



JAEA-Data/Code

2022-013

DOI:10.11484/jaea-data-code-2022-013

**Data of Groundwater Chemistry Obtained
in the Horonobe Underground Research Laboratory Project
(FY2022)**

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March 2023

Japan Atomic Energy Agency

日本原子力研究開発機構

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(Received December 13, 2022)

In the Horonobe Underground Research Laboratory (URL) project, groundwater chemistry was analyzed to investigate changes due to the excavation of the underground facility and to review geochemical models until the fiscal year 2019. From the fiscal year 2020, to proceed remaining important issues deduced from the conclusion of the investigations during the fiscal year 2015–2019, primary data such as groundwater chemistry need to be successively acquired. Here, the chemical analysis of 54 groundwater samples in 2022 from boreholes drilled in the 140 m, 250 m, 350 m gallery in the Horonobe URL, and water rings settled in three vertical shafts is presented. Analytical results include groundwater chemistry such as pH, electrical conductivity, dissolved components (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Li^+ , NH_4^+ , F^- , Cl^- , Br^- , NO_3^- , NO_2^- , PO_4^{3-} , SO_4^{2-} , Total-Mn, Total-Fe, Al, B, Sr, Ba, I, alkalinity, dissolved organic carbon, dissolved inorganic carbon, CO_3^{2-} , HCO_3^- , Fe^{2+} , sulfide), and $\delta^{18}\text{O}$, δD along with a detailed description of analytical methods.

Keywords: Groundwater, Chemistry, Horonobe URL

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幌延深地層研究計画で得られた地下水の水質データ (2022 年度)

日本原子力研究開発機構
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(2022 年 12 月 13 日受理)

幌延深地層研究計画において、2019 年度までは主に地下施設建設時の坑道掘削に伴う地下水の水質変化の調査や地球化学モデルの構築および見直しを目的として、2020 年度からは必須の課題へ対応するため、地下水の水質データを取得している。2022 年度は、引き続き必須の課題に対応するため、地下施設を利用して得られた地下水の水質データを取得している。地下施設の 140m, 250m および 350m 調査坑道から掘削されたボーリング孔や 3 本の立坑に設置されている集水リングなどから 54 試料の地下水を採取し、分析を実施した。

本報告は、2022 年度に得られた地下水の水質データとして、pH や電気伝導度、溶存成分 (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Li^+ , NH_4^+ , F^- , Cl^- , Br^- , NO_3^- , NO_2^- , PO_4^{3-} , SO_4^{2-} , Total-Mn, Total-Fe, Al, B, Sr, Ba, I, アルカリ度, 溶存有機炭素, 溶存無機炭素, CO_3^{2-} , HCO_3^- , Fe^{2+} , 硫化物) および酸素水素同位体比の測定・分析結果を取りまとめたものである。

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1. Introduction

The surface-based investigation phase (Phase 1) of the Horonobe Underground Research Laboratory (URL) Project started in March 2001, and the Phase I investigations were completed in March 2006. Subsequently, a construction phase (Phase 2, investigations during the URL construction) was initiated during the excavation of the tunnels¹⁾. In parallel with the Phase 2 investigations, an operation phase (Phase 3, research in the URL) at the URL has been started in FY2010, following the construction of a tunnel at the URL¹⁾. The results of phase 2, which was conducted from April 2005 to June 2014 until the completion of the excavation of the 350 m galleries, are summarized by Sato et al²⁾. Since FY2015, we have been working on the important issues identified by the reform of the Japan Atomic Energy Agency, and the results of this research have been compiled by Nakayama et al.³⁾ as the outcome of the third phase of the research project. From FY2020, as part of the Horonobe URL Project after FY2020, we will continue to work on the research results of the essential subjects compiled by Nakayama et al.³⁾, which are considered to require further research and development⁴⁾.

In the Horonobe URL Project, the development of techniques for investigating the characteristics of the subsurface geological environment and modeling techniques based on the obtained geological environmental characteristics were promoted. One of the geological environment models is a groundwater geochemical model. Amano et al.⁵⁾ compiled data on surface water (river water) and groundwater around URL obtained during the first and second phases of investigations from 2001 to 2010 as baseline data for the model. Amano et al.⁵⁾ reported a wide range of existing information on groundwater physicochemical parameters (pH, redox potential, electrical conductivity), water quality (dissolved constituents, oxygen and hydrogen isotopes in water, dissolved gases, organic matter, and microorganisms) from water samples obtained through surface-based investigations (river water, rainwater, groundwater and water extracted from rock cores) in Phase I and from water samples obtained during URL construction in Phase II (water from shaft walls and boreholes excavated from the shafts and galleries).

Water sampling from existing surface boreholes and from within the URL has continued since FY2011. Since FY2013, the third phase of the research using the loop galleries excavated to a depth of 350 m began in earnest. Water sampling from the boreholes excavated from the 350 m galleries has also been underway. The results of these analyses of water samples obtained from FY2011 to 2013 are summarized by Sasamoto et al⁶⁾. After the completion of the Phase 2 study, the Phase 3 study has continued to obtain water quality data mainly to investigate the impact of the construction of underground facilities on groundwater quality. The results of groundwater analyses obtained from FY2014 to 2019 were compiled by Miyakawa et al^{7), 8)}.

