Ultra-acid volcanic waters: origin and response on volcanic activity. A review

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The moth of the Craterny Creek,
Kuntomintar, Kuril Islands
(pH = 2.1)

1. Here we discuss mainly ultra-acidic sulphate-chloride waters (pH <3) that discharge at volcanic edifices, <u>that generally, do not host crater lakes.</u>

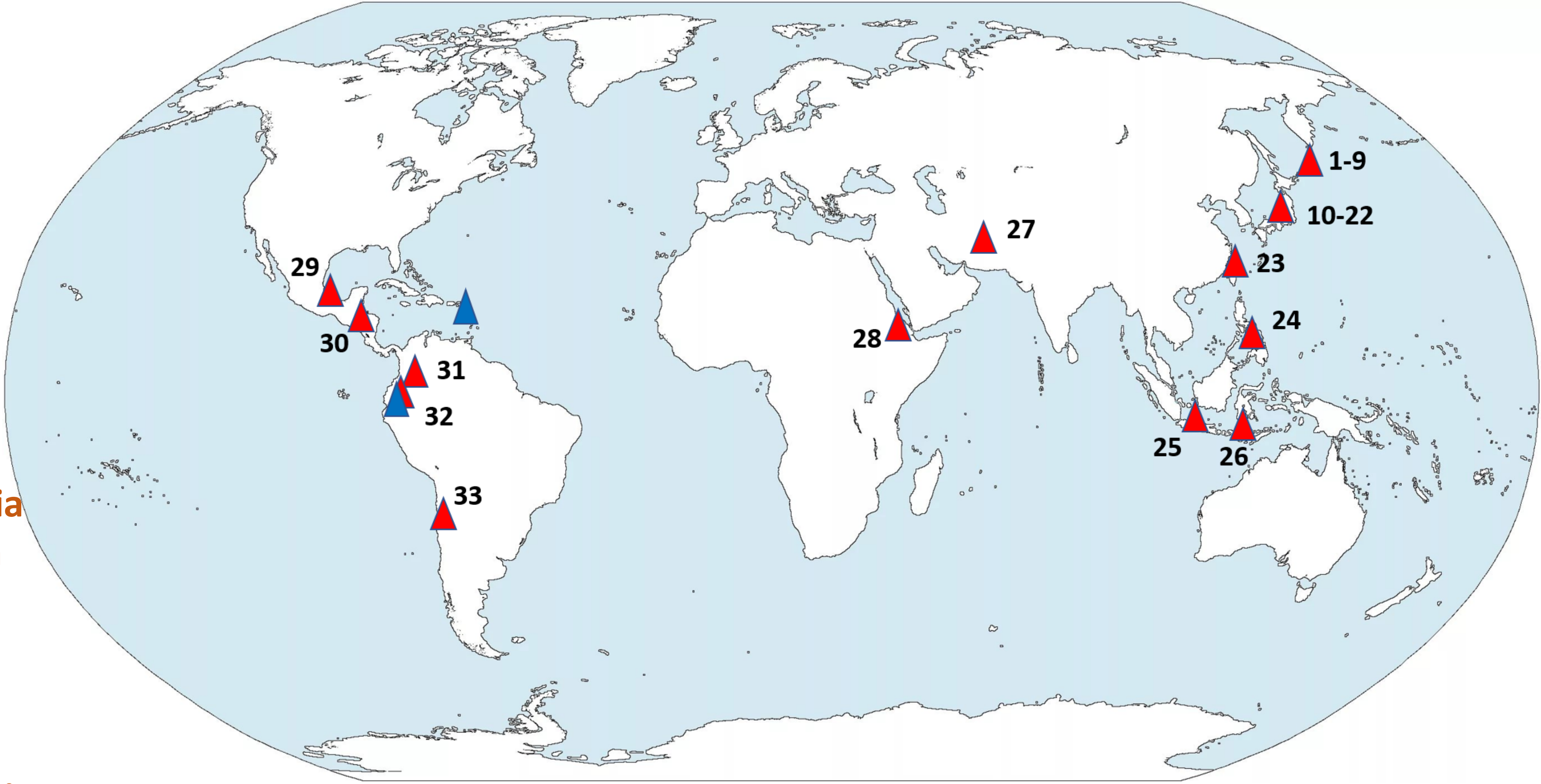
2. The geographical distribution of this type of thermal water is considered.

3. It is shown what processes can be responsible for the formation of these waters

4. Criteria are proposed to assess the origin of waters using their chemical and isotopic composition.

5. An overview of available data on temporal variations in the composition of such waters over time is made with the discussion about a potential of these waters for monitoring of the volcanic activity.

6. Hydrogeological conditions that contribute to the appearance of sources of such waters are also briefly discussed.



Geography

1-9	Kuril Islands
10-22	Japan
23	Taiwan, Tatun
24	Philippines, Kaloan
25	Kawa Ijen, Java, Indonesia
26	Sirung, Pantar, Indonesia
27	Taftan, Iran
28	Dallol, Ethiopia
29	El Chichón, Mexico
30	Poás, Costa Rica
31	Nevado del Ruiz, Colombia
32	Puracé, Colombia
33	Copahue, Argentina

