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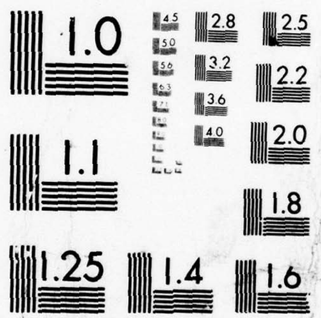

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DRILL PARAMETER STUDY
(MM&T PROJECT 2769779)

JACK QUINTANA
TOM WEISMULLER
HUGHES AIRCRAFT CO.
FULLERTON, CA 92634

JANUARY 1979
FINAL REPORT FOR PERIOD 2 JANUARY 1977 - 30 OCTOBER 1978

PREPARED FOR:

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FORT MONMOUTH, NJ 07703

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of the Drill Parameter Study was to evaluate methods of monitoring the hole drilling process and determining when the drill becomes dull and inadequate for producing high quality holes in multilayer circuit boards (MLBs). Several candidate sensing techniques were proposed for evaluation. However, a literature search/vendor survey provided sufficient information to conclude that the detection of heat (OVER)

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generated by the drilling process would be the best means of accomplishing this task.

In Phase II, two types of infrared sensing devices were used to monitor the temperature increase of the drills during the hole drilling operation and the results were correlated with microsections of the holes. Various drill geometries and surface finishes were evaluated in this study and a significant difference in performance was obtained using the newer micro-grade type drills.

The Scanning Electron Microscope (SEM) was used in the evaluation of the drilled hole microsections and in the examination of the cutting surfaces of the carbide drills before and after drilling. In the last phase of the study

In Phase III portion of the program, four various sized drills were monitored at drill speeds of 50,000 and 80,000 RPM using the IR sensing device. Every 500th hole was cross-sectioned, stained and examined for evidence of smear.

PREFACE

This final report documents the results obtained during the "Drill Parameter Study". This report was prepared by the Hughes Aircraft Company, Fullerton, California, under contract DAAB07-77-C-2640.

The effort was sponsored by U.S. Army Electronics Command (ECOM), under the technical direction of D. Ruppe. The principal Hughes contributors were Jack Quintana, Project Manager, and Tom Weismuller.

The work covered by the report was performed between 2 January 1977 and 30 October 1978.

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SUMMARY

Steps in Development of a Drill Failure Sensing Device and Drill Bit Evaluation

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Phase I –

- Review of Sensing Techniques
- Selection of Candidates
- Preliminary Screening
- Review With ECOM
- Develop and Process Data for Selected System
- Review With ECOM

Phase II –

- Obtain ECOM Drills
- Examine Drills With SEM
- Fabricate MLBs
- Drill and Monitor Performance
- Microsection Every 500th Hole and Examine for Epoxy Smear
- Obtain Data and Correlate With Microsections

Phase III –

- Evaluate 4 Drill Sizes at 50,000 and 80,000 RPM
- Monitor Drill Temperature With Van Zetti Sensor
- Microsection Every 500th Hole and Examine for Epoxy Smear
- Correlate Smear With Temperature Data

One of the most common, and often considered the most important problems with plated-through-holes in multilayer boards is that of epoxy smearing over the inner layers of copper. This problem ultimately affects the reliability of the finished product. This study effort was initiated in order to develop a real-time drill sensing technique which would monitor the drilling process so that epoxy smearing could be detected as the hole is being drilled. Various mechanical and thermal techniques were evaluated. Data produced by those techniques finally selected were compared to the amount of smear produced, as measured by an innovative sample staining method. Various sizes, types, finishes, and speeds of drills were evaluated in order to gain an understanding of which conditions result in epoxy smearing and therefore of how it may possibly be prevented.

The figure above illustrates the main tasks of the "Drill Parameter Study". The tasks in Phase I were to design, develop, and validate an on-line technique for drill monitoring, which would enable operators to tell when drills start to become dull and begin producing holes that are affected by epoxy smear. This technique was to be easily implemented and cost less than $5,000.

The task in Phase II was to evaluate drills with various finishes and point geometries by use of the technique developed in Phase I in conjunction with scanning electron microscope (SEM) examination.

In Phase III, the task was to monitor four different drill sizes at two different drill speeds and correlate this to the amount of smear observed in every 500th hole of the test board. Again, SEM examination was employed.

Drill Tip Temperatures, as Measured by IR Sensors, Provide Positive Correlation With Epoxy Smear

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- IR Temperature Sensors Successfully Used to Monitor Temperature of Drills in Operation
  - Easy to implement and operate
  - Cost less than $5K
- Observed Temperature (T_O) of Drills Increased as Number of Hits Increased
- Results of Drill Finish and Point Geometry Evaluation
  - T_O was higher for standard carbide than for microfinished drills
  - Microlube coating did not improve hole quality or lower T_O
  - Quality of drilled holes and T_O were relatively independent of drill point geometries
- An Innovative Ammonium Sulfide Solution Staining Technique was Used for Smear Detection
- T_O was Higher at 80,000 RPM than at 50,000 RPM
- Holes Produced at 80,000 RPM had a Greater Smear Factor than Holes at 50,000 RPM
- Smear Factor Increases as T_O Increases

Various techniques of detecting drill wear were evaluated. The most effective method was determined to be an infrared (IR) temperature sensing device which would measure the drill temperature as it exists from the hole. Temperature was found to correlate positively with the formation of epoxy smear. The observed temperature (T_O) of the drills increased as the number of hits increased and this information was used to classify standard production drills into two categories – standard and microfinish types.

Various drill finishes and point geometries were evaluated using the IR sensors. This was accomplished by drilling approximately 3500 holes in MLBs using ECOM-supplied drills and monitoring the temperature of the drill as it exits from the board. The results were (1) T_O was higher for standard finish than for microfinish drills, (2) microlube coating did not improve hole quality or result in lower T_O, (3) no significant differences in T_O or hole quality was observed using various drill point geometries on microfinish drills.

An innovative staining technique was developed for coloring the unmounted cross-sections of the drilled holes. This technique utilizes a solution of ammonium sulfide which causes the copper to blacken in areas not covered by epoxy smear. This technique provided a faster method of hole examination for smear detection.

The quality of drilling was found to have little dependency upon drill point geometries, but was dependent upon the finish of the drills (microfinish drills were superior to standard finish drills). In addition, drilling MLBs at 80,000 RPM/200 IPM resulted in higher temperatures and greater smear factor than drilling at 50,000 RPM/200 IPM. This was true for all the drill sizes tested (#55, #56, #60, #68).

A method of pre-categorizing drills into their appropriate finish types (standard, micro, etc.) was attempted using SEM examination as well as hardness measurements. These attempts were not successful.

With Some Additional Study, IR Sensors Can be Developed to Determine Drill Failure in Real-Time

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- Recommend Investigating Factors Associated With IR Sensing Devices Prior to Implementation
  - Different temperature versus smear factor curves needed for each drill
  - Improve temperature response of sensor and use filters to eliminate light interference to reduce scatter
- Recommend Use of Microfinish Drills
- Recommend Evaluating IR Sensing Units Under Production Conditions
- Recommend Implementing Ammonium Sulfide Staining Technique to Evaluate Amount of Epoxy Smear

The IR radiation scope and fiberoptic thermal monitor both provide inexpensive methods of monitoring drill wear, and can be used to automatically trigger shutdown of a drilling operation when a predetermined drill temperature is observed. The following two factors should be further examined relative to this technique in order to make it more suitable for production use: the smear factor versus temperature curves must be obtained for each drill type, size and drilling condition; and the IR sensor should be modified by improving the temperature response and using filters to eliminate light interference in order to reduce the scatter in the smear factor curves.

Microfinish drills were found superior to other drill types, and these are recommended for use for drilling multilayer boards.

It is recommended that the IR sensing unit be evaluated in a production environment under the parameters used in this test. The use of the staining technique to evaluate smear is recommended over the conventional potting method. This method is more cost effective.

SECTION 1
INTRODUCTION

1. BACKGROUND OF PROBLEM AND SCOPE OF CURRENT EFFORT

Degradation of the quality of plated-through holes drilled in multilayer boards (MLBs) affects the reliability of the MLBs. The primary objective of this study was to determine a reliable, on-line technique for predicting the point at which the drill fails to produce an acceptable hole.

Current and future military systems continue to use high reliability multilayer boards (MLBs) governed by specifications such as MIL-P-55640 whose quality requirements are necessarily stringent. It is widely recognized that the most common failures occur in the plated-through holes (PTHs). Fabricators of MLBs have been concerned with the recurring problem of drilled hole degradations such as epoxy smear, nail heading, burrs, epoxy gouging, etc. This concern is justified since the sidewall of the drilled hole is the surface upon which copper is chemically deposited and electroplated to make electrical contact between the internal layers and the external circuitry. The condition of the hole surface is also important in determining the quality of the electroplated interconnections and affects the ultimate reliability of the MLB.

Current practices in the drilling of circuit boards vary considerably among manufacturers. Little, if any, standardization exists in drill design, spindle speed, drill feed, and similar parameters. Usually a manufacturer, through experimentation, determines an optimum combination of these variables to achieve acceptable hole quality. Within the last few years, a number of improved numerically controlled (NC) drilling machines have appeared on the market which when used with the new, high quality carbide drills produce better holes as reported in the literature.

In spite of efforts to improve the quality of drilled holes in MLBs, epoxy smear is still one of the most common problems in achieving reliable PTHs.

This Drill Parameter Study was initiated by the United States Army Electronics Command (ECOM) and undertaken by Hughes Aircraft Company to develop a real-time drill sensing technique to monitor the drilling process so that hole quality can be measured as the hole is being drilled.

Hughes' Ground Systems Group, Fullerton, California, was awarded MM&T contract from the United States Army Electronics Command (ECOM) entitled "Drill Parameter Study". The effective date was 6 January 1977. The program, as proposed by Hughes, was a two-phase program. Later, a third phase was added. Figure 1 summarizes the activities.

In Phase I, the task was to design, develop, and validate an on-line method of automatically detecting the point at which a given printed circuit board drill becomes dull and fails to produce a good, burr-free, smear-free hole in MLBs. Drill life, therefore, would relate to actual production conditions, and the machine could be stopped automatically for drill replacement. The developed method must be capable of being easily implemented on drilling machines from many manufacturers and have a hardware implementation cost of less than $5,000.

In Phase II, the task was to use the established method from Phase I to evaluate fourteen variations of drill geometry and finish to determine trends for improvement of drill geometry and establish a baseline for possible future investigations.

In Phase III, the task was to monitor the temperature of four various sized drills at two different drill speeds. Every 500th hole was to be microsectioned, examined for epoxy smear, and correlated with the temperature measurements. In addition, some drills were examined using a scanning electron microscope (SEM) before and after drilling.

Figure 1. Major Activities of the MLB Drill Parameter Study.

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Phase I

- Review of Possible Sensing Techniques
  - Literature search
  - Coordinate with sensor manufacturers
  - Review available sensors
  - Assess characteristics
- Selection of Candidates for Evaluation Based on Characteristics
- Preliminary Screening
  - Verify response and sensitivity
  - Ensure technique is valid
  - Modify if required
  - Correlate with microsections
  - Select most promising system
- Review Results with ECOM
- Develop and Process Data for Selected System
  - Adapt to drilling machine
  - Fabricate MLB test panels
  - Obtain sensing data
  - Correlate with microsections
  - Improve if necessary
- Review Results with ECOM

Phase II

- Obtain Drills from ECOM
  - 14 types of geometry and finish
- Examine Drills Using SEM
  - Before drilling
  - After drilling
  - Catalog
- Fabricate MLB Panels
- Drill MLBs and Monitor Drill Performance
- Obtain Data
- Correlate with Microsections

Phase III

- Examine Drills with SEM
  - Some before drilling
  - Some after every 500 hits
- Monitor Drill Temperature with Van Zetti Sensor
  - No. 60 (0.040 inch) drill as standard
  - Compare results with that from 0.020, 0.030, and 0.050 inch drills
- Microsection every 500th hole and examine for epoxy smear
- Correlate smear and temperature data

SECTION 2
PHASE I – TECHNIQUE TO DETECT DRILL FAILURE

1. REVIEW AND SELECTION OF POSSIBLE SENSING TECHNIQUES

Review and consideration of several mechanical and thermal techniques for determining drill failure has resulted in the selection of two infrared (IR) measurement techniques. One employs a lens, while the other uses fiberoptics.

An in-depth review of the literature was performed in order to obtain sufficient background information on other drilling studies as well as methods of detecting drill erosion and wear. The bibliographic references are listed in Appendix A.

Reports from other drill studies (6, 7, 12, 13) indicate that good holes in MLBs can be consistently produced by using:

- The proper drill speeds and feeds to obtain an advance per revolution (chip load) of 3 mils or greater,
- The proper backup and entry material (layup geometry),
- Maximum holddown pressure, and
- Carbide drills specifically designed for printed wiring boards.

Most investigators agree that heat generated in the hole during the drilling operation is the main cause for epoxy smear and the formation of bad holes. As the number of hits increase, the cutting edges of the drill wear down gradually and the resultant duller drill produces higher temperatures due to the increased friction. The use of the techniques recommended above help to minimize the buildup of heat generated during the drilling operation and this has provided the industry with a greatly improved process. However, the time eventually arrives when the drill becomes sufficiently worn to produce bad holes in spite of high chip loads and proper layup geometry. Ideally, what is needed is a device which would monitor the drilling operation and turn the machine off when a bad drill is detected, thereby preventing the formation of any rejectable holes. For the purpose of selecting the most promising instrumentation to accomplish this task, a general review of possible sensing techniques was conducted. The general techniques considered are listed in Figure 2.

Dimensional Variation – During normal drilling operations, the cutting edges of a drill are continuously being abraded as they cut through the copper, fiberglass, and epoxy resin. As drilling continues, these peripheral edges are worn to a point where the diameter of the drill point is less than the required hole dimension. Drill failures can thus be defined when this condition occurs. An approach to dimensional monitoring of the drill point during drilling was explored with several manufacturers of "Image Change" sensing equipment. In this approach, measurement of the drill diameter at the cutting edges would be performed using a stroboscopic light source which in effect stops visible drill rotation, thus allowing measurement. Through the use of microsections, "go-no-go" conditions could be established and limits thereby set for determining when the drill becomes unacceptable. These approaches were judged to be unsatisfactory by the manufacturers of "Image Change" sensing equipment who were contacted during this evaluation. The excessive "wobble" or whipping action of the drill at high RPMs (40,000 to 80,000) would prevent any realistic measurements from being made. Therefore, this approach was not pursued further.

Mechanical Variation Detection – In this case, the object was to determine if measurable changes occur in the performance of the drill motor as the drill becomes duller, i.e., changes in the drill entry force, feedrate, and motor torque.

The drill entry force can be described as the thrust required to drive the drill through the board material. This thrust can be measured by using a

Figure 2. Techniques Investigated.

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- **Dimensional Change Measuring Techniques**
  - **Monitor change in drill diameter due to wear**
- **Mechanical Variation Sensing Techniques**
  - **Monitor change in drill motor performance (torque, drill entry force, feedrate)**
- **Thermal Sensing Techniques**
  - **Monitor temperature of drill**
  - **Monitor temperature in hole.**

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6. Kobayashi, A. and Tsukada, T., "Drilling of Multilayer Printed Circuit Board." Toshiba Review, Nov 1971.
7. Kosmowski, W. B., "Breaking the .002 Inches/Revolution Barrier to High Feed Drilling." I. P. C. Proceedings, April 1976.
12. Weng, G., "Drilling of Printed Circuits." Precision and Production Engineering, Nov 1974.
13. Williams, R. A., "A Study of the Drilling Process." Journal of Engineering for Industry. Nov 1974.

1. REVIEW AND SELECTION OF POSSIBLE SENSING TECHNIQUES (Continued)

piezoelectric load cell mounted in the feed drive linkage of the drilling machine. However, investigators have reported that the noise level caused by the pressure foot overshadowed the weak signal from the load transducer, and, therefore, could not be used to differentiate between new and worn drills.

The torque and feedrate deltas are practically nonexistent on the newer drilling machines because of the large capacity motors (3/4 to 1 HP) being used. This together with the high RPMs easily overpower any resistance during the drilling operation. Therefore, none of the mechanical variation detection techniques were used for this drill study.

Thermal Sensing Techniques – A study of various thermal sensing techniques was made in order to select the most promising sensors which could be used at various locations within the drilling operation. These locations include the drill as it exits from the hole, the copper land surrounding the holes, or the copper inner layers of the MLB being drilled. Because of the limiting confines of the drilling equipment, certain thermal sensors were judged to be impractical and unsatisfactory.

Thermocouples can be used for measuring the surface temperature on various test points on the MLB as well as for measuring the temperature of internal pads when the thermocouples are attached to interlayer pads and laminated into into place. The attachment of the thermocouples are made to test circuits located in the trim area of the MLB and would not be part of the fabricated board. This technique is satisfactory for laboratory experimentation, but impractical for use in production. It was, therefore, not considered for use in this evaluation.

Thermistors and temperature sensitive paints were also deemed suitable for laboratory use, but impractical for use in a manufacturing mode.

An infrared radiation thermometer with a close focus lens, properly mounted in an area remotely located from the drilling machine, permits viewing of the drill as it exits the hole and measures the IR energy emitted by the drill during the hole drilling operation. The output signal from the IR detector is displayed on a millivolt scale and can be recorded and converted to a temperature reading. This device, as depicted graphically in Figure 3, was adapted for use in the preliminary evaluation task.

An infrared fiberoptic thermal monitor also measures IR energy and uses fiberoptics to transmit the IR from the target to a remotely located detector. The output signal from the detector can also be displayed, recorded, and converted to temperature as in the case of the IR radiation thermometer. Figure 4 illustrates this type of device. This unit was also selected for evaluation.

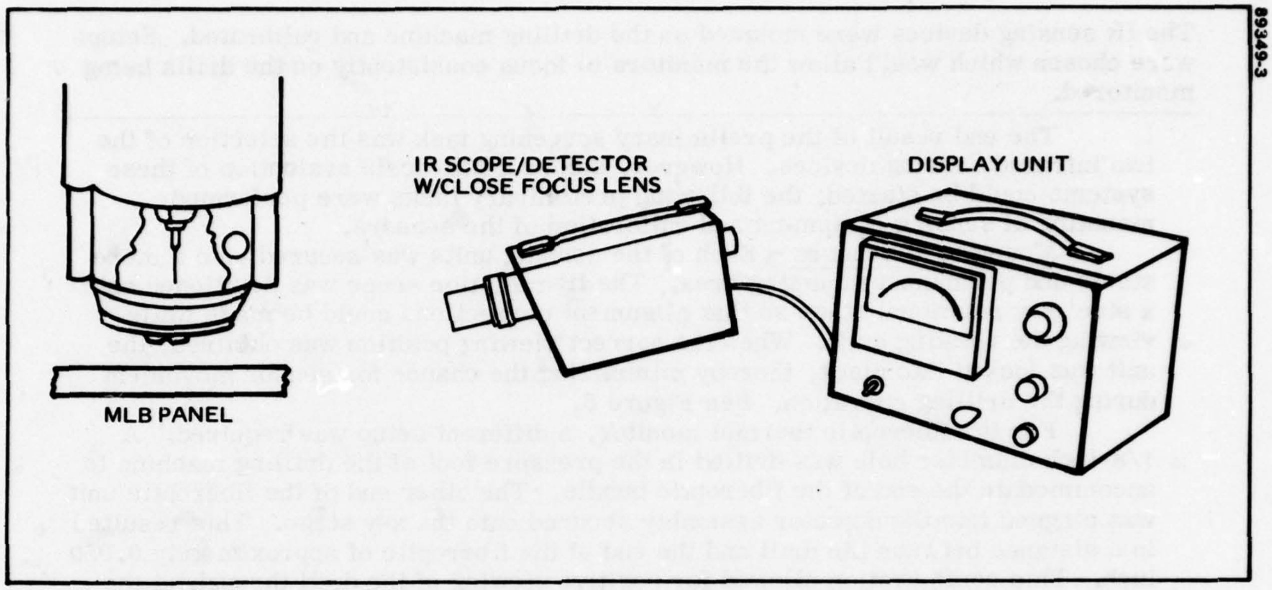

Figure 3. IR Scope System for Monitoring Drill Bit Temperature. Lens must be fixed precisely on drill exit location in order to accurately detect IR emission.

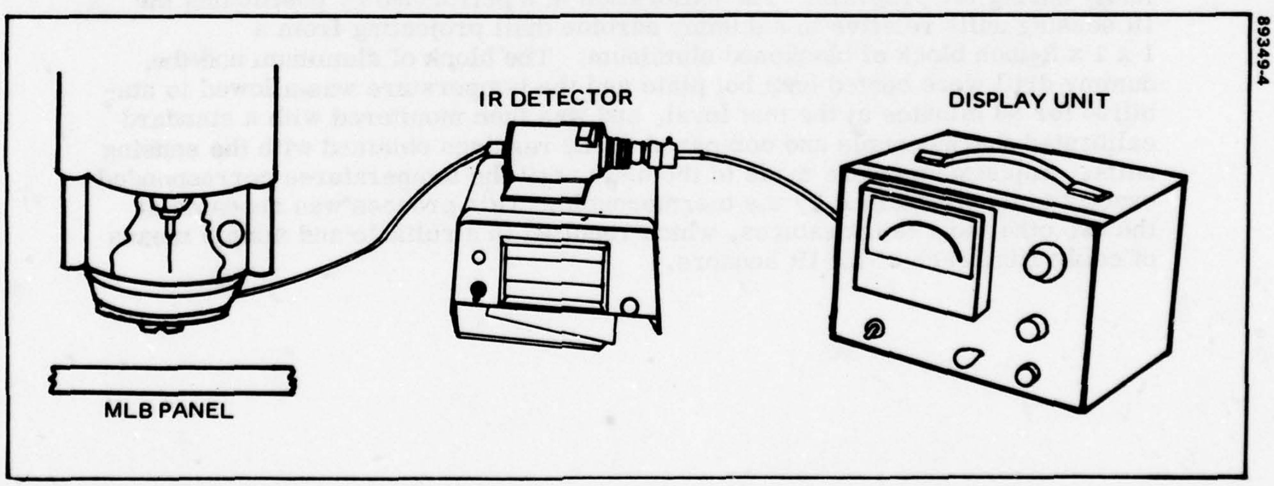

Figure 4. Fiberoptic Thermal Monitor System Used for Monitoring Drill Bit Temperature. The fiberoptic cable allows the sensing probe to be fixed in the foot of the drill, and thereby positioned accurately facing the drill head.

2. IMPLEMENTATION OF SENSING TECHNIQUES

The IR sensing devices were mounted on the drilling machine and calibrated. Setups were chosen which would allow the monitors to focus consistently on the drills being monitored.

The end result of the preliminary screening task was the selection of the two infrared sensing devices. However, before a full-scale evaluation of these systems could be started, the following preliminary tasks were performed: mounting of sensing equipment and calibration of the sensors.

Mounting of Sensors – Each of the sensing units was secured onto a more stable and permanent mounting area. The IR radiation scope was positioned onto a steel x-y rotational stage so that alignment corrections could be made while viewing the rotating drill. When the correct viewing position was obtained, the unit was locked into place, thereby minimizing the chance for sensor movement during the drilling operation. See Figure 5.

For the fiberoptic thermal monitor, a different setup was required. A 1/8-inch diameter hole was drilled in the pressure foot of the drilling machine to accommodate the end of the fiberoptic bundle. The other end of the fiberoptic unit was plugged into the detector assembly secured onto the x-y stage. This resulted in a distance between the drill and the end of the fiberoptic of approximately 0.050 inch. This configuration allowed for positive viewing of the drill throughout the drilling cycle. See Figure 6.

Calibration – Each of the IR sensing units was initially calibrated at three different temperatures (200°, 300°, and 500°F) and recalibrated periodically during the program. The calibration was performed by positioning the IR sensing units relative to a dummy carbide drill projecting from a 1 x 1 x 3-inch block of blackened aluminum. The block of aluminum and the dummy drill were heated on a hot plate and the temperature was allowed to stabilize for 30 minutes at the test level, and was then monitored with a standard calibrated thermocouple and compared to the readings obtained with the sensing units. Adjustments were made to the units until the temperatures corresponded exactly to those obtained by the thermocouple. This process was repeated at the two other test temperatures, which resulted in a reliable and simple means of calibrating each of the IR sensors.

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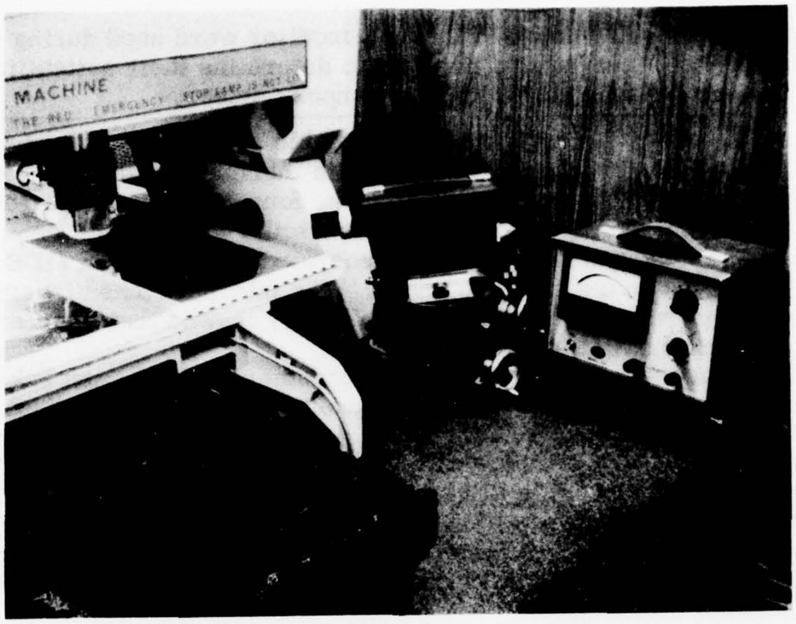

Figure 5. Infrared Radiation Scope. Alignment of the camera towards the drill bit must be accurately maintained. An x-y rotational stage was employed for this purpose.

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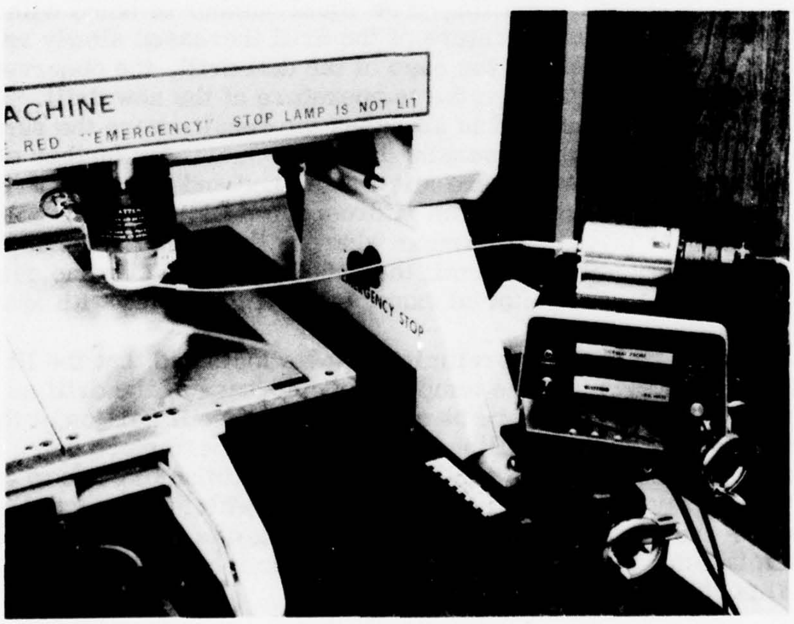

Figure 6. Fiberoptic Thermal Monitor. The flexible fiberoptic cable allows direct attachment to the pressure foot of the drill.

3. PRELIMINARY EVALUATION OF SELECTED TEMPERATURE SENSING TECHNIQUES

An IR radiation scope and fiberoptic thermal monitor were used during the trial drilling of a 4200-hole test pattern in order to determine their suitability for use in detecting drill temperature and relating it to epoxy smear.

As a result of the review of the available sensors, the two infrared sensing devices (IR radiation scope and the fiberoptic thermal monitor) were selected for further evaluation. To accomplish this task, four-layer MLBs were fabricated using material conforming to the appropriate military specifications. A special test drill tape and artwork pattern was generated to provide an MLB with approximately 2200 holes on a 9 x 9-inch board. The internal etched layers consisted of isolated pad patterns since previous studies (11) showed that isolated pads in MLBs get hotter during the drilling operation.

The etched details were laminated together and then post baked at 350°F for 3 hours in order to ensure complete cure of the resin and reduce variability between the laminated boards.

An N.C. drilling machine with three spindles was used for all the drilling operations in this study. A drill size of 0.040 inch diameter and a drill speed of 50,000 RPM was standardized by ECOM, and therefore no other drill size or drill speed was used for Phase I of this study. A drill feed of 200 inches per minute (IPM) was chosen for the feedrate resulting in a chip load of approximately 4 mils per revolution.

The IR radiation scope was evaluated first. It was mounted onto a tripod and positioned approximately seventeen inches from the drill chuck (17 inches is the focal distance for this device). A sighting slot had been machined into the metal pressure foot of the drilling machine providing a direct line of sight between the scope and the drill.

The unit was evaluated by drilling 4200 holes in two MLBs using a new carbide drill followed by the drilling of an equal number of holes with a worn out drill. In both cases, the temperature of the drill increased slowly as the number of hits increased. However, in the case of the dull drill, the observed temperature was considerably higher than the temperature of the new drill. These tests were repeated several times and in all cases the results were the same indicating that this method of temperature sensing had some merit for further evaluation.

The drilled test boards were microsectioned and every 500th hole was examined using the Scanning Electron Microscope (SEM). All the holes produced with the bad drill exhibited epoxy smear whereas the holes produced with the new drill did not exhibit epoxy smear until the 1500th hole and in some cases, the 2000th hole. Figure 7 is a pictorial example of typical holes with epoxy smear on the internal copper pads.

The results from these preliminary tests indicated that the IR radiation scope could be used to detect the temperature increase of the drill as it exited from the hole and would therefore be used in the Phase II portion of this study.

The above described drilling tests were also performed using the fiberoptic thermal monitors, but the results were not satisfactory due to the slow response of the display unit. However, it did show sufficient potential, and conversations with the vendor resulted in the ordering of a redesigned model of the detector-display unit as well as a newer fiberoptic lens system for use during the Phase II portion of the study.

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11. Weiss, R.E., "The Effect of Drilling Temperature on Multilayer Board Hole Quality." Precision and Production Engineering, Nov. 1974.

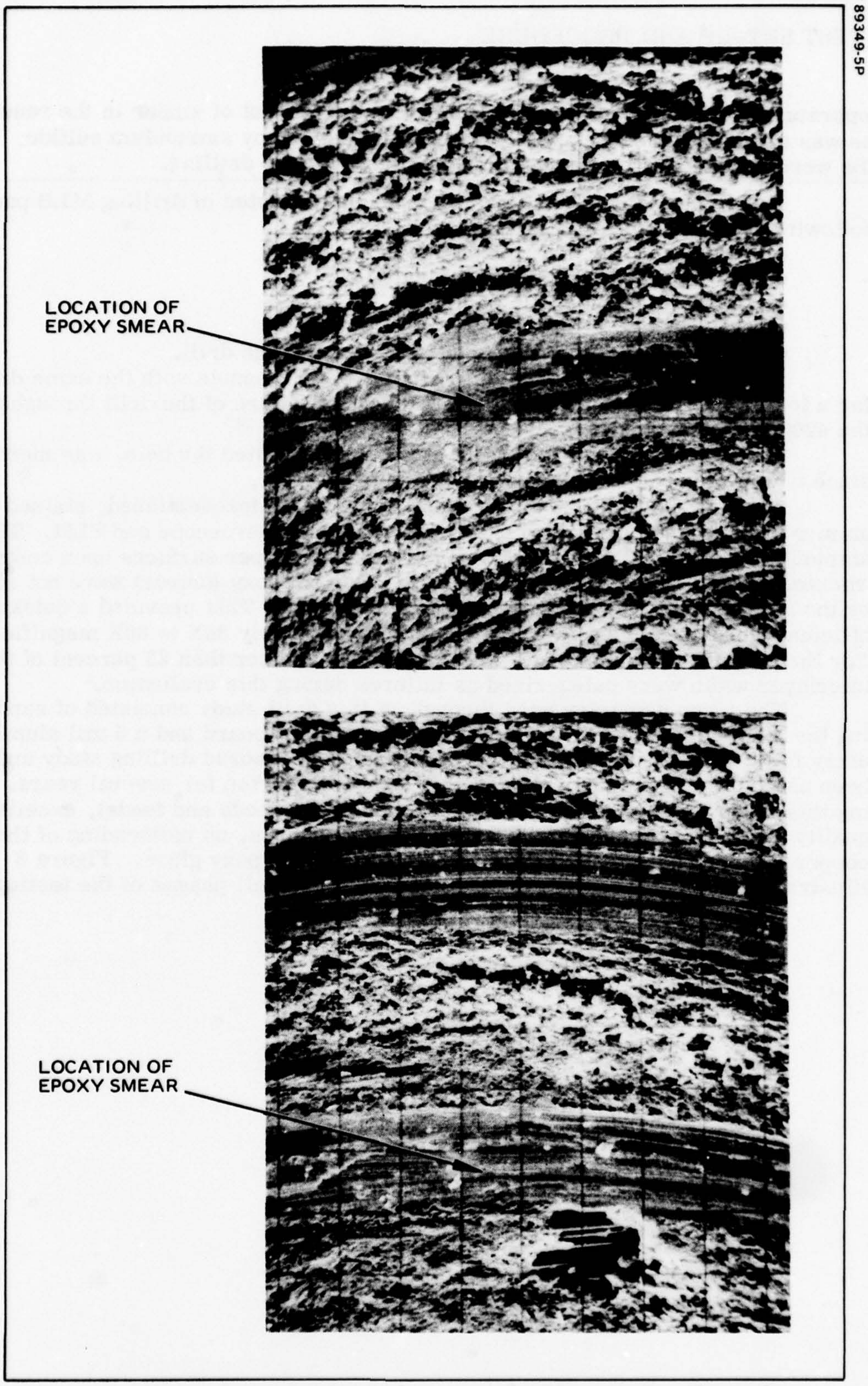


Figure 7. Epoxy Smear on Internal Layers of MLB – 300X. These photos depict inner layers that are heavily smeared.

4. TEST SET-UP AND PROCEDURE

Temperature of the drill tip was monitored and the amount of smear in the resultant holes was examined microscopically after being stained by ammonium sulfide. The MLBs were sandwiched between aluminum sheets for the drilling.

The evaluation of the IR radiation scope consisted of drilling MLB panels following the procedure outlined below.

- Layup MLB on drill machine.
- Position IR sensor to monitor drill.
- Drill at 50,000 RPM, 200 IPM.
- Observe and record temperature of drill.
- Repeat procedure on second MLB using same drill.

Each sequence consisted of drilling two MLB panels with the same drill for a total of 4200 holes and monitoring the temperature of the drill throughout the 4200 hits.

The temperature of the drill, at the time it exited the hole, was monitored since it was the peak temperature that was of interest.

At every 500th hit, a group of six holes was microsectioned, stained with ammonium sulfide solution and examined using the microscope and SEM. The ammonium sulfide solution blackened the exposed copper surfaces upon contact whereas copper areas covered with a thin layer of epoxy (smear) were not affected by the sulfide solution and remained copper colored. This provided a quick and efficient technique for epoxy smear detection using only 30X to 60X magnification. For the purpose of consistency, areas of smear greater than 25 percent of the interlayer width were categorized as failures during this evaluation.

The layup geometry used throughout this drill study consisted of sandwiching the MLB panel between an aluminum clad backup board and a 5 mil aluminum entry foil. This layup is the result of a Hughes-sponsored drilling study and has been used in the manufacturing area of Hughes-Fullerton for several years. Using this layup (in conjunction with the proper drill speeds and feeds), excellent quality holes were obtained with no exit or entry burrs, no nailheading of the copper interlayers, and no excessive gouging of the epoxy glass. Figure 8 illustrates the layup of the drilling operation used in all phases of the testing.

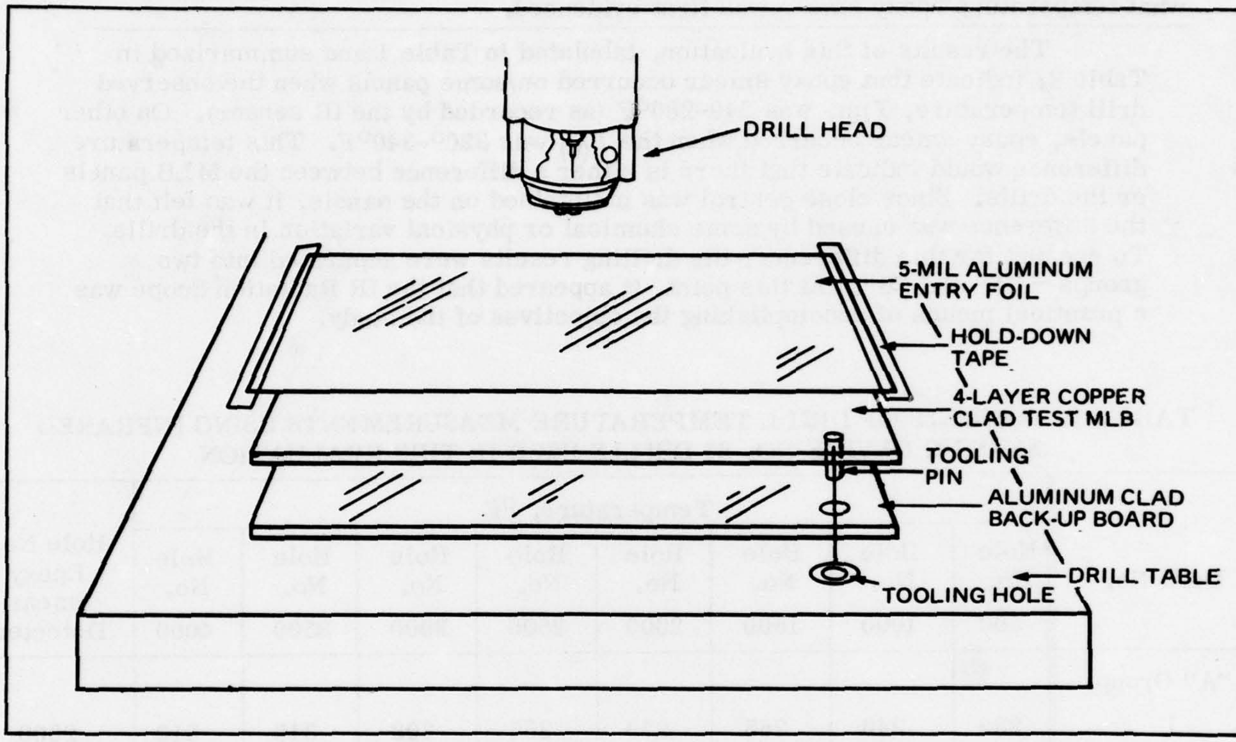


Figure 8. Drill Lay-Up (Exploded View). This lay-up was used for all phases of the investigation.

5. TEST RESULTS

Drill temperature was monitored for 4200 hits for various drills. This showed an increase in temperature occurred as more holes were drilled, as well as showing what temperature epoxy smear was first evidenced.

The results of this evaluation, tabulated in Table 1 and summarized in Table 2, indicate that epoxy smear occurred on some panels when the observed drill temperature, $T_{(0)}$, was 240-280°F (as recorded by the IR sensor). On other panels, epoxy smear occurred when the $T_{(0)}$ was 320°-340°F. This temperature difference would indicate that there is either a difference between the MLB panels or the drills. Since close control was maintained on the panels, it was felt that the difference was caused by some chemical or physical variation in the drills. To account for this difference, the drilling results were separated into two groups – "A" and "B". At this point, it appeared that the IR Radiation Scope was a practical means of accomplishing the objectives of the study.

TABLE 1. RESULTS OF DRILL TEMPERATURE MEASUREMENTS USING INFRARED SENSING DEVICE NO. 60 DRILLS USED IN THIS EVALUATION

Drill No.	Temperature, °F								Hole No. Epoxy Smear Detected
	Hole No. 500	Hole No. 1000	Hole No. 1500	Hole No. 2000	Hole No. 2500	Hole No. 3000	Hole No. 3500	Hole No. 4000	
"A" Group:									
1	230	240	265	270	285	300	310	310	2000
3	220	220	230	240	255	265	265	270	2000
4	225	240	240	265	270	275	300	300	2000
5	230	250	270	290	295	310	320	320	1500
6	220	240	260	280	300	310	310	320	2000
7	230	245	270	280	290	295	300	310	1500
8	230	240	250	260	275	295	300	310	2000
14	225	245	260	270	290	300	320	325	2000
15	230	245	270	280	290	300	310	310	1500
16	210	250	260	270	280	290	300	300	2000
17	220	250	270	280	290	300	305	305	1500
18	265	275	290	300	305	305	310	315	1000
20(0)	265	270	280	290	300	310	310	315	1500
20E3	230	250	265	270	280	300	305	310	1500

TABLE 1. RESULTS OF DRILL TEMPERATURE MEASUREMENTS USING INFRARED SENSING DEVICE NO. 60 DRILLS USED IN THIS EVALUATION (Continued)

Drill No.	Temperature, °F								
	Hole No. 500	Hole No. 1000	Hole No. 1500	Hole No. 2000	Hole No. 2500	Hole No. 3000	Hole No. 3500	Hole No. 4000	Hole No. Epoxy Smear Detected
"B" Group:									
10	310	340	370	380	385	390	400	400	1000
12	300	330	340	350	390	400	405	410	1000
13	320	335	345	365	385	390	400	400	1000
20E1	300	325	330	340	345	350	350	355	1500
20E2	270	300	320	330	335	340	345	345	1500
20E4	300	330	340	350	370	380	400	410	1000

TABLE 2. SUMMARY OF PHASE I DRILL TEMPERATURE EVALUATIONS

No. of Drills Evaluated	Bad Hole/Smear Failures	Temp Of Drill At Failure	No. Of MLBs Drilled	Total No. Of Holes
14 each Group A	None at 500th hole 1 at 1000th hole 6 at 1500th hole 7 at 2000th hole	1 at 240°F 1 at 260°F 2 at 265°F 7 at 270°F 1 at 275°F 2 at 280°F	28	62,000
6 each Group B	None at 500th hole 4 at 1000th hole 2 at 1500th hole	1 at 320°F 3 at 330°F 1 at 335°F 1 at 340°F	12	26,000

5. TEST RESULTS (Continued)

The observed temperature of the drill increased steadily in proportion to the number of holes drilled as shown graphically in Figure 9. Various temperatures are shown for each 500-hole group shown. This represents the entire range of temperatures recorded in the vicinity of the hole group. This data was preliminary to the data generated in phase 3, in which the temperatures recorded were correlated with a numerical smear value.

The presence of epoxy smear on the interlayers of the MLB holes was the main defect found in this evaluation. Figure 10 depicts hole No. 20, 1000, 2000, and 3000 of a typical MLB panel evaluated in this task with clear indications of epoxy smear on holes 2000 and 3000, as shown by the large areas of unstained copper in these photos. The surrounding dark areas are where the unsmeared exposed copper has been stained by the ammonium sulfide solution.

