equipment on hand, on order, or otherwise available for use are appropriate for the needs of this study.

Results obtained so far, particularly during the past six months, hold much promise for the project's fulfilling all of its major objectives, as originally planned, by January 1974.

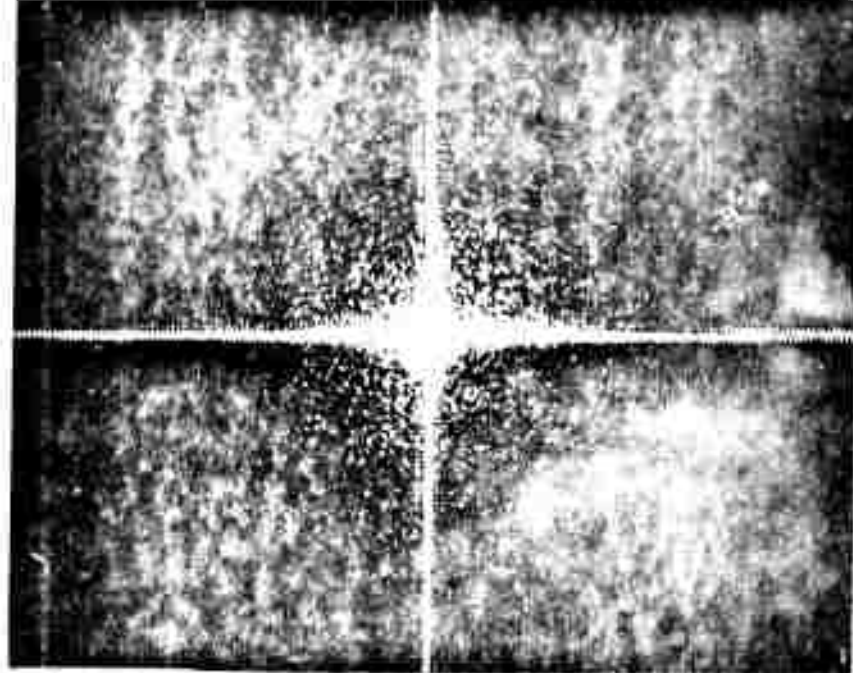
**APPENDIX A**

**Figures Accompanying Text**

**(Figures 1-11)**

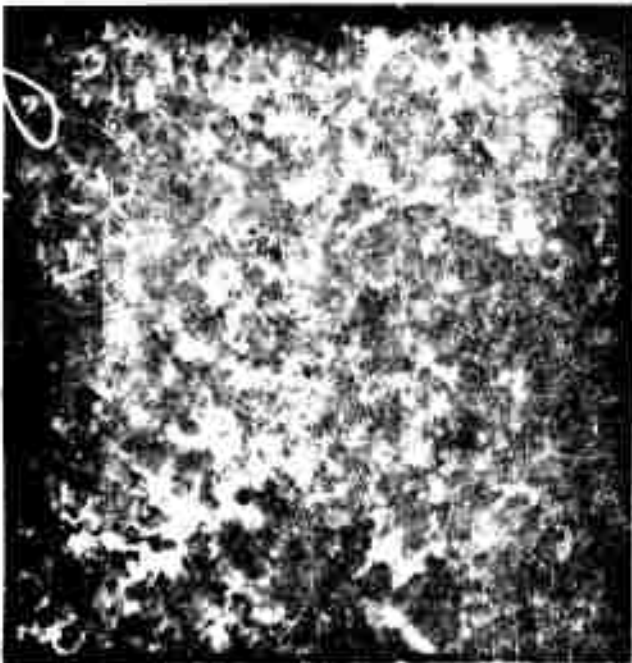


a

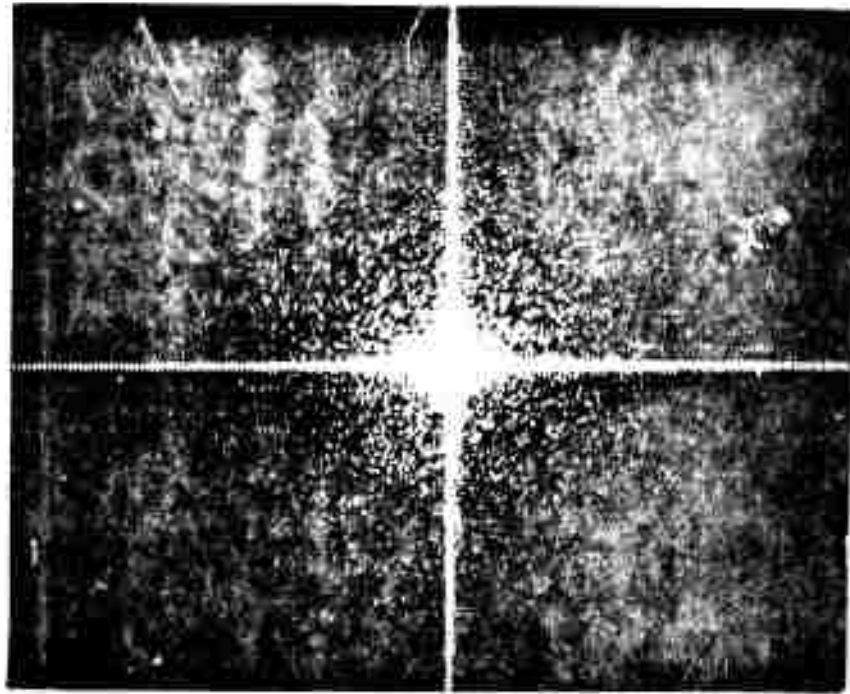


b

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c

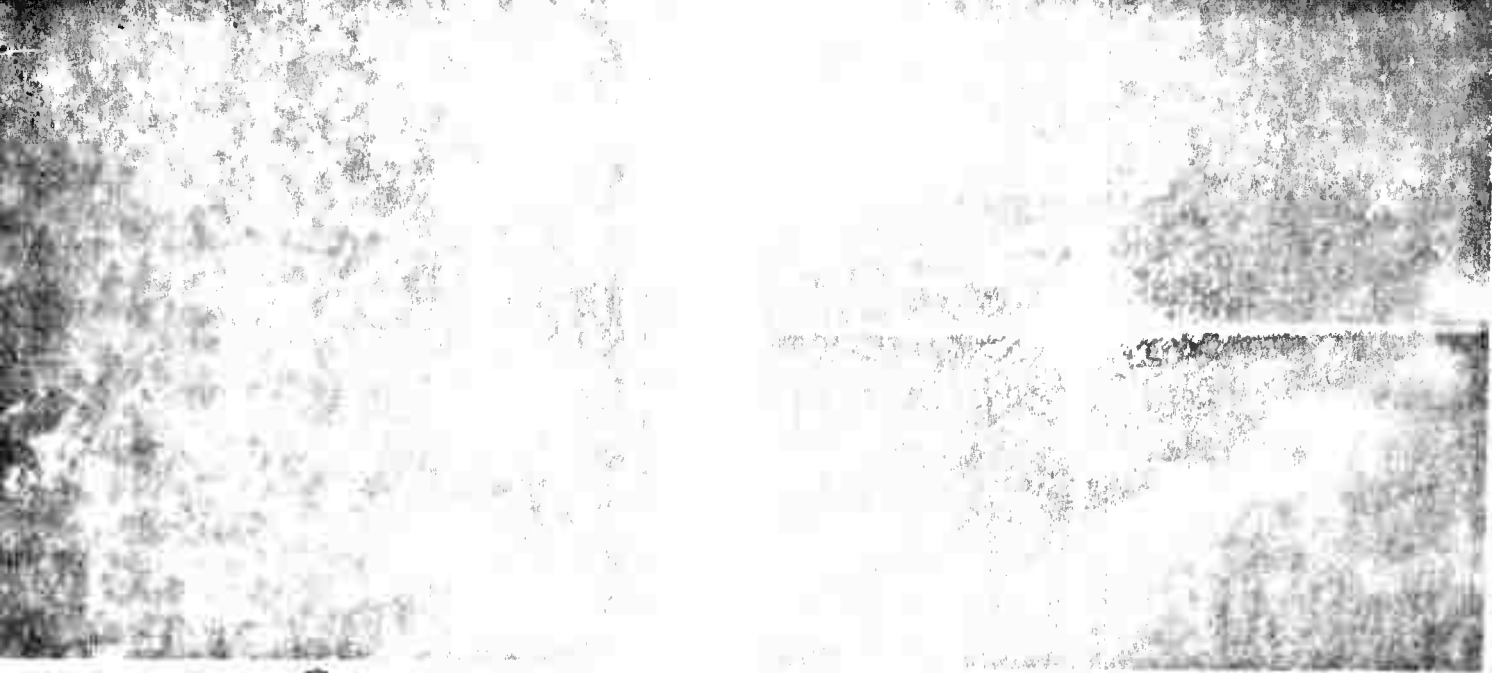


