Tin in tourmaline

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Abstract

Tourmaline is a common mineral in Sn-W mineralizations. It is commonly strongly zoned, both optically and chemically, and may host a range of trace elements. High levels of Sn have been observed in tourmaline throughout the world, whereas W is typically very low, even in mineralized areas. Tourmaline from subeconomic cassiterite mineralizations and hydrothermally altered granite from the Land's End granite, SW England, was analyzed by EPMA in order to identify Sn-rich zones. LA-ICP-MS is typically the go-to instrument for trace element analyses, but spatial resolution is strongly compromised compared to EPMA. The behavior of Sn in tourmaline varies from patchy to concentric zoning between different samples, and the highest recorded value was 2.48 wt% SnO2 in a patchily zoned rim. A high resolution WDS map of the area did not show any major Sn spikes, and TiO2, a common minor element in cassiterite, is low in the Sn-rich regions. Also, cassiterite in these samples are commonly light brown in plane polarized light, and the Sn-rich zones can be related to dark green zones. This indicates that the high Sn-values are not due to cassiterite inclusions, and may be structurally bound in tourmaline, most likely substituting into the Y-site. The highest Sn-values (>0.4 wt% SnO2) are coupled with a substantial substitution of Fe for Al in the Z-site, and the structural formula calculation indicate that some Fe is present as Fe3+ in the analyses with over ca. 20 wt% FeO. Trends between Sn and other elements are erratic, except for a weak positive correlation with Sr. The Sn-content in tourmaline combined with the inferred Fe3+ and the observed cassiterite in the samples may indicate that oxidation of the ore fluid caused cassiterite precipitation.

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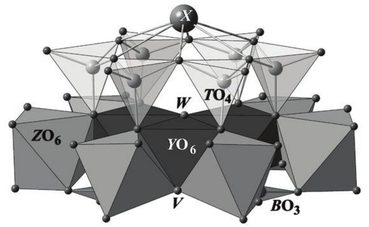
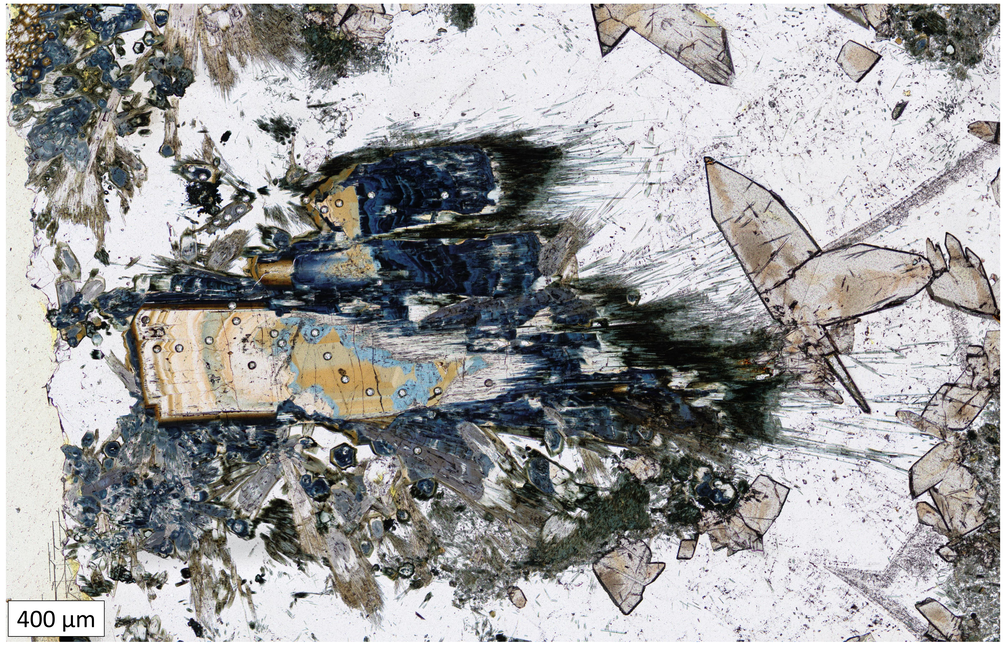