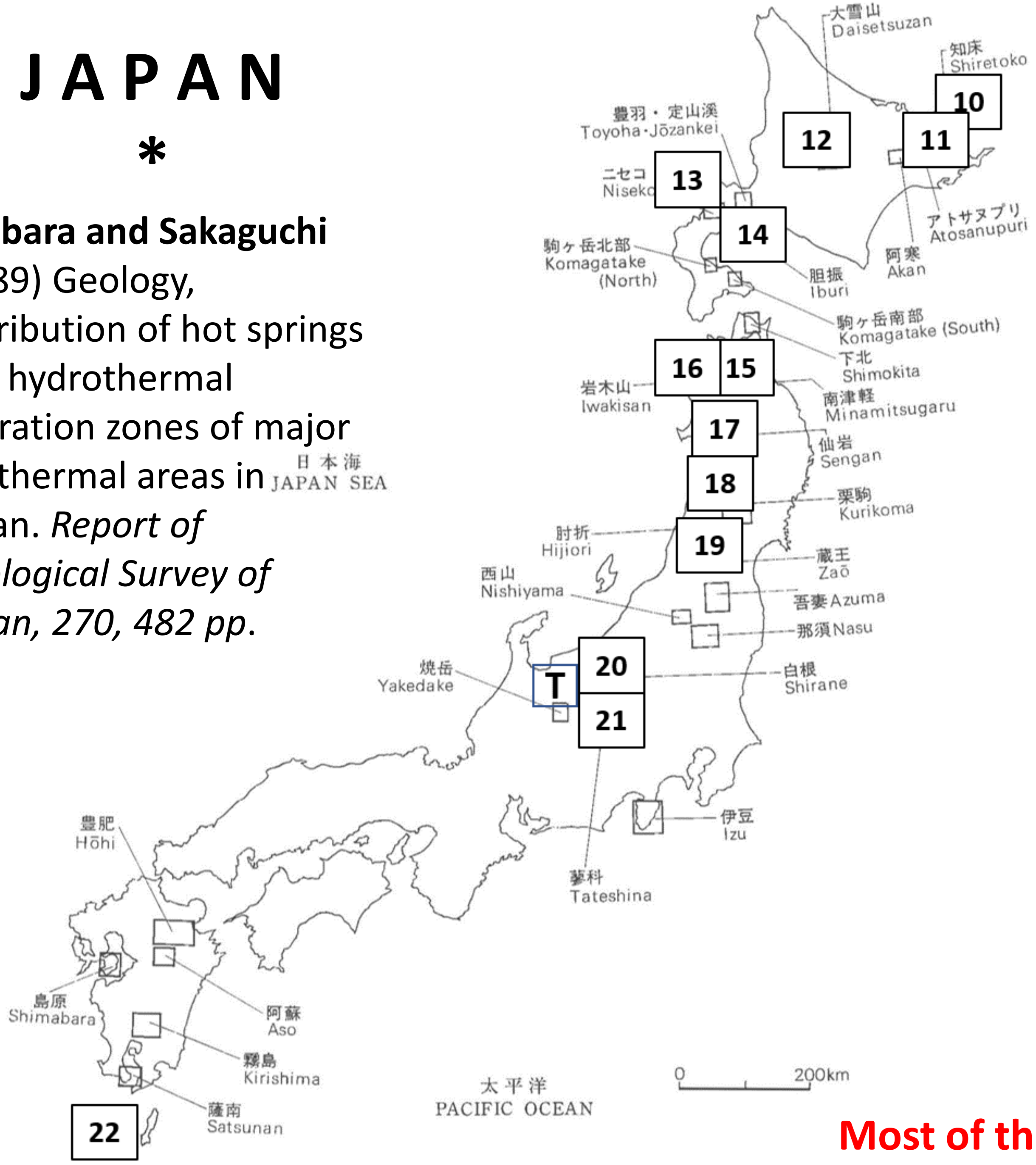
ULTRA-ACID VOLCANIC WATERS - UVW

Blue triangles are acidic systems at Galeras volcano, Colombia, and Dominica island in the Lesser Antilles arc. But the published data are controversial

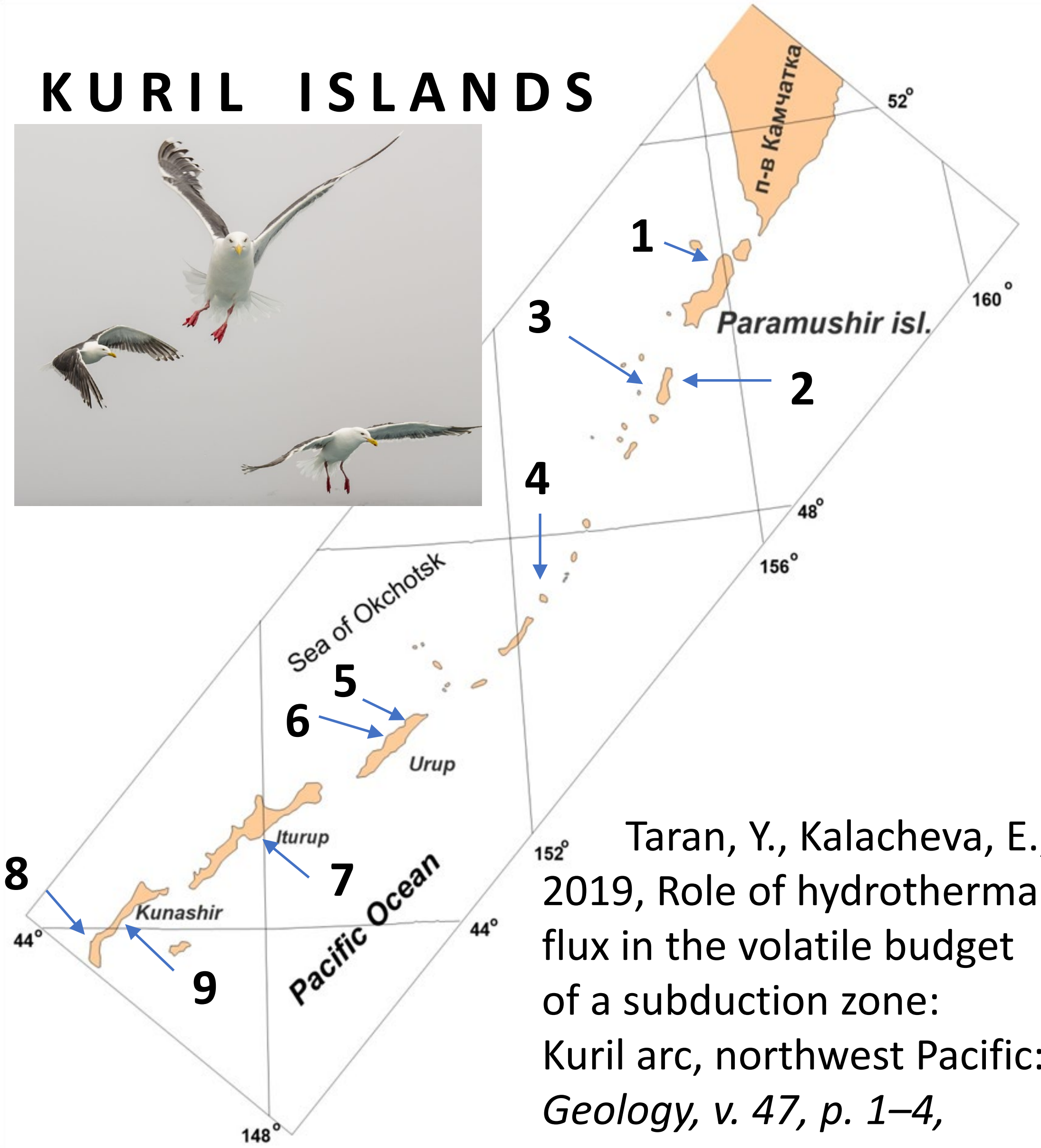
To authors' knowledge, there are no such systems in Kamchatka and New Zealand

JAPAN
*

Kimbara and Sakaguchi (1989) Geology, distribution of hot springs and hydrothermal alteration zones of major geothermal areas in Japan. *Report of Geological Survey of Japan, 270, 482 pp*.



