Hydrothermal Alteration and Mineralogy Characterization at the Lake-Assal and the Hatchobaru Geothermal Fields

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ABSTRACT

Twenty-one samples were collected from Lake-Assal and Otake-Hatchobaru fields. The samples were analysed by petrography and XRD to identify clay minerals, and XRF to identify to chemical constituents. In Addition, thin Section observation of two samples from Assal and one sample Otake-Hatchobaru. Results indicate that plagioclase, forsterite and fayalite, are the main primary minerals while chl/Sme, Illite/sme and hematite are the prominent secondary alterations. Advanced argilic surface alterations composed of alunite, cristobalite, and kaolin were also noted to have developed due to the alteration by steam-heated waters.

1. INTRODUCTION

Lake-Assal is located in Central Djibouti where three major extensional structures; Red Sea, the East African Rift and the Gulf of Aden join to forming the "Afar Depression". The most active structure is the Asal Rift, which is the westward prolongation of the Gulf of Aden-Gulf of Tadjourah ridge. Geothermal exploration in the Republic of Djibouti was initiated by drilling of two wells in the rift Asal in 1975 (BRGM 1975), a deep reservoir at 1000 m depth with high salinity and a temperature of 260°C was identified. Additional geothermal exploration in the Asal area, including field studies and exploration drilling between 1970 and 1990, revealed the high salinity, a deep Asal geothermal reservoir and additional potential geothermal areas.

The Hatchobaru geothermal field is located on the northwest slopes of kuyju volcano (about 1000 to 1100 m above sea level), north central Kyushu (Figure 2). The geothermal system is water-dominated type and fluid flow is controlled by fracture. The field is one of the most productive geothermal fields in Japan; Hatchobaru Unit I (55MW) and Unit II (55MW) geothermal power plants have been operating since 1977. The northern part of the Hatchobaru geothermal field is a reinjection area. At the surface above the acid alteration zone, the advanced argilic alteration zone is composed of alunite is predominantly in and around Komatsu Jigoku. The highest fumarole temperature was 508°C in 1960 (Mizutani et al.; 1986), and before the recent eruption it was 320°C.

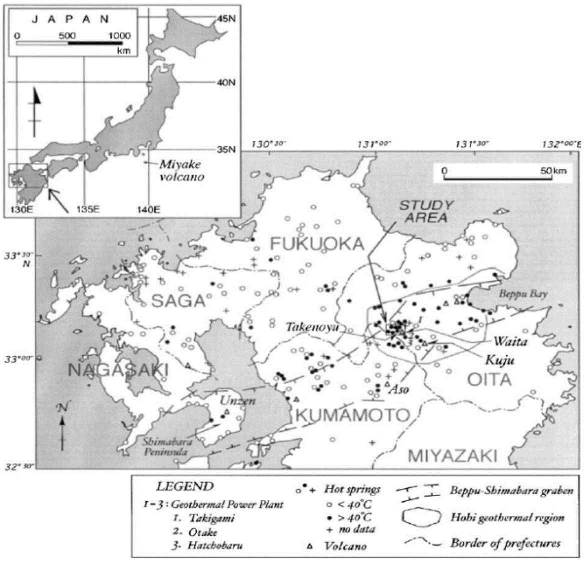

Figure 1: Location of Hatchobaru geothermal field

The main purpose of this report is to analysis the subsurface samples from Lac-Assal and Otake-Hatchobaru by XRD, XRF and thin section observations to compare, the hydrothermal alteration minerals between Assal and Hatchobaru systems.

1.1 Geology of Lake-Assal

The Asal Rift is tectonically the most active structure in the zone of crustal divergence in Afar. The Asal area constitutes a typical oceanic type rift-valley, with a highly developed graben structure displaying axial volcanism.

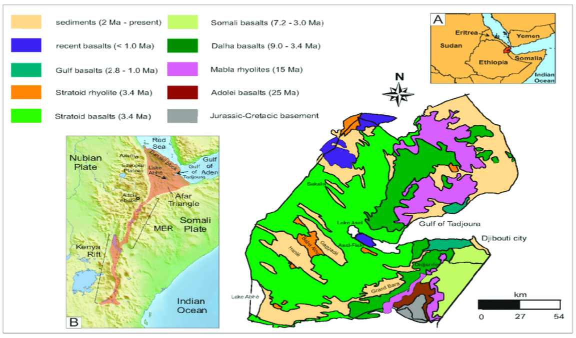

Figure 2: Schematic geological map of the Republic of Djibouti. Inset A: location of the Republic of Djibouti (red) in the Horn of Africa. Inset B: a subdivision of the East African Rift System (light red; location of Djibouti).