After FY2020, data acquisition will be focused on groundwater geochemistry, which is necessary to address critical issues in the Horonobe URL Project^{9), 10)}. This report presents the analytical results of groundwater samples obtained in FY2022.

2. Location and sampling

Groundwater samples were collected from the water rings of the East, West, and Ventilation Shafts (Fig. 1a) and boreholes excavated from each of the galleries (Fig. 1b) at the Horonobe URL located in Horonobe,

Hokkaido. The groundwater sampling method from the water ring was as follows: upwelling groundwater from the surrounding rocks flowed contacting the shotcretes and was collected at 30 to 40 m depth intervals on the shaft wall. Groundwater was collected under open-air conditions through a water sampling hose extending from the water ring to each gallery. Groundwater samples from the water ring correspond to discharging water from the surrounding rocks between the water ring installed one depth above.

Groundwater was sampled from the boreholes excavated from each of the galleries through tubes extending from sampling zones in the boreholes. The groundwater samples were collected from naturally gushing groundwater under open-air conditions. In the 350 m niche no. 4, groundwater from 350 m depth was injected into the area of the full-scale engineered barrier system (EBS) performance experiment. The injection water was sampled for the analysis. In the 350 m niche no. 4, groundwater seeped out from the tunnel wall around the area where the full-scale EBS performance experiment was conducted, and this was collected (Fig. 1b, Water-from-EBS-area). Figure 2 shows pictures of groundwater seeping from the wall around the test site. The URL supplies water for work purposes from an external source. This water was supplied from a depth of approximately 50 m in another borehole settled in the central part of Horonobe town and was analyzed because its origin differs from groundwater collected from a depth of 140-350 m.

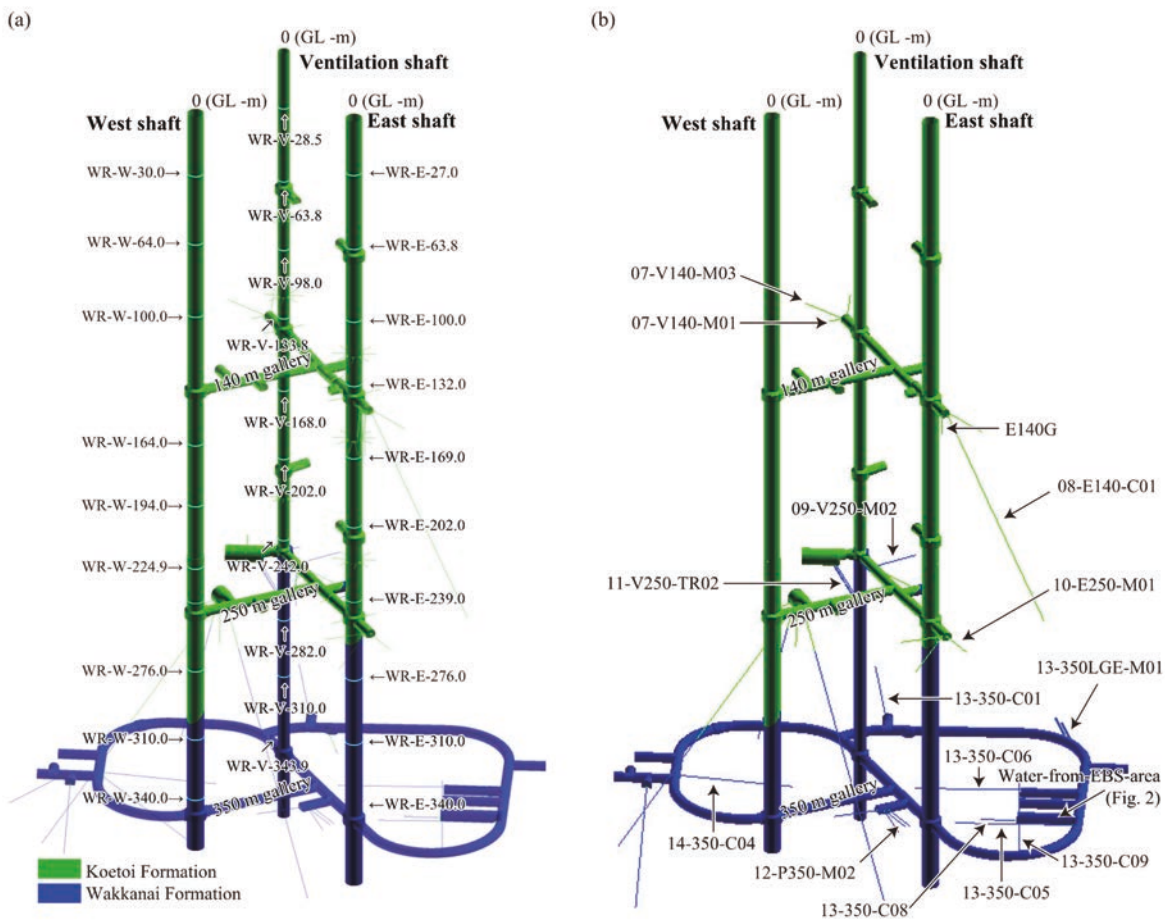


Fig. 1 Schematic illustration of the Horonobe underground research laboratory and location maps of (a) water rings and (b) boreholes



Fig. 2 Picture of sampling point of the water-from-EBS-area

3. Analytical methods

The following items were measured and analyzed: pH, electrical conductivity, water temperature, concentrations of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Li^+ , NH_4^+ , F^- , Cl^- , Br^- , NO_3^- , NO_2^- , PO_4^{3-} , SO_4^{2-} , Total-Mn, Total-Fe, Al, B, Sr, Ba, I, dissolved organic carbon, dissolved inorganic carbon, sulfide (H_2S , HS^-), and alkalinity, oxygen isotope ratios, and hydrogen isotope ratios. Table 1 shows a list of analytical items and methods.

