Lynchburg Technology Center

Babcock & Wilcox

Nuclear Environmental Services

FINAL REPORT: CRACKED LPI PIPE AT OCONEE-3

PREPARED FOR
DUKE POWER COMPANY

LTC:92:0017-01:01

JANUARY 1992

Babcock & Wilcox
a McDermott company

Lynchburg Technology Center

FINAL REPORT: CRACKED LPI PIPE AT OCONEE-3

PREPARED BY
THE BABCOCK & WILCOX COMPANY
NUCLEAR ENVIRONMENTAL SERVICES
POST OFFICE BOX 11165
LYNCHBURG, VIRGINIA 24506
(804) 522-6000

PREPARED BY: K. R. Redmond 1/31/92
K.R. Redmond, Engineer
Nuclear Materials, LTC

APPROVED BY: C R Frye 1/31/92
C. R. Frye, Supervisor
Nuclear Materials, LTC

LTC:92:0017-01:01

JANUARY 1992

CUSTOMER FEEDBACK QUESTIONNAIRE

Please help us do a better job for you.

Report Title: Final Report: Cracked LPI Pipe at Oconee-3

Report No.: LTC:92:0017-01:01

Customer feedback on our work is important to us. We would like to have your comments concerning this report. Your cooperation in completing this form and returning it to the address shown will assist us in improving our service to you.

Do the contents of this report meet your needs? ❑ Yes Not Entirely, because ____________

Did you receive this report when we promised it? ❑ Yes ❑ No

Comment: ____________

How could we have made this report more useful to you? ____________

Thank you.

Name: ____________ Date: ____________

Organization: ____________

Please fold and return this form to address shown on the reverse side.

(TEAR OFF)

L.P. Williams, Manager, Business Developement
The Babcock & Wilcox Company
Nuclear Environmental Services
#1 Forest Plaza West
3225 Old Forest Road
Lynchburg, VA 24501

SUMMARY

Recently, during heat up preparations, a throughwall crack was discovered in a twelve inch Schedule 10 stainless steel pipe in the low pressure injection (LPI) system at the Oconee Unit 3 Nuclear Station. The crack was located at a welded half coupling, joining a seven inch long vertical run of one inch Schedule 40 stainless steel pipe, with an attached 14 pound relief valve, to the twelve inch pipe. A section of the twelve inch pipe containing the crack with the attached one inch pipe assembly was removed and sent to the LTC for a laboratory examination to determine the mode of failure.

It was found that the pipe failed due to mechanical fatigue. With the joint under a high-frequency/low-amplitude cyclic load, the crack initiated on the OD surface of the twelve inch pipe at the toe of the half coupling weld, which acted as a stress raiser. The most likely source of the cyclic loading was mechanical vibration of the LPI system piping. There was no evidence that corrosion or preexisting weld defects may have influenced the failure.

1.0 INTRODUCTION

The Oconee 3 Nuclear Plant is a B&W designed 846 MWe pressurized water reactor plant owned and operated by Duke Power Company (DPC). The plant has been in commercial operation since December 1974. A recent loss of coolant accident (LOCA) resulted in a forced shutdown of the unit. The LOCA was caused by the failure of a 3/4 inch compression fitting in the reactor vessel level indicating system (RVLIS). After repairs were completed on the RVLIS system and preparations were being made for heatup, a throughwall crack was discovered in a twelve inch Schedule 10 pipe in the low pressure injection (LPI) system. The crack was located at a welded half coupling, joining a one inch Schedule 40 pipe to the twelve inch pipe. The one inch pipe consisted of a seven inch long vertical run to relief valve 3LP-25. The relief valve weighed about 14 pounds. Details of the piping arrangement and crack location and orientation are shown in Figure 1. The principal material of construction was 304 stainless steel.

An approximately nine inch square section of the twelve inch pipe containing the crack with the attached welded half coupling and one inch pipe was removed and sent to the Lynchburg Technology Center (LTC) for a laboratory examination to determine the mode of failure. Since this project was not classified as safety related, the QA requirements of the B&W R&DD Standard Practice Manual were implemented.

2.0 METHODS AND RESULTS

2.1 RECEIPT & INITIAL VISUAL INSPECTIONS

The subject pipe section was received at the LTC on December 23, 1991 at 10:00 PM. The pipe section was packed in a wooden crate and had been shipped LSA via Roberts Express. Shortly after receipt, the part was unpacked, surveyed and visually inspected. Contact radiation levels were 300 mRad/hr β and 36 mR/hr γ. Smearable contamination on the ID surface was 50 mRad/hr β. The entire assembly is shown as-received in Figure 2. An arbitrary orientation and angular convention was established for the assembly as shown in Figure 1.

The central portion of the throughwall crack was located at the toe of the half coupling weld. In this region, the crack extended approximately 50° around the circumference of the weld (from 180° to 230°) and followed the contours of the weld toe (see Fig. 3). Near the ends, the crack had propagated into base metal and had turned such that the crack was oriented nearly parallel to the axis of the twelve inch pipe. The overall length of the crack on the OD surface was approximately 2-1/2 inches. As a result of leakage, a rust colored stain had developed below the crack and boric acid deposits had formed in several locations (see Fig. 2). An ID view of the assembly and the crack is shown in Figure 4. The crack was located within the heat tinted region caused by the welding operation. The crack was shorter on the ID surface, measuring about 1-1/2 inches long.

Another crack was observed on the OD surface adjacent to the throughwall crack at about 150° (see Fig. 3). One end of this crack from 140° to 160° was located at the toe of the half coupling weld. Similar to the larger crack, the end of the crack had propagated into base metal and had started to reorient itself parallel to the axis of the twelve inch pipe.

2.2 SECTIONING AND ADDITIONAL VISUAL INSPECTIONS

The ID surface of the twelve inch pipe was wiped down with clean absorbents saturated with ethanol to remove the bulk of the loose surface contamination and permit handling of the assembly outside of a fume hood.* The pipe stub was removed by making a transverse cut about 1-1/4 inch from the OD surface of the twelve inch pipe section, and the throughwall crack was further isolated as shown in Figure 5. Initial sectioning was performed dry on a horizontal band saw.

*Since the crack was apparently OD initiated, there was no harm in removing these deposits.

After isolating the crack, it was bent open to expose the fracture surfaces. Specimen A is shown in Figure 6 prior to bending. After bending, the second crack noted adjacent to the throughwall crack opened up slightly (see Fig. 6).

The exposed fracture surfaces are shown at higher magnification in Figure 7. The crack face had a classic thumbnail shape, with the concave side of the crack tip oriented toward the OD. The fracture surface was oriented essentially perpendicular to the surface of the twelve inch pipe and there was no evidence of necking near the fracture. Near the ID surface, however, there was an abrupt change in crack direction producing a lip oriented at a finite angle to the pipe surface. Rust colored deposits were noted on the fracture surfaces along the OD edge, although the main portion of the fracture was essentially free of deposits. These deposits were heaviest near the central portion of the crack. At higher magnifications, ratchet markings on the fracture surfaces indicated crack propagation from OD to ID with the origin located in the central portion of the crack along the weld toe, where the rust colored deposits were heaviest (see Fig. 8). There was no evidence of ductile rupture, except near the ends of the crack and at isolated points along the crack tip; these were most likely ligaments of solid metal which were torn apart upon bending the crack open in the laboratory. Also, there was no evidence of intergranular failure. In some small isolated areas it appeared as if there were some cleaved grains (see Fig. 9).

Specimen A1 was further sectioned to isolate the fracture surface for SEM examinations and to obtain metallography samples as shown in Figure 5. The SEM specimens (A1.4A and A1.4B) were ultrasonically cleaned in ethanol to remove loose surface deposits prior to the SEM examination.

2.3 SCANNING ELECTRON MICROSCOPY

SEM examination of Specimens A1.4A and A1.4B indicated the crack had propagated in a transgranular mode. Possible fatigue striations were observed near the crack origin, but the fracture surface was covered with a light deposit in this region, which obscured fine surface detail (see Figs. 10 and 11). The deposits in this region were most likely the rust colored deposits noted previously along the OD edge of the fracture. There was no evidence of any weld defects which may have initiated the crack.

Examination of the main part of the fracture, which was essentially deposit free, revealed the presence of fine fatigue striations in several locations (see Figs. 12 - 14). Although the striations were poorly developed, in most cases, they were visible in small isolated areas over much of the main fracture surface. In general, the striations were bowed away from the OD and were oriented perpendicular to rachet markings in the fracture surface. Striation spacings were typically less than 1 micron. There was no evidence of any significant corrosion on the fracture surface.

For the most part, the lip observed near the ID edge did not fail in a ductile manner. The general topography and some areas with possible fatigue striations indicated the predominant fracture mode along the ID edge was fatigue (see Fig. 15). Near the ends of the crack and at isolated points along the crack tip, dimpled rupture was observed however (see Fig. 16). As stated previously, these areas were most likely ligaments of solid metal which were torn apart upon bending the crack open in the laboratory.

2.4 METALLOGRAPHY

The metallography specimens were mounted in Epomet and prepared for metallographic examination by grinding from 60 through 600 grit SiC paper, polishing using 3 to 0.05 μm Al_2O_3 suspensions, and electrolytic etching in 10 wt% oxalic acid. The specimens were examined on a LECO 300 metallograph at magnifications up to 800X.

The microstructures of both specimens exhibited relatively equiaxed grains and significant numbers of annealing twins, which is typical of an annealed austenitic stainless steel. Some residual cold work was present in the mid-wall portion of the pipe. The microstructure of specimen A1.3 indicated there was no significant heat affected zone associated with the weld. The crack in specimen A1.5 was about 75% throughwall. This crack was verified to be entirely transgranular and essentially no crack branching was observed. Crack propagation was apparently not influenced by the material microstructure. A small crack was noted at the weld toe in specimen A1.3; this crack also appeared to be transgranular.

2.5 LIQUID PENETRANT INSPECTION

The balance of the half coupling weld (Piece C) and specimens A1.4A and A1.4B were inspected by liquid penetrant testing to detect any additional cracks or defects which may have initiated in or near the weld. No additional defects were identified.

3.0 DISCUSSION

The presence of striations on the fracture surface clearly indicates the failure mode for the LPI pipe is fatigue.[1,2] The crack dimensions and shape, as well as the fracture surface deposits and topography all indicate the crack initiated at the OD surface along the toe of the half coupling weld.[1,2] The submicron fatigue striation spacings suggest a high frequency, low amplitude cyclic load drove the crack.[1,2] The most likely source of such loading would be mechanical vibration of the LPI piping. There was no evidence of corrosion, nor was there any evidence of weld defects which may have influenced the failure, indicating the crack was caused purely by mechanical fatigue.