The Asal series is a relatively complex in structure, due to different series of active volcanism in Quaternary times, each with very different characteristics depending on the sites of appearance.

Generally, the Asal series is composed of porphyritic basalt formations and hyaloclastites. The Stratoid series essentially constitutes by basalts, where the top series is marked by Pleistocene clays. Sedimentary layers between basalt flows characterize the basalt series of Dalha. Asal-Ghoubet rift is one of the youngest rifts with an age of 0.9Ma (Varet. 1978; courtillot et al.. 1980; Manighetti et al.. 1998). As any other rift in Afar, Asal-Ghoubet is a narrow zone (15km) of localized active faulting and magmatism. It is currently opening at 16mm/year in a N40 ± 5°E direction (Reugg and kasser. 1987. Vigny et al... 2007). The only clear finding is that magmatic and tectonic activities have been combining over the whole rift evolution; phases of dominant magmatic activity have alternated with phases of major faulting (stein et al.. 1991; Manighetti et al.. 1998).

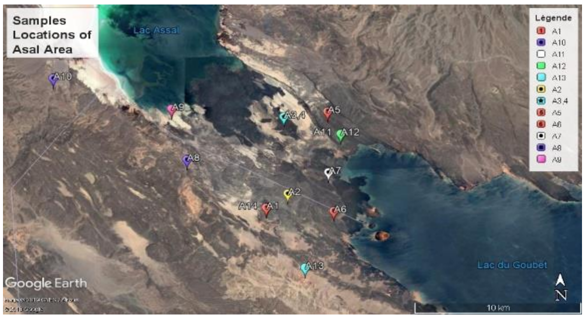

Figure 3: Location of sampling surface rock of Lake-Assal (from Google Earth).

1.2 Geology of Hatchobaru

The surface geology of the Hatchobaru geothermal system is composed of Hohi and the Kuju volcanic rocks, the only units exposed in the area. The late Pliocene to early Pleistocene Hohi volcanic rocks composed of pyroxene andesite outcrop to the west of the jigoku, and is altered to kaolinite. To the east of Komatsu jigoku, the Kuju volcanic rocks are mainly composed of hornblende andesite. As the rocks of Komatsu jigoku are almost completely altered and it is difficult to discern identify the origin of the altered rocks.

Figure 4: Location of sampling surface rock of Otake-Hatchobaru (from Google Earth).

2. METHODS AND MATERIALS

Twenty-one samples in total were collected for this study. Thirteen samples from Lake Asal area (Figure3) and eight Samples were from Hatchobaru geothermal system (Figure 4).

2.1 Xrd Analysis

Xrd (X-ray diffraction) can identify the clay minerals. A secondary minerals formation is dependent on fluid temperature, water chemistry, and type of host rocks. In the Laboratory, four different types of sample were measured, bulk, oriented, Ethylene Glycolated (EG) and Hcl for X-ray diffractometer (Figure 5). For, oriented samples, the main purpose are to collect and identify the clay mineral content from the rock sample. Crushed sample are immersed in ionized water in a glass suspended in an ultrasonic bath for 30 minutes. After 4 hours, the clay minerals appeared in the upper part of the solution was collected and centrifuged to collect concentrated clay mineral at the bottom of tube.

Figure 5: Rigaku Ultima IV X-ray diffractometer (XRD machine).

For Bulk sample, the sample was crumpled into smaller pieces and dried an oven at 45°C for 24 hours to remove the moisture from the sample. Then dried sample crushed further into clay sized powder using mortar and pestle. So the powder on metal plate can analyze to indicate the alteration minerals by X-ray diffractometer.

2.2 – Xrf Analysis

XRF (X-ray fluorescence analysis) can determine the major elements and trace elements in the rocks. Based on the chemical composition of rocks, determination of rock type (name) can be derived. This information will be utilized to understand magmatic processes and activity.

After having finished using the XRD method, 13samples from Lake-Assal and 8 samples from Hatchobaru samples were measuring using by XRF method (Figure 6) to determine their chemical composition of the rock, Based on major and the trace elements.