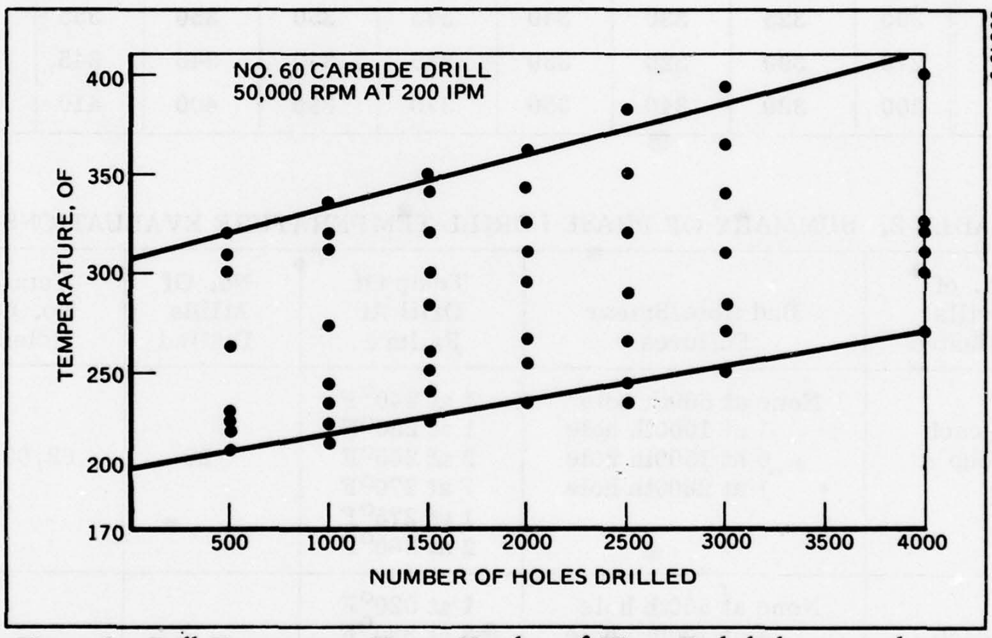
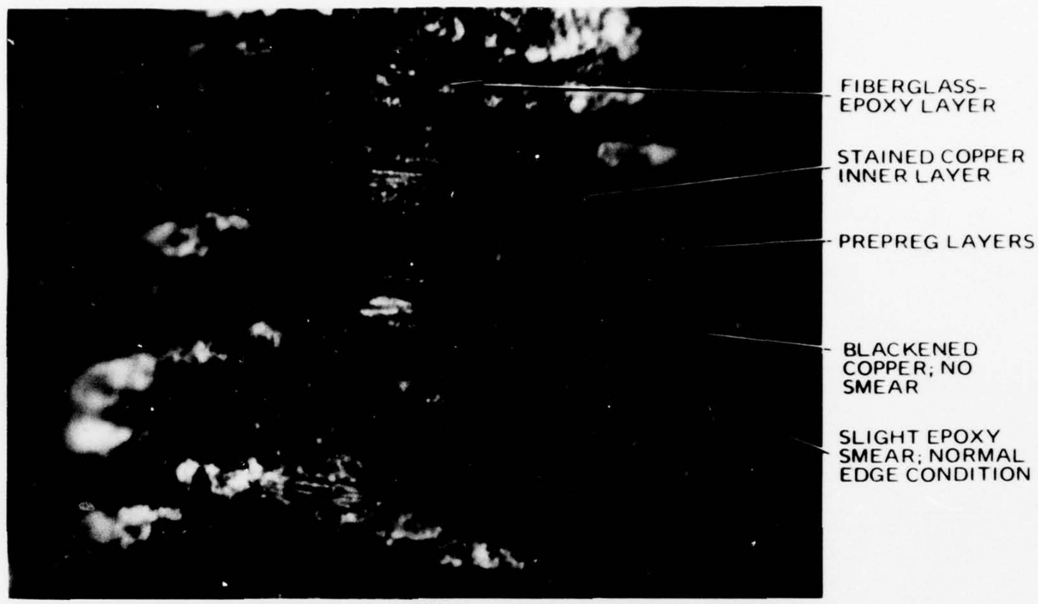
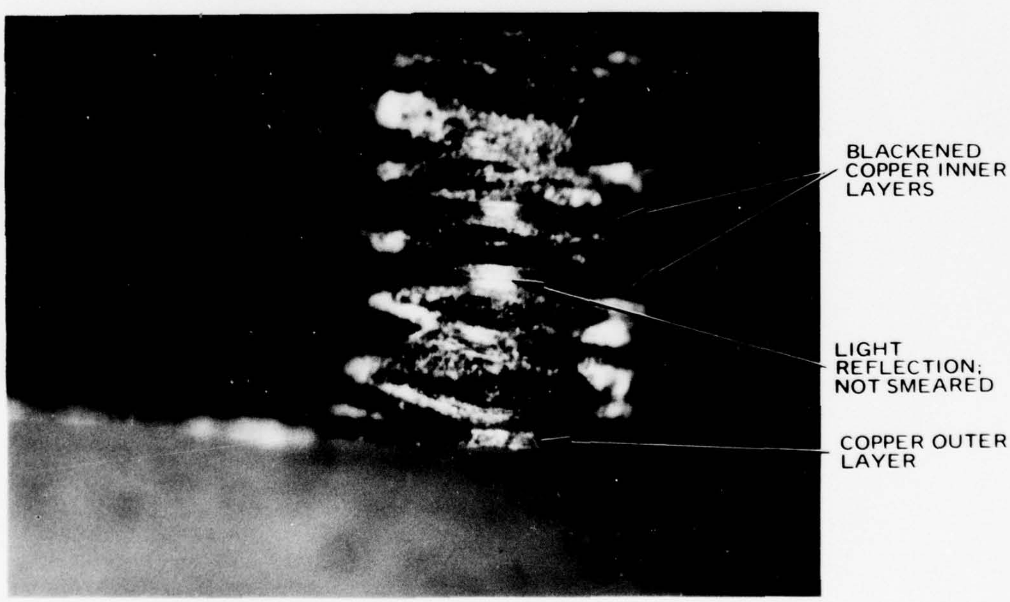


Figure 9. Drill Temperature Versus Number of Hits. Each hole group shows the entire range of temperatures recorded in the vicinity of that hole group.

89349-60



100X



50X

Figure 10A. Cross-Section of Drilled Hole No. 20 Processed Through the Copper Staining Solution. Cross-section shows little evidence of smear on drilled hole.

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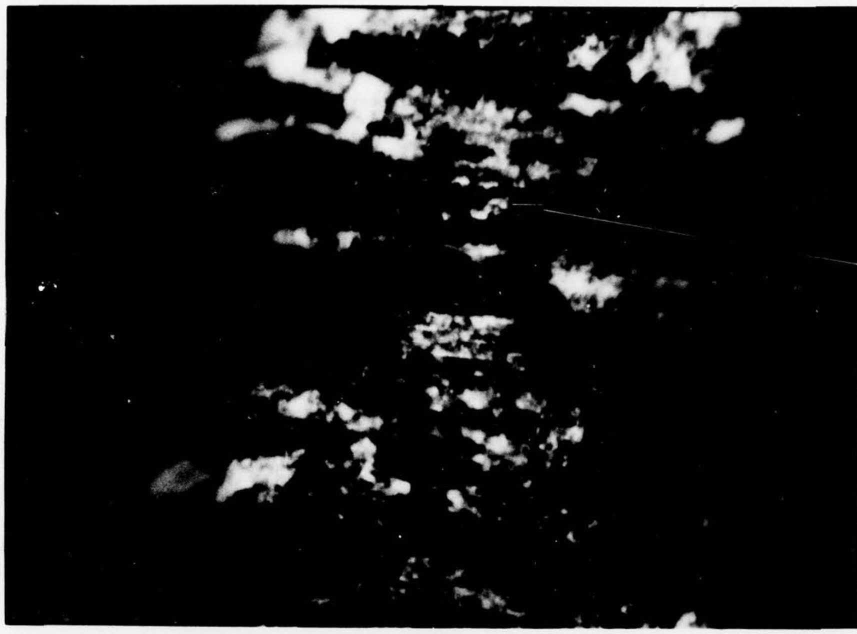

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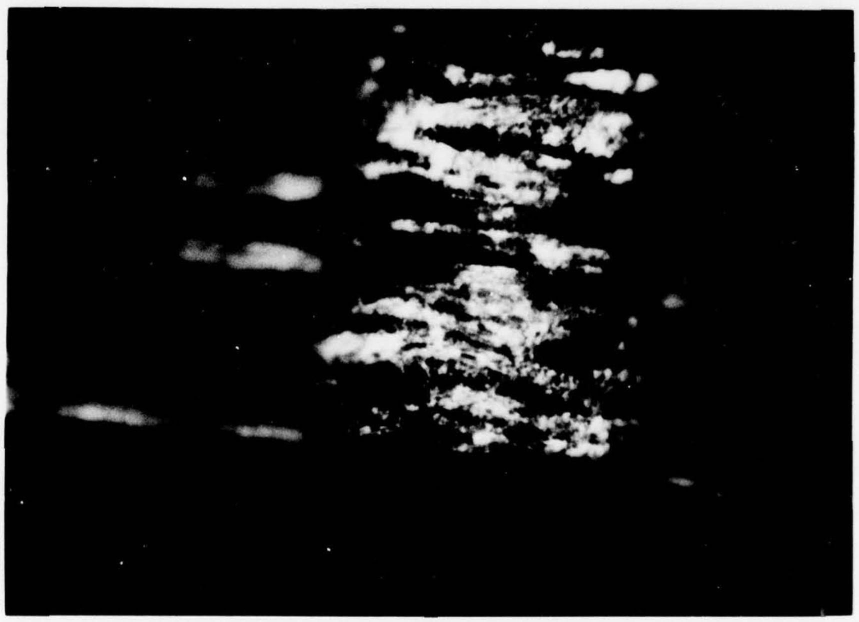

50X

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Figure 10B. Cross-Section of Drilled Hole No. 1000 Processed Through Copper Staining Solution. Greater evidence of smearing is shown than on Hole No. 20.

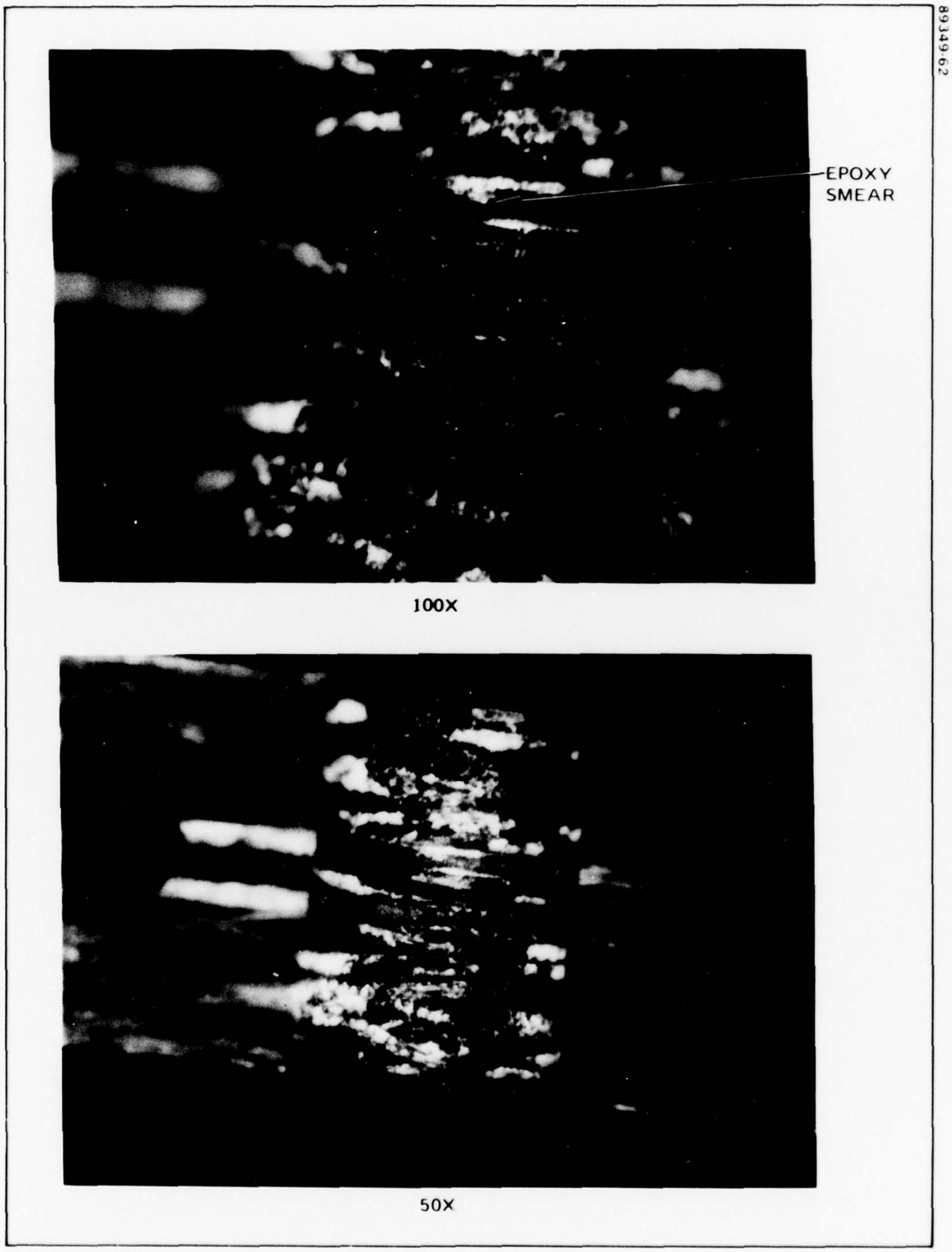


Figure 10C. Cross-Section of Drilled Hole No. 2000 Processed Through Copper Staining Solution. Epoxy smear has caused large areas of exposed copper in this sample.

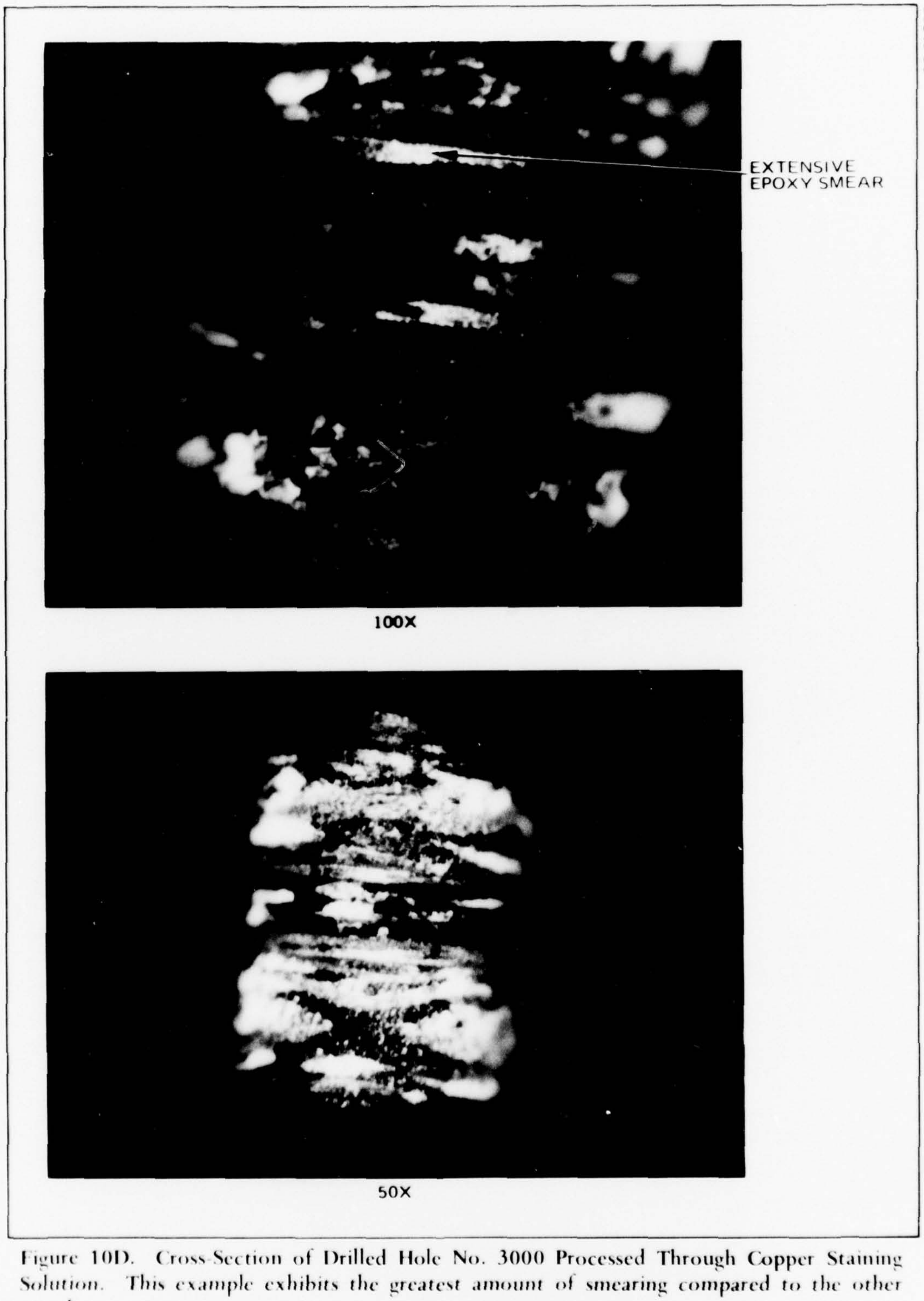


Figure 10D. Cross-Section of Drilled Hole No. 3000 Processed Through Copper Staining Solution. *This example exhibits the greatest amount of smearing compared to the other samples.*

SECTION 3
PHASE II – DRILL EVALUATION

Section 3 – Phase II – Drill Evaluation

1. SCOPE OF PHASE II

The task in Phase II was to determine the quality of holes produced with drills having various finishes and point geometries. In addition, the suitability of IR temperature measurement for drill failure detection was investigated.

A listing of drills supplied by ECOM, and tested by Hughes, is given in Table 3. These include drills with different finish grades, such as standard, fine, and microfinish. They also include some drills with a microlube coating (vacuum deposited with a dry lubricant), and drills with various point geometries. In addition to evaluation of these drills, the purpose of this phase was to determine possible trends for improvement of the drill finish and/or geometry for manufacturing use and to establish a baseline for possible future investigations.

This phase would also provide additional data for determining the validity of the IR technique of drill failure detection. The chart in Figure 11 was used as a guideline for the Phase II evaluation.

The fourteen types of ECOM-supplied drills were examined before drilling using the SEM. Photographs were made of the cutting surfaces, and the resultant information was cataloged for use during this effort. One set of photographs of each of the fourteen drill types is contained in Appendix B of this report.

When the drills were properly cataloged, the drilling evaluation commenced. Each of the candidate drills was used to produce 4200 holes in the MLB panels following the procedures outlined in Topic 2-4. The IR radiation scope was used to monitor the drill temperatures during the first half of the Phase II task, and the fiberoptic thermal monitor was used during the second half of the task in order to duplicate the results obtained with the first unit.

After the drilling operation, the drills were again examined using the SEM. Photographs of the drills in the "after drill" condition also appear in Appendix B. These were typical of drills evaluated in this task.

Every 500th hole was microsectioned, stained with the sulfide solution and examined for epoxy smear as described earlier in this report.

TABLE 3. ECOM-SUPPLIED DRILLS FOR PHASE II EVALUATION

No. 60 Carbide Drills for Phase II Evaluation

1. **Standard Carbide**
2. **Fine Grade Carbide**
3. **Micro Grade Carbide**
4. **Standard with Microlube**
5. **Fine Grade with Microlube**
6. **Micro Grade with Microlube**
7. **118° Point, 12° Relief**
8. **118° Point, 15° Relief – Micro Grade**
9. **118° Point, 20° Relief – Micro Grade**
10. **140° Point, 12° Relief – Micro Grade**
11. **140° Point, 15° Relief – Micro Grade**
12. **140° Point, 20° Relief – Micro Grade**
13. **130° Point, 12° Relief – Micro Grade**
14. **130° Point, 20° Relief – Micro Grade**

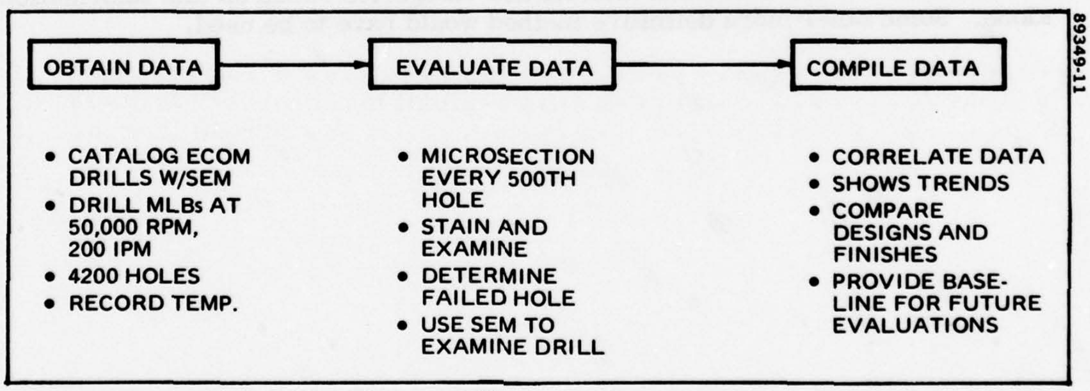


Figure 11. Guidelines for Phase II Effort. Used to determine validity of IR sensing technique to detect drill wear.

2. PHYSICAL EXAMINATION OF DRILLS

Epoxy build-up and drill wear occurred on drills as observed by SEM comparison of new drills with those after 4200 hits. Little difference could be detected between new standard finish and micro finish drills by SEM analysis or hardness determinations.

As outlined in the previous topic, the SEM was used to catalog the cutting surfaces of the drills before and after drilling the 4200-hole test pattern. A typical example of this is shown in Figure 12 for a standard carbide drill before and after drilling 4200 holes in a test board. Additional photos can be found in Appendix B. These SEM photos revealed a buildup of epoxy-like material on the cutting surfaces, as well as a breakdown or chipping away of these surfaces. This would be expected to partially account for the temperature rise of the drill as it drills the later holes in the test board.

It was also discovered from the SEM examination of the drills that it was very difficult to discern any difference between the standard and the micrograde drills in the new condition. Compare the SEM photo in Figures 12 and 13 for an example of this.

In addition, hardness measurements were taken of the micrograde and standard drills in an attempt to find a difference between the two types of drills. This was done in response to the drill manufacturers' claim that the micrograde drills had a greater hardness than the standard drills. However, the readings of each drill type were in the same range with some overlapping in hardness values. This method was therefore ruled out as a possible method of differentiating between the two types of drills.

Based on the above results, it would be very difficult to precatalog a batch of new drills into standard and microfinish categories based on this information alone. Some other more definitive method would have to be used.

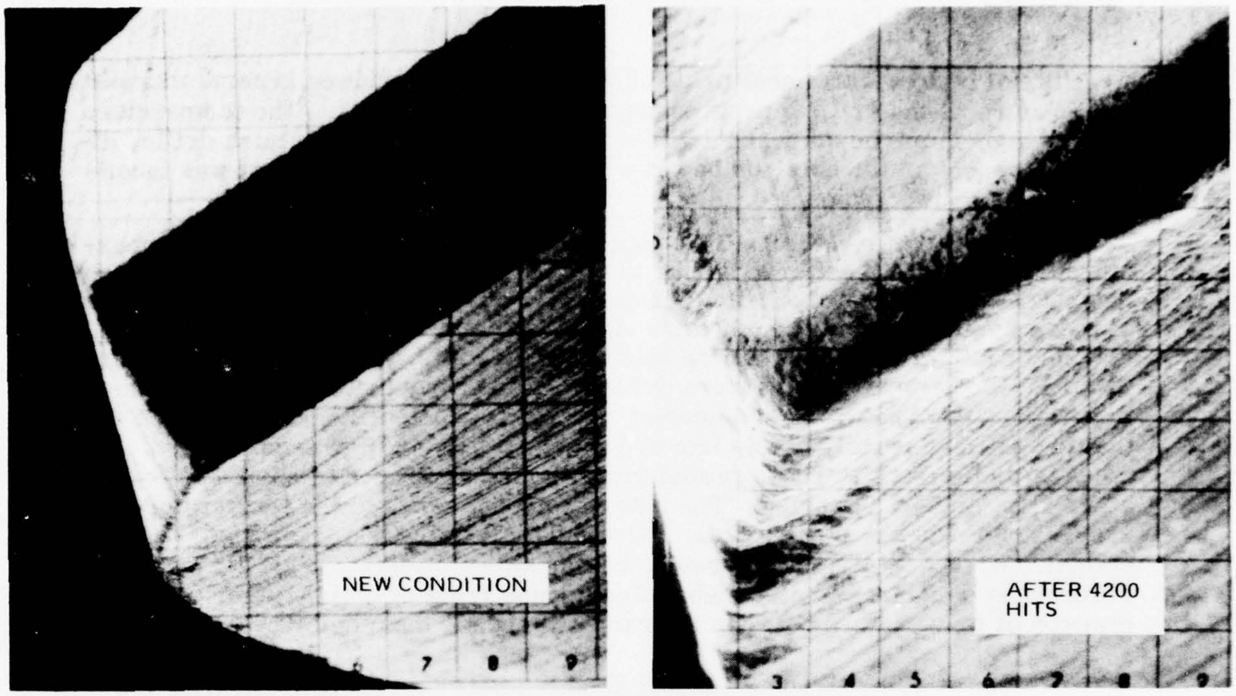


Figure 12. Standard Carbide Drill – 700X Magnification. Note degradation of the cutting edge after 4200 hits.

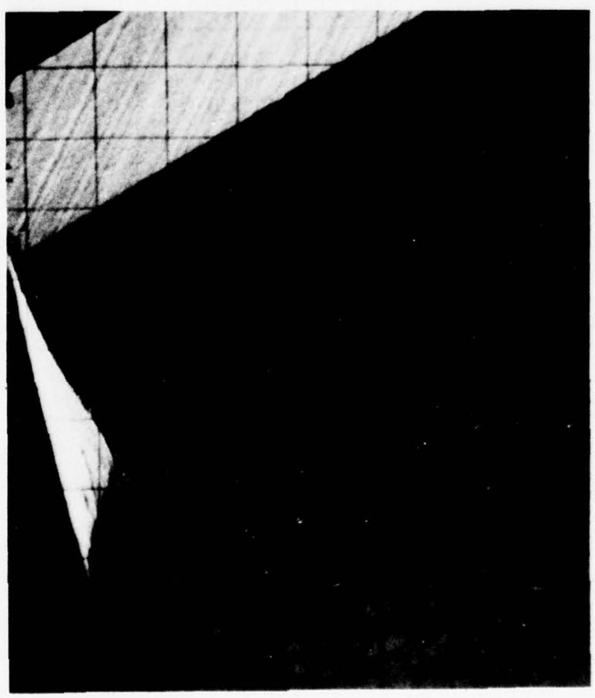


Figure 13. Micro Grade Carbide Drill – New Condition. Little difference is seen between this drill and the standard drill above.

3. THERMAL RESULTS

The results of temperature monitoring of the drills tested showed general increases in temperature as the drilling progressed for all types of drills. The temperature range was higher for the standard drills as compared to the microfinish drills, although differences in the hole number at which smear first was evident was inconclusive for these two groups.

In conjunction with the SEM photographs taken of the drills, the temperatures of each was monitored during the drilling operation and recorded. Table 4 summarizes the results. Table 5 shows the breakdown of each drill run in terms of the temperature at every 500 hits. Duplicate samples were run for each drill type and configuration. As can be seen from the table, the temperature of each run increased as more holes were drilled. Also shown in Table 5 are results showing at what temperature hole smearing was first detected. Again, it can be seen that the drills generally divide into two groups with regard to temperature. Two types of drills (both standard grade) produced temperatures of about 330 to 335°F at the first sign of smearing. The other group had much lower temperatures (about 230 to 250°F when this occurred. For almost all of the boards drilled, the first detection of smear occurred between the 1500th and 2500th holes. No significant differences could be detected among the various types of drills, other than the division of temperature between the standard and all the other types of drills.

TABLE 4. SUMMARY OF PHASE II DRILL TEMPERATURE EVALUATION

Drill Type	1st Detection of Smear-Hole No.		Temp of Drill When Bad Hole was Produced – °F	
	Run #1	Run #2	Run #1	Run #2
Standard Grade Carbide	1500	2000	330	330
Std W/Microlube	1500	1500	330	335
Fine Grade Carbide	1500	1500	230	230
Fine W/Microlube	1500	1500	235	230
Micro Grade Carbide	2000	1500	230	235
Micro W/Microlube	2000	1500	230	230
118° Point – 12° Relief	2000	2000	235	240
118° Point – 15° Relief	1500	2500	230	270
118° Point – 20° Relief	2500	2000	230	240
130° Point – 12° Point	1000	2000	230	235
130° Point – 20° Relief	4000	1500	210	240
140° Point – 12° Relief	2000	2500	230	250
140° Point – 15° Relief	2500	1500	235	230
140° Point – 20° Relief	1500	2000	230	230

TABLE 5. RESULTS OF DRILL TEMPERATURE (°F) MEASUREMENTS (ECOM DRILLS)

Drill No.		Temperature - °F								Hole No. Epoxy Smear Detected
		Hole No. 500	Hole No. 1000	Hole No. 1500	Hole No. 2000	Hole No. 2500	Hole No. 3000	Hole No. 3500	Hole No. 4000	
Standard	-E1	300	325	330	340	345	345	350	350	1500
Standard	-E2	270	290	315	330	335	340	340	345	2000
Std. W/Microlube	-L1	265	300	330	340	350	350	355	355	1500
Std. W/Microlube	-L2	270	310	335	340	345	345	350	350	1500
Fine Grade	-A1	210	220	230	230	240	245	250	250	1500
Fine Grade	-A2	200	210	230	240	245	250	250	255	1500
Fine W/Microlube	-D1	210	225	235	250	255	260	260	260	1500
Fine W/Microlube	-D2	220	225	230	240	250	260	270	270	1500
Micro Grade	-J1	200	210	220	230	240	245	250	250	2000
Micro Grade	-J2	200	220	230	240	250	250	260	260	1500
Micro W/Lube	-B1	200	210	220	230	240	245	245	245	2000
Micro W/Lube	-B2	210	220	230	240	250	250	255	255	1500
118° Point										
12° Relief	-F1	210	220	230	235	245	250	250	255	2000
12° Relief	-F2	205	210	230	240	250	260	265	270	2000
118° Point										
15° Relief	-M1	210	220	230	235	240	250	250	255	1500
15° Relief	-M2	220	230	235	250	270	290	300	300	2500
118° Point										
20° Relief	-C1	200	200	210	215	230	230	240	240	2500
20° Relief	-C2	205	210	230	240	240	250	255	265	2000
140° Point										
12° Relief	-N1	210	210	220	230	230	240	250	250	2000
12° Relief	-N2	210	220	230	240	250	260	270	270	2500
140° Point										
15° Relief	-H1	200	210	220	225	235	235	240	240	2500
15° Relief	-H2	210	220	230	250	270	275	280	285	1500
140° Point										
20° Relief	-G1	210	210	220	230	240	240	250	255	2000
20° Relief	-G2	200	210	220	230	230	240	240	250	2000
130° Point										
20° Relief	-11	190	200	200	200	210	210	210	210	4000
20° Relief	-12	210	220	240	260	270	280	300	310	1500
130° Point										
12° Relief	-K1	200	230	230	240	255	260	260	265	1000
12° Relief	-K2	200	210	200	235	260	280	290	295	2000

SECTION 4
PHASE III – ADDITIONAL DRILL EVALUATION AND SMEAR CORRELATION

Section 4 – Phase III – Additional Drill Evaluation and Smear Correlation

1. OBJECTIVES AND METHODOLOGY FOR SMEAR EVALUATION

The main objective was to monitor the temperature during drilling of a series of various sized drills at two drill speeds, and analyze the holes with a SEM. A method was created to quantitatively express the amount of epoxy smear observed on the samples.

Objectives – The objective of Phase III was to expand the epoxy smear versus drill temperature correlation as performed in Phase II by using four drill sizes at two different drill speeds. The drill sizes chosen for evaluation were 0.020, 0.030, 0.040 and 0.050 inches in diameter. Each drill size was to be monitored at speeds of 50,000 and 80,000 RPM at a feed rate of 200 IPM. Micro-finish drills were to be used for this phase of the drill study. In addition, some standard finish drills were scheduled to be monitored under the same conditions for comparison purposes.

Some of the drills were to be randomly selected for SEM analysis after every 500 holes were drilled. The results of these evaluations are discussed in the following topics.

Methodology – A method was devised for assigning a numerical value to the amount of smear observed. This allowed a more quantitative analysis to be made for correlating the amount of smear to the observed temperature. Six consecutively drilled holes are examined for each smear determination. Each is rated 0 points (no smear), 1 point (greater than 0 but less than 25% smear), or 4 points (greater than 25% and up to 100% smear). The point values are added up for each hole and the combined value is used for plotting graphs of smear value versus temperature. Thus, the smear value for any particular determination can be from zero (no smear) to 24 points (all 6 holes greater than 25% smear). A hypothetical example is given in Figure 14. This figure represents the results of a board drilled with a test pattern of 3510 holes. The six holes nearest every 500th holes are sectioned, stained and examined for smear. Note that six digits are listed under each hole group. On hole group 1000, for example, 001001 means that holes numer 998, 999, 1001, and 1002 showed no smear, while holes 1000 and 1003 showed greater than zero and less than 25% smear. Therefore, the smear value for the hole group 1000 would be 0+0+1+0+0+1 = 2. For the example shown, the smear factors in order of their hole group would be 0, 0, 2, 3, 6, 8, 10, and 15, corresponding to hole group number 1, 500, 1000, 1500, 2000, 2500, 3000, and 3500, consecutively.

Figure 15 shows a representative test panel from which every 500th hole group was punched for epoxy smear analysis by the above method. Each hole group is marked and kept in order.

89349-14

HOLE GROUP NUMBER	1	500	1000	1500	2000	2500	3000	3500
SMEAR EVALUATION	000000	000000	001001	001101	104001	040040	044011	144141

Figure 14. Smear Observations for a Hypothetical Test Board. Typical smear factor increases as the hole group number increases

89349-15P

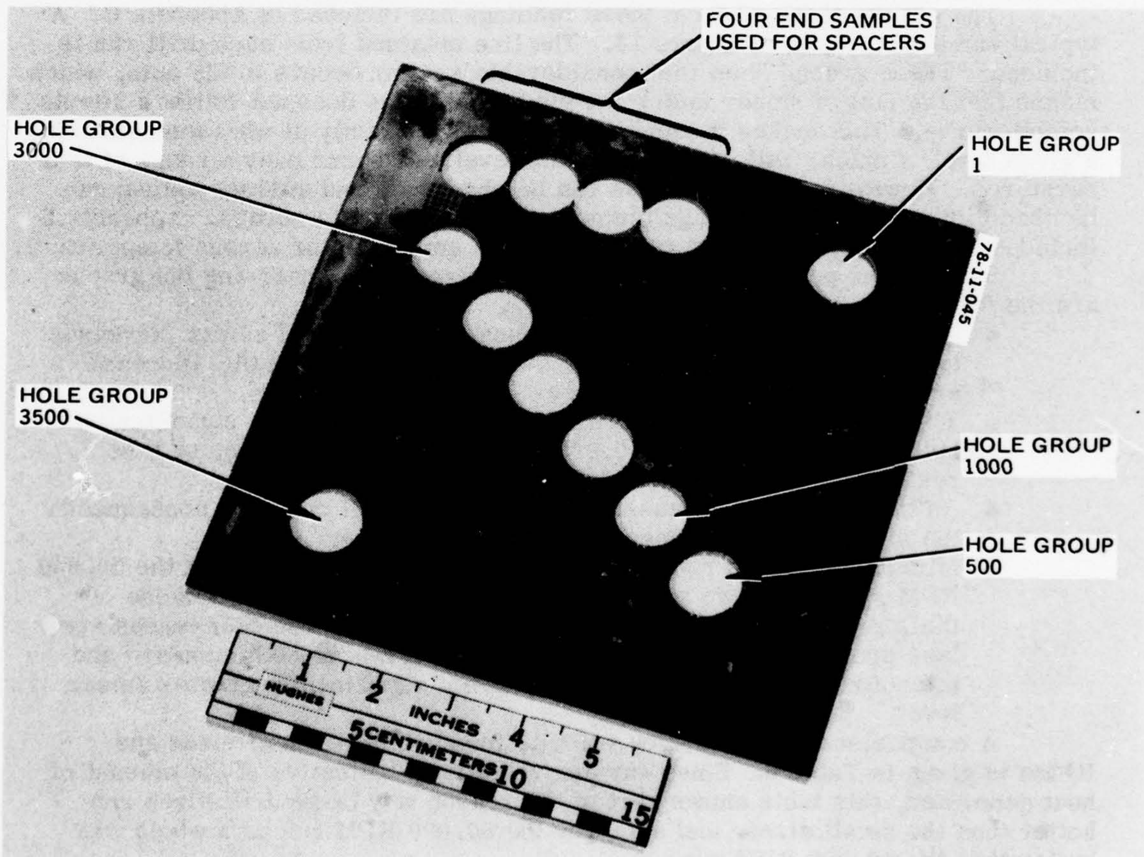


Figure 15. Typical Test Board After Sampling. Every 500 holes, starting with the first holes, a round sample is punched from the panel for analysis.

2. TEMPERATURE MEASUREMENTS AND SMEAR/TEMPERATURE CORRELATIONS

Graphs of the amount of epoxy smear versus temperature show differences between the drills run at 50,000 RPM and those at 80,000 RPM, and also differences in quality between standard drills and the superior microfinish drills.

The temperature measurements were taken for standard and microfinish drills of sizes #68, #60, #56, and #55 with the Van Zetti temperature monitor and the fiber optic probe attachment. Readings were monitored continuously and the average was recorded every 250 holes.

Originally it was planned to test #76, #68, #60, and #55 drills. However, it was found that the 200 IPM feed rate was excessive for the #76 drill, which has a diameter of only 0.020 inches. Attempts to drill with this size drill resulted in breakage of the bit after only a few holes. Therefore, it was decided to substitute a #56 drill in its place. It has a diameter of 0.0465 inch, a size which is about halfway between the #60 and #56 drills. It was also chosen because, being a larger size, it was expected that more smear would result.

The graphs obtained from these readings are included in Appendix C. A typical sample is shown in Figure 16. The line obtained from each drill run is included. These graphs show that considerable scatter occurs in the data, which means that the plot of smear factor versus temperature does not follow a simple smooth curve. This makes it impossible to predict exactly at what temperature a given level of smear will occur since this level will occur over a range of temperatures. However, general trends can be observed, and average values can be used to determine the average temperature at which this occurs. Appendix D includes the graphs of the average values of the smear factor versus temperature.

Some of the points which may be emphasized from observing the graphs are the following.

- As the temperature of the drill rises, the amount of smear increases for each drill size. However, the characteristics of this increase are different for each drill size.
- The temperatures of the drills run at 80,000 RPM are consistently hotter than those run at 50,000 RPM (for all drill sizes), and the resultant epoxy smear is significantly greater.
- As the drill size increases, the hotter the drill runs and consequently the amount of epoxy smear is greater.
- Microfinish drills run cooler and smear less (especially at the 50,000 RPM speed) than do standard finish drills, presumably because of their reduced friction and smoother surface. These differences are less pronounced at the 80,000 RPM speeds where both standard and microfinish drills run hotter and have a significantly greater smear level.

A comparison of the surface velocity for each of the drill sizes and RPMs is given in Table 6. Since surface velocity is indicative of the amount of heat generated, this table shows part of the reason why large drill sizes run hotter than the small sizes, and also why the 80,000 RPM run as a whole was hotter than the 50,000 RPM run.

TABLE 6. SURFACE VELOCITY OF DRILLS
(Surface FPM)

RPM	#68 (0.031")	#60 (0.040")	#56 (0.0465")	#55 (0.052")
50,000	406	524	609	681
80,000	649	838	974	1089

Note: The chip load for the 50,000 RPM drills was 0.0040" @200 IPM; while for the 80,000 RPM drills, it was 0.0025" @200 IPM.

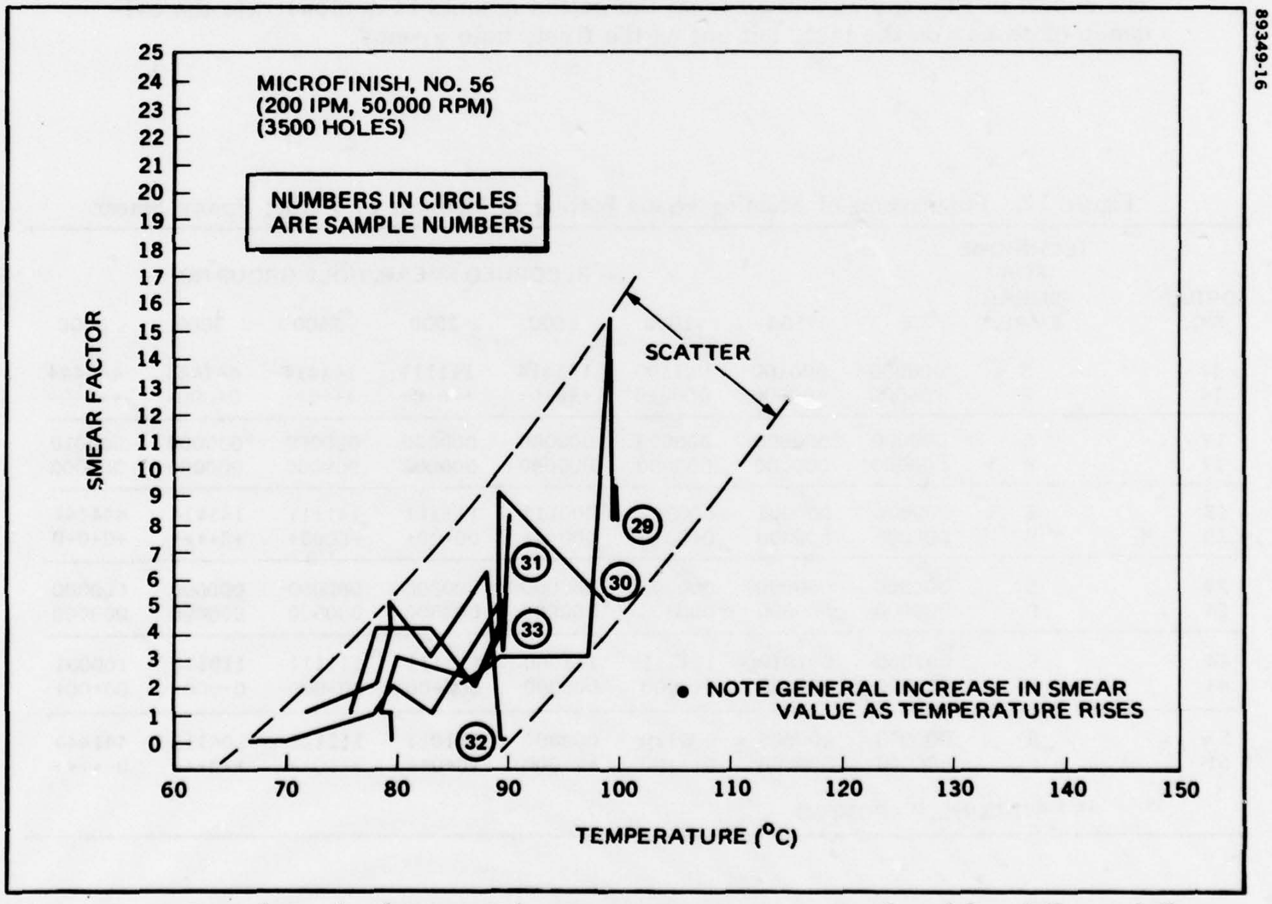


Figure 16. A Typical Graph of Smear Value Versus Temperature. Results of five different drill runs are plotted. Sample numbers are given adjacent to the point representing the 3500th hole drilled.

3. VALIDITY OF STAINING AS AN EVALUATION OF SMEAR

Comparison of test panels rated for epoxy smear to those potted by conventional means showed excellent agreement as to which holes were smeared, giving validity to the staining method as a means of rating epoxy smear.