Bending fatigue often occurs at welded joints when mechanical vibration is present and the attached pipes are not sufficiently supported.[3] Crack initiation typically occurs on the OD along the weld toe, which acts as a stress raiser.[1,2,3] This is consistent with observations made on the Oconee-3 LPI pipe. Several failures of this type have been examined at the LTC.[4,5] Additionally, the circumstances surrounding the fatigue failure of an eight inch Schedule 10 pipe in the Spent Fuel Cooling system at the McGuire Nuclear station were very similar to the Oconee-3 LPI failure.[6]

4.0 CONCLUSIONS

The conclusions to this report are listed as follows:

- The Oconee-3 LPI pipe failed due to mechanical fatigue.
- The loading on the joint is expected to be high-cycle, low amplitude, with the most likely source being mechanical vibration of the LPI system piping.
- There was no evidence of any corrosion or weld defects which may have influenced the failure.

5.0 REFERENCES

1. Metals Handbook, Ninth Edition, Vol. 11, Failure Analysis and Prevention, American Society for Metals, Metals Park, Ohio, 1987.

2. Metals Handbook, Ninth Edition, Vol. 12, Fractography, American Society for Metals, Metals Park, Ohio, 1987.

3. J. C. Danko, "Stress Corrosion Cracking and Corrosion Fatigue in Reactor Coolant Piping", Corrosion in Power Generating Equipment, Plenum Press, New York, New York, 1984.

4. K. Redmond, "Examination of Pipe Tee from Surry Unit One", B&W R&DD Report No. RDD:89:5225-01:01, September 1988.

5. K. Redmond, "Examination of Letdown Vent and Drain Piping from McGuire Unit 1", B&W R&DD Report No. RDD:88:5170-01:01, October 1987.

6. Memo from J. M. Shuping to R. L. Williams, "McGuire Unit 1 NCI MC-754 8 inch Schedule 10 Pipe/Vent Assembly Metallurgy Sample No. 352", Duke Power Company, May 29, 1986.

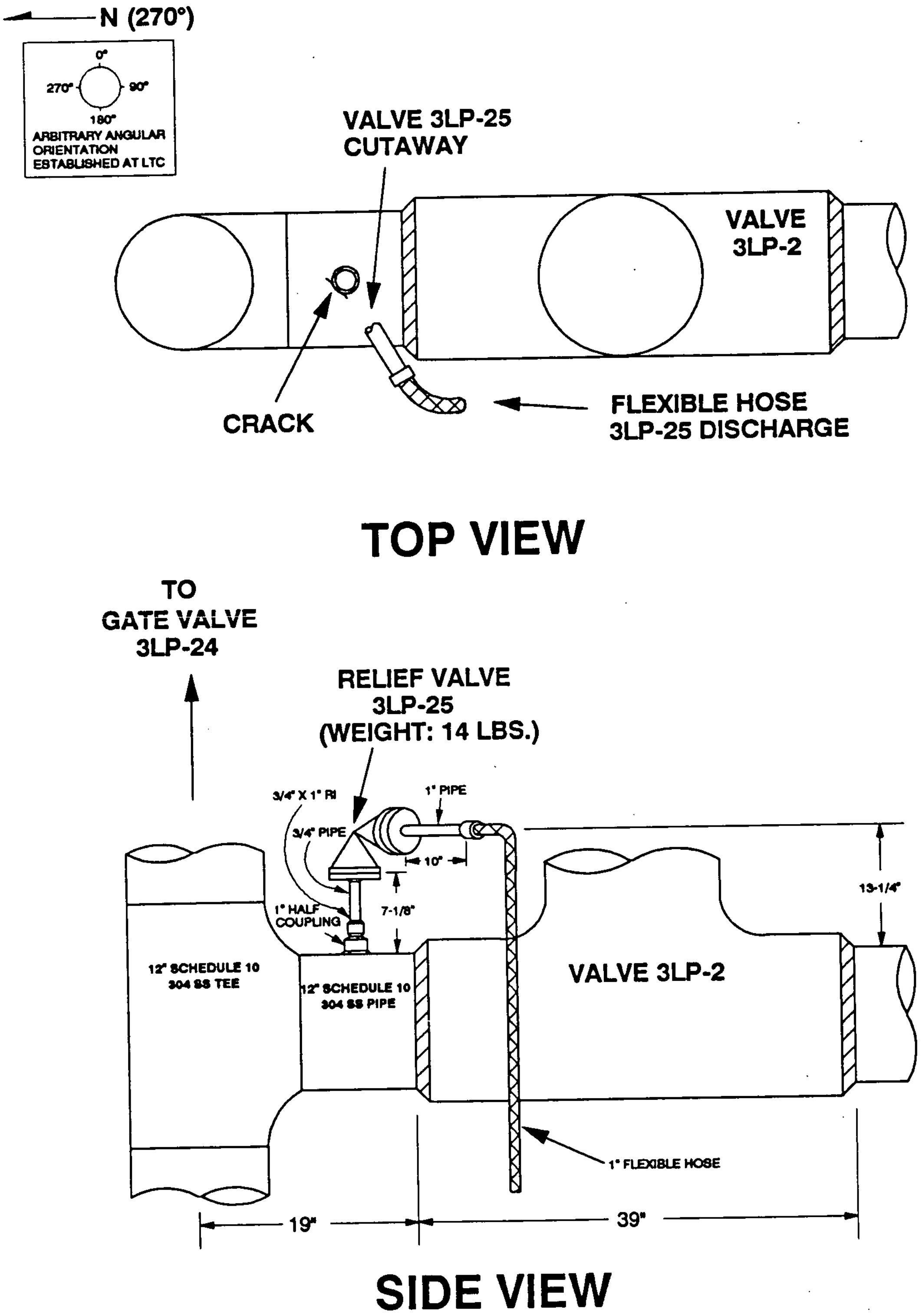
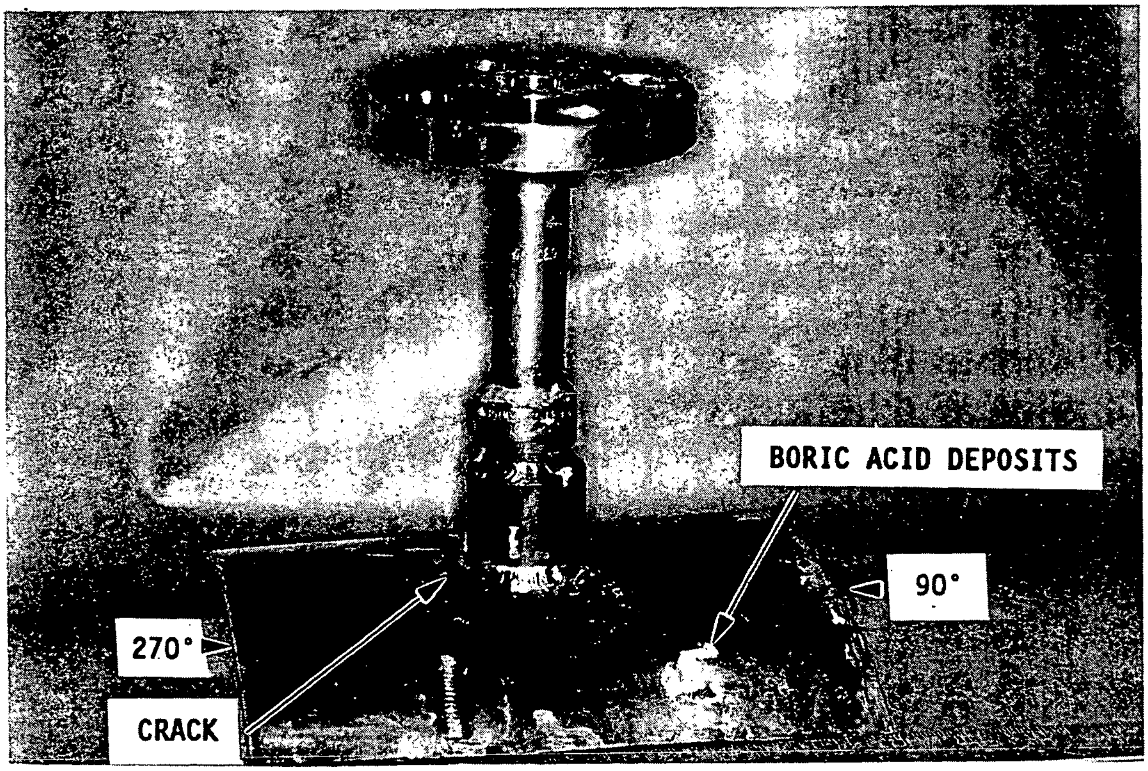
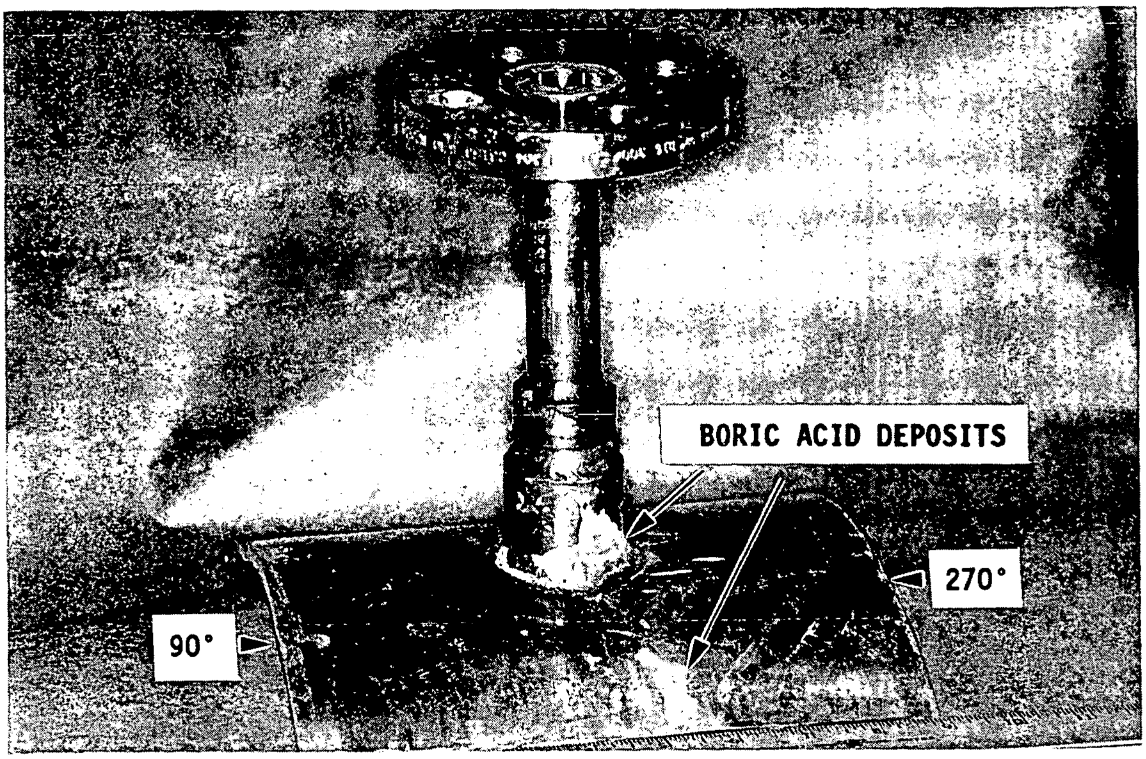