Table 1 List of analytical methods

| Analytical species | Analytical method | Reference | |
|---|--|---|-----------------|
| pH | | JIS K 0102 12.1 | |
| Electric conductivity (EC) | Glass electrode method | JIS K 0102 13 | |
| Temperature | | JIS K 0102 7.2 | |
| HCO ₃ ⁻ CO ₃ ²⁻ | Calculated from pH and DIC content | | |
| M-Alkalinity | Neutralization titration | JIS K 0102 15 | |
| Dissolved organic carbon (DOC) Dissolved inorganic carbon (DIC) | Combustion catalytic oxidation and nondispersive infrared detection | JIS K 0102 22.2 | |
| Na ⁺ | | JIS K 0102 48.3 | |
| K ⁺ | | JIS K 0102 49.3 | |
| Ca ²⁺ | | JIS K 0102 50.4 | |
| Mg ²⁺ | | JIS K 0102 51.4 | |
| Li ⁺ | | JIS K 0127 | |
| NH ₄ ⁺ | | JIS K 0102 42.5 | |
| F ⁻ | Ion chromatography | JIS K 0102 34.3 | |
| Cl ⁻ | | JIS K 0102 35.3 | |
| Br ⁻ | | JIS K 0102 37.2 | |
| NO ₃ ⁻ | | JIS K 0102 43.2.5 | |
| NO ₂ ⁻ | | JIS K 0102 43.1.2 | |
| PO ₄ ³⁻ | | JIS K 0102 46.1.3 | |
| SO ₄ ²⁻ | | JIS K 0102 41.3 | |
| Total-Mn | | | JIS K 0102 56.5 |
| Total-Fe | | | JIS K 0133 |
| Al | | Inductively coupled plasma mass spectrometry | JIS K 0102 58.5 |
| B | JIS K 0102 47.4 | | |
| Sr | JIS K 0133 | | |
| Ba | JIS K 0133 | | |
| I | JIS K 0133 | | |
| | | | |
| Oxygen isotope ratio (δ ¹⁸ O) Hydrogen isotope ratio (δD) | Mass spectrometry | | |
| Fe ²⁺ and total Fe | Phenanthroline absorptiometry | JIS K 0400 57.10 | |
| Sulfide (H ₂ S, HS ⁻ , etc.) | Methylene blue absorptiometry | JIS K 0102 39.1 | |

3.1 pH, electrical conductivity, and temperature

The pH, electrical conductivity, and water temperature of groundwater samples were measured by the glass electrode method. EC/pH meter WM-32EP, pH electrode (GST-2729C), and conductivity cell (CT-2712B) manufactured by DKK-TOA Corp. were used for measurement. The following three reagents were used as pH standard reagents. (1) Powder reagent for phthalate pH standard solution (DKK-TOA Corp.), (2) Powder reagent for phosphate pH standard solution (DKK-TOA Corp.), (3) Powder reagent for tetraborate pH standard solution (DKK-TOA Corp.).

3.2 Dissolved components in groundwater

3.2.1 Na⁺, K⁺, Ca²⁺, Mg²⁺, Li⁺, NH₄⁺, F⁻, Cl⁻, Br⁻, NO₃⁻, NO₂⁻, PO₄³⁻, and SO₄²⁻

Groundwater samples were filtered through a 0.45 µm filter (PES membrane, Millex, Merck Millipore Ltd.), and the concentration of each dissolved ion in the filtrate was analyzed by ion chromatography. The measurement device used was an ion chromatograph IC-2010 manufactured by TOSOH Corp.

For cations: TSKgel SuperIC-CR (TOSOH Corp.) was used as the separation column. Eluents were aqueous solutions of 2 M Methanesulfonic Acid Solution (FUJIFILM Wako Pure Chemical Corp.) and 18-Crown-6 (FUJIFILM Wako Pure Chemical Corp.) prepared to concentrations of 2.2 mM and 1.0 mM, respectively. The eluent flow rate was 0.70 mL/min. The detector was an electrical conductivity detector, and the sample injection volume was 30.0 µL. Multication Standard Solution III from FUJIFILM Wako Pure Chemical Corp. was used as the standard reagent.

For anions: TSKgel SuperIC-Anion HS (TOSOH Corp.) was used as the separation column. The eluents were aqueous solutions of sodium carbonate (FUJIFILM Wako Pure Chemical Corp.) and sodium bicarbonate (FUJIFILM Wako Pure Chemical Corp.) prepared to concentrations of 0.8 mM and 7.5 mM, respectively. The eluent flow rate was 1.0 mL/min. TSKgel suppress IC-A (TOSOH Corp.) was used as the suppressor gel. The detector was an electrical conductivity detector, and the sample injection volume was 30.0 µL. Multication Standard Solution 1 from FUJIFILM Wako Pure Chemical Corp. was used as the standard reagent.