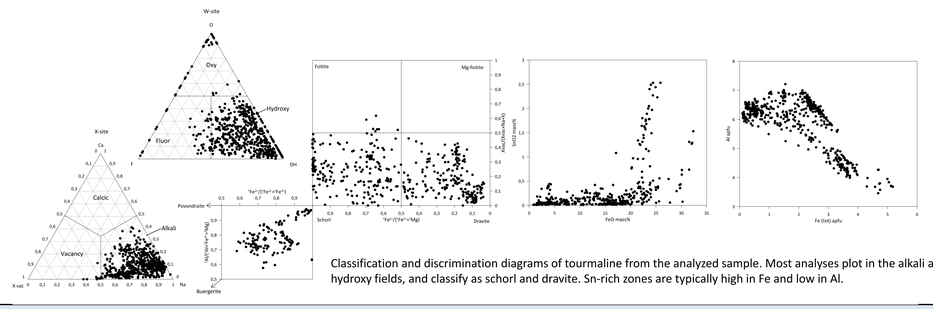
Abstract

Tourmaline is a common mineral in Sn-W mineralizations. It is commonly strongly zoned, both optically and chemically, and may host a range of trace elements. High levels of Sn have been observed in tourmaline throughout the world, whereas W is typically very low, even in mineralized areas. Tourmaline from a cassiterite-bearing quartz-tourmaline rock from the Land's End granite, SW England, was analyzed by EPMA in order to better understand the distribution of Sn in tourmaline. Multiple coarse chemical maps of selected areas of interest were used to identify the Sn-rich zones, which were subsequently mapped using a smaller step size and lower beam current. The finer maps were used to locate the points for quantitative spot analyses.

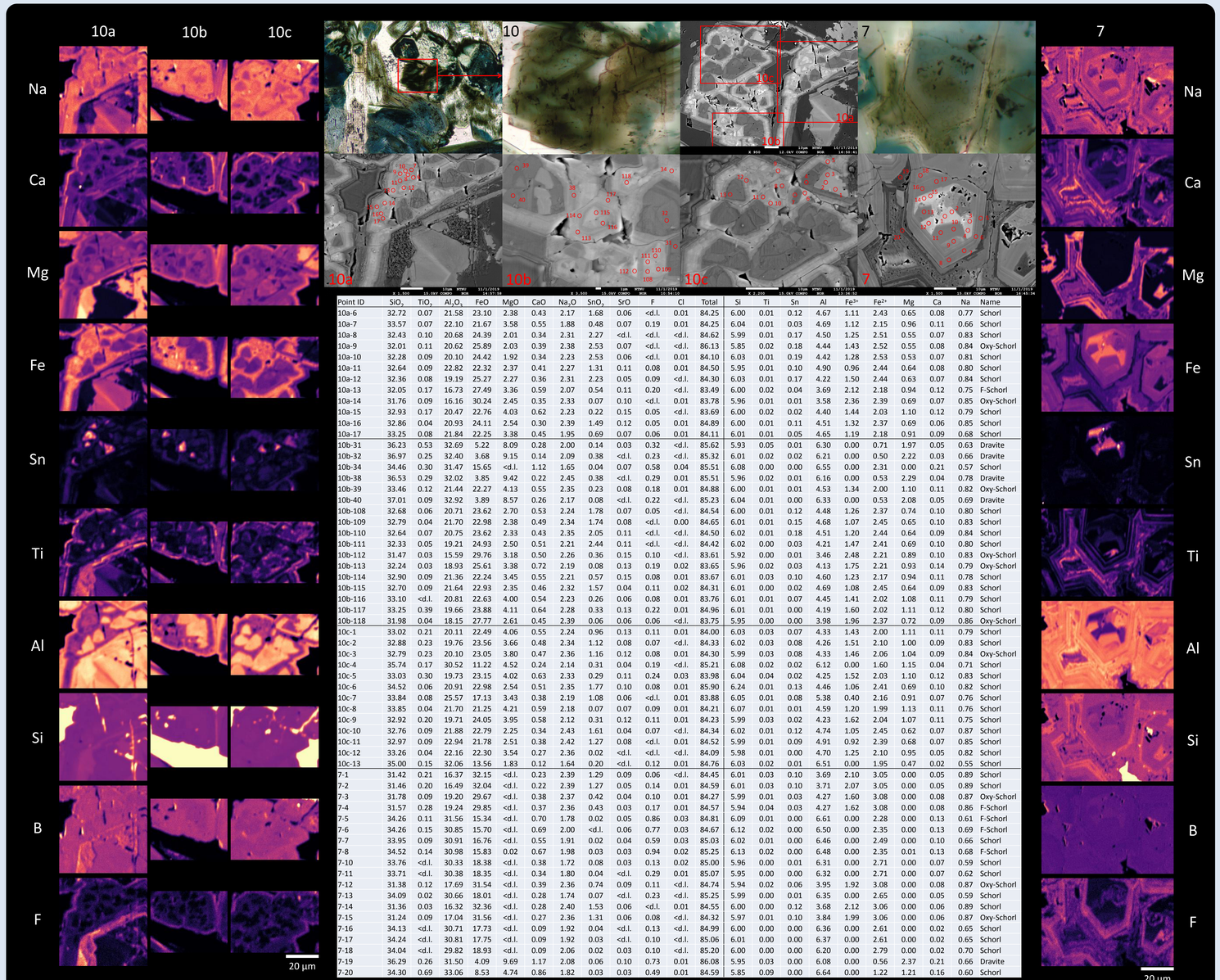
The behavior of Sn in tourmaline varies from patchy to concentric zoning between different samples, and concentrations above 2.50 wt% SnO_2 were recorded. High resolution WDS maps and BSE images do not indicate that these zones are due to inclusions of cassiterite. Sn is probably structurally bound in tourmaline, most likely substituting into the Y-site. The highest Sn-values (>0.4 wt% SnO_2) are coupled with a substantial substitution of Fe for Al in the Z-site, and the structural formula calculation indicate that some Fe is present as Fe^{3+} in the analyses with over ca. 20 wt% FeO. Trends between Sn and other elements are erratic, except for a weak positive correlation with Sr. The Sn-content in tourmaline combined with the inferred Fe^{3+} and the observed cassiterite in the samples may indicate that oxidation of the ore fluid played a role in cassiterite precipitation.



