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International Database of Hydrothermal Chemistry: a Case of Task-A of Annex VIII of IEA-GIA

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ABSTRACT

Under a framework of the Geothermal Implementing Agreement (GIA) of the International Energy Agency (IEA), an international database of hydrothermal chemistry is now under construction among the six participating countries including Iceland, Japan, South Korea, USA, Switzerland and New Zealand. The pH value of thermal water in Iceland shows 9 or 10, that is evidently higher than those of other silicic crust countries. It is ascribed to the host rock controls that hydrothermal water only attacks anorthite in basalt. Thermal water in Japan separately forms a strong acid cluster associated with sulfur-rich andesite volcanoes. The boron and chloride components of thermal water in Iceland are significantly lower than those in Japan and the USA. Their variation ranges show that the boron component in Iceland is 1 magnitude lower than other two countries and the chloride component is 0.5 magnitudes lower. It is also explained by the host rock controls that the basaltic crust in Iceland is 1 magnitude lower in boron and 0.5 magnitudes lower in chloride than the silicic crust in Japan and the USA. An attempt at mapping of the discharge temperature of thermal water delineates outlines of geothermal fields. The database can be applied to the characterization of hydrothermal systems for multiple purposes and more numbers of participating countries will be expected in the near future.

1. INTRODUCTION

Geothermal Implementing Agreement (GIA) of the International Energy Agency (IEA) provides a flexible framework for wide-ranging international cooperation. One of the operating Annexes is "Direct Use of Geothermal Energy", where the Task A is conducted for " Resource Characterization". Participating countries are currently Iceland, Japan, New Zealand, South Korea, Switzerland and the USA.

Chemistry of hydrothermal water has often been compared through binding individual country reports, but the direct diagrammatic comparison by the international database has seldom been made until the present. The framework of the IEA-GIA enables us to achieve this. We have preliminarily reported an interim result of this database (Muraoka et al., 2008), but the data sets are still updating. We here show the global comparison of thermal water chemistry as an updated result in this task.

2. METHODOLOGY

2.1 Data Sets

Numbers of submitted hydrothermal chemistry data sets are as follows: 352 from Iceland, 7,203 from Japan, 404 from South Korea and 6,675 from the USA. New Zealand and Switzerland are under preparation to submit the data sets. The numbers of the data sets depend on the availability of hydrothermal systems related to volcanoes in general. South Korea is a less volcanic country, but relatively large numbers of the data sets are obtained from hot springs developed by shallow-depth wells mostly with a depth of several hundreds meters. The data sets from Japan, Korea and the USA completely provide coordinates and those of Iceland partially provide coordinates. The data sets of Korea are lacking for boron analyses. The data sets of the USA were already published as CD-ROM (Geo-Heat Center, 2004), and geographically cover western part of the country. The data sets of the USA include a small number of fluids from high-temperature geothermal wells and special attention is required for their interpretation. The data sets of Japan were already published as an atlas (Muraoka et al., 2007) as well as CD-ROM (Geological Survey of Japan, 2009).

2.2 Tectonic Settings

Participating countries are still few, but the combination of the four countries is interesting from a comparative point of view: Iceland represents a spreading ocean ridge, South Korea represents a less-volcanic continental margin, Japan represents an active island-arc and the USA represents an active continental margin (Figure 1).

In terms of composition of the earth's crust, Japan, South Korea and the USA are fundamentally composed of silicic or granitic crust, whereas Iceland basically consists of basaltic crust, making it unique in comparison to hydrothermal chemistry.

3. RESULTS

3.1 Discharge Temperature Mapping

Coordinated data of chemistry of hydrothermal water enable to draw a variety of maps such as an individual component map (Muraoka et al., 2007). As a first attempt, discharge temperature maps are made in South Korea, the USA and Japan where plenty of coordinated data are available (Figures 2, 3 and 4). Although the US data include fluids from high-temperature geothermal wells (Geo-Heat Center, 2004), such temperatures are intentionally masked by the maximum temperature threshold 100ºC on the map (Figure 3).

