NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

December 1, 2000

MATERIALS LABORATORY FACTUAL REPORT Report No. 00-157

A. ACCIDENT

Place	:	Bellingham, Washington
Date	:	June 10, 1999
Vehicle	:	Olympic Pipe Line Company, 16-inch diameter gasoline pipeline
NTSB No.	:	DCA99-M-P008
Investigator	:	Allan Beshore

B. COMPONENTS EXAMINED

Two mating segments of a 16-inch outside diameter gasoline transmission pipe.

C. DETAILS OF THE EXAMINATION

On July 20, 1999, two pipe segments were submitted to the Safety Board Materials Laboratory. A photograph of the as-received pipe segments is shown in figure 1. The pipe segments were cut from the remainder of the pipeline in the field to facilitate shipping and handling. For the purpose of this report, the segments of the pipe will be referred to as the north and south segments. The north segment of the pipe contained a gaping crack (referred as "the fracture" in the remainder of this report) in the area indicated by arrow "G". This fracture extended over a longitudinal distance of approximately 27 inches and had a maximum separation of 7 inches.

Background

The pipe reportedly was manufactured to American Petroleum Institute (API) Standard 5LX, grade X52[1], as 16-inch diameter, 0.312 inch nominal wall thickness, electric resistance weld (ERW) steel pipe, coated at the exterior surface with a tar-like coating. The pipe was manufactured by US Steel and installed in 1965.

The pipe in the area of the fracture reportedly was oriented north-south, and the gasoline was flowing south (downstream) in the direction indicated by unmarked (unlabeled) arrows in figure 1. The north end of the pipe is referred to as the upstream

[1] Grade 52 indicates the steel for the pipe should have a minimum yield strength of 52,000 pounds per square inch.

end. Several areas of the pipe segments were marked with a yellow dot surrounded by a yellow circle indicating the top dead center. For the purpose of this examination, the top dead center is the 12:00 o'clock position. All references to a clock position along the wall of the pipe will be made looking downstream.

Participants in the Examination of the Pipe

Preliminary inspection of the pipe was performed on October 12, 1999, at the Safety Board Materials Laboratory in Washington, D.C. On this day, the pipe segments were removed from wooden crates for visual inspection and photographic documentation. The size of the pipe was also documented on this day. The list of attendees who participated in this inspection is shown in Figure 2A. Metallurgical examination of the pipe was made between May 8 and 11, 2000. This examination was attended by those who were given status by the Safety Board as parties to the investigation, and observers who represented the U.S. Department of Justice. Figure 2B shows a list of representatives who participated in the metallurgical examination. The results of the examination from both sessions were incorporated into this report.

How Coating is Typically Applied to the Outside Diameter of the Pipe

Prior to installation in the ground, the outside diameter of a bare pipe is coated at the factory with a layer of tar-like substance (referred in this report as tar). The external surface of this coating typically is reinforced with glass fiber mat and a layer of kraft paper[2]. The tar coating typically is wrapped around the pipe, and a few inches at each end of the pipe is kept bare. In the field location, the bare ends of the pipe are welded together and the exposed metal portions are covered with tar coating.

Overall Condition of the Coating

Inspection of the as-received pipe segments at the Safety Board materials laboratory disclosed that most of the outside diameter was covered with black material whose texture was consistent with tar coating. The coating on both segments appeared smooth at the top half of the pipe circumference, compared to the bottom half of the pipe circumference that contained wrinkle[3] marks. These wrinkle marks generally were oriented longitudinal, as if the tar coating had sagged down. Typical wrinkle marks are indicated by arrows "W"R" in figure 9. The surface of the coating contained gouge mark[4] damage that will be discussed in detailed later in the report.

The outside diameter of the south segment contained two ring sections (patches). The location of the two patches is shown in figure 3. The patches were installed over the tar coating. The texture and thickness of each patch appeared similar to the coating on

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[2] According to Academic Press Dictionary of Science and Technology, kraft paper is defined as a sturdy tan paper made from unbleached sulfate pulp, often used in combination with other fibers to make container board, wrapping and bag paper, and the like. Also, kraft. (A German word meaning "strength.")

[3] A crease on a smooth surface.

[4] Damage to the coating that may or may not contact the pipe surface and cause denting.

other portions of the pipe. The outside diameter of the larger patch on the top side contained resolidified tar whose drip marks extended down to the bottom of the pipe. Resolidified tar was found all around the edges of both patches. No evidence of other patches was found on the outside diameter of the pipe.

A small portion of the coating had been removed in the field from all around the pipe at the cut ends, prior to shipping to the Safety Board Materials Laboratory. This was necessary to expose the pipe for cutting. The length of the north and south pipe segments measured approximately 124.5 inches and 119.6 inches, respectively. The tar coating also was removed in the field from the top side of the pipe in order to establish the location of the girth weld[5]. The location of the girth weld is indicated in figure 3. No other portions of the coating had been removed in the field.

Labeling of Gouges, Dents, and Points of Interest

Initial examination of the pipe pieces showed that the coating was not present in various areas and that the external surface contained various gouge marks. Most of the gouge marks were identified by disruptions in the exterior coating, and many of these disruptions had been filled with deposits. However, some of the gouge marks were not filled with deposits, and the damaged surface of the pipe was visible. Most of the gouge marks resulted in inward deformation of the pipe wall, causing dents[6] that were most easily viewed on the inside diameter surface.

As will be discussed elsewhere in this report, the various gouge marks on the outside surface of the pipe were labeled with numbers ("1" through "27") or letters ("A", "X", "Y", and "H", "I", and "J"). Gouge marks that intersected the fracture were labeled randomly with letters "A", "X", and "Y". The remaining gouge marks in the north segment were labeled with numbers "1" through "27". Gouge marks on the south segment were labeled with letters "H", "I", and "J". In addition, ten samples were taken from various gouge marks for examination. These samples were labeled "A" through "J". Samples "A", "H", "I", and "J" were removed from gouge marks with the same respective letter designation. Samples "B" through "F" were removed from gouge marks with a number designation.

Initial Inspection of the Inside Diameter

The inside diameter of the pipe segments was visually inspected through the open ends. This inspection disclosed a girth weld at the location found on the outside diameter. The portion of the pipe located upstream from the girth weld contained an ERW longitudinal weld seam at the 8 o'clock position, whereas, the portion of the pipe located downstream from the girth weld contained an ERW longitudinal weld seam at the 6:30 o'clock position. The inside diameter of the pipe segments contained no evidence of

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[5] A circumferential weld that joins the ends of a pipe.

[6] A depression or deformation in the wall of the pipe that results from applied pressure or blow to the outside diameter of the pipe. The impression can be the result of an object that applied pressure to a point or slid on the outside diameter.

corrosion degradation. With the exception of the 27-inch fracture, the inside diameter of the pipe segments contained no evidence of a crack.

Examination of the Fracture

The fracture faces of the pipe were covered with soil. For the purpose of this report, the two faces of the fracture will be referred to as the east face and the west face. The wall of the pipe adjacent to the west face of the fracture had deformed outward from its original position, similar to a flap or lip. The wall of the pipe adjacent to the east face of the fracture did not flap away from its original position. The Safety Board's examination of the fracture was limited to the east face.[7]

The east face of the fracture was cleaned in place with a soft nylon bristle brush to remove soil. Subsequent visual examination of the east face of the fracture revealed a flat region that was oriented on a longitudinal plane aligned at 90 degrees to the exterior surface of the pipe. The length of the flat region measured approximately 3.5 inches. This flat region contained radial marks indicative of a fracture origin area that emanated from a gouge mark at the outside diameter, in the area indicated by bracket "O" in figures 1, and 3 through 6. The gouge mark associated with the origin of the fracture is indicated by arrows "X" in figure 5. This gouge mark penetrated the coating and exposed the underlying metal surface. This gouge mark and the fracture origin area were oriented parallel to each other and nearly longitudinal with respect to the pipe axis. The inside diameter of the pipe contained no evidence of a dent in the area that was coexistent with external gouge mark "X".

The thickness of the pipe wall was measured at both ends of the north segment. The wall thickness measured between 0.308 and 0.314 inches, which was within the specified tolerances for 0.312-inch wall thickness pipe (0.272 and 0.362 inch). The wall thickness of the pipe in the area where the fracture origin intersected gouge mark "X" measured between 0.24 and 0.25 inches. This corresponds to a reduction of the original 0.312-inch nominal wall thickness by as much as 20 percent.

The fracture origin area was located at approximately 11:00 o'clock. This corresponds to a position of approximately 6.5 inches circumferential below the top dead center of the pipe and 10 inches circumferential above the weld seam of the pipe. The fracture at the origin area appears to have extended through the deepest portion of the gouge mark on the east face of the fracture. The width of the exposed gouge mark at the east face of the fracture in the area of the fracture origin area measured approximately 0.8 inch. Any portion of the gouge mark on the west face of the fracture was not examined or measured because it was covered with a deposit.

The downstream end of gouge mark "X" was relatively clean, whereas, the upstream portion was covered with dirt deposits. A closer look at the surface of this gouge mark in

[7] In response to concerns raised by prosecutors from the United States Attorney's Office for the Western District of Washington, the Materials Laboratory preserved one face of the fracture for possible future testing.

cleaner areas revealed metal flow consistent with an object moving upstream relative to the pipe. This indicated that the starting end of the gouge mark was the downstream end of the gouge mark in the area indicated by arrow "S" in figure 6. The surface of the gouge mark exhibited multiple longitudinally oriented cracks (see figure 7). These cracks were generally oriented parallel to each other and in the general orientation of the gouge mark. The length of the relatively clean portion of the gouge mark measured approximately 8.5 inches.

Other Gouge Marks Found Adjacent to the East Face of the Fracture

The 27-inch gaping fracture intersected two other gouge marks that are indicated by brackets "A" and "Y" in figure 5. These two gouge marks extended upstream from the upstream end of the gouge mark "X" and were distinguished from each other and gouge mark "X" by slight changes in angle and surface metal flow characteristics.

Gouge mark "A" was 4.5 inches long and was covered with deposits. Examination of the inside surface showed that the pipe had been dented inward at gouge mark "A". The internal dent was coexistent with the external gouge. Gouge mark "Y", on the upstream end of gouge mark "A", was found exposed down to bear metal. This gouge mark penetrated the tar coating and measured approximately 5 inches long. The surface of the pipe in gouge mark "Y" was relatively clean, and this gouge mark was oriented approximately 20 degrees[8] relative to the length of gouge mark "X". Examination of the inside surface showed that the pipe did not contain noticeable inward denting at gouge mark "Y".

The deposit associated with gouge mark "A" was manually scrapped off the exterior surface of the pipe using a wooden tongue depressor. On several occasions, the end of the tongue depressor was struck with a hammer to assist removal of the deposit. The deposit particles that were removed from the outside diameter easily could be broken up by hand into smaller pieces, typical of compacted dirt (soil). Figure 8 shows a photograph of gouge marks "X", "A", and "Y" after the deposits had been removed from the surface of gouge mark "A". Gouge mark "A" had penetrated through the coating and exposed the bare metal surface of the pipe.

Bench binocular microscope examination of the surface of gouge marks "A" and "Y" revealed multiple cracks that were oriented parallel to their respective gouges marks. Many of these multiple cracks were interconnecting and appeared similar to those found in gouge mark "X" (see figure 7). The fracture adjacent to the multiple cracks also exhibited soil deposits similar to those removed from the fracture origin. The fracture in the pipe propagated through the portions of gouge marks "A" and "Y" that contained the multiple cracks.

Post-cleaning examination of the outside diameter revealed that the width and depth of gouge mark "X" had gradually reduced toward the upstream end. Gouge marks "X", "A",

[8] Looking down and turning counterclockwise with respect to the pipe axis.

and "Y" intersected each other. The greatest reduction in wall thickness associated with gouge marks "X", "A", and "Y" was at the downstream of gouge mark "A", where the wall thickness measured approximately 0.23 inches. The surface of all these gouge marks contained evidence of metal flow. However, visual examination of the of the metal flow in the general area where the three gouge marks had intersection disclosed no clear indication which gouge mark preceded the other.

Removing Portion of Tar Coating and Fracture

The tar coating was peeled away from the outside diameter between the east face of the fracture and the dashed line position in figure 9. A putty knife was forced between the pipe and coating to assist removal. The excised tar coating in this area had strongly adhered to the pipe. One continuous layer of tar coating was peeled away from this area. This process exposed an additional gouge mark that is indicated by arrow "17" in figure 9. Gouge mark "17" did not intersect the other gouge marks. The area from which the coating was removed intersected the fracture over a distance of 19 inches, extending beyond the ends of the combined gouge marks "X", "A", and "Y". This portion of the east fracture face will be referred to as the 19-inch fracture.

Cleaning the Fracture with Replica Tape

The 19-inch fracture was cleaned with replica tape[9] to remove adhering soil and other deposits. The 19-inch fracture was divided into 4 sections, and each section was cleaned separately. Each cleaning cycle consisted of wetting the replica tape with acetone, applying to the fracture surface, allowing the replica tape to dry, and peeling replica tape from the fracture surface. The section that contained the fracture origin was cleaned in four cycles. The remaining sections also were cleaned as many as four cycles.[10] After it was cleaned, the 19-inch fracture was excised from the pipe to facilitate bench binocular microscope examination. The dashed line in figure 9 also indicates the saw cut positions.

Bench Binocular Microscope Examination of the Fracture Origin

Bench binocular microscope examination of the excised 19-inch fracture revealed that the fracture origin area, indicated by bracket "O" in figures 1, 3 through 6, 8, and 9, contained a flat region (90 degrees relative to the exterior surface of the pipe) and a shear[11] region. The shear region extended from the surface of the gouge mark to a distance of approximately 0.075 inch radially[12] below the surface of the gouge mark. The

[9] Acetate-base tape that is applied to the fracture to replicate the topographical features of a fracture surface. After peeling the tape, topographical features on the tape typically is examined by transmission electron microscope work. However, the peeling process removes debris from the fracture, serves as a good cleaning process as well as allowing retention of any debris removed by the replication process.

[10] In the metallurgical community, a fracture that is cleaned with replica tape in four cycles, is also referred to as fracture that was "replica stripped four times."

[11] A fracture that is oriented at an angle of approximately 45 degrees to the surface of the pipe.

[12] The distance measured radially is different than the distance measured along the contour (path) of the fracture.

flat region extended from the bottom of the shear region to the inside diameter of the pipe. This extent of the flat region is indicated by the dashed line positions in figure 10. As indicated earlier, the maximum longitudinal extent of the flat region was 3.5 inches. Detailed visual examination of the flat region showed that it contained radial marks that emanated from two origin areas located at the boundary between the shear region and the flat region. The two fracture origin areas are indicated by brackets "O1" and "O2" in figures 10 and 11. In the area of origin "O2", the distance between the shear region and the inside diameter (inside pipe surface) measured approximately 0.17 inch. Unmarked arrows in figures 10 and 11 indicate general directions of fracture propagation in the flat region away from origin areas "O1" and "O2". Furthermore, the downstream end of the flat region contained chevron marks[13]. The orientation of these chevron marks indicated that the fracture in the area of the chevron marks propagated downstream and away from the origin "O2".

The shear region intersected a network of many interconnected longitudinal cracks at the surface of the gouge mark. Even after cleaning, a portion of the shear region that was located adjacent to the surface of the gouge mark contained a longitudinal brown deposit. The width of this brown deposit varied along the length of the fracture. This deposit extended from the surface of the gouge mark to a maximum distance of 0.026 inch radial below the surface of the gouge mark. The brown deposit was tightly adherent and had remained despite four separate replica stripping cleaning attempts. Energy dispersive X-ray spectroscopy (EDS) analysis of the brown deposit produced a spectrum that contained a major peak of calcium and minor peaks of silicon, iron, oxygen, aluminum, carbon, magnesium, phosphorus, sulfur, chloride, and potassium. An EDS spectrum from another area of the brown deposit contained major peaks of silicon and calcium, and minor peaks of the same elements as in the previous spectrum. Later in the examination, the fracture was ultrasonically cleaned in acetone for one minute. Despite the numerous cleaning attempts, the brown deposit remained on the fracture surface. Following the ultrasonic cleaning, additional EDS analysis of the brown deposit on the fracture surface produced a spectrum that contained major peaks of iron and oxygen, typical of iron oxide, and little or no evidence of the other elements previously detected.

Scanning Electron Microscope Examination of Fracture Origin

A 4-inch longitudinal section of the fracture that incorporated the flat region was excised from the 19-inch fracture. Scanning electron microscope (SEM) examination of this excised fracture revealed the flat region contained radial marks that emanated from the transition area between the flat and shear region in the areas indicated by origins "O1" and "O2". Figures 12 and 13 are SEM photographs of the fracture surface at these origin areas. No metallurgical anomalies (manufacturing defects), such as slag or laminations[14], were noted at the fracture origin areas. The flat region that incorporated origins "O1" and "O2" contained cleavage facets (see figure 14). Many areas within the flat and shear region contained alternating band-like features that were oriented in the longitudinal

[13] An overstress fracture that contains features similar to nested letters "V", where the points of the chevrons are traced back to the fracture origin,

[14] A lamination is an internal metal separation creating layers generally parallel to the surface.

direction. Figures 15 and 16 show typical areas that contain such alternating band-like features. A typical band-like feature is located between unmarked arrows in figure 16.