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Fig.1 a) Slice of Charcoal granite (St. Cloud Gray Granodiorite), no load. b) Transform generated from a); no preferred orientation is apparent. c) Same slice as in a), under third-part load (axis of compression: top-bottom of photograph). d) Transform generated from c); shows two weak diagonal low-frequency concentrations and slightly higher concentrations of high frequencies than in b).

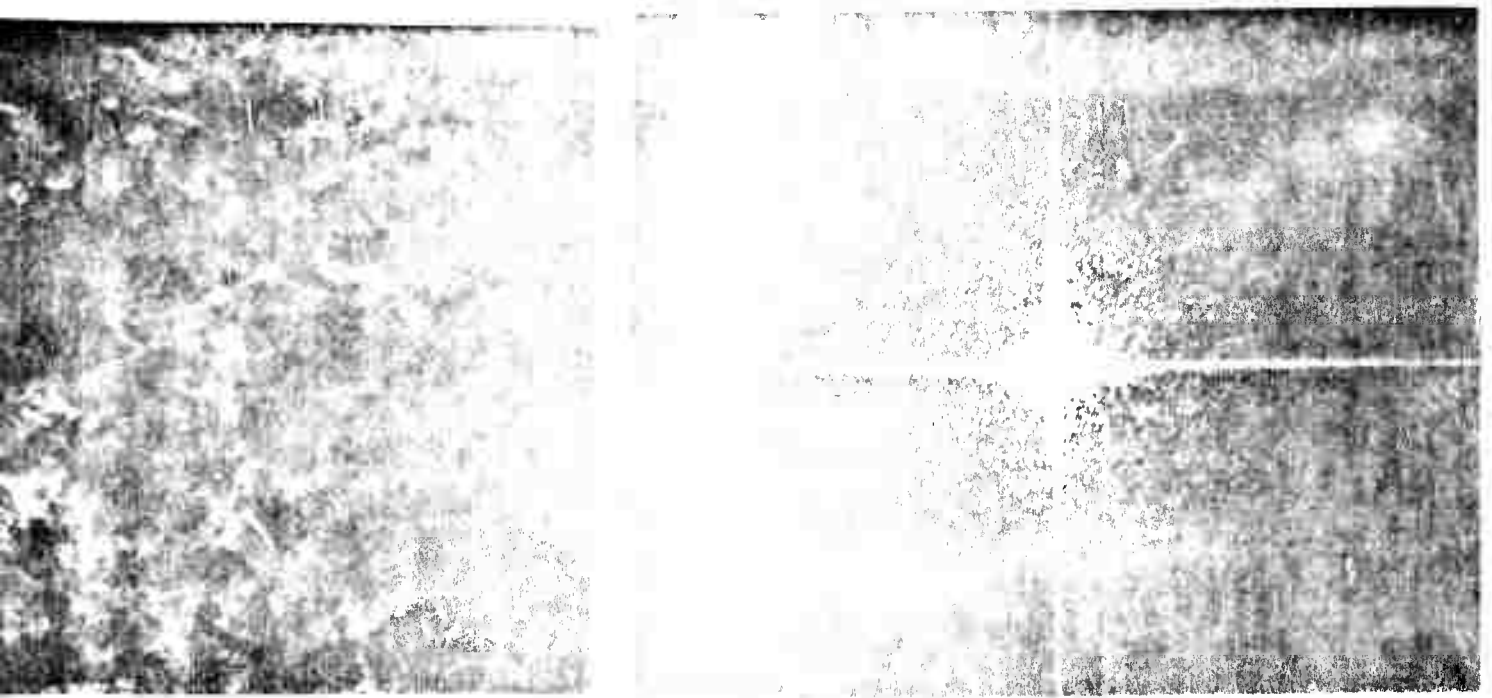
Scales: a) and c) - Magnification 2.8X  
b) and d) - Radial distance of 10 mm corresponds to 1 line/4.76mm in a) and c)