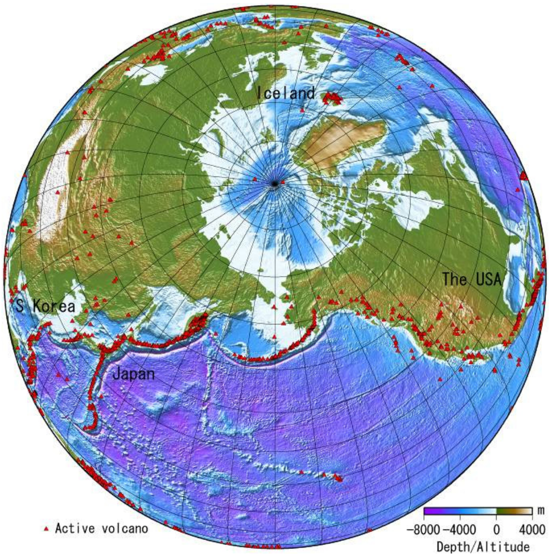

Figure 1: Tectonic settings of Iceland, Japan, South Korea and the USA.

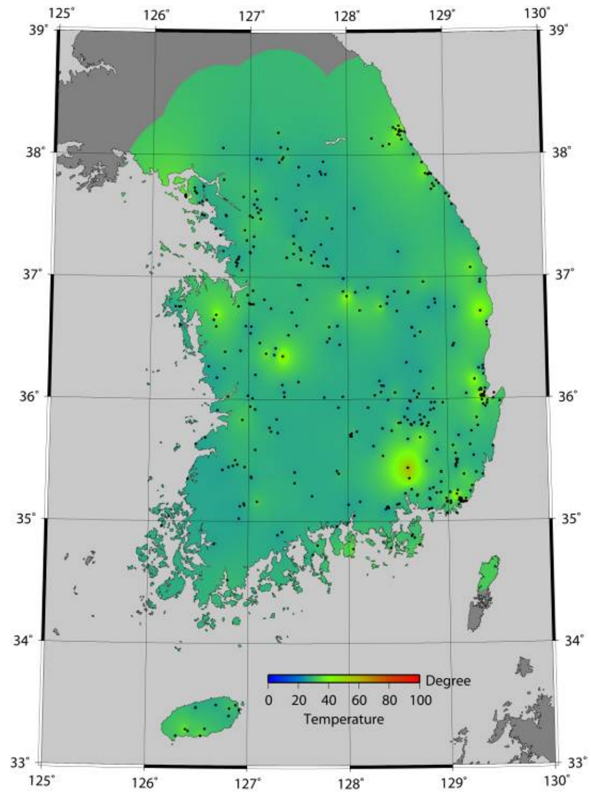

Figure 2: Discharge temperature map of thermal water in South Korea.