The SEM examination showed that the flat region did not extend all of the way to the inside diameter of the pipe. A shallow shear lip, with a minimum width of approximately 0.003 inch, was found between the bottom of the flat region and the inside diameter. The SEM examination also showed that all fracture areas outside the flat fracture region, including the shear region adjacent to gouge "X" and shear lips adjacent to the inside diameter surface, contained ductile dimple features. No evidence of a crack arrest mark or marks[15] were found on the flat fracture area or elsewhere on the fracture. At the interface between the shear region at the exterior surface and the flat region, the transition from ductile dimple overstress to predominantly cleavage was gradual. Figure 17 shows a close-up photograph of a typical transition area between the flat and shear region.

Fracture Features Outside the Origin Area

Visual and bench binocular examination of the east face of the fracture revealed the fracture areas located outside the 4-inch excised portion of the fracture were on a shear plane. No evidence of crack arrest marks or an additional flat region was found in the remainder of the fracture away from the 4-inch excised portion. .

Metallurgical Section through Fracture Origin "O2"

A metallurgical section was made at the edge of the fracture origin "O2" in the orientation indicated by section line "U-U" in figure 11. This excised section measured approximately 0.3 inch longitudinally and 0.9 inch circumferentially. The section was polished and etched with 2% nital reagent. Figure 18 shows a photograph of the fracture profile. Metallographic examination of this section revealed the fracture contained a gradual transition between the shear region and flat region. The profile of the fracture was rough for the most part of the fracture length. The surface adjacent to the gouge mark contained a white layer, in the area between unmarked arrows in figure 19. The thickness of this layer measured approximately 0.001 inch. This white layer exhibited barely visible deformation lines. The wall of the pipe exhibited severe deformation lines in areas below the white layer. Figures 19 and 20 show close-up photographs of the deformation lines in the area adjacent to the white layer. The severity of the deformation lines gradually decreased as the distance increased away from the gouge mark.

The wall of the pipe in areas outside the white layer contained a microstructure of pearlite and ferrite grains, normal for a low alloy steel. Figures 21A through 21C show typical microstructure of ferrite and pearlite. The ferrite and pearlite grains exhibited alternating band-like layers that were oriented in the longitudinal direction. The pearlite grains were discontinuous and interrupted the band-like layers in the microstructure. The size of the ferrite and pearlite grains in the microstructure appeared similar to the size of

[15] A crack arrest mark is a "step" on the fracture surface and indicates an intermittent stopping point during fracture propagation.

the band-like features on the fracture. Banding in the microstructure is not addressed in API Standard 5LX. No microstructure anomalies (such as laminations, voids, or porosity) were found in the metallurgical section. The section when viewed macroscopically (by eye) exhibited no evidence of segregation bands or lamination.

EDS analysis of the base metal produced a spectrum that contained major peaks of iron and a minor peak of manganese, consistent with plain carbon steel. An EDS spectrum of the white layer contained the same elemental peaks as the base metal with additional peaks from the elements chromium and silicon. Figures 22 and 23 show the EDS spectrum of the base metal and white layer, respectively. The additional elemental peaks found in the white layer are consistent with the composition of a steel alloy that is different from that of the base metal.

To establish a baseline for the hardness of the base metal, traverse microhardness testing was performed on section "U-U" across the entire wall thickness in an area that contained no deformation, and away from any gouge mark. The results of the microhardness testing are shown in Figure 24. This microhardness testing disclosed that the core of the pipe contained a hardness that was between 159 and 208 Knoop (78 and 91 HRB by conversion).

Traverse microhardness testing was also performed on the section ("U-U") of the wall in the area that incorporated gouge mark "X". The results of this testing are shown in Figure 25. The microhardness testing indicated that the white layer was much harder (between 740 and 908 Knoop [60 and 67 HRC[16] by conversion]) than any other area measured on the pipe. The testing showed that the hardness of the pipe material was also significantly elevated in the work-hardened area below the white layer and rapidly decreased to a hardness below 208 Knoop (90 HRB by conversion) at a distance of 0.08 inch below the exterior surface.

Examination of section "U-U" through origin area "O2" also revealed the presence of a secondary gaping crack that is indicated by arrow "T" in figure 18. This crack was on the opposite shear plane to the plane of the shear region associated with the fracture and was found on the surface of the gouge mark in the proximity of the fracture. The crack extended to a radial depth of 0.04 inch from the gouged surface. However, the length of the crack was approximately 0.06 inch, measured along its length. A portion of the crack that extended between surface of the gouge mark and approximately 0.02-inch radial from the surface of the gouge mark was filled with a deposit. EDS analysis of this deposit produced a spectrum that contained peaks of iron and oxygen, consistent with iron oxide.

The fracture surface adjacent to the gouge mark also contained a layer of iron oxide (verified by EDS analysis). The location of the thickest portion of the iron oxide layer is indicated by arrow "L" in figure 19. The iron oxide layer on the fracture surface extended from the surface of the gouge mark to a distance located approximately 0.016 inch radial from the surface of the gouge mark, slightly less than the depth of the iron oxide deposit

[16] Note that the "C" scale (HRC) is used for hardness values that extend above the "B" scale (HRB).

(0.02 inch) found in crack arrowed "T" in figure 18. The depth of the oxide layer on the fracture surface (0.016 inch) was also slightly less than the depth of the brown deposit that was found on the same fracture surface prior to mounting and sectioning (0.026 inch).

Electrolytic Cleaning and Re-examination of Fracture Origin "O1"

After section "U-U" was excised from the fracture, the remaining portion of the 4-inch fracture that incorporated the flat region and fracture origin "O1" was electrolytically cleaned with Endox 214, a commercial cleaner that removes oxides from ferrous alloys. SEM examination of the fracture revealed features similar to those described earlier in the report. This cleaning procedure revealed no evidence of crack arrest marks.

Description of other Goüge Marks and Dents

Figures 26A through 26C show composite photographs of the top side of the north segment of the pipe. The top side of the north segment contained many gouge marks. These gouge marks for the most part were covered or filled with a deposit. Figure 27 shows a trace of the top side of the north segment and location of gouge marks. Each gouge mark and dent was assigned a unique number or letter that specifically identified that mark.

Figure 28 shows a photograph of the inside diameter of the north segment. This examination disclosed the inside diameter contained many inward dents. Two dents were isolated and appeared to be located at a single point, indicated by arrows "10" and "12" in figure 28, whereas, the remaining dents extended linearly over a distance. With the exception of dents arrowed "10" and "12", the remaining linear dents were coincident with gouge marks with the same numbers located on the pipe exterior. Figures 29 through 31 show the location of the gouge marks and dents when viewed through the gaping crack and with the aide of an oval mirror that was placed inside the pipe.

When the pipe was received in the laboratory, the exterior coating was missing from several small areas associated with gouge marks. Exposed bare metal areas of the pipe are indicated by a shaded areas in figure 32. The full length of gouge marks "1", "14", "23", 24", "25", "26", and "27" were found exposed to bare metal. A portion of gouge marks "2", "7", "16", were found exposed to the bare metal. Gouge marks indicated by "X" and "Y" were also exposed. A small amount of material was missing from the surface of the coating in the area of gouge marks "5" and "15". However, the damage in these two areas did not penetrate or expose bare metal surface. No evidence of a dent or deformation was noted on the inside diameter of the pipe in the areas that correspond to gouge marks "5", "14", "15", "17", "21", and "25" through 27". Gouge marks "25" through "27" (see figures 3, 26C, and 27) were intersected by the saw cut that separated the north and south segments of the pipe.

Figures 33 and 34 show photographs of the inside diameter of the south segment of the pipe. The inside diameter of this segment contained three dents, each consistent with the location of an exterior gouge mark. Gouge marks "H", "I" and "J" in figures 33 and 34, were located at 3:30 o'clock, 4:00 o'clock, and 4:00 o'clock, respectively. They were also located approximately 22, 18 and 16 inches longitudinally, downstream from the girth weld, respectively. Figure 3 shows the longitudinal distance between the three gouge marks and various points of interest relative to the girth weld.

The outside diameter of the as-received south segment of the pipe was wrapped with duct tape in the general area that corresponded to the location of the three gouge marks "H, "I", and "J", see figures 35A and 35B. (These three gouge marks were located within one of the two areas where the exterior coating was patched.) Upon unwrapping the duct tape, two pieces of coating were found torn and dislodged from the outside diameter in the area that overlapped the three gouge marks. Figures 36 and 37 show photographs of the three exposed gouge marks after the dislodged pieces of coating were removed from the surface of the pipe. The three gouge marks penetrated through the patch and exposed the bare metal surface of the pipe. The gouge mark areas were covered with a deposit. Gouge mark "H" appeared to be located within a deep dent, relative to the depth of the other two gouge marks. The length of gouge marks "F", "G", and "H" measured approximately 7, 8.5, and 7 inches, respectively. The length was measured in the location between arrows in figures 36 and 37. A close look at the pipe revealed the largest patch was damaged in the area located between arrows "D" in figure 35A. However, the inside diameter of the pipe in the area that coincided with the damage on the external surface of the patch contained no dents.

As many as 23 dents and gouges were identified in the two submitted pipe segments. In accessing the overall condition of the pipe, gouge mark "2" appeared to be the longest, and its length measured approximately 36 inches. Gouge mark "H" was located in the deepest dent when viewed from the inside diameter. Approximately 5-inch square area of the coating and patch had been torn away from the outside diameter of the pipe in the vicinity of gouge mark "H".

Deposits

A sample of a deposit was removed with a wooded tongue depressor, using methods described earlier in the report, from gouge marks in areas indicated by regions "A" through "E" in figure 38. Samples of deposits removed from these regions could easily be separated by hand into smaller pieces, were brown in color, and appeared consistent with compacted dirt (soil).

Deposits that were located within gouge mark "F" in figure 38, and those within gouge marks "H", "I" and "J" in figure 3 were hard. These hard deposits could not be removed from the gouge marks with the scrapping action of a wood tongue depressor. A wood tongue depressor was placed over the area of interest and was struck several times with a hammer. This caused minute particles of the hard deposit to fall out of gouge marks "H", "I" and "J". Such action was unsuccessful in removing the hard deposit from area "F". A sample of the deposit from area "F" was removed from the pipe with repeated blows with a tool steel.

One portion of gouge mark "23" (see figure 27) contained another type of deposit. A grease-like, viscous, substance was found in the area indicated by arrow "G" in figure 38. A portion of this deposit was removed with a wooden tongue depressor, and it was placed and stored on a carbon stub. The Safety Board contracted with Artech Testing, Chantilly, Virginia to perform Fourier Transform Infrared Spectroscopy analysis on this sample. It was compared to FTIR analysis performed on reference samples of molybdenum-disulfide base grease and lithium base grease supplied by the Safety Board materials laboratory. The analysis indicated that the FTIR spectrum of a sample from the grease-like substance was similar to the sample of molybdenum grease in the high region of the spectrum, but similar to the sample of lithium grease in the low region of the spectrum. The FTIR analysis performed by Artech could not conclusively identify the substance as either molybdenum-disulfide or a lithium grease.

Only limited samples of the material were removed from each of the gouge areas on the pipe exterior. The remaining portions of the gouges that were not subject to destructive testing were preserved for follow-up investigations. The pipe surface in gouge marks that were exposed as a result of sampling at the Safety Board materials laboratory or were exposed in the as-received condition showed evidence of metal flow.

Depth of a Gouge Mark and Dent when Measured from the Outside Surface of the Coating

The depth of a gouge mark was measured from the outside diameter of the coating in areas where samples of deposit had been removed. These are indicated by areas "A" through "F" in figure 38, and areas "H" through "J" in figure 3. The deposits had been removed down to the full depth of the gouge mark, and in each area of sampling the gouge mark had exposed bare metal. These areas were selected during the examination because they were located for the most part in the deepest portion of the gouge marks.

The depth of a gouge mark from the outside diameter of the coating was determined by placing a ruler longitudinally across the surface of the coating, then measuring the vertical distance between the deepest part of the gouge mark and bottom end of the ruler. The vertical distance was measured with a caliper. The measured depth and width of a gouge mark from the outside diameter at the point of sampling (point of interest) is shown in figure 39.

Depth of Dents when Measured from the Inside Diameter

The depth of a dents was measured from the inside diameter with a caliper. The longitudinal body portion of the caliper was attached with a "C" clamp in a perpendicular orientation to a narrow rigid plastic block. Within the pipe, the longitudinal body portion of the caliper was positioned radial with respect to the axis of the pipe and the block was positioned in a circumferential plane on the inside diameter surface. The caliper contained an internal needle that slides out of the caliper body when the mouth of the caliper is open. To measure the depth of a dent, the internal needle portion of the caliper was positioned over the dent, such that the tip of the extending needle portion was resting on the deepest portion of the dent (from the inside diameter it was the most protruding portion of the dent). A reading was made in this position. The caliper was moved to an adjacent area that contained no dent, and the needle portion was extended until it touched the inside diameter. Another reading was made in this area. The calculated difference between the two measurements indicated the depth of the dent. The calculated depth from the inside diameter of various dents is also shown in Figure 39.

Examination and Analysis of the Coating

A small sample of coating was excised from the downstream end of the north segment of the pipe. The thickness of this coating sample measured approximately 0.13 inch. Bench binocular microscope examination of a longitudinal fracture created as the sample was broken off revealed that the coating contained a black tar-like material. The inside diameter portion of the coating was reinforced with rows of fiber strands that appeared to be oriented circumferentially and parallel to each other. The distance between each row of fiber strands measured between 0.24 and 0.40 inch. The inside diameter of the coating in the same general area as the rows of fiber strands also contained a layer of random oriented fibers. The outside diameter of the coating contained a cardboard-like layer that was reinforced with rows of fiber strands. The thickness of the cardboard-like layer measured approximately 0.03 inch.

The exterior surface of the coating contained irregular cracking, similar to mud cracking, in the area indicated by arrow "M" in figure 5. This area was located between the beginning of gouge mark "X" and the downstream end of the fracture. The surface of the coating in this area contained evidence of severe scrape marks. No evidence of mud cracking was found in other areas of the coating. The wall thickness of the coating in the area of mud cracking measured approximately 0.14 inch. A sample of the coating in area "M" in figure 5 was excised from the pipe. Examination of a longitudinal fracture on this sample revealed the coating contained a tar-like material. However, the outside diameter surface of the coating in the area of severe scrape marks contained no cardboard layer or fiber strands. The inside diameter surface of the sample contained parallel rows of fibers and random oriented fibers similar to the sample that was excised from the downstream end of the pipe.

The coating sample removed from within the dashed line region in figure 9 was also examined. This sample contained wrinkle marks, and its thickness measured approximately 0.2 inch. A longitudinal fracture on this sample contained a tar-like material at the core, cardboard-like material on the outside diameter, and fibers on the inside and outside diameter similar to the small sample removed from the downstream end of the north segment.

EDS analysis of the core from each of the three samples of coating removed from the pipe produced a spectrum that contained a major peak of carbon and minor peaks of oxygen, silicon, aluminum, and sulfur (see figure 40). The height of the minor peaks would vary slightly depending on the location on the fracture. The spectrum in several areas of the fracture had barely visible peaks of iron. The spectrum from each coating sample is consistent with the specified tar coating.

Other Dimensions of the Pipe

The circumference of the outside diameter of the pipe at the north end measured 50.3125 inches. This calculates to an outside diameter of 16.02 inches, which was within the API 5LX specified range (between 15.88 and 16.12 inches).

Impression Mold of Gouge Mark "X"

An impression was made by use of a polyurethane molding mixture from gouge mark "X" in the area of the fracture origin.[17] This impression was made prior to excising the 19-inch segment from the pipe. A wall of flexible clay was erected around the gouge mark in the area of the fracture origin. The area enclosed by the clay wall incorporated the gouge mark and edges of the fracture. One end of a copper wire was inserted into the mold. The other end of the copper wire was cut at the distance that corresponds to the location of the girth weld. Liquid resin was mixed with a hardener and poured into the area bound by the clay wall. The molding mixture was cured overnight, and removed from the pipe the following morning. The impression was preserved to provide a reference of the original configuration before cutting was performed.

Mechanical Testing, Chemical Composition

The March 1973 and January 2000 issues of API 5LX indicates that transverse tensile specimens in welded pipe shall be taken opposite the weld, and Charpy V-notch specimens shall be taken from an area of the pipe that is located 90 degrees circumferentially away from the longitudinal weld. Two pieces of the wall from the pipe were excised from the most upstream end of the north segment in an area located near the top dead center. As indicated earlier in the report, the ERW longitudinal weld seam at the most upstream end was located at the 8 o'clock position. The plate for the tensile specimens was excised from an area of the pipe located between 12:30 and 3:00 o'clock in the area opposite the ERW longitudinal weld as specified in the API 5LX. The plate for the Charpy V-notch specimens was excised from an area between 10 and 11:30 o'clock, an area located 90 degrees circumferentially away from the ERW longitudinal weld as specified in API 5LX. Tensile and Charpy V-notch specimens were machined and tested by Artech Testing, Chantilly Virginia. Artech also performed a chemical composition analysis on a sample that was removed from one of the excised pieces of the pipe.