a

b

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c

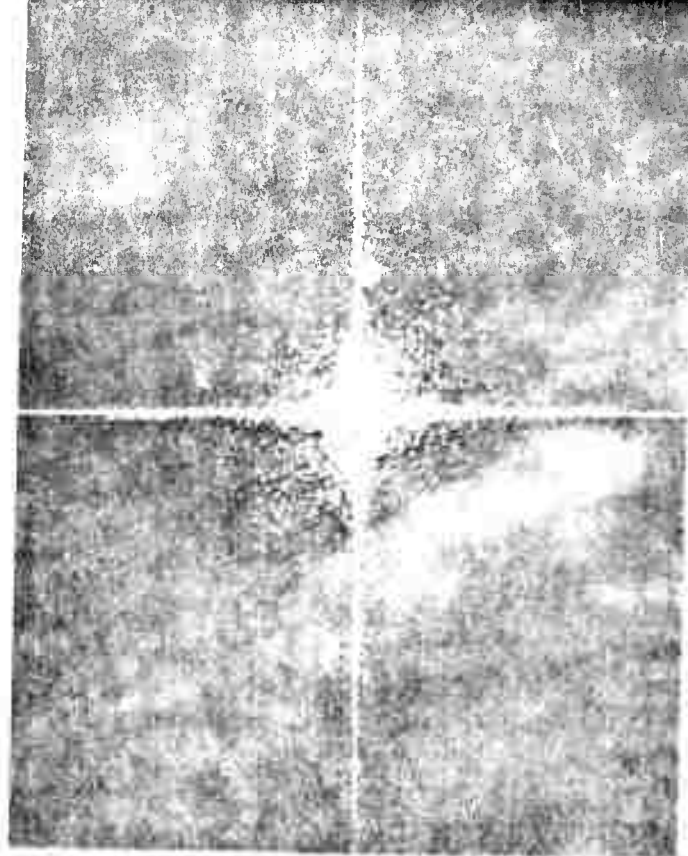
d

Fig.2 a) Slice of Charcoal granite (St. Lawrence Granodiorite), no load. b) Transform generated from a); no preferred orientation is apparent. c) Same slice as in a) under cantilever load (axis of tension perpendicular to photograph; load toward bottom). d) Transform generated from c); elongated vertically, corresponding to development of horizontal fractures with more high frequency content than in b).

Scales: a) and c) Magnification  $\times 100$   
 b) and d) Radial distance  $\times 100$  corresponds to 1 line/4.76mm  
 in a) and c)



a

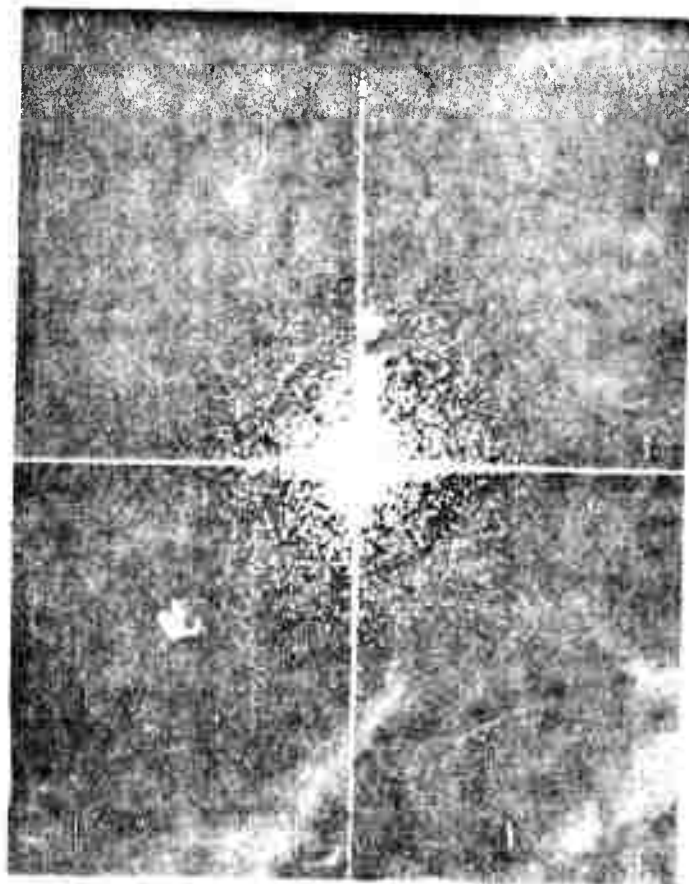


b

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c



d

19

Fig. 3 a) Acetate peel of Barre Granite, no load. b) Transform of a); wear diagonal concentrations. c) Acetate peel of same slice as in a), under three-part load (compression: top-bottom). d) Transform of c); same diagonal concentrations as in b); more high frequencies than in b). Scales: a) and c)-Magnification 3.75X; b) and d) 10 mm corresponds to 1 line/6.75 mm in

