

Sn/Mn/Bi₂O₃ ternary pyrotechnic time delay compositions

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Number of pages: 19

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Supporting Information

S1. Particle size distribution

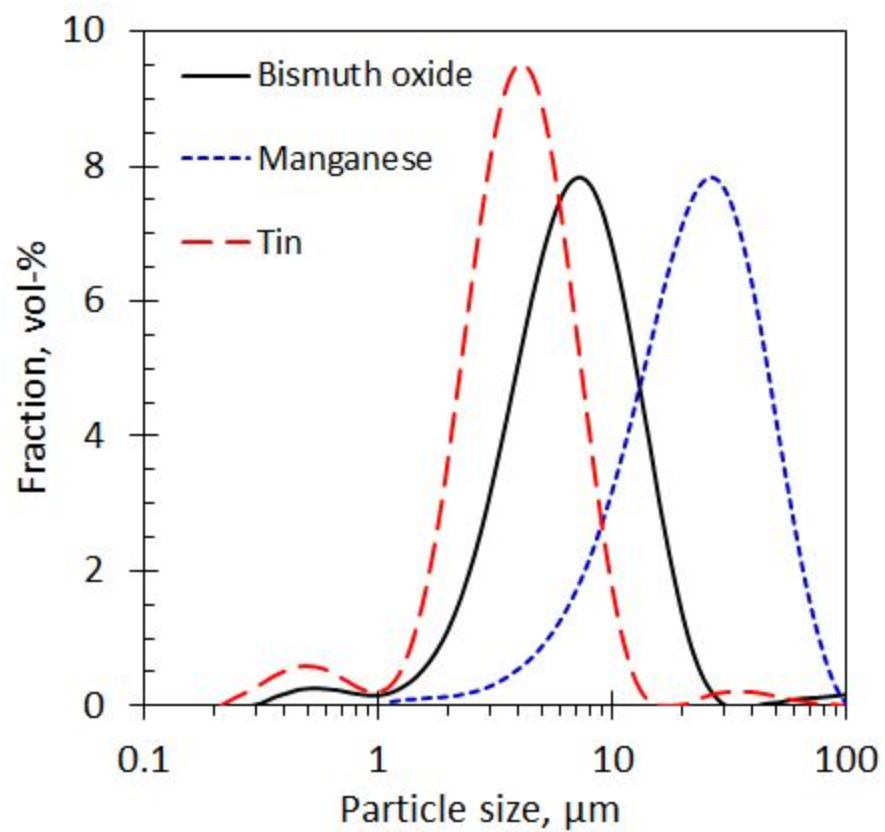


Figure S1. Particle size distributions for the Sn, Mn and Bi₂O₃ powders

S2. X-ray Diffraction diffractograms

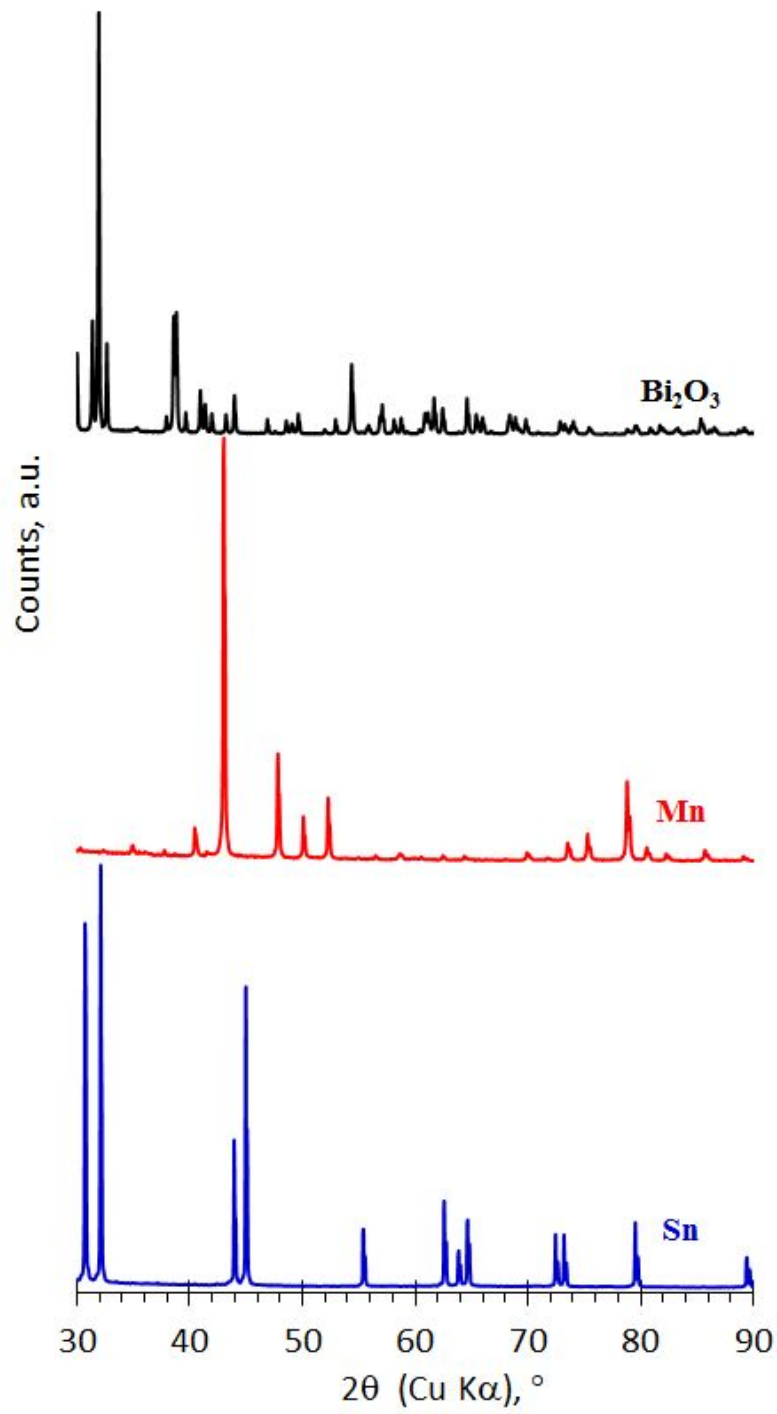


Figure S2. XRD diffractograms of Sn, Mn and Bi_2O_3 powders.

The burn residue slags were milled into fine powders using a tungsten carbide mill. The samples for XRD were prepared according to the standardized Panalytical backloading system, which provides nearly random distribution of the particles. The samples were analyzed using a PANalytical X'Pert Pro powder diffractometer in θ - θ configuration with an X'Celerator detector and variable divergence- and fixed receiving slits with Fe filtered Co-K α radiation ($\lambda=1.789\text{\AA}$). The mineralogy was determined by selecting the best-fitting pattern from the ICSD database compared to the measured diffraction pattern, using X'Pert Highscore plus software. The relative phase amounts (weight% of crystalline portion) were estimated using the Rietveld method (X'Pert Highscore plus software). The recorded XRD diffractograms, for the samples listed in Table S1A, are presented below. The estimated phase amounts are listed in Table S1B

Table S1A. Details of reagents in the glass tubes before combustion

Code in Paper	Sample Code	Component (amounts in wt-%)
A3	Sample 1	27.7Sn/72.4Bi ₂ O ₃
A4	Sample 2	30.0Sn/70.0 Bi ₂ O ₃
A5	Sample 3	40.0Sn/60.0 Bi ₂ O ₃
A6	Sample 4	50.0Sn/50.0 Bi ₂ O ₃
A9	Sample 5	22.5Sn/11.3Mn/66.2Bi ₂ O ₃
A1	Sample 6	15.0Sn/22.5Mn/62.5Bi ₂ O ₃
B4	Sample 7	7.5Sn/33.8Mn/58.7Bi ₂ O ₃
A11	Sample 8	31.2Sn/5.8Mn/63.0Bi ₂ O ₃
B3	Sample 9	10.0Sn/40.5Mn/49.5Bi ₂ O ₃
B6	Sample 10	8.1Sn/42.4Mn/49.5Bi ₂ O ₃
A10	Sample 11	27.0Sn/10.0Mn/63.0Bi ₂ O ₃
A8	Sample 12	20.7Sn/11.3Mn/68.0Bi ₂ O ₃
A2	Sample 13	13.8Sn/22.5Mn/63.7Bi ₂ O ₃
B5	Sample 14	6.9Sn/33.8Mn/59.3Bi ₂ O ₃
A7	Sample 15	27.0Sn/4.5Mn/68.5Bi ₂ O ₃
B1	Sample 16	3.0Sn/40.5Mn/56.5Bi ₂ O ₃
B2	Sample 17	2.8Sn/40.5Mn/56.7Bi ₂ O ₃

