Supplementary Materials

Supplementary Note S1

Description. Scanning electron microscopy (SEM) images obtained in secondary electron imaging (SEI) mode show representative cassiterite grains recovered from the cleaning products of spiral separator concentrates. The investigated particles exhibit angular to subangular morphologies, irregular fracture surfaces, and varying degrees of surface roughness. Energy-dispersive spectroscopy (EDS) analyses confirm that the grains are predominantly composed of tin and oxygen, consistent with the composition of cassiterite (SnO_2). Variations in the measured Sn and O contents are attributed to local surface heterogeneity, grain morphology, and analytical conditions during EDS measurements.

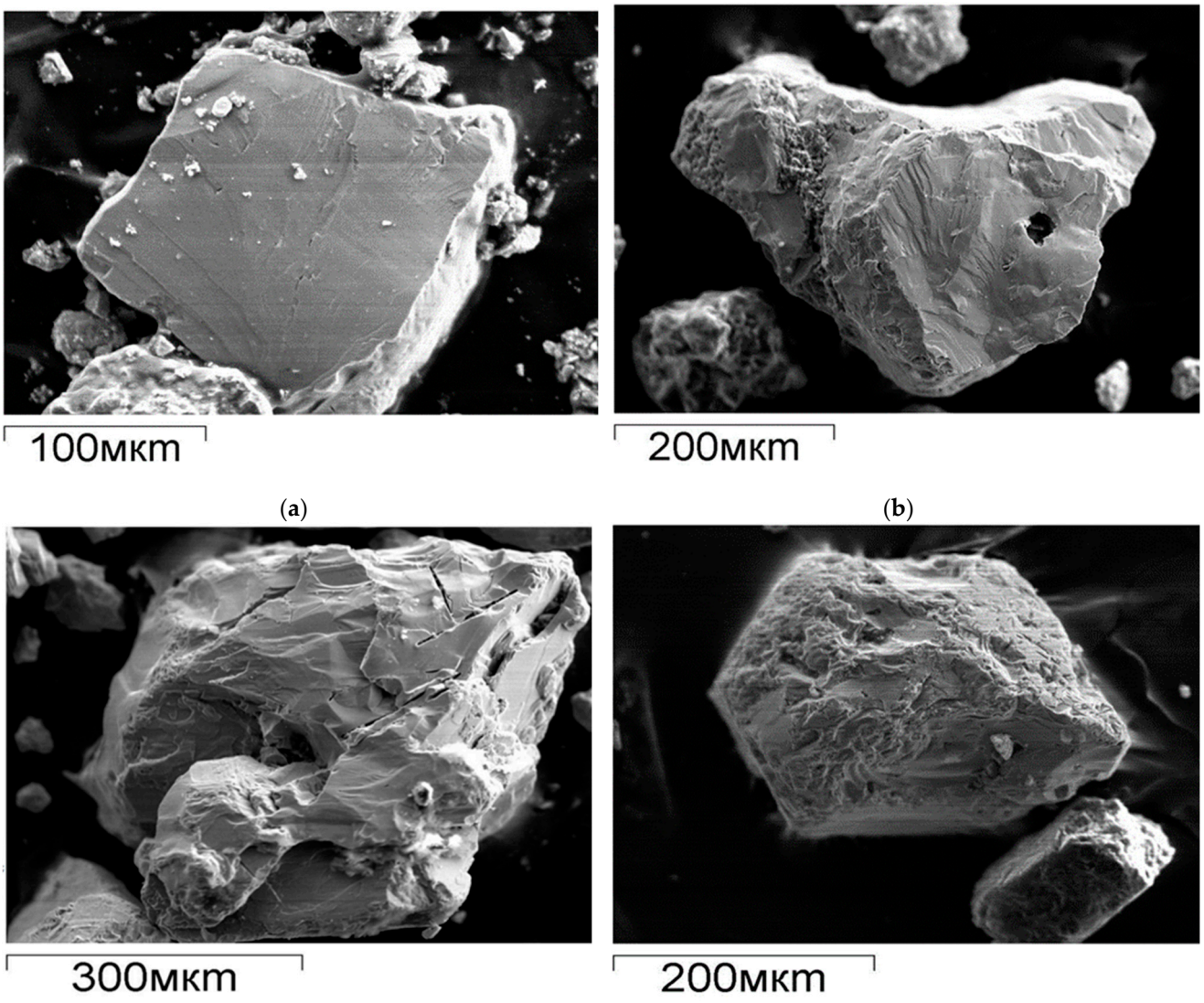
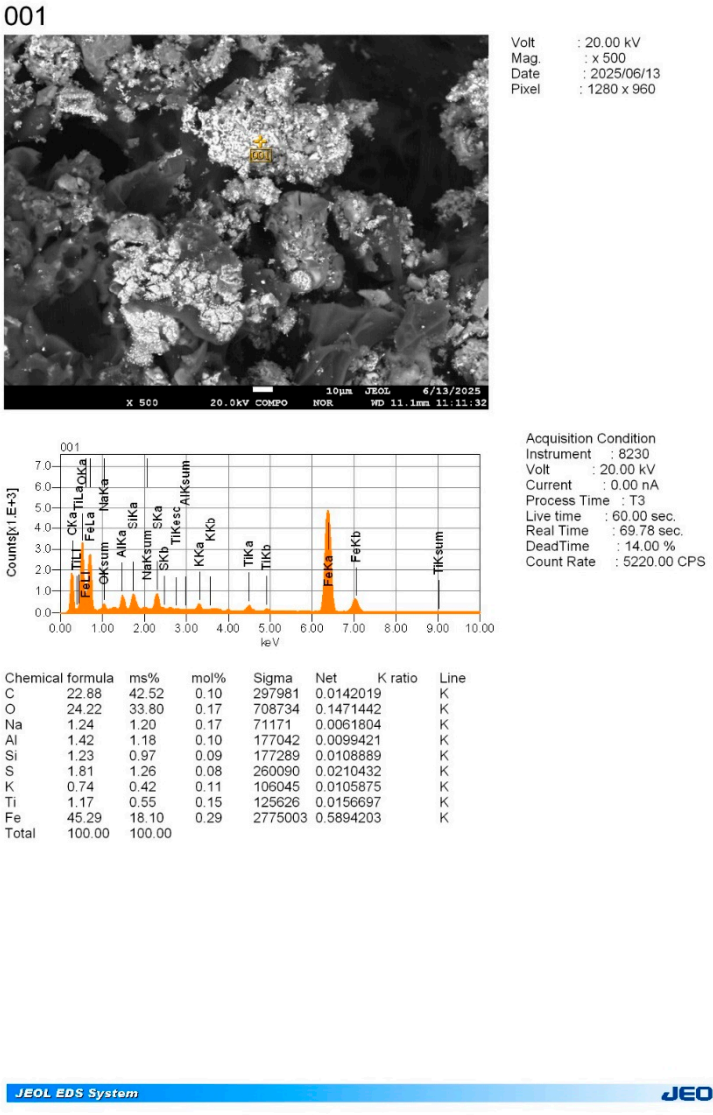