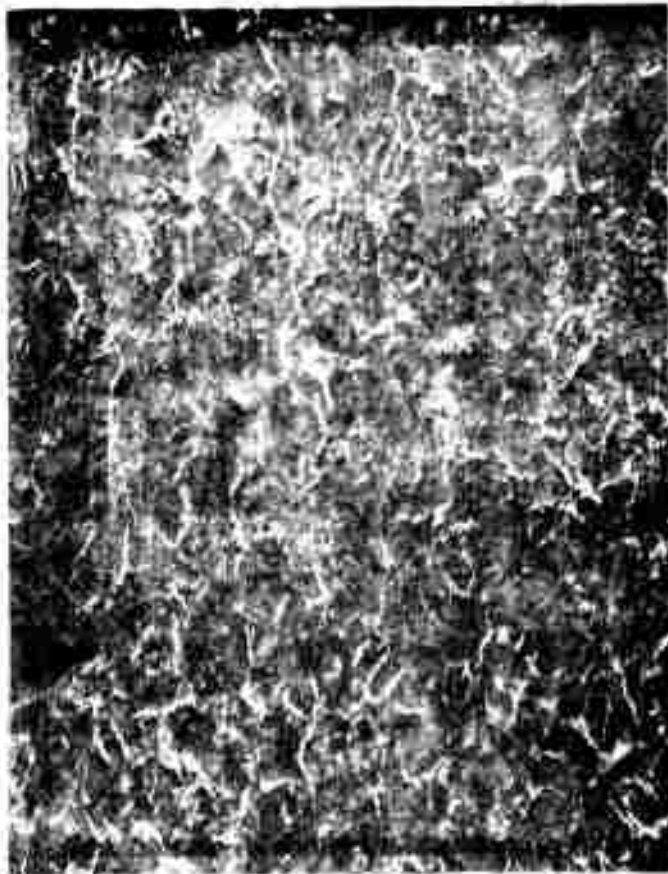


a

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b



c



d

20

Fig.4 a) Acetate peel of Barre Granite, no load. b) Transform of a); no preferred orientation. c) Acetate peel of same slice as in a) under cantilever load (tension: left-right; load back and forth). d) Transform of c); elongated horizontally, especially in low-frequency range. Scales: a) and c) - Magnification 3.75X ; b) and d) 10 mm corresponds to 1 line/6.75 mm in a) and c).



a



b



c

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d

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.5 Charcoal granite treated with fluorescent dye penetrant, u.v. illumination, no load. b) Transform of a); slight left-right elongation. c) Same as a) under cantilever load (tension: left-right; compression: top toward right). d) Transform of c); more low and high frequency content than in b); left-right elongation more prominent in the low frequencies. Scales: a) and c) - Magnification 2.8X; b) and d) - Magnification 1.0X. Radial distance of 10mm corresponds to 1 line/4.76 mm in a) and c).



