



남극 중앙해령(AAR) 멜트포유물 및 휘발성 원소 기초 연구

인하대학교 양윤석

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Introduce

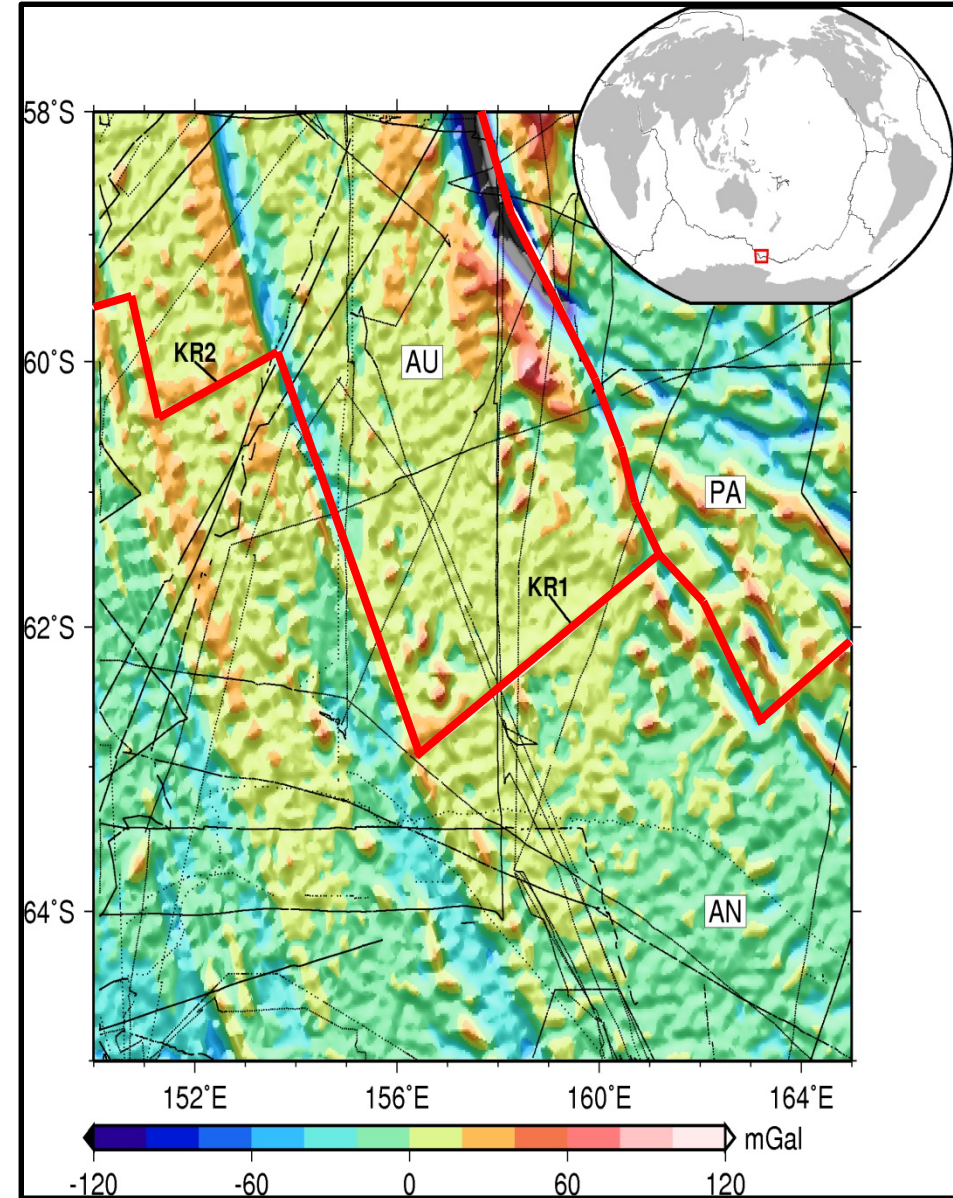


남극 중앙해령 (Australian-Antarctic Ridge: AAR(KR1, KR2))

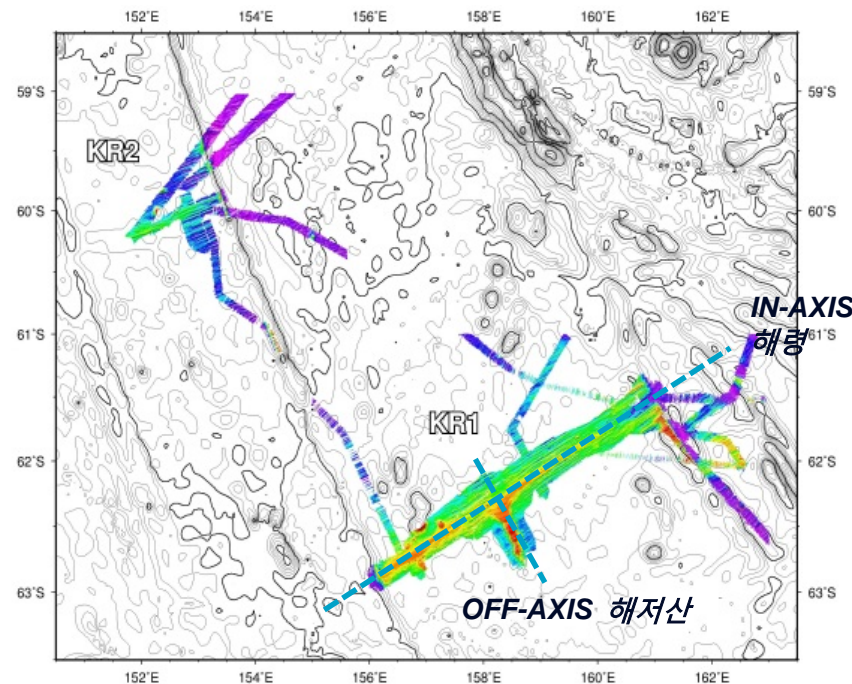
인도-호주판 중앙해령 중 가장 동쪽에 위치
(62°51.2790S, 158°36.9480E)



쇄빙연구선 : 아라온



Introduce



탐사 및 실험 진행 방향

Introduce

남극 중앙해령 암석 시료 (Pillow basalt)

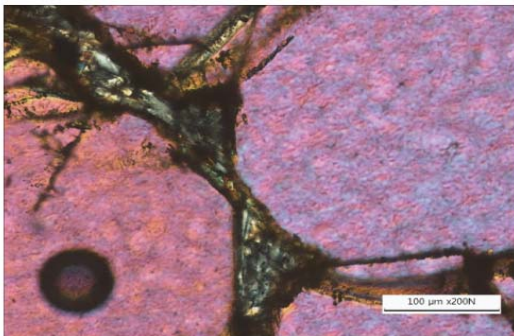
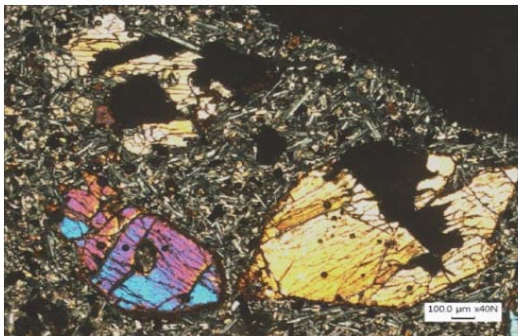
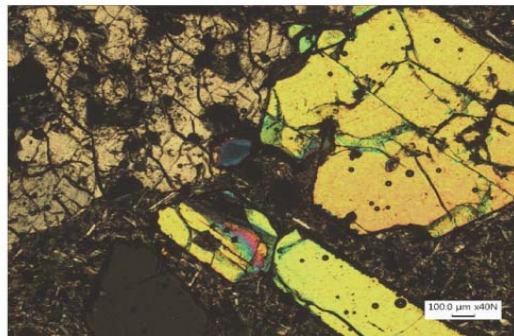
세립질이며 반자형 또는 타형의 감람석, 사장석, 휘석 반정이 관찰됨

