



# 남극 중앙해령(AAR) 멜트포유물 및 휘발성 원소 기초 연구

인하대학교 양윤석

# CONTENT

**1**

**Introduce**

**2**

**Melt Inclusion  
Test**

**3**

**Standard Reference  
Material (SRM)  
for halogens**

**4**

**Conclusion**

# Introduce

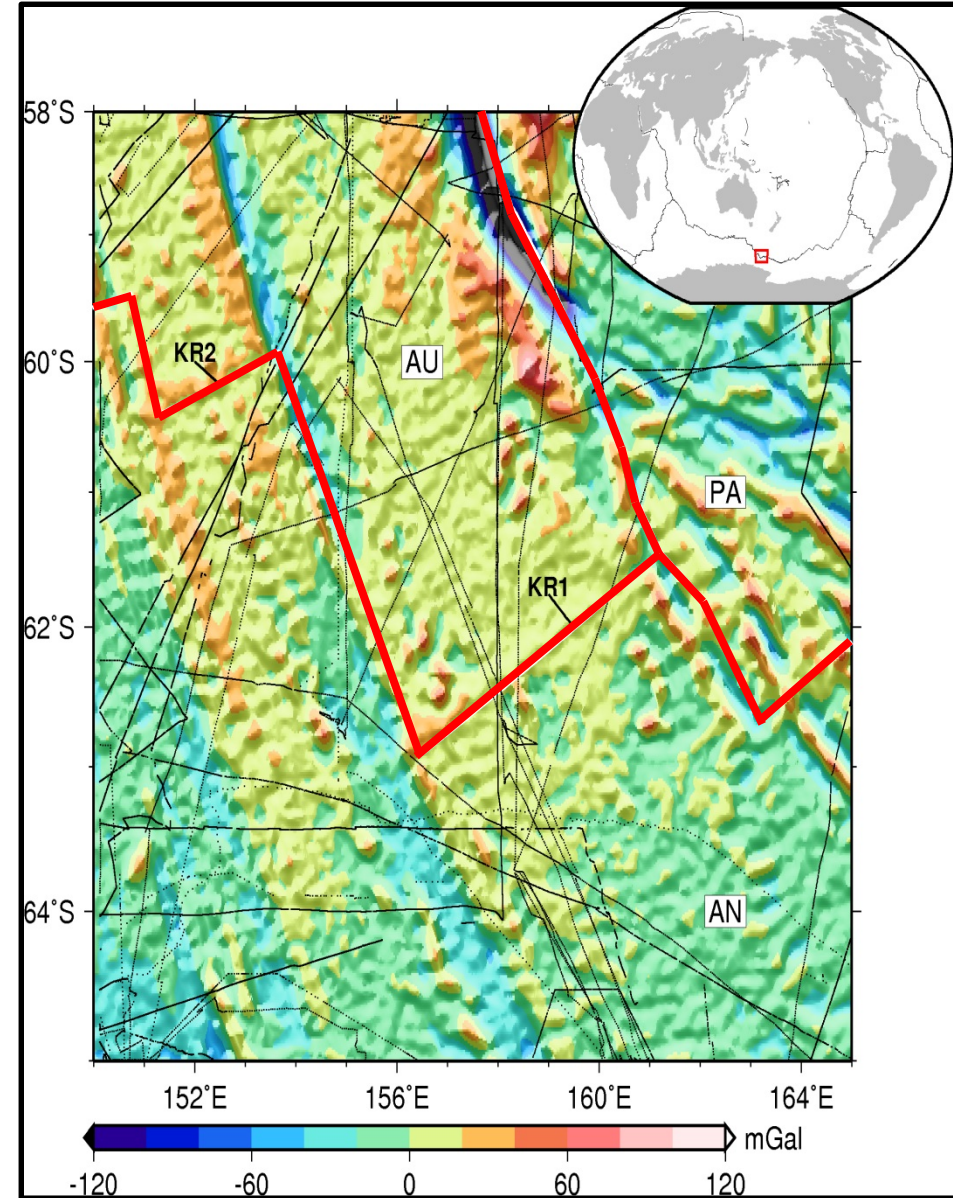


남극 중앙해령 (Australian-Antarctic Ridge: AAR(KR1, KR2))

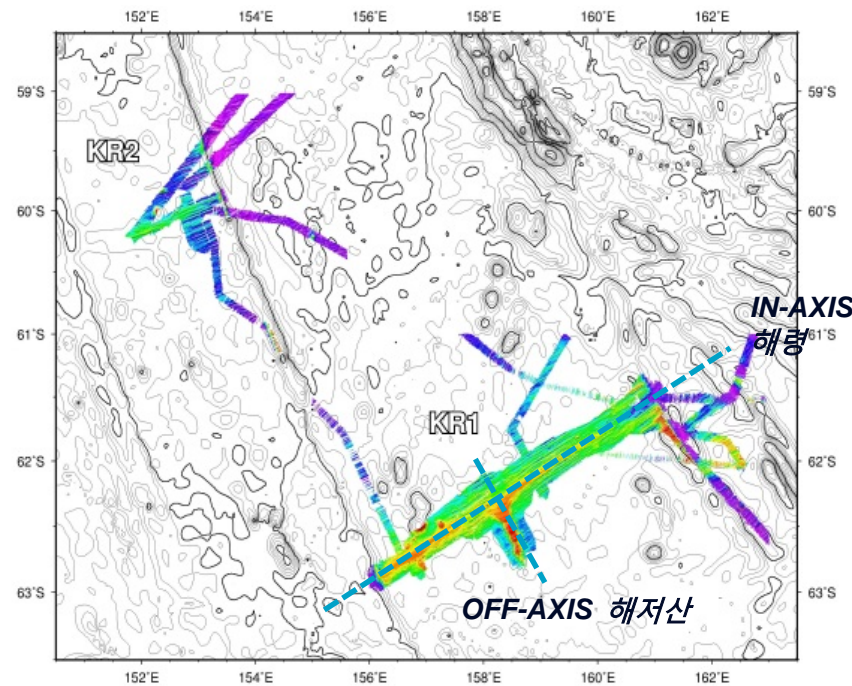
인도-호주판 중앙해령 중 가장 동쪽에 위치  
(62°51.2790S, 158°36.9480E)