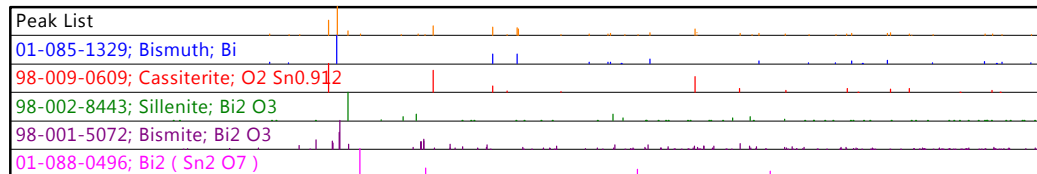
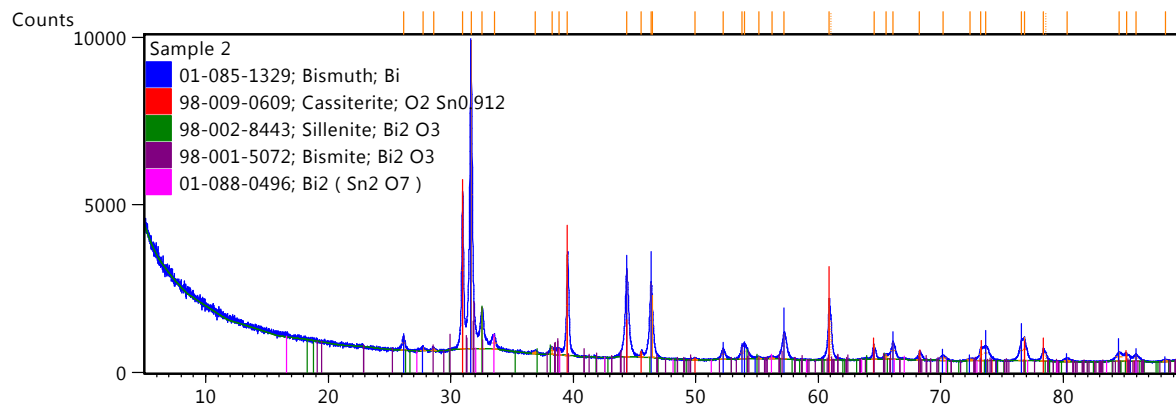
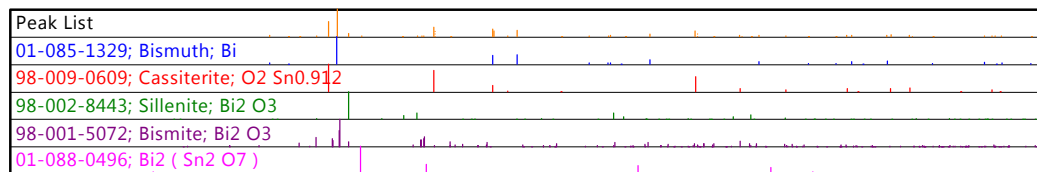
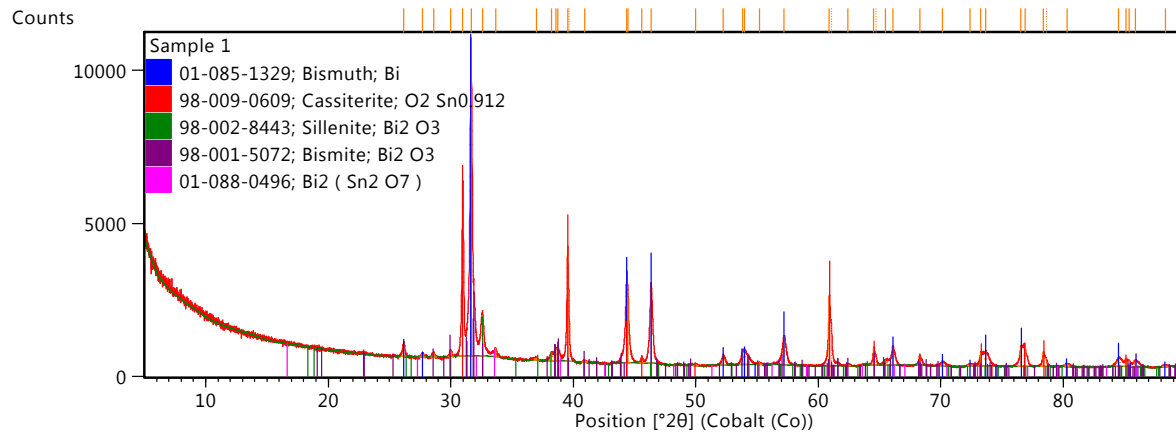
Sample 18	17.0Sn/27.0Mn/56.0Bi ₂ O ₃
Sample 19	23.0Sn/23.0Mn/54.0Bi ₂ O ₃
Sample 20	27.0Sn/17.0Mn/56.0Bi ₂ O ₃
Sample 21	15.0Sn/35.0Mn/50.0Bi ₂ O ₃
Sample 22	20.0Sn/30.0Mn/50.0Bi ₂ O ₃
Sample 23	30.0Sn/20.0Mn/50.0Bi ₂ O ₃

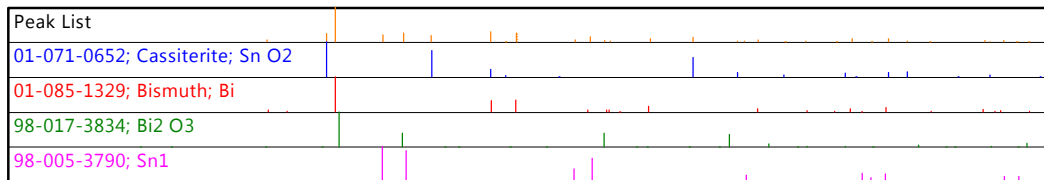
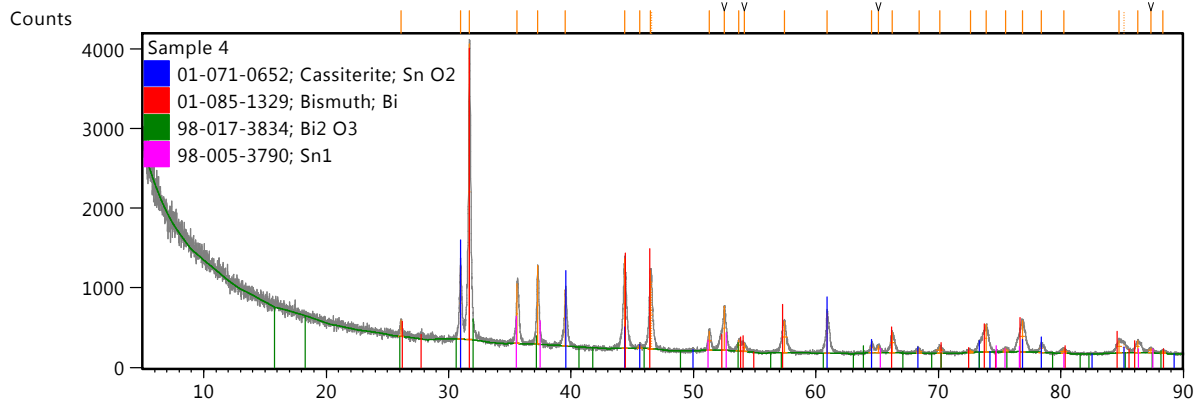
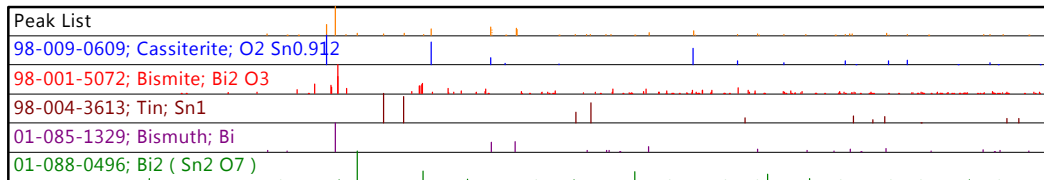
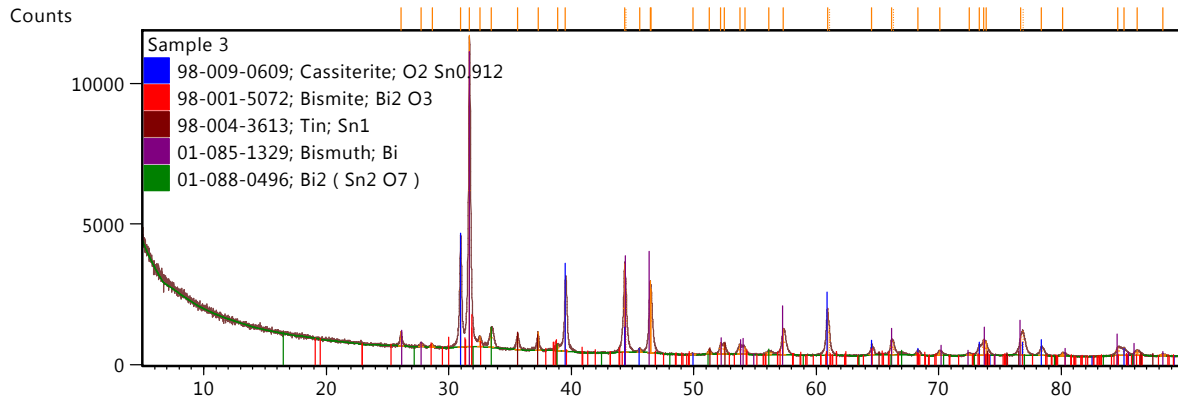
Table S1B. Quantitative XRD analysis of the residues obtained after combustion in glass tubes