As a way of verifying the validity of the staining method as a means of smear measurement, six boards previously sampled for smear were copper plated and resampled at the holes adjacent to those originally sampled. This was done in order to produce examples of smear as close as possible to the first samples. These plated samples were then potted, cross-sectioned and examined microscopically for smear by conventional means. Since cross-sectional analysis cannot give a good indication of the percentage of area that is smeared, each hole was recorded with a simple + (for presence of smear) or o (no smear) after microscopic analysis. The comparison between the two techniques is given in Figure 17.

Photomicrographs of the first and last hole groups for drill number 51 are shown in Figures 18 and 19 from the potted mounts to demonstrate the evidence of smear on the last, but not on the first, hole groups.

Figure 17. Comparison of Staining versus Potting as Methods of Rating Epoxy Smear.

89349-17

DRILL NO.	TECHNIQUE FOR SMEAR EVAL.*	RECORDED SMEAR, HOLE GROUP NO. 1	500	1000	1500	2000	2500	3000	3500
14	S	000000	000100	001100	141414	111111	141414	441444	444444
14	P	+00000	+00000	0000+0	++0+0+	++0+0+	+++0++	0+000+	++++0+
17	S	000000	000000	000000	000000	000000	000000	000000	000010
17	P	000000	000000	000000	000000	000000	000000	000000	000000
18	S	000000	000001	000001	000111	111111	141111	141414	444144
18	P	000000	000000	0+00+0	000+0+	00+00+	+0000+	+0++++	+0+0+0
24	S	000000	000000	000000	000000	000000	000000	000000	000000
24	P	000000	000000	000000	000000	000000	000000	000000	000000
44	S	001000	001010	111111	111000	111111	111111	110111	100001
44	P	00+000	000+00	000000	000000	000+00	00+000	0+000+	00+00+
51	S	000000	000000	000110	000000	111011	111111	104111	441444
51	P	000000	000+00	0+++00	+++000	+0+0++	++00++	++0+++	0+++++

*S = STAINING, P = POTTED

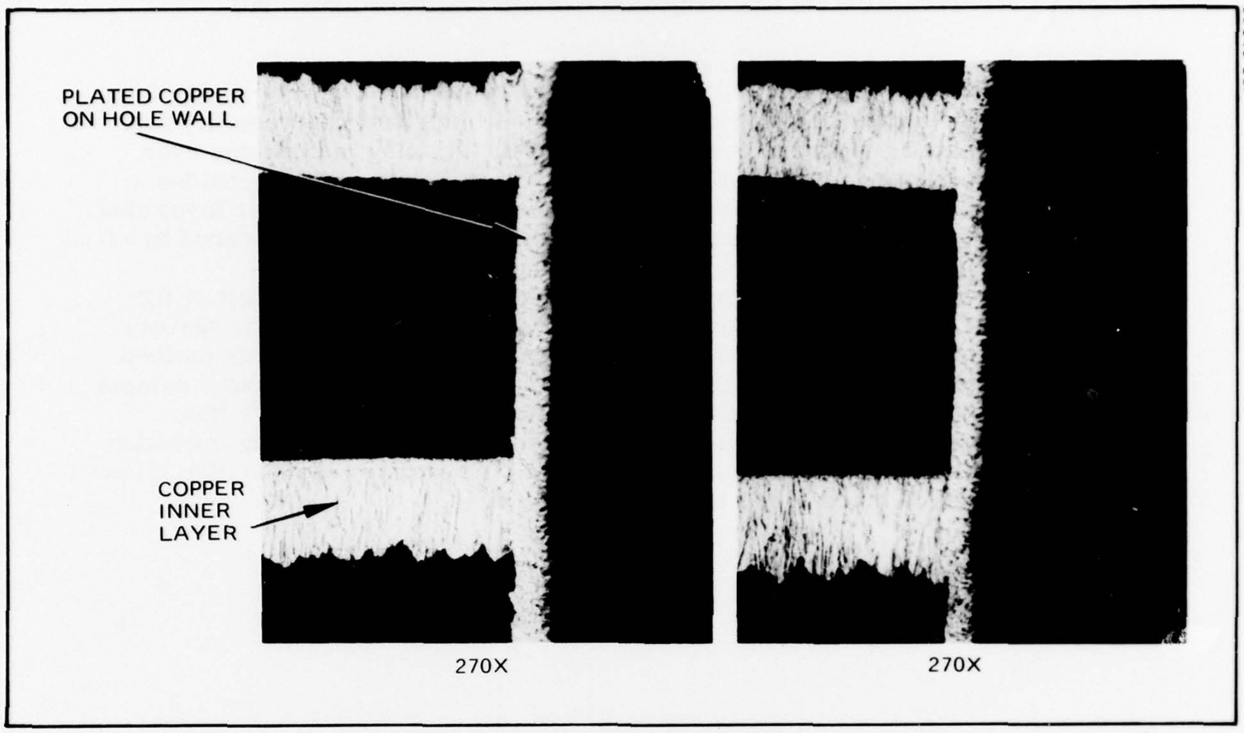


Figure 18. Photomicrographs of Hole Group No. 1, Drill Sample No. 51. No smear present between plated copper and inner layers. (Holes plates as drilled; no etchback.)

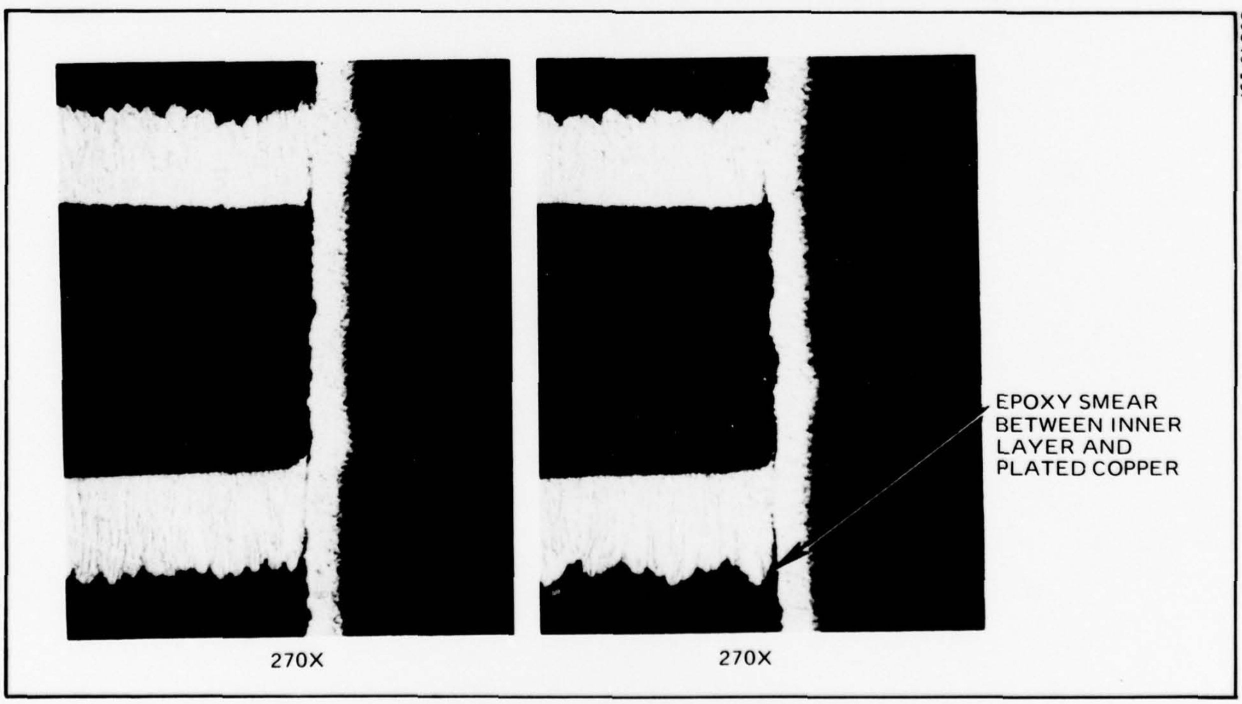


Figure 19. Photomicrographs of Hole Group No. 3500, Drill Sample No. 51. Smear evidenced between plated copper and inner layers. (Holes plated as drilled; no etchback.) Smear factor by staining method was 21.

3. VALIDITY OF STAINING AS AN EVALUATION OF SMEAR (Continued)

Also shown, in Figure 20, is a horizontal cross-section of a copper inner layer with plated copper showing epoxy smear as a black band between the inner layer and the plated copper. The advantage that the staining method has over these two types of potted cross-sections is that the staining method provides a means of obtaining a numerical value for the relative area of the inner layer that is smeared by the epoxy. In addition, sample preparation time is reduced by about 50% resulting in a cost advantage over the potting method.

The preparation of the sample mount, which is shown on the left of figure 21, consists of gluing all of the hole groups together (separated by spacers cut from the panel) and grinding down halfway into the test holes. This method requires considerably less skill than preparation of a conventional potted sample (shown on the right side of figure 20), since potted samples must have flat, smooth surfaces, and must be skillfully prepared so that the polishing operation does not alter the features of the cross-section. The staining method also allows observation of much more of the hole area at one time.

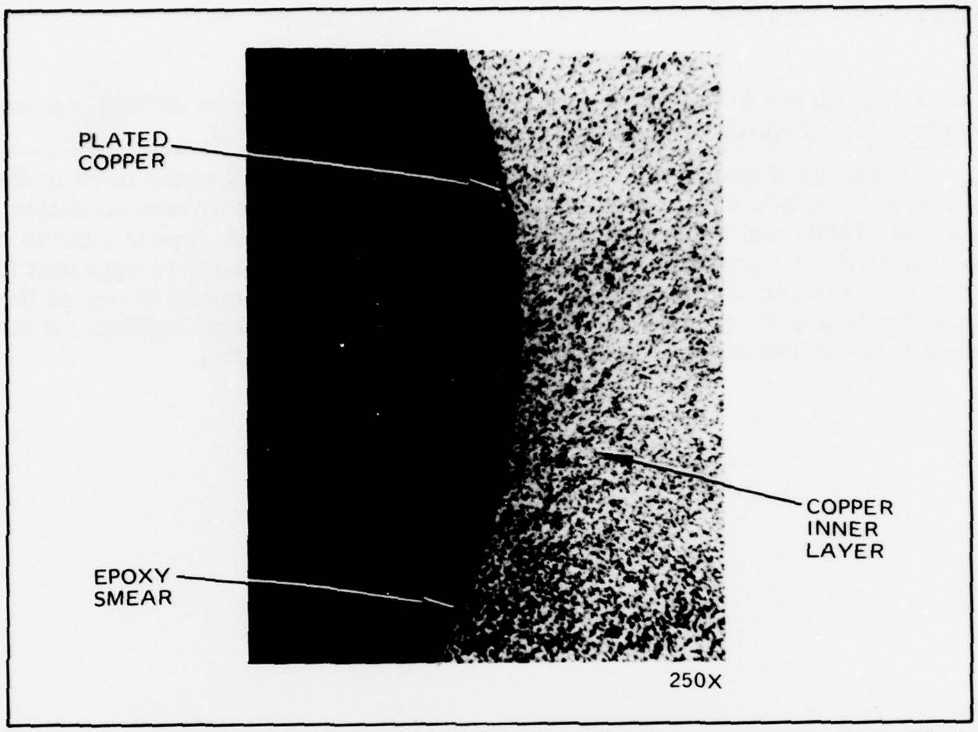


Figure 20. Horizontal Cross Section of Copper-Plated Inner Layer. Note black line from epoxy smear between plated copper and inner layer.

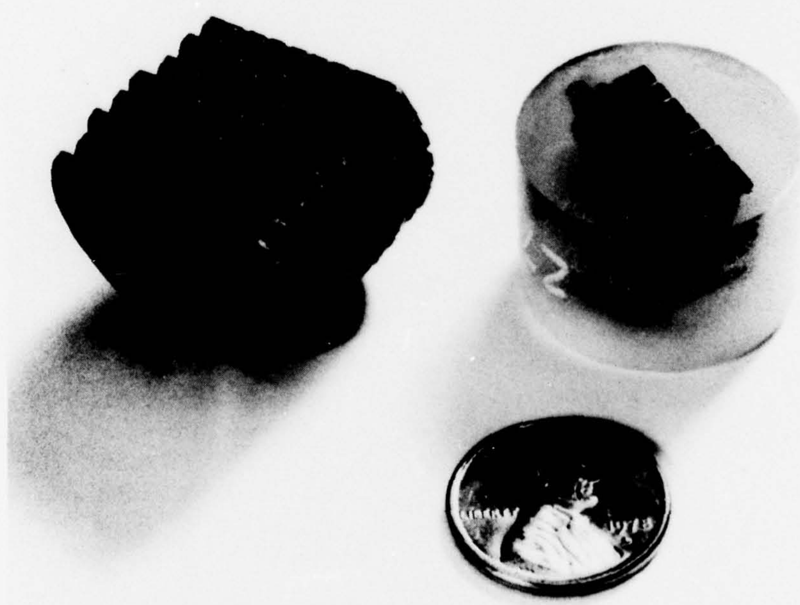
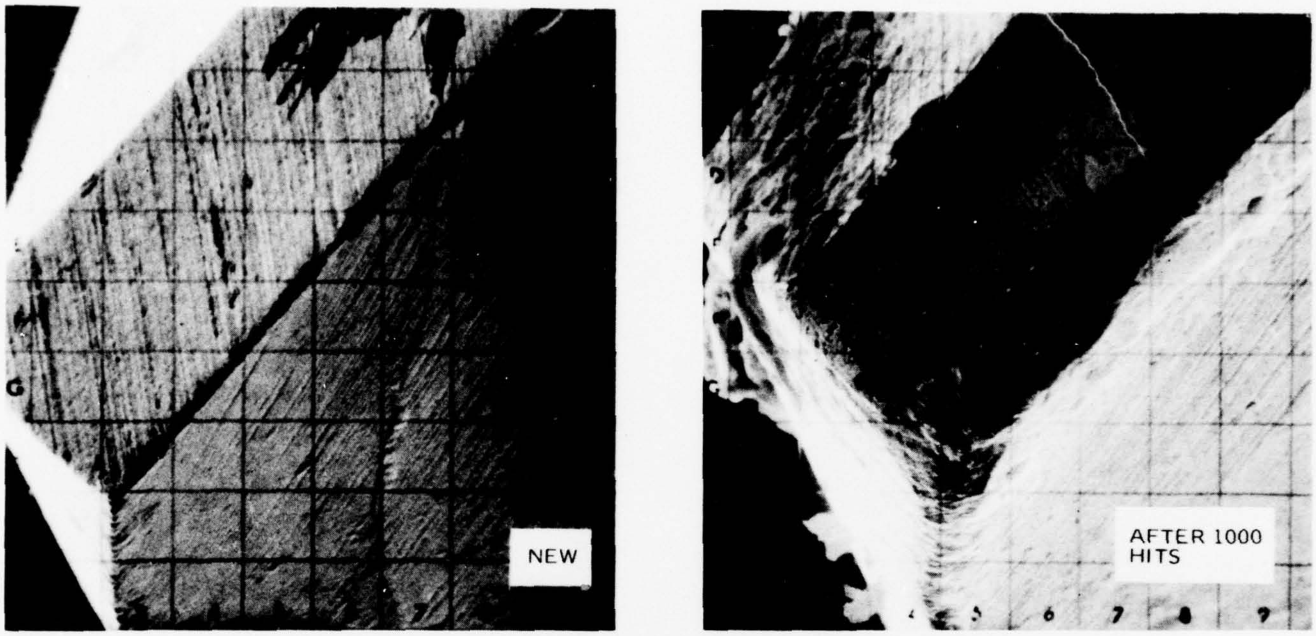


Figure 21. A Comparison of Mounts Prepared by the Staining Technique and by Potting. Considerably less preparation time is required for the stained samples, due to lack of need for potting and polishing. In addition, more quantitative results for smear are obtained by the staining technique.

4. DRILL EVALUATION

Drill wear was shown to increase noticeably as more holes were drilled. In addition, an accumulation of epoxy was evident on all sizes of drills used.

Appendix E shows photomicrographs of all four drill sizes used in the study (#68, #60, #56, and #55). The photos show the drills in their new condition and after 500, 1000, and 3500 hits for all four sets of drills. A representative new and used drill are shown in Figure 22. Accumulation of epoxy is apparent in the photos of the drills that have been used. This build up of epoxy is one of the factors contributing to the heating up of the drill and its eventual dulling. It can be seen that wear becomes more evident by the end of 3500 hits.



700X 700X

Figure 22. Representative – Drill New and After 1000 Hits. Note epoxy build-up on cutting edge of used drill.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

1. RESULTS OF STUDY AND RECOMMENDATIONS FOR FUTURE EFFORTS

The study results indicate that there are methods by which the probably presence of epoxy smear can be detected indirectly while drilling. When this happens, the drill can be automatically shut down to reduce the number of rejected boards.

Results – Two types of IR detectors were successfully used to continuously monitor the temperature increase of #60 carbide drills during the drilling operation of MLB panels. These detectors were an IR radiation scope and a fiberoptic thermal monitor. However, large amounts of scatter or variability in the temperature data makes it difficult to predict the exact temperature of epoxy smearing. Each of these systems with modifications to improve the temperature response time can be used to trigger the shutdown of a drilling machine when a predetermined drill temperature is observed. The cost of each system is less than $5000.

Temperature monitoring of #60 drills operating at 50,000 RPM/200 IPM revealed a general increase in temperature in proportion to the number of hits. This temperature monitoring allowed categorizing the drills into two groups: group "A" with an observed temperature [$T_{(o)}$] range of 190°-330°F; and group "B" with a $T_{(o)}$ range of 270°-410°F. Most of the standard carbide drills tested were categorized in group B and micro grade type drills were in group A.

The evaluation of ECOM-supplied #60 drills (with various finishes and point geometries) resulted in twelve of the fourteen types performing in group A category. Only the standard type drills performed in the group B category. Microlube coating on the drills did not significantly improve the performance of the drills. This was true for both the standard and micrograde type drills evaluated. There was no significant difference in the $T_{(o)}$ or performance of various drill point geometries. All were similar in performance to the regular micrograde drills.

Of the four drill sizes evaluated at 50,000 and 80,000 RPM (#55, #56, #60, #68), the larger sizes (#55, #56) ran hotter and the smear factor was greater. The $T_{(o)}$ of drills evaluated at 80,000 RPM/200 IPM was higher than those at 50,000 RPM/200 IPM (for all drill sizes evaluated). The resultant epoxy smear factor was also greater in holes drilled at 80,000 RPM. The micrograde drills had a lower $T_{(o)}$ than the standard type drills, especially at 50,000 RPM.

Placing the MLB between an aluminum clad backup board and a 5 mil aluminum entry foil resulted in drilled holes with no exit or entry burrs, no nailheading of the copper inner layers, and no excessive gouging of the epoxy glass. In general, the quality of the hole wall was good and epoxy smear was the major defect observed in the holes.

The use of ammonium sulfide solution to blacken the copper innerlayers of cross-sectioned MLB holes proved to be an innovative technique for epoxy smear detection.

SEM examination of the drills after drilling reveals an erosion of the cutting surfaces as well as a buildup of epoxy on these leading edges.

Recommendations – The IR thermal monitors should be modified by improving the temperature response of the sensor and attaching an optical filter to reject extraneous IR radiation interference.

Temperature vs smear curves should be obtained on the commonly used drill sizes using various surface speeds and chip loads. Micro grade drills should be used for drilling MLBs in a production environment and monitored using a thermal monitor modified as described above. In addition, the layup geometry used in this program (sandwiching the MLB between 5 mil aluminum entry foil and aluminum clad backup board) should be used when drilling MLBs.

The ammonium sulfide method of staining cross-sections of drilled holes should be used for smear evaluation.

Figure 23. Summary of Key Observations

89349-499

Drill Size #60 @ 50,000 RPM/200 IPM

- Drill temperature sensed by either an IR radiation scope or fiberoptic IR monitor can be used to stop the drill machine before epoxy smearing.
- The cost of either IR system is less than $5,000.
- Temperature increased as the number of hits increased.
- The drill types studied fell into two temperature rise categories: A (190-330°F) and B (270-410°F).
- Most standard carbide drills fell into category B; micrograde fell into category A.
- 12 of the 14 types of ECOM-supplied drills fell into group A, the other 2 (standard) fell into group B.
- Neither drill point geometry nor microlube coating had a significant effect on the temperature-rise performance of the ECOM-supplied drills.

Drill Sizes #55, #56, #60, #68 at 50,000 RPM and 80,000 RPM and 200 IPM

- Sizes #55 and #56 ran hotter with greater smear than the smaller sizes #60 and #68
- 80,000 RPM resulted in higher temperatures and greater smear.
- Micro-grade drills had lower operating temperatures than standard type drills, especially at 50,000 RPM
- Layup geometry used in this study resulted in drilled holes without burrs, nailheading or epoxy gouging

Epoxy Detection

- Use of ammonium sulfide solution to blacken the copper layers proved effective in detecting smear.
- The SEM revealed that drill cutting surfaces after use were eroded and had epoxy buildup.

Figure 24. Summary of Recommendations

89349-500

- Modify IR monitors to improve temperature response
- Add optical filter to IR monitors
- Generate temperature vs smear curves for commonly used drill sizes and various drilling conditions
- Use micro-grade drills for drilling MLBs
- Use ammonium sulfide staining for smear evaluation

APPENDIX A
BIBLIOGRAPHY

BIBLIOGRAPHY

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APPENDIX B
BEFORE AND AFTER PHOTOS OF DRILL TIPS (70X AND 700X MAGNIFICATION) – PHASE II

Figure B1. Standard Carbide Drill – Before

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

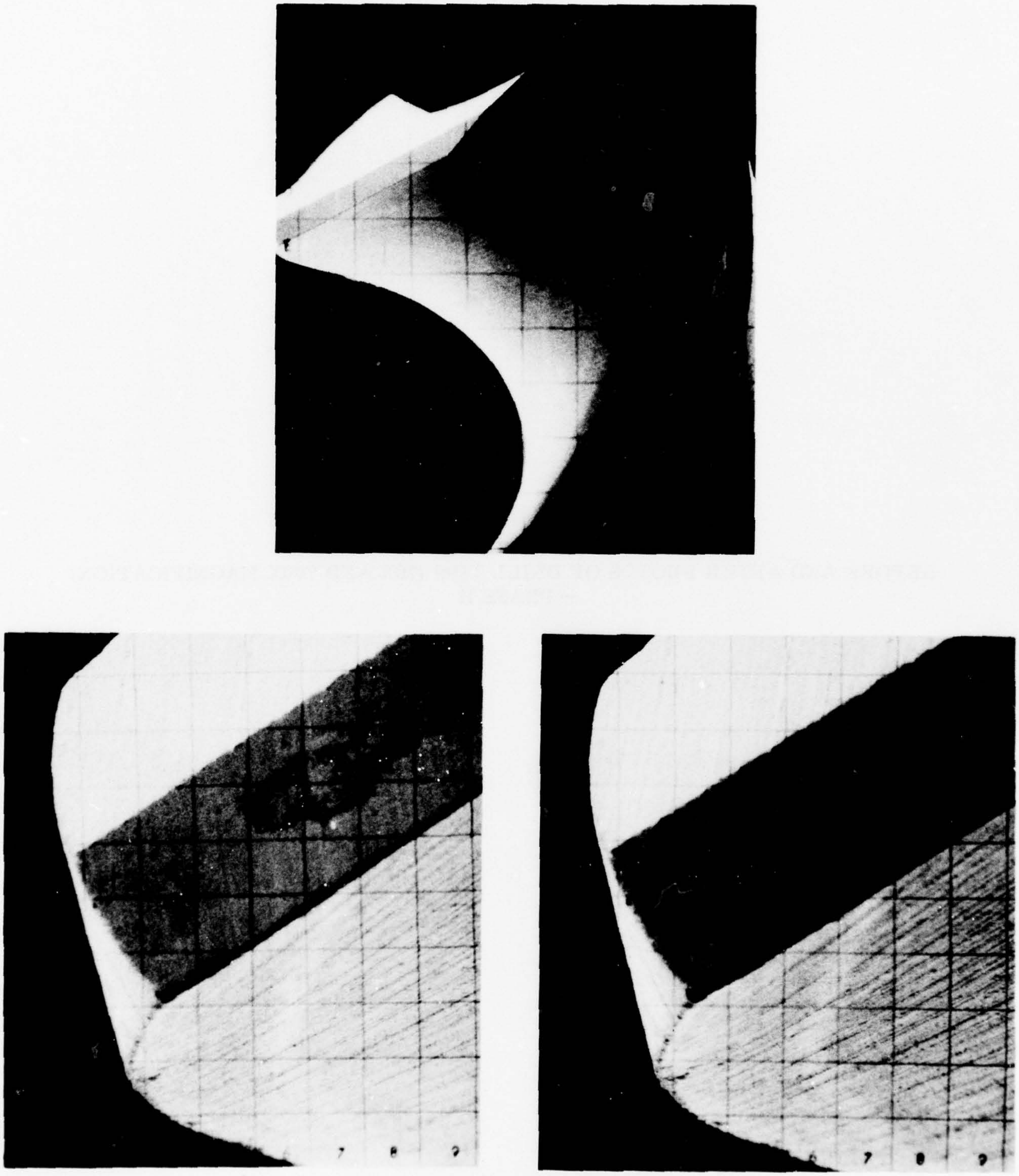


Figure B1. Standard Carbide Drill – Before

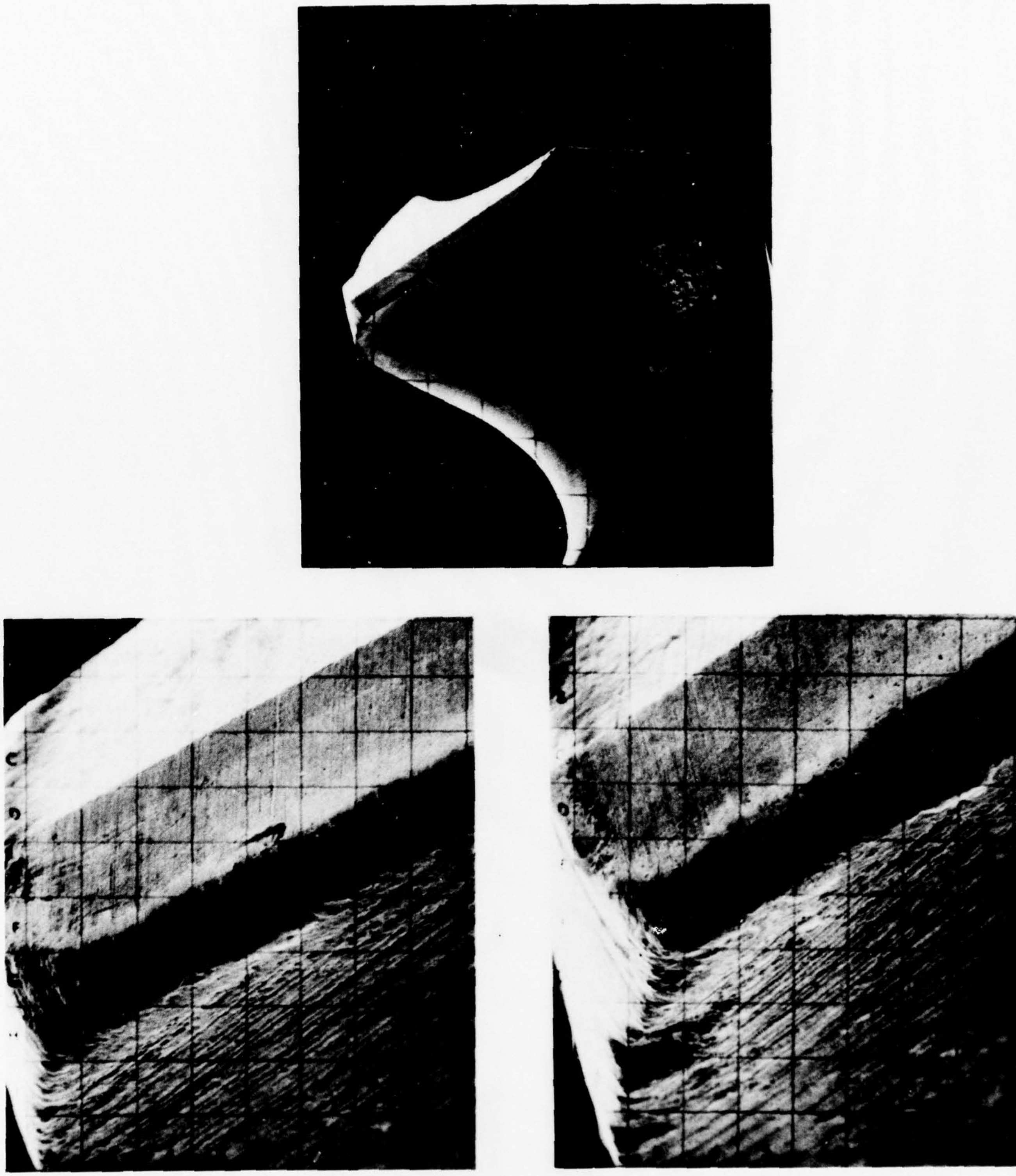


Figure B2. Standard Carbide Drill – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips (70X and 700X Magnification) – Phase II

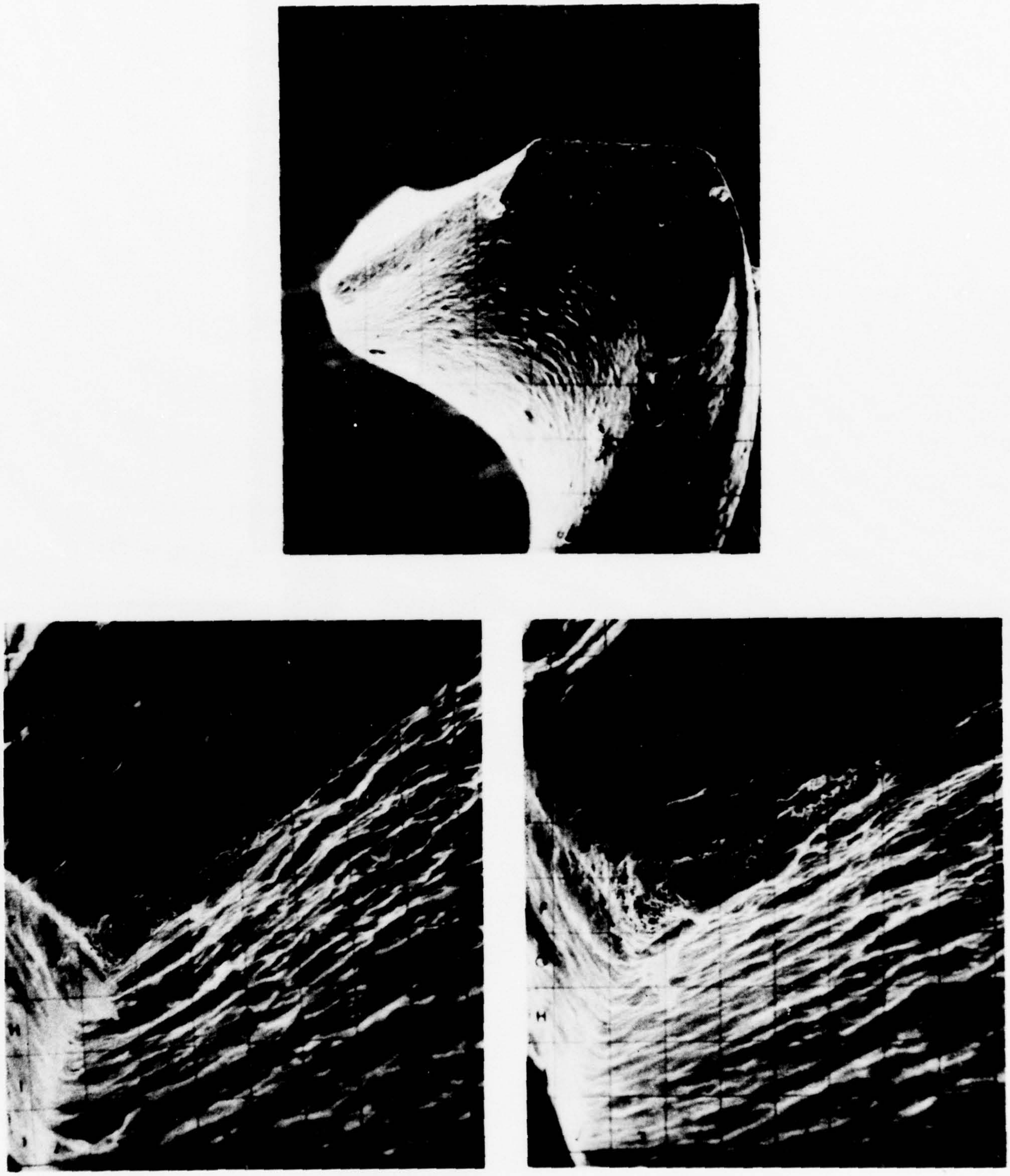


Figure B3. Standard Carbide Drill with Microlube – Before

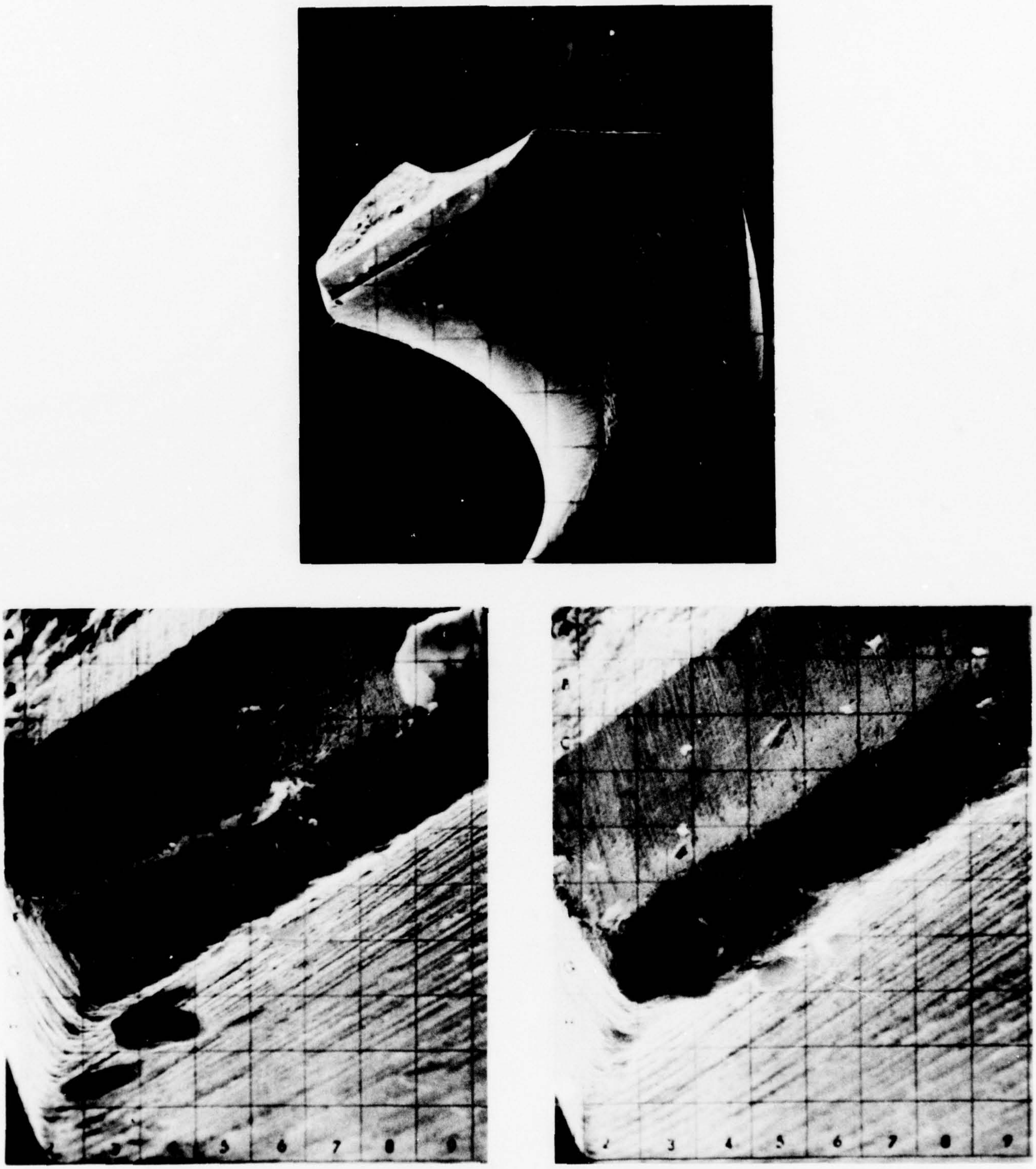


Figure B4. Standard Carbide Drill w/Microlube – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips (70X and 700X Magnification) – Phase II

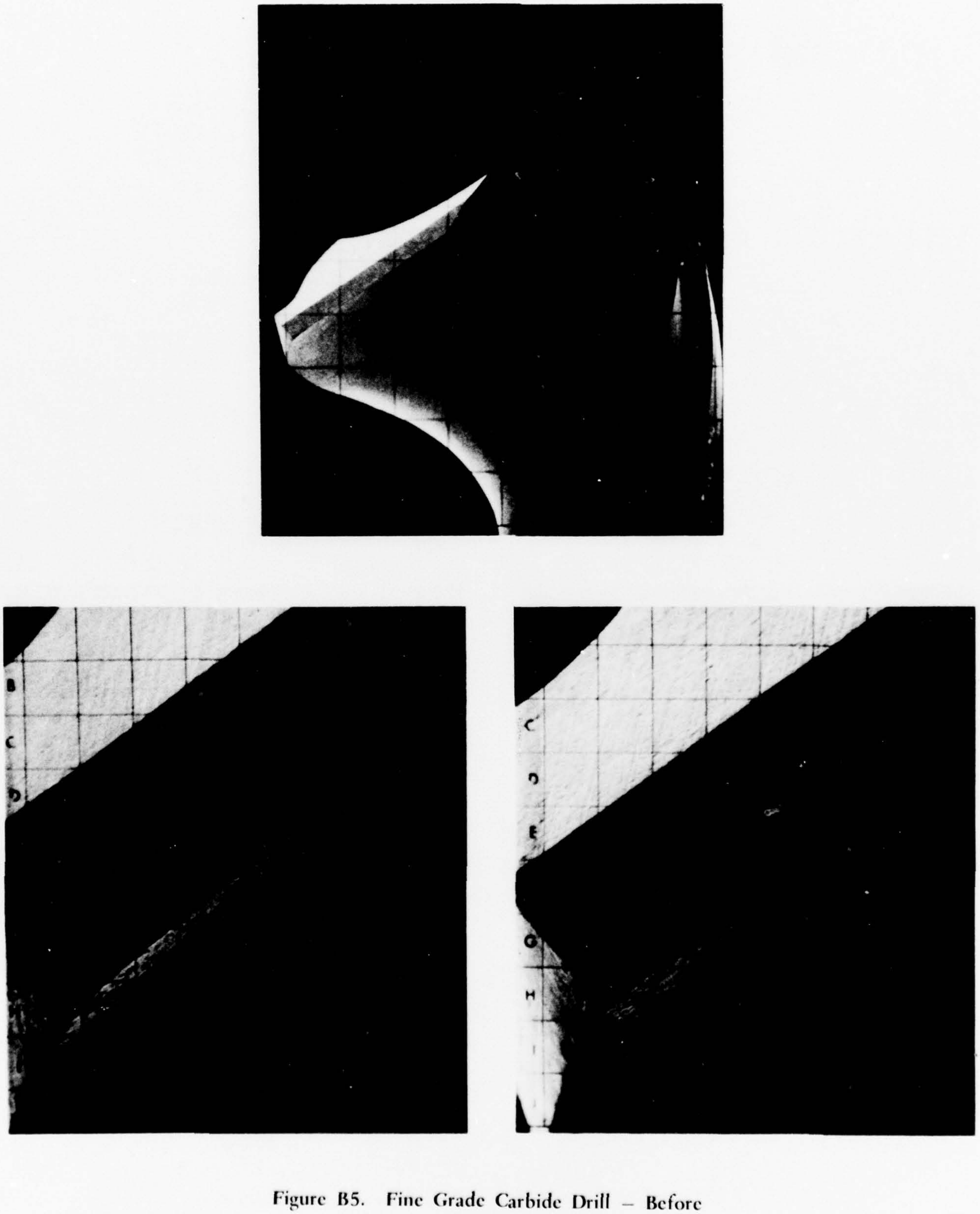


Figure B5. Fine Grade Carbide Drill – Before

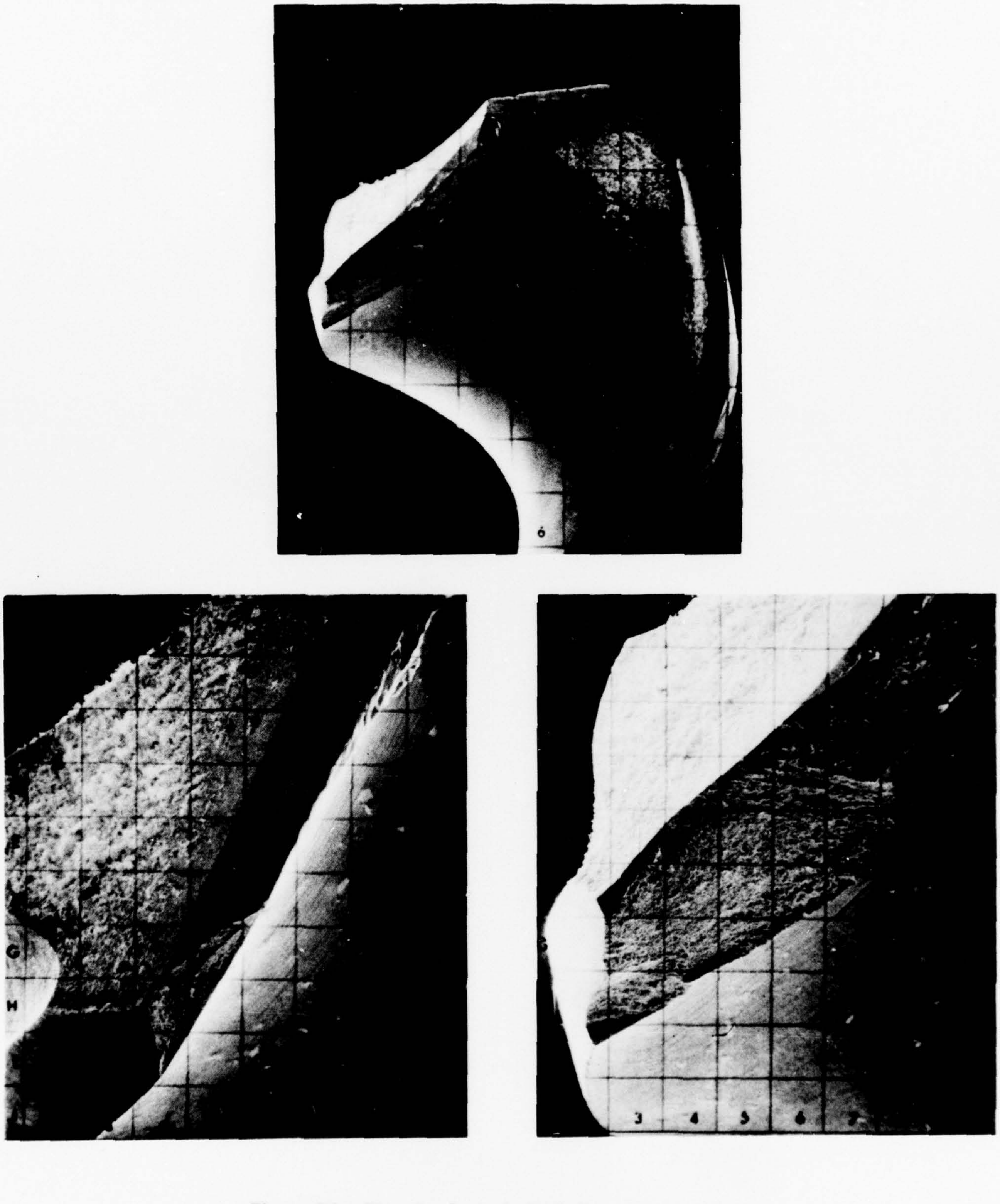


Figure B6. Fine Grade Carbide Drill – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