KURIL ISLANDS



Taran, Y., Kalacheva, E., 2019, Role of hydrothermal flux in the volatile budget of a subduction zone: Kuril arc, northwest Pacific: *Geology, v. 47, p. 1–4,*

Most of the UVW are known in Japan and Kuril Islands

Typical low-pH springs with temperature < 50°C

Possible mechanisms of formation of UVW

Condensation of volcanic gases in groundwaters, recombination of SO_2 to H_2S, S, and HSO_4^-

Shallow or superficial mixing of Cl-Na deep and steam-heated shallow SO_4 waters. SO_4 is the result of oxidation of H_2S by O_2

Hydrolysis of elemental S at high temperature by Cl-Na water

Water-rock interaction with highly altered rock (advanced arigillic alteration) with additional hydrolysis of S

Superficial oxidation of the dissolved and free H_2S of hot hydrothermal Cl-Na fluid.

A combination of two or more mechanisms

Hot Yurieva River. Q ~ 1.5 m3/s, pH < 2, Cl ~ 1 g/l . Paramushir, Kuril Islands

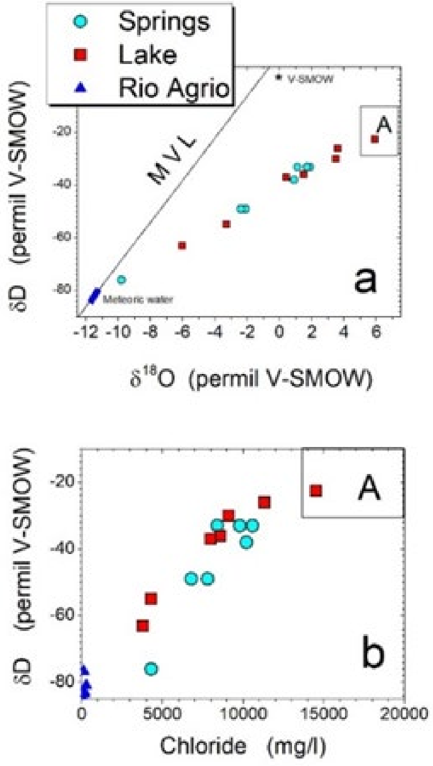
How to choose between the proposed mechanisms?

1. Isotopic composition
   1.1 Water
   1.2 Sulfur

2. Chemical composition
   2.1 Anions
   2.2 Cations

Water isotopes

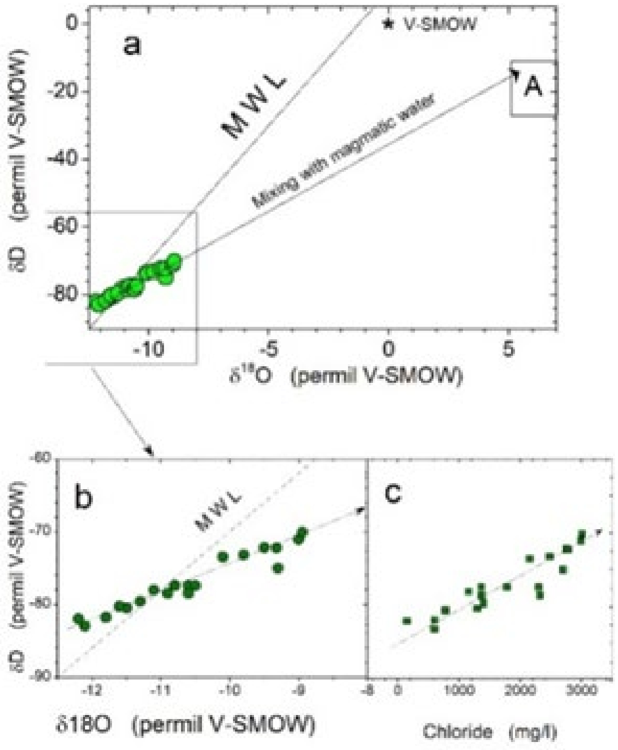
Copahue
(Agusto and Varekamp, 2016)



High Cl concentration, mixing between magmatic and meteoric endmembers. High probability for the mechanism of the condensation of mgmatuc gases in groundwater

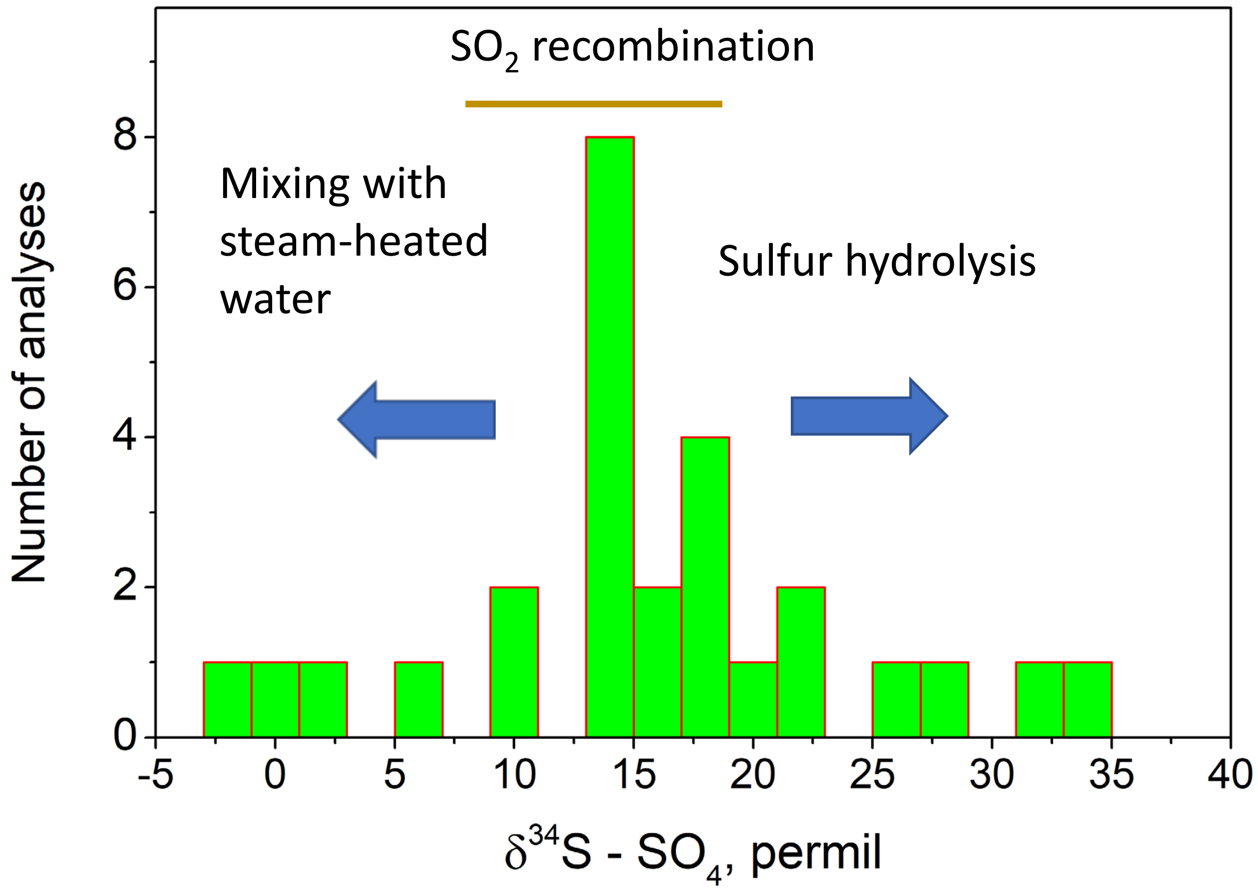
Does not work with low Cl concentration and in tropical zones (high δD in meteoric water)