FIGURE 1: LPI PIPING ARRANGEMENT, SHOWING CRACK LOCATION AND ORIENTATION

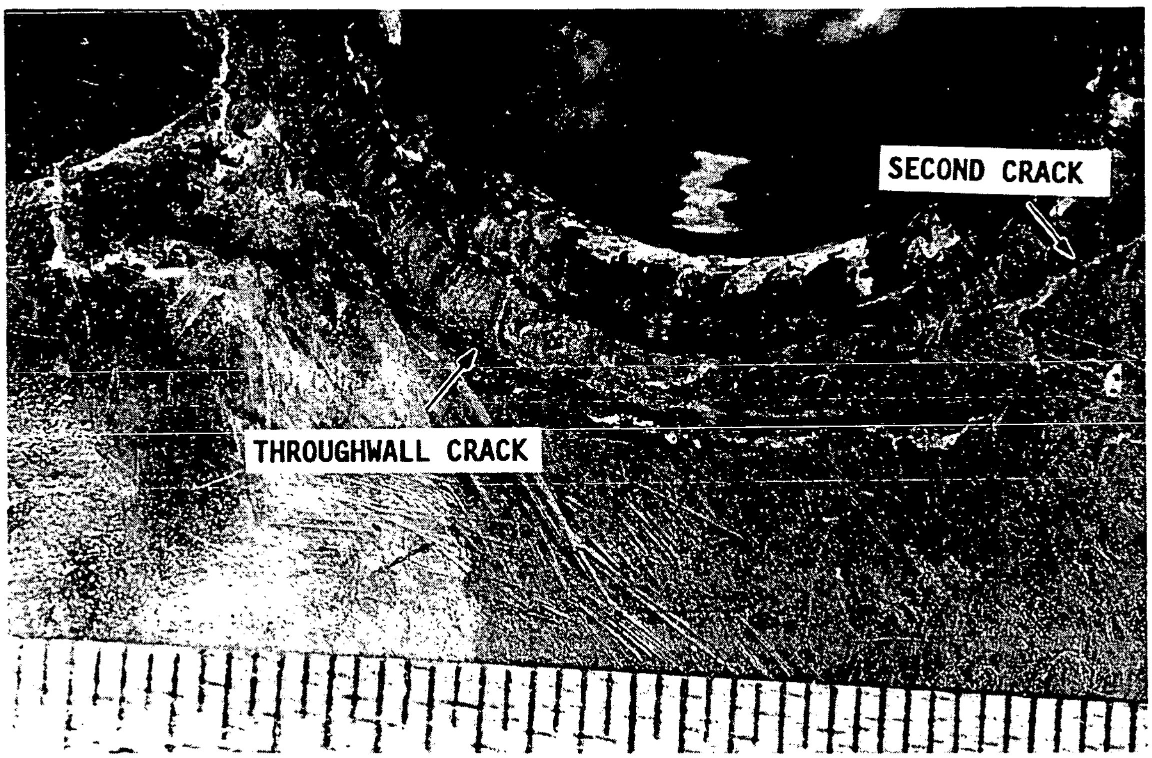


RUST COLORED DEPOSITS 180° VIEW NEG. NO. 105



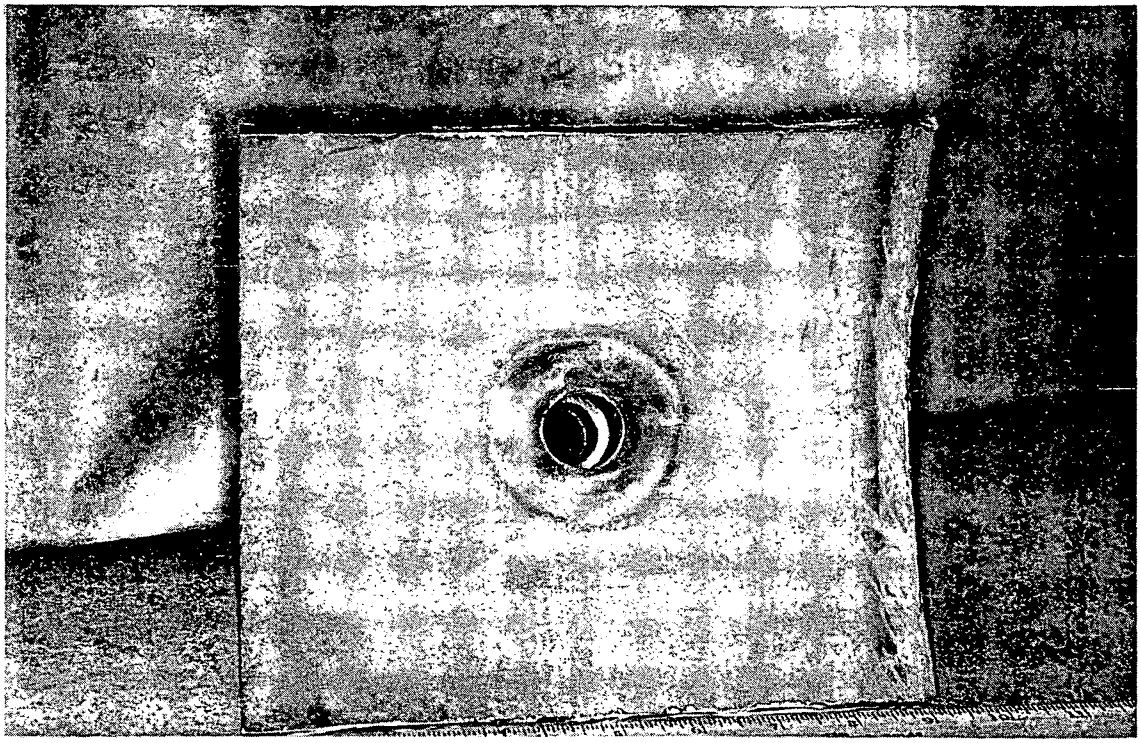
0° VIEW NEG. NO. 113

FIGURE 2: LPI PIPE SECTION AND ATTACHED PIPE STUB, AS-RECEIVED (0.4X)

