Does the Denjozan Fault intersect the Sabae Fault?
~Fault route tracing by using bicarbonate ions as tracers~

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[Abstract] We investigated the relationship between the Denjozan Fault and the Sabae Fault located in the Reihoku region of Fukui Prefecture, by using bicarbonate ions as tracers. As a result, we found out that the Denjozan Fault extends move westward from the route shown on the active fault map by the Geospatial Information Authority of Japan. We also found the Denjozan Fault reaches just before the Sabae Fault, but does not intersect it. This means the Sabae Fault is more dominant than Denjozan Fault. We could not clarify the position of the Denjozan Fault in this research, so we will try to elucidate it in the future.

1 Introduction

There are many active faults in the Reihoku area, Fukui Prefecture. The Sabae Fault is one of them, a reverse fault and extending in a direction from southern Fukui City to Echizen City. The latest activity of this fault is thought that it may be slide at 500-3000 years ago, and this area has attracted attention as less seismic area. (Okamoto et al., 2010) (Fig.1). Further, there is another active fault named Denjozan Fault which extends from southeastern Fukui City to eastern Sabae City. It is a reverse fault with a lateral displacement component. Okamoto et al.(2008) pointed out that the Denjozan Fault may be a boundary of seismic activity because of the difference strike for the Fukui Plain East Margin Fault Zone and the Neotani Fault system at the Denjozan Fault (Fig. 2). Actually, in the Fukui Earthquake (1948, M7.1) and the Nobi Earthquake (1891, M8.0), faults' rupture did not progress beyond the Denjozan Fault that boundary (Okamoto et al., 2008). We elcidated the Denjozan Fault will reach to the seismic blank area near the Sabae Fault or not. Okamoto speculate that the Denjozan Fault intersects the Sabae Fault near Chudoin (Fig.3) in Sabae City. Water of the pond at Chudoin began to gush at a crack (Fig.4) from the November 2, 2018 earthquake (Kii Channel).

The fault crossing is one of the important problems in topography but hasn't been studied in detail. The relationship between the Denjozan Fault and the Sabae Fault is unknown. However, the relationship between active faults is extremely important information when considering disaster prevention at seismic blank. Therefore, we investigated the relationship between the Denjozan Fault and the Sabae Fault, and confirm whether they intersect or not.

2 Method

Tracers are sometimes used to pick up the route of a streams. In a previous study, we researched by tracing the route of the Sabae Fault by using the tracers. The method is observing fluoride ions in spring water and groundwater (Ishizuka et al., 2020; Otomo et al., 2021; Adachi et al., 2022). Therefore, we first investigated substances that we could be used as tracers for the Denjozan Fault. But, we could not find out fruoride ion such water. We focused on bicarbonate springs. Carbonate springs are called "natural ramune", because the carbon dioxide produced by underground magma is dissolved into groundwater on high concentrations. There are some carbonate springs in Sabae City and the eastern part of Echizen City (Fig.5). This carbonate spring is thought to gush out along the Denjozan Fault. We compared the ions containing in that carbonate spring with water in Chudoin Pond. The concentration of bicarbonate ions was determined by using bromocresol green/methyl red ethanol solution as reagent. And, bicarbonate ion concentrations were analyzed by neutralization titration using aforesaid substance as a reagent (Ministry of the Environment, 2014). Other ion concentrations were analyzed by ion chromatography (Educational Research Center). The results are shown in Table 1. The groundwater at Takefu High School was used as a basement data. The spring water at Chudoin, located on the Sabae Fault, contains more fluoride ions than the carbonate springs. On the other hand, the carbonate spring associated with the Denjozan Fault contains little fluoride ions and a large bicarbonate ion. This means that the water quality for Denjozan Fault System is clearly different from the spring water at Chudoin. Therefore, we thought that bicarbonate ions could be used as a tracer of the Denjozan Fault System. The reason is as follows. When a fault exists underground with underground pressure increasing at deep underground, water rise up through the fault zone. If the deep groundwater contains high levels of bicarbonate ions, shallow ground water for rich bicarbonate ion. It is also thought that ground water spread laterally through the fault zone (Fig.6). As a result, the concentration of bicarbonate ion in spring water and groundwater near a fault zone is considered to be higher than that in the surrounding area. This theory has been confirmed by our previous research on fluoride ions at the Sabae Fault(Adachi et al., 2022). Furthermore, by applying Okada (1979), it has been confirmed that this concept can be applied to areas with thick alluvium zone on the fault. Therefore, we traced the route of the Denjozan Fault and investigated its relationship with the Sabae Fault by measuring and comparing the concentrations of bicarbonate and fluoride ions in spring water and groundwater.

3 Result

In this study, shown in the red box in Fig.7, the survey area extends from in Sabae City to northern Echizen City. The route of the Denjozan Fault shown in the active fault map by the Geographical Survey Institute to the Hino- River area in the E-W direction. Table 2 shows the fluoride and bicarbonate ion concentrations in spring water and groundwater at 110 sites those we have been surveyed (Fig.8). However, there were some sites for no sample information (left blank).