Figure 6: Xrf Machin Rigaku RIX 3100.

2.3 Thin Section Analysis

Thin section preparation is a laboratory method to prepare rock, to identify mineral using a polarizing petrographic microscope (Figure 7). As different minerals have different optical properties, most rock forming minerals can be easily identified. Thin sections are prepared in order to investigate the optical properties of the minerals in the rock. This analyze is a part of petrology and helps to reveal the origin and evolution of the parent rock.

Figure 7: Thin section Microscope MET.

3. Results and Discussion

3.1. Xrd Results from Lake-Asal and Hatchobaru Samples

Lake-Assal samples, exhibit the following results obtained for clay mineral alteration analysis, show in Table 1. Alteration minerals such as plagioclase, fayalite, forsterite and serpentine were identified.

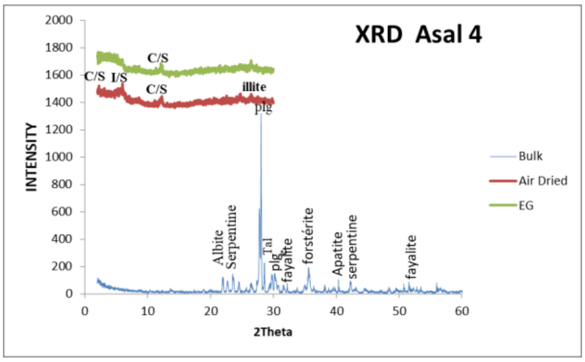

Figure 8: Xrd pattern of Asal 4 for Bulk sample, Oriented Sample and Ethylene Glycolated (EG).

For the Hatchobaru samples shows clay mineral such as quartz-feldspars, serpentine, pyrite, illite and chlorites. Hydrothermal alteration minerals in Hatchobaru such as quartz, plagioclase and pyrite were identified.

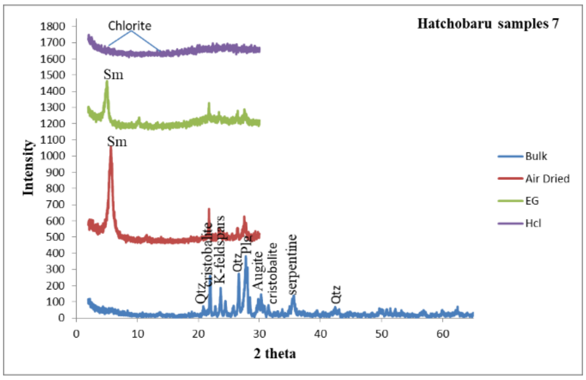

Figure 9: Xrd pattern of Hatchobaru samples 7 for Bulk sample, Oriented Sample, Ethylene Glycolated (EG) and Hcl.

Table 1: Xrd Results for Lake-Asal. Alteration Mineral Type and Typical Minerals

		Type IV		Plg	Hematite	K-feldspars	Calcite	Hornblende	Fayalite	Forstérite	Serpentine
Samples	**Sme**	**Chl/Sme**	**ill/sme**								
A-1				XXX							X
A-2				XXX		X			X		X
A-3				XXX	X		X				
A-4		XX	XX	XXX					X	X	X
A-5				XXX					X		
A-6				XXX						X	X
A-7				XXX	X	X				X	X
A-8				XX	X	X		X			X
A-9				XX	X					X	
A-10				XX		X		X			
A-11				XX			XXX		X		X
A-12				XXX	X						X
A-13				X		XXX	X				
A-14				XXX				XX			

Table 2: Xrd Results for Otake-Hatchobaru. Alteration Mineral Type and Typical Minerals

	Type I			Type II	Type III	Type IV		Others Minerals	Primary Minerals
Samples	**Cristobalite**	**Quartz**	**Tridymite**	**Alunite**	**Kaolinite**	**Smectite**	**Illite**	**Pyrite**	**Plagioclase**
H-1		**17.1**				**2**			
H-2		**21.5**		**2**	**3**			**4**	
H-3		**15.4**		**4**		**4**		**2**	
H-4		**12.5**				**2**			**3**
H-5	**10**	**4.9**				**4**		**2**	
H-6		**32.26**			**4**				
H-7	**8**	**5.11**				**2**			**10**
H-8	**10**	**8.87**	**6**	**6**	**3**				