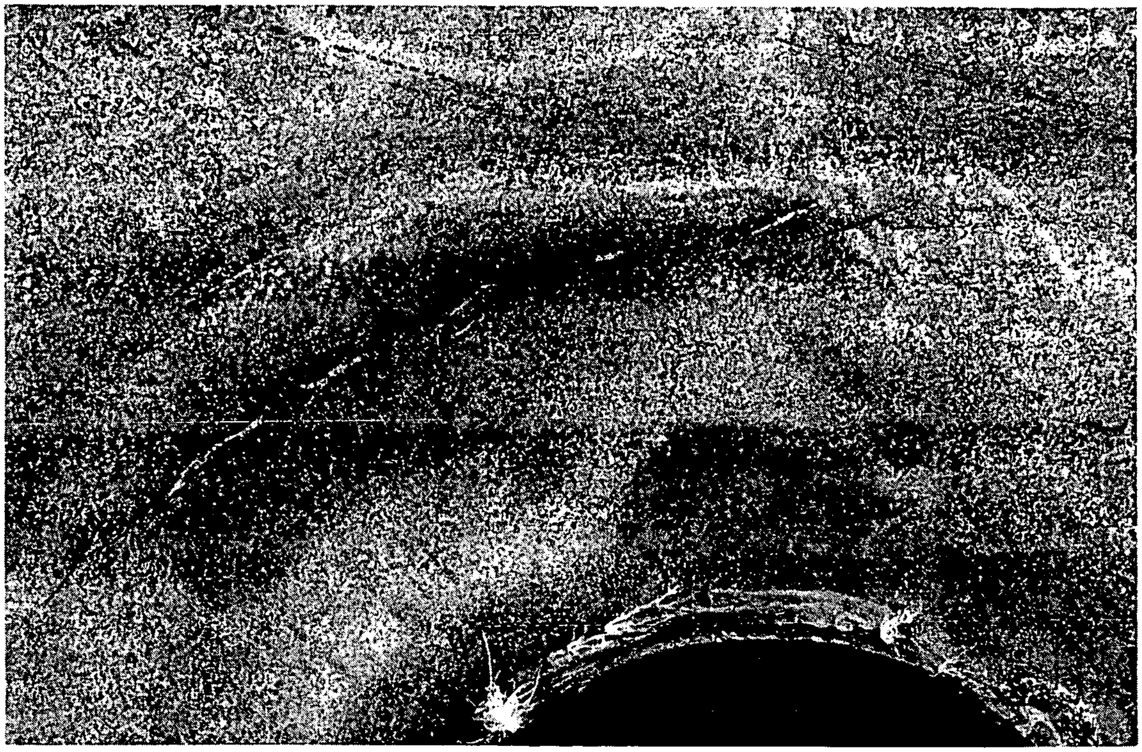


2.1X NEG. NO. 129

FIGURE 3: OD VIEW OF THROUGHWALL CRACK; NOTE SECOND CRACK ADJACENT TO THROUGHWALL CRACK



0.4X NEG. NO. 116



3.6X NEG. NO. 120

FIGURE 4: ID VIEW OF THROUGHWALL CRACK

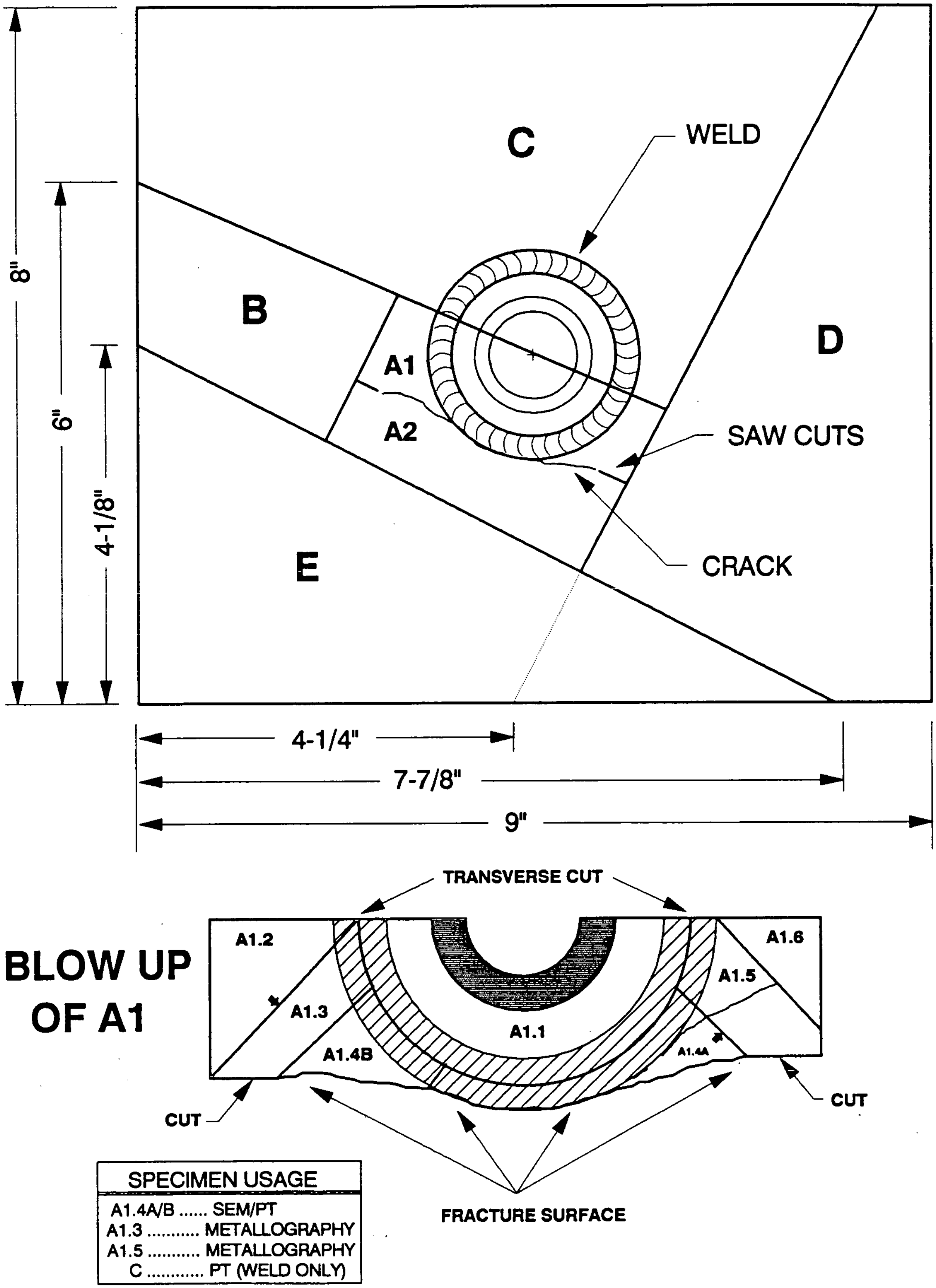
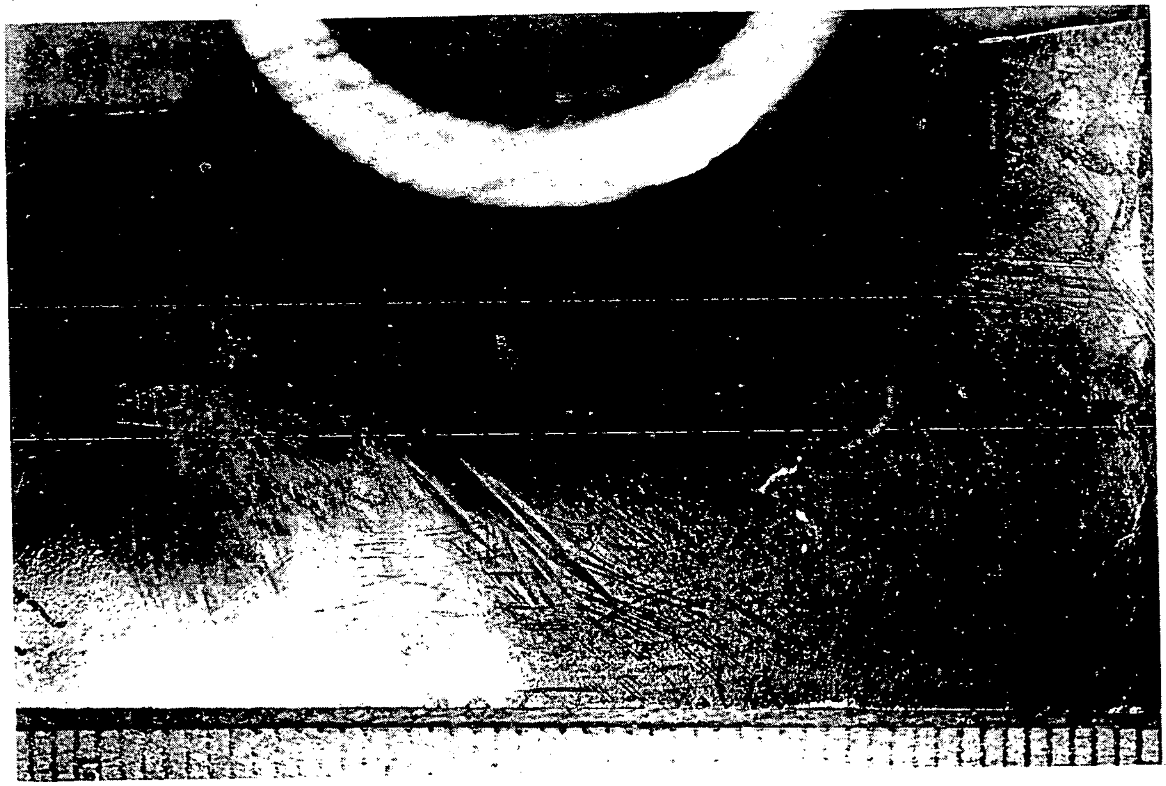
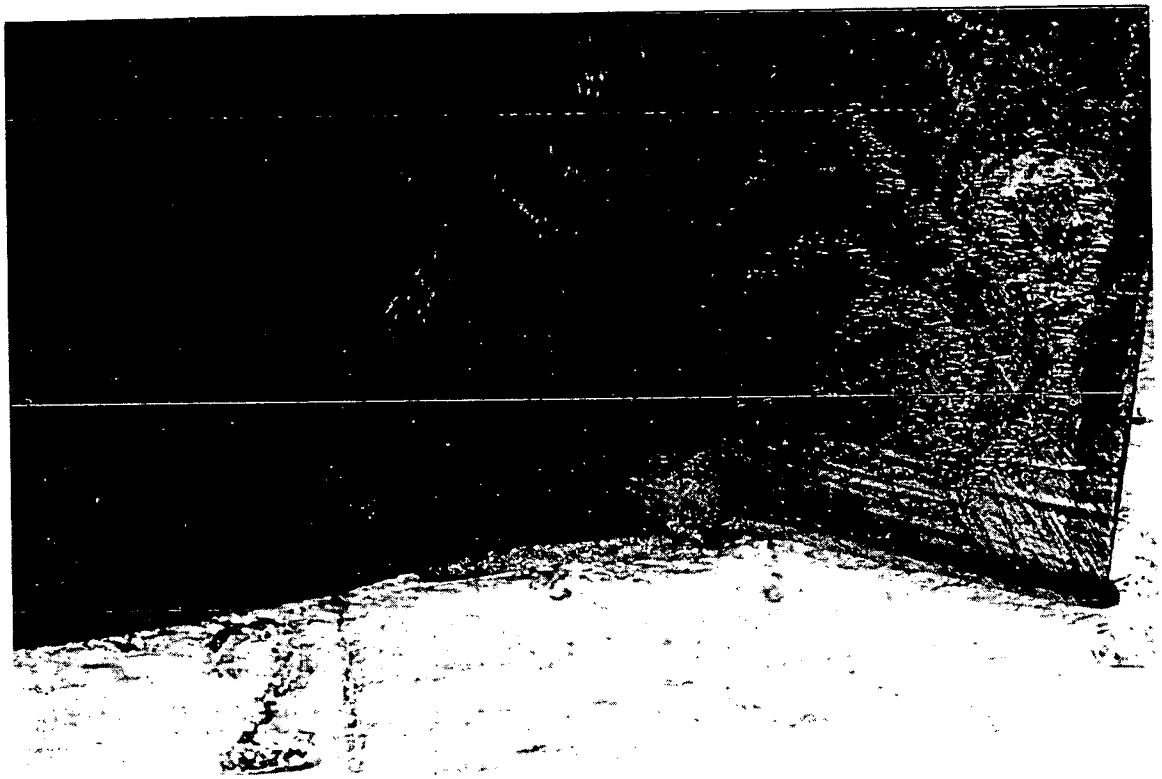


