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METALLURGICAL INVESTIGATION OF WALL THINNING AND LEAKAGE OF THE BMI THIMBLE TUBING AT D.C. COOK UNIT 2

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SECTION 1.0
INTRODUCTION

This report summarizes the findings of the metallurgical investigation of the wear and leakage of the reactor vessel bottom mounted instrumentation (BMI) thimble tubes at D. C. Cook Unit 2. The reactor vessel instrumentation thimble is a small tubing with an outside diameter ranging from 0.300 in. to 0.385 in. and a wall thickness ranging from 0.05 in. to 0.06 in. respectively, depending on the plant. The thimble tubing is made of cold worked 316 stainless steel material although most recently cold worked 316L grade has been applied to limit the cobalt content. A schematic representation of the reactor vessel BMI thimble system is illustrated in Figure 1.1.

The current report summarizes the evaluations and results of one severely worn and one leaky thimble tube from D.C. Cook Unit 2. The evaluations, conducted at the Westinghouse hot cell facilities centered on two, approximately three feet long thimble tube segments containing the wear affected regions and included the following major tasks:

- Surface examinations
- Metallographic examinations
- Detailed wear morphology evaluations, and
- Hardness measurements

The overall purpose of the investigation was to establish the mechanism and cause of the thimble tube leakage and further to develop information that would be helpful for taking corrective actions.

SECTION 2.0
TESTS AND EXAMINATIONS

2.1 Surface Examinations

The as-received condition of the thimble tube samples were examined visually and by low magnification light optical microscopy for evidence of cracks, wear, surface attack or other damage and deposits. The results of the surface examination were documented by the macrophotographs illustrated in Figures 2.1 and 2.2.

2.2 Metallographic Examinations

Metallographic examinations were conducted on the thimble tube samples sectioned axially and transversely through the worn and/or leak regions to examine the location and extent of wear damage, the wear scar geometry and the material microstructure. The results of the metallurgical examinations are illustrated in Figures 2.3 and 2.4.

2.3 Wear Morphology Examinations by Surface Replication

Prior to sectioning for metallography, the worn and leak region of the thimble tube samples were prepared for surface replication and plastic replicas were pulled from the affected region. The replicas were prepared by gold sputtering under vacuum and were examined by scanning electron microscopy to establish the morphology and mechanism of the wear damage. The results of these examinations are illustrated in Figures 2.5 through 2.17.

2.4 Hardness Measurements

Hardness traverse measurements were conducted on polished sections of the worn region of the thimble tubes to examine the nature of deformation and work hardening associated with the wear damage. The results of the hardness traverse measurements are summarized in Table 1.

2.5 Fuel Nozzle Geometry Examinations

The inside diameter surface geometry of the fuel bundle bottom nozzle at the entry of the instrument tube was examined and compared with thimble wear scar geometry to establish their relationship if any. The nozzle geometry is schematically illustrated in Figure 2.18.

SECTION 3.0
RESULTS AND DISCUSSION

The results of the surface examination of the as-received thimble tube samples are illustrated in Figures 2.1 and 2.2. Figure 2.1 illustrates the surface appearance of the wear scar inflicted on the leaked thimble C-7. The scar which extended approximately over 0.5 in. in length is made up of two steps. The deepest step which corresponds to the most severely worn region contained a through-wall perforation contributing to the leakage.

The side view shown in the top photomacrograph clearly shows the presence of circumferentially oriented wear marks associated with the wear scar. In addition to the two stepped wear scar, the presence of an axially oriented wavy scar can also be seen here. The scar appearance suggests that it may have been inflicted by surface scraping or tooling action against a sharp corner most likely during insertion or retraction of the thimble. Figure 2.2 illustrates the surface appearance (side and top views) of the wear scar in thimble A-9. The scar appearance is very similar to the one seen in thimble C-7. The two stepped wall thinning and the presence of circumferential wear marks can be clearly seen. The thinning at the deepest scar location appears to have just fallen short of a through-wall perforation. The total length of the two stepped wear region again corresponded to approximately 0.5 in. in length.

The results of the metallographic examination of the thimble tube samples are illustrated in Figures 2.3 and 2.4. Figure 2.3 illustrates the metallography results of a transverse section through the through-wall perforation on thimble tube C-7. The locations where hardness measurements were taken from are also indicated here. Several significant observations are apparent from the illustration. The thimble tube wear (thinning) appears to have extended circumferentially over an angular region of 240°. The general microstructure did not reveal any evidence of substructure characteristics of deformation except at the thinnest region of the terminations near the perforation. The thinnest section near the terminations measured approximately 0.06 in. thick. No evidence of any cold work was apparent at the wear surface. The hardness measurements (summarized in Table 1) confirmed some work hardening of the thin

terminations presumably due to bending at the perforation. Figure 2.4 illustrates the metallography results of an axial section through the worn region of the thimble A-9. Here again, although there is a significant reduction in wall thickness due to wear, no gross deformation or coldwork is seen in the material. This is further evidenced by the hardness values listed in Table 1. The hardness values at the thinnest region here are comparable to the hardness values taken from the region affected by wear. These observations suggest that the contact and/or impact loads involved in the wear process may have been relatively low. Noticeable is the lack of deformation or bending at the thin ligament section of the wear scar in Figure 2.4.

The higher magnification scanning electron microscopy results of the wear morphology by surface replication are illustrated in Figures 2.5 through 2.17. Figures 2.5 through 2.7 illustrate the low magnification photomacrographs of the surface replicas taken from the worn regions of the C-7 and A-9 thimbles identifying locations where higher magnification SEM was conducted. Figures 2.8 through 2.17 illustrate the higher magnification scanning electron micrographs detailing the wear morphology seen at designated locations (indicated in Figures 2.5 through 2.7). Figure 2.8 illustrates the surface morphology of the unaffected (as finished) and wear affected regions in thimble C-7. The unaffected region (micrograph #16) suggests the presence of mechanical tooling marks perhaps characteristic of the tube fabrication process while the morphology seen at the affected region appears distinctly different, characterizing the wear process. Figure 2.9 illustrates the region of intersection of worn and unaffected regions in thimble C-7. The axially oriented (horizontal) tooling marks representing the unaffected surface region terminates into a worn region of circumferentially oriented (vertical) wear scars. Similar observations seen at the unaffected and wear regions of thimble A-9 are illustrated in Figures 2.13 and 2.16. Figures 2.10 and 2.17 illustrate the typical wear morphology seen at the less severely worn regions (upper step region of wear scar) of the thimbles C-7 and A-9. The morphology resembles circumferentially oriented, regularly spaced "boat shaped" shallow marks. Higher magnification views of these marks, illustrated in Figures 2.10(b) and 2.11 suggests a surface formed by rubbing or fretting action. The morphology seen here also suggests some rate of jetting or errosive action of the fluid. A second type of wear morphology seen at the more severely (deep)

worn lower step regions of the wear scar are illustrated in Figures 2.12 and 2.13. The morphology seen here suggests material loss in the form of irregularly shaped flakes, presumably due to higher deformation or loads. This type of planar flake-like morphology is seen at the deeper step surface and closer to the perforation regions. The surface morphology seen at the terminations immediately adjacent to the perforation is illustrated in Figure 2.14. The surface morphology seen here resembles deformation bands characteristic of slip bands in each grain. The thickness of the thimble tube here is considered very small approaching that of a grain size so that the deformation slip bands in each crystal (grain) are clearly apparent here.

A schematic representation of the geometry of the fuel bundle bottom nozzle is illustrated in Figure 2.18. Close examinations of the nozzle inside diameter surface geometry at the thimble penetration clearly reveals a close and consistent relationship with the two stepped geometry of the thimble tube wear scar. The nozzle penetration width (0.5 in) is also in close agreement with the axial length of the wear scar. This clearly establishes that the thimble tube wear occurred by the movement of the thimble at the nozzle penetration. The primary water flow velocities and flow conditions in this region are known to induce thimble tube vibrations. It is believed that these vibrations may have caused adequate motion and contact loads resulting in the observed thimble tube wear.

TABLE 1

SUMMARY OF HARDNESS MEASUREMENT RESULTS
(LOCATIONS AS MARKED IN FIGURES 2.2 AND 2.3)

	Hardness (VHN, 400 gms)	
Location I.D.	Transverse Section	Axial Section
1	285	274
2	290	297
3	270	309
4	392	250
5	410	280
6	374	260

SECTION 4.0
CONCLUSIONS

- Based on the overall results of the evaluations it is concluded that leakage in the D. C. Cook thimble tube occurred by the OD surface wear at the bottom fuel nozzle penetration, most likely caused by flow induced vibrations of the thimble tube.

- The wear morphology of the thimble tube showed at least two distinctly different types of wear conditions depending on the location and depth of the wear suggesting varying degrees of displacement, contact loads and fluid jetting conditions along the length of the thimble tubes at the nozzle penetration.

- Circumferential configuration of the wear scar suggested that the thimble tube to nozzle bore contact occurred only on one side of the thimble tube during the wear process.

- Lack of cold work at the wear scar suggested that relatively low impact loads were involved in the wear process.

