

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



April 4, 2018

MATERIALS LABORATORY ADDENDUM REPORT

Report No. 17-018B

1. EVENT

Place : Ft. Lauderdale, Florida
Date : October 28, 2016
Vehicle : FedEx MD-10-10F, N370FE
NTSB No. : DCA17MA022
Investigator : Daniel Bower, AS-10

2. COMPONENTS EXAMINED

Pieces of left main landing gear

3. RESULTS OF LABORATORY INVESTIGATION

This NTSB Materials Laboratory Addendum Report details the fatigue analysis performed on the thumbnail crack at the radius transition of the Schrader valve bore and inner diameter of a main landing gear (MLG) cylinder (see Figure 1). The thumbnail crack, originating at a corrosion pit at this radius transition, exhibited alternating bands of fatigue and overstress, as well as a band of intergranular fracture. The extent of these fatigue features extended to a minimum of approximately 0.110 inches along the inner diameter of the cylinder and a maximum of approximately 0.192 inches (4.871 mm) along the air valve bore.

As stated previously, there was a band of intergranular fracture surrounding the first half-millimeter of fatigue and three overstress bands alternating with fatigue, before a final mixed fatigue and overstress band (illustrated in Figure 2 with measurements from the initiation site). A closer view of these bands, along with their measured depths, are illustrated in Figure 3 through Figure 6.

The fatigue striation counts were taken at over 35 random, unique, and non-duplicated places on the fracture surface, with the distances from the initiation site (the corrosion pit) recorded as well. The distances were measured using the field emission scanning electron microscope (FESEM). These locations and the measurements are shown in Figure 7 through Figure 45. No measurements taken in the final mixed overstress/fatigue region (shown in Figure 6).

Using a FESEM, a number of striations were counted and the distance of the counted striations was measured. This analysis assumed that each counted striation (a feature

consistent with crack growth) correlated directly to a landing cycle with no other comparable stresses (such as from braking). The analysis also assumed that sampled regions were representative regions of fatigue crack growth at each particular crack depth, the fracture surface was flat, and that the fatigue striation spacing increased with crack depth. The summary of the results is recorded in Table I.

The estimated total number of cycles for each band are summarized below (the number in parentheses represent the total striation quantity summation to that point):

- Striation count in 1st fatigue thumbnail (origin to intergranular): 526
- Striation count in 1st fatigue thumbnail (intergranular to overstress band 1): 165 (691 total to this point)
- Striation count before overstress band 1: 691
- Striation count in 2nd band: 253 (944)
- Striation count in 3rd band: 242 (1186)
- Striation count in 4th band: 218 (1404)

Figure 46 shows a chart plotting the data of Table I, which illustrated the calculated striation spacing at each distance from the fatigue crack initiation site. The relative locations of the intergranular zone and overstress bands are overlaid on the figure.

Erik Mueller
Materials Research Engineer

Table I – Estimated fatigue striation count thumbnail crack, including the lower estimate of striation counts in the calculations.

Location	Distance (μm)	Spacing (μm)	Count	Total
1	134.46	0.69		
2	158.62	0.77	33	33
6	219.67	0.55	93	126
4	306.88	0.63	147	273
3	311.96	0.55	8	281
5	320.4	0.59	14	295
28	399.15	0.80	114	409
29	403.70	0.51	7	416
9	420.0	0.48	32	448
8	421.8	0.94	2	450
26	436.51	0.53	20	470
30	454.04	0.66	29	499
10	473.4	0.76	27	526
7	481.9	1.02	9	535
27	487.68	0.59	7	542
31	550.04	0.52	112	654
33	561.79	0.62	20	674
32	572.55	0.60	17	691
OVERSTRESS BAND 1				
11	973.8	1.08	108	799
12	975.5	0.81	1	800
13	1064.22	1.86	70	870
14	1132.38	2.18	33	903
18	1226.49	2.42	41	944
OVERSTRESS BAND 2				
15	1331.91	2.47	43	987
16	1433.62	1.03	61	1048
17	1518.1	1.65	64	1112
34	1552.9	0.66	32	1144
35	1582.05	0.72	42	1186
OVERSTRESS BAND 3				
20	1628.17	3.02	28	1214
19	1638.15	3.54	3	1217
21	1710.46	3.61	20	1237
18	1742.63	3.88	8	1245
22	1831.86	1.26	38	1283
23	1844.08	2.20	7	1290
24	1943.02	1.69	51	1341
25	2043.79	1.49	63	1404

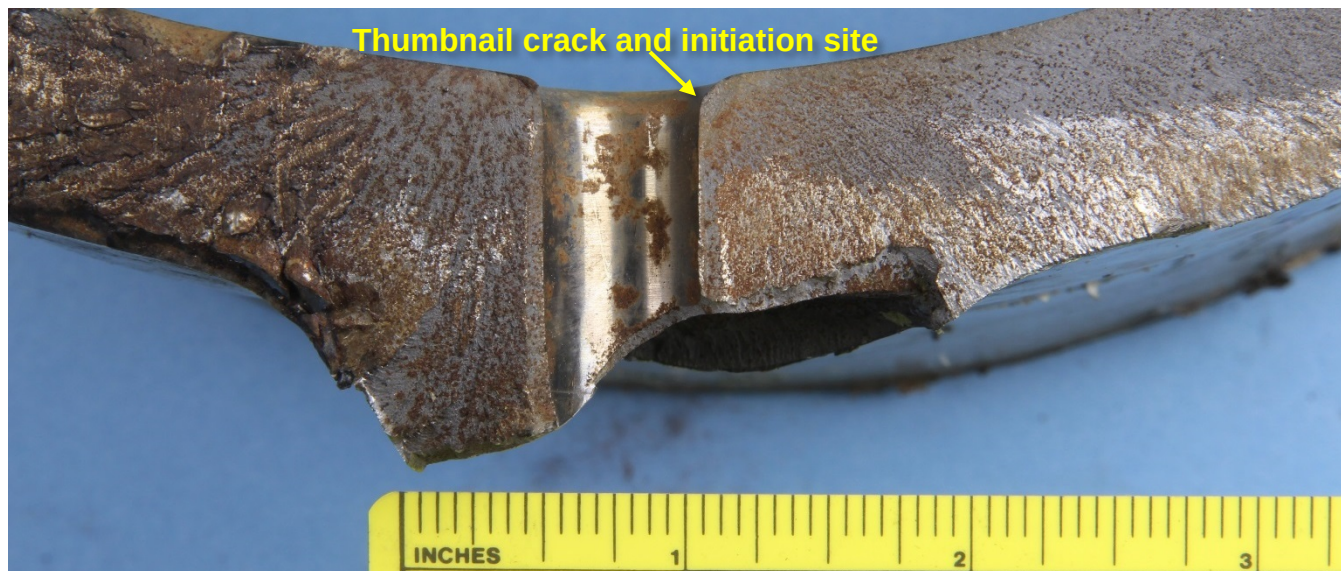


Figure 1 – The landing gear fracture about the bore, after sectioning from the landing gear.

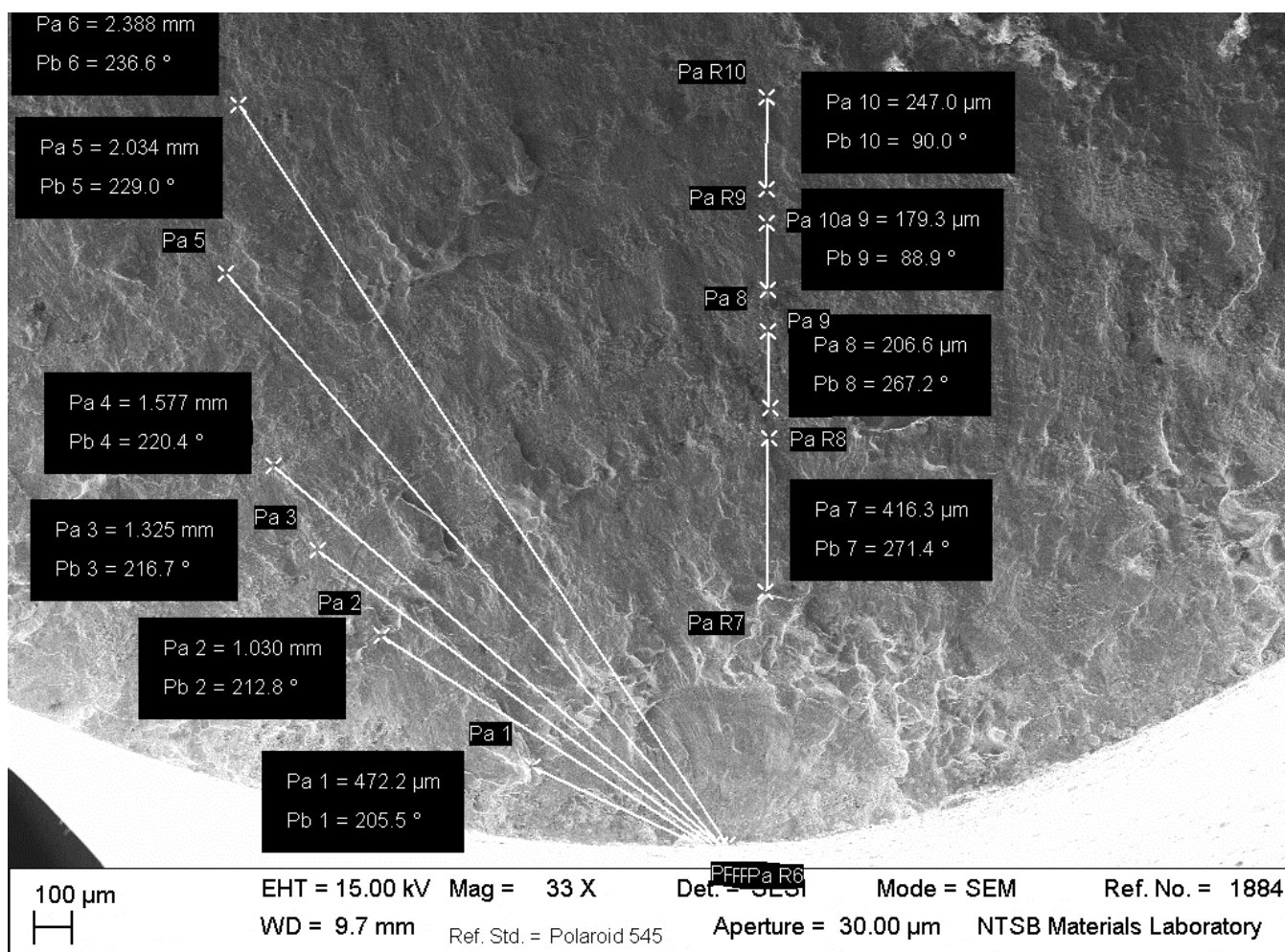


Figure 2 – Secondary electron (SE) micrograph showing the distances from the initiation site to the different failure mode bands (left side), and the depths of the secondary fatigue bands (right).

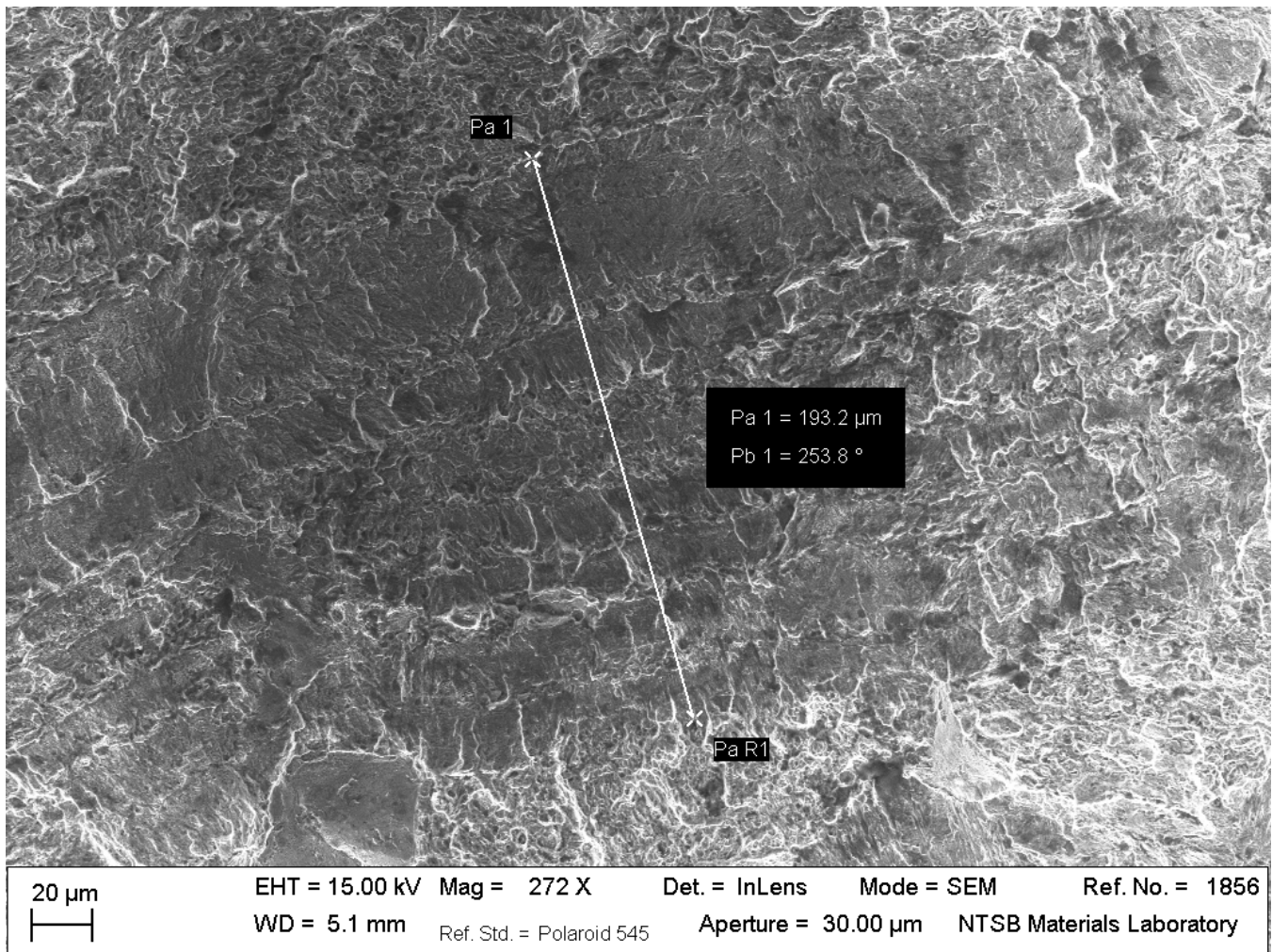


Figure 3 – SE micrograph of the 2nd fatigue band (after overstress).

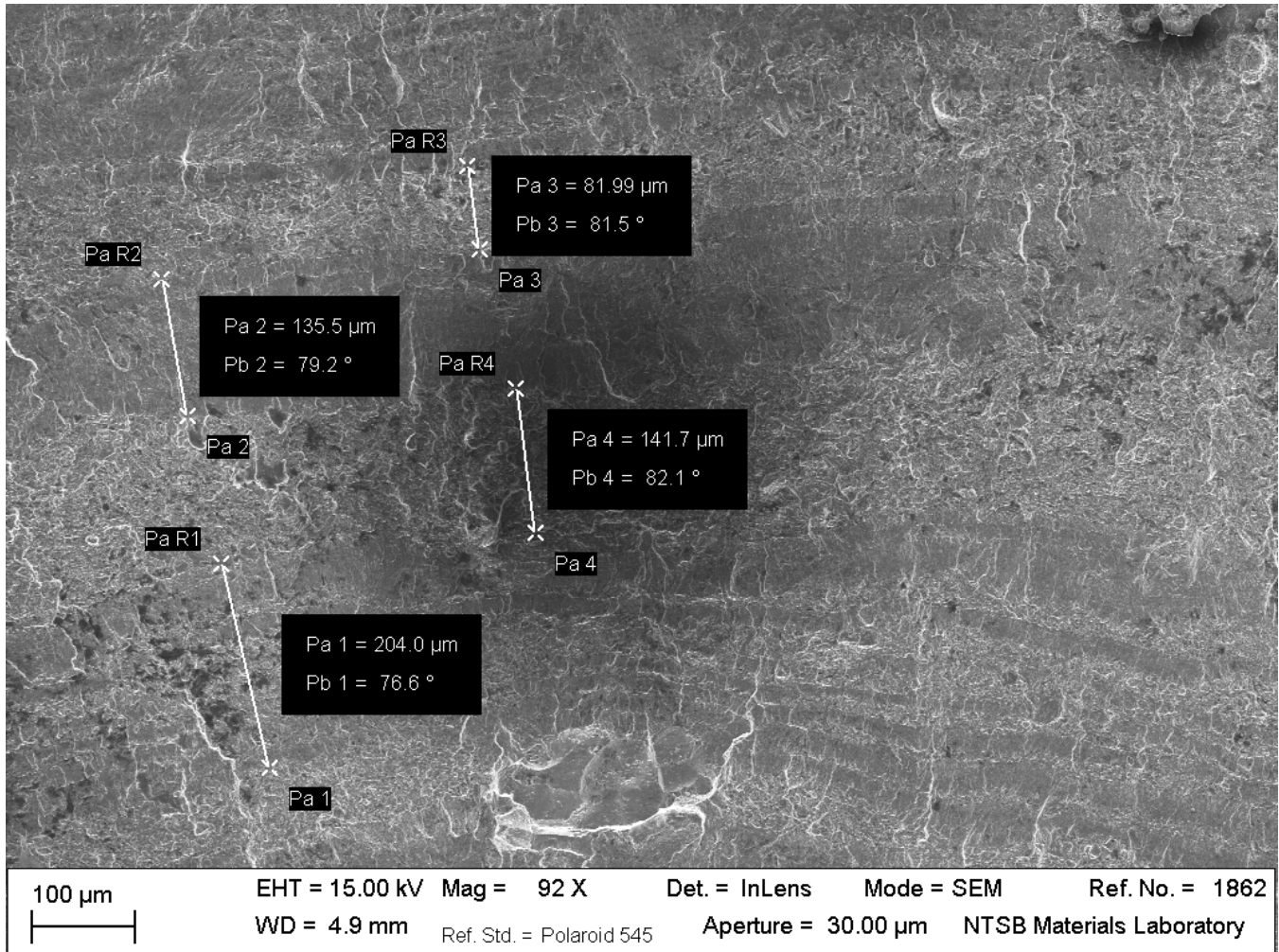


Figure 4 – SE micrograph showing fatigue bands 2 and 3 (left measurements) and overstress bands 2 and 3 (right measurements).

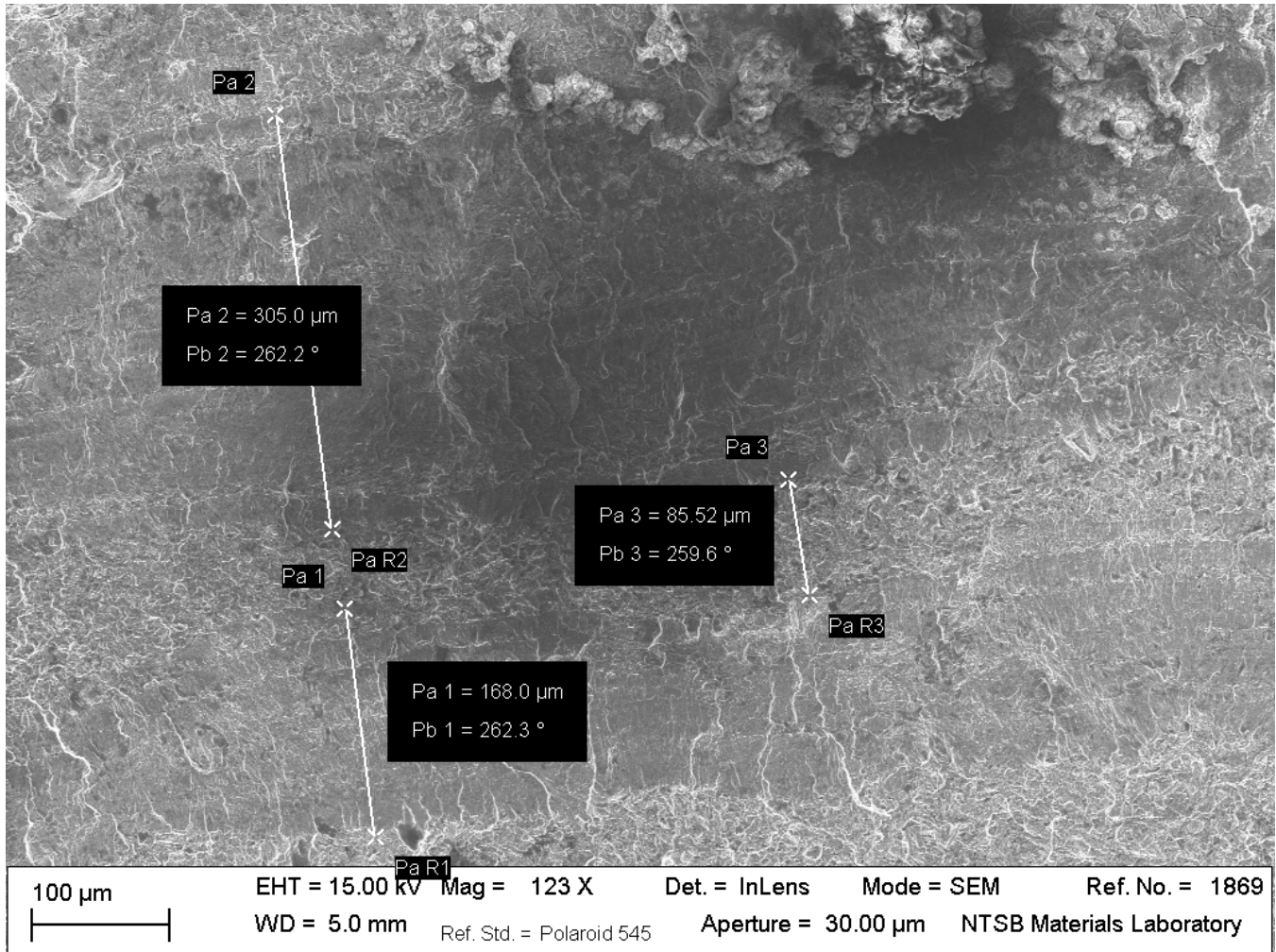


Figure 5 – SE micrograph showing fatigue bands 4 and 5 (left measurements) and overstress bands 4 (right measurement).