Off-axis 해저산 암석 시료

: In-axis 해령 암석 시료에 비해서 반정의 크기가 크고 더 많은 감람석 반정을 포함하고 있음



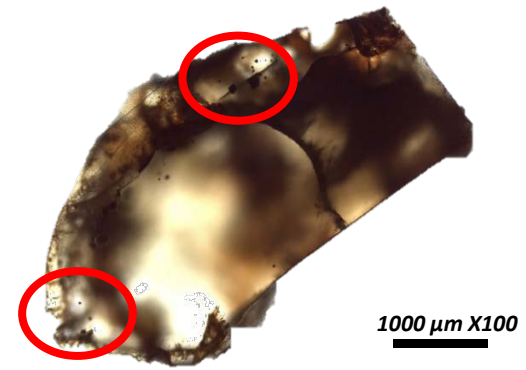
Olivine
Plagioclase
Pyroxene



박편관찰

- ✓ 반상조직이 뚜렷하며 석기가 치밀함.
- ✓ 높은 사장석 함량을 보임
- ✓ 비교적 큰 자형 내지 반자형 감람석 결정이 나타남

Melt inclusion test



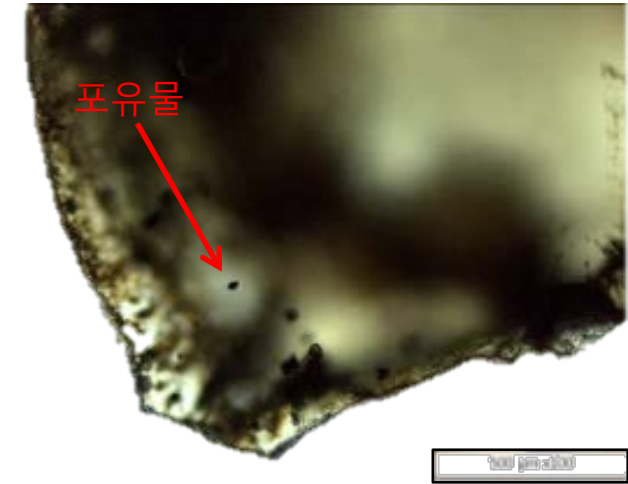
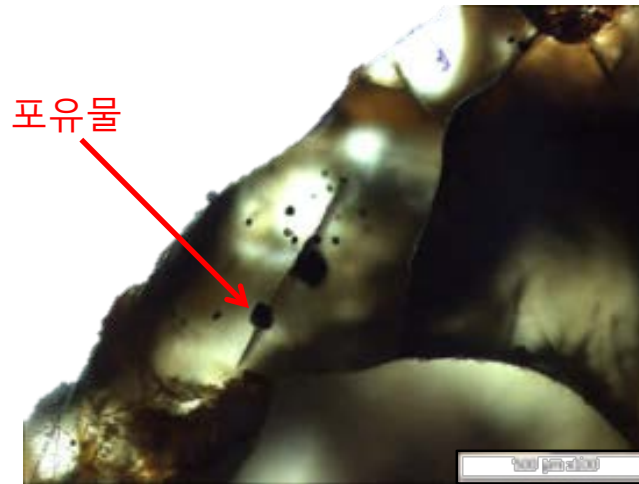
Off-axis에서 채취한 KRR3-DG03-1
현무암의 감람석 반정 내 포유물

Melt inclusion(멜트포유물) 이란?

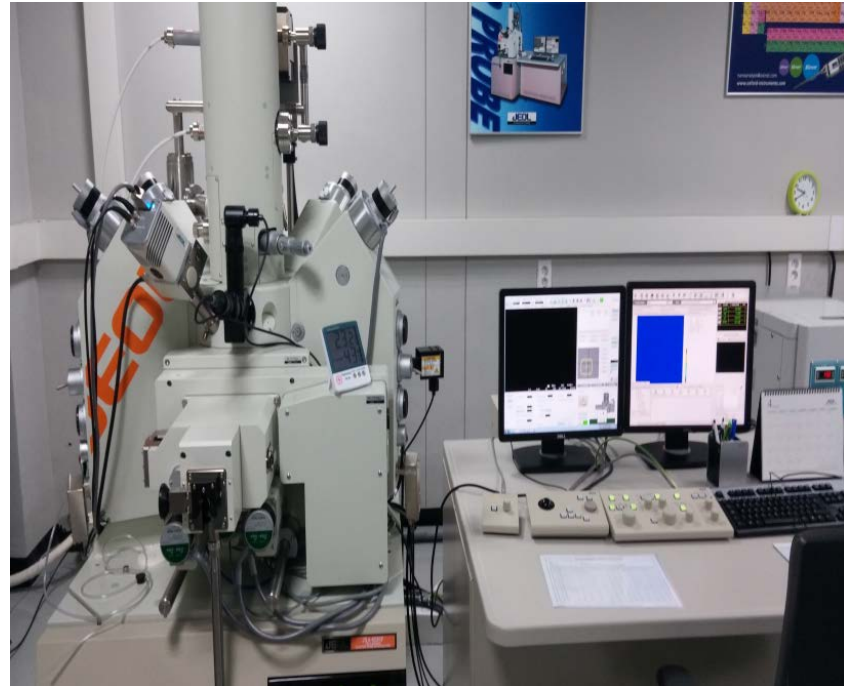
A: 마그마 내에서 결정이 성장하는 과정 중 포획됨.
마그마의 성분과 분화과정을 연구하는데 중요한
포유물.
마그마의 휘발성 물질을 저장함.

남극 중앙해령 암석의 감람석 반정 내 포유물

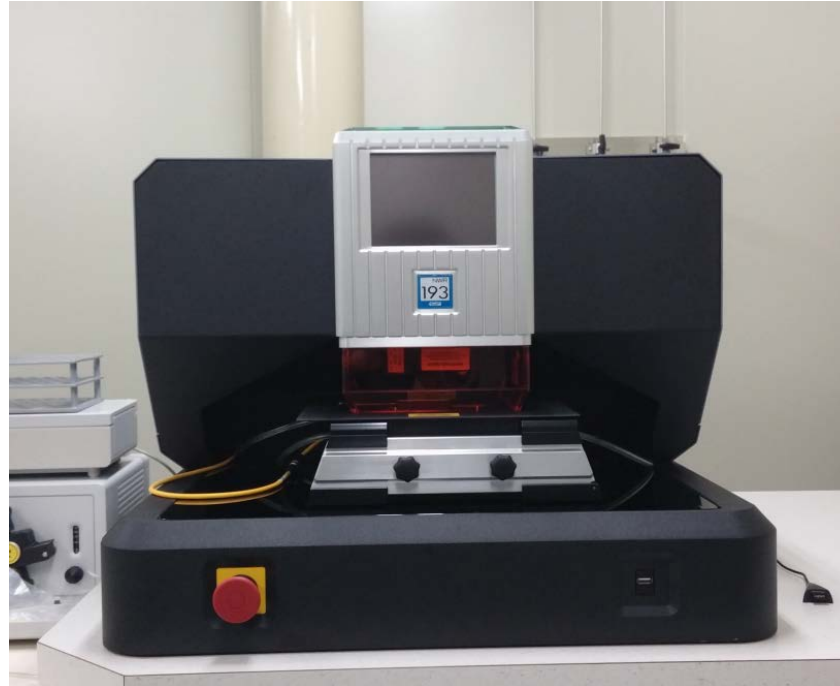
- ✓ Off-axis 해저산 현무암의 감람석 반정 중 일부에서 포유물들이 관찰됨.
- ✓ 관찰된 포유물 중 대부분은 내부적으로 결정화가 진행되었으나, 소수의 감람석 반정만은 유리질 포유물을 포함함.