Table 3: The results of analysis for Asal samples with their major elements oxides (wt. %) and trace elements (ppm)

Samples	Asal 1	Asal 2	Asal 3	Asal 4	Asal 5	Asal 6	Asal 7	Asal 8	Asal 9	Asal 10	Asal 11	Asal 12	Asal 13	Asal 14
SiO2	47.40	50.23	50.48	46.36	47.25	46.61	47.27	45.73	40.86	49.79	44.57	47.22	69.46	74.38
TiO2	1.48	1.65	1.13	1.25	2.67	1.75	2.84	3.25	1.26	3.4	1.66	1.38	0.51	0.01
Al2O3	20.75	19.43	17.99	19.30	14.47	21.96	13.48	14.65	18.54	12.92	17.37	20.97	10.43	0.13
FeO	8.05	6.95	7.36	8.40	12.67	7.03	13.96	15.42	6.59	13.78	7.81	7.92	3.99	6.73
MnO	0.14	0.11	0.16	0.15	0.23	0.12	0.24	0.26	0.10	0.21	0.13	0.13	0.1	0.49
MgO	4.53	3.97	7.17	6.84	6.66	4.13	6.53	5.47	4.96	5.88	4.89	4.7	1.56	0.3
CaO	15.26	15.58	12.73	15.39	12.11	16.26	12.14	10.82	21.83	9.09	17.82	15.3	2.45	2.15
Na2O	1.96	1.71	1.51	1.55	2.51	1.73	2.54	2.87	1.73	2.74	1.44	1.8	2.22	6.17
K2O	0.15	0.14	0.31	0.35	0.38	0.13	0.54	0.46	0.38	1.55	0.61	0.15	3.83	0.86
P2O5	0.10	0.09	0.11	0.10	0.29	0.09	0.19	0.41	0.15	0.41	0.2	0.09	0.05	0.01
H2O	0.08	0.03	0.93	0.14	0.6	0.06	0.03	0.47	0.62	0.08	3.31	0.23	5.27	7.37
Ox	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CH600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	0.00	0.0107	0.0133	0.0294	0.0232	0.0066	0.0747	0.013	2.821	0.0056	0.0533	0.0008	0.0167	0.0782
Trace Elements (ppm)														
V	133.00	113	97	119	241	119	257	269	90	252	125	124	20	0
Cr	128.00	142	217	361	132	133	146	129	230	16	111	115	3	2
Co	28.00	10	23	20	7	13	26	14	38	25	22	26	7	0
Ni	59.00	57	113	113	70	59	66	73	82	53	63	61	30	0
Cu	97.00	127	73	96	201	120	231	257	92	168	139	95	32	2646
Zn	80.00	71	87	89	124	76	140	152	73	128	84	79	239	4861
Pb	0.00	0	0	0	0	0	0	0	0	0	0	0	7	3849
As	19.00	19	16	27	20	16	18	28	36	34	25	15	42	1280
Mo	0.00	0	0	0	0	0	0	0	0	2	0	0	6	0
Rb	2.00	1	9	7	5	1	10	5	5	40	10	2	141	53
Sr	401.00	425	302	382	358	463	373	389	689	378	484	406	115	186
Ba	28.00	63	80	55	142	41	136	167	28	180	89	15	84	456
Y	13.00	13	15	16	26	12	29	37	12	38	17	14	95	0
Zr	70.00	70	77	77	149	69	149	193	92	243	95	69	264	5

Table 4: The results of analysis from the Hatchobaru samples with their major elements oxides (wt. %) and traces elements (ppm).

