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Laser-ablation ICP-MS analyses of rutile from the Bamble region, S. Norway

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REPORT

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Laser-ablation ICP-MS analyses of rutile from the Bamble region, S. Norway

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Summary:

The Bamble Sector (Arendal-Bamble region) of the Fennoscandian Shield in S. Norway is affected by metasomatic processes related to large-scale fluid migration during Sveconorwegian (Grenvillian) tectonothermal events. In some areas such as at Ødegårdens Verk, pervasive fluid infiltration has transformed gabbroic amphibolites into a characteristic scapolite-hornblende rock (ødegårdite). Ilmenite in the gabbroic protolith breaks down to rutile during the metasomatic process while iron is removed from the system by the fluids. Thus, the metasomatism creates rutile ores.

The region has been regarded to have a potential for economic rutile deposits. However, a disadvantage is a relatively high content of uranium in the rutile. In order to obtain additional information on the character of rutile in various parts of the region and the U contents, rutile from stream sediment heavy fractions have been studied by SEM and analysed for U by laser-ablation ICP-MS.

Mixed mineral grains with ilmenite, rutile and titanite are common in the stream sediments indicating that rutile-forming geological processes in the respective areas have been incomplete; some stream sediment samples have "good rutile" without ilmenite or titanite intergrowths.

Based on the laser-ablation ICP-MS, analysed rutile from the Arendal-Bamble region contains 30-80 ppm U in general, although values up to 180 ppm U have been identified. Values below 10 ppm U are common in ilmenite-rutile-titanite intergrowths representing incomplete rutile transformation.

The potential for economically attractive rutile deposits in the Arendal-Bamble region is probably small due to the overall high uranium content in rutile.

Keywords: Mineral resources	Stream sediments	Titanium
Rutile	LA-ICP-MS	

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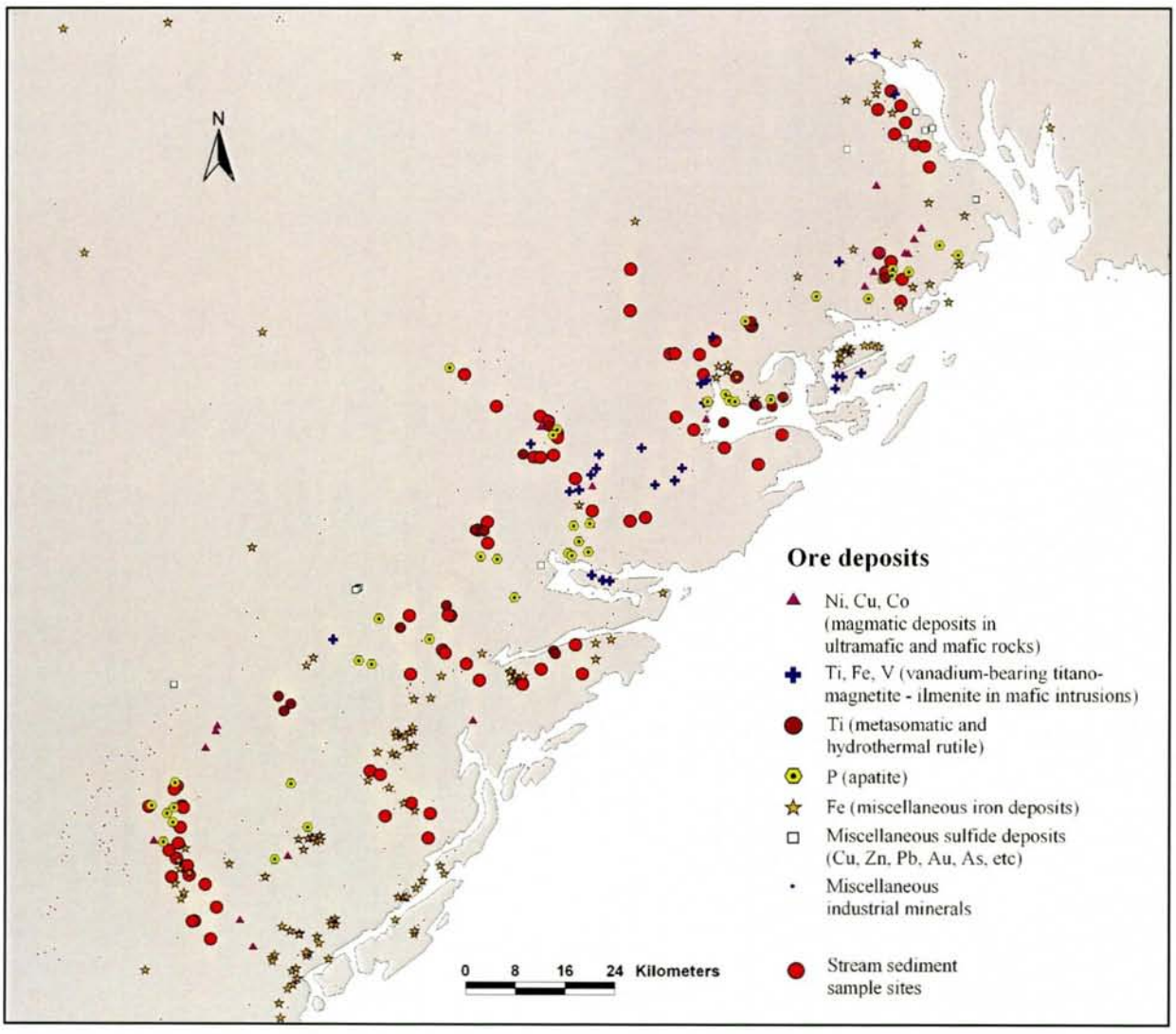


Fig. 1: Ore deposits and stream sediment localities, Arendal – Bamble region, S. Norway

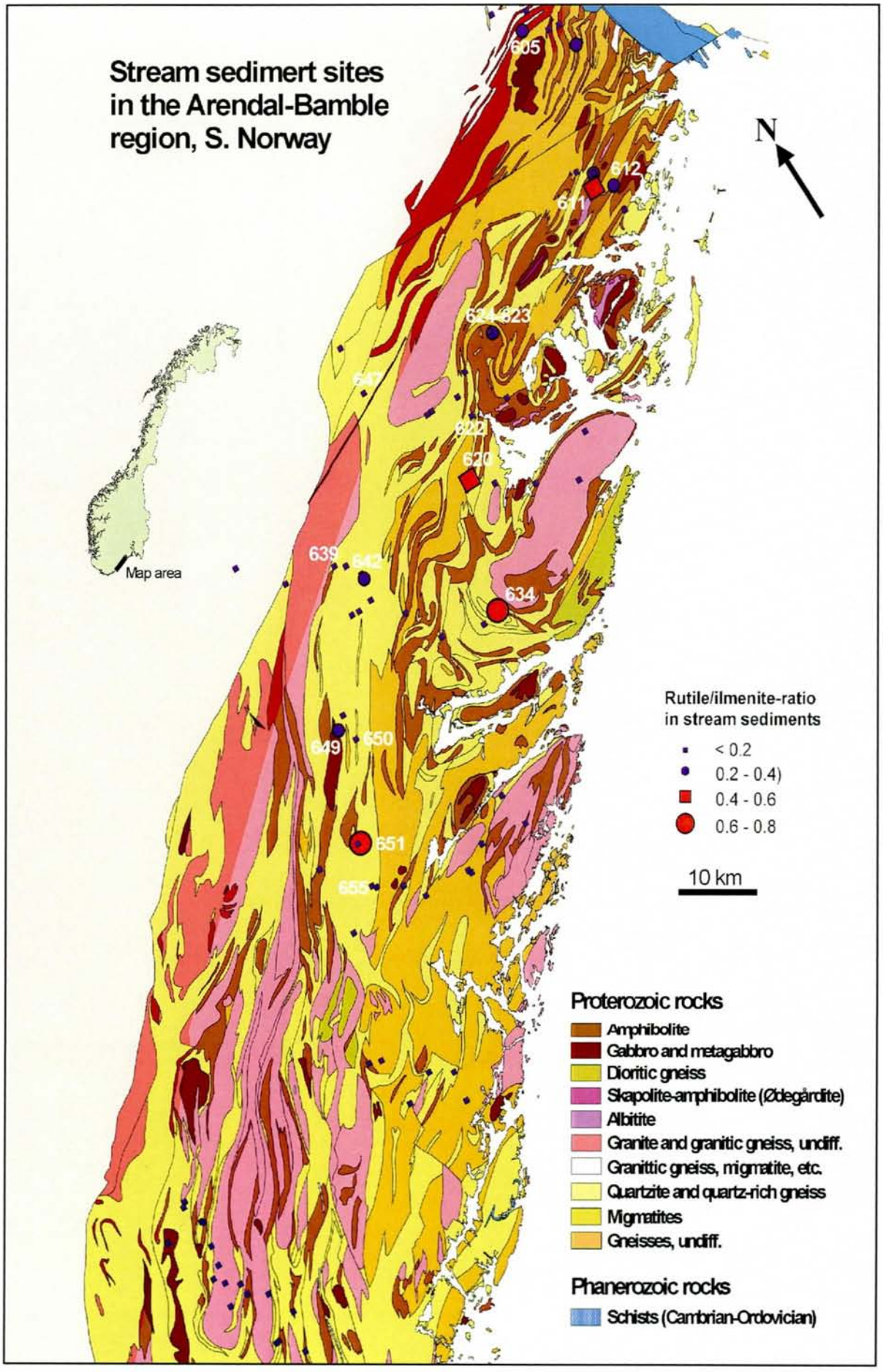


Fig. 2: Simplified geological map and stream sediment sites, Arendal-Bamble region.
Stream sediment sites listed in Table 1 are labelled.

1. Introduction

The collaboration between NGU and the Canadian mining company Rio Tinto Iron & Titanium (RTIT) that started in 1999 originally focused on rutile-bearing eclogite deposits in Western Norway, but some attention was also given to the Arendal-Bamble province since it is a distinct rutile-bearing metallogenetic province. Information on uranium in rutile was available from a few locations based on analyses of rutile separates made by NGU in 1992-93 (Korneliussen et al 1999).

To obtain additional information about the character of rutile from a variety of areas in the Arendal-Bamble province, 100 stream sediments samples were collected on October 2000 (Finne 2000). After sieving at NGU these samples were sent to RTIT for analyses.

Analytical results were received by NGU in autumn 2001, containing XRF-analyses of the stream sediment heavy mineral fractions (density > 3.33 g/cm^3) and SEM-based semi-quantitative mineralogical information done before the heavy mineral separation.

The titanium pigment industry prefers rutile with low uranium contents (< 10 ppm U). Therefore, uranium content in rutile is a key factor concerning economic viability of the deposits. Indications of overall high uranium content in rutile from the Arendal-Bamble region will make the area less attractive from a rutile exploration point of view while good indications for low-U rutile would be positive in this respect.

Therefore, the purpose of this investigation is to obtain information on the uranium content in rutile from various places in the Arendal-Bamble region; thereby adding information making it possible to make a reliable assessment of the potential for rutile deposits of economic interest

2. Arendal – Bamble region geological overview

The Bamble Sector of the Fennoscandian Shield in S. Norway, is affected by metasomatic processes related to large-scale fluid migration during Sveconorwegian (Grenvillian) tectonothermal events. The sector contains a high concentration, and wide spectrum, of mineral deposits, ranging from magmatic Ni-Cu and Fe-Ti-V deposits via stratabound massive sulphide ores of Cu-Zn-Pb-Au-Ag to epigenetic Ti (rutile), P (apatite), Fe, Fe-P, Cu and Au-As deposits.

At the Ødegårdens Verk apatite mines NE of Kragerø, which were in operation from 1872 to 1945, three distinct hydrothermal/metasomatic stages are recognised:

1. Early pervasive fluid infiltration transforming gabbroic amphibolites into a characteristic scapolite-hornblende rock (ødegårdite). In this process plagioclase was replaced by Cl-rich scapolite and the mafic minerals were replaced mainly by Fe-poor hornblende.
2. An intermediate stage with pronounced Na-metasomatism causing extensive albitisation of the ødegårdite as well as other rocks in the area.
3. Late hydrothermal activity that resulted in the formation of numerous phlogopite - enstatite - apatite veins along fractures in the ødegårdite.

Based on analyses of cores from gabbro/amphibolites and their metasomatised equivalents at Ødegårdens Verk, chemical changes during metasomatism can be deduced. Metasomatism of the gabbro and formation of ødegårdite leads to a strong depletion of elements such as Fe, Zn

and Cu, while enrichment is distinct for U and V. This suggests that metasomatism of large volumes of rocks can contribute significant amounts of metals to the permeating hydrothermal fluids, from which precipitation and formation of hydrothermal ore deposits are likely to occur due to changes in physiochemical conditions. Less mobile elements such as titanium remain in the metasomatised rock. Ilmenite in the gabbroic protolith breaks down to rutile during the metasomatic process while iron is removed from the system by the fluids. Thus, the metasomatism creates rutile ores.

On a regional scale there also exists a number of additional types of rutile deposits associated with the metasomatism of mafic intrusions. These include rutile-enriched albitites (kragerøites), amphibolites, phlogopite-cordierite rocks, and apatite-bearing albitic pegmatites. There appears to be an overall, but poorly defined, relationship between the rutile deposits and apatite deposits, both occurring in areas affected by metasomatism.

Another important aspect is the general presence of structurally controlled deposits of apatite-bearing Fe-oxides, Fe-oxides and/or Fe-Cu-sulphides occurring both proximally and distally to areas with pervasive sodium metasomatism. The different styles of epigenetic mineralisation and alteration in the Bamble sector have many features in common with regional scale metasomatism in connection with auriferous Cu-Fe systems in the Paleo- and Mesoproterozoic terrains elsewhere.

3. Titanium mineral relationships

The following main types of titanium deposits are found in the Arendal-Bamble region:

1. Magmatic ilmenite-titanomagnetite deposits within mafic intrusions believed to have formed during the 1250 Ma magmatic event and metamorphosed into metagabbros and amphibolites at about 1140 ma.

2. Mafic rocks in the region have experienced distinct scapolitisation and/or albitisation which was initiated under high- to medium-grade conditions at about 1140 Ma. In this process iron was leached out of the rock by hydrothermal fluids, presumably as $FeCl_2$; ilmenite and titanomagnetite broke down leaving the relatively immobile titanium as rutile.

Rutile deposits such as the Ødegården Verk rutile-bearing scapolite-hornblende rock (ødegårdite) and the Lindvikkollen rutile-bearing albitite (kragerøite), were formed by this process (see Korneliussen et al 1999, Korneliussen & Furuhaug 2000).

Fig. 3 shows an example of rutile from the Ødegården Verk scapolite-hornblende rock. In this case the rutile-forming process has been complete, although this rutile has been affected by some later fracturing along which titanite has formed. In cases where the scapolitisation (or albitisation) process has been incomplete relics of the original ilmenite can still be seen within the rutile, as shown in Figs 4 & 5.

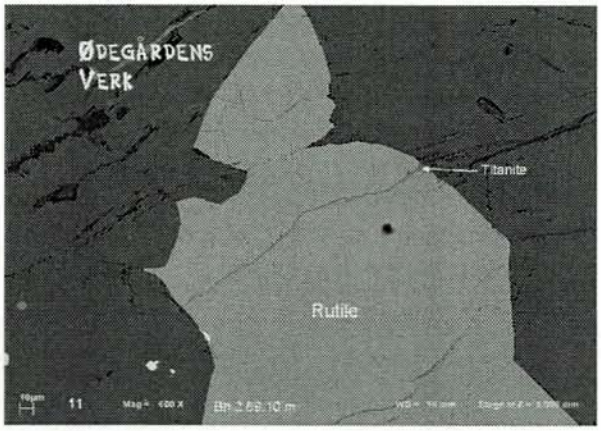


Fig. 3: SEM BSE image of rutile from the scapolite-hornblende rock at Ødegården Verk.

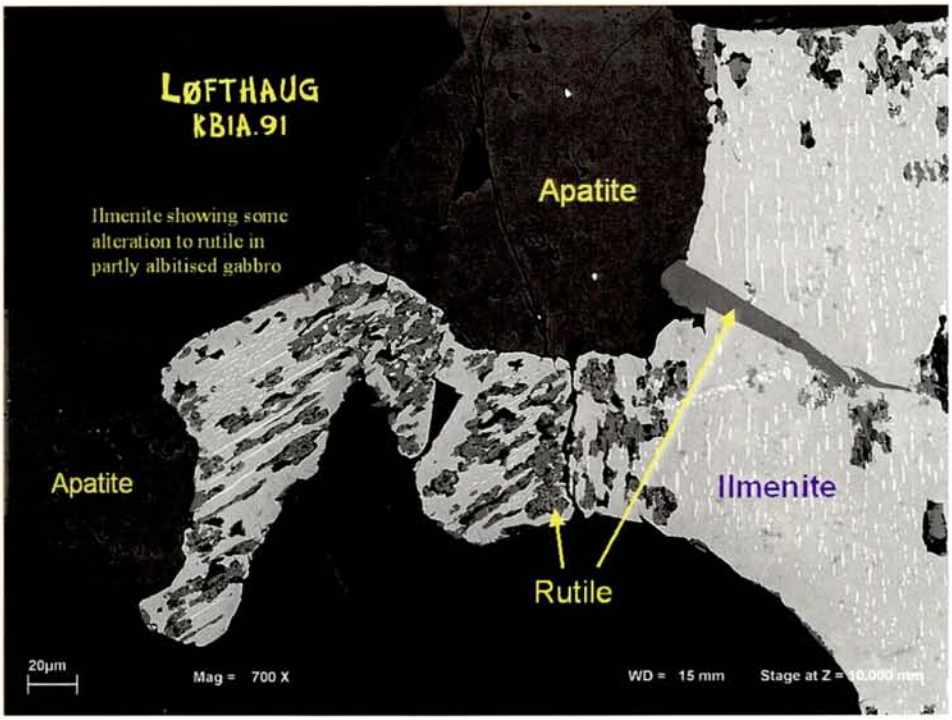


Fig. 4: SEM BSE image of incompletely transformed ilmenite to rutile in partly albitised metagabbros at Lofthaug.

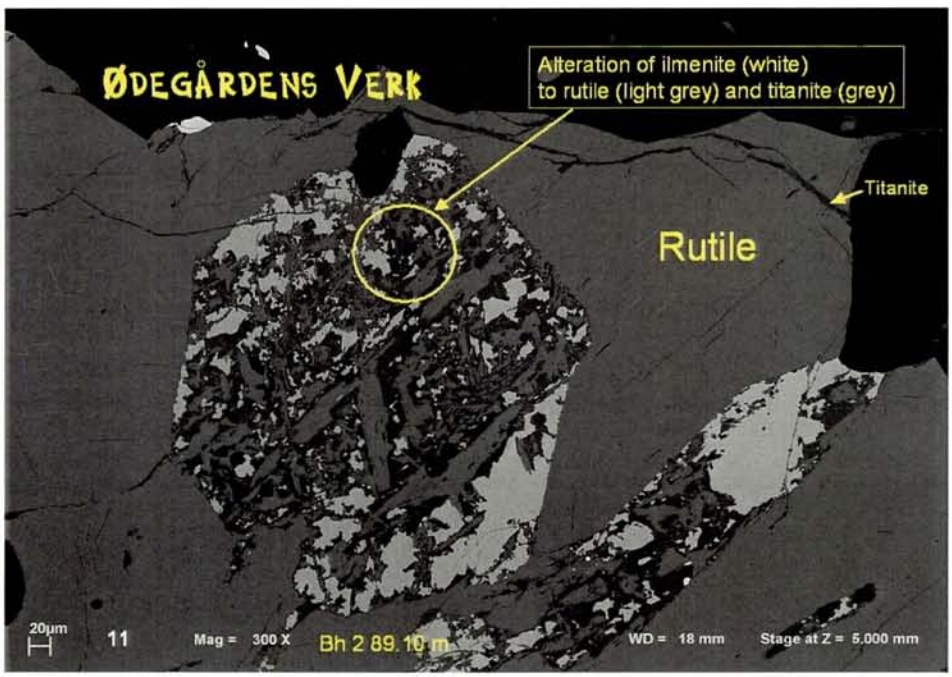


Fig. 5: SEM BSE image of incomplete transformation of ilmenite to rutile in scapolitized gabbro at Ødegården Verk.

Similar incomplete ilmenite to rutile transformations are also found in gabbro/amphibolite to albitite transition zones. The SEM BSE image of Fig 4 shows how ilmenite (hemoilmenite) from a partly albitised metagababbro at Løfthaug in the Kragerø area has been transformed into rutile. Fig 5 is another example showing the early stage of the ilmenite breakdown. In such situations titanite tend to form together with rutile at the early stage of the ilmenite breaking down process, but as the process forms increasingly more rutile, titanite tend to disappear.

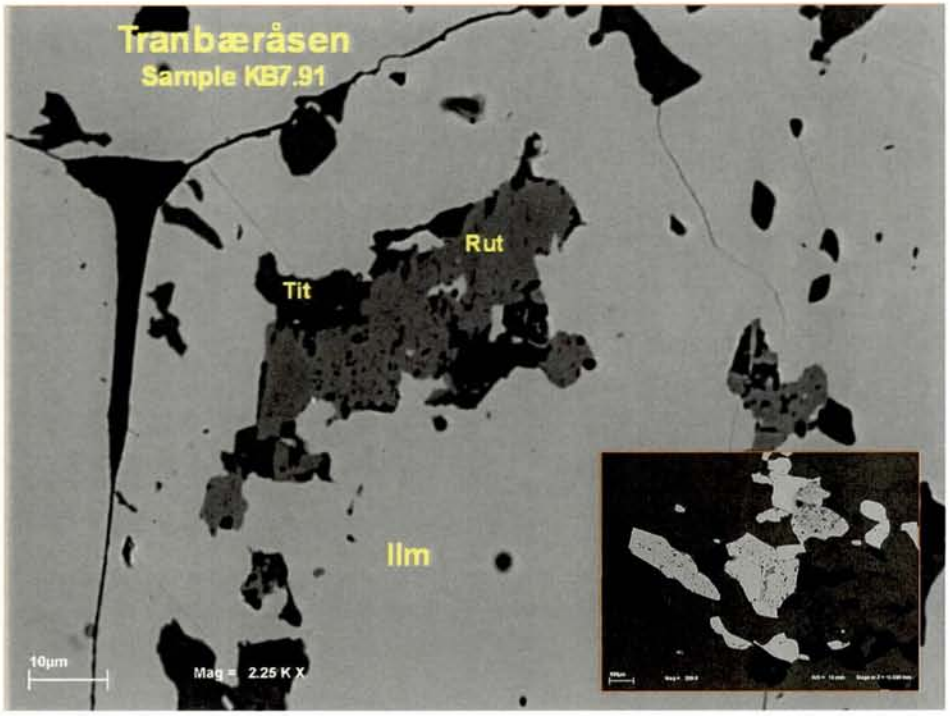
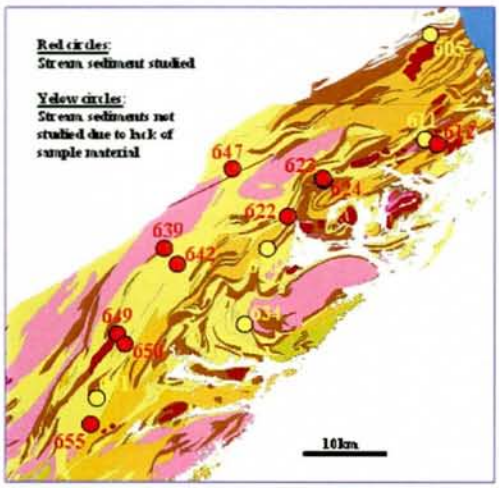


Fig. 6: BSE SEM image of incomplete transformed ilmenite to rutile and titanite in scapolitised metagabbros at Tranbæråsen.

4. Stream sediment characteristics



Geologic legend: See Fig. 2.

NGU sampled 100 stream sediments in October 2000 (Finne 2000). These were sieved (< 0.6 mm) in the field, and after sieving at NGU the 0.6/0.18 mm fraction was shipped to RTIT. A SEM-based mineral quantification of the screened samples and major element XRF-analyses on heavy mineral fractions were then conducted by RTIT. The stream sediments chosen for further study are listed in Table 1 and their locations are shown in Fig. 7 and Appendix 3. Relationships between geographic variations and stream sediment characteristics are shown in Fig. 2 & 3 and in Appendix 3.

Fig. 7: Locations of stream sediment studied.

Miscellaneous map-presentations of stream sediment characteristics are shown in the following appendixes:

Appendix 2: Ore deposits and stream sediment localities.
Appendix 3: Stream sediment localities.
Appendix 4: Rutile content in stream sediments based on semi quantitative SEM analyses by Rio Tinto Iron & Titanium.
Appendix 5: Rutile/ilmenite-ratios of stream sediments based on semi quantitative SEM analyses by Rio Tinto Iron & Titanium.
Appendix 6: Heavy mineral contents in the stream sediments.

Appendix 7: Relative portion (percent) of heavy minerals in the stream sediments.

The amounts of heavy minerals (d > 3.33 g/cm^3) present in stream sediments vary widely (Appendix 6) as well as the percentage of heavy minerals present (Appendix 7).

The "rutile in stream sediment" map (Appendix 4) illustrates the considerable variation in rutile content. Some of the samples chosen for further study are among those with most rutile. An interesting observation is that the Ødegården area with its rutile-bearing scapolitised gabbros and some rutile-bearing albitites (Korneliussen et al 1999) does not show up in this map. However, in the rutile/ilmenite ratio map (Appendix 5) the Ødegården area does show up, indicating that the rutile/ilmenite ratio is a good indicator for rocks for which rutile-forming processes (from ilmenite) have been active in the area.

The oxide mineralogy in stream sediment (heavy fractions) and in rock mineralisation is shown in a number of SEM-images. Titanite is commonly present as intergrowths with rutile; see for example Appendix 13, page 4.

Only stream sediment heavy fraction sample 649 (Fig 7, Appendix 11) of the ten samples studied contains a considerable amount of "good rutile", i.e. rutile grains without significant intergrowths of other titanium minerals such as ilmenite and titanite. The mineralogy in this sample indicates that favourable rutile ore-forming processes have been active in the area.

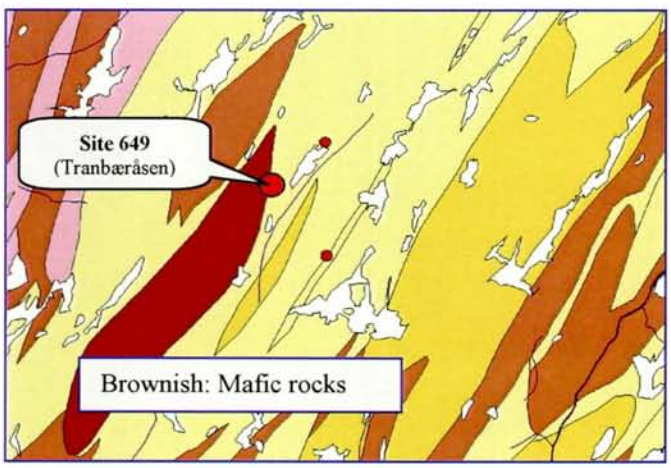


Fig. 8: Stream sediment site 649, Tranbæråsen area. The rutile/ilmenite-ratio in the stream sediments is indicated by the symbol size.

Stream sediment heavy fraction sample 624 (Appendix 8) is particularly rich in hematite; some of the hematite grains have distinct intergrowths of rutile, indicating that rutile ore-forming processes has been active in the area. The mineralogical relationships are, however, poorly understood.

In stream sediment heavy fraction sample 639 (Appendix 9) one rutile grain was found (not analysed); this grain is a part of a larger composite grain together with two undefined minerals.

Stream sediment heavy fraction Sample 647 (Appendix 10) has a number of grains showing a characteristic alteration of ilmenite to rutile and titanite, indicating that rutile ore-forming processes has been active in the area.

Stream sediment heavy fraction Sample 650D (Appendix 12) contains few rutile grains and a significant number of ilmenite grains with partly alteration to rutile. This indicates that rutile ore-forming processes have been active in the area.

Stream sediment heavy fraction Sample 655 (Appendix 13) contains ilmenite that has been alteration to rutile and titanite, indicating that rutile ore-forming processes have been active in this area.

Stream sediment heavy fraction Sample 622 (Appendix 14) is distinctly hematite-rich. The Ti-oxide relationships are complex. Rutile is found in two mineralogical associations: in ilmenite grains showing incomplete alteration to rutile, and as rutile intergrowths in hematite. This indicates that rutile ore-forming processes have been active in the area.

Stream sediment heavy fraction Sample 623 (Appendix 15) is characterised by incomplete transformation of ilmenite to rutile. This indicates that rutile ore-forming processes have been active in the area.

In stream sediment heavy fraction Sample 642 (Appendix 16) no Ti-mineral grains were found.

In stream sediment heavy fraction sample 612 (Appendix 17) a number of ilmenite grains show partial alteration to rutile, indicating that rutile ore-forming processes has been active in the area.

Table 1: Stream sediment heavy mineral fractions chosen for further investigation. Coordinates are in the WGS84 UTM coordinate system (zone 32).

Site	LabNo	FieldNo	East-coord.	Nort-coord.	Comments
605	T840L5	605	532670	6547760	Not studied due to lack of sample material
611	T840M4	611	532037	6536197	Not studied due to lack of sample material
612	T840M5	612	533416	6535644	Polished section no 10
620	T840N6	620C	514575	6524049	Not studied due to lack of sample material
622	T840N8	622	516842	6527651	Polished section no 7
623	T840N9	623	520864	6531677	Polished section no 8
624	T840P1	624	520729	6531860	Polished section no 1
634	T840Q6	634	512080	6515611	Not studied due to lack of sample material
639	T840R2	639	503243	6524086	Polished section no 2
642	T840R7	642	504687	6522298	Polished section no 9
647	T840S3	647	510719	6532921	Polished section no 3
649	T840S5	649	498065	6514513	Polished section no 4
650	T840S7	650D	498891	6513400	Polished section no 5
651	T840S9	651	495789	6507346	Not studied due to lack of sample material
655	T840T4	655	495107	6504467	Polished section no 6

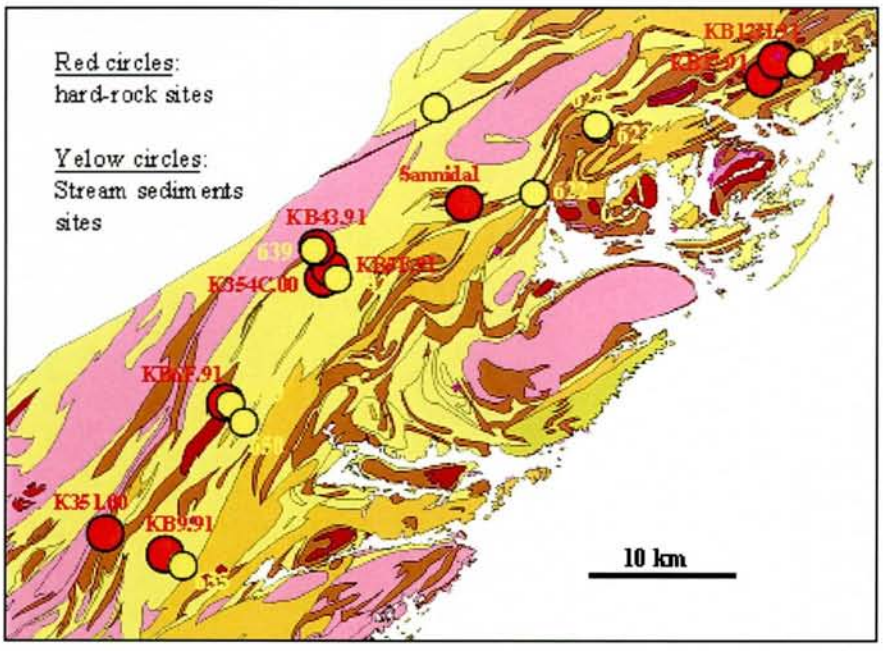


Fig. 9: Stream sediment and hard-rock localities studied. See Fig. 2 for geological legend.

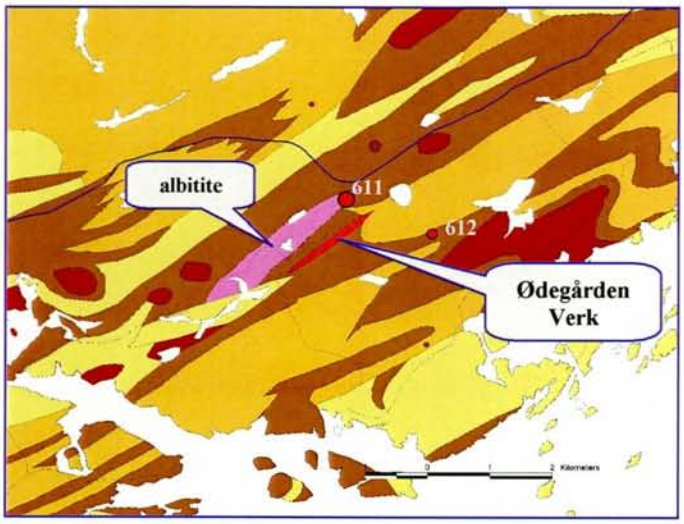


Fig. 10: Stream sediment sites in the Ødegården area and the Ødegården Verk rutil-bearing scapolite-hornblende rock (red). See the legend in Fig 2. The rutile/ilmenite-ratio in the stream sediments is indicated by the symbol size.

Stream sediment heavy fraction Sample 612 (Fig 11, Appendix 17) is another sample with complex oxide relations and incomplete transformation of ilmenite to rutile. However, an interesting observation is that this site is located close to the Ødegårdens Verk rutile deposit, which contains partly altered Fe-Ti-oxides in the surrounding amphibolites. Stream sediment site 611 is near the Ødegården Verk rutile deposit (marked with red in Fig. 11); this sample has a high rutile/ilmenite ratio but unfortunately no material is left for further mineralogical studies.

5. Laser-ablation ICP-MS analyses

32 samples (24 hard-rock and 8 stream sediments) from 15 localities were analysed by laser-ablation ICP-MS. Some sample information including average values of Zr, U, Th, Nb and Ta is given in Table 2; the respective locations are plotted on Figs 4, 5 & 6. The complete analytical data is given in Appendix 1.

Uranium:

- In general the uranium contents of rutile are in the range 30-80 ppm (Fig. 12).
- The highest U-values are found in rutile from sample KB37.91 which is from a cordierite - phlogopite rock in the Ødegården area, with values in the range 150-200 ppm U (average 175.6 ppm U).
- The uranium contents is low (1-10 ppm U) when the rutile-forming processes have been incomplete, i.e. in the mixed ilmenite + rutile ± titanite grains as illustrated in Figs 4 & 5. This may indicate that the uranium contents in the hydrothermal fluids at the earliest stage of the rutile ore-forming process is low, but increases as the process continues to develop.

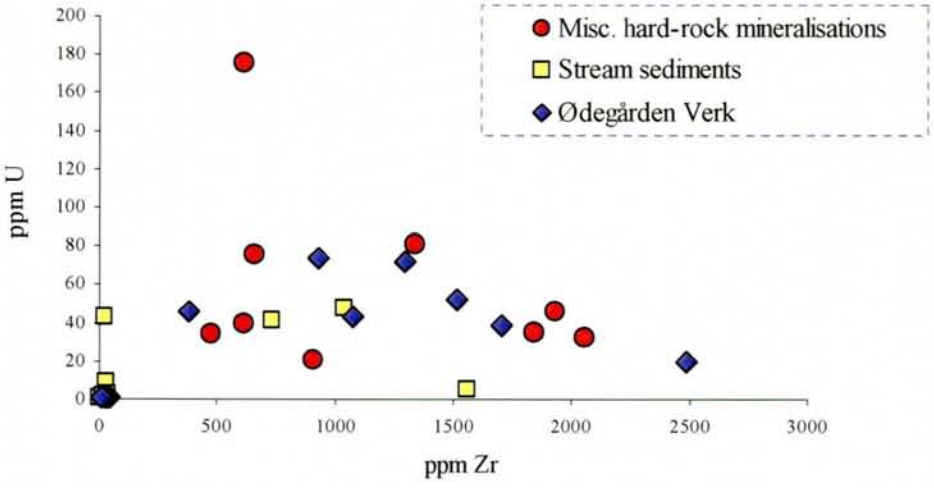


Fig. 11: Zr-U scattergram plots based on laser-ablation ICP-MS average values given in Table 2.

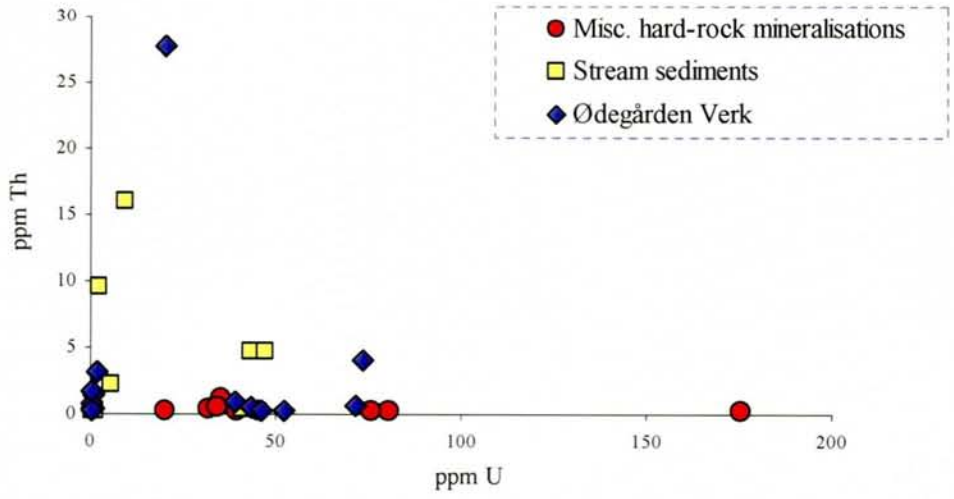


Fig. 12: U-Th scattergram plots based on laser-ablation ICP-MS average values given in Table 2.

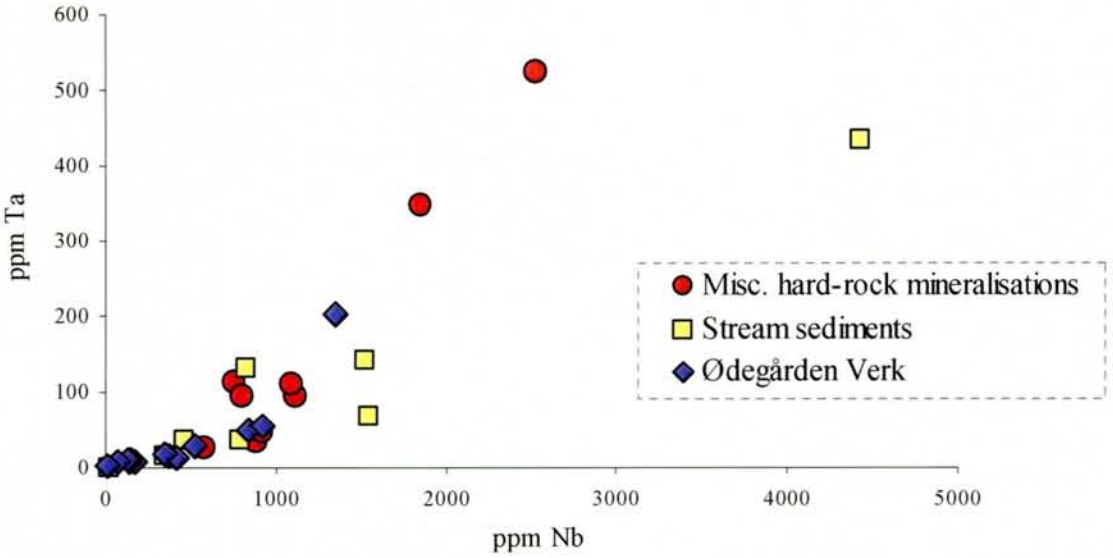


Fig. 13: Nb-Ta scattergram plots based on laser-ablation ICP-MS average values given in Table 1.

Thorium:

- In general the thorium contents in rutile are in the range 0.1-5 ppm.
- Distinctly high Th-values are found in samples 2Ø62.6 (partly scapolitised gabbro) from Ødegårdens Verk and in stream sediment samples 622 and 623, with 27.7, 16.1 and 9.6 ppm (average values) respectively (Table 1). These three samples define a distinct positive Th/U-correlation trend (Fig. 13).

Zirconium:

- Zirconium varies widely up to 2500 ppm Zr. Rutile with low Zr-content is usually also uranium poor. One exception is rutile from stream sediment sample 647 that has 23.4 ppm Zr and 43.6 ppm U; this sample is also unusual by having 4429 and 434 ppm Nb and Ta, respectively (Table 1, Fig 14).

Niobium and tantalum:

- Niobium and Tantalum are well correlated (Fig 14) and varies from a few ppm to ca. 4000 ppm Nb and 500 ppm Ta. The variations may be considerable within the same deposit, i.e. Ødegårdens Verk, as well as within individual samples.

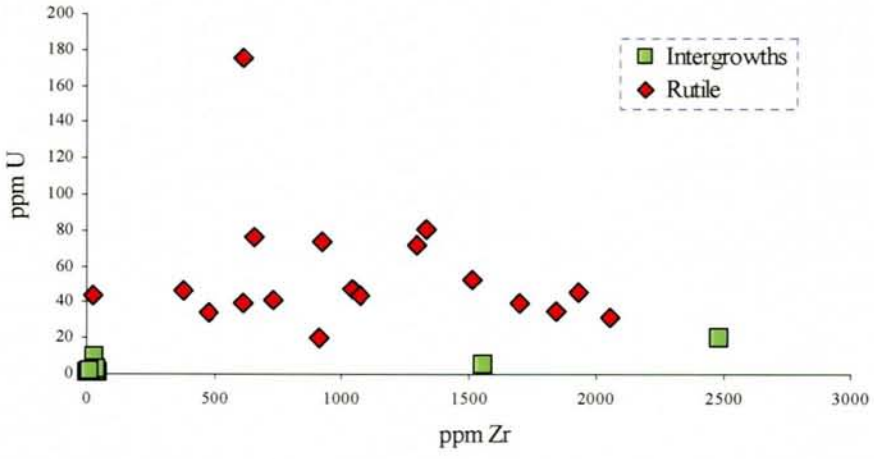


Fig. 14: Scattergram plot showing the U and Zr contents in rutile vs. mixed ilmenite-rutile-titanite grains (intergrowths), based on laser-ablation ICP-MS average values given in Table 1.

Table 2: Laser-ablation ICP-MS rutile analyses (average values) of rutile and associated minerals.

Locality	Sample	Rock	Mineral	Type	#	Zr	U	Th	Nb	Ta
Stream sediment site 622	622	Stream sediment heavy fraction (d >3.33)	Intergrown hematite-ilmenite-rutile	ssthm	3	32,2	9,3	16,1	352,0	14,8
Stream sediment site 623	623	Stream sediment heavy fraction (d >3.33)	Intergrown ilmenite-rutile-titanite	ssthm	2	39,6	2,3	9,6	471,2	38,1
Stream sediment site 624	624	Stream sediment heavy fraction (d >3.33)	Intergrown hematite-ilmenite-rutile	ssthm	1	1555,3	5,6	2,3	797,1	37,3
Stream sediment site 647	647	Stream sediment heavy fraction (d >3.33)	Rutile	ssthm	1	23,4	43,6	4,7	4429,5	434,4
Stream sediment site 649	649	Stream sediment heavy fraction (d >3.33)	Rutile	ssthm	3	731,3	41,1	0,4	827,5	131,3
Stream sediment site 650	650	Stream sediment heavy fraction (d >3.33)	Intergrown ilmenite-rutile	ssthm	1	2,3	0,6	0,2	20,3	0,6
Stream sediment site 650	650	Stream sediment heavy fraction (d >3.33)	Rutile	ssthm	2	1040,6	47,4	4,8	1527,0	143,1
Stream sediment site 655	655	Stream sediment heavy fraction (d >3.33)	Intergrown ilmenite-rutile-titanite	ssthm	1	13,3	1,5	0,2	1551,1	69,5
Bårknuten	K351.00	Pegmatite	Rutile	rock	3	612,9	39,5	0,2	1113,4	93,8
Fone	K111B.99	Amphibolite	Rutile	rock	3	2053,3	32,0	0,4	1850,6	346,4
Fone	K354C.00	Amphibolite	Rutile	rock	3	1933,9	45,5	0,2	760,6	114,5
Fone	KB5F.91	Amphibolite	Rutile	minconc	5	1843,9	35,3	1,2	2529,6	524,3
Gjerstadvatnet	KB43.91	Cordierite-bearing rock	Rutile	minconc	5	910,3	20,5	0,2	583,6	27,3
Gruvetjønn	KB6F.91	Amphibolite	Rutile	minconc	5	478,4	34,3	0,5	801,3	95,0
Haukåsen	KB9.91	Pegmatite	Rutile	minconc	5	1338,0	80,8	0,2	888,8	35,4
Sannidal	Sannidal	Cordierite-bearing rock	Rutile	minconc	4	655,7	75,9	0,2	1093,8	111,3
Ødegård	KB37.91	Scapolitised gabbro	Rutile	minconc	5	612,3	175,6	0,2	923,7	46,7
Ødegårdens Verk	1Ø66-79	Scapolitised gabbro	Rutile	minconc	5	1076,8	43,4	0,5	372,4	15,1
Ødegårdens Verk	2Ø120-	Scapolitised gabbro	Rutile	minconc	4	1702,0	39,0	0,9	834,1	49,9
Ødegårdens Verk	2Ø60.74	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	36,6	1,9	3,2	145,8	11,0
Ødegårdens Verk	2Ø62.6	Partly scapolitised gabbro	Intergrown rutile-titanite	rock	3	2485,7	20,1	27,7	174,5	8,1
Ødegårdens Verk	2Ø66.02	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	30,0	0,6	0,4	132,5	10,3
Ødegårdens Verk	2Ø86.2	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	37,7	0,9	1,5	519,1	29,3
Ødegårdens Verk	2Ø88.05	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	44,5	0,8	0,4	139,5	9,0
Ødegårdens Verk	2Ø88.4	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	34,0	0,9	1,5	139,7	11,5
Ødegårdens Verk	2Ø88.55	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	36,2	0,7	0,8	124,0	9,7
Ødegårdens Verk	2Ø88.8	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	3	19,5	0,6	1,7	72,4	8,0
Ødegårdens Verk	2Ø89.1	Partly scapolitised gabbro	Intergrown ilmenite-rutile	rock	1	7,5	0,6	0,3	11,2	1,9
Ødegårdens Verk	2Ø89.1	Scapolitised gabbro	Rutile	rock	2	1297,7	71,7	0,6	415,7	11,9
Ødegårdens Verk	2Ø89.35	Scapolitised gabbro	Rutile	rock	3	1517,3	52,3	0,3	346,7	17,9
Ødegårdens Verk	2Ø98-114	Scapolitised gabbro	Rutile	minconc	5	925,8	73,5	4,1	922,5	54,8
Ødegårdens Verk	KB12H.91	Scapolitised gabbro	Rutile	minconc	5	378,9	46,3	0,3	1354,8	201,6

6. Discussion and conclusion

Since there is no precedent available in Norway in the use of stream sediments in rutile exploration, the present interpretations must be regarded as indicative only. Comparable information from other titanium provinces would have been a distinct advantage for improving the Bamble interpretations.

An important observation is that uranium in rutile is low (< 10 ppm U) at the early stage of the ilmenite to rutile transformation; in this situation the new rutiles are incompletely developed and are still dominated by intergrowths of ilmenite, titanite and rutile (Figs 3, 4 & 5). The uranium content in the fully developed rutile is in the range 30-80 ppm U. This may indicate that uranium content is low in the hydrothermal system at the early stage, but increases gradually as the system develops. This particular problem requires further studies. However, it is unlikely that the Arendal-Bamble region contains rutile deposits of sufficient size and grade to be of economic interest where the U content in rutile is less than 30-50 ppm.

Due to topographic and local variations, this measurement of absolute value of rutile in the stream sediments is probably not a good indicator for rutile deposits. The best indicator for localising areas where rutile ore-forming processes have been active may be the rutile/ilmenite ratio. It is interesting to observe that the Ødegårdens Verk area shows up in the rutile/ilmenite-ratio map (Appendix 5 and Fig. 10) but not in the rutile map (Appendix 4).

Titanite is present in most observed rutile mineralizations either as intergrowths with ilmenite and rutile in incomplete ilmenite to rutile transitions, or as an effect of retrograde alteration along fractures or at the margin of rutile grains.

There is no doubt that the mineralogy in the stream sediments (heavy fraction) reflects the character of the rocks in the respective area. However, due to the limited time available for the present project a detailed study of these relationships have not been done.

It is advisable that the remaining stream sediment heavy separates should be studied in order to obtain more information about the regional variations. It is also advisable to follow up this study by field investigations of those sample sites that have "good rutile".

In conclusion: The uranium content in rutile from various places in the Arendal-Bamble region is in the range 30-80 ppm U. This information was the main objective of this investigation.

7. References

Finne, T.E. 2000: Field notes for stream sediment collection Bamble-Arendal. NGU report 2000.141.

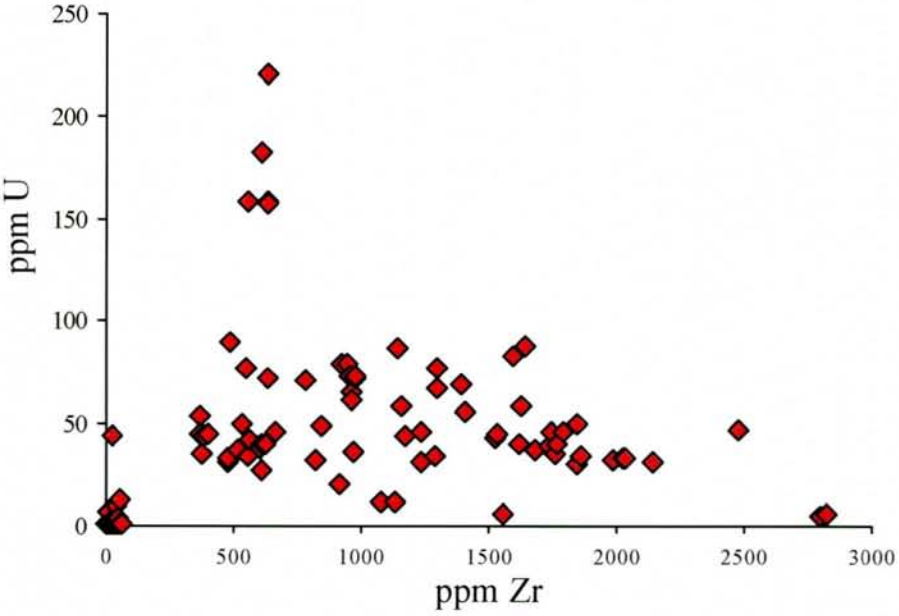
Korneliussen, A., Furuhaug, L. 2000: On the rutile deposit Ramsgrønova, Orkheia, Ødegården and Lindvikkollen, S. Norway. NGU report 2000.123.