Of the results, the bicarbonate ions are shown on the topographic map with color-coded (Fig.9). The locations where carbonate springs do not exist today but where there is evidence of the existence of carbonate springs in the past are indicated on the topographic map by the symbols shown in Fig.9. Fig.10 shows the distribution on bicarbonate ions concentration at 110 sites. By examining the distribution of bicarbonate ions, we were able to infer the line shown by the blue arrows in Fig.10.

4 Consideration

(1) Can bicarbonate ions be used as a tracer for the Denjozan fault?

The fluoride ions that could be used in the Sabae Fault are not so common in the carbonate springs, gushing at pound in association with the Denjozan Fault, as seen in Table 1. Therefore, it cannot be used as a tracer for the Denjozan Fault. In addition, in the area of the Denjozan Fault (the distribution of fluoride ions is discontinuous), so we cannot examine the route.

On the other hand, bicarbonate ions are rich in carbonated springs. But in the area of the Sabae Fault with the exception of the 45 sites in Fig.8, there were no sites where the concentration of bicarbonate ions exceeded 100 mg/L. Therefore, high concentrations of bicarbonate ions are effective tracers of the Denjozan Fault.

(2) Does the Denjozan Fault intersect the Sabae Fault?

The survey revealed that the Denjozan Fault reaches to point 45 in Fig.8 just before the Sabae Fault. This location (point 45 in Fig.8) is on the northwest side of the Sun Dome in Funatsu-cho in Sabae City where an underground passage passes under the JR Hokuriku Line (Fig.11). The Sabae Fault passes through this point. As shown Table 3, the collected groundwater contains bicarbonate ions equivalent to those of a carbonate spring. It also contains fluoride ions rarely found in carbonated spring water, as much as the spring water from Chudoin. Therefore, it contains both properties of spring water from the Denjozan Fault and the Sabae Fault.

However, no points with high bicarbonate ion concentrations have been found western point (Fig.12). We concluded that the Denjozan Fault does not extend west of this point. If the Denjozan Fault is in contact with the Sabae Fault, then groundwater with high concentrations of bicarbonate ions migrating from the east through the fault zone would be spread around the Sabae Fault. However, there were no areas where the bicarbonate ion concentration exceeded 100 mg/L other than in the groundwater in the area surrounding the Sabae Fault. This meaned that the Denjozan Fault is not considered to intersect the Sabae Fault. Therefore, the Sabae Fault is more dominant than the Denjozan Fault.

5 Future

In this study, we measured the concentration of bicarbonate ions of groundwater to investigate the route of the Denjozan Fault. We were able to clarify the following.

· Bicarbonate ion can be used as a tracer of the Denjozan Fault.

· The Denjozan Fault extends westward from the route shown on the active fault map by the Geospatial Information Authority of Japan.

· The Denjozan Fault does not intersect the Sabae Fault, and the Sabae Fault has influence on the Denjozan Fault.

We concluded that one line extends further west than the route in the GSI's active fault map, as shown in Fig.10. However, from a different perspective, there could be two lines as shown in Fig.13. In fig.14, Okamoto (2014) shows the epicenters of earthquakes in the studying area during the period from April 2006 to March 2009 and the routes of the Denjozan Fault and the Shirotsubakiyama Fault shown by the active fault map by the GSI. This figure seems to indicate the existence of the two lines in Fig.13. But since earthquakes tend to occur near estimated faults, the actual faults are thought to pass through the area where the epicenters of earthquakes are concentrated (the area circled in red in Fig.14). This area is about 2,000 to 3,000 m south of the route of the two faults shown on the active fault map by the

GSI, so further investigation is required and will be the subject of a future study.

Thanks

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https://www.gsi.go.jp/top.html (GSI home page)