Figure S1. Secondary electron (SEI) images of representative cassiterite grains recovered from gravity concentration products. (**a**) Sample 1: Sn = 77.87 wt.%, O = 22.13 wt.%; (**b**) Sample 1: Sn = 69.52 wt.%, O = 30.48 wt.%; (**c**) Sample 2: Sn = 72.05 wt.%, O = 27.95 wt.%; (**d**) Sample 2: Sn = 61.43 wt.%, O = 38.57 wt.%. This is a figure. Schemes follow another format. If there are multiple panels, they should be listed as: (**a**) Description of what is contained in the first panel; (**b**) Description of what is contained in the second panel. Figures should be placed in the main text near to the first time they are cited.

Supplementary Note S2.

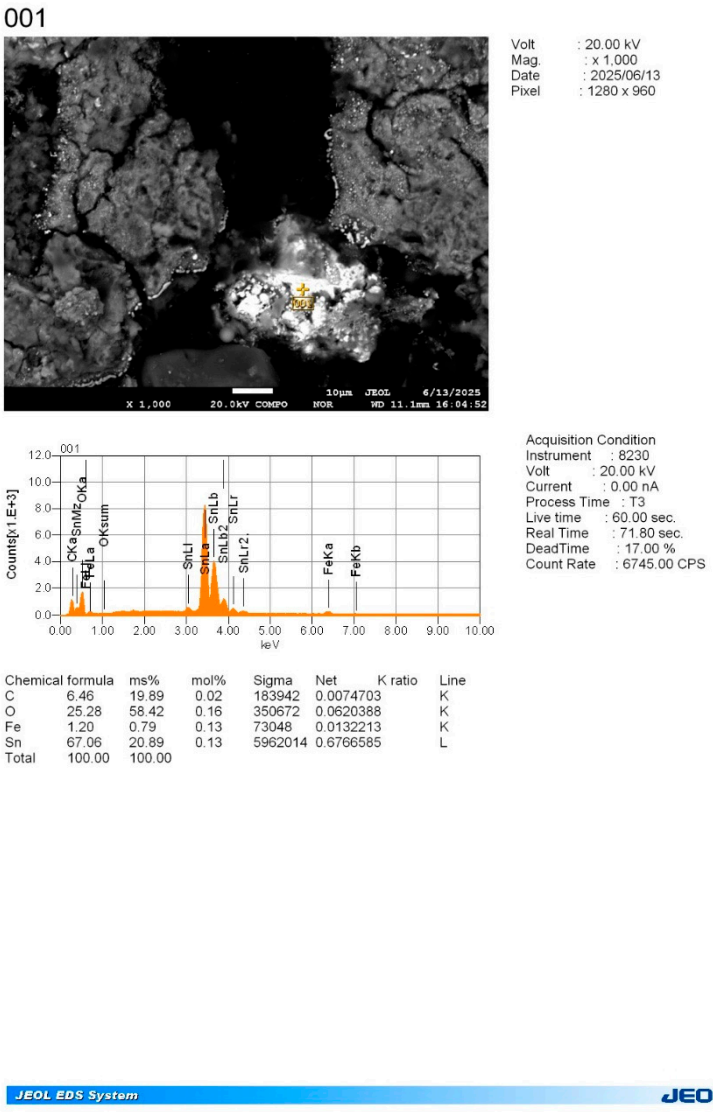
SEM–EDS investigation of tin-bearing phases in thermally activated products.

Scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM–EDS) was used to investigate the composition of newly formed phases occurring in thermally activated products of the Syrymbet weathering crust material. The phases were identified exclusively in thermally activated products and were not observed in untreated samples, indicating their formation during thermal processing. None of the investigated phases correspond completely to valid mineral species recognized by the International Mineralogical Association (IMA). The observed compositions likely represent products formed during thermal transformation of primary cassiterite-bearing material.



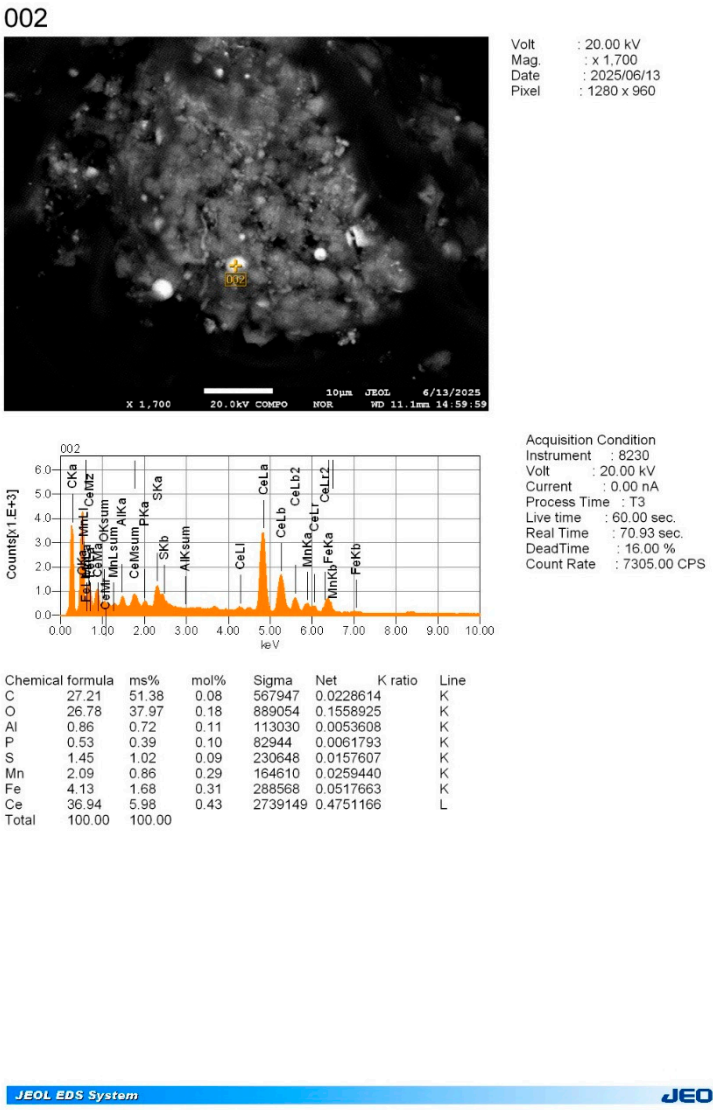
Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	22.88	42.52	0.10	297981	0.0142019	K
O	24.22	33.80	0.17	708734	0.1471442	K
Na	1.24	1.20	0.17	71171	0.0061804	K
Al	1.42	1.18	0.10	177042	0.0099421	K
Si	1.23	0.97	0.09	177289	0.0108889	K
S	1.81	1.26	0.08	260090	0.0210432	K
K	0.74	0.42	0.11	106045	0.0105875	K
Ti	1.17	0.55	0.15	125626	0.0156697	K
Fe	45.29	18.10	0.29	2775003	0.5894203	K
Total	100.00	100.00				