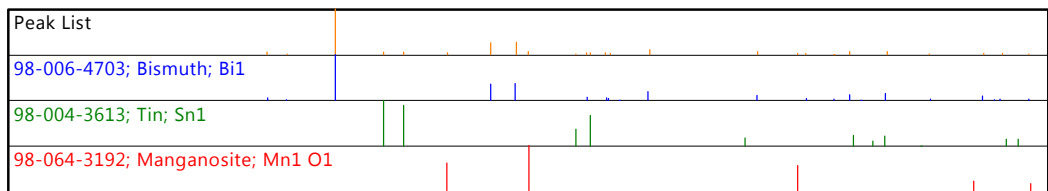
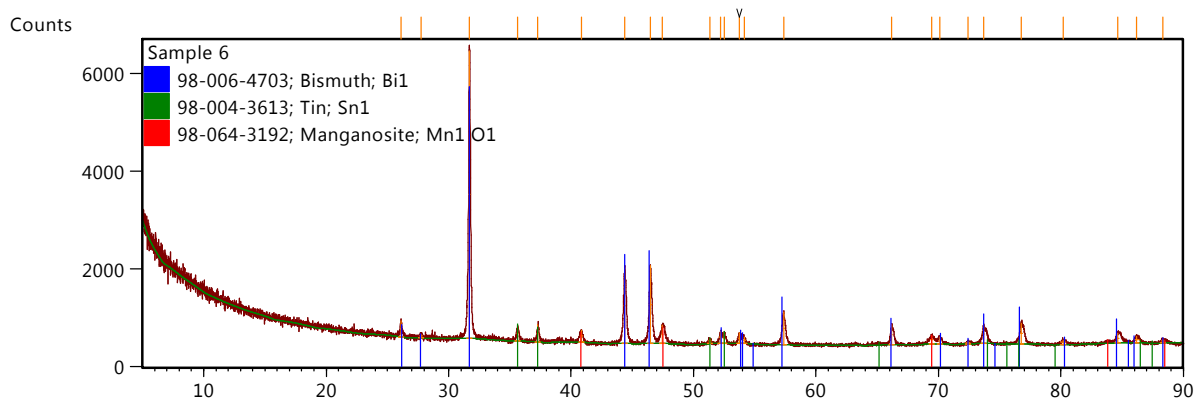
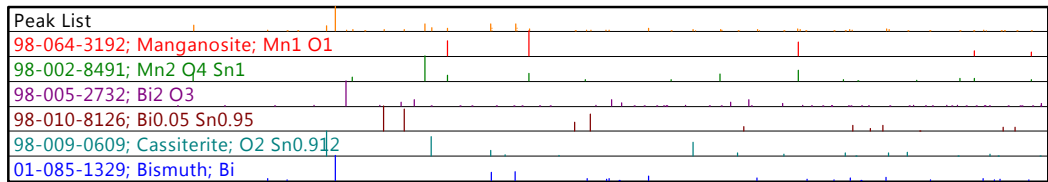
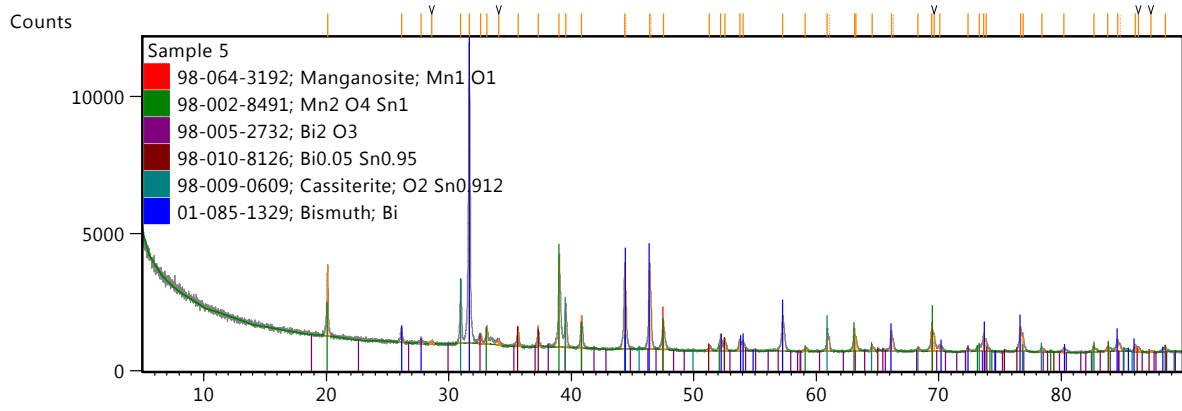
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Bi ₂ O ₃	72.4	70.0	60.0	50.0	66.2	62.5	58.7	63.0	49.5	49.5	63.0	68.0	63.7	59.3	56.5	56.5	56.7	56.0	54.0	56.0	50.0	50.0	50.0	
Mn					11.3	22.5	33.8	5.8	40.5	42.4	10.0	11.3	22.5	33.8	4.5	40.5	40.5	27.0	23.0	17.0	35.0	30.0	20.0	
Sn	27.7	30.0	40.0	50.0	22.5	15.0	7.5	31.2	10.0	8.1	27.0	20.7	13.8	6.9	27.0	3.0	3.0	17.0	23.0	27.0	15.0	20.0	30.0	
Products																								
Bi	33.9	36.7	43.4	43.9	30.7	51.5	38.9	46.2	37.6	31.9	56.9	52.0	46.1	33.3	45.8	29.1	41.9	37.2	37.5	33.0	38.2	36.9	37.8	
MnO					2.0	41.0	47.6		41.3	46.7	1.1	2.1	34.6	47.6	1.2	53.2	44.9	52.1	46.6	35.0	46.5	39.7	19.3	
SnO ₂	45.1	46.5	48.5	29.8	16.6			35.1			7.9	12.5		1.0	33.8	1.2							20.2	
2MnO·SnO					46.9						24.6	28.5	4.9		10.0					18.5				
Bi ₂ O ₃ ·2SnO	1.0	2.1	3.2	0.0				18.2							2.2									
MnBi							0.9			1.7				2.3		1.8								
Mn ₃ Sn							12.6		19.3	18.5				12.0		11.5	13.3				13.0	0.8		
MnSn ₂																		2.7	2.1		1.3	6.2	1.2	
Unreacted reagents																								
Bi ₂ O ₃	20.0	14.6	1.9	0.0	0.9	7.5							5.6	1.4	7.1	1.5								
Sn	0.0	0.0	3.0	26.4				0.5			9.4	1.6		1.1		1.3		0.7		0.3	1.0		1.1	