Tensile Testing

Three transverse[18] tensile specimens were machined from the wall of the pipe. Each tensile specimen was manufactured with a gauge length of 2 inches and a width of

[17] The mold of the gouge mark was made at the request of representatives from the U.S. Dept. of Justice.
[18] Oriented circumferential with respect to the length of the pipe.

1.5 inches, in accordance with API and American Society for Testing and Materials (ASTM) A370, titled "Standard Methods and Definitions for Mechanical Testing of Steel Products".

The March 1963 issue of API Standard 5LX indicates that the ultimate tensile strength and yield strength for grade X52 pipe should be no less than 66,000 pounds per square inch (psi) and 52,000 psi, respectively. Testing of the tensile specimens indicated that ultimate tensile strength values of the specimens were between 69,300 and 70,100 psi, and that the yield strength values for the specimens were between 52,600 and 56,500 psi. The measured ultimate tensile strength and yield strength of the tensile specimens were above the minimum specified values. The results of the tensile testing are shown in Appendix A.

The same issue of API Standard 5LX indicates that the minimum elongation for a pipe with a 0.312 inch nominal wall thickness should be 22 per cent. The elongation for the three specimens measured between 32.6 and 33.8 percent, which were above the minimum specified value (22 percent).

Chemical Composition Analysis of a Sample from the Wall of the Pipe

According to March 1963 issue of API 5LX, the maximum amount of carbon, manganese, phosphorus, and sulfur, by percent, that is permitted in the steel is governed by the grade of steel, how the steel was processed (i.e., seamless versus welded, electric or open-hearth furnace).

The Safety Board materials laboratory determined the maximum amount in percent for each element that would have been permitted for each process described in API, and calculated the range that would have cover all manufacturing processes. The March 1963 issue of API Standard 5LX was consulted because its issue date is closely associated with the time the pipe was installed in the ground, and because the manufacturing date of the pipe is not known. The calculations indicated that the range permitted for the maximum amount of carbon was between 0.30 and 0.36%, for manganese was between 1.3 and 1.4%, for phosphorus was between 0.05 and 0.11%, and for sulfur was 0.06%.

Chemical analysis was performed by Artech on a sample that was removed from the wall of the pipe. The analysis indicated that the pipe contained 0.24% carbon, 1.08% manganese, 0.014% phosphorus and 0.011% sulfur. The results of the analysis indicate the composition of the pipe was within the limits specified for all processes described in API 5LX, for grade X52 pipe. A copy of the report from Artech is shown in Appendix A.

Fracture Toughness (Charpy V-Notch Impact) Testing

Nineteen transverse subsize Charpy V-notch specimens were made according to ASTM A370 and API Specification 5L, forty-second edition, January 2000. Each subsize specimen was 2/3 the size of a standard specimen, to accommodate the wall thickness of the pipe, 0.312 inch (7.9 mm). The specimens measured 0.394 inch x 0.262 inch x 6.67 inch (10mm x 6.67mm x 55mm). Two specimens were tested at minus 100, minus 50, minus 10, 32, 70, 110, 150, and 212 degrees Fahrenheit. Three specimens were tested at 50 degrees Fahrenheit. The results from the Charpy V-notch tests performed at Artech are shown in Appendix A. The data was plotted on a graph and is shown in figure 41.

Frank P. Zakar

Frank P. Zakar
Senior Metallurgist

Figure 1. Photograph of the as-received segments of the pipe showing the gaping crack in the area indicated by arrow "G". The north end is indicated by "N" and the south end is indicated by "S". Gasoline reportedly was flowing south (downstream) in the direction indicated by unmarked arrows. The mating ends of a cut in the pipe are indicated by arrows "Z".

Figure 2A. List of representatives who participated in the pipe examination on October 12, 1999.

Allan Beshore	Investigator-In-Charge, NTSB
Frank Zakar	Senior Metallurgist, NTSB
Derek Nash	Mechanical Engineer, NTSB
Gopala Vinjamuri	Department of Transportation Office of Pipeline Safety
Douglas Beu	Olympic Pipe Line Company
William Maxey	Kiefner & Associates. Inc. representing Olympic Pipe Line Co.
Michael Langer	IMCO General Construction Company
Bob Eiber	Robert J. Eiber Consultant, Inc representing City of Bellingham
Bradley James	Exponent Failure Analysis representing Olympic Pipe Line Company
R. Craig Jerner	J.E.I. Metallurgical, Inc. representing IMCO General Construction Company

Figure 2B. List of representatives who participated in the pipe examination between May 8 and 11, 2000.

Allan Beshore	Investigator-In-Charge, NTSB
Frank Zakar	Senior Metallurgist, NTSB
Spencer Phillips	Physical Science Technician (Metallurgy), NTSB
Gopala Vinjamuri	Department of Transportation Office of Pipeline Safety
Geoffrey Smyth	City of Bellingham
Bob Eiber	Robert J. Eiber Consultant, Inc representing City of Bellingham
Douglas Beu	Olympic Pipe Line Company
Robert Caligiuri	Exponent Failure Analysis representing Olympic Pipe Line Company
Timothy Smith	Exponent Failure Analysis representing Olympic Pipe Line Company
Leigh Klien	Arco Products Company
W. Gregory Morris	Kiefner & Associates, Inc. representing Olympic Pipe Line Company
Carmine D'Antonio	Professor of Metallurgical Engineering, Polytechnic University representing U.S. Dept. Justice
Paul Kovach	Stress Engineering Services, Inc representing U.S. Dept. of Justice
Patti Imhof	IMCO General Construction Company
R. Craig Jerner	J.E.I. Metallurgical, Inc. representing IMCO General Construction Company
Scot Roswurm	J.E.I. Metallurgical, Inc. representing IMCO General Construction Company

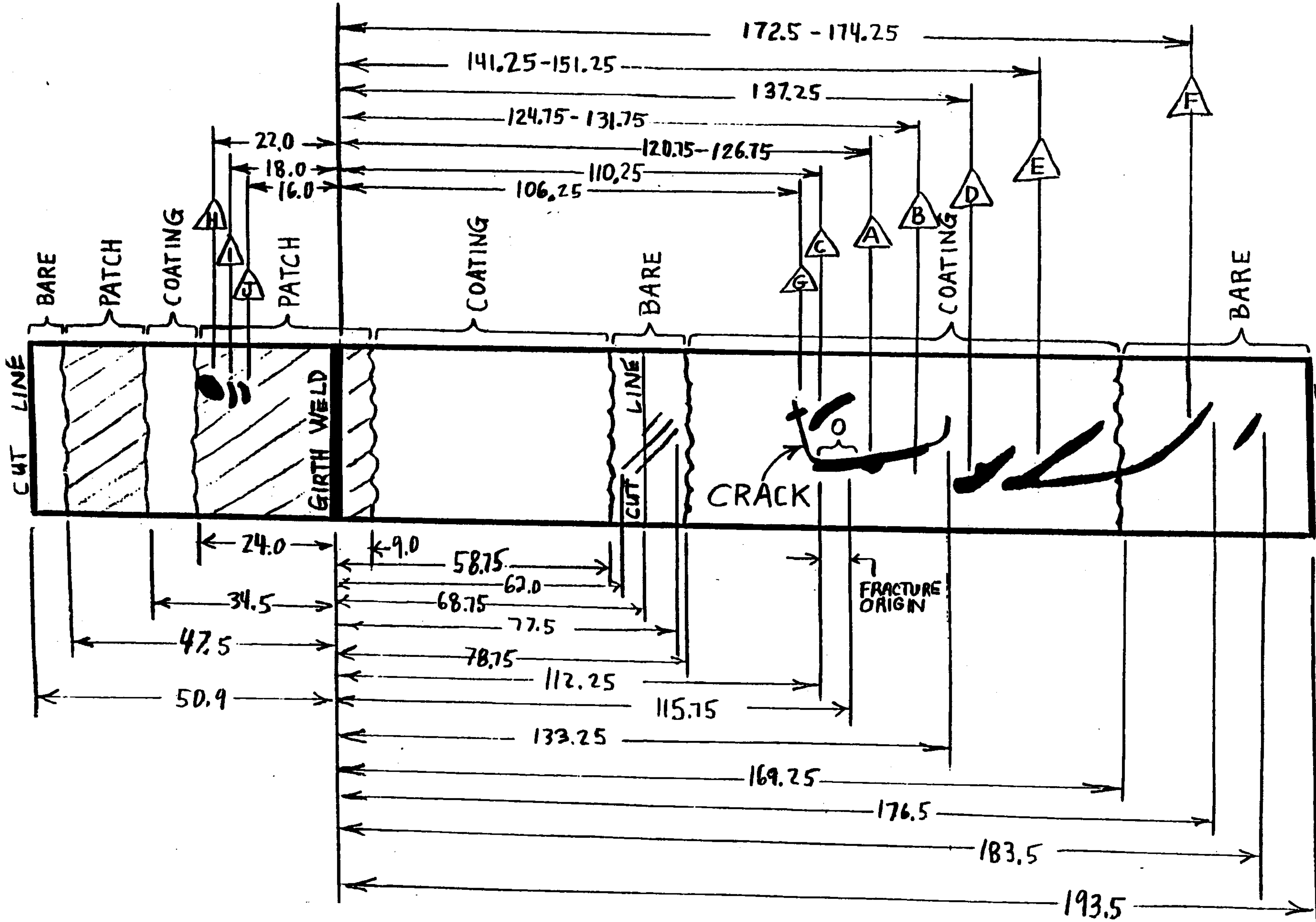

Figure 3. Sketch of the north and south segments of the pipe as if intact showing points of interest relative to the distance to the girth weld. Distance is measured in inches and reflects only the longitudinal distance between points. Not to scale. Samples were removed from areas indicated by characters enclosed by a triangle. The majority of gouge marks were found in the north segment. This sketch displays only a few of the gouge marks that were discovered on the north segment, and the relative distance between the locations where samples were removed for examination. A detailed [illegible]h of gouge marks found in the north segment is shown in f[illegible]27. The north (upstream) end is located on the right side [illegible] sketch.

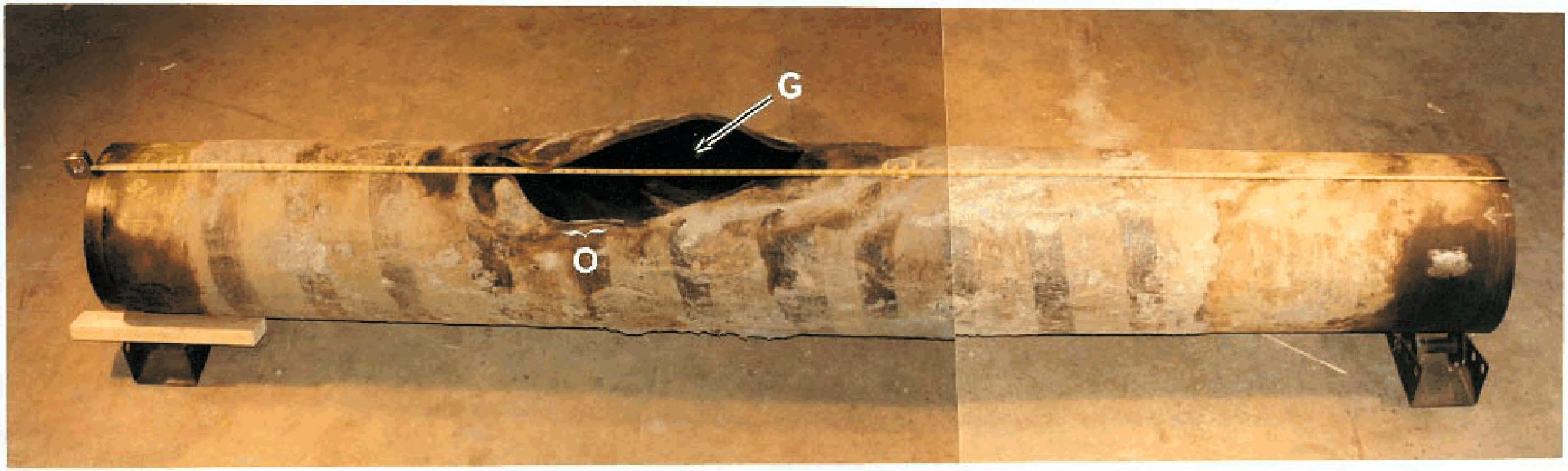

Figure 4. Composite photograph looking down at the north segment of the pipe showing the gaping crack indicated by arrow "G". Downstream (south) is located on the left side of the photograph.

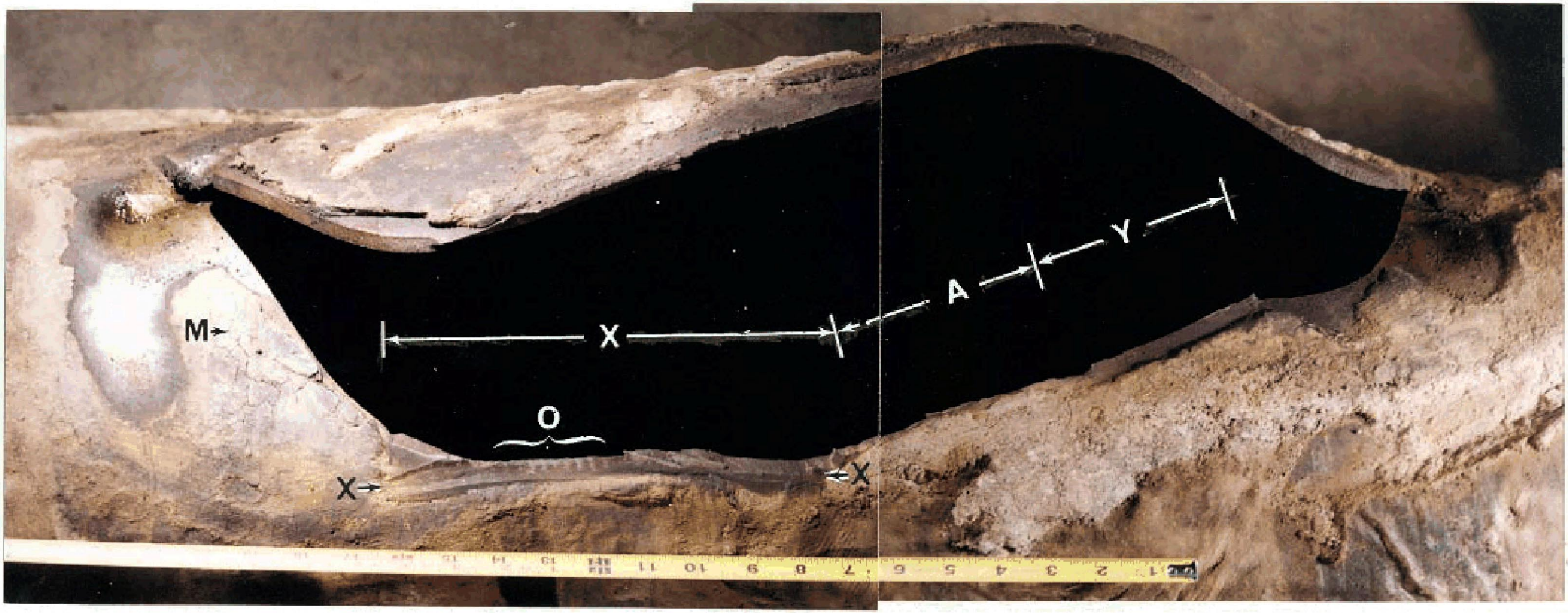

Figure 5 Composite photograph of the gaping crack. Downstream (south) is located on the left side of the photograph. The gouge mark located adjacent to the fracture in the area indicated by "A" was covered with soil deposit, whereas gouge marks in the areas indicated by "X" and "Y" were relatively clean. (3.5X)

Figure 6. Close-up photograph of the fracture origin area indicated by bracket "O". This fracture origin was located at the base of gouge mark "X", whose downstream end is indicated arrow "S". Downstream (south) is located on the left side of the photograph.