쇄빙연구선 : 아라온



# Introduce



탐사 및 실험 진행 방향

# Introduce

## 남극 중앙해령 암석 시료 (Pillow basalt)

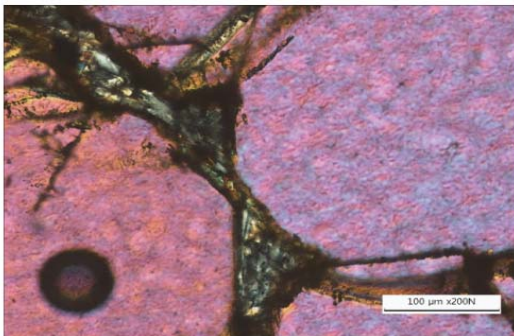
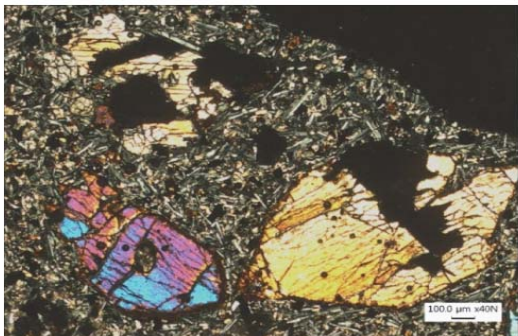
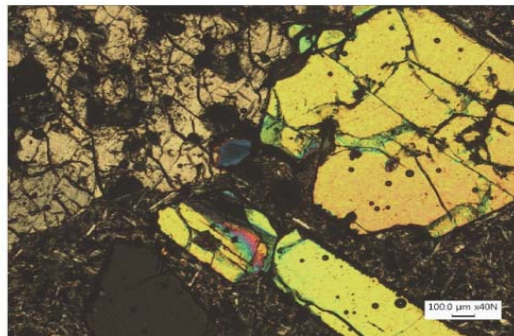
세립질이며 반자형 또는 타형의 감람석, 사장석, 휘석 반정이 관찰됨

### Off-axis 해저산 암석 시료

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



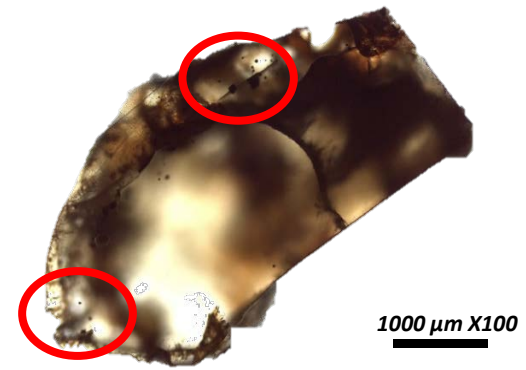
Olivine  
Plagioclase  
Pyroxene



## 박편관찰

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

# Melt inclusion test



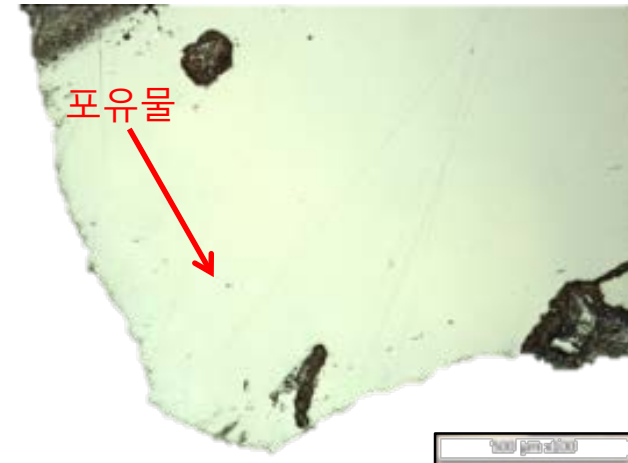
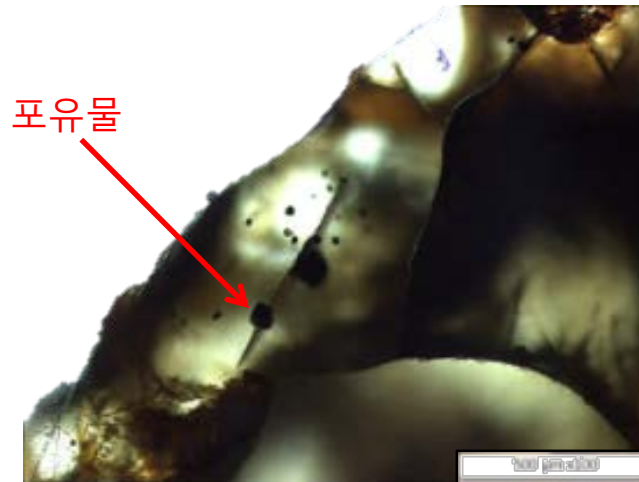
Off-axis에서 채취한 KRR3-DG03-1  
현무암의 감람석 반정 내 포유물