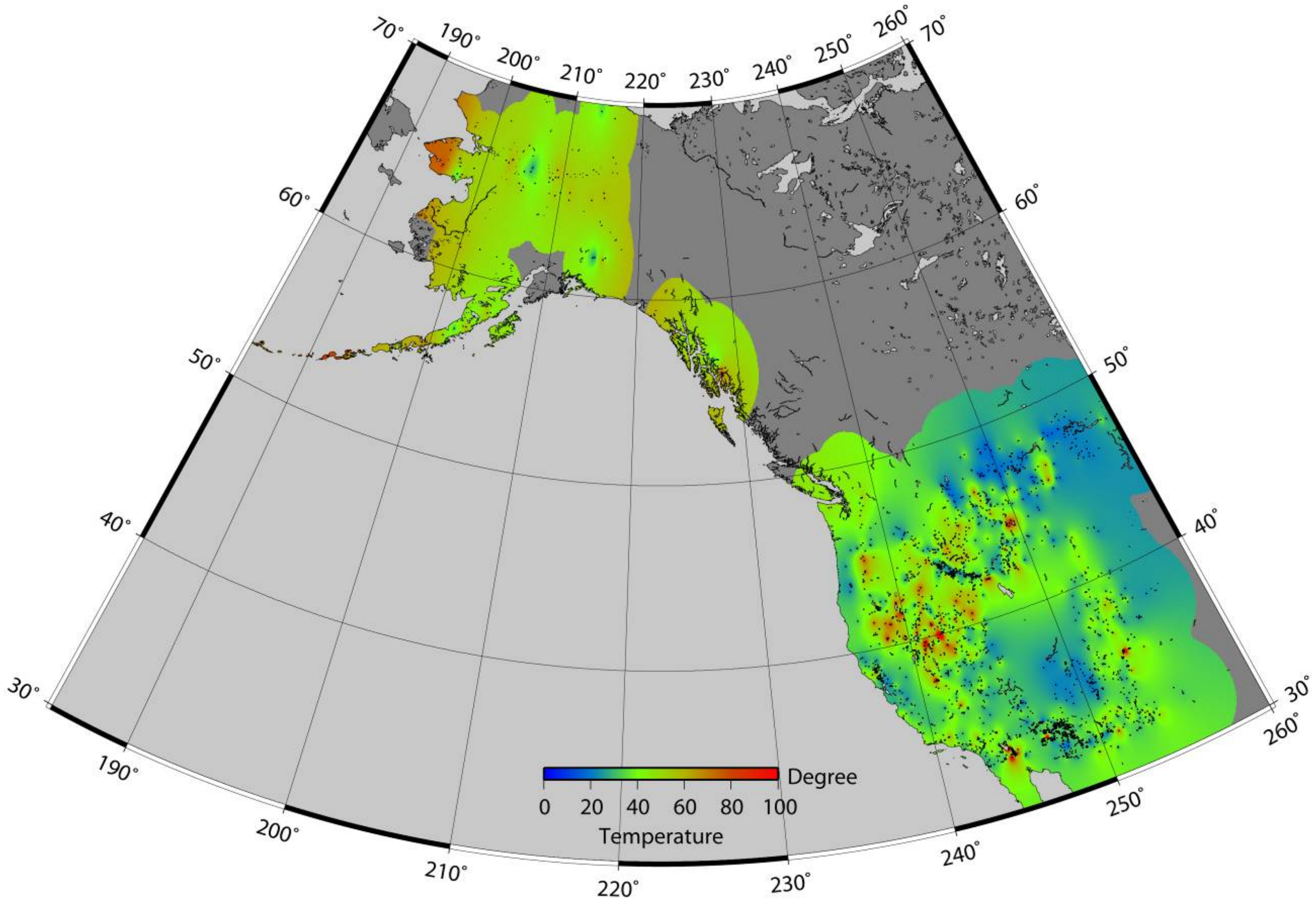

Figure 3: Discharge temperature map of thermal water in the USA.