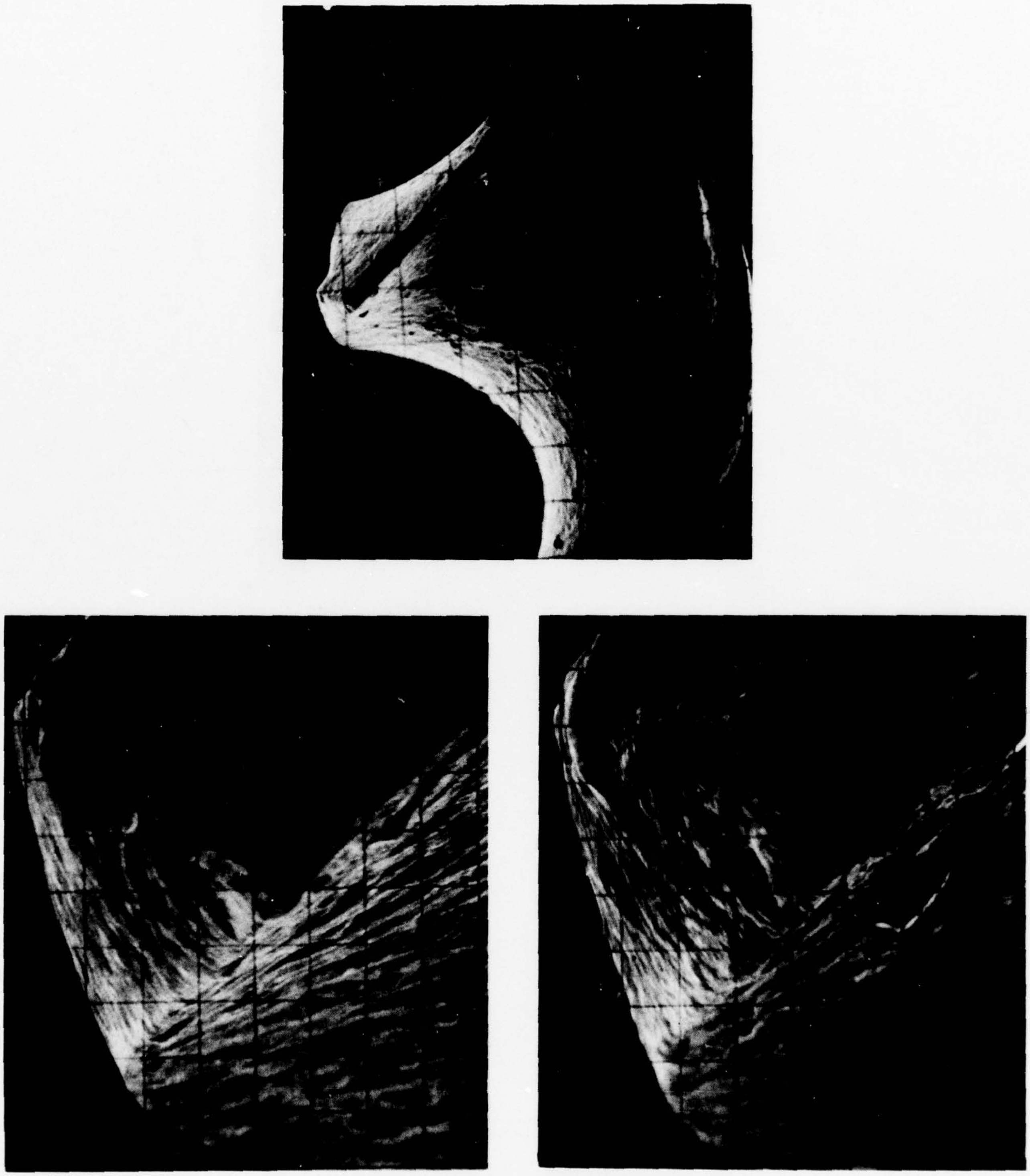


Figure B7. Fine Grade Carbide Drill with Microlube – Before

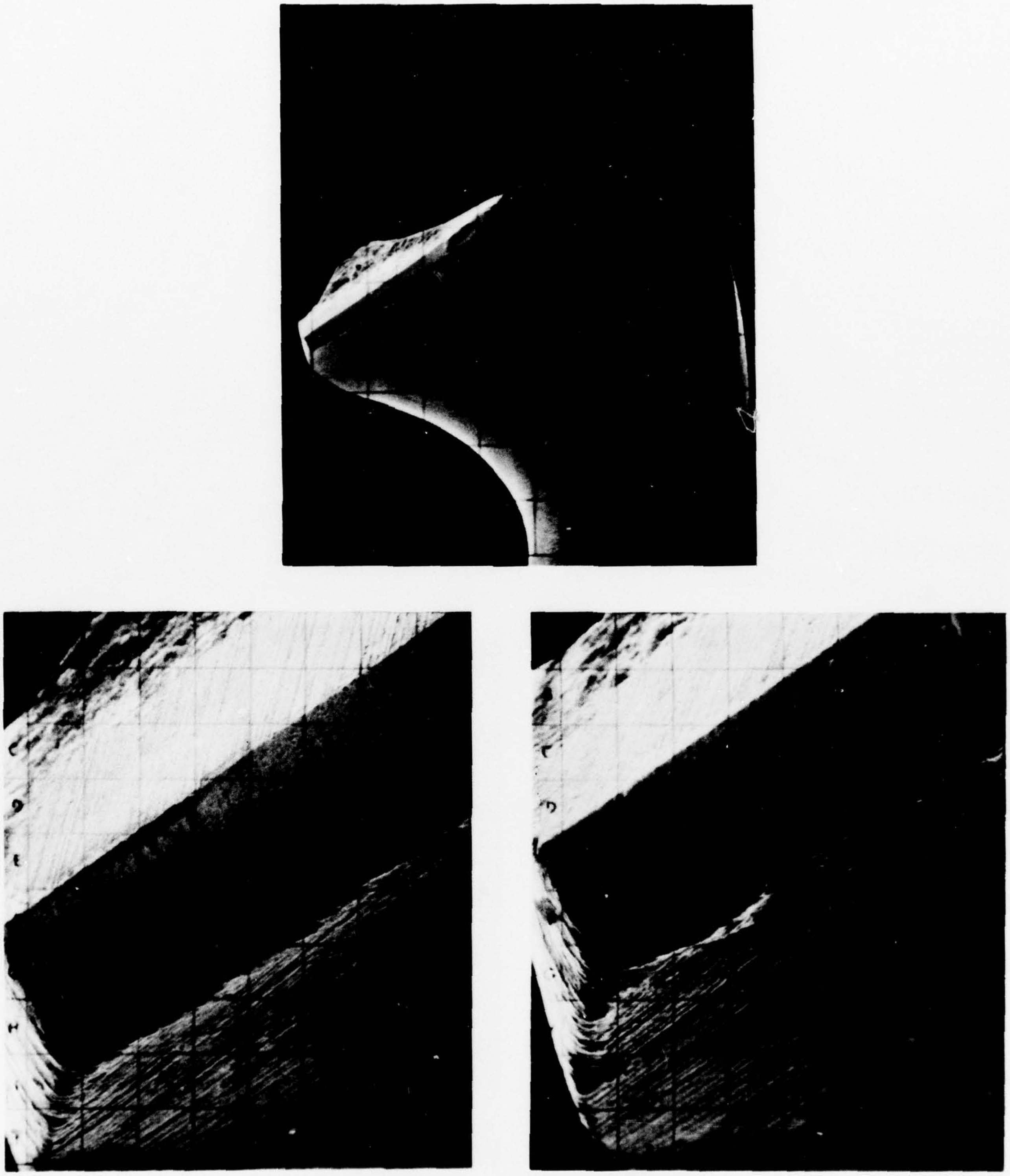


Figure B8. Fine Grade Carbide Drill w/Microlube – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

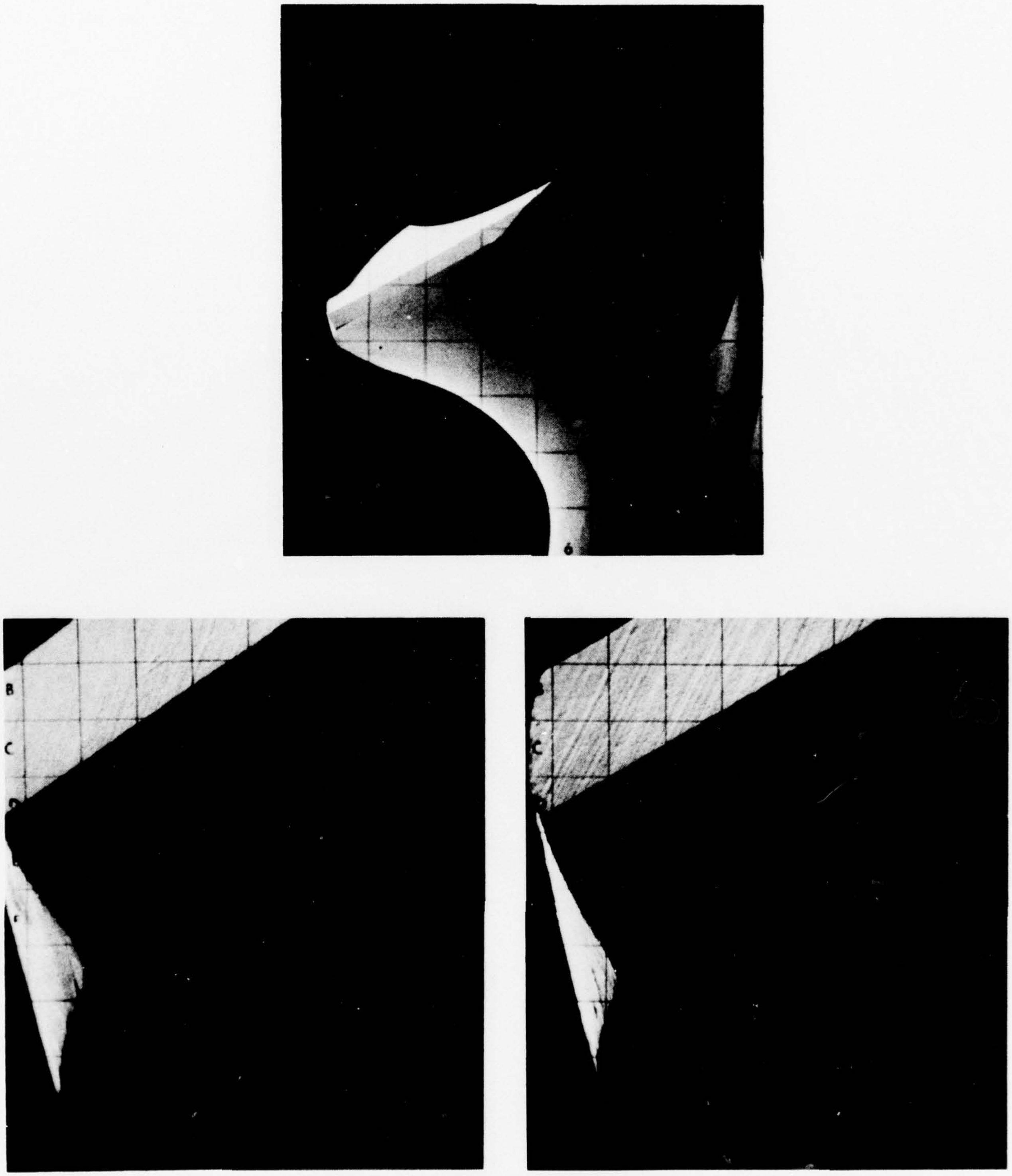


Figure B9. Micro Grade Carbide Drill – Before

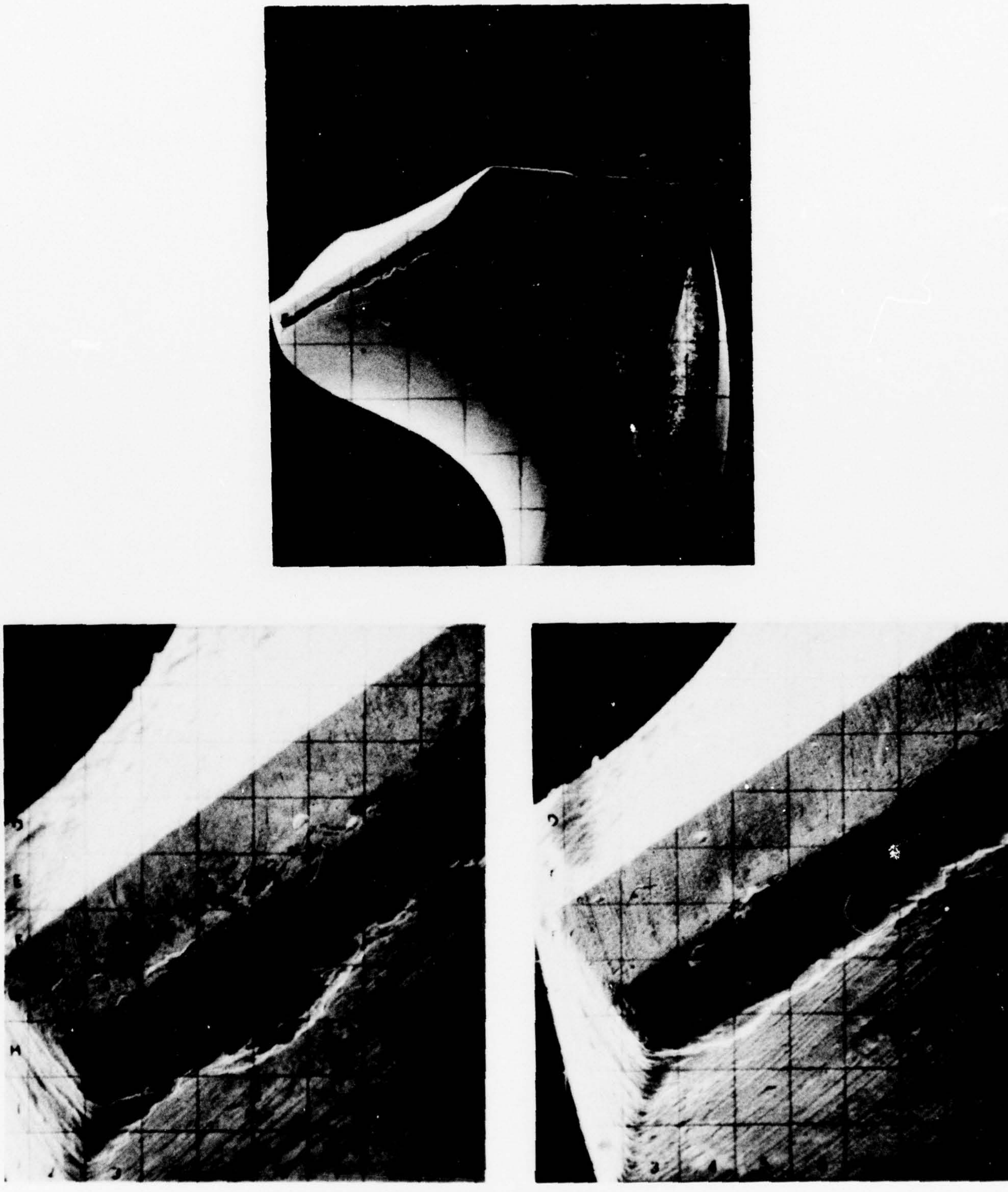


Figure B10. Micro Grade Carbide Drill – After 4200 Hits

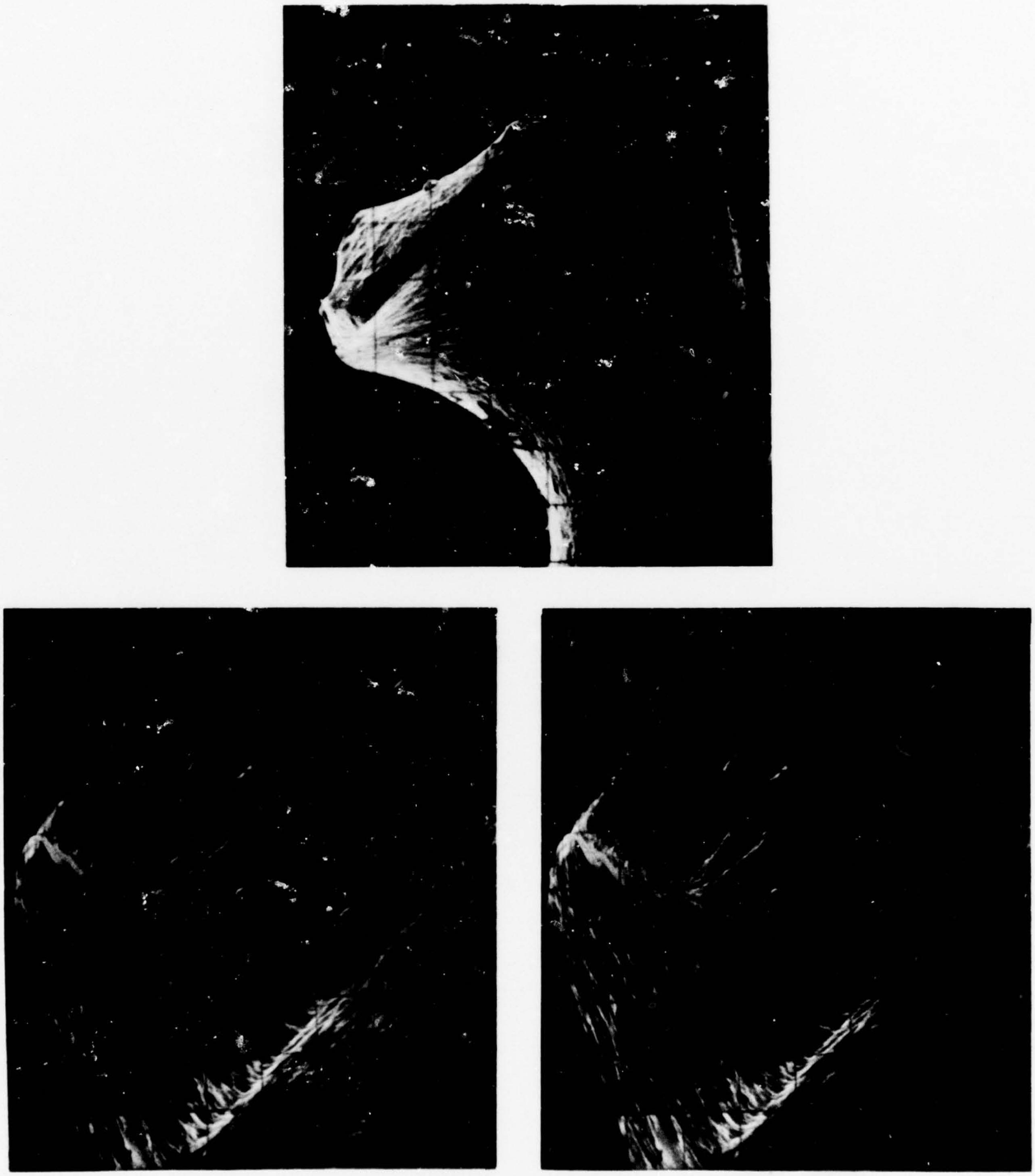


Figure B11. Micro Grade Carbide Drill with Microlube – Before

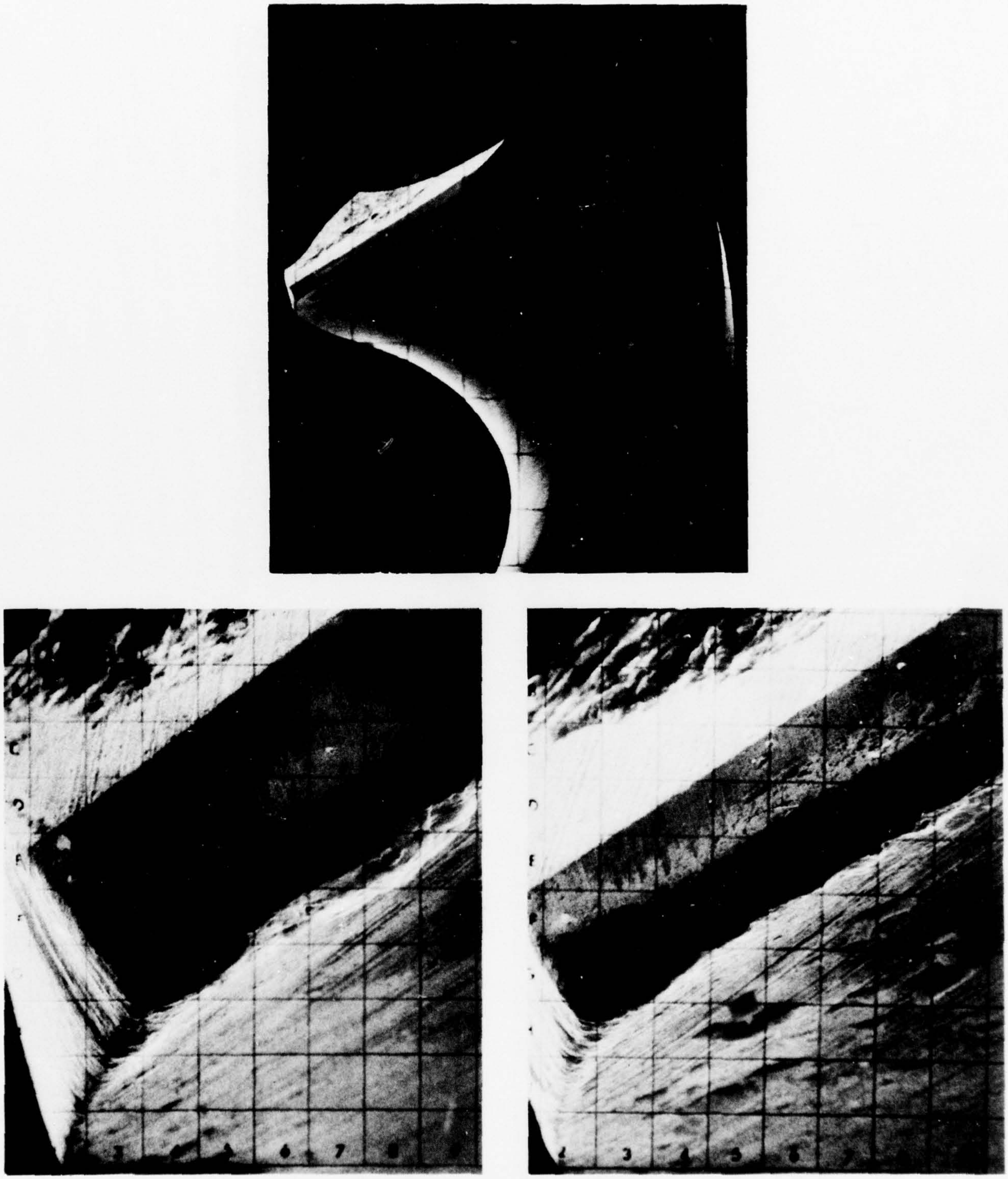


Figure B12. Micro Grade Carbide Drill w/Microlube – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

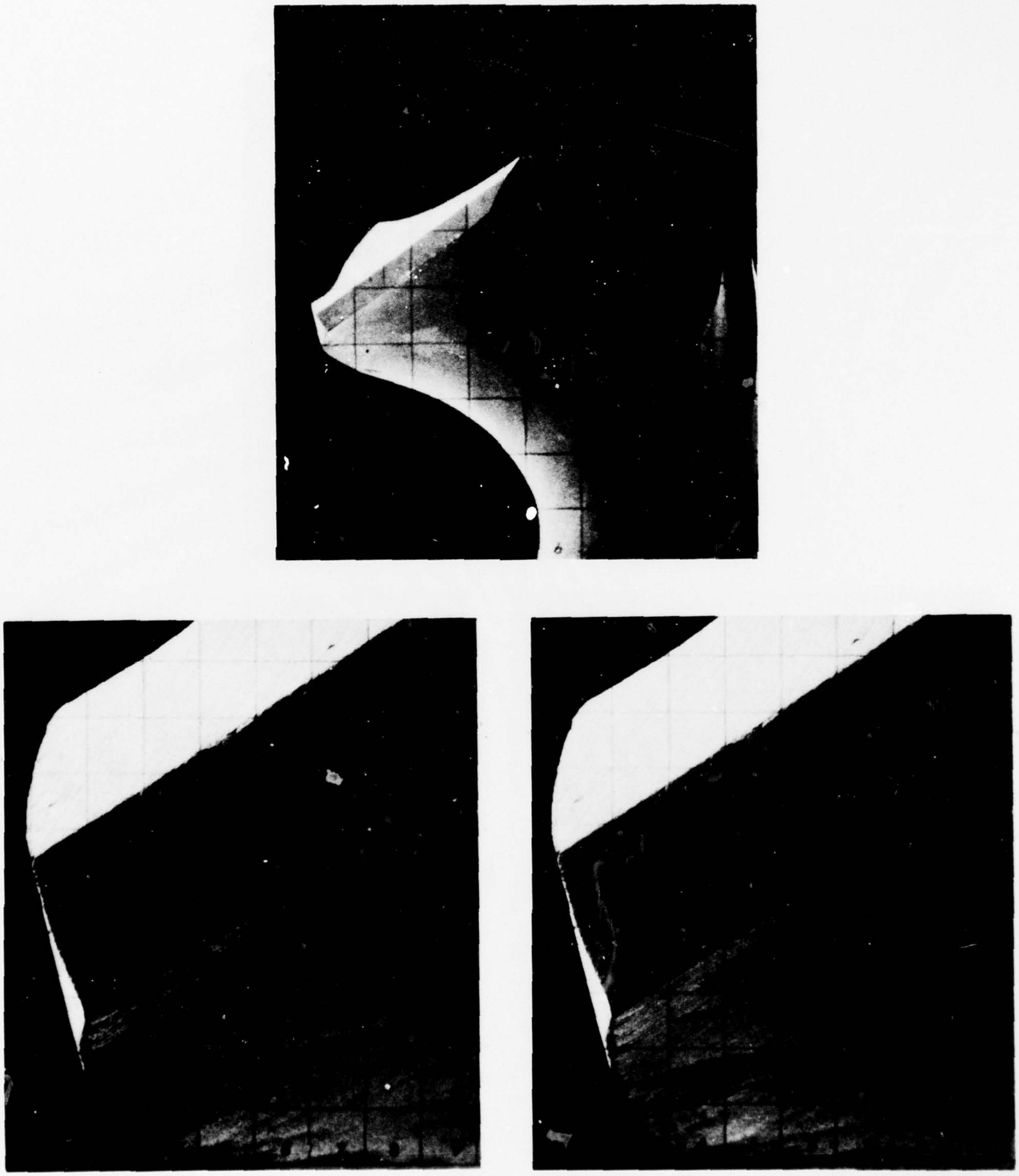


Figure B13. Micro Grade Drill – 118° Point, 12° Relief – Before

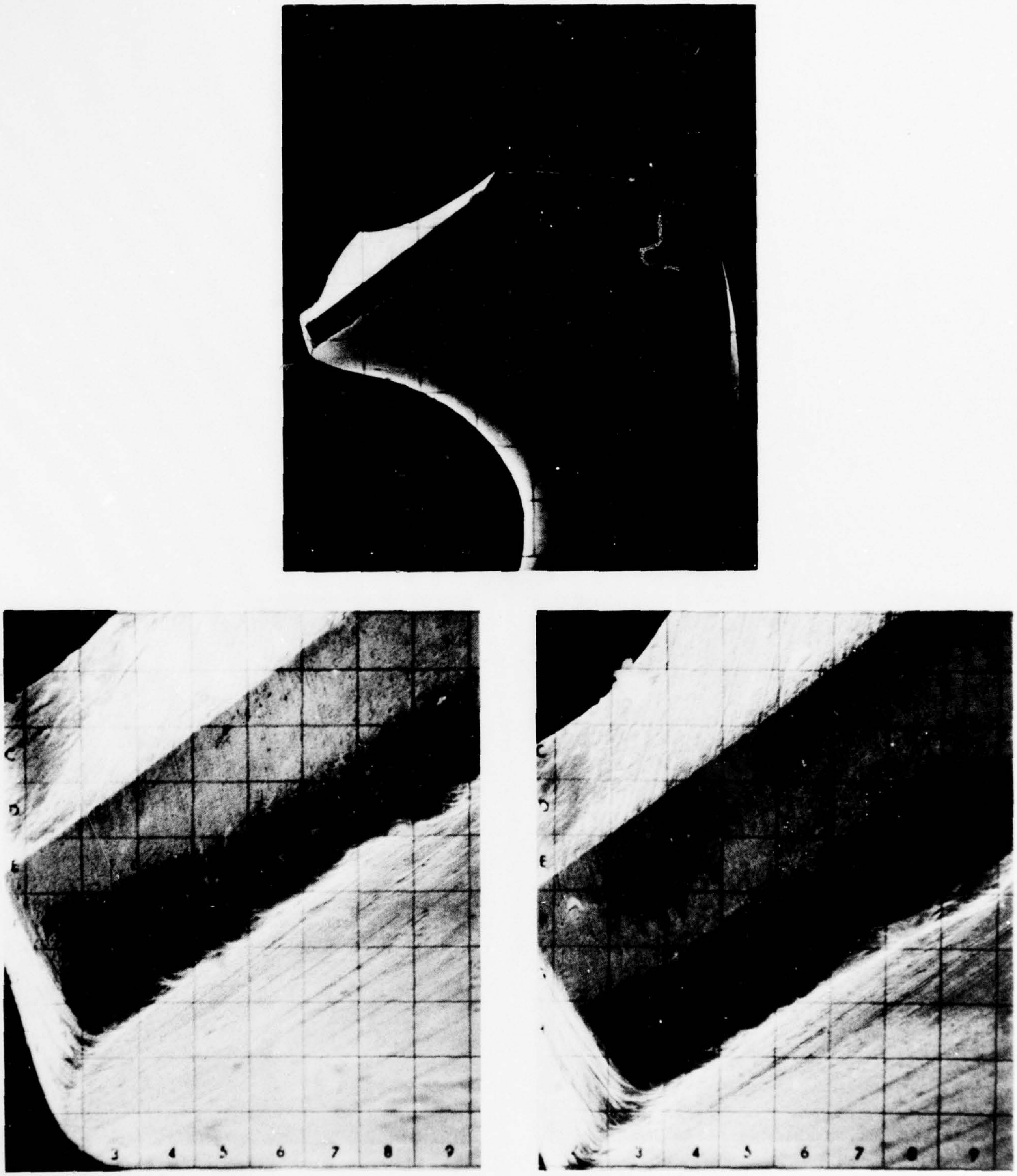


Figure B14. Micro Grade Drill - 118° Point, 12° Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

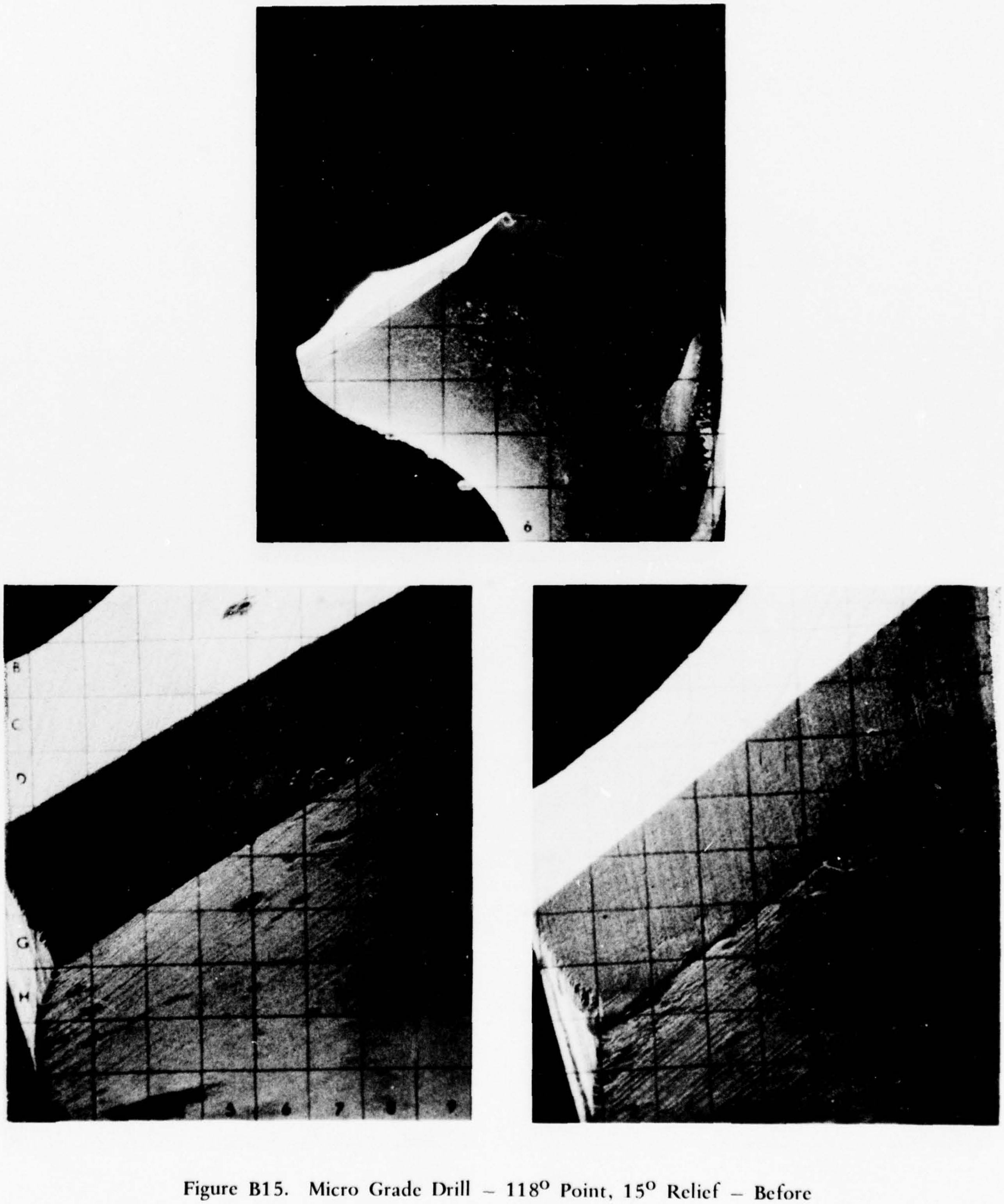


Figure B15. Micro Grade Drill – 118° Point, 15° Relief – Before

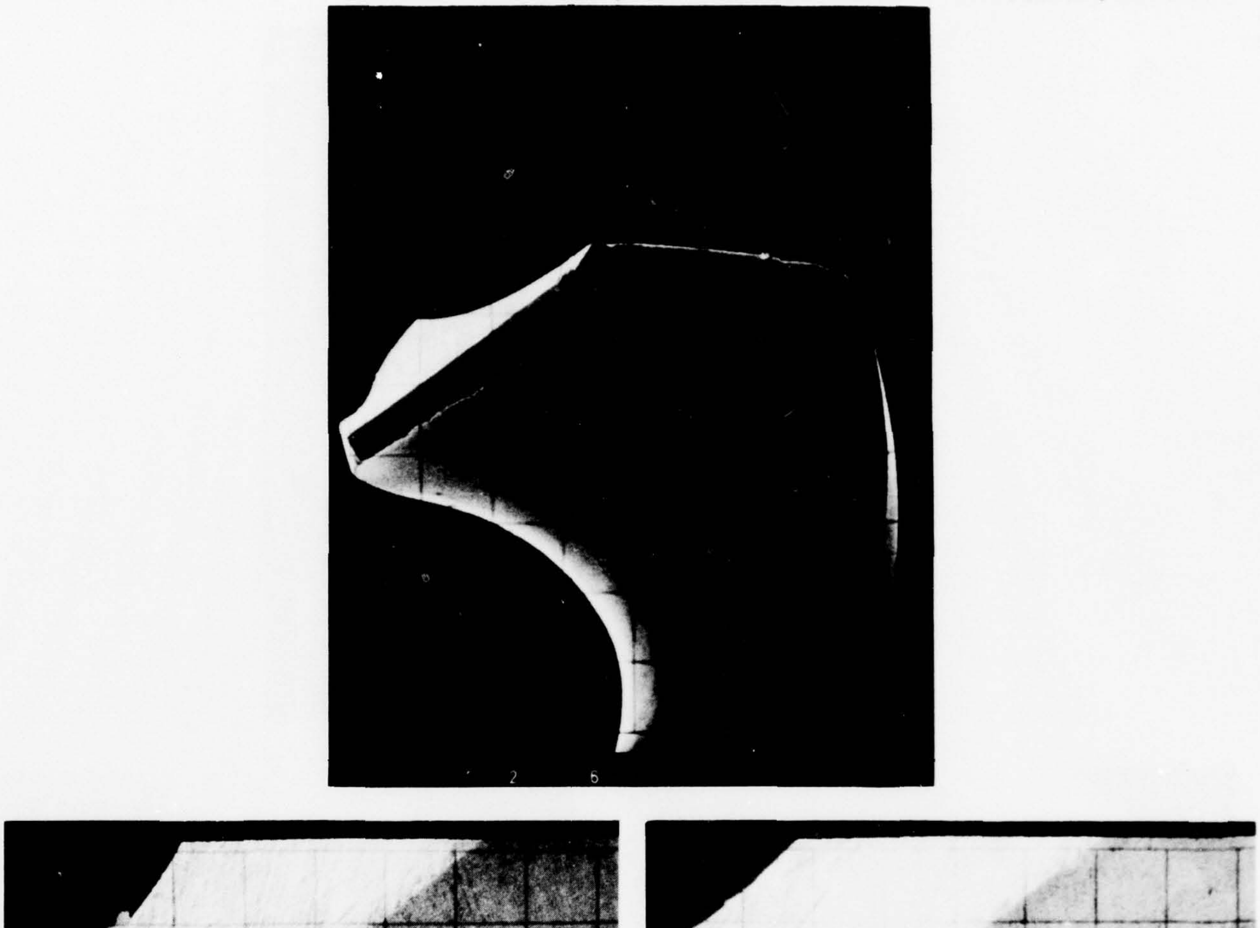


Figure B16. Micro Grade Drill – 118^{o} Point, 15^{o} Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

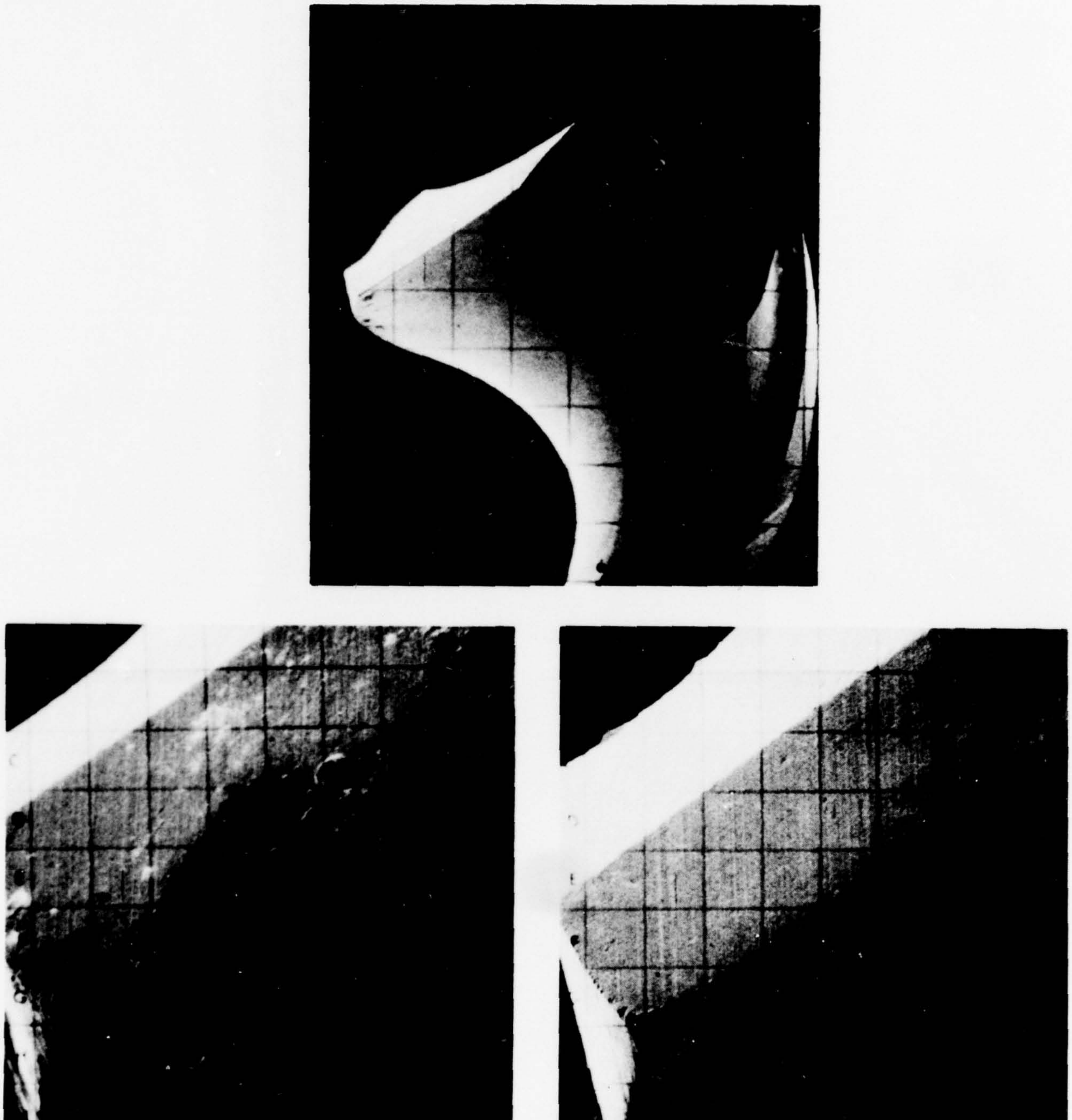


Figure B17. Micro Grade Drill – 118° Point, 20° Relief – Before

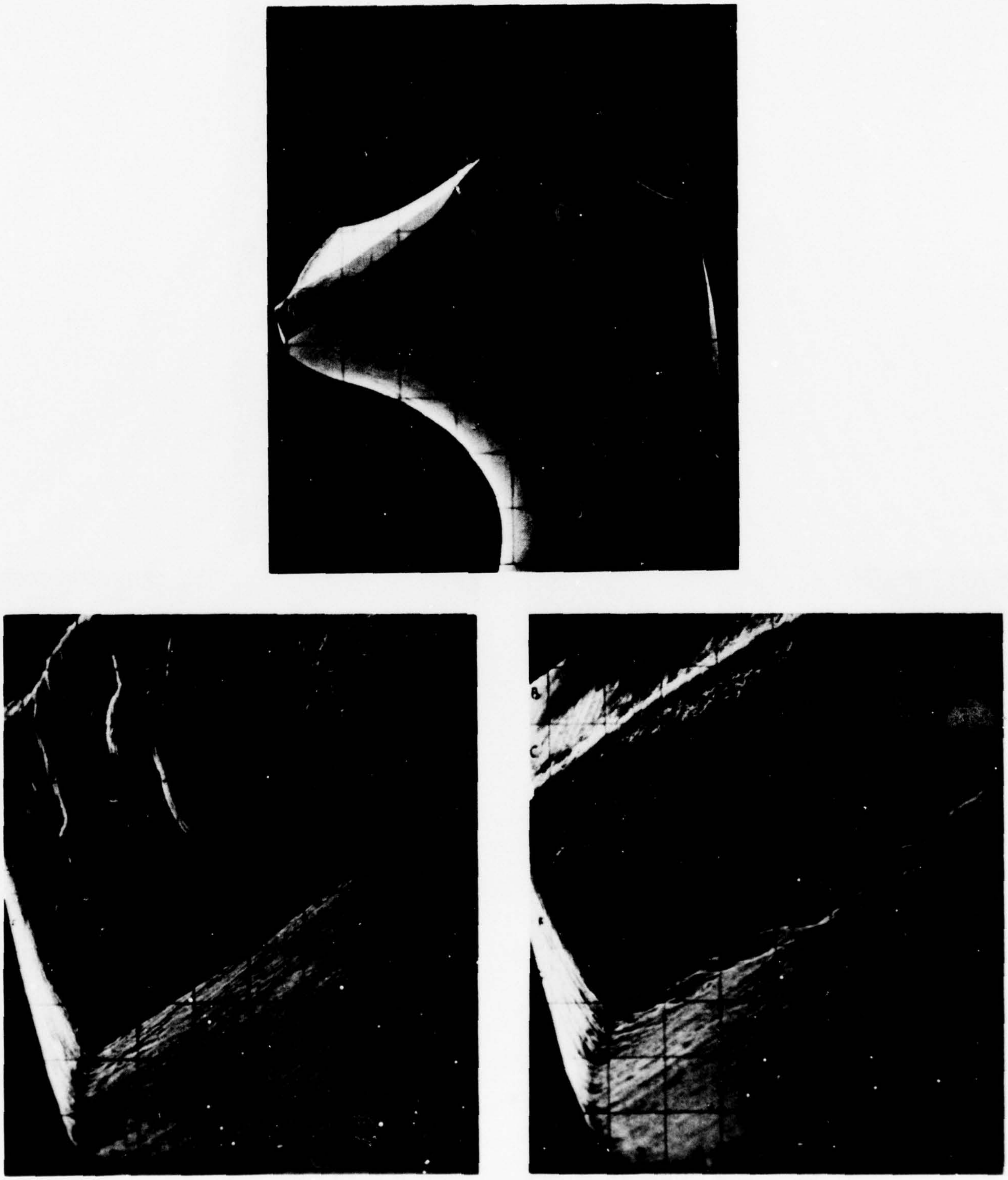


Figure B18. Micro Grade Drill – 118° Point, 20° Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips (70X and 700X Magnification) – Phase II