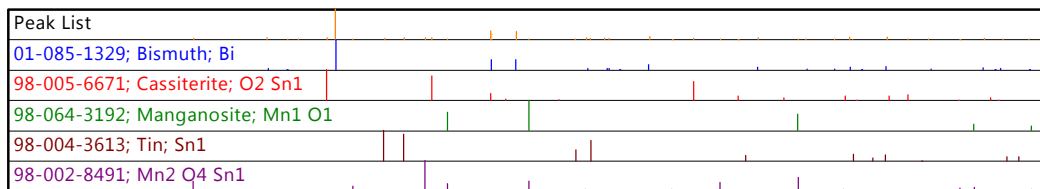
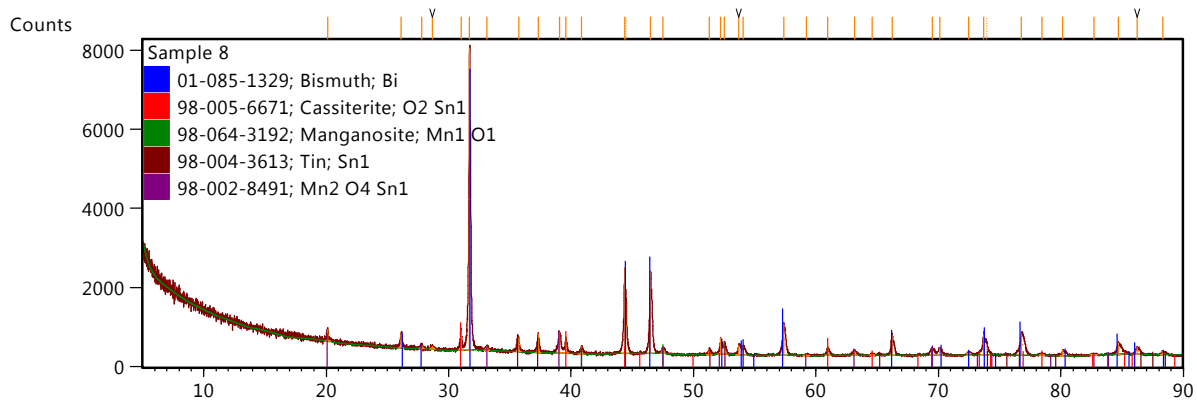
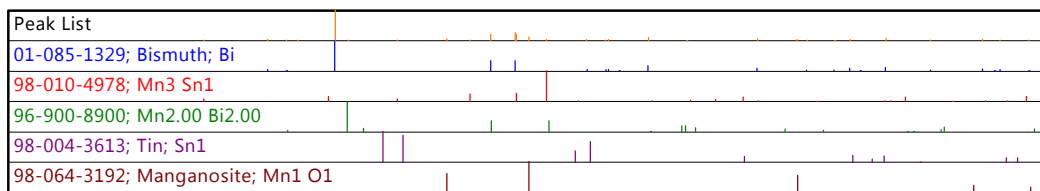
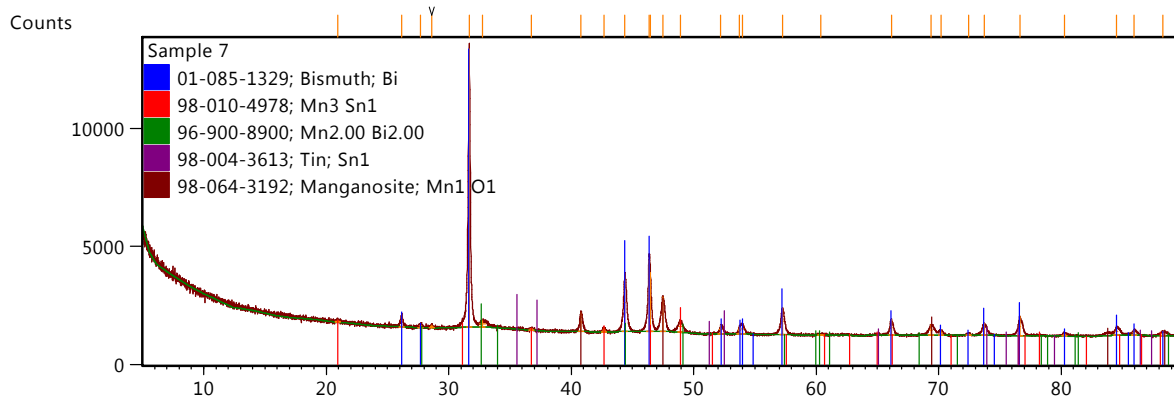
Mn		1.8	1.2	0.1	1.4	0.4								
Minor products														
Bi _{0.05} Sn _{0.95}	3.0				8.9		7.3	12.5	13.2		2.7	20.4		
MnO·SnO ₂				3.3										
Mn ₃ Sn ₂												13.8		
MnO ₂								1.1						

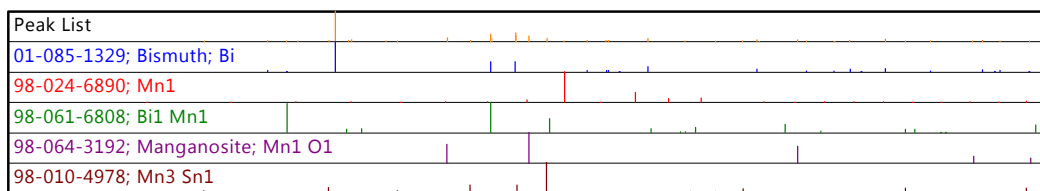
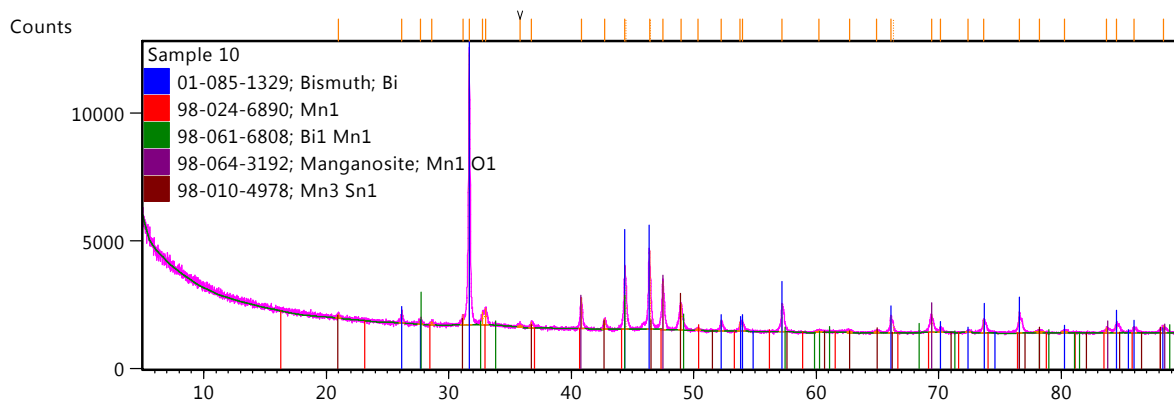
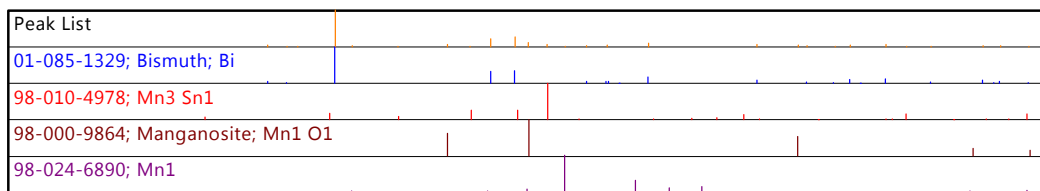
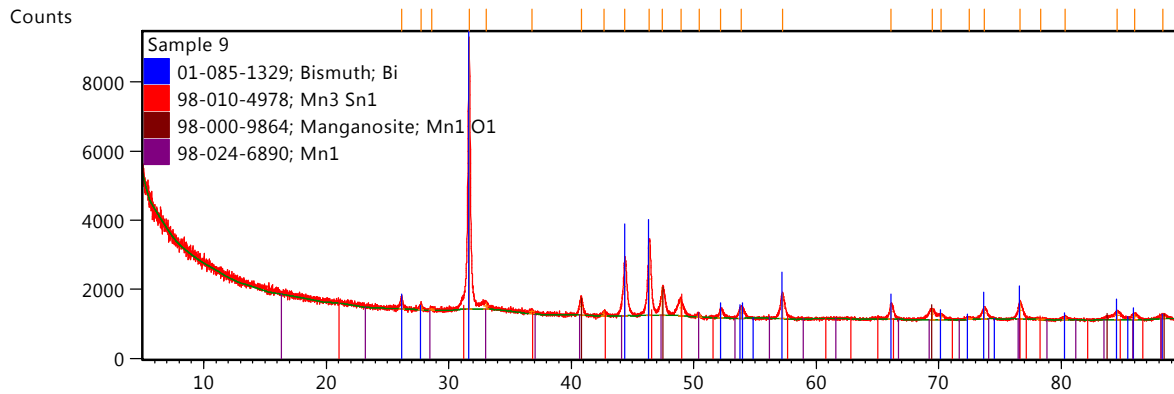
Values are given in wt-%