Figure and Table

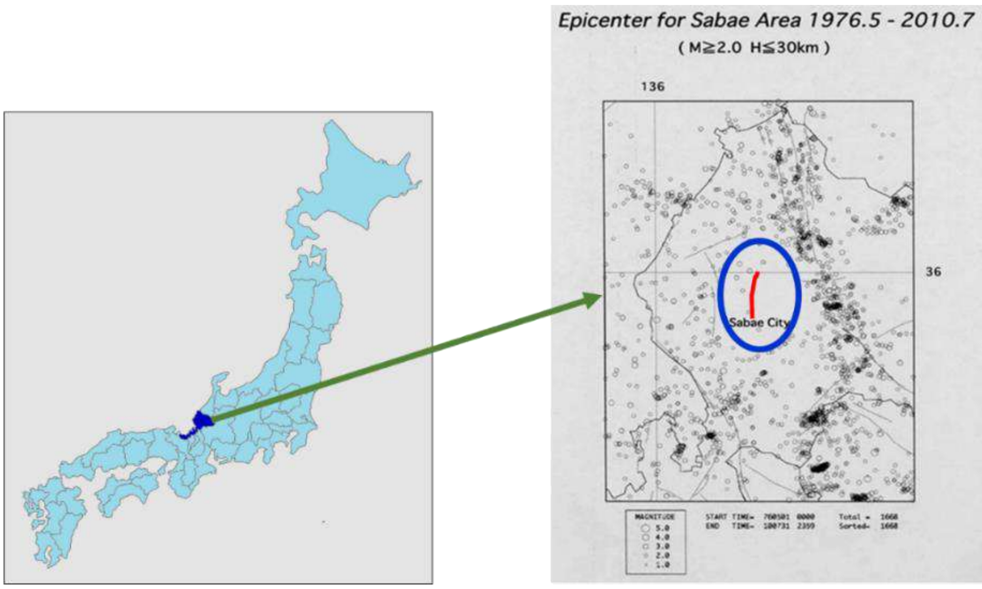

Fig.1 Less Seismic Blank Zone around the Sabae Fault. (Okamoto et al., 2010)

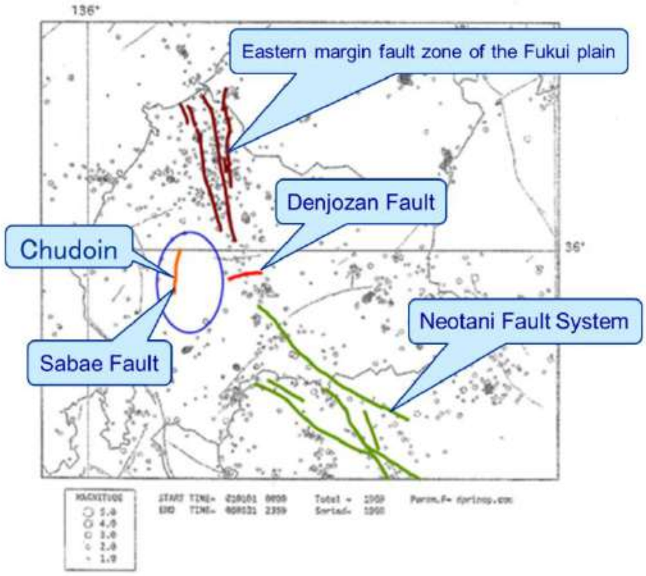

Fig. 6 Distribution of earthquakes with M≧1.0, h ≦30km after Okamoto et al.,2007

Fig.2　Active Faults in the Reihoku Area, Fukui Prefecture. (Okamoto et al., 2008)

Fig.3　Chudoin Temple.

Fig.4　Water gushing from a crack in the pond.

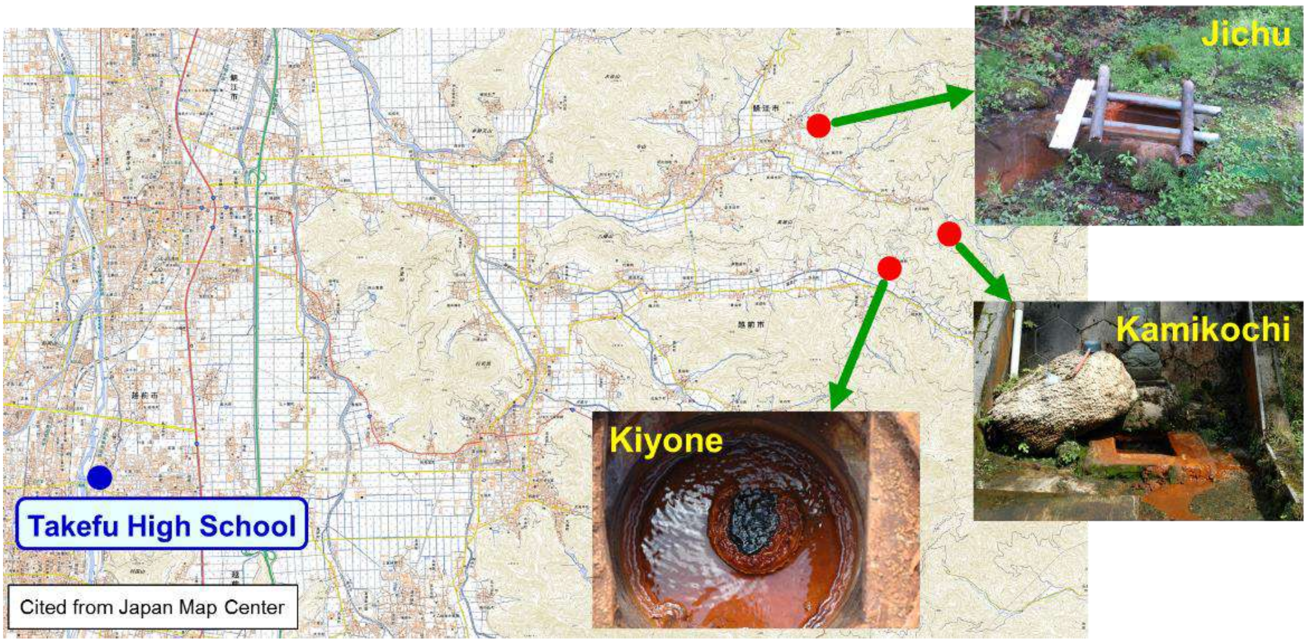

Fig.5　Carbonate springs in Sabae City and the eastern part of Echizen City.