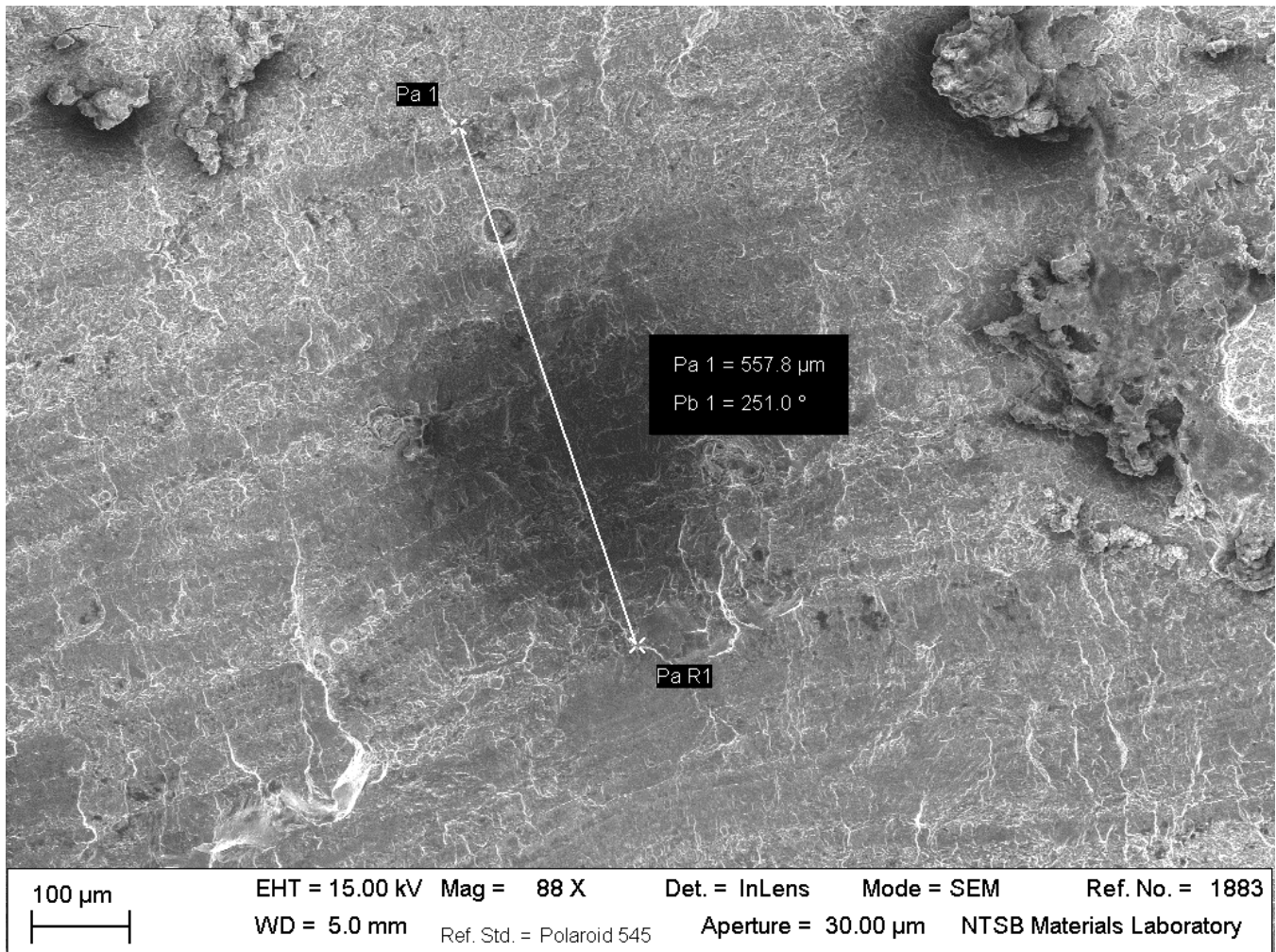


Figure 6 – SE micrograph showing the mixed mode band after fatigue band 4 in Figure 5.

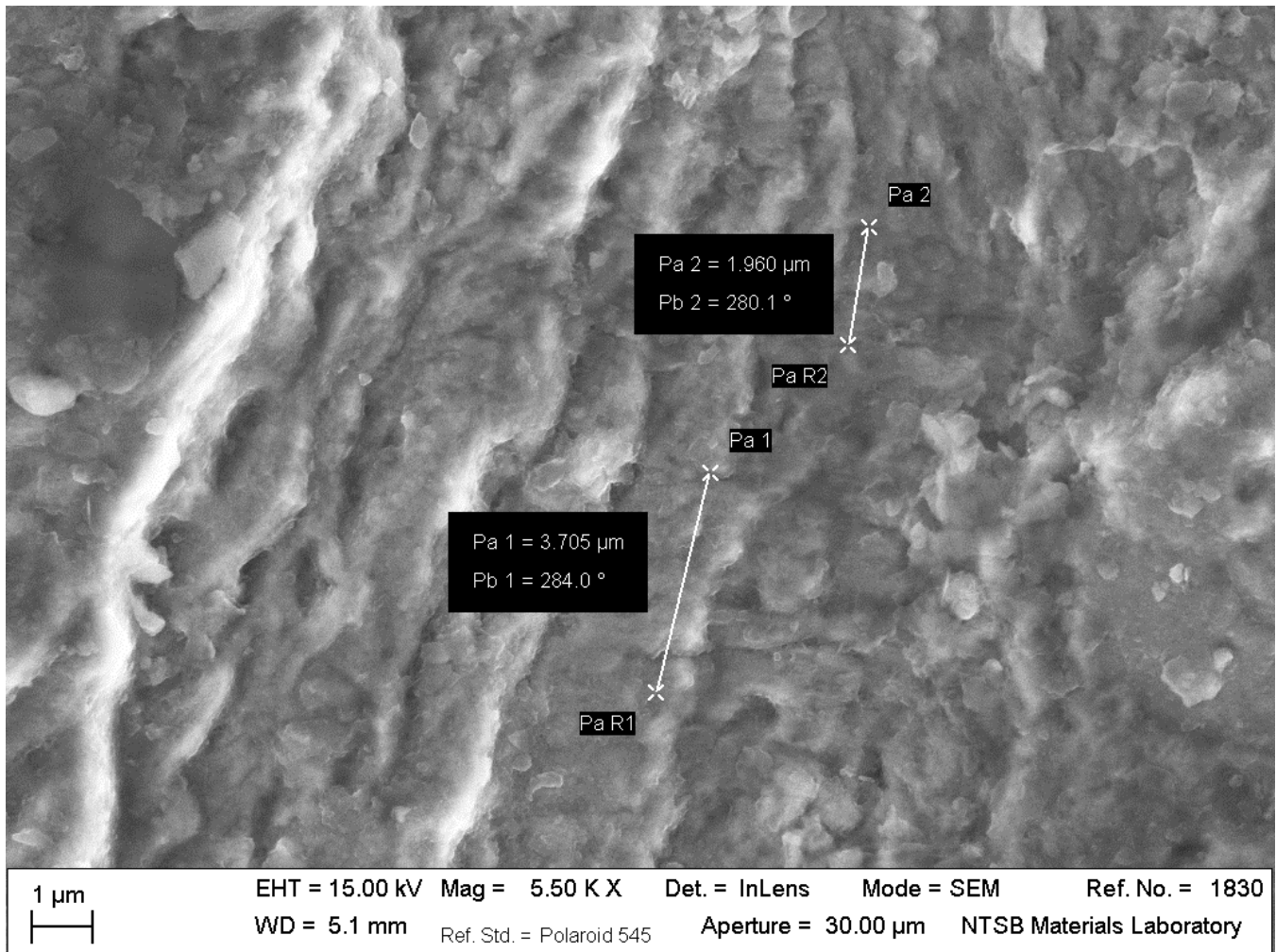


Figure 7 – SE micrograph with striation measurements at site 1 on the fracture surface.

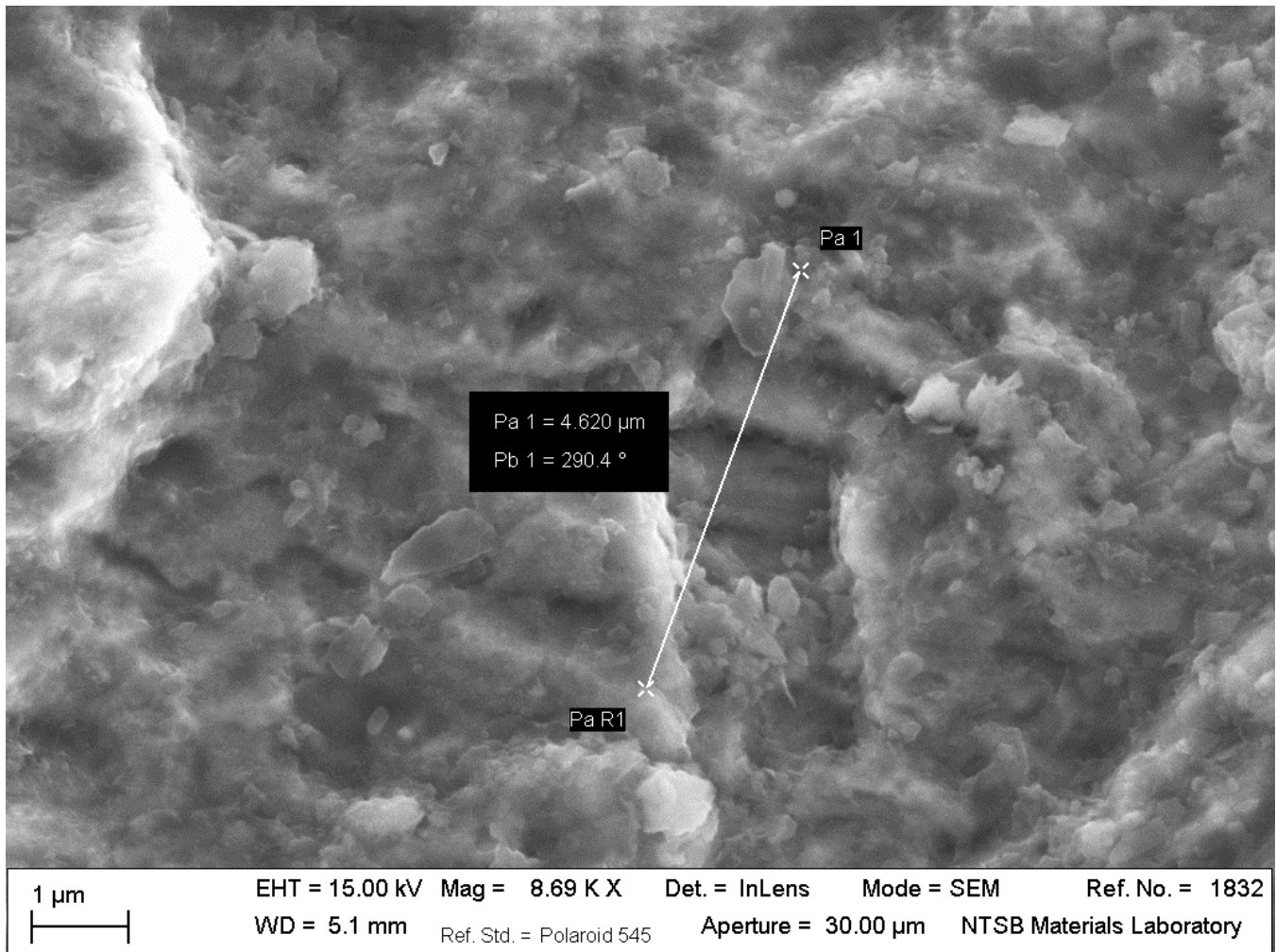


Figure 8 – SE micrograph with striation measurements at site 2 on the fracture surface.

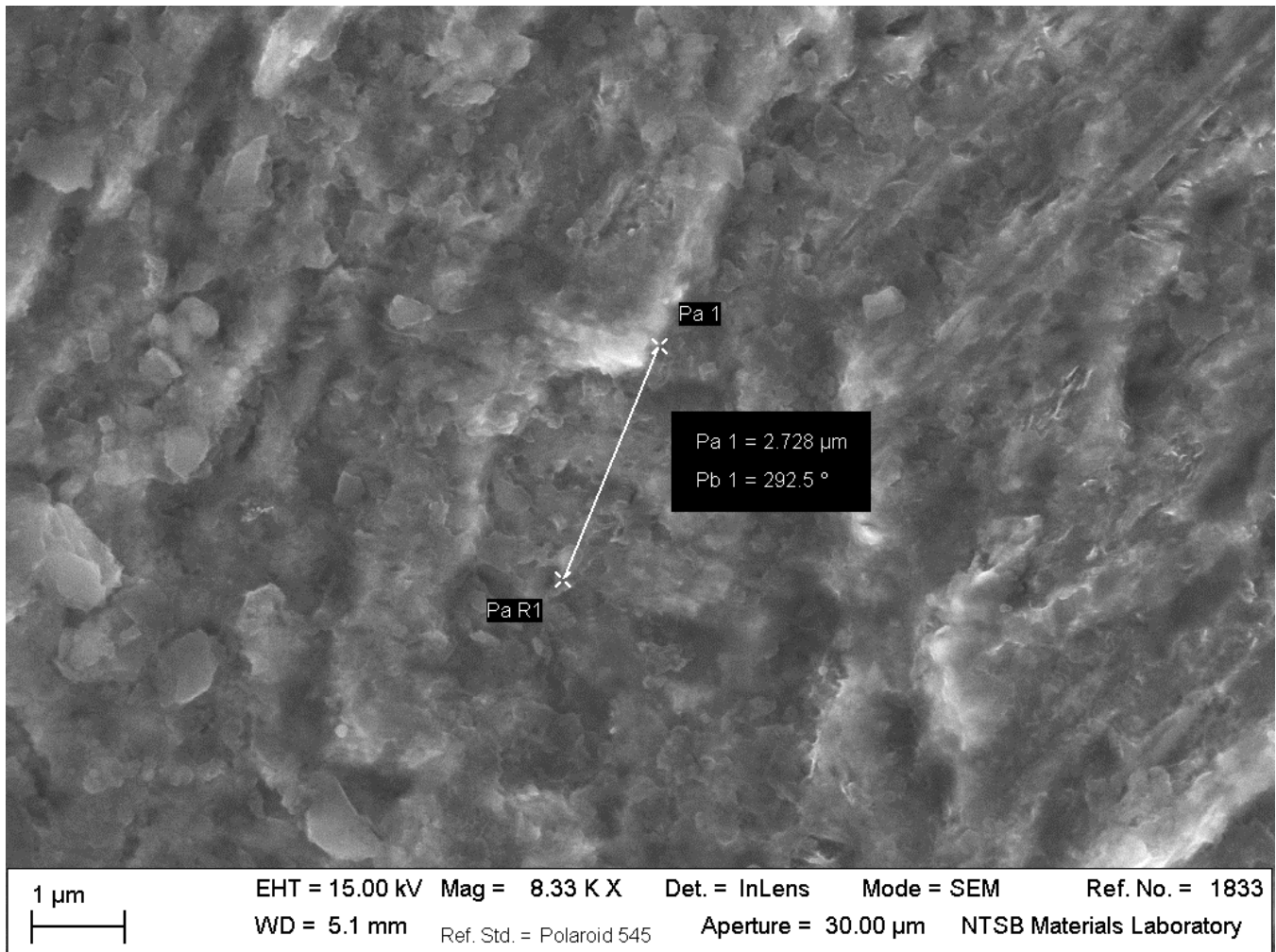


Figure 9 – SE micrograph with striation measurements at site 3 on the fracture surface.

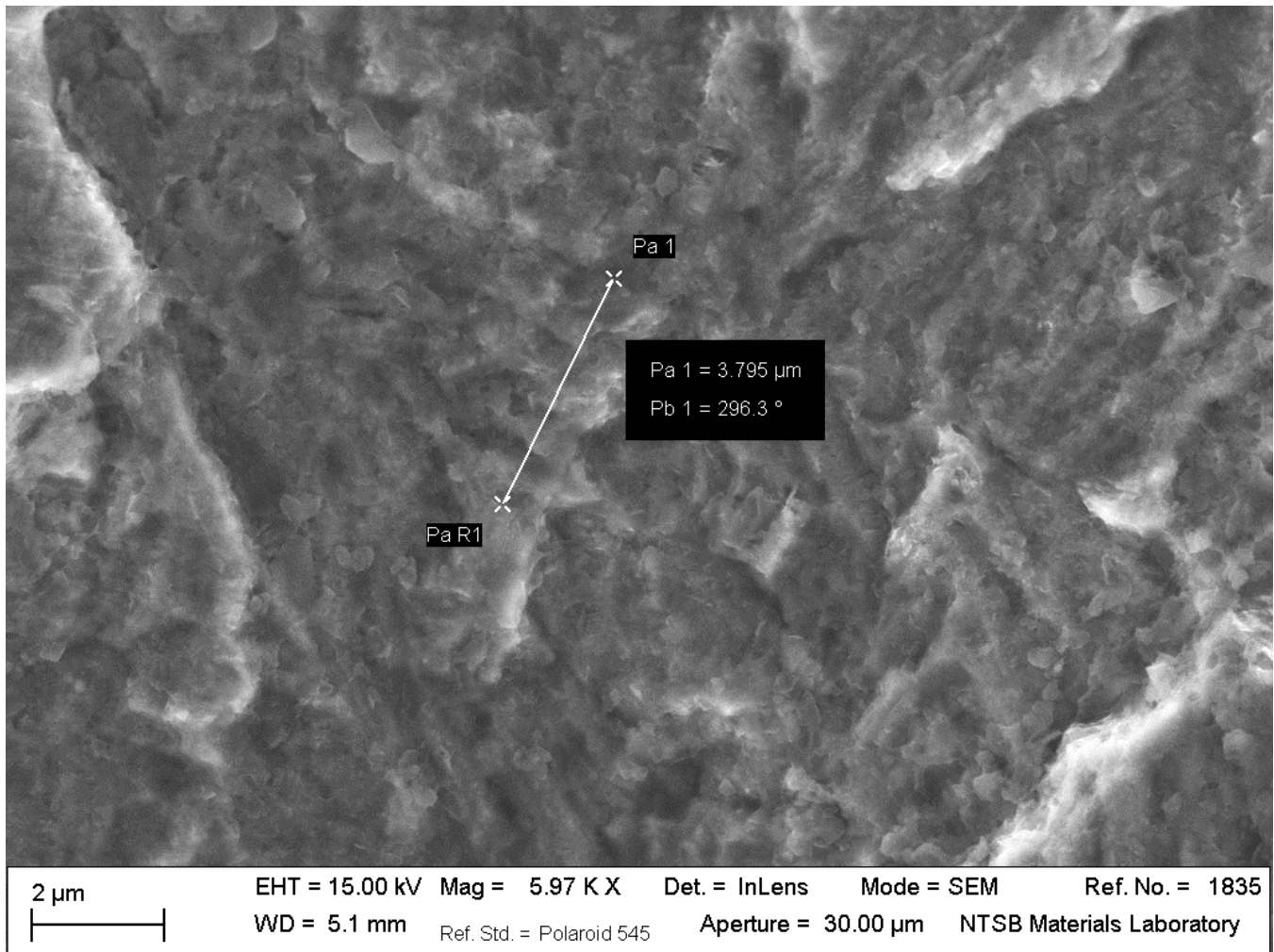


Figure 10 – SE micrograph with striation measurements at site 4 on the fracture surface.

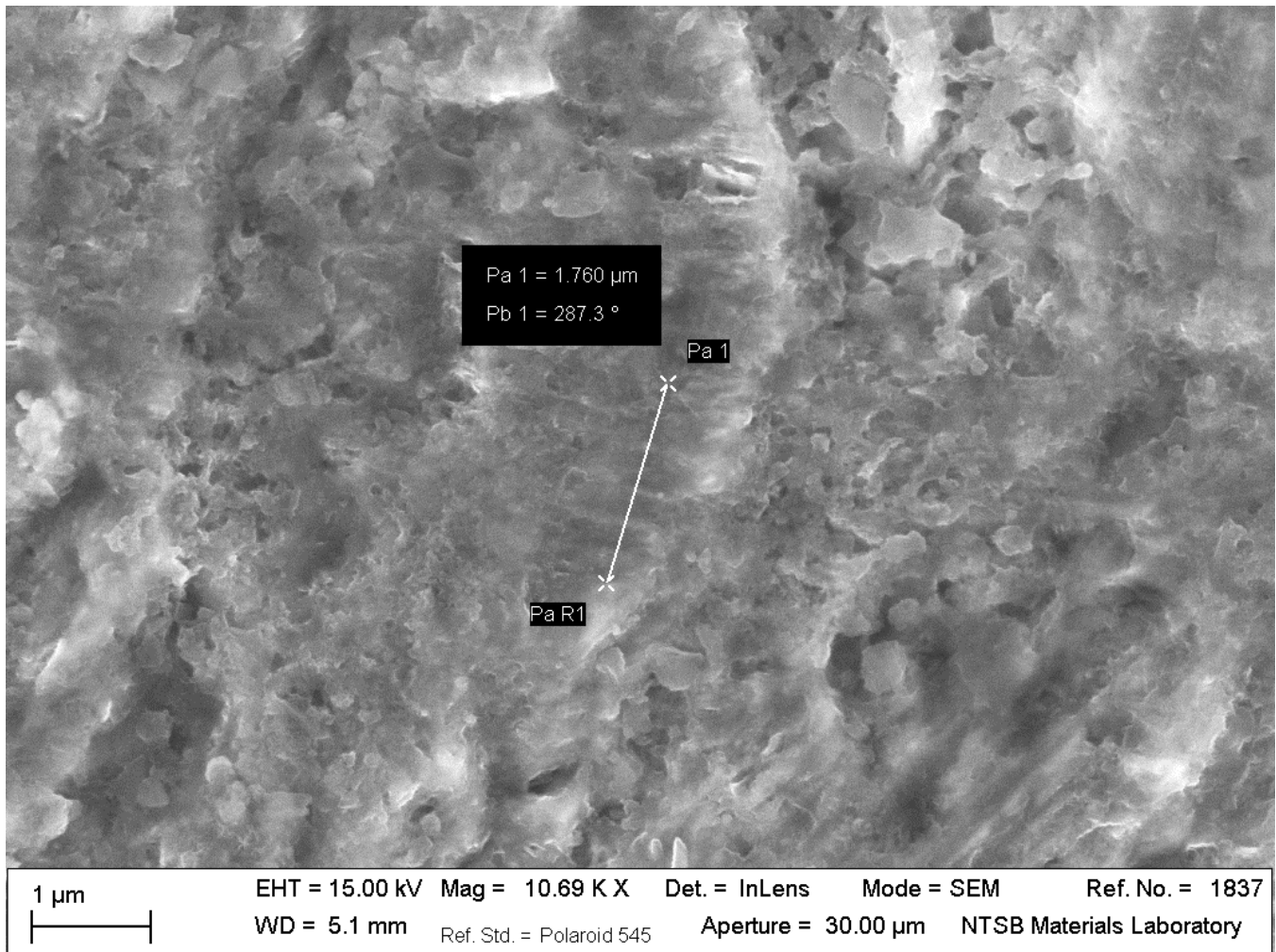


Figure 11 – SE micrograph with striation measurements at site 5 on the fracture surface.