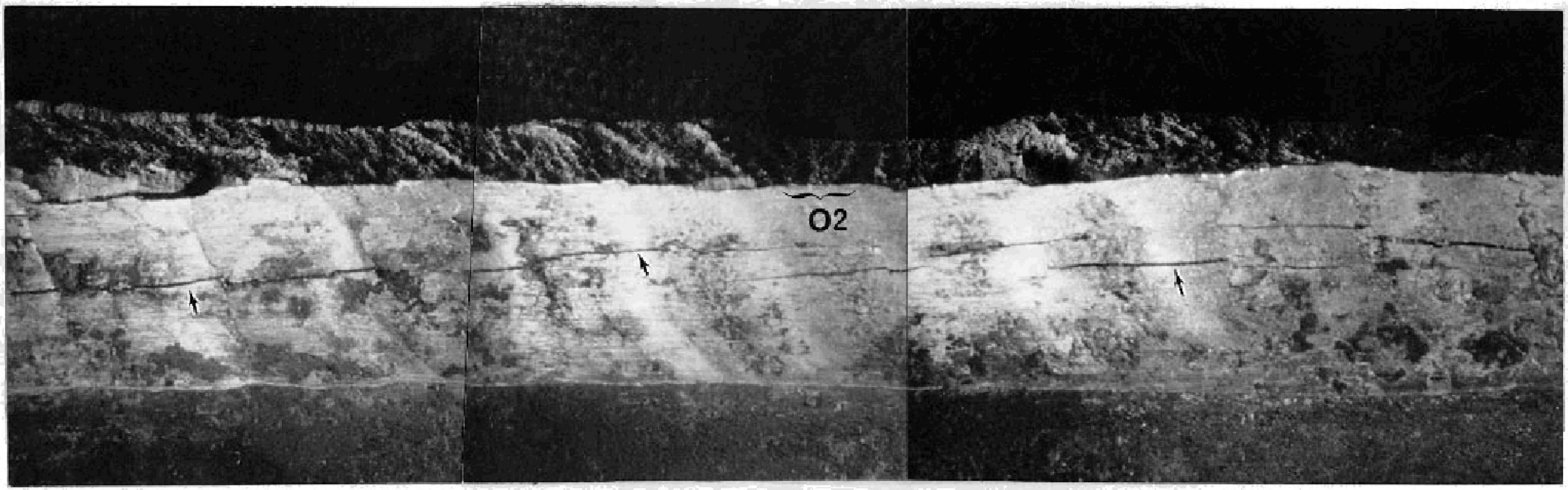

Figure 7. View looking down at the surface of gouge mark "X" in the area of the fracture origin area showing nearly longitudinal cracks. Unmarked arrows indicate typical cracks. (3.5X)

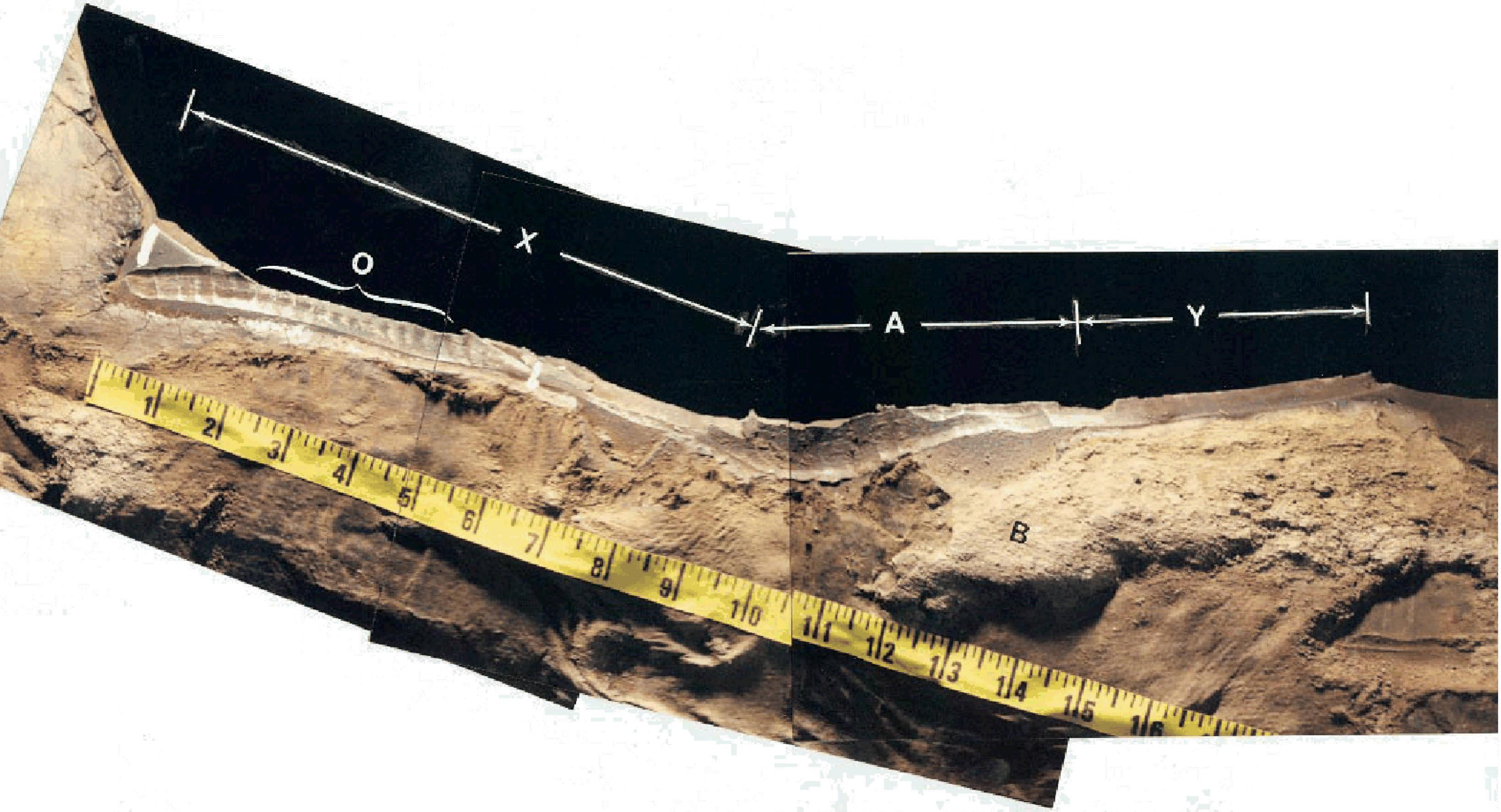

Figure 8. Close-up photograph of the outside diameter in the area of the east fracture in figure 5, showing gouge marks "X", "A", and "Y". This photograph was taken after soil was removed from gouge mark "A".

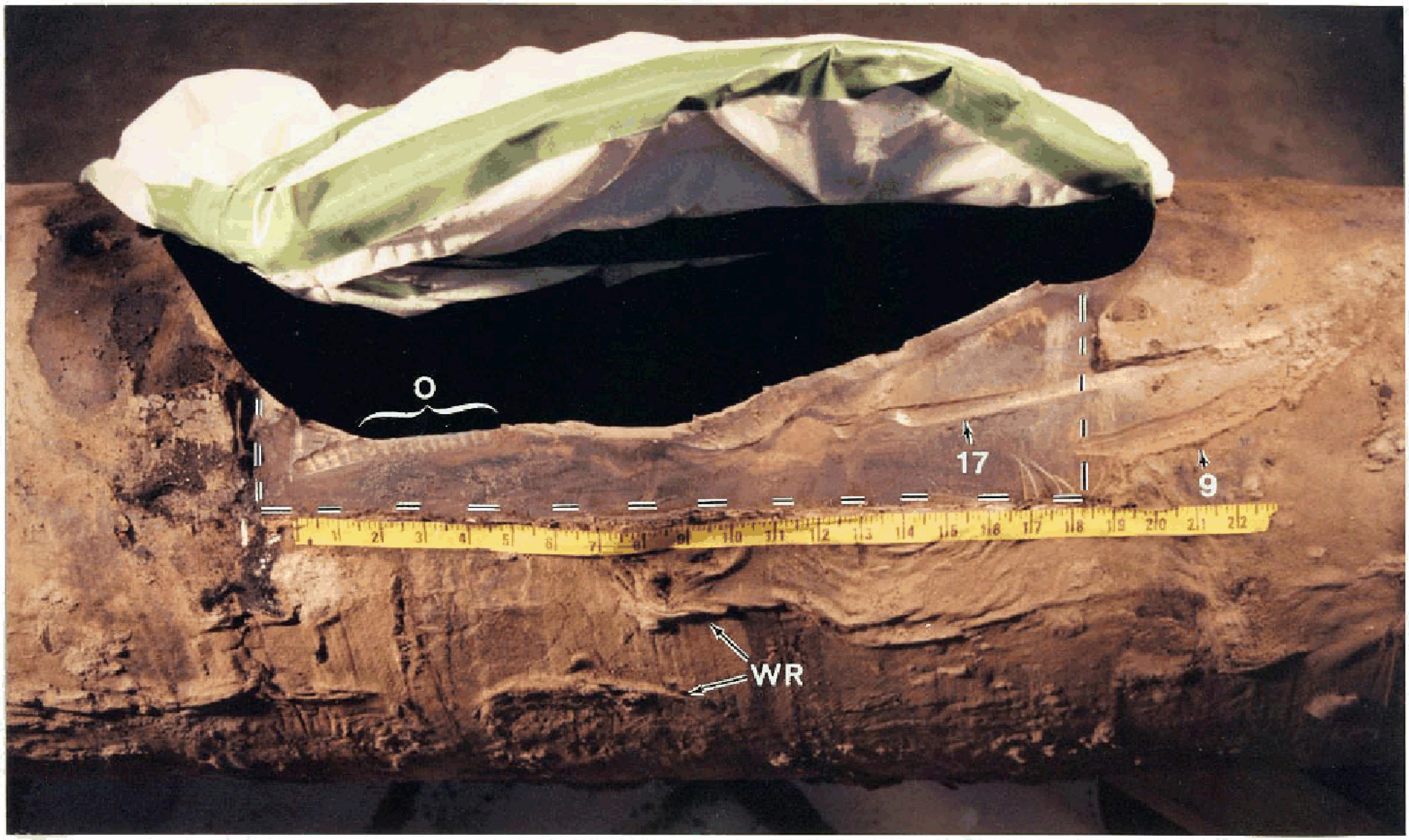

Figure 9. Overall view of the outside diameter in the area of the gaping crack after the coating was removed from the region inside the dashed line.

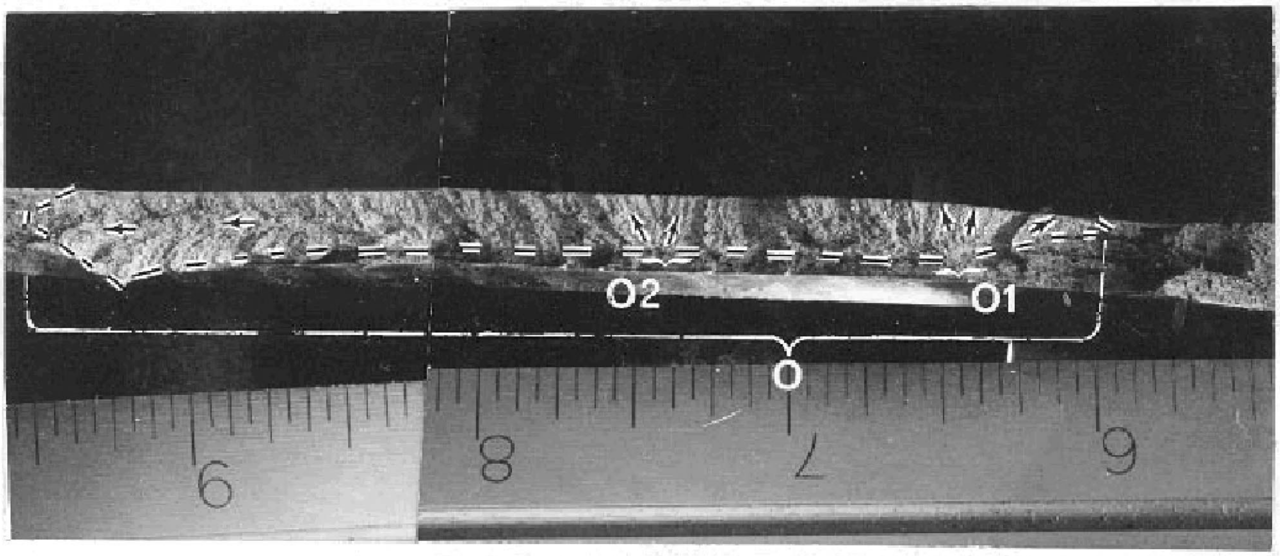

Figure 10. A close-up photograph of the fracture origin area, indicated by bracket O". The flat region is bound by the dashed line and the inside diameter. Gouge mark "X" is at the bottom side of the photograph and down stream is located to the left side of the photograph.

Figure 11. Close-up photograph of a portion of the fracture origin area showing a brown deposit layer (in the area between arrows "K") adjacent to gouge mark "X". Outside diameter is located on the bottom side of photograph. (7.5X)

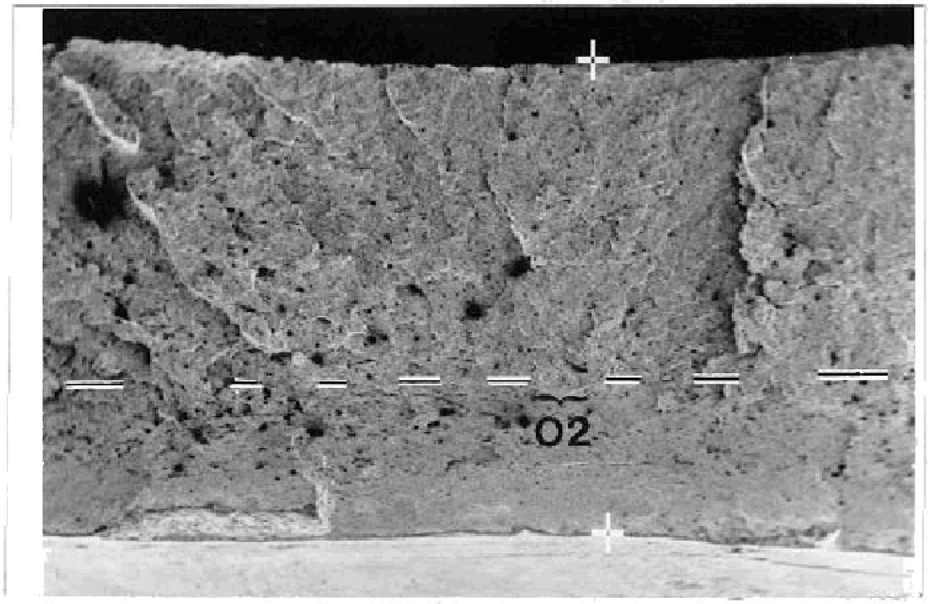

Figure 12. Scanning electron microscope (SEM) photograph of a portion of the flat region on the fracture showing radial marks that emanated from the bottom of the shear region in the area indicated by bracket "O2". The dash line indicates the transition area between the shear and flat regions. Inside diameter is located at the top side of the photograph. (10.6X)

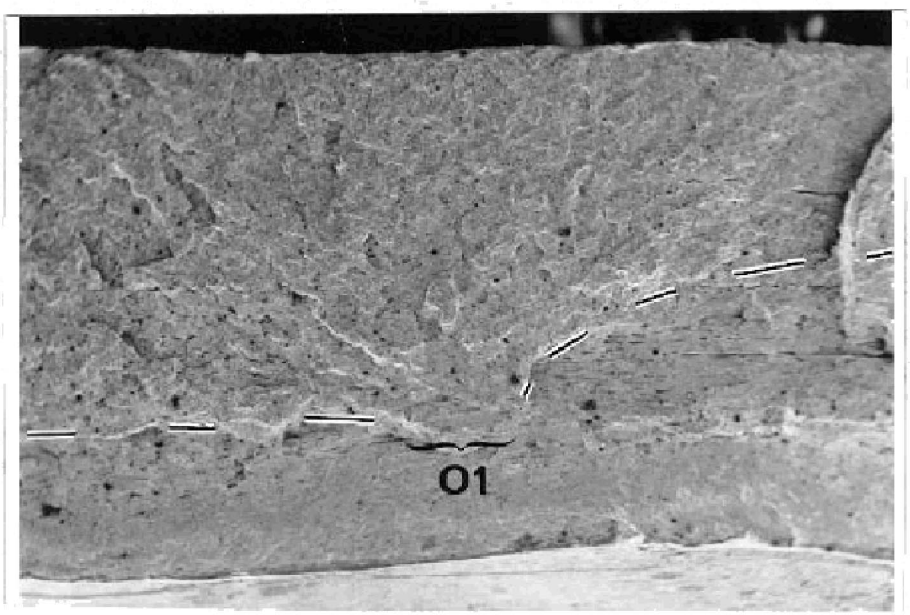

Figure 13. SEM photograph of a portion of the flat fracture region showing radial marks that emanated from another area at the bottom of the shear fracture region in the area indicated by bracket "O1". The dash line indicates the transition area between the shear and flat regions of the fracture. Inside diameter is located at the top side of the photograph. (10.6X)

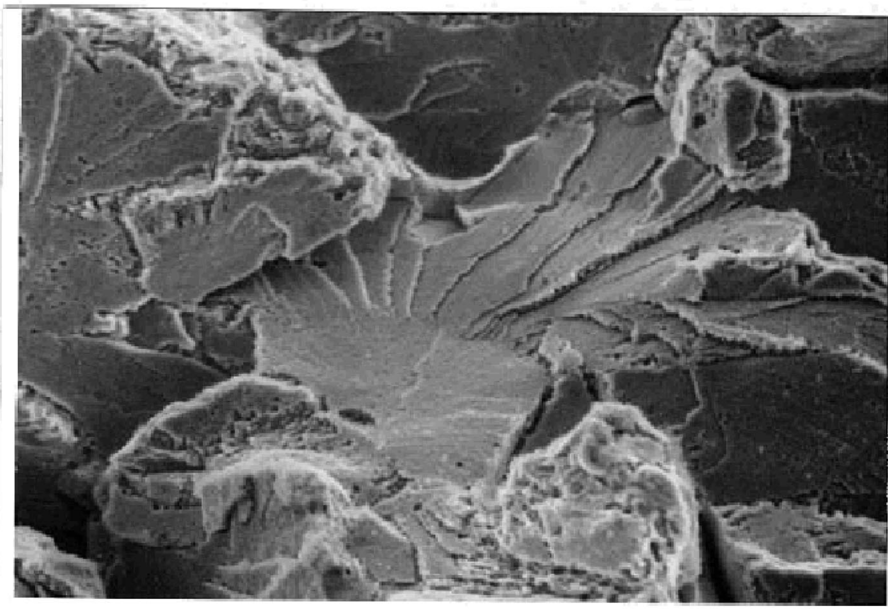

Figure 14. SEM photograph of a typical cleavage fracture region. (1,050X)