Table1 Ionic Concentration for Carbonate Spring and Chudoin spring water. (unit : mg/L)

Location	F^-	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
Kamikochi	—	unmeasurable	—	122.07	2977.8
Jichu	—	47.85	—	171.90	1751.3
Kiyone	0.02	53.00	—	8.38	1587.7
Chudoin	0.51	14.48	2.16	7.45	81.2
Takefu High Schoo	0.03	8.30	2.06	7.23	33.6

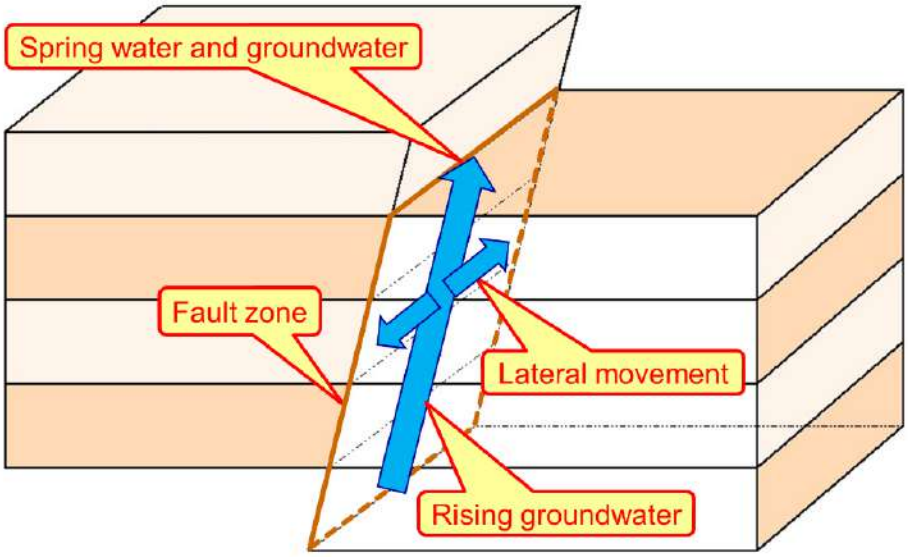

Fig.6 Rising and Movement of Groundwater through Fault zone.

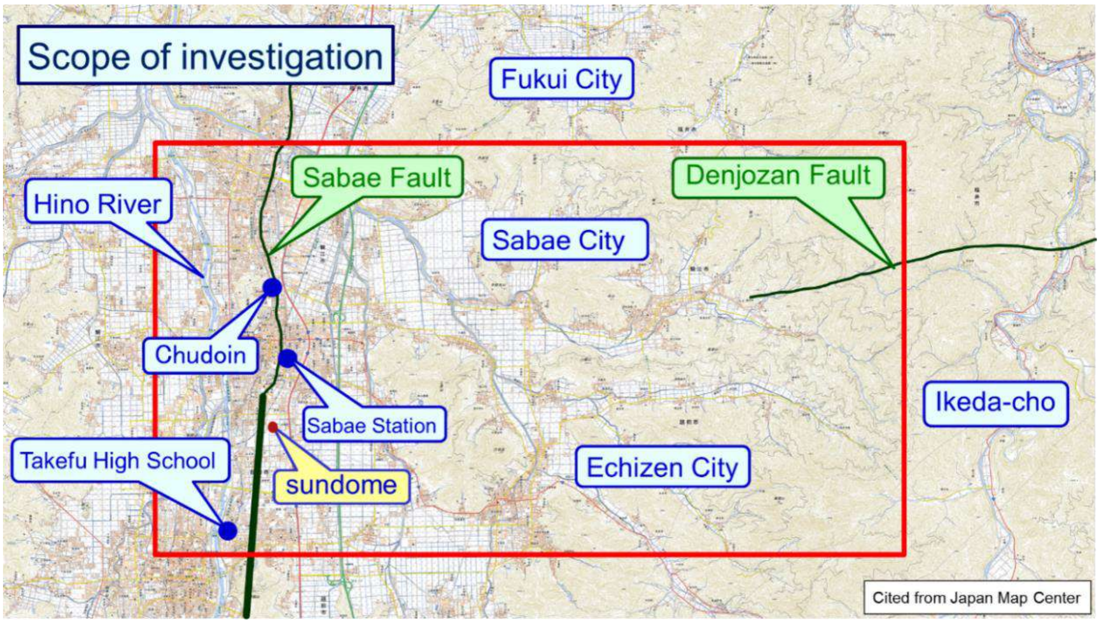

Fig.7 Area of surveying. (inside red frame)