Yurieva, Paramushir – Kurils
(Kalacheva et al., 2016)

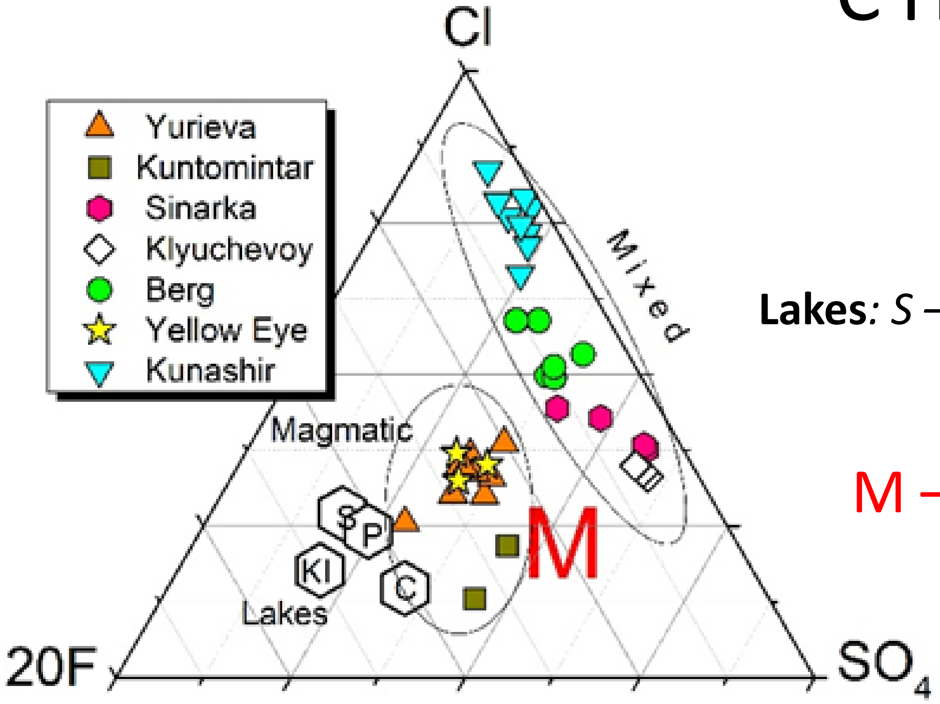


Same, but with much lower Cl concentrations.