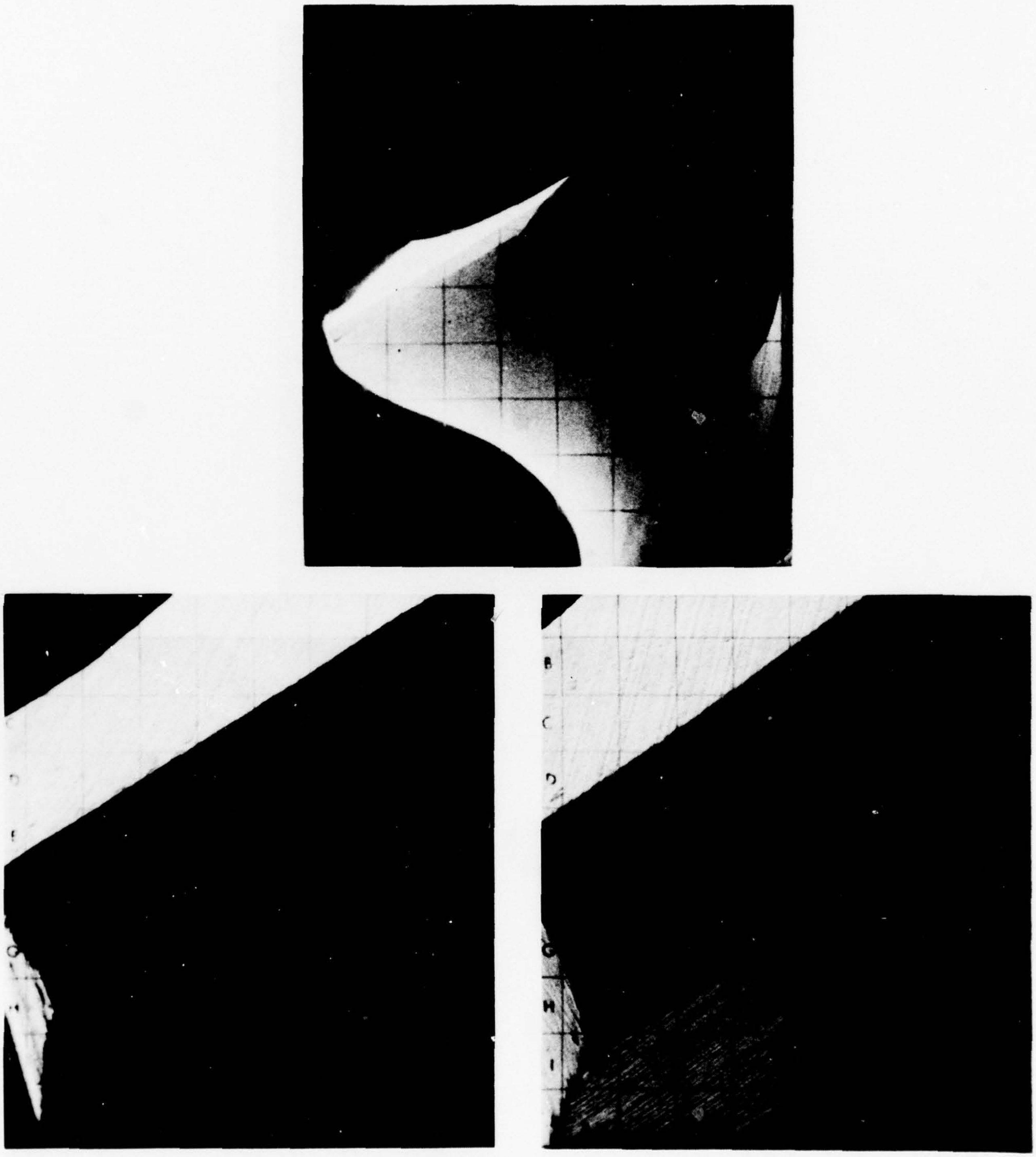


Figure B19. Micro Grade Drill – 130° Point, 12° Relief – Before

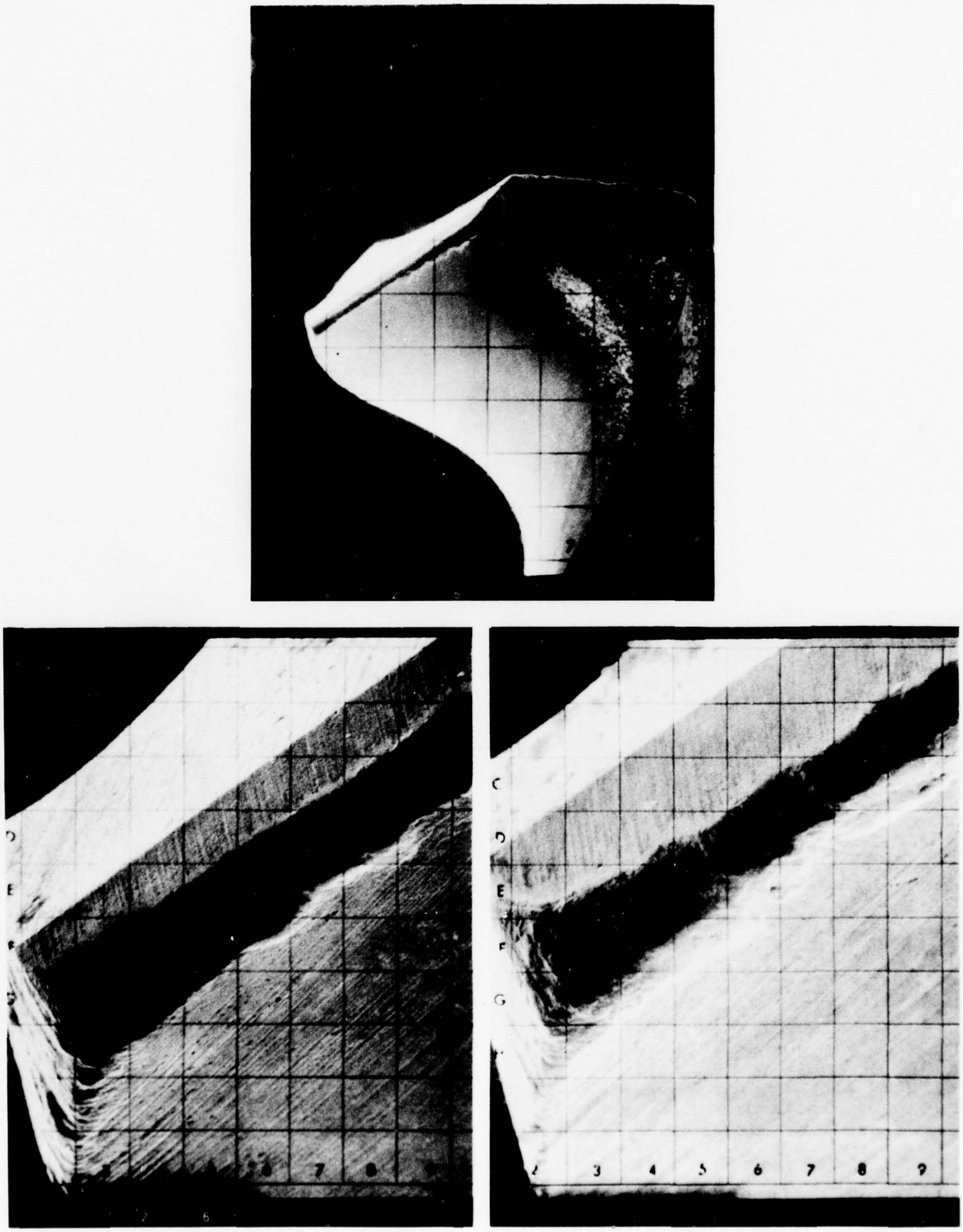


Figure B20. Micro Grade Drill – 130° Point, 12° Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

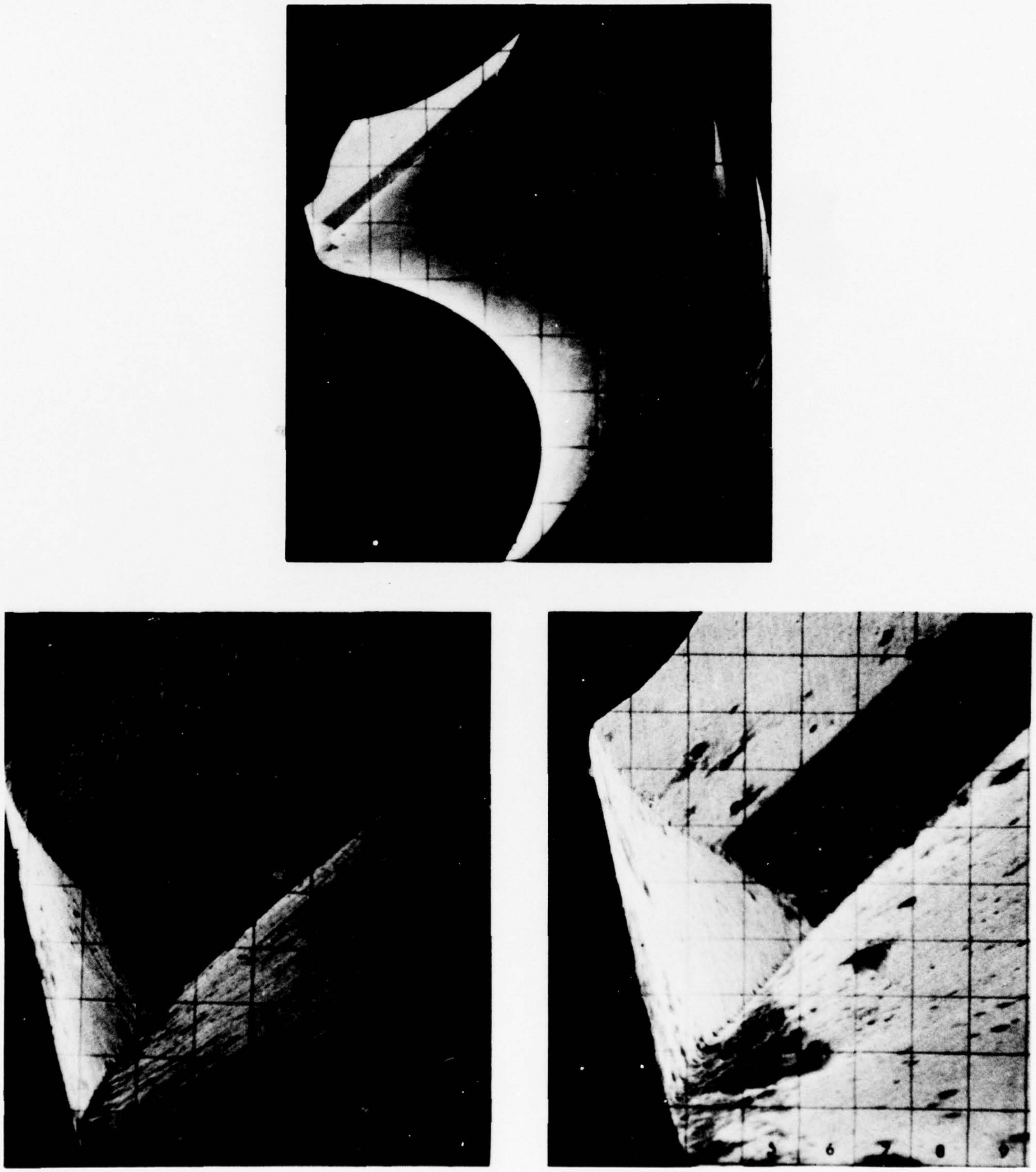


Figure B21. Micro Grade Drill – 130° Point, 20° Relief – Before

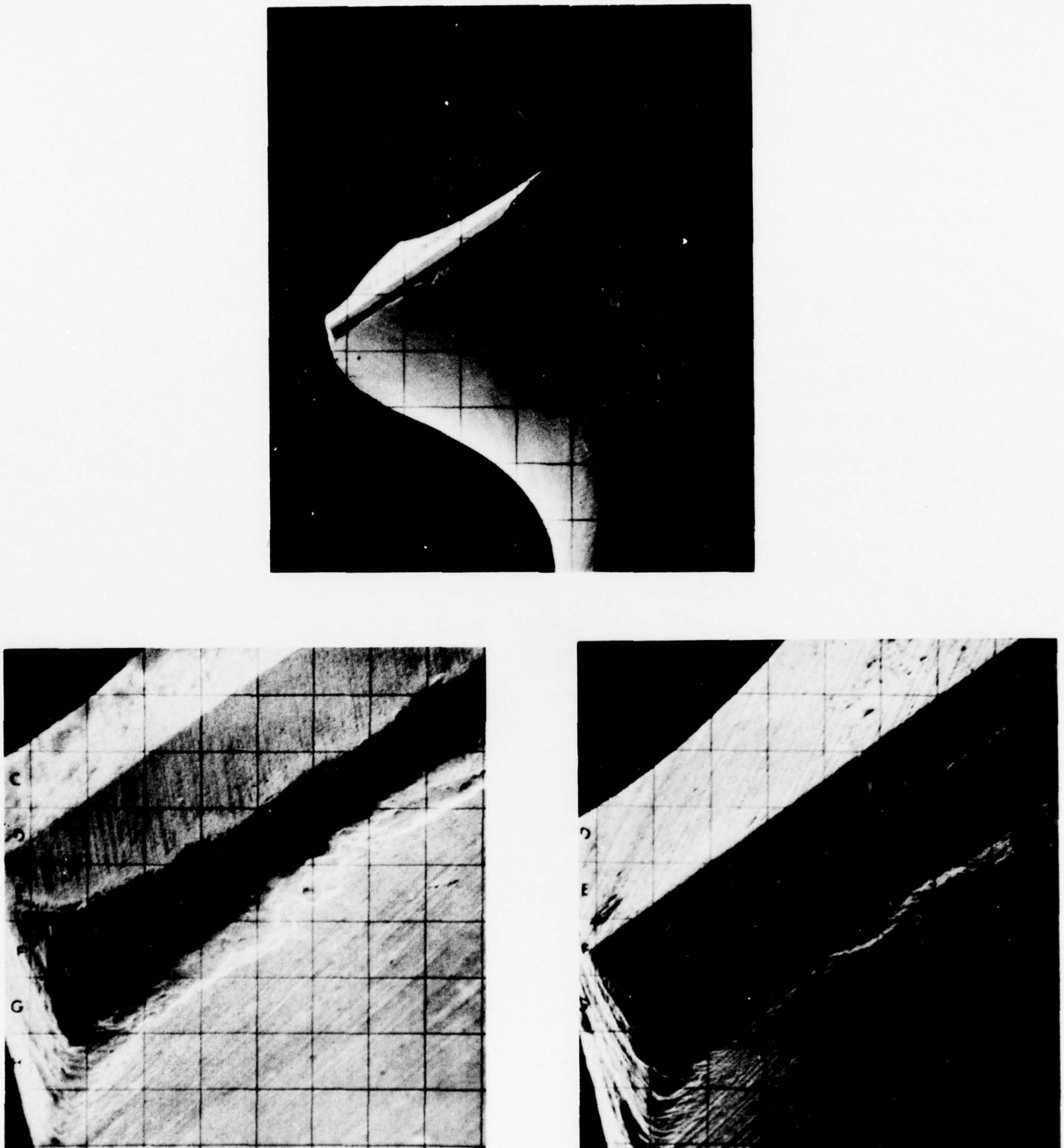


Figure B22. Micro Grade Drill – 130° Point, 20° Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

Figure B23. Micro Grade Drill – 140° Point, 12° Relief – Before

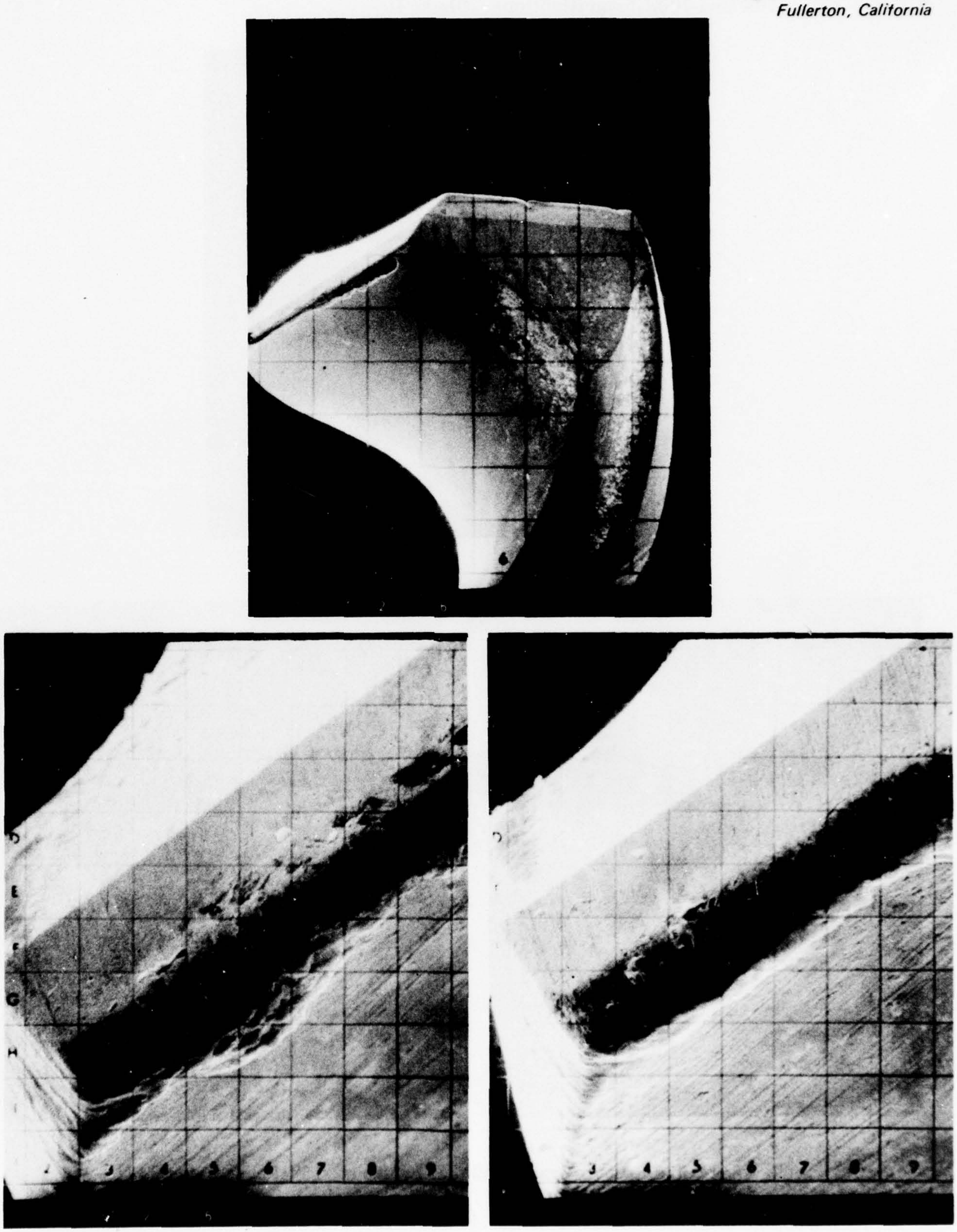


Figure B24. Micro Grade Drill – 140° Point, 12° Relief – After 4200 Hits

Appendix B – Before and After Photos of Drill Tips
(70X and 700X Magnification) – Phase II

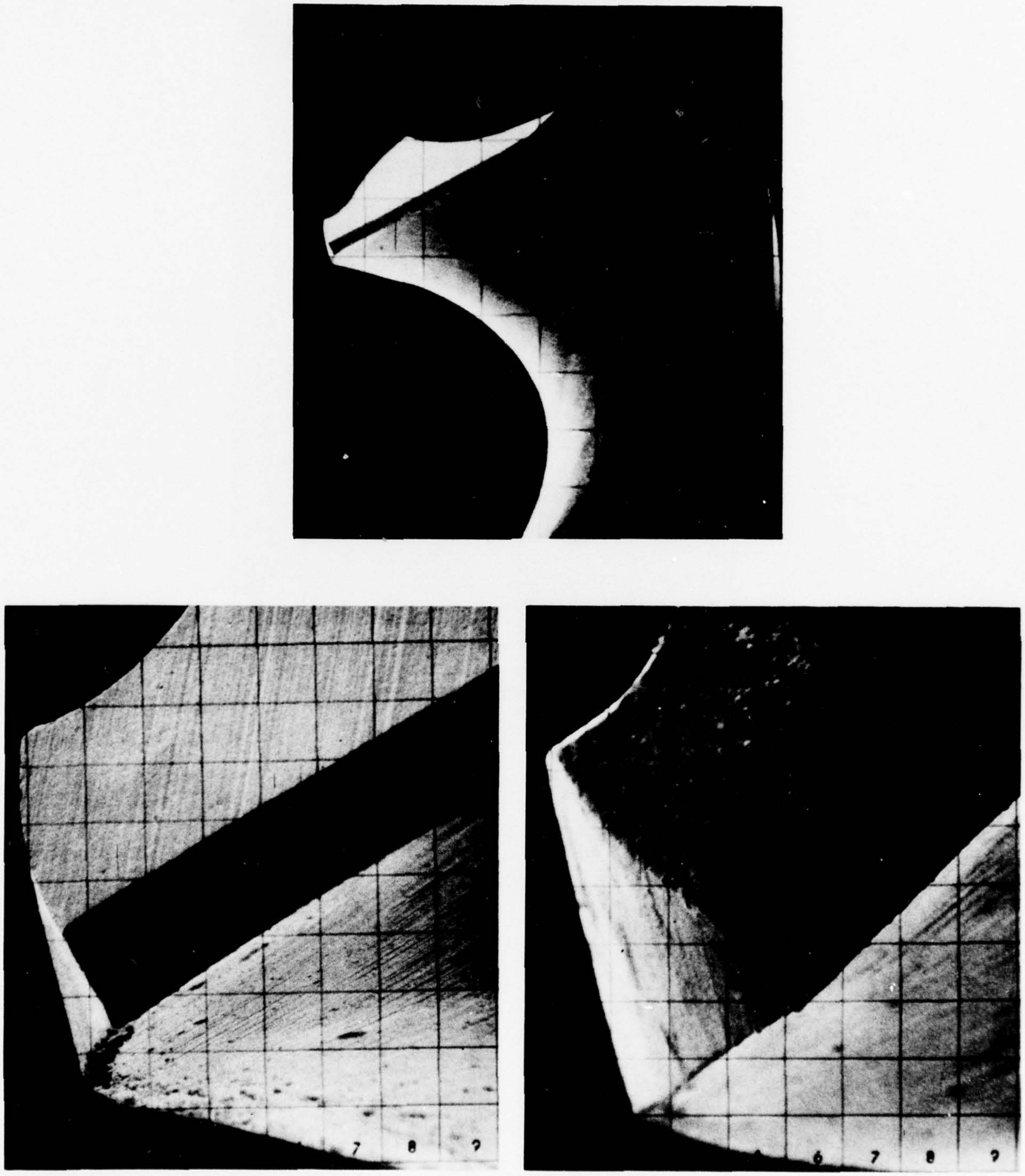


Figure B25. Micro Grade Drill – 140° Point, 15° Relief – Before

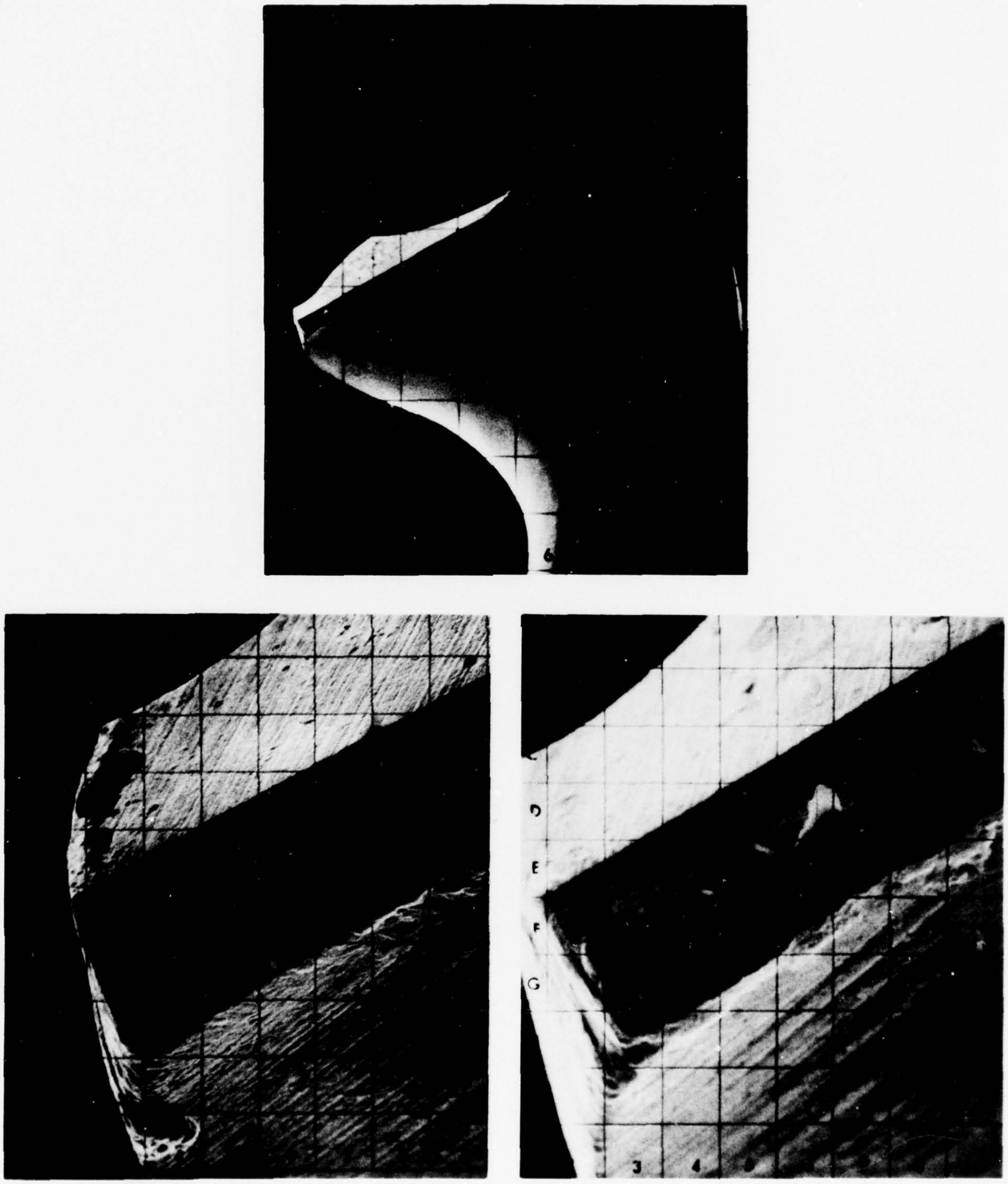


Figure B26. Micro Grade Drill – 140° Point, 15° Relief – After 4200 Hits

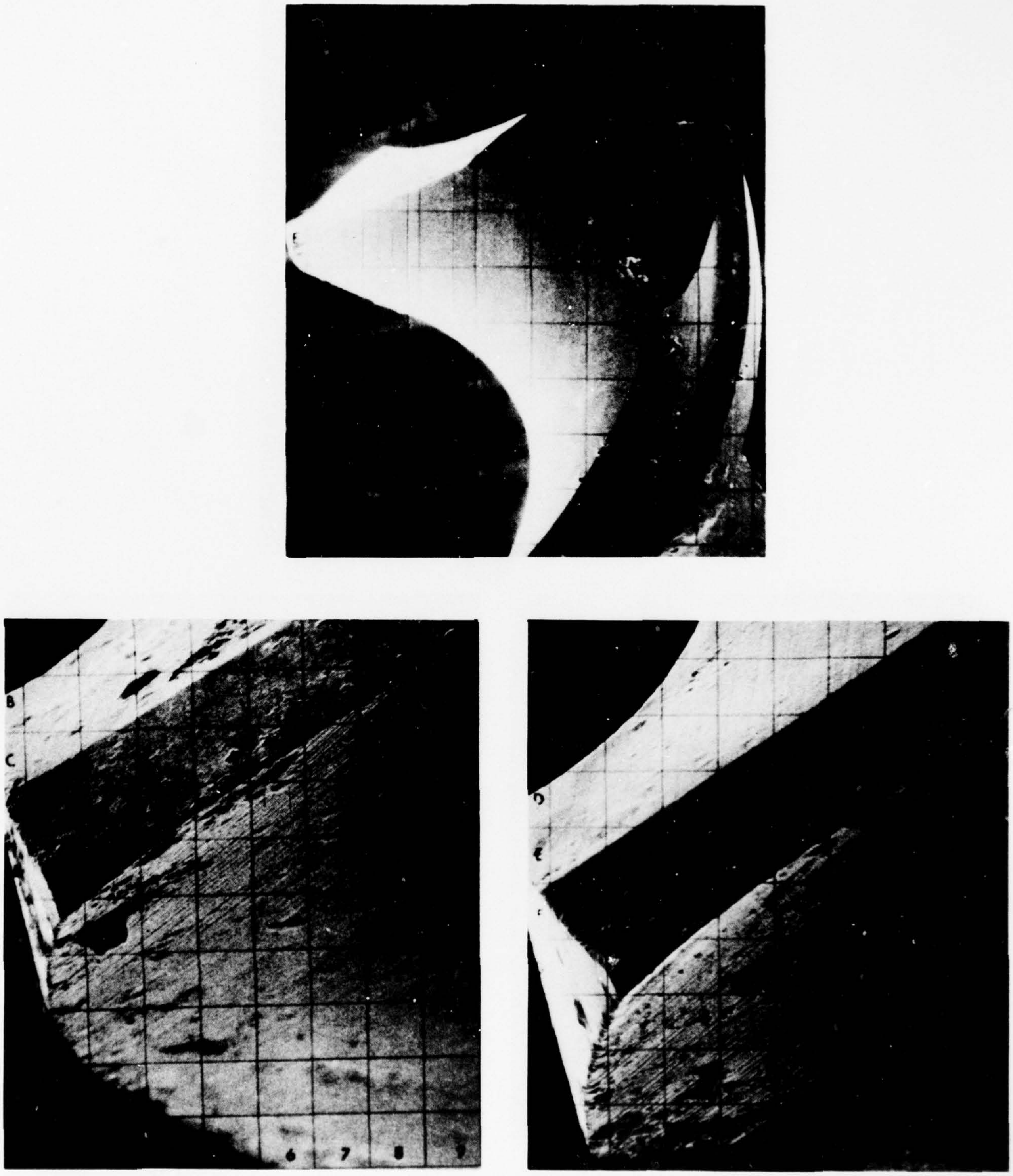


Figure B27. Micro Grade Drill – 140° Point, 20° Relief – Before

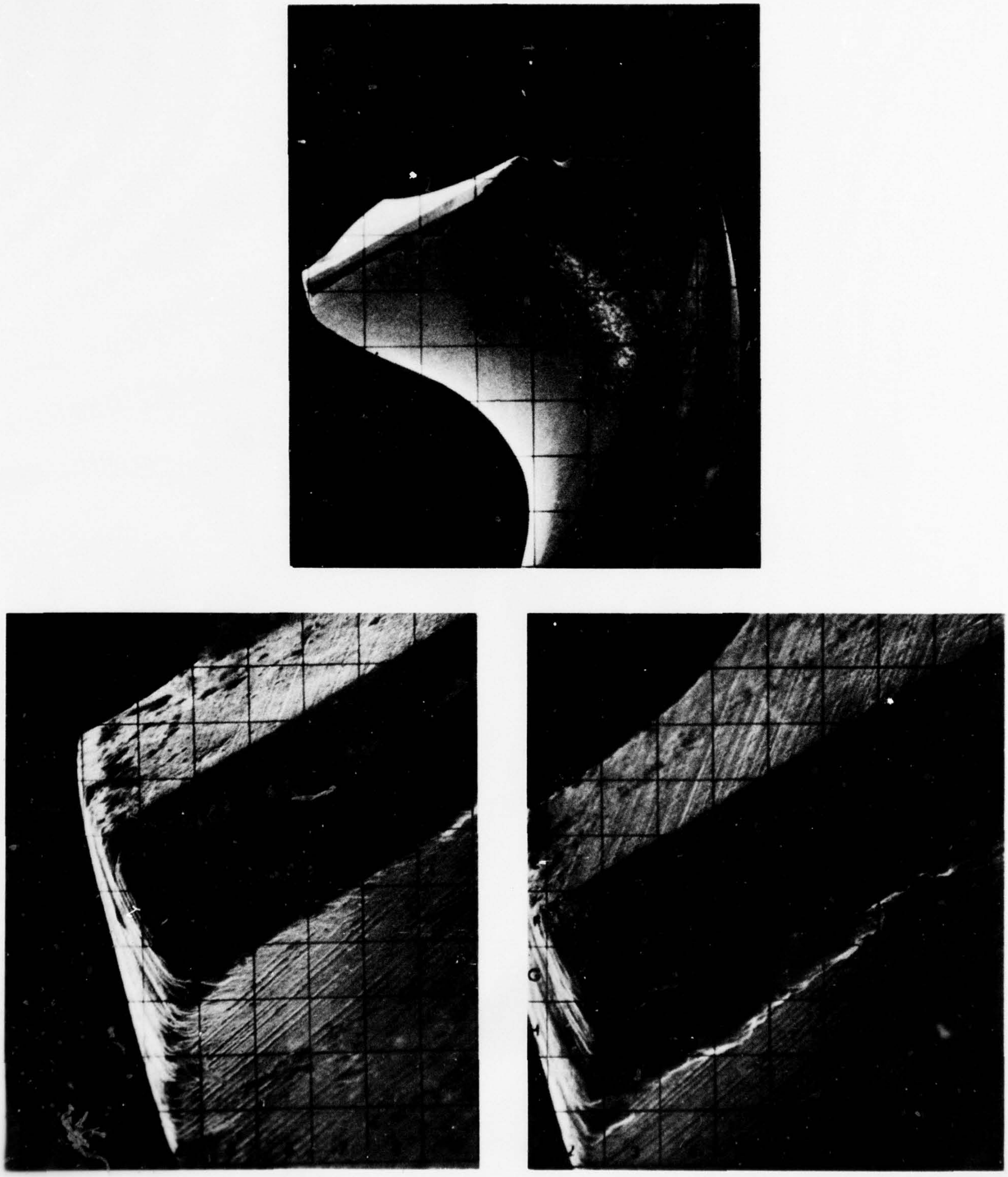
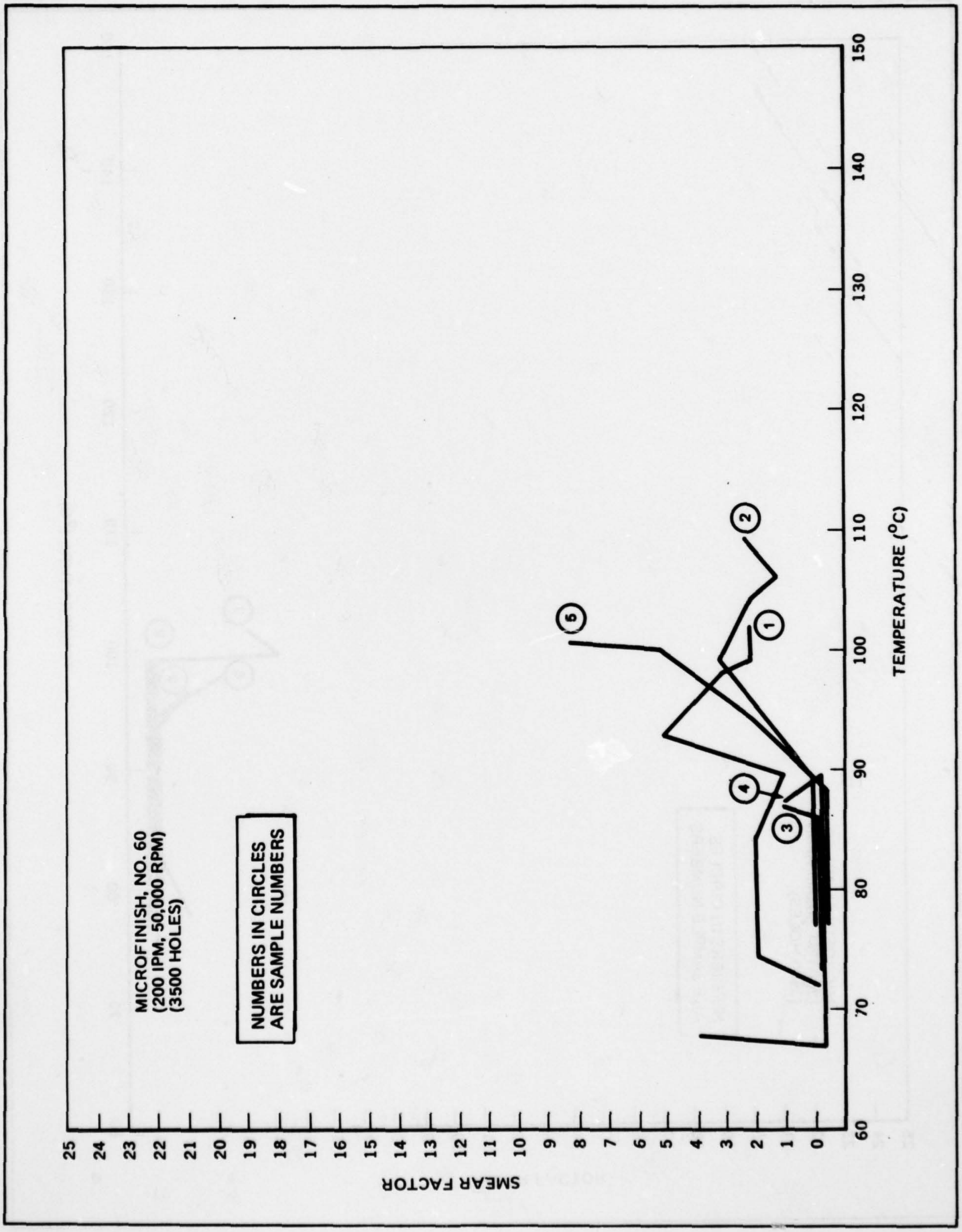