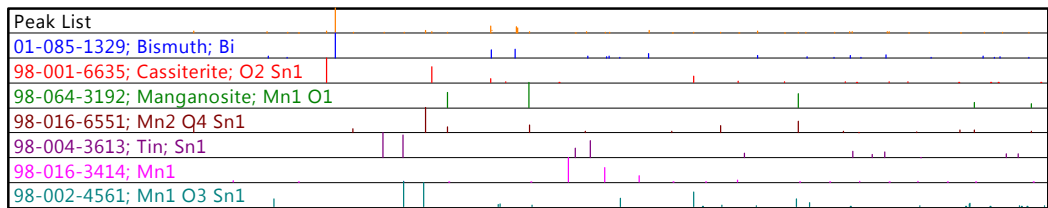
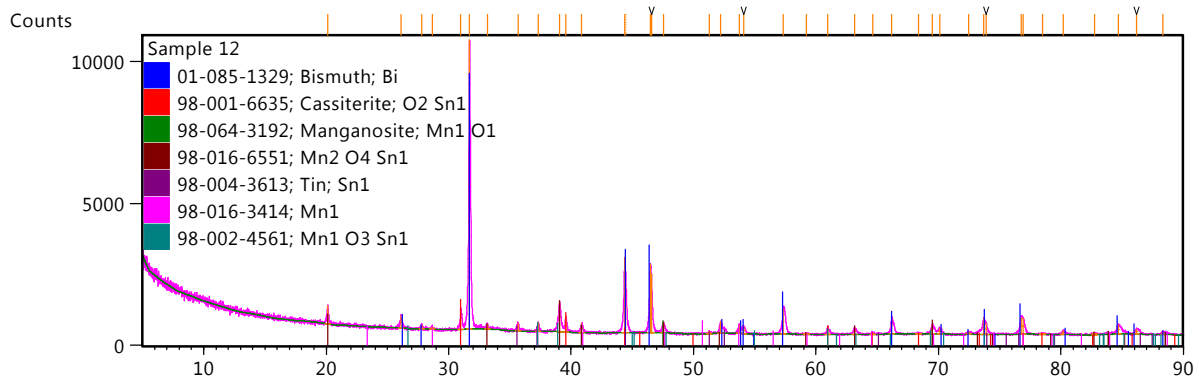
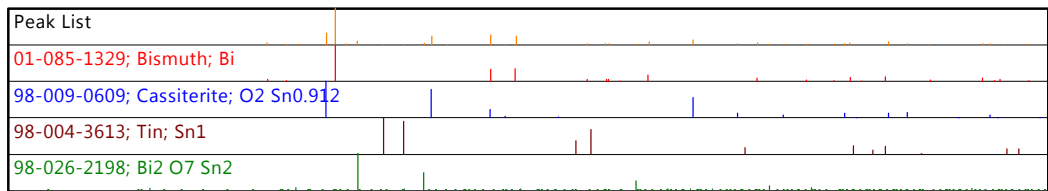
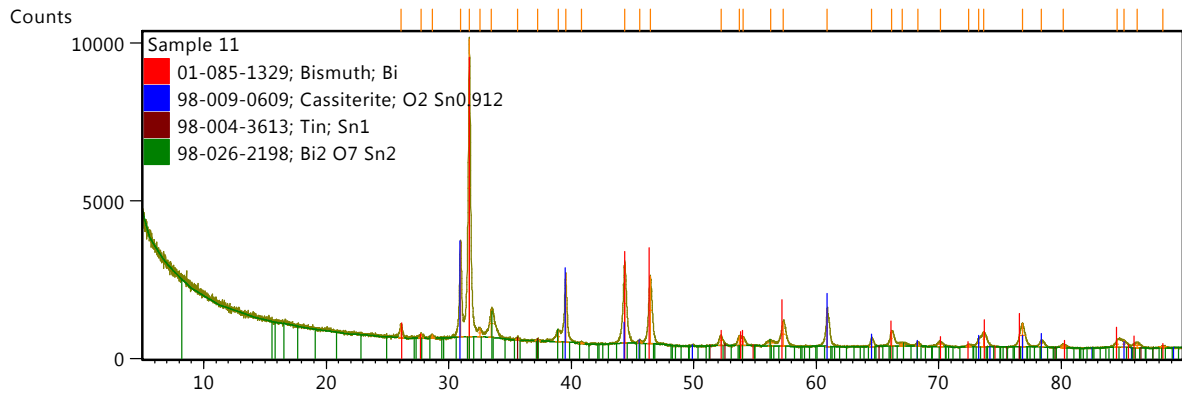