Figure S2. BSE image and EDS spectrum of Fe–O-C aggregate.



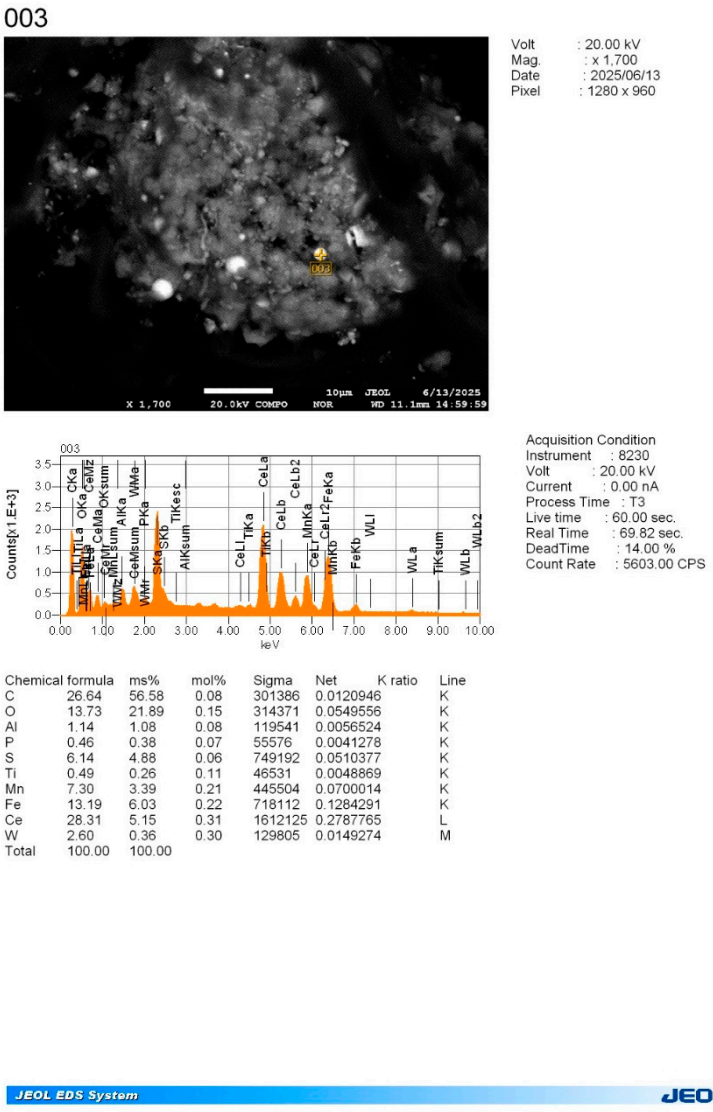
Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	6.46	19.89	0.02	183942	0.0074703	K
O	25.28	58.42	0.16	350672	0.0620388	K
Fe	1.20	0.79	0.13	73048	0.0132213	K
Sn	67.06	20.89	0.13	5962014	0.6766585	L
Total	100.00	100.00				

Figure S3. BSE image and EDS spectrum of Sn-O-C phase.