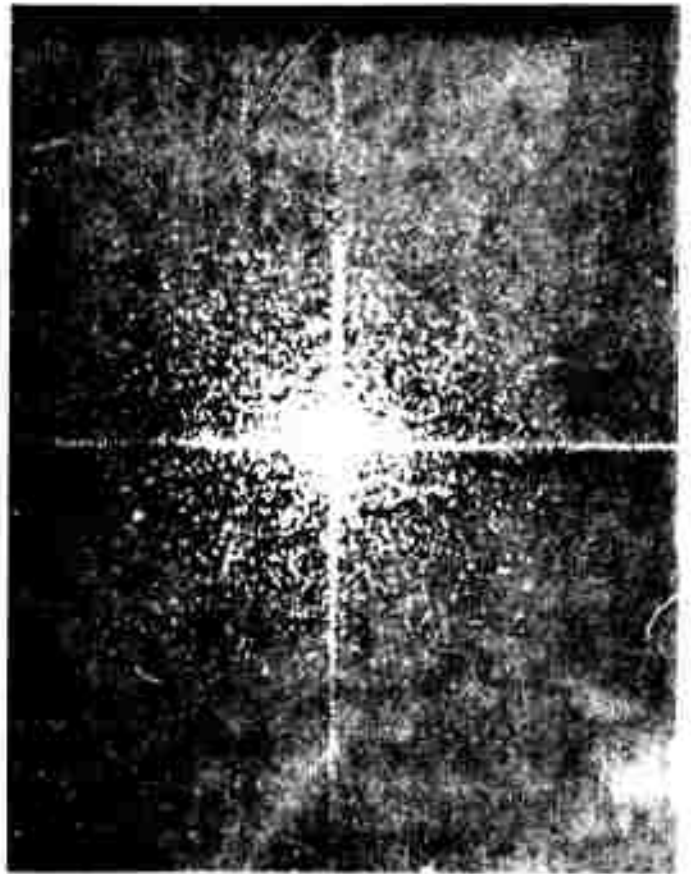
a



b



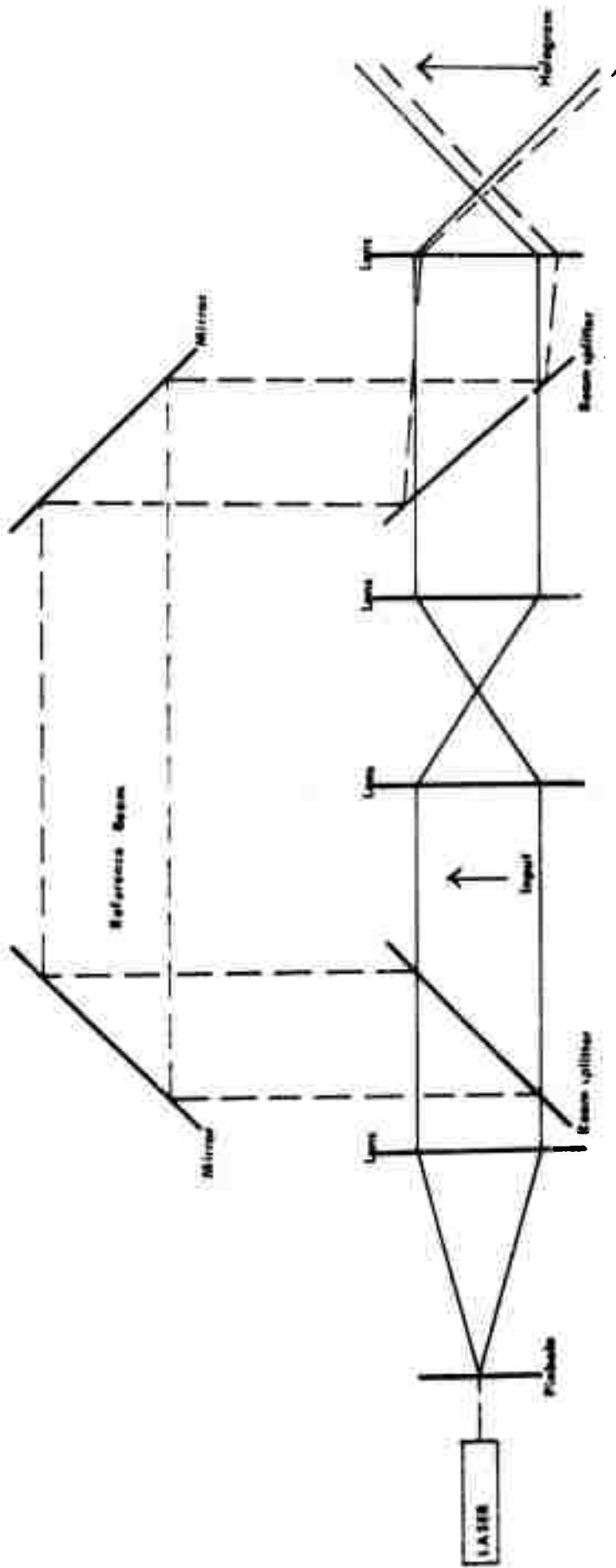
c



d

Reproduced from  
best available copy.

.5 Charcoal granite treated with fluorescent dye penetrant, u.v. illumination, no load. b) Transform of a); slight left-right elongation. c) Same as a) under cantilever load (tension: left-right; d toward right). d) Transform of c); more low and high frequency content than in b); left-right elongation more prominent in the low frequencies. Scales: a) and c) - Magnification 2.8X; b) and d) - Magnification 2.8X. Radial distance of 10mm corresponds to 1 line/4.76 mm in a) and c).



**Fig.6 Optical configuration for the production of an image plane hologram**

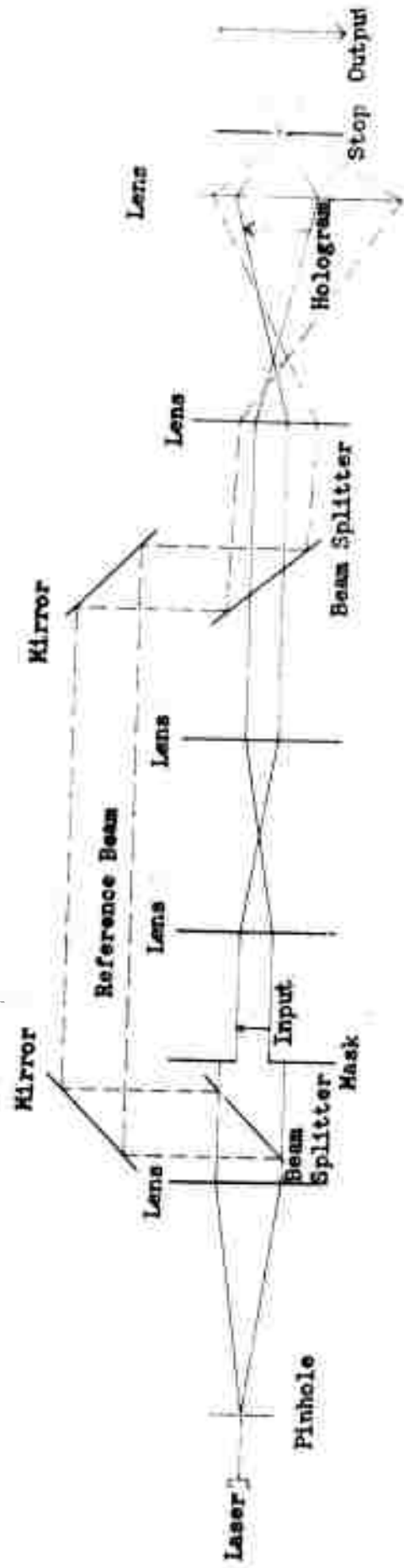


Fig.7 Optical configuration for the production of difference images using image plane holograms.