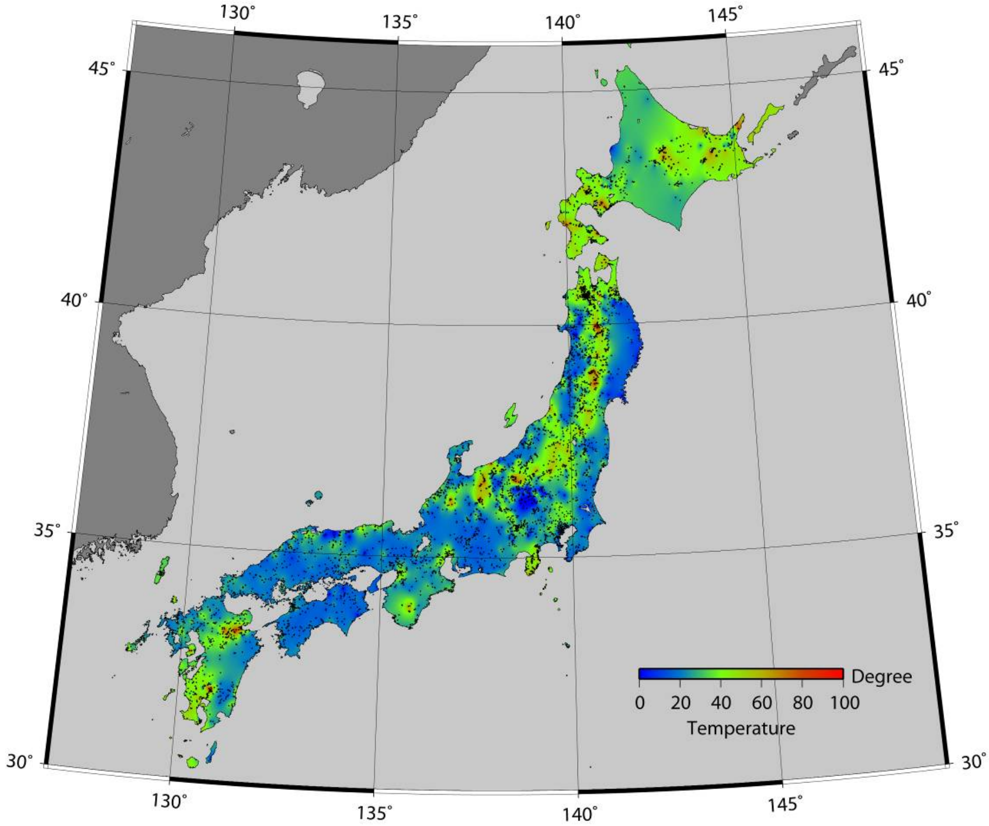

Figure 4: Discharge temperature map of thermal water in Japan.

3.2 Major Component Diagrams

Major components are compared on piper diagrams (Figures 5, 6, 7 and 8). The piper diagrams with too high density data give chaotic images, but a broad feature of thermal water in each country can be observed on the diagrams. A variety of major component diagrams are made by way of trial. Among them, two representative diagrams are shown here: one is a chalcedony temperature-discharge temperature diagram (Figure 9) and the other is a discharge temperature−pH diagram (Figure 10).

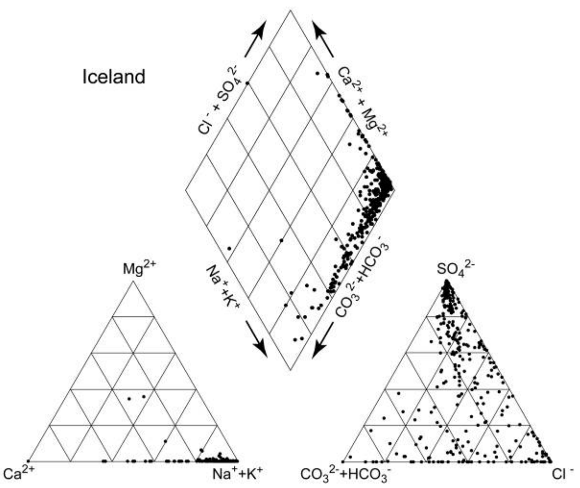

Figure 5: Piper diagram of thermal water in Iceland.

3.3 B and Cl Component Diagrams

For the minor components boron and chloride show a dramatic contrast among the countries (Figure 11) and a special attention is placed on B-Cl geochemistry in this paper.

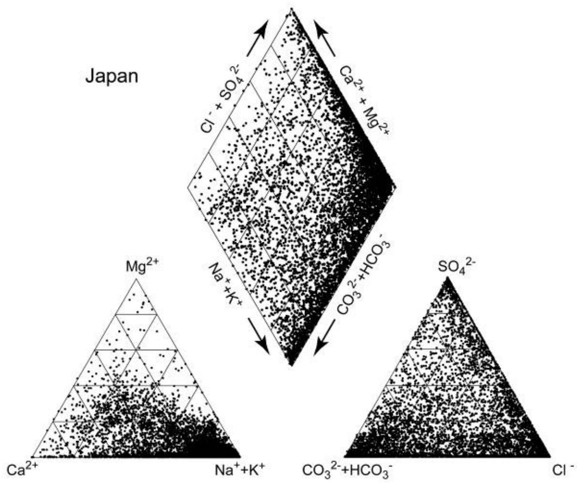

Figure 6: Piper diagram of thermal water in Japan.