Analytical methods

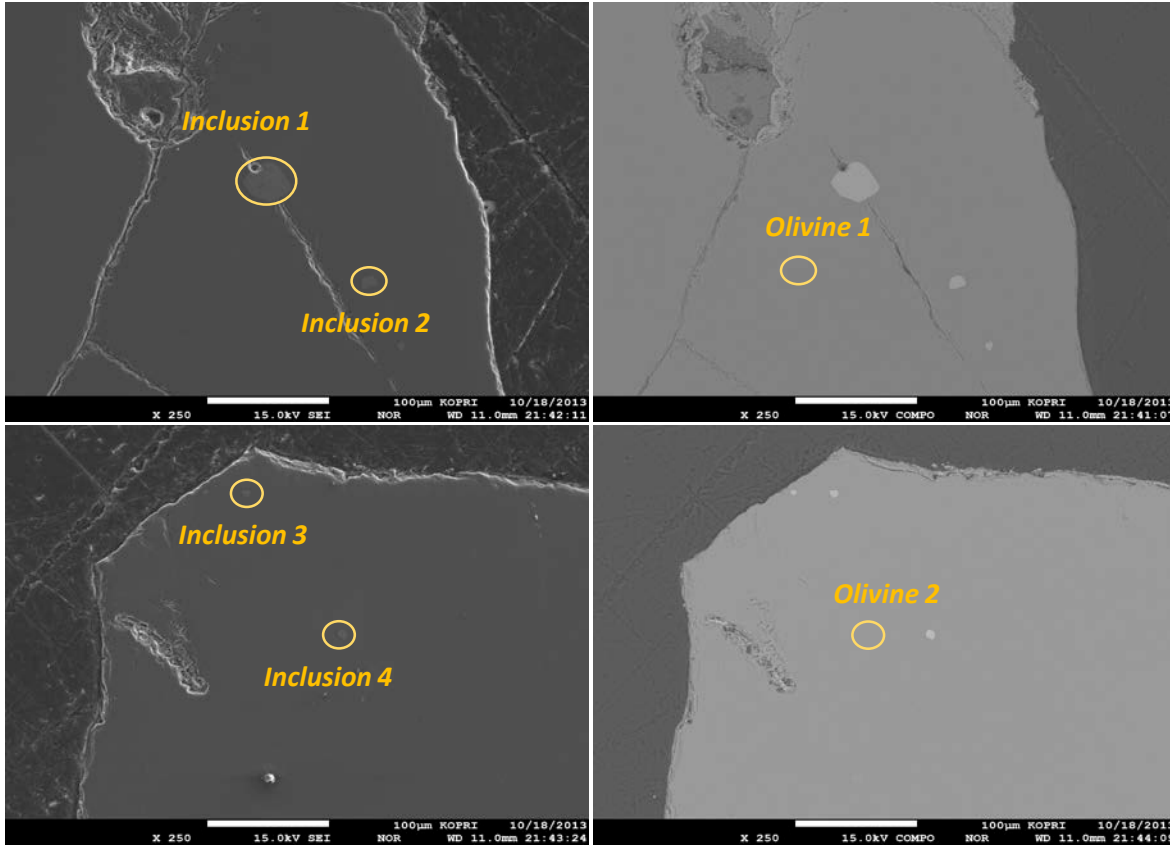


**Electron Probe Micro Analyzer
(EPMA)**



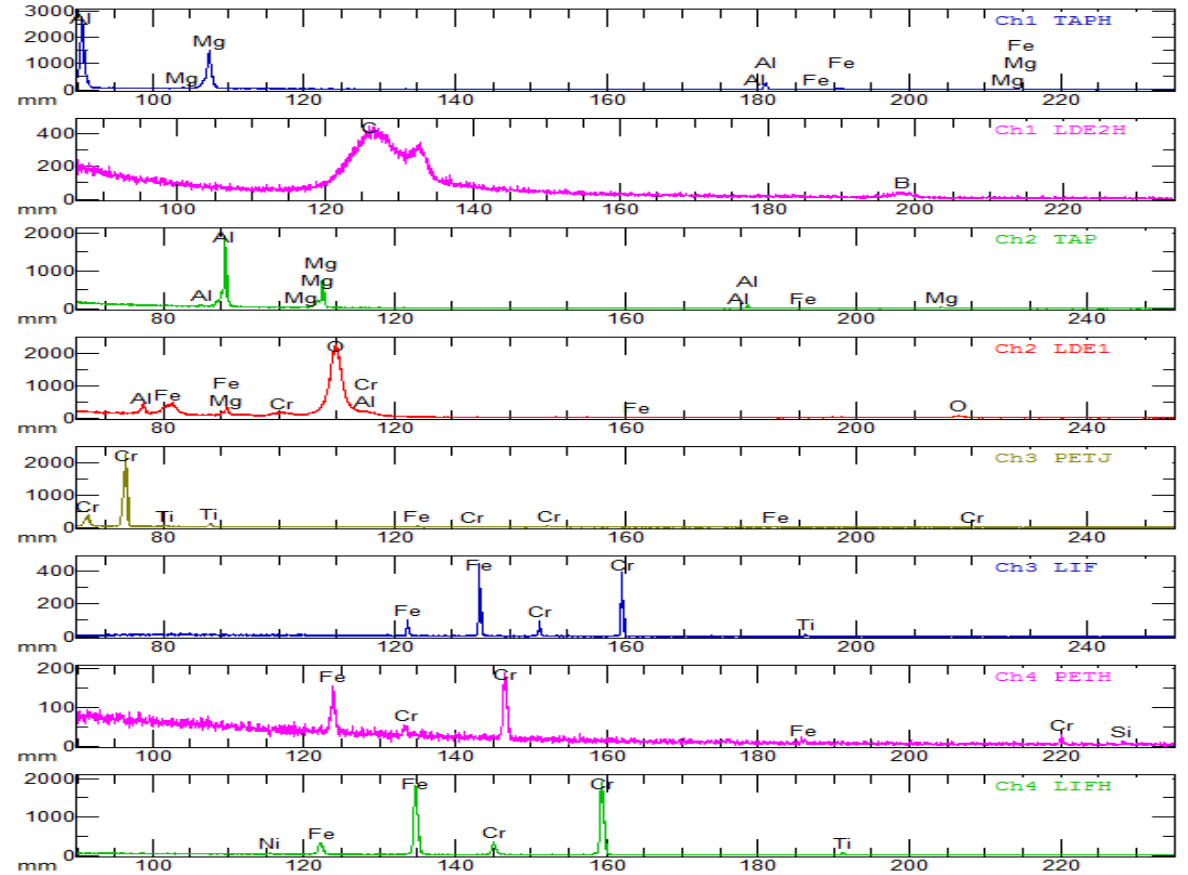
**Laser Ablation (LA)
Inductively coupled plasma
mass spectrometry (ICP-MS)**

Electron Probe Micro Analyzer (EPMA)



SE & BSE Image

감람석 반정과 inclusion의 SE & BSE 이미지



Qualitative analysis

Inclusion 1 정성분석

: Al, Mg, Si, Ti, Cr, Fe, Ni 원소 peak가 측정됨

: 이를 바탕으로 inclusions 정량 분석 실시

Electron Probe Micro Analyzer (EPMA)