## Melt inclusion(멜트포유물) 이란?

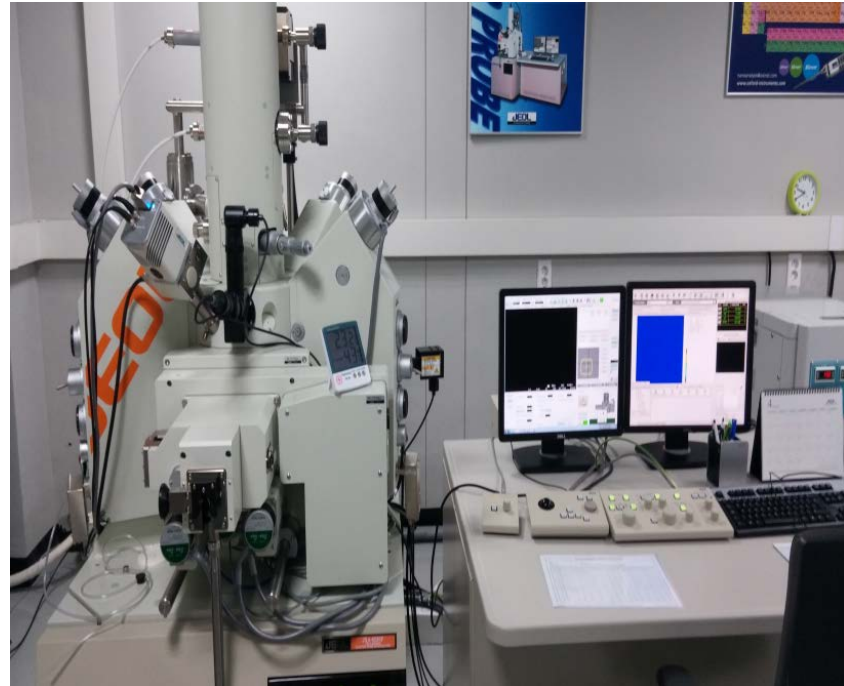
A: 마그마 내에서 결정이 성장하는 과정 중 포획됨.  
마그마의 성분과 분화과정을 연구하는데 중요한  
포유물.  
마그마의 휘발성 물질을 저장함.

## 남극 중앙해령 암석의 감람석 반정 내 포유물

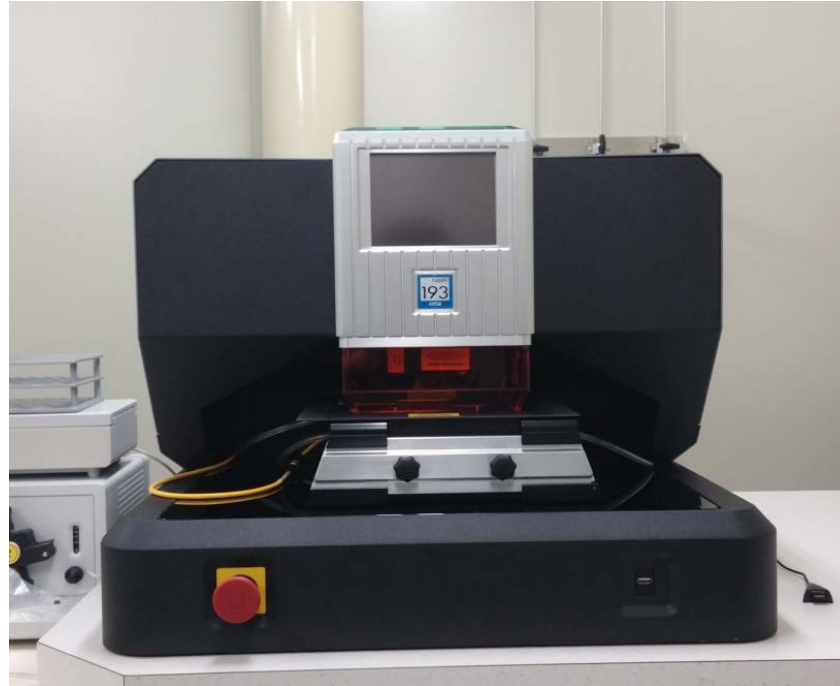
- ✓ Off-axis 해저산 현무암의 감람석 반정 중 일부에서 포유물들이 관찰됨.
- ✓ 관찰된 포유물 중 대부분은 내부적으로 결정화가 진행되었으나, 소수의 감람석 반정만은 유리질 포유물을 포함함.