4. DISCUSSION

4.1 Discharge Temperature Mapping

Discharge temperature mapping well depicts up-flow zones of hydrothermal convections and is one of the useful tools to extract prospective geothermal fields (Figures 2, 3 and 4). Spatial density of the data is not enough in some areas as seen in Alaska State, the USA (Figure 3). As Japan is a hot spring culture country, numbers of hot spring sources are known to be 28,090 as of March 2008 that cover all over the country. In such a case, hot springs can be used not only as geothermal resources but also as subsurface exploration tools (Figure 4). When the database will be advanced, geothermometric and chemical mapping can be made in the near future.

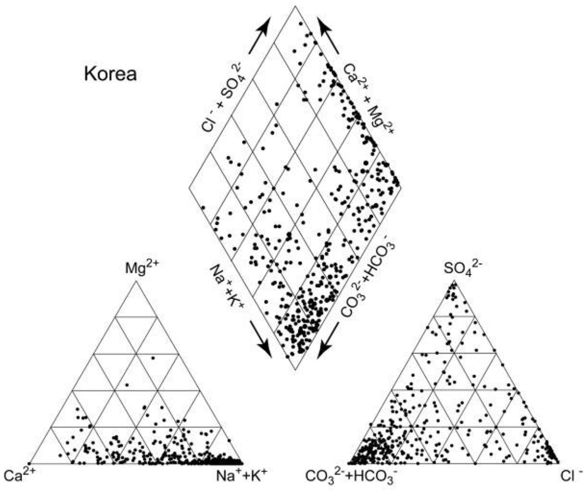

Figure 7: Piper diagram of thermal water in South Korea.

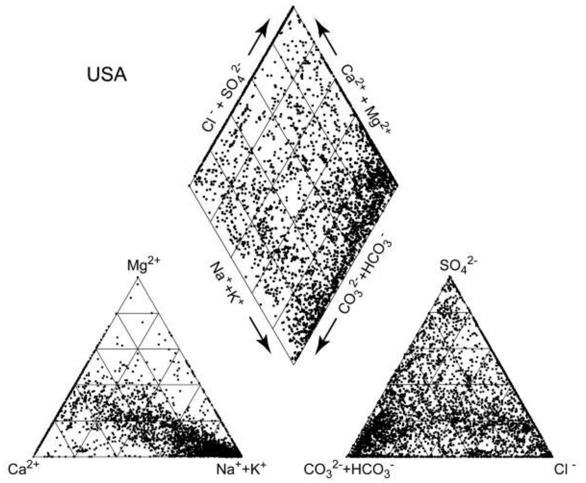

Figure 8: Piper diagram of thermal water in the USA.

4.2 Major Component Diagrams

Piper diagrams display mixing trends in Iceland and the USA; the former is mixing between SO_4 and Cl-HCO_3 and the latter is between Na-K and Ca-Mg (Figures 5 and 8). Piper diagrams of Japan and South Korea are similar to each other. On their anion diagrams, the population increases in the order of the SO_4 apex, Cl apex and CO_3-HCO_3 apex. This is reasonably ascribed to the two dimensional spatial statistics in geothermal areas where the SO_4–rich fluid is found in the center of geothermal areas and it is surrounded by the Cl-rich fluid and then by the CO_3-HCO_3–rich fluid. Population of peripheral type fluids can be statistically dominant.

Figure 9 shows a relation between the chalcedony temperature and discharge temperature of thermal water. The majority of the cluster is found in the high chalcedony temperature region and is bounded by the 1:1 line, excepting the low temperature data. This confirms reliability of the silica geothermometer. Geothermometer can not be used in the low temperature region. The large gap of the given chalcedony temperature from the 1:1 line suggests a higher and deeper reservoir condition being away from the given discharge temperature.