3.2.2 Total-Mn, Total-Fe, Al, B, Sr, Ba, and I

Groundwater samples were filtered through a 0.45 µm filter (PES membrane, Millex, Merck Millipore Ltd.), and the concentration of each dissolved element in the filtrate was analyzed by ICP-mass spectrometry. The analyzer was an Agilent 7700x manufactured by Agilent Technologies International Japan, Ltd. For Total-Mn and Total-Fe, Al, Sr, and Ba, the custom assurance standard (XSTC-331, Spex Certiprep, Inc.) from Seishin Trading Co. Ltd. was used as the standard reagent. The matrix was prepared using a 2% nitric acid solution diluted in ultrapure water (Milli-Q, Academic-A10, Millipore Corp.) with nitric acid (TAMAPURE-AA-10, Tama Chemicals Co. Ltd.). For boron, Boron standard solution (B 1000, FUJIFILM Wako Pure Chemical Corp.) was used as the standard reagent. The matrix was prepared using a 2% nitric acid solution diluted in Milli-Q with nitric acid (TAMAPURE-AA-10, Tama Chemicals Co. Ltd.). For iodine, Anion Standard Iodine (Spex Certiprep, Inc.) from Seishin Trading Co. Ltd. was used as the standard reagent. The matrix was prepared using a 1% TMAH solution of 25% tetramethylammonium hydroxide solution (FUJIFILM Wako Pure Chemical Corp.) diluted with Milli-Q.

3.2.3 M-Alkalinity

Groundwater samples were filtered through a 0.45 µm filter (PES membrane, Millex, Merck Millipore Ltd.) and the alkalinity of the filtrate was determined by titration. SR-100 (Sansyo Co. Ltd.) was used as the magnetic stirrer, and Digital Burette dTrite YA219BA (DLAB Scientific Inc.) as the dispenser. The reagent for titration was prepared at 0.01 M using 1 M sulfuric acid (FUJIFILM Wako Pure Chemical Corp.) diluted in Milli-Q. The pH was measured using a DKK-TOA Corp. multi-water quality meter (MM-43X) and a pH electrode (GST-5846C).

The procedure for measuring M-alkalinity (acid consumption (pH 4.8)) is as follows. 3-12 mL of the sample was taken in a beaker, and the pH meter electrode was dipped in the sample. The sample was titrated with 0.01 M sulfuric acid while stirring in a magnetic stirrer until the pH of the sample reached 4.8. The M-alkalinity was calculated according to the following equations:

$$\text{M-alkalinity (CaCO}_3 \text{ mg/L)} = a \times f \times 1000/v \times 1.00087,$$

$$\text{M-alkalinity (mEq/L)} = a \times f \times 0.02 \times 1000/v,$$

where a is the volume of 0.01 M sulfuric acid required for titration (mL), f is the factor for 0.01 M sulfuric acid, v is the sample's volume (mL), 1.00087 is the equivalent amount of calcium carbonate (mg) in 1 mL of 0.01 M sulfuric acid, and 0.02 is the equivalent hydrogen ion amount (mmol) in 1 mL of 0.01 M sulfuric acid.

3.2.4 Dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC)

Groundwater samples were filtered through a 0.45 μm filter (PES membrane, Millex, Merck Millipore Ltd.). DOC and DIC concentrations in the filtrate were analyzed by combustion oxidation-infrared TOC automated measuring method. The measuring device used was a TOC-V_{CSH} total organic carbon meter (Shimadzu Corp.). Pure air gas was used as the carrier gas. Potassium hydrogen phthalate (FUJIFILM Wako Pure Chemical Corp.) was used as the standard reagent for DOC. Sodium bicarbonate (FUJIFILM Wako Pure Chemical Corp.) and sodium carbonate (FUJIFILM Wako Pure Chemical Corp.) were used as standard reagents for DIC. For the DOC measurement, 2 M hydrochloric acid (FUJIFILM Wako Pure Chemical Corp.) was added to the sample to adjust 4wt% and aired to remove inorganic carbon and volatile organic compounds before measuring DOC concentration. DOC detected in this way does not include volatile organic compounds such as methane gas dissolved in groundwater, which means non-purgeable organic carbon (NPOC). In the DIC measurement, 85wt% phosphoric acid (FUJIFILM Wako Pure Chemical Corp.) was adjusted to 25wt% using Milli-Q to acidify the sample.

3.2.5 CO_3^{2-} and HCO_3^-

From the total carbonate concentration in the sample and the pH of the sample, the CO_3^{2-} and HCO_3^- concentrations were calculated using the following equations. The total carbonate concentration was calculated from the DIC concentration. Table 2 shows the percentages of carbonate and bicarbonate ions at each pH.

$$\text{HCO}_3^- \text{ (mg)} = C \times a \times 1.387.$$

$$\text{CO}_3^{2-} \text{ (mg)} = C \times b \times 1.364.$$

C is the total carbonate concentration (CO_2 mg/L), and a is the percentage of bicarbonate ions present relative to total carbonate. b is the percentage of carbonate ions present relative to total carbonate, 1.387 is the coefficient for converting the amount of total carbonate to bicarbonate ion equivalent (61.02/44.01), and 1.364 is the coefficient for converting the amount of total carbonate to carbonate ion equivalent (60.01/44.01).