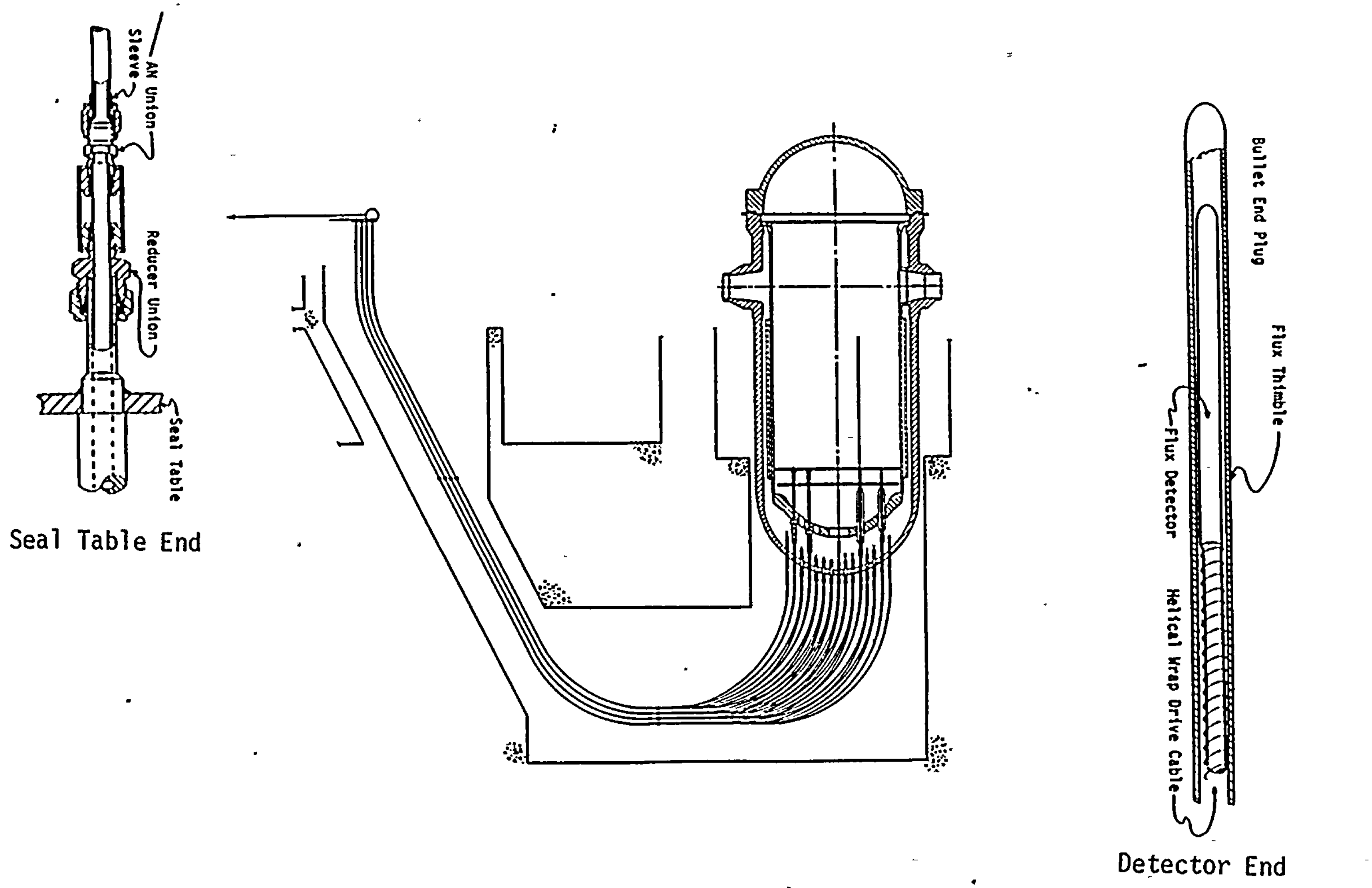


Figure 1.1 Schematic Representation of the Reactor Vessel Bottom Mounted Instrumentation Thimble Tube System

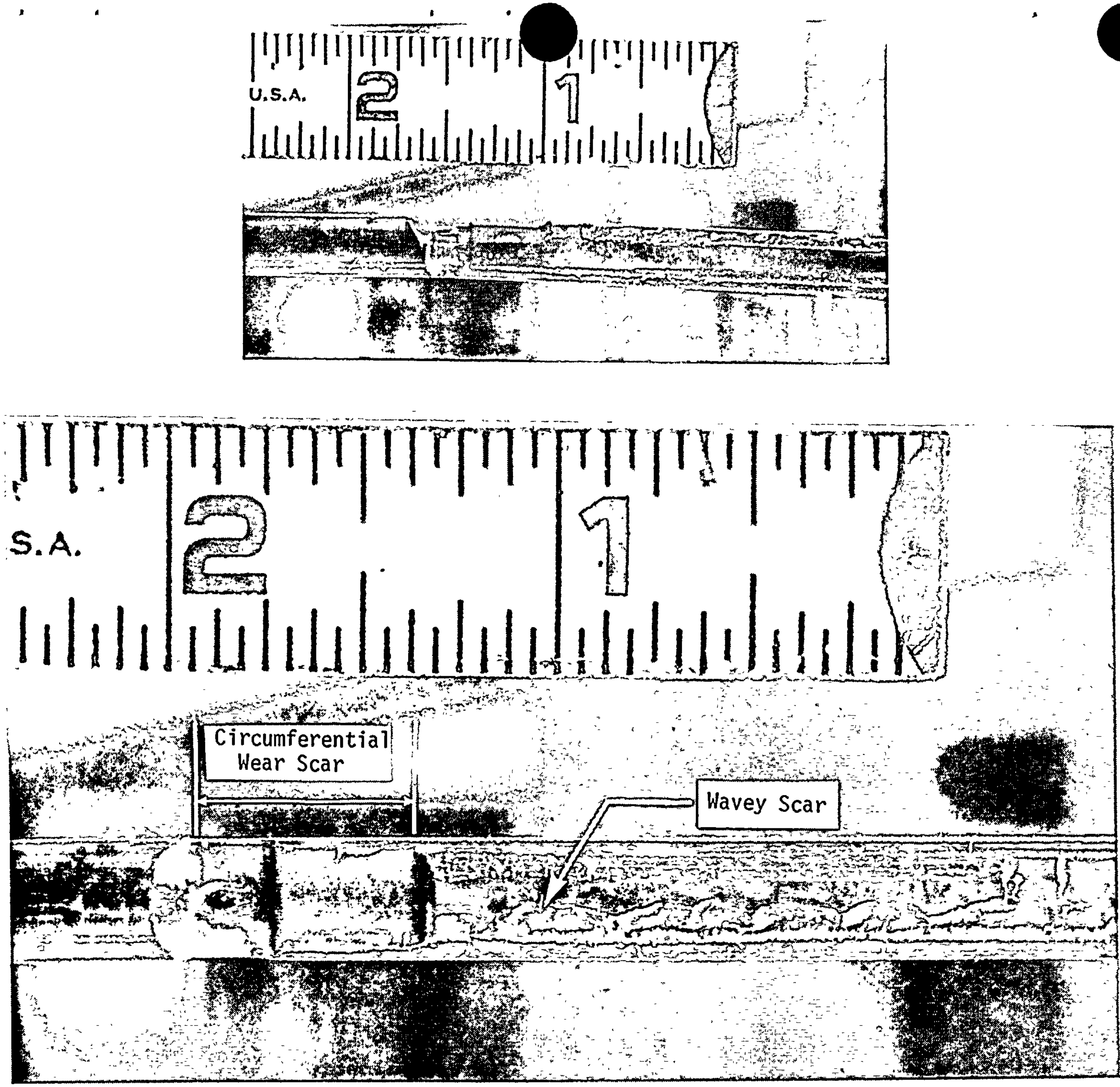


Figure 2.1 Macrophotograph Illustrating the As-Received Condition of the Leaked (Perforated) Thimble Tube "C-7"

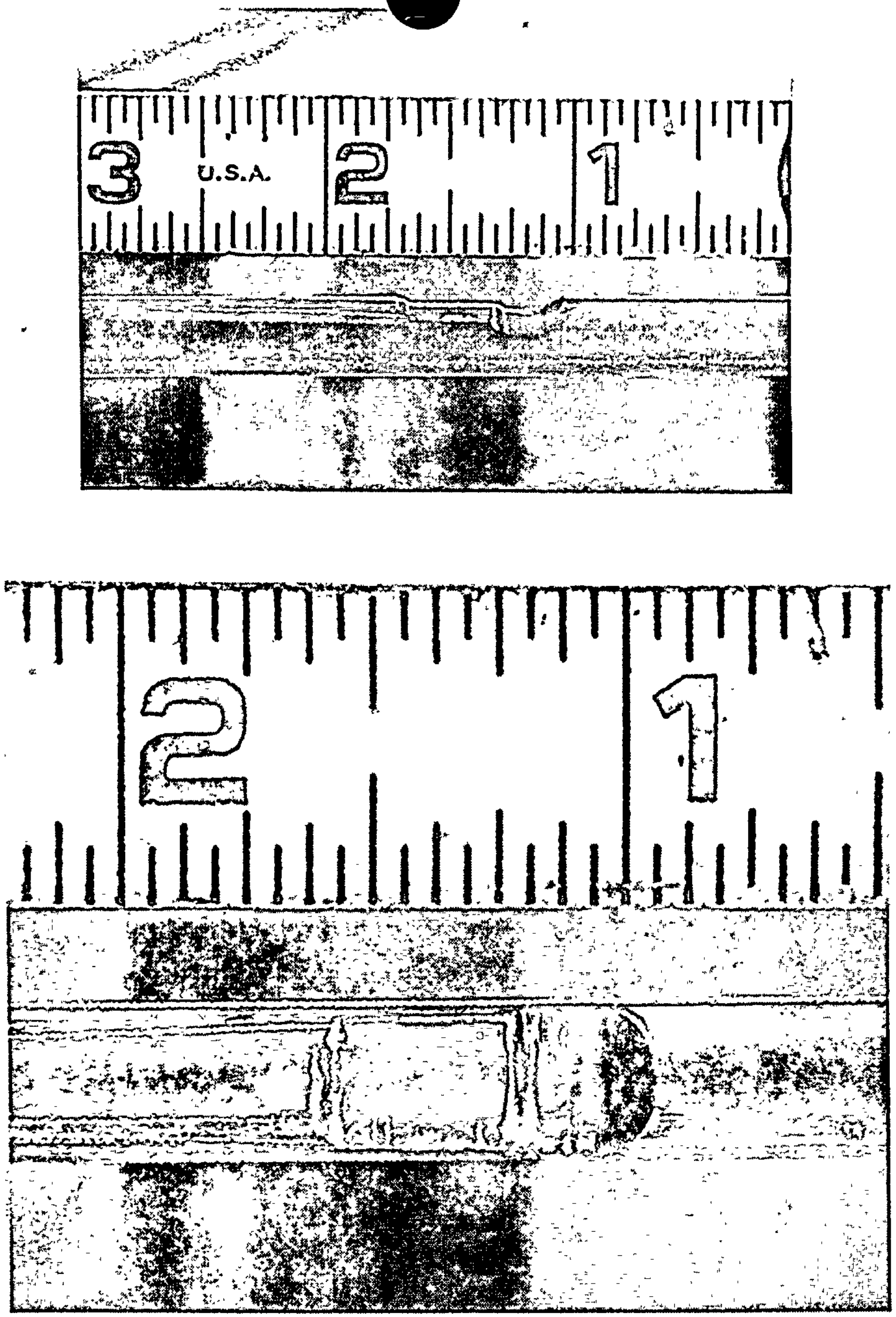


Figure 2.2 Macrophotograph Illustrating the As-Received Appearance of Severely Worn Thimble Tube "A-9"