Sulfur isotopes



CHEMISTRY

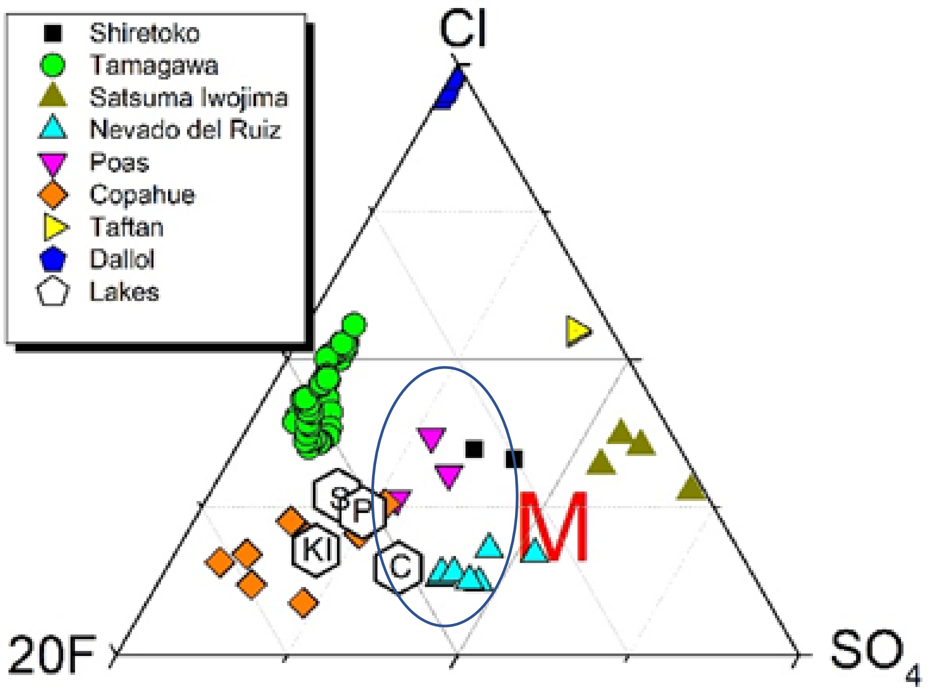


Kuril Islands

Anions

Lakes: *S –Sirung; P – Poas; KI – Kawa Ijen; C – Copahue*

M – magmatic gases



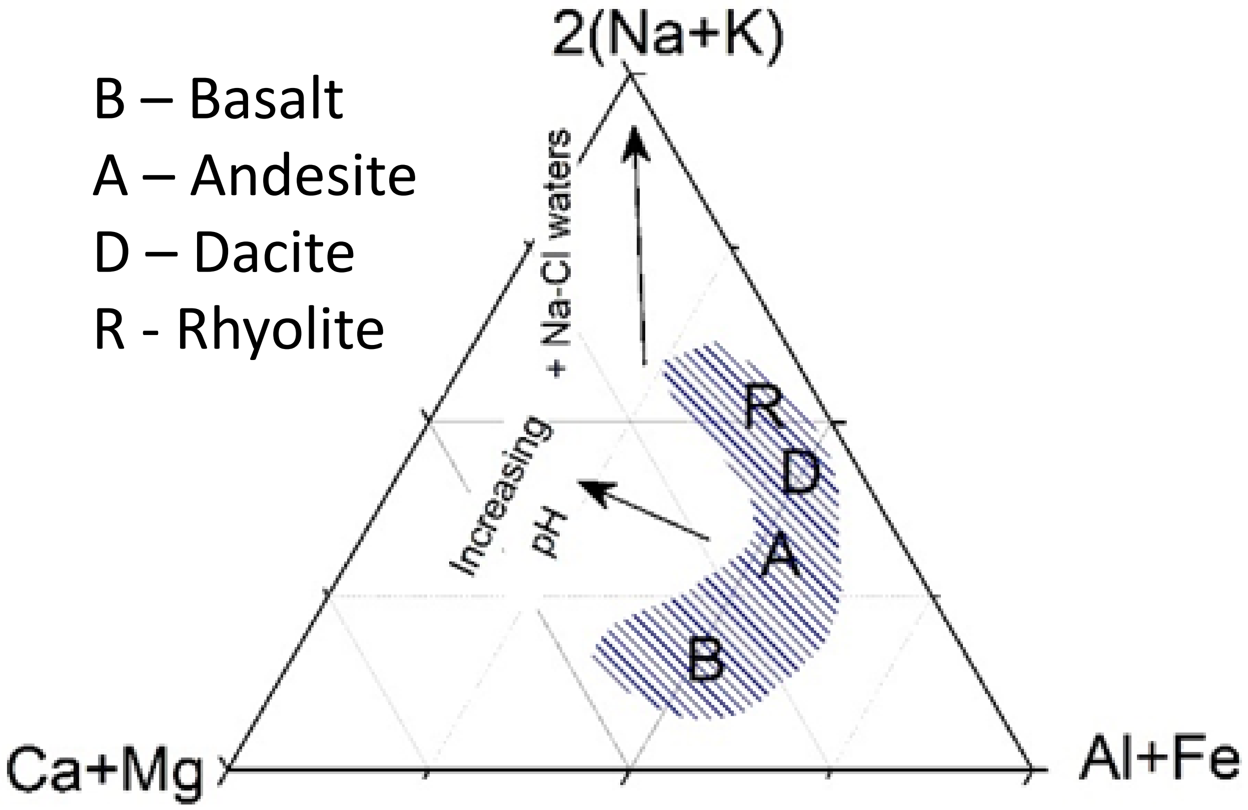
World

Higher Cl, lower F – more hydrothermal component

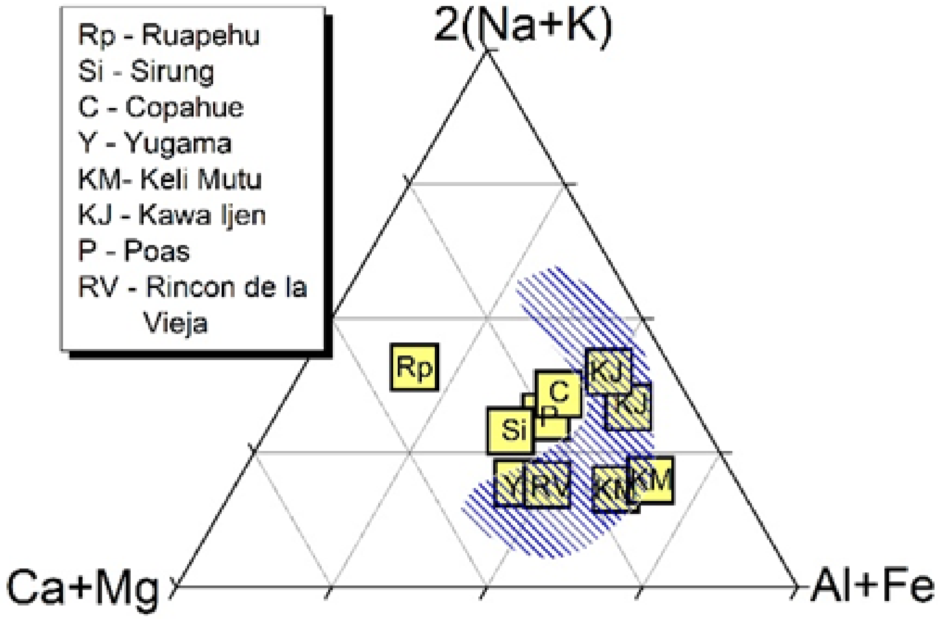
C H E M I S T R Y

Cations

B – Basalt
A – Andesite
D – Dacite
R - Rhyolite



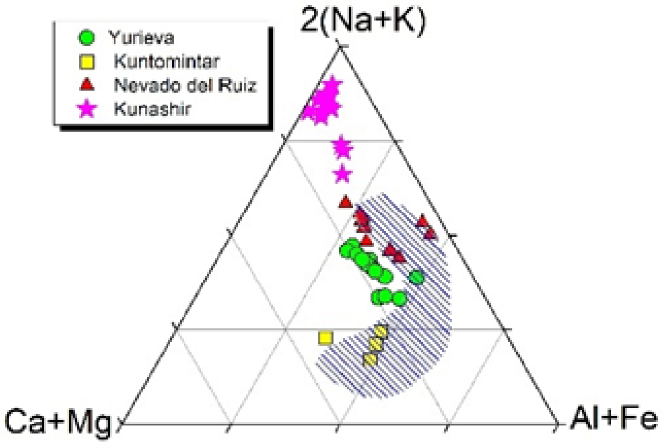
Calc-alkaline rocks



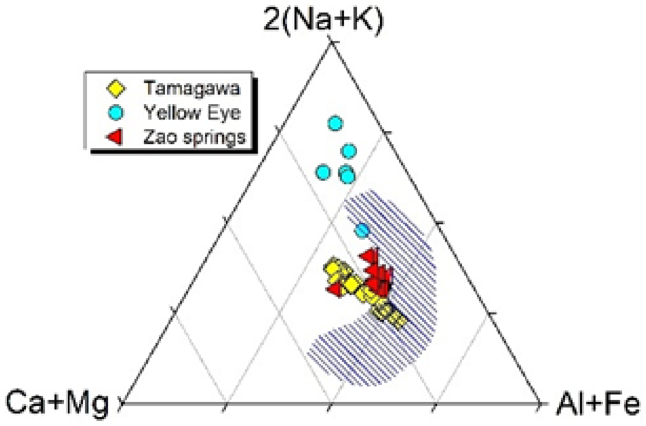
Crater lakes

C H E M I S T R Y

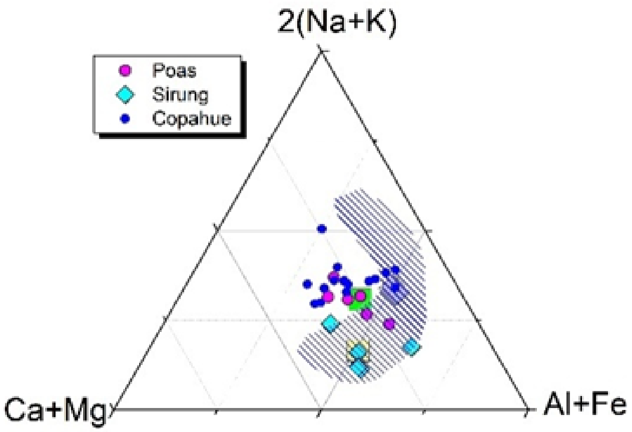
Cations



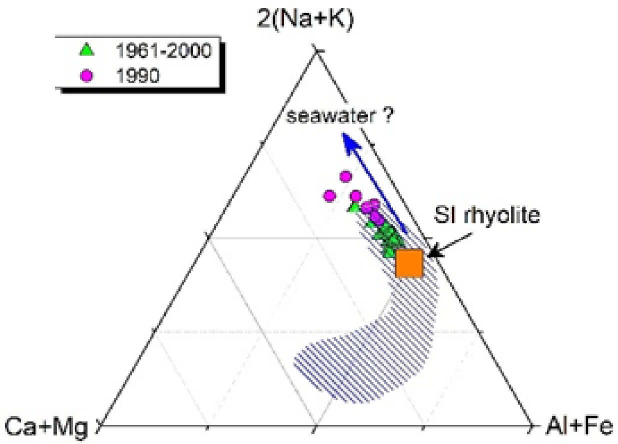