Table 2 Abundance ratios of bicarbonate and carbonate ions at pH of 2.0–13.0

| pH | Abundance ratio (25°C) | | pH | Abundance ratio (25°C) | | pH | Abundance ratio (25°C) | |
|-----|------------------------------------|------------------------------------|-----|------------------------------------|------------------------------------|------|------------------------------------|------------------------------------|
| | a (HCO ₃ ⁻) | b (CO ₃ ²⁻) | | a (HCO ₃ ⁻) | b (CO ₃ ²⁻) | | a (HCO ₃ ⁻) | b (CO ₃ ²⁻) |
| 2.0 | 0.00004 | - | 6.0 | 0.30118 | 0.00001 | 10.0 | 0.68012 | 0.31972 |
| 2.1 | 0.00005 | - | 6.1 | 0.35174 | 0.00002 | 10.1 | 0.62814 | 0.37175 |
| 2.2 | 0.00007 | - | 6.2 | 0.40584 | 0.00003 | 10.2 | 0.57300 | 0.42692 |
| 2.3 | 0.00009 | - | 6.3 | 0.46233 | 0.00004 | 10.3 | 0.51597 | 0.48397 |
| 2.4 | 0.00011 | - | 6.4 | 0.51980 | 0.00006 | 10.4 | 0.45852 | 0.54144 |
| 2.5 | 0.00014 | - | 6.5 | 0.57675 | 0.00009 | 10.5 | 0.40215 | 0.59782 |
| 2.6 | 0.00017 | - | 6.6 | 0.63172 | 0.00012 | 10.6 | 0.34824 | 0.65174 |
| 2.7 | 0.00022 | - | 6.7 | 0.68345 | 0.00016 | 10.7 | 0.29796 | 0.70202 |
| 2.8 | 0.00027 | - | 6.8 | 0.73098 | 0.00022 | 10.8 | 0.25213 | 0.74786 |
| 2.9 | 0.00034 | - | 6.9 | 0.77371 | 0.00029 | 10.9 | 0.21123 | 0.78876 |
| 3.0 | 0.00043 | - | 7.0 | 0.81137 | 0.00038 | 11.0 | 0.17541 | 0.82459 |
| 3.1 | 0.00054 | - | 7.1 | 0.84396 | 0.00050 | 11.1 | 0.14455 | 0.85545 |
| 3.2 | 0.00068 | - | 7.2 | 0.87173 | 0.00065 | 11.2 | 0.11833 | 0.88166 |
| 3.3 | 0.00086 | - | 7.3 | 0.89508 | 0.00084 | 11.3 | 0.09634 | 0.90366 |
| 3.4 | 0.00108 | - | 7.4 | 0.91445 | 0.00108 | 11.4 | 0.07807 | 0.92193 |
| 3.5 | 0.00136 | - | 7.5 | 0.93036 | 0.00138 | 11.5 | 0.06303 | 0.93697 |
| 3.6 | 0.00171 | - | 7.6 | 0.94326 | 0.00177 | 11.6 | 0.05072 | 0.94928 |
| 3.7 | 0.00216 | - | 7.7 | 0.95361 | 0.00225 | 11.7 | 0.04072 | 0.95928 |
| 3.8 | 0.00271 | - | 7.8 | 0.96178 | 0.00285 | 11.8 | 0.03261 | 0.96739 |
| 3.9 | 0.00341 | - | 7.9 | 0.96811 | 0.00362 | 11.9 | 0.02608 | 0.97392 |
| 4.0 | 0.00429 | - | 8.0 | 0.97285 | 0.00457 | 12.0 | 0.02083 | 0.97917 |
| 4.1 | 0.00540 | - | 8.1 | 0.97623 | 0.00578 | 12.1 | 0.01662 | 0.98338 |
| 4.2 | 0.00678 | - | 8.2 | 0.97839 | 0.00729 | 12.2 | 0.01324 | 0.98676 |
| 4.3 | 0.00853 | - | 8.3 | 0.97942 | 0.00919 | 12.3 | 0.01055 | 0.98945 |
| 4.4 | 0.01071 | - | 8.4 | 0.97939 | 0.01156 | 12.4 | 0.00840 | 0.99160 |
| 4.5 | 0.01345 | - | 8.5 | 0.97828 | 0.01454 | 12.5 | 0.00668 | 0.99332 |
| 4.6 | 0.01687 | - | 8.6 | 0.97604 | 0.01827 | 12.6 | 0.00531 | 0.99469 |
| 4.7 | 0.02114 | - | 8.7 | 0.97258 | 0.02291 | 12.7 | 0.00423 | 0.99577 |
| 4.8 | 0.02647 | - | 8.8 | 0.96774 | 0.02870 | 12.8 | 0.00336 | 0.99664 |
| 4.9 | 0.03310 | - | 8.9 | 0.96130 | 0.03590 | 12.9 | 0.00267 | 0.99733 |
| 5.0 | 0.04132 | - | 9.0 | 0.95299 | 0.04480 | 13.0 | 0.00212 | 0.99788 |
| 5.1 | 0.05147 | - | 9.1 | 0.94248 | 0.05578 | | | |
| 5.2 | 0.06394 | - | 9.2 | 0.92939 | 0.06925 | | | |
| 5.3 | 0.07919 | - | 9.3 | 0.91328 | 0.08566 | | | |
| 5.4 | 0.09769 | - | 9.4 | 0.89365 | 0.10553 | | | |
| 5.5 | 0.11995 | - | 9.5 | 0.87002 | 0.12934 | | | |
| 5.6 | 0.14645 | - | 9.6 | 0.84194 | 0.15757 | | | |
| 5.7 | 0.17764 | - | 9.7 | 0.80901 | 0.19061 | | | |
| 5.8 | 0.21380 | - | 9.8 | 0.77102 | 0.22870 | | | |
| 5.9 | 0.25504 | - | 9.9 | 0.72796 | 0.27183 | | | |