# Analytical methods

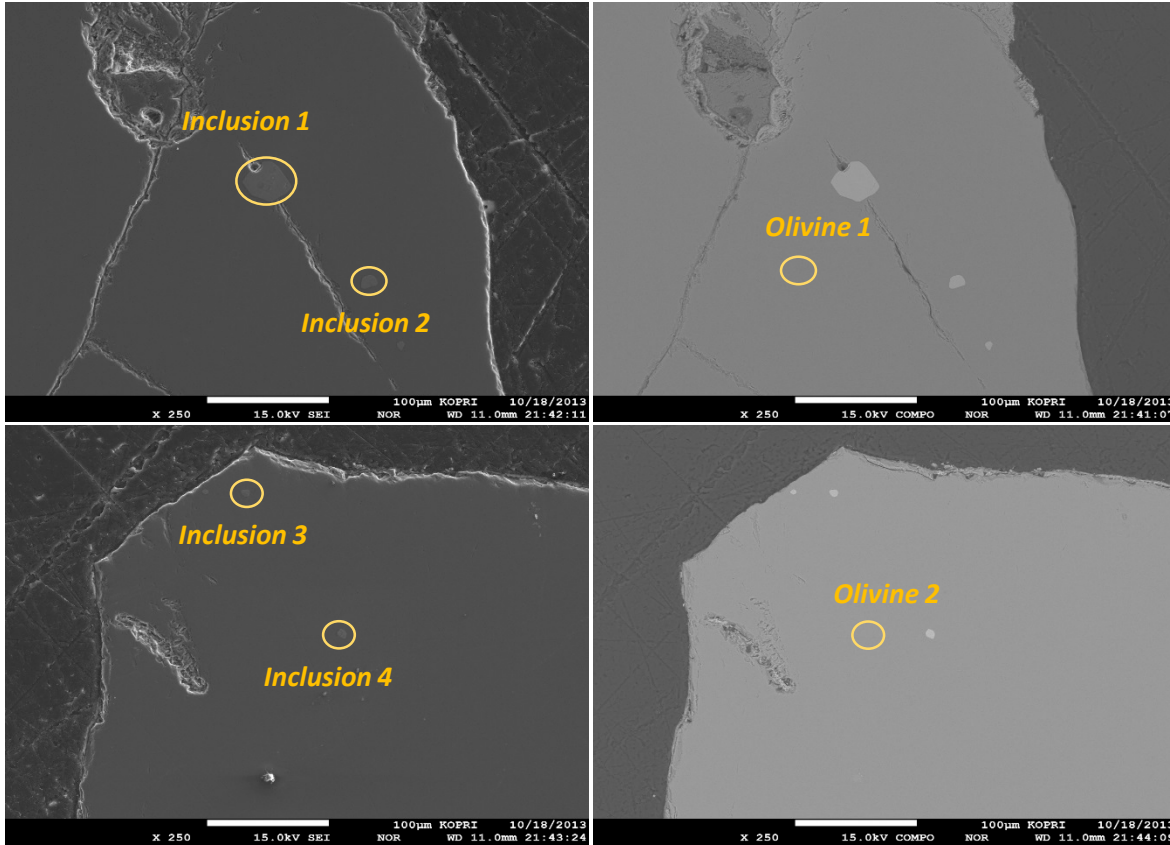


**Electron Probe Micro Analyzer  
(EPMA)**



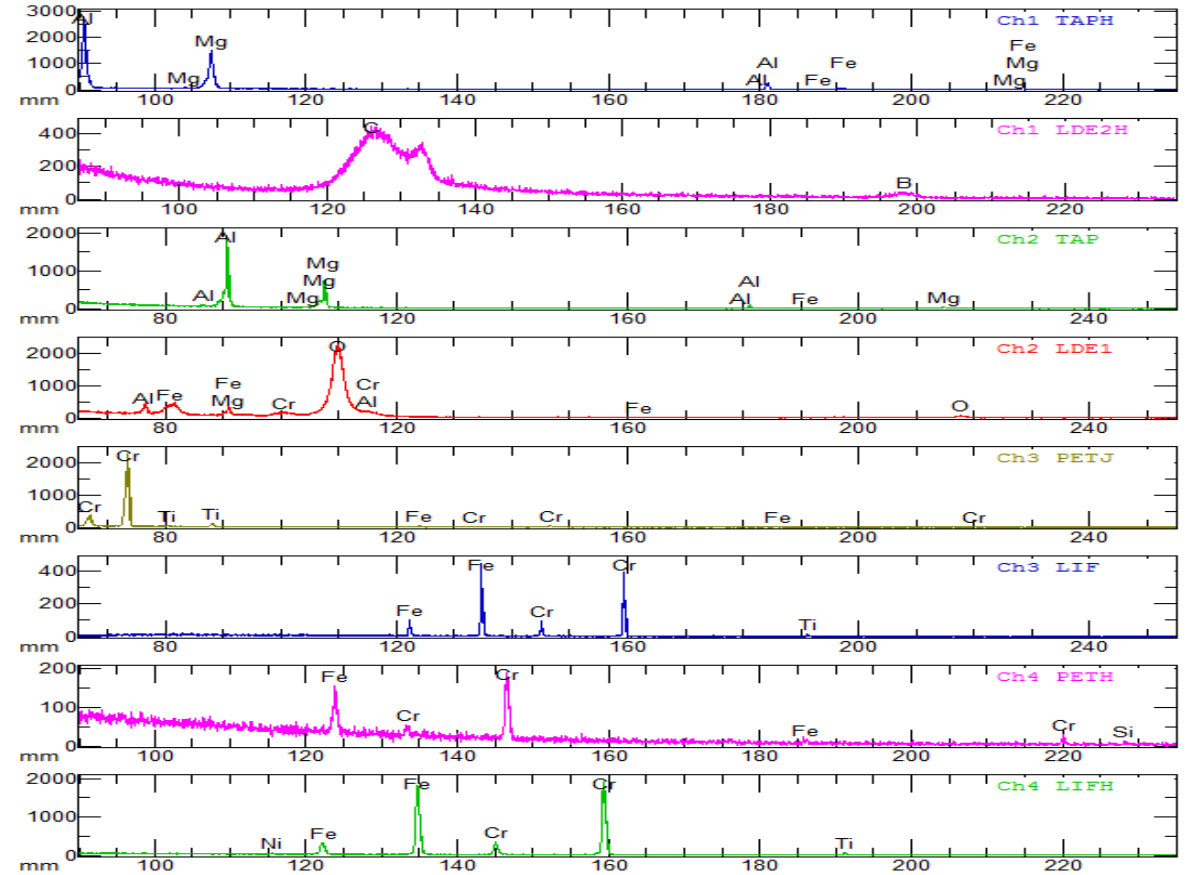
**Laser Ablation (LA)  
Inductively coupled plasma  
mass spectrometry (ICP-MS)**

# 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 <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	Cr <sub>2</sub> O <sub>3</sub>	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