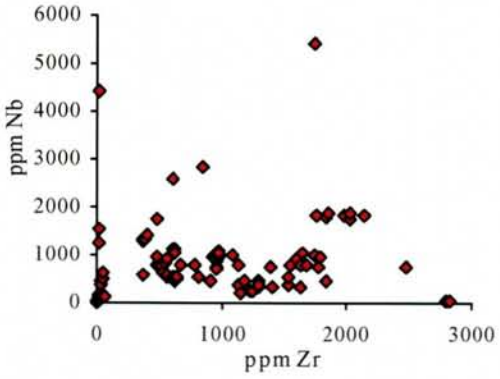
Korneliussen, A., Furuhaug, L., Gautneb, H., Ihlen, P. 1999: Rutile deposits in Norway. NGU report 1999.129A, B, C.

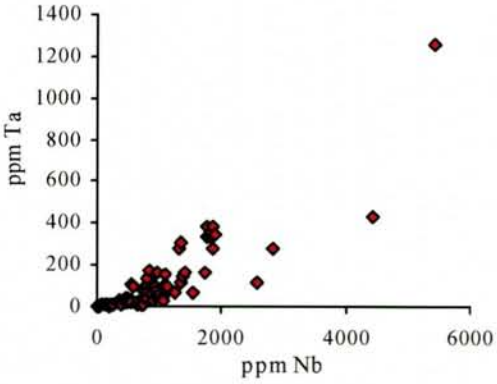
APPENDIX 1:

LASER ABLATION
ICP-MS ANALYSES

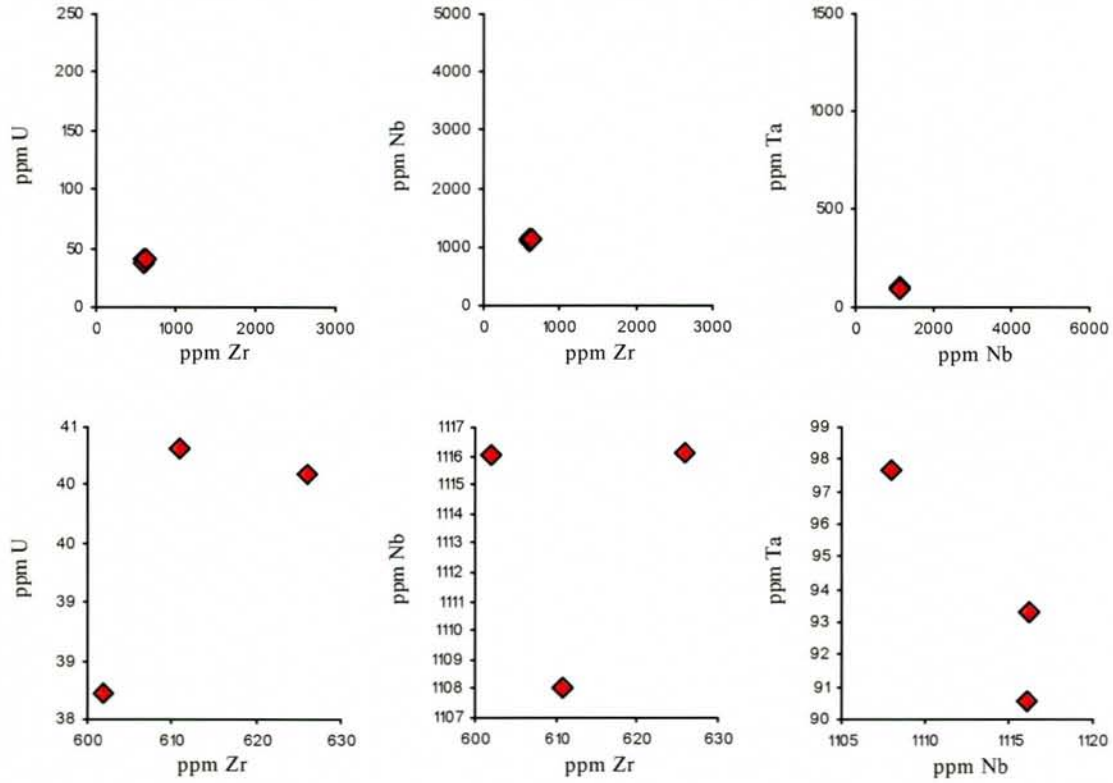
RUTILE





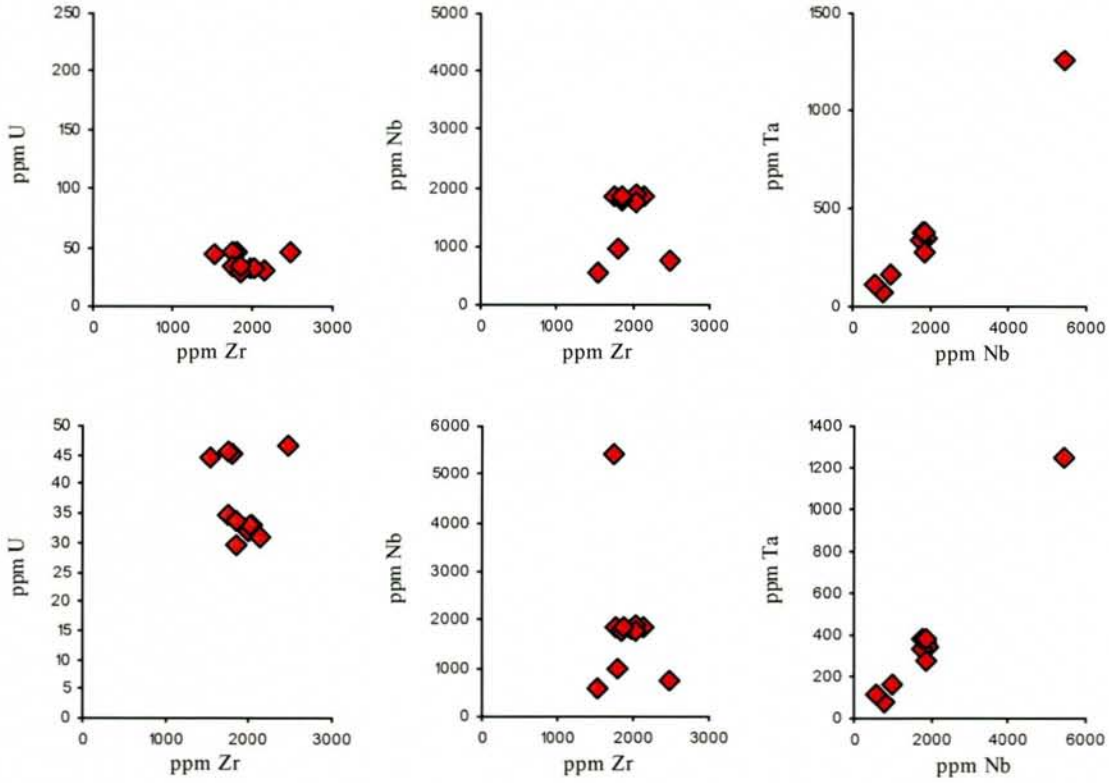


BÅRKNUTEN



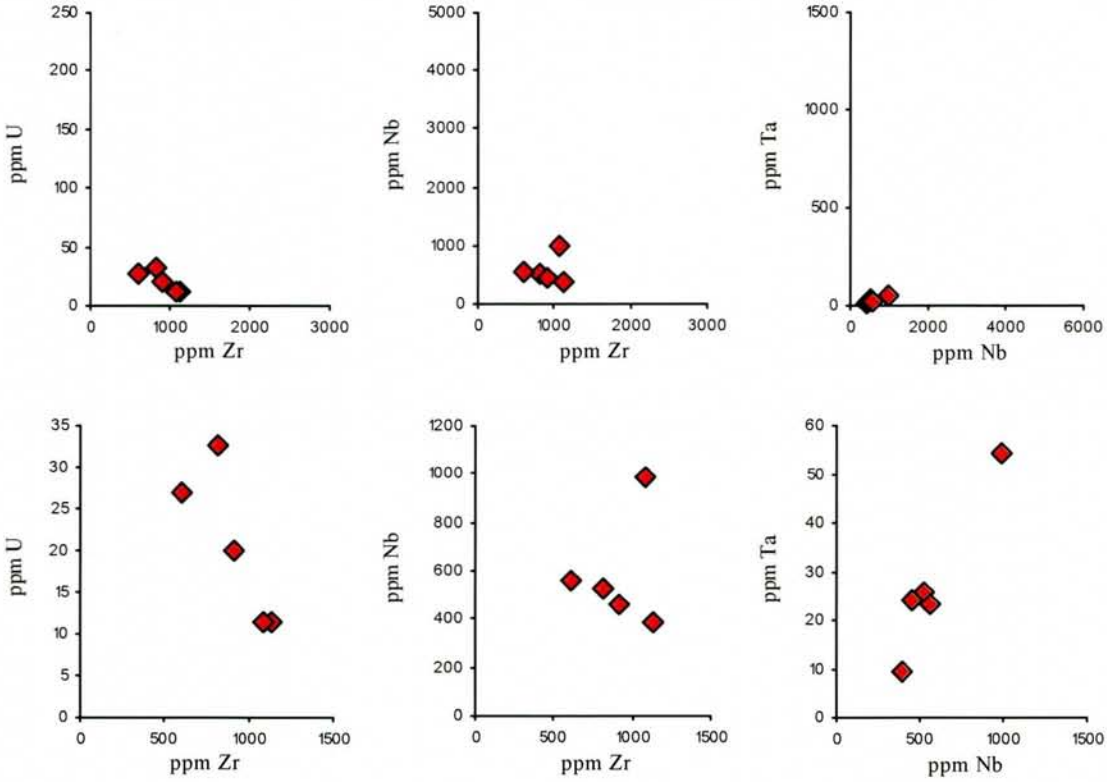
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	K351.00	3	rock	1	610.79	108.03	97.66	0.2	40.3
Rutile	K351.00	3	rock	2	601.88	116.05	90.52	0.2	38.2
Rutile	K351.00	3	rock	3	625.91	116.14	93.33	0.2	40.1
Bårknuten			Average:		612.86	113.40	93.84	0.2	39.5

FONE



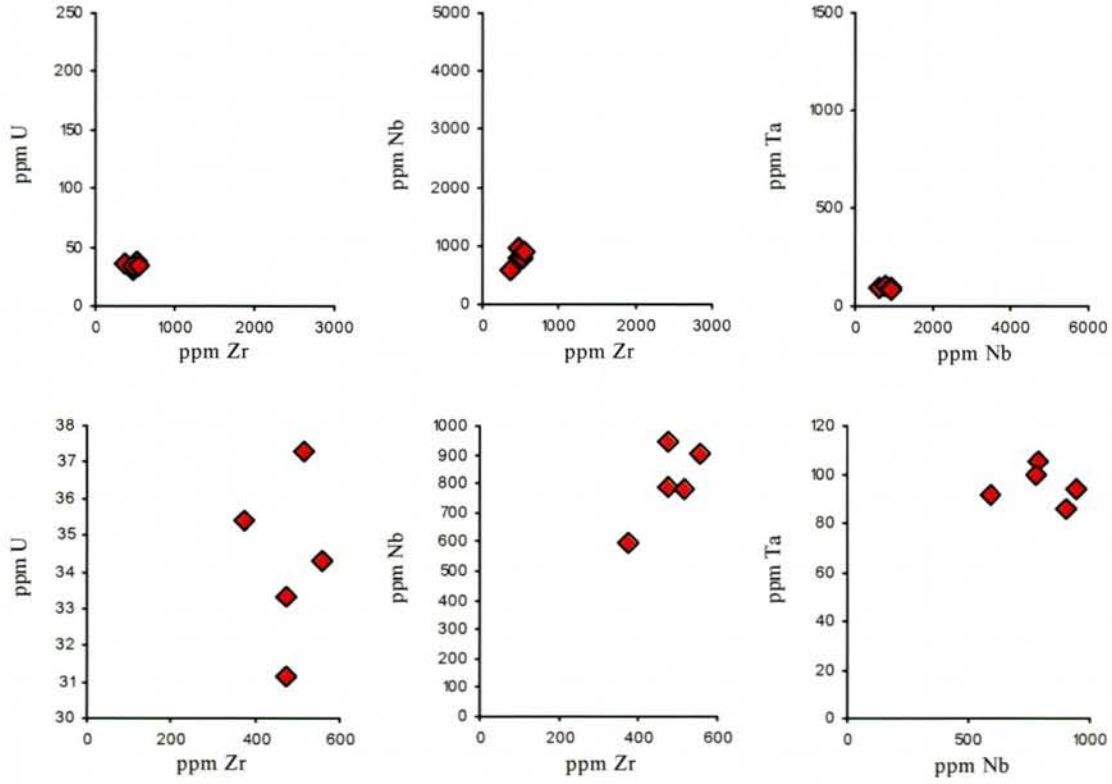
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	K111B.99	13	rock	1	1985.97	822.41	332.75	0.6	32.0
Rutile	K111B.99	13	rock	2	2144.29	839.50	359.38	0.2	31.1
Rutile	K111B.99	13	rock	3	2029.57	889.78	347.18	0.3	32.9
Rutile	K354C.00	9	rock	1	2480.25	751.36	73.48	0.2	46.6
Rutile	K354C.00	9	rock	2	1532.56	558.80	109.99	0.2	44.6
Rutile	K354C.00	9	rock	3	1788.80	971.65	159.92	0.2	45.4
Rutile	KB5F.91	16	minconc	1	2022.57	753.19	332.48	1.6	32.9
Rutile	KB5F.91	16	minconc	2	1742.66	412.25	252.01	1.2	45.4
Rutile	KB5F.91	16	minconc	3	1757.15	851.49	275.12	0.6	34.6
Rutile	KB5F.91	16	minconc	4	1839.89	776.04	379.32	1.2	29.7
Rutile	KB5F.91	16	minconc	5	1857.36	854.80	382.46	1.2	33.8
Fone			Average:		1925.55	861.93	364.01	0.7	37.2

GJERSTADVATNET



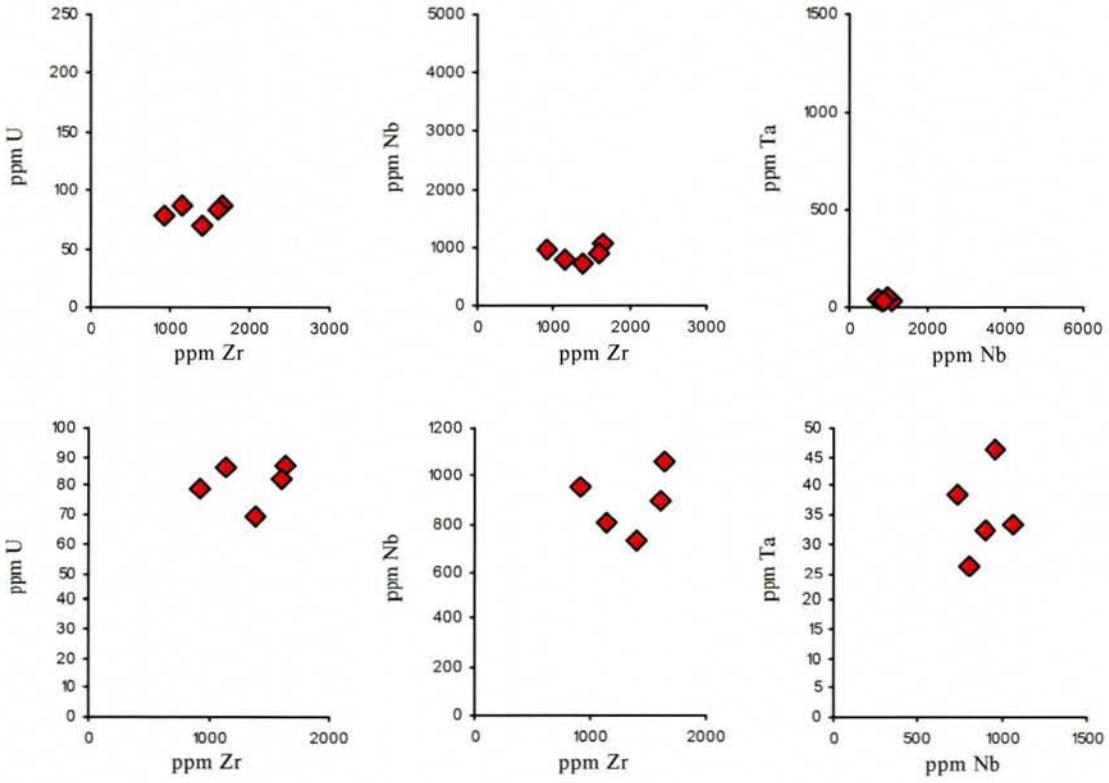
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	KB43.91	11	minconc	1	818.94	525.79	25.55	0.2	32.6
Rutile	KB43.91	11	minconc	2	1132.16	389.14	9.35	0.2	11.5
Rutile	KB43.91	11	minconc	3	1081.89	986.55	54.22	0.2	11.4
Rutile	KB43.91	11	minconc	4	911.72	456.95	23.92	0.2	20.0
Rutile	KB43.91	11	minconc	5	606.65	559.45	23.45	0.2	26.9
Gjerstadvatnet			Average:		910.27	583.57	27.30	0.2	20.5

GRUVETJØNN



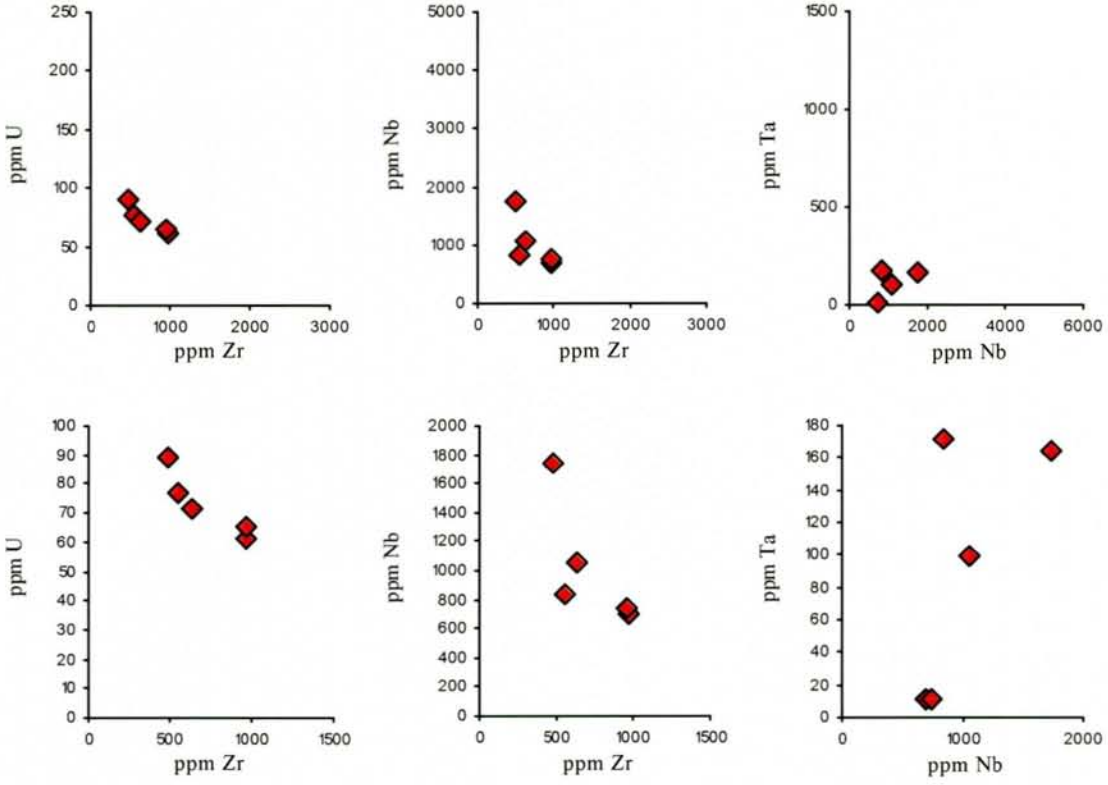
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	KB6F.91	14	minconc	1	473.32	790.19	105.42	1.1	31.2
Rutile	KB6F.91	14	minconc	2	373.78	592.77	91.24	0.3	35.4
Rutile	KB6F.91	14	minconc	3	515.20	778.92	99.42	0.6	37.3
Rutile	KB6F.91	14	minconc	4	473.48	943.50	93.53	0.2	33.3
Rutile	KB6F.91	14	minconc	5	556.24	900.92	85.37	0.2	34.3
Gruvetjønn			Average:		478.40	801.26	95.00	0.5	34.3

HAUKÅSEN



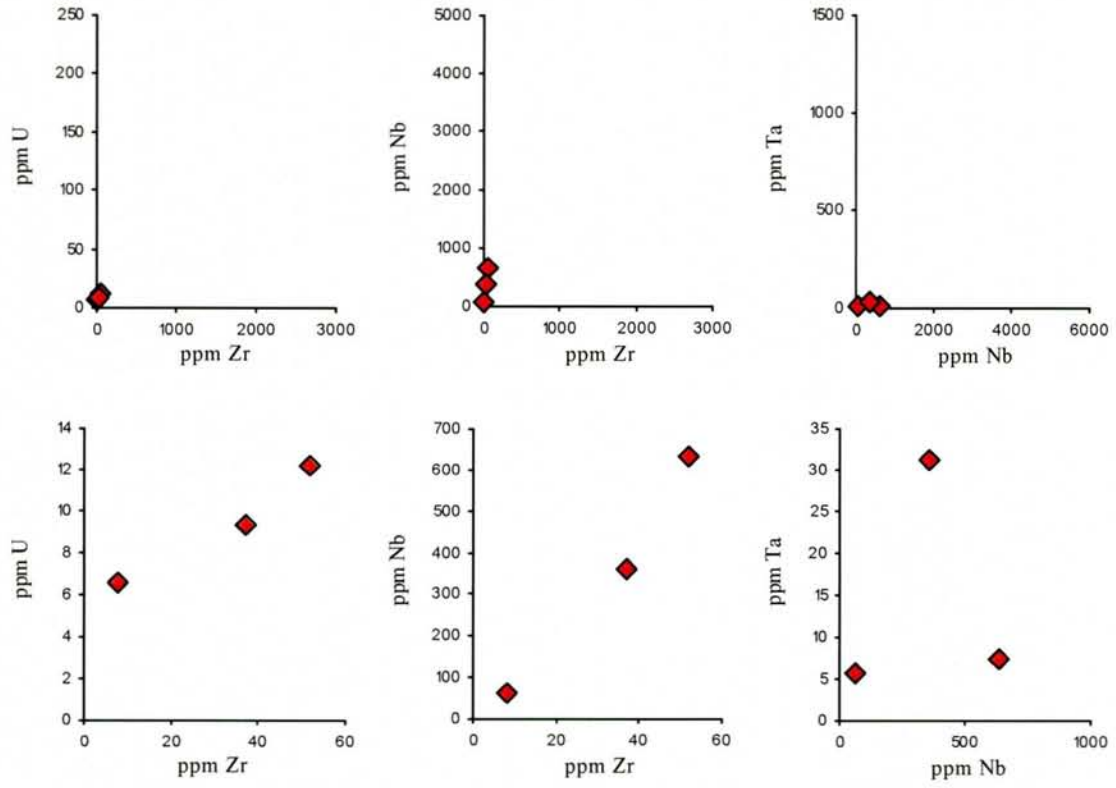
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	KB9.91	9	minconc	1	1642.86	057.91	33.29	0.2	87.3
Rutile	KB9.91	9	minconc	2	919.88	957.15	46.27	0.2	78.6
Rutile	KB9.91	9	minconc	3	1140.33	802.95	26.34	0.2	86.3
Rutile	KB9.91	9	minconc	4	1390.01	729.80	38.44	0.2	69.5
Rutile	KB9.91	9	minconc	5	1597.06	896.28	32.48	0.2	82.5
Haukåsen			Average:		1338.03	888.82	35.36	0.2	80.8

SANNIDAL



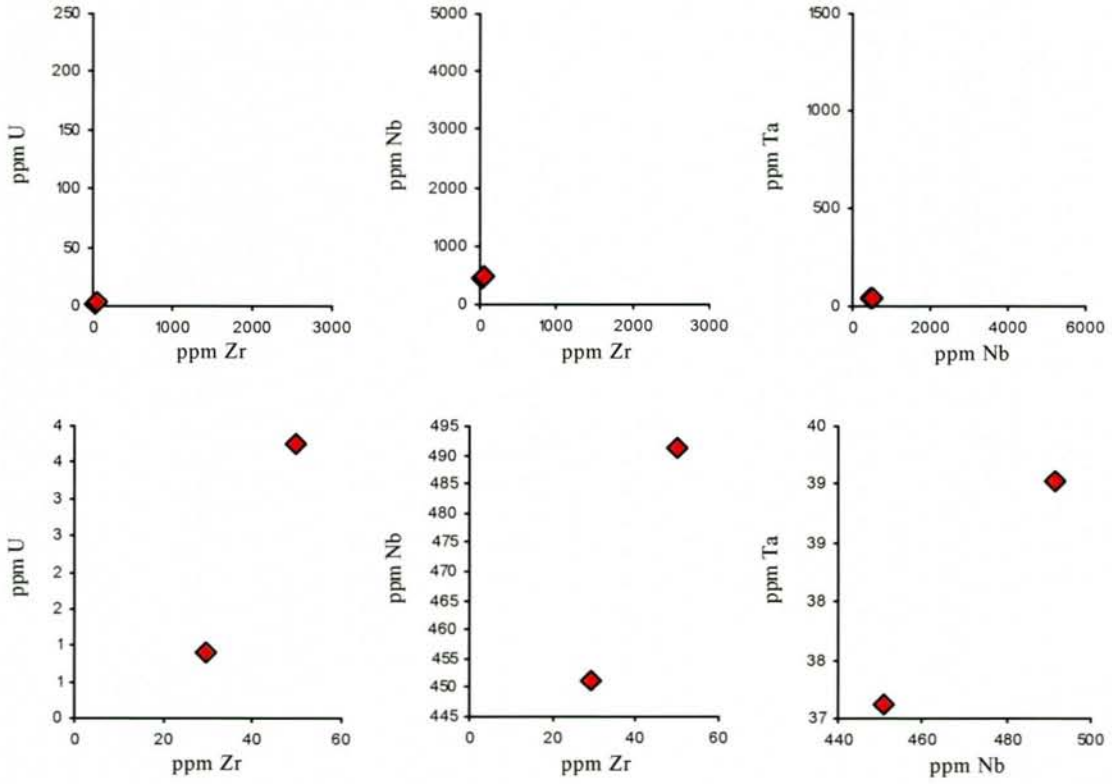
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	Sannidal		minconc	1	483.90	739.90	164.33	0.2	89.4
Rutile	Sannidal		minconc	2	963.94	696.47	10.96	0.2	61.4
Rutile	Sannidal		minconc	3	959.83	742.66	10.91	0.2	65.4
Rutile	Sannidal		minconc	4	549.62	837.92	170.83	0.2	77.2
Rutile	Sannidal		minconc	5	629.44	054.74	99.13	0.2	71.7
Sannidal			Average:		717.35	014.34	91.23	0.2	73.0

STREAM SEDIMENT SITE 622



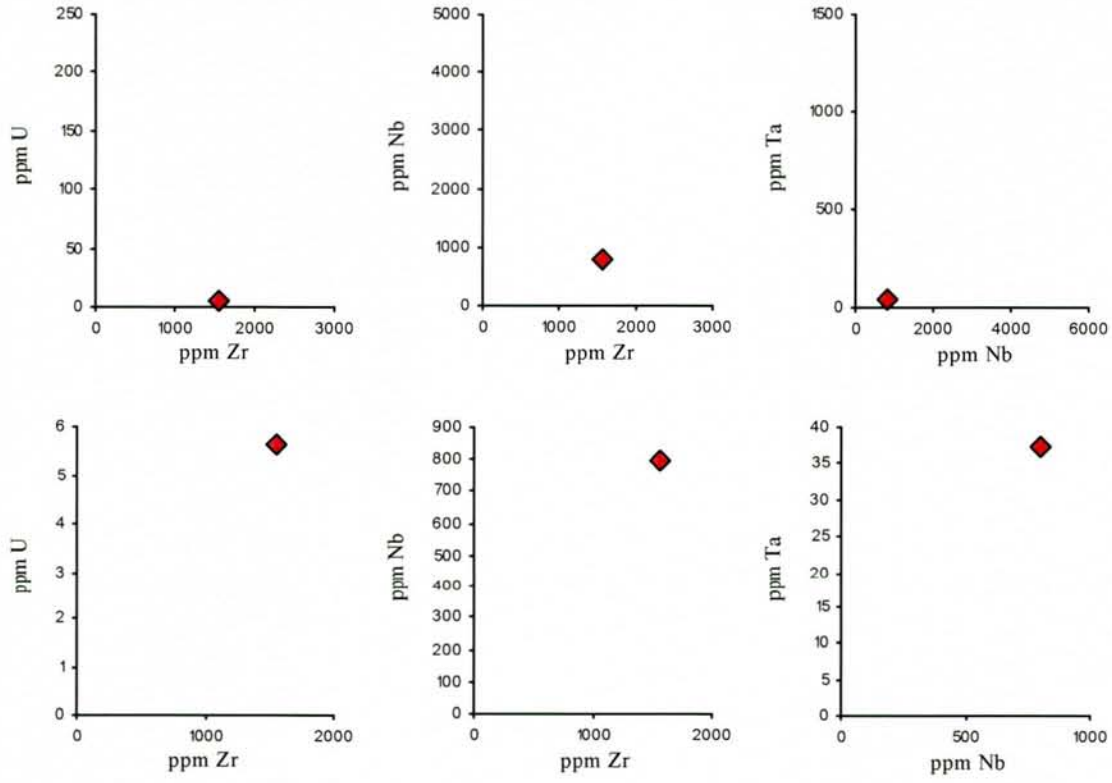
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Intergrown he	622	7	ssthm	1	7.95	61.45	5.80	14.4	6.6
Intergrown he	622	7	ssthm	2	51.63	634.70	7.36	23.7	12.2
Intergrown he	622	7	ssthm	3	36.99	359.79	31.28	10.2	9.3
Stream sediment site 622			Average:		32.19	351.98	14.82	16.1	9.3

STREAM SEDIMENT SITE 623



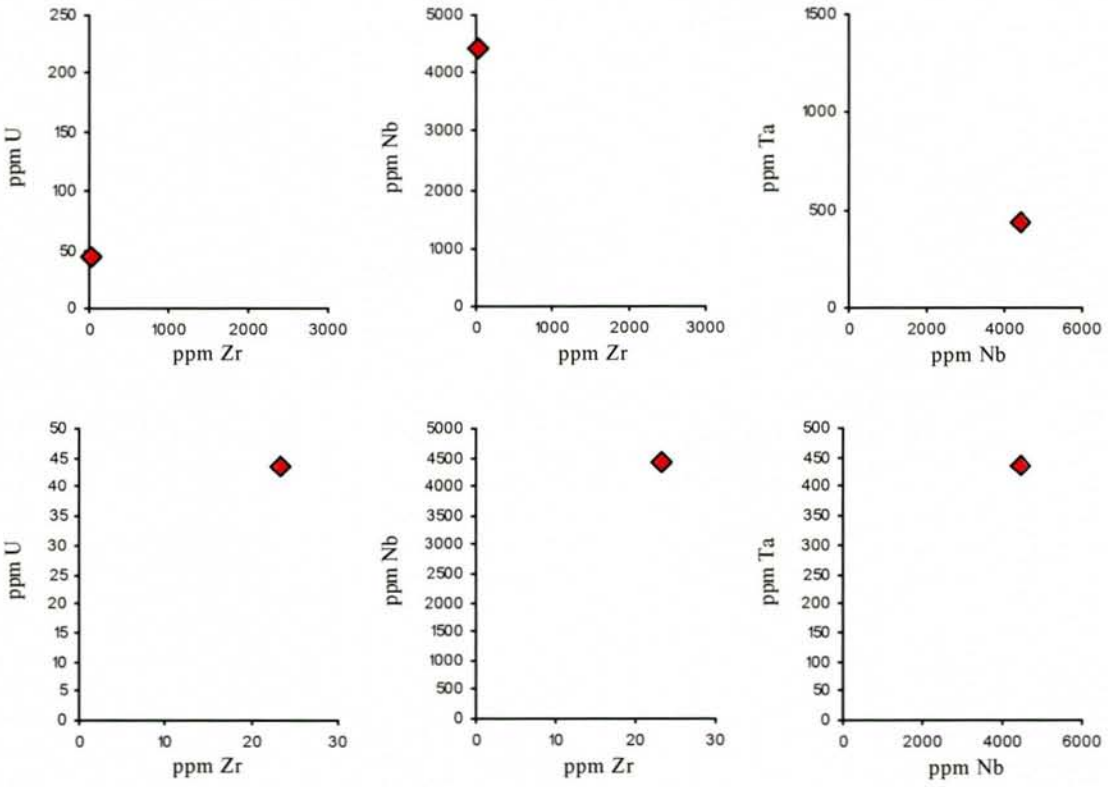
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Intergrown il	623	8	ssthm	1	29.39	451.09	37.12	5.1	0.9
Intergrown il	623	8	ssthm	2	49.76	491.32	39.02	14.1	3.8
Stream sediment site 623			Average:		39.57	471.20	38.07	9.6	2.3

STREAM SEDIMENT SITE 624



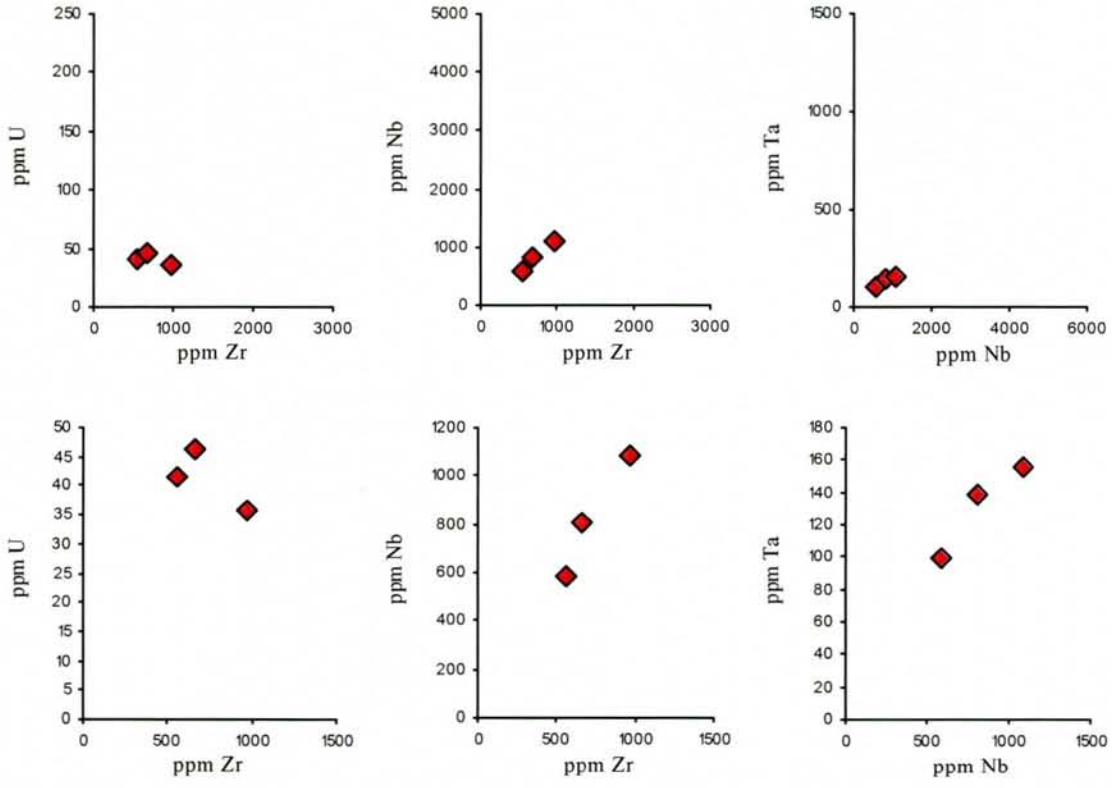
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Intergrown he	624	2	ssthm	1	1555.34	797.11	37.27	2.3	5.6
Stream sediment site 624			Average:		1555.34	797.11	37.27	2.3	5.6

STREAM SEDIMENT SITE 647



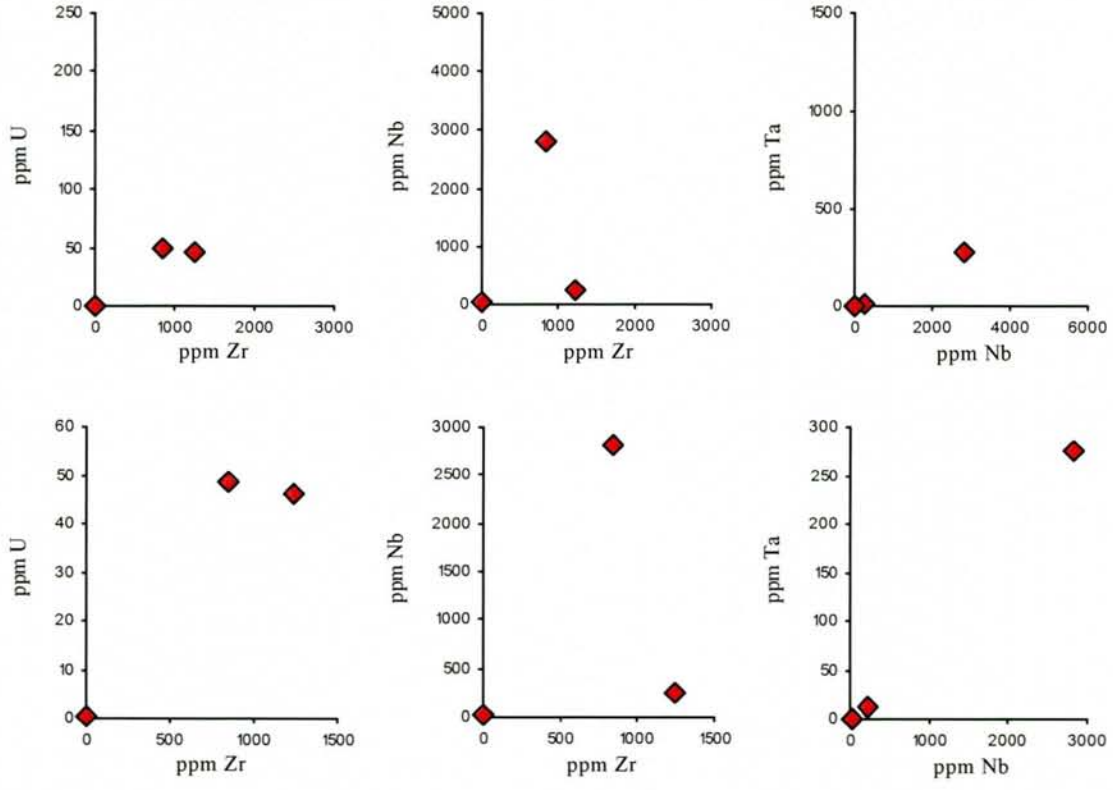
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	647	3	ssthm	1	23.37	429.47	434.41	4.7	43.6
Stream sediment site 647			Average:		23.37	429.47	434.41	4.7	43.6

STREAM SEDIMENT SITE 649



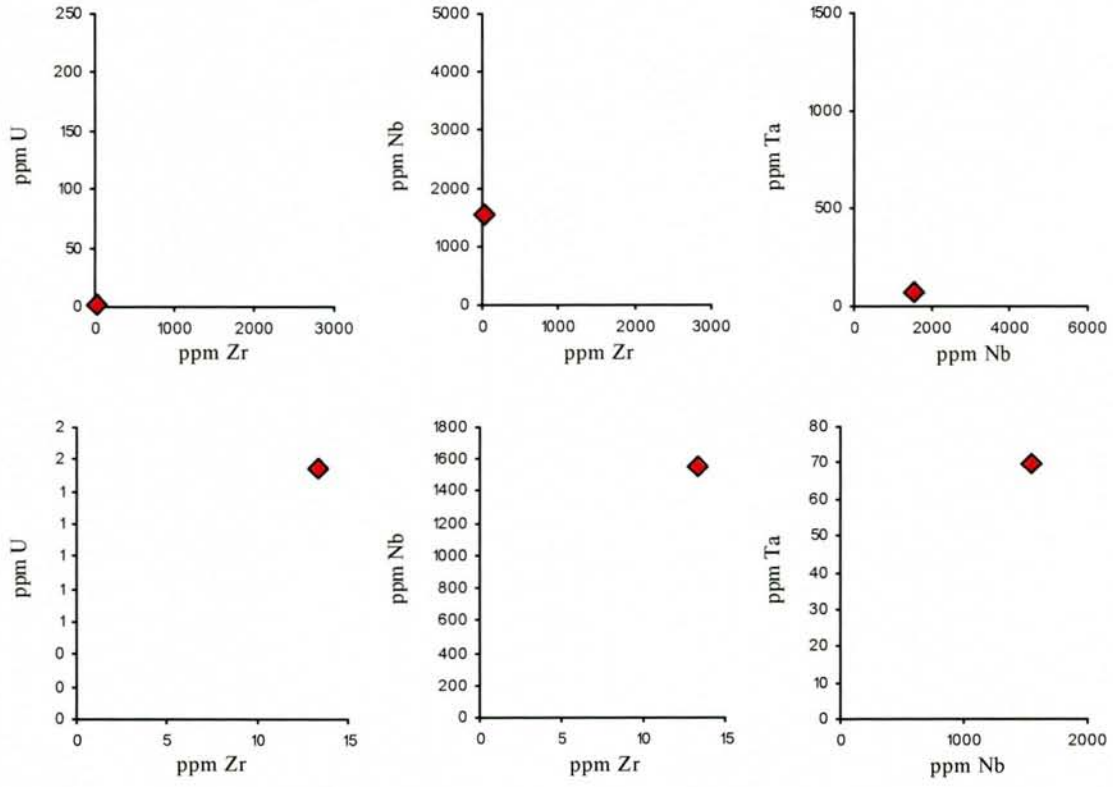
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	649	4	ssthm	1	559.78	584.42	99.56	0.2	41.6
Rutile	649	4	ssthm	2	666.76	809.10	138.87	0.7	46.2
Rutile	649	4	ssthm	3	967.49	088.92	155.41	0.2	35.6
Stream sediment site 649			Average:		731.34	827.48	131.28	0.4	41.1

STREAM SEDIMENT SITE 650



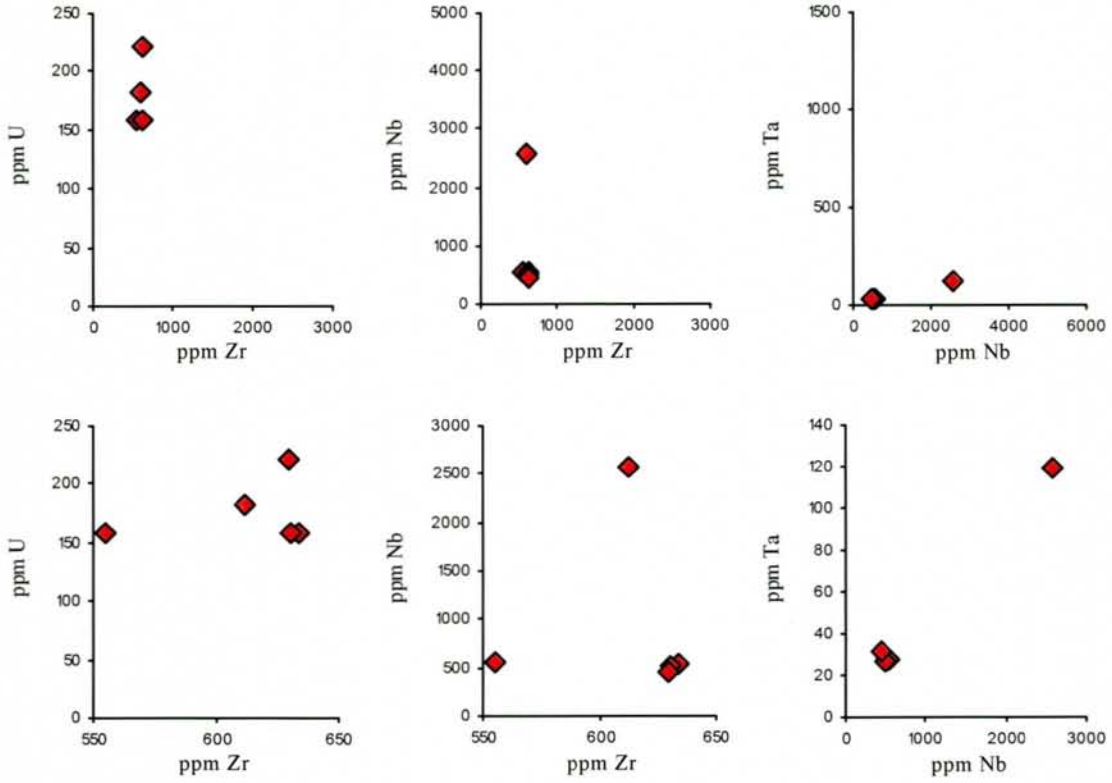
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	650	5	ssthm	1	1237.65	238.62	11.30	9.3	46.1
Intergrown il	650	5	ssthm	2	2.34	20.28	0.63	0.2	0.6
Rutile	650	5	ssthm	3	843.63	815.44	274.83	0.2	48.6
Stream sediment site 650			Average:		694.54	024.78	95.59	3.2	31.8

STREAM SEDIMENT SITE 655



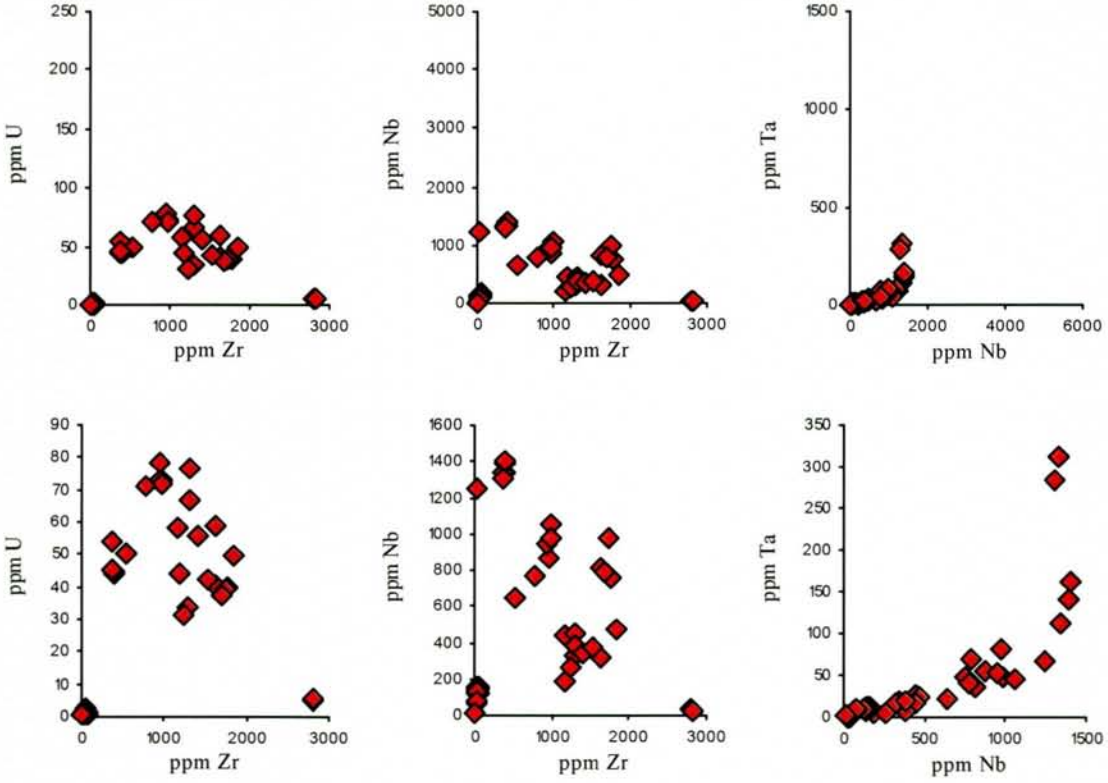
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Intergrown il	655	6	ssthm	1	13.35	551.13	69.45	0.2	1.5
Stream sediment site 655			Average:		13.35	551.13	69.45	0.2	1.5