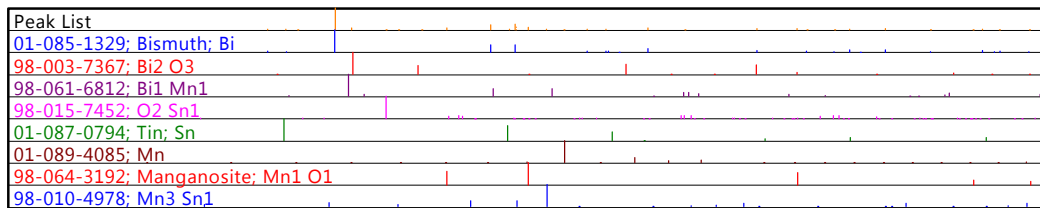
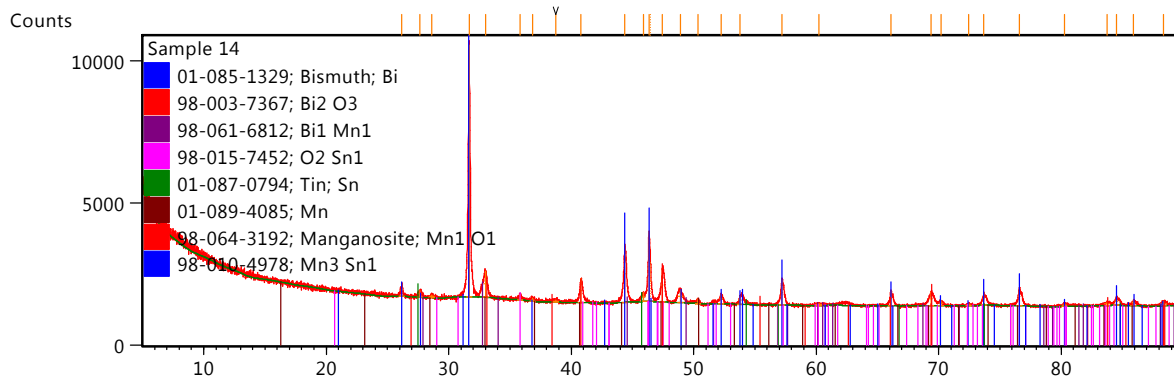
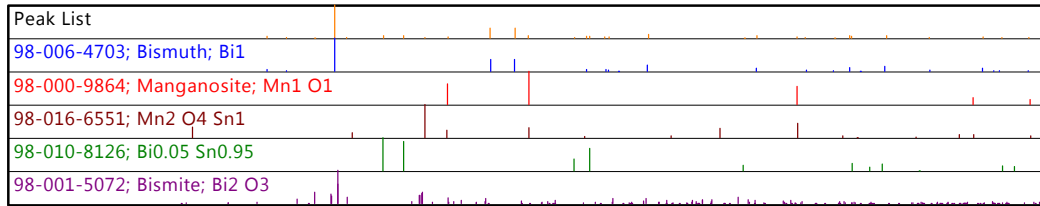
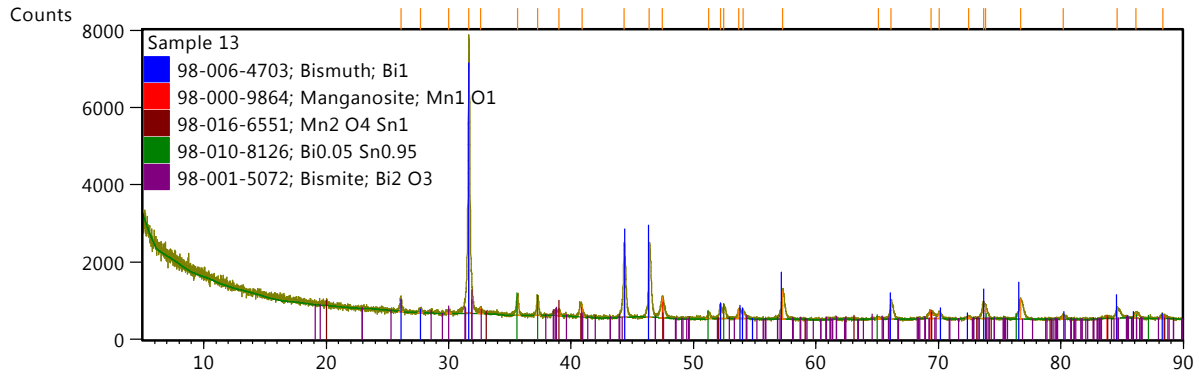


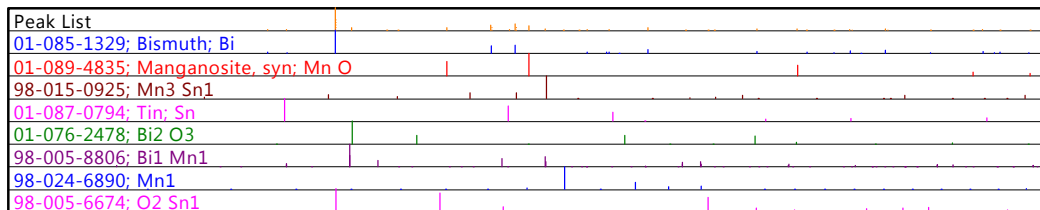
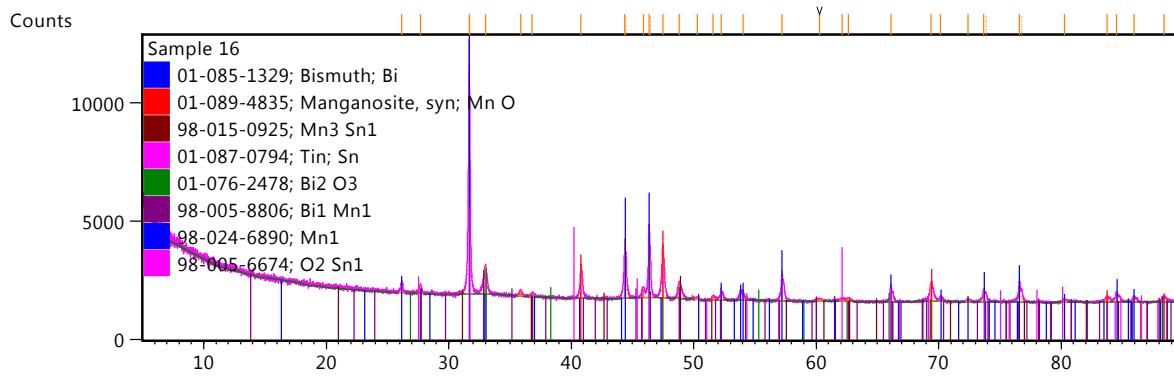
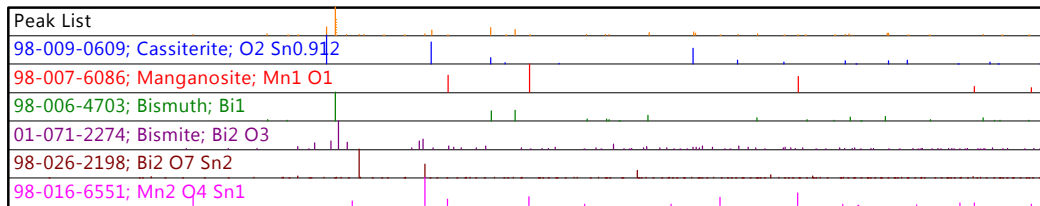
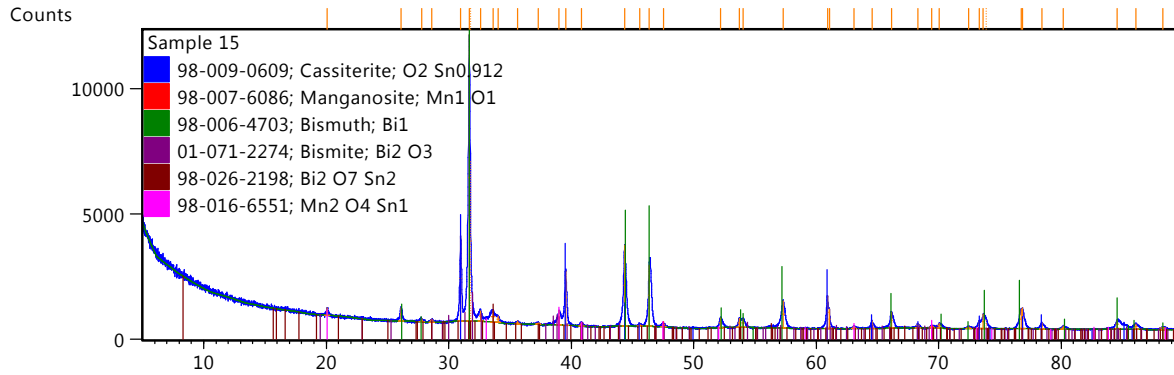