FIGURE 5: SECTIONING DIAGRAM FOR TWELVE INCH LPI PIPE SECTION

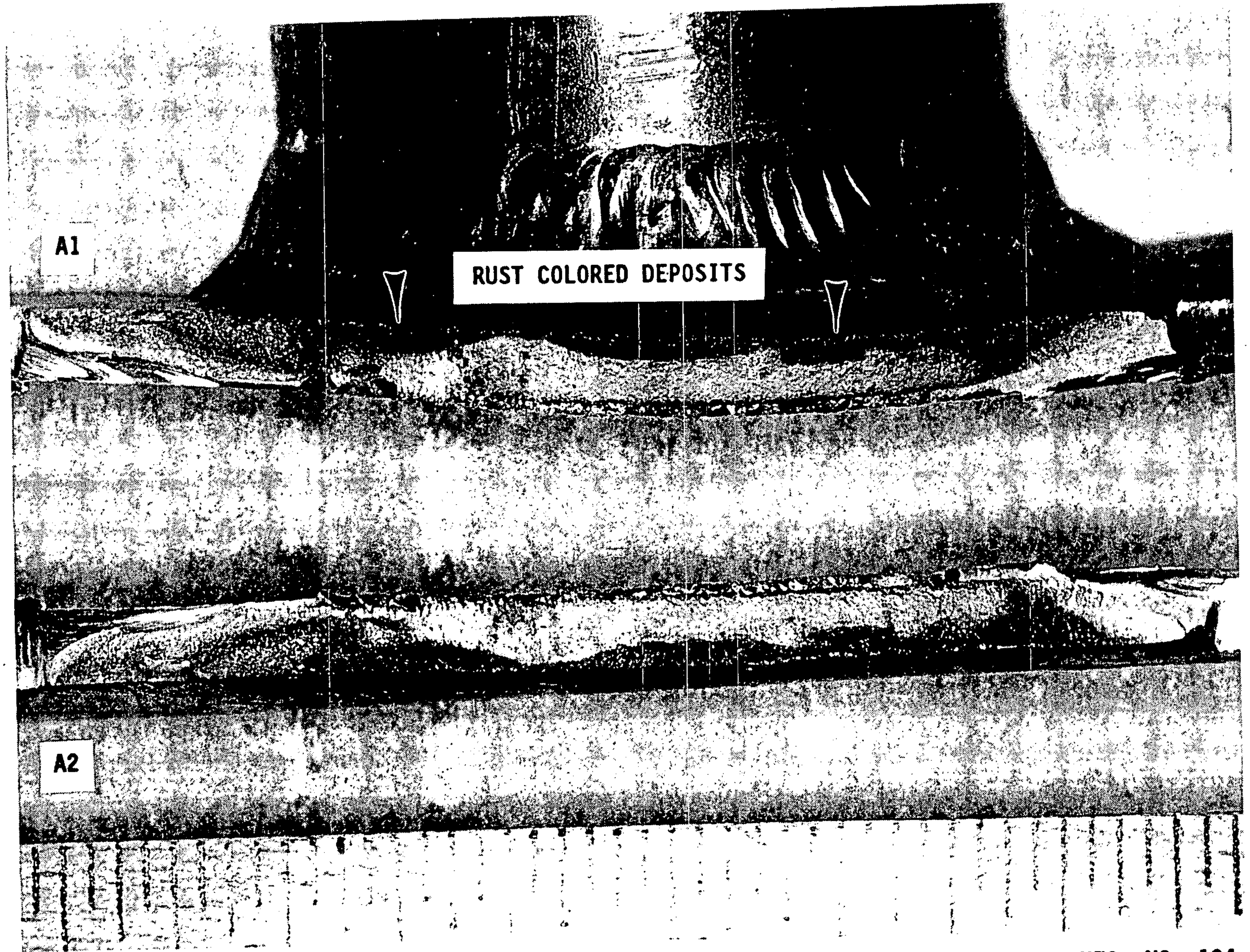


MAIN CRACK & SECOND CRACK 1.8X NEG. NO. 133



CLOSE UP OF SECOND CRACK 4.7X NEG. NO. 135

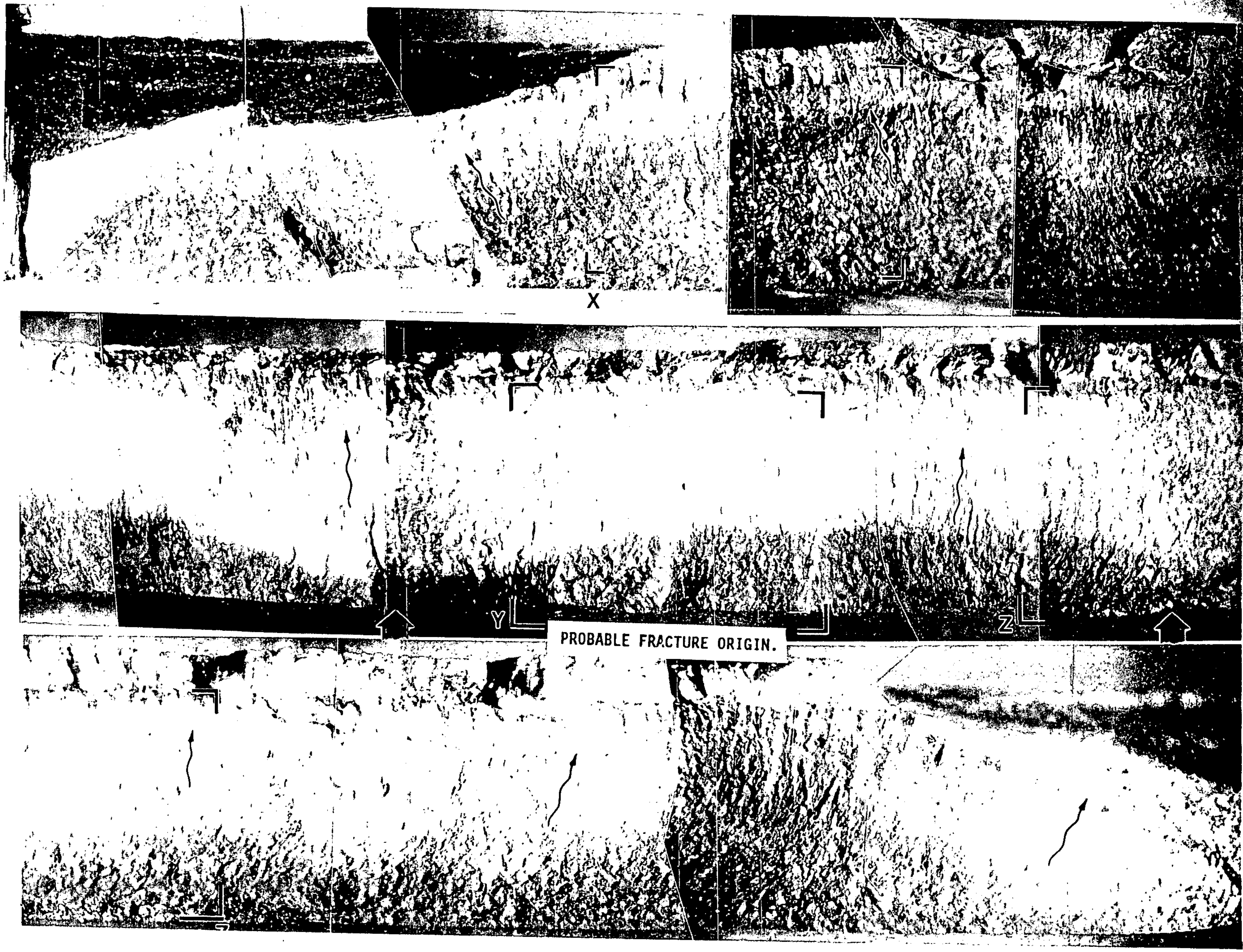
FIGURE 6: SPECIMEN A, AFTER INITIAL SECTIONING



2.9X

NEG. NO. 134

FIGURE 7: CRACK FACE, SPECIMENS A1 (TOP) AND A2 (BOTTOM) AFTER BENDING; ARROWS INDICATE LOCATION WHERE CRACK DEVIATED FROM WELD TOE

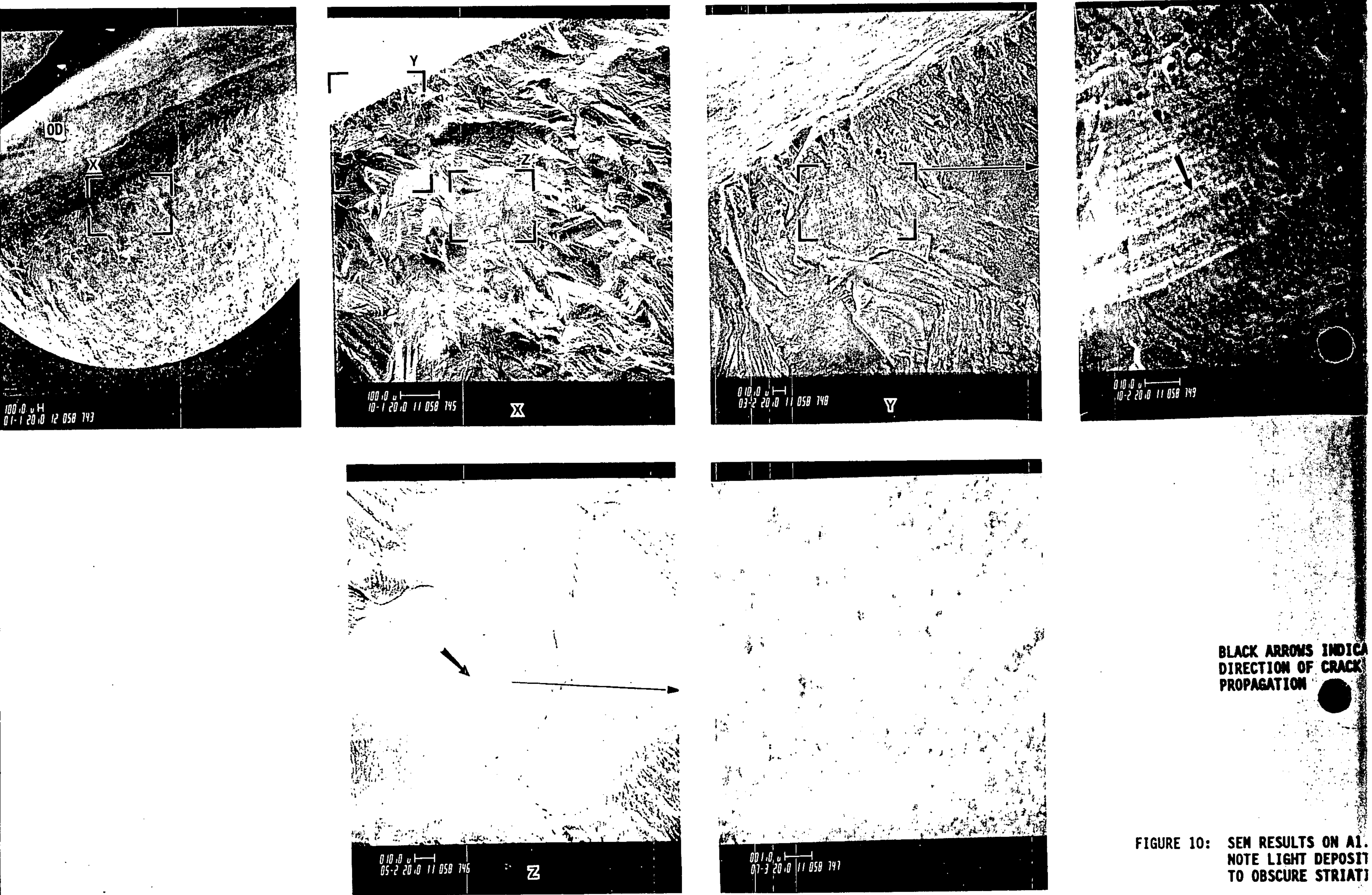


SQUIGGLY ARROWS INDICATE DIRECTION OF CRACK PROPAGATION.