ØDEGÅRD



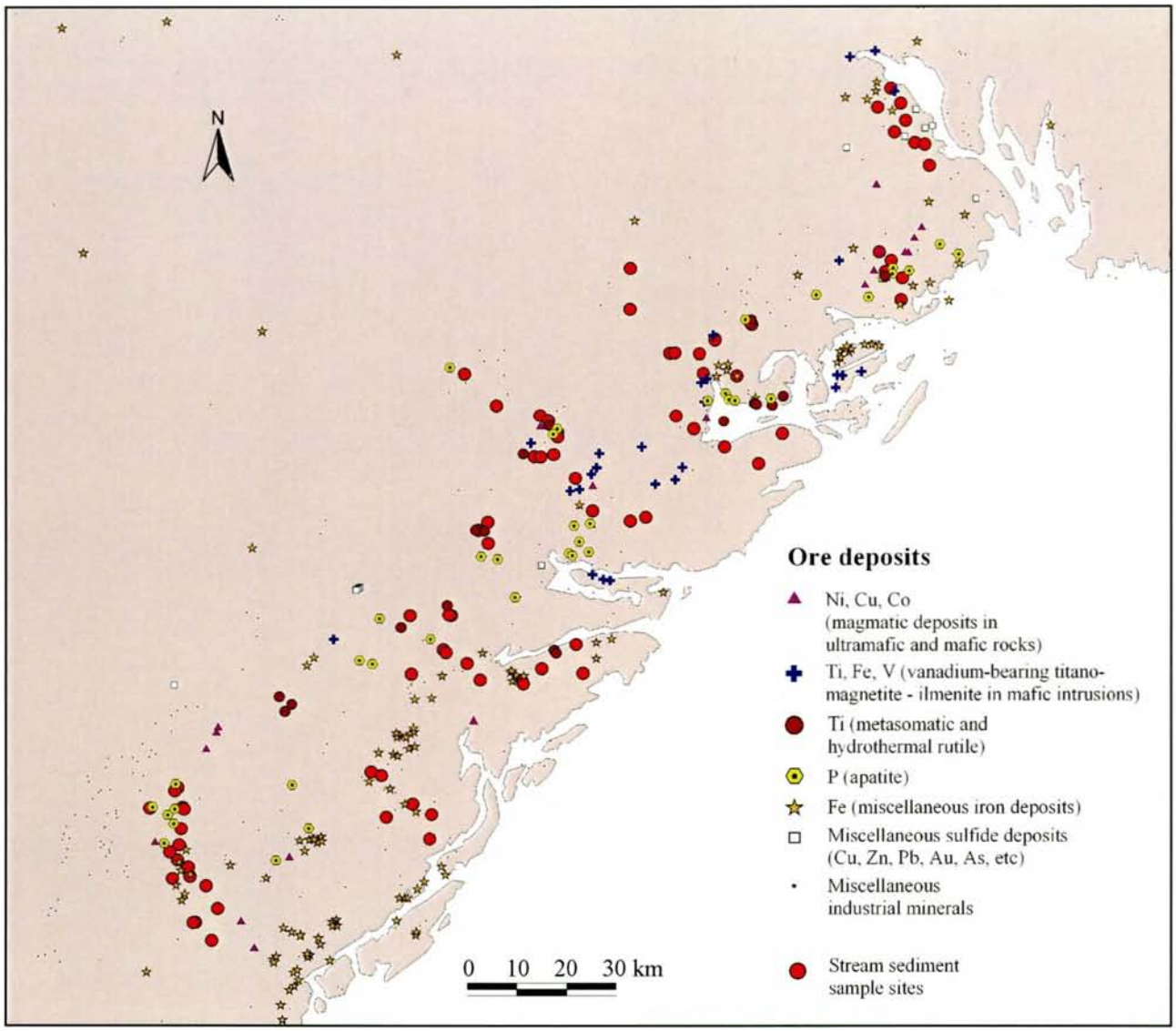
Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	KB37.91	10	minconc	1	555.26	548.30	27.93	0.2	158.8
Rutile	KB37.91	10	minconc	2	633.82	541.19	27.62	0.2	158.0
Rutile	KB37.91	10	minconc	3	630.58	506.51	27.04	0.2	158.4
Rutile	KB37.91	10	minconc	4	629.59	446.62	31.73	0.2	220.5
Rutile	KB37.91	10	minconc	5	612.14	575.90	119.00	0.2	182.4
Ødegård			Average:		612.28	923.71	46.66	0.2	175.6

ØDEGÅRDENS VERK

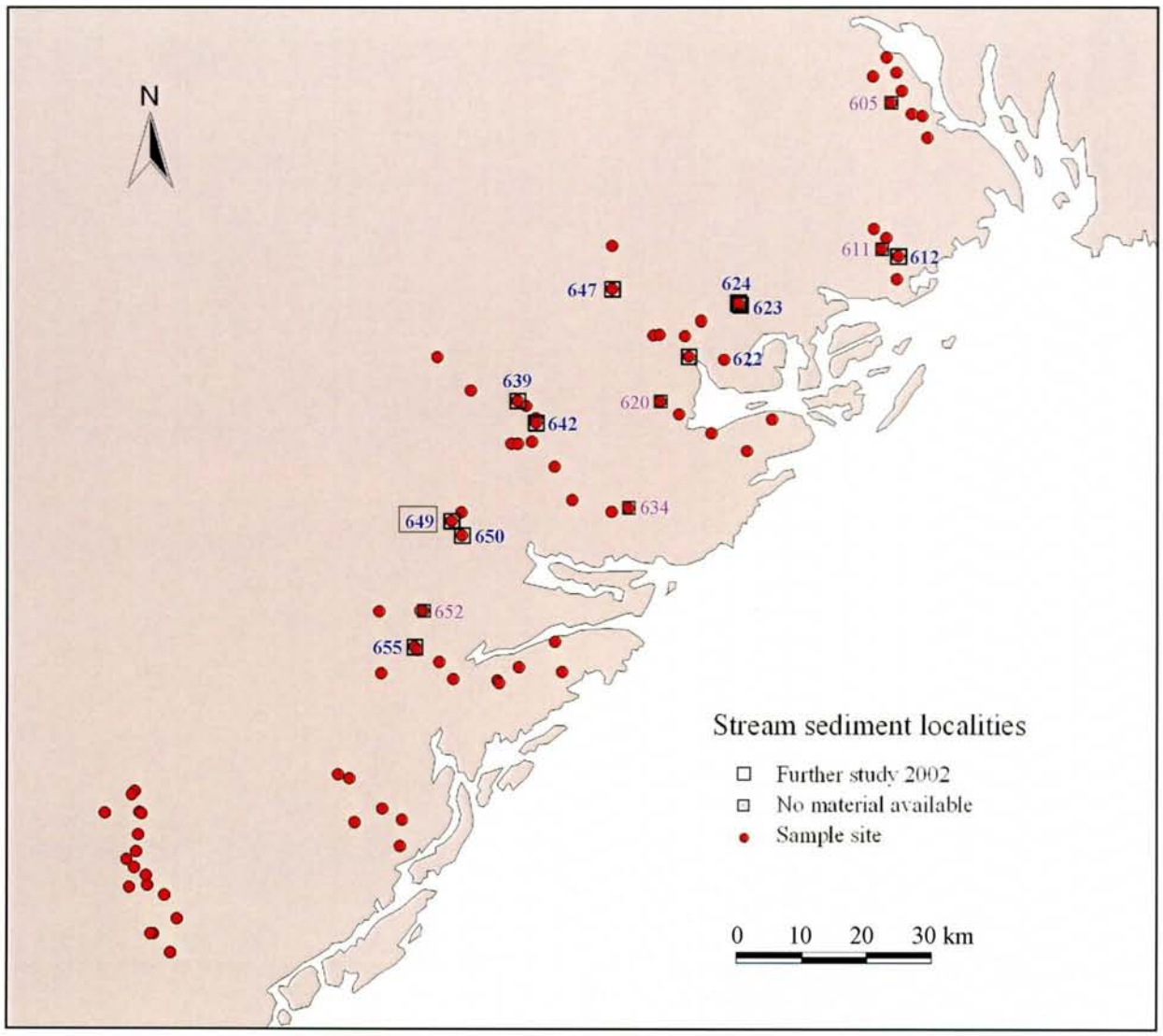


Mineral	SampNo1	SampNo2	SampType	AnalNo	Zr	Nb	Ta	Th	U
Rutile	1Ø66-79	5	minconc	1	1156.32	189.36	4.78	0.2	58.2
Rutile	1Ø66-79	5	minconc	2	1289.65	324.46	16.95	1.3	33.9
Rutile	1Ø66-79	5	minconc	3	527.83	643.98	21.37	0.7	49.9
Rutile	1Ø66-79	5	minconc	4	1174.49	441.88	26.80	0.2	44.2
Rutile	1Ø66-79	5	minconc	5	1235.54	262.51	5.78	0.2	30.9
Rutile	2Ø120-	7	minconc	2	1768.45	755.77	47.89	0.2	39.5
Rutile	2Ø120-	7	minconc	3	1619.90	809.40	34.61	0.4	40.2
Rutile	2Ø120-	7	minconc	4	1736.34	979.78	47.92	2.7	39.1
Rutile	2Ø120-	7	minconc	5	1683.33	791.47	69.23	0.2	37.4
Intergrown il	2Ø60.74	1	rock	1	46.74	144.03	11.23	2.8	2.2
Intergrown il	2Ø60.74	1	rock	2	42.93	146.48	10.75	4.9	2.0
Intergrown il	2Ø60.74	1	rock	3	20.27	146.75	11.04	1.9	1.3
Intergrown rut	2Ø62.6	3	rock	1	2800.03	31.19	0.64	32.8	4.9
Intergrown rut	2Ø62.6	3	rock	2	2816.97	25.42	0.60	48.0	5.6
Intergrown rut	2Ø62.6	3	rock	3	1840.14	466.84	22.92	2.3	49.8
Intergrown il	2Ø66.02	4	rock	1	29.05	152.96	11.68	0.4	0.6
Intergrown il	2Ø66.02	4	rock	2	28.68	125.30	9.81	0.2	0.6
Intergrown il	2Ø66.02	4	rock	3	32.16	119.36	9.53	0.5	0.6
Intergrown il	2Ø86.2	6	rock	1	13.99	245.06	66.99	1.5	1.1
Intergrown il	2Ø86.2	6	rock	2	44.58	156.74	10.05	0.2	0.6
Intergrown il	2Ø86.2	6	rock	3	54.47	155.52	10.83	3.0	0.9
Intergrown il	2Ø88.05	7	rock	1	62.40	137.06	9.53	0.3	0.9
Intergrown il	2Ø88.05	7	rock	2	34.16	140.56	9.47	0.4	0.8
Intergrown il	2Ø88.05	7	rock	3	36.87	141.02	8.08	0.4	0.7

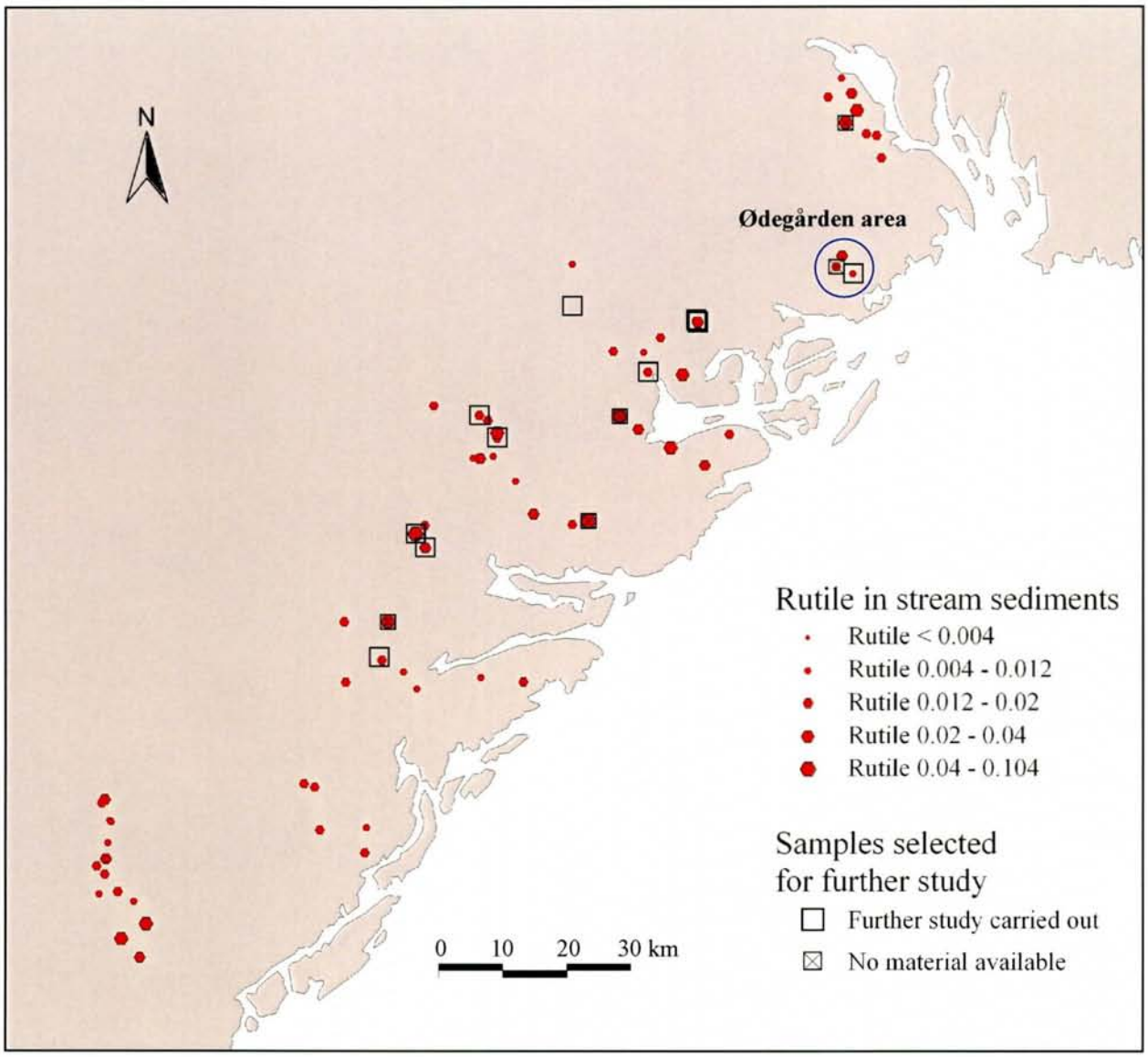
Intergrown il	2Ø88.4	8	rock	1	37.80	140.50	11.60	2.4	0.9
Intergrown il	2Ø88.4	8	rock	2	37.84	140.14	11.38	1.7	0.9
Intergrown il	2Ø88.4	8	rock	3	26.42	138.52	11.47	0.3	0.7
Intergrown il	2Ø88.55	9	rock	1	23.90	125.62	10.18	0.4	0.6
Intergrown il	2Ø88.55	9	rock	2	60.89	119.48	9.11	1.8	0.9
Intergrown il	2Ø88.55	9	rock	3	23.83	126.78	9.84	0.2	0.6
Intergrown il	2Ø88.8	10	rock	1	20.36	69.46	7.78	0.3	0.6
Intergrown il	2Ø88.8	10	rock	2	18.20	68.32	7.78	1.3	0.6
Intergrown il	2Ø88.8	10	rock	3	19.83	79.48	8.45	3.5	0.6
Intergrown il	2Ø89.1	11	rock	1	7.53	11.22	1.94	0.3	0.6
Rutile	2Ø89.1	11	rock	2	1295.28	448.60	15.88	0.2	66.8
Rutile	2Ø89.1	11	rock	3	1300.19	382.81	7.88	1.0	76.5
Rutile	2Ø89.35	12	rock	1	1404.40	345.18	18.29	0.4	55.6
Rutile	2Ø89.35	12	rock	2	1621.57	317.02	16.47	0.2	58.8
Rutile	2Ø89.35	12	rock	3	1525.88	377.83	18.96	0.2	42.5
Rutile	2Ø98-114	6	minconc	1	978.54	055.64	45.83	0.2	72.7
Rutile	2Ø98-114	6	minconc	2	954.07	867.66	55.55	0.3	73.0
Rutile	2Ø98-114	6	minconc	3	941.99	945.86	51.39	19.5	78.4
Rutile	2Ø98-114	6	minconc	4	973.46	971.26	80.48	0.4	71.8
Rutile	2Ø98-114	6	minconc	5	781.01	772.28	40.59	0.3	71.3
Rutile	KB12H.91	8	minconc	1	384.36	333.21	311.35	0.2	43.9
Rutile	KB12H.91	8	minconc	2	366.52	336.50	111.09	0.2	53.6
Rutile	KB12H.91	8	minconc	3	380.65	394.68	140.26	0.2	44.0
Rutile	KB12H.91	8	minconc	4	394.92	402.37	162.52	0.2	44.8
Rutile	KB12H.91	8	minconc	5	368.18	307.26	282.54	0.7	45.1
Ødegårdens Verk			Average:		694.75	465.52	39.33	2.9	27.6



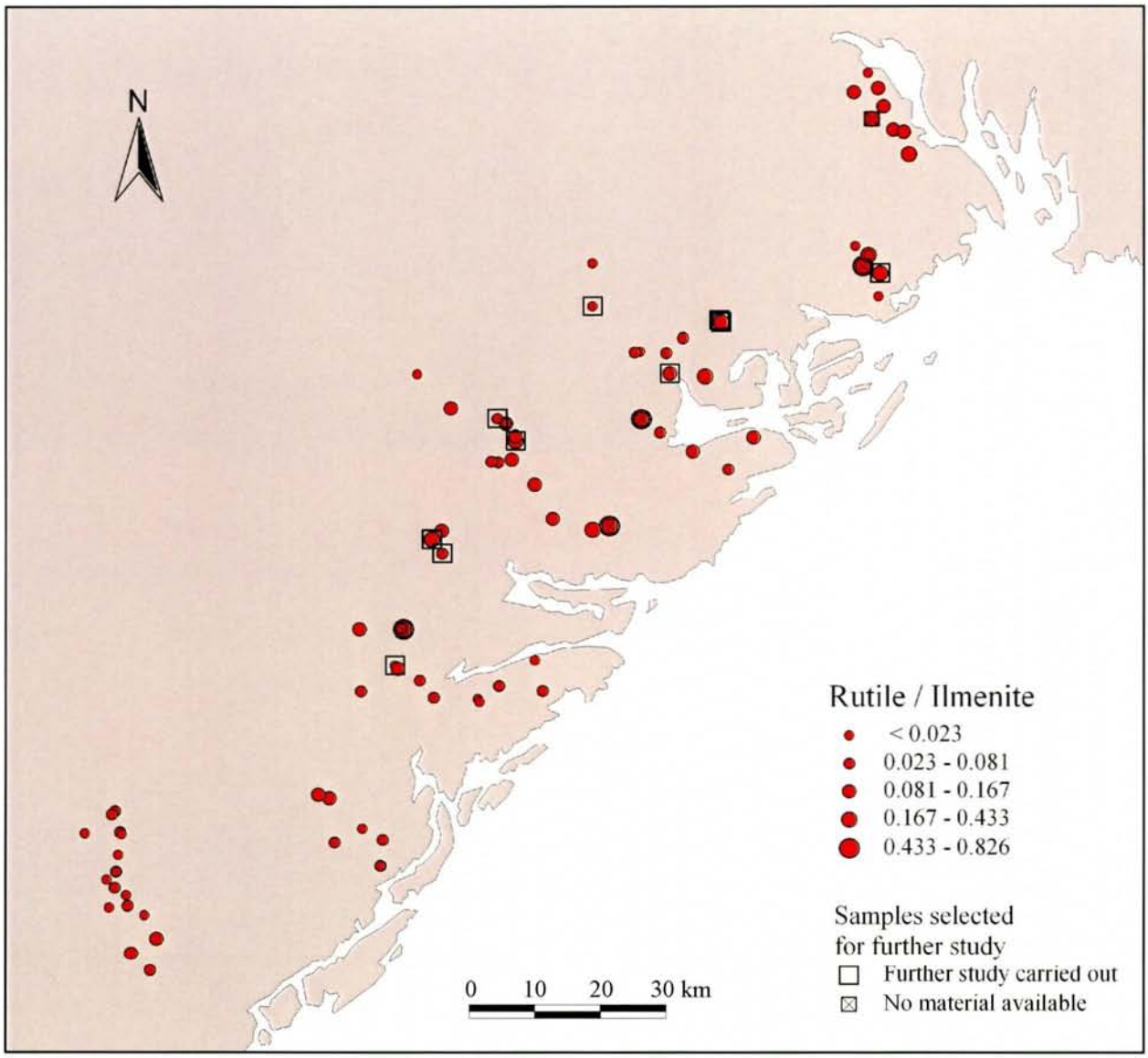
Appendix 2: Ore deposits and stream sediment localities, Arendal – Bamble region, S. Norway



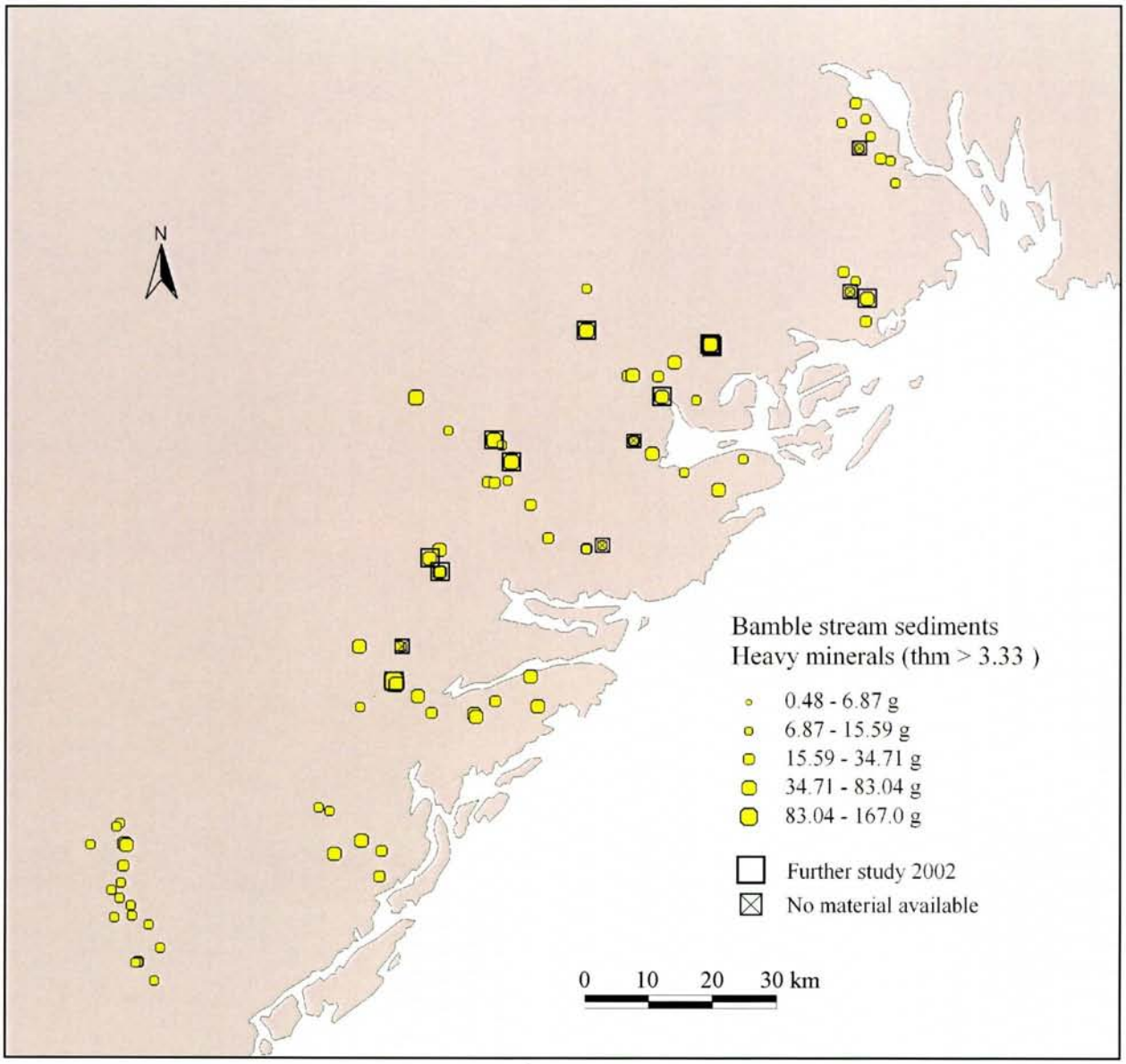
Appendix 3: Stream sediment localities, Arendal – Bamble region, S. Norway (Finne 2000).



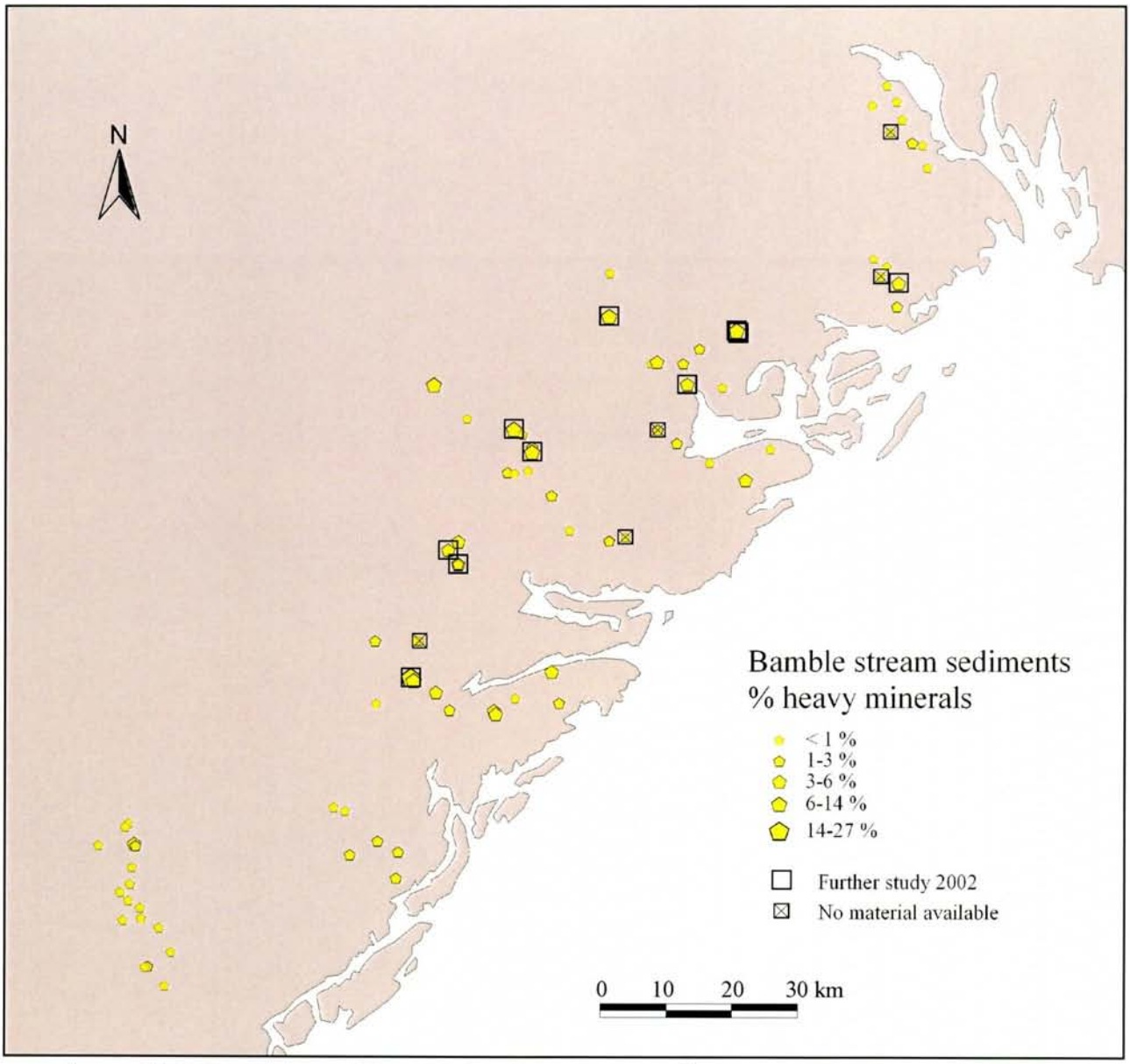
Appendix 4: Rutile in stream sediments, Arendal – Bamble region, S. Norway.



Appendix 5: Rutile / Ilmenite in stream sediments, Arendal – Bamble region, S. Norway.



Appendix 6: Heavy mineral (> 3.33 g/cm^3) contents in stream sediments, Arendal – Bamble region, S. Norway.

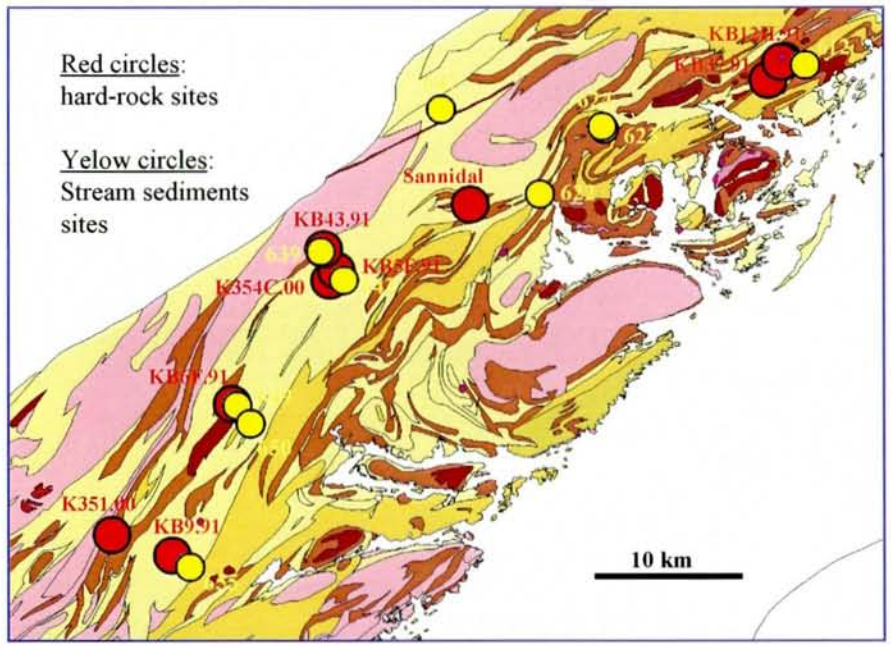


Appendix 7: Percentage of heavy mineral (> 3.33 g/cm^3) in stream sediments, Arendal – Bamble region, S. Norway.

Appendix 8:

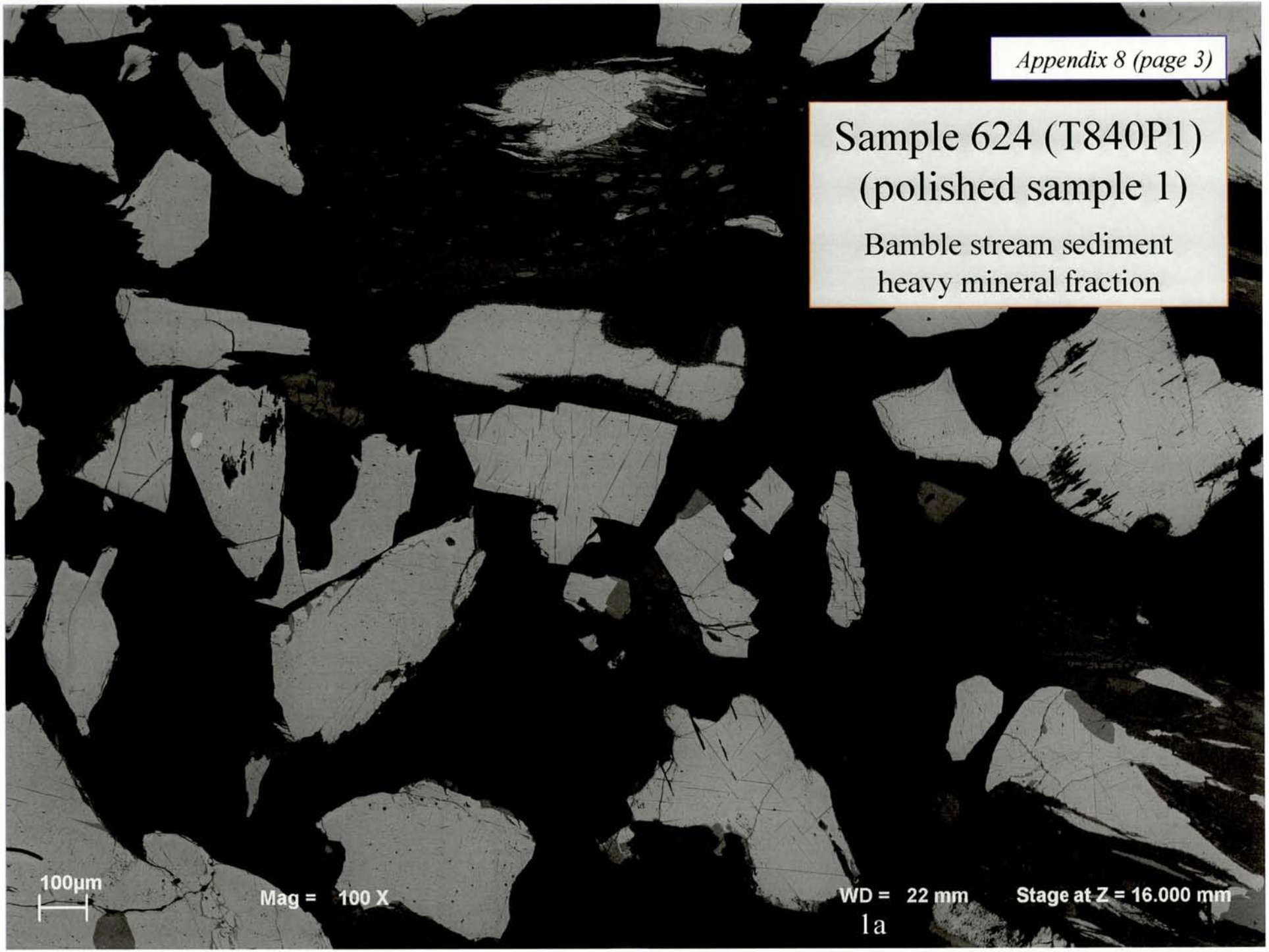
SEM-images of Bamble stream sediment heavy fraction

Sample 624 (T840P1)

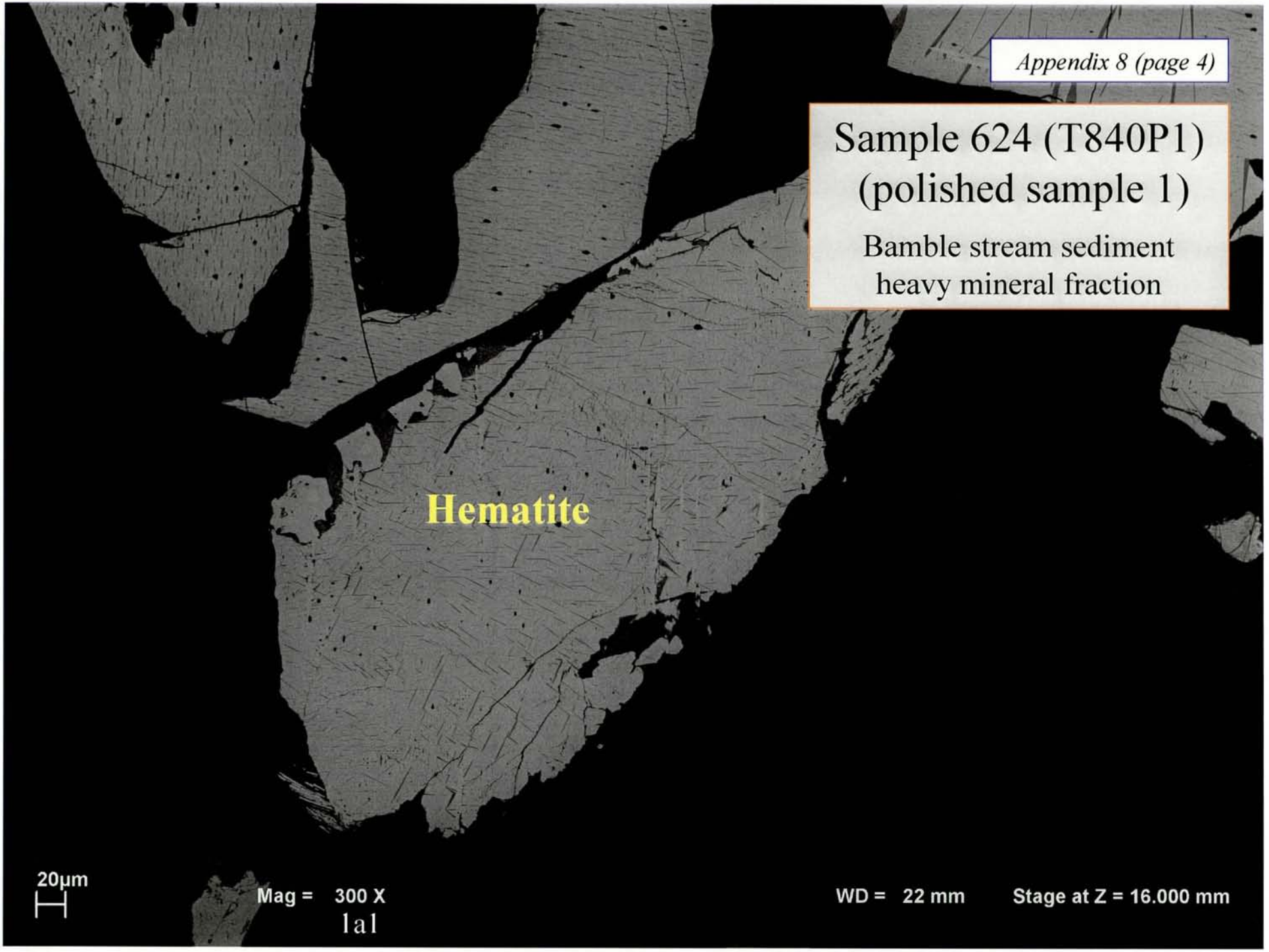


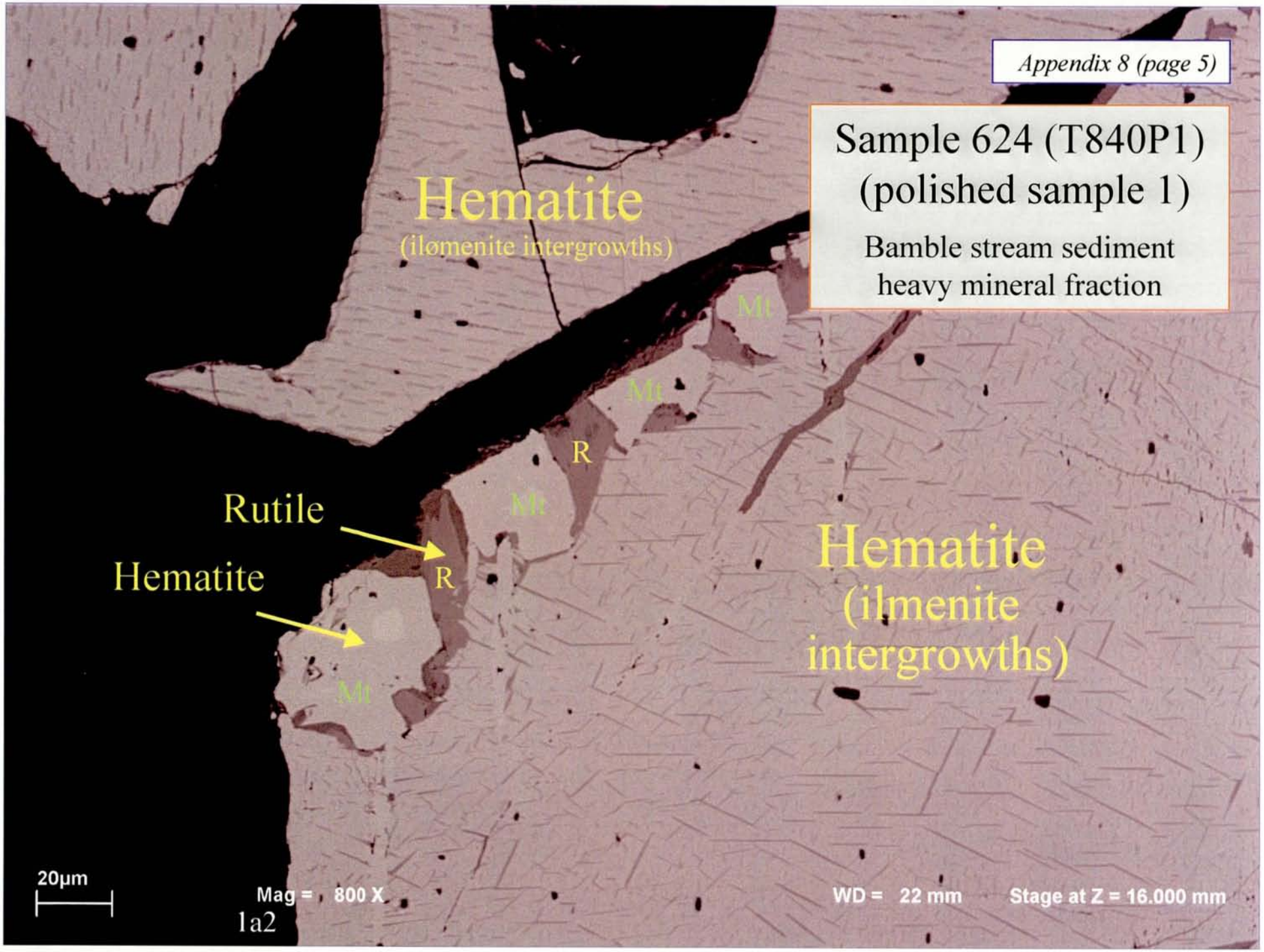
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
624	ssthm	Intergrown hematite-ilmenite-rutile	1555,3	797,1	37,3	2,3	5,6


Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
200µm
1
Mag = 33 X
WD = 16 mm
Stage at Z = 2.000 mm


Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
100µm
Mag = 100 X
WD = 22 mm
Stage at Z = 16.000 mm

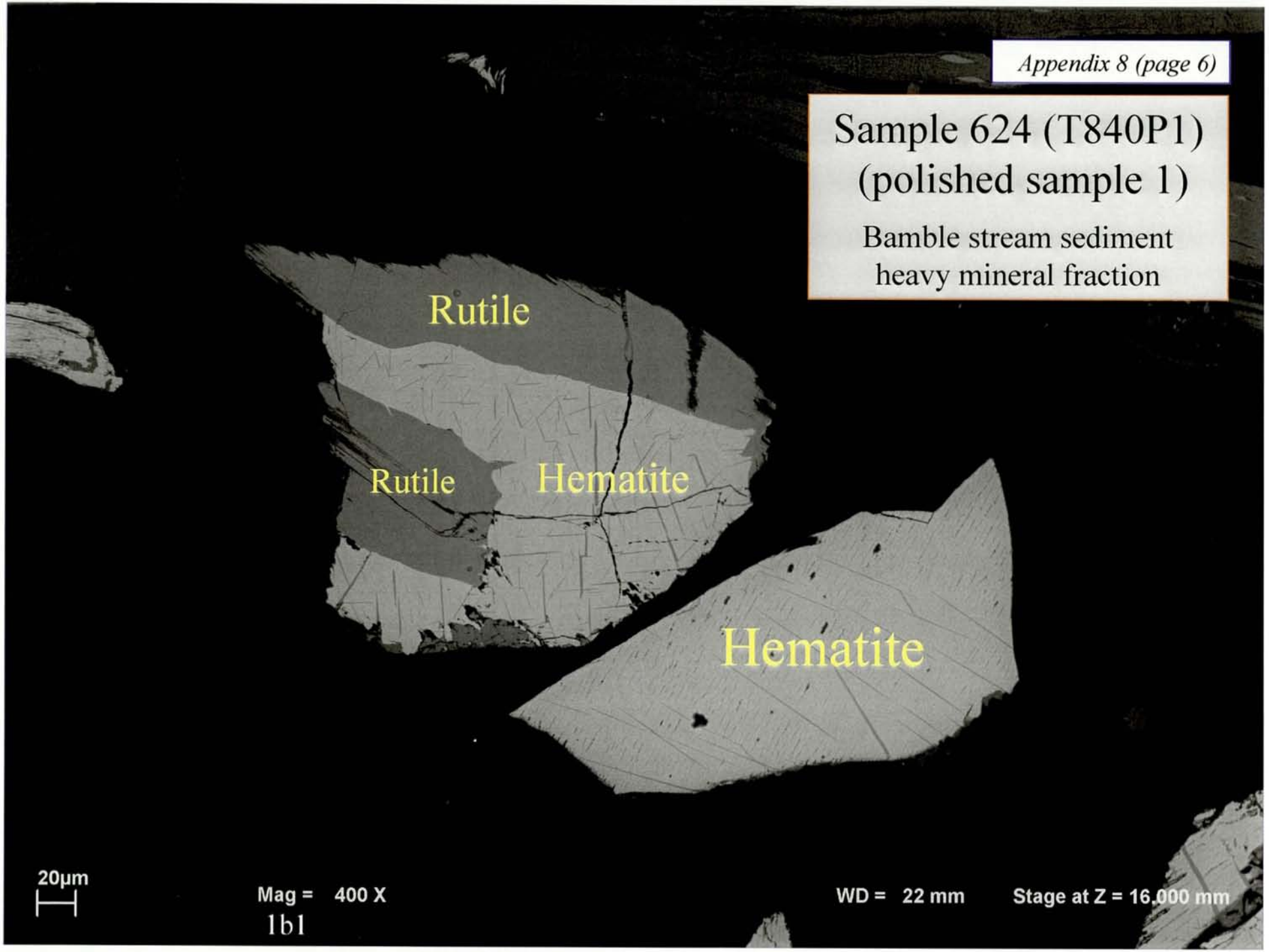
1a

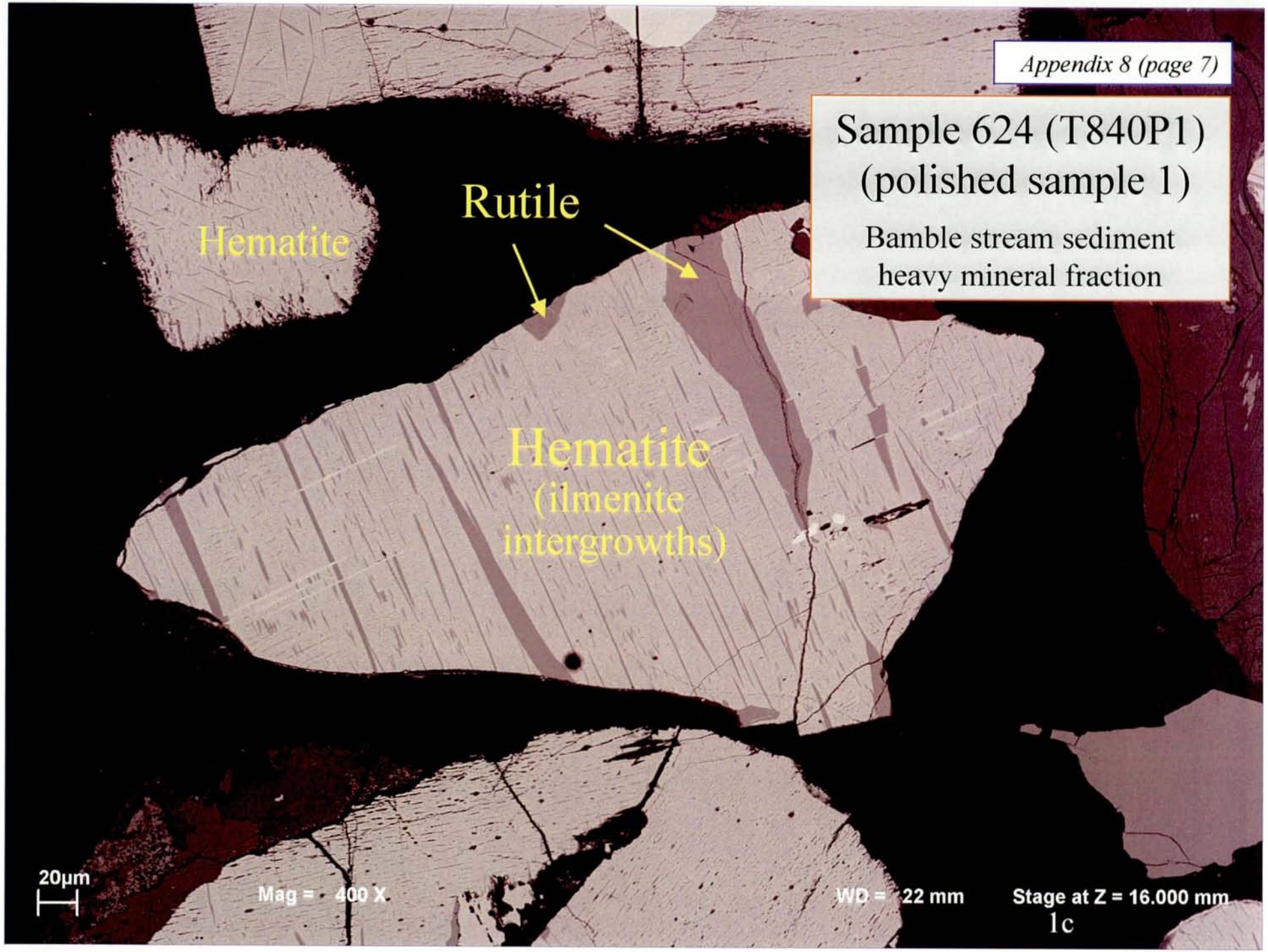

Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Hematite
20µm
Mag = 300 X
WD = 22 mm
Stage at Z = 16.000 mm