Sample name	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Cr ₂ O ₃	NiO	Total
Inclsion 1	0.14	1.75	23.14	25.13	0.21	12.12	0.00	0.00	0.00	0.00	33.62	0.15	96.25
Inclsion 2	2.92	1.73	22.33	24.04	0.24	14.29	0.02	0.00	0.00	0.01	27.52	0.17	93.26
Inclsion 4	1.53	1.74	22.73	24.58	0.23	13.20	0.01	0.00	0.00	0.00	30.57	0.16	94.76
Olivine1	39.07	0.02	0.04	13.95	0.21	45.08	0.29	0.01	0.00	0.01	0.09	0.22	98.98
Olivine2	38.99	0.00	0.05	14.05	0.23	45.14	0.30	0.01	0.00	0.01	0.06	0.24	99.09

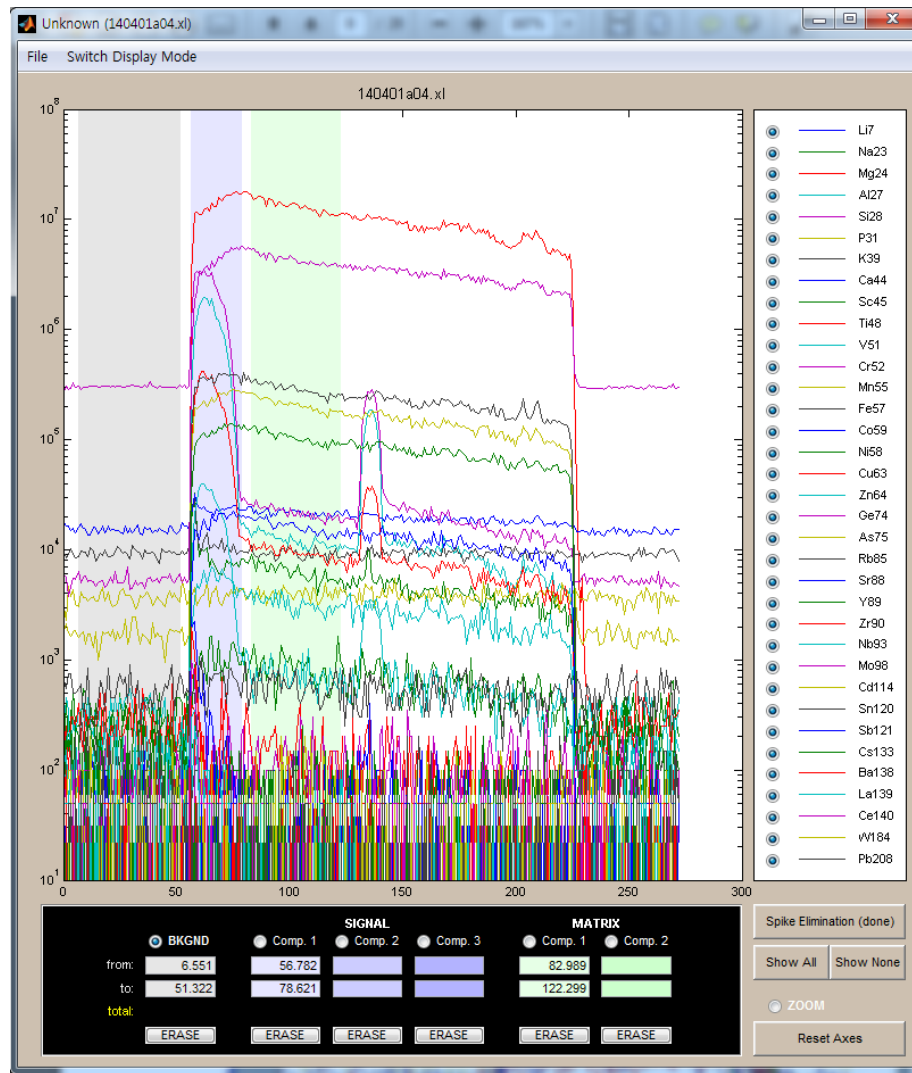
KRR3-DG03-1의 Host mineral과 inclusions의 EPMA 정량분석 표

Quantitative analysis

Inclusion과 host mineral 주원소 정량 분석 : Si, Al, Fe, Mg, Cr 원소량 차이가 매우 큼

Inclusion Fe함량이 Mg함량 보다 많은 이유 : Mg보다 더 불호정원소인 Fe 원소가 마그마에 잔류하여 inclusion 내 Fe함량을 높인 것으로 생각함