NOTE HEAVY RUST DEPOSITS.

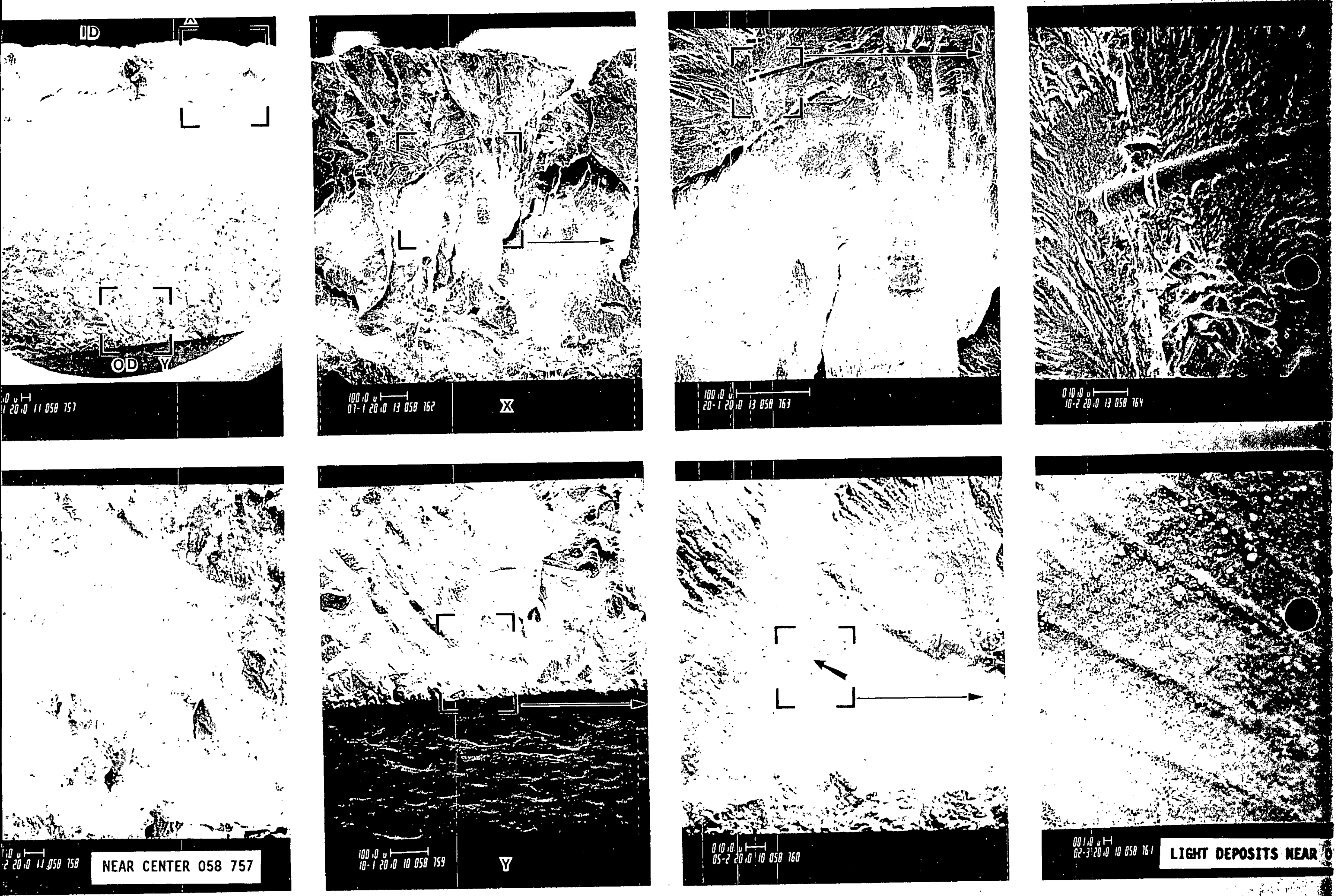
NEG. NOS. 142 - 159

FIGURE 8: SPECIMEN A2, FRACTUR
OD EDGE AT BOTTOM (



BLACK ARROWS INDICA
DIRECTION OF CRACK
PROPAGATION

FIGURE 10: SEM RESULTS ON A1.
NOTE LIGHT DEPOSIT
TO OBSCURE STRIATI



BLACK ARROW INDICATES DIRECTION OF CRACK PROPAGATION

FIGURE 11: SEM RESULTS ON
AND NEAR ID EDG

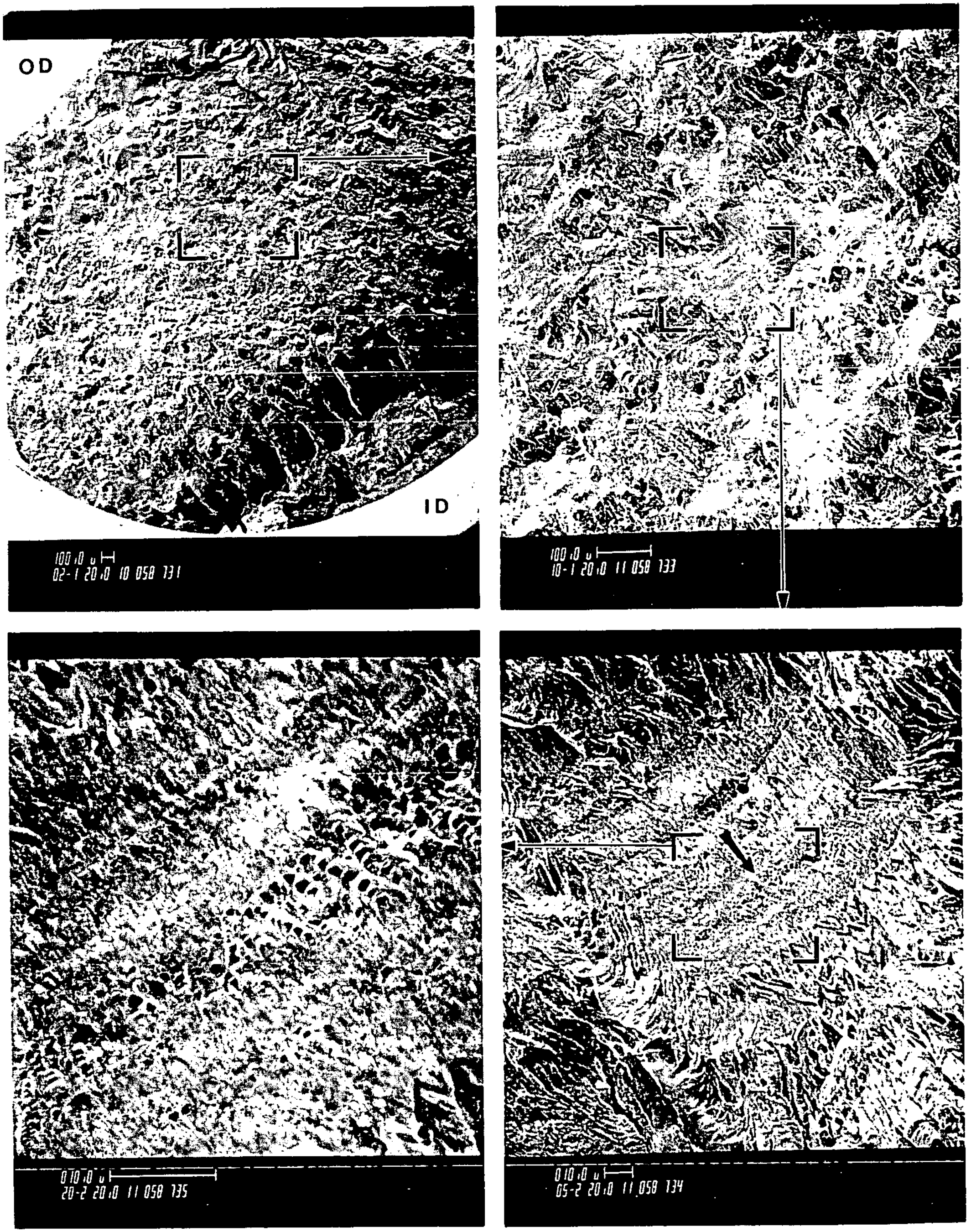


FIGURE 12: SEM RESULTS ON A1.4A NEAR CENTRAL PART OF FRACTURE MID-WAY BETWEEN OD AND ID; BLACK ARROW INDICATES DIRECTION OF CRACK PROPAGATION