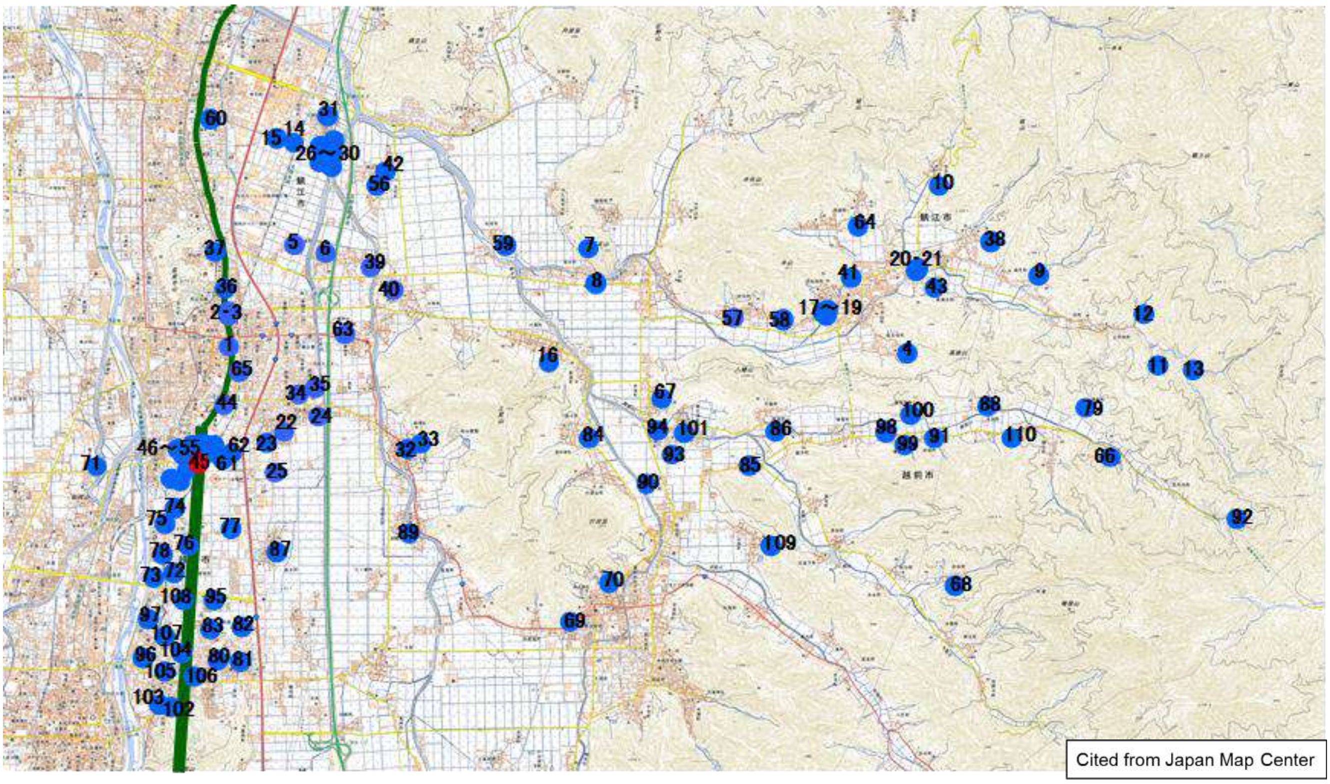

Fig.8 Sampling site.

Phase	Mark
More than 1000	●
500 ～ 999	●
100 ～ 499	●
50 ～ 99	●
less than 50	●
Past carbonate spring records	◆
(unit : mg/L)	

Fig.9 Mark of bicarbonate ions. (ranking)

Table2　Ion concentrations at each survey site. (numbers correspond to Fig. 8)