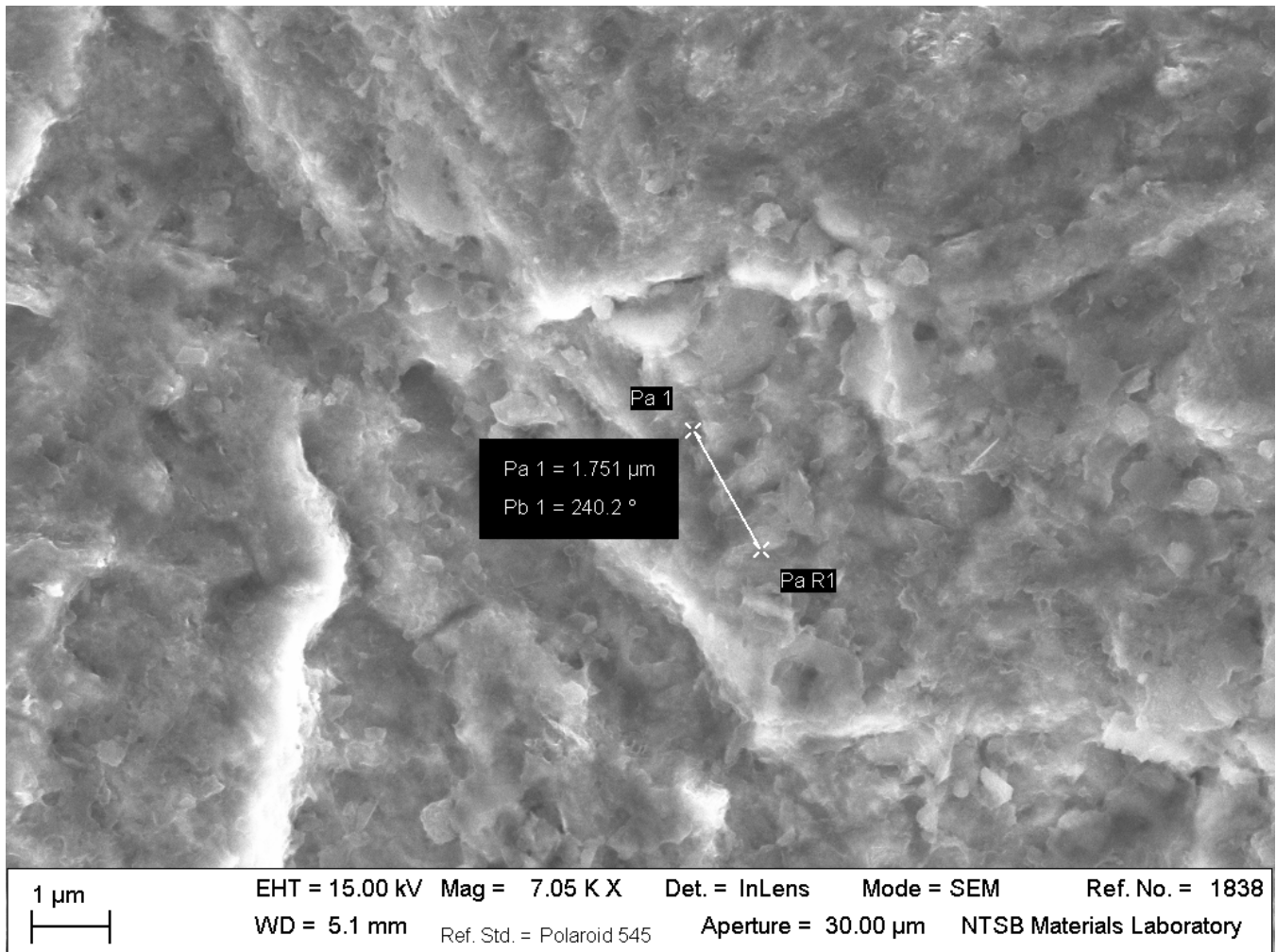


Figure 12 – SE micrograph with striation measurements at site 6 on the fracture surface.

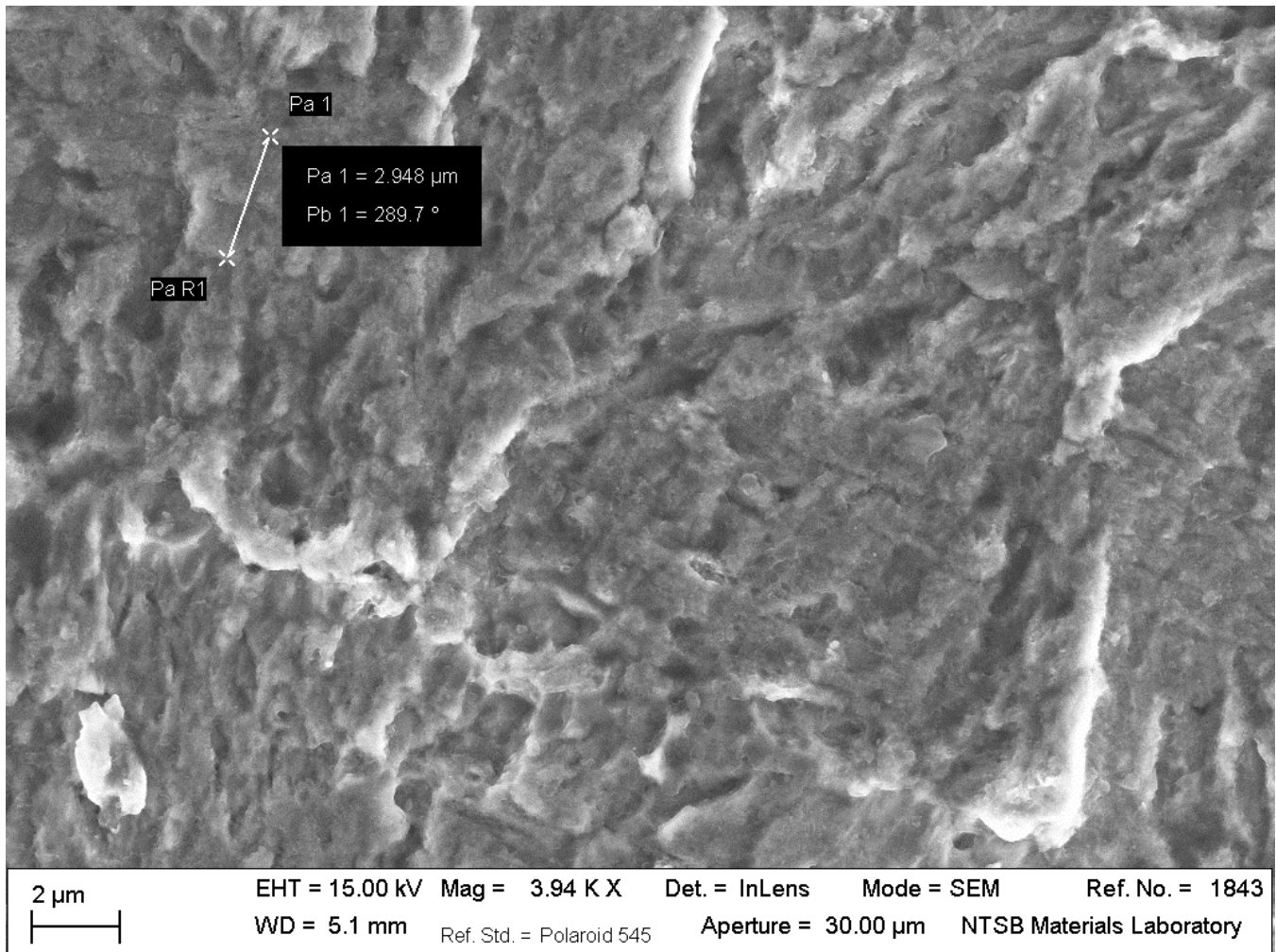


Figure 13 – SE micrograph with striation measurements at site 7 on the fracture surface.

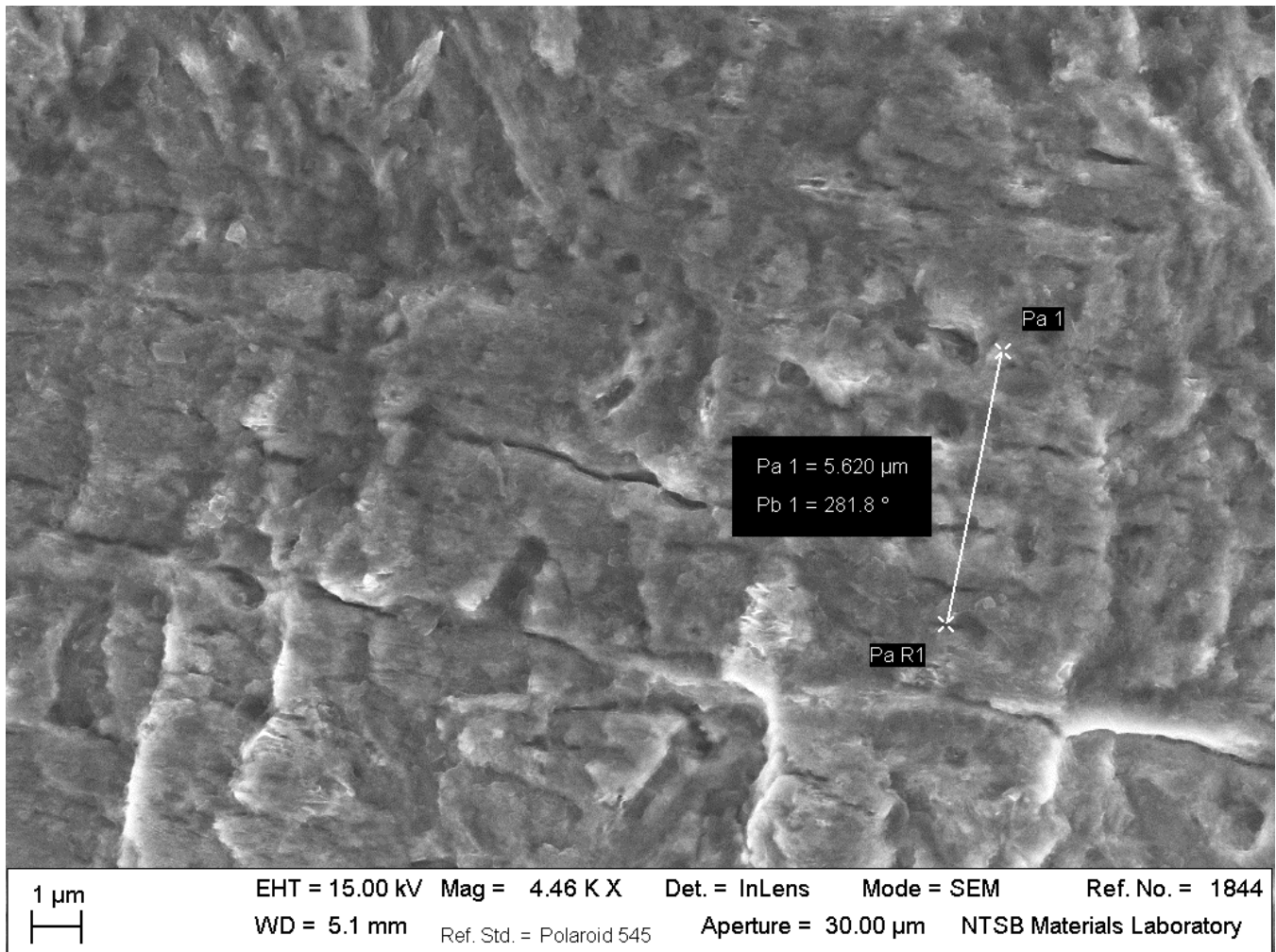


Figure 14 – SE micrograph with striation measurements at site 8 on the fracture surface.

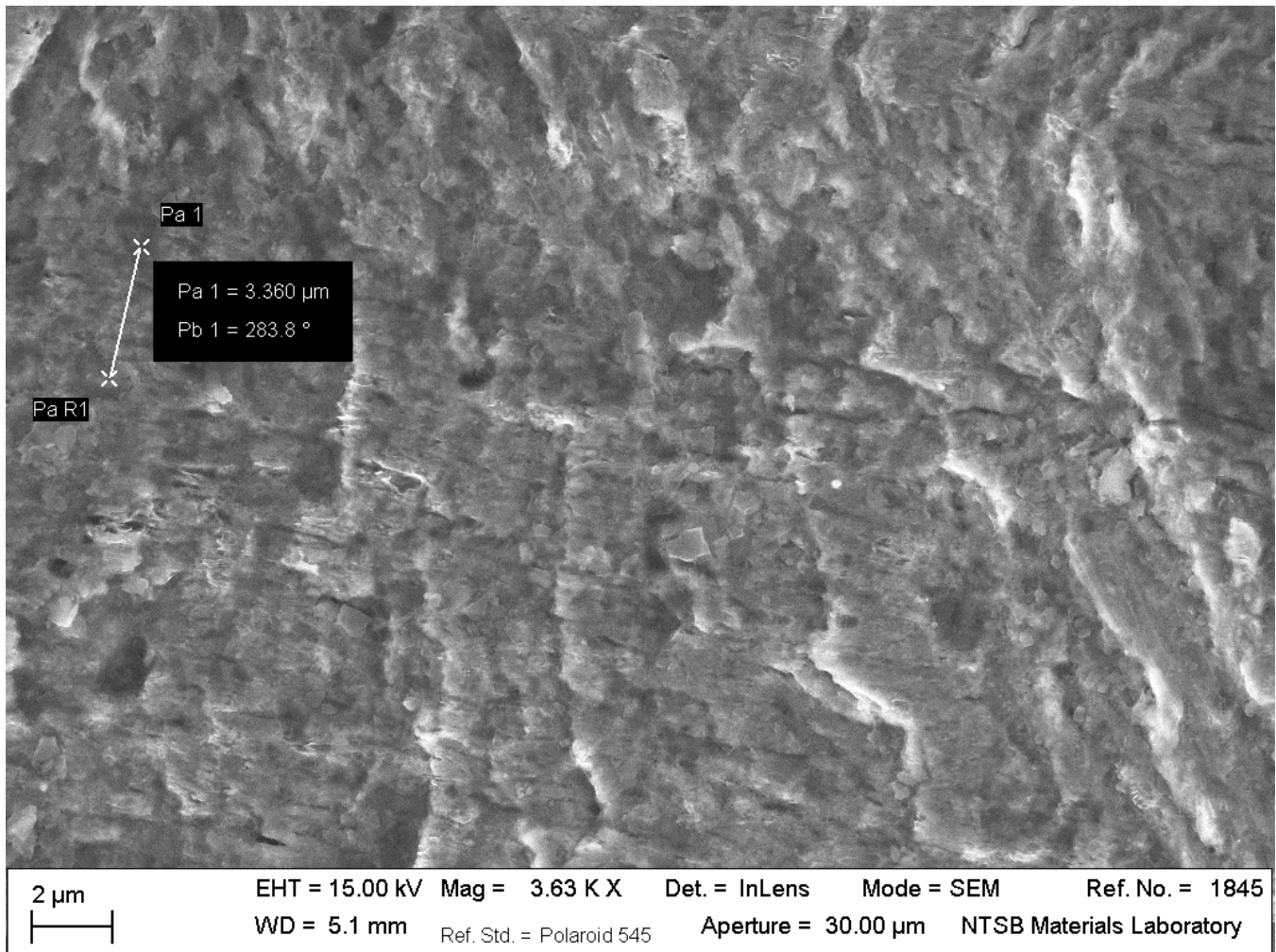


Figure 15 – SE micrograph with striation measurements at site 9 on the fracture surface.

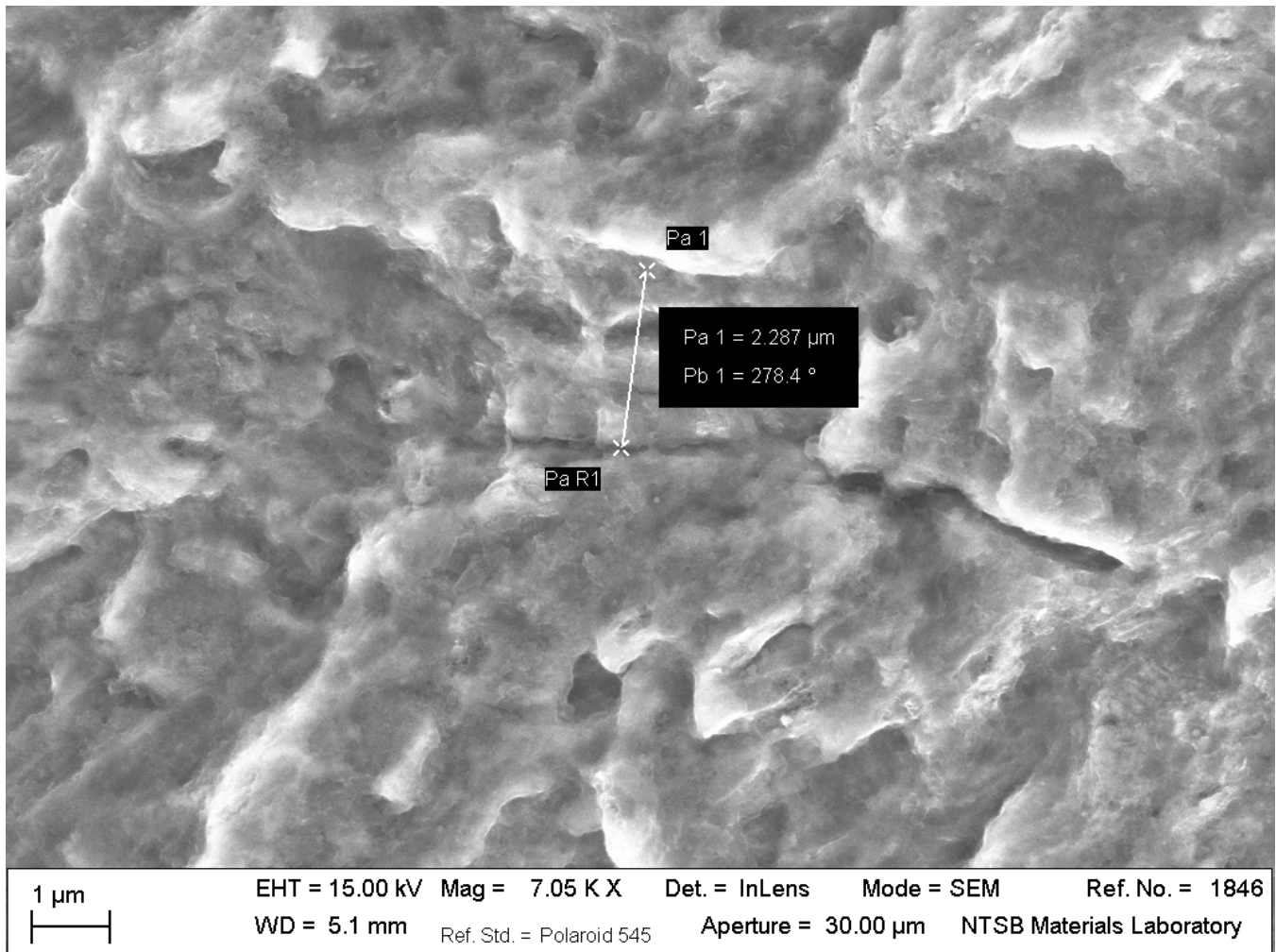


Figure 16 – SE micrograph with striation measurements at site 10 on the fracture surface.

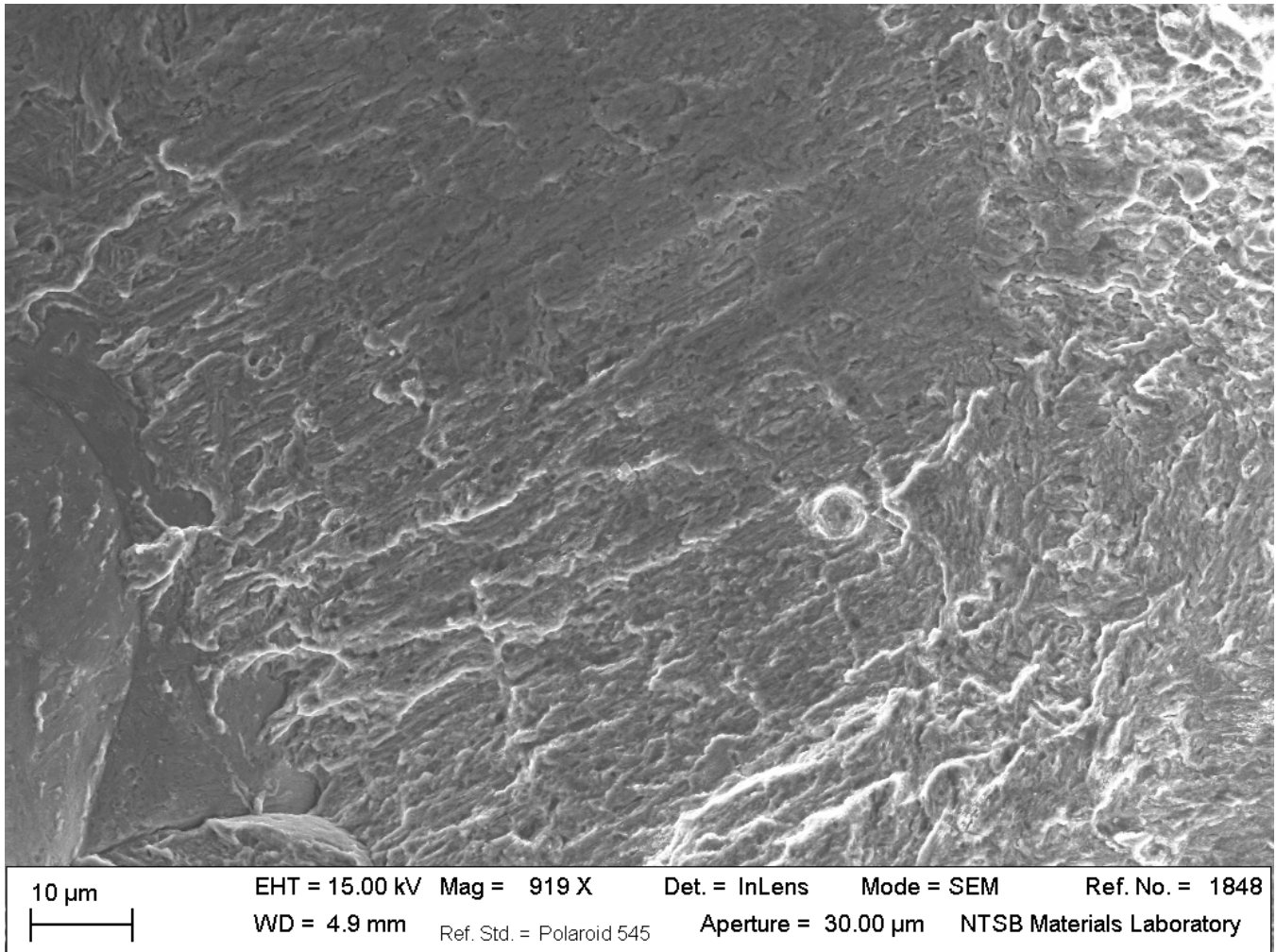


Figure 17 – SE micrograph with striation measurements at site 11 on the fracture surface.