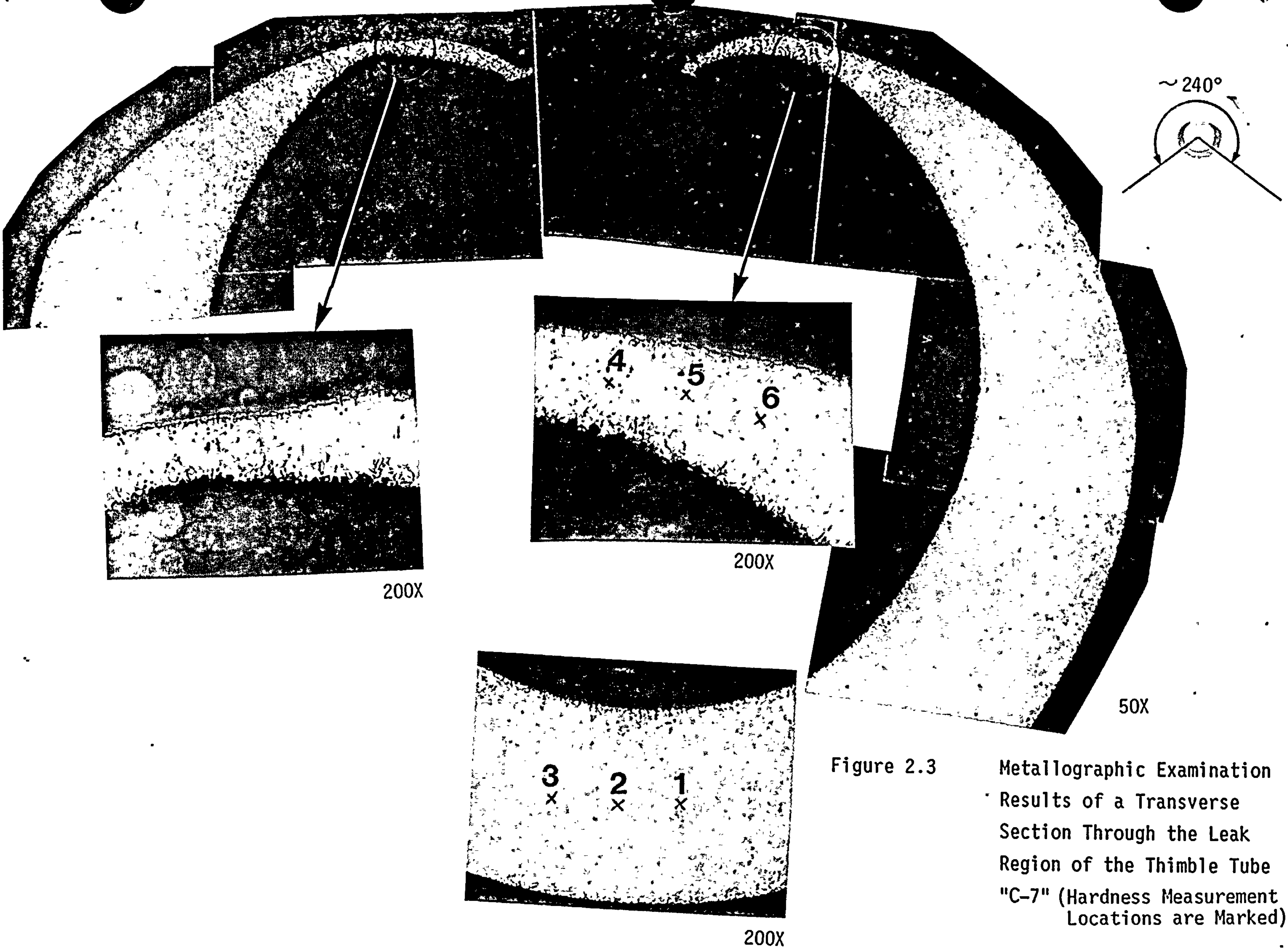


Figure 2.3 Metallographic Examination Results of a Transverse Section Through the Leak Region of the Thimble Tube "C-7" (Hardness Measurement Locations are Marked)

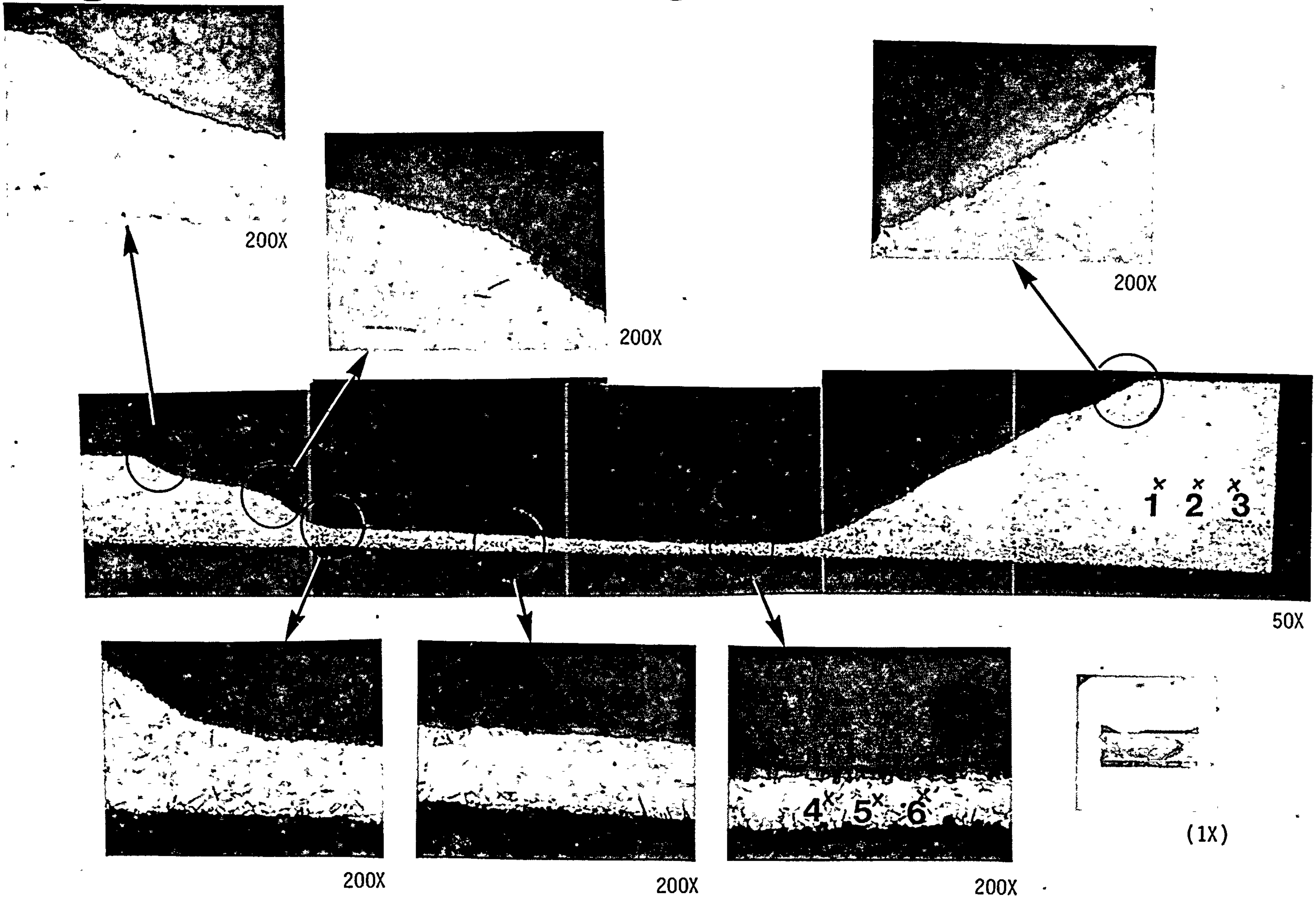


Figure 2.4 Metallography Results of An Axial Section Through the Severly Worn Region of the Thimble Tube "A-9" (Hardness Measurement Locations are Indicated)