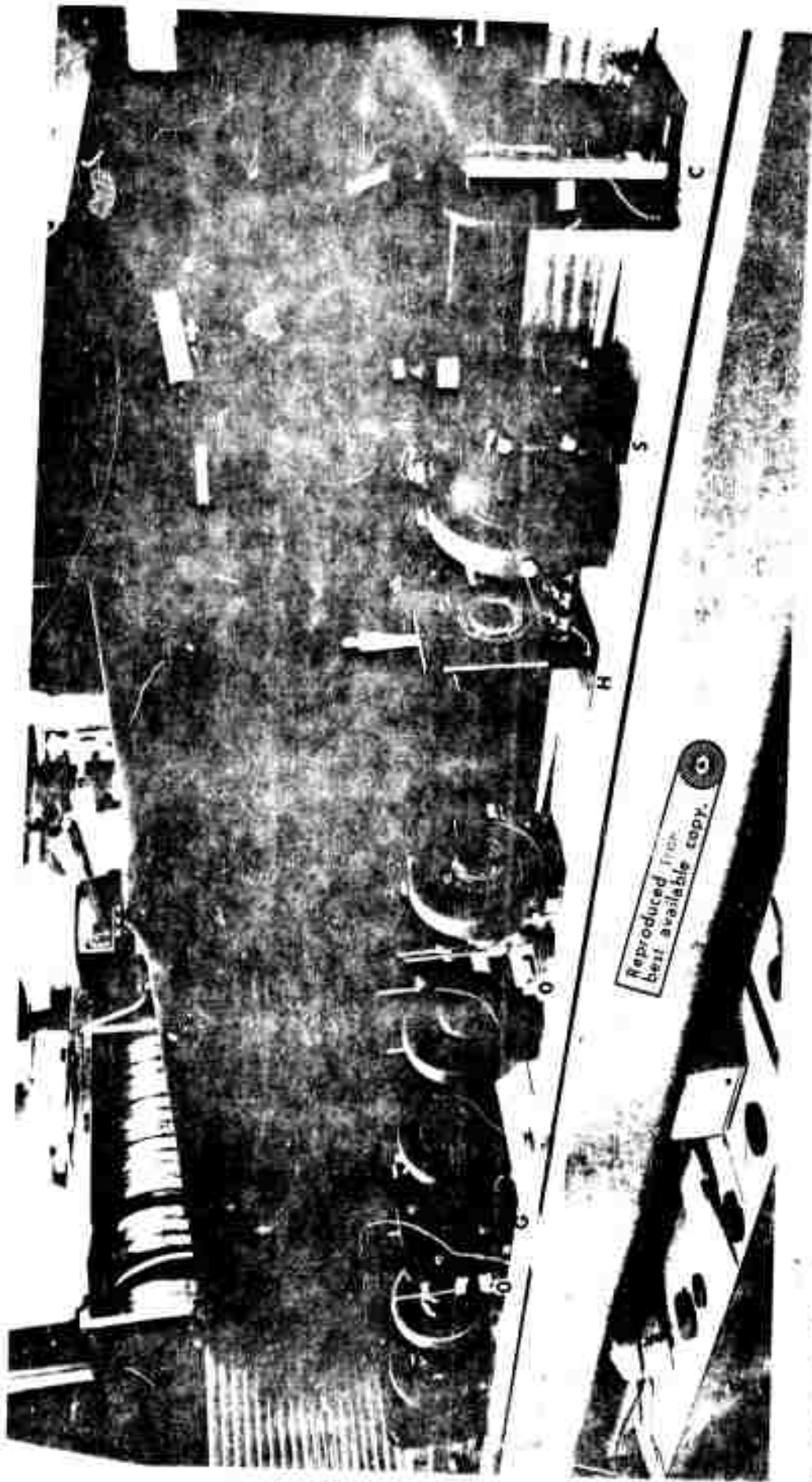


Fig.8 Optical bench configuration corresponding to the diagram in Fig.7: Laser(L), Beam splitter-mirror assembly(O) (See Fig. 10 for details), Input Gate(G), Holographic plate holder(H) (See Fig.9 for details), Stop(S) and Camera back(C). Scale: App. 19 cm between S and C.