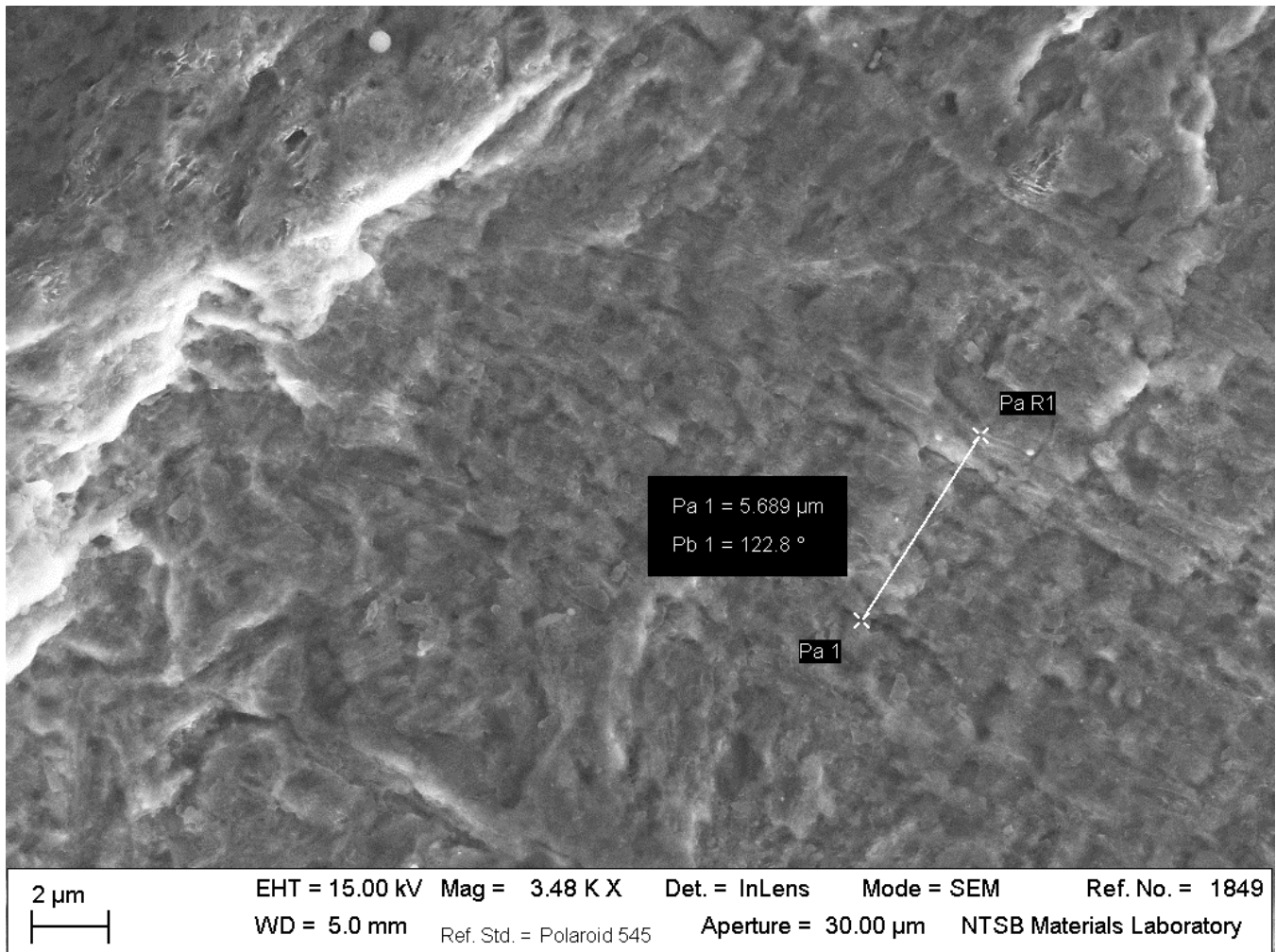


Figure 18 – SE micrograph with striation measurements at site 12 on the fracture surface.

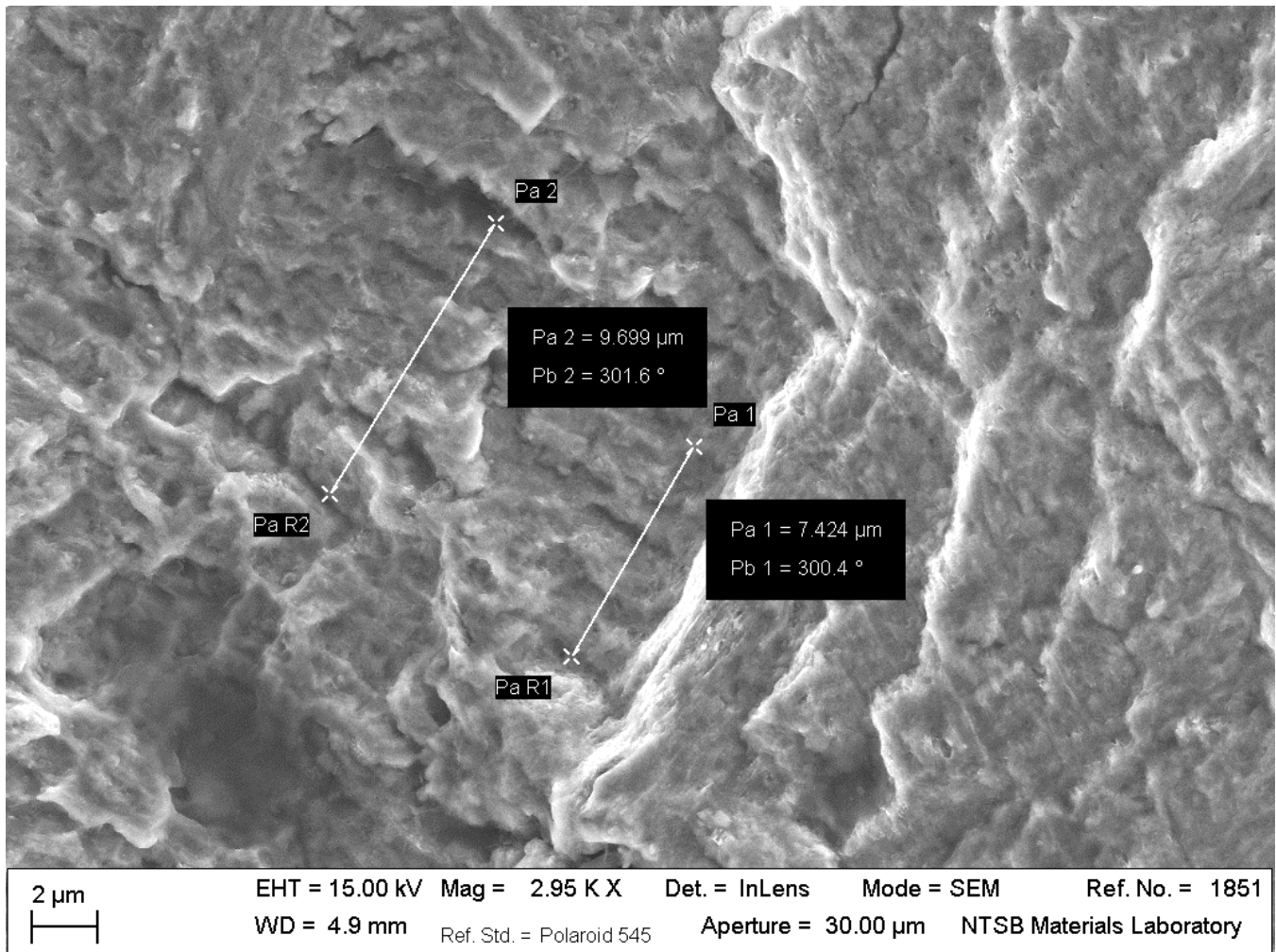


Figure 19 – SE micrograph with striation measurements at site 13 on the fracture surface.

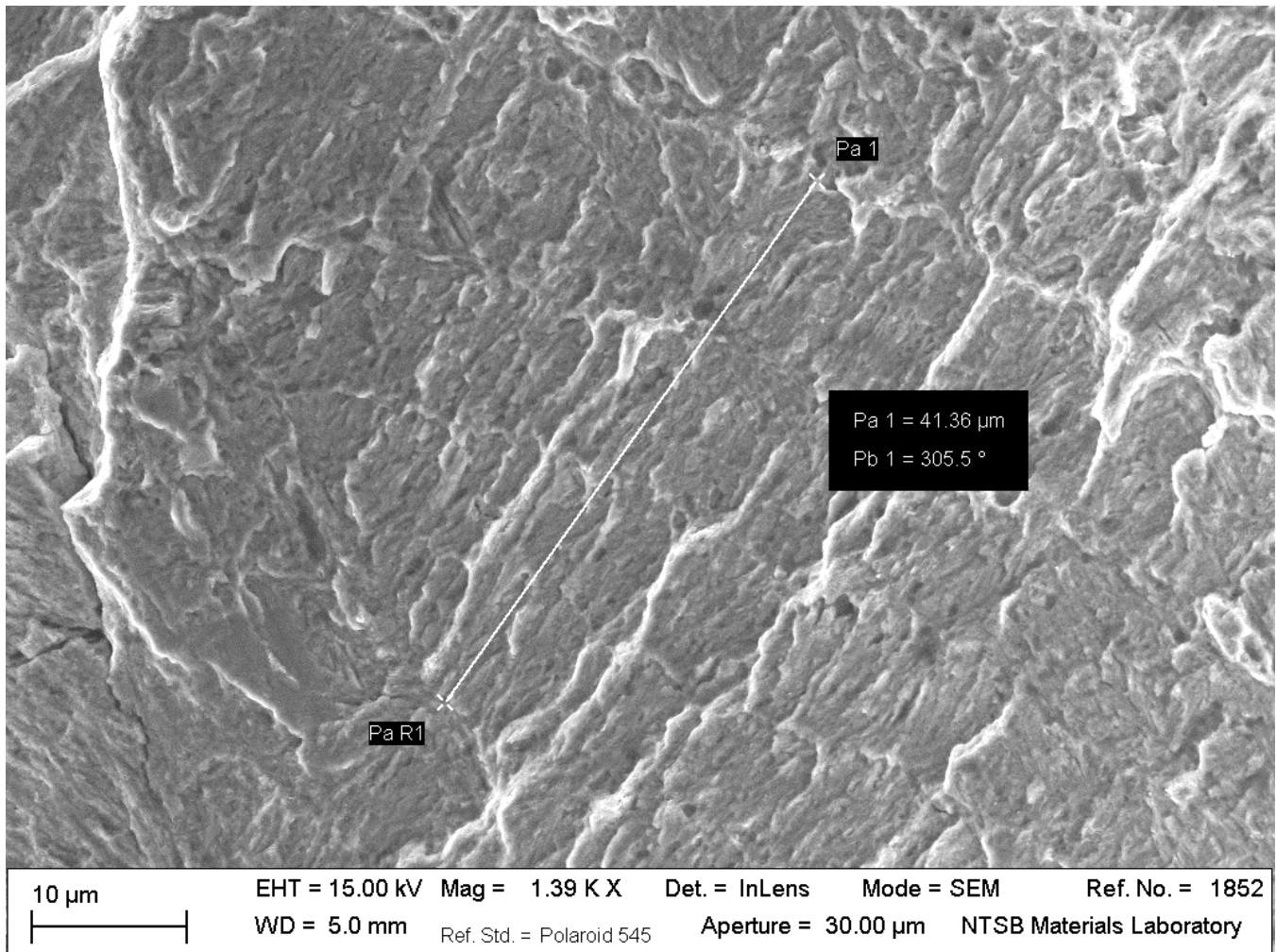


Figure 20 – SE micrograph with striation measurements at site 14 on the fracture surface.

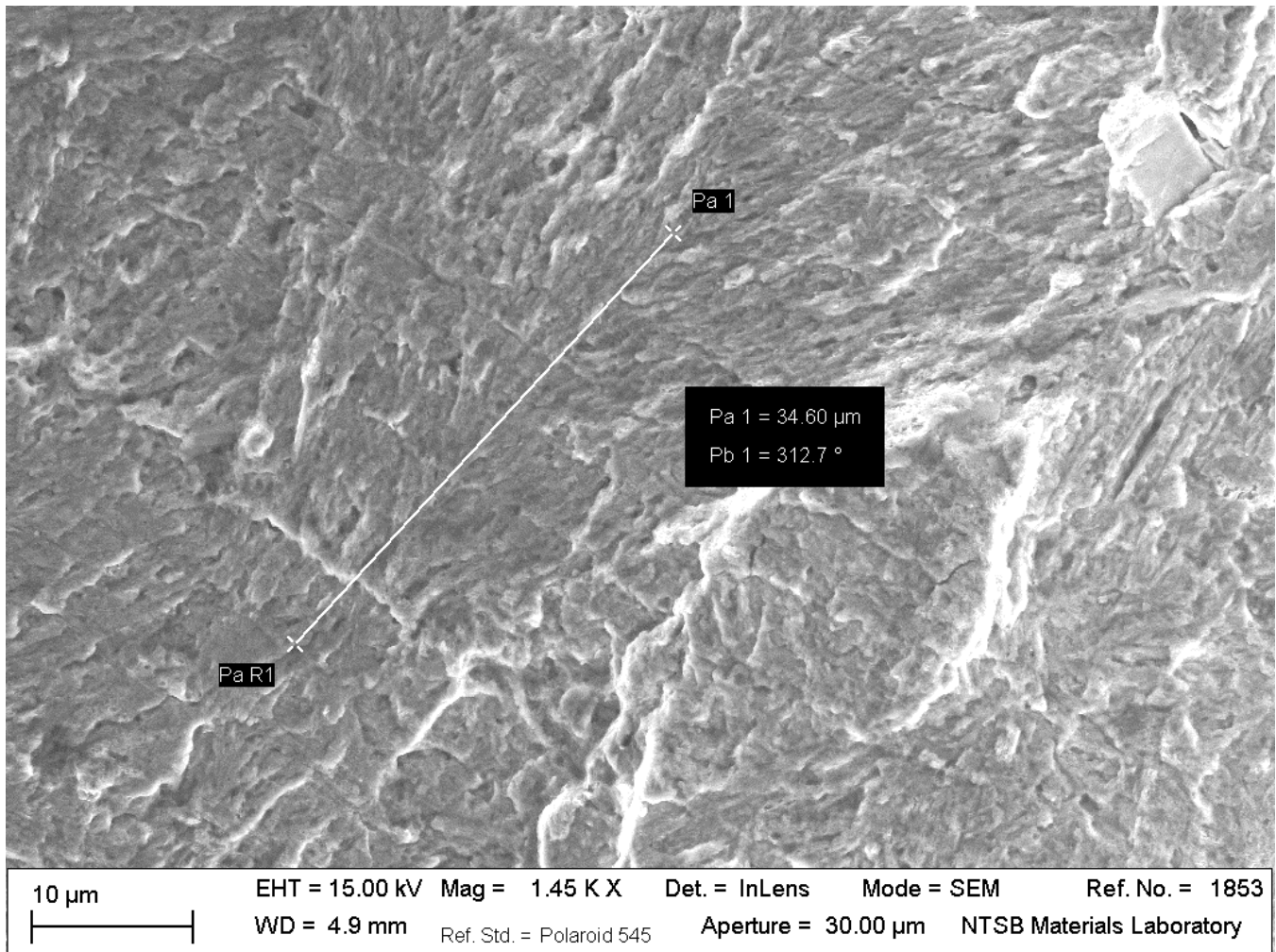


Figure 21 – SE micrograph with striation measurements at site 15 on the fracture surface.

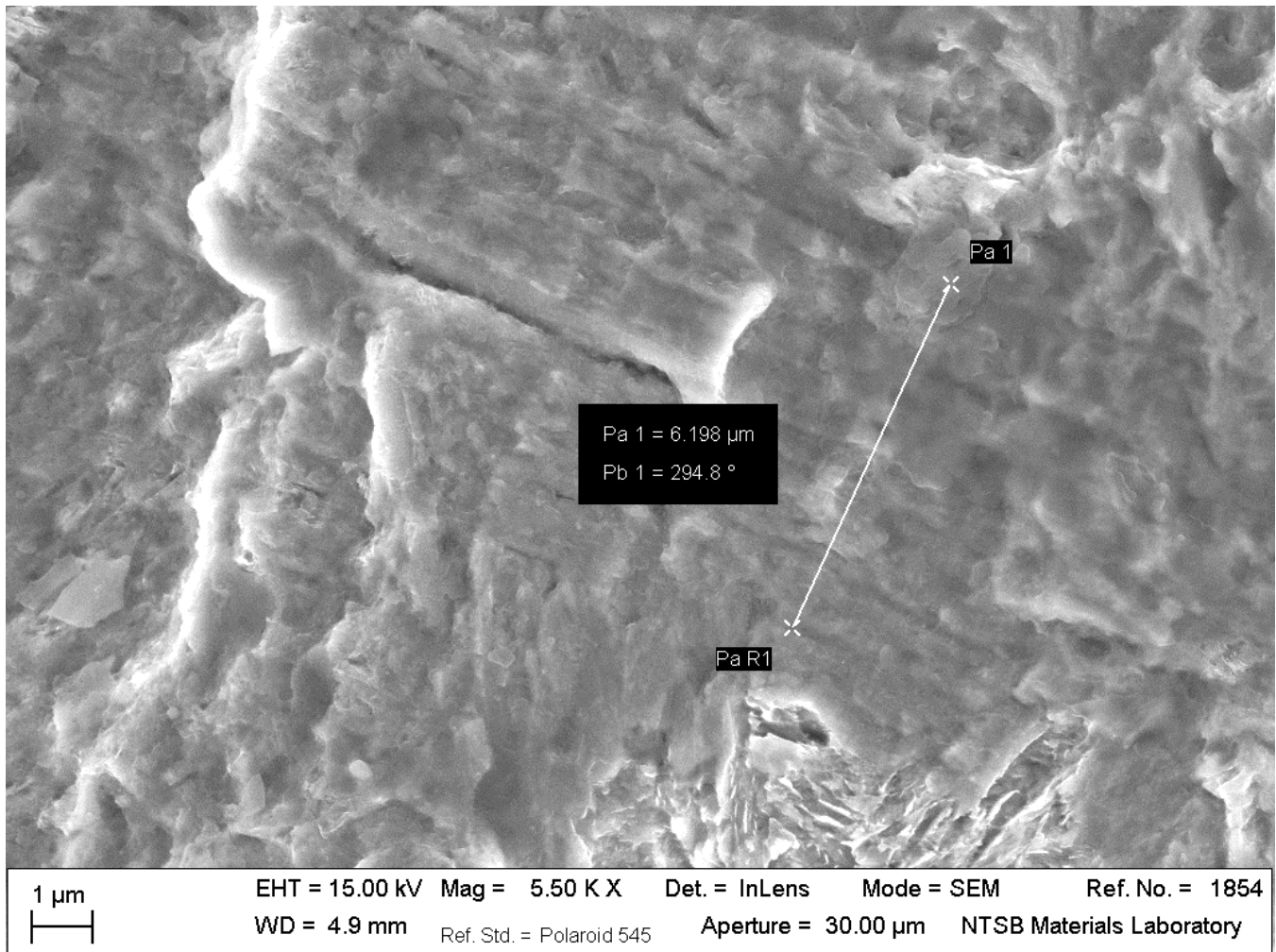


Figure 22 – SE micrograph with striation measurements at site 16 on the fracture surface.

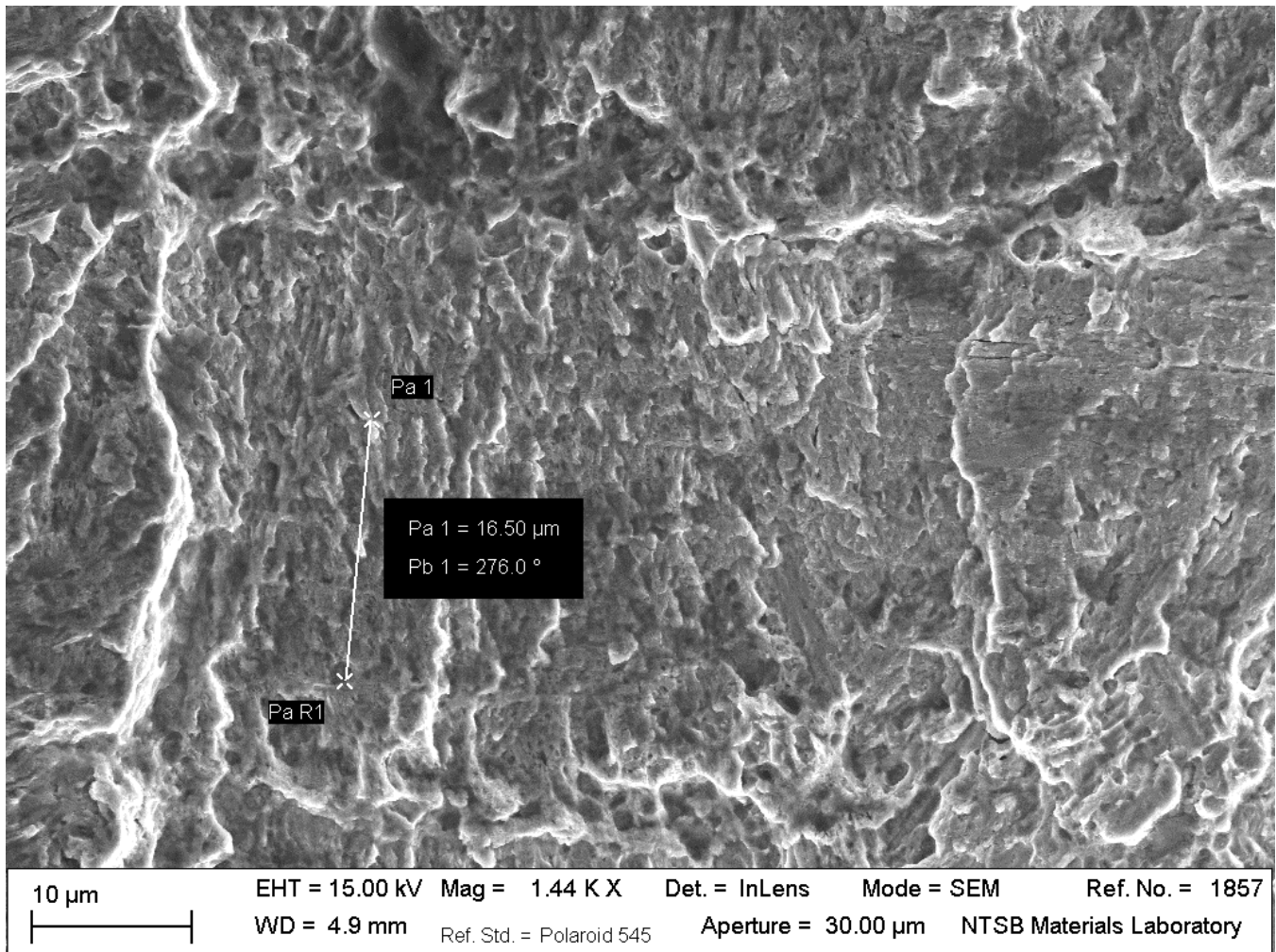


Figure 23 – SE micrograph with striation measurements at site 17 on the fracture surface.