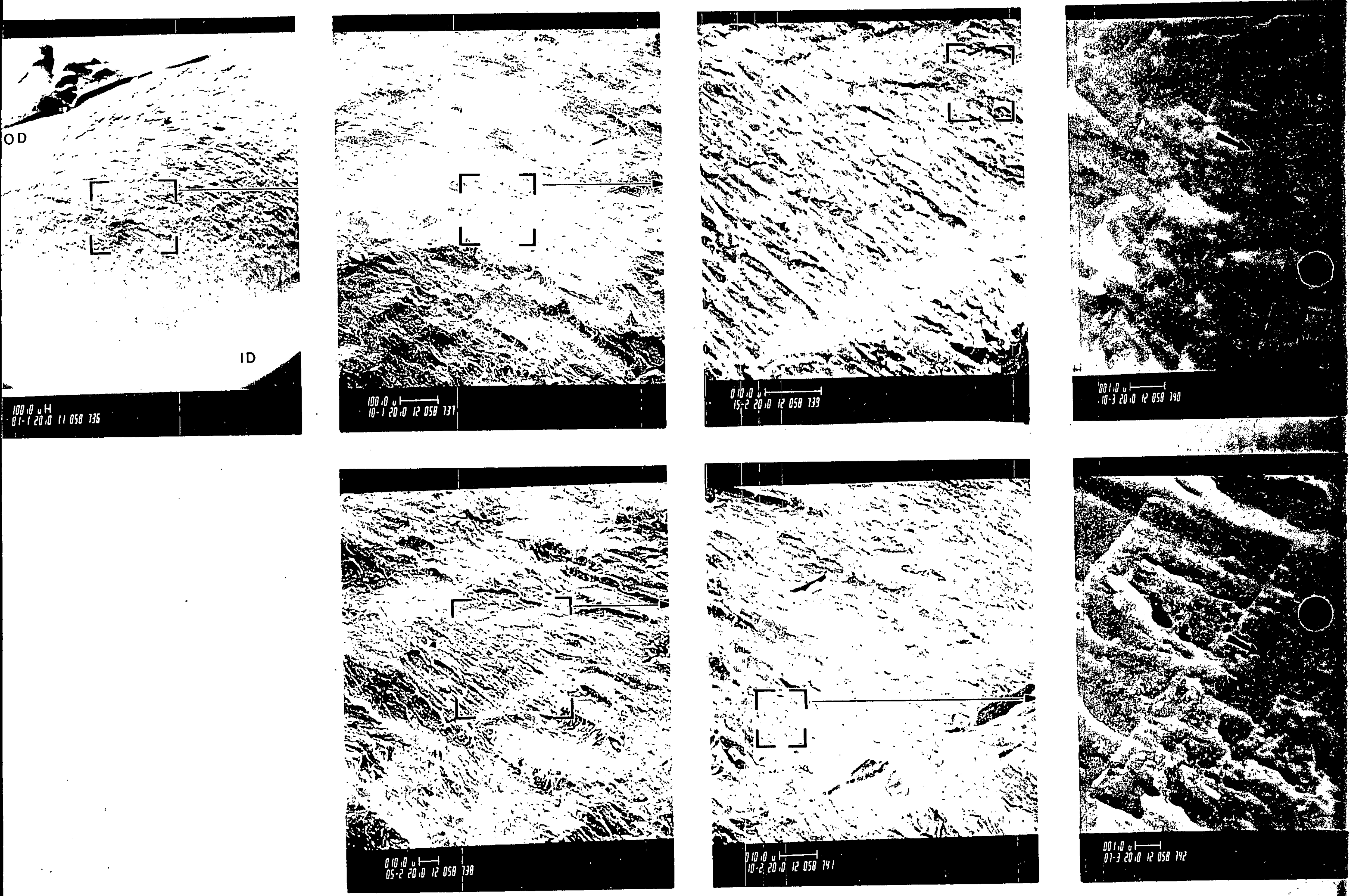


FIGURE 13: SEM RESULTS ON A1.4A NEARER END OF FRACTURE MID-WAY
AND ID; BLACK ARROWS INDICATE DIRECTION OF CRACK PRO

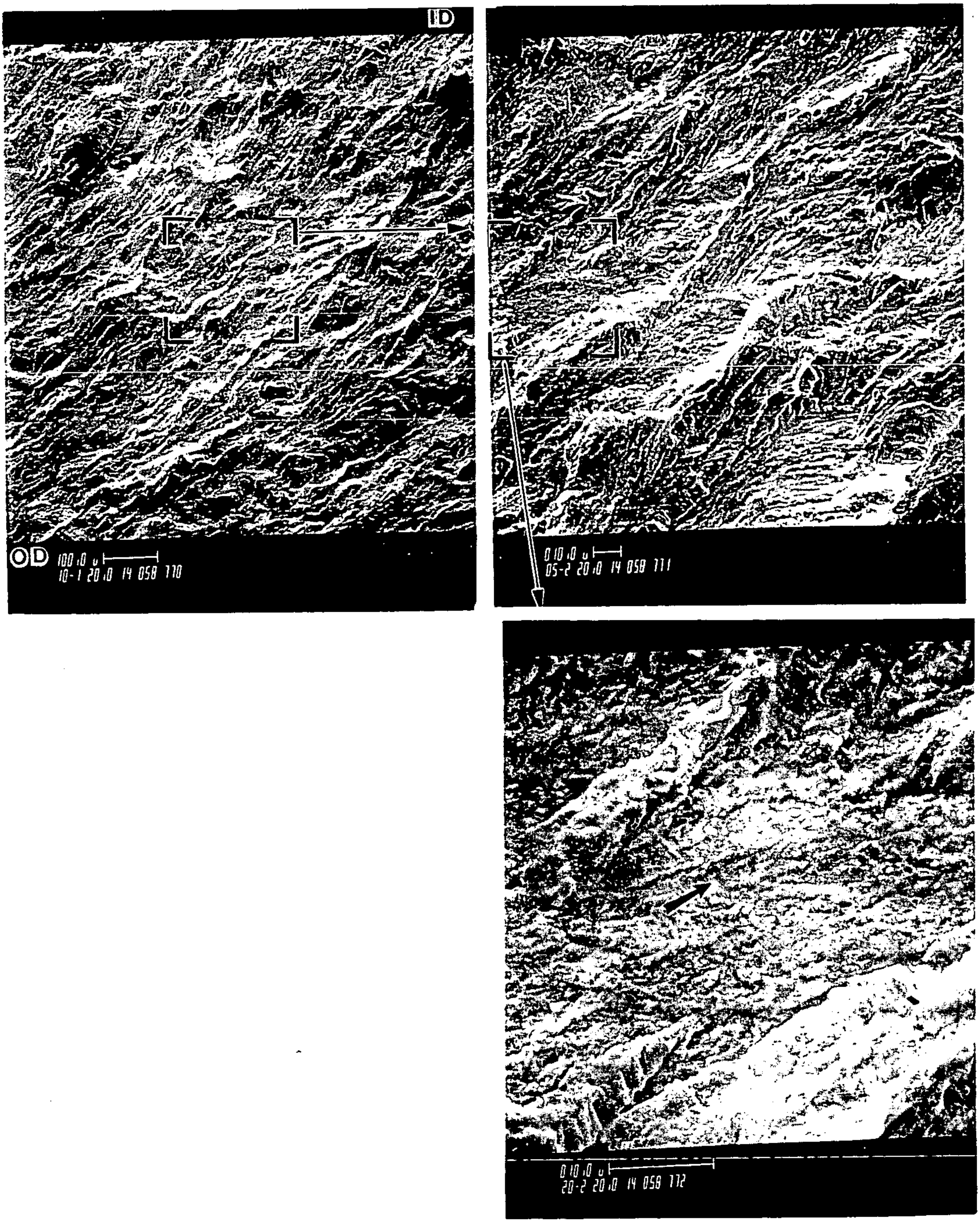


FIGURE 14: SEM RESULTS ON A1.4B NEAR CENTRAL PART OF FRACTURE MID-WAY BETWEEN OD AND ID; BLACK ARROW INDICATES DIRECTION OF CRACK PROPAGATION

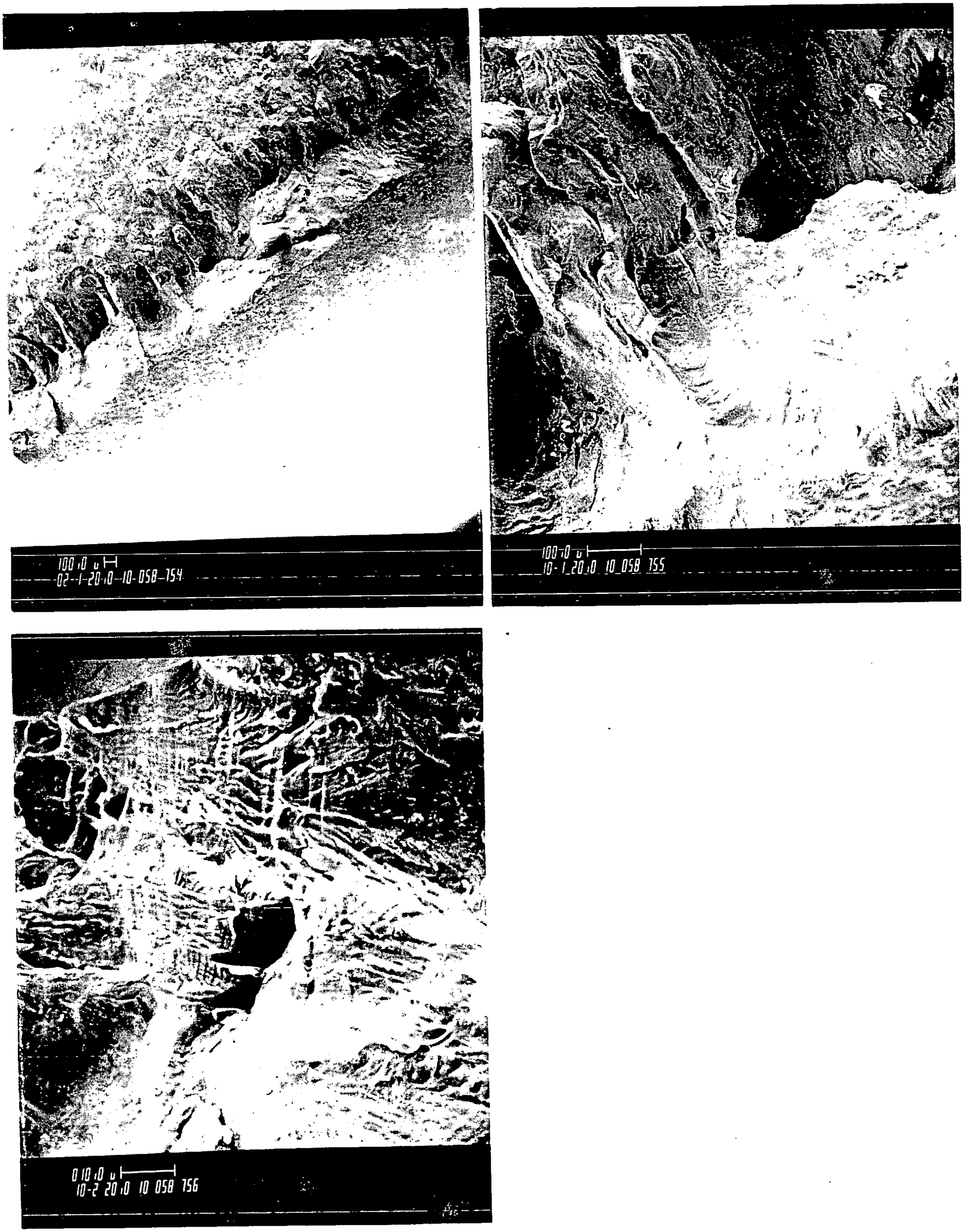


FIGURE 15: SEM RESULTS ON A1.4A SHOWING TYPICAL FRACTURE SURFACE APPEARANCE NEAR THE ID EDGE; NOTE ABSENCE OF DIMPLED RUPTURE AND POSSIBLE FATIGUE STRIATIONS