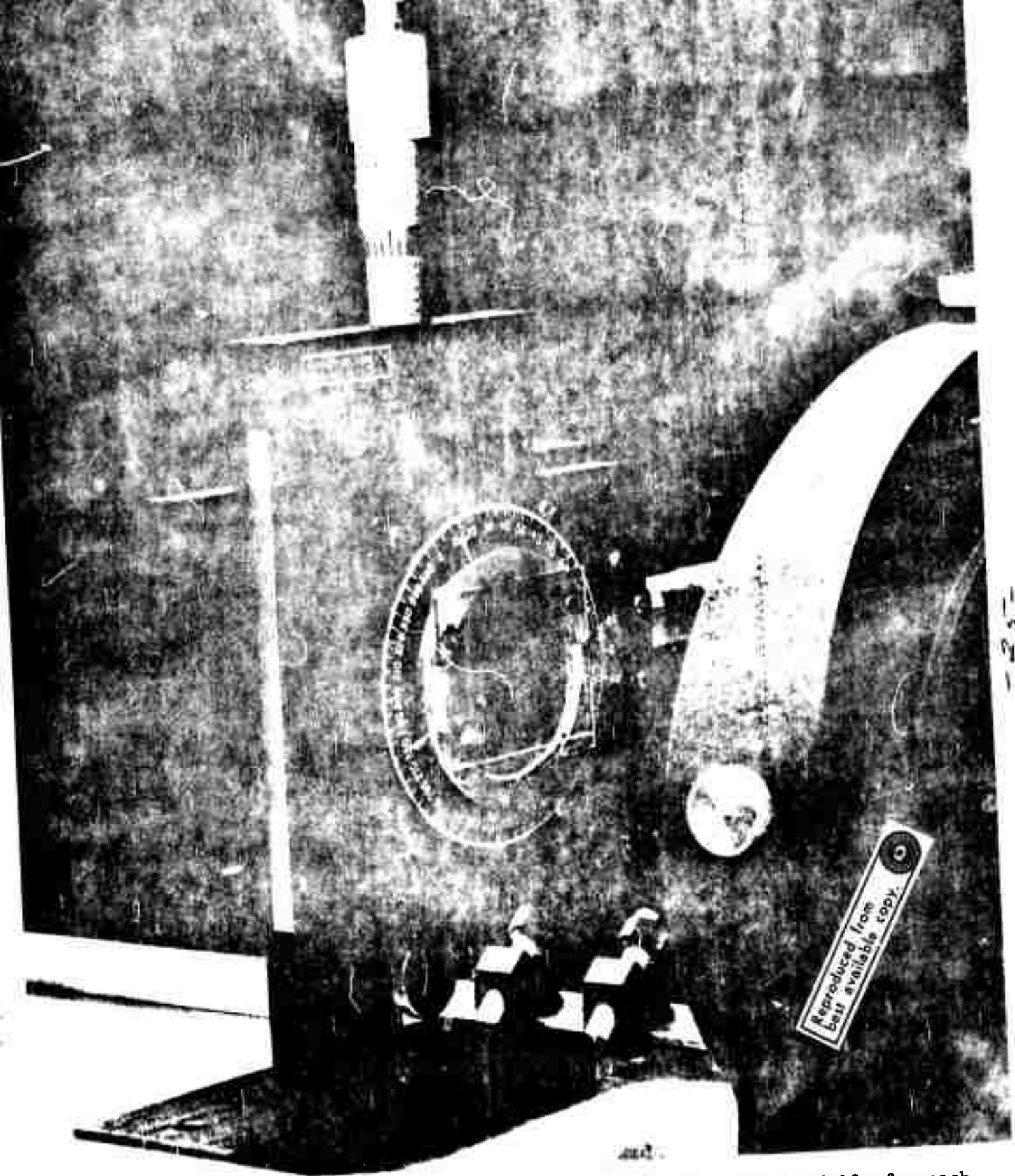


Fig. 9 Detail of holographic plate holder. Four degrees of freedom are available for each bench position: vertical and horizontal translation, and rotation about the vertical and optical (horizontal) axes. Different sizes of plates can be used. Shown in the gate is a phase hologram, which appears to be blank in this photograph. Scale: Phase hologram plate is 1.5 X 2.0 in. (38.1 X 50.8 mm)