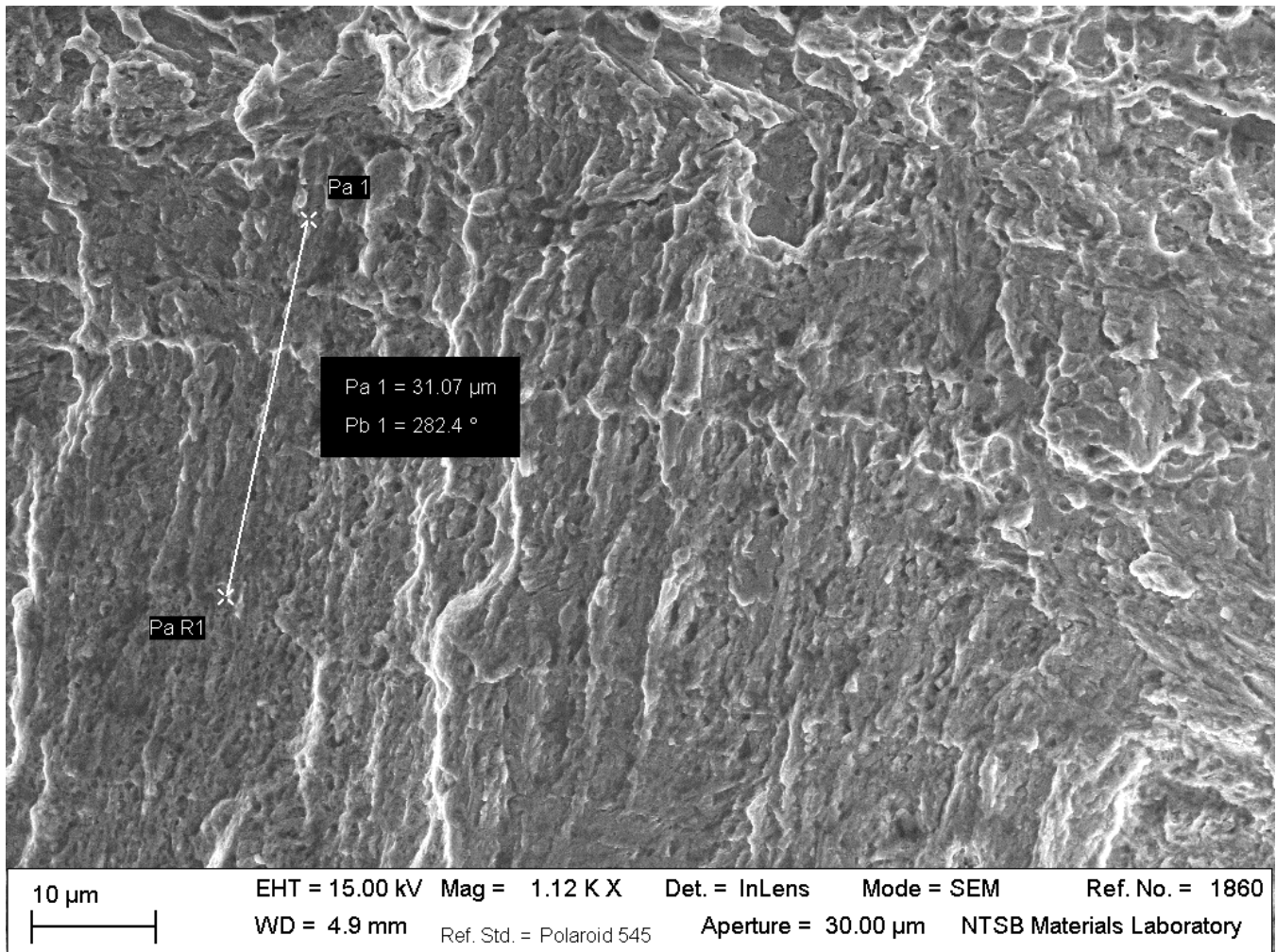


Figure 24 – SE micrograph with striation measurements at site 18 on the fracture surface.

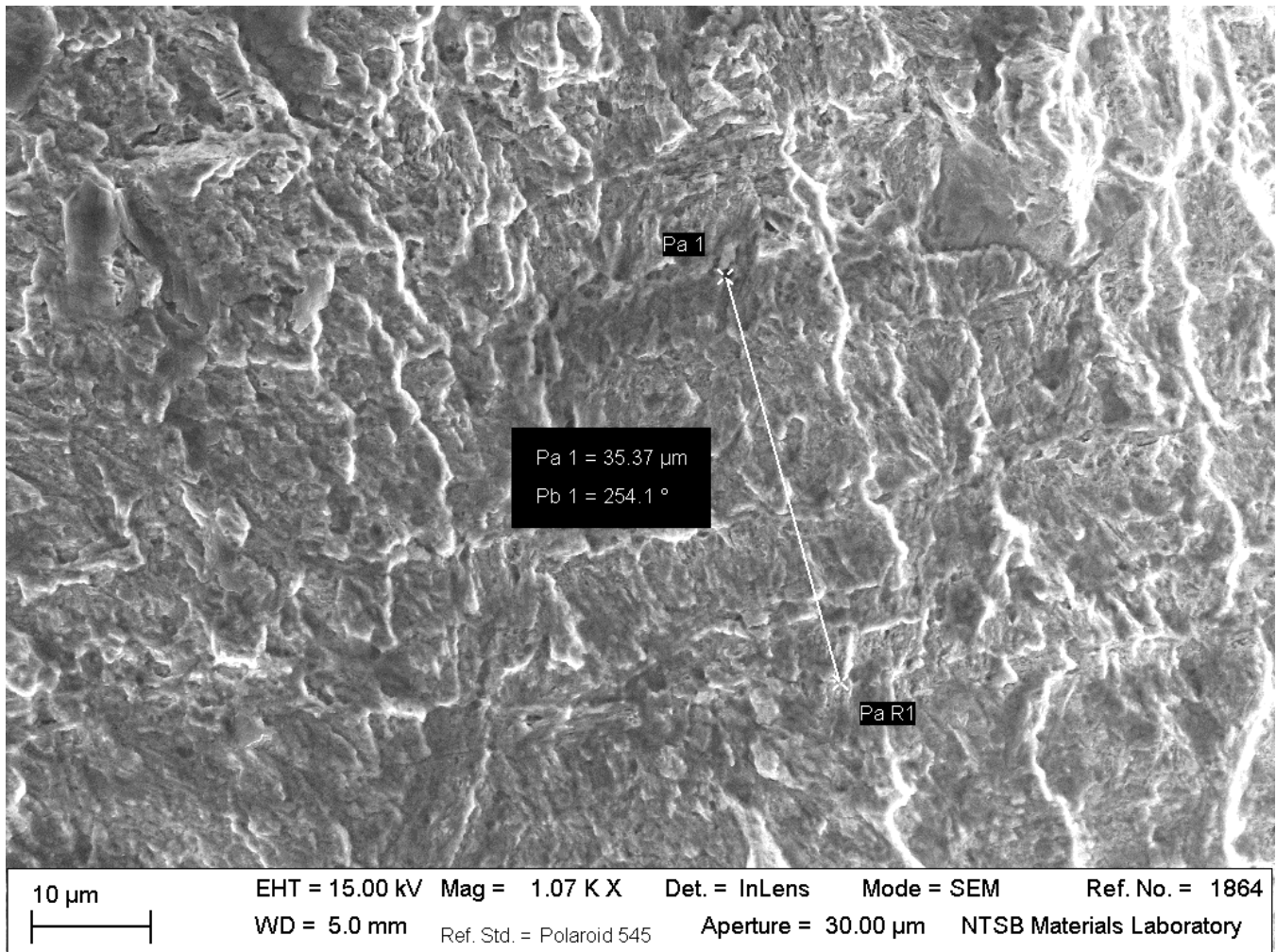


Figure 25 – SE micrograph with striation measurements at site 19 on the fracture surface.

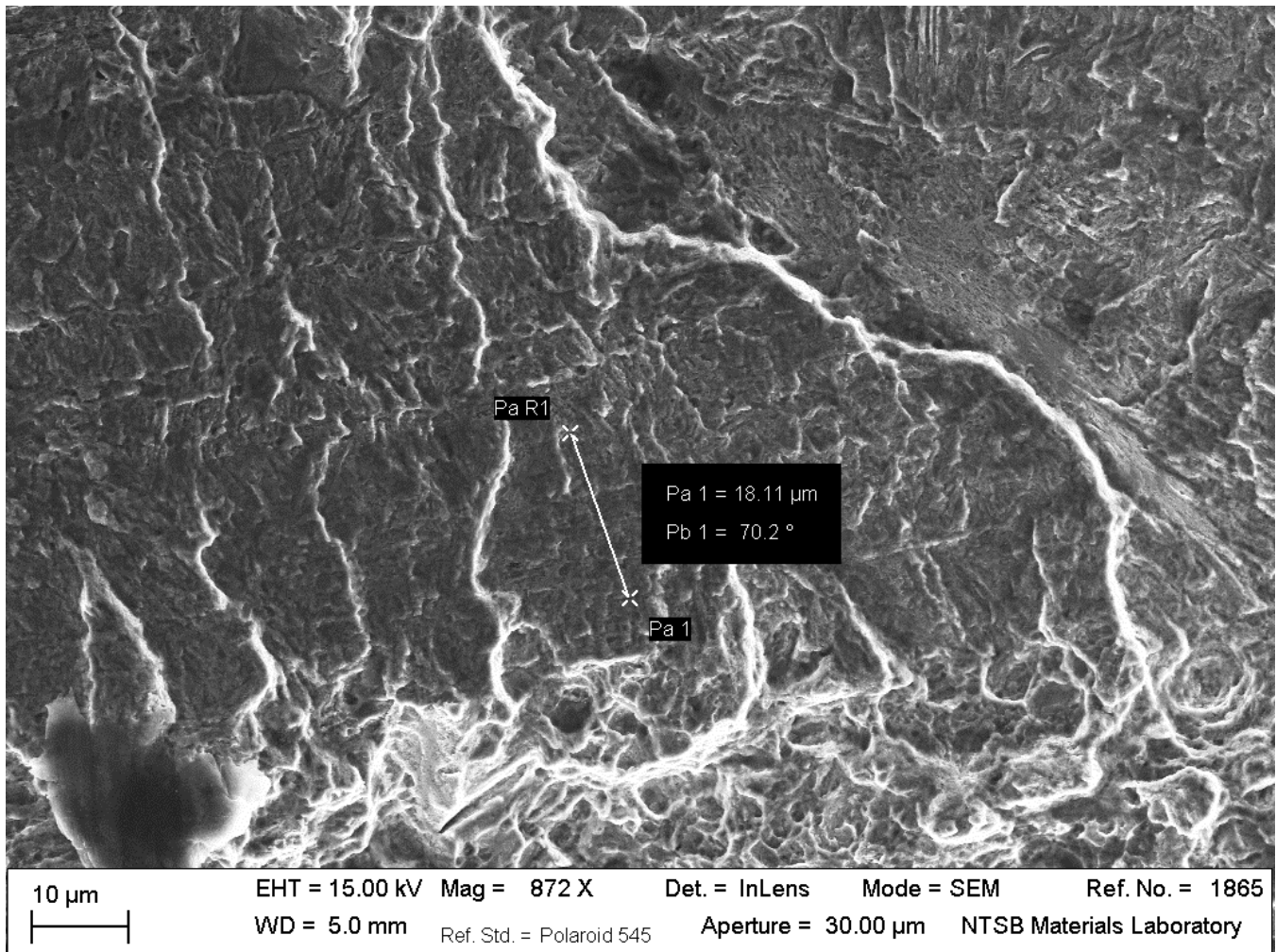


Figure 26 – SE micrograph with striation measurements at site 20 on the fracture surface.

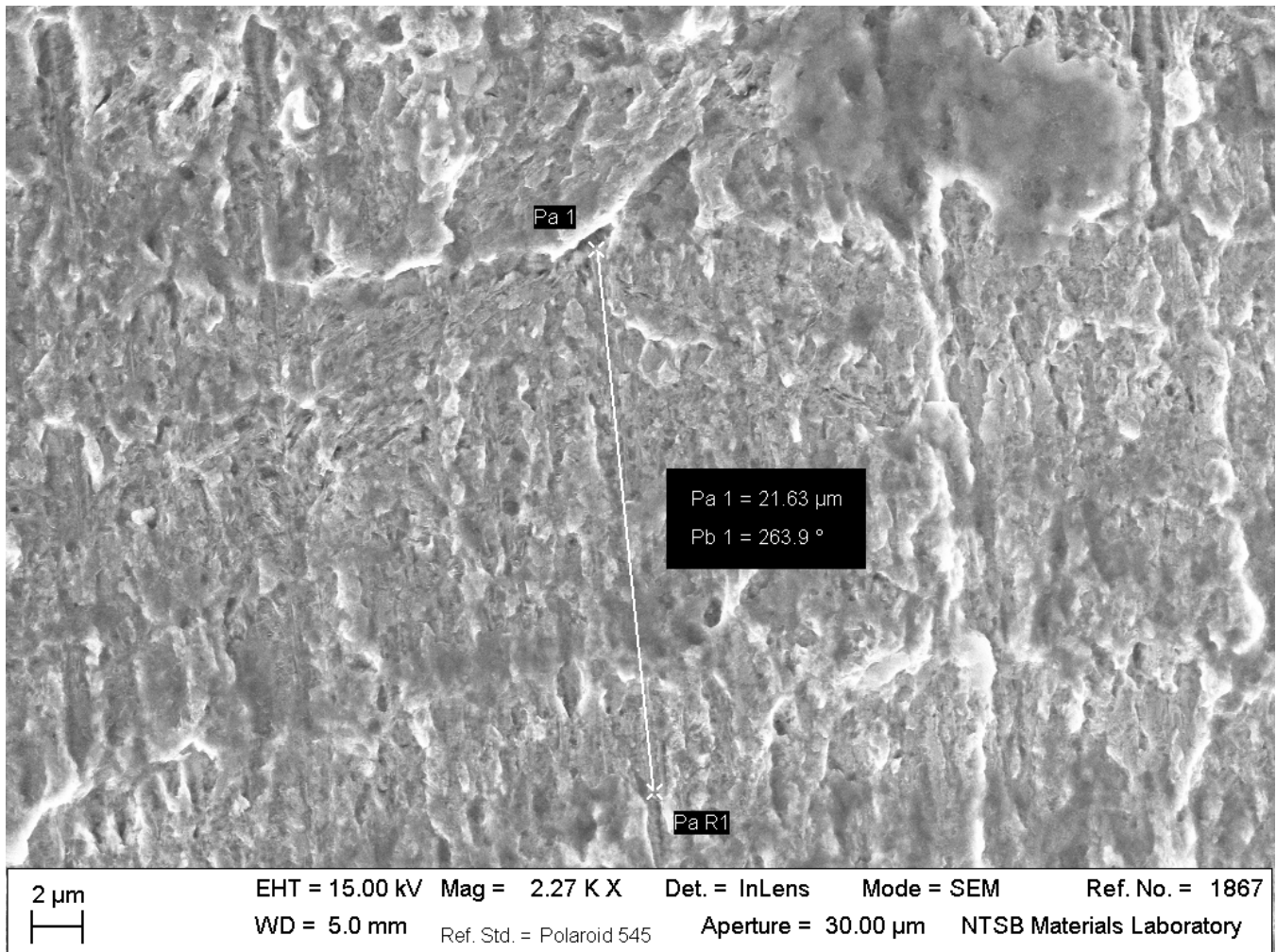


Figure 27 – SE micrograph with striation measurements at site 21 on the fracture surface.

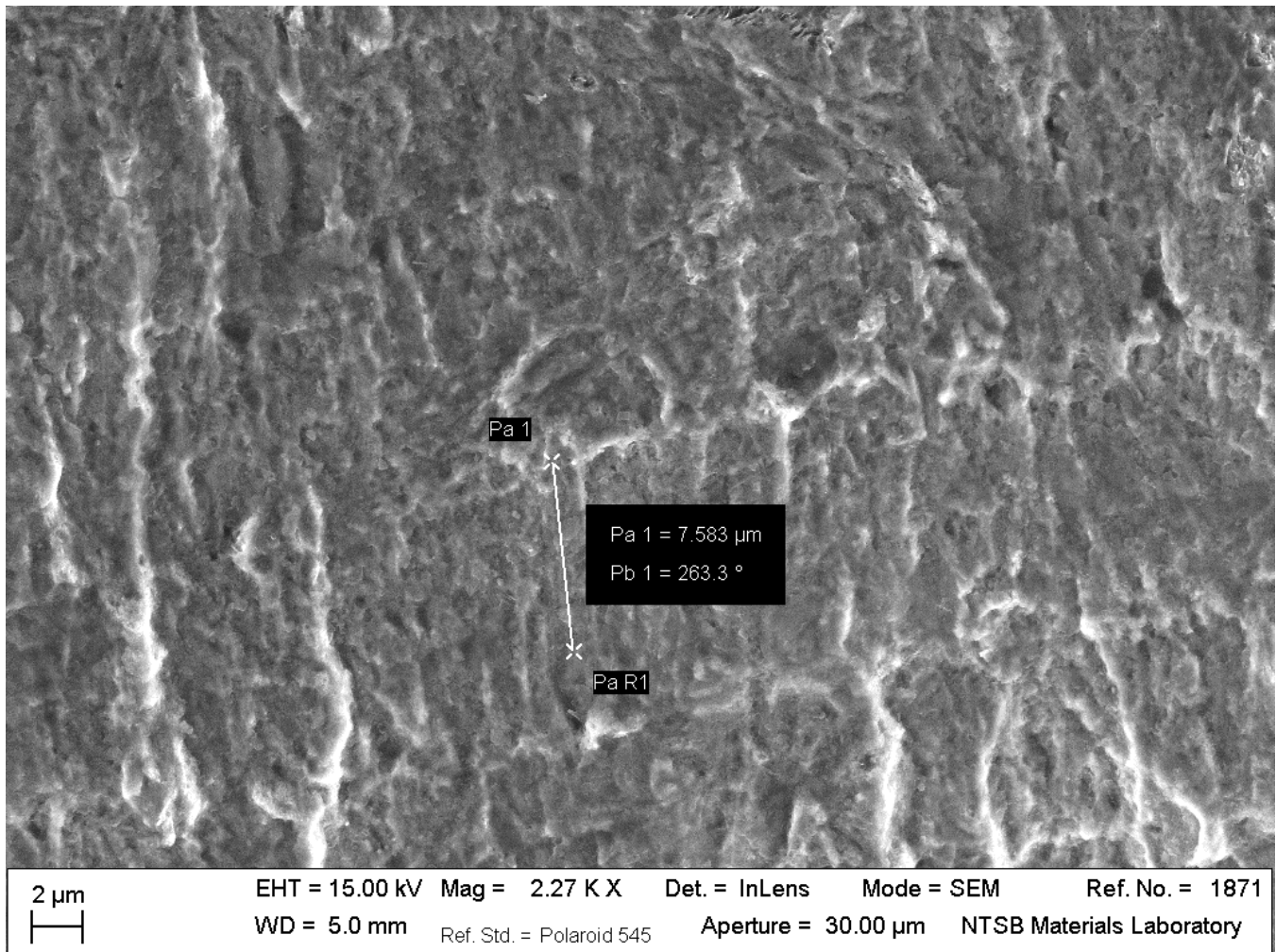


Figure 28 – SE micrograph with striation measurements at site 22 on the fracture surface.