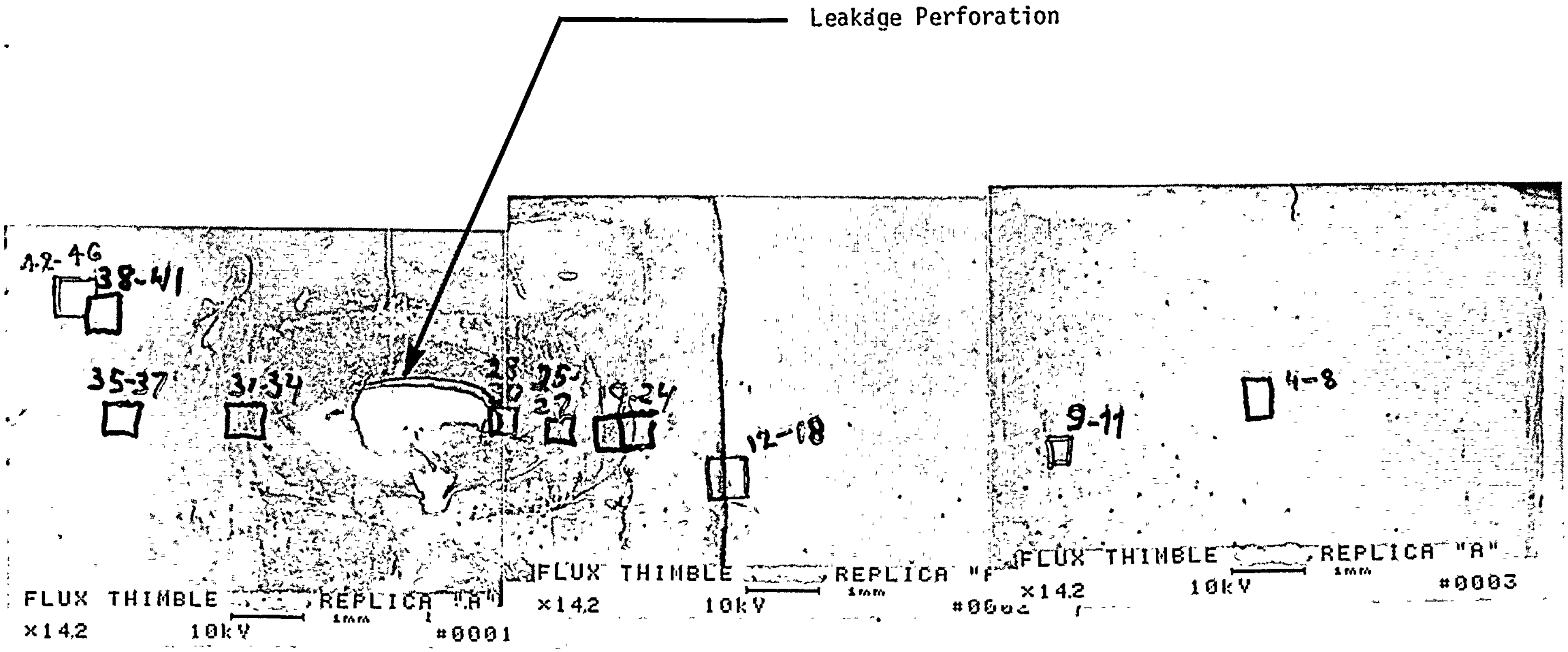


Figure 2.5 Scanning Electron Macrograph Illustrating the Overview of the Plastic Replica of the Worn Region in Thimble Tube C-7 Identifying Locations and Micrograph Numbers Where Higher Magnification SEM was Conducted.

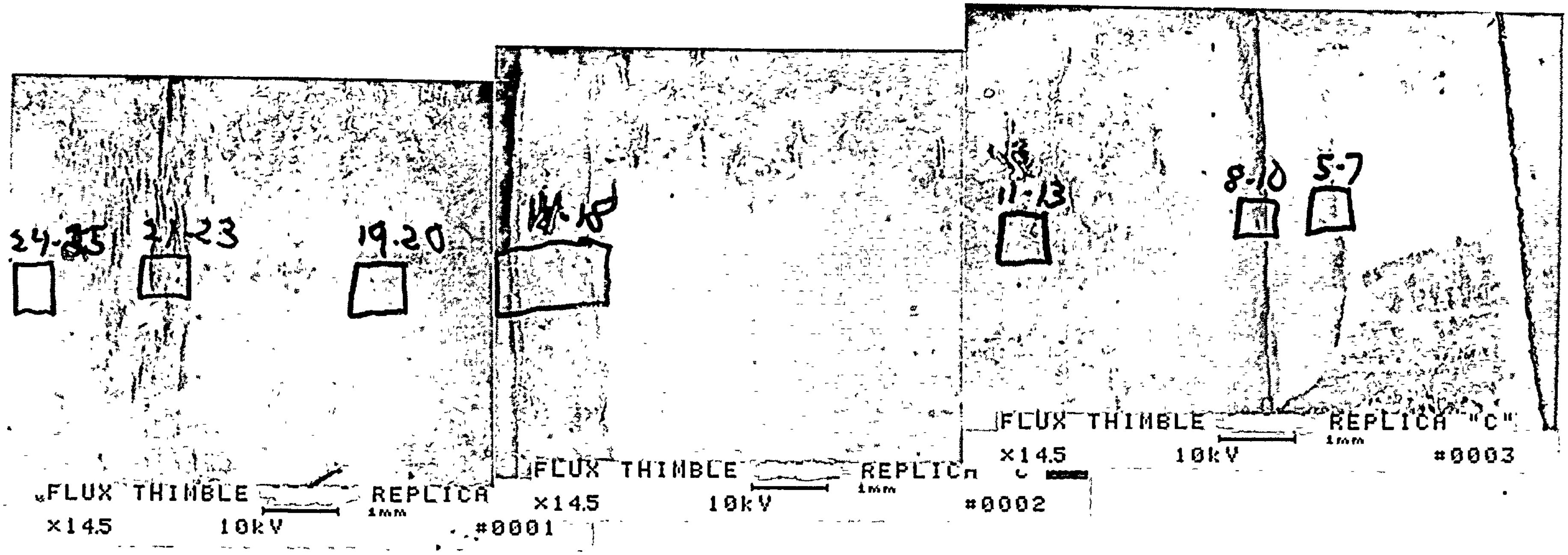


Figure 2.6 Scanning Electron Macrograph of the Plastic Replica Taken from the Worn Region of Thimble Tube "A-9" Identifying Locations and Micrograph Numbers Where Higher Magnification SEM was Conducted.

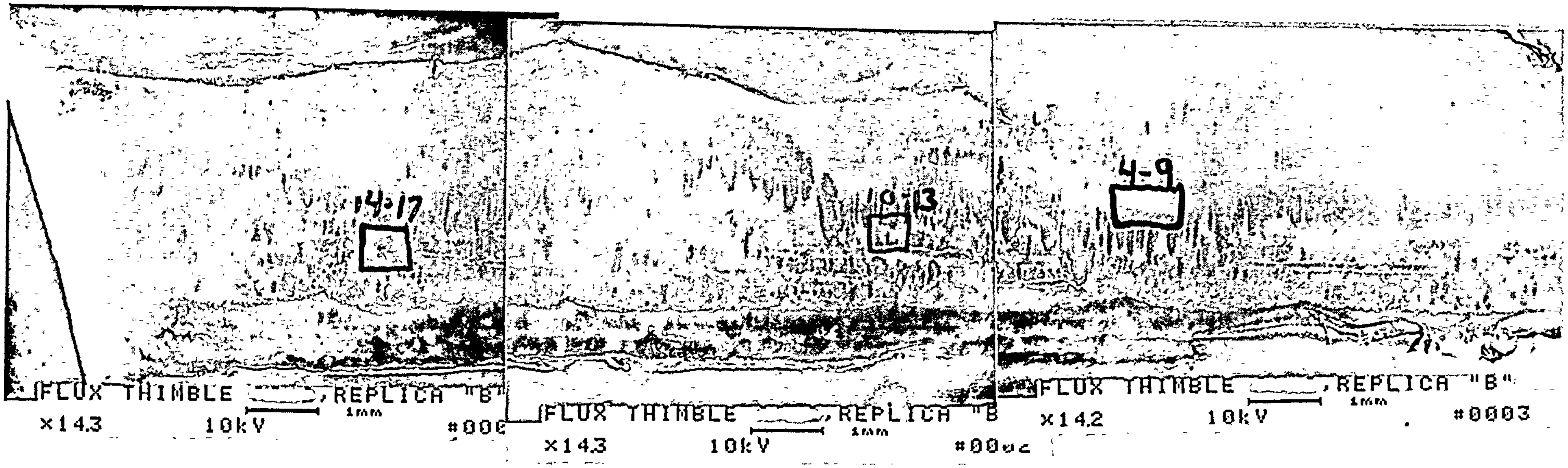


Figure 2.7 Scanning Electron Macrograph of the Plastic Replica Taken from the Worn Region of the Thimble Tube C-7, Identifying Locations Where Higher Magnification SEM was Conducted.