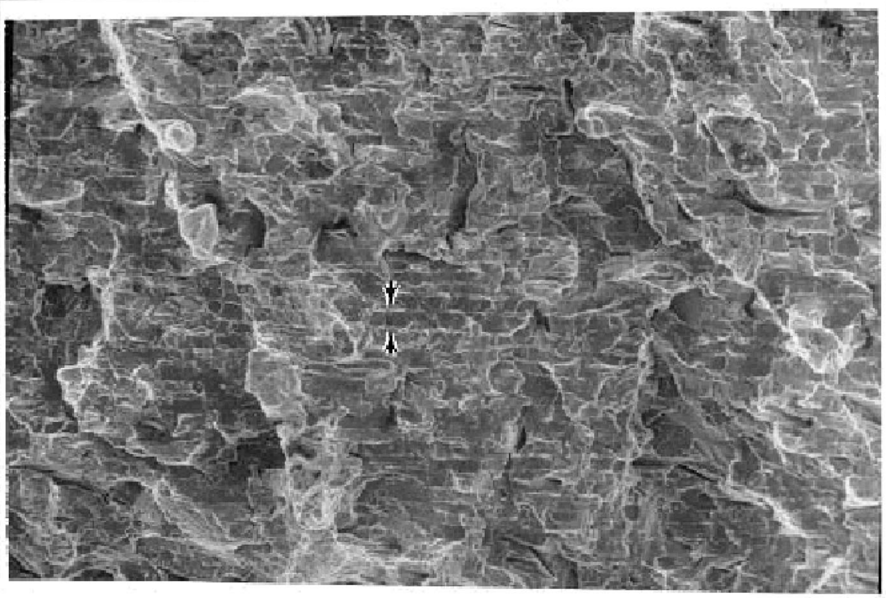

Figure 15. Lower magnification SEM photograph of a portion of the flat region showing typical longitudinal band-like features. A typical band is located between unmarked arrows. (161X)

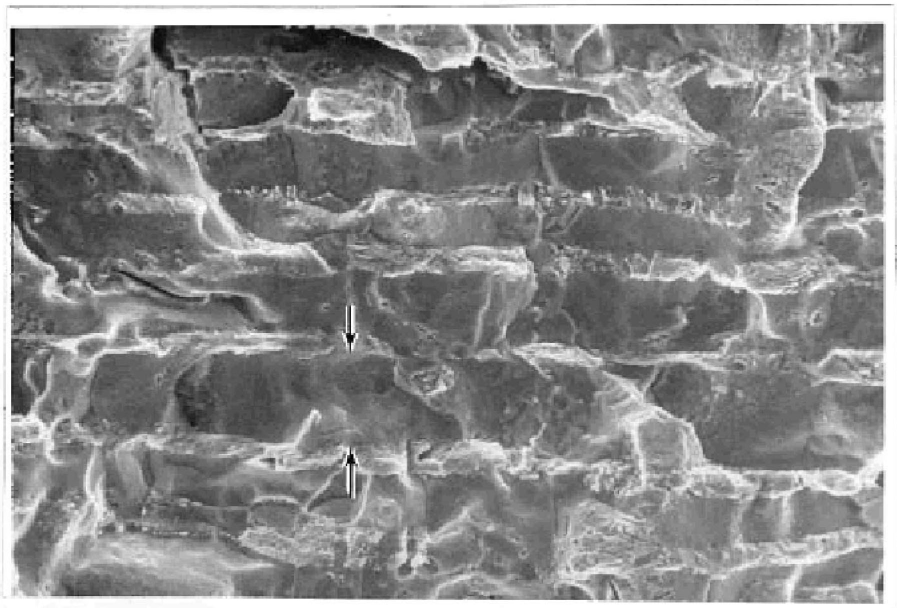

Figure 16. Higher magnification SEM photograph of the band-like feature between unmarked arrow. (867X)

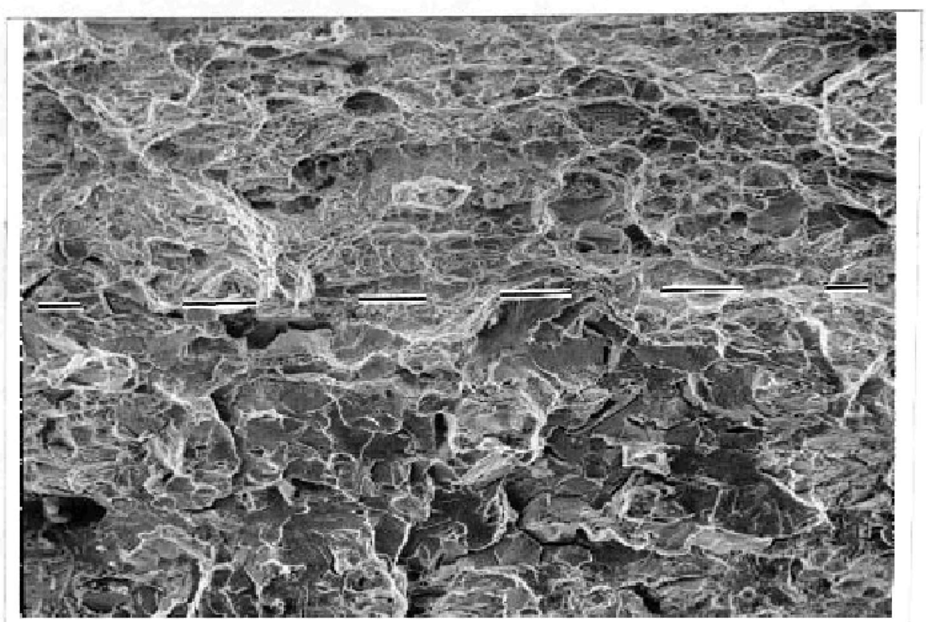

Figure 17. SEM photograph of the transition area, indicated by a dash line, between the shear region (upper) and the flat region (lower) of the fracture. Note that the flat fracture region contains cleavage features and the shear fracture region contains ductile dimple features. (204X)

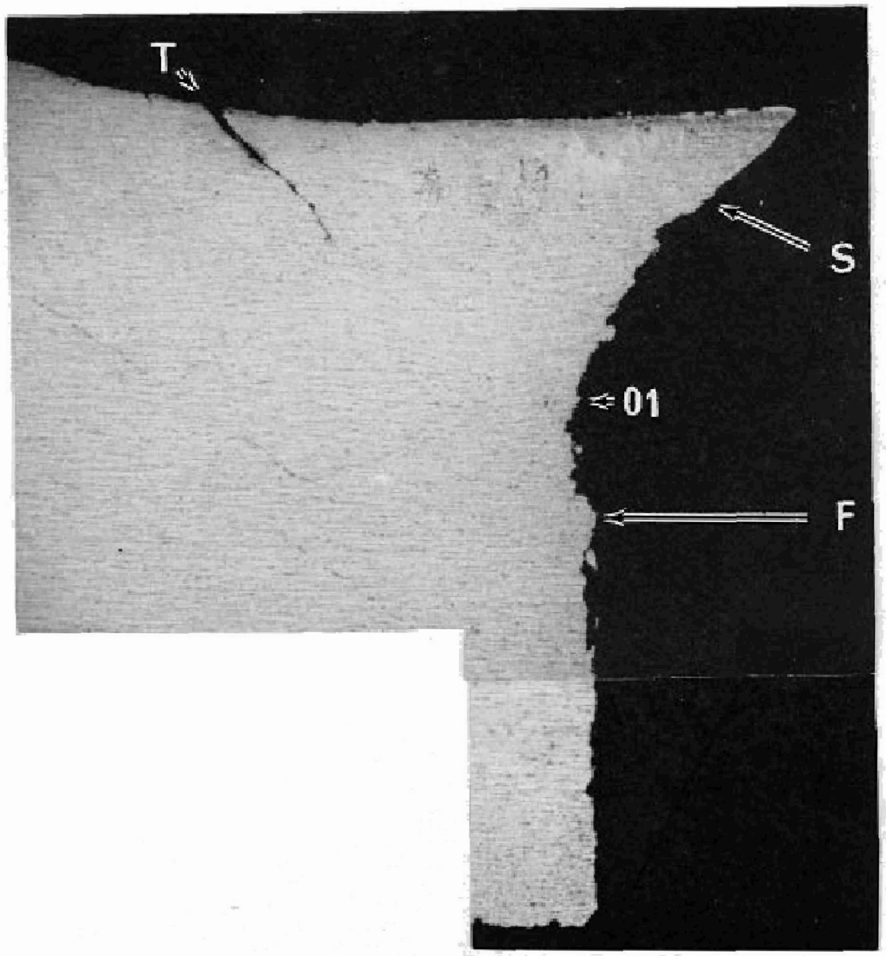

Figure 18. Composite photograph of a portion of metallurgical section "U-U" showing the fracture profile and fracture origin indicated by arrow "O1". Gouge mark "X" is located on the top side of the photograph. The shear region indicated by arrow "S" is located above the fracture origin area and the flat region indicated by arrow "F" is located below the fracture origin. Etched with 2% nital reagent. (16X).

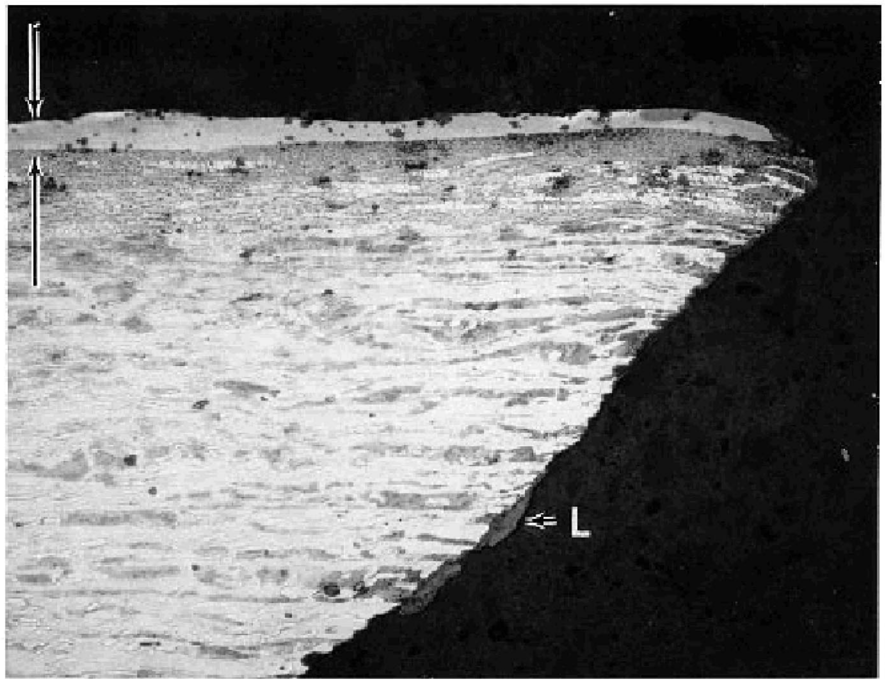

Figure 19. Close-up photograph of a portion of the section showing a white layer that was located at the surface of gouge mark "X" in the area between unmarked arrows. (160X)

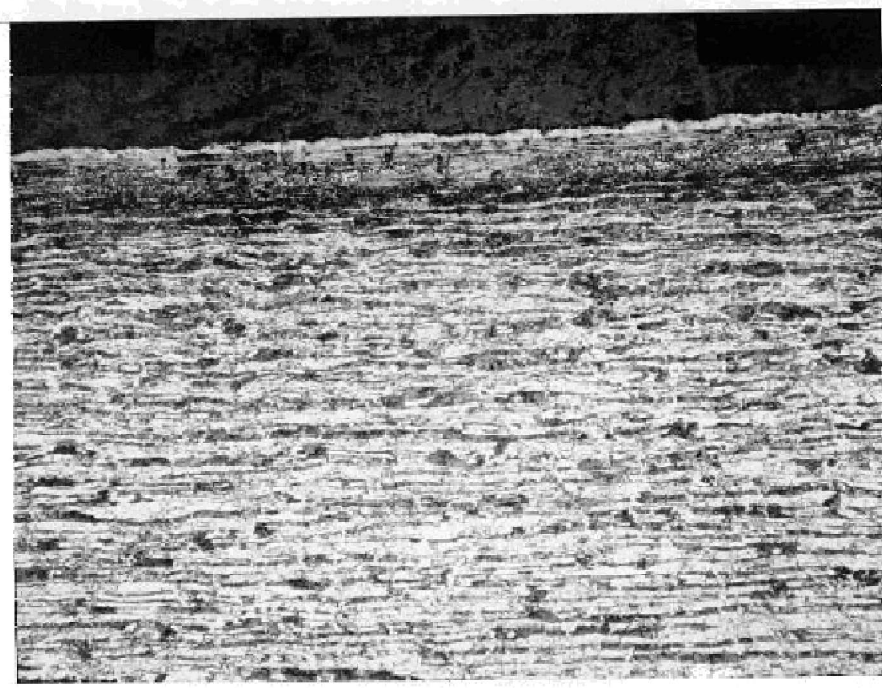

Figure 20. Another view of the section in the area adjacent to gouge mark "X" showing the white layer (at top of photograph). Note the deformed grains adjacent to the white layer. (100X)

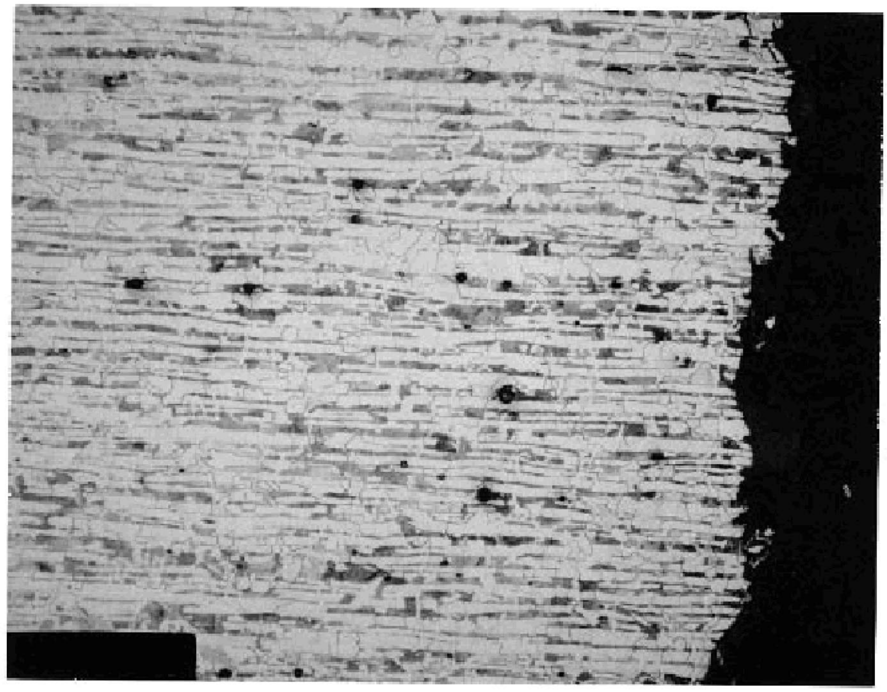

Figure 21A. Photomicrograph of typical microstructure found in the area adjacent to the flat region of the fracture. The microstructure exhibited ferrite grains (light areas) and pearlite grains (dark areas). 100X