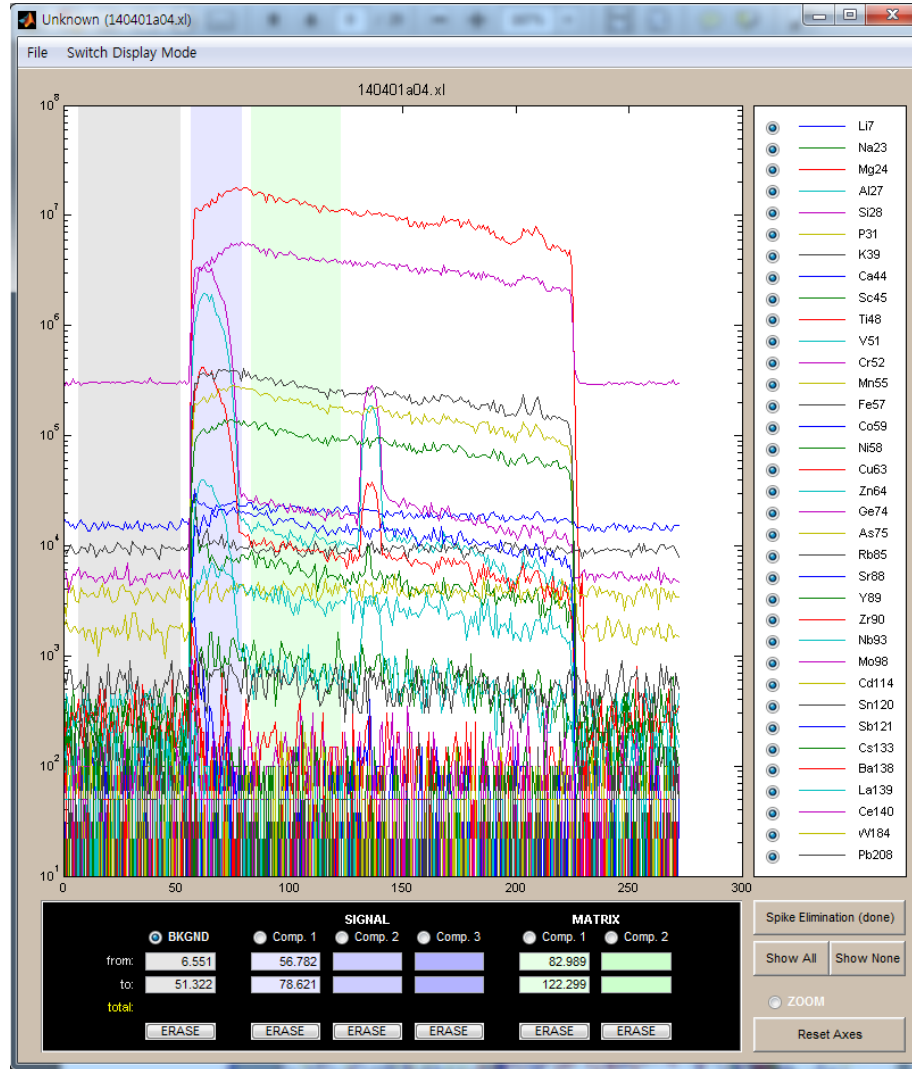
*KRR3-DG03-1의 Host mineral과 inclusions의 EPMA 정량분석 표*