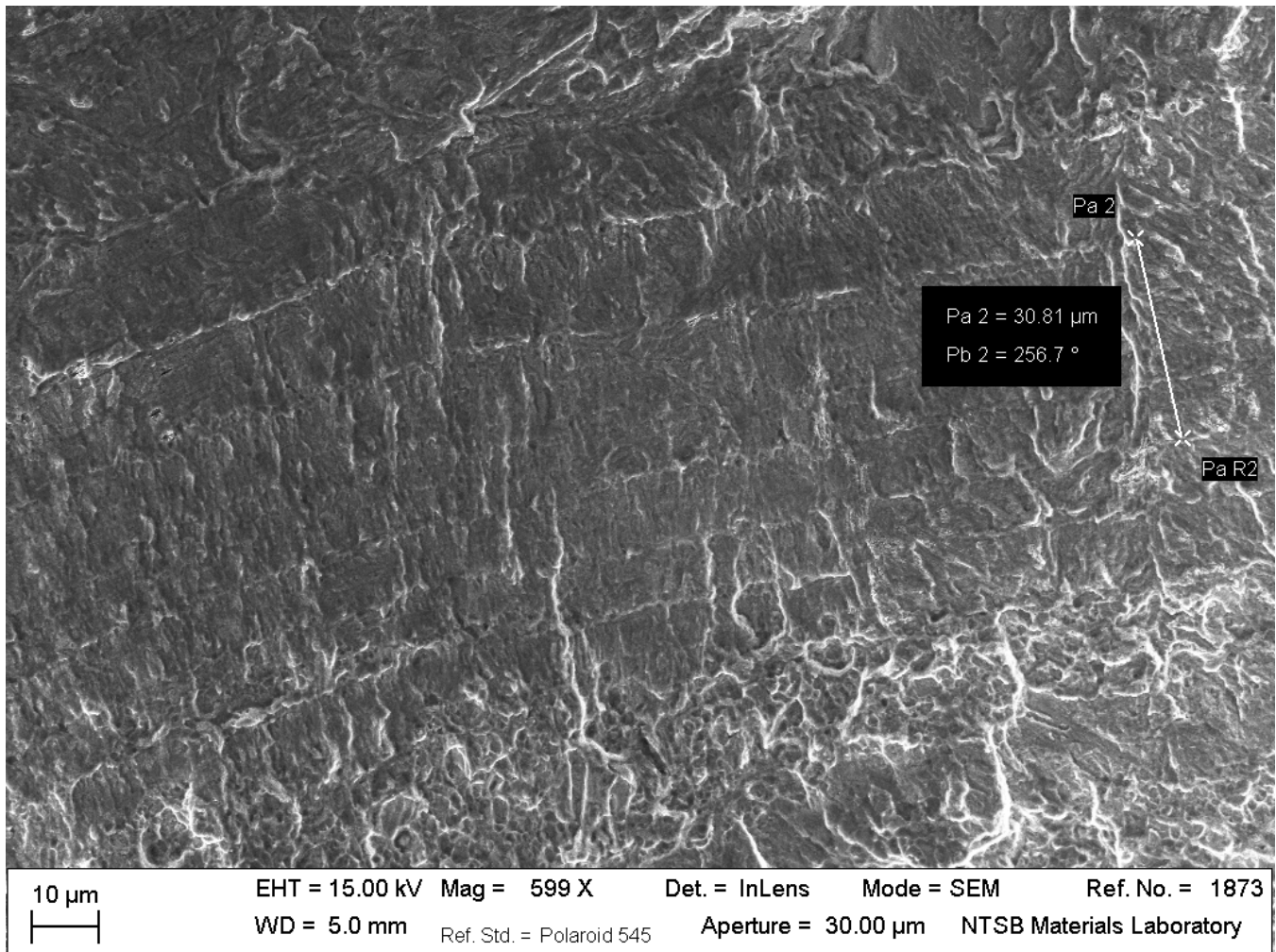


Figure 29 – SE micrograph with striation measurements at site 23 on the fracture surface.

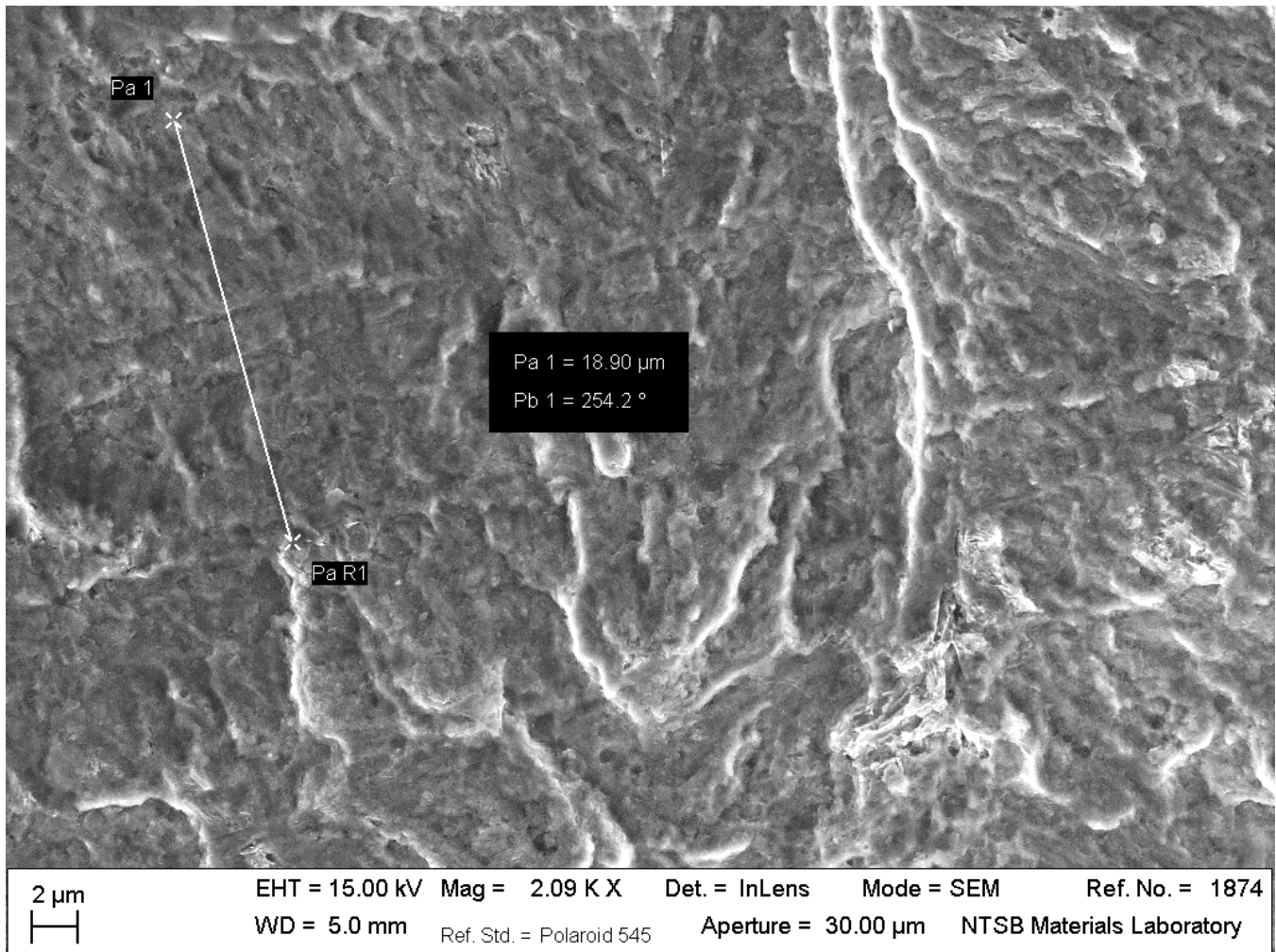


Figure 30 – SE micrograph with striation measurements at site 23a on the fracture surface.

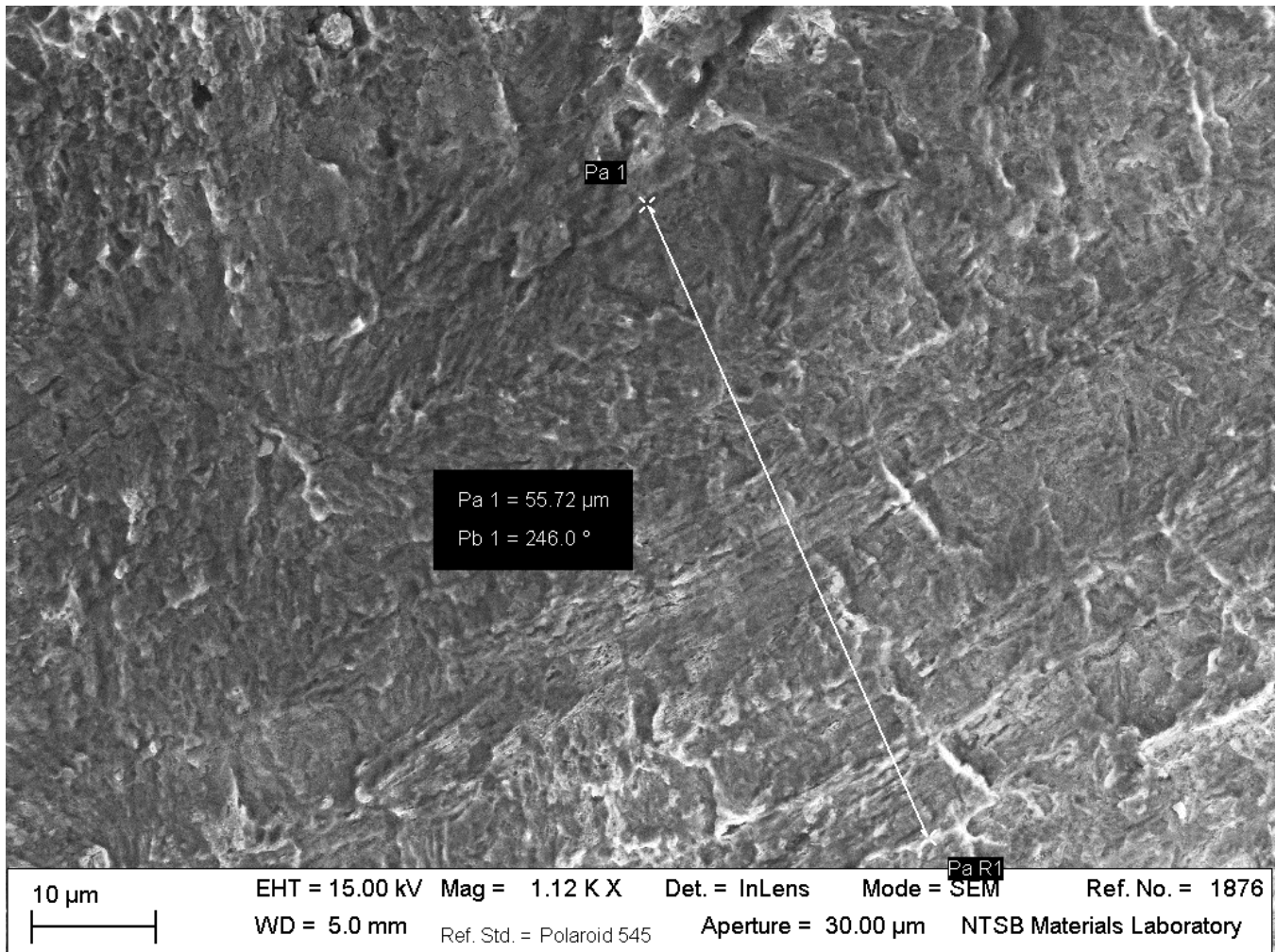


Figure 31 – SE micrograph with striation measurements at site 24 on the fracture surface.

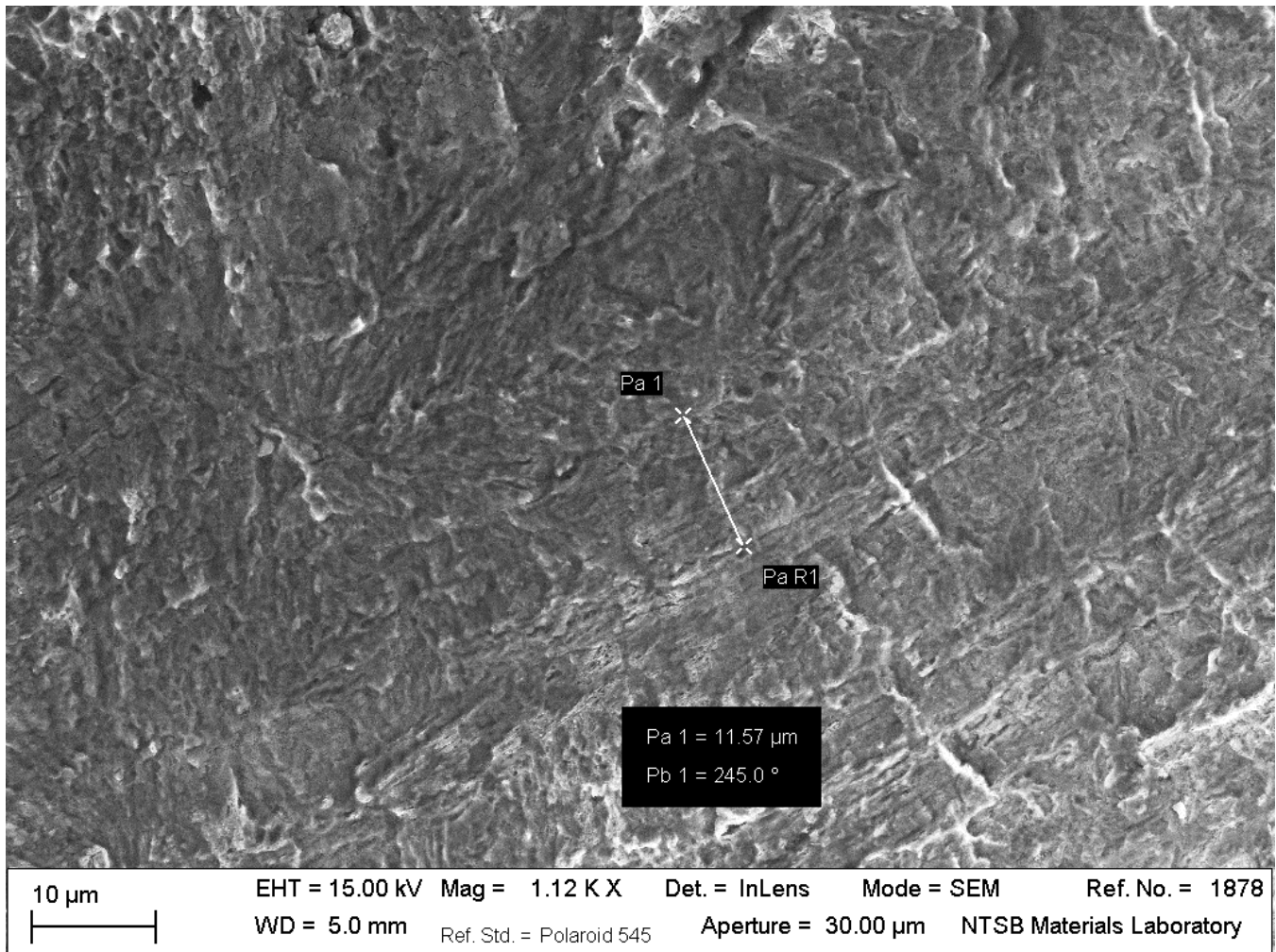


Figure 32 – SE micrograph with striation measurements at site 24a on the fracture surface.

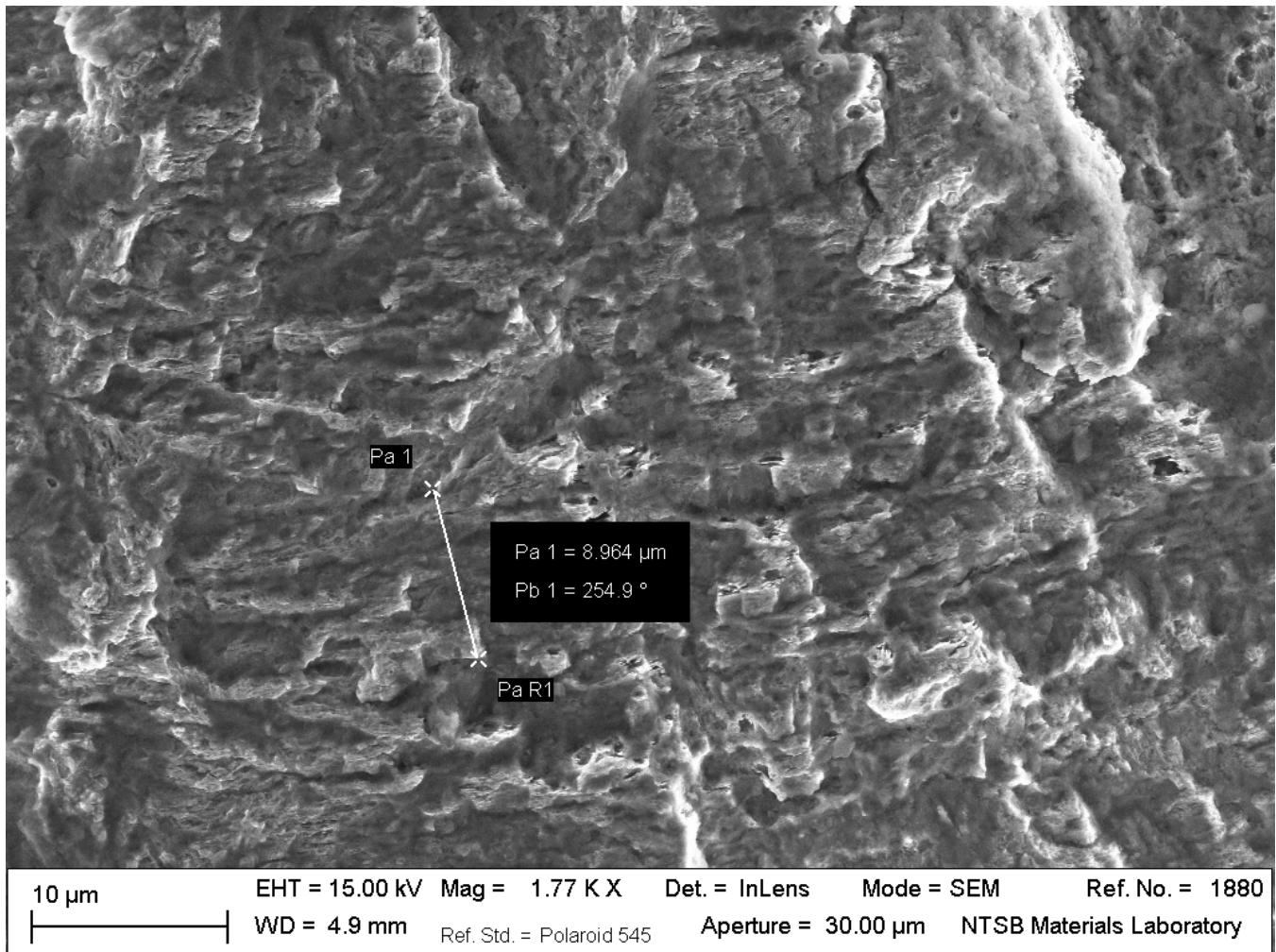


Figure 33 – SE micrograph with striation measurements at site 25 on the fracture surface.

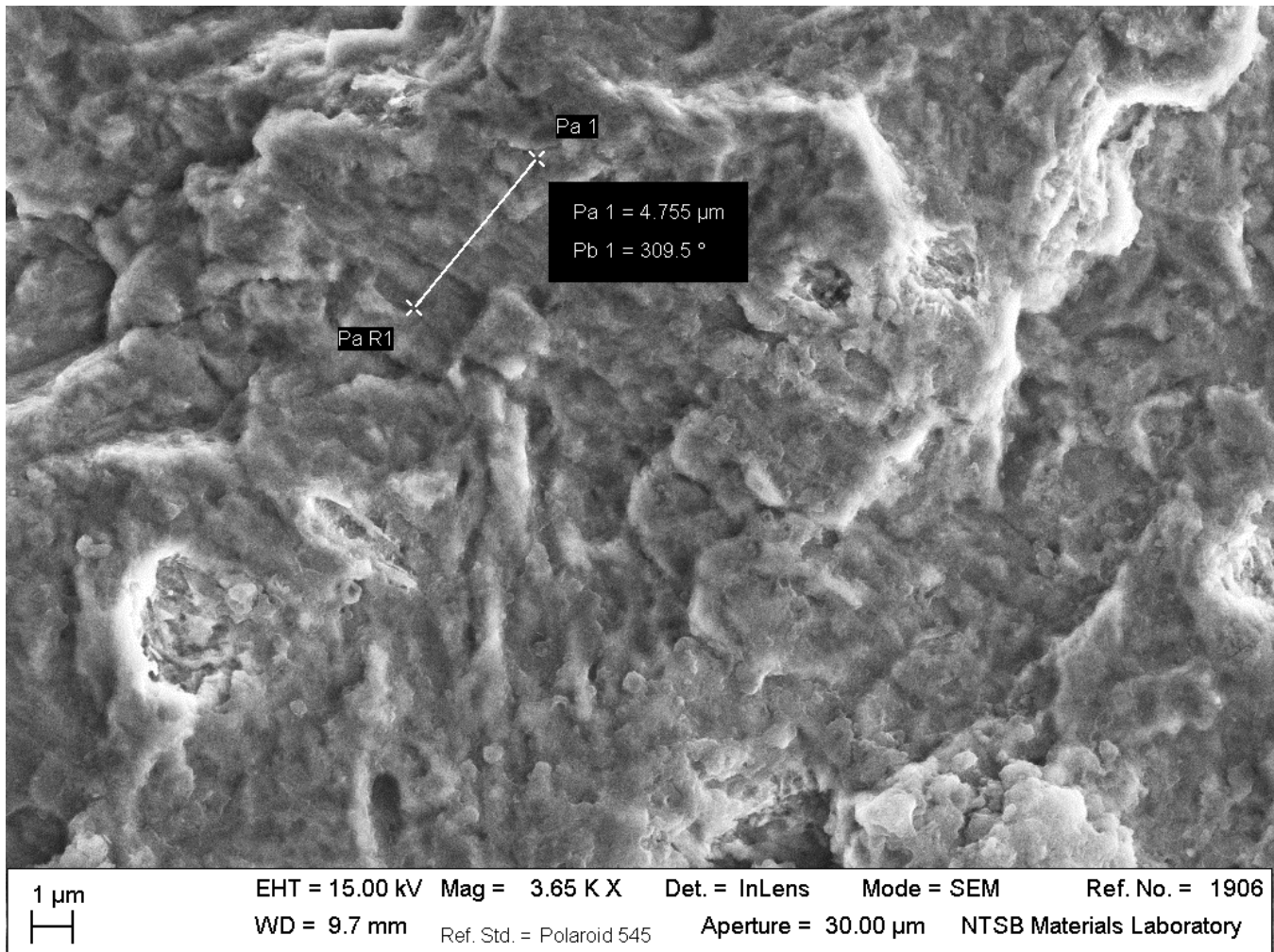


Figure 34 – SE micrograph with striation measurements at site 26 on the fracture surface.