LA-ICP-MS



SILLS Program

Inclusion transient signal data
deconvolution

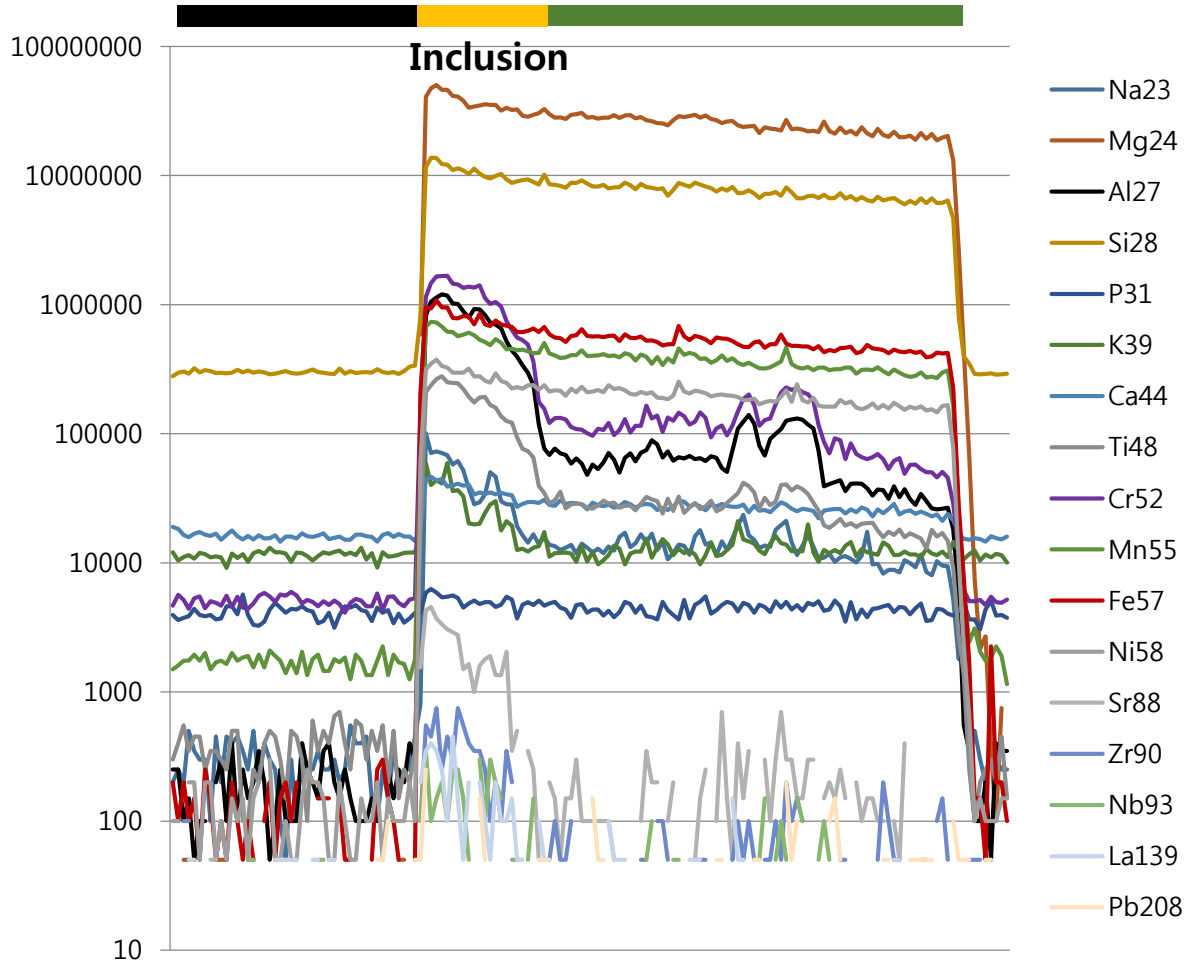
표준 물질 : NIST SRM 610

1grain , 13 inclusions 분석

LA-ICP-MS

Gas background

Host



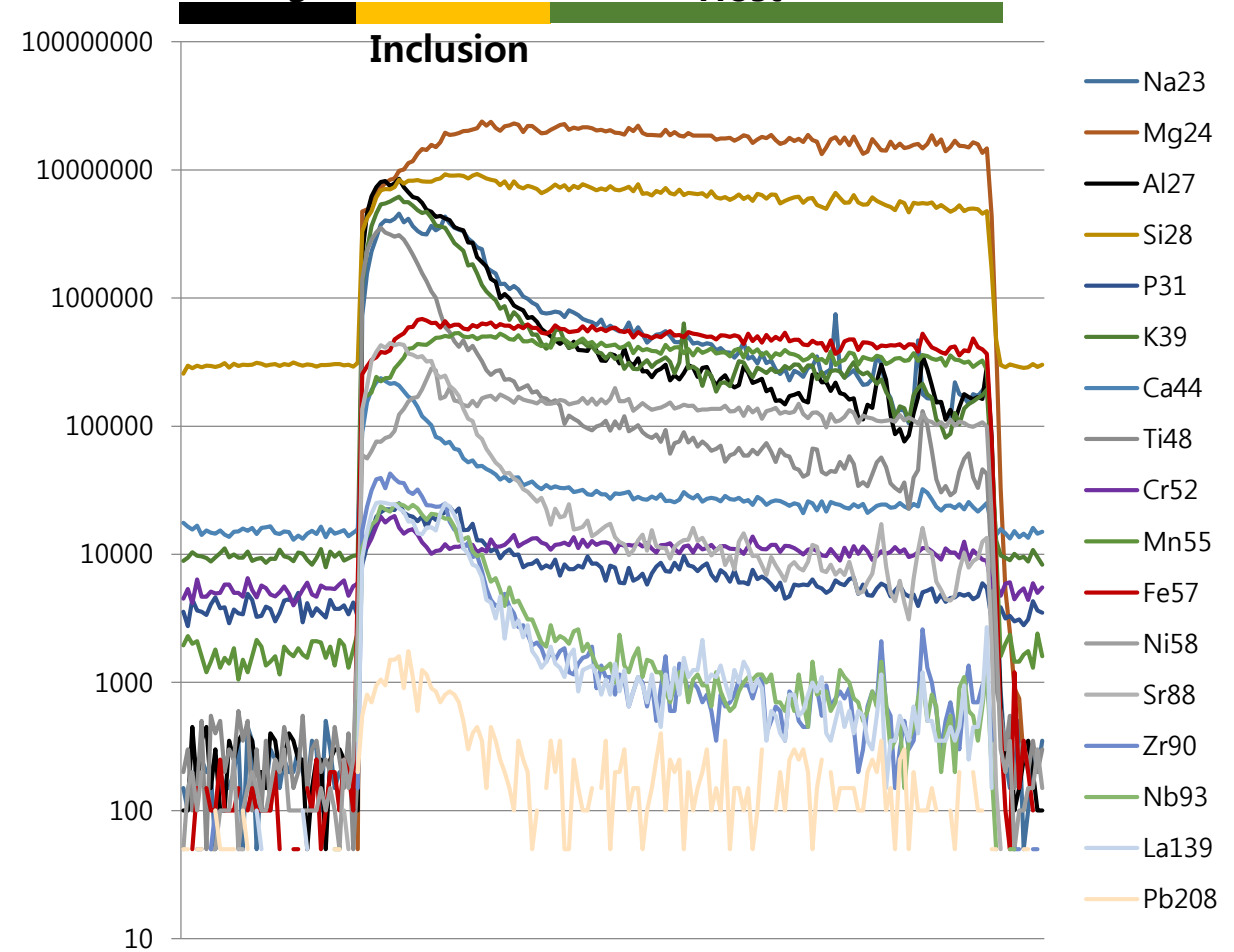
Cr-spinel(?) type

Cr 양이 많으며 이는 epma에서 분석 inclusion과 일치함.

Inclusion – 2 phase

Gas background

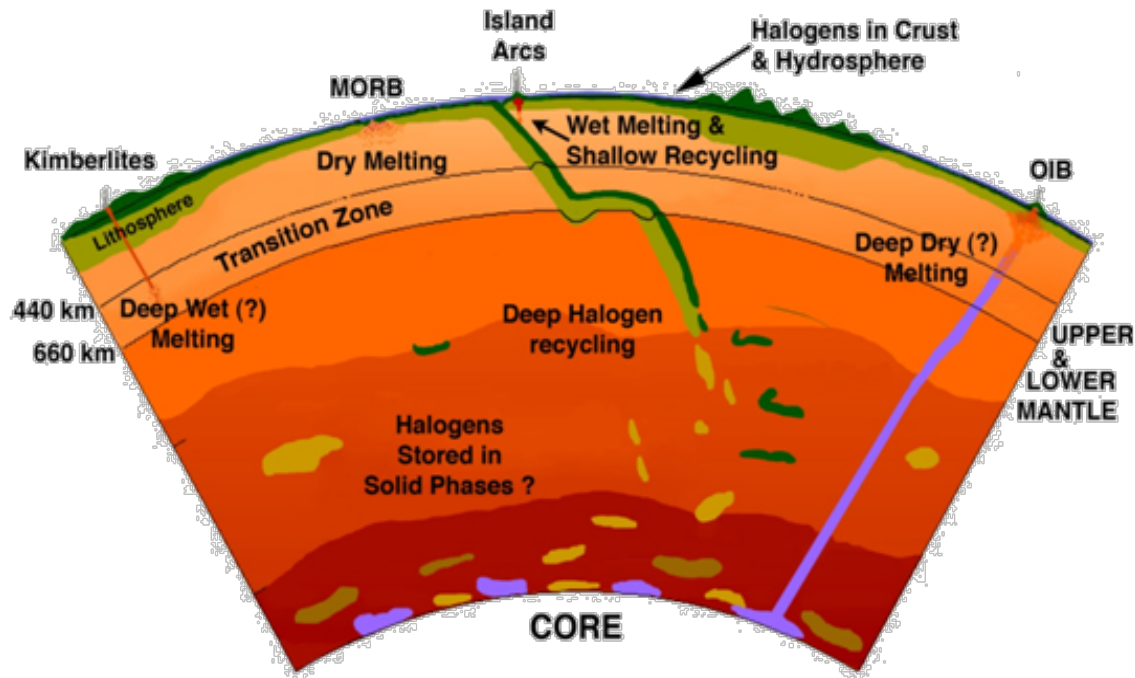
Host



Melt inclusion

특히, Cr 양이 적으며 Al와 알칼리원소가 많은 것이 관찰됨.