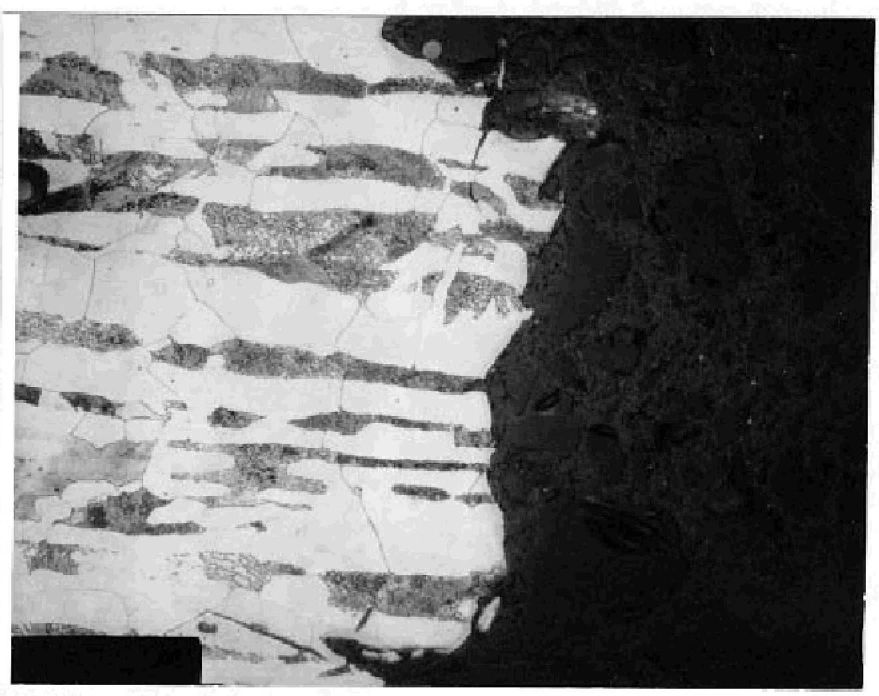

Figure 21B. Higher magnification photomicrograph of the microstructure in the area adjacent to the flat region of the fracture. (500X)

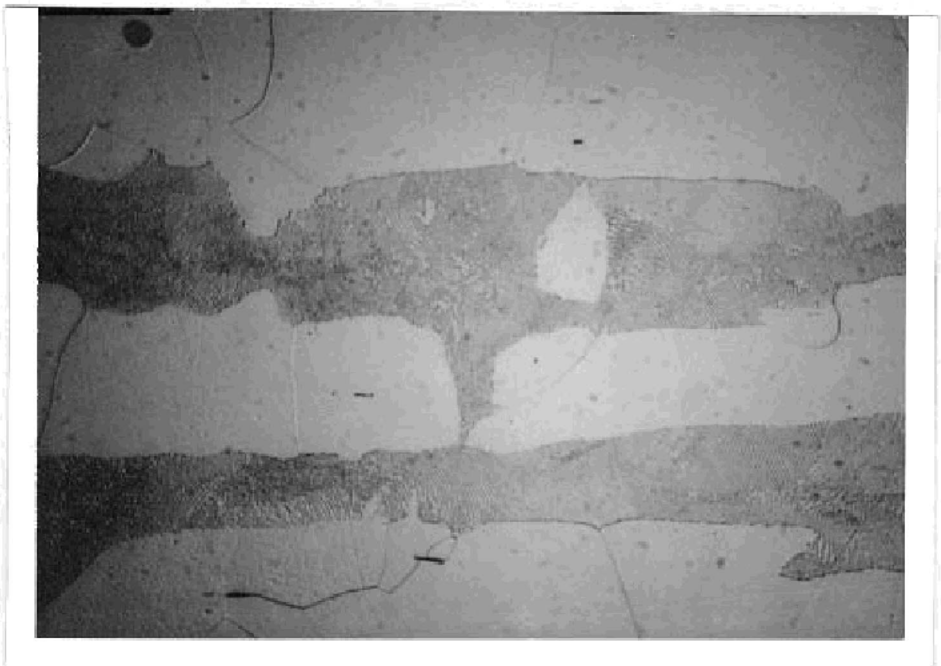

Figure 21C. Higher magnification photograph of the microstructure found at the wall of the pipe showing ferrite (light) and pearlite (dark zebra-like pattern) grains. This area was located at the inside diameter in an area that contained no evidence of deformation. (1,000X)

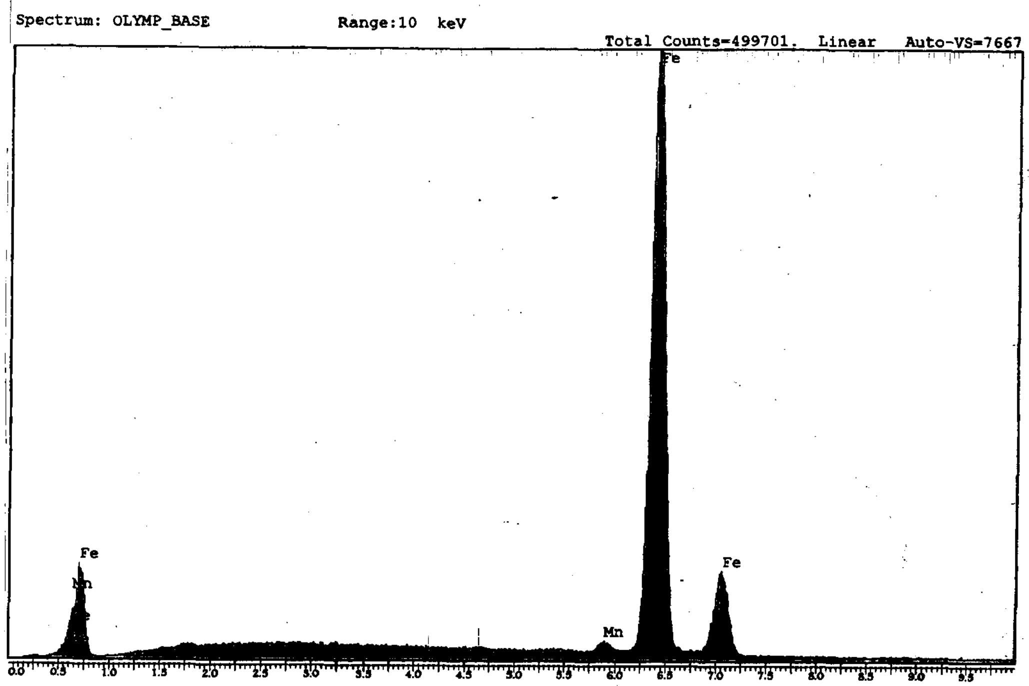

Figure 22. EDS spectrum of the wall of the pipe (base metal).

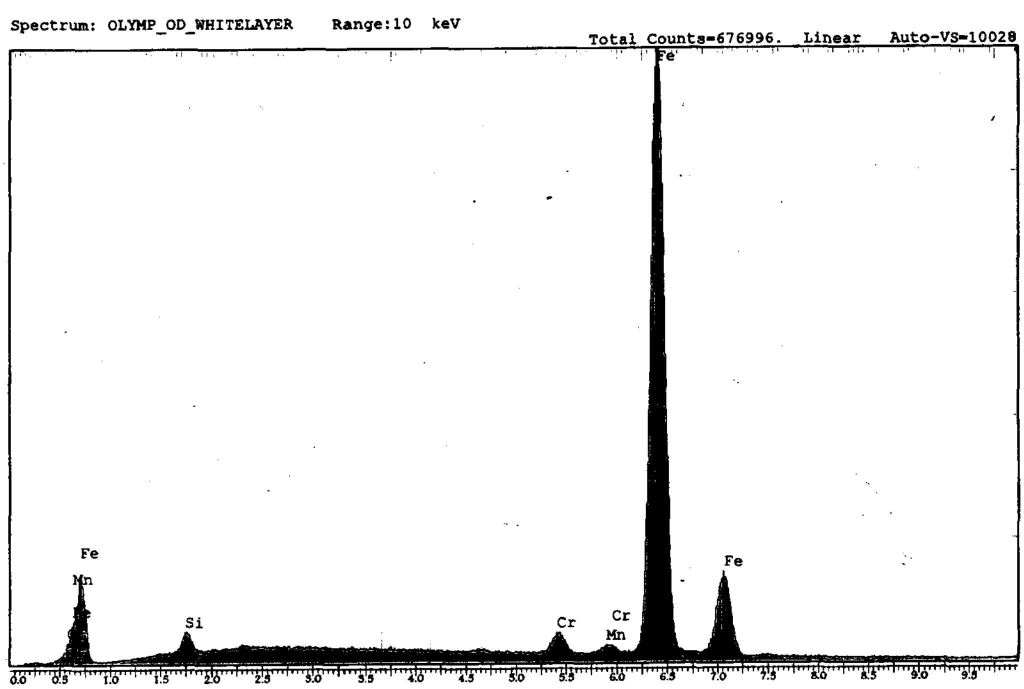

Figure 23. EDS spectrum of the white layer.

Figure 24. Traverse microhardness test results from a section of the wall with no gouge mark. 500 gram load.		
Distance from the outside diameter (inch)	Measured Knoop Hardness (KH)	Converted Hardness (HRB)
0.03	210	91
0.06	187	87
0.09	166	80
0.12	187	87
0.15	162	79
0.18	159	78
0.21	173	83
0.24	171	82
0.27	176	84
0.30	187	86
0.33	208	91

Figure 25. Traverse microhardness test results from section "U-U" in the area below gouge mark "X". 500 gram load, with exceptions as noted.		
Distance from the surface of the gouge mark (inch)	Measured Knoop Hardness (KH)	Converted Hardness
0.0005	740 – 908 at 50 gram load	60 - 67 HRC
0.0010	Bottom of white layer	
0.026	255	21 HRC
0.052	230	96 HRB
0.078	189	87 HRB
0.104	199	89 HRB
0.130	199	89 HRB
0.156	193	88 HRB
0.182	180	85 HRB
0.208	197	89 HRB
0.234	193	88 HRB
0.206	215	93 HRB

Figure 26A. Composite photograph of the outside diameter of the pipe looking down at the downstream end of the north segment.

Figure 26B. Composite photograph of the outside diameter of the pipe looking down at the central portion of the north segment. The upstream end is located on the right.

Figure 26C. Composite photograph of the outside diameter of the pipe looking down at the upstream end of the north segment.

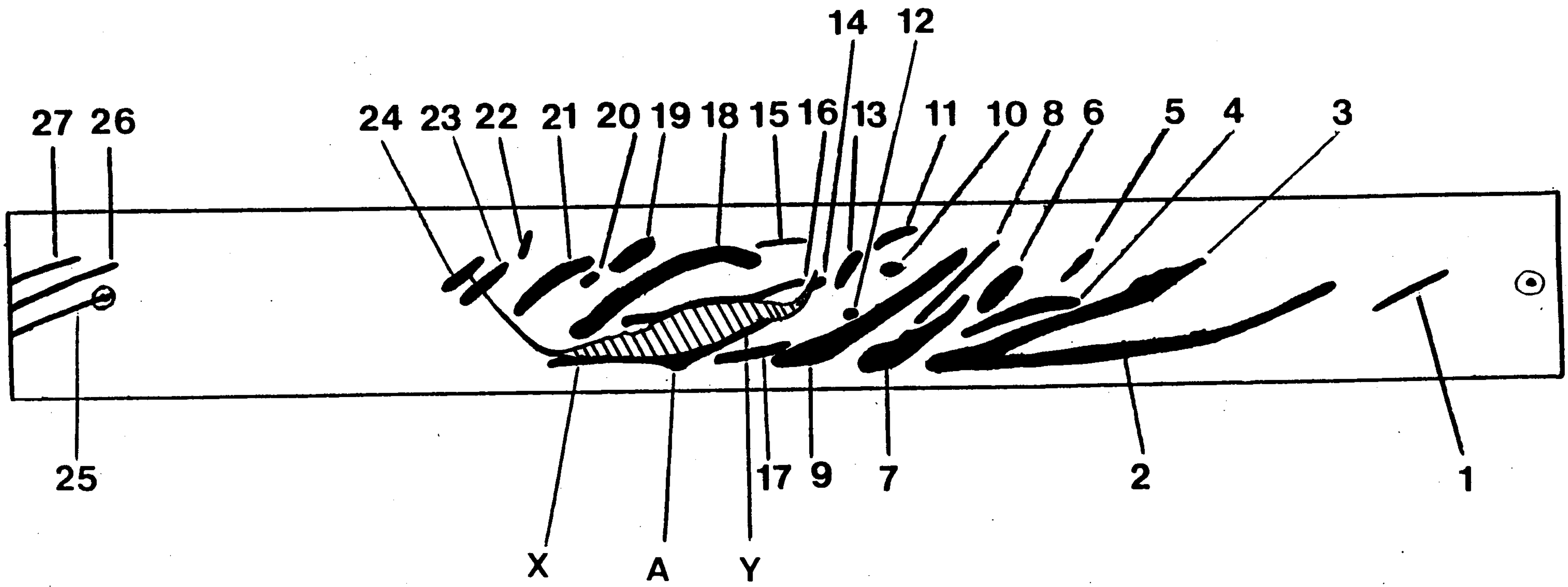

Figure 27. Sketch of the north segment of the pipe showing the location of gouge marks (black regions). Each gouge mark is indicated with a number or a letter. The sketch was traced by hand from a composite photograph of this pipe segment. Diagonal lines indicate the gaping crack. This sketch shows all the gouge marks in the north segment compared with the sketch in figure 3. Figure 3 shows only the gouge marks where samples were removed for examination. The north (upstream) end is located on the right side of the sketch, and a circle with a dot in the middle indicates the top dead center of the pipe

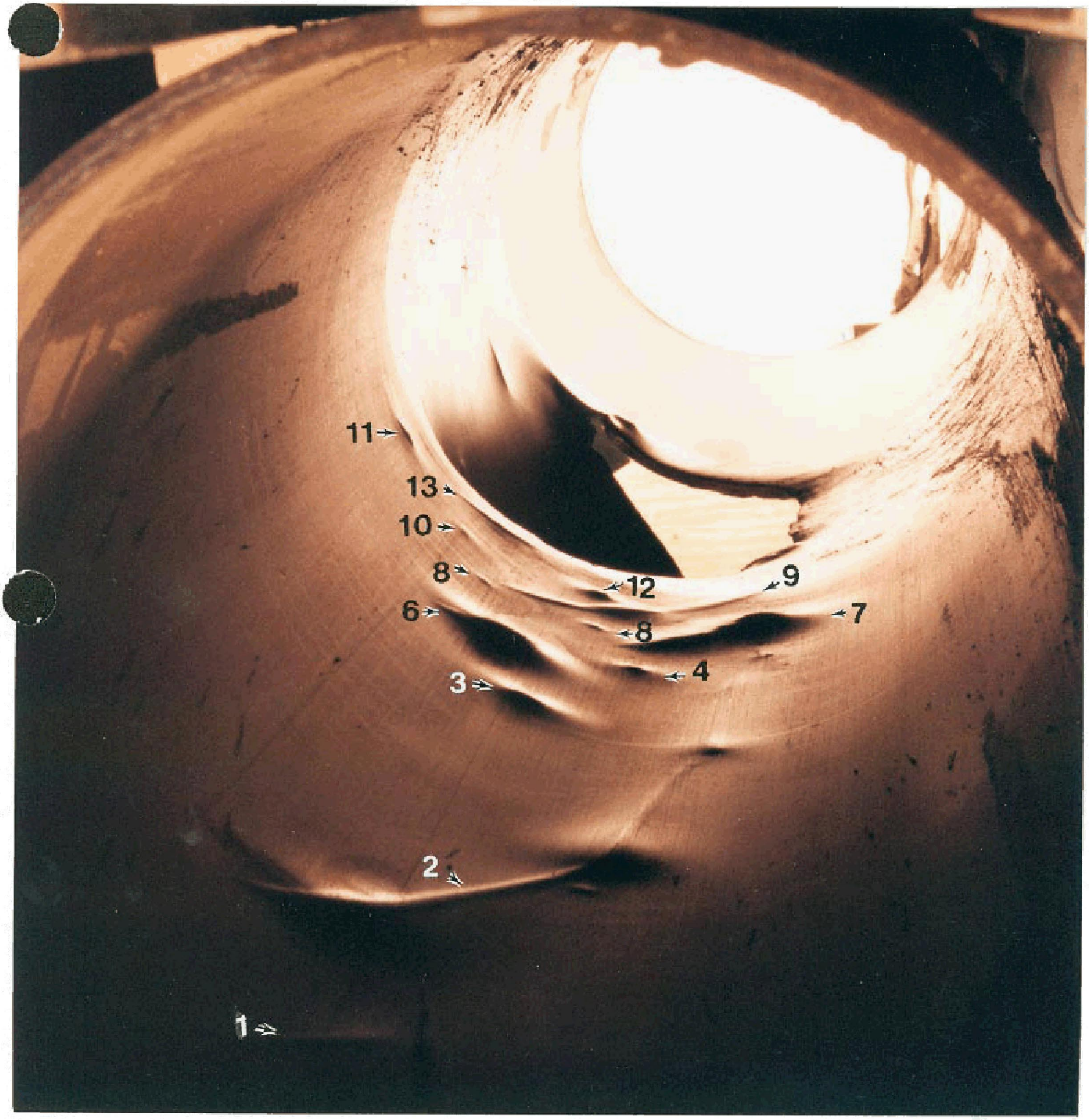

Figure 28. View looking downstream at the inside diameter of the north segment of the pipe. The number next to each arrow identifies the gouge mark associated with the indicated dent.