A part of the analyzed sample in plane polarized light. The white matrix is quartz, the euhedral, colorless-pale brown minerals are cassiterite. The rest is tourmaline.



Classification and discrimination diagrams of tourmaline from the analyzed sample. Most analyses plot in the alkali and hydroxy fields, and classify as schorl and dravite. Sn-rich zones are typically high in Fe and low in Al.



Point ID	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	SnO_2	SrO	F	Cl	Total	Si	Ti	Sn	Al	Fe^{3+}	Fe^{2+}	Mg	Ca	Na	Name
10a-6	32.72	0.07	21.58	23.10	2.38	0.43	2.17	1.68	0.06	<d.l.	0.01	84.25	6.00	0.01	0.12	4.67	1.11	2.43	0.65	0.08	0.77	Schorl
10a-7	33.57	0.07	22.10	21.67	3.58	0.55	1.88	0.48	0.07	0.19	0.01	84.25	6.04	0.01	0.03	4.69	1.12	2.15	0.96	0.11	0.66	Schorl
10a-8	32.43	0.10	20.68	24.39	2.01	0.34	2.31	2.27	<d.l.	<d.l.	<d.l.	84.62	5.99	0.01	0.17	4.50	1.25	2.51	0.55	0.07	0.83	Schorl
10a-9	32.01	0.11	20.62	25.89	2.03	0.39	2.38	2.53	0.07	<d.l.	<d.l.	86.13	5.85	0.02	0.18	4.44	1.43	2.52	0.55	0.08	0.84	Oxy-Schorl
10a-10	32.28	0.09	20.10	24.42	1.92	0.34	2.23	2.53	0.06	<d.l.	0.01	84.10	6.03	0.01	0.19	4.42	1.28	2.53	0.53	0.07	0.81	Schorl
10a-11	32.64	0.09	22.82	22.32	2.37	0.41	2.27	1.31	0.11	0.08	0.01	84.50	5.95	0.01	0.10	4.90	0.96	2.44	0.64	0.08	0.80	Schorl
10a-12	32.36	0.08	19.19	25.27	2.27	0.36	2.31	2.23	0.05	0.09	<d.l.	84.30	6.03	0.01	0.17	4.22	1.50	2.44	0.63	0.07	0.84	Schorl
10a-13	32.05	0.17	16.73	27.49	3.36	0.59	2.07	0.54	0.11	0.20	<d.l.	83.49	6.00	0.02	0.04	3.69	2.12	2.18	0.94	0.12	0.75	F-Schorl
10a-14	31.76	0.09	16.16	30.24	2.45	0.35	2.33	0.07	0.10	<d.l.	0.01	83.78	5.96	0.01	0.01	3.58	2.36	2.39	0.69	0.07	0.85	Oxy-Schorl
10a-15	32.93	0.17	20.47	22.76	4.03	0.62	2.23	0.22	0.15	0.05	<d.l.	83.69	6.00	0.02	0.02	4.40	1.44	2.03	1.10	0.12	0.79	Schorl
10a-16	32.86	0.04	20.93	24.11	2.54	0.30	2.39	1.49	0.12	0.05	0.01	84.89	6.00	0.01	0.11	4.51	1.32	2.37	0.69	0.06	0.85	Schorl
10a-17	33.25	0.08	21.84	22.25	3.38	0.45	1.95	0.69	0.07	0.06	0.01	84.11	6.01	0.01	0.05	4.65	1.19	2.18	0.91	0.09	0.68	Schorl
10b-31	36.23	0.53	32.69	5.22	8.09	0.28	2.00	0.14	0.03	0.32	<d.l.	85.62	5.93	0.05	0.01	6.30	0.00	0.71	1.97	0.05	0.63	Dravite