3.2.6 Fe²⁺ and total Fe (Fe²⁺ HACH and Total-Fe HACH)

Groundwater samples were filtered through a 0.45 μm filter (PES membrane, Millex, Merck Millipore Ltd.), and the concentration of dissolved iron in the filtrate was analyzed by 1, 10-phenanthroline absorption spectrophotometry. The analyzer used was an absorption spectrophotometer DR2800 (HACH Company).

The analysis procedure is as follows. 1,10-phenanthroline reagent (HACH Cat. 1037-69) was added to the sample solution, stirred, and stood for 3 minutes. The absorbance at a wavelength of 510 nm was measured, and the concentration of divalent iron was determined using the calibration curve provided with the instrument. For total iron, 1,10-phenanthroline reagent and reducing agents such as sodium hyposulfite (HACH Cat. 21057-69) were added to the sample solution, stirred, allowed to stand for 3 minutes, and the absorbance at a wavelength of 510 nm was measured and determined using the calibration curve provided

with the instrument. This analysis was conducted in the field immediately after sample collection.

3.2.7 Sulfide (H_2S , HS^-) (HS⁻ HACH)

Groundwater samples were filtered through a 0.45 μm filter (PES membrane, Millex, Merck Millipore Ltd.), and the dissolved sulfide concentration in the filtrate was analyzed by methylene blue absorption spectrophotometry. The analyzer used was an absorption spectrophotometer DR2800 (HACH Company).

The analysis procedure is as follows. A sulfuric acid reagent containing N, N-dimethyl-p-phenylenediamine and dichromic acid reagent (HACH Cat. 1816-32 and 1817-32) was added to the sample solution, stirred, and allowed to stand for 5 minutes. The absorbance was measured at a wavelength of 665 nm, and the concentration of sulfide was determined using the calibration curve provided with the instrument. This analysis was conducted in the field immediately after sample collection.

3.3 Isotope analysis

3.3.1 Oxygen isotope ratio ($\delta^{18}\text{O}$)

Groundwater samples were filtered through a 0.45 μm filter (PES membrane, Millex, Merck Millipore Ltd.), and the oxygen isotope ratio of the filtrate was measured by mass spectrometry. Oxygen isotopic ratio analysis was performed using an equilibrium pretreatment device for solution (iso FLOW for solution, Elementar Inc.) and a stable isotope ratio mass spectrometer (isoprime precisION, Elementar Inc.).

First, the sample was filtered through a filter with a pore diameter of 0.2 μm , and 200 μL of the filtrate was sealed in a designated vial. Then the appropriate amount of CO_2 was added to the headspace of each vial. The vials were kept at 30°C for at least 12 hours to allow the equilibrium of O in water of the sample solution and CO_2 in the headspace. The preliminary experiment confirmed that isotopic equilibrium was achieved in the vial when solution and CO_2 were contacted over 12 hours. The laboratory standard samples that have known isotopic ratios of oxygen were also sealed into vials in the same manner. These operations were performed using iso FLOW for solution.

Prior to the analysis, a "Stability test" was performed. The warming up of the device was followed by the measurement of reference gas (CO_2 gas) several times. After confirming that the device was sufficiently stable, the sample was analyzed. At least 12 hours after CO_2 injection, a portion of the headspace gas was taken, and the gas was passed through a GC column to extract CO_2 . The isotopic ratio of O in CO_2 was measured with a mass spectrometer. A calibration curve was obtained from the relationship between the analyzed values and known isotopic ratios in lab standards, and the calibration curve was used to convert the analyzed values to isotope ratios. The analysis was conducted three times, and the average value of the three times was used as the analytical value.

The analysis results are expressed as the delta value (δ) as the thousandths of the deviation from the standard substance of Vienna Standard Mean Ocean Water (VSMOW), which is expressed by the following equation,

$$\delta = (R)_{\text{sample}} / (R)_{\text{VSMOW}} - 1,$$

where R is the oxygen isotope ratio ($^{18}\text{O}/^{16}\text{O}$).

3.3.2 Hydrogen isotope ratio (δD)

Groundwater samples were filtered through a 0.45 μm filter (PES membrane, Millex, Merck Millipore Ltd.) and the hydrogen isotope ratio of the filtrate was measured by mass spectrometry. Hydrogen isotopic ratio analysis was performed using an equilibrium pretreatment device for solution (iso FLOW for solution, Elementar Inc.) and a stable isotope ratio mass spectrometer (isoprime precisION, Elementar Inc.).