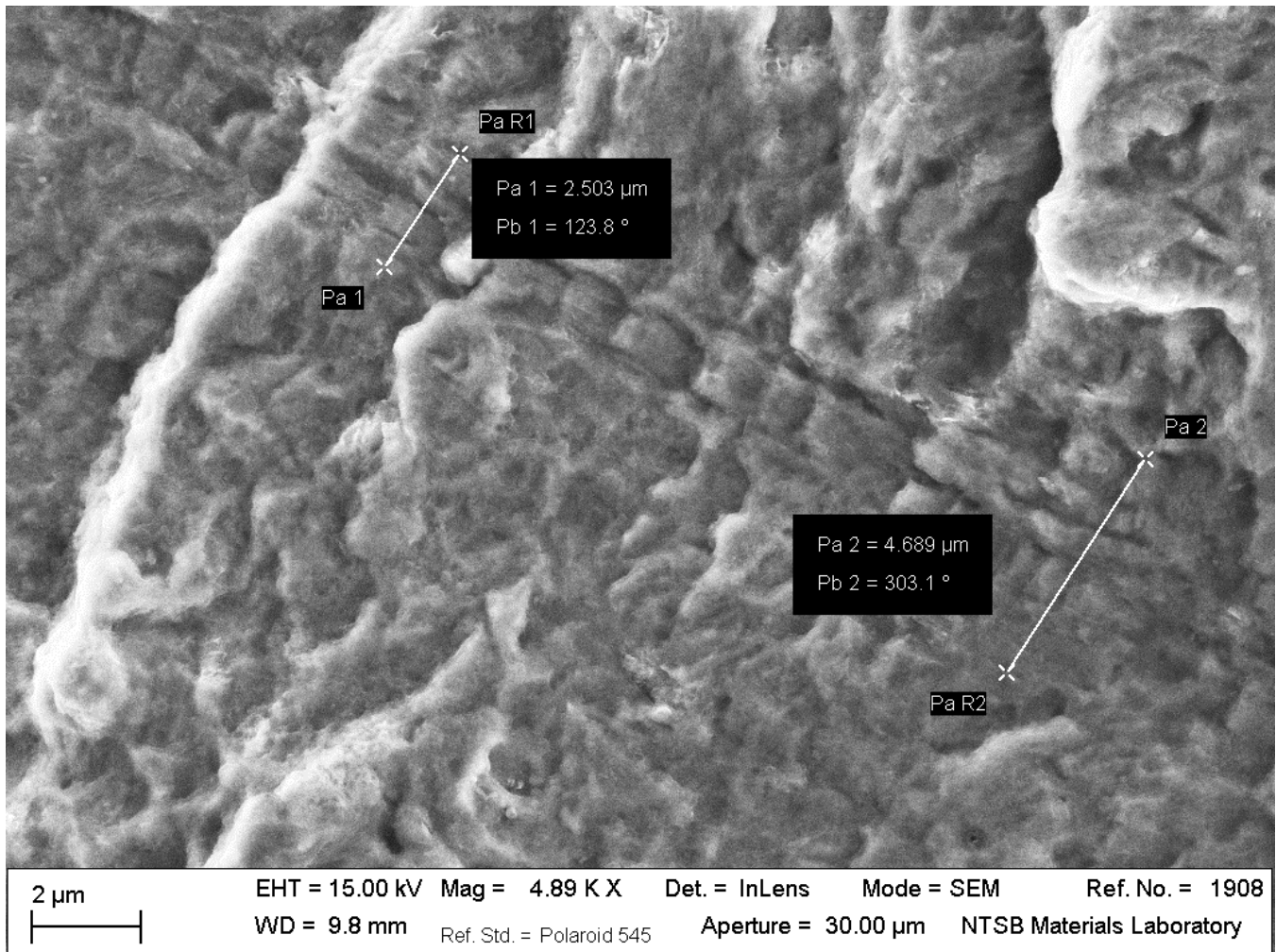


Figure 35 – SE micrograph with striation measurements at site 27 on the fracture surface.

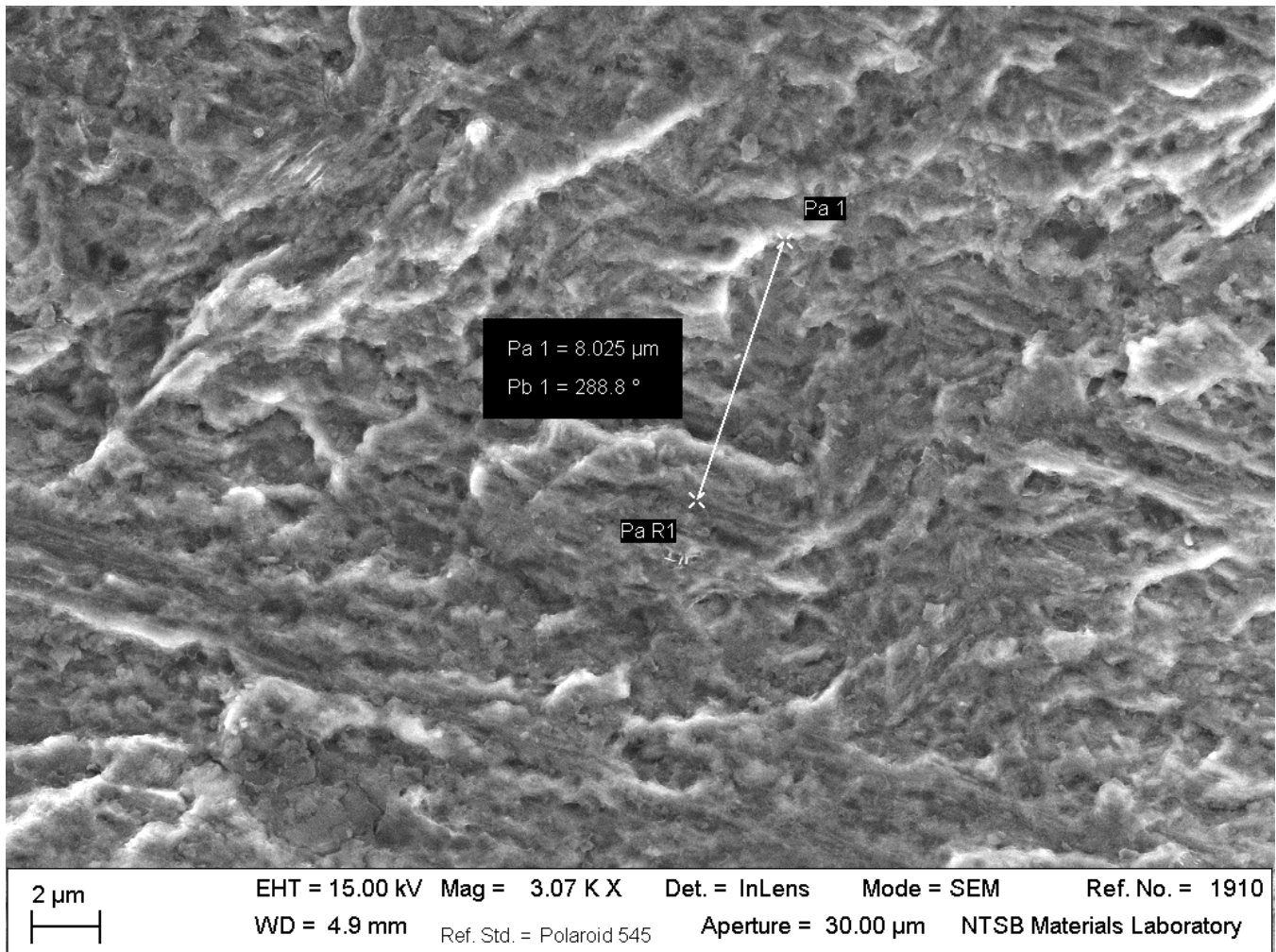


Figure 36 – SE micrograph with striation measurements at site 28 on the fracture surface.

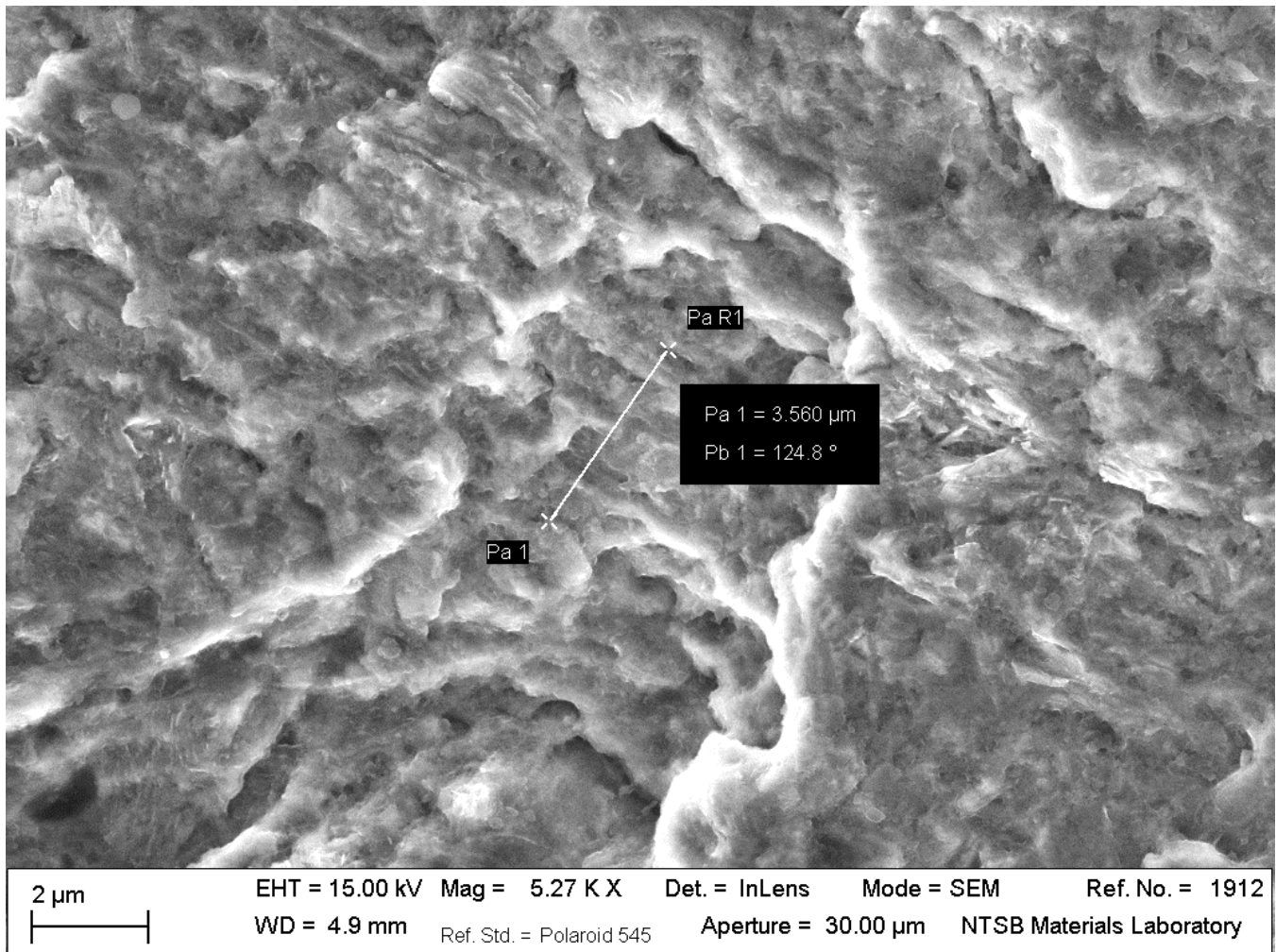


Figure 37 – SE micrograph with striation measurements at site 29 on the fracture surface.

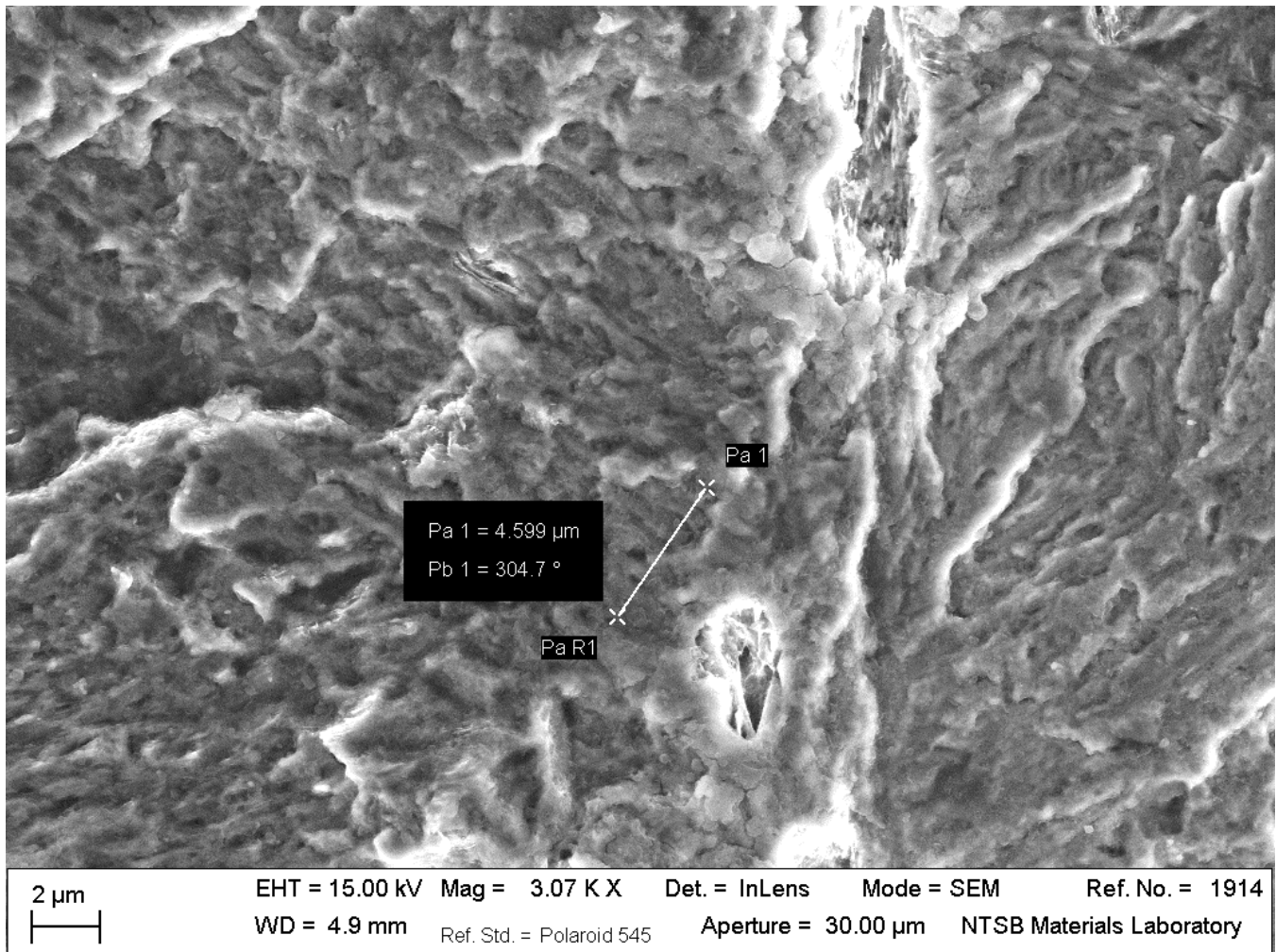


Figure 38 – SE micrograph with striation measurements at site 30 on the fracture surface.

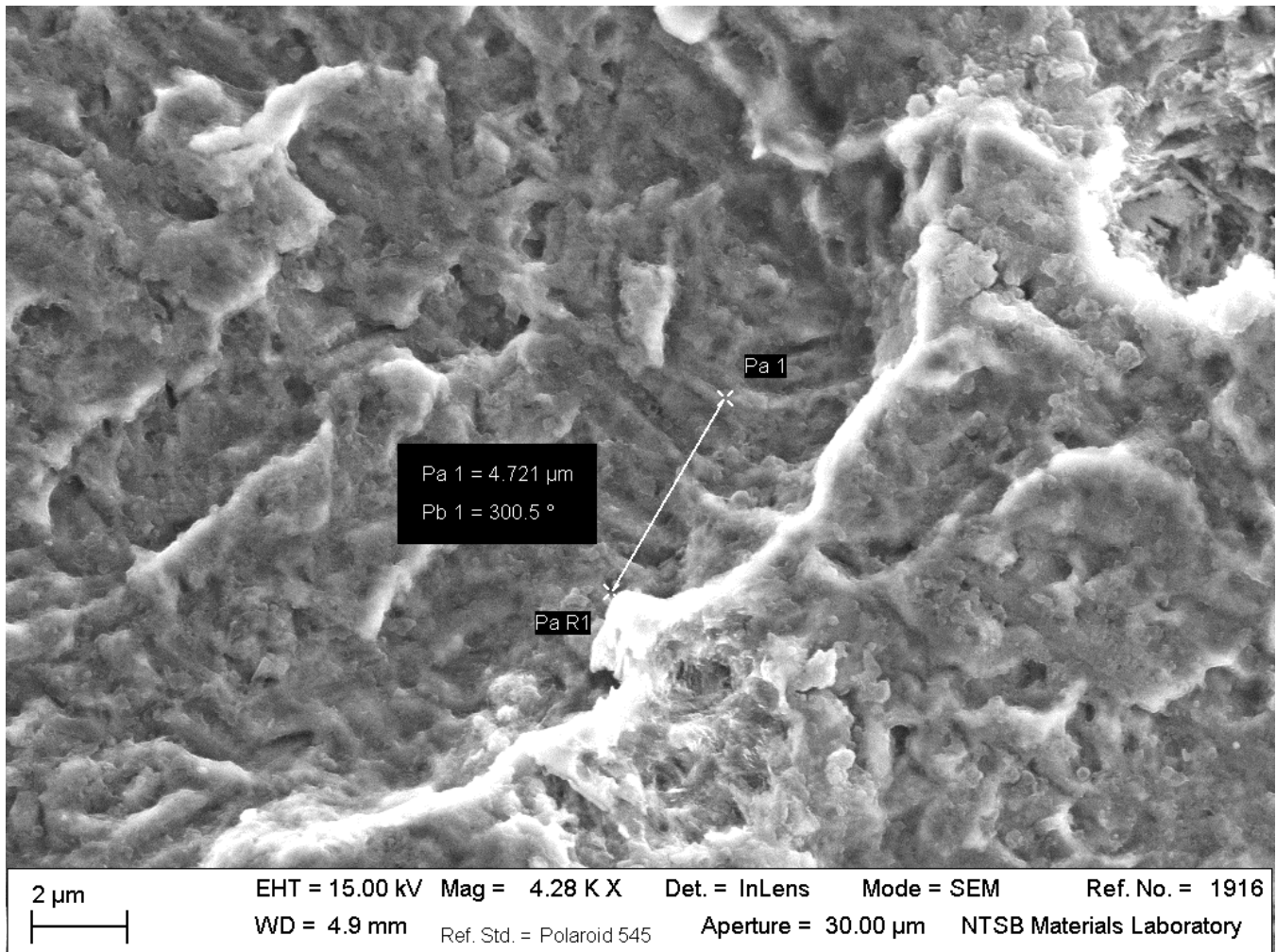


Figure 39 – SE micrograph with striation measurements at site 31 on the fracture surface.

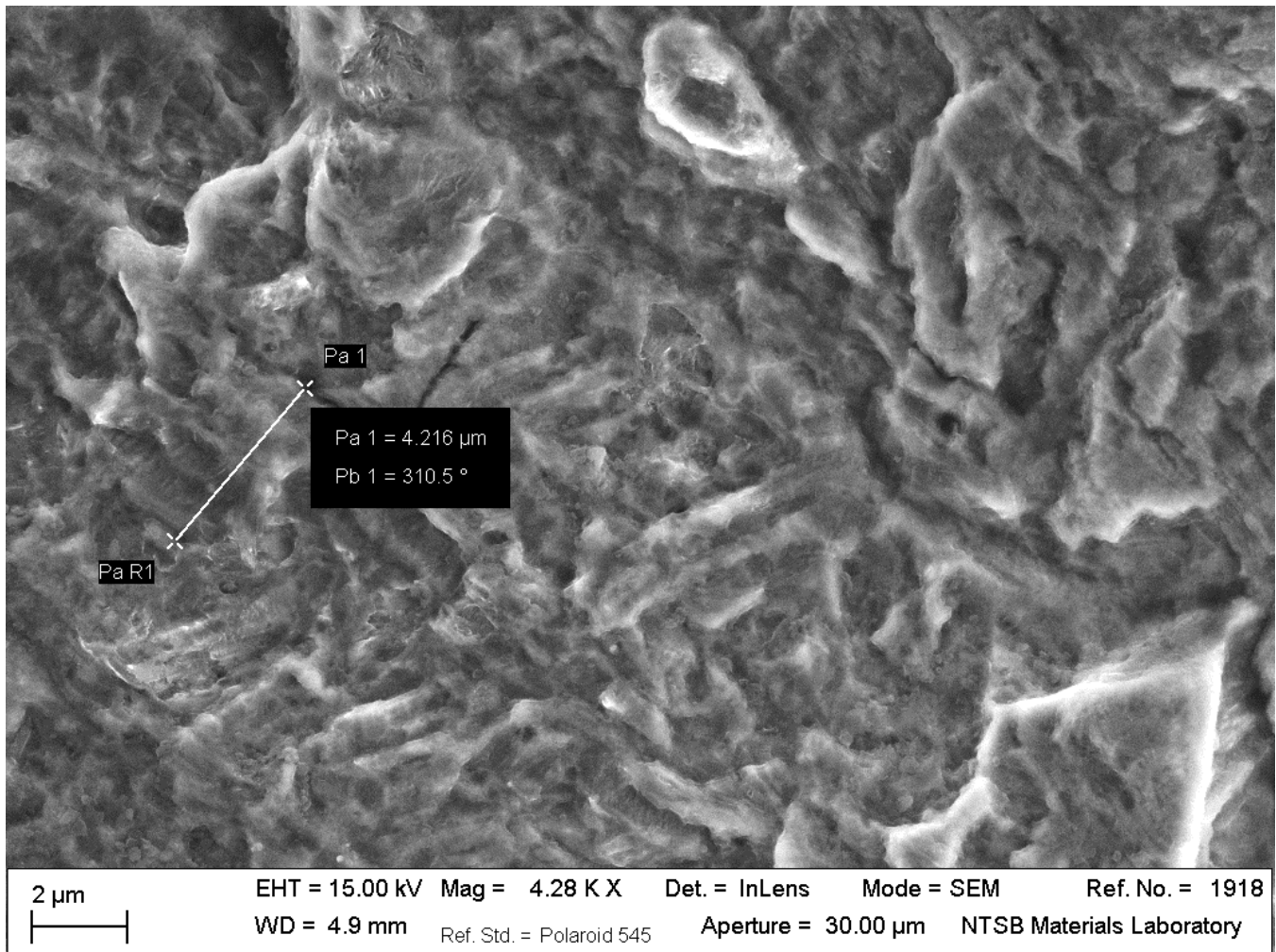


Figure 40 – SE micrograph with striation measurements at site 32 on the fracture surface.