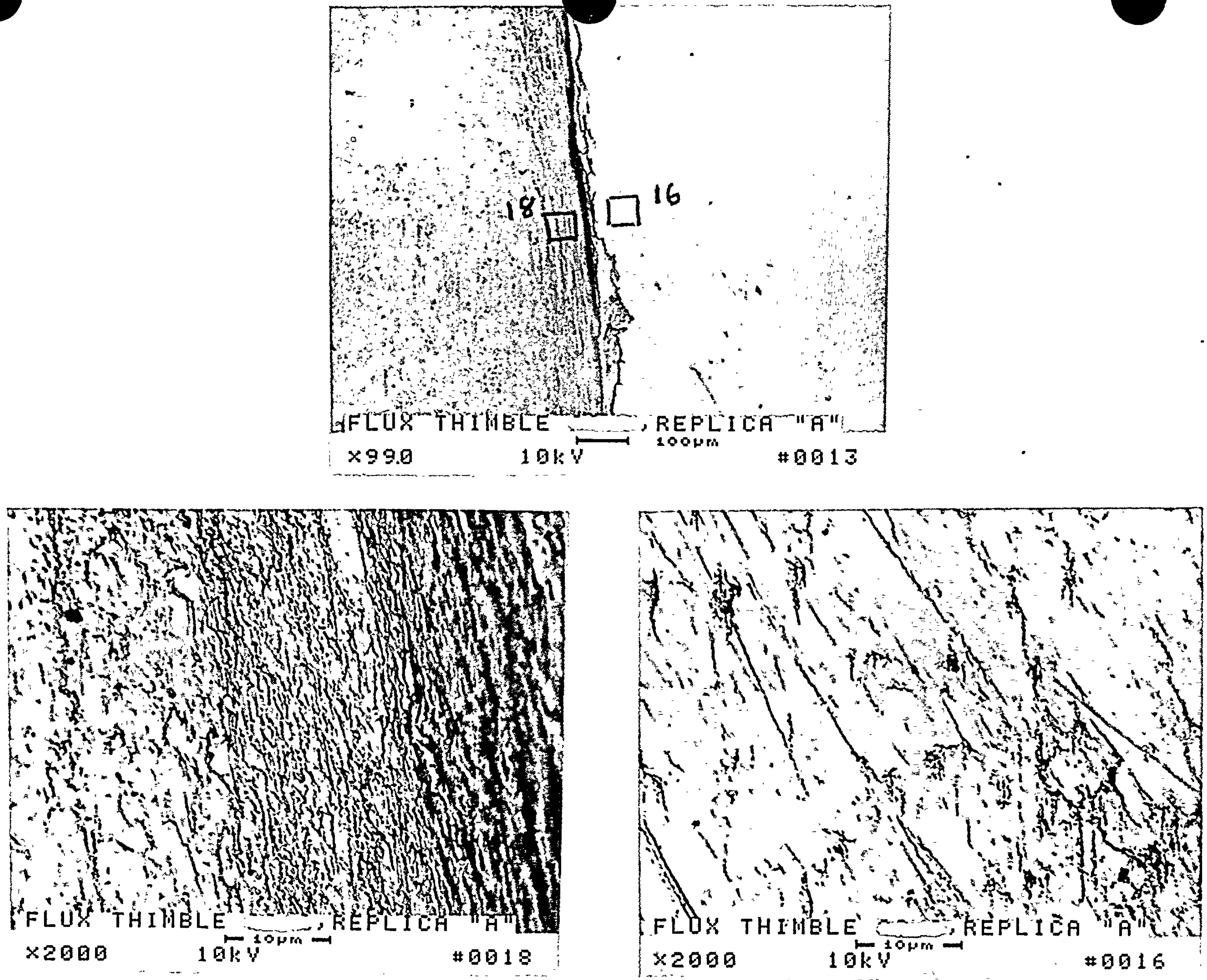


Figure 2.8 SEM Photomicrographs Illustrating the Surface Morphology of the Unscarred and Scarred Regions in Sample C-7.

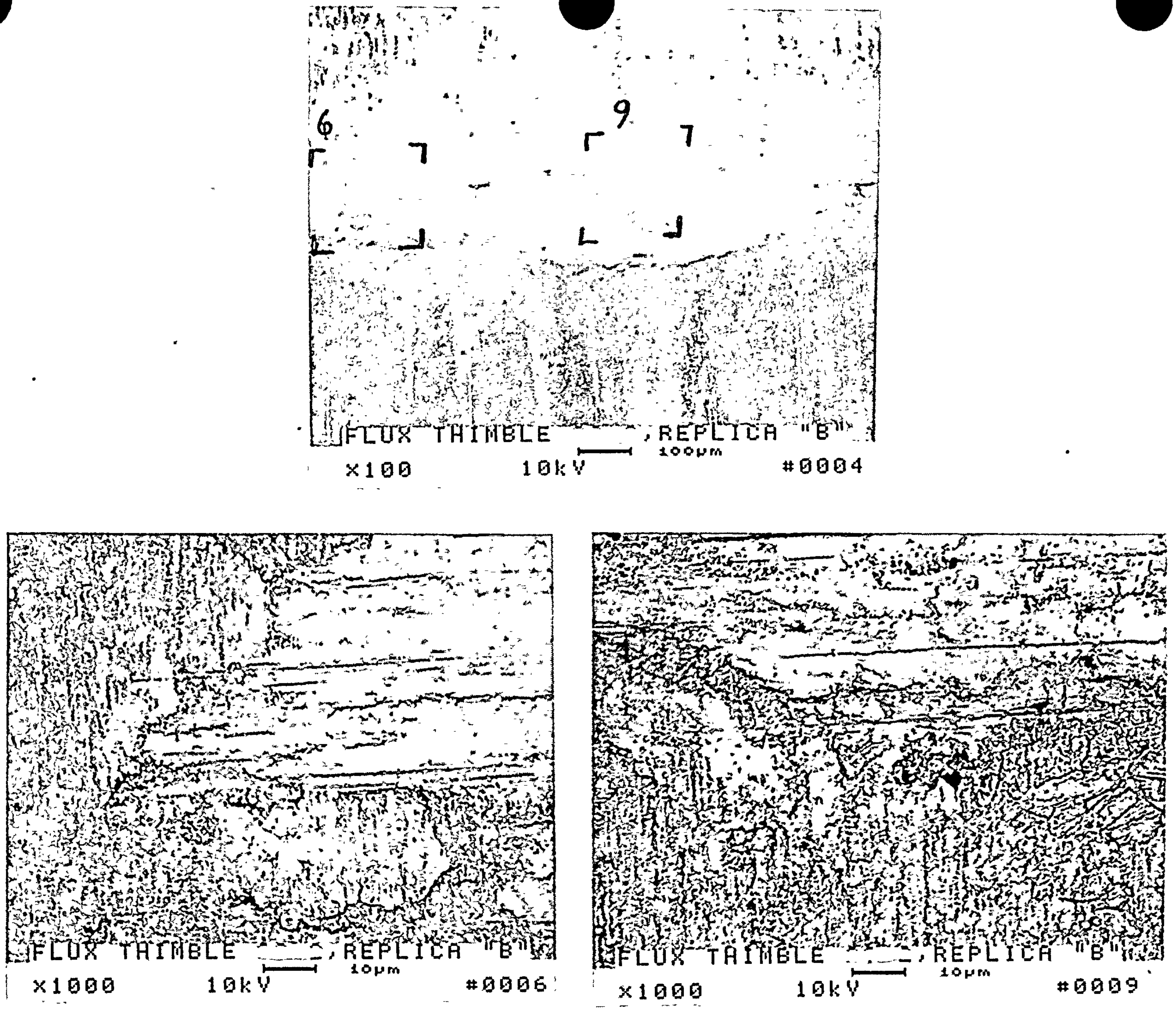
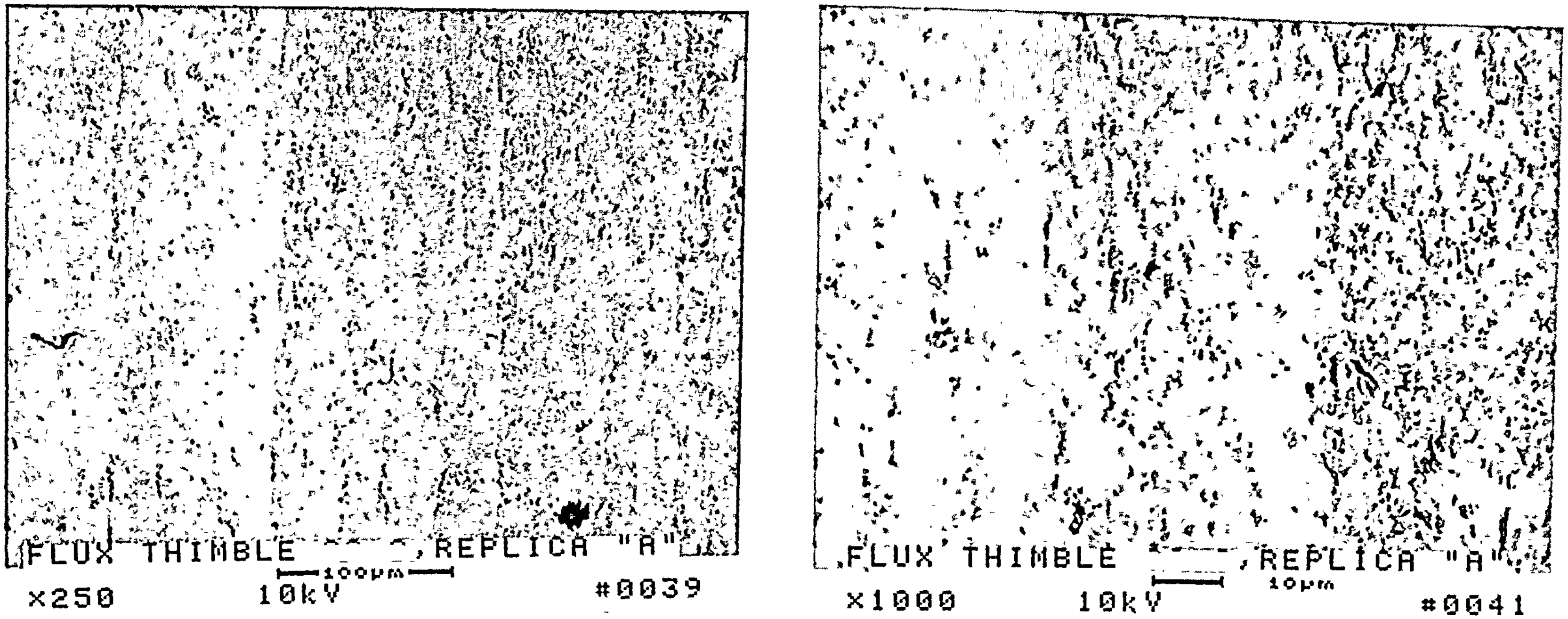


Figure 2.9 SEM Photomicrographs Illustrating the Surface Morphology of the Unscarred and Scarred Regions in Sample C-7.