10b-32	36.97	0.25	32.40	3.68	9.15	0.14	2.09	0.38	<d.l.	0.23	<d.l.	85.32	6.01	0.02	0.02	6.21	0.00	0.50	2.22	0.03	0.66	Dravite
10b-34	34.46	0.30	31.47	15.65	<d.l.	1.12	1.65	0.04	0.07	0.58	0.04	85.51	6.08	0.00	0.00	6.55	0.00	2.31	0.00	0.21	0.57	Schorl
10b-38	36.53	0.29	32.02	3.85	9.42	0.22	2.45	0.38	<d.l.	0.29	0.01	85.51	5.96	0.02	0.01	6.16	0.00	0.53	2.29	0.04	0.78	Dravite
10b-39	33.46	0.12	21.44	22.27	4.13	0.55	2.35	0.23	0.08	0.18	0.01	84.88	6.00	0.01	0.01	4.53	1.34	2.00	1.10	0.11	0.82	Oxy-Schorl
10b-40	37.01	0.09	32.92	3.89	8.57	0.26	2.17	0.08	<d.l.	0.22	<d.l.	85.23	6.04	0.01	0.00	6.33	0.00	0.53	2.08	0.05	0.69	Dravite
10b-108	32.68	0.06	20.71	23.62	2.70	0.53	2.24	1.78	0.07	0.05	<d.l.	84.54	6.00	0.01	0.12	4.48	1.26	2.37	0.74	0.10	0.80	Schorl
10b-109	32.79	0.04	21.70	22.98	2.38	0.49	2.34	1.74	0.08	<d.l.	0.00	84.65	6.01	0.01	0.15	4.68	1.07	2.45	0.65	0.10	0.83	Schorl
10b-110	32.64	0.07	20.75	23.62	2.33	0.43	2.35	2.05	0.11	<d.l.	<d.l.	84.50	6.02	0.01	0.18	4.51	1.20	2.44	0.64	0.09	0.84	Schorl
10b-111	32.33	0.05	19.21	24.93	2.50	0.51	2.21	2.44	0.11	<d.l.	<d.l.	84.42	6.02	0.00	0.03	4.21	1.47	2.41	0.69	0.10	0.80	Schorl
10b-112	31.47	0.03	15.59	29.76	3.18	0.50	2.26	0.36	0.15	0.10	<d.l.	83.61	5.92	0.00	0.01	3.46	2.48	2.21	0.89	0.10	0.83	Oxy-Schorl
10b-113	32.24	0.03	18.93	25.61	3.38	0.72	2.19	0.08	0.13	0.19	0.02	83.65	5.96	0.02	0.03	4.13	1.75	2.21	0.93	0.14	0.79	Oxy-Schorl
10b-114	32.90	0.09	21.36	22.24	3.45	0.55	2.21	0.57	0.15	0.08	0.01	83.67	6.01	0.03	0.10	4.60	1.23	2.17	0.94	0.11	0.78	Schorl
10b-115	32.70	0.09	21.64	22.93	2.35	0.46	2.32	1.57	0.04	0.11	0.02	84.31	6.01	0.00	0.02	4.69	1.08	2.45	0.64	0.09	0.83	Schorl
10b-116	33.10	<d.l.	20.81	22.63	4.00	0.54	2.23	0.26	0.06	0.08	0.01	83.76	6.01	0.01	0.07	4.45	1.41	2.02	1.08	0.11	0.79	Schorl
10b-117	33.25	0.39	19.66	23.88	4.11	0.64	2.28	0.33	0.13	0.22	0.01	84.96	6.01	0.01	0.00	4.19	1.60	2.02	1.11	0.12	0.80	Schorl
10b-118	31.98	0.04	18.15	27.77	2.61	0.45	2.39	0.06	0.06	0.06	<d.l.	83.75	5.95	0.00	0.00	3.98	1.96	2.37	0.72	0.09	0.86	Oxy-Schorl
10c-1	33.02	0.21	20.11	22.49	4.06	0.55	2.24	0.96	0.13	0.11	0.01	84.00	6.03	0.03	0.07	4.33	1.43	2.00	1.11	0.11	0.79	Schorl