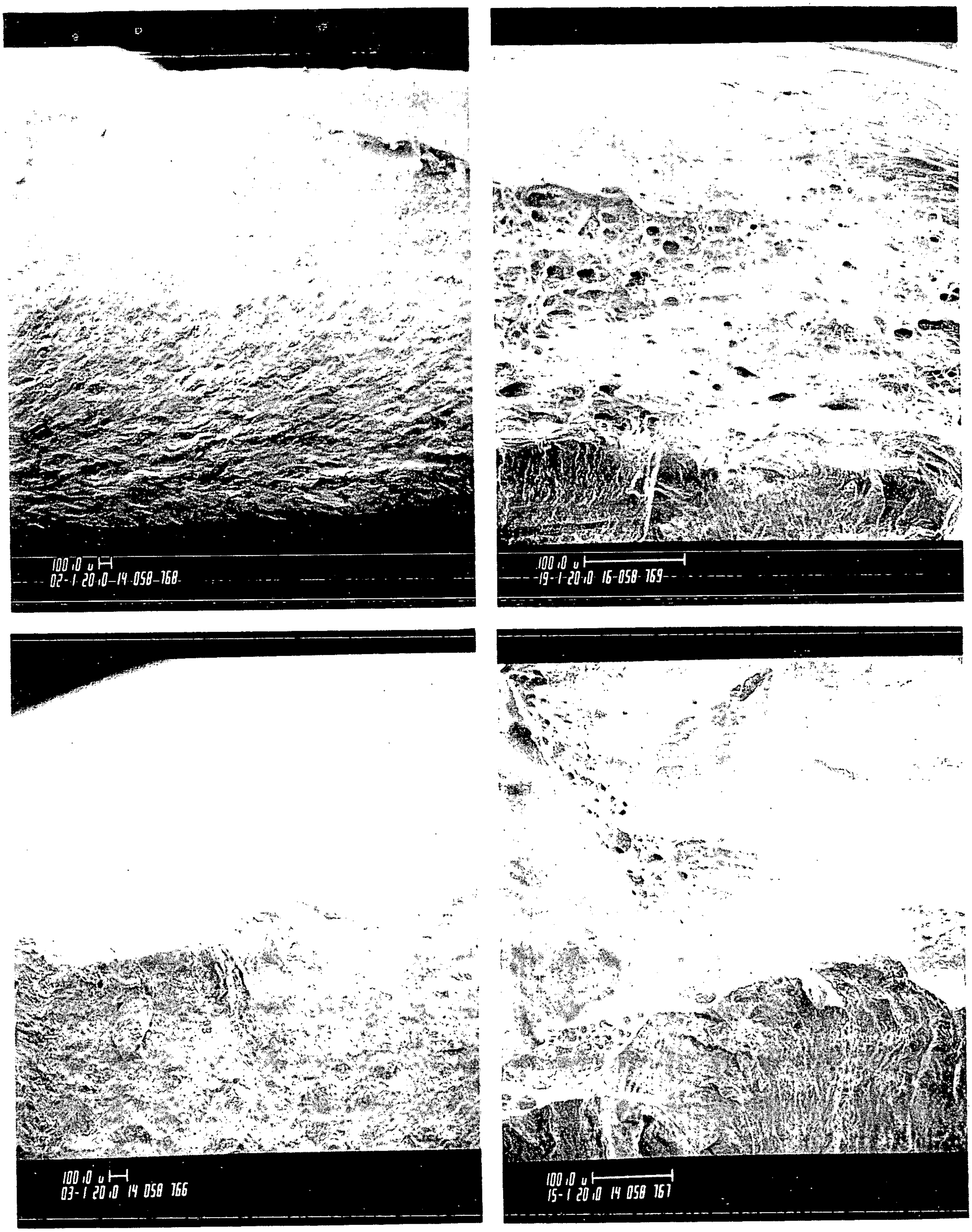
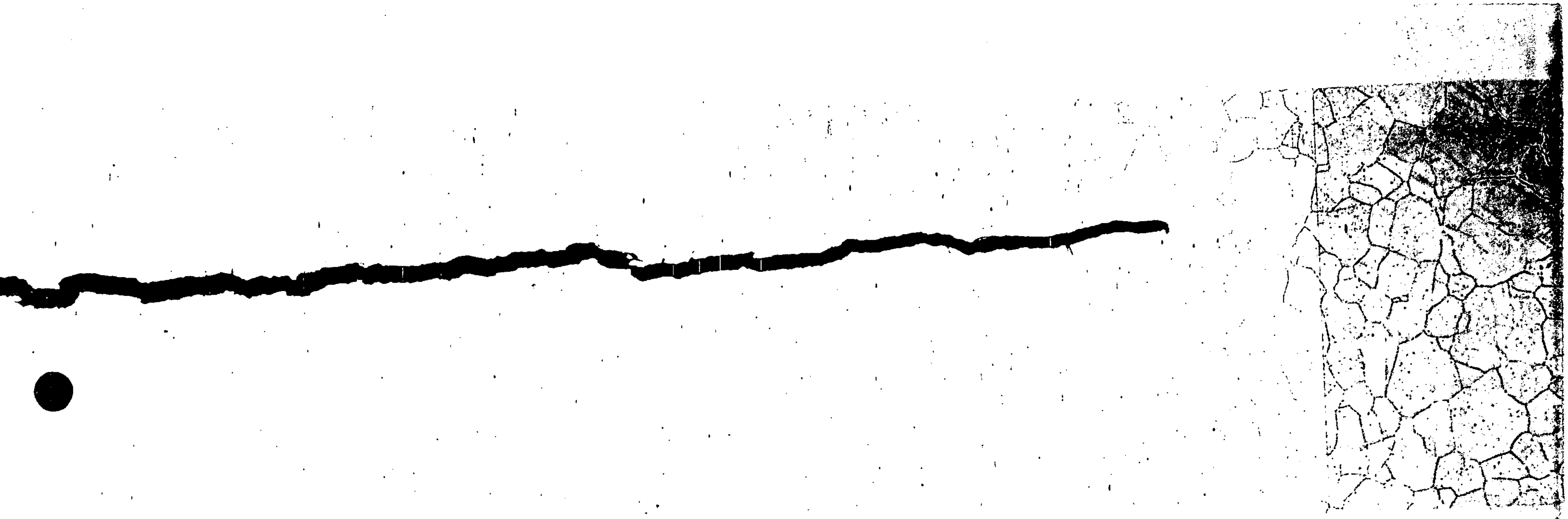
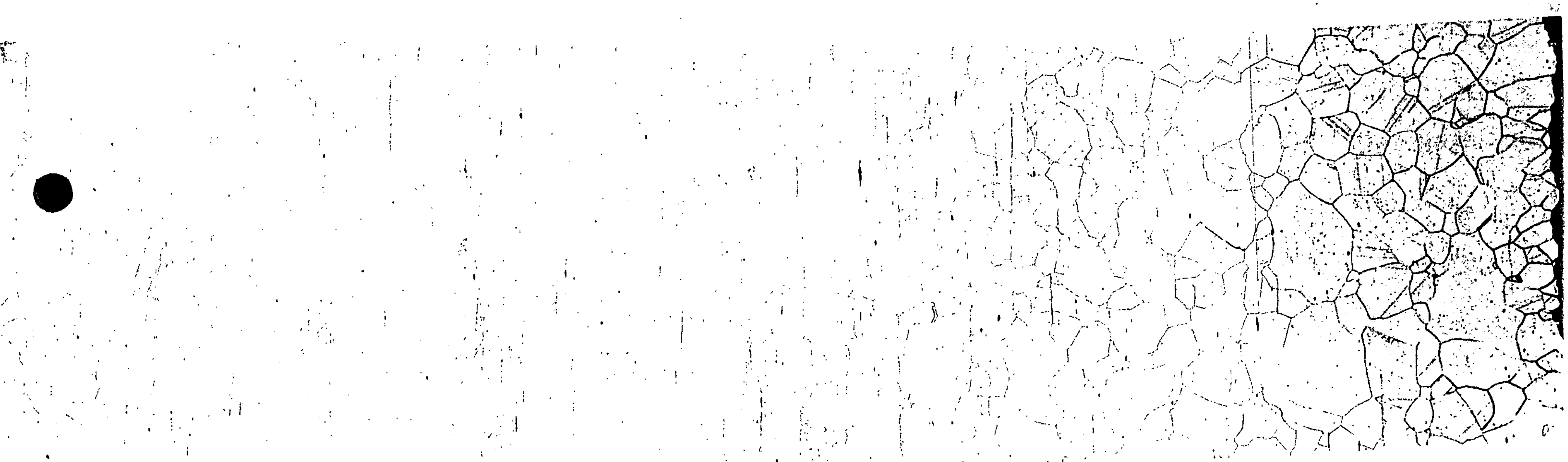


FIGURE 16: SEM RESULTS ON A1.4B SHOWING DIMPLED RUPTURE NEAR THE END OF THE CRACK (TOP PHOTOS) AND OF SMALL LIGAMENTS ALONG ID EDGE (BOTTOM PHOTOS)



100X

OXALIC ACID



100X

OXALIC ACID

FIGURE 17: METALLOGRAPHY RESULTS ON A1.
AND A1.3 (BOTTOM)

F92-010 500X OXALIC ACID

FIGURE 18: METALLOGRAPHY RESULTS ON A1.3 SHOWING SMALL CRACK AT WELD TOE

DISTRIBUTION (COMPANY-LIMITED): This information is freely available to all Company personnel. Written approval by the Manager of Nuclear Materials is required only if release outside of the Company is requested.

LRC	BWNS	ARC
C.R. Frye	D.J. Firth (6)	L.M. Sarver
G.O. Hayner		CIC Library (4)
R.C. Luken		
R.E. Napolitano		
Project File (5)		

KEY WORDS: Low Pressure Injection
Fatigue
304 Stainless Steel