Hatchobaru Samples	H1	H2	H3	H4	H5	H6	H7	H8
SiO2	66.035	53.617	67.794	65.750	69.920	62.336	59.667	63.652
TiO2	0.525	0.433	0.630	0.718	0.653	0.457	0.837	0.662
Al2O3	16.503	13.955	15.784	16.627	18.661	8.614	15.510	15.199
FeO	3.033	8.458	3.613	4.277	3.126	7.367	6.957	2.513
MnO	0.005	0.000	0.111	0.065	0.000	0.000	0.125	0.000
MgO	0.820	0.259	1.759	2.974	1.000	0.303	3.992	0.385
CaO	1.521	0.193	2.729	2.908	0.345	0.087	6.955	0.199
Na2O	2.809	0.677	2.915	2.427	1.192	0.495	2.658	0.911
K2O	2.519	0.367	2.215	2.845	3.032	1.203	1.986	1.819
P2O5	0.196	0.210	0.194	0.202	0.114	0.153	0.232	0.218
H2O	4.650	14.400	1.650	1.010	0.660	12.630	0.520	11.150
S	1.2793	7.3176	0.4726	0.0551	1.1933	6.2666	0.4173	3.1568
			Trace Elements (ppm)					
V	70.000	52.000	76.000	96.000	97.000	49.000	165.000	77.000
Cr	0.000	0.000	0.000	0.000	0.000	3.000	48.000	0.000
Co	34.000	11.000	8.000	53.000	17.000	29.000	34.000	22.000
Ni	3.000	0.000	4.000	4.000	4.000	3.000	5.000	3.000
Cu	0.001	0.001	0.001	0.001	0.001	0.003	0.003	0.002
Zn	0.002	0.000	0.007	0.009	0.002	0.000	0.006	0.000
Pb	0.001	0.001	0.001	0.000	0.001	0.000	0.001	0.000
As	7.000	0.000	2.000	2.000	1.000	19.000	0.000	10.000
Mo	6.000	5.000	6.000	6.000	8.000	3.000	5.000	10.000
Rb	70.000	2.000	61.000	89.000	89.000	2.000	55.000	34.000
Sr	248.000	658.000	419.000	379.000	204.000	298.000	535.000	635.000
Ba	381.000	270.000	438.000	420.000	332.000	298.000	316.000	344.000
Y	24.000	7.000	31.000	36.000	28.000	11.000	25.000	13.000
Zr	171.000	104.000	187.000	206.000	203.000	135.000	139.000	187.000
Ta	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nb	9.000	5.000	0.000	11.000	10.000	7.000	8.000	9.000

Chemical analysis shows that sample 13 is rich in iron and poor in alkaline matter, it indicates that the magma during the formation was enriched in iron and poor in alkaline element.

It is noted that in the samples H1. H3. H4. H5 and H7 Hatchobaru are classified Type 4 according to the weathering mineral depending on their temperature between 120 to 220°C. These samples, such as H6 and H8 are highly altered and are classified as Type 3 and have a formation temperature of between 100 and 200°C. While, H2 samples are Type 2 altered with a formation temperature of 350°C.

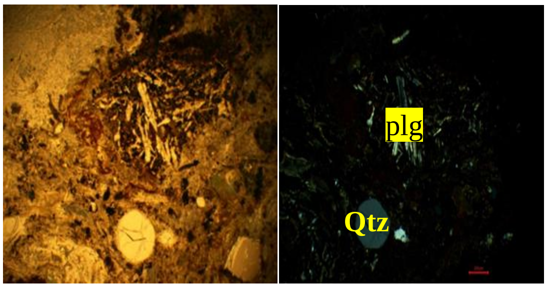

Figure 10: A volcanic magmatic rock of microlithic structure and mineralogical composition such as the phenocrysts of quartz, amphiboles and K-feldspars.

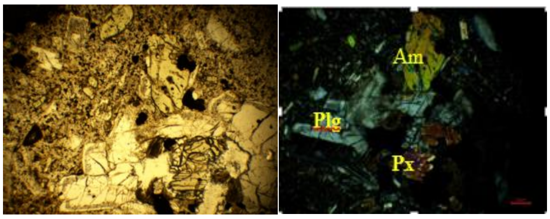

Figure 11: The Hatchobaru Sample 7 is Andesite; it is a volcanic magmatic rock of microlithic structure and mineralogical composition such as the phenocrysts of plagioclase, amphibole (Hornblende), and pyroxene, so the matrix of the rock is essentially plagioclase

CONCLUSION

According to the results of the different methods used for this study, we notice that the lake-Assal rocks are basic type. Rich in ferromagnesian elements and that most samples of fresh rocks, the case of porphyry basalt. It is concluded that the Hatchobaru rock is highly altered from type 2, 3 and 4 alteration minerals, as well as primary minerals observed in the XRD results, it is deduced that the main alteration minerals in this site correspond to: Alunite, kaolinite and smectite and that these rocks are totally acidic due to the high percentage of silica and the main rock is pyroxene andesite and hornblende andesite, andesite is a magmatic rock from a subduction zone.

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