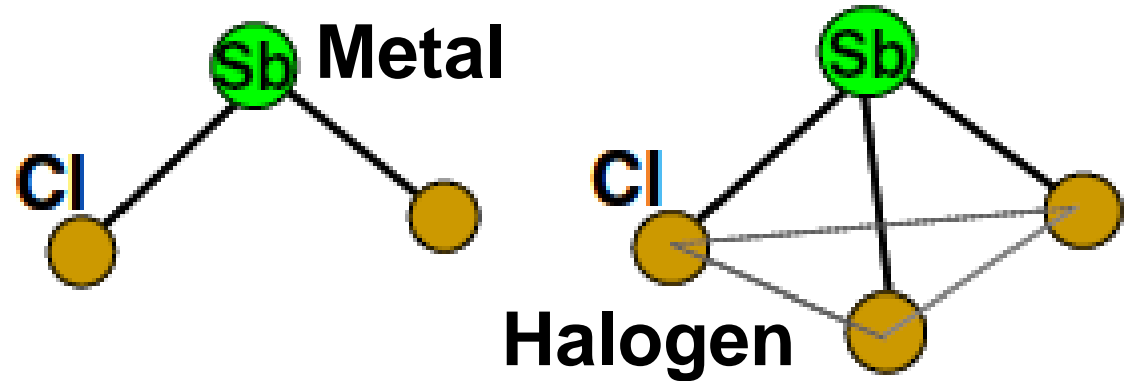
Halogen geochemistry



S. Kohn, unpublished image

Magma origin

- ❖ 암석보다는 바닷물과 해양퇴적물에 많이 포함됨
- 해양지각의 섭입을 추적하고 마그마 기원을 유추하는데 근본적인 정보 제공



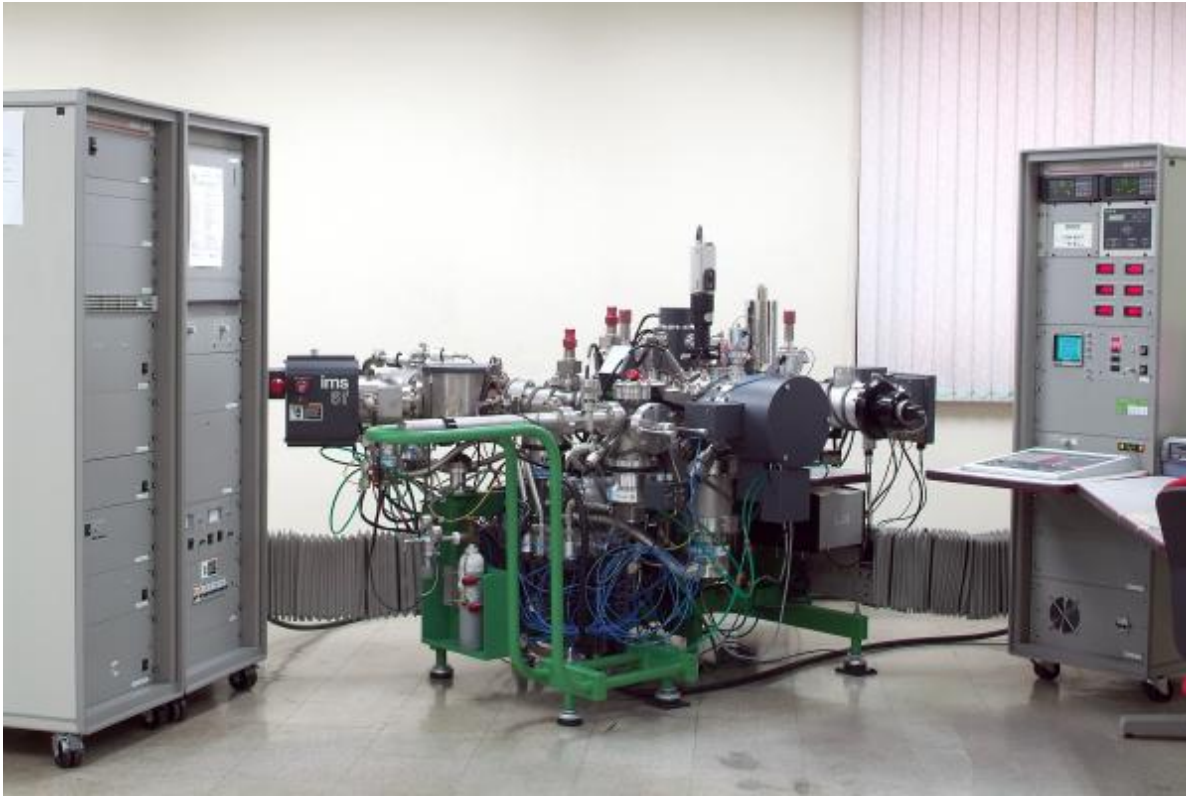
Pokrovski et al., 2006

Hydrothermal ore formation

- ❖ 열수작용에서 할로겐원소는 금속을 이동시킴
- 1. 화산암석, glass, 및 melt inclusion 내의 할로겐 원소 분석은 마그마의 광상 형성의을 지시자.
- 2. 열수기원의 광물 형성과정과 광상 탐사에 적용

Standard Reference Material (SRM) for halogens

Halogen (F, Cl, Br, I +S) standard 제작하는 이유



Cameca 6F SIMS instrument
(기초과학지원연구원 부산센터)

- ✓ 할로겐 원소 분석을 위해서 SIMS (Secondary Ion Mass Spectroscopy) 테크닉을 사용
- ✓ SIMS 분석을 위한 외부표준물질을 제작

Standard Reference Material (SRM) for halogens

Halogen standard 제작과정

현무암 시료
JB-1b

첨가물
KI, NaI, CaCl₂
KCl, FeS₂, CaF₂
Fe₃O₄, LiBr

Flux
Li₂B₄O₇
Lithium tetraborate

혼합



XRF 전처리 장비
“Bead machine”

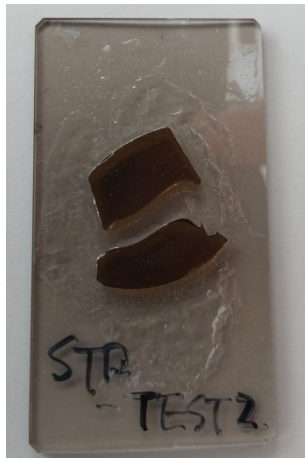
Standard Reference Material (SRM) for halogens