No	Location	ion concentrations(mg/L)		No	Location	ion concentrations(mg/L)	
		F−	HCO3−			F−	HCO3−
1	2-chome,Asahi-machi,Sabae-Shi	0.023	14	56	Funaeda-cho,Sabae-Shi	0.051	109.8
2	4-chome,Asahi-machi,Sabae-Shi		9.8	57	Besshi-cho,Sabae-Shi		31.7
3	4-chome,Asahi-machi,Sabae-Shi	−	15.3	58	Besshi-cho,Sabae-Shi	0.040	58
4	Azouda-cho,Sabae-Shi	0.024	101.3	59	Matsunari-cho,Sabae-Shi	0.074	440.6
5	Kamikobata-cho,Sabae-Shi		34.8	60	4-chome,Mizuochi-cho,Sabae-Shi		19.5
6	Kamikobata-cho,Sabae-Shi		34.2	61	2-chome,Miyamae-cho,Sabae-Shi		42.1
7	Ochii-cho,Sabae-Shi(Benzaiten-yama)	0.043	45.8	62	2-chome,Miyamae-cho,Sabae-Shi	0.030	36.6
8	Ochii-cho,Sabae-Shi	0.127	168.4	63	Yokogoshi-cho,Sabae-Shi		37.8
9	Obana-cho,Sabae-Shi	0.033	112.9	64	Tsubae,Nishibukuro-cho,Sabae-Shi		68.3
10	Kanadani-cho,Sabae-Shi		79.3	65	Hinode-cho,Sabae-Shi		37.2
11	Kamikochi-cho,Sabae-Shi(Kamikochi-kosen)	−	2977.8	66	Ainoki-cho,Echizen-Shi	0.026	89.1
12	Kamikochi-cho,Sabae-Shi(Sanbazaka-syozu)	0.039	70.8	67	Akasaka-cho,Echizen-Shi	0.024	58.6
13	Kamikochi-cho,Sabae-Shi(Togen-syozu)	0.008	65.9	68	Akadani-cho,Echizen-Shi(Uriwari-syozu)	0.023	50
14	1-chome,Kaminaka-cho,Sabae-Shi		50	69	Awatabe-cho,Echizen-Shi	0.001	47.6
15	2-chome,Kaminaka-cho,Sabae-Shi		35.4	70	Awatabe-cho,Echizen-Shi	0.015	59.2
16	Kawashima-cho,Sabae-Shi	−	4.3	71	Iehisa-cho,Echizen-Shi	0.027	70.8
17	Kawada-cho,Sabae-Shi	0.066	133	72	Inayose-cho,Echizen-Shi	0.023	48.8
18	Kawada-cho,Sabae-Shi	0.065	85.4	73	Uriu-cho,Echizen-Shi	0.059	30.5
19	Kawada-cho,Sabae-Shi	0.079	89.7	74	Uriu-cho,Echizen-Shi	0.022	22.4
20	Kitanaka-cho,Sabae-Shi	0.047	90.9	75	Uriu-cho,Echizen-Shi	0.025	16.3
21	Kitanaka-cho,Sabae-Shi	0.032	90.3	76	Uriu-cho,Echizen-Shi	0.032	38.6
22	Goromaru-cho,Sabae-Shi		37.8	77	Uriu-cho,Echizen-Shi	0.024	42.7
23	Goromaru-cho,Sabae-Shi(Kosarae-syozu)	0.034	35.4	78	Uriu-cho,Echizen-Shi	0.036	38.6
24	Sadatugu-cho,Sabae-Shi		34.2	79	Kiyone-cho,Echizen-Shi	0.020	1587.7
25	Sadatugu-cho,Sabae-Shi		40.3	80	1-chome,Kunitaka,Echizen-Shi	0.032	48.3
26	Shimokobata-cho,Sabae-Shi	0.061	96.4	81	2-chome,Kunitaka,Echizen-Shi	0.076	93.7
27	Shimokobata-cho,Sabae-Shi		37.8	82	3-chome,Kunitaka,Echizen-Shi	0.032	51.6
28	Shimokobata-cho,Sabae-Shi		34.2	83	3-chome,Kunitaka,Echizen-Shi	0.051	30.5
29	Shimokobata-cho,Sabae-Shi		50.7	84	Kuninaka-cho,Echizen-shi	−	502.8
30	Shimokobata-cho,Sabae-Shi		26.9	85	Kudashi-cho,Echizen-Shi	0.014	67.7
31	Shimokobata-cho,Sabae-Shi		54.9	86	Takaoka-cho,Echizen-Shi	0.043	137.9
32	Shimosinjo-cho,Sabae-Shi		58.6	87	Takagi-cho,Echizen-Shi	0.031	46.3
33	Shimosinjo-cho,Sabae-Shi	0.112	299	88	Teraji-cho,Etizen-Shi	0.076	107.4
34	2-chome,Shinyokoe-cho,Sabae-Shi		42.7	89	Nakashinjo-cho,Echizen-Shi		12.2
35	2-chome,Shinyokoe-cho,Sabae-Shi		31.7	90	Nakatsuyama-cho,Echizen-Shi	−	292.3
36	1-chome,Chosenji-cho,Sabae-Shi(osyozu)	0.194	62.2	91	Namigaki-cho,Echizen-Shi		53.7
37	2-chome,Chosenji-cho,Sabae-Shi(Chudoin)	0.510	81.2	92	Nishikochi-cho,Echizen-Shi	0.010	67.1
38	Jichu-cho,Sabae-Shi	−	1751.3	93	Nishisyozakai-cho.Echizen-Shi	0.111	268.5
39	Nakano-cho,Sabae-Shi		25.6	94	Nishisyozakai-cho.Echizen-Shi	0.043	113.5
40	Nakano-cho,Sabae-Shi		28.1	95	Bajyome-cho,Echizen-Shi	0.062	57
41	Nishibukuro-cho,Sabae-Shi	0.036	109.2	96	1-chome,Hachiman(Takefu High School)	0.028	33.6
42	Hashitate-cho,Sabae-Shi	0.082	96.4	97	2-chome,Hachiman,Echizen-Shi	0.068	36.6
43	Higashishimizu-cho,Sabae-Shi	0.051	175.7	98	Haruyama-cho,Echizen-Shi		83
44	1-chome,Fumatsu-cho,Sabae-Shi	0.028	21.4	99	Haruyama-cho,Echizen-Shi		65.3
45	4-chome,Fumatsu-cho,Sabae-Shi	0.208	648	100	Higashikashio-cho,Echizen	0.031	91.5
46	4-chome,Fumatsu-cho,Sabae-Shi	0.034	41.4	101	Higashisyozakai,Echizen	0.042	107.4
47	4-chome,Fumatsu-cho,Sabae-Shi	0.025	58.7	102	1-chome,Murakuni,Echizen-Shi	0.041	34.6
48	4-chome,Fumatsu-cho,Sabae-Shi	0.023	24.4	103	2-chome,Murakuni,Echizen-Shi	0.038	25.4
49	4-chome,Fumatsu-cho,Sabae-Shi	0.031	10.9	104	3-chome,Murakuni,Echizen-Shi	0.039	41.4
50	4-chome,Fumatsu-cho,Sabae-Shi	0.052	21.1	105	3-chome,Murakuni,Echizen-Shi	0.045	41.4
51	4-chome,Fumatsu-cho,Sabae-Shi	0.029	39.2	106	3-chome,Murakuni,Echizen-Shi	0.038	38.6
52	4-chome,Fumatsu-cho,Sabae-Shi	0.036	24.4	107	3-chome,Murakuni,Echizen-Shi	0.042	19.6
53	4-chome,Fumatsu-cho,Sabae-Shi	0.025	43.6	108	4-chome,Murakuni,Echizen-Shi	0.037	56.3
54	4-chome,Fumatsu-cho,Sabae-Shi	0.052	48.8	109	Yamamuro-cho,Echizen-Shi	0.020	79.9
55	4-chome,Fumatsu-cho,Sabae-Shi	0.022	32.7	110	Yokozumi-cho,Echizen-Shi(Enoki-syozu)	0.032	78.7