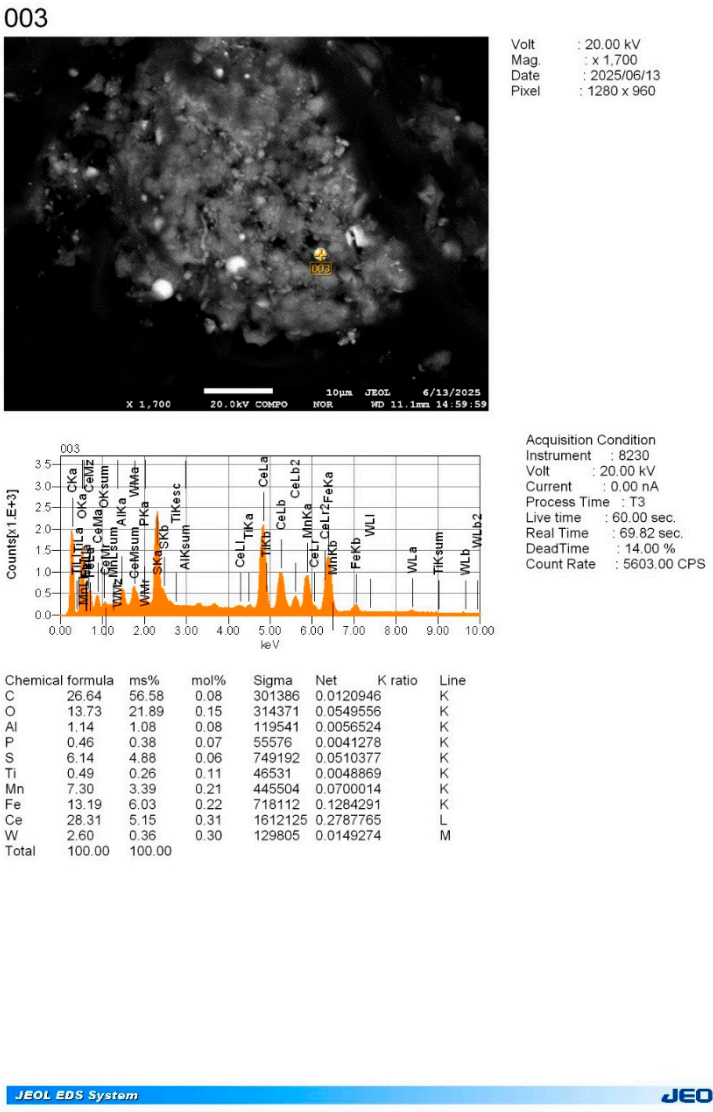
Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	27.21	51.38	0.08	567947	0.0228614	K
O	26.78	37.97	0.18	889054	0.1558925	K
Al	0.86	0.72	0.11	113030	0.0053608	K
P	0.53	0.39	0.10	82944	0.0061793	K
S	1.45	1.02	0.09	230648	0.0157607	K
Mn	2.09	0.86	0.29	164610	0.0259440	K
Fe	4.13	1.68	0.31	288568	0.0517663	K
Ce	36.94	5.98	0.43	2739149	0.4751166	L
Total	100.00	100.00				

Figure S4. BSE image and EDS spectrum of Ce-dominated phase.



Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	26.64	56.58	0.08	301386	0.0120946	K
O	13.73	21.89	0.15	314371	0.0549556	K
Al	1.14	1.08	0.08	119541	0.0056524	K
P	0.46	0.38	0.07	55576	0.0041278	K
S	6.14	4.88	0.06	749192	0.0510377	K
Ti	0.49	0.26	0.11	46531	0.0048869	K
Mn	7.30	3.39	0.21	445504	0.0700014	K
Fe	13.19	6.03	0.22	718112	0.1284291	K
Ce	28.31	5.15	0.31	1612125	0.2787765	L
W	2.60	0.36	0.30	129805	0.0149274	M
Total	100.00	100.00				

Figure S5. BSE image and EDS spectrum of Ce-dominated phase.



Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	26.64	56.58	0.08	301386	0.0120946	K
O	13.73	21.89	0.15	314371	0.0549556	K
Al	1.14	1.08	0.08	119541	0.0056524	K
P	0.46	0.38	0.07	55576	0.0041278	K
S	6.14	4.88	0.06	749192	0.0510377	K
Ti	0.49	0.26	0.11	46531	0.0048869	K
Mn	7.30	3.39	0.21	445504	0.0700014	K
Fe	13.19	6.03	0.22	718112	0.1284291	K
Ce	28.31	5.15	0.31	1612125	0.2787765	L
W	2.60	0.36	0.30	129805	0.0149274	M
Total	100.00	100.00				

Figure S6. BSE image and EDS spectrum of Ce-dominated phase.

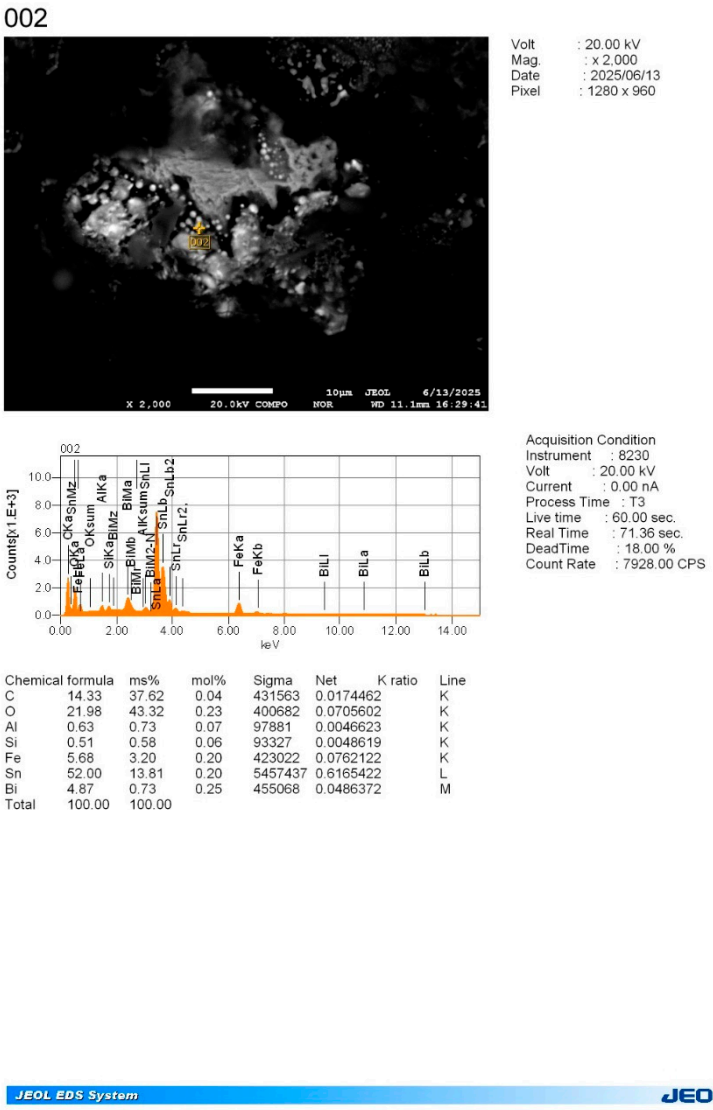


Figure S7. BSE image and EDS spectrum of Sn-O-C phase.