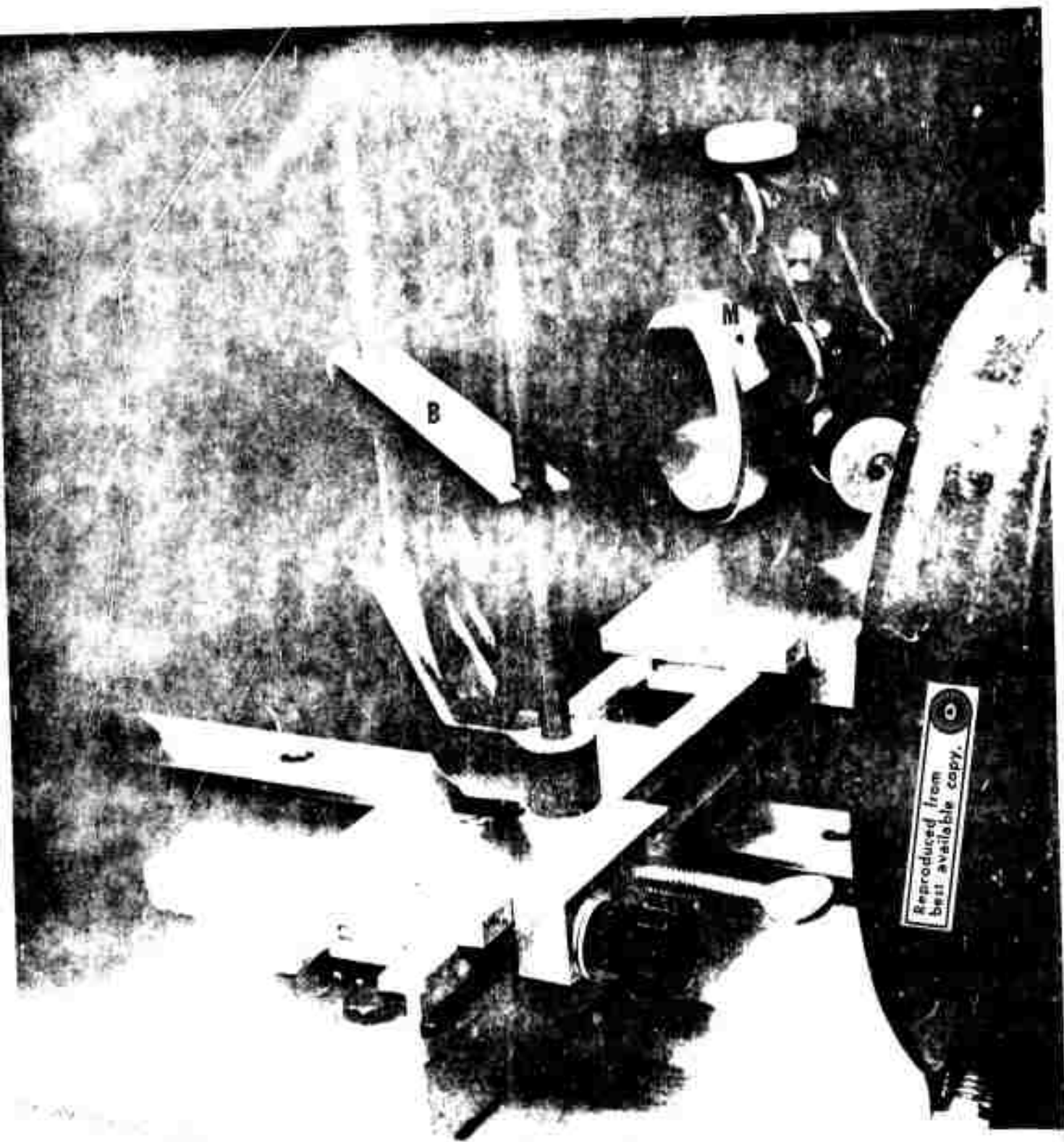
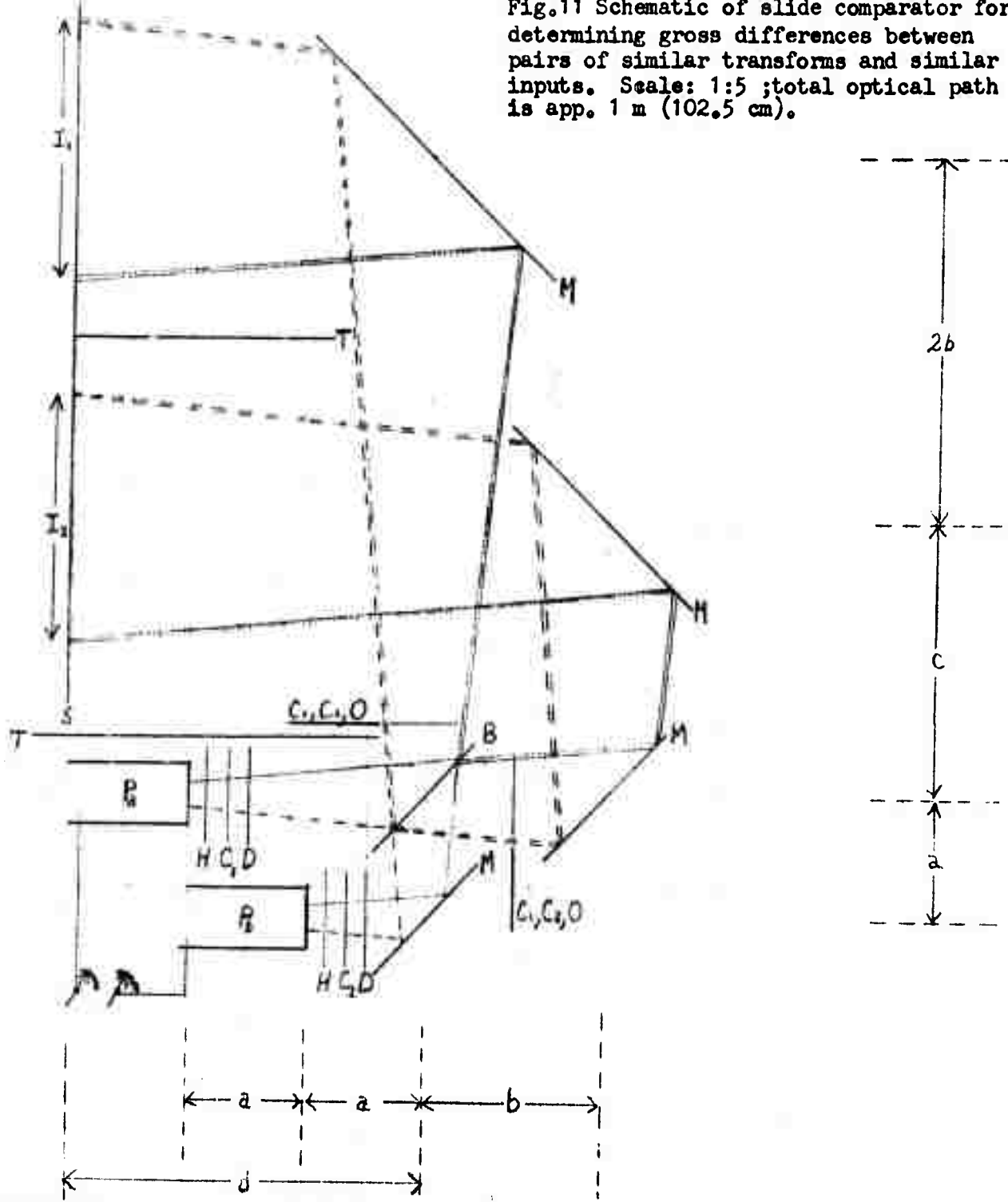


Fig.10 Detail of the beam splitter(B)- mirror(M) assembly. The beam splitter can be rotated about a vertical axis and the mirror mount allows fine adjustment about both vertical and horizontal axes. Both elements can be translated horizontally along the rail, i.e., perpendicular to the axis of the bench. Scale: Diameter of mirror face is 2 in (50.8mm).

Fig. 11 Schematic of slide comparator for determining gross differences between pairs of similar transforms and similar inputs. Scale: 1:5 ; total optical path is app. 1 m (102.5 cm).



LEGEND

- |               |                                   |            |                            |     |                    |
|---------------|-----------------------------------|------------|----------------------------|-----|--------------------|
| $P_2, P_6$    | Film strip projectors             | M          | Front surface mirrors      | T   | Light trap         |
| H             | Heat filters                      | B          | Beam splitter (50:50)      | 2-d | Critical dimension |
| $C_1, C_2$    | Filters, colored or polarizing    | S          | Screen (rear illumination) |     |                    |
| D             | Diaphragms                        | $I_1, I_2$ | Projected images           |     |                    |
| O             | Opaque shields                    |            |                            |     |                    |
| $C_1, C_2, O$ | Assemblies of filters and shields |            |                            |     |                    |
|               | Variable intensity controls       |            |                            |     |                    |

Total axial ray length, projector to image,  
 $= 2a + 2b + c + d$   
 Divergence half-angle of projection  $= 5^\circ$

APPENDIX B

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