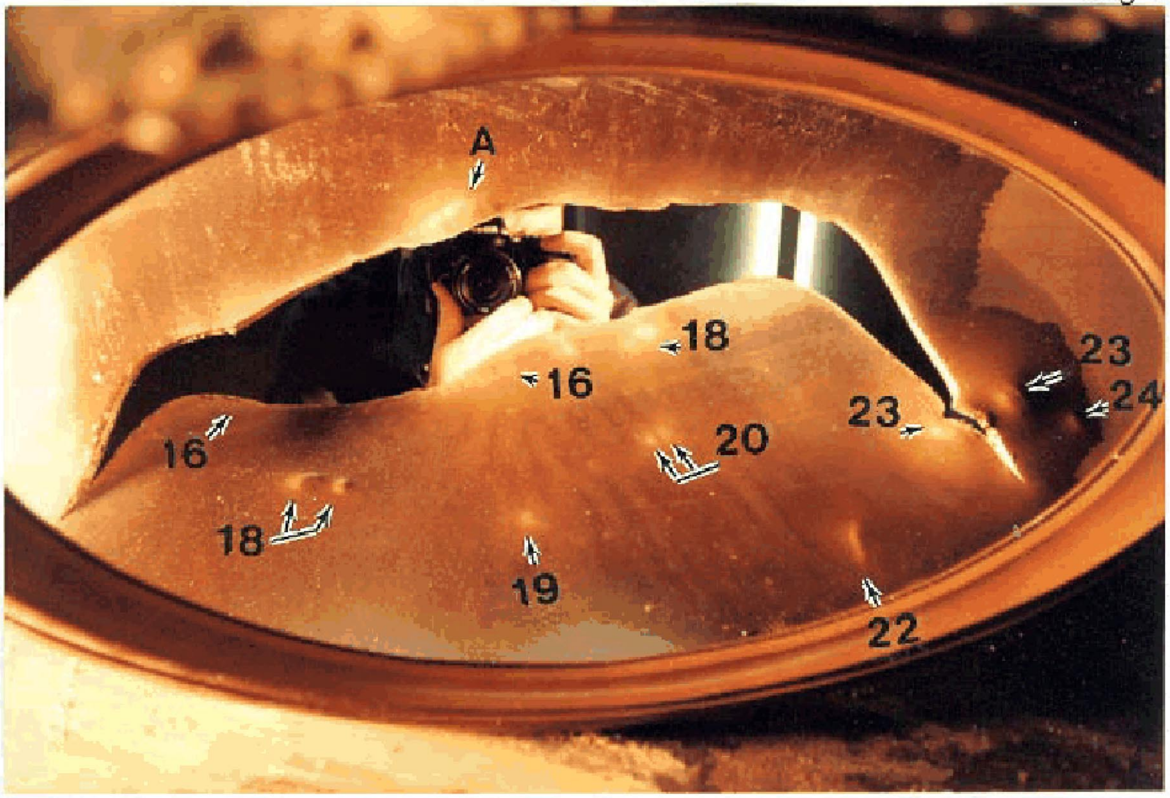

Figure 29. Photograph through a mirror of the inside diameter wall showing the full length of the gaping crack. Photograph was taken through the gaping crack from outside the pipe and with an oval mirror positioned inside the pipe. East face of the fracture is located on the top side of the photograph, and the downstream end is located at the right side.

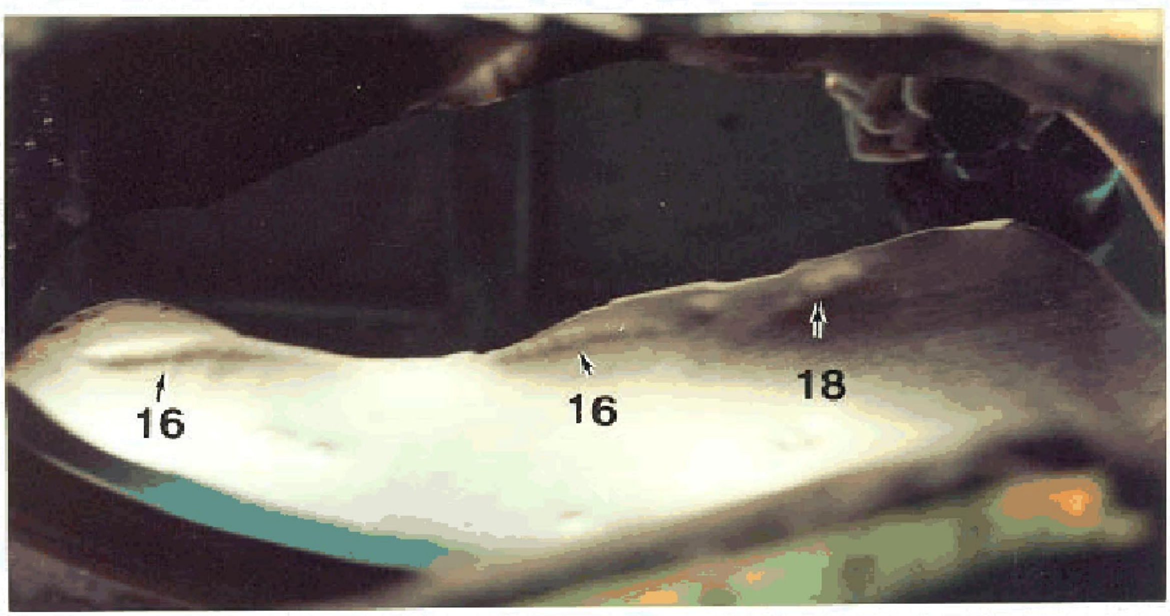

Figure 30. Photograph through a mirror of the inside diameter wall showing a close-up view of a portion of west face of the fracture. Downstream end is located at the right side.

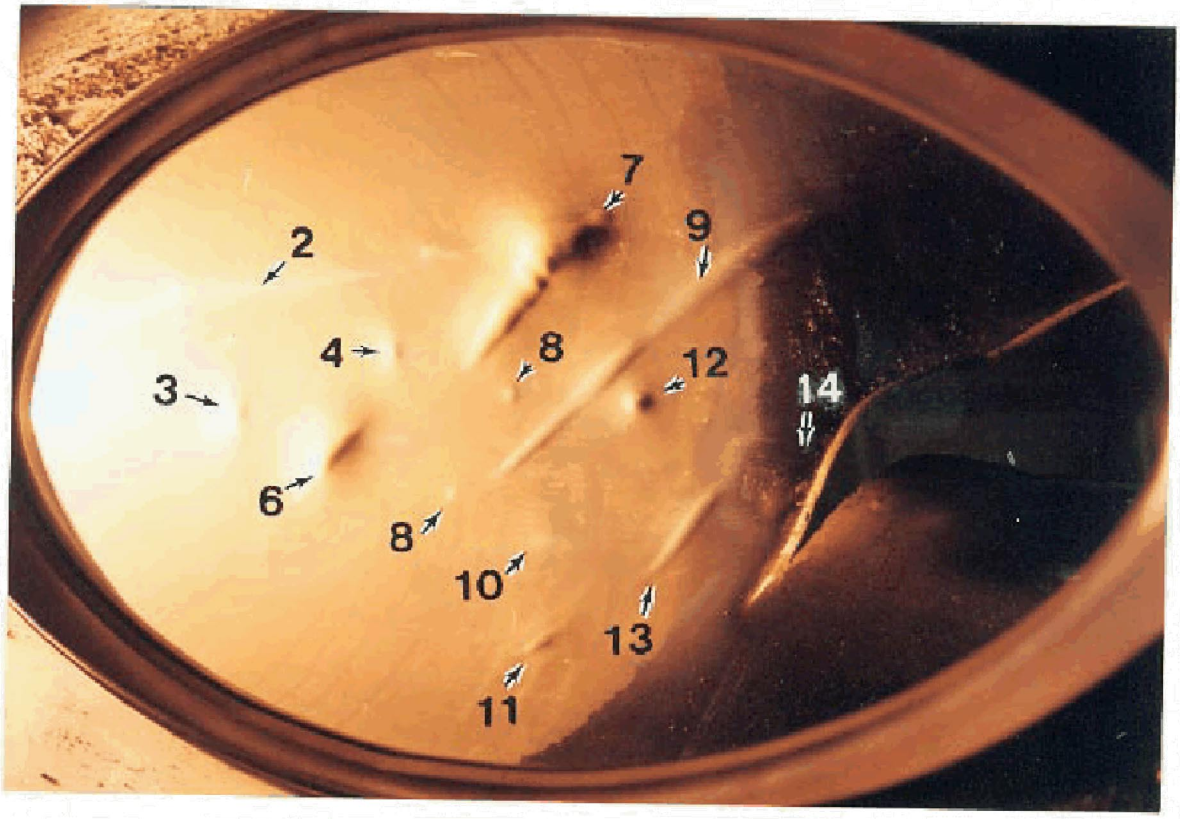

Figure 31. Photograph through a mirror of the inside diameter wall in the area located adjacent to the upstream end of the gaping crack. Photograph taken through the gaping crack from outside the pipe with a mirror positioned inside the pipe.

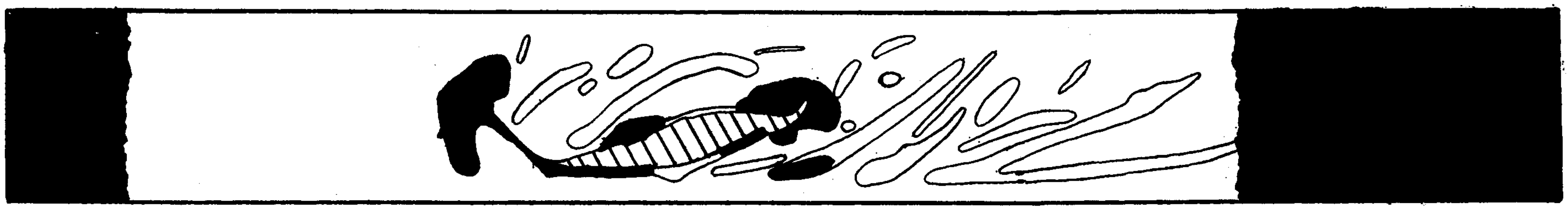

Figure 32. Sketch of the as-received north segment of the pipe showing the locations (black regions) where coating was either missing or had been removed from the exterior surface of the pipe. Note that areas without coating overlap portions of several gouge marks. Diagonal lines indicate gaping crack. The north (upstream) end is located on the right side of the sketch. Compare to figure 27.

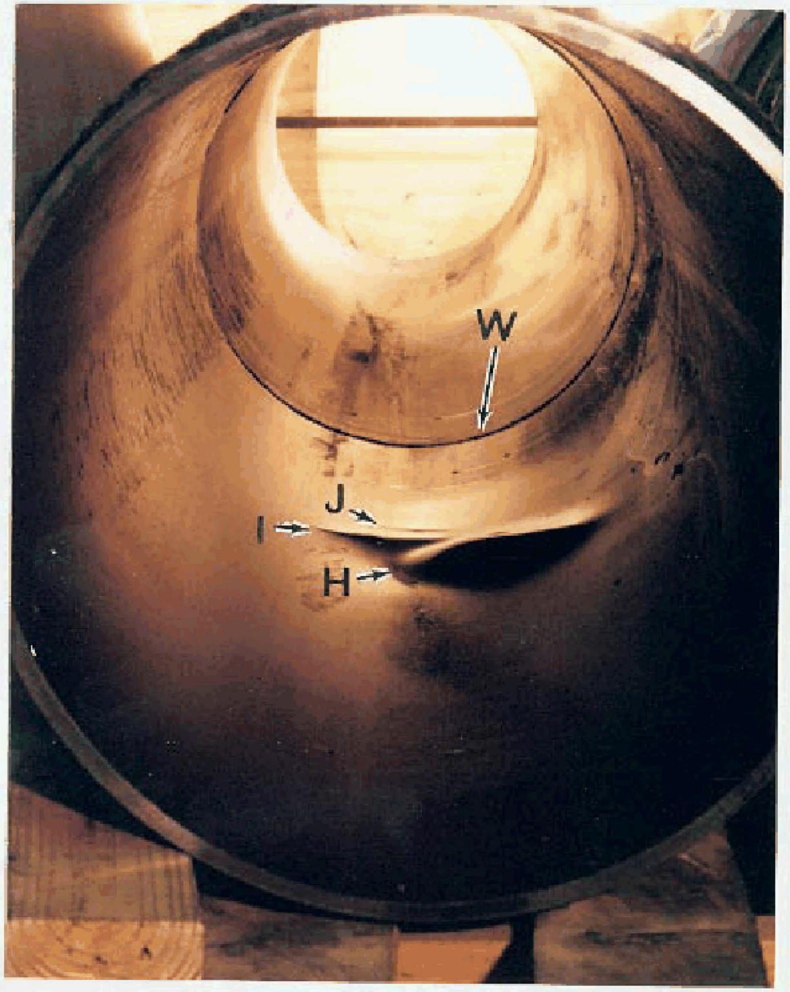

Figure 33. Photograph of the inside diameter of the south segment looking upstream showing the girth weld, indicated by arrow "W", and three gouge marks, indicated by arrows "H", "I", and "J".

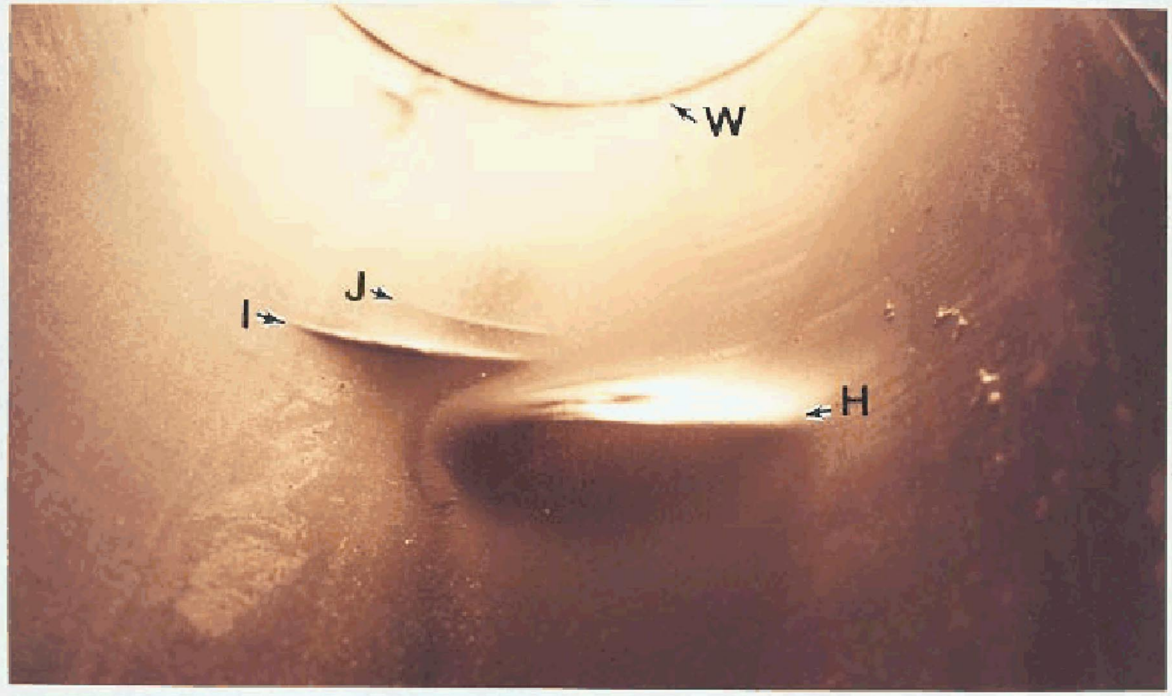

Figure 34. Close-up view of gouge marks "H", "I", and "J".

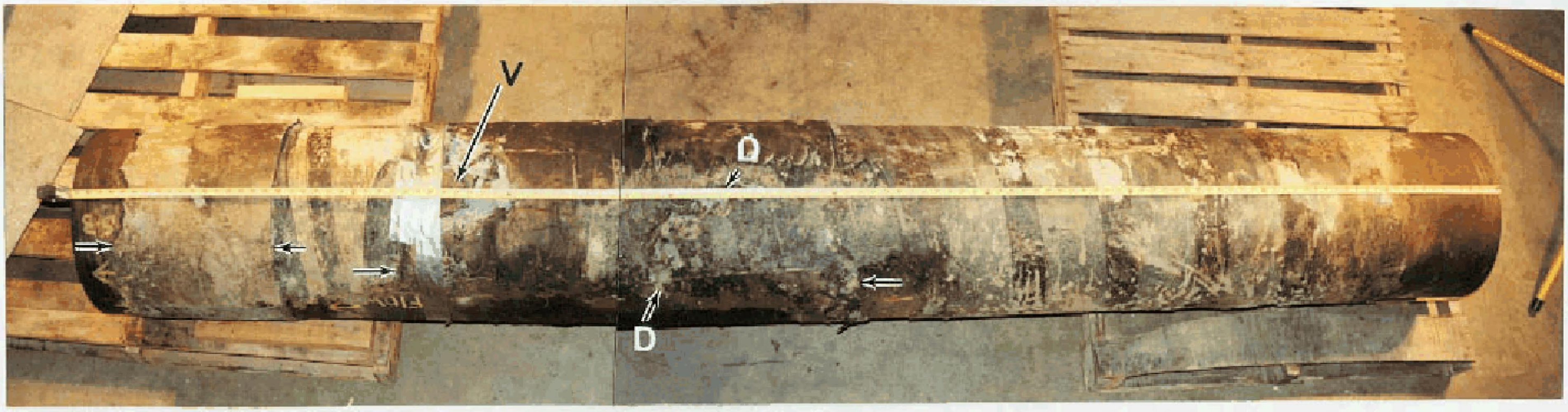

Figure 35A. Composite photograph of the as-received south segment of the pipe showing a ruler that was placed longitudinally at 3:30 o'clock. Two dislodged pieces of the coating, arrowed "V", are held in place by duct tape. The patches are located between unmarked arrows. Refer to figure 3 for the length of each patch.