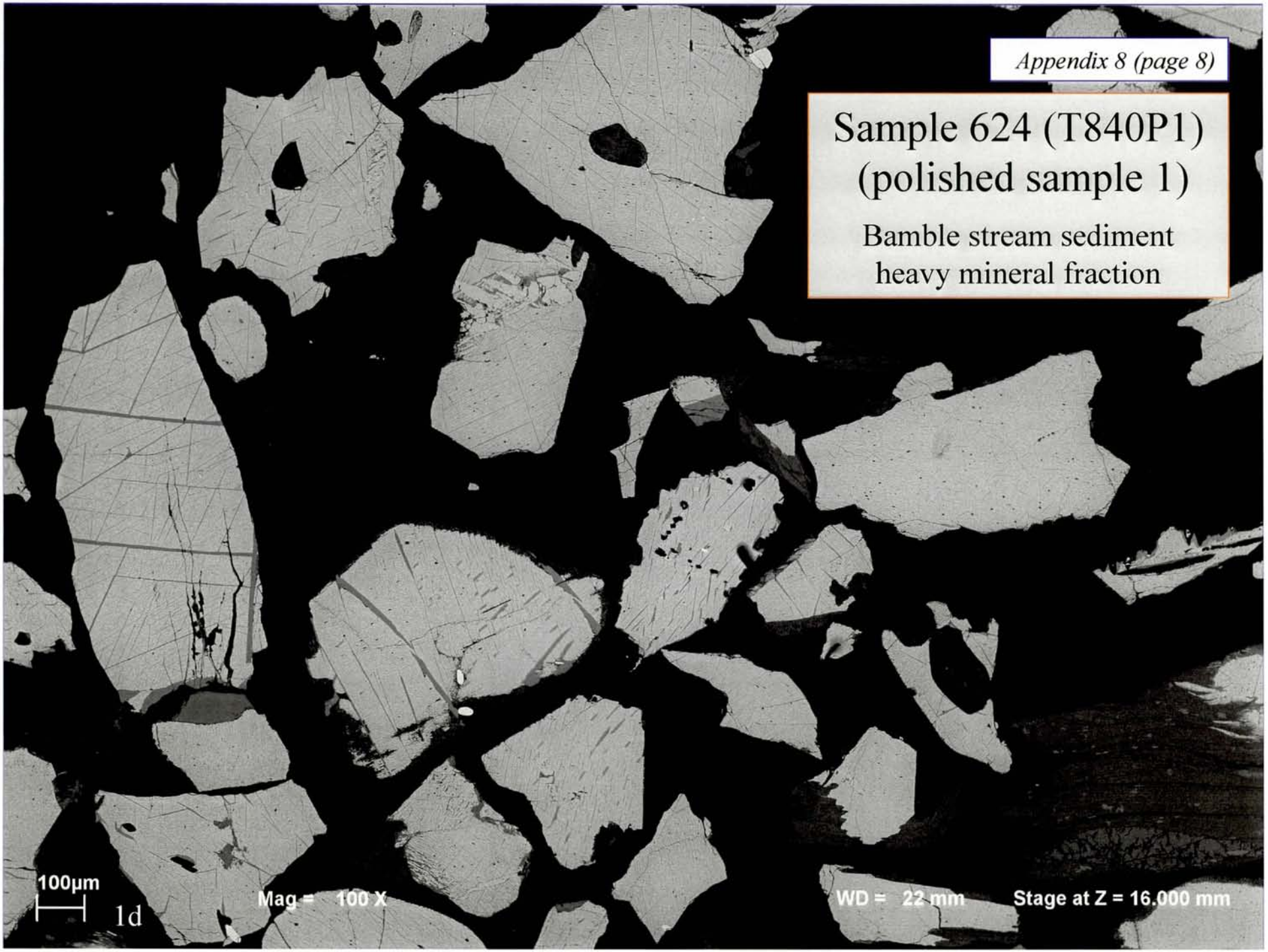


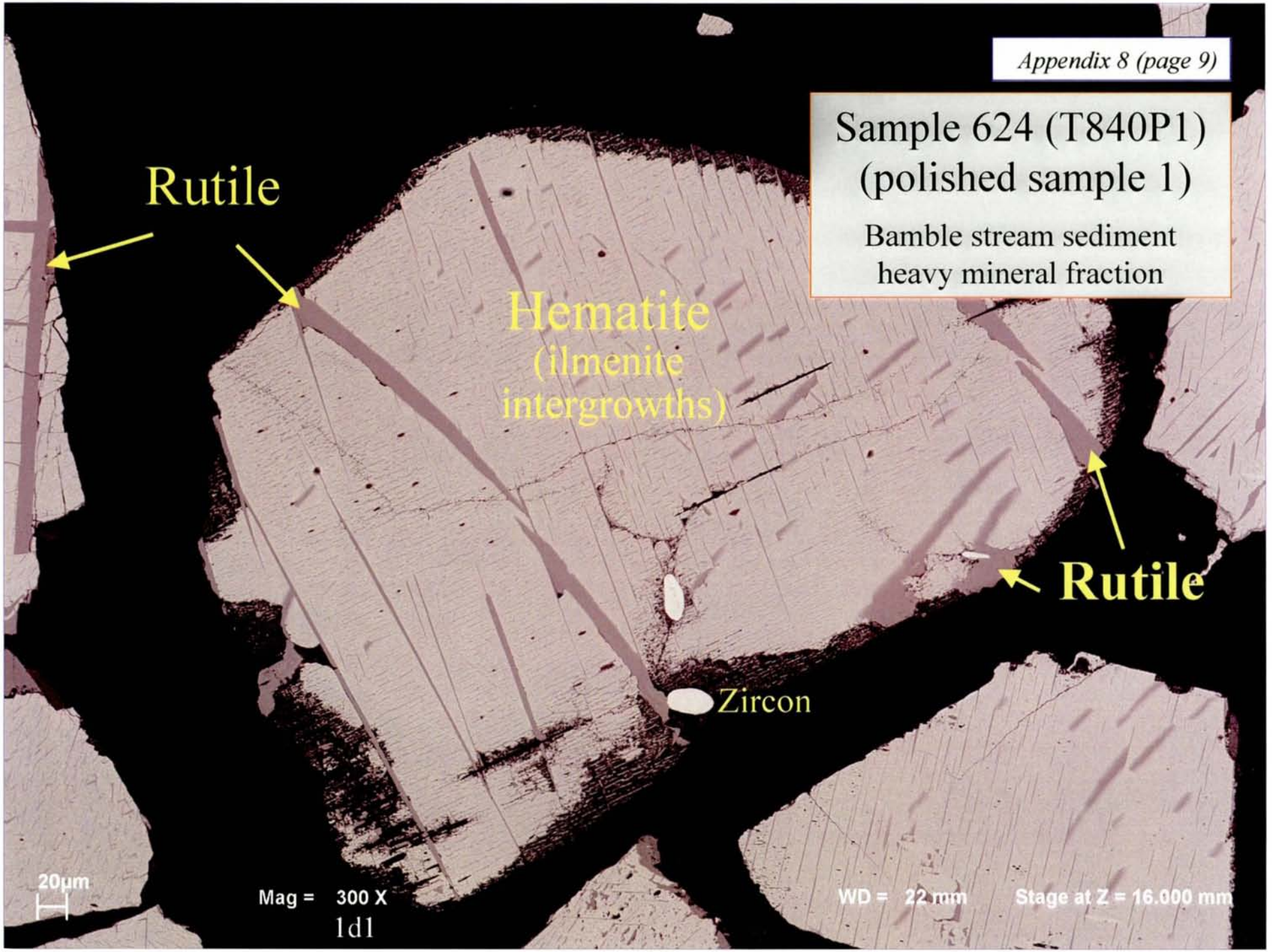
Sample 624 (T840P1)
(polished sample 1)

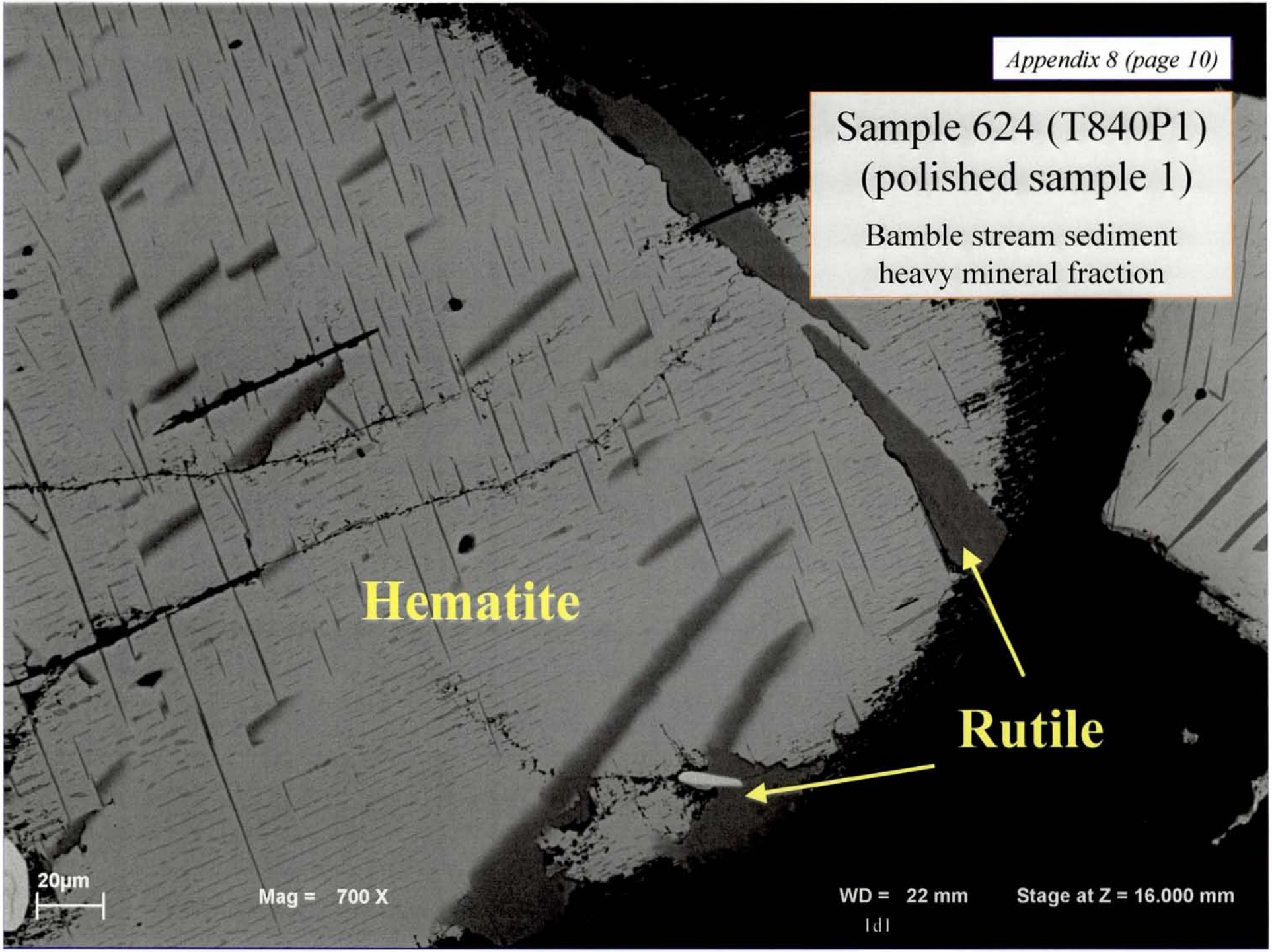
Bamble stream sediment
heavy mineral fraction

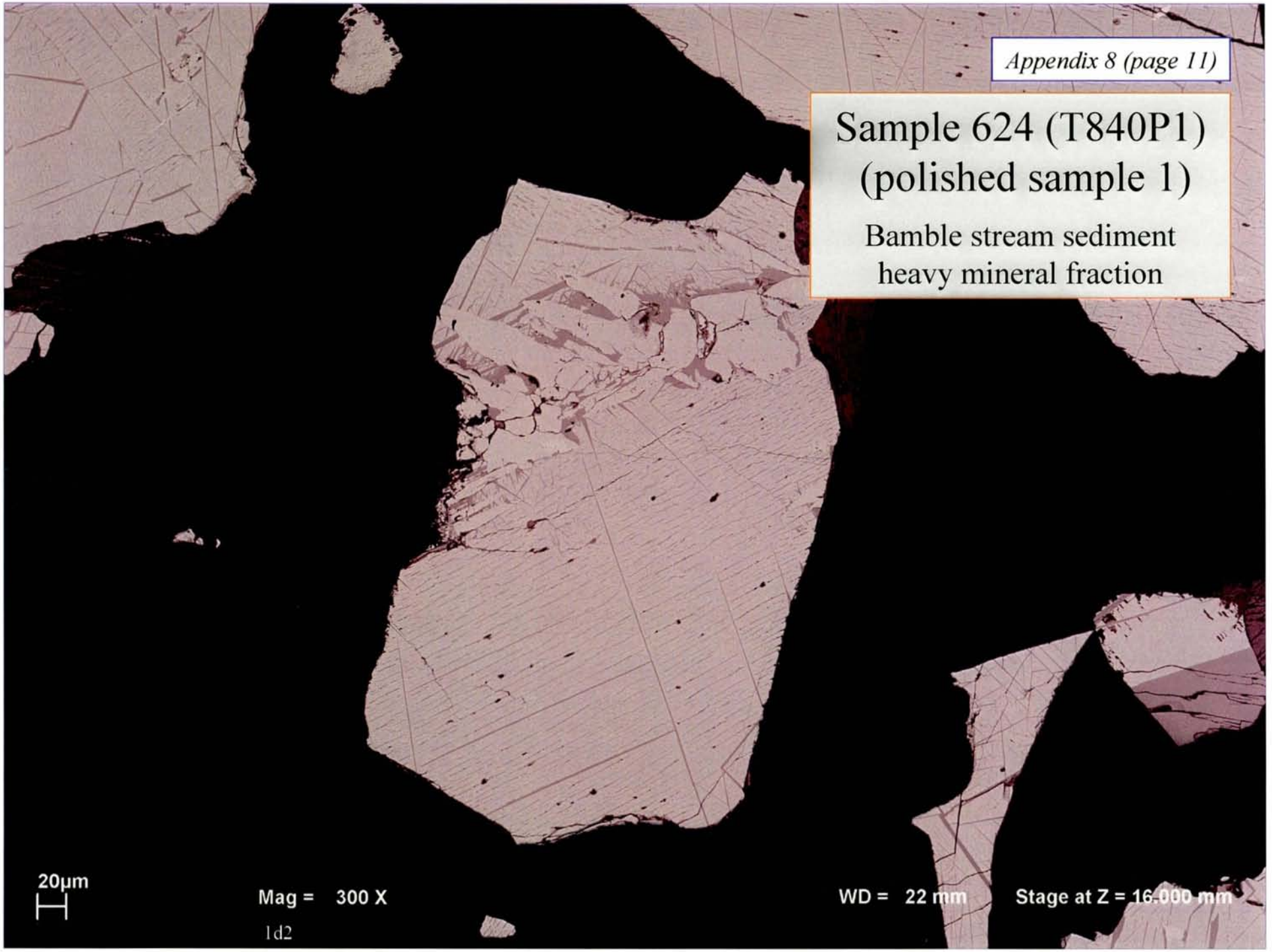

Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Rutile
Rutile
Hematite
Hematite
20µm
Mag = 400 X
1b1
WD = 22 mm
Stage at Z = 16.000 mm

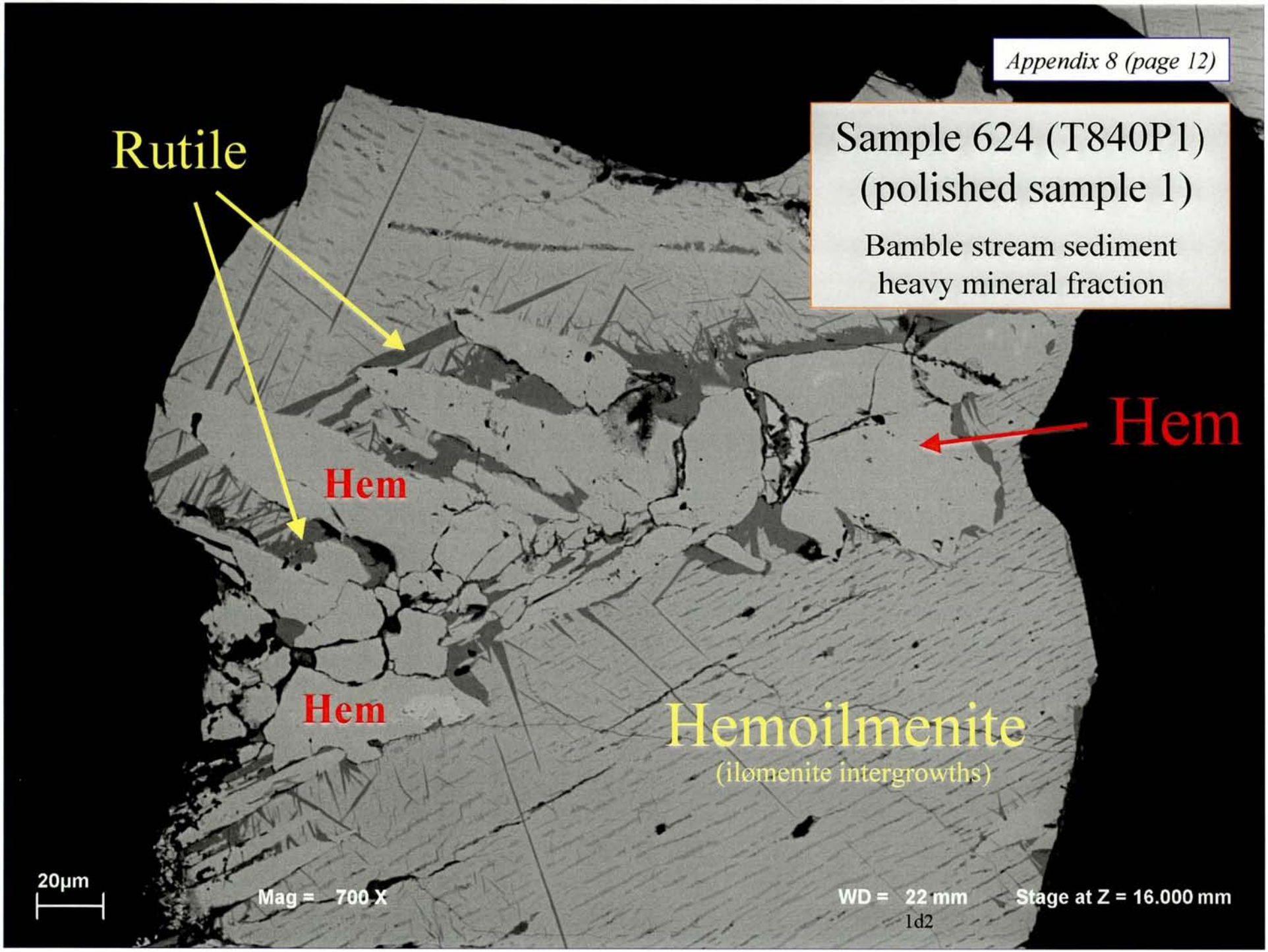

Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Hematite
Rutile
Hematite
(ilmenite
intergrowths)
20µm
Mag = 400 X
WD = 22 mm
Stage at Z = 16.000 mm
1c


Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
100µm
1d
Mag = 100 X
WD = 22 mm
Stage at Z = 16.000 mm


Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Rutile
Hematite
(ilmenite
intergrowths)
Rutile
Zircon
20µm
Mag = 300 X
1d1
WD = 22 mm
Stage at Z = 16.000 mm


Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Hematite
Rutile
20µm
Mag = 700 X
WD = 22 mm
Stage at Z = 16.000 mm

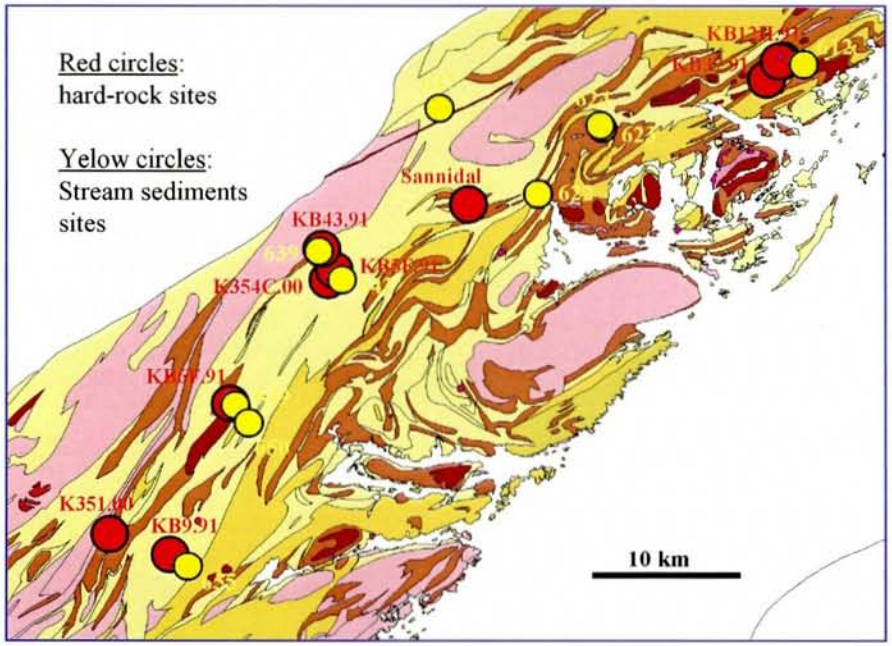

Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
20µm
Mag = 300 X
1d2
WD = 22 mm
Stage at Z = 16.000 mm


Appendix 8 (page 12)
Sample 624 (T840P1)
(polished sample 1)
Bamble stream sediment
heavy mineral fraction
Rutile
Hem
Hem
Hem
Hemoilmenite
(ilømenite intergrowths)
20µm
Mag = 700 X
WD = 22 mm
Stage at Z = 16.000 mm
1d2

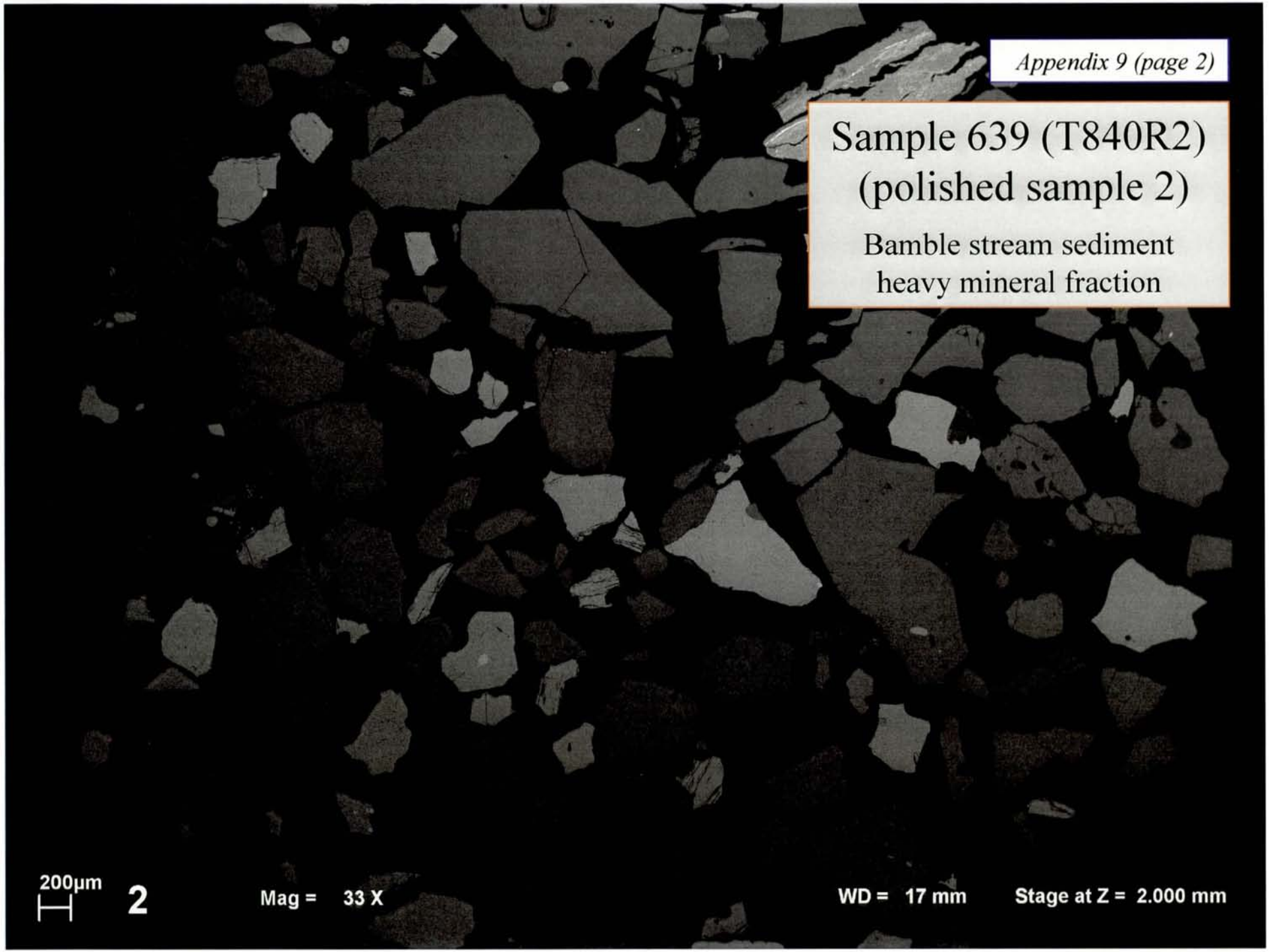
Appendix 9:

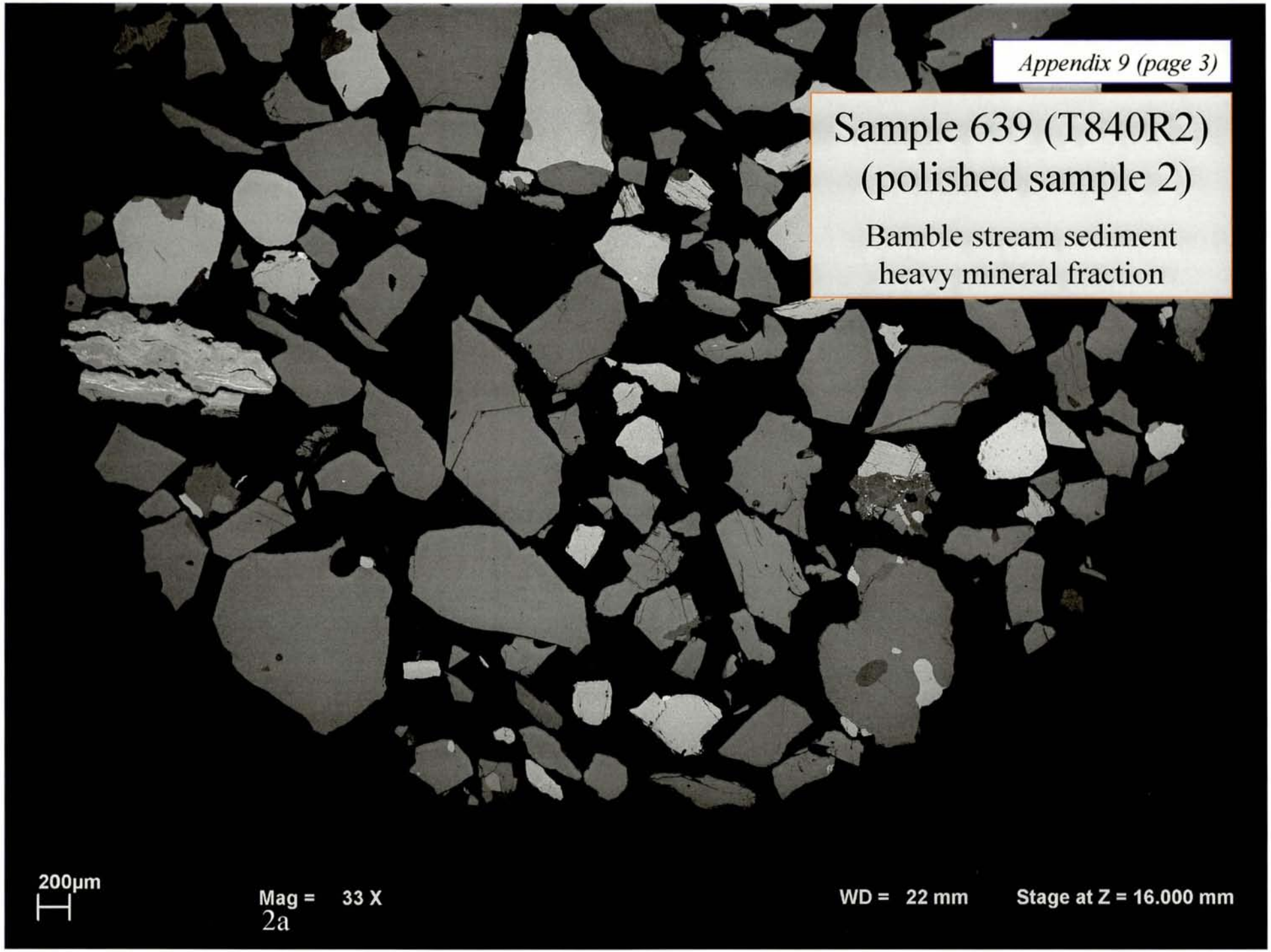
SEM-images of Bamble stream sediment heavy fraction

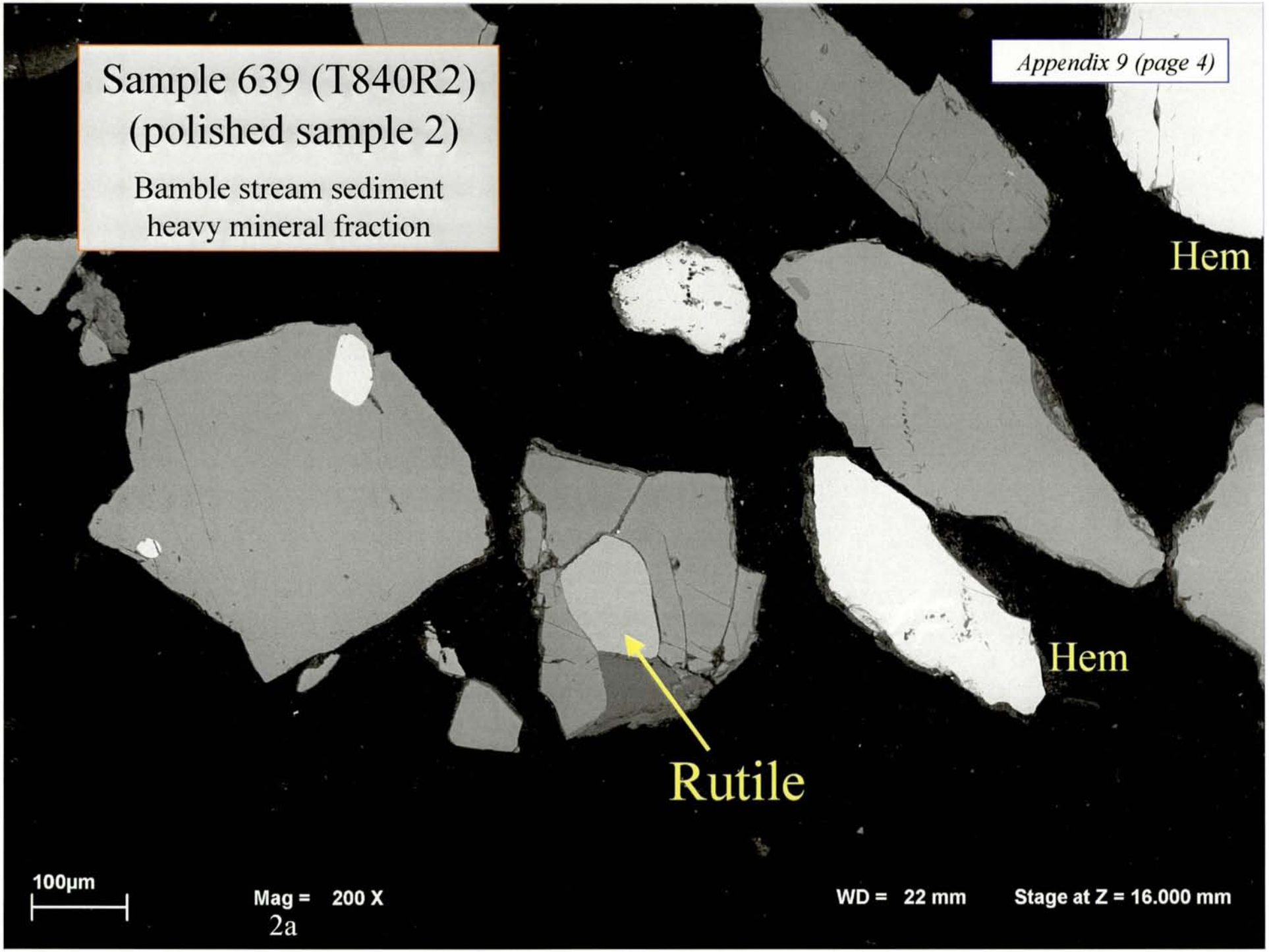
Sample 639 (T840R2)



No analyses available


Sample 639 (T840R2)
(polished sample 2)
Bamble stream sediment
heavy mineral fraction
200µm
2
Mag = 33 X
WD = 17 mm
Stage at Z = 2.000 mm

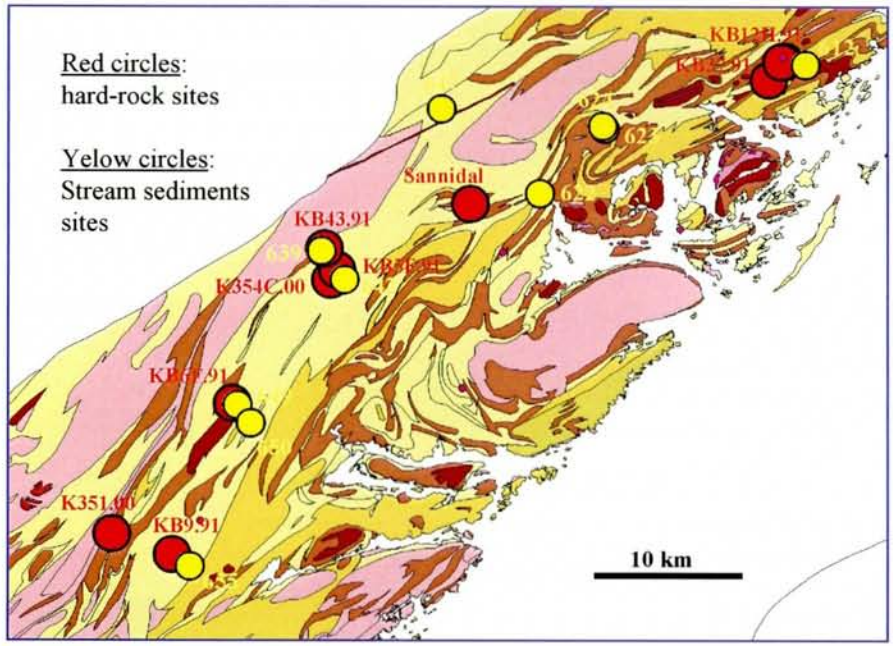

Sample 639 (T840R2)
(polished sample 2)
Bamble stream sediment
heavy mineral fraction
200µm
Mag = 33 X
2a
WD = 22 mm
Stage at Z = 16.000 mm


Sample 639 (T840R2)
(polished sample 2)
Bamble stream sediment
heavy mineral fraction
Appendix 9 (page 4)
Hem
Hem
Rutile
100µm
Mag = 200 X
2a
WD = 22 mm
Stage at Z = 16.000 mm

Appendix 10:

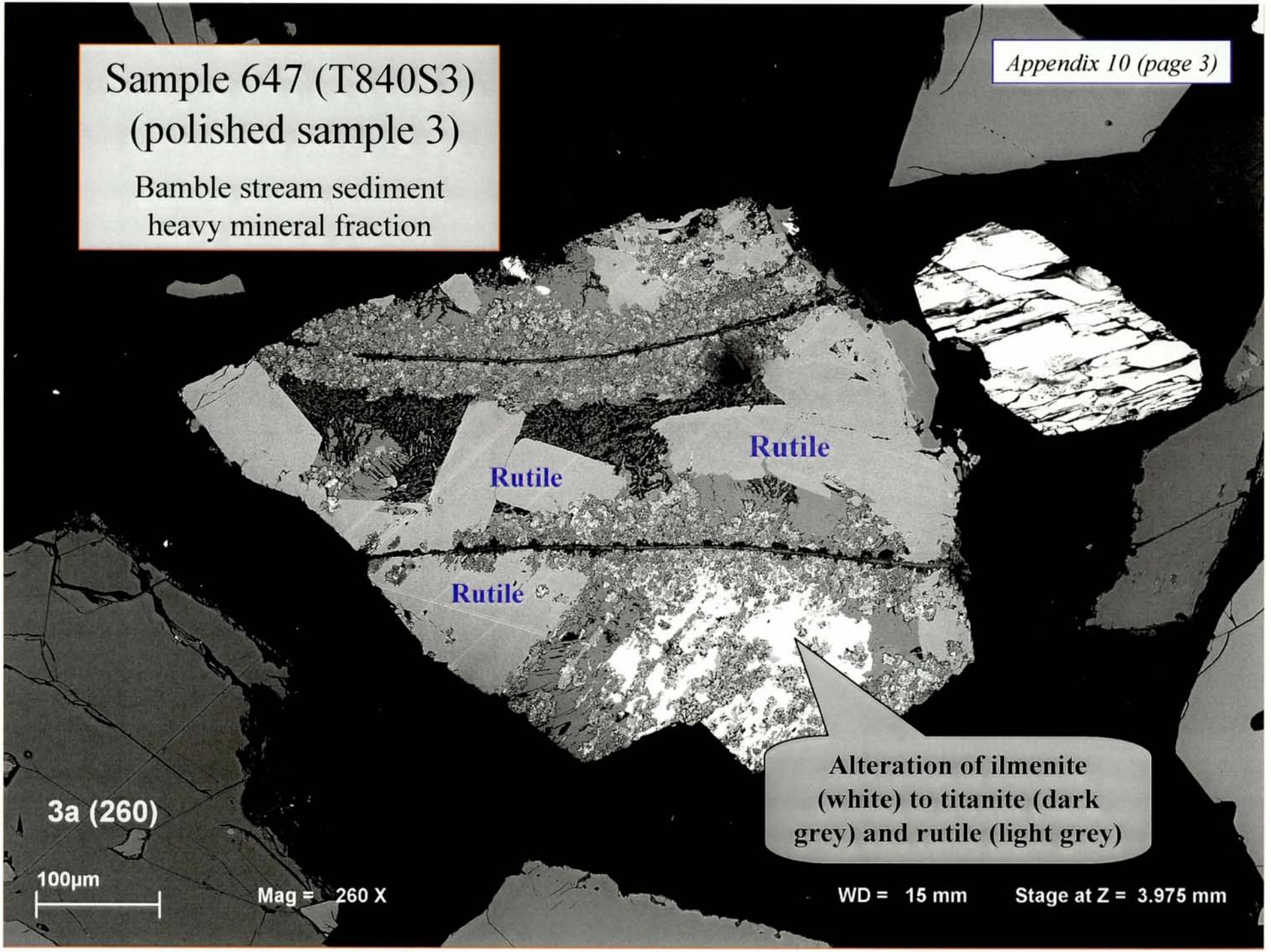
SEM-images of Bamble stream sediment heavy fraction

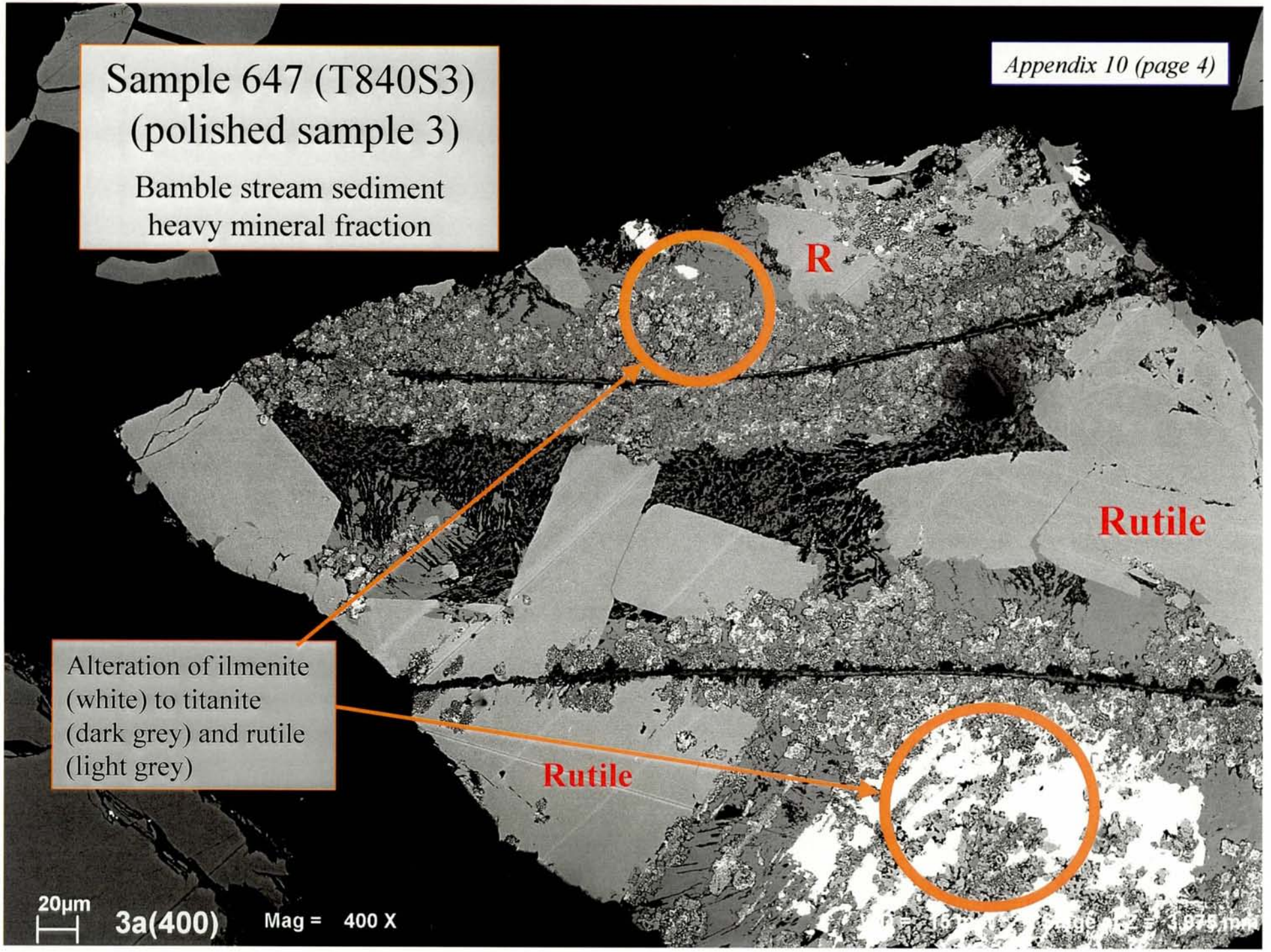
Sample 647 (T840S3)

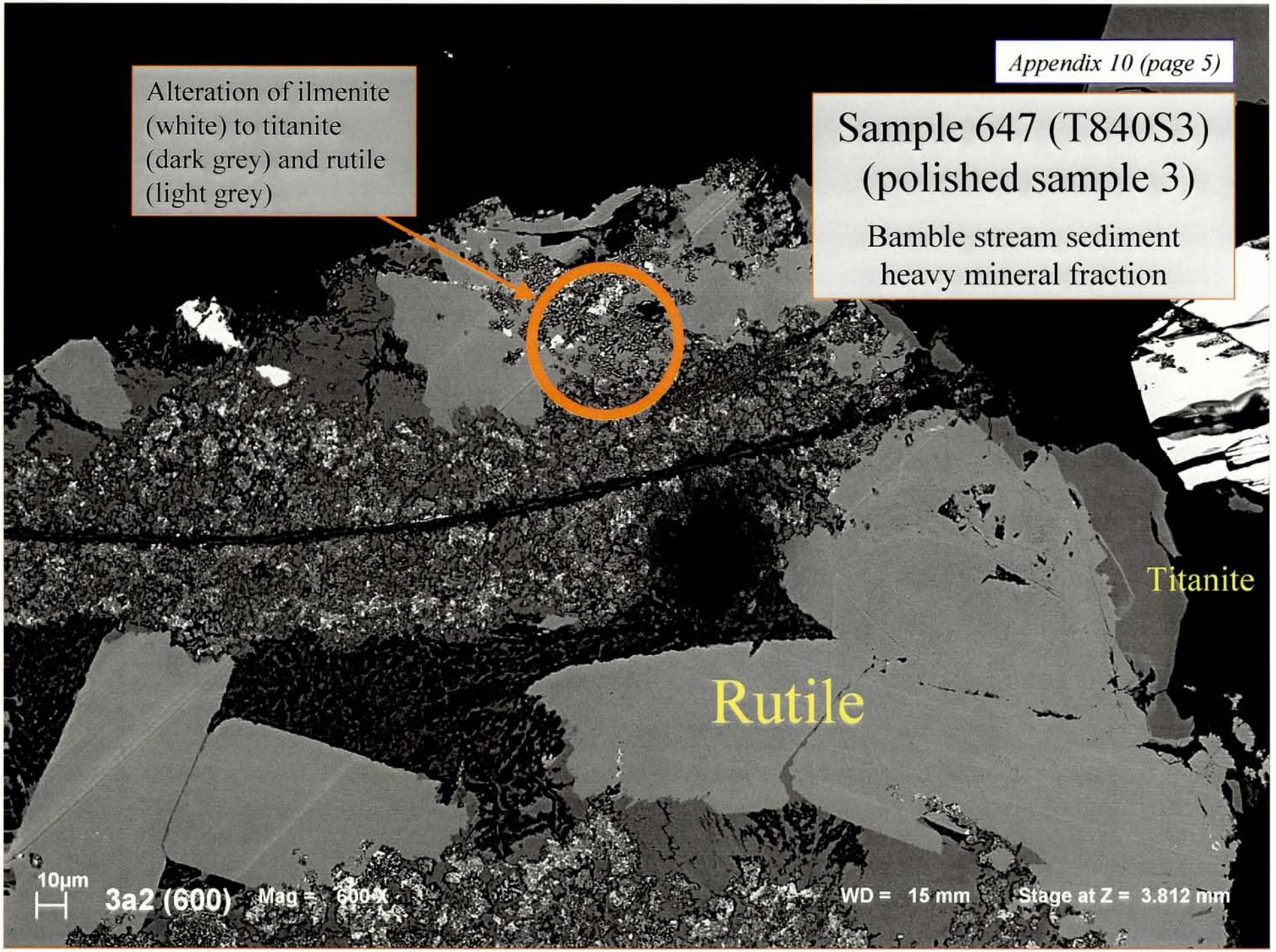


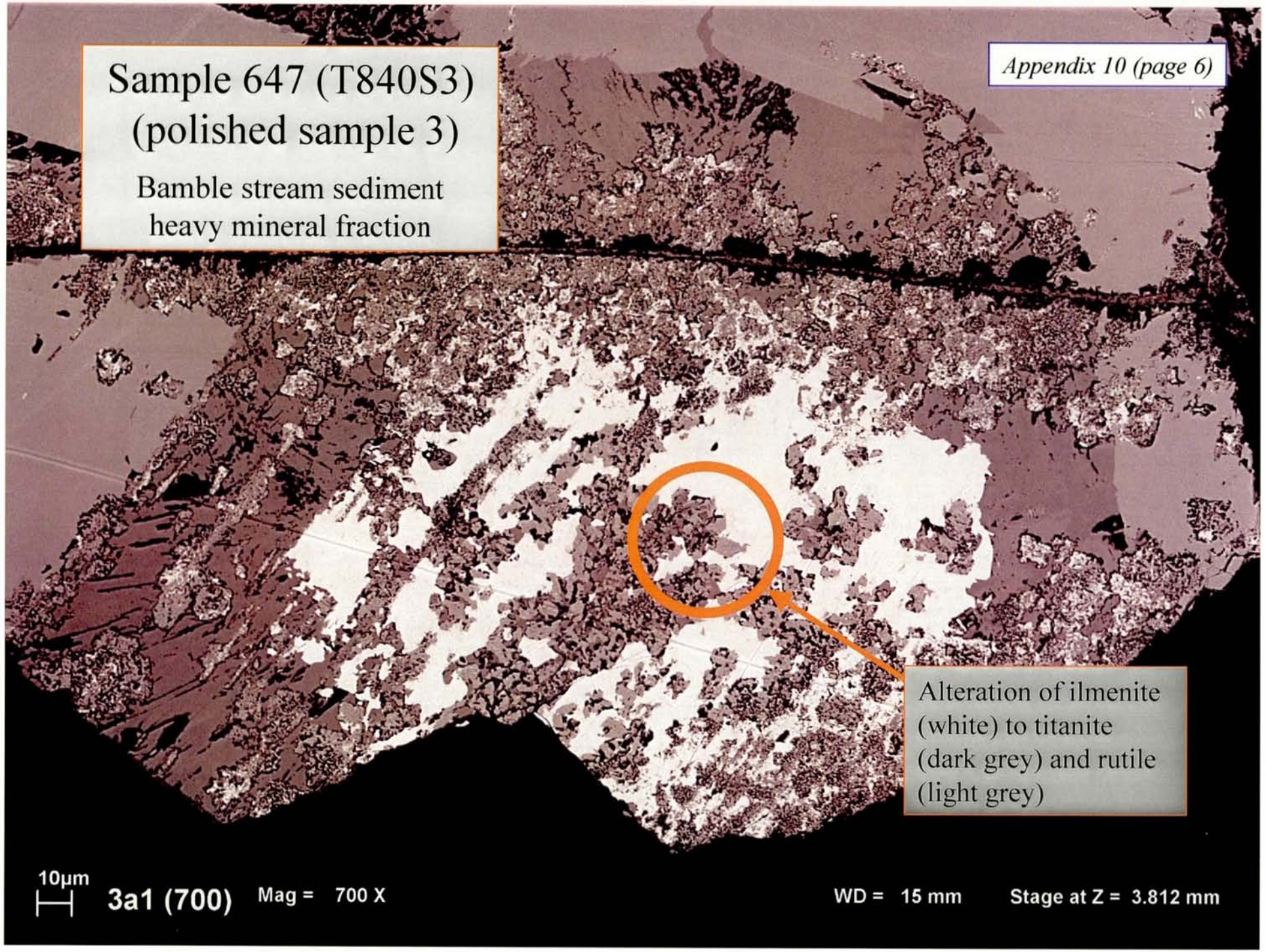
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
647	ssthm	Rutile	23,4	4429,5	434,4	4,7	43,6