(a) (b)

Figure 2.10 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 39 and 41 Identified (in Figure 2.5) on the Replica from "C-7"

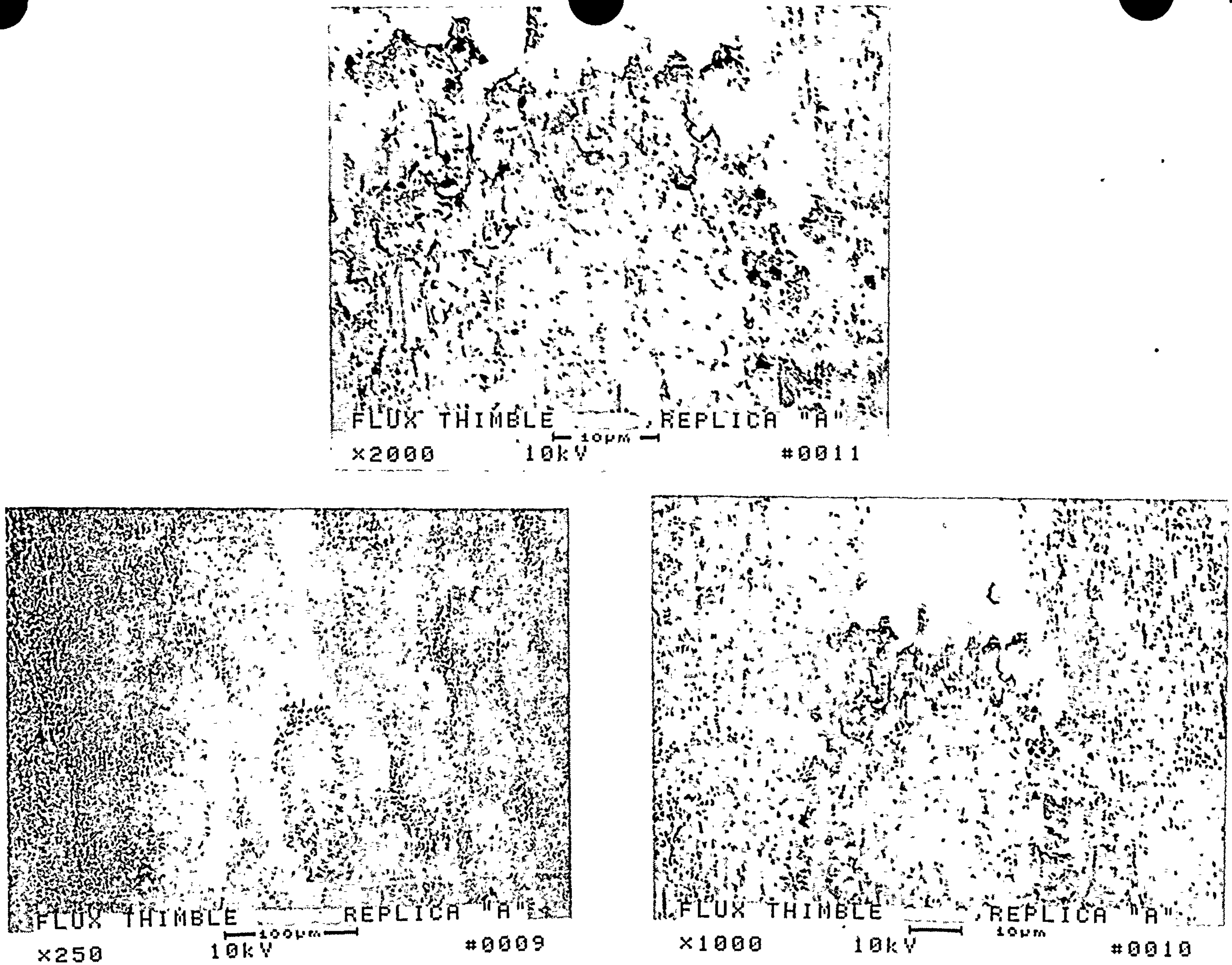


Figure 2.11 Higher Magnification SEM Photomicrographs Illustrating the Wear Morphology Seen at Location 39 of the Replica from C-7 (Figure 2.10).

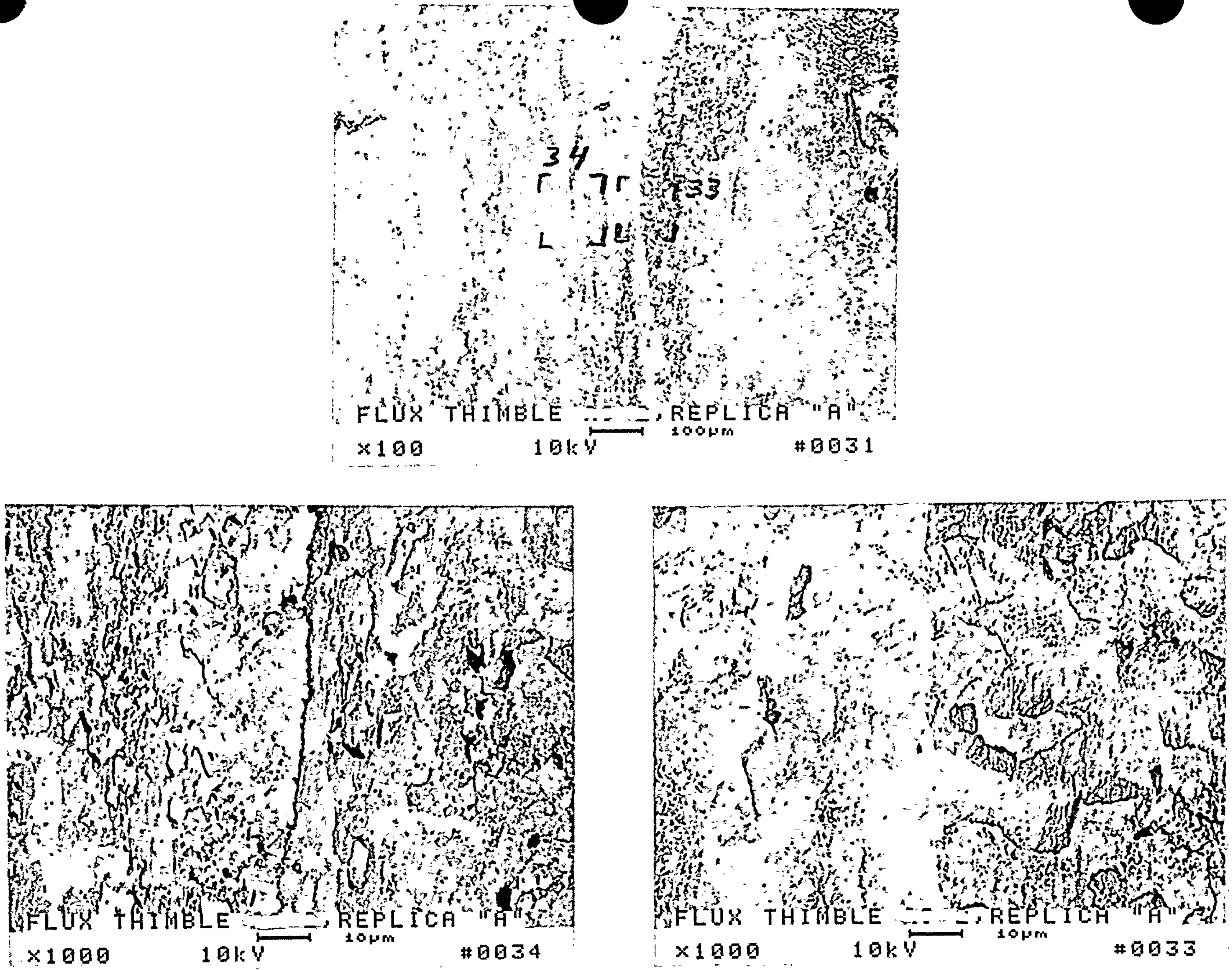


Figure 2.12 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 31, 33 and 34 of Replica (Figure 2.5) from C-7 Sample.

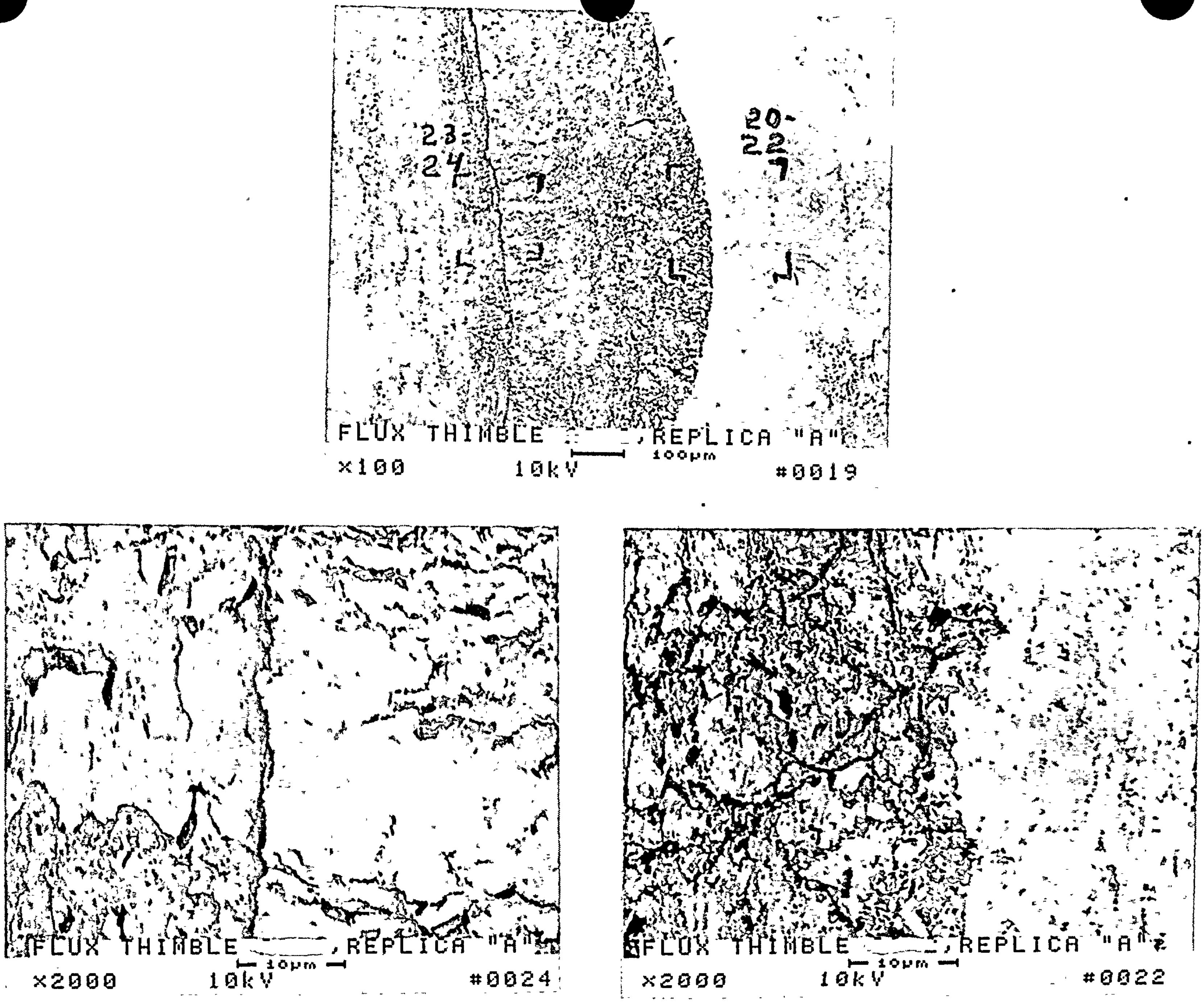


Figure 2.13 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 19, 22 and 24 (Figure 2.5) of the Replica Taken from Sample C-7.