10c-2	32.88	0.23	19.76	23.56	3.66	0.48	2.34	1.12	0.08	0.07	<d.l.	84.33	6.02	0.03	0.08	4.26	1.51	2.10	1.00	0.09	0.83	Schorl
10c-3	32.79	0.23	20.10	23.05	3.80	0.47	2.36	1.16	0.12	0.08	0.01	84.30	5.99	0.03	0.08	4.33	1.46	2.06	1.04	0.09	0.84	Oxy-Schorl
10c-4	35.74	0.17	30.52	11.22	4.52	0.24	2.14	0.31	0.04	0.19	<d.l.	85.21	6.08	0.02	0.02	6.12	0.00	1.60	1.15	0.04	0.71	Schorl
10c-5	33.03	0.30	19.73	23.15	4.02	0.63	2.33	0.29	0.11	0.24	0.03	83.98	6.04	0.04	0.02	4.25	1.52	2.03	1.10	0.12	0.83	Schorl
10c-6	34.52	0.06	20.91	22.98	2.54	0.51	2.35	1.77	0.10	0.08	0.01	85.90	6.24	0.01	0.13	4.46	1.06	2.41	0.69	0.10	0.82	Schorl
10c-7	33.84	0.08	25.57	17.13	3.43	0.38	2.19	1.08	0.06	<d.l.	0.01	83.88	6.05	0.01	0.08	5.38	0.40	2.16	0.91	0.07	0.76	Schorl
10c-8	33.85	0.04	21.70	21.25	4.21	0.59	2.18	0.07	0.07	0.09	0.01	84.21	6.07	0.01	0.01	4.59	1.20	1.99	1.13	0.11	0.76	Schorl
10c-9	32.92	0.20	19.71	24.05	3.95	0.58	2.12	0.31	0.12	0.11	0.01	84.23	5.99	0.03	0.02	4.23	1.62	2.04	1.07	0.11	0.75	Schorl
10c-10	32.76	0.09	21.88	22.79	2.25	0.34	2.43	1.61	0.04	0.07	<d.l.	84.34	6.02	0.01	0.12	4.74	1.05	2.45	0.62	0.07	0.87	Schorl
10c-11	32.97	0.09	22.94	21.78	2.51	0.38	2.42	1.27	0.08	<d.l.	0.01	84.52	5.99	0.01	0.09	4.91	0.92	2.39	0.68	0.07	0.85	Schorl
10c-12	33.26	0.04	22.16	22.30	3.54	0.27	2.36	0.02	<d.l.	<d.l.	<d.l.	84.09	5.98	0.01	0.00	4.70	1.25	2.10	0.95	0.05	0.82	Schorl
10c-13	35.00	0.15	32.06	13.56	1.83	0.12	1.64	0.20	<d.l.	0.12	0.01	84.76	6.03	0.02	0.01	6.51	0.00	1.95	0.47	0.02	0.55	Schorl
7-1	31.42	0.21	16.37	32.15	<d.l.	0.23	2.39	1.29	0.09	0.06	<d.l.	84.45	6.01	0.03	0.10	3.69	2.10	3.05	0.00	0.05	0.89	Schorl
7-2	31.46	0.20	16.49	32.04	<d.l.	0.22	2.39	1.27	0.05	0.14	0.01	84.59	6.01	0.03	0.10	3.71	2.07	3.05	0.00	0.05	0.89	Schorl
7-3	31.78	0.09	19.20	29.67	<d.l.	0.38	2.37	0.42	0.04	0.10	0.01	84.27	5.99	0.01	0.03	4.27	1.60	3.08	0.00	0.08	0.87	Oxy-Schorl
7-4	31.57	0.28	19.24	29.85	<d.l.	0.37	2.36	0.43	0.03	0.17	0.01	84.57	5.94	0.04	0.03	4.27	1.62	3.08	0.00	0.08	0.86	F-Schorl
7-5	34.26	0.11	31.56	15.34	<d.l.	0.70	1.78	0.02	0.05	0.86	0.03	84.81	6.09	0.01	0.00	6.61	0.00	2.28	0.00	0.13	0.61	F-Schorl
7-6	34.26	0.15	30.85	15.70	<d.l.	0.69	2.00	<d.l.	0.06	0.77	0.03	84.67	6.12	0.02	0.00	6.50	0.00	2.35	0.00	0.13	0.69	F-Schorl