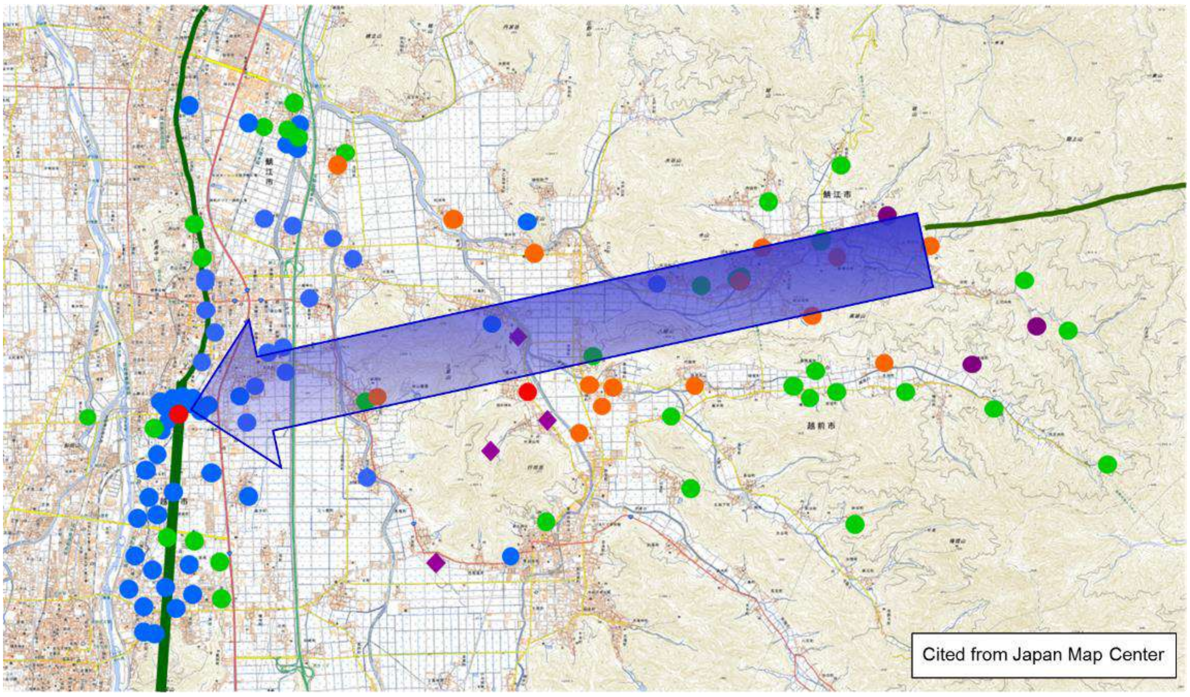

Fig.10　Distribution of bicarbonate ion concentrations in spring water and groundwater.