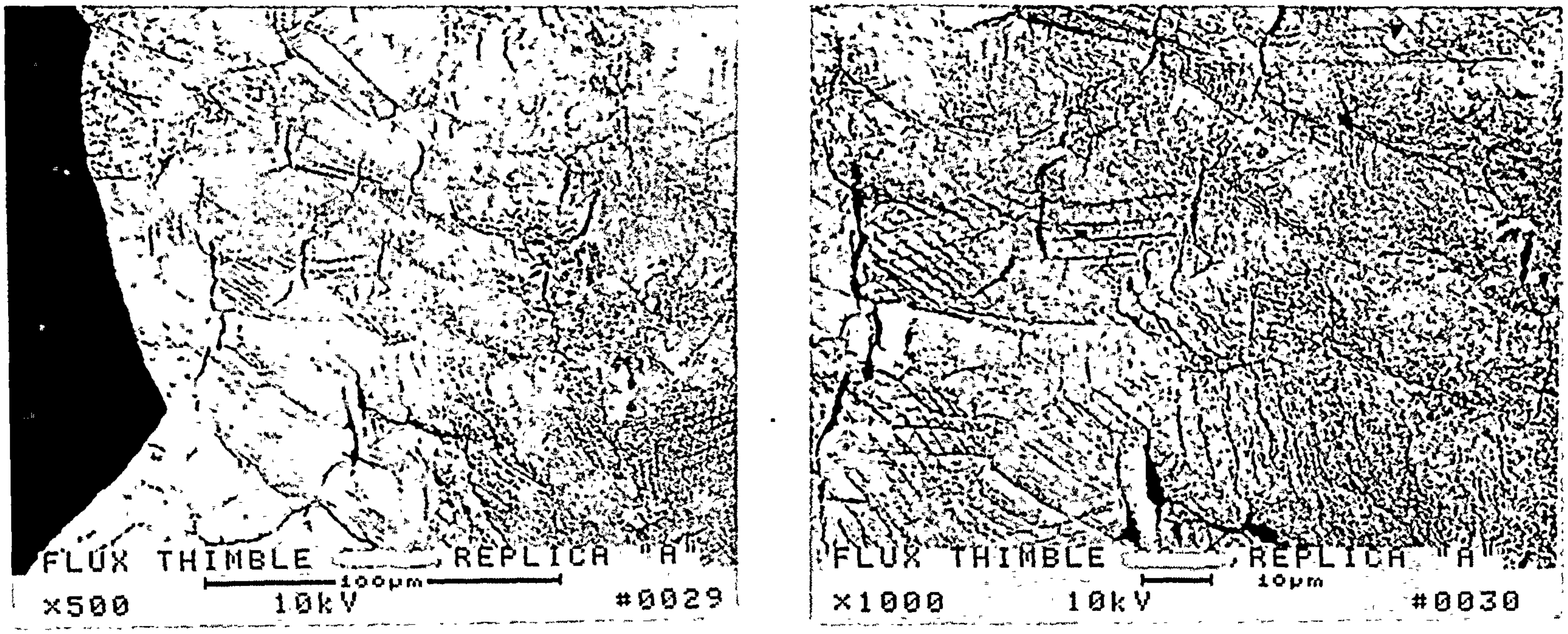


Figure 2.14 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 29 and 30 (Figure 2-5), Close to the Through Wall Leakage Region of the Sample C-7.

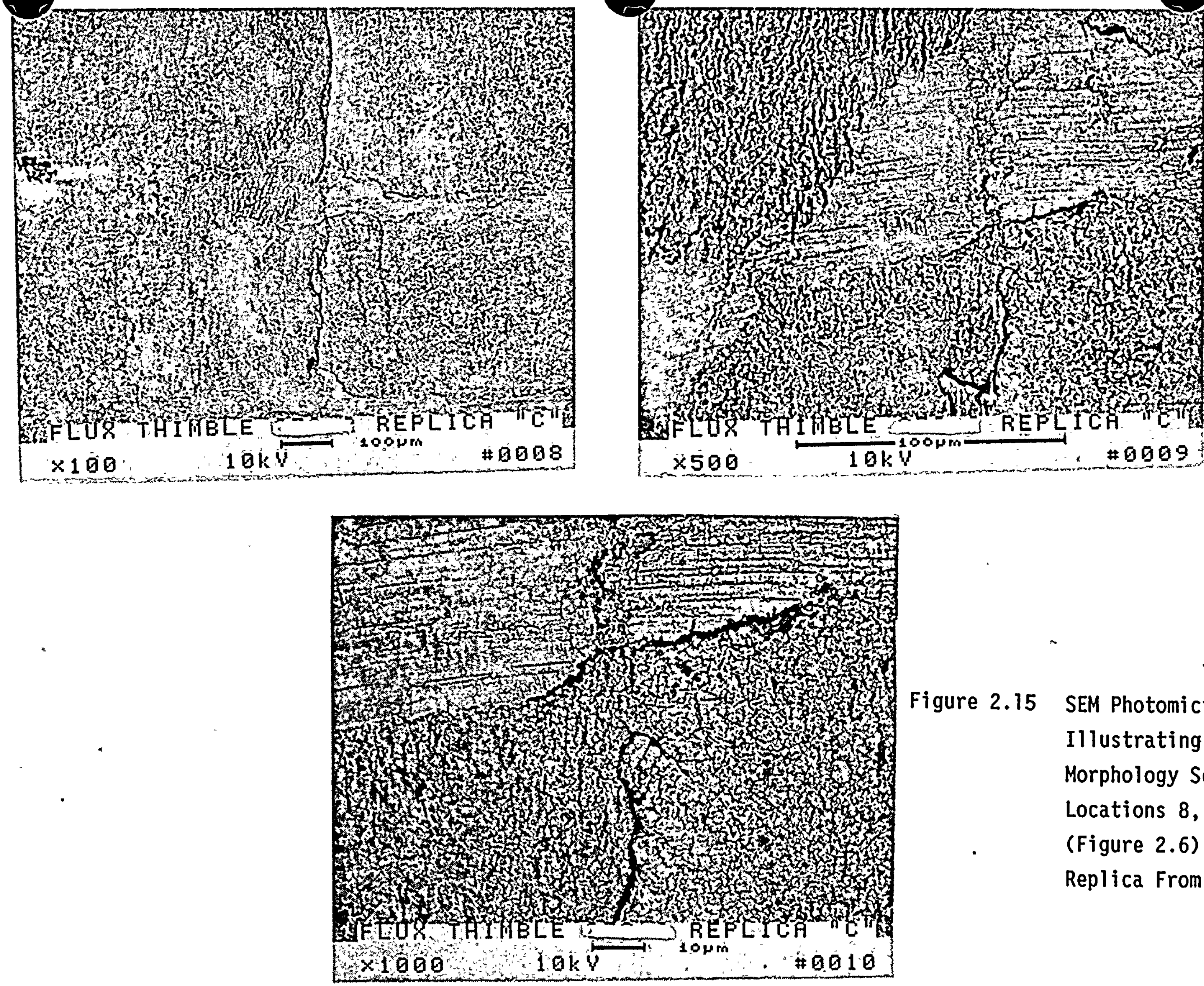
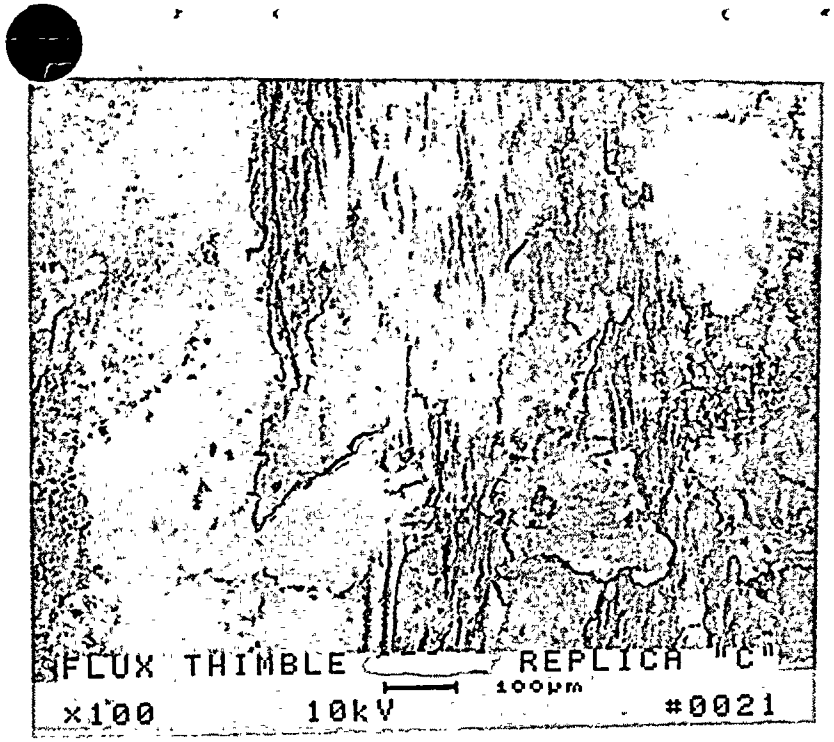


Figure 2.15 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 8, 9, and 10 (Figure 2.6) of the Replica From A-9 Sample.