The pH value of thermal water in Japan shows bimodal clusters, one of which is strong acid water related to solfatara (Figure 10). The pH value in Iceland shows 9 or 10, that is evidently higher than those of other silicic crust countries. The low-cation nature of thermal water causes the high pH value (Arnórsson, 1992). It is ascribed to the host rock controls that hydrothermal water only attacks anorthite-molecule rich plagioclase in basalt, yielding low-cation and high pH fluids such as a Ca^{2+} - $2OH^-$ or Na^+ - OH^- type.

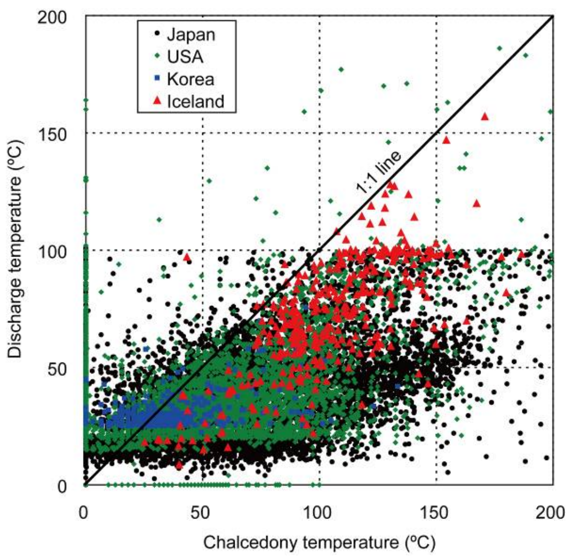

Figure 9: Chalcedony temperature - discharge temperature diagram of thermal water.

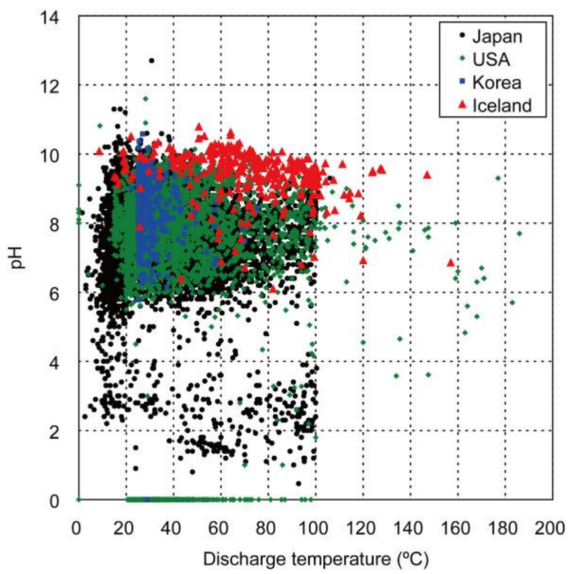

Figure 10: Discharge temperature – pH diagram.

4.3 B and Cl Component Diagram

Figure 11 shows a bi-logarithmic relation between B and Cl concentration of thermal water. The isolated cluster of the USA with the large B/Cl ratio is ascribed to the steam condensates from high-temperature geothermal wells (Figure 11). Except for the cluster, the B/Cl ratio systematically increases in the order of Iceland, the USA and Japan, where the ratio of Iceland is significantly lower than those of other two countries. The variation range of the boron component in Iceland is about 1 magnitude lower than other two countries and the chloride component is about 0.5 magnitudes lower.