7-7	33.95	0.09	30.91	16.76	<d.l.	0.55	1.91	0.02	0.04	0.59	0.03	85.03	6.02	0.01	0.00	6.46	0.00	2.49	0.00	0.10	0.66	Schorl
7-8	34.52	0.14	30.98	15.83	0.02	0.67	1.98	0.03	0.03	0.94	0.02	85.25	6.13	0.02	0.00	6.48	0.00	2.35	0.01	0.13	0.68	F-Schorl
7-10	33.76	<d.l.	30.33	18.38	<d.l.	0.38	1.72	0.08	0.03	0.13	0.02	85.00	5.96	0.00	0.01	6.31	0.00	2.71	0.00	0.07	0.59	Schorl
7-11	33.71	<d.l.	30.38	18.35	<d.l.	0.34	1.80	0.04	<d.l.	0.29	0.01	85.07	5.95	0.00	0.00	6.32	0.00	2.71	0.00	0.07	0.62	Schorl
7-12	31.38	0.12	17.69	31.54	<d.l.	0.39	2.36	0.74	0.09	0.11	<d.l.	84.74	5.94	0.02	0.06	3.95	1.92	3.08	0.00	0.08	0.87	Oxy-Schorl
7-13	34.09	0.02	30.66	18.01	<d.l.	0.28	1.74	0.07	<d.l.	0.23	<d.l.	85.25	5.99	0.00	0.01	6.35	0.00	2.65	0.00	0.05	0.59	Schorl
7-14	31.36	0.03	16.32	32.36	<d.l.	0.28	2.40	1.53	0.06	<d.l.	0.01	84.55	6.00	0.00	0.12	3.68	2.12	3.06	0.00	0.06	0.89	Schorl
7-15	31.24	0.09	17.04	31.56	<d.l.	0.27	2.36	1.31	0.06	0.08	<d.l.	84.32	5.97	0.01	0.10	3.84	1.99	3.06	0.00	0.06	0.87	Oxy-Schorl
7-16	34.13	<d.l.	30.71	17.73	<d.l.	0.09	1.92	0.04	<d.l.	0.13	<d.l.	84.99	6.00	0.00	0.00	6.36	0.00	2.61	0.00	0.02	0.65	Schorl
7-17	34.24	<d.l.	30.81	17.75	<d.l.	0.09	1.92	0.03	<d.l.	0.10	<d.l.	85.06	6.01	0.00	0.00	6.37	0.00	2.61	0.00	0.02	0.65	Schorl
7-18	34.04	<d.l.	29.82	18.93	<d.l.	0.09	2.06	0.02	0.03	0.10	<d.l.	85.20	6.00	0.00	0.00	6.20	0.00	2.79	0.00	0.02	0.70	Schorl
7-19	36.29	0.26	31.50	4.09	9.69	1.17	2.08	0.06	0.10	0.73	0.01	86.08	5.95	0.03	0.00	6.08	0.00	0.56	2.37	0.21	0.66	Dravite
7-20	34.30	0.69	33.06	8.53	4.74	0.86	1.82	0.03	0.03	0.49	0.01	84.59	5.85	0.09	0.00	6.64	0.00	1.22	1.21	0.16	0.60	Schorl

Chemical maps, optical and backscatter electron images, and selected elements from quantitative spot analyses of tourmaline grains. The maps were collected using a JEOL 8530FPlus at 12 kV, 120 nA, 300 nm step size, and 500 (map 7) or 750 (maps 10a-c) ms dwell time, respectively. Maps 10a-c have identical intensity scales, and are comparable. B, F, Ca, Ti, and Sn were collected by WDS, and Na, Mg, Fe, Al, and Si were simultaneously collected by EDS.

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