First, the sample was filtered through a filter with a pore diameter of 0.2 μm , and 200 μL of the filtrate was sealed in a designated vial. A platinum coil was placed in the vial to accelerate the equilibrium reaction. Then the appropriate amount of H_2 was added in the headspace of each vial. The sample were kept at 30°C for at least 12 hours to allow the equilibrium of H in water of the sample solution and H_2 in the headspace. The preliminary experiment confirmed that isotopic equilibrium was achieved in the vial when solution and H_2 were contacted over 12 hours. The laboratory standard samples that have known isotopic ratios of oxygen were also sealed into vials in the same manner. These operations were performed using iso FLOW for solution.

Prior to the analysis, a " H_3 factor test" and a "Stability test" were performed. The warming up of the device was followed by the H_3 factor test and the H_3 factor was determined and used to correct the effect of H_3 to HD. Then the reference gas (H_2 gas) was measured several times to confirm the stability of the device. After confirming that the device was sufficiently stable, the sample was analyzed. At least 12 hours after hydrogen injection, a portion of the headspace gas was taken, and the gas was passed through a GC column to extract H_2 . The isotopic ratio of H in H_2 was measured with a mass spectrometer. A calibration curve was obtained from the relationship between the analyzed values and known isotopic ratios in lab standards, and the calibration curve was used to convert the analyzed values to isotope ratios. The analysis was conducted three times, and the average value of the three times was used as the analytical value.

The analysis results are expressed as the delta value (δ) as the thousandths of the deviation from the standard substance of Vienna Standard Mean Ocean Water (VSMOW), which is expressed by the following equation,

$$\delta = (R)_{\text{sample}} / (R)_{\text{VSMOW}} - 1$$

where R is the hydrogen isotope ratio (D/H).

4. Results

Table 3 shows the measurement and analysis results, along with the sampling point's depth information and coordinates. The measurement dates in Table 3 refer to the total period required for each analysis. "Total-Fe HACH," " Fe^{2+} HACH," and " HS^- HACH" correspond to the results of the on-site analysis immediately after sample collection, as described in Sections 3.2.6 and 3.2.7. A blank field for an analyte in a sample means no analysis has been performed. The sample of index no. 52 is groundwater supplied from a depth of about 50 m in the central part of Horonobe-town.

4.1 Ion balance

To evaluate the results of the analysis of dissolved constituents in groundwater, assuming that all elements are dissolved as ions, we calculated the total equivalent of cations (Σ_{cation}) and anions (Σ_{anion}) dissolved in groundwater and checked whether electroneutrality was maintained for the balance of charges (Table 3).

In the calculations, Na^+ , K^+ , NH_4^+ , Li^+ , Ca^{2+} , and Mg^{2+} were used as cations and F^- , Cl^- , Br^- , NO_3^- , SO_4^{2-} , PO_4^{3-} , HCO_3^- , and CO_3^{2-} as anions. Friedman and Erdmann¹¹⁾ have presented a range of ion balances, based on Σ_{anion} , that are considered desirable for groundwater that meets each of the following conditions. (1) For $\Sigma_{\text{anion}} = 0.0\text{--}3.0$ mEq/L: $|\Sigma_{\text{anion}} - \Sigma_{\text{cation}}| < 0.2$ mEq/L. (2) For $\Sigma_{\text{anion}} = 3.0\text{--}10.0$ mEq/L: $|(\Sigma_{\text{anion}} - \Sigma_{\text{cation}})/(\Sigma_{\text{anion}} + \Sigma_{\text{cation}})| < 0.02$. (3) For $\Sigma_{\text{anion}} = 10.0\text{--}800$ mEq/L: $|(\Sigma_{\text{anion}} - \Sigma_{\text{cation}})/(\Sigma_{\text{anion}} + \Sigma_{\text{cation}})| < 0.05$. By applying these criteria to the analytical results of the 54 samples from this year, all the analytical results meet the criteria.

4.2 Stiff diagram

The graphical representation of water quality analysis results as a stiff diagram effectively discriminates groundwater of different origins since water quality composition can be understood easily. The stiff diagram shows the concentrations of each principal dissolved constituent, Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Cl^- , SO_4^{2-} , and HCO_3^- , as equivalent values (mEq/L), divided into cations and anions. Figure 3 shows stiff diagrams of the analysis results.