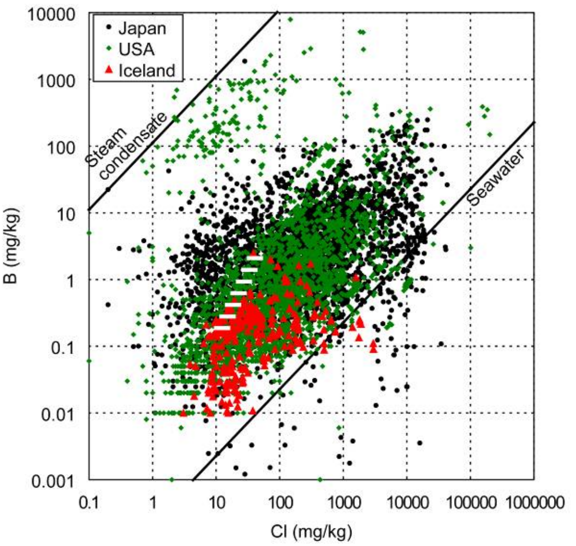

Figure 11: B-Cl diagram. White steps show a model of mafic crust at 47.5 wt % silica to silicic crust at 62.5 wt% silica.

Boron and chloride are soluble and less-volatile components under the hydrothermal temperature range that can be used as an indicator to host rock species (Ellis and Mahon, 1964; 1967; Shigeno, 1992). The systematic difference in the B/Cl ratio is explained by the host rock controls that the basaltic crust in Iceland is 1 magnitude lower in boron and 0.5 magnitudes lower in chloride than the silicic crust in Japan and the USA.

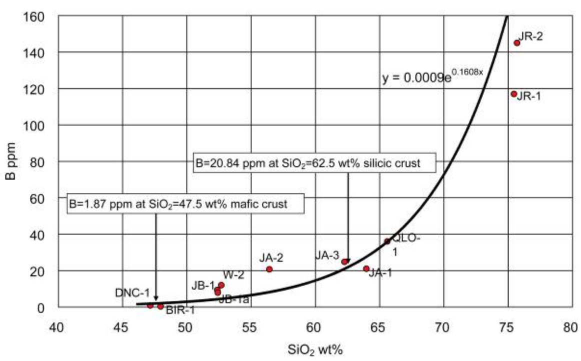

Figure 12: B-SiO$_2$ relation in volcanic rocks.

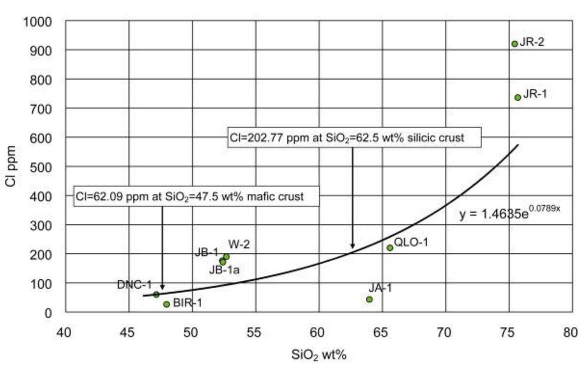

Figure 13: Cl-SiO2 relation in volcanic rocks.

The boron and chloride abundances in volcanic rocks are rarely analyzed, but they are analyzed in the geochemical reference rock samples (Imai et al., 1995; U.S. Geological Survey, 2009). Based on these data, the boron and chloride abundances in volcanic rocks with silica contents are shown in Figures 12 and 13. The both of components increase with silica contents, but the boron component more rapidly increases with silica contents than the chloride component. White steps in Figure 11 show model calculations of boron and chloride abundances in mafic crust at 47.5 wt% silica to silicic crust at 62.5 wt% silica based on the relations of Figures 12 and 13 under assumption of the fractionation factor 0.1 for boron and 0.2 for chloride between the rock and liquid phase (Arnórsson and Andrésdóttir, 1995). There still remains quantitative explanation in detail but the boron and chloride abundances in volcanic rocks broadly explain that the basaltic crust in Iceland is 1 magnitude lower in boron and 0.5 magnitudes lower in chloride than the silicic crust in Japan and the USA.

5. CONCLUSIONS

The flexible cooperation framework of the IEA-GIA enables us to achieve an international database of hydrothermal chemistry that provides not only prospective hydrothermal fields in a given region but also geneses of the global hydrothermal systems. The database can be applied to the characterization of hydrothermal systems for multiple purposes and more numbers of participating countries will be expected in the near future.

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