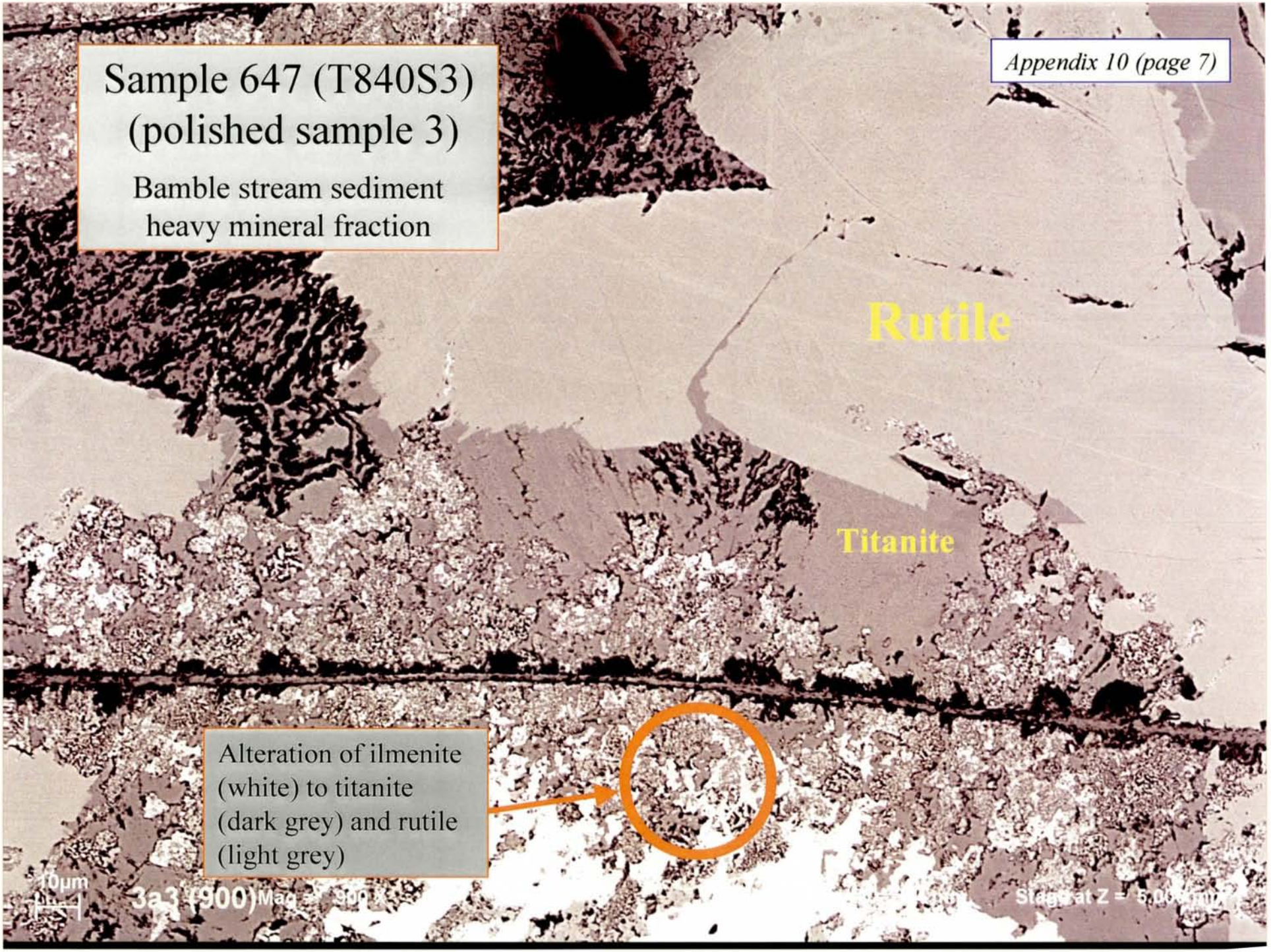

Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Appendix 10 (page 2)
200µm
3
Mag = 33 X
WD = 16 mm
Stage at Z = 2.000 mm

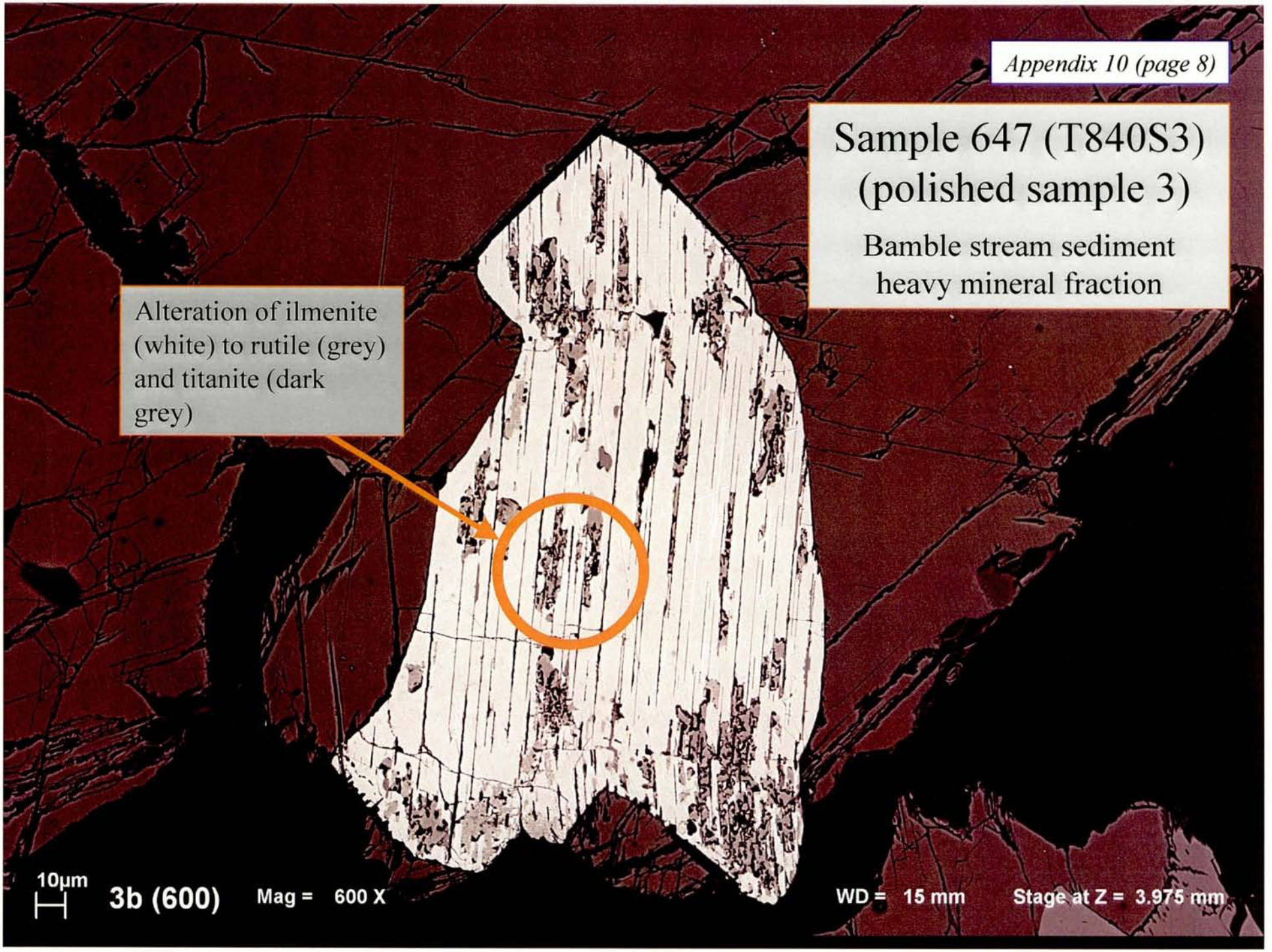

Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Appendix 10 (page 3)
Rutile
Rutile
Rutile
Alteration of ilmenite (white) to titanite (dark grey) and rutile (light grey)
3a (260)
100µm
Mag = 260 X
WD = 15 mm
Stage at Z = 3.975 mm


Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Appendix 10 (page 4)
R
Rutile
Alteration of ilmenite
(white) to titanite
(dark grey) and rutile
(light grey)
Rutile
20µm
3a(400)
Mag = 400 X


Appendix 10 (page 5)
Alteration of ilmenite (white) to titanite (dark grey) and rutile (light grey)
Sample 647 (T840S3) (polished sample 3)
Bamble stream sediment heavy mineral fraction
Titanite
Rutile
10µm
3a2 (600)
Mag = 600 X
WD = 15 mm
Stage at Z = 3.812 mm


Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Appendix 10 (page 6)
Alteration of ilmenite (white) to titanite (dark grey) and rutile (light grey)
10µm
3a1 (700)
Mag = 700 X
WD = 15 mm
Stage at Z = 3.812 mm

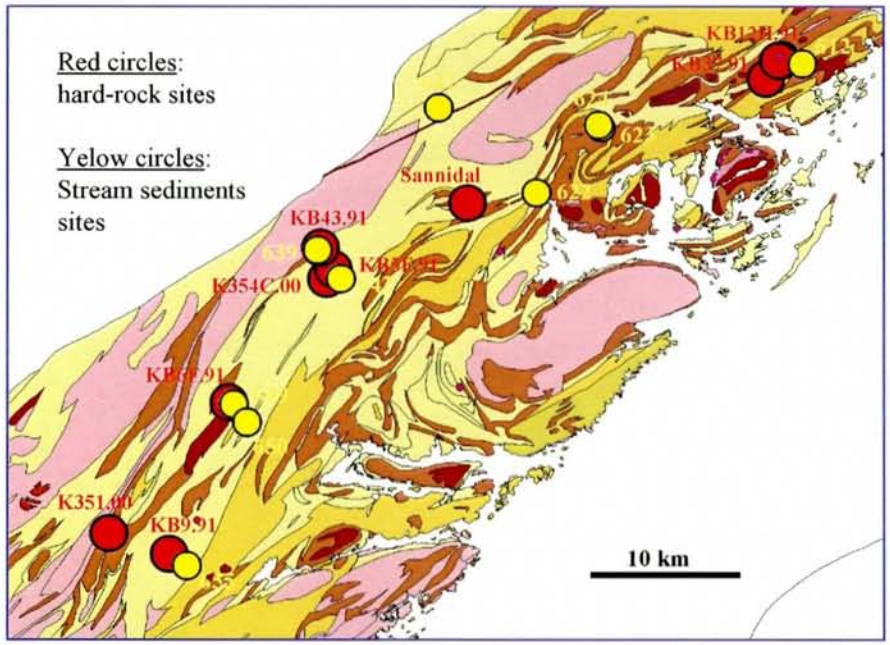

Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Rutile
Titanite
Alteration of ilmenite
(white) to titanite
(dark grey) and rutile
(light grey)
10µm


Sample 647 (T840S3)
(polished sample 3)
Bamble stream sediment
heavy mineral fraction
Alteration of ilmenite (white) to rutile (grey) and titanite (dark grey)
10µm
3b (600)
Mag = 600 X
WD = 15 mm
Stage at Z = 3.975 mm

Appendix 11:

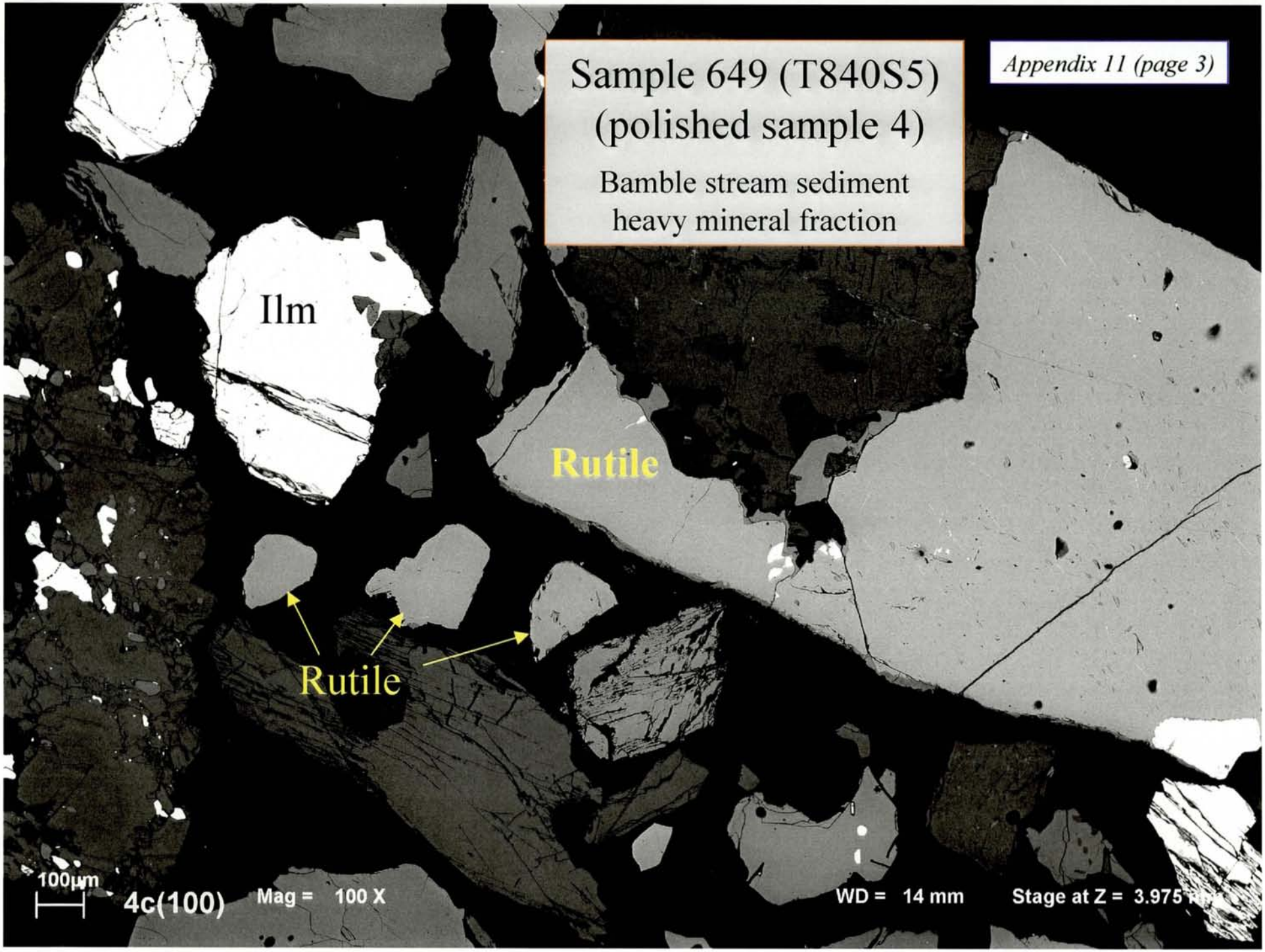
SEM-images of Bamble stream sediment heavy fraction

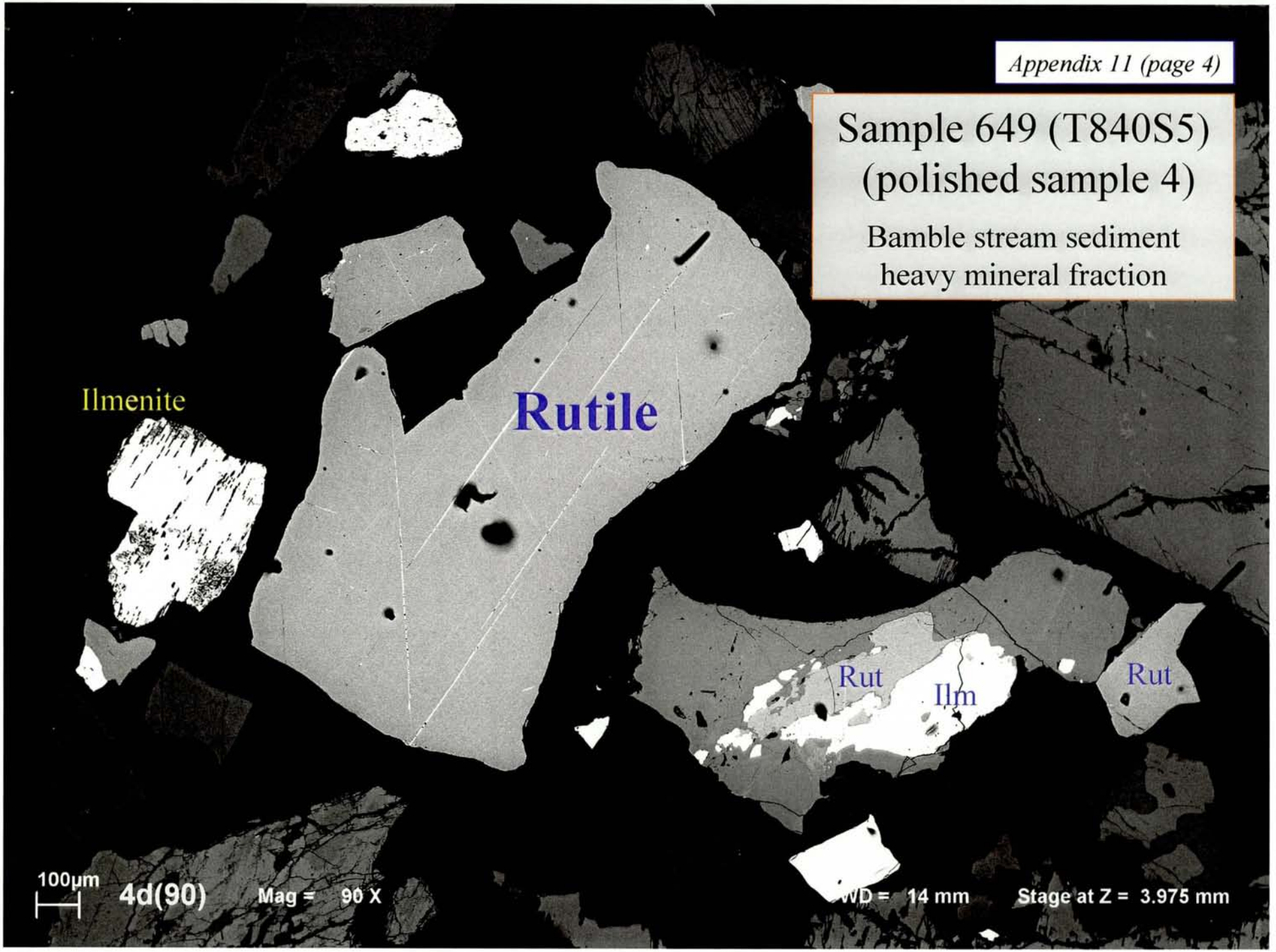
Sample 649 (T840S5)

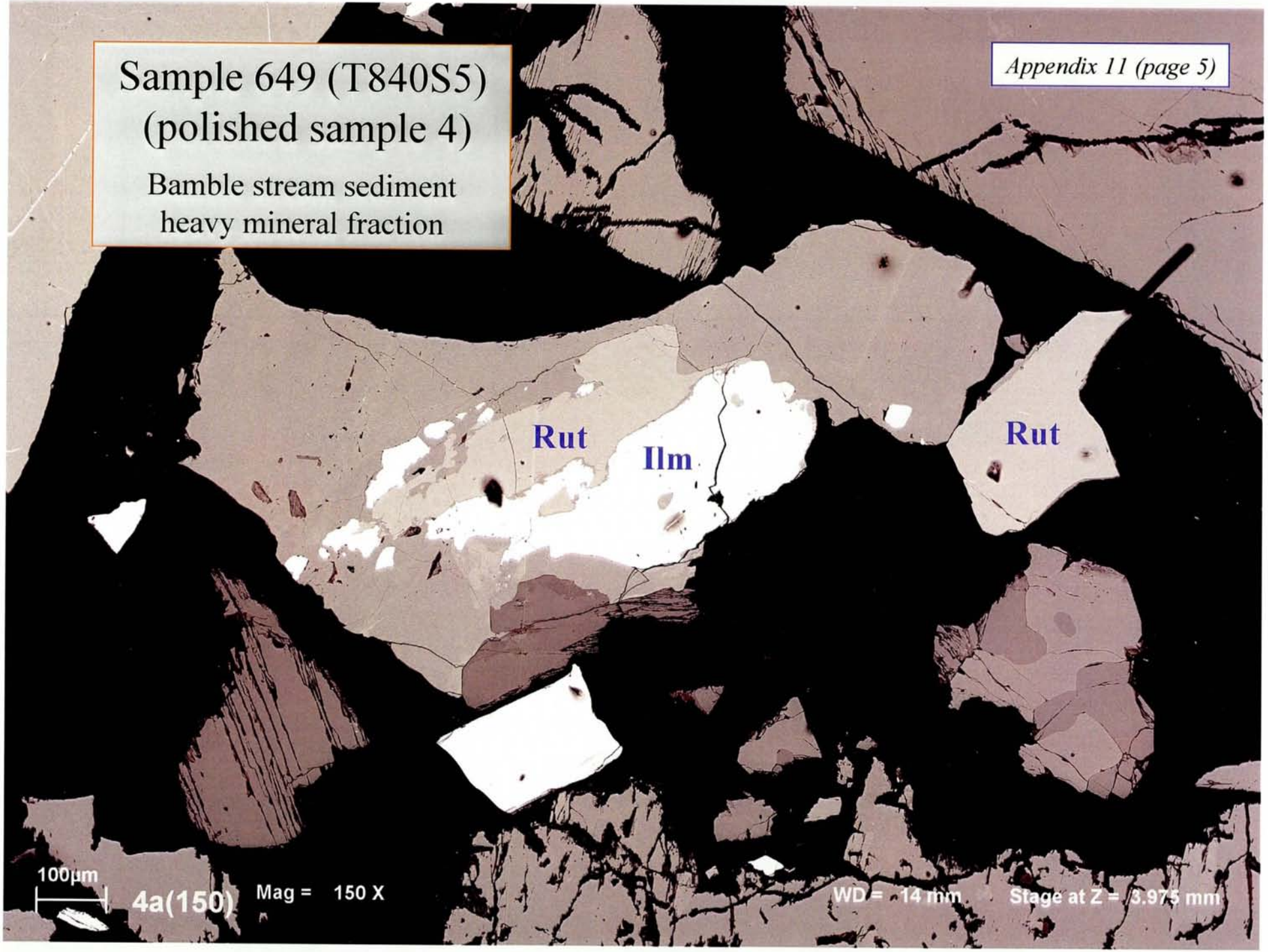


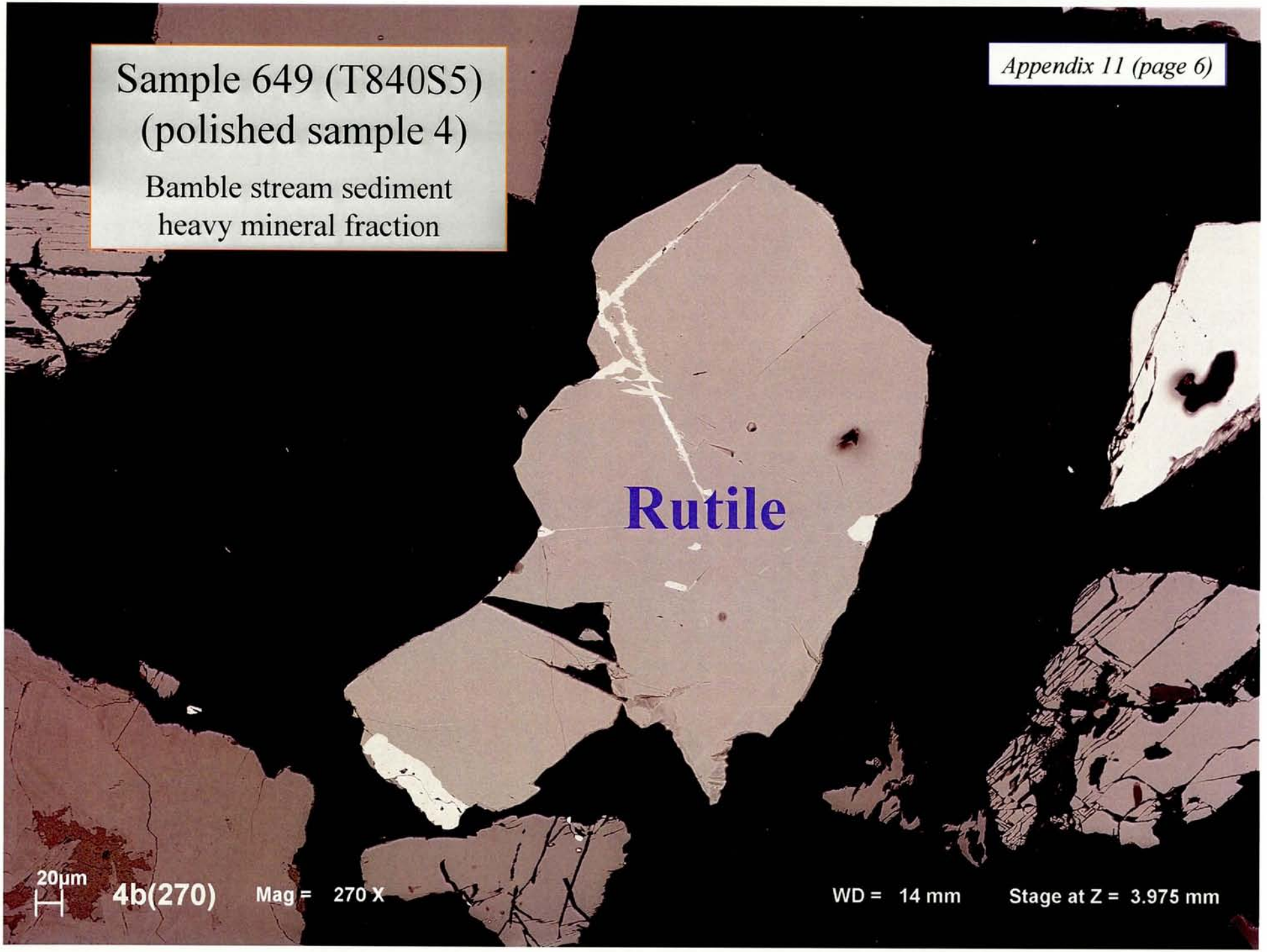
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
649	ssthm	Rutile	559,8	584,4	99,6	0,2	41,6
649	ssthm	Rutile	666,8	809,1	138,9	0,7	46,2
649	ssthm	Rutile	967,5	1088,9	155,4	0,2	35,6


Sample 649 (T840S5)
(polished sample 4)
Bamble stream sediment
heavy mineral fraction
200µm
4
Mag = 33 X
WD = 17 mm
Stage at Z = 2.000 mm


Sample 649 (T840S5)
(polished sample 4)
Bamble stream sediment
heavy mineral fraction
Appendix 11 (page 3)
Ilm
Rutile
Rutile
100µm
4c(100)
Mag = 100 X
WD = 14 mm
Stage at Z = 3.975


Sample 649 (T840S5)
(polished sample 4)
Bamble stream sediment
heavy mineral fraction
Ilmenite
Rutile
Rut
Ilm
Rut
100µm
4d(90)
Mag = 90 X
WD = 14 mm
Stage at Z = 3.975 mm

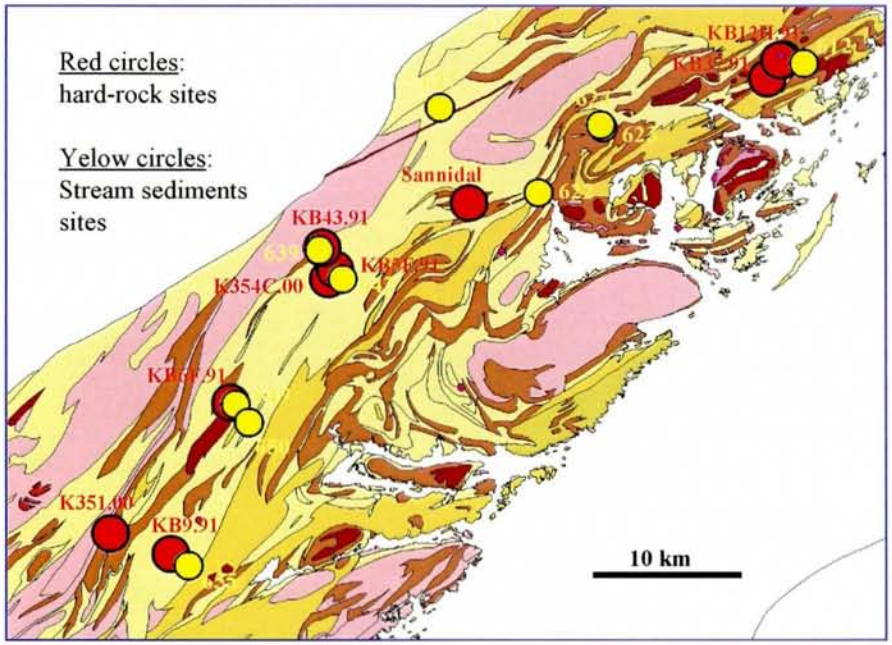

Sample 649 (T840S5)
(polished sample 4)
Bamble stream sediment
heavy mineral fraction
Appendix 11 (page 5)
Rut
Ilm
Rut
100µm
4a(150)
Mag = 150 X
WD = 14 mm
Stage at Z = 3.975 mm


Sample 649 (T840S5)
(polished sample 4)
Bamble stream sediment
heavy mineral fraction
Appendix 11 (page 6)
Rutile
20µm
4b(270)
Mag = 270 X
WD = 14 mm
Stage at Z = 3.975 mm

Appendix 12:

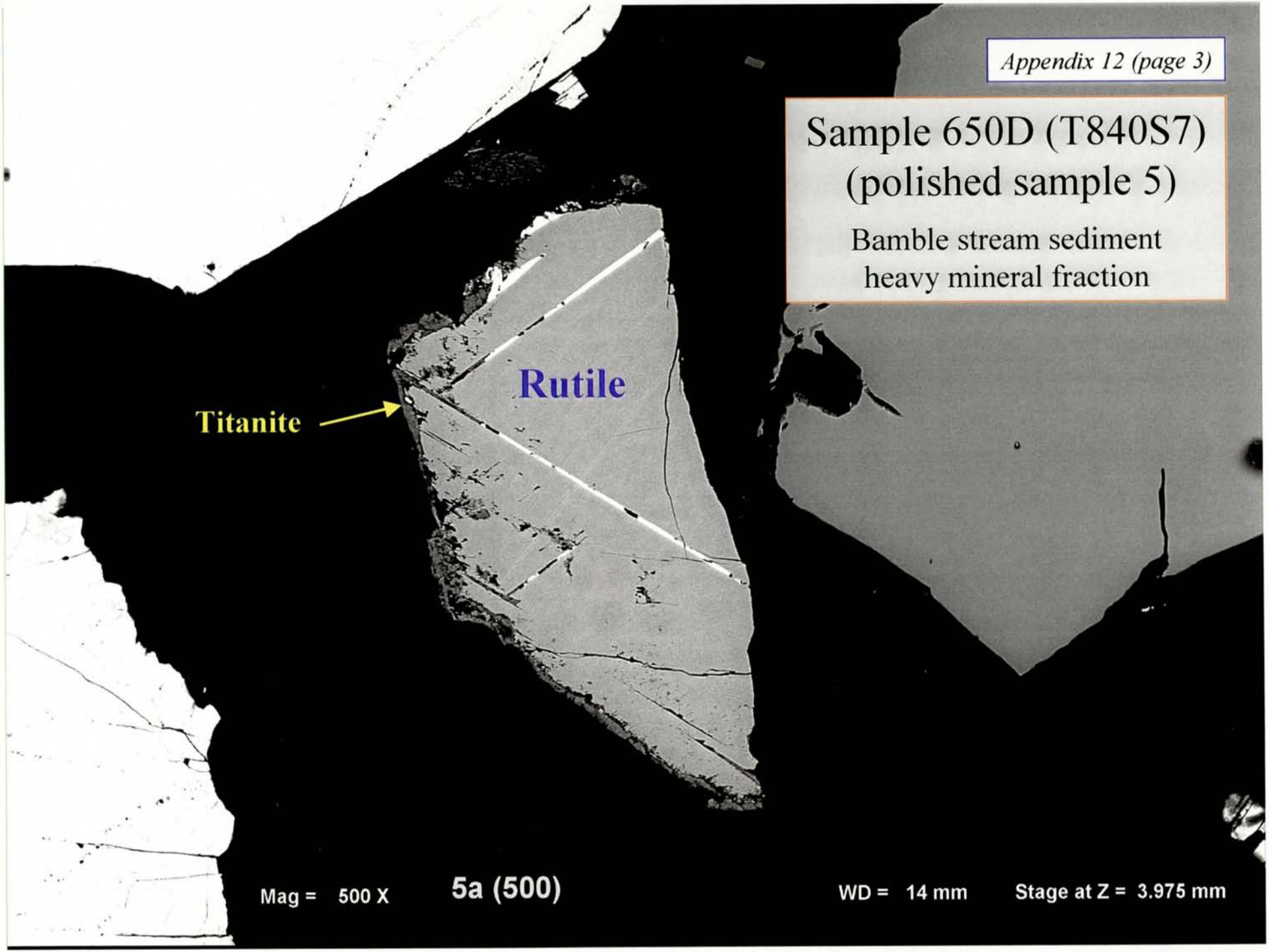
SEM-images of Bamble stream sediment heavy fraction

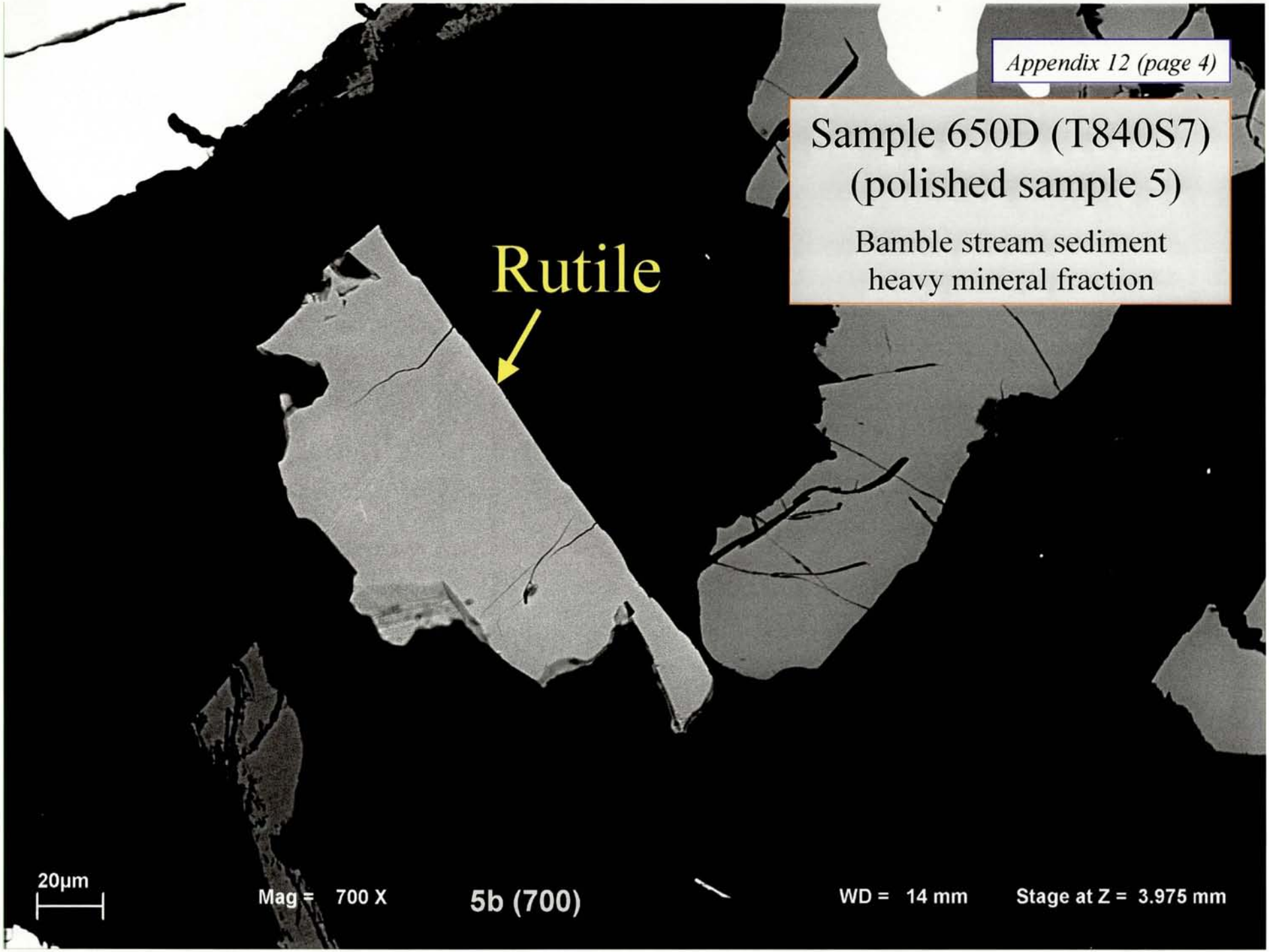
Sample 650D (T840S7)

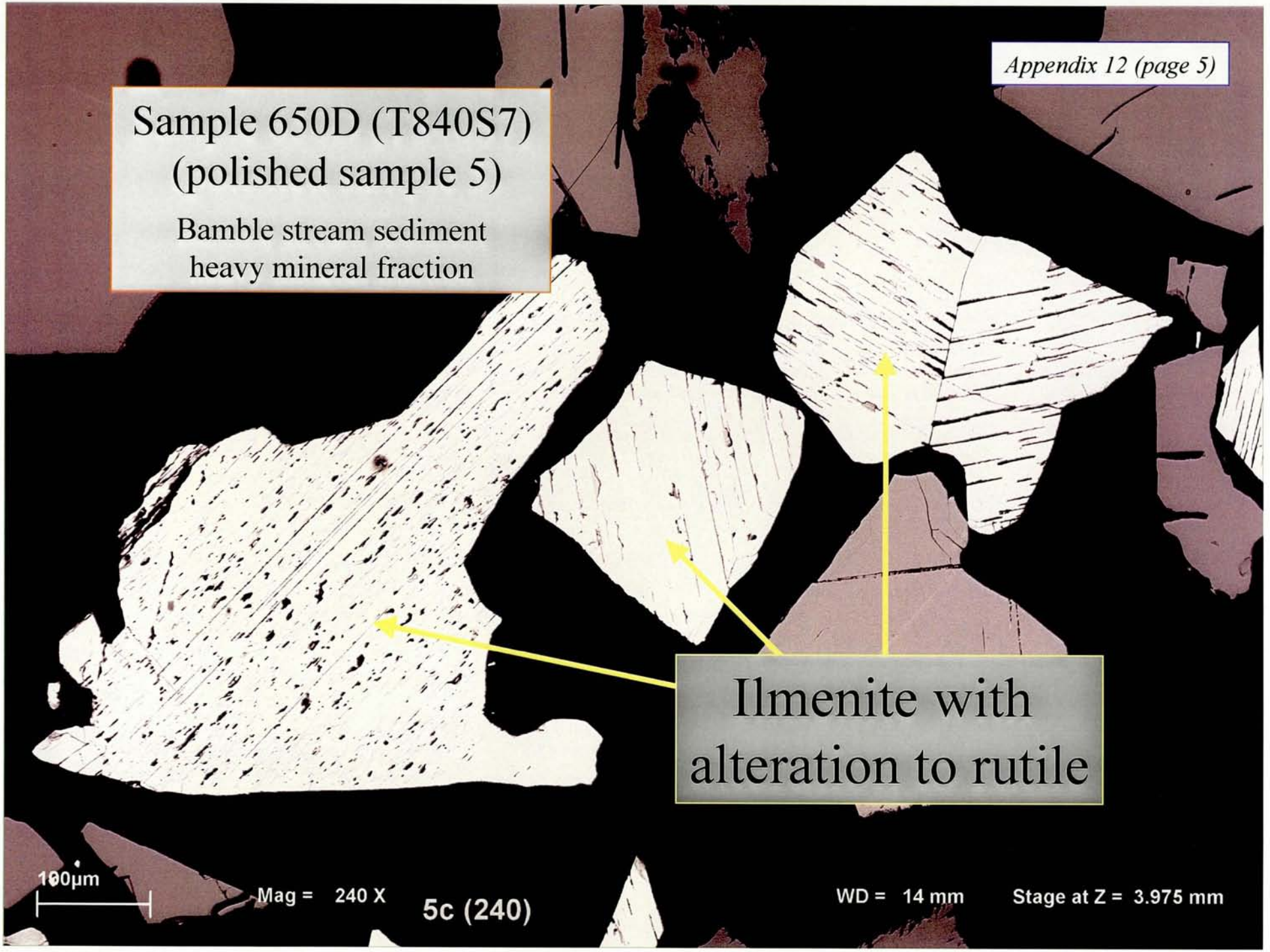


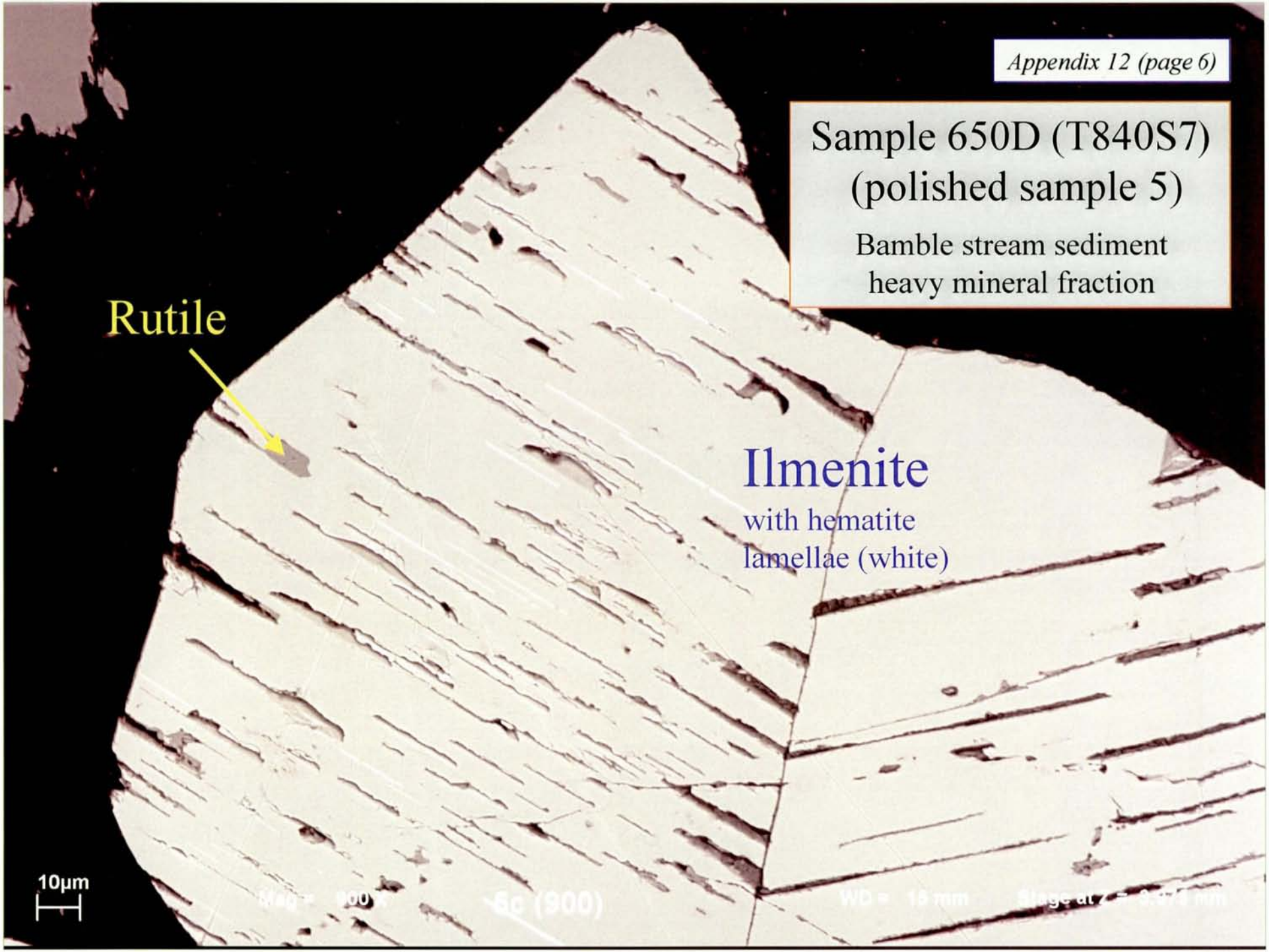
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
650	ssthm	Rutile	1237,7	238,6	11,3	9,3	46,1
650	ssthm	Intergrown ilmenite-rutile	2,3	20,3	0,6	0,2	0,6
650	ssthm	Rutile	843,6	2815,4	274,8	0,2	48,6

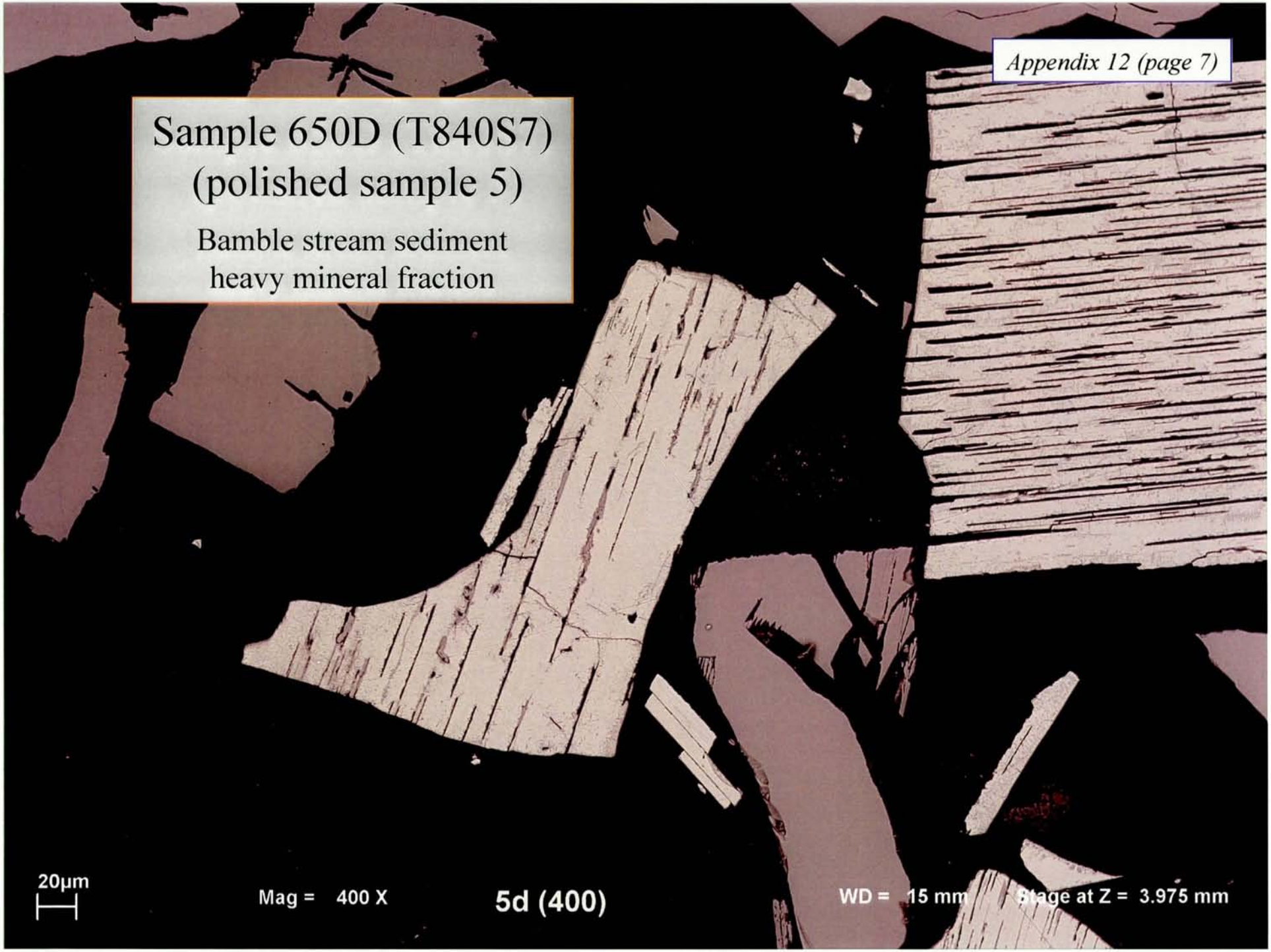

Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
200µm
5
Mag = 33 X
WD = 17 mm
Stage at Z = 2.000 mm

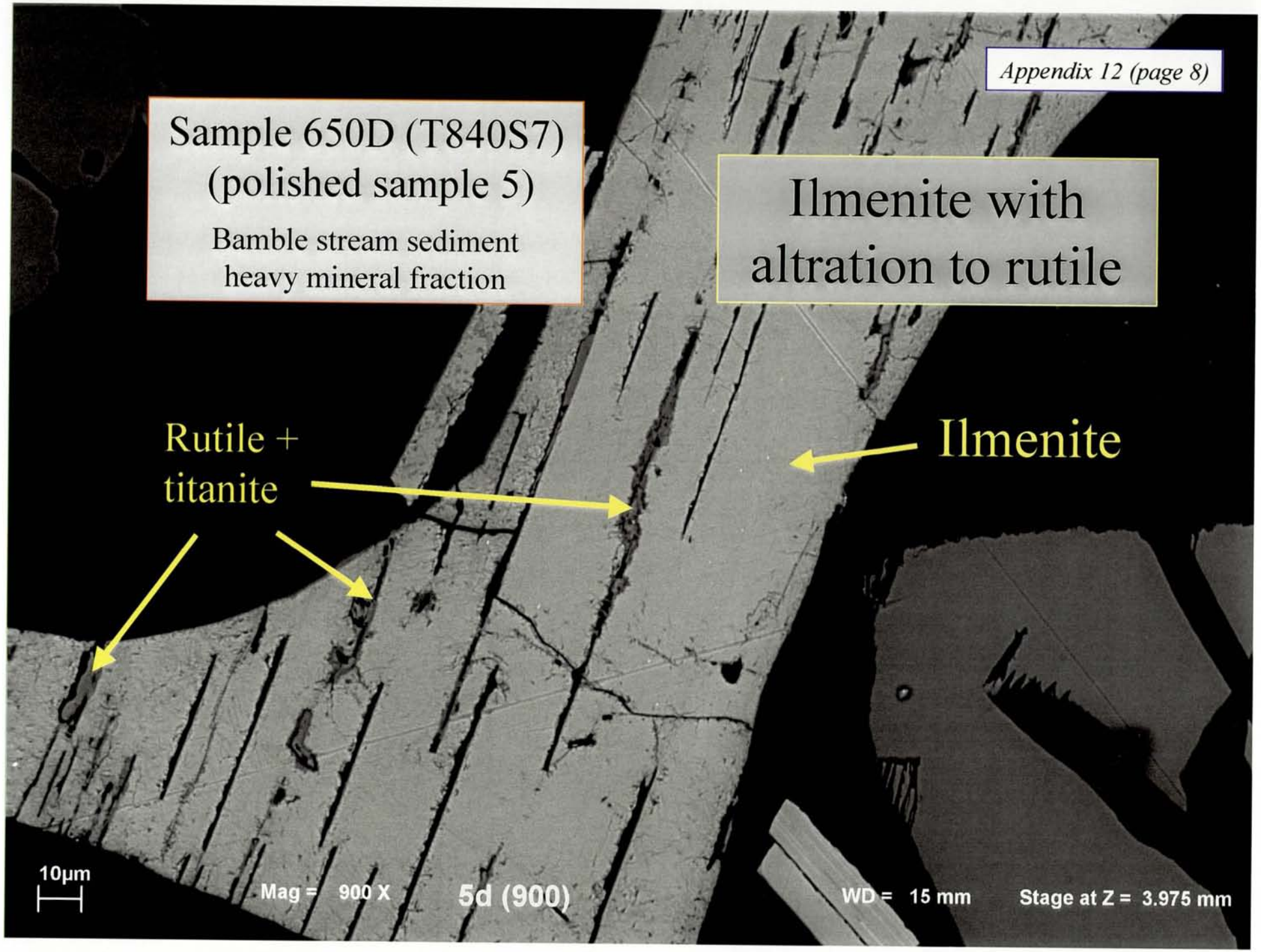

Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Rutile
Titanite
Mag = 500 X
5a (500)
WD = 14 mm
Stage at Z = 3.975 mm