Fig.11　JR Hokuriku Line underpass.(4-chome,Funatsu-cho,Sabae-Shi)

Table3　Analyzing results of spring water at JR Hokuriku Line underpass.

Location	F^-	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
Kamikochi	—	unmeasurable	—	122.07	2977.8
Jichu	—	47.85	—	171.90	1751.3
Kiyone	0.02	53.00	—	8.38	1587.7
Chudoin	0.51	14.48	2.16	7.45	81.2
Underpass	0.21	21.82	35.66	71.38	648.0
Takefu High Schoo	0.03	8.30	2.06	7.23	33.6

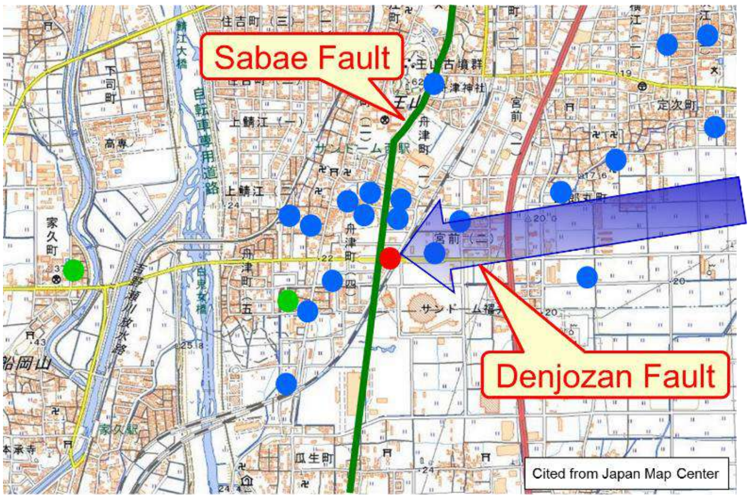

Fig.12　Distribution of bicarbonate ion concentration rank in groundwater around JR Hokuriku Line underground passage. (the red plot is underpass's)

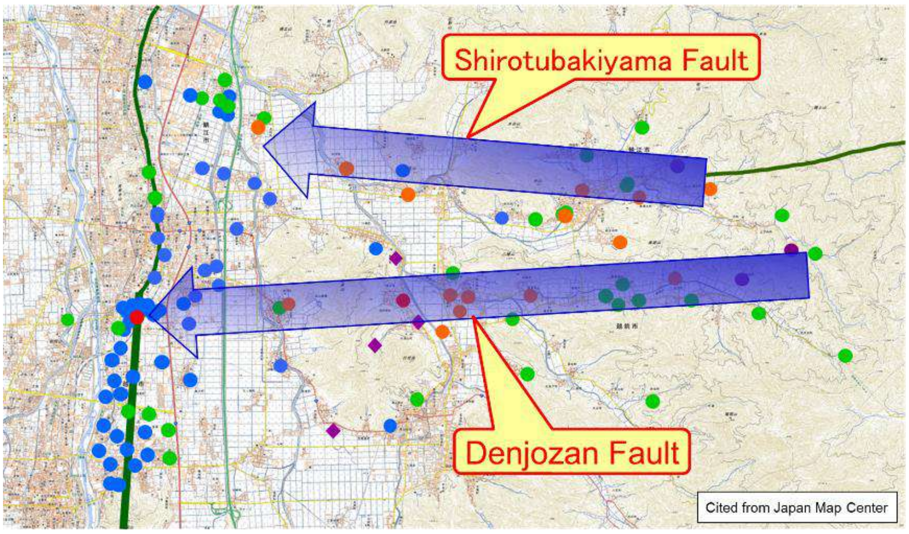

Fig.13　Two lines seen in the analyzing results.

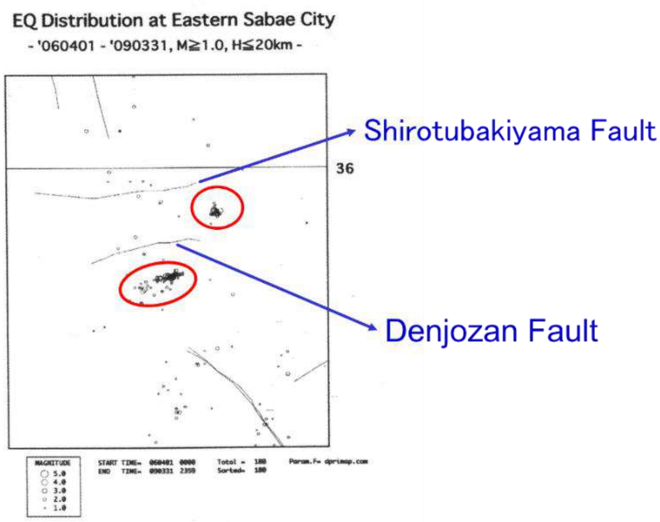

Fig.14　Distribution of two faults and epicenters (The red circle is the Concentrated zone of the epicenter). (Okamoto et al., 2014)