## 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

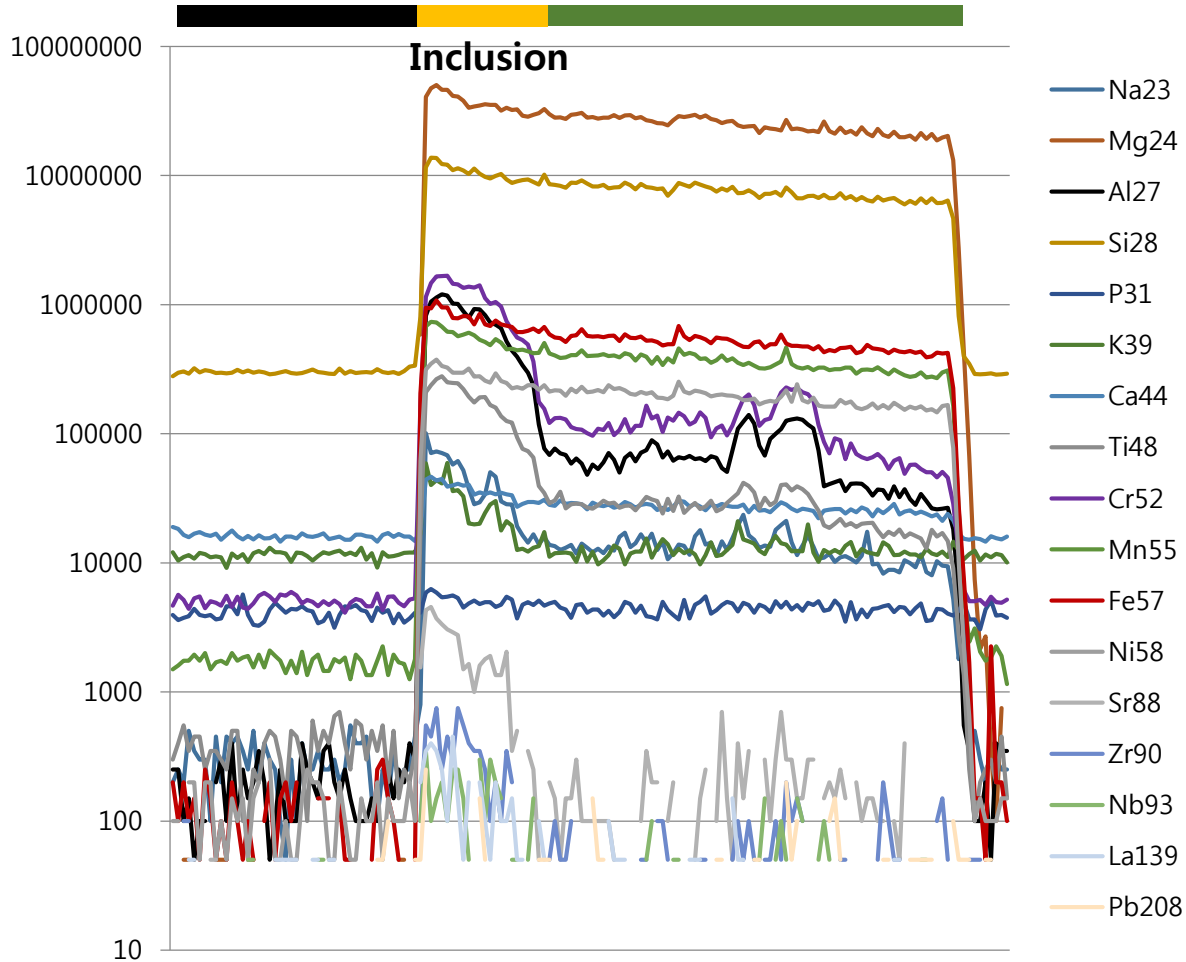
표준 물질 : NIST SRM 610

1grain , 13 inclusions 분석

# LA-ICP-MS

Gas background

Host



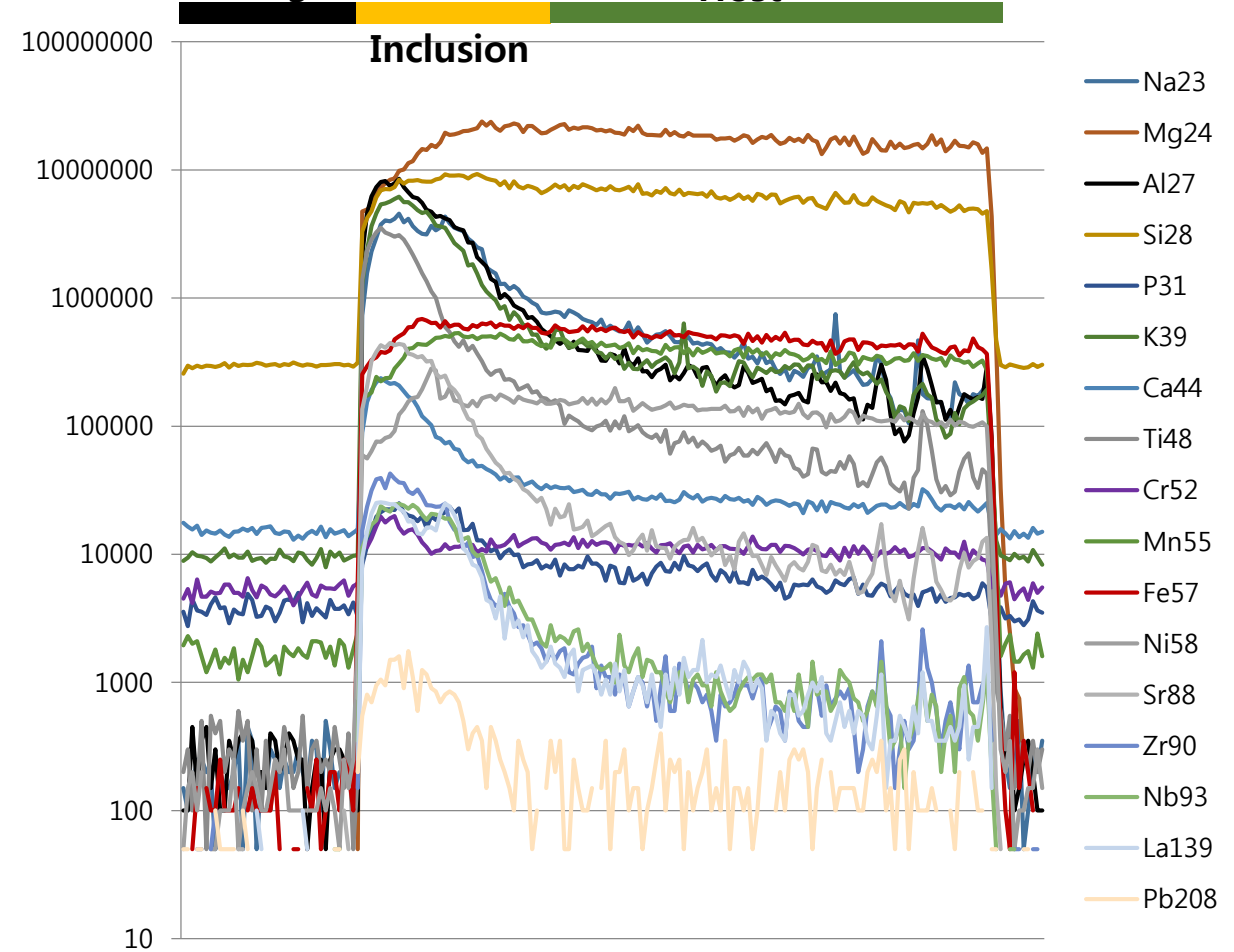
## Cr-spinel(?) type

Cr 양이 많으며 이는 epma에서 분석 inclusion과 일치함.

# Inclusion – 2 phase

Gas background

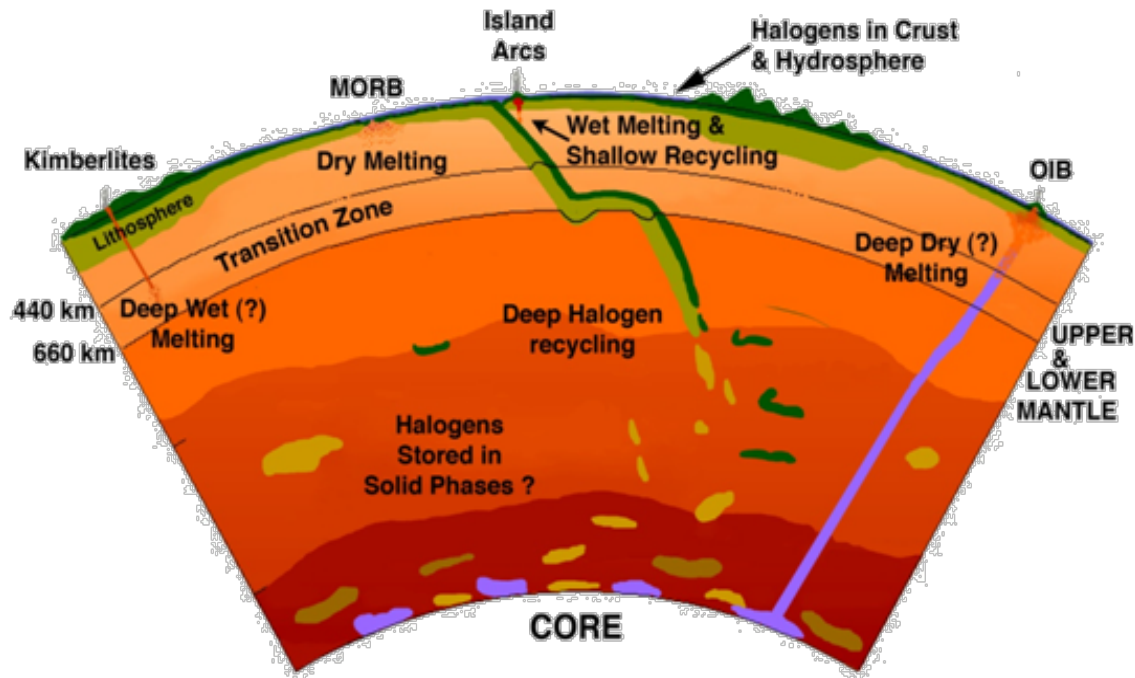
Host



## Melt inclusion

특히, Cr 양이 적으며 Al와 알칼리원소가 많은 것이 관찰됨.