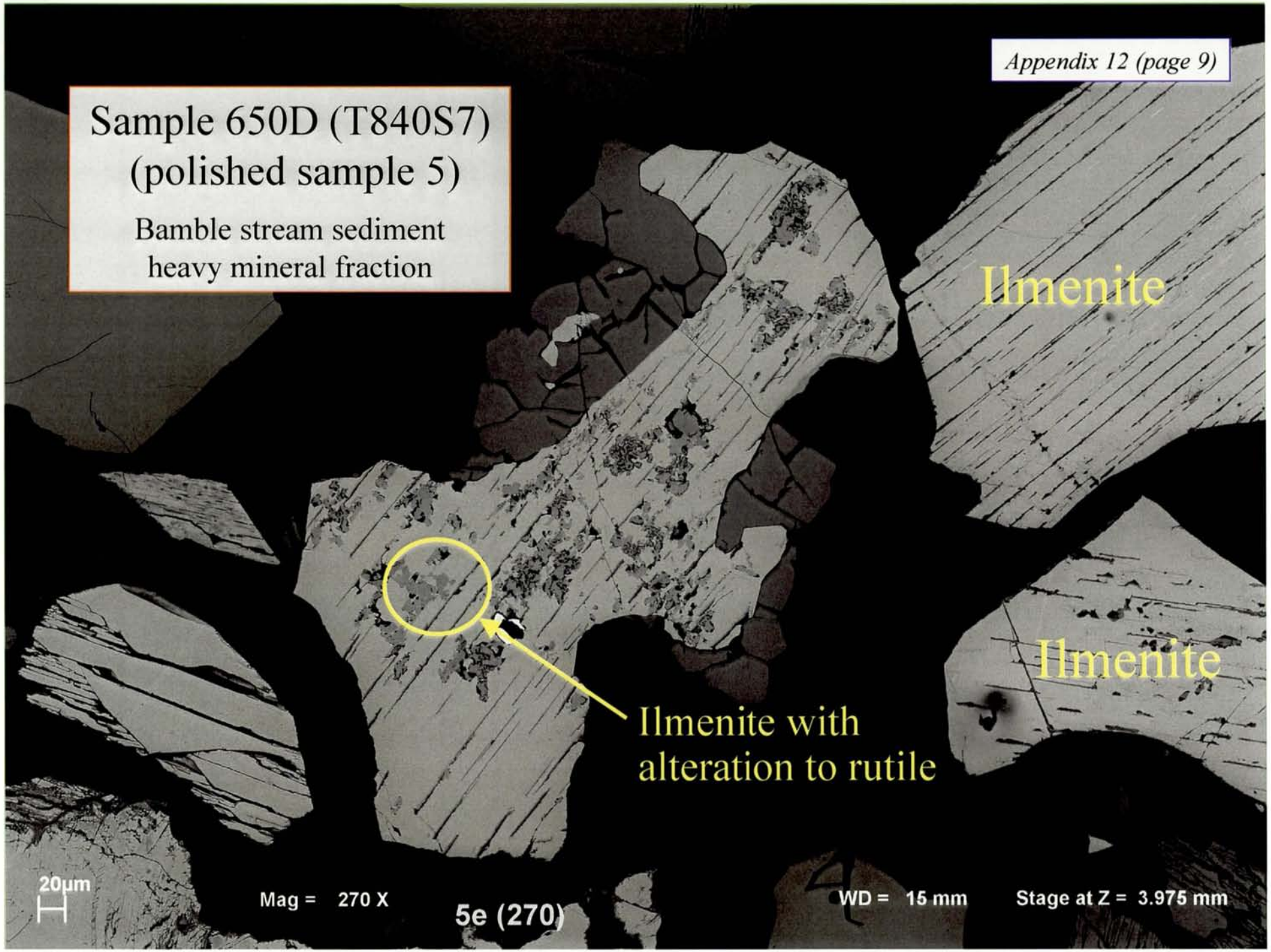

Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Rutile
20µm
Mag = 700 X
5b (700)
WD = 14 mm
Stage at Z = 3.975 mm

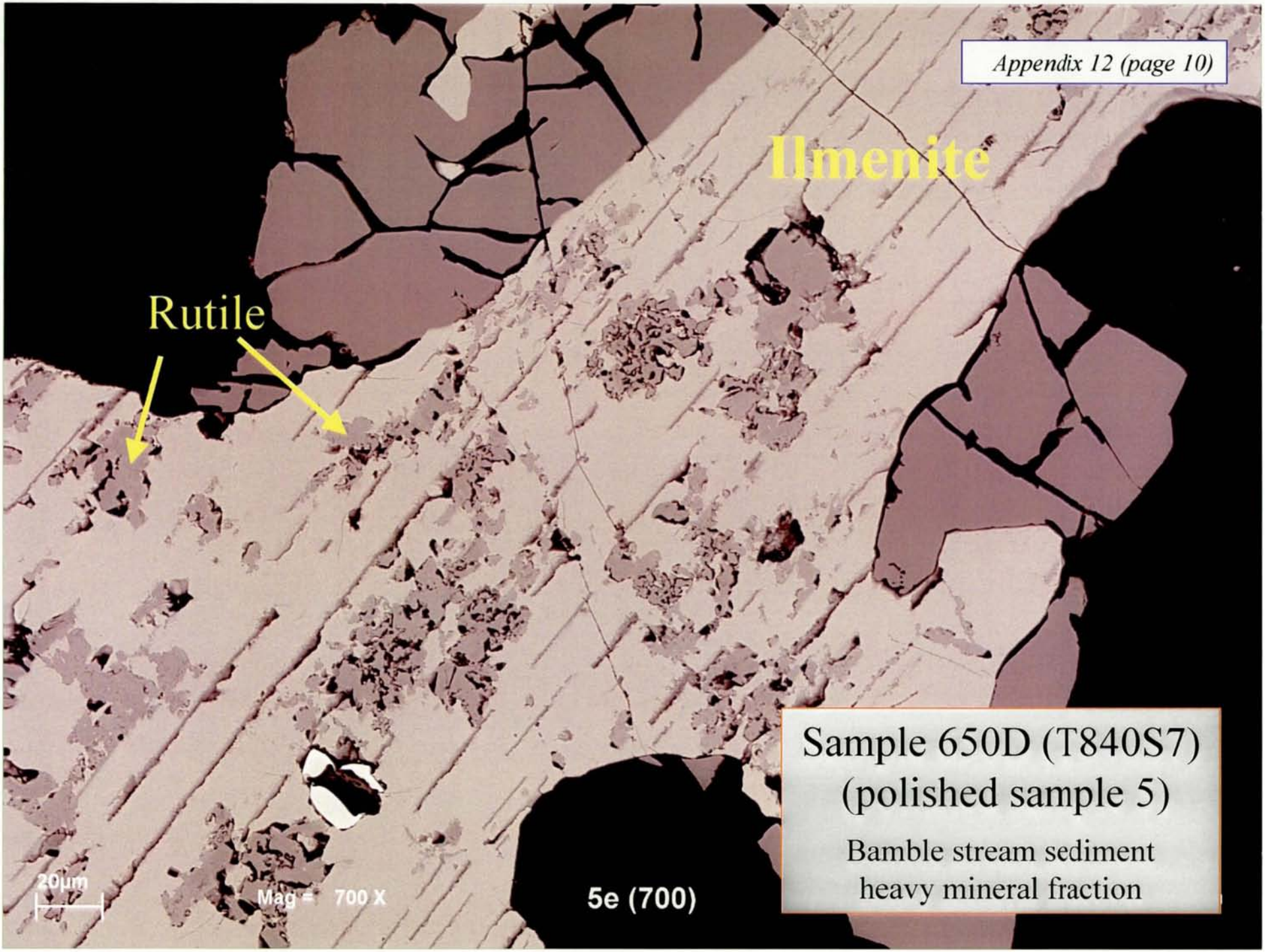

Appendix 12 (page 5)
Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Ilmenite with
alteration to rutile
100µm
Mag = 240 X
5c (240)
WD = 14 mm
Stage at Z = 3.975 mm


Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Rutile
Ilmenite
with hematite
lamellae (white)
10µm


Appendix 12 (page 7)
Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
20µm
Mag = 400 X
5d (400)
WD = 15 mm
Stage at Z = 3.975 mm


Appendix 12 (page 8)
Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Ilmenite with
altration to rutile
Rutile +
titanite
Ilmenite
10µm
Mag = 900 X
5d (900)
WD = 15 mm
Stage at Z = 3.975 mm

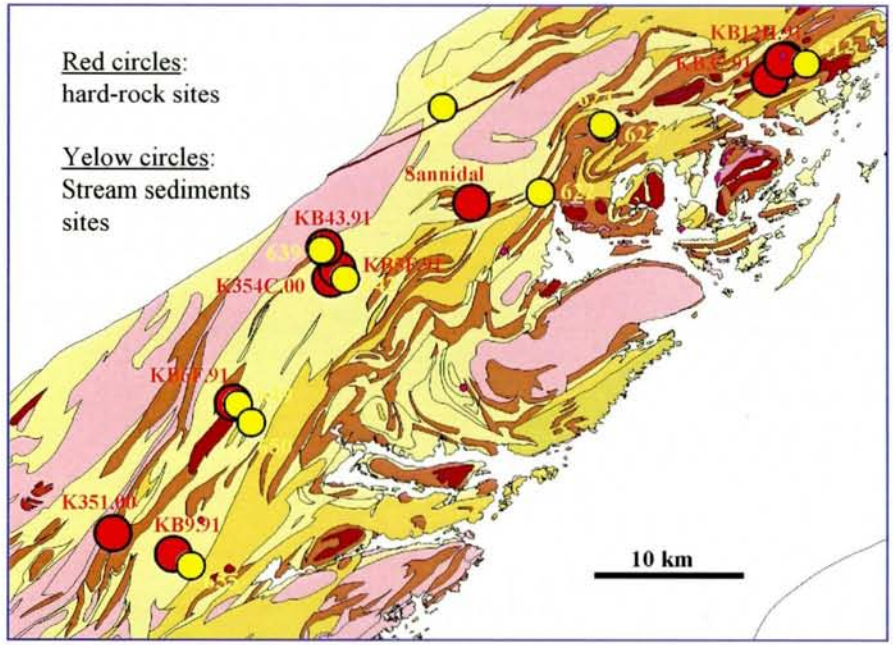

Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction
Ilmenite
Ilmenite
Ilmenite with
alteration to rutile
20µm
Mag = 270 X
5e (270)
WD = 15 mm
Stage at Z = 3.975 mm


Appendix 12 (page 10)
Ilmenite
Rutile
20µm
Mag = 700 X
5e (700)
Sample 650D (T840S7)
(polished sample 5)
Bamble stream sediment
heavy mineral fraction

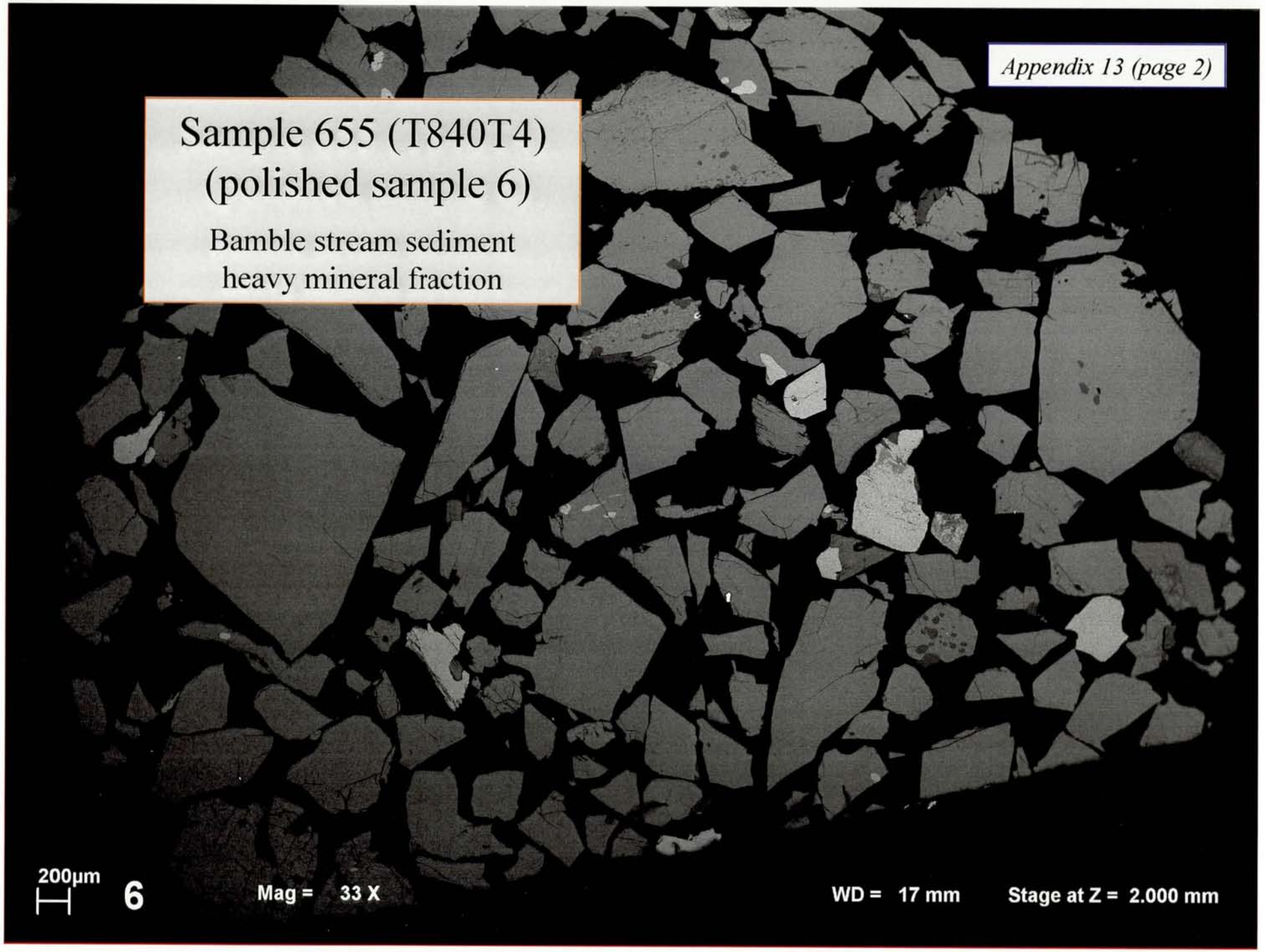
Appendix 13:

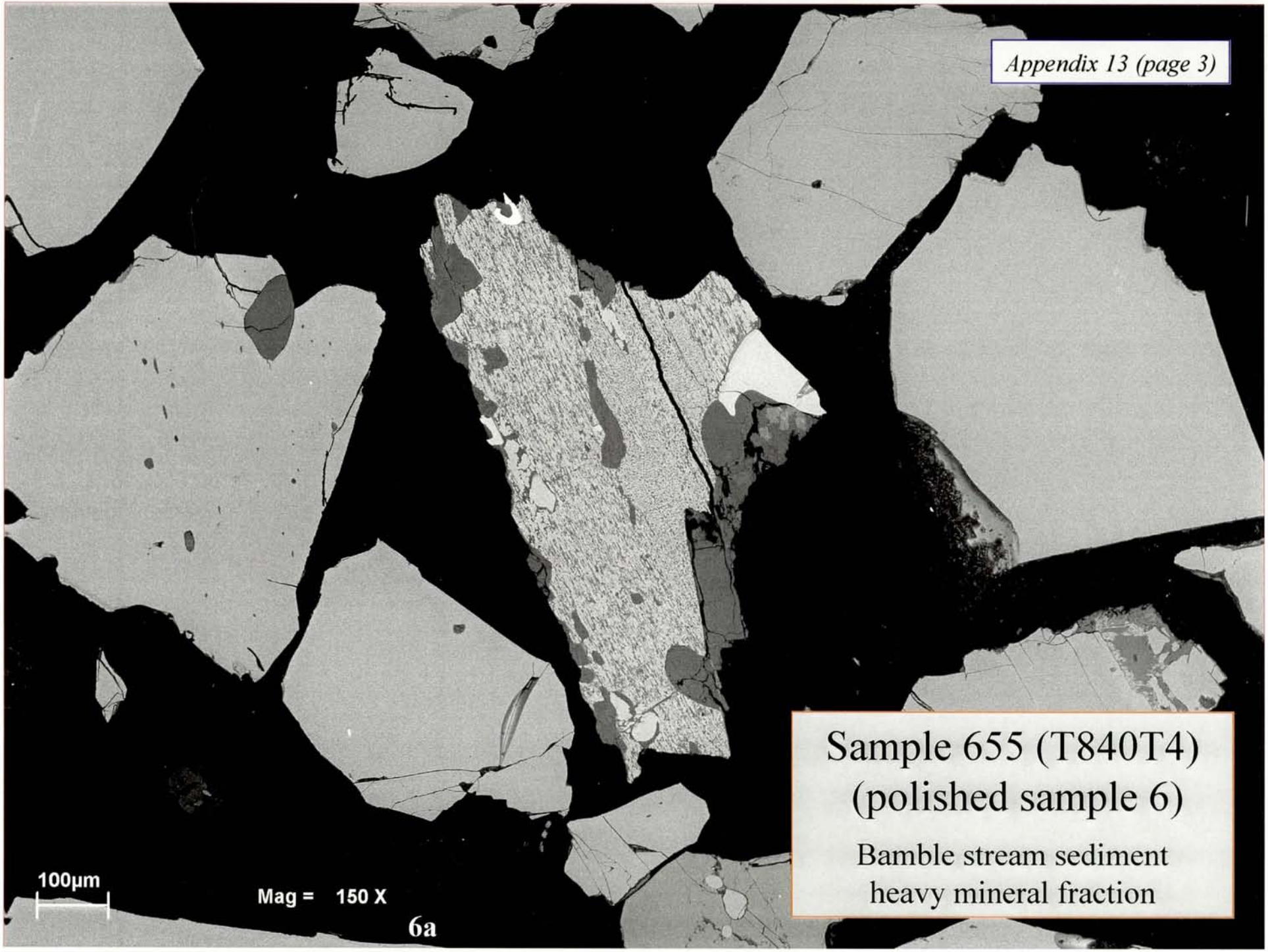
SEM-images of Bamble stream sediment heavy fraction

Sample 655 (T840T4)



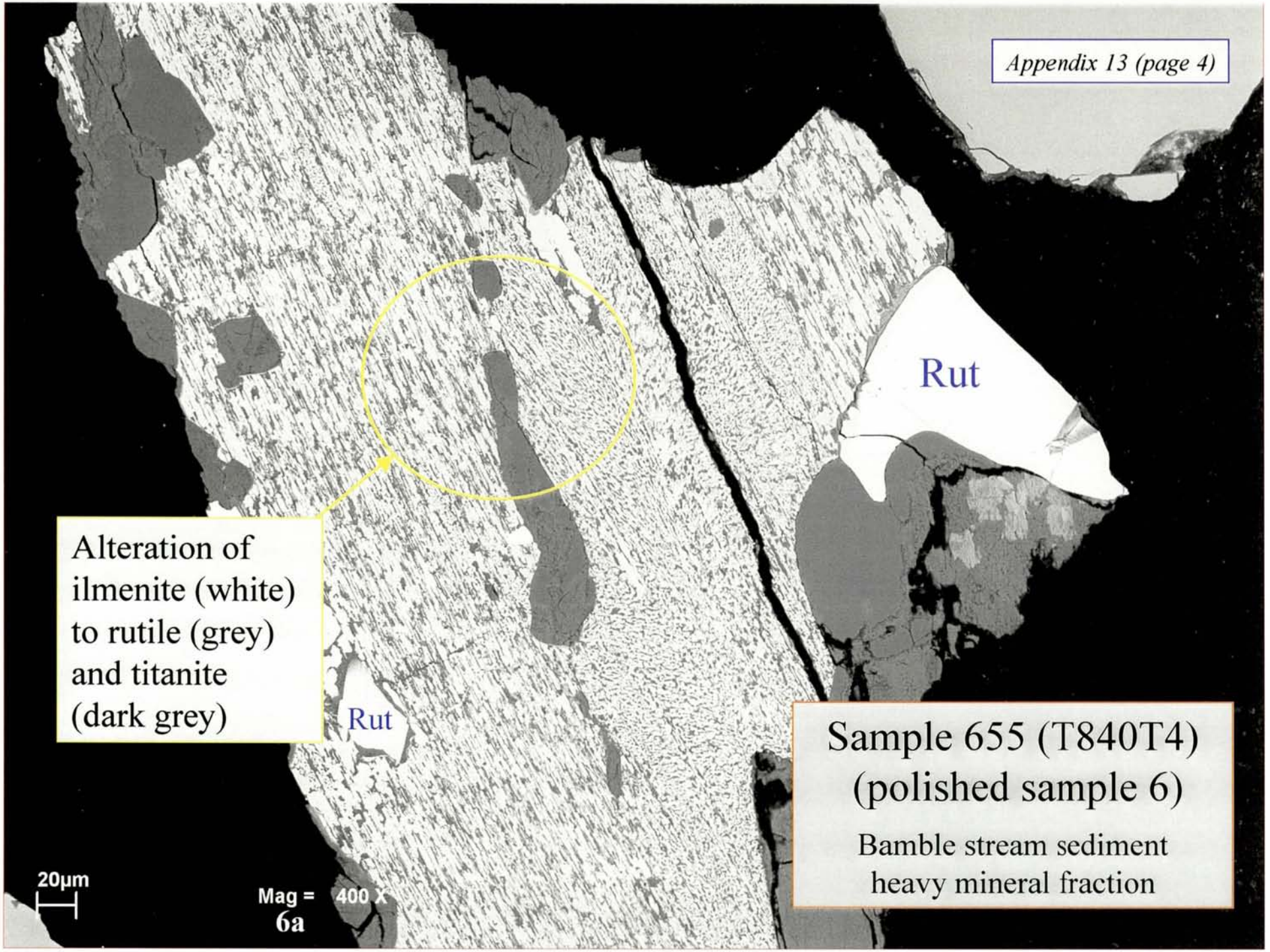
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
655	ssthm	Intergrown ilmenite-rutile-titanite	13,3	1551,1	69,5	0,2	1,5


Sample 655 (T840T4)
(polished sample 6)
Bamble stream sediment
heavy mineral fraction
200µm
6
Mag = 33 X
WD = 17 mm
Stage at Z = 2.000 mm



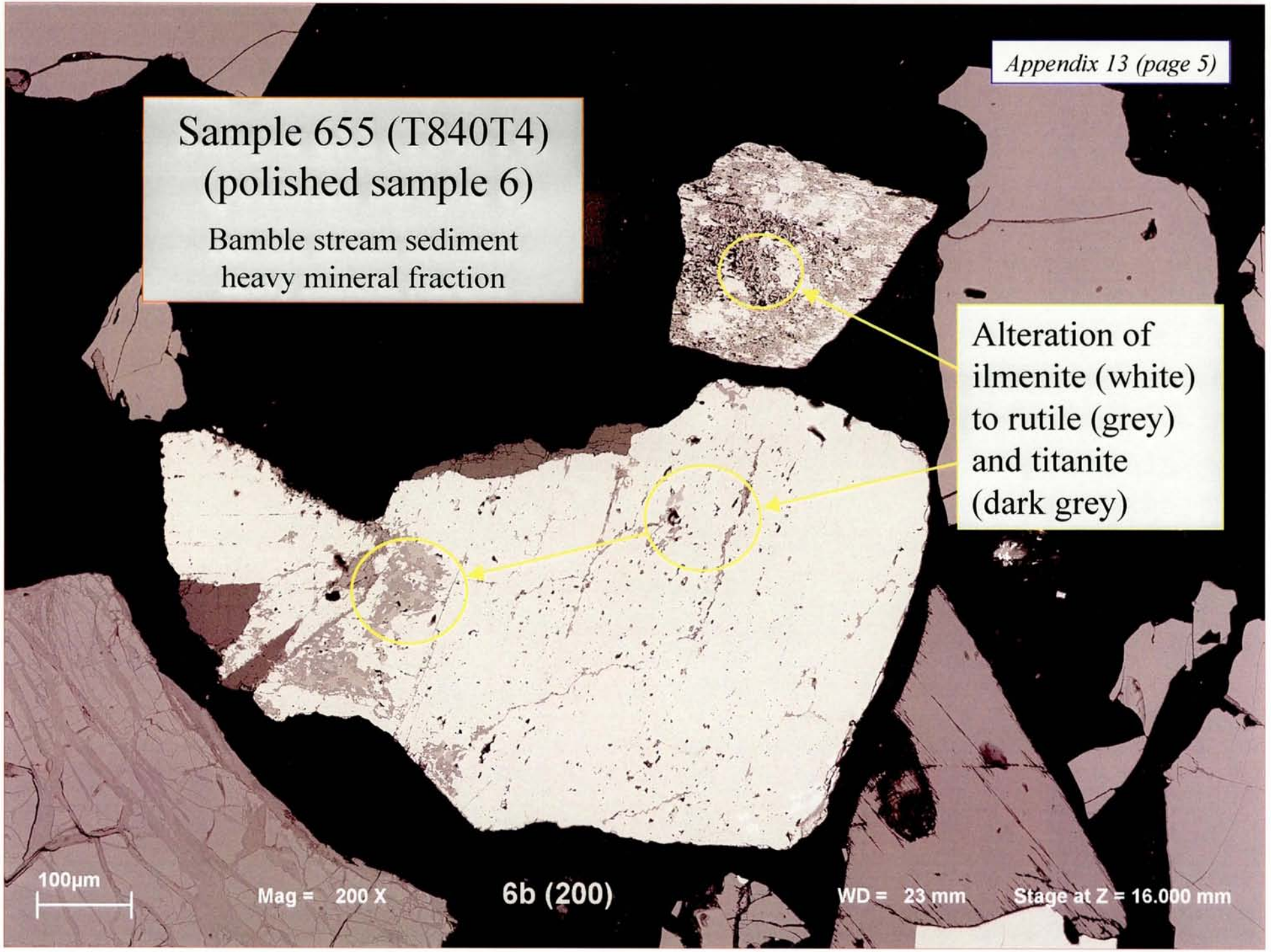
Sample 655 (T840T4)
(polished sample 6)

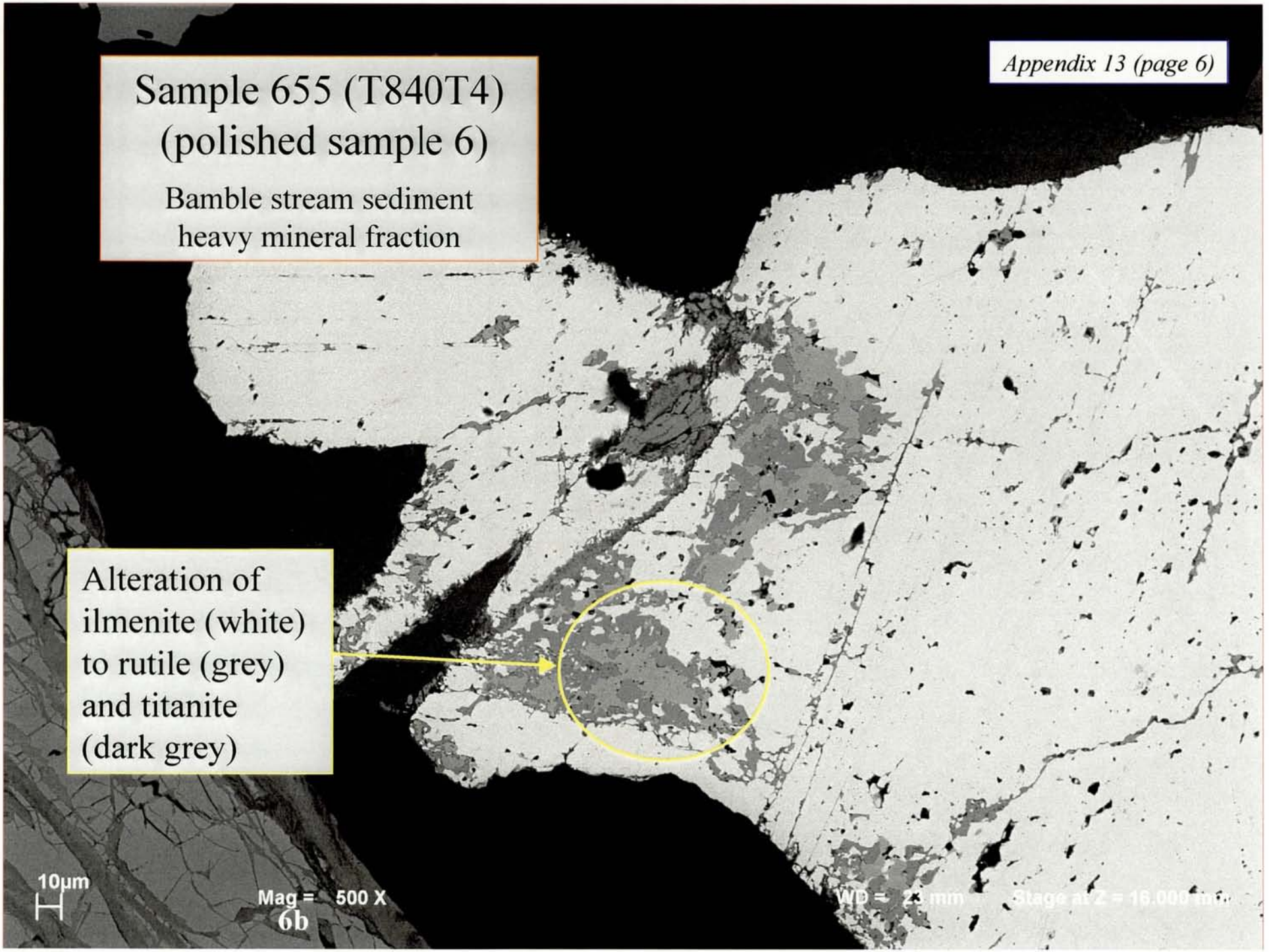
Bamble stream sediment
heavy mineral fraction

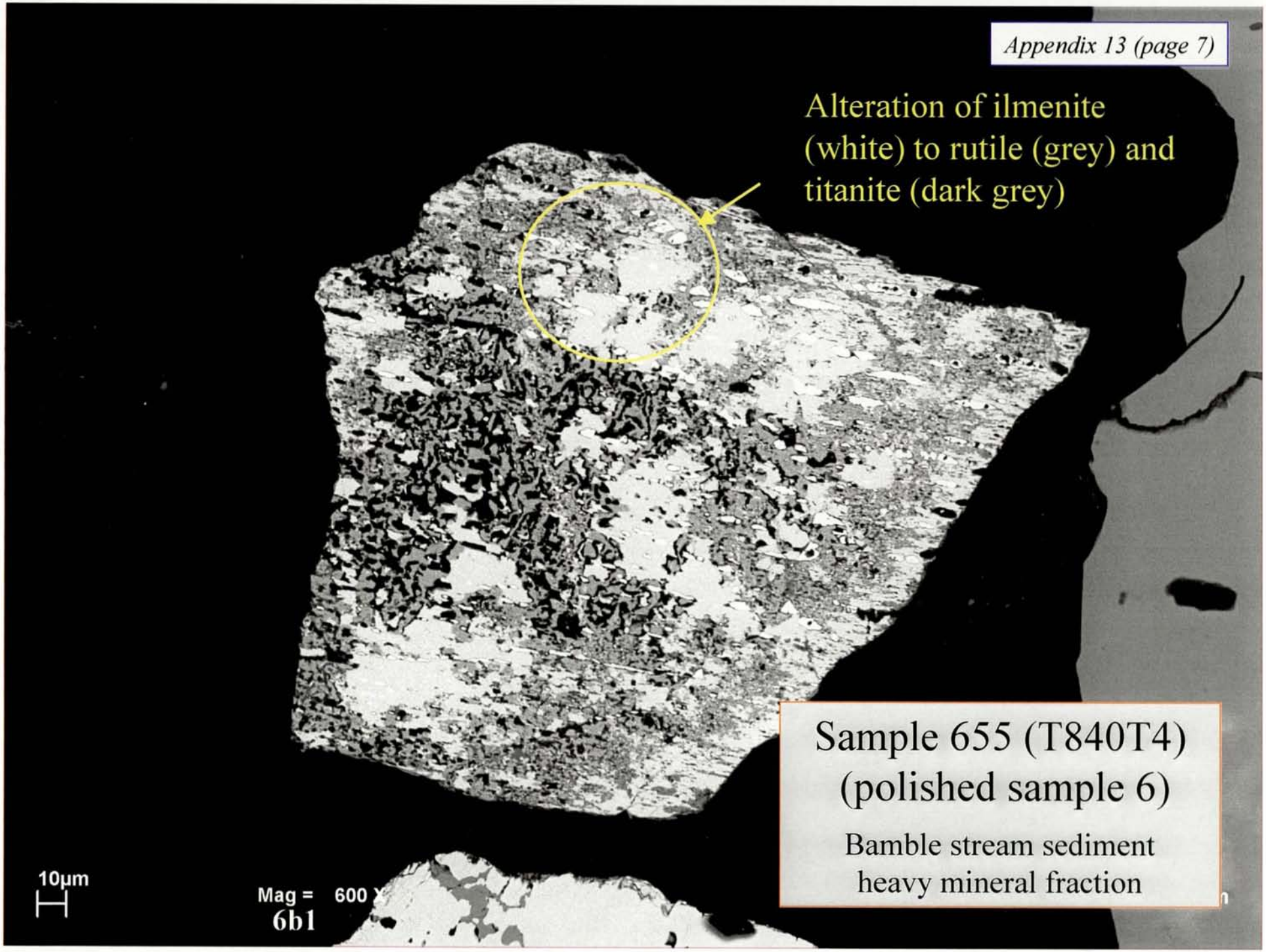


Sample 655 (T840T4)
(polished sample 6)

Bamble stream sediment
heavy mineral fraction

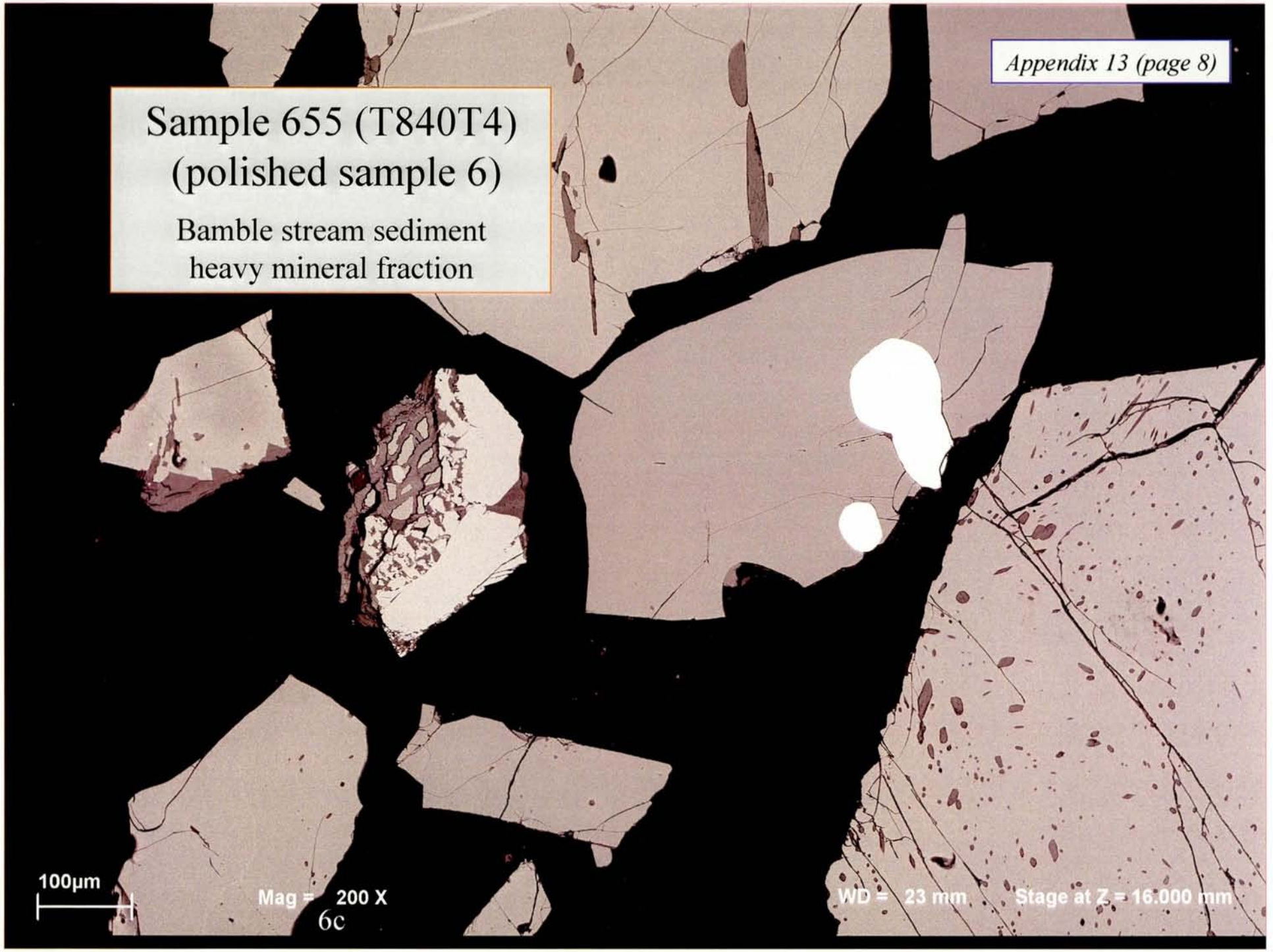

Appendix 13 (page 5)
Sample 655 (T840T4)
(polished sample 6)
Bamble stream sediment
heavy mineral fraction
Alteration of
ilmenite (white)
to rutile (grey)
and titanite
(dark grey)
100µm
Mag = 200 X
6b (200)
WD = 23 mm
Stage at Z = 16.000 mm

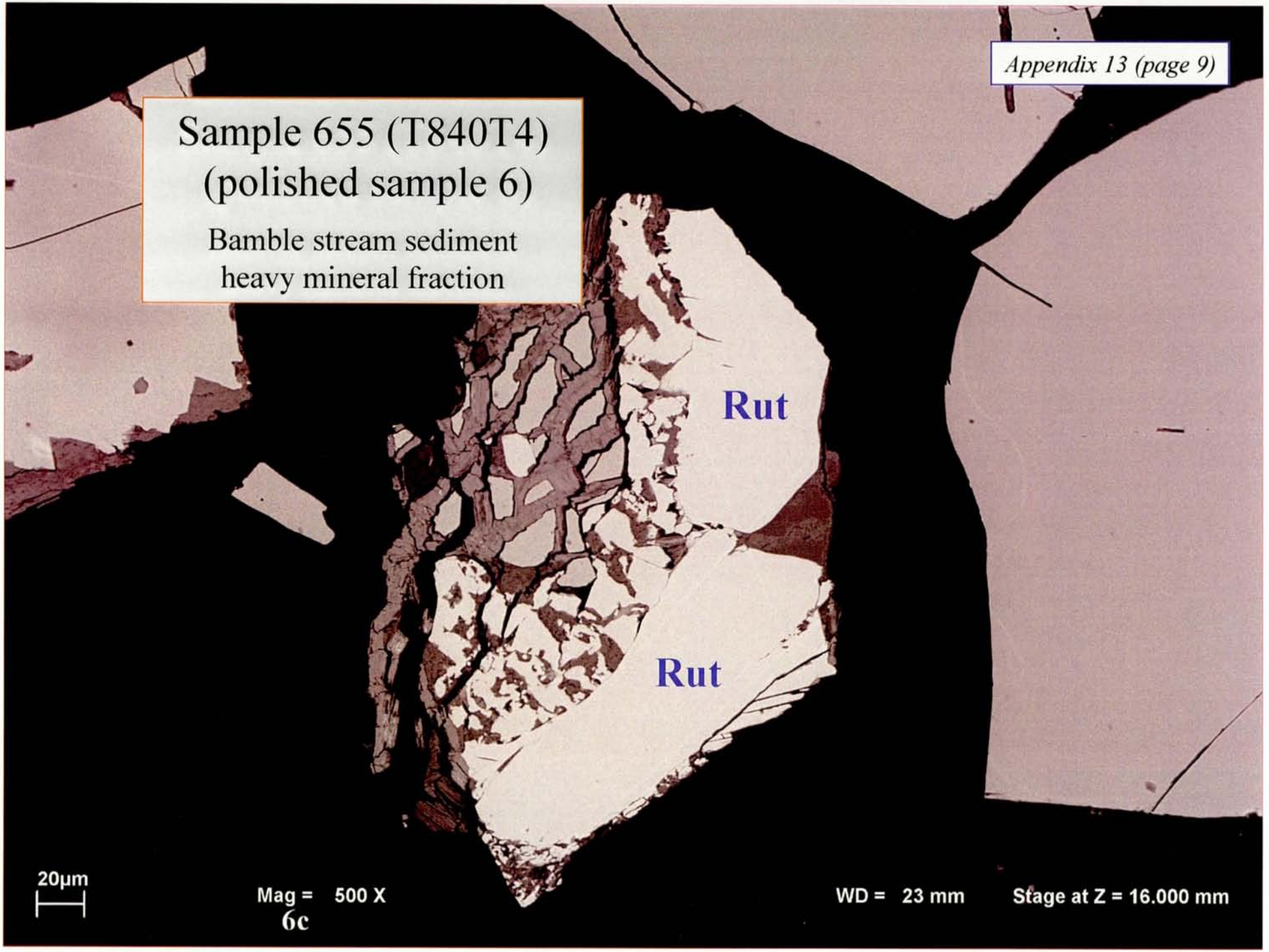

Sample 655 (T840T4)
(polished sample 6)
Bamble stream sediment
heavy mineral fraction
Alteration of
ilmenite (white)
to rutile (grey)
and titanite
(dark grey)
10µm
Mag = 500 X
6b



Sample 655 (T840T4)
(polished sample 6)

Bamble stream sediment
heavy mineral fraction


Sample 655 (T840T4)
(polished sample 6)
Bamble stream sediment
heavy mineral fraction
100µm
Mag = 200 X
WD = 23 mm
Stage at Z = 16.000 mm
6c

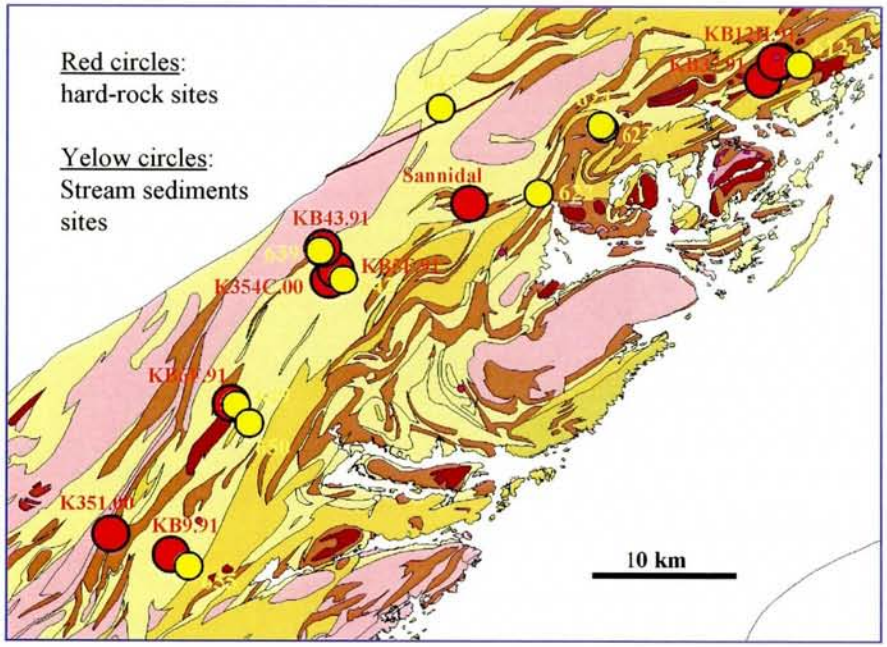

Sample 655 (T840T4)
(polished sample 6)
Bamble stream sediment
heavy mineral fraction
Rut
Rut
20µm
Mag = 500 X
WD = 23 mm
Stage at Z = 16.000 mm

6c

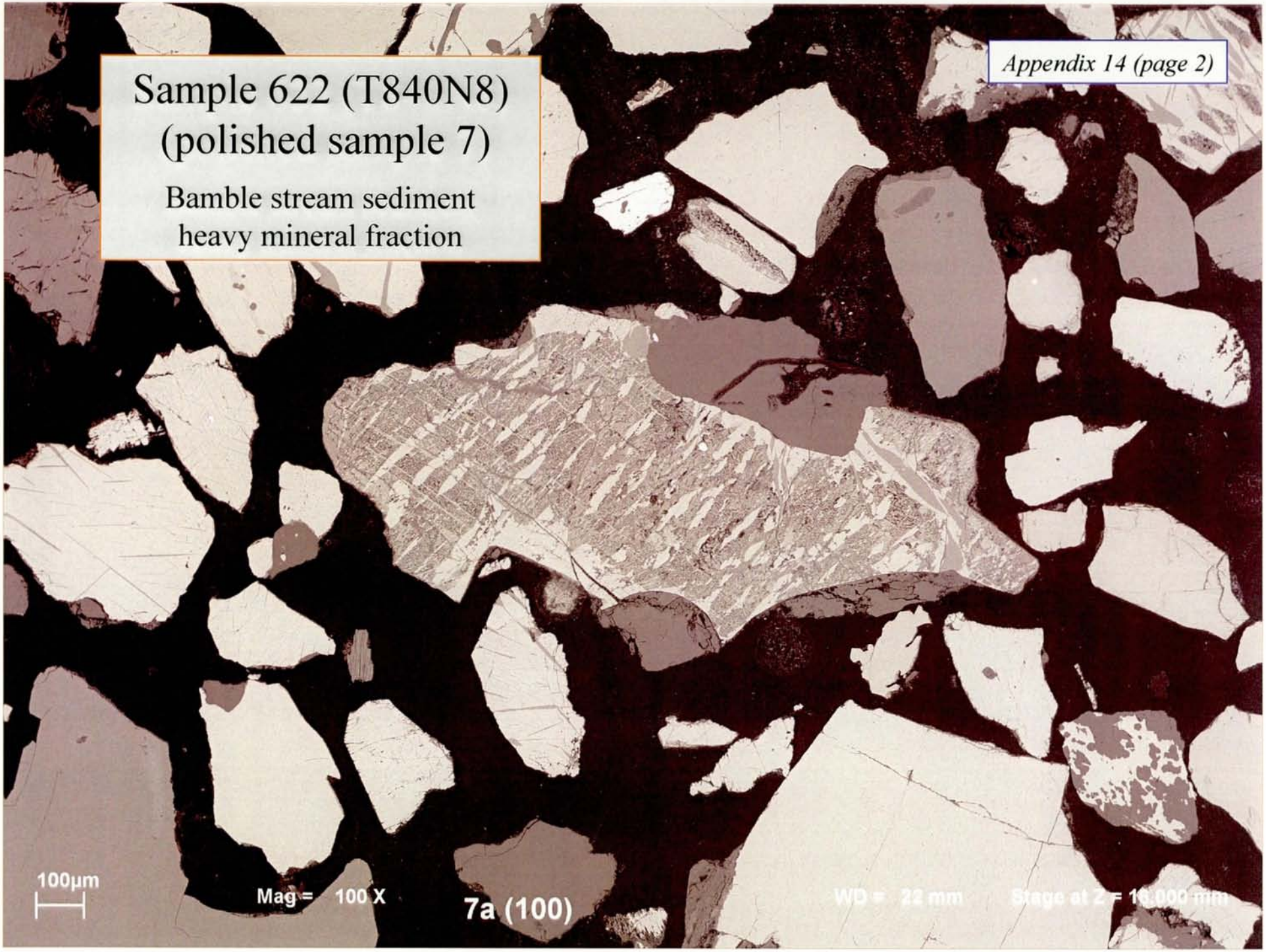
Appendix 14:

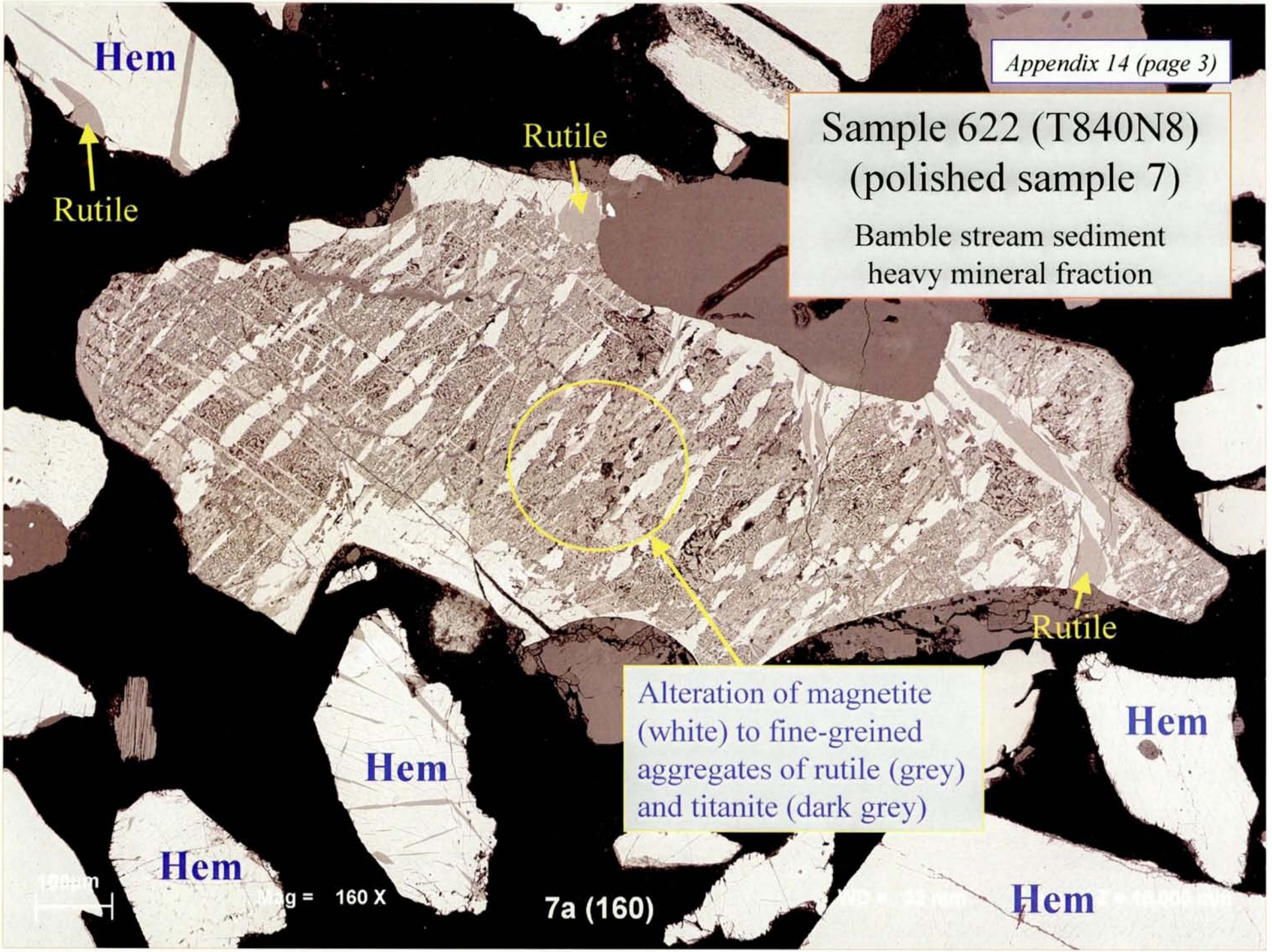
SEM-images of Bamble stream sediment heavy fraction

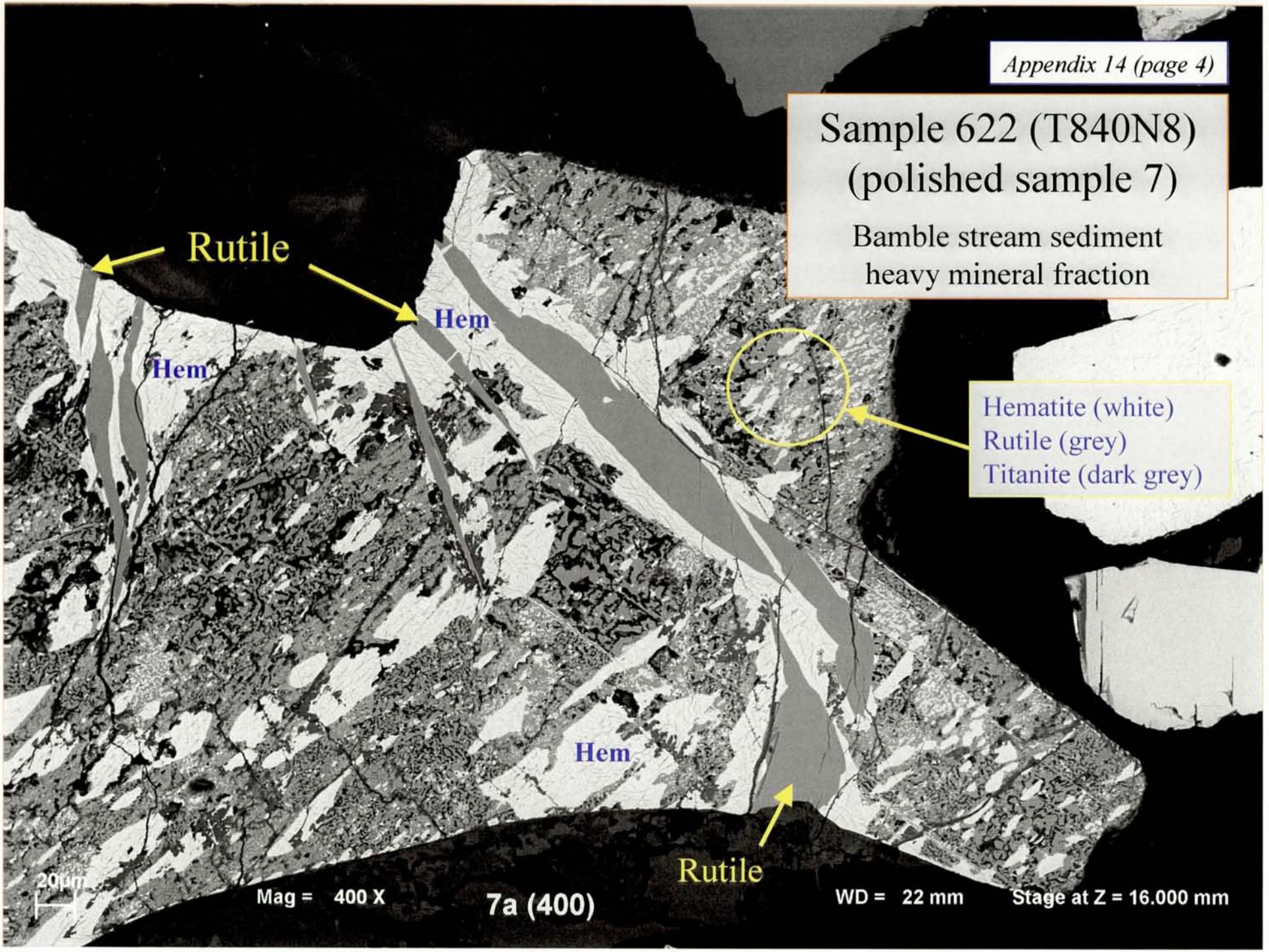
Sample 622 (T840N8)

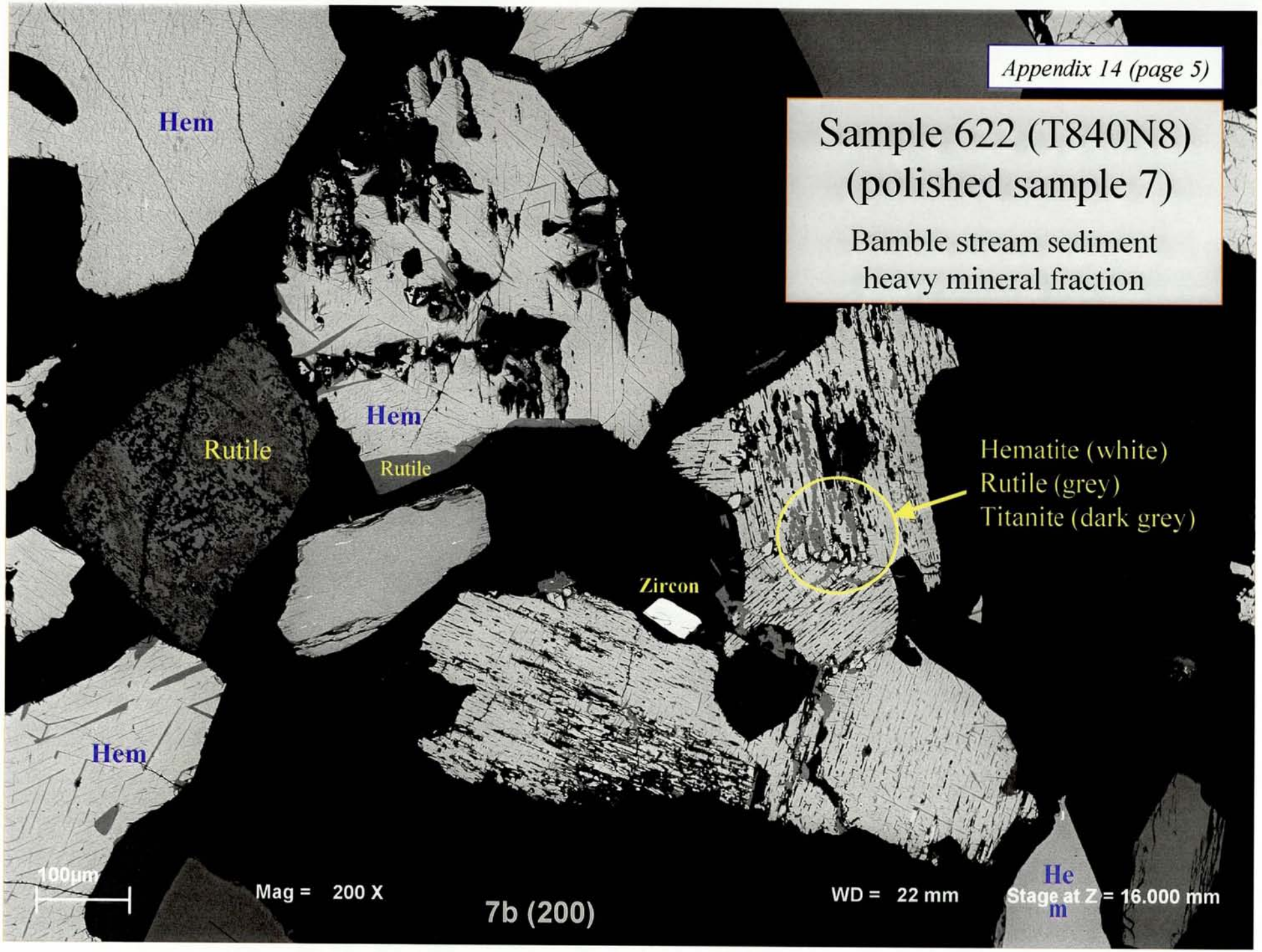


Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
622	ssthm	Intergrown hematite-ilmenite-rutile	8,0	61,5	5,8	14,4	6,6
622	ssthm	Intergrown hematite-ilmenite-rutile	51,6	634,7	7,4	23,7	12,2
622	ssthm	Intergrown hematite-ilmenite-rutile	37,0	359,8	31,3	10,2	9,3


Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
100µm
Mag = 100 X
7a (100)
WD = 22 mm
Stage at Z = 10.000 mm

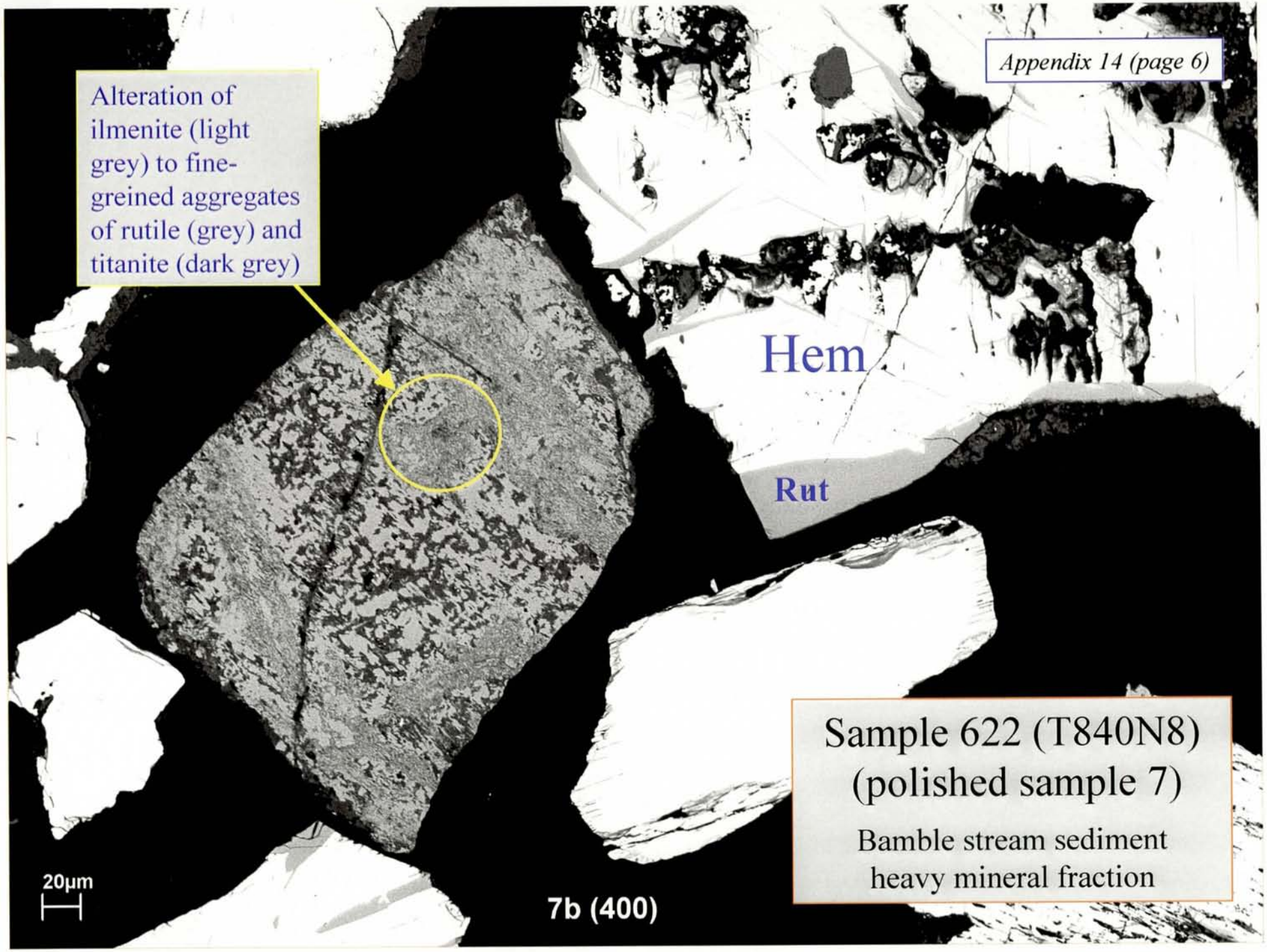

Hem
Rutile
Rutile
Appendix 14 (page 3)
Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
Rutile
Alteration of magnetite
(white) to fine-greined
aggregates of rutile (grey)
and titanite (dark grey)
Hem
Hem
Hem
Hem
Mag = 160 X
7a (160)

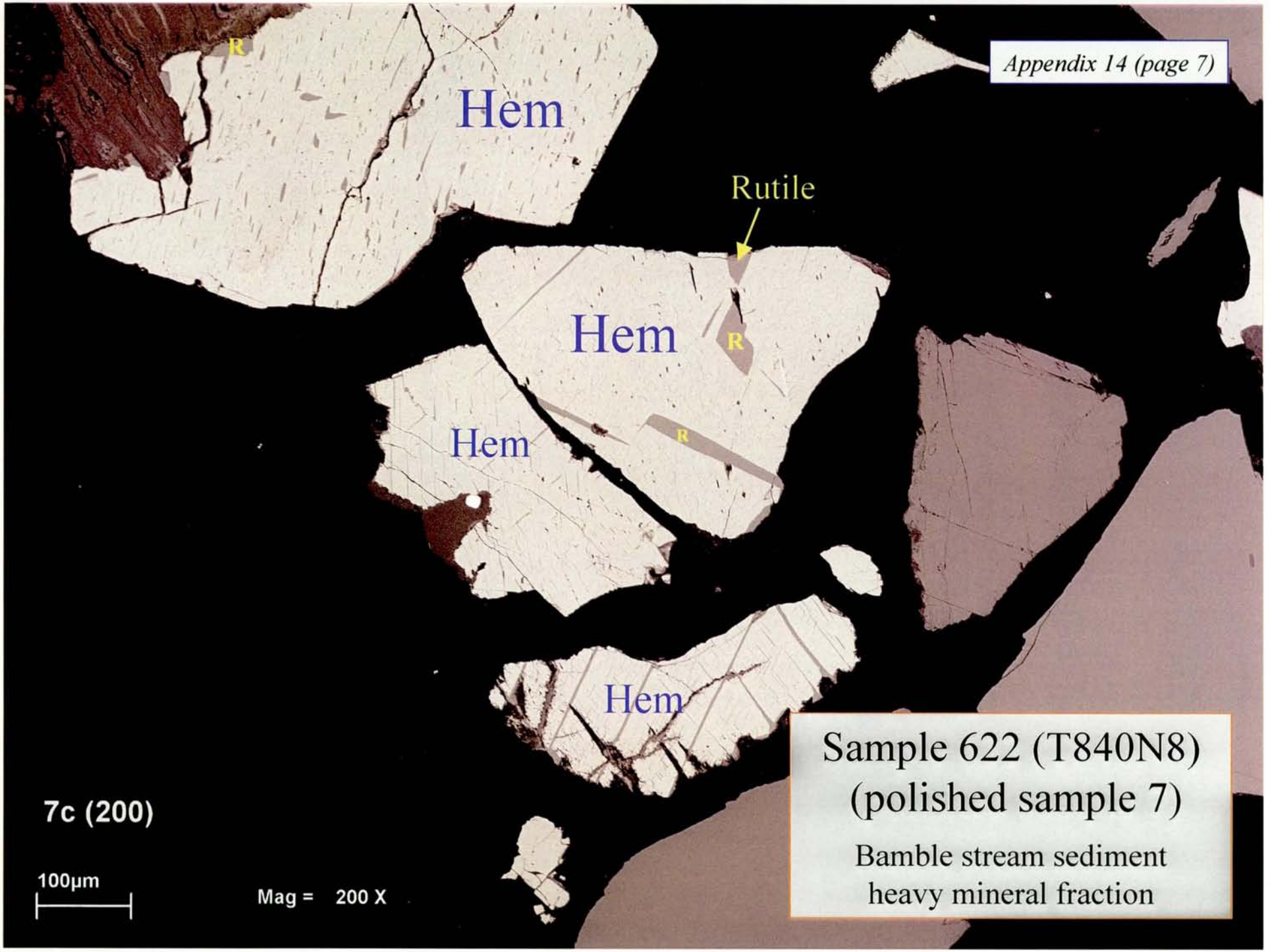

Appendix 14 (page 4)
Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
Rutile
Hem
Hem
Hematite (white)
Rutile (grey)
Titanite (dark grey)
Hem
Rutile
20µm
Mag = 400 X
7a (400)
WD = 22 mm
Stage at Z = 16.000 mm

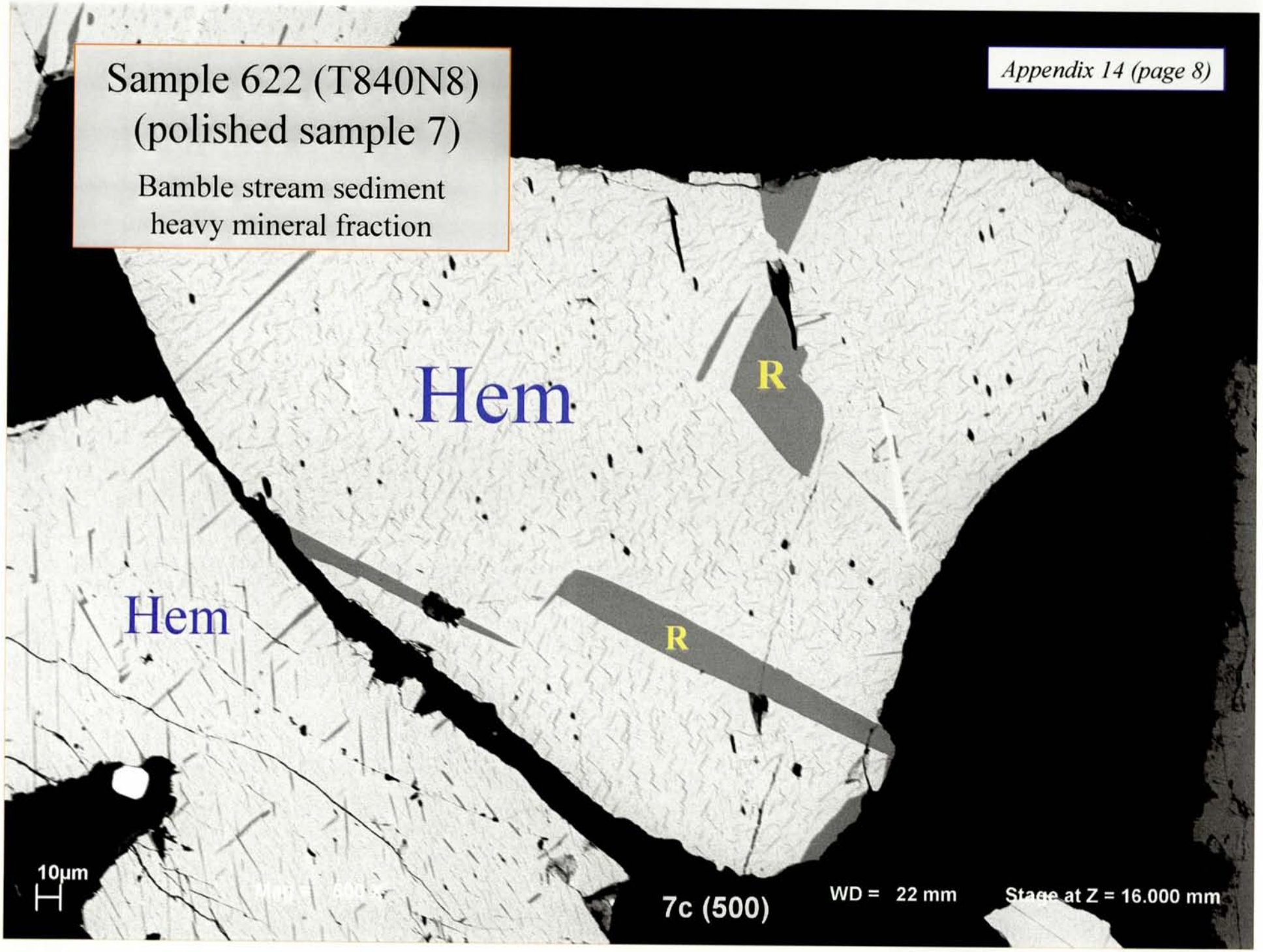


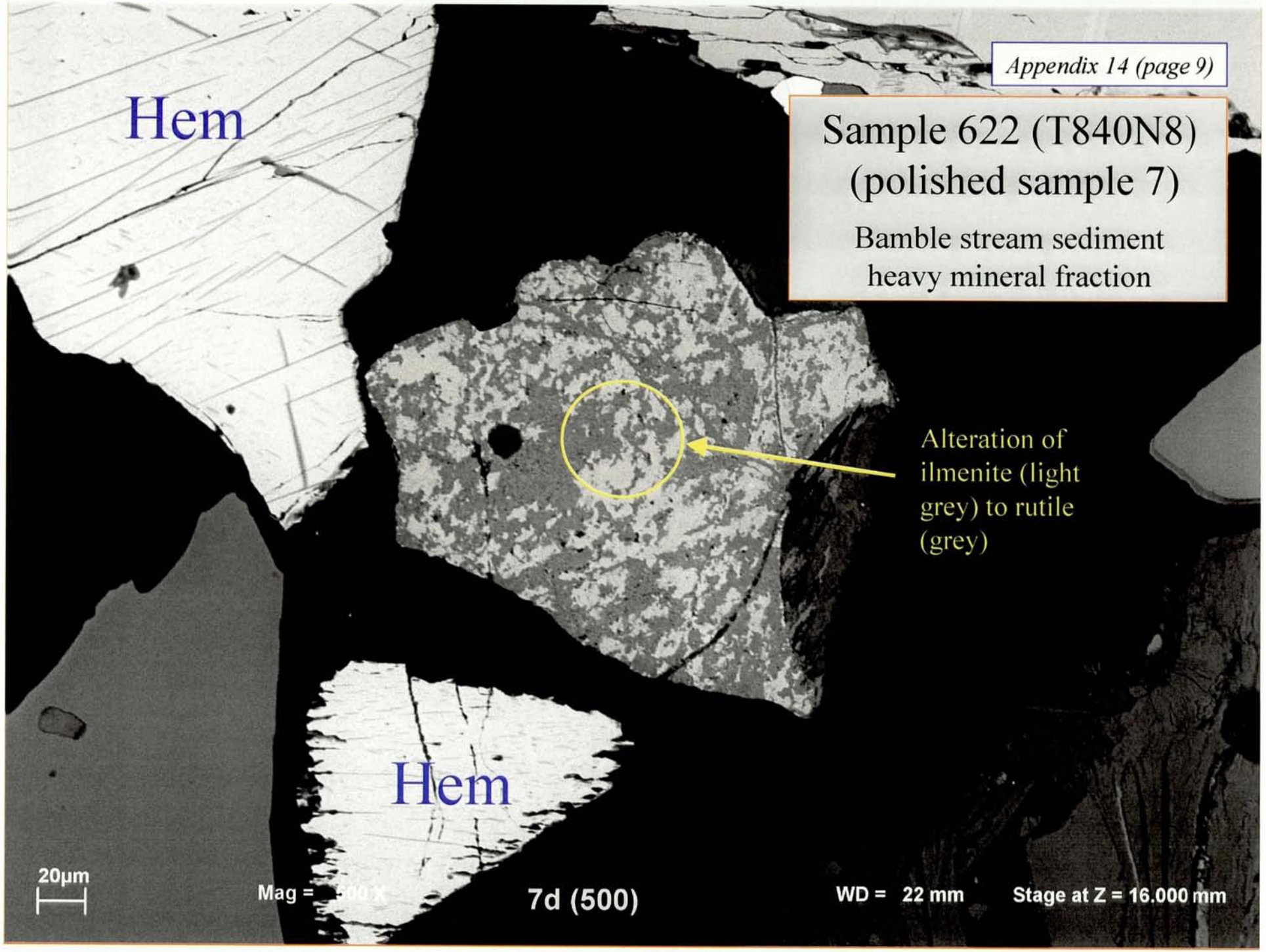
Sample 622 (T840N8) (polished sample 7)

Bamble stream sediment heavy mineral fraction


Appendix 14 (page 6)
Alteration of ilmenite (light grey) to fine-greined aggregates of rutile (grey) and titanite (dark grey)
Hem
Rut
Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment heavy mineral fraction
20µm
7b (400)


Appendix 14 (page 7)
Hem
Rutile
Hem
R
Hem
R
Hem
R
Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
7c (200)
100µm
Mag = 200 X

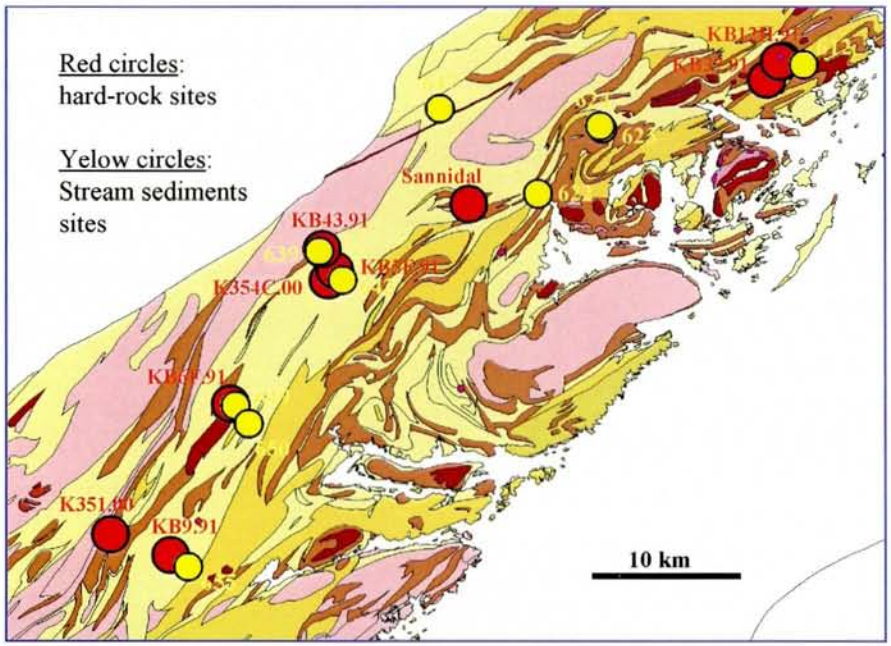

Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
Appendix 14 (page 8)
Hem
R
Hem
R
10µm
7c (500)
WD = 22 mm
Stage at Z = 16.000 mm


Appendix 14 (page 9)
Sample 622 (T840N8)
(polished sample 7)
Bamble stream sediment
heavy mineral fraction
Hem
Hem
Alteration of
ilmenite (light
grey) to rutile
(grey)
20µm
Mag = 500 X
7d (500)
WD = 22 mm
Stage at Z = 16.000 mm

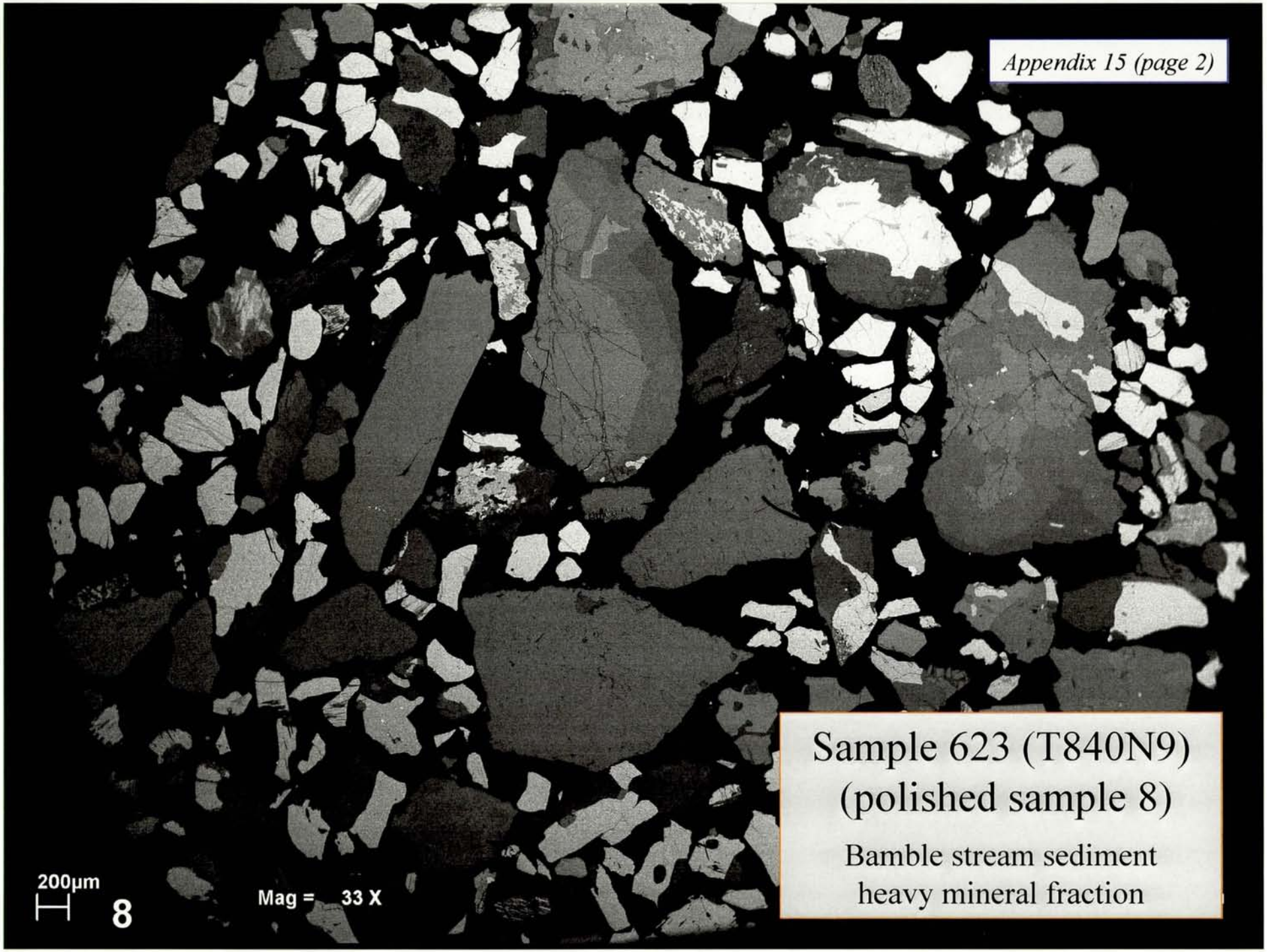
Appendix 15:

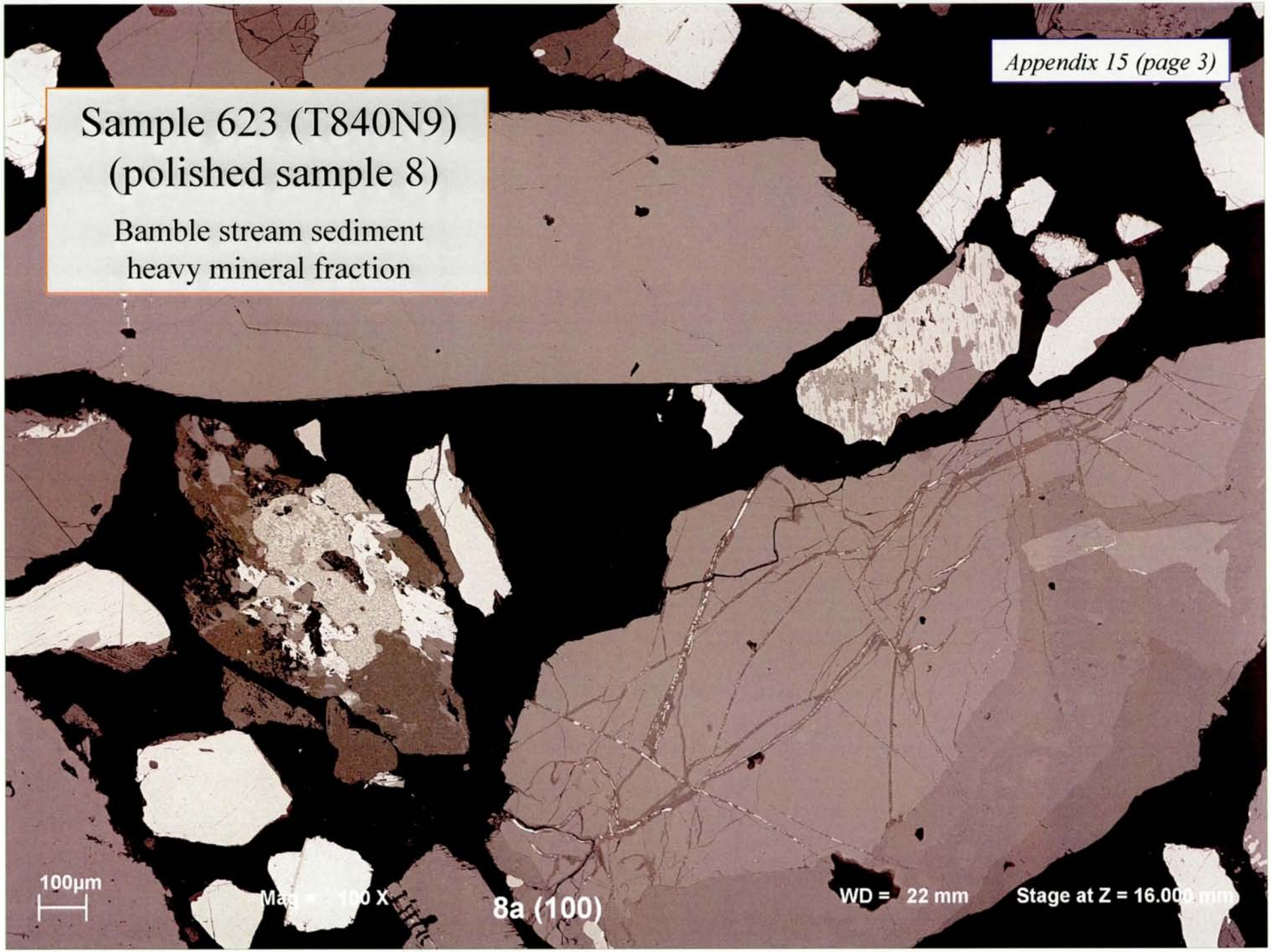
SEM-images of Bamble stream sediment heavy fraction

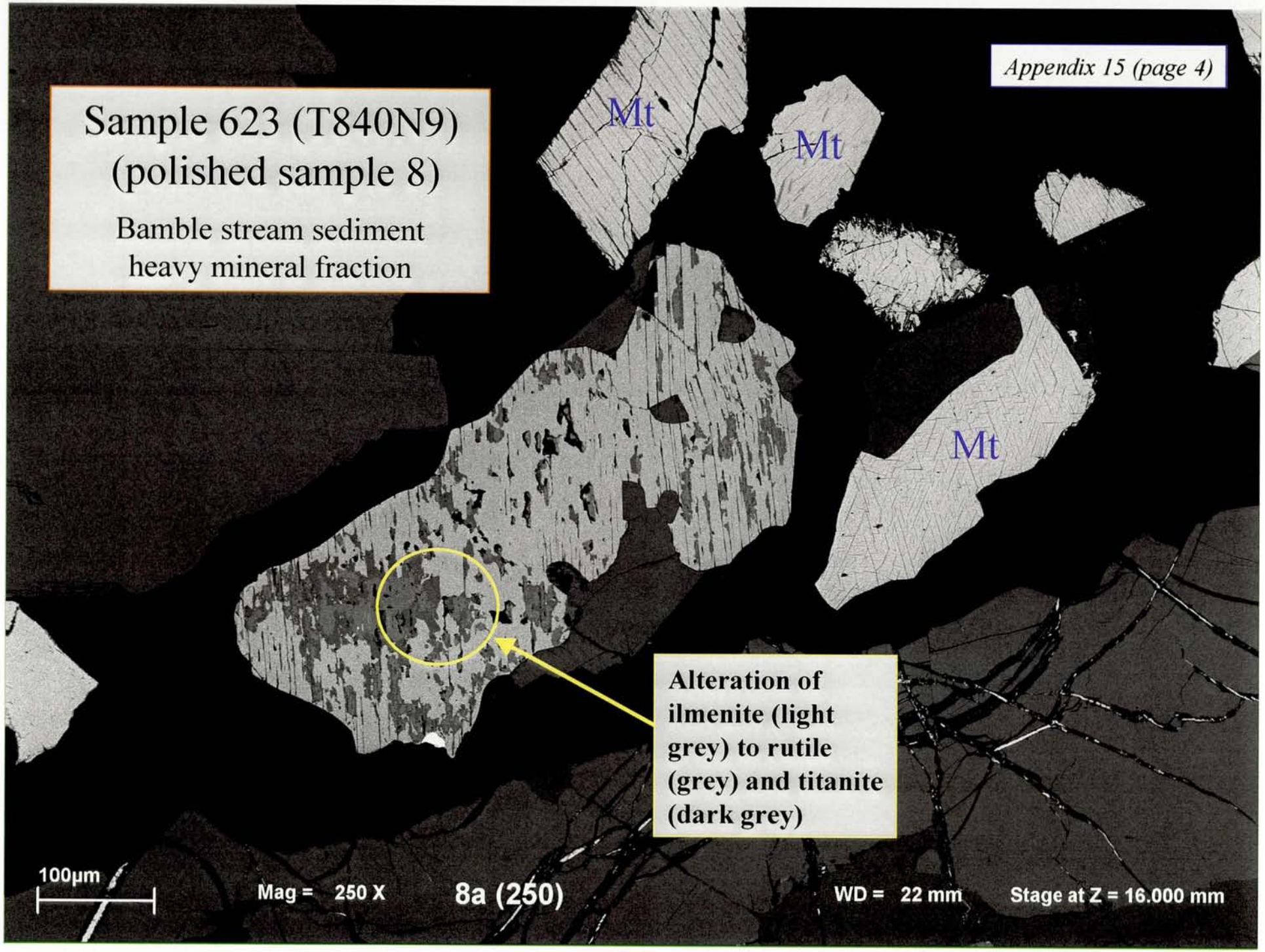
Sample 623 (T840N9)

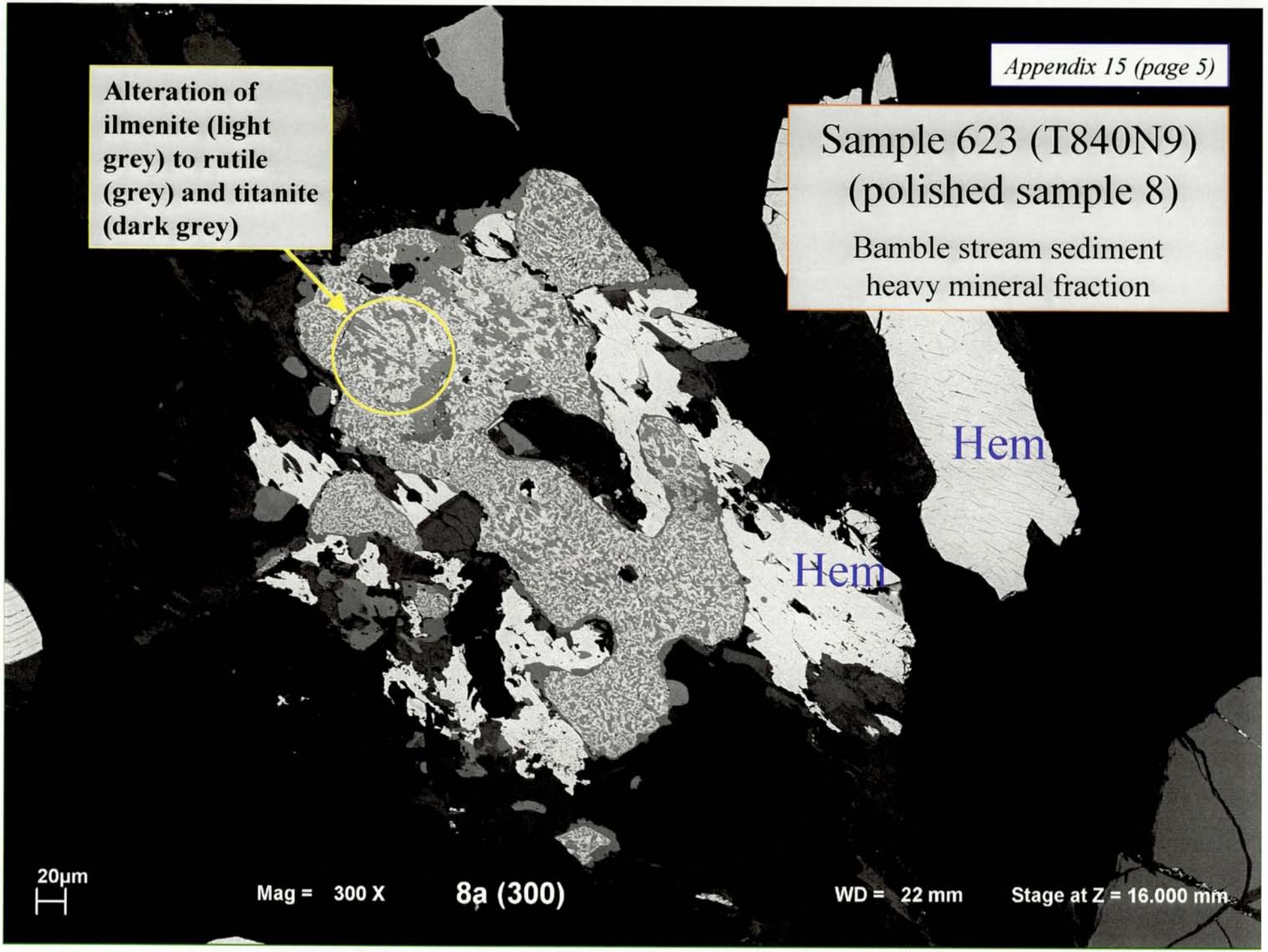


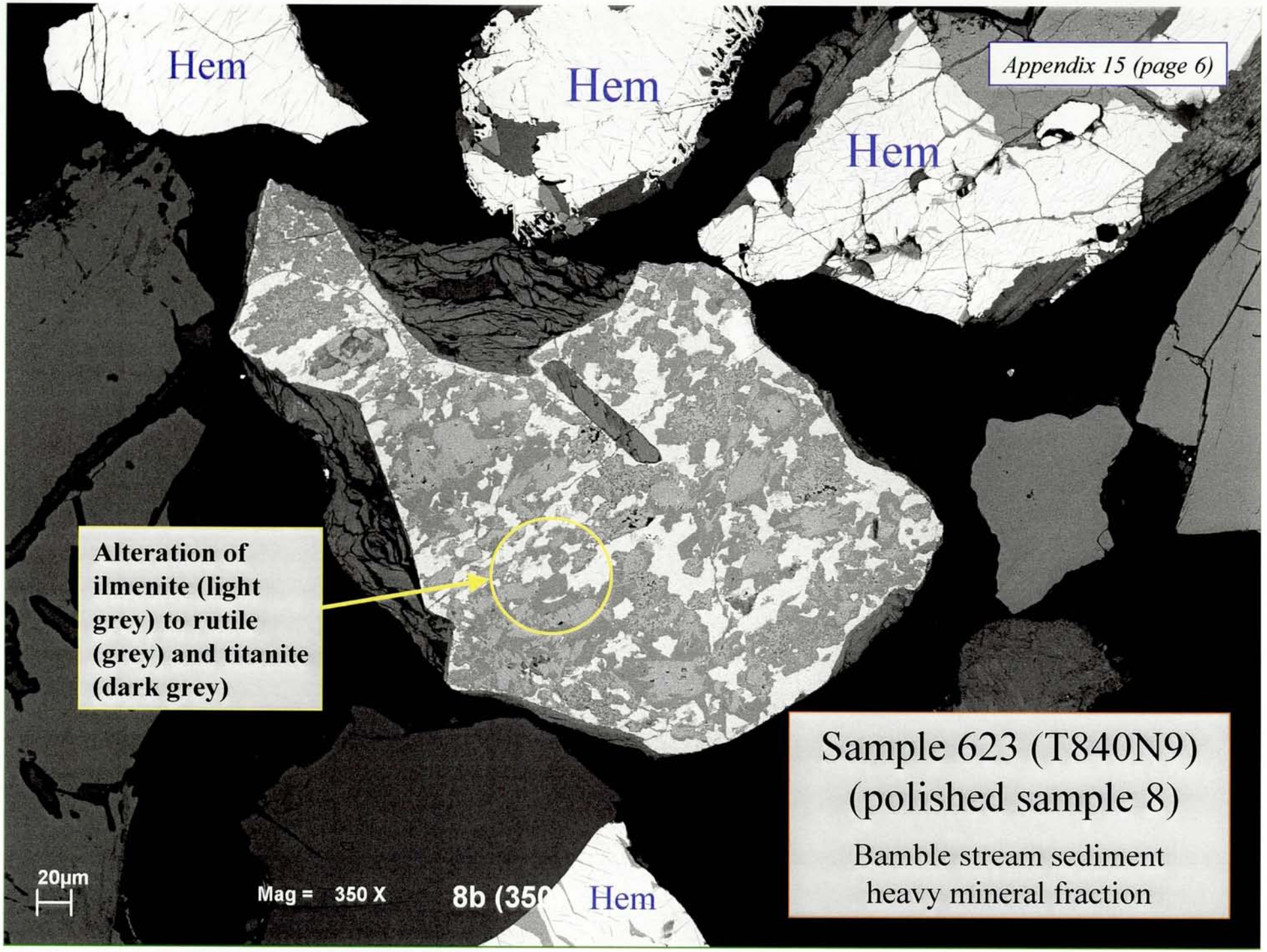
Sample	Type	Mineral	ppm Zr	ppm Nb	ppm Ta	ppm Th	ppm U
623	ssthm	Intergrown ilmenite-rutile-titanite	29,4	451,1	37,1	5,1	0,9
623	ssthm	Intergrown ilmenite-rutile-titanite	49,8	491,3	39,0	14,1	3,8

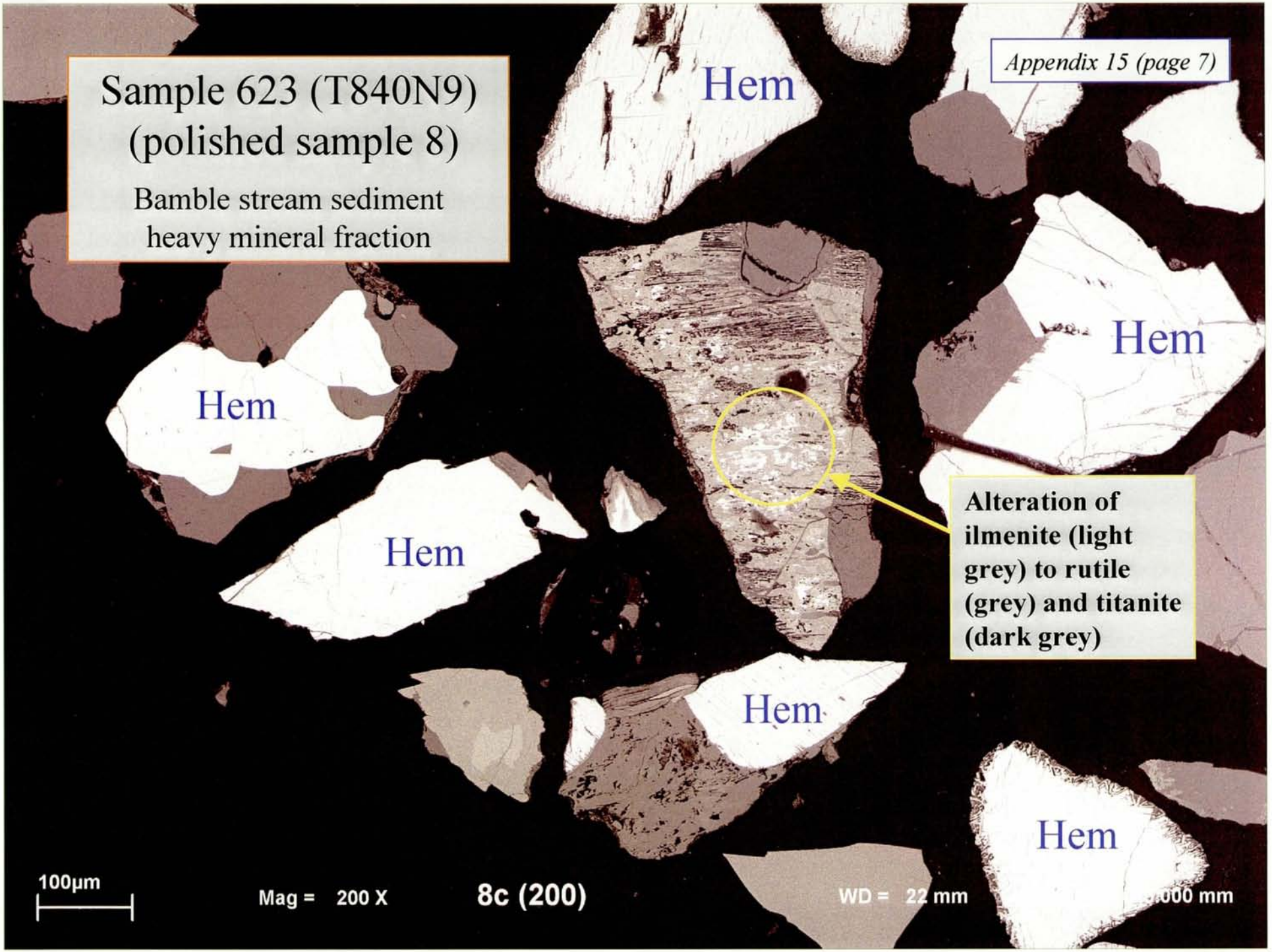

Appendix 15 (page 2)
Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
200µm
8
Mag = 33 X