Figure B28. Micro Grade Drill – 140° Point, 20° Relief – After 4200 Hits

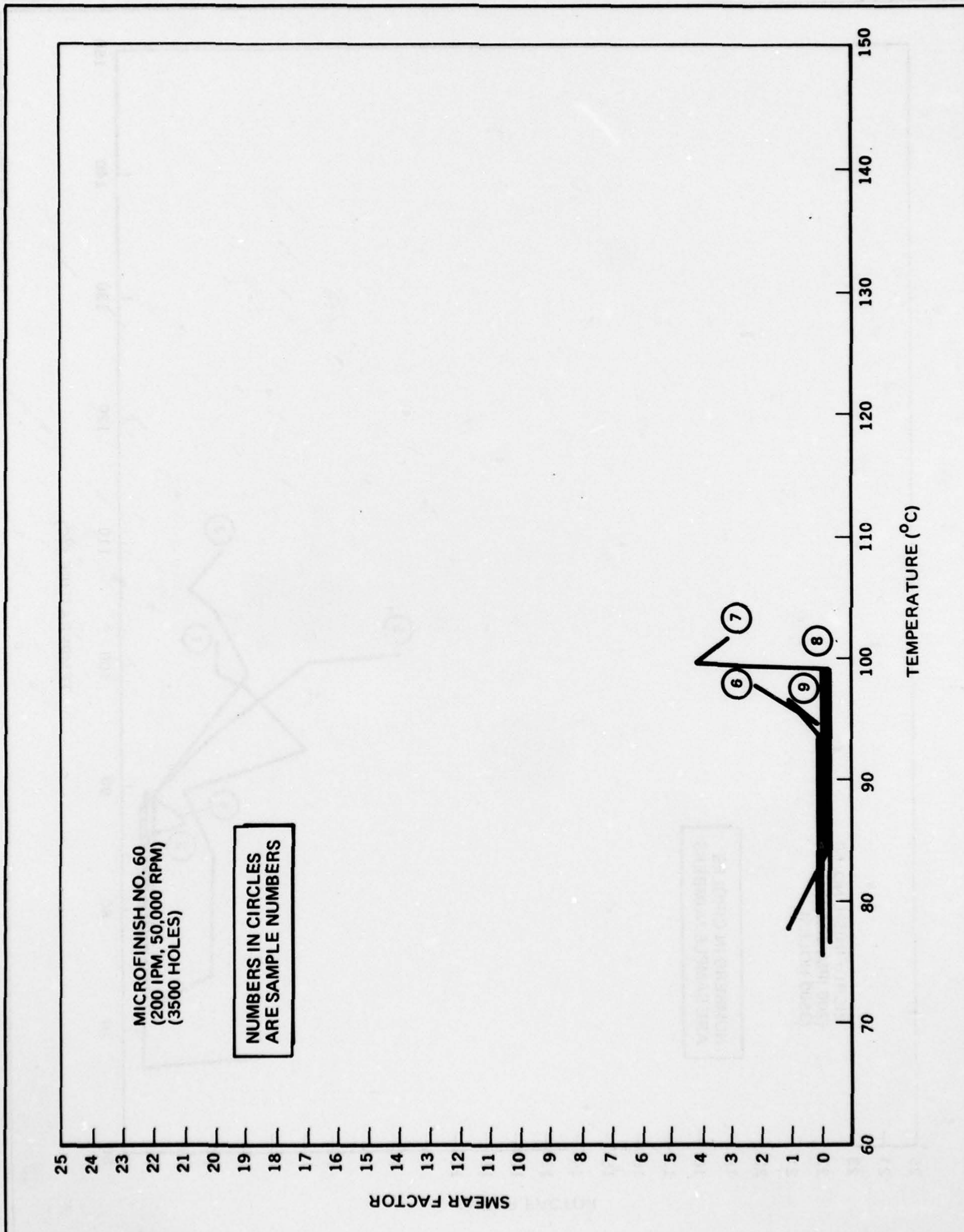
APPENDIX C

DRILL TEMPERATURE/SMEAR CORRELATION

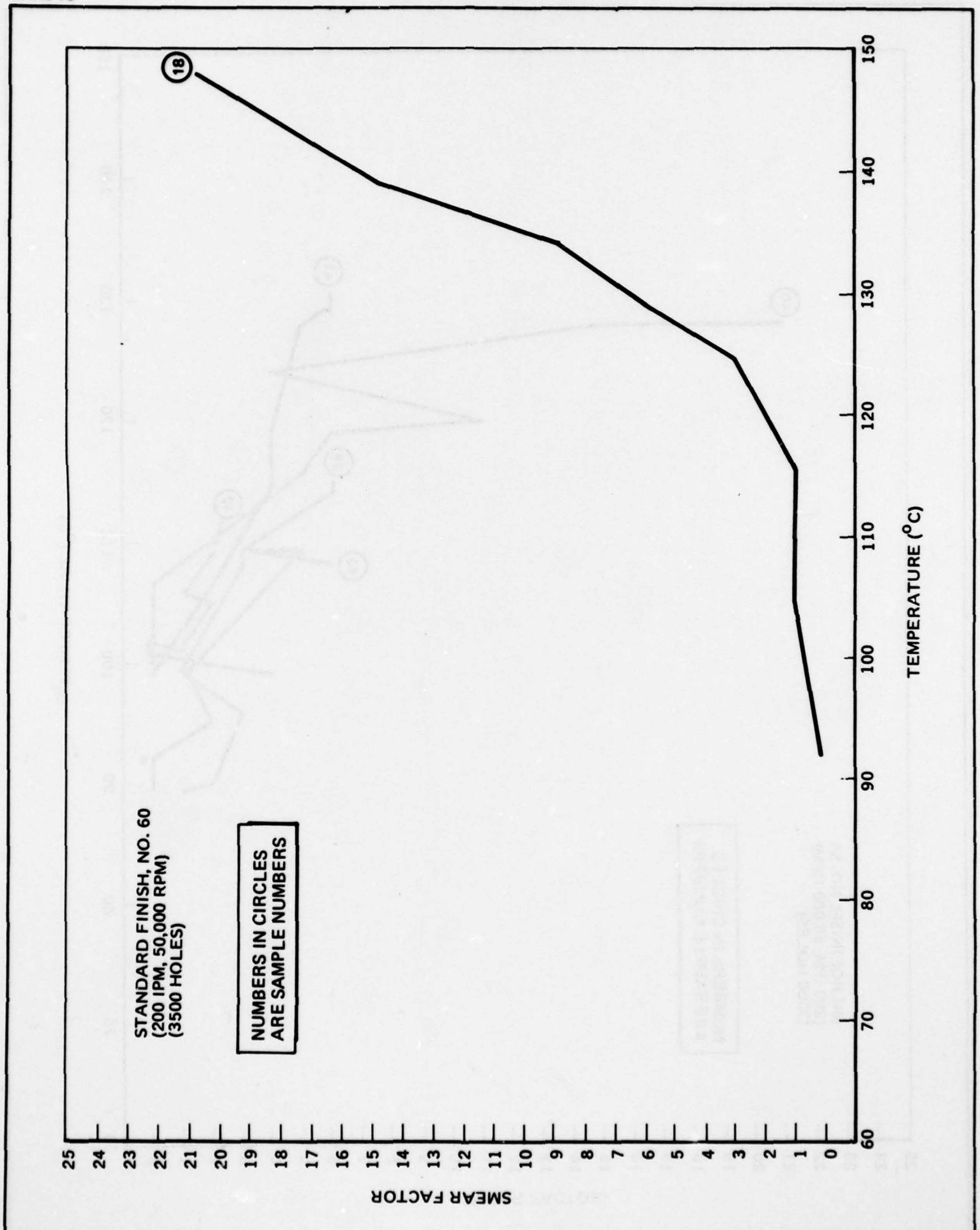
89349-76


MICROFINISH, NO. 60
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
SMEAR FACTOR
TEMPERATURE (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
60
70
80
90
100
110
120
130
140
150
1
2
3
4
5

89349-77

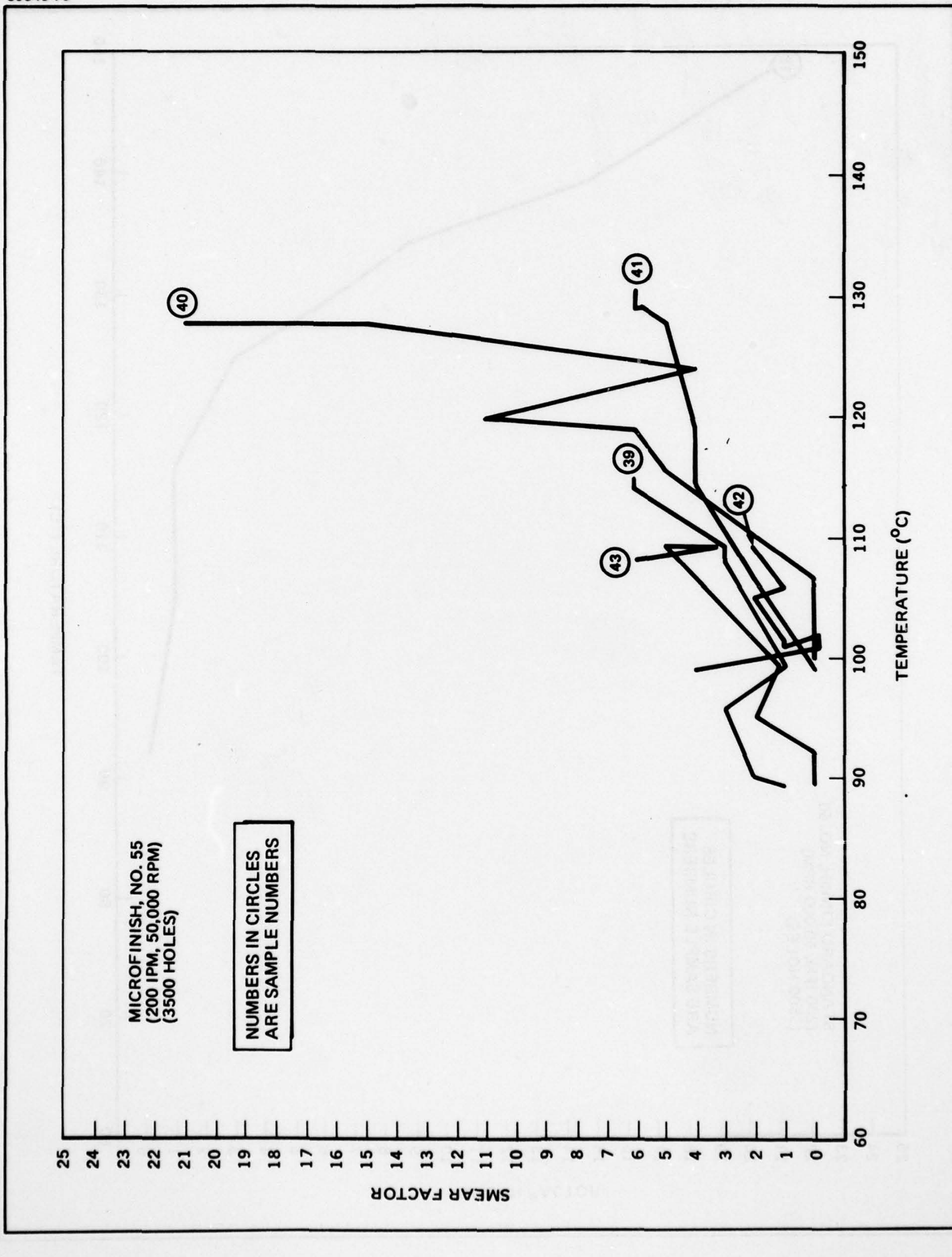

MICROFINISH NO. 60
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
SMEAR FACTOR
TEMPERATURE (°C)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
60 70 80 90 100 110 120 130 140 150
6
7
8
9

89349-78

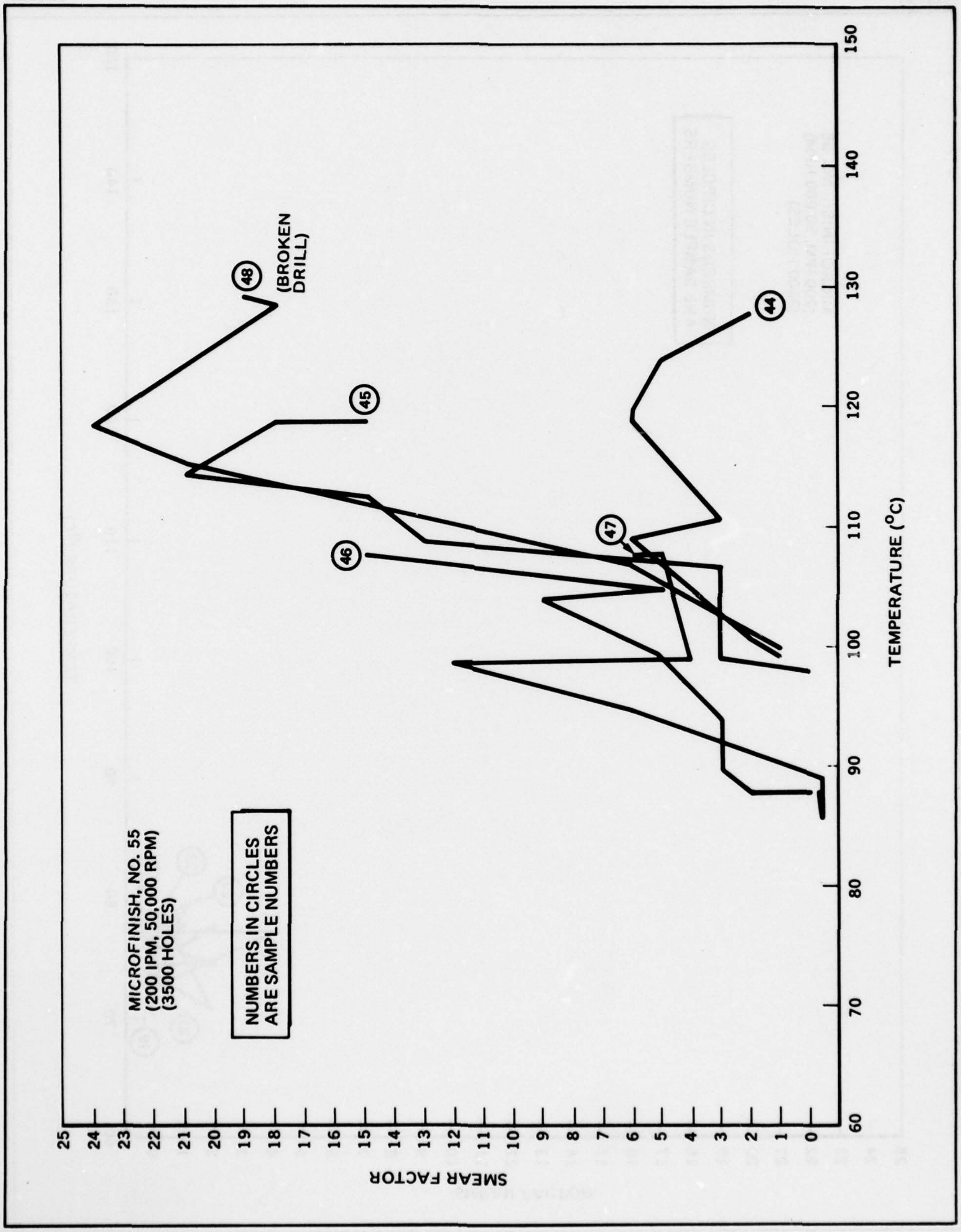

SMEAR FACTOR
TEMPERATURE (°C)
STANDARD FINISH, NO. 60
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
60 70 80 90 100 110 120 130 140 150

Appendix C – Drill Temperature/Smear Correlation

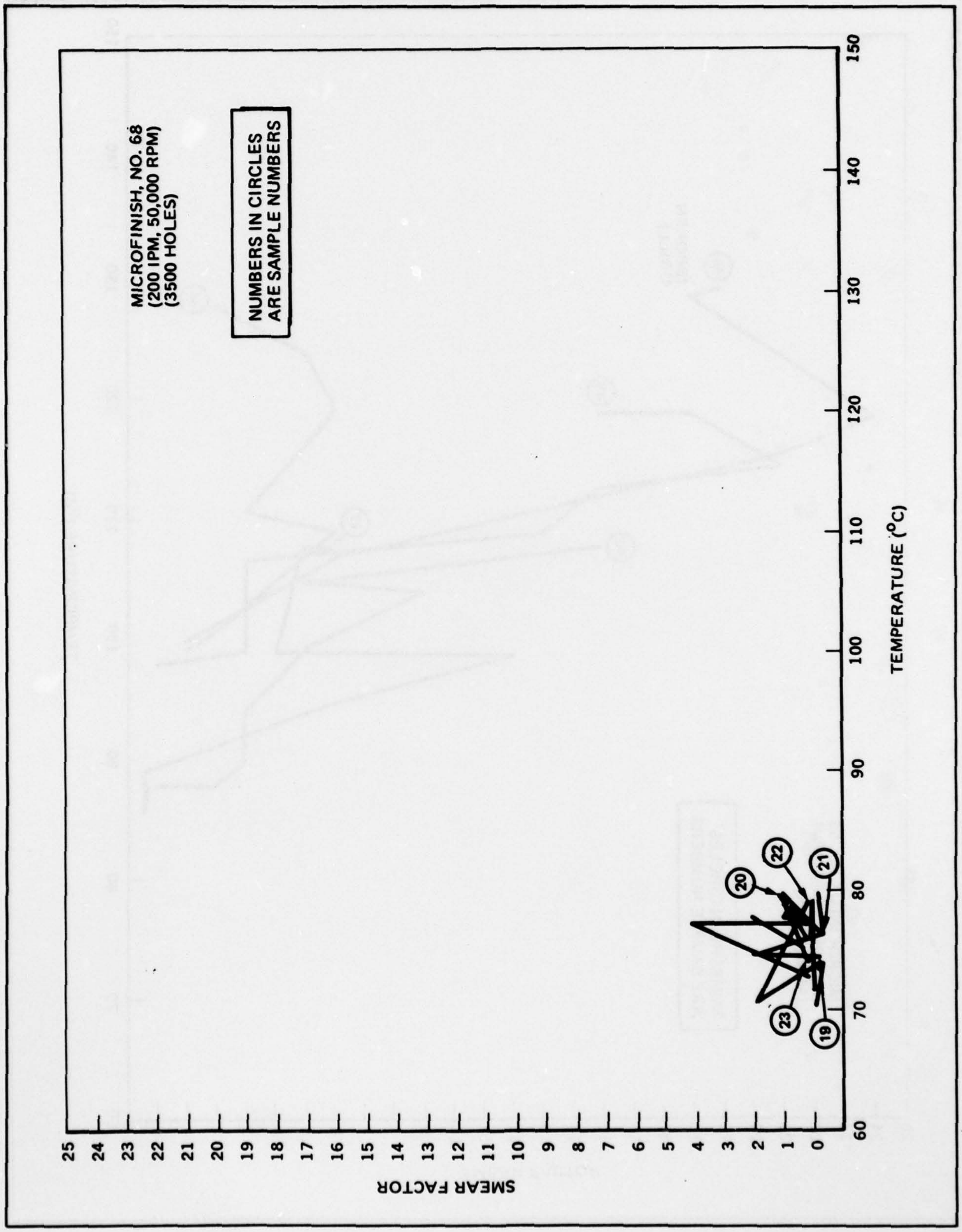
89349-79



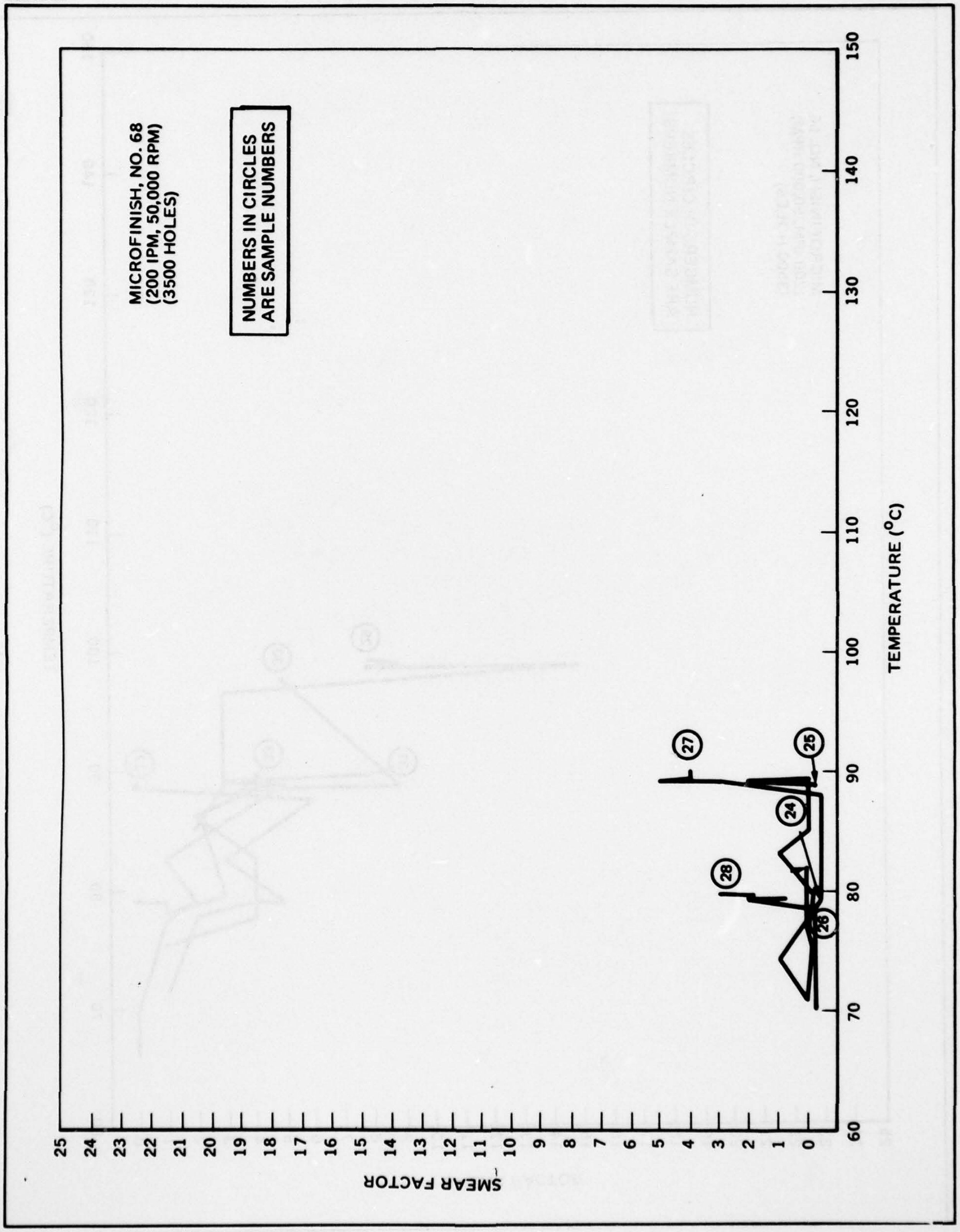
89349-80


MICROFINISH, NO. 55
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
48
(BROKEN
DRILL)
45
44
46
47
SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
TEMPERATURE (°C)
60
70
80
90
100
110
120
130
140
150

89349-81

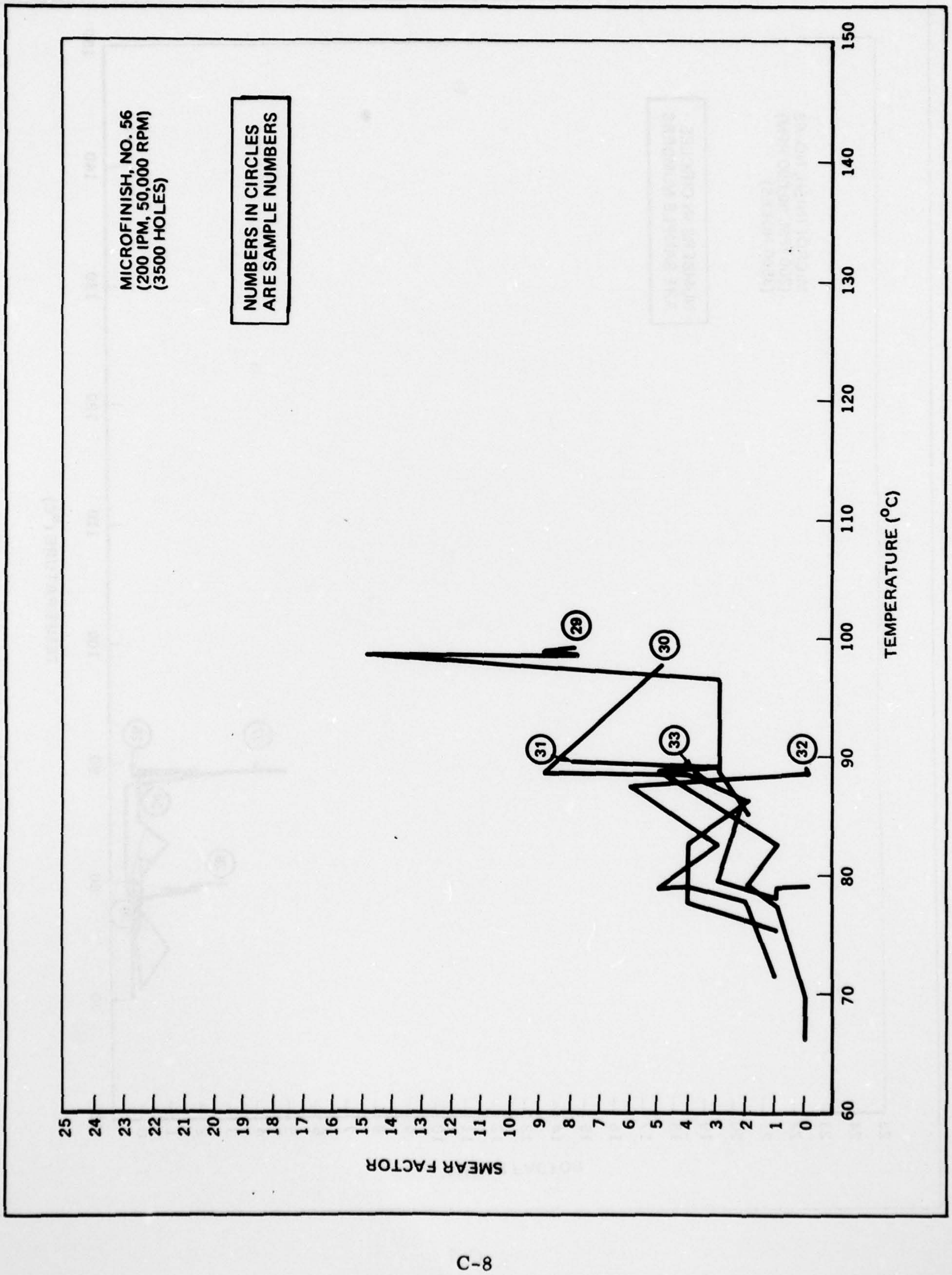

MICROFINISH, NO. 68
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
SMEAR FACTOR
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
TEMPERATURE (°C)
60 70 80 90 100 110 120 130 140 150
19
20
21
22
23

89349-82

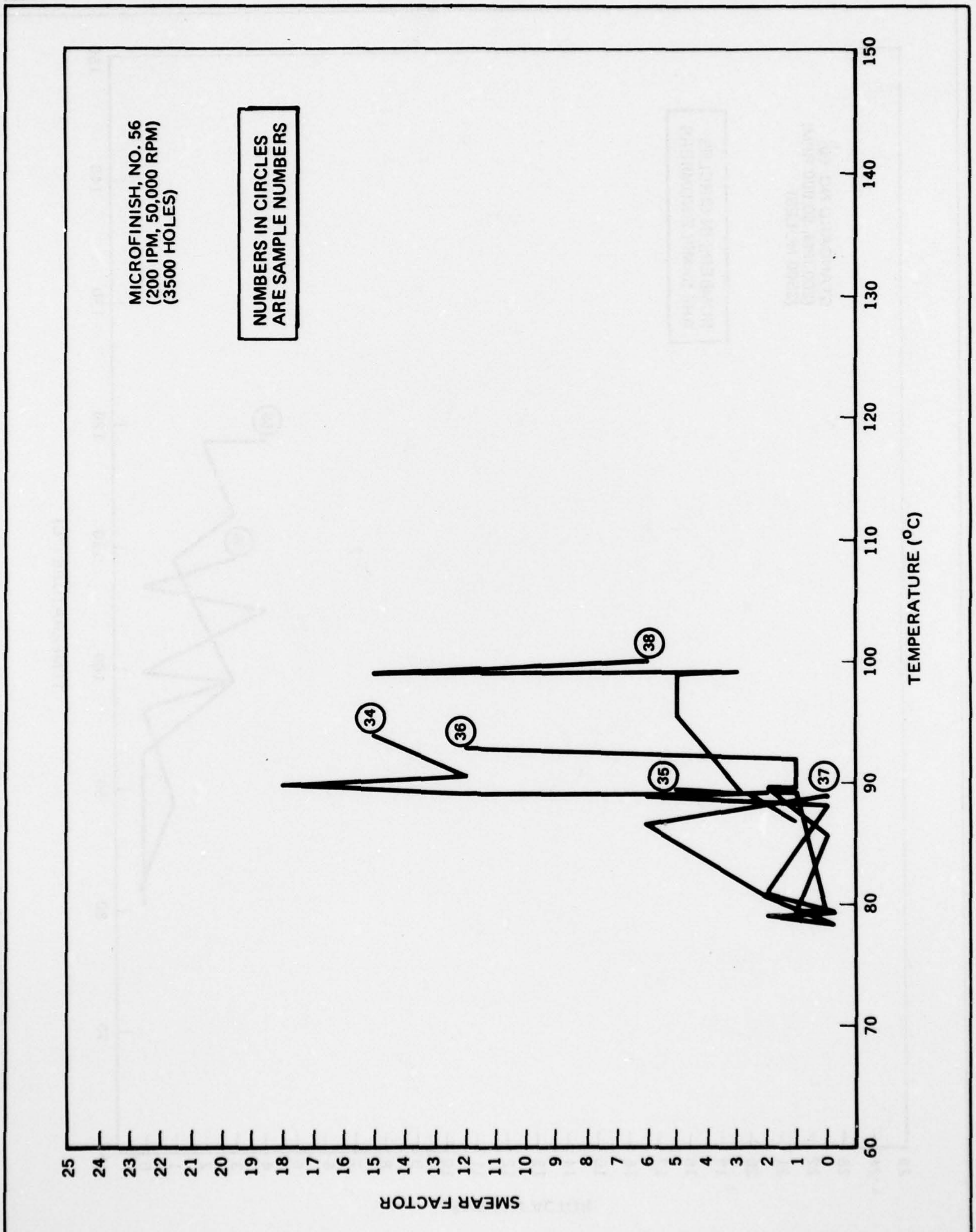

SMEAR FACTOR
TEMPERATURE (°C)
MICROFINISH, NO. 68
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
60 70 80 90 100 110 120 130 140 150
24
25
26
27
28

Appendix C – Drill Temperature/Smear Correlation

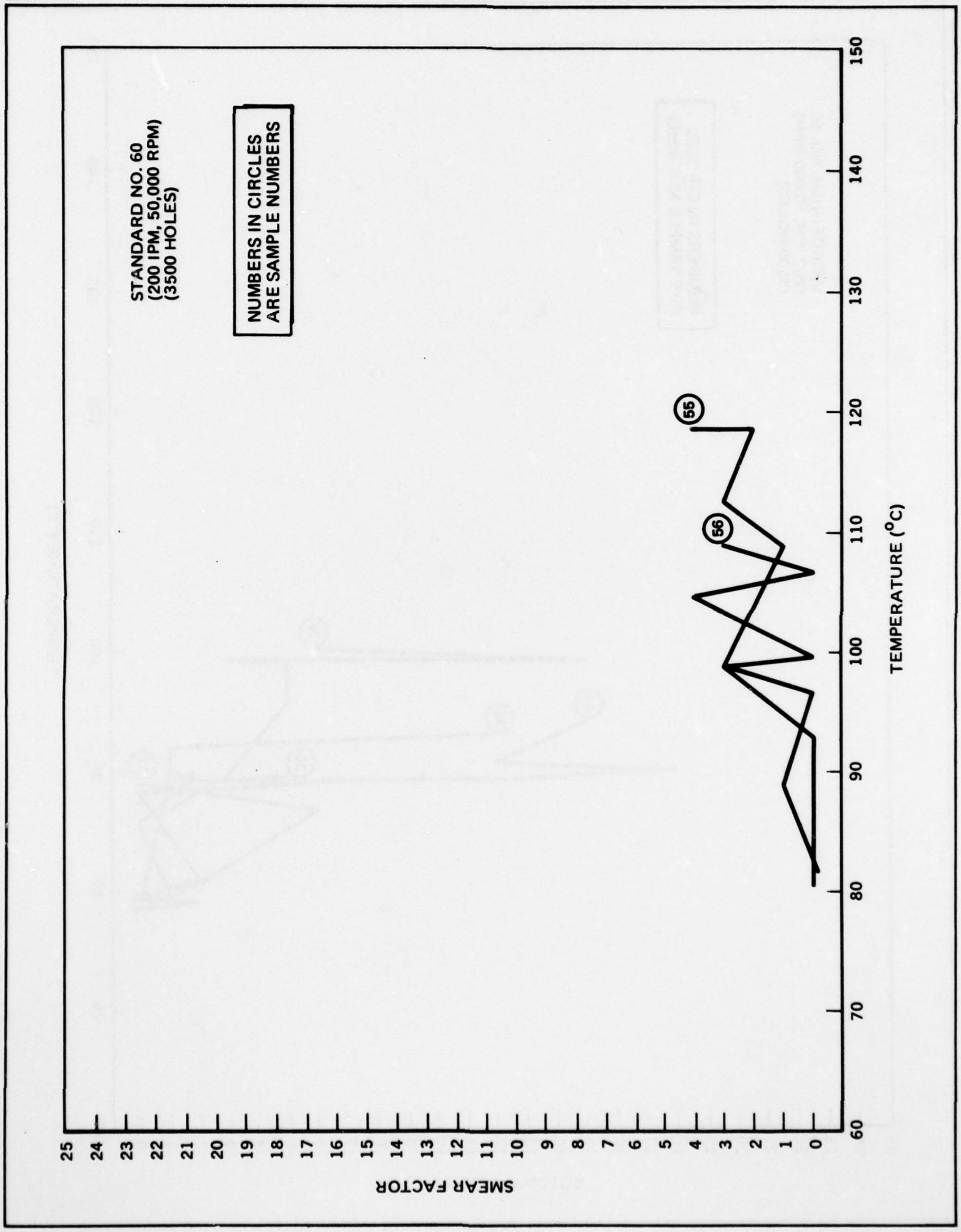
89349-83



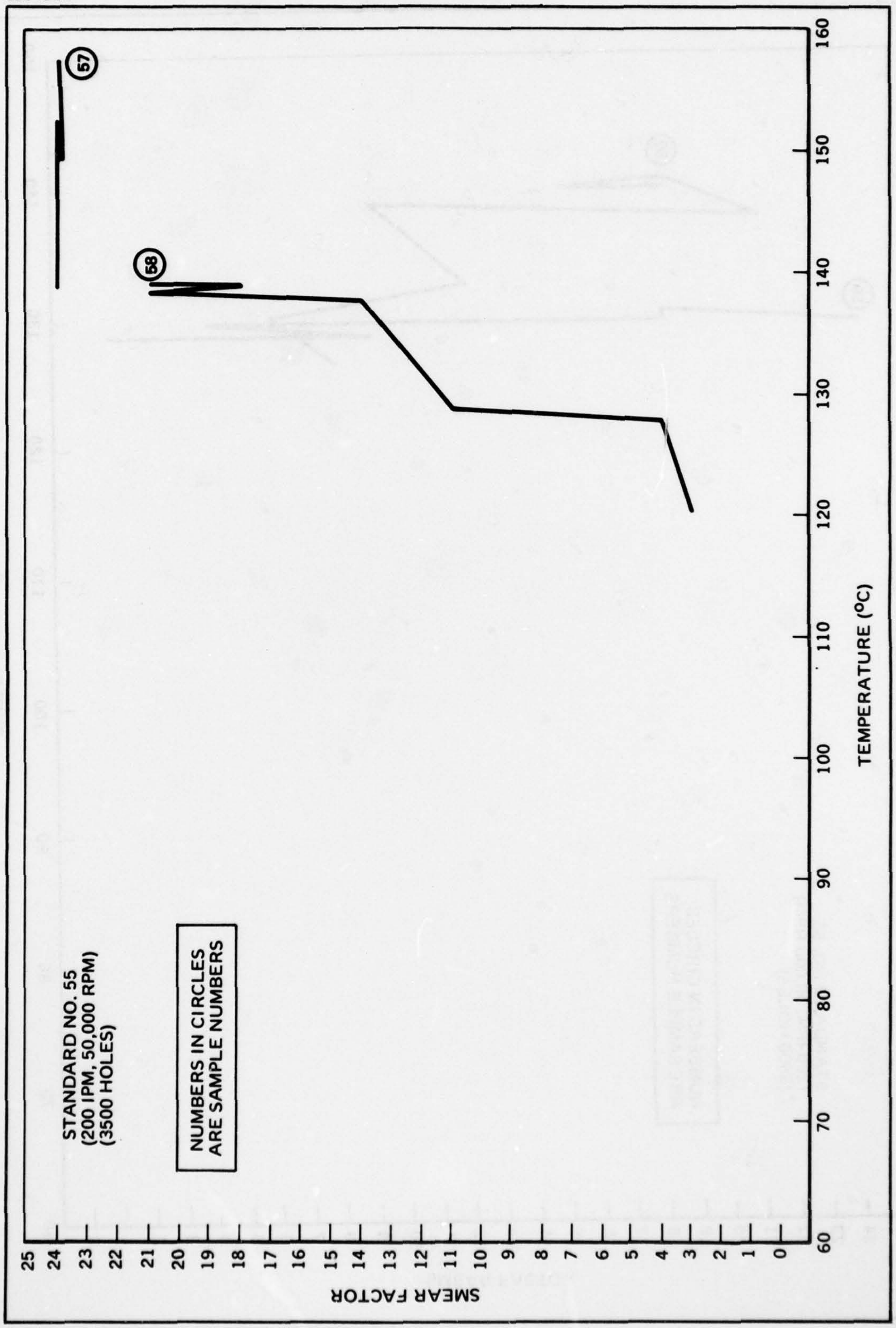
89349-84


MICROFINISH, NO. 56
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
TEMPERATURE (°C)
60
70
80
90
100
110
120
130
140
150
34
35
36
37
38

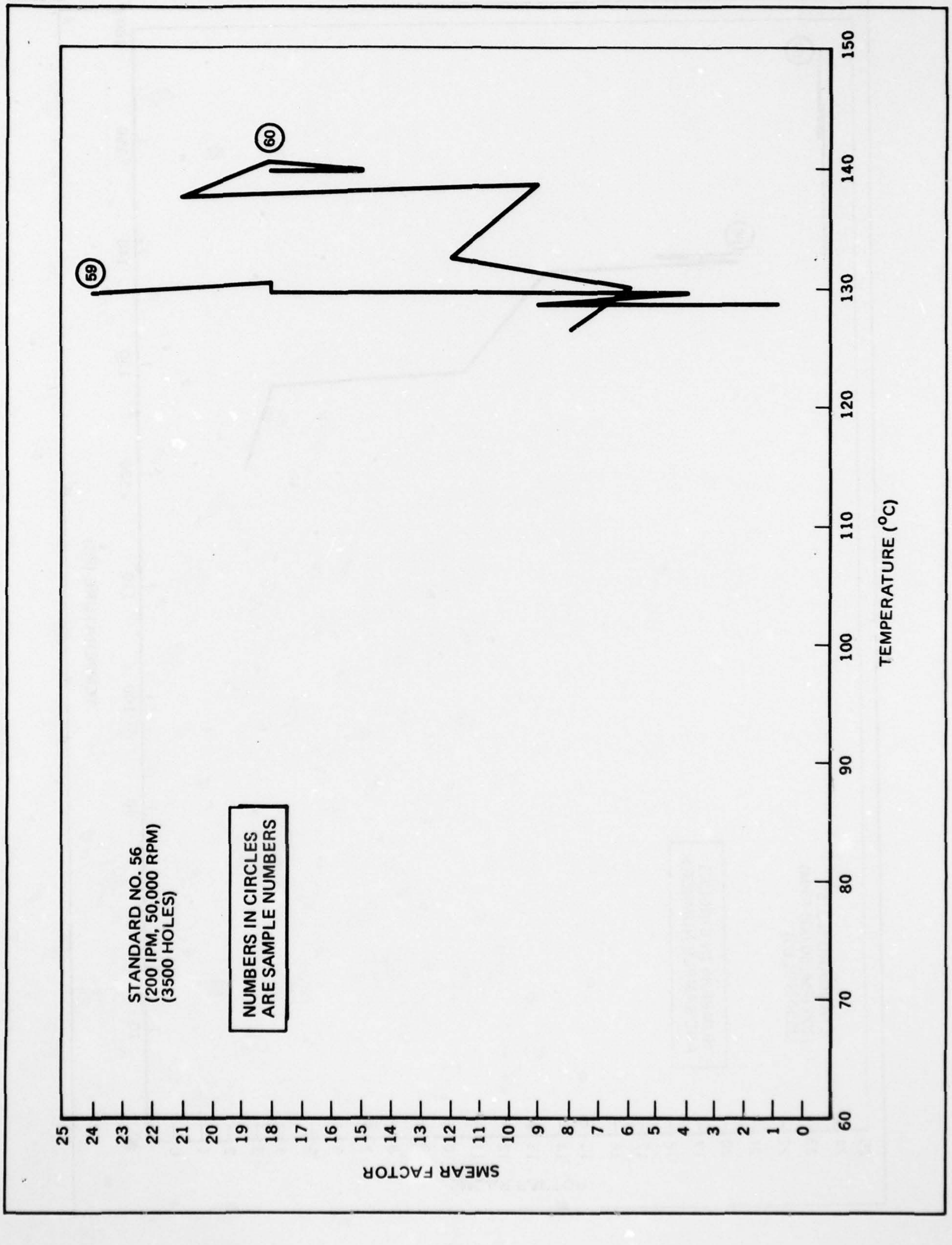
89349-85


STANDARD NO. 60
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
55
56
SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
TEMPERATURE (°C)
60
70
80
90
100
110
120
130
140
150

89349-86

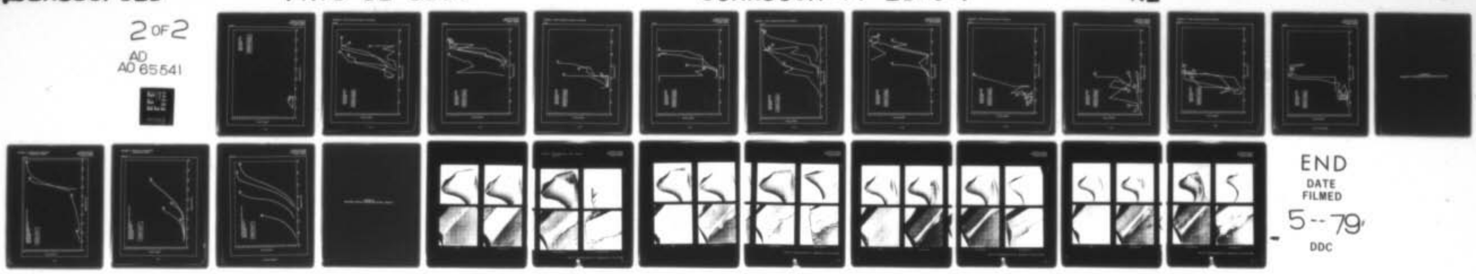

SMEAR FACTOR
TEMPERATURE (°C)
STANDARD NO. 55
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
57
58
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
60 70 80 90 100 110 120 130 140 150 160

89349-87

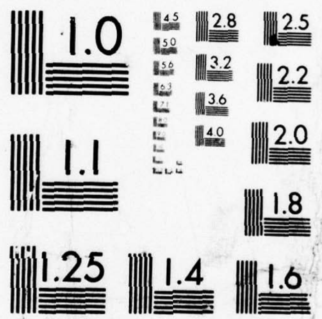

STANDARD NO. 56
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
59
60
SMEAR FACTOR
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
TEMPERATURE (°C)
60 70 80 90 100 110 120 130 140 150

AD-A065 541 HUGHES AIRCRAFT CO FULLERTON CALIF F/G 14/2
DRILL PARAMETER STUDY.(U)
JAN 79 J QUINTANA, T WEISMULLER DAAB07-77-C-2640
UNCLASSIFIED FR78-12-1275 CORADCOM-77-2640-F NL