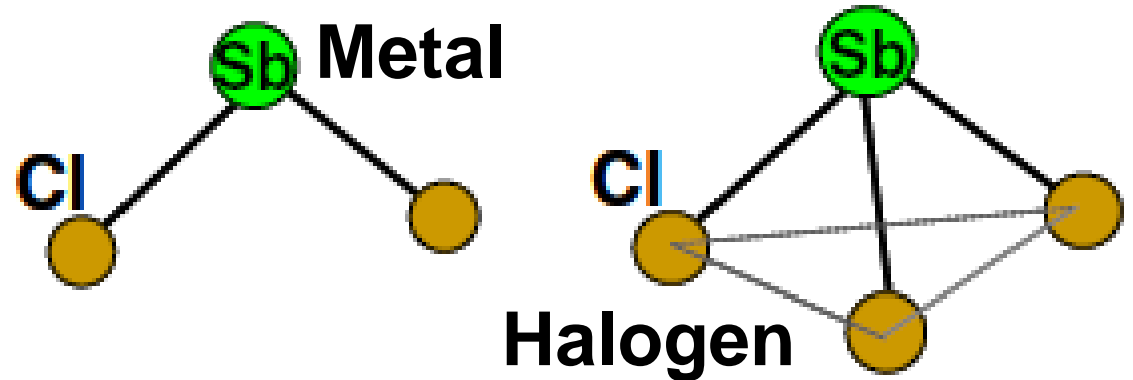
# Halogen geochemistry



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, CaCl<sub>2</sub>  
KCl, FeS<sub>2</sub>, CaF<sub>2</sub>  
Fe<sub>3</sub>O<sub>4</sub>, LiBr

Flux  
Li<sub>2</sub>B<sub>4</sub>O<sub>7</sub>  
Lithium tetraborate

혼합



XRF 전처리 장비  
“Bead machine”

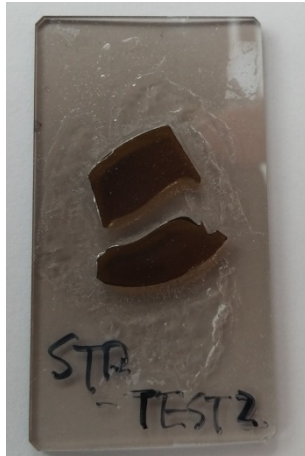
# Standard Reference Material (SRM) for halogens

제작된 SRM - 함량비

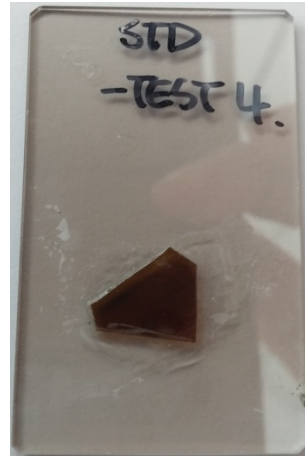
STD1



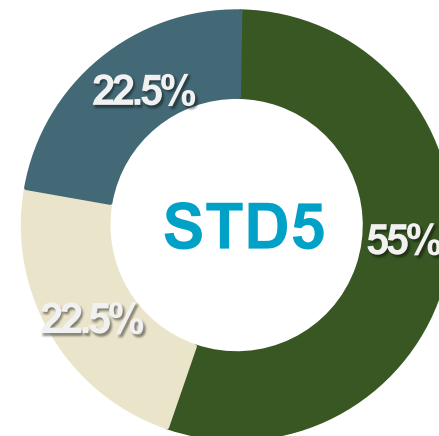
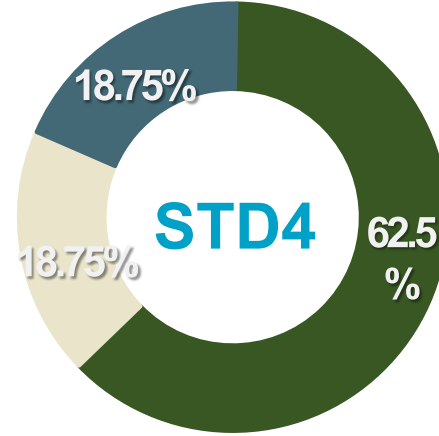
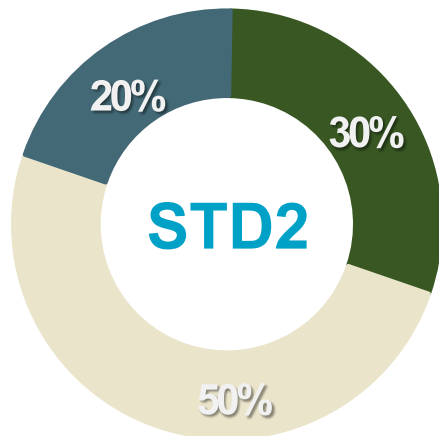
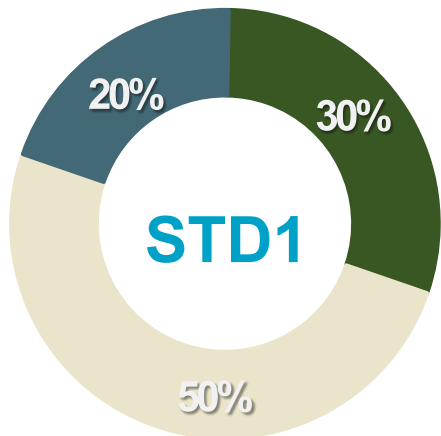
STD2