1.5 <p H<2



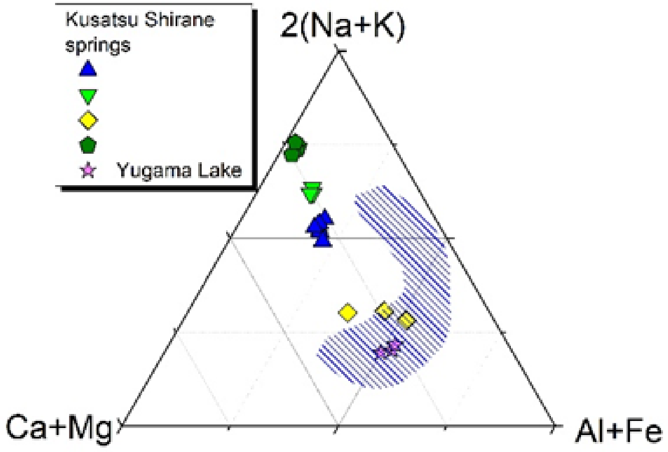
pH < 1.5



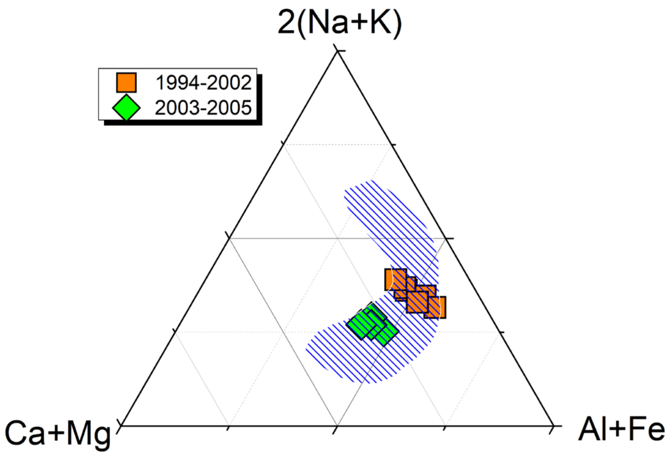
UVW associated with crater lakes



Satsuma Iwojima

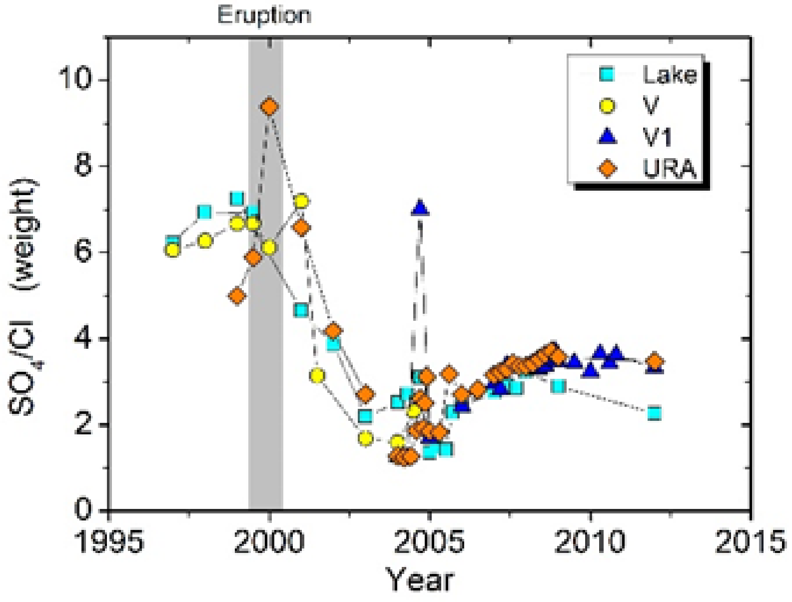


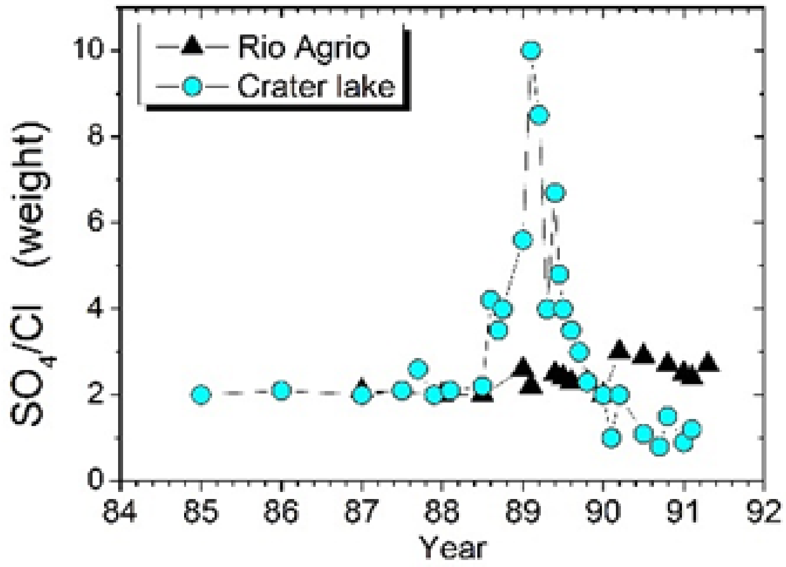
Kusatsu Shirane



Papandayan

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS
1. UVW associated with crater lakes: Copahue and Poás





Copahue: spring V1 and Rio Agrio repeat variations in SO4/Cl recorded for the crater lake. Short recharge time

Poás: Rio Agrio springs repeat SO4/Cl Ratio recorded in the crater lake before 1986 Long recharge time, > 3 years.