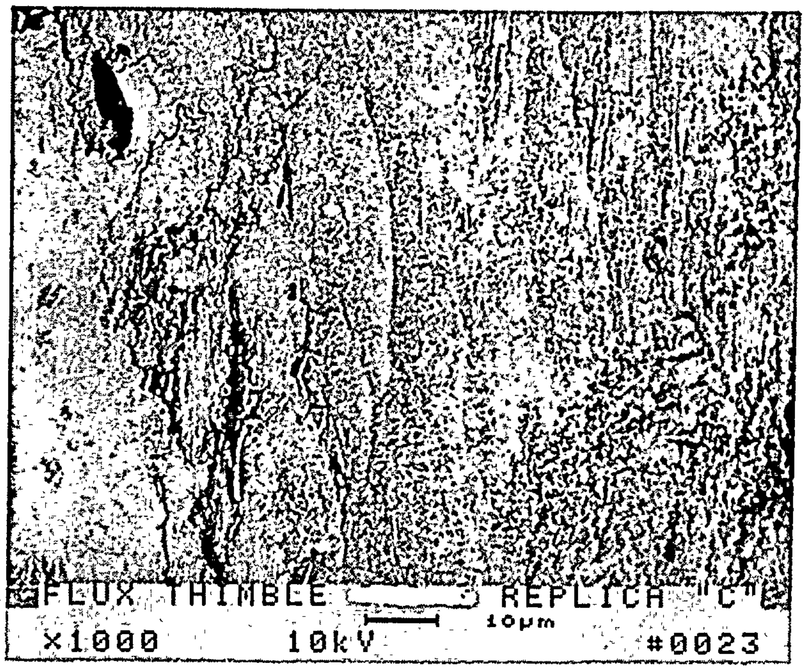


Figure 2.16 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 21, 22 and 23 (Figure 2.6) of the Replica from Sample A-9.

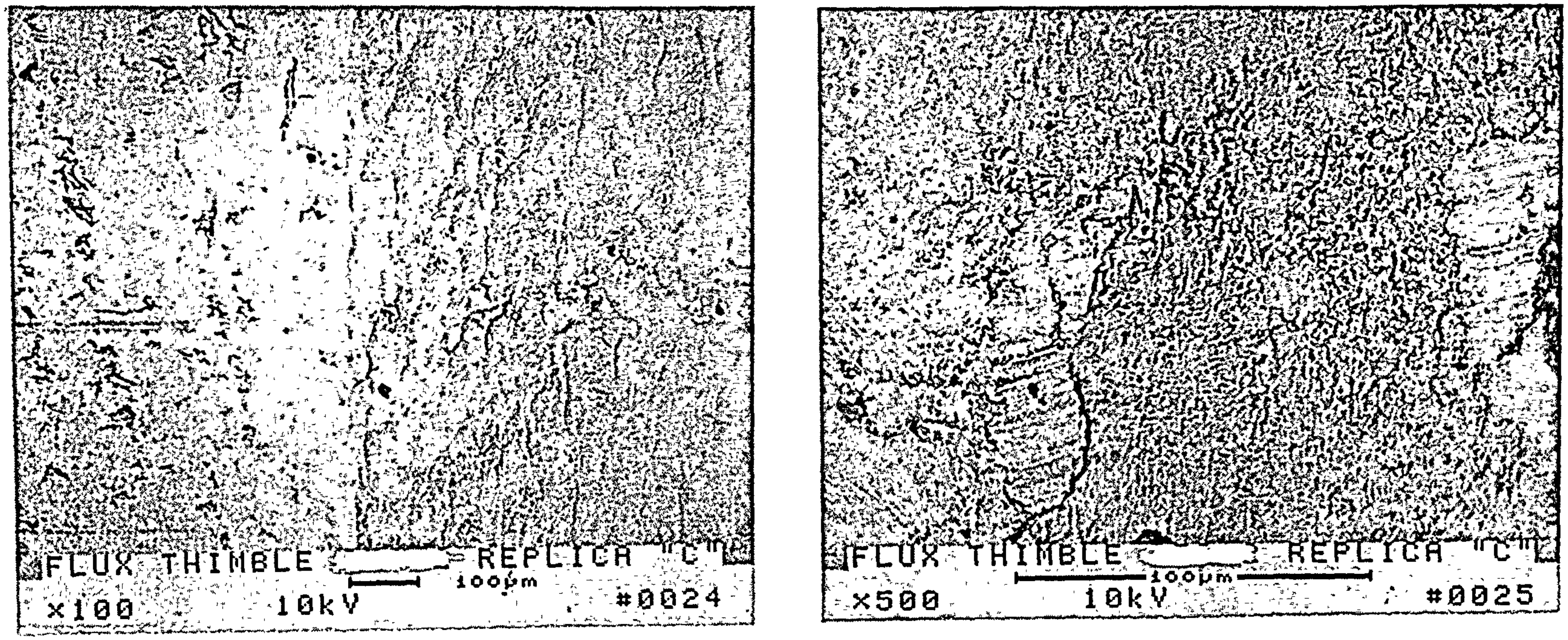


Figure 2.17 SEM Photomicrographs Illustrating the Wear Morphology Seen at Locations 24 and 25 (Figure 2.6) of the Replica from Sample A-9.

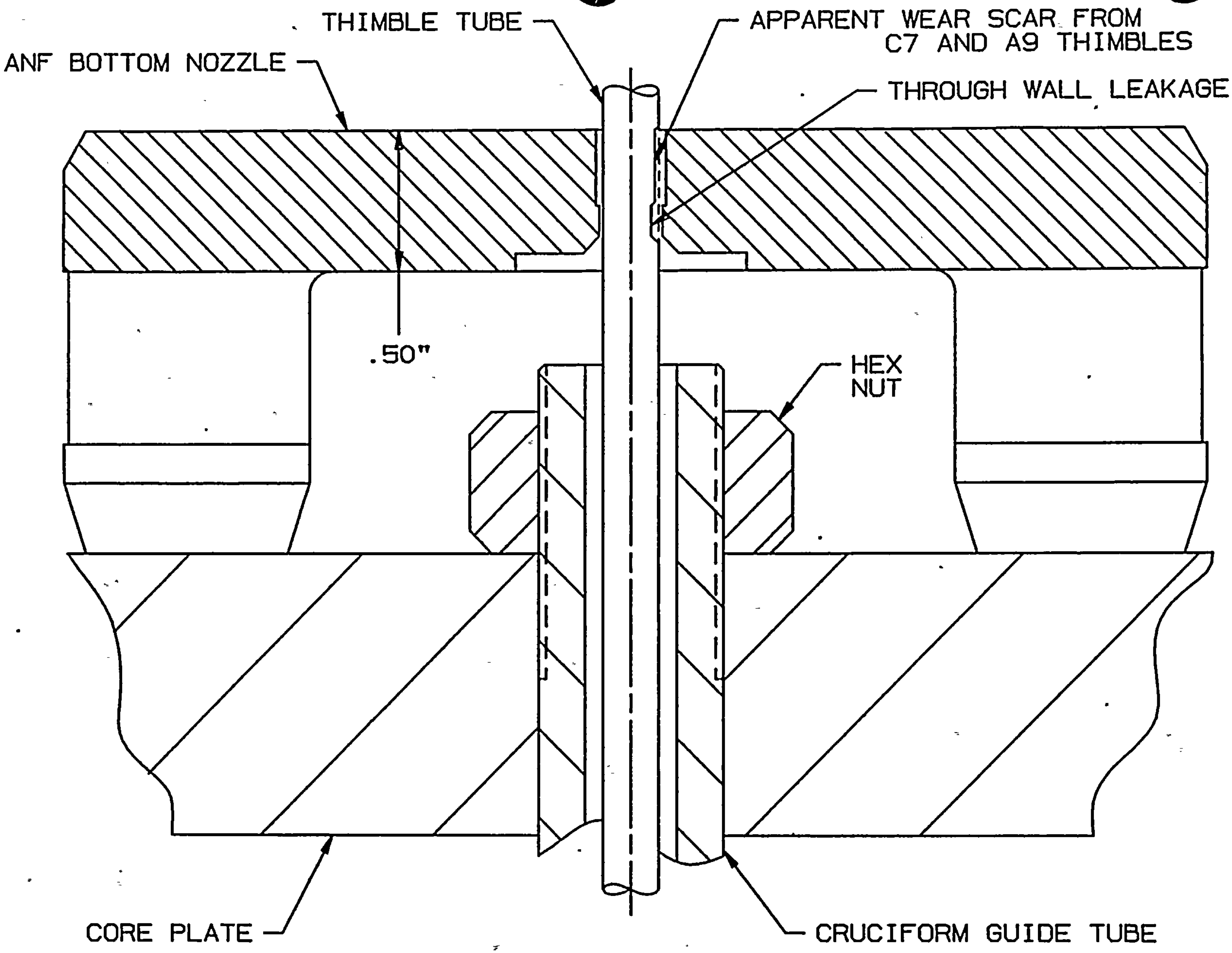


Figure 2.18 Schematic Representation of the Geometry at the Thimble Tube to Fuel Bundle Bottom Nozzle Intersection Illustrating the Wear Location.