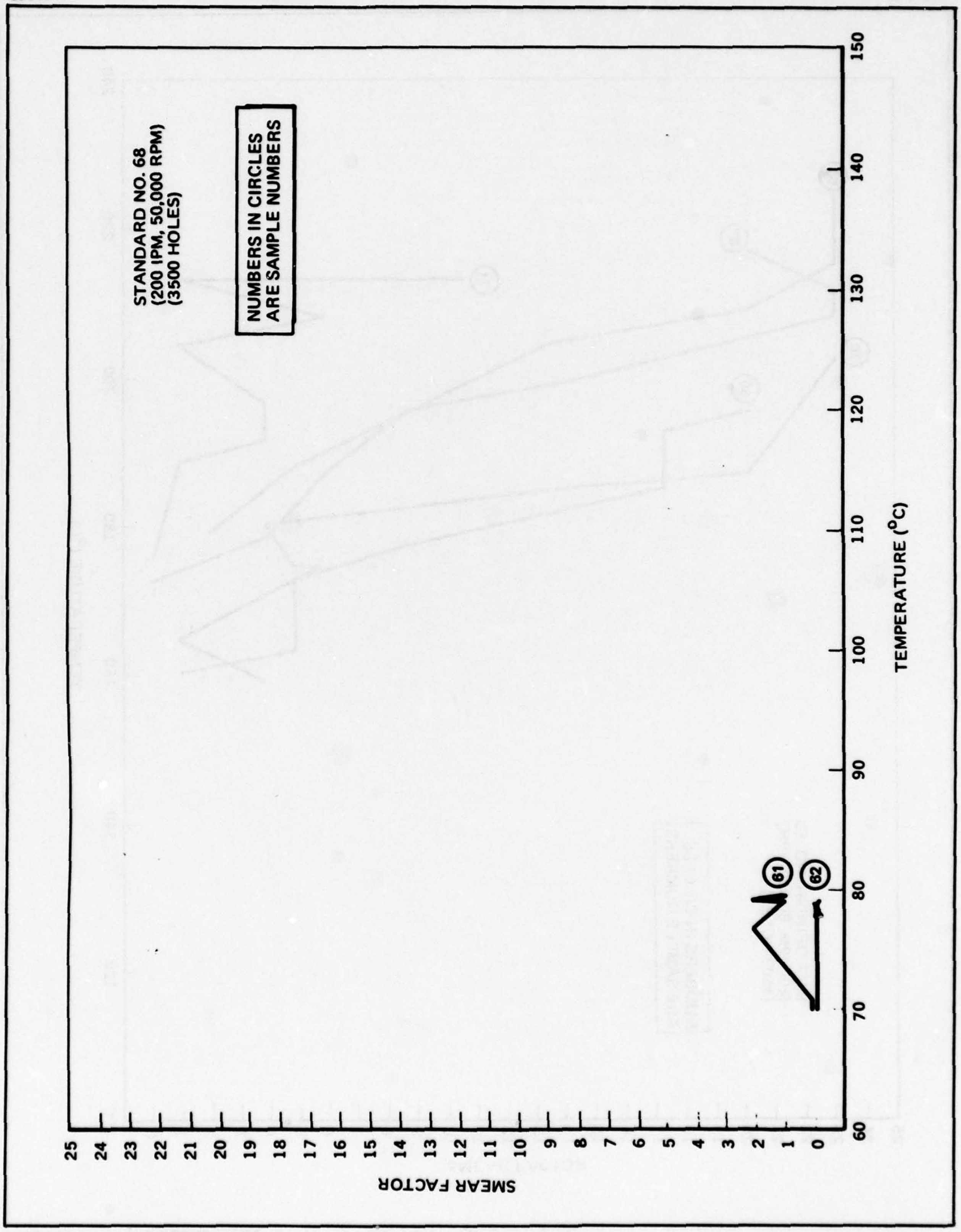
2 OF 2
AD A065541



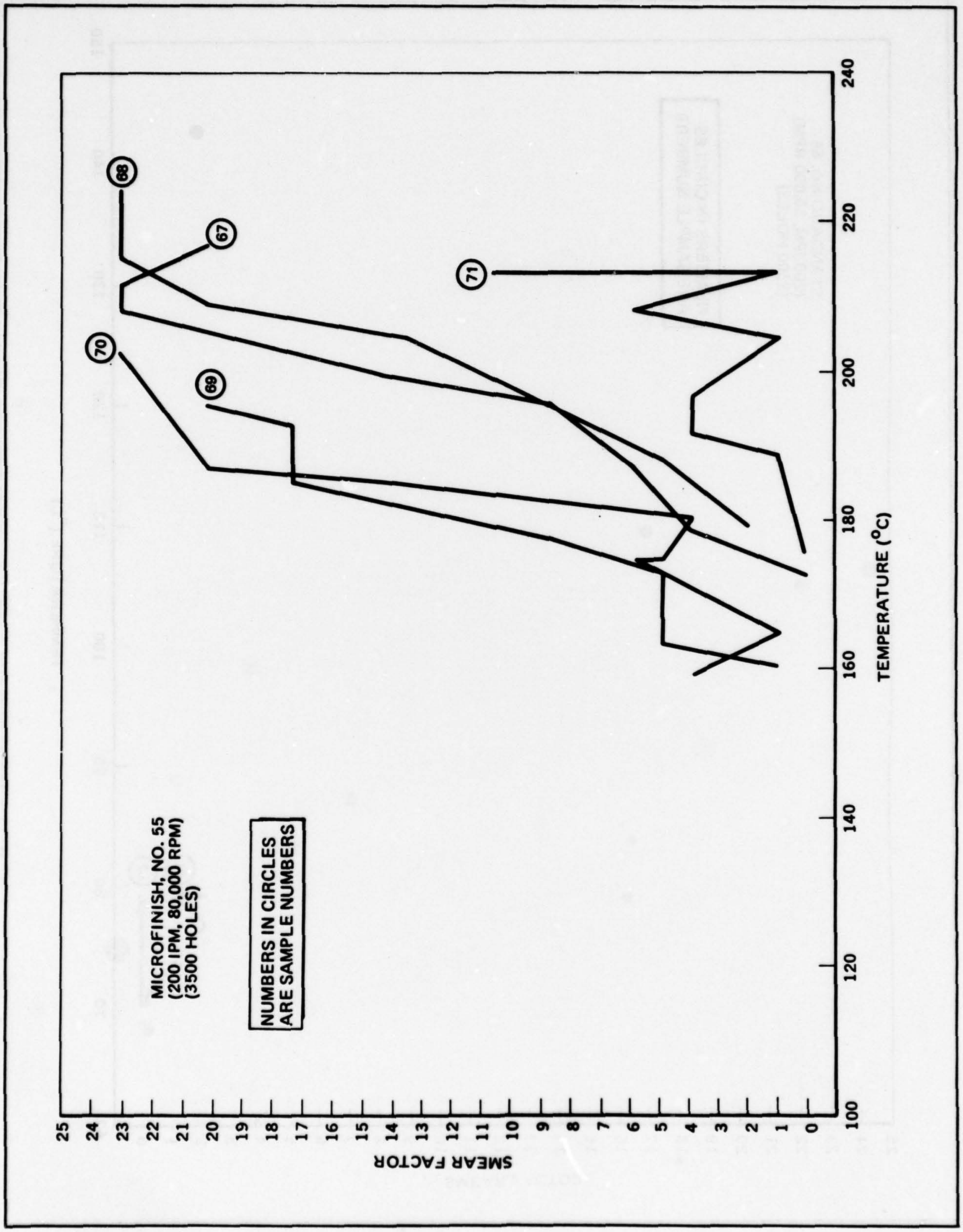
END
DATE FILMED
5-79
DDC


1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

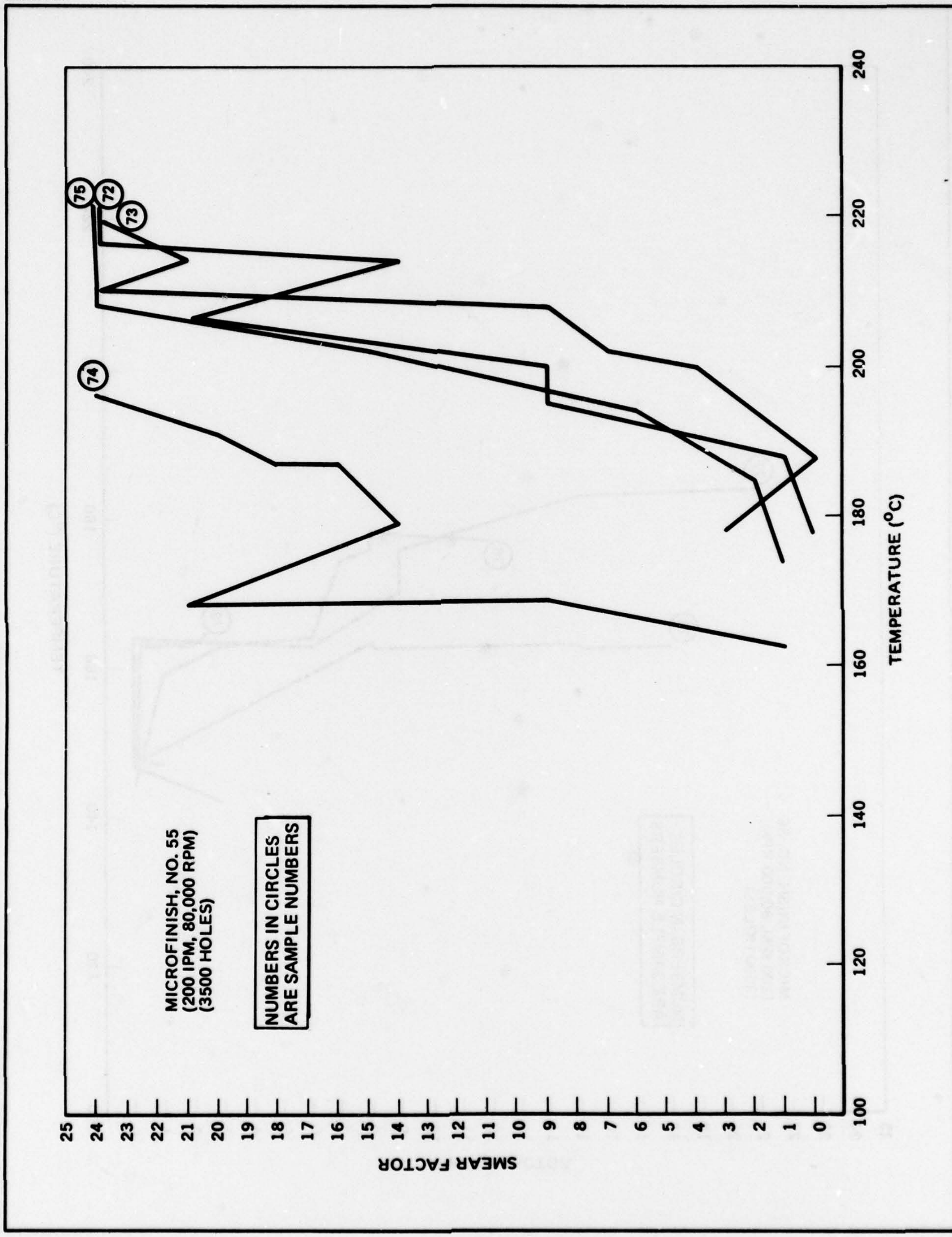
89349-88


STANDARD NO. 68
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
61
62
TEMPERATURE (°C)
60 70 80 90 100 110 120 130 140 150
SMEAR FACTOR
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

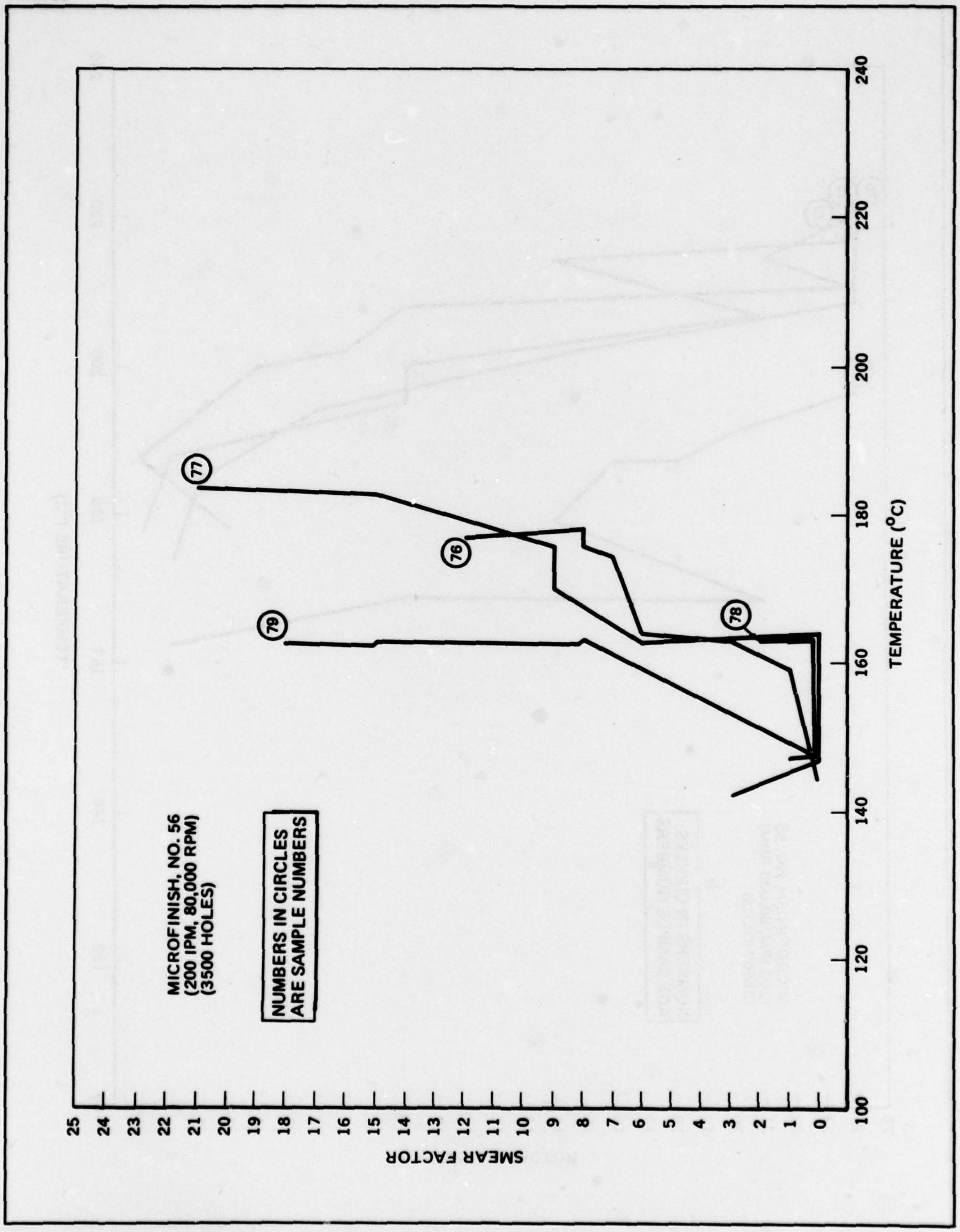
89349-89


MICROFINISH, NO. 55
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
SMEAR FACTOR
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
TEMPERATURE (°C)
100 120 140 160 180 200 220 240
67
68
69
70
71

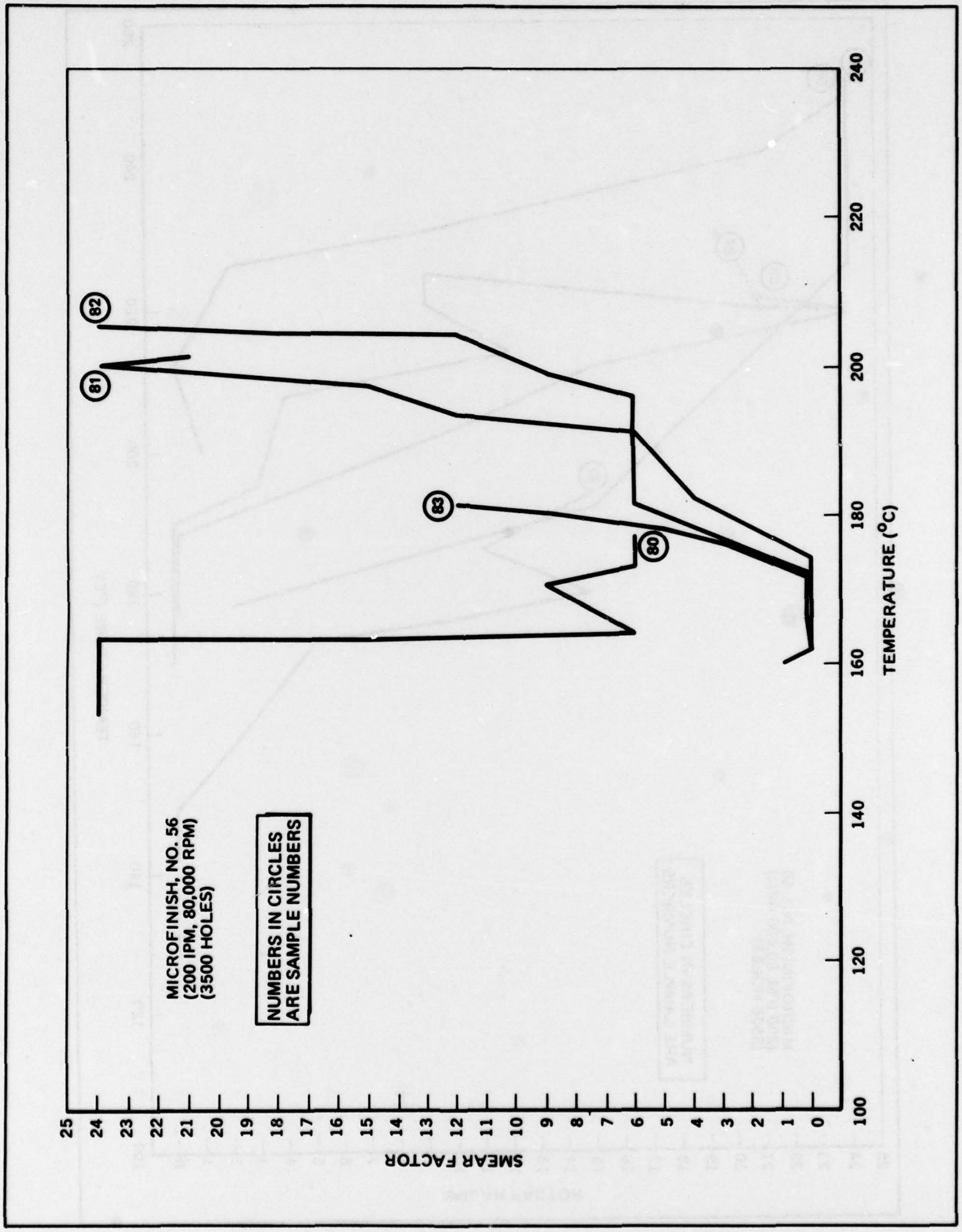
89349-90


MICROFINISH, NO. 55
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
SMEAR FACTOR
TEMPERATURE (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
100
120
140
160
180
200
220
240
72
73
74
75

89349-91

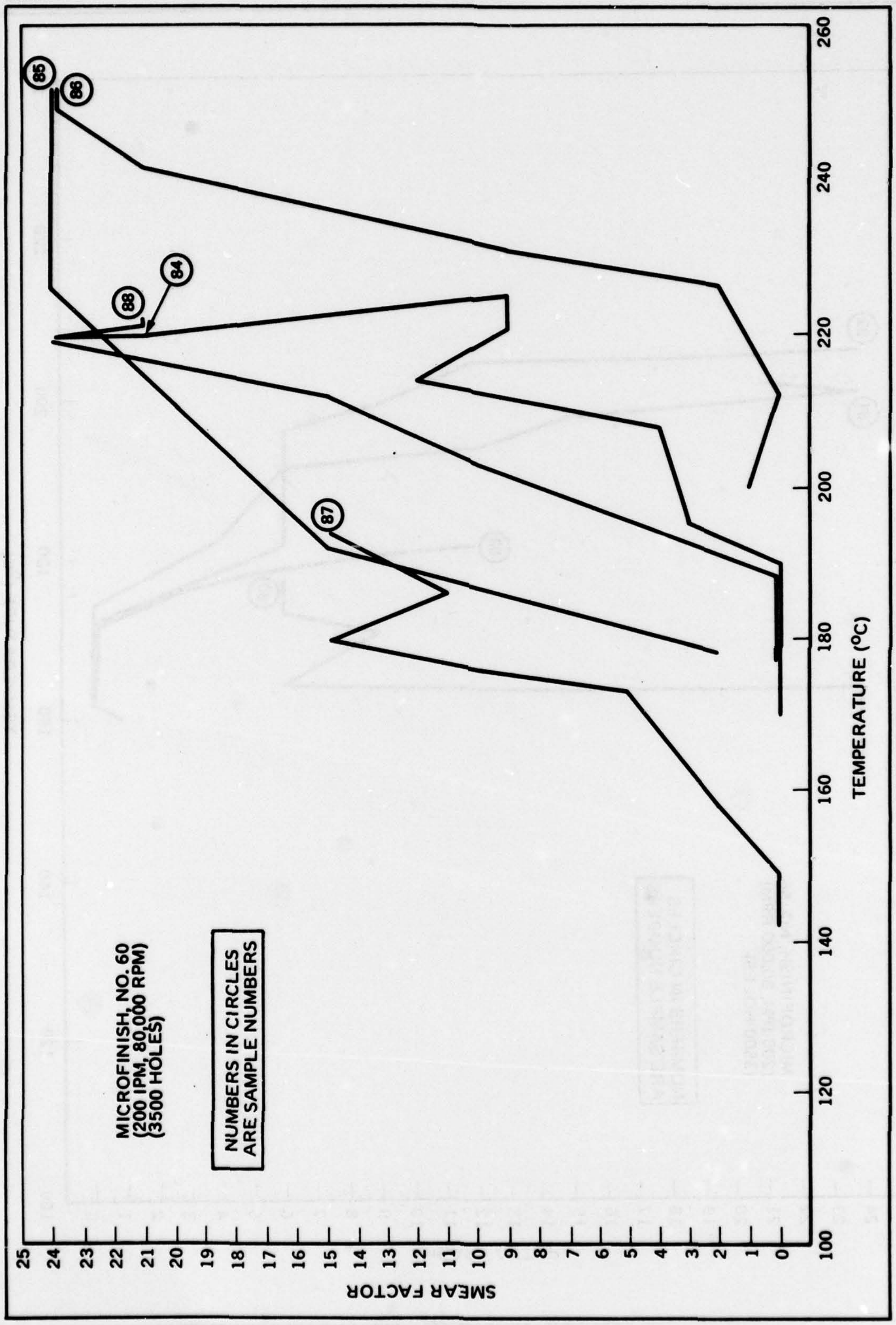

MICROFINISH, NO. 56
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
77
76
78
79
TEMPERATURE (°C)
100
120
140
160
180
200
220
240
SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

89349-92

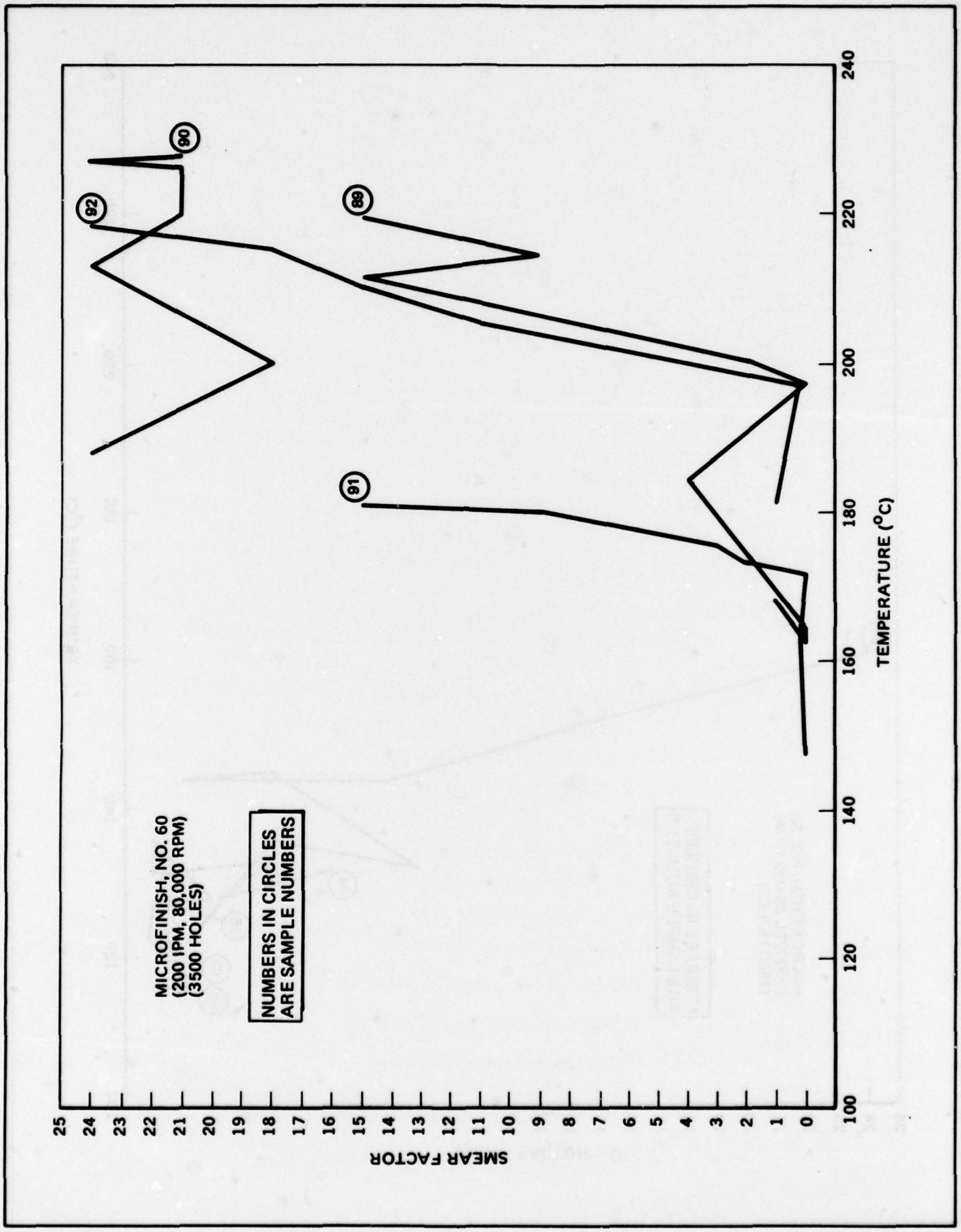

MICROFINISH, NO. 56
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
SMEAR FACTOR
TEMPERATURE (°C)
80
81
82
83
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
100
120
140
160
180
200
220
240

Appendix C – Drill Temperature/Smear Correlation

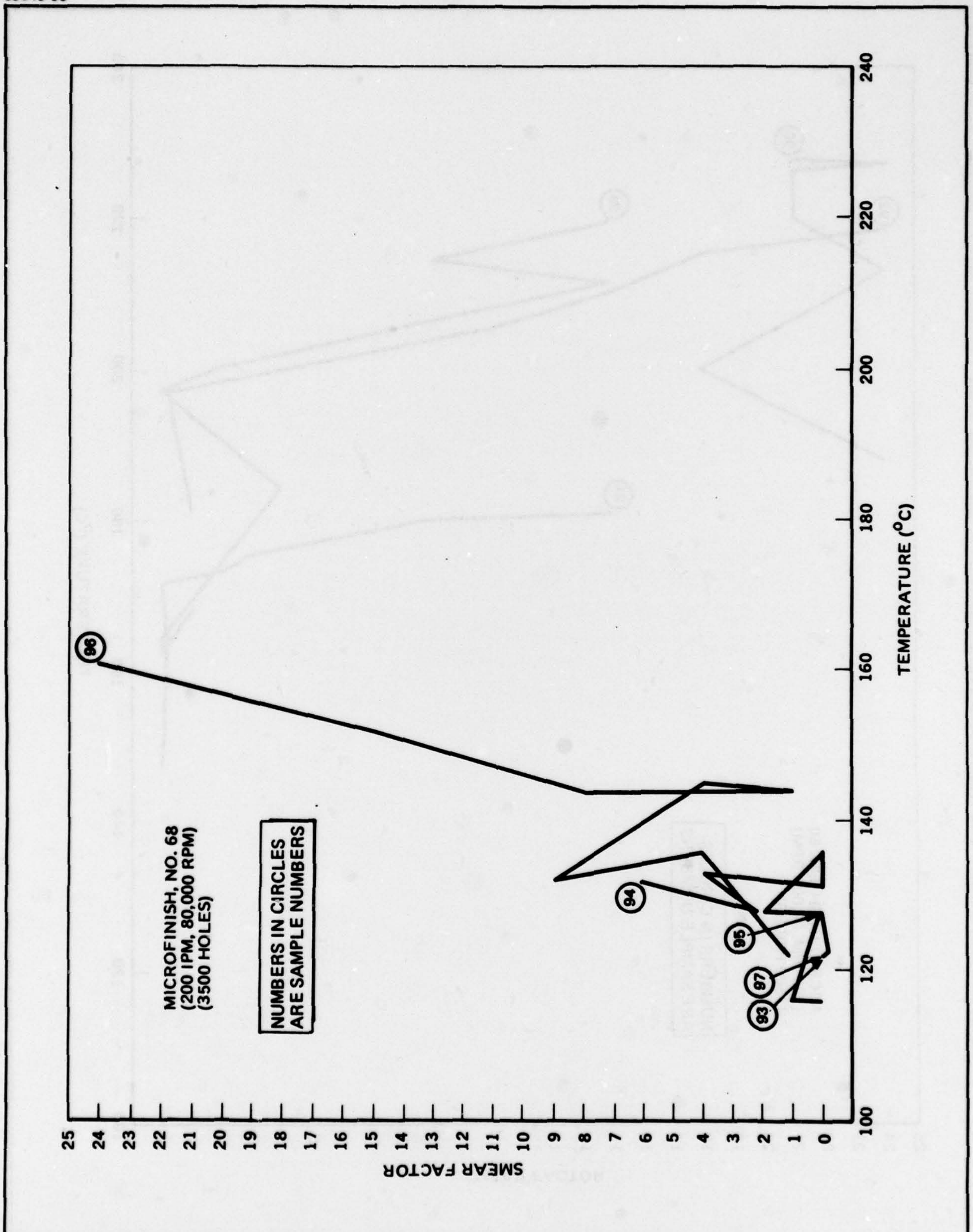
89349-93



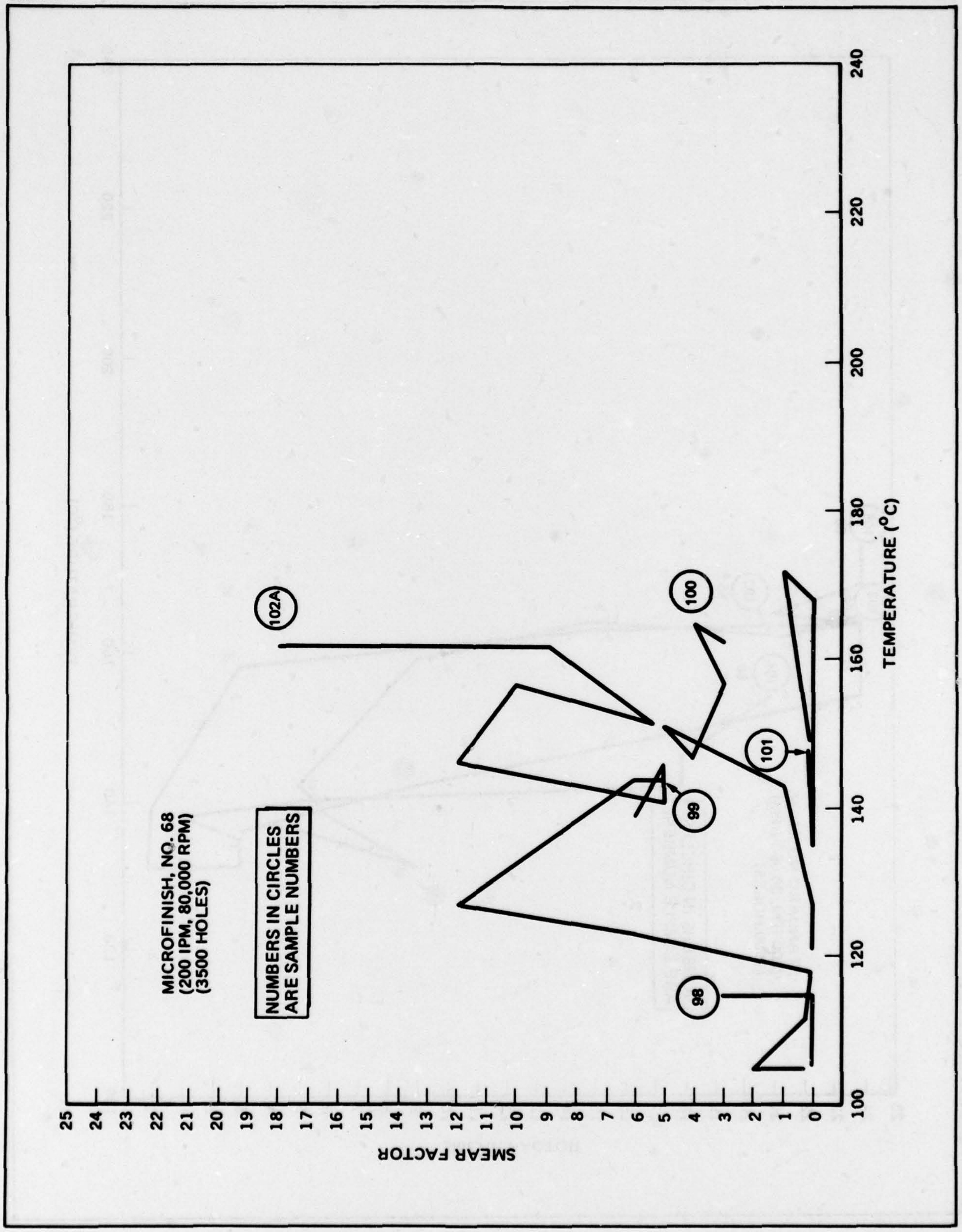
89349-94


MICROFINISH, NO. 60
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
90
92
89
91
SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
TEMPERATURE (°C)
100
120
140
160
180
200
220
240

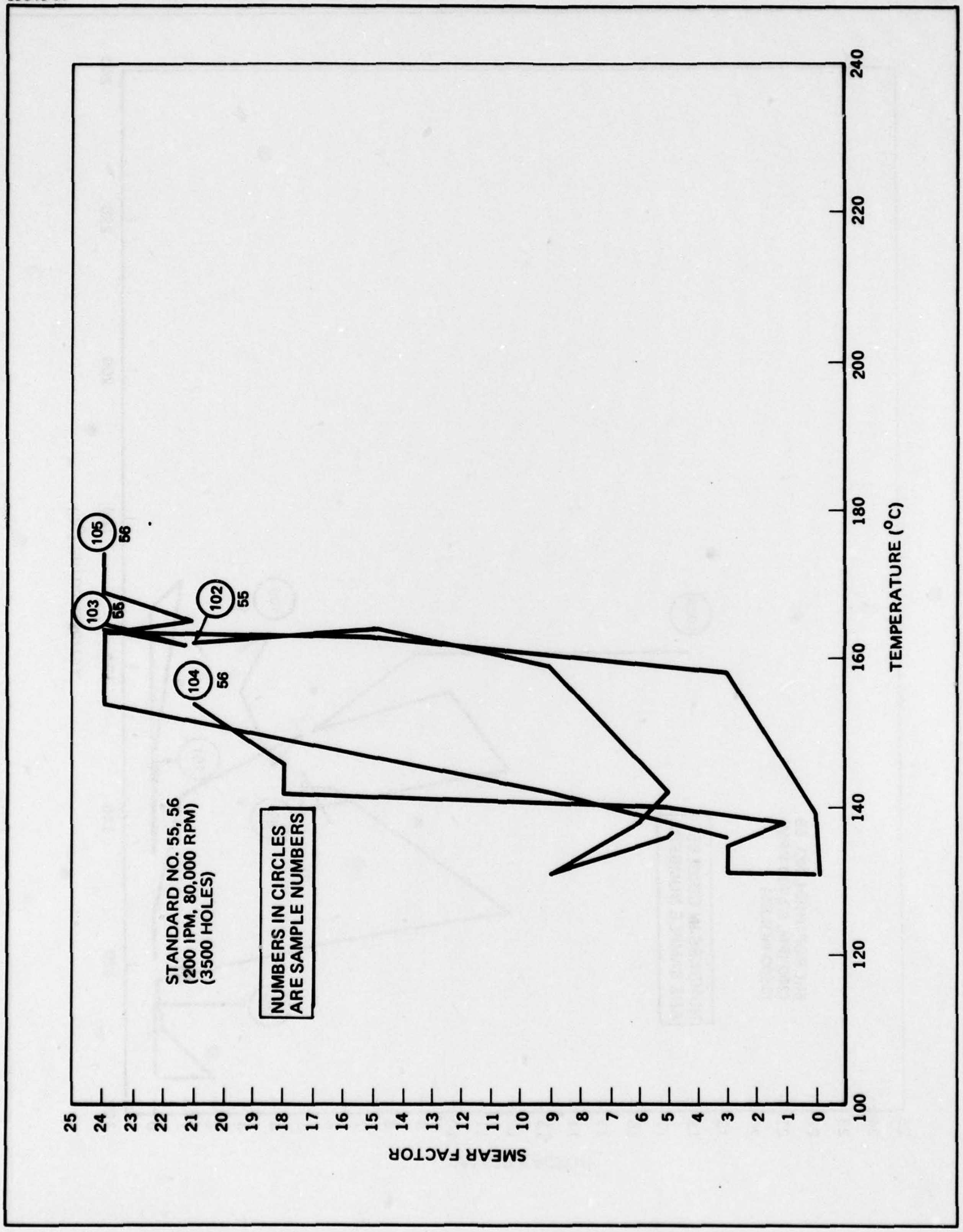
89349-95


MICROFINISH, NO. 68
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
96
94
95
97
93
SMEAR FACTOR
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
TEMPERATURE (°C)
100 120 140 160 180 200 220 240

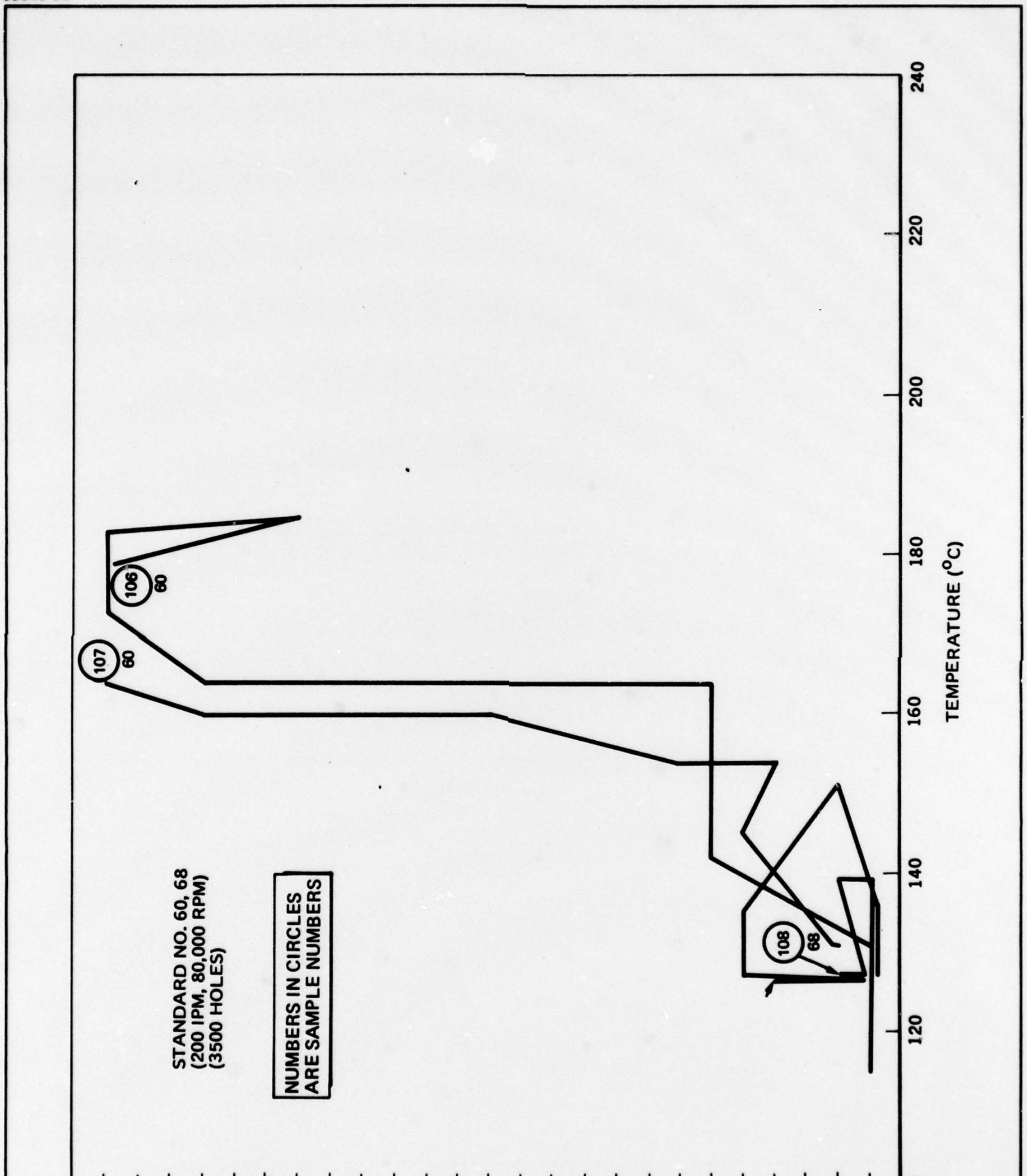
89349-96


MICROFINISH, NO. 68
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES ARE SAMPLE NUMBERS
SMEAR FACTOR
TEMPERATURE (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
100
120
140
160
180
200
220
240
98
99
100
101
102A

89349-97

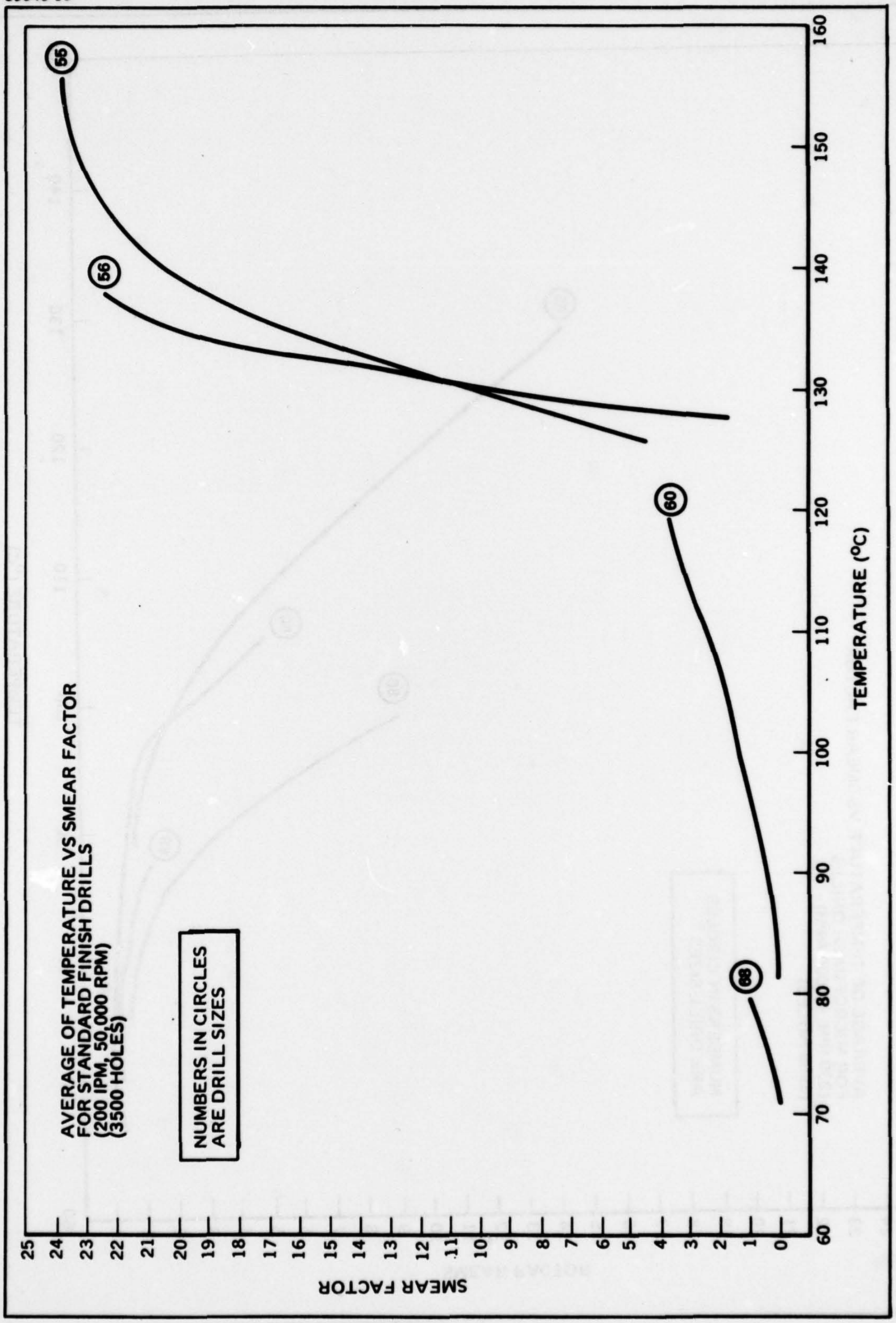

STANDARD NO. 55, 56
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
102
55
103
55
104
56
105
56
SMEAR FACTOR
TEMPERATURE (°C)

89349-98


SMEAR FACTOR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
TEMPERATURE (°C)
100
120
140
160
180
200
220
240
STANDARD NO. 60, 68
(200 IPM, 80,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE SAMPLE NUMBERS
107
60
106
60
108
68