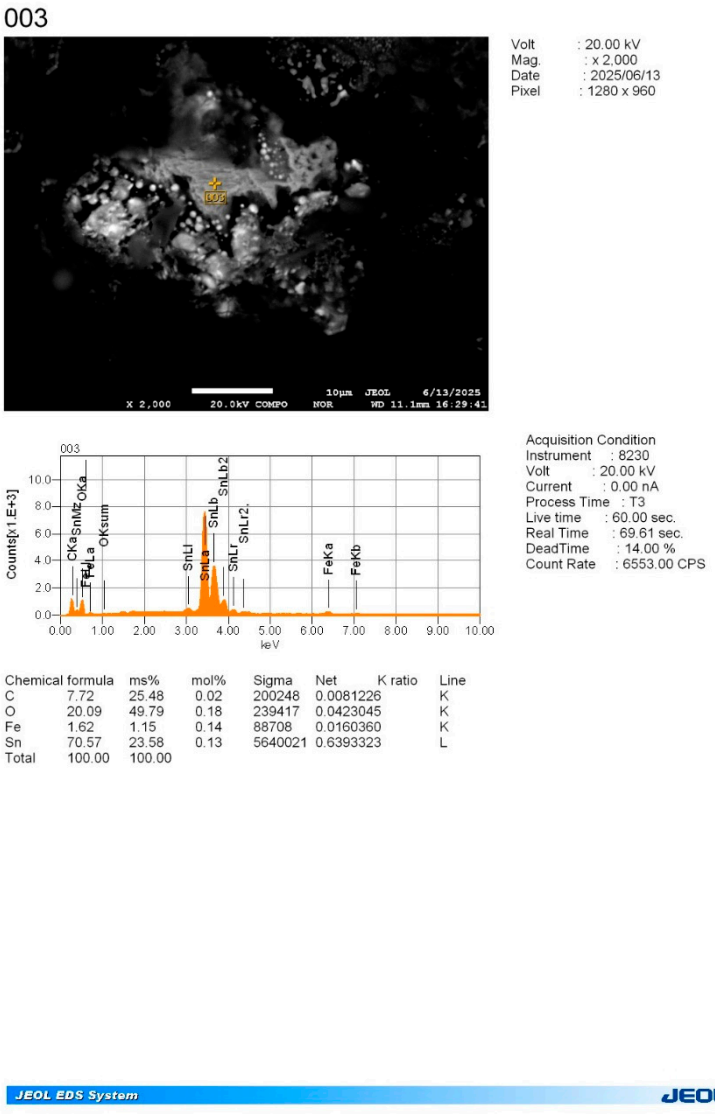
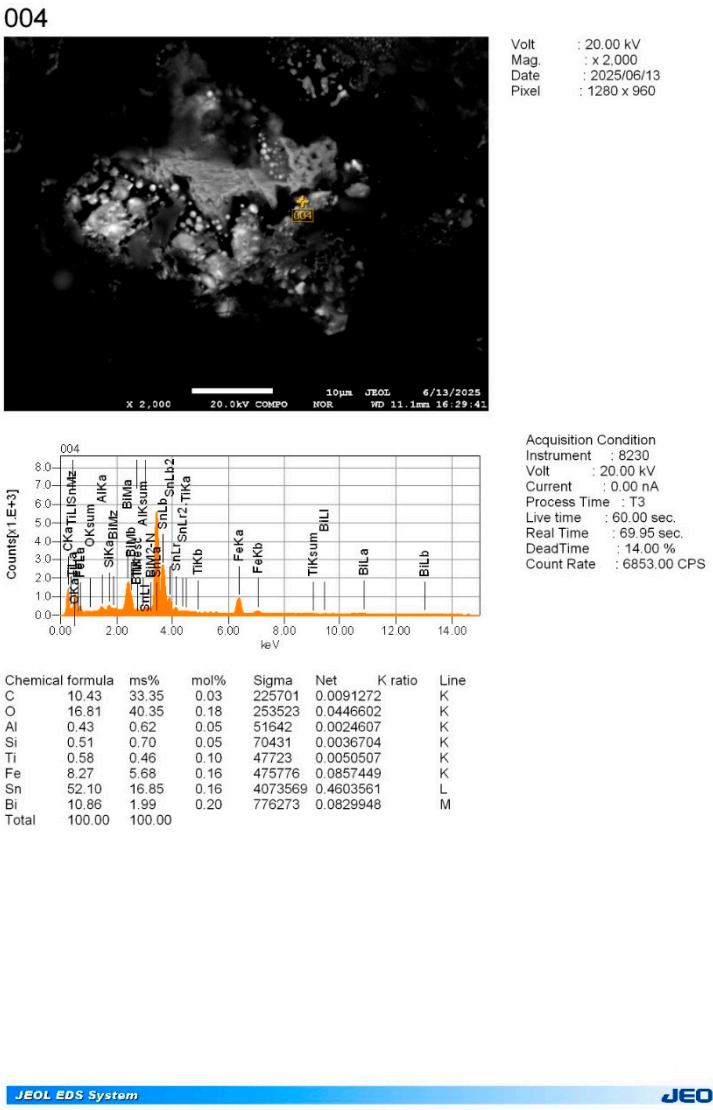
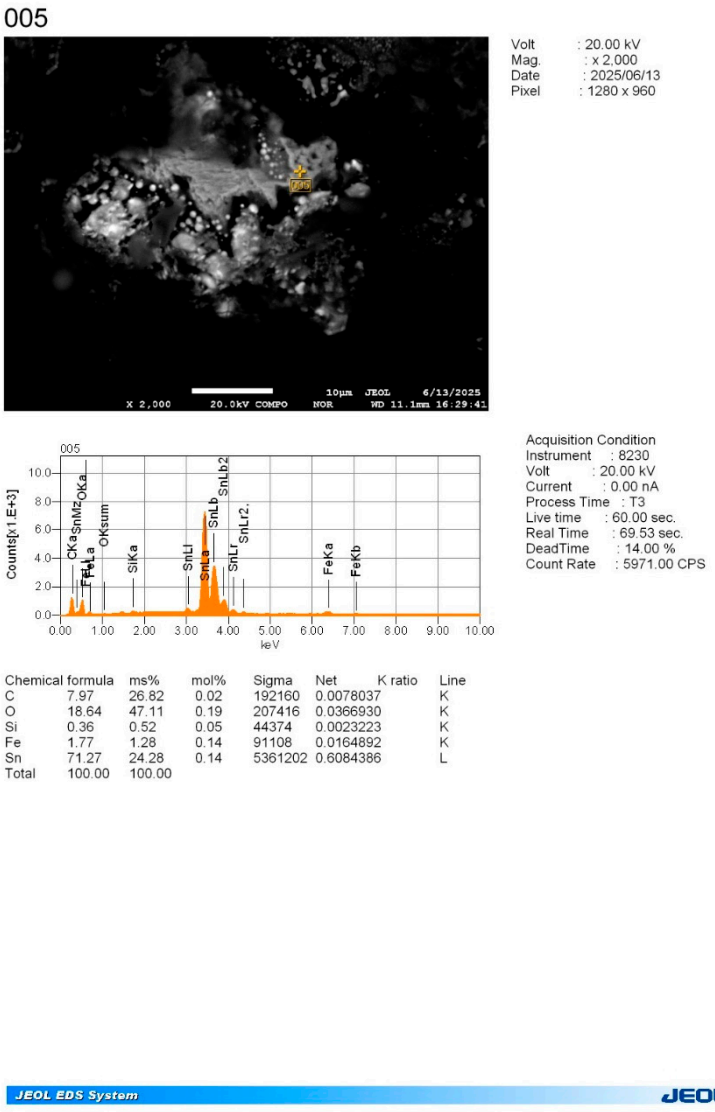


Figure S8. BSE image and EDS spectrum of Sn-O-C phase.



Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	10.43	33.35	0.03	225701	0.0091272	K
O	16.81	40.35	0.18	253523	0.0446602	K
Al	0.43	0.62	0.05	51642	0.0024607	K
Si	0.51	0.70	0.05	70431	0.0036704	K
Ti	0.58	0.46	0.10	47723	0.0050507	K
Fe	8.27	5.68	0.16	475776	0.0857449	K
Sn	52.10	16.85	0.16	4073569	0.4603561	L
Bi	10.86	1.99	0.20	776273	0.0829948	M
Total	100.00	100.00				

Figure S9. BSE image and EDS spectrum of Sn–Bi-O-C phase.



Chemical formula	ms%	mol%	Sigma	Net	K ratio	Line
C	7.97	26.82	0.02	192160	0.0078037	K
O	18.64	47.11	0.19	207416	0.0366930	K
Si	0.36	0.52	0.05	44374	0.0023223	K
Fe	1.77	1.28	0.14	91108	0.0164892	K
Sn	71.27	24.28	0.14	5361202	0.6084386	L
Total	100.00	100.00				

Figure S10. BSE image and EDS spectrum of Sn–O-C aggregate.