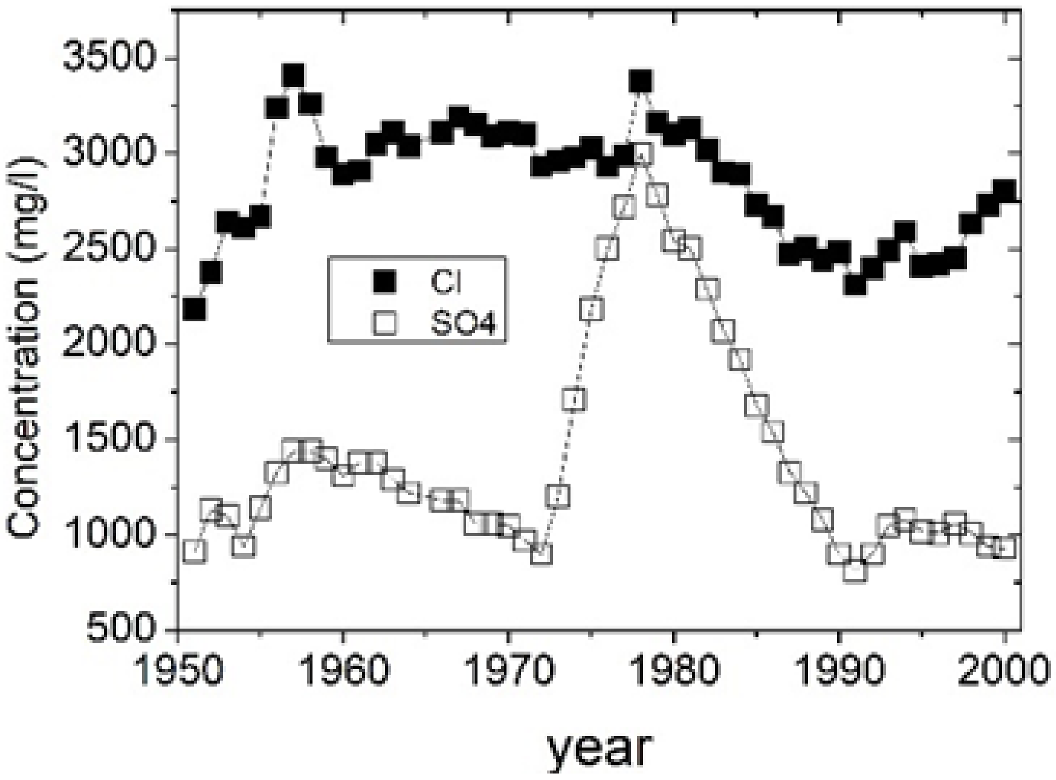
Agusto and Varekamp, 2016; Rowe et al., 1995

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS

2. UVW associated with volcanoes without historical eruptions

Obuki springs, Tamagawa Group, Japan

Yoshiike, 2003



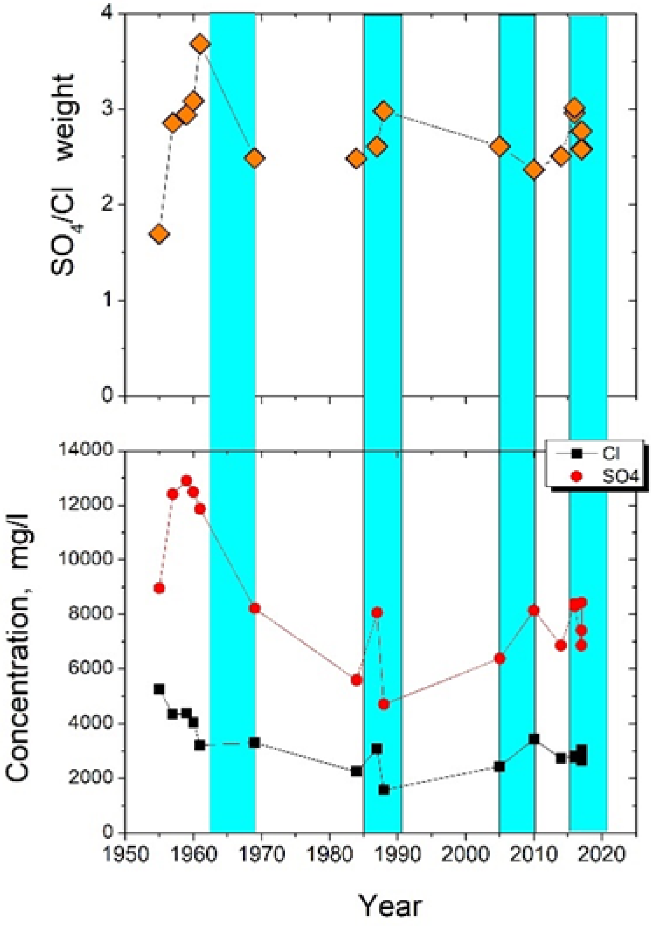
SO4/Cl (weight) from 0.3 to 0.9

Isotopic data suggest a temporal increase in the magmatic contribution

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS

3. UVW associated with volcanoes with phreatic and phreatic-magmatic eruptions

3.1



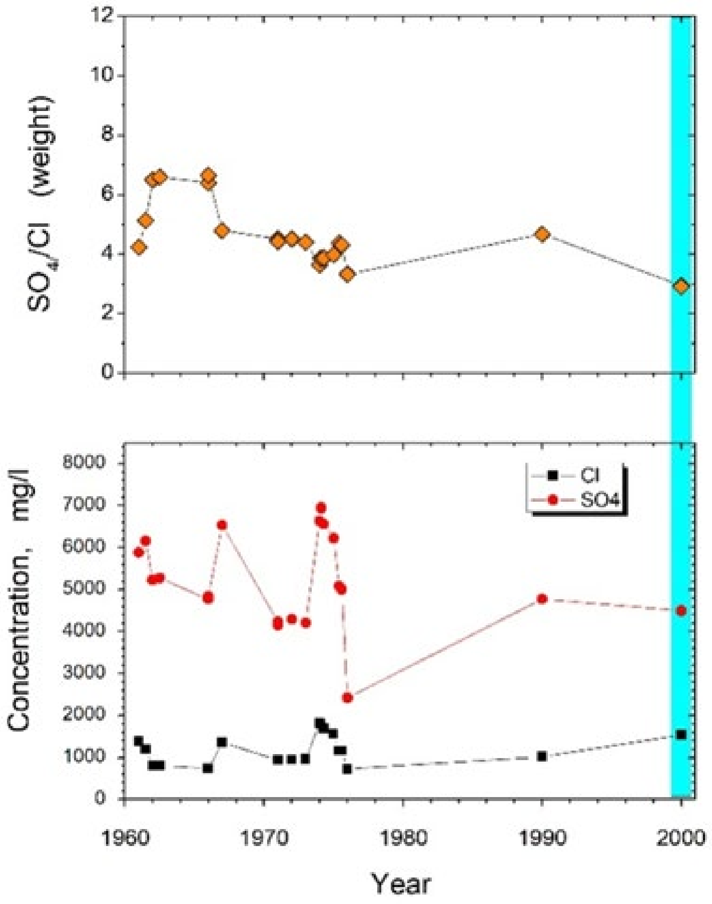
Yurieva Springs, Paramushir, Kuril Islands. 500 m lower the fumarolic fields of Ebeko volcano. 90°C, Flow rate > 200 l/s.
Blue bands – periods of phreatic activity of Ebeko

The response is seen in the increase of concentrations of SO4 and Cl and in the SO4/Cl ratio. Difficult to say about precursors

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS

3. UVW associated with volcanoes with phreatic and phreatic-magmatic eruptions

3.2



Higashi Springs, Satsuma Iwojima Island – volcano 70°C, at the base of the volcano on the seashore. Explosions in the cráter with formation of a small pit crater in 1998

Strong variations in concentrations but not in ratios, and without visible response on the phreatic event.