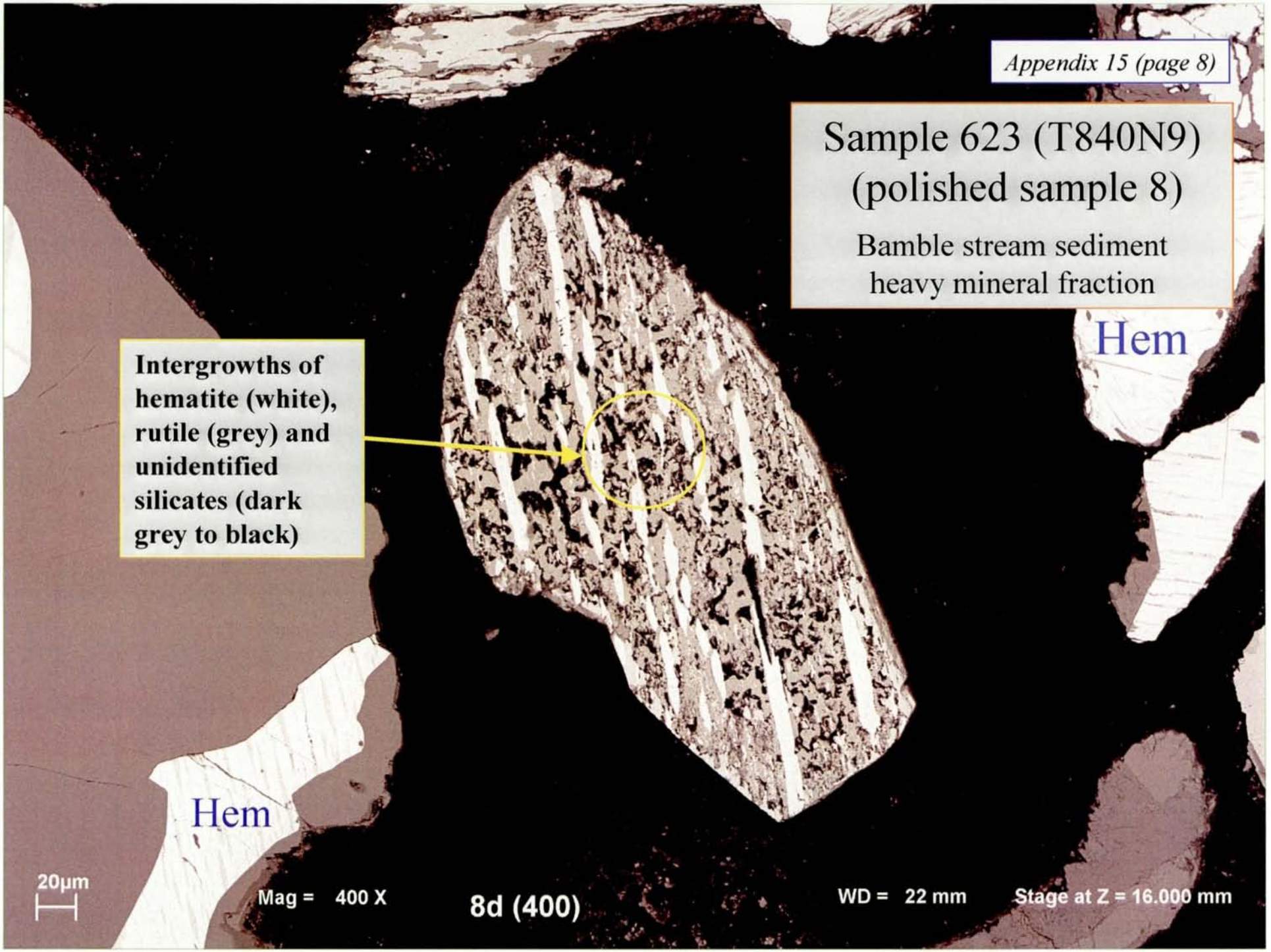

Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
100µm
8a (100)
WD = 22 mm
Stage at Z = 16.000 mm


Appendix 15 (page 4)
Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
Mt
Mt
Mt
Alteration of ilmenite (light grey) to rutile (grey) and titanite (dark grey)
100µm
Mag = 250 X
8a (250)
WD = 22 mm
Stage at Z = 16.000 mm


Appendix 15 (page 5)
Alteration of ilmenite (light grey) to rutile (grey) and titanite (dark grey)
Sample 623 (T840N9) (polished sample 8)
Bamble stream sediment heavy mineral fraction
Hem
Hem
20µm
Mag = 300 X
8a (300)
WD = 22 mm
Stage at Z = 16.000 mm


Hem
Hem
Hem
Appendix 15 (page 6)
Alteration of ilmenite (light grey) to rutile (grey) and titanite (dark grey)
Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
20µm
Mag = 350 X
8b (350
Hem

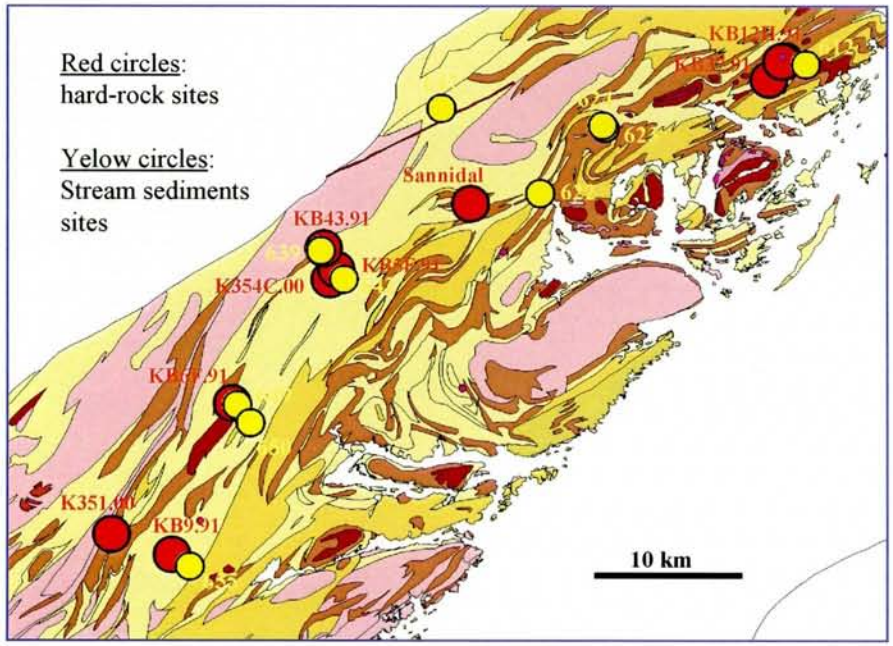

Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
Appendix 15 (page 7)
Hem
Hem
Hem
Hem
Hem
Hem
Alteration of ilmenite (light grey) to rutile (grey) and titanite (dark grey)
100µm
Mag = 200 X
8c (200)
WD = 22 mm


Appendix 15 (page 8)
Sample 623 (T840N9)
(polished sample 8)
Bamble stream sediment
heavy mineral fraction
Hem
Intergrowths of hematite (white), rutile (grey) and unidentified silicates (dark grey to black)
Hem
20µm
Mag = 400 X
8d (400)
WD = 22 mm
Stage at Z = 16.000 mm

Appendix 16:

SEM-images of Bamble stream sediment heavy fraction

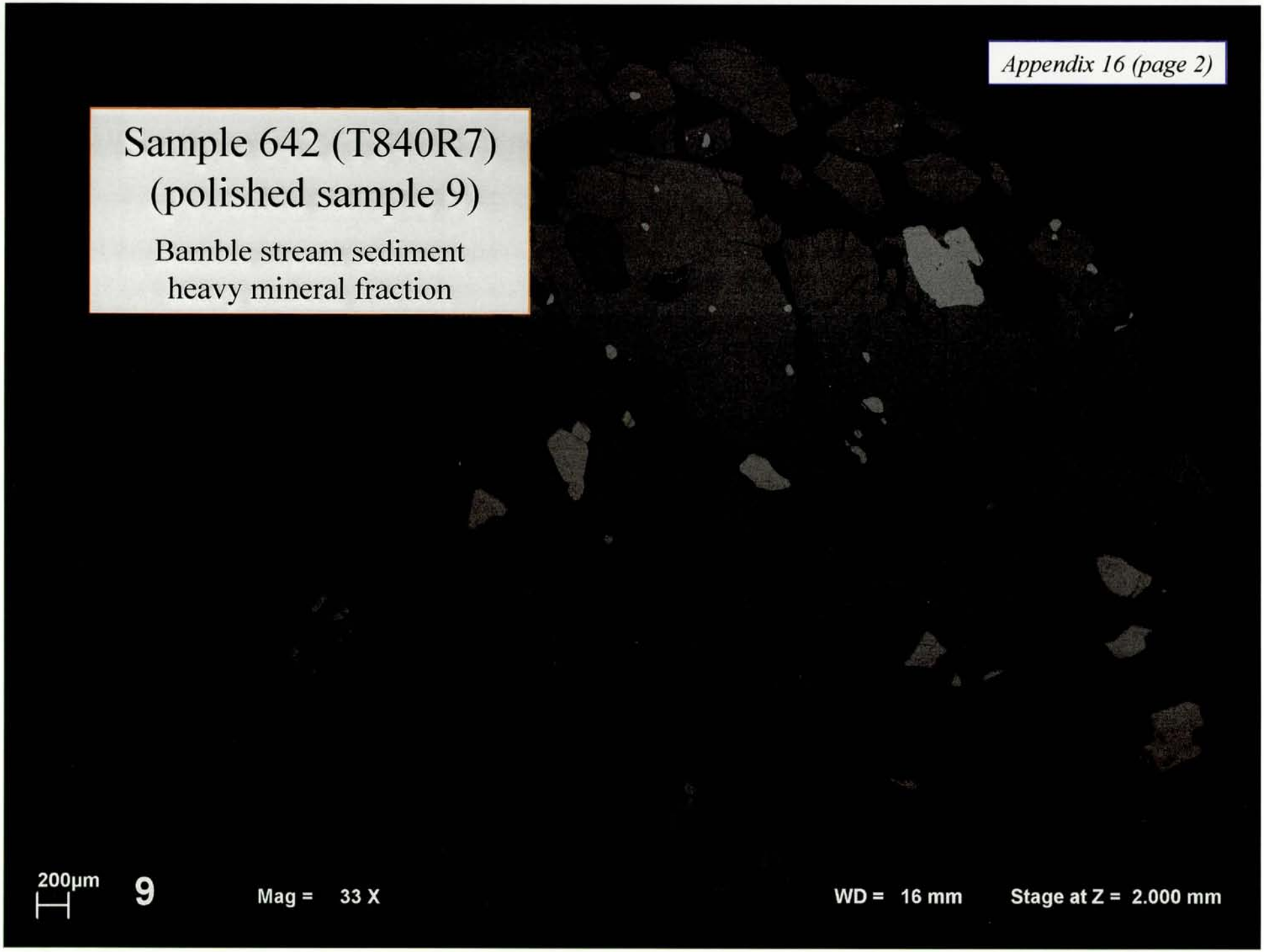
Sample 642 (T840R7)



No analyses available

Sample 642 (T840R7) (polished sample 9)

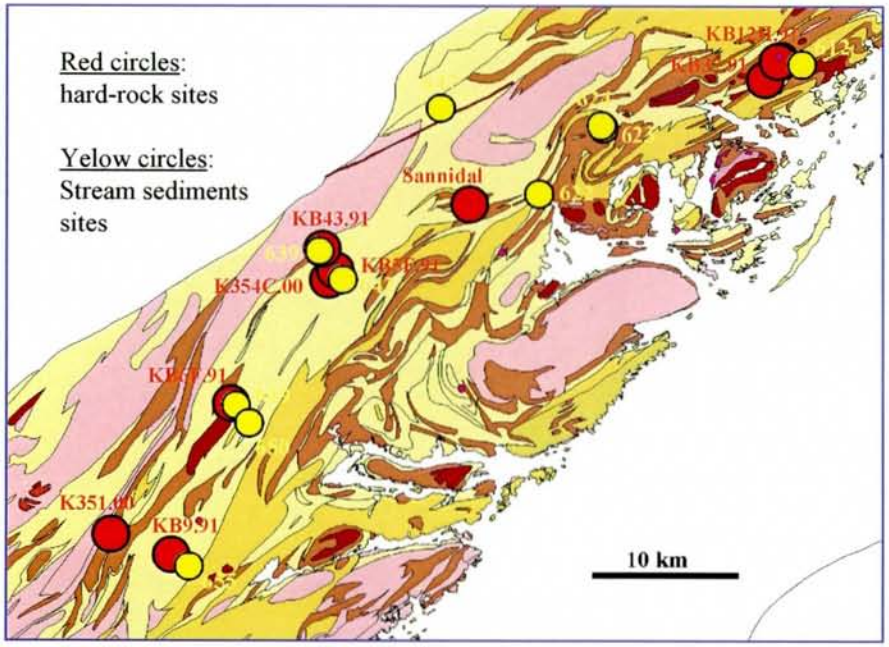
Bamble stream sediment heavy mineral fraction



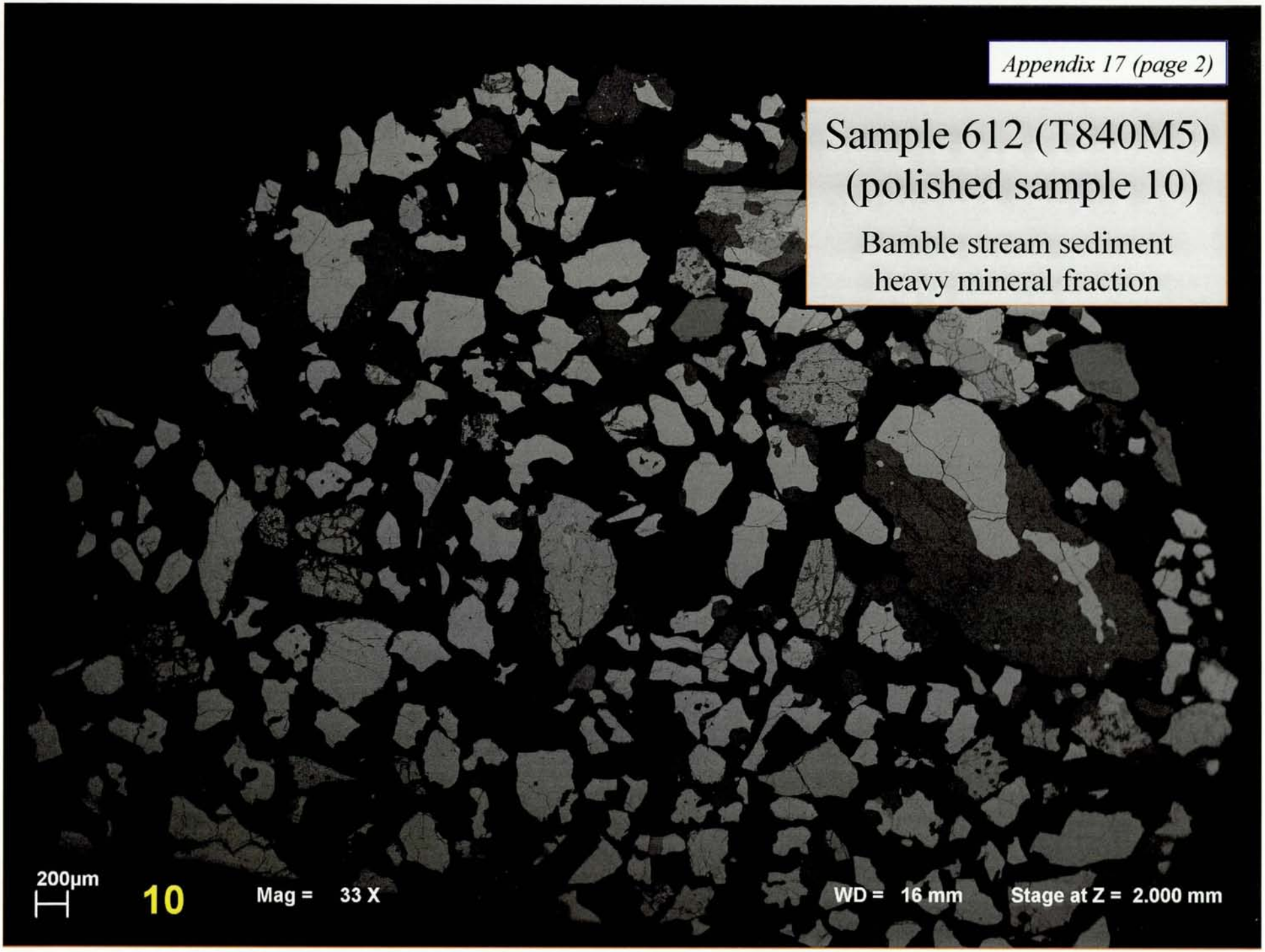
Appendix 17:

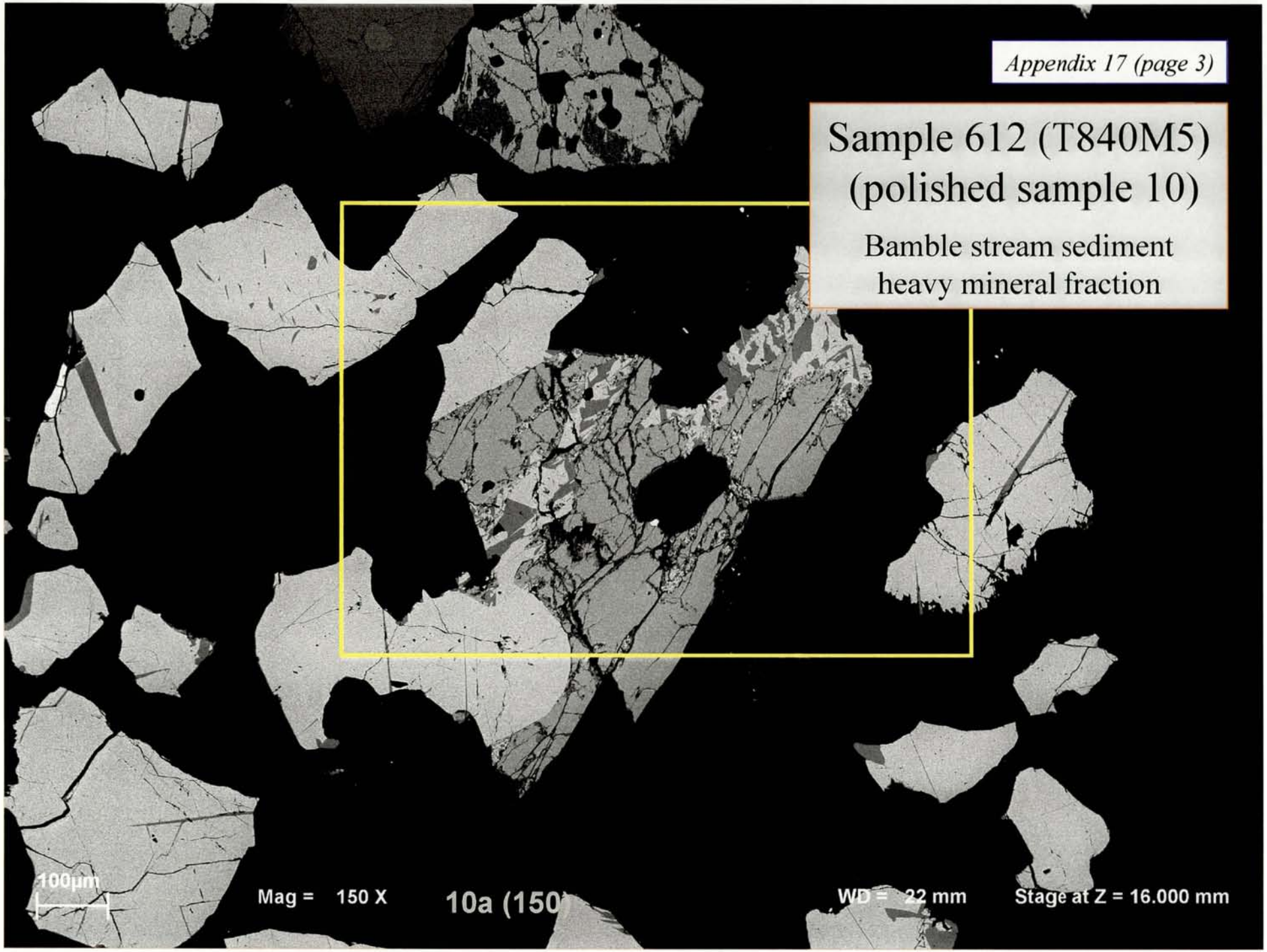
SEM-images of Bamble stream sediment heavy fraction

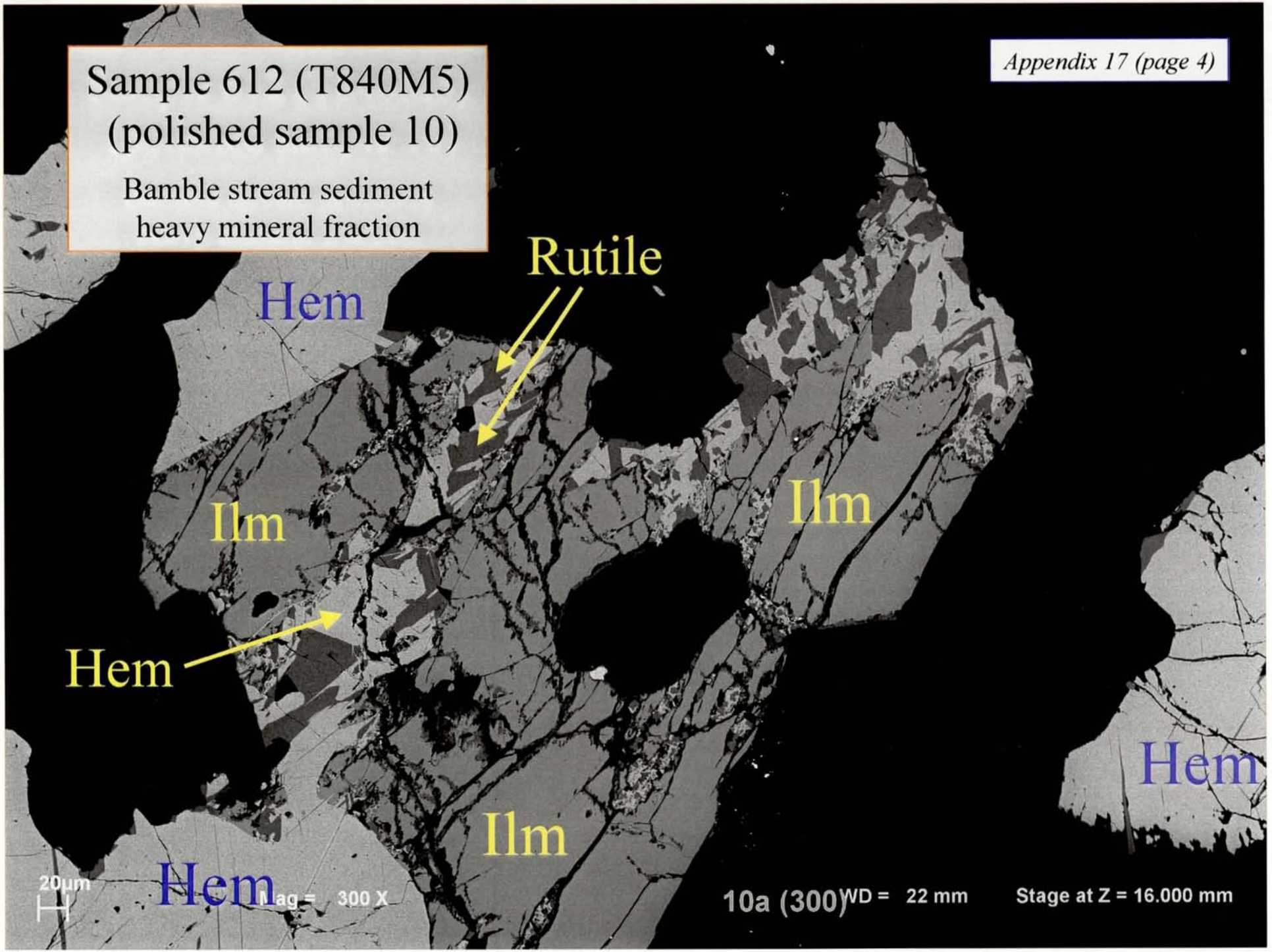
Sample 612 (T840M5)

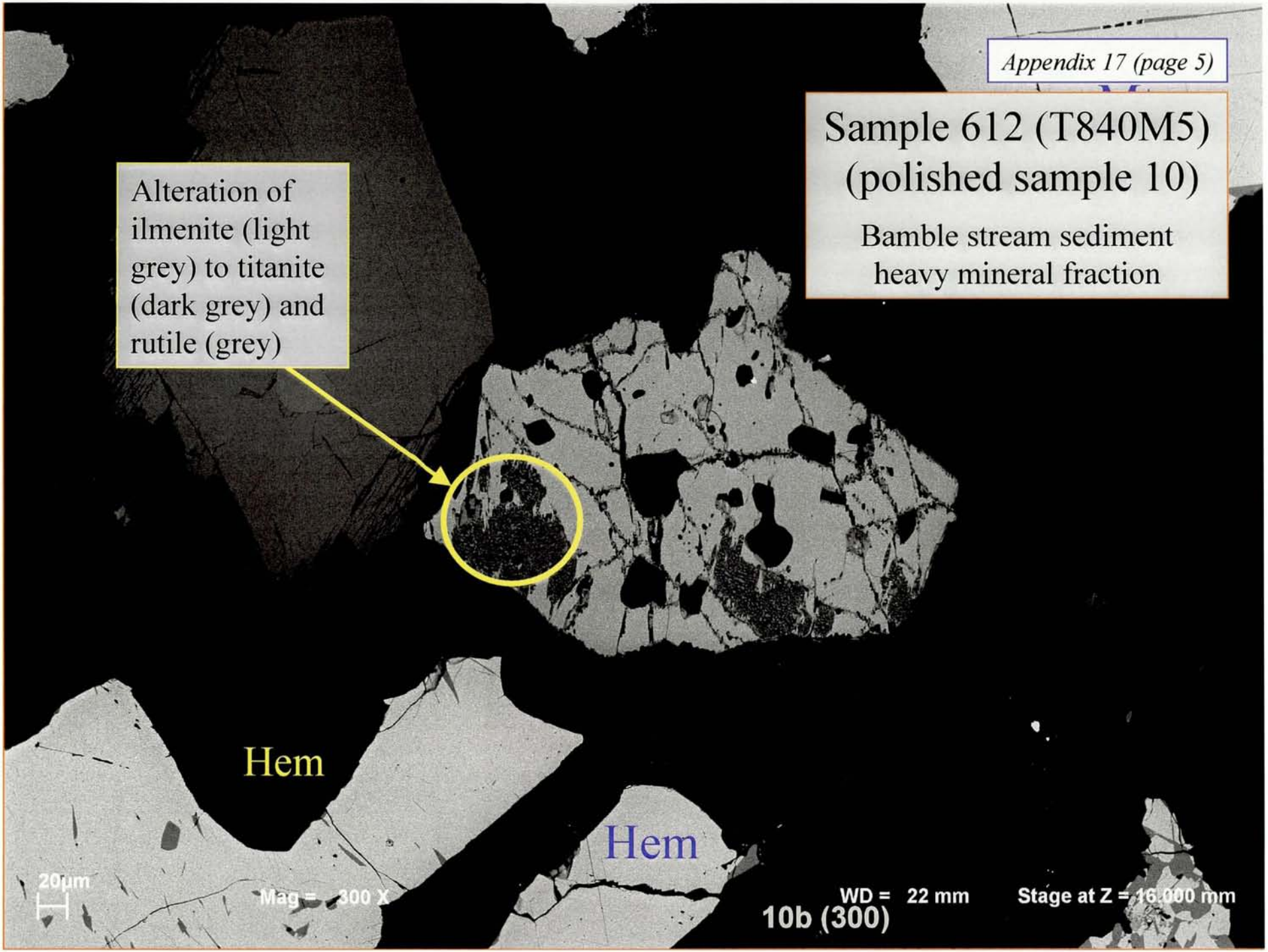


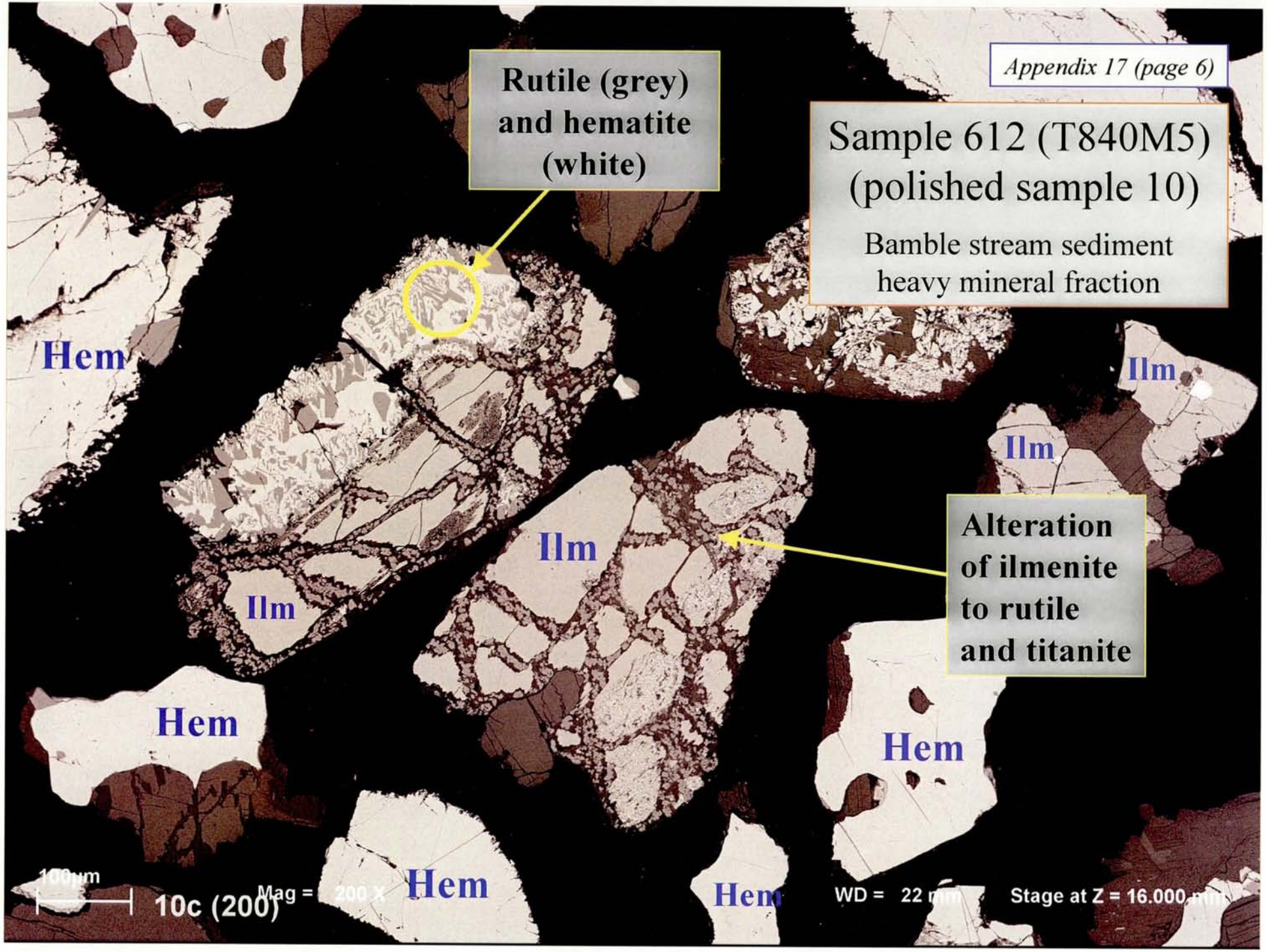
No analyses available

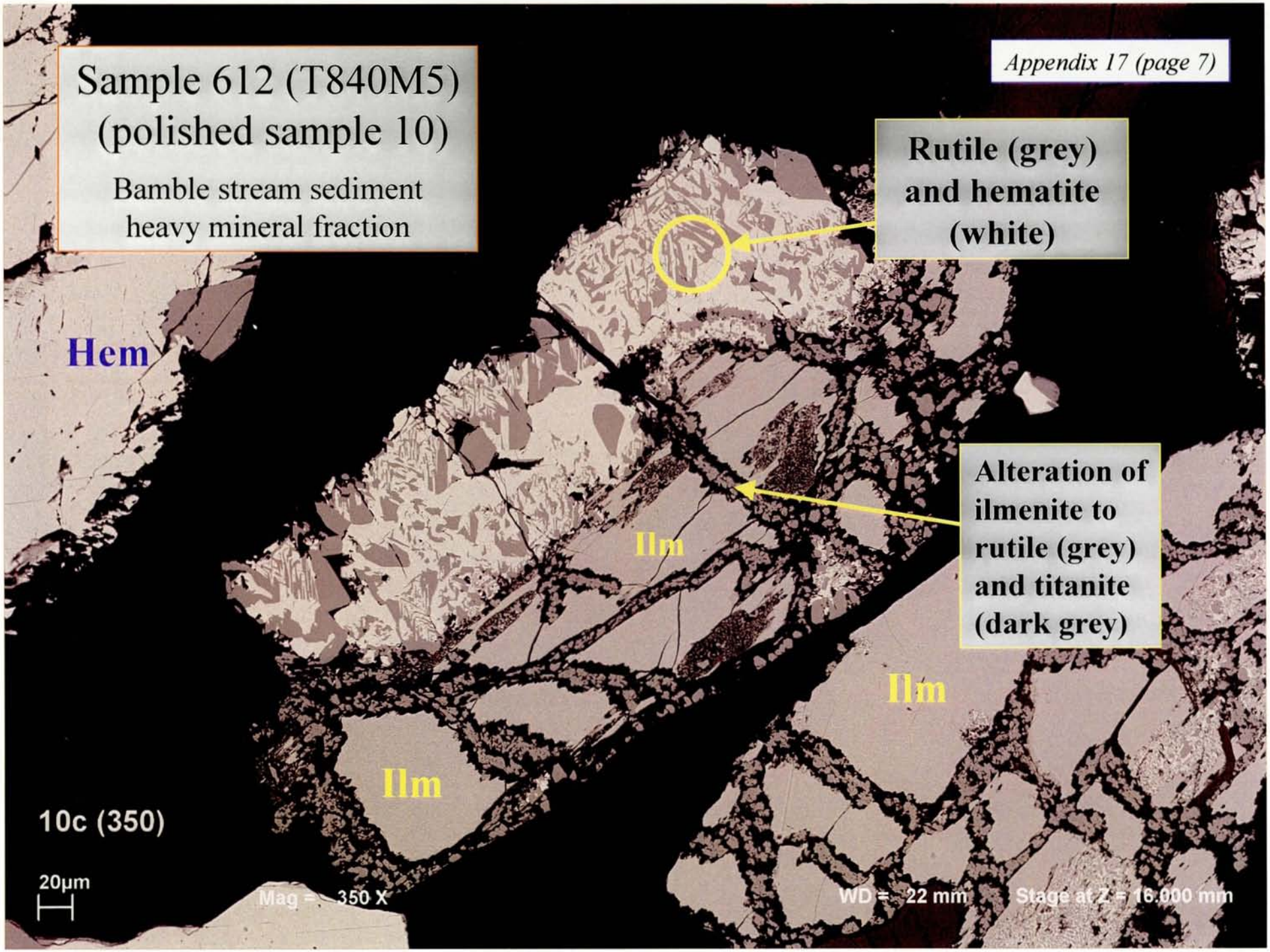

Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
200µm
10
Mag = 33 X
WD = 16 mm
Stage at Z = 2.000 mm

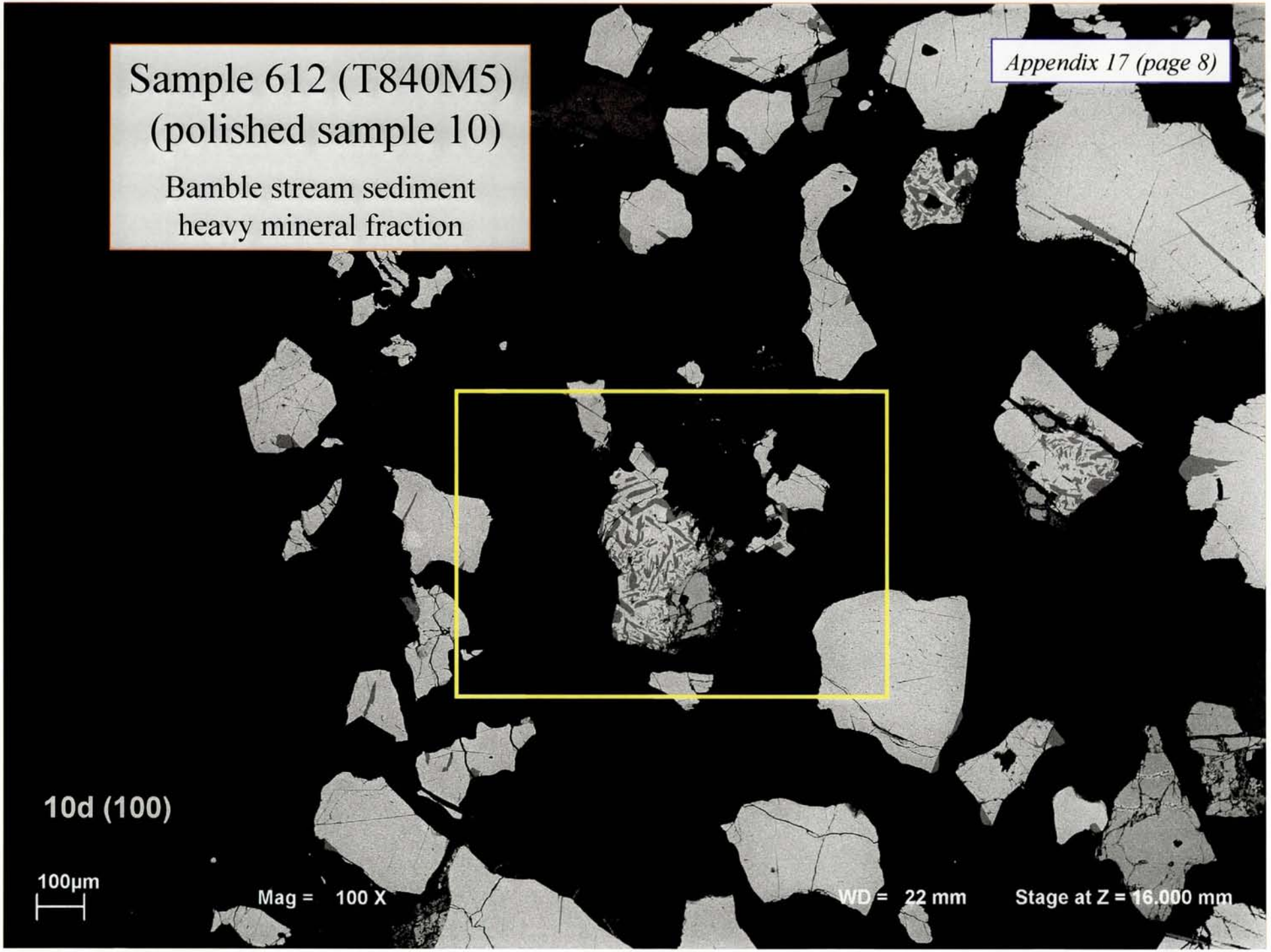

Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
100µm
Mag = 150 X
10a (150
WD = 22 mm
Stage at Z = 16.000 mm

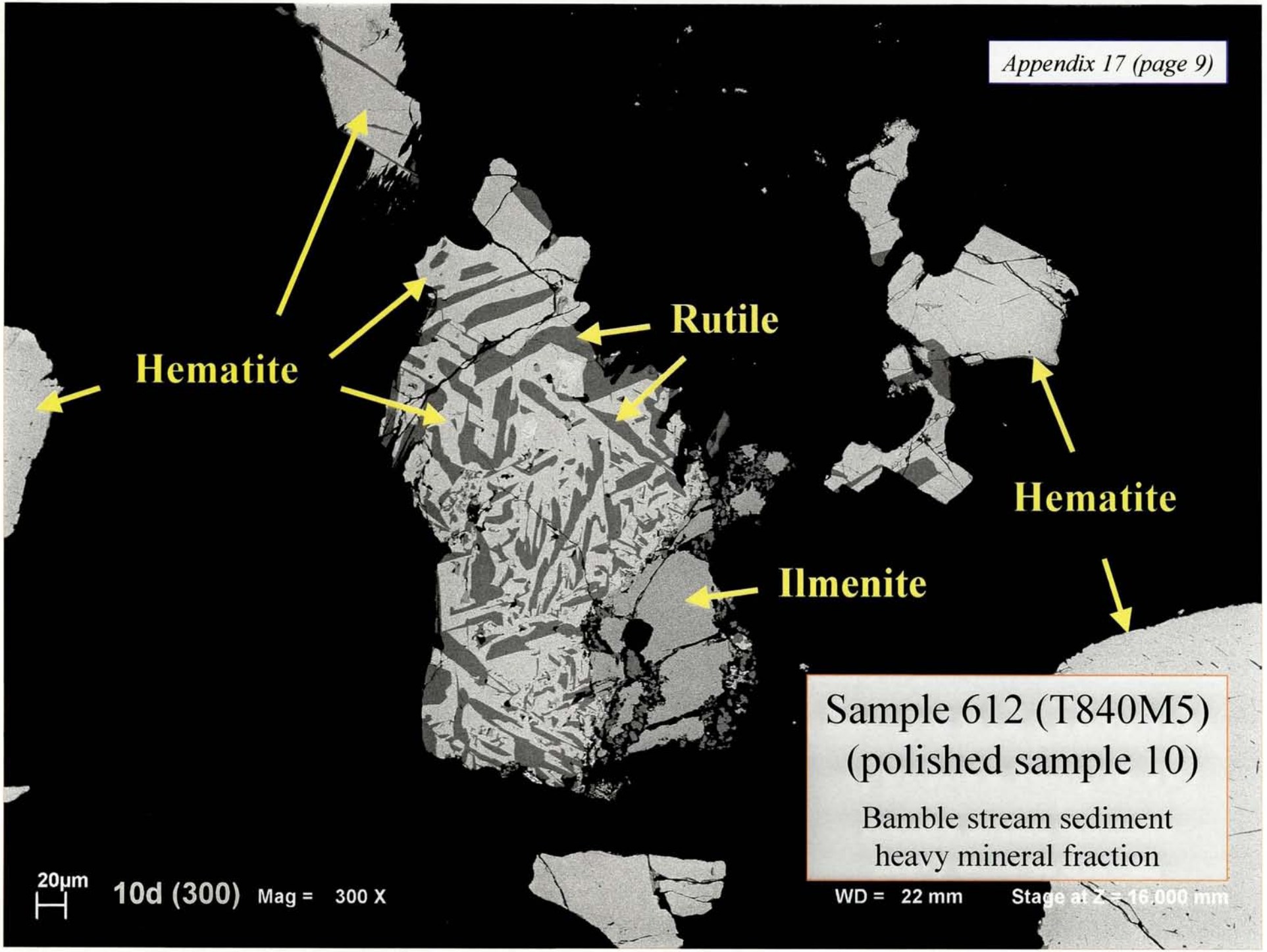

Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
Rutile
Hem
Ilm
Ilm
Hem
Ilm
Hem
Hem
20µm
Mag = 300 X
10a (300)
WD = 22 mm
Stage at Z = 16.000 mm

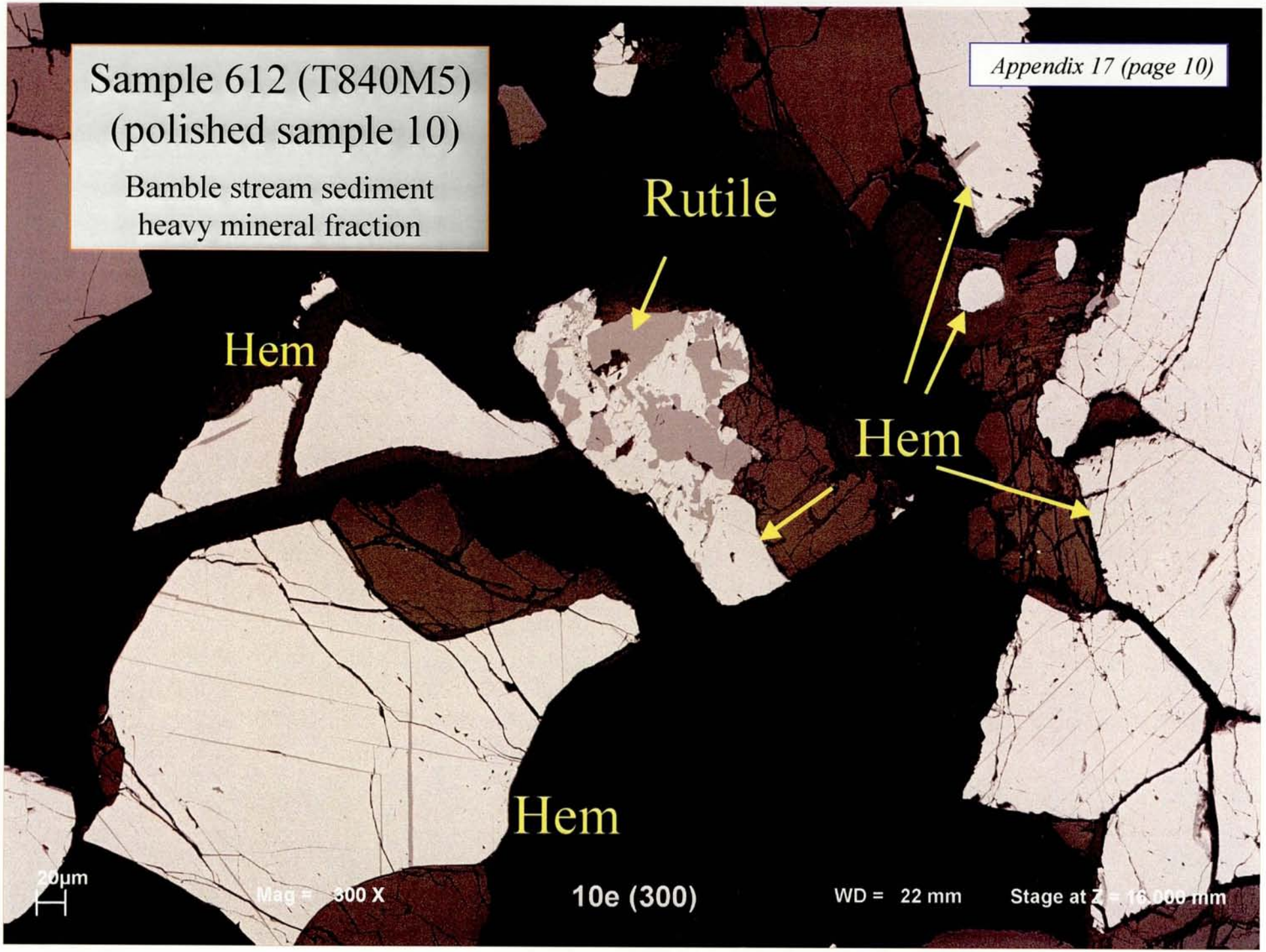

Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment heavy mineral fraction
Alteration of ilmenite (light grey) to titanite (dark grey) and rutile (grey)
Hem
Hem
20µm
Mag = 300 X
WD = 22 mm
Stage at Z = 16.000 mm
10b (300)


Appendix 17 (page 6)
Rutile (grey) and hematite (white)
Sample 612 (T840M5) (polished sample 10)
Bamble stream sediment heavy mineral fraction
Hem
Ilm
Ilm
Ilm
Alteration of ilmenite to rutile and titanite
Hem
Hem
Hem
Hem
100µm
10c (200)
Mag = 200 X
WD = 22 mm
Stage at Z = 16.000 mm


Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
Rutile (grey)
and hematite
(white)
Hem
Ilm
Alteration of
ilmenite to
rutile (grey)
and titanite
(dark grey)
Ilm
Ilm
10c (350)
20µm
Mag = 350 X
WD = 22 mm
Stage at Z = 16.000 mm


Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
Appendix 17 (page 8)
10d (100)
100µm
Mag = 100 X
WD = 22 mm
Stage at Z = 16.000 mm


Appendix 17 (page 9)
Hematite
Rutile
Hematite
Ilmenite
Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
20µm
10d (300) Mag = 300 X
WD = 22 mm
Stage at Z = 16.000 mm


Sample 612 (T840M5)
(polished sample 10)
Bamble stream sediment
heavy mineral fraction
Appendix 17 (page 10)
Rutile
Hem
Hem
Hem
20µm
Mag = 300 X
10e (300)
WD = 22 mm
Stage at Z = 16.000 mm