STD4



STD5

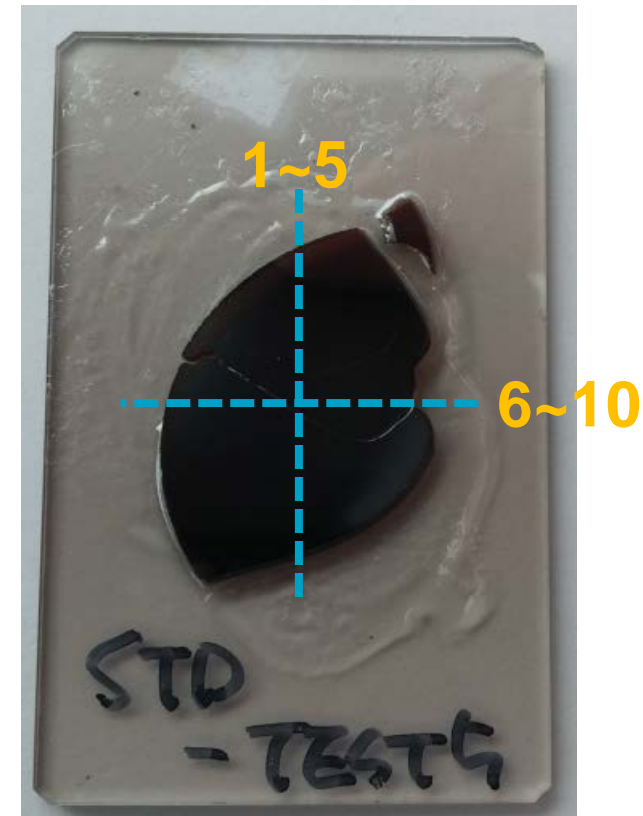


# Standard Reference Material (SRM) for halogens

## Analytical method



Electron Probe Micro Analyzer  
(EPMA)



Ex) 각 STD - 10 point



# Standard Reference Material (SRM) for halogens

**균질도 TEST**

## STD1

No.	F	Al <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	FeO	SO <sub>3</sub>	Br	CuO	MnO	TiO <sub>2</sub>	Cl	I	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CaO	Li <sub>2</sub> O	B <sub>2</sub> O <sub>3</sub>	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
<b>Average</b>	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
<b>STDEV</b>	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
<b>ERROR</b>	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 <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	FeO	SO <sub>3</sub>	Br	CuO	MnO	TiO <sub>2</sub>	Cl	I	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CaO	Li <sub>2</sub> O	B <sub>2</sub> O <sub>3</sub>	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
<b>Average</b>	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
<b>STDEV</b>	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
<b>ERROR</b>	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 <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	FeO	SO <sub>3</sub>	Br	CuO	MnO	TiO <sub>2</sub>	Cl	I	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CaO	Li <sub>2</sub> O	B <sub>2</sub> O <sub>3</sub>	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
<b>Average</b>	<b>0.28</b>	<b>10.05</b>	<b>5.95</b>	<b>2.33</b>	<b>35.12</b>	<b>9.40</b>	<b>0.24</b>	<b>0.29</b>	<b>0.03</b>	<b>0.00</b>	<b>0.80</b>	<b>0.32</b>	<b>0.04</b>	<b>4.19</b>	<b>0.17</b>	<b>10.97</b>	<b>3.30</b>	<b>15.43</b>	<b>98.69</b>
<b>STDEV</b>	<b>0.19</b>	<b>0.18</b>	<b>0.15</b>	<b>0.10</b>	<b>0.23</b>	<b>2.66</b>	<b>0.03</b>	<b>0.40</b>	<b>0.03</b>	<b>0.00</b>	<b>0.03</b>	<b>0.12</b>	<b>0.02</b>	<b>0.07</b>	<b>0.03</b>	<b>0.07</b>	<b>0.00</b>	<b>0.00</b>	<b>3.16</b>
<b>ERROR</b>	<b>69.74</b>	<b>1.78</b>	<b>2.53</b>	<b>4.28</b>	<b>0.65</b>	<b>28.30</b>	<b>12.12</b>	<b>136.10</b>	<b>119.66</b>	<b>0.00</b>	<b>3.98</b>	<b>37.70</b>	<b>52.22</b>	<b>1.67</b>	<b>16.36</b>	<b>0.68</b>	<b>0.00</b>	<b>0.00</b>	<b>3.20</b>

## STD5

No.	F	Al <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	FeO	SO <sub>3</sub>	Br	CuO	MnO	TiO <sub>2</sub>	Cl	I	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CaO	Li <sub>2</sub> O	B <sub>2</sub> O <sub>3</sub>	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
<b>Average</b>	<b>0.38</b>	<b>9.17</b>	<b>5.51</b>	<b>2.27</b>	<b>32.32</b>	<b>10.70</b>	<b>0.13</b>	<b>0.21</b>	<b>0.02</b>	<b>0.00</b>	<b>0.74</b>	<b>0.34</b>	<b>0.03</b>	<b>3.62</b>	<b>0.15</b>	<b>11.26</b>	<b>3.87</b>	<b>18.11</b>	<b>98.56</b>
<b>STDEV</b>	<b>0.19</b>	<b>0.12</b>	<b>0.10</b>	<b>0.04</b>	<b>0.24</b>	<b>2.20</b>	<b>0.02</b>	<b>0.27</b>	<b>0.02</b>	<b>0.00</b>	<b>0.05</b>	<b>0.04</b>	<b>0.02</b>	<b>0.08</b>	<b>0.03</b>	<b>0.09</b>	<b>0.00</b>	<b>0.00</b>	<b>2.45</b>
<b>ERROR</b>	<b>51.88</b>	<b>1.25</b>	<b>1.85</b>	<b>1.76</b>	<b>0.73</b>	<b>20.51</b>	<b>15.53</b>	<b>126.64</b>	<b>131.83</b>	<b>0.00</b>	<b>7.00</b>	<b>10.80</b>	<b>65.77</b>	<b>2.07</b>	<b>16.65</b>	<b>0.77</b>	<b>0.00</b>	<b>0.00</b>	<b>2.49</b>

# 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**