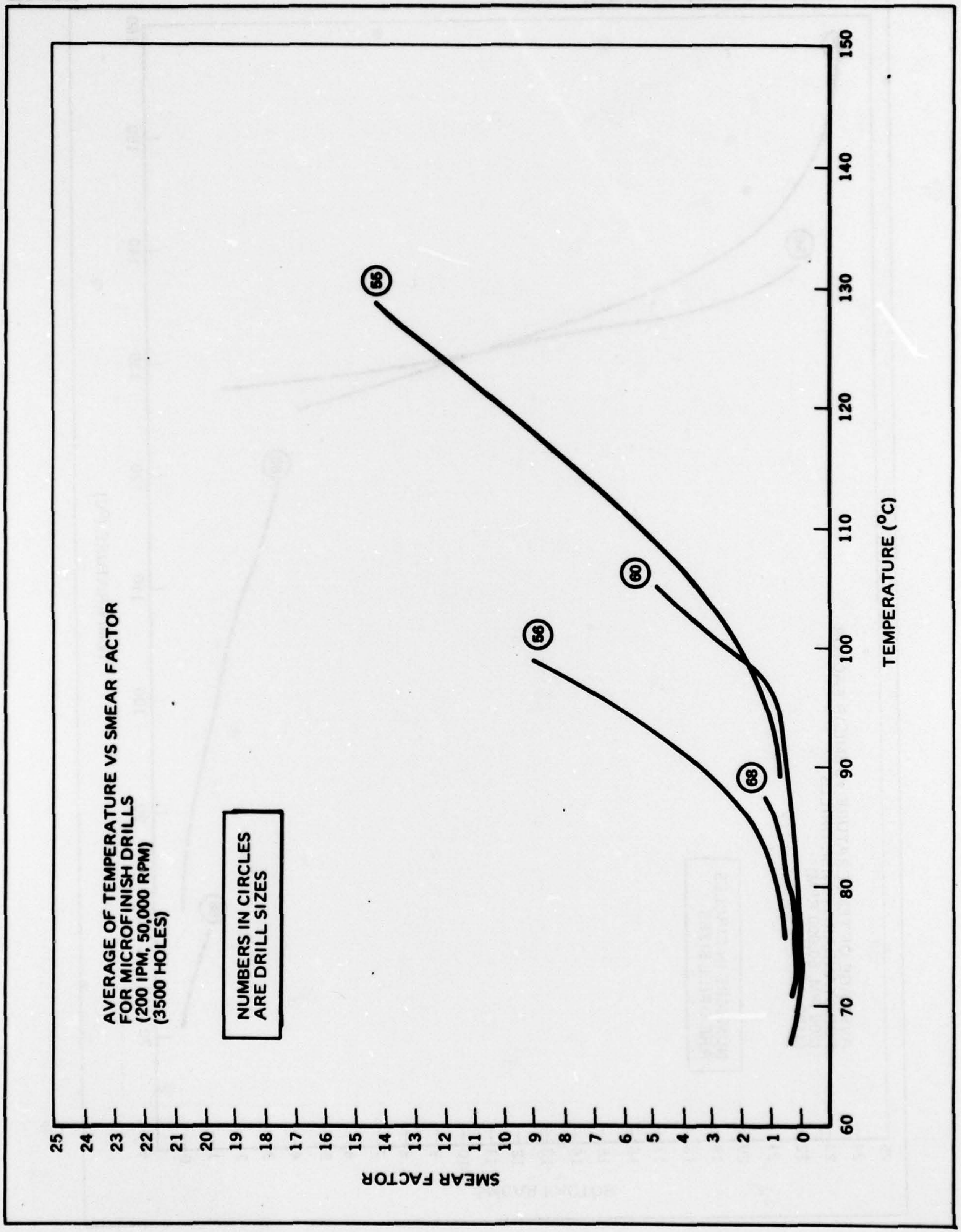
APPENDIX D
SUMMARY OF TEMPERATURE VERSUS SMEAR FACTOR

89349-99


AVERAGE OF TEMPERATURE VS SMEAR FACTOR
FOR STANDARD FINISH DRILLS
(200 IPM, 50,000 RPM)
(3500 HOLES)
NUMBERS IN CIRCLES
ARE DRILL SIZES
55
56
60
68
SMEAR FACTOR
TEMPERATURE (°C)

Appendix D – Summary of Temperature Versus Smear Factor

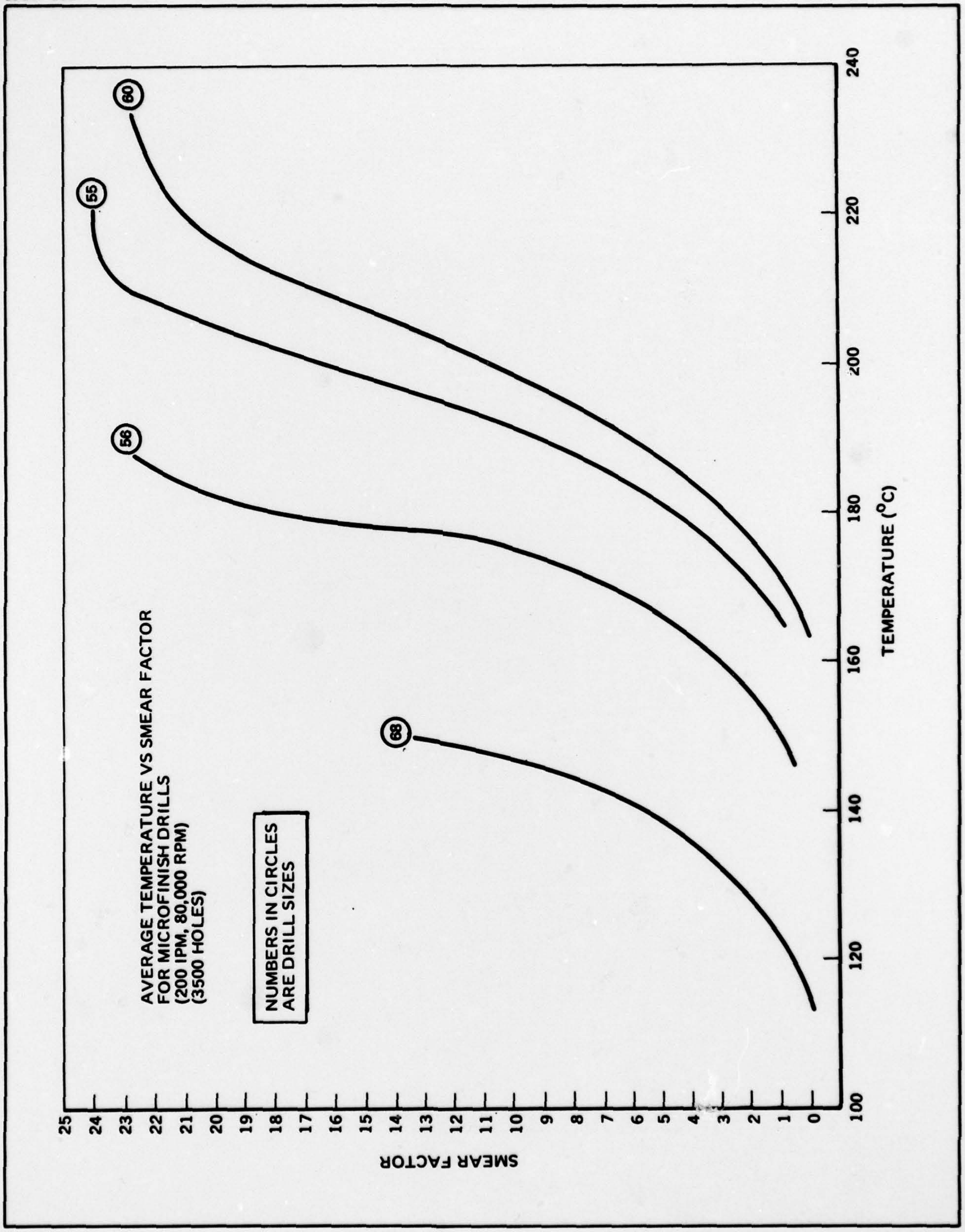
89349-100



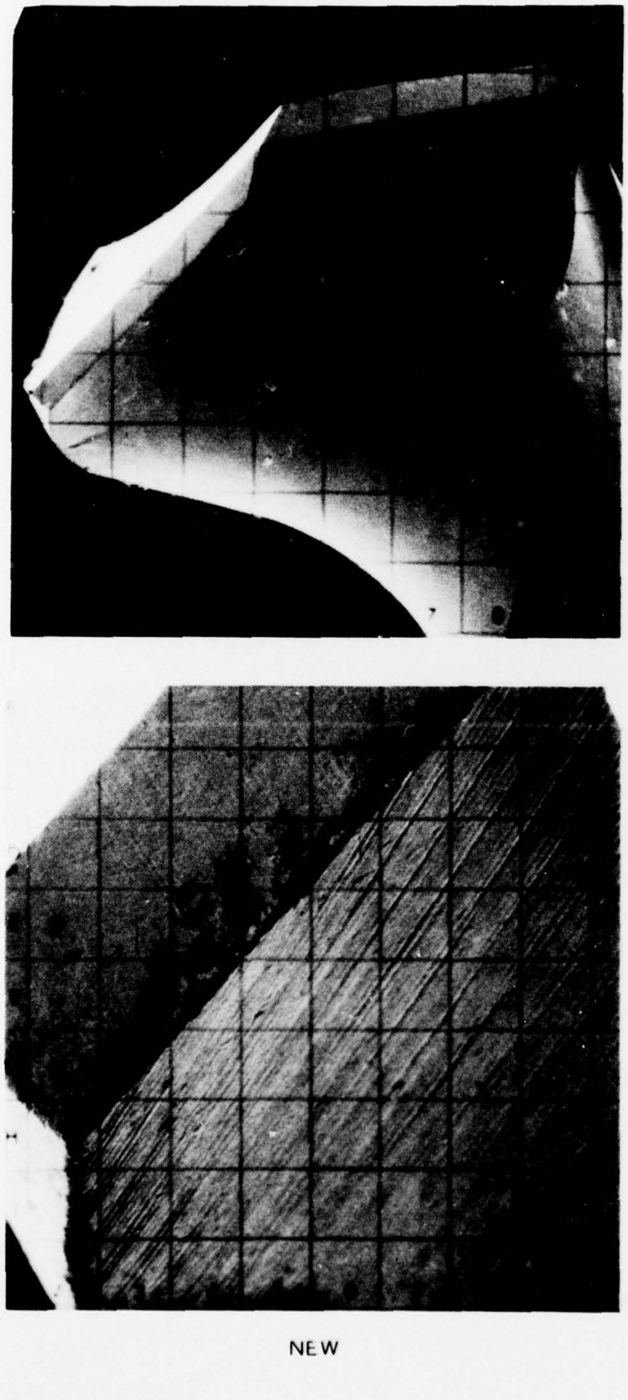
89349

HUGHES-FULLERTON
Hughes Aircraft Company
Fullerton, California

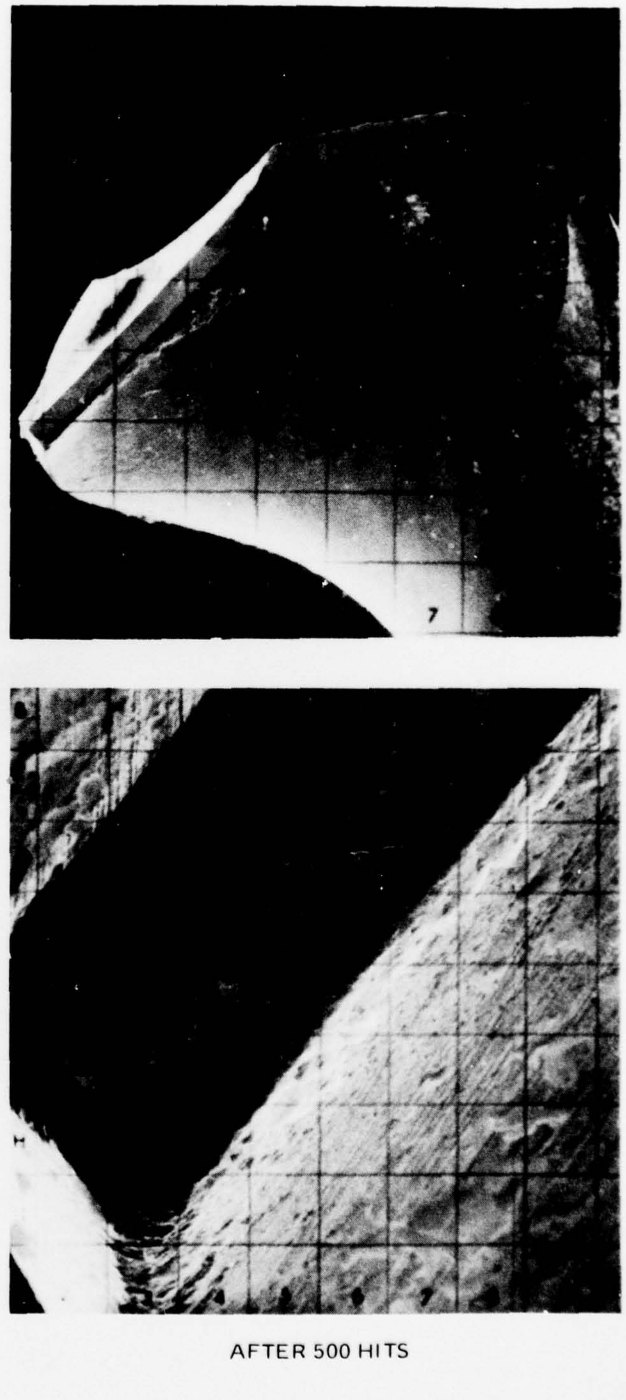
89349-101



APPENDIX E
SEM DRILL PHOTOS – BEFORE AND AFTER – PHASE III

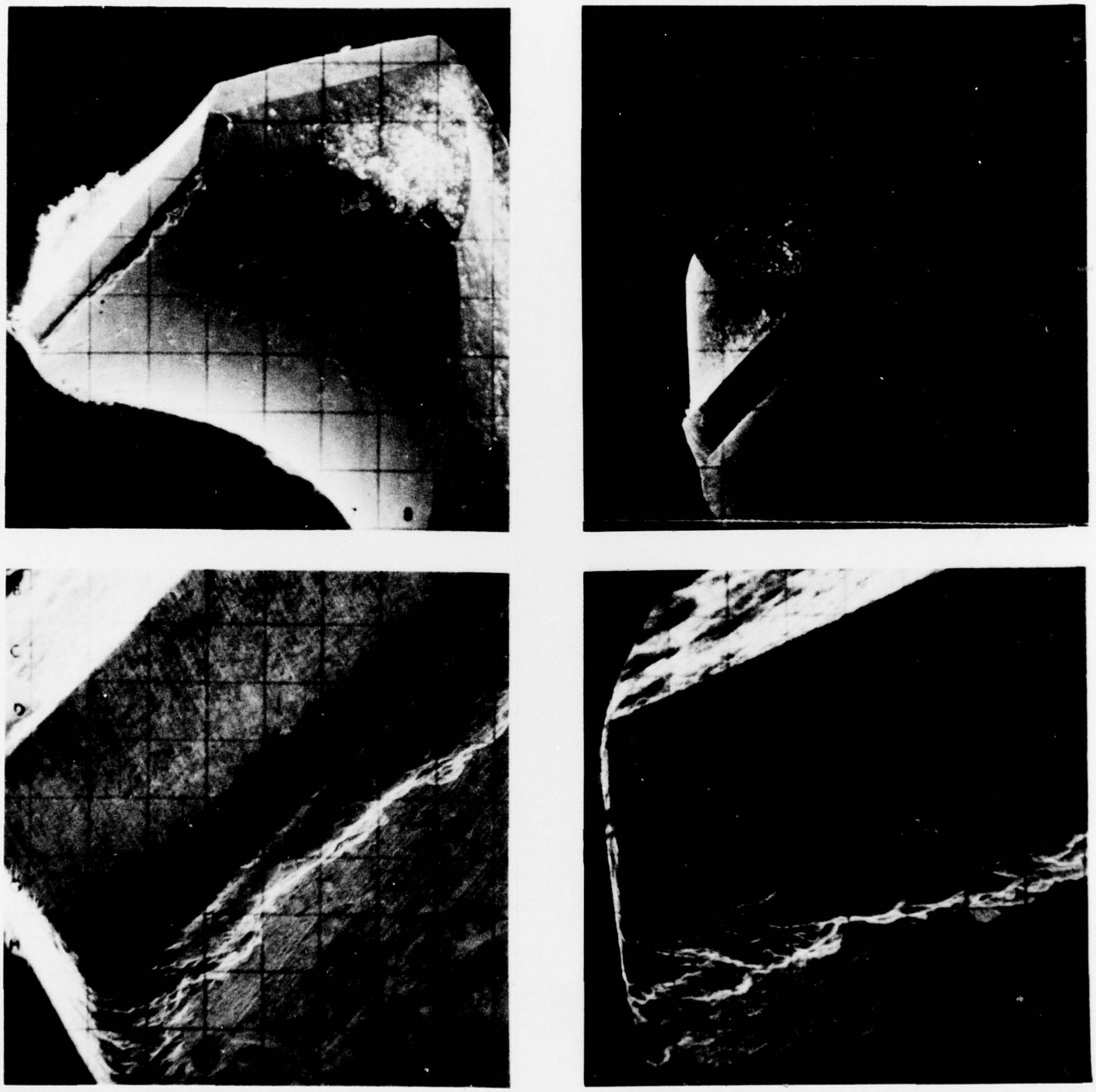


NEW



AFTER 500 HITS

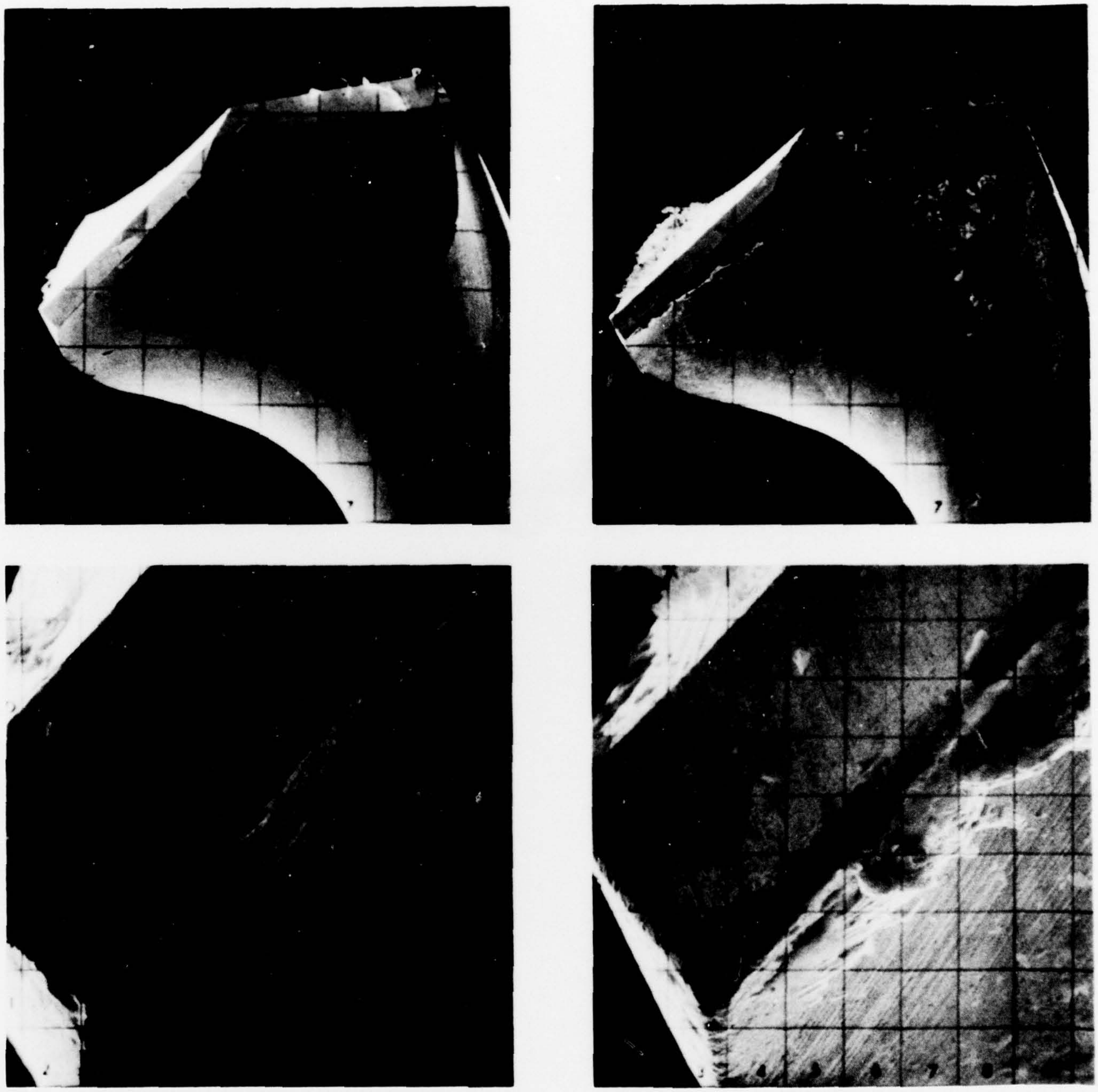
89349-40



AFTER 1000 HITS

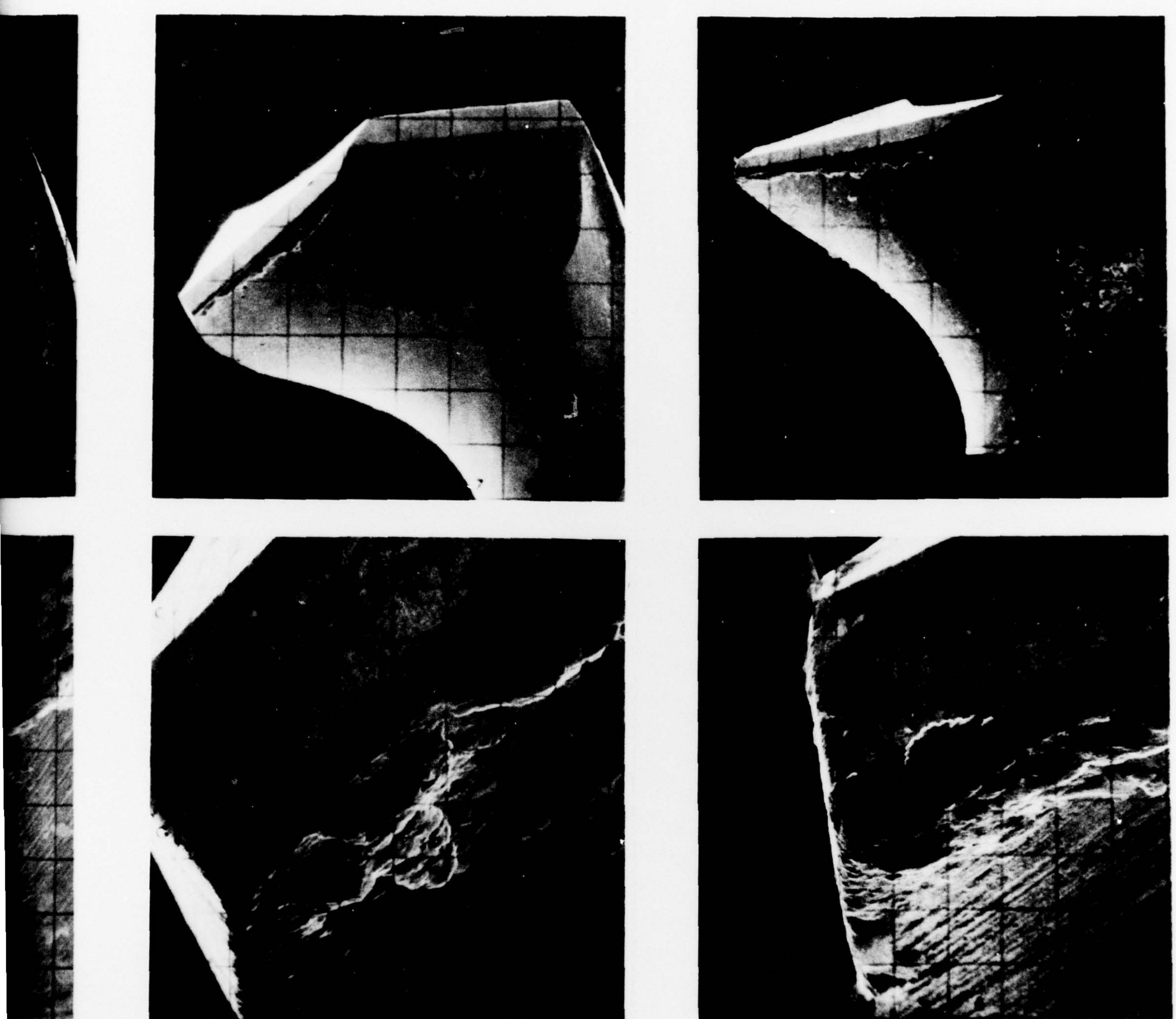
AFTER 3500 HITS

Figure E-1. Microfinish Drill, No. 55. Magnifications are 70X and 700X.



NEW

AFTER 500 HITS

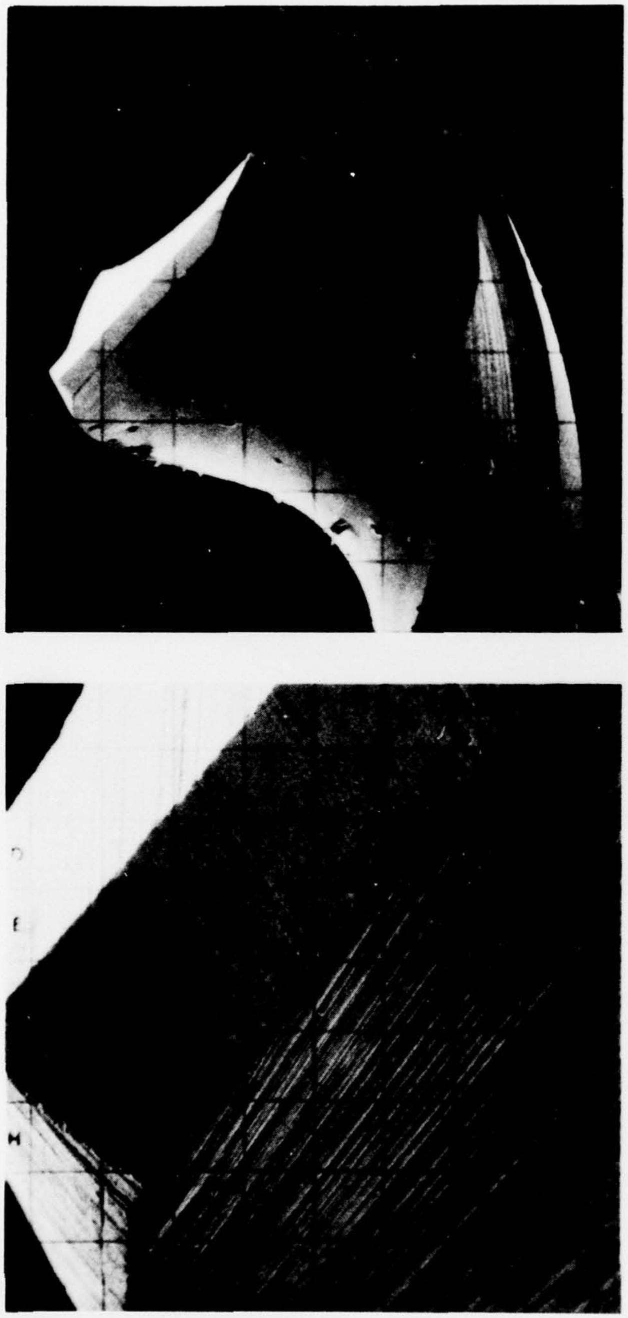


89349-41

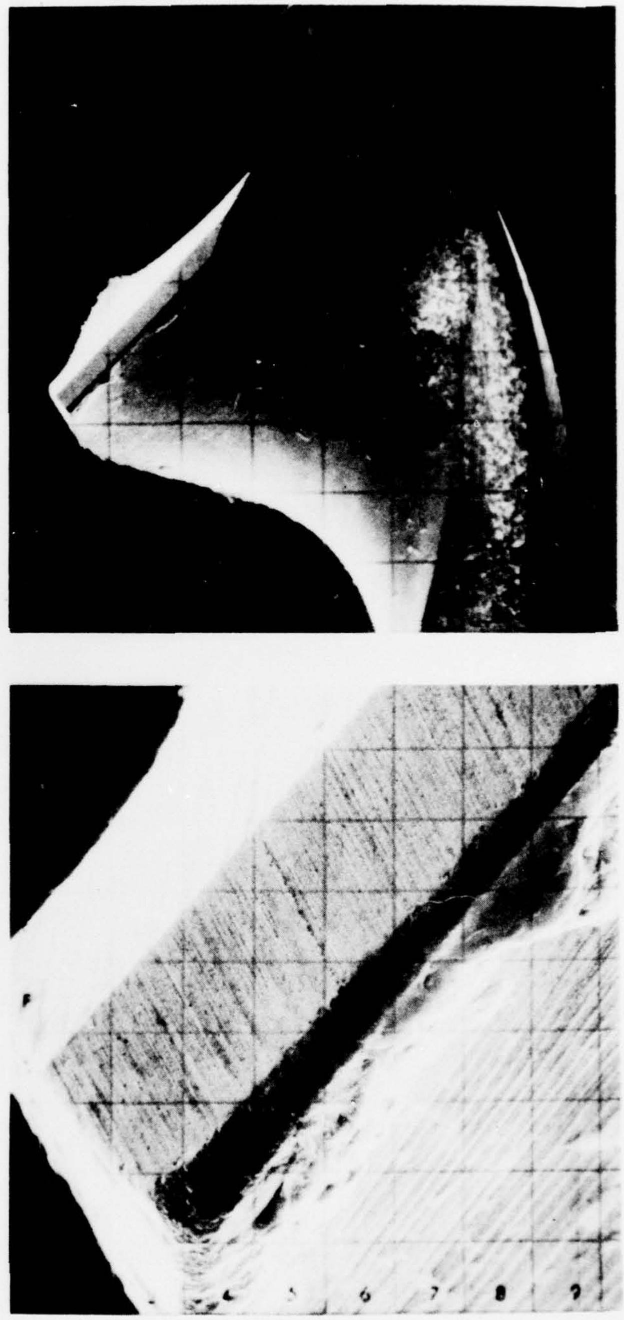
AFTER 1000 HITS

AFTER 3500 HITS

Figure E-2. Microfinish Drill, No. 56. Magnifications are 70X and 700X.

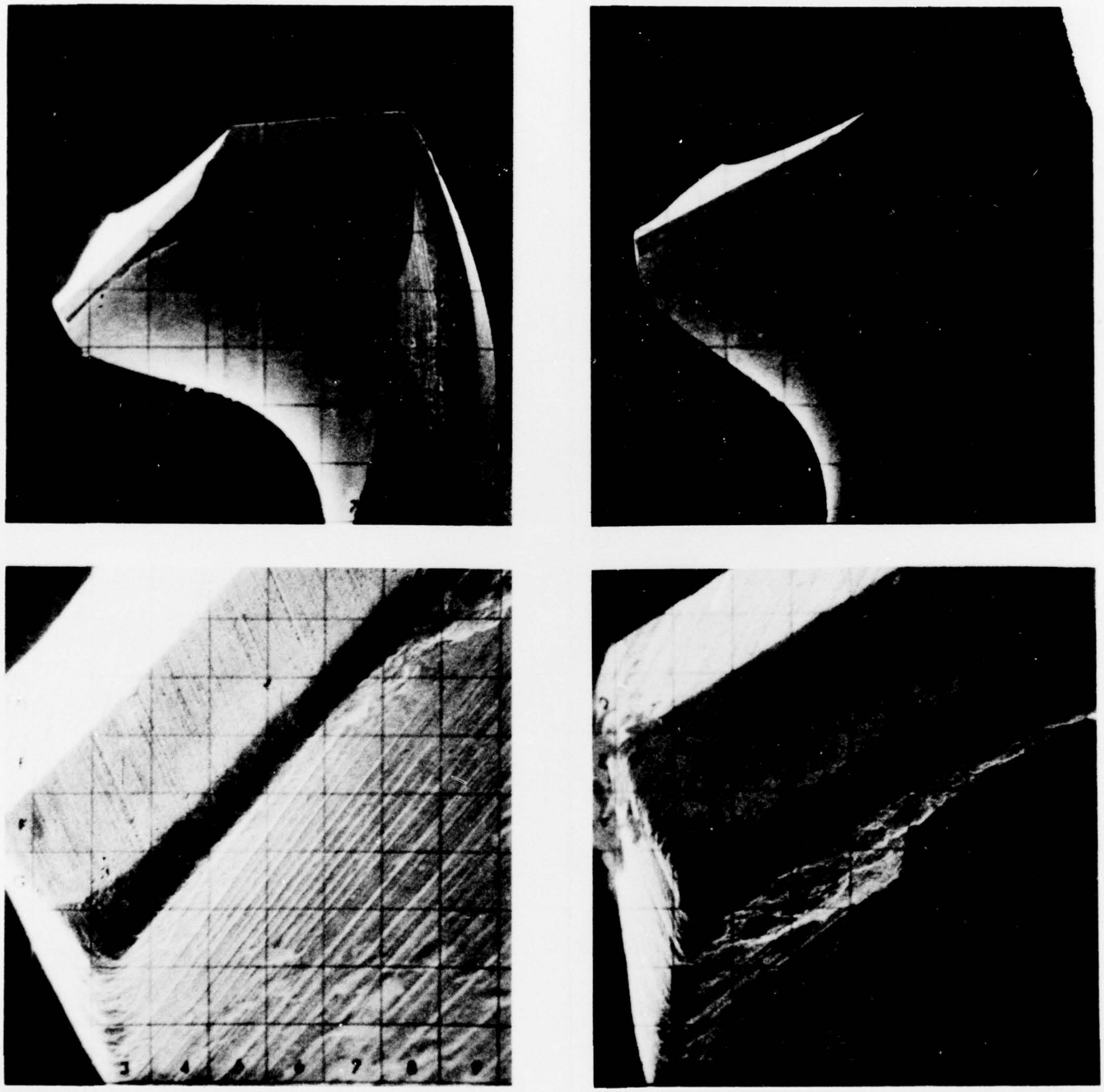


NEW



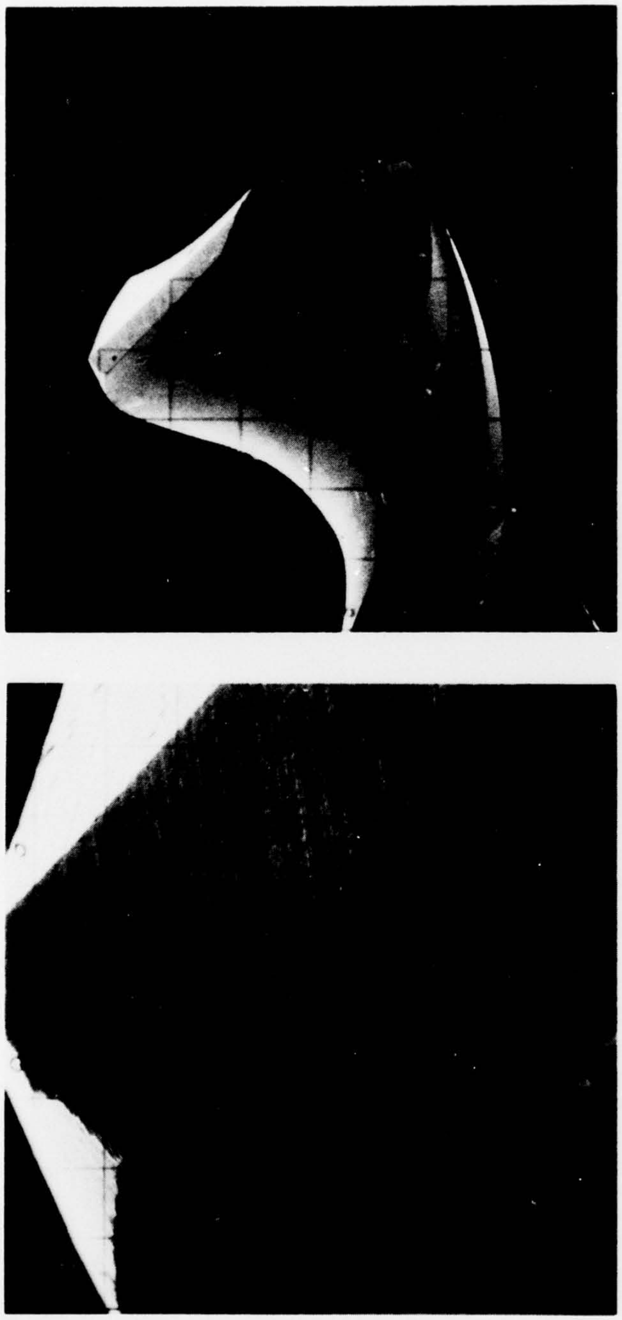
AFTER 500 HITS

89349-42

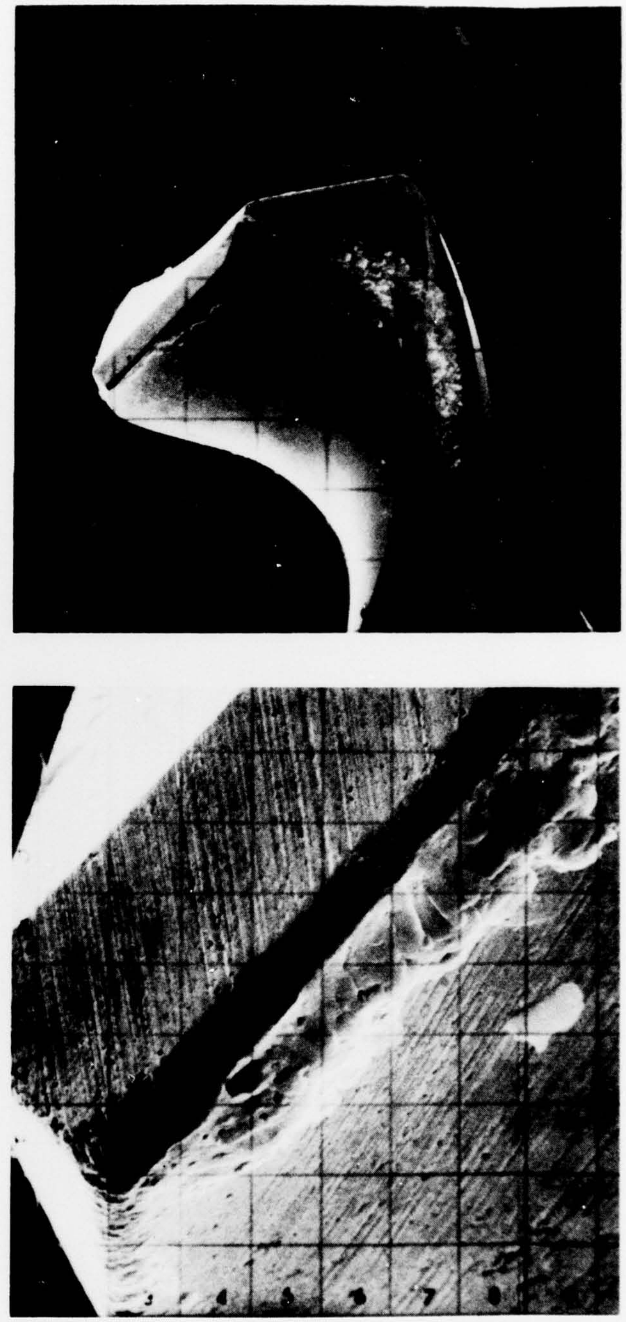


AFTER 1000 HITS   AFTER 3500 HITS

Figure E-3. Microfinish Drill, No. 60. Magnifications are 70X and 700X.

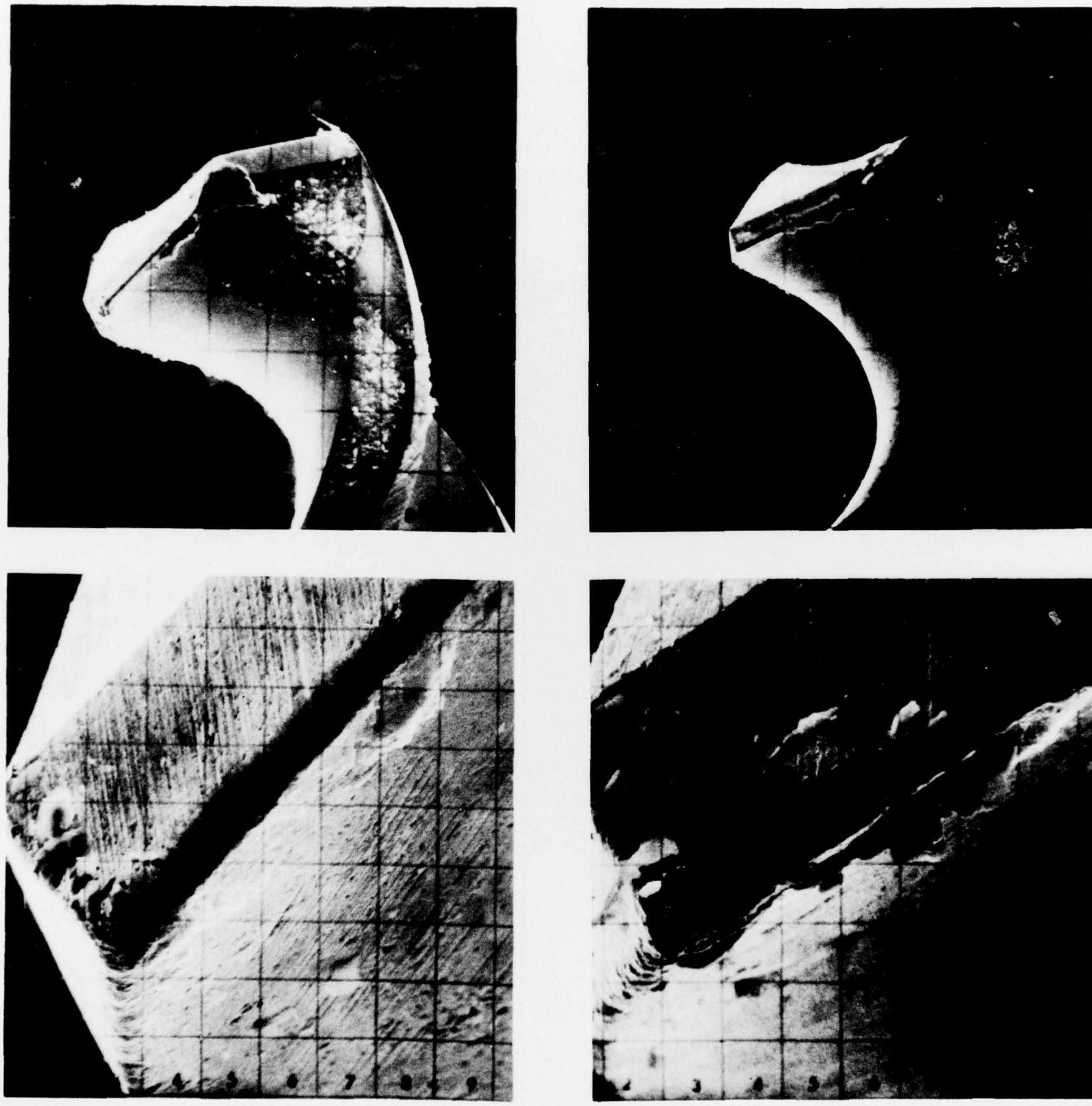


NEW



AFTER 500 HITS

89349-43



AFTER 1000 HITS

AFTER 3500 HITS

Figure E-4. Microfinish Drill, No. 68. Magnifications are 70X and 700X.