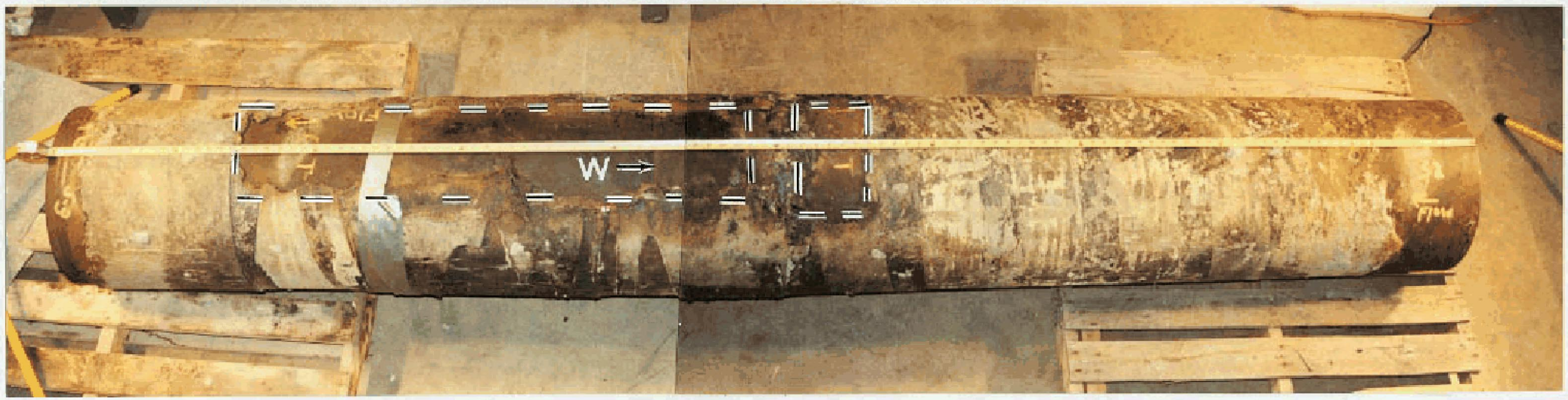

Figure 35B. Composite photograph of the as-received south segment of the pipe showing a ruler that was placed longitudinally at 12:00 o'clock. Coating reportedly was removed in the field, in the areas bound by a dashed line, to expose the girth weld arrowed "W".

Figure 36. Photograph of the outside diameter showing gouge marks "H", "I", and "J". These gouge marks correspond to those shown in figure 3.

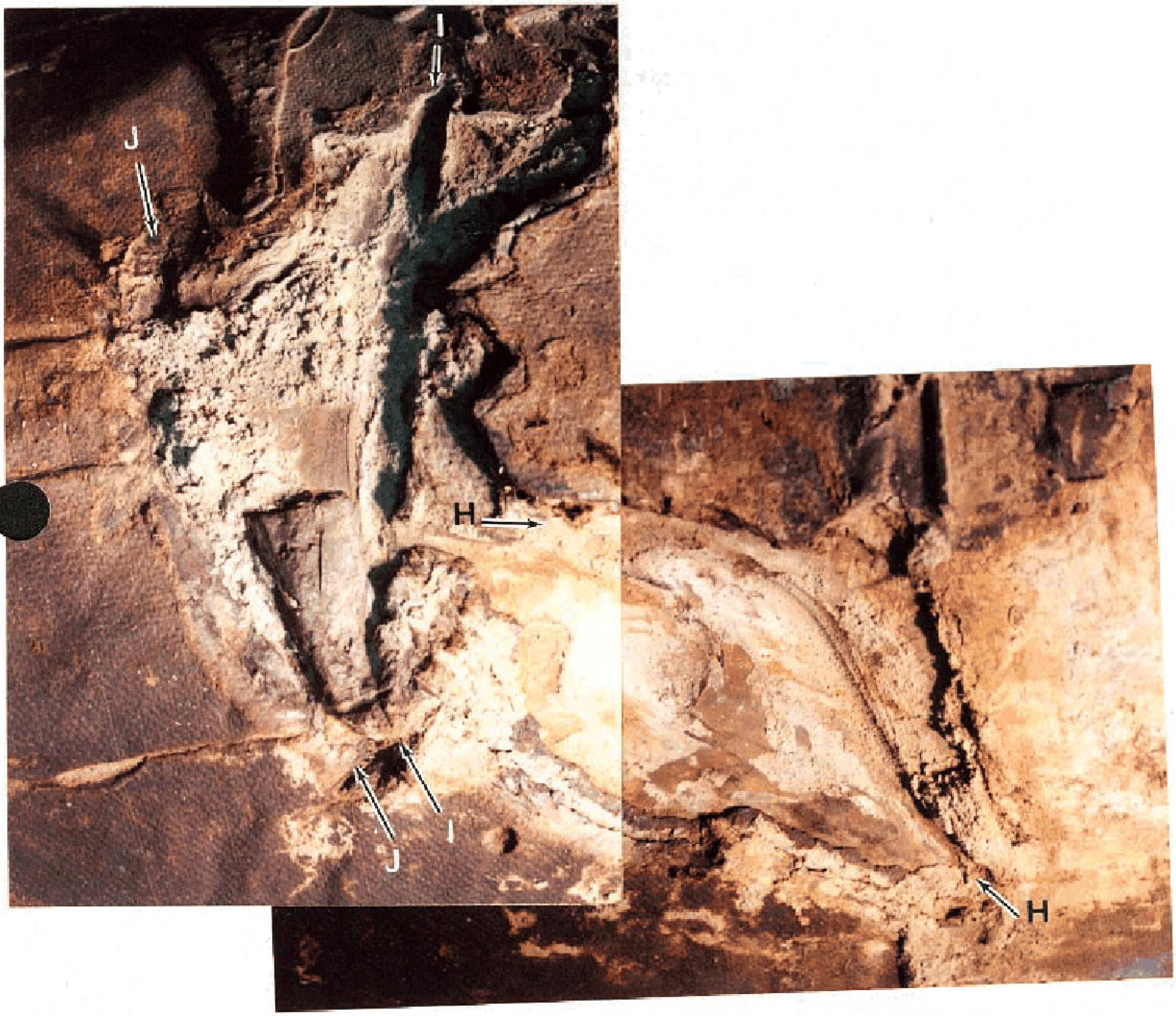

Figure 37. Close-up photograph the gouge marks "H", "I", and "J". Length of each gouge mark is located between arrows. Letters correspond to those in figure 36.

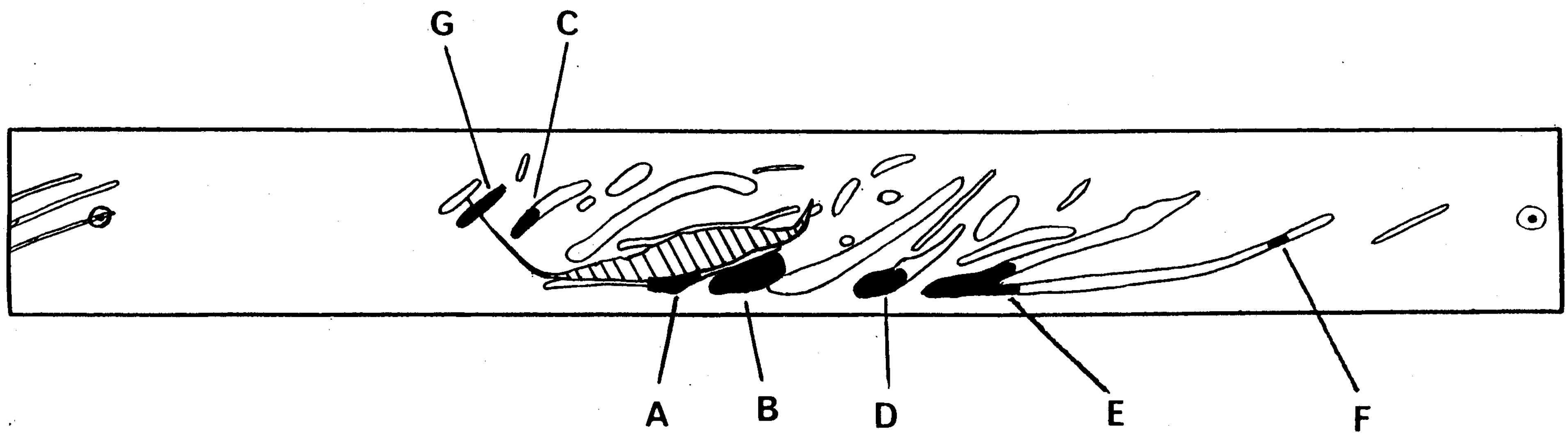

Figure 38. Sketch of the north segment of the pipe. Black regions ("A" through "G") indicate areas where a deposit sample was removed for examination, and diagonal lines indicate location of gaping crack. The north (upstream) end is located on the right side of the sketch, and a circle with a dot in the middle indicates the top dead center of the pipe. Compare with figures 27 and 32. The letters in this figure correspond to the same letters enclosed by a triangle in figure 3. The triangles in figure 3 assist in finding the location where samples were removed for examination.

Figure 39. Points of Interest at Specific Areas within a Gouge Mark.				
Point of Interest (refer to Figure 3 and Figure 38)	Gouge Mark Associated with Point of Interest (refer to Figure 27 and Figure 38)	Width of Gouge Mark as measured at Point of Interest (inch)	Depth of Gouge Mark as measured from External Surface of Coating (inch)	Depth of Dent as measured from the Inside Diameter of Pipe (inch)
A	A	1.00	---	---
B	overlap 17	0.50	---	---
C	21	0.46	0.2	---
D	7	0.90	0.6	0.40
E	2 & 3	0.33	0.2	---
F	2	0.50	0.2 ***	0.14
G	23	1.00	0.2	---
H	H	0.50	---	0.69
I	I	0.50	---	---
J	J	0.50	---	---

This table provides results of various measurements that were made at a specific point of interest within a gouge mark. Samples were also removed for examination from gouge marks in regions (black areas) indicated in figure 38. Use the data in this table in conjunction with alpha-numeric characters in figures 3, 27, and 38.

*** The depth of gouge at point of interest “F” was measured in relation to the bare metal exterior surface of the pipe since the coating had been removed in the field from this area. It was also noted at this location that the overall pipe wall at this location had been deformed inward. A ruler was placed flat against the bare wall and oriented longitudinally. The inward deformation at this location measured as deep as 0.2 inch, and extended over a distance of approximately 5 inches.

--- Indicates that a measurement was not made in this area.

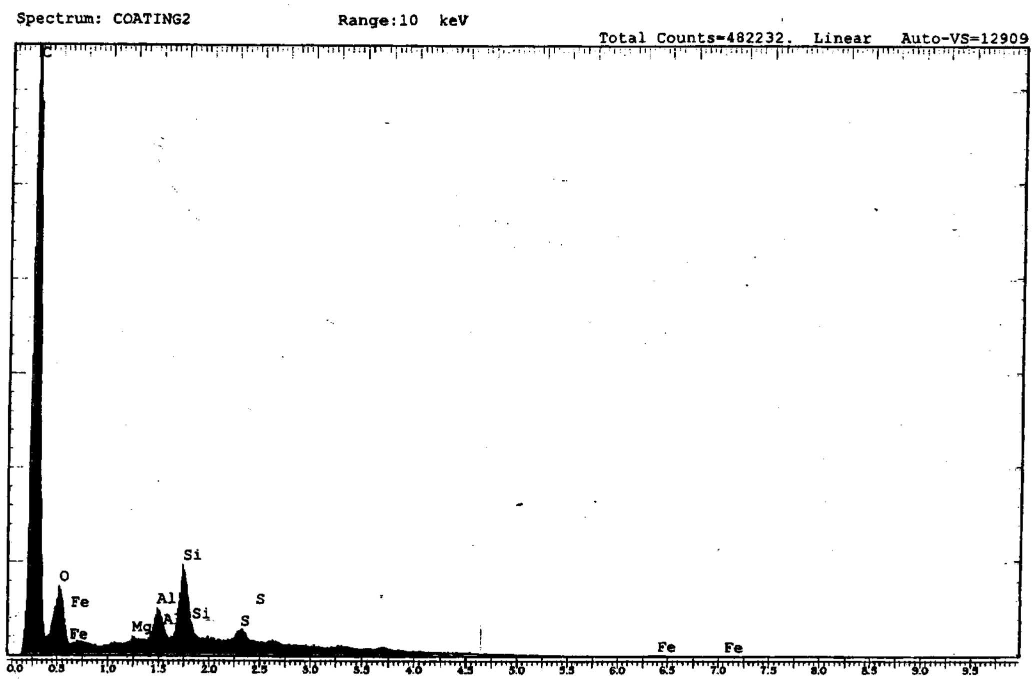

Figure 40. EDS spectrum of a sample of coating.

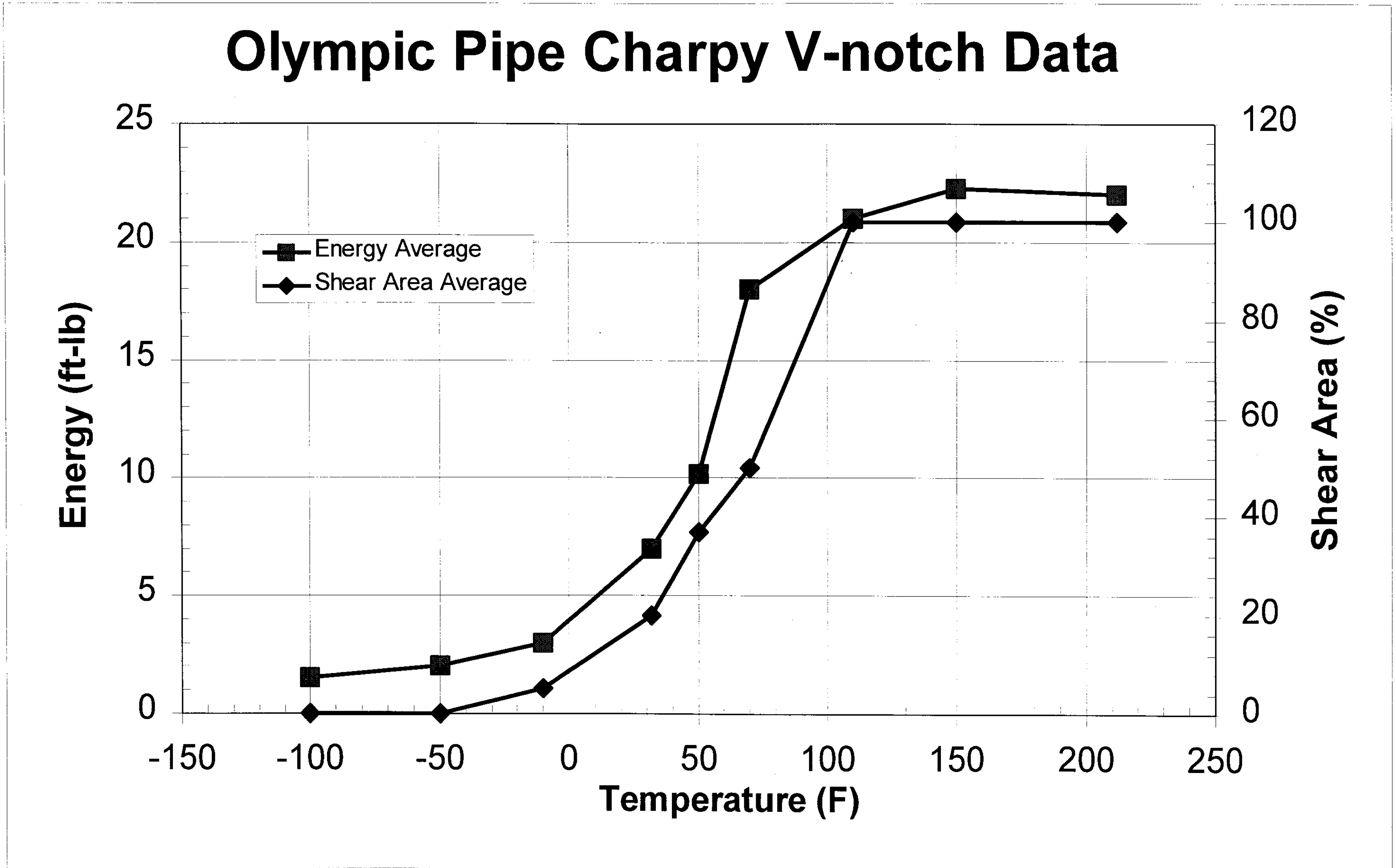

Figure 41. Plot of the Charpy V-notch testing results, showing average values for shear area of a specimen fracture surface and energy required to break a specimen.