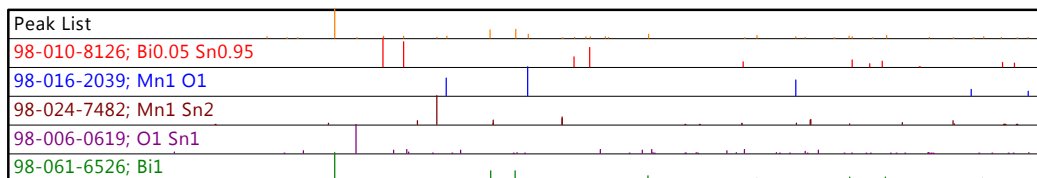
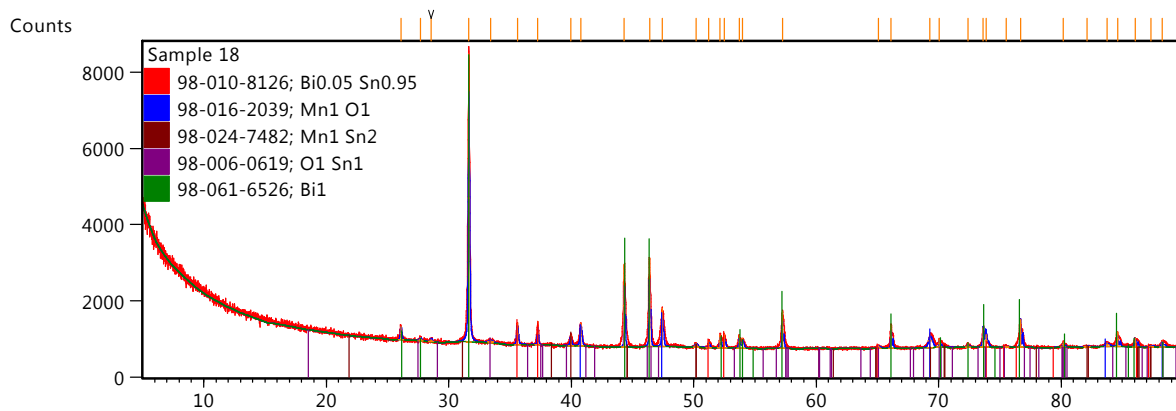
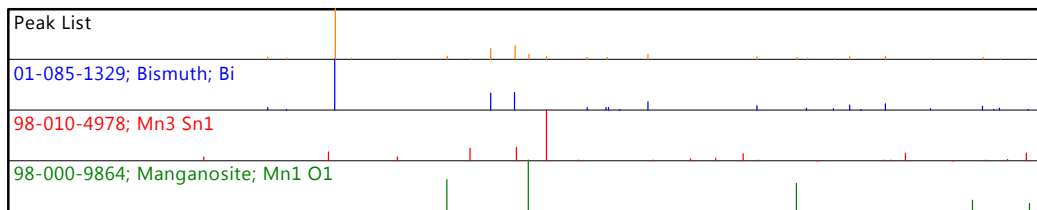
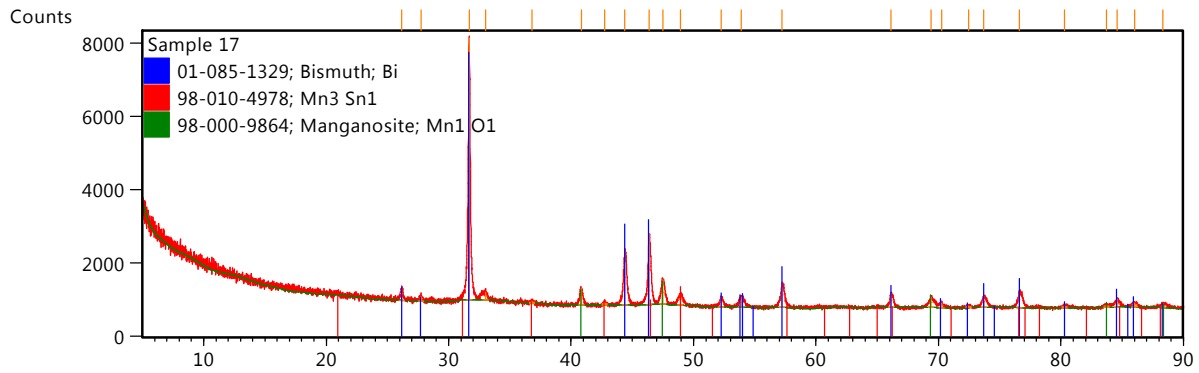


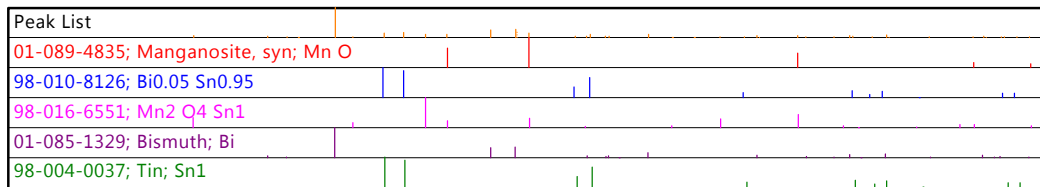
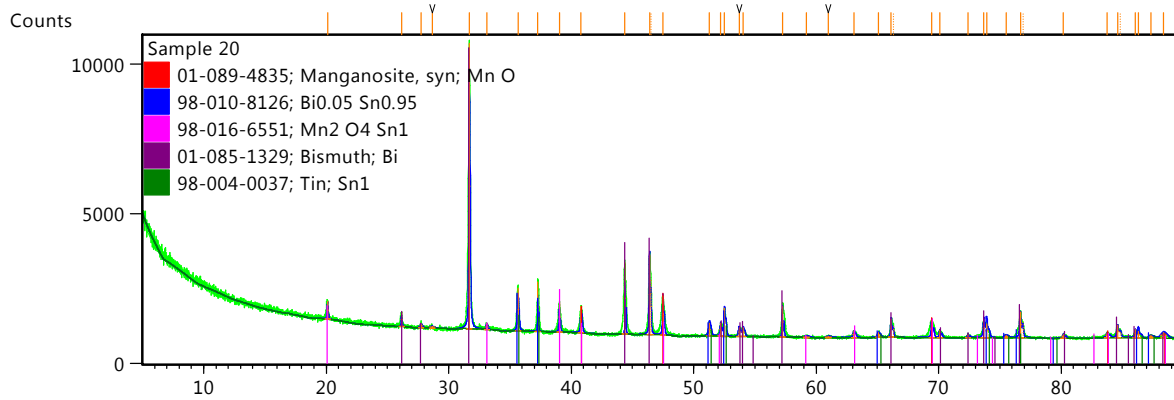
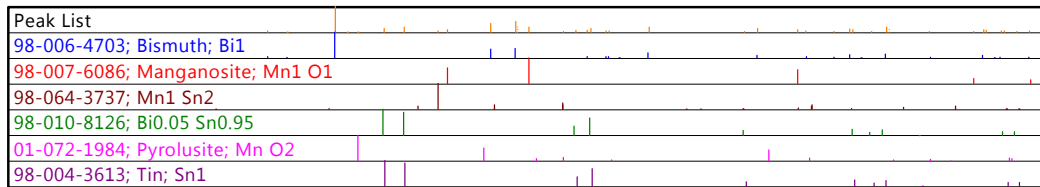
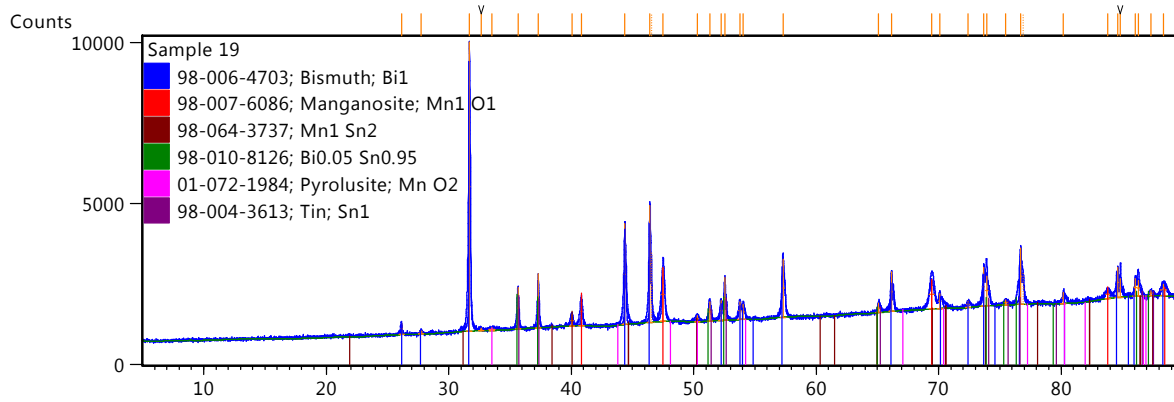