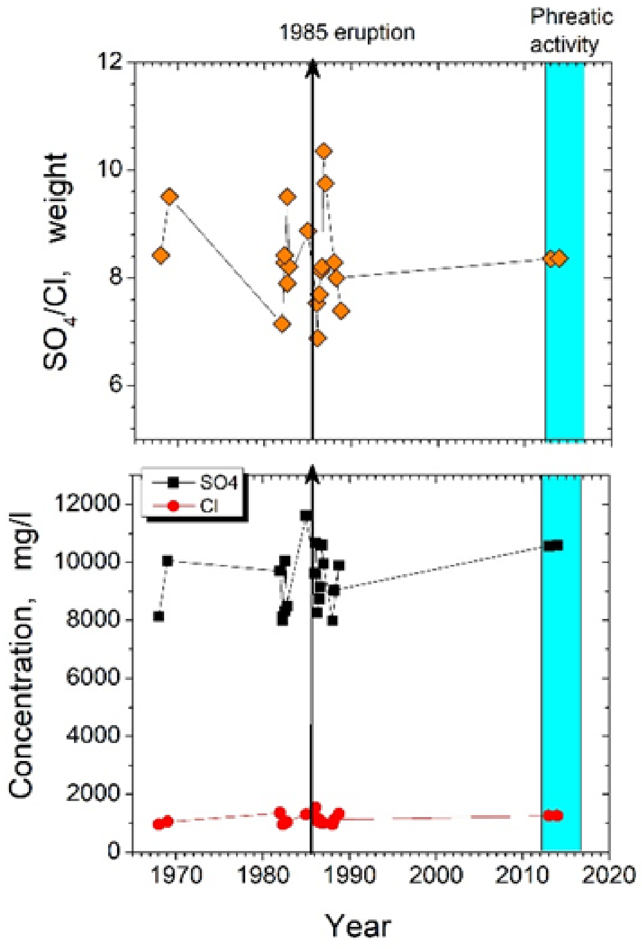
Need more data…

Shinohara et al., 1993; Sakamoto, 2015

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS

3. UVW associated with volcanoes with phreatic and phreatic-magmatic eruptions

3.3



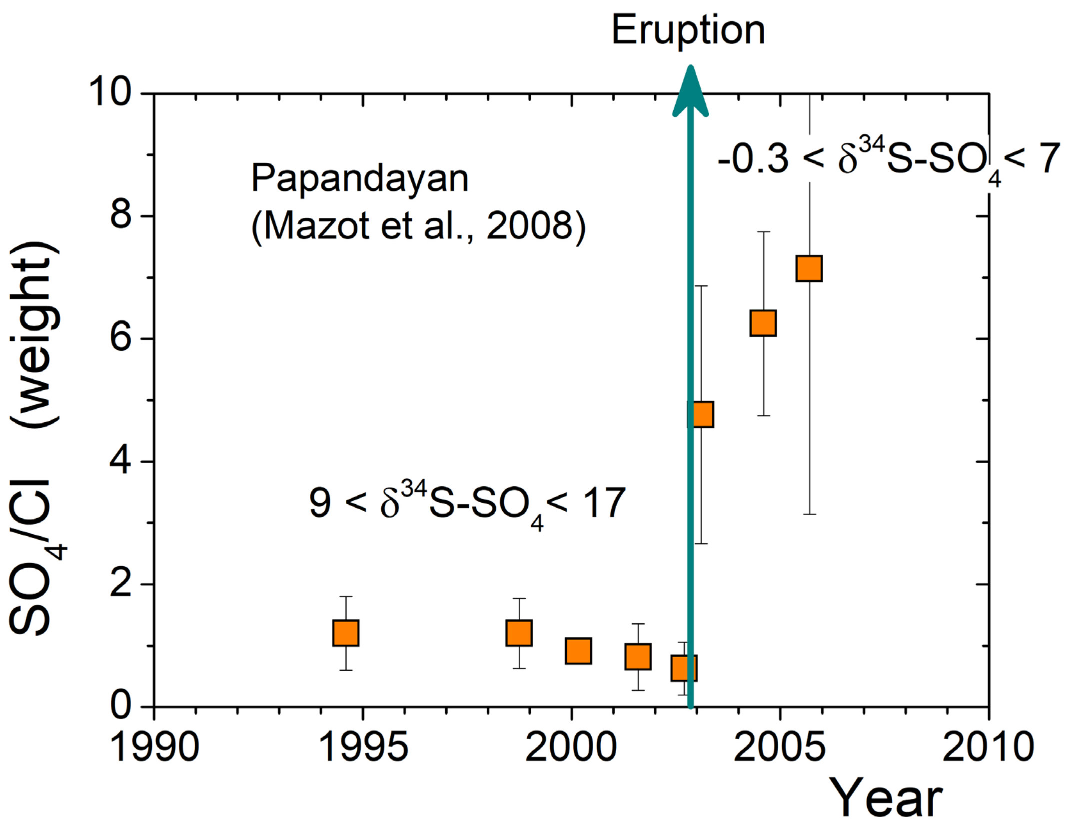
Nevado del Ruiz, Colombia. Agua Caliente springs. Strong fluctuations around the date of the 1985 eruptions in both concentrations and ratios. No more data

Sturchio et al., 1990, Federico et al., 2017

TEMPORAL VARIATIONS OF ULTRA-ACID VOLCANIC WATERS

3. UVW associated with volcanoes with phreatic and phreatic-magmatic eruptions

3.4



Papandayan volcano, Java, Indonesia

Acidic springs. Response on the phreatic eruption in November 2002. Increase in the SO4/Cl ratio with additional contribution of sulfate from hydrothermal source (see differences in the sulfur isotopic composition of disolved sulfate)

Mazot et al., 2008

CONCLUSIONS

- The data are presented on the chemical composition of more than 30 systems of ultra-acid thermal waters discharging on the slopes of volcanoes in various volcanic regions of the world (UVW - ultra-acidic volcanic waters).

- The systematics of these waters is presented based on their chemical composition, the isotopic composition of sulfur sulfate and partially based on the isotopic composition of water.

- The mechanisms of formation of UVW are discussed and it is shown how, using their anionic and cationic composition, as well as the isotopic composition of sulfur sulfate, it is possible to interpret the features of formation of a specific UVW system.

- Temporal variations in the composition of some UVW systems are shown, with relation to the discussion of the problem of UVW monitoring in order to track the activity of the host volcano. It is assumed that an important parameter in this case is the recharge time of the system. Only with short recharge times the UVW chemical response may precede the observed volcano activity, and monitoring can make sense.


THANK YOU