제작된 SRM - 함량비

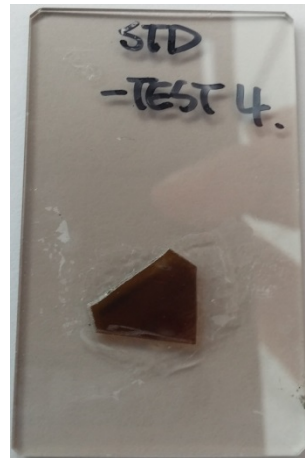
STD1



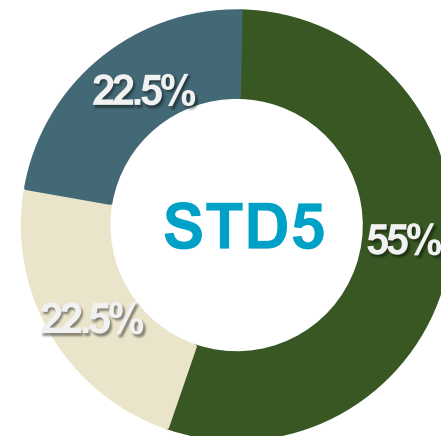
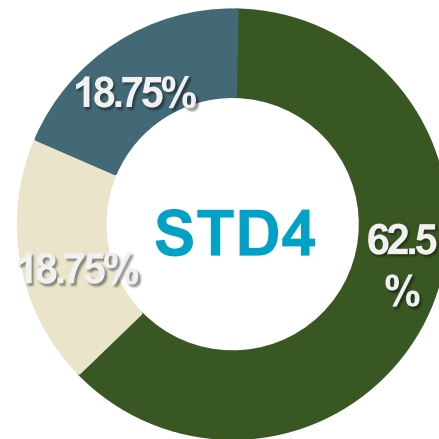
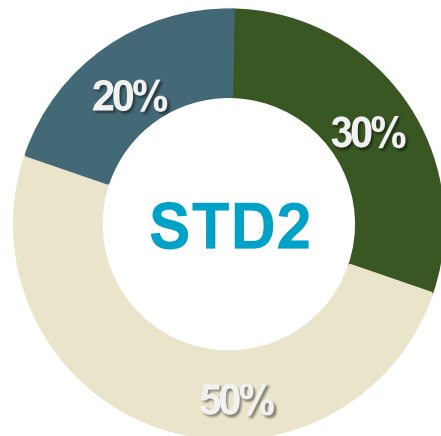
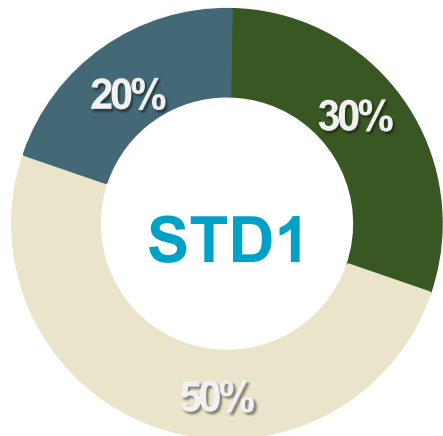
STD2



STD4



STD5

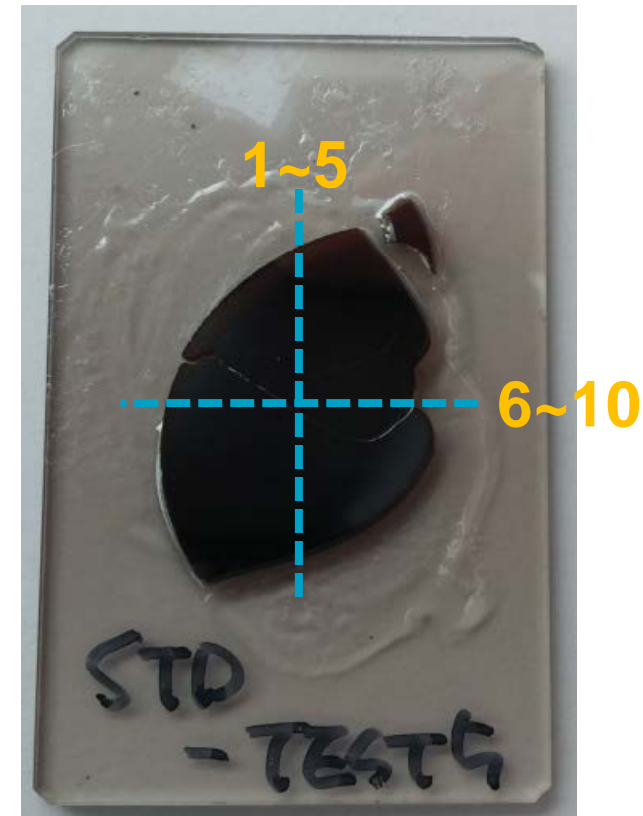


Standard Reference Material (SRM) for halogens

Analytical method



Electron Probe Micro Analyzer
(EPMA)



Ex) 각 STD - 10 point

Standard Reference Material (SRM) for halogens

균질도 TEST

STD1

No.	F	Al ₂ O ₃	MgO	Na ₂ O	SiO ₂	FeO	SO ₃	Br	CuO	MnO	TiO ₂	Cl	I	K ₂ O	P ₂ O ₅	CaO	Li ₂ O	B ₂ O ₃	Total
1	0.357	4.413	2.668	1.138	15.518	3.413	0.195	0.039	0.006	0	0.406	0.329	0.042	1.681	0.045	6.945	8.8	41.15	86.914
2	0.05	4.367	2.682	1.148	15.419	5.982	0.199	0	0	0	0.358	0.335	0.011	1.742	0.088	7.095	8.8	41.15	89.328
3	0.213	4.43	2.681	1.161	15.677	5.747	0.212	0.351	0.013	0	0.384	0.393	0.057	1.739	0.096	7.049	8.8	41.15	89.935
4	0.287	4.285	2.659	1.26	15.705	6.203	0.194	0.506	0	0	0.376	0.328	0.018	1.751	0.092	7.037	8.8	41.15	90.404
5	0.505	4.362	2.633	1.127	15.361	4.364	0.193	0	0.051	0	0.333	0.399	0.011	1.746	0.072	7.004	8.8	41.15	87.807
6	0.31	4.31	2.673	1.143	15.817	7.582	0.184	0.194	0	0	0.359	0.339	0.012	1.738	0.102	6.926	8.8	41.15	91.411
7	0.25	4.319	2.67	1.159	15.346	6.21	0.228	0	0	0	0.36	0.362	0	1.703	0.043	6.988	8.8	41.15	89.401
8	0.338	4.457	2.681	1.279	15.687	5.987	0.184	0	0.006	0	0.368	0.36	0.037	1.633	0.108	7.084	8.8	41.15	89.934
9	0.491	4.528	2.783	0.734	15.981	8.952	0.146	0	0.013	0	0.362	0.356	0.032	1.551	0.065	6.908	8.8	41.15	92.563
10	0.379	4.425	2.588	1.219	15.768	9.358	0.192	0.349	0	0	0.341	0.374	0.013	1.674	0.08	6.959	8.8	41.15	93.389
Average	0.32	4.39	2.67	1.14	15.63	6.38	0.19	0.14	0.01	0.00	0.36	0.36	0.02	1.70	0.08	7.00	8.80	41.15	90.11
STDEV	0.13	0.08	0.05	0.15	0.21	1.84	0.02	0.19	0.02	0.00	0.02	0.03	0.02	0.06	0.02	0.07	0.00	0.00	1.98
ERROR	41.80	1.71	1.82	13.30	1.35	28.89	10.94	133.70	176.42	0.00	5.70	7.11	76.46	3.78	28.60	0.94	0.00	0.00	2.20

STD2

No.	F	Al ₂ O ₃	MgO	Na ₂ O	SiO ₂	FeO	SO ₃	Br	CuO	MnO	TiO ₂	Cl	I	K ₂ O	P ₂ O ₅	CaO	Li ₂ O	B ₂ O ₃	Total
1	0.306	4.487	2.816	1.791	15.676	10.08	0.344	0	0.032	0	0.346	0.443	0.019	3.465	0.084	7.691	8.8	41.15	97.3
2	0.539	4.411	2.704	1.739	15.869	9.876	0.402	0.193	0.013	0	0.336	0.434	0.078	3.357	0.082	7.654	8.8	41.15	97.288
3	0.568	4.599	2.662	1.668	15.604	4.842	0.288	0.427	0.006	0	0.409	0.44	0.023	3.478	0.094	7.693	8.8	41.15	92.369
4	0.663	4.396	2.677	1.847	15.257	8.745	0.31	0.271	0	0	0.298	0.353	0	3.666	0.086	7.626	8.8	41.15	95.759
5	0.508	4.46	2.726	1.972	15.773	7.843	0.251	0	0	0	0.315	0.444	0.015	3.352	0.07	7.656	8.8	41.15	95.02
6	0.534	4.527	2.787	1.767	15.646	7.386	0.312	0	0.109	0	0.321	0.442	0.033	3.444	0.09	7.597	8.8	41.15	94.618
7	0.249	4.645	2.551	1.77	15.702	7.837	0.319	0	0	0	0.393	0.462	0	3.598	0.096	7.692	8.8	41.15	95.055
8	0.485	4.818	2.795	1.249	16.16	11.407	0.281	0.116	0.025	0	0.333	0.483	0.019	2.878	0.112	7.701	8.8	41.15	98.486
9	0.427	4.513	2.688	1.813	15.499	5.776	0.349	0	0.07	0	0.346	0.431	0.051	3.384	0.091	7.683	8.8	41.15	92.791
10	0.35	4.524	2.683	1.836	15.664	12.238	0.327	0.346	0	0	0.4	0.456	0.023	3.39	0.08	7.589	8.8	41.15	99.57
Average	0.46	4.54	2.71	1.75	15.69	8.60	0.32	0.14	0.03	0.00	0.35	0.44	0.03	3.40	0.09	7.66	8.80	41.15	95.83
STDEV	0.13	0.12	0.08	0.19	0.23	2.35	0.04	0.16	0.04	0.00	0.04	0.03	0.02	0.21	0.01	0.04	0.00	0.00	2.34
ERROR	27.78	2.74	2.87	10.97	1.49	27.31	13.09	121.48	143.98	0.00	10.92	7.71	90.01	6.19	12.66	0.54	0.00	0.00	2.44