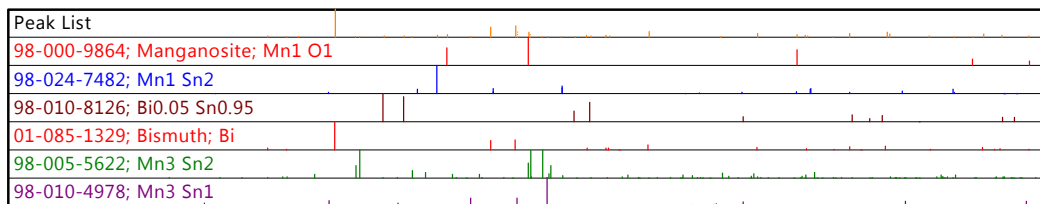
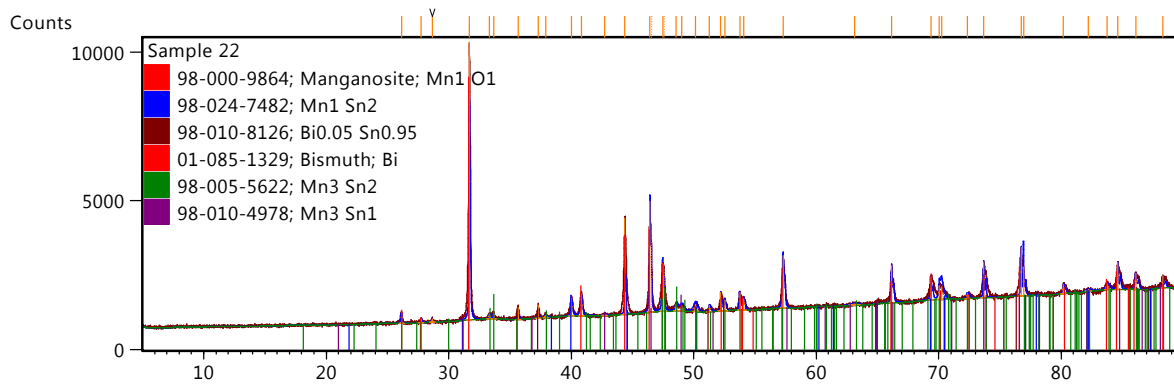
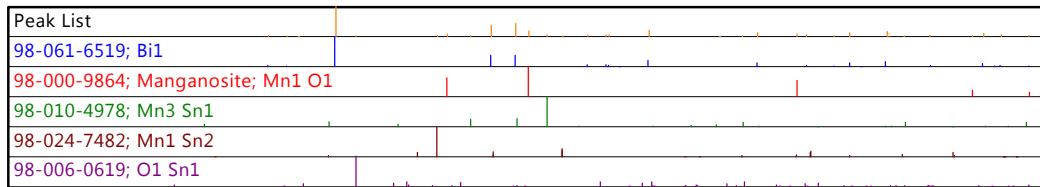
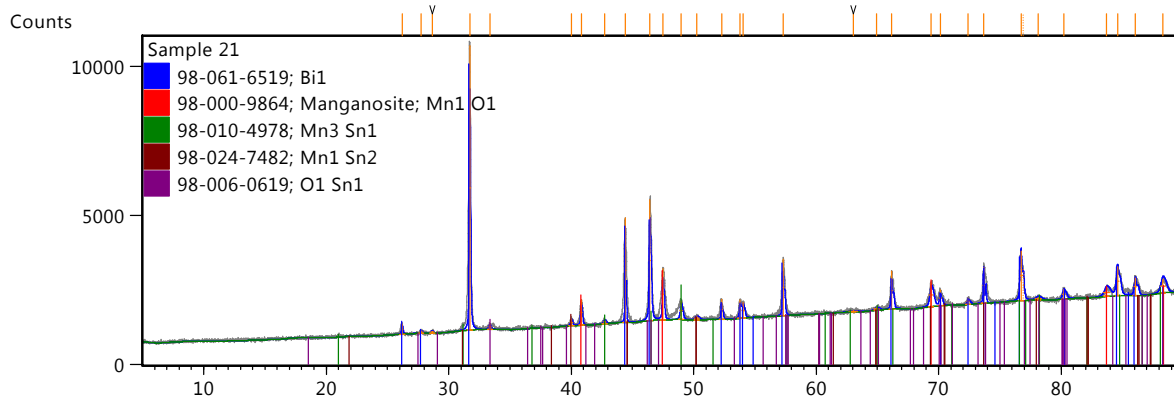












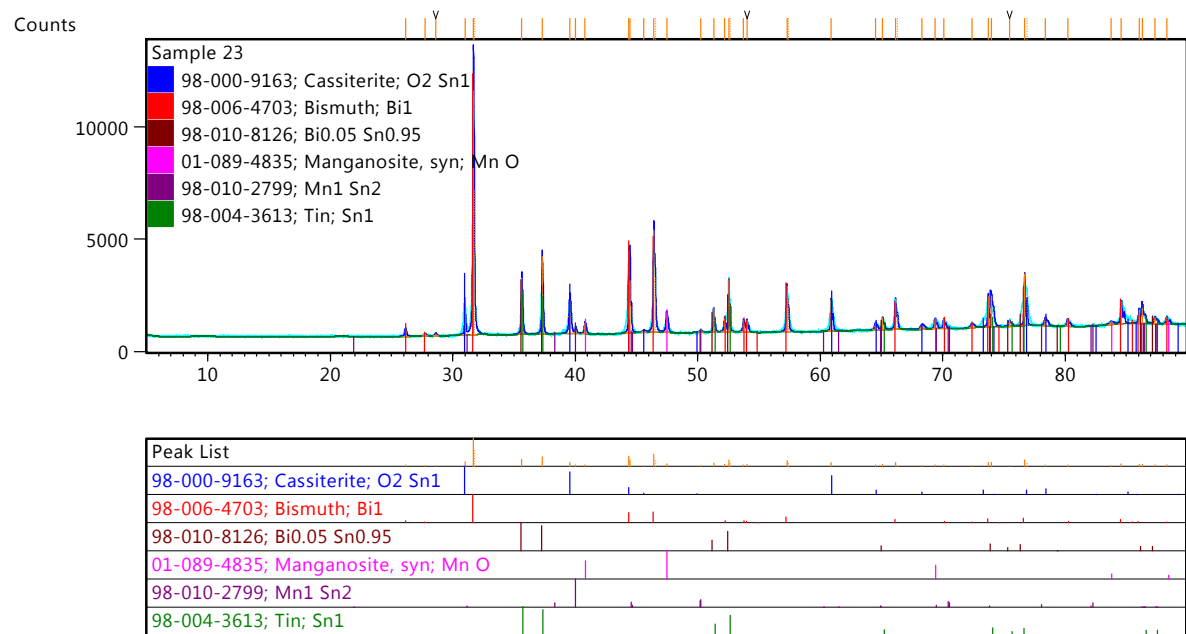


Figure S3. XRD diffractograms of residues obtained after combustion in the glass tubes.

S3. Mixture model details

The mixture model used for correlating the burning rate ($\text{mm}\cdot\text{s}^{-1}$) in the glass tubes was:

$$u = a/b$$

$$a = a_{111}w_1^3 + 3a_{112}w_1^2w_2 + 3a_{113}w_1^2w_3 + \\ a_{222}w_2^3 + 3a_{122}w_1w_2^2 + 3a_{223}w_2^2w_3 + \\ a_{333}w_3^3 + 3a_{133}w_1w_3^2 + 3a_{113}w_2w_3^2 + 6a_{123}w_1w_2w_3$$

$$b = b_{11}w_1^2 + b_{22}w_2^2 + b_{33}w_3^2 + 2a_{12}w_1w_2 + 2a_{13}w_1w_3 + 2a_{123}w_2w_3$$

Where the w_i are the mass fractions corresponding to $i=1$: Bi_2O_3 ; $i=2$: Mn, and $i=3$:

Sn.

The constants were determined by least squares regression and their values are listed in **Table S2**. The correlation coefficient was 0.974.

Table S2. Mixture model coefficients

a_{111}	a_{112}	a_{113}	a_{221}	a_{222}	a_{223}	a_{331}	a_{332}	a_{333}	a_{123}
-0.849	1.099	-1.069	-0.060	-2.737	6.485	13.685	-7.616	23.900	-1.558
b_{11}	b_{22}	b_{33}	b_{12}	b_{13}	b_{23}				
0.0000	0.1076	1.0000	0.0001	0.0000	0.2692				
0	5	0	0	4	9				