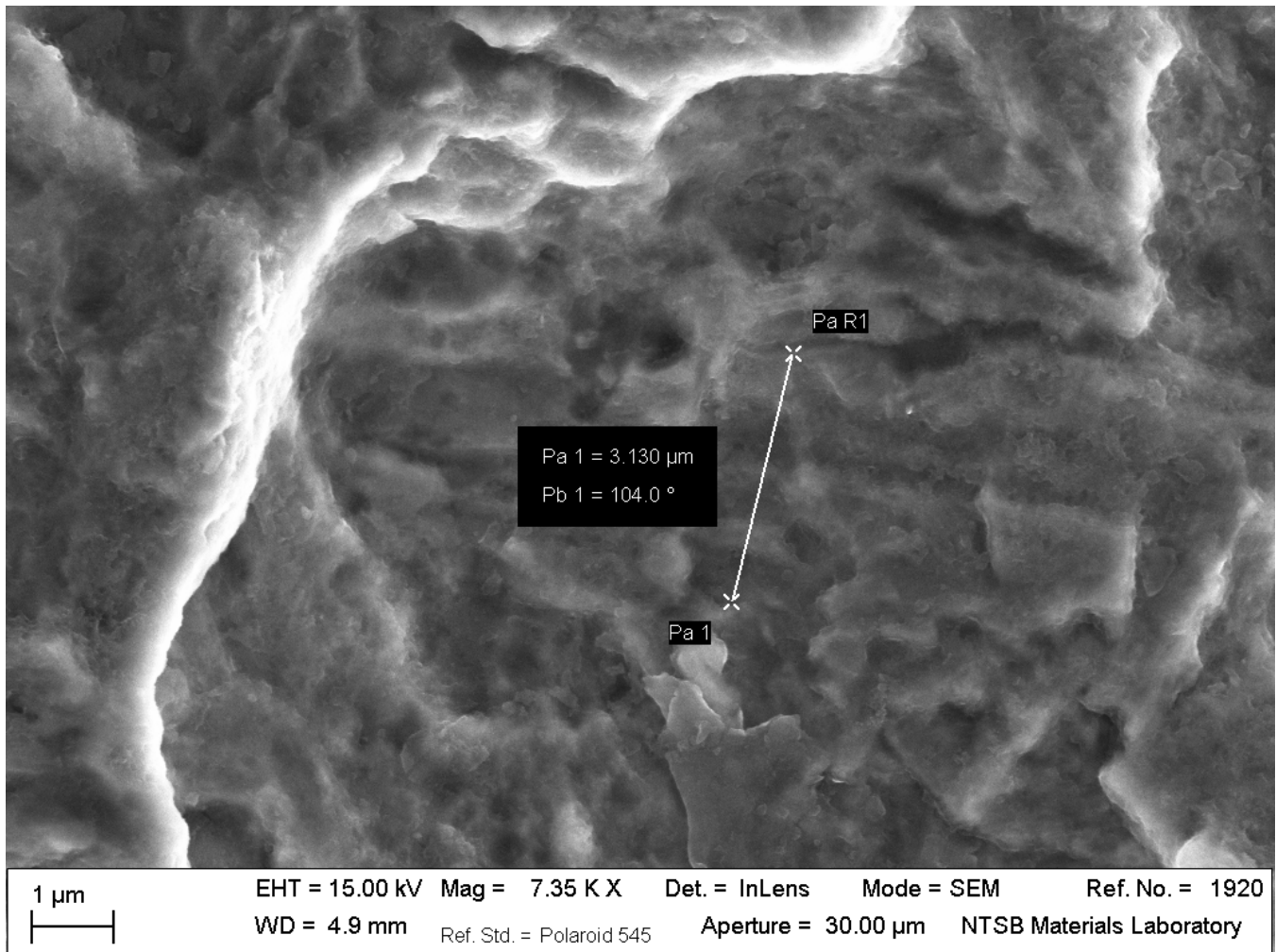


Figure 41 – SE micrograph with striation measurements at site 33 on the fracture surface.

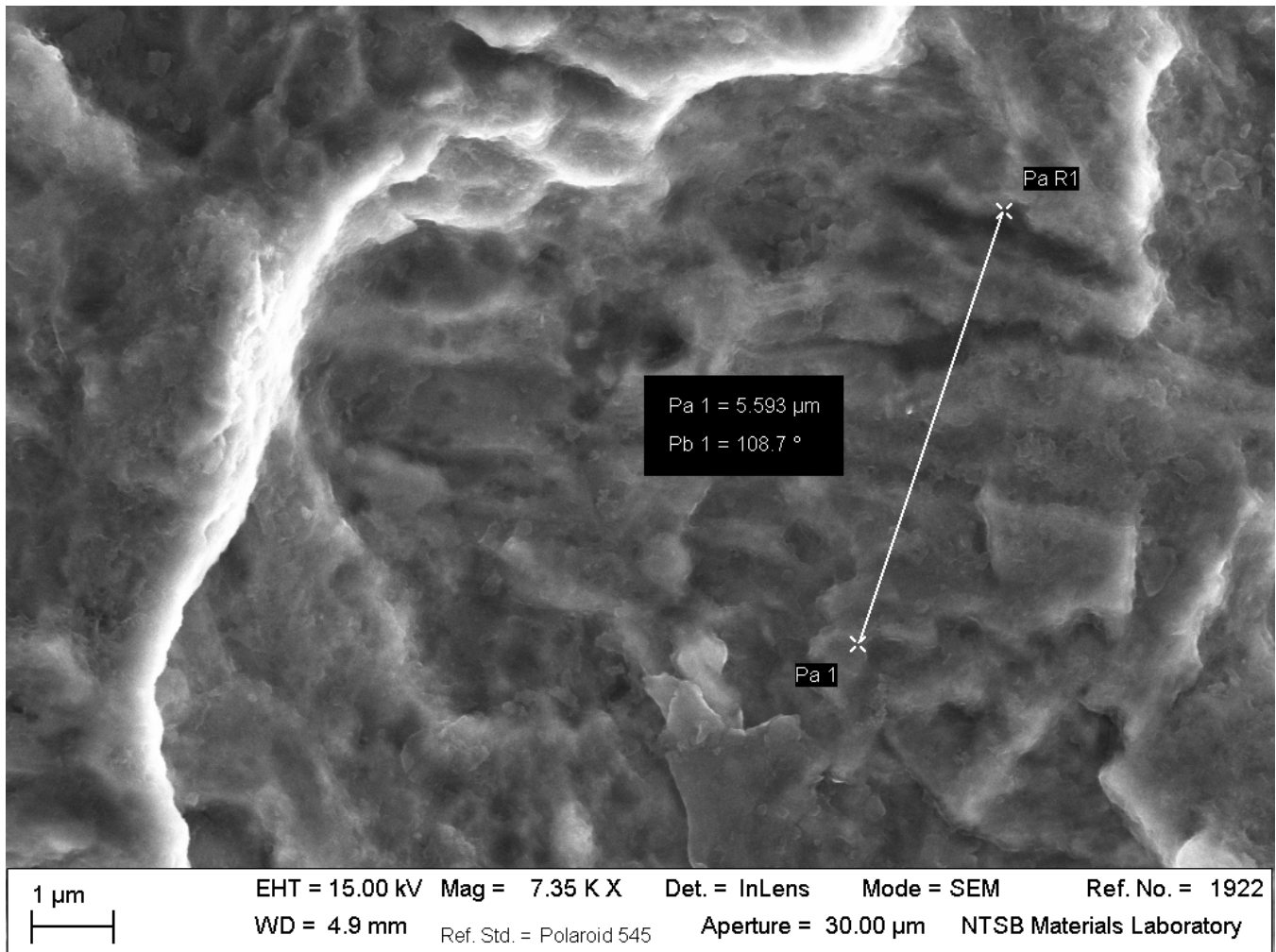


Figure 42 – SE micrograph with striation measurements at site 33a on the fracture surface.

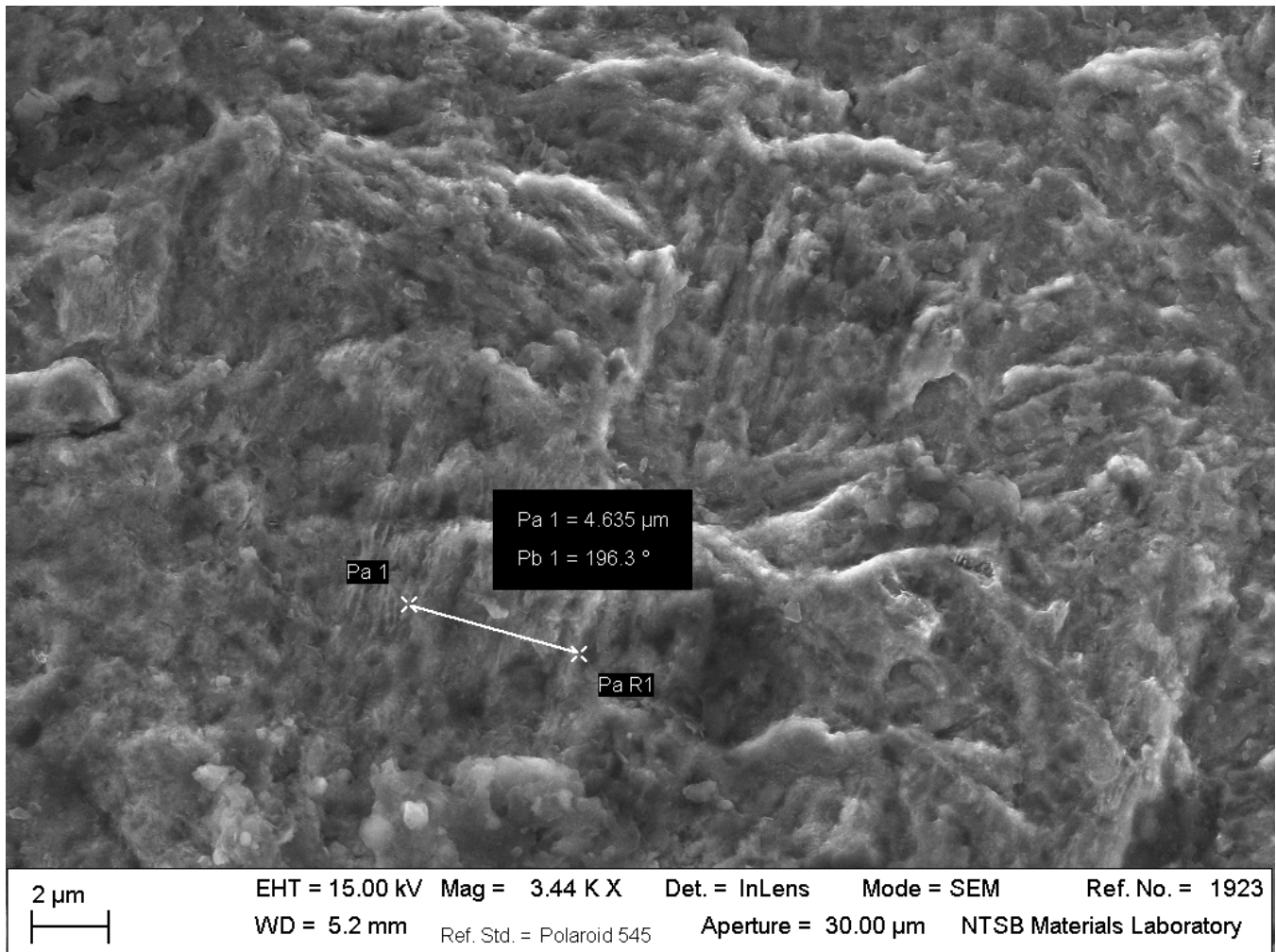


Figure 43 – SE micrograph with striation measurements at site 34 on the fracture surface.

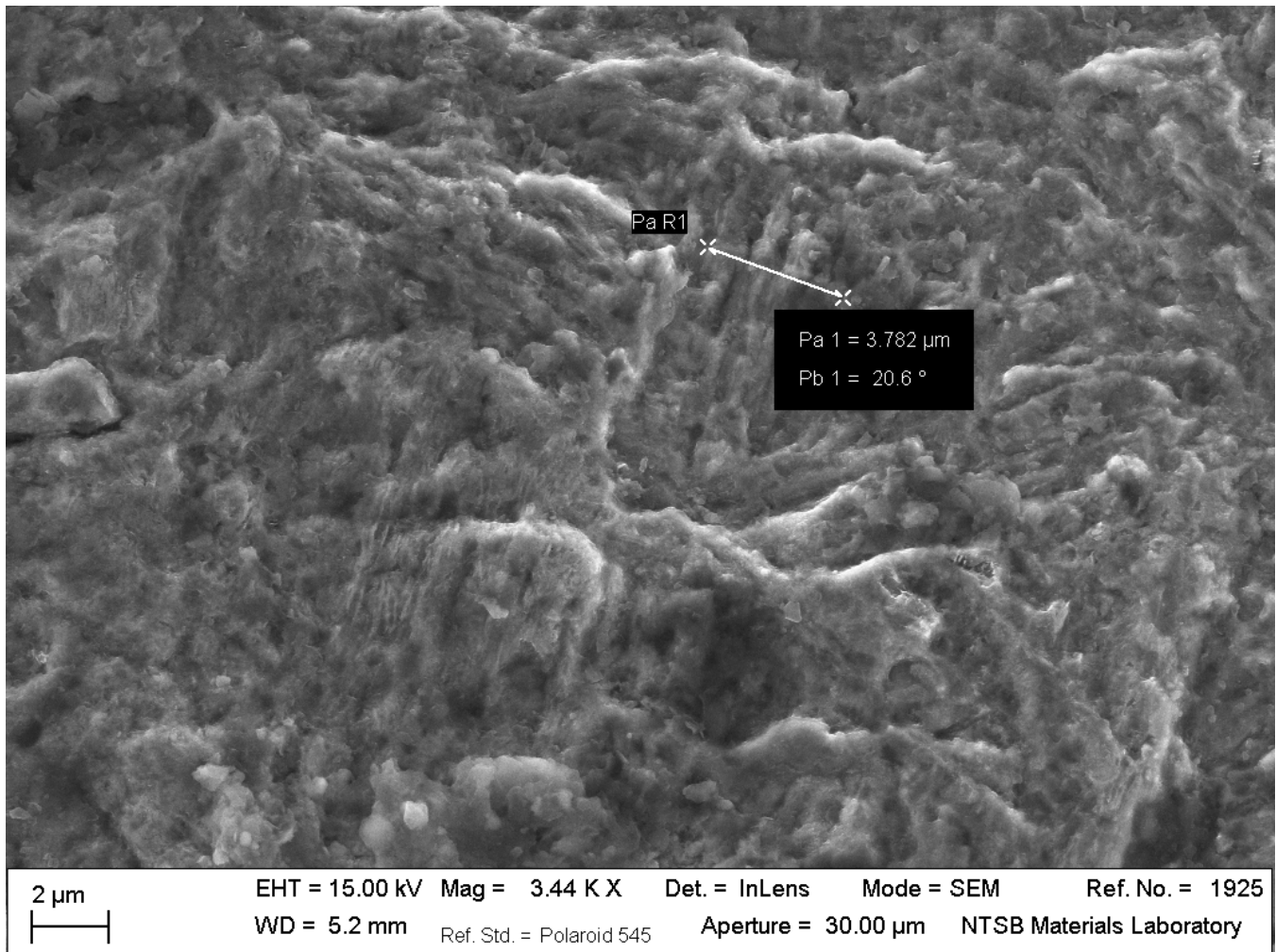


Figure 44 – SE micrograph with striation measurements at site 34a on the fracture surface.

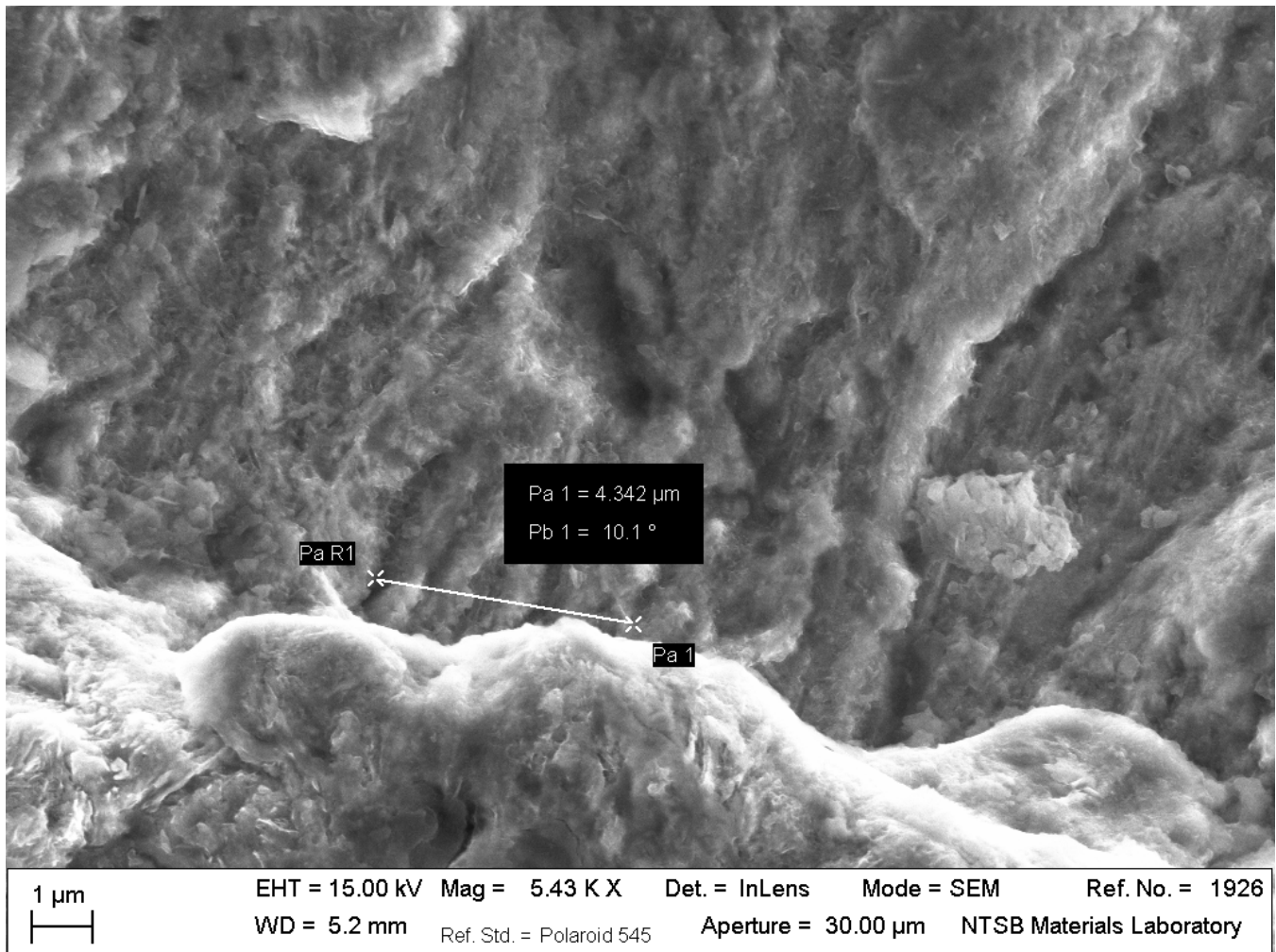


Figure 45 – SE micrograph with striation measurements at site 35 on the fracture surface.

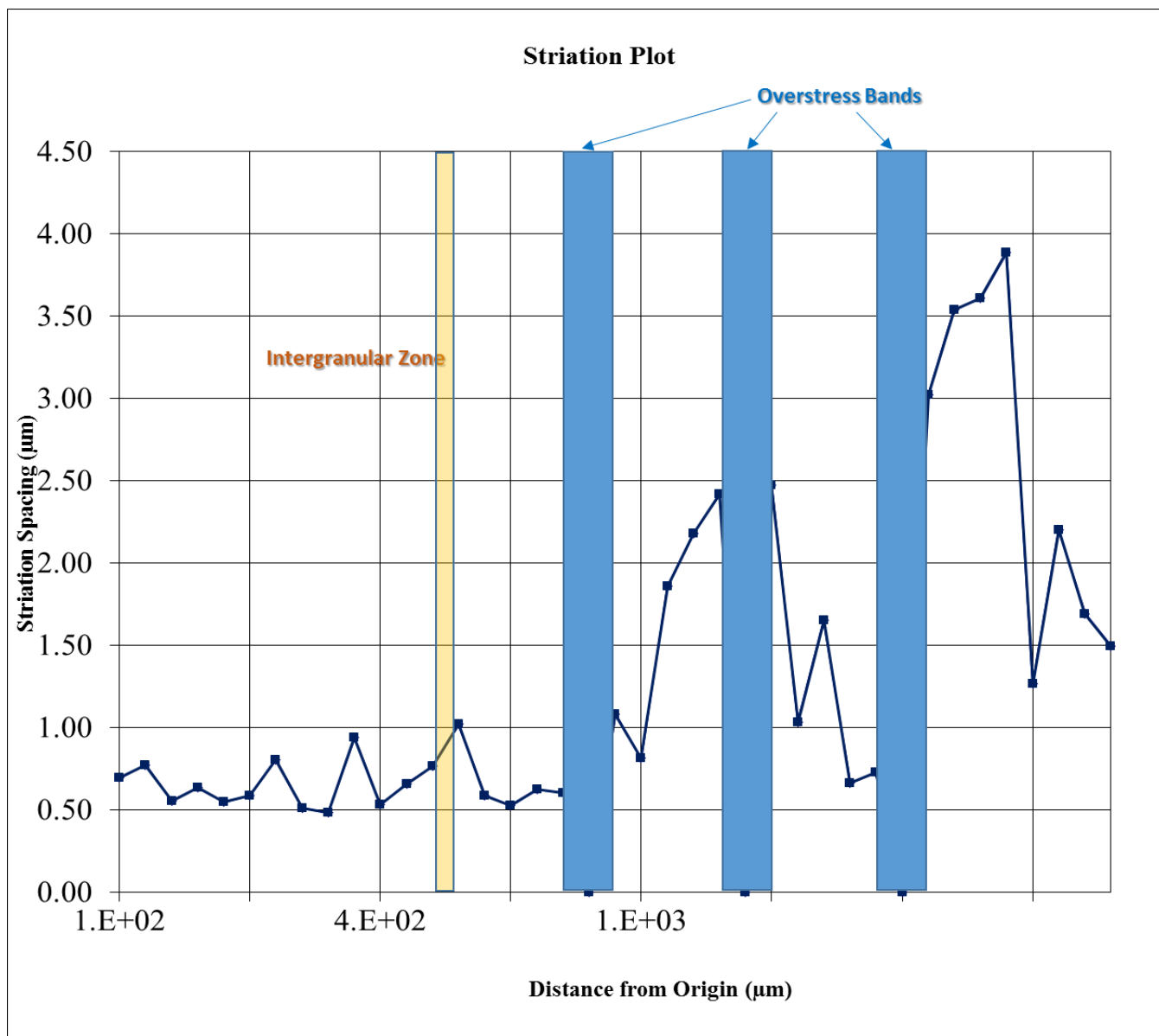


Figure 46 – Chart summarizing the fatigue analysis results from Table I, plotting the striation spacing, in μm , versus the distance from the fatigue crack origin, also in μm . The intergranular zone is represented in light orange, and three of the overstress bands are represented in blue.