Standard Reference Material (SRM) for halogens

균질도 TEST

STD4

No.	F	Al ₂ O ₃	MgO	Na ₂ O	SiO ₂	FeO	SO ₃	Br	CuO	MnO	TiO ₂	Cl	I	K ₂ O	P ₂ O ₅	CaO	Li ₂ O	B ₂ O ₃	Total
1	0.389	10.209	6.131	2.193	35.389	12.408	0.228	1.028	0	0	0.77	0.385	0	4.233	0.144	10.946	3.3	15.431	102.83
2	0.458	10.103	5.863	2.332	35.229	8.374	0.301	0.115	0.051	0	0.786	0.402	0.062	4.185	0.152	10.984	3.3	15.431	97.828
3	0.316	9.572	5.698	2.291	34.863	4.713	0.245	0.845	0.032	0	0.772	0.369	0.012	4.235	0.191	10.995	3.3	15.431	93.578
4	0.034	10.105	5.902	2.405	35.065	8.335	0.246	0.306	0	0	0.794	0.245	0.058	4.185	0.22	10.916	3.3	15.431	97.443
5	0.265	10.008	5.878	2.357	34.895	7.945	0.222	0	0.102	0	0.821	0.392	0.055	4.243	0.18	10.96	3.3	15.431	96.851
6	0	10.082	5.978	2.16	34.981	7.727	0.193	0	0.032	0	0.864	0.025	0.024	4.02	0.189	10.993	3.3	15.431	95.991
7	0.045	10.156	6.124	2.443	35.455	13.245	0.231	0	0	0	0.809	0.416	0.046	4.276	0.179	11.045	3.3	15.431	103.085
8	0.432	10.001	5.878	2.438	34.82	9.41	0.257	0	0.032	0	0.799	0.382	0.049	4.173	0.163	10.827	3.3	15.431	98.121
9	0.273	10.068	5.908	2.284	35.188	9.179	0.214	0.612	0.019	0	0.786	0.24	0.059	4.214	0.123	11.101	3.3	15.431	98.765
10	0.546	10.16	6.185	2.416	35.334	12.679	0.245	0	0	0	0.75	0.373	0.051	4.169	0.156	10.921	3.3	15.431	102.399
Average	0.28	10.05	5.95	2.33	35.12	9.40	0.24	0.29	0.03	0.00	0.80	0.32	0.04	4.19	0.17	10.97	3.30	15.43	98.69
STDEV	0.19	0.18	0.15	0.10	0.23	2.66	0.03	0.40	0.03	0.00	0.03	0.12	0.02	0.07	0.03	0.07	0.00	0.00	3.16
ERROR	69.74	1.78	2.53	4.28	0.65	28.30	12.12	136.10	119.66	0.00	3.98	37.70	52.22	1.67	16.36	0.68	0.00	0.00	3.20

STD5

No.	F	Al ₂ O ₃	MgO	Na ₂ O	SiO ₂	FeO	SO ₃	Br	CuO	MnO	TiO ₂	Cl	I	K ₂ O	P ₂ O ₅	CaO	Li ₂ O	B ₂ O ₃	Total
1	0.056	9.285	5.448	2.248	32.763	15.117	0.145	0.266	0	0	0.676	0.374	0.033	3.62	0.151	11.243	3.872	18.106	103.266
2	0.395	9.326	5.643	2.306	32.554	11.722	0.128	0.686	0	0	0.764	0.348	0.041	3.63	0.151	11.318	3.872	18.106	100.673
3	0.685	9.093	5.561	2.265	32.115	7.397	0.152	0	0.013	0	0.678	0.334	0	3.701	0.184	11.246	3.872	18.106	95.039
4	0.263	9.051	5.522	2.206	32.074	10.514	0.112	0.115	0.051	0	0.76	0.353	0	3.588	0.151	11.197	3.872	18.106	97.732
5	0.613	9.162	5.41	2.273	31.995	8.034	0.132	0	0.044	0	0.745	0.366	0.022	3.623	0.119	11.145	3.872	18.106	95.319
6	0.528	9.157	5.335	2.208	32.46	9.514	0.091	0.038	0	0	0.745	0.355	0.032	3.688	0.184	11.216	3.872	18.106	97.221
7	0.263	9.203	5.535	2.299	32.332	9.87	0.116	0.612	0.057	0	0.693	0.334	0.03	3.642	0.172	11.327	3.872	18.106	98.214
8	0.193	9.175	5.4	2.33	32.369	11.748	0.13	0	0	0	0.732	0.335	0.03	3.636	0.174	11.243	3.872	18.106	99.314
9	0.431	9.272	5.602	2.264	32.167	11.346	0.159	0.382	0.013	0	0.832	0.303	0.055	3.659	0.107	11.221	3.872	18.106	99.501
10	0.329	8.947	5.596	2.284	32.348	11.773	0.14	0	0	0	0.809	0.249	0.017	3.43	0.155	11.458	3.872	18.106	99.317
Average	0.38	9.17	5.51	2.27	32.32	10.70	0.13	0.21	0.02	0.00	0.74	0.34	0.03	3.62	0.15	11.26	3.87	18.11	98.56
STDEV	0.19	0.12	0.10	0.04	0.24	2.20	0.02	0.27	0.02	0.00	0.05	0.04	0.02	0.08	0.03	0.09	0.00	0.00	2.45
ERROR	51.88	1.25	1.85	1.76	0.73	20.51	15.53	126.64	131.83	0.00	7.00	10.80	65.77	2.07	16.65	0.77	0.00	0.00	2.49

Standard Reference Material (SRM) for halogens

추후 연구 방향

1. Fe함량에 의해 total의 양이 변동
: Fe 첨가하였던 자철석과 황철석의 비율을 줄이거나 안 넣는 할로겐 SRM 제작 예정
2. Flux - Lithium tetraborate($\text{Li}_2\text{B}_4\text{O}_7$) 의 Li, B 경우 EPMA를 측정이 어려움
: 이번 실험에서는 원자량으로 고정하였기 때문에 오차 가능성이 큼

Conclusion



최종목표: 남극 중앙해령 마그마 성인

1. 멜트포유물 조성에 대한 기초 연구 착수

2. 할로겐원소의 정량화를 위하여 균질한 할로겐 외부표준물질을 제작 중

추후 연구를 토대로 남극 중앙해령의 더 자세한 마그마 성인과 맨틀 프로세스를 연구할 예정

Thank you