Table 3 Groundwater chemistry

| Index no. | Name | Depth (GL-) | | | Depth (EL) | | | Sampling date (yyyy/mm/dd) | Analyzing date (yyyy/mm/dd) | Geological formation | Location (WGS84, UTM, Zone54) | | | Physico-chemical parameter | | | | Temperature at site (°C) | Total-Fe HACH | | | | | | | | | | | | | | | | | M-Alkalinity (meq/L) | TOC (mg/L) | TIC (mg/L) | Σcation (mEq/L) | Σanion (mEq/L) | ionic balance (%) | δD (‰) | δ ¹⁸ O (‰) | | | | | | |
|-----------|-------------------|-------------|-------|-------|------------|--------|--------|----------------------------|-----------------------------|----------------------|-------------------------------|-----------|------------------|----------------------------|-------------------|------------|------------|--------------------------|-----------------|----------------|------------------|------------------|-----------------|-----------------|------|-------|-----------------|------------------------------|-------|------------------|----------------|-----------------|------|------|------------------------------|----------------------|------------|------------|-----------------|----------------|-------------------|--------|-----------------------|------------------------------|------------------------------|-------------------------------|-------------------------------|-----------------------------|-------------------------------|
| | | Min. | Max. | Mid. | Min. | Max. | Middle | | | | East | North | Z (middle depth) | EC at site (mS/m) | EC at lab. (mS/m) | pH at site | pH at lab. | | Na ⁺ | K ⁺ | Ca ²⁺ | Mg ²⁺ | Total-Mn (mg/L) | Li ⁺ | B | Sr | Total-Fe (mg/L) | Fe ²⁺ HACH (mg/L) | Ba | Al ³⁺ | F ⁻ | Cl ⁻ | Br | I | NO ₃ ⁻ | | | | | | | | | NO ₂ ⁻ | NH ₄ ⁺ | PO ₄ ³⁻ | SO ₄ ²⁻ | HS ⁻ HACH (μg/L) | HCO ₃ ⁻ |
| 1 | WR-V-70_20220614 | 63.8 | 63.8 | 63.8 | -3.8 | -3.8 | -3.8 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -3.8 | 200 | 210 | 7.2 | 7.3 | 13.4 | 380 | 23 | 31 | 4.7 | 0.14 | 2.5 | 9.0 | 0.16 | 0.27 | 0.050 | <0.01 | 0.2 | 320 | 2.6 | 23 | 13.0 | 4.4 | 14.0 | 2.2 | 46 | 490 | <1 | 480 | 9.7 | 9.7 | 108 | 20 | 18.5 | 4.4 | -55.7 | -8.1 |
| 2 | WR-V-100_20220613 | 98.0 | 98.0 | 98.0 | -38.0 | -38.0 | -38.0 | 2022/06/13 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -38.0 | 580 | 610 | 8.5 | 8.5 | 14.0 | 1260 | 53 | 30 | 18.5 | <0.05 | 3.7 | 39 | 0.34 | 0.05 | 0.165 | <0.01 | 0.2 | 1280 | 9.5 | 19.6 | 191 | <0.1 | 0.2 | 2.2 | 39 | 980 | 14 | 900 | 17.9 | 16.0 | 197 | 60 | 57 | 2.6 | -53.6 | -6.6 |
| 3 | WR-V-136_20220613 | 133.8 | 133.8 | 133.8 | -73.8 | -73.8 | -73.8 | 2022/06/13 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -73.8 | 1670 | 1720 | 8.2 | 8.2 | 14.5 | 3800 | 137 | 54 | 44 | <0.05 | 11.9 | 116 | 1.27 | 0.14 | 1.15 | <0.01 | 0.1 | 4600 | 31 | 23 | 155 | 230 | 97 | 1.3 | 4.9 | 2500 | 18 | 2600 | 52 | 32 | 500 | 181 | 178 | 0.8 | -43.9 | -1.9 |
| 4 | WR-V-168_20220614 | 168.0 | 168.0 | 168.0 | -108.0 | -108.0 | -108.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -108.0 | 950 | 980 | 8.6 | 8.5 | 15.0 | 2200 | 77 | 18.2 | 20 | <0.05 | 2.8 | 64 | 0.45 | 0.08 | 0.21 | <0.01 | 0.2 | 2000 | 13.7 | 3.7 | 145 | 12.2 | 50 | 1.2 | 1.3 | 2200 | 32 | 2100 | 42 | 19.3 | 440 | 102 | 97 | 2.8 | -51.7 | -4.8 |
| 5 | WR-V-200_20220614 | 202.0 | 202.0 | 202.0 | -142.0 | -142.0 | -142.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -142.0 | 1340 | 1390 | 8.0 | 8.0 | 15.1 | 2900 | 101 | 32 | 38 | <0.05 | 8.7 | 94 | 0.67 | 0.07 | 0.52 | <0.01 | 0.1 | 3200 | 23 | 13.3 | 27 | 13.4 | 84 | 1.8 | 3.0 | 2800 | 13 | 2500 | 50 | 26 | 570 | 141 | 139 | 0.8 | -50.5 | -3.3 |
| 6 | WR-V-210_20220614 | 202.0 | 202.0 | 202.0 | -142.0 | -142.0 | -142.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -142.0 | 1100 | 1140 | 8.3 | 8.2 | 15.8 | 2500 | 86 | 26 | 29 | <0.05 | 7.3 | 72 | 0.47 | 0.04 | 0.32 | <0.01 | 0.2 | 2700 | 17.8 | 9.2 | 102 | 29 | 38 | 2.8 | 3.1 | 2400 | 17 | 2100 | 43 | 22 | 470 | 120 | 117 | 1.0 | -50.5 | -4.1 |
| 7 | WR-V-246_20220614 | 242.0 | 242.0 | 242.0 | -182.0 | -182.0 | -182.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567688.1 | 4988346.5 | -182.0 | 930 | 970 | 7.7 | 7.8 | 15.9 | 1980 | 60 | 34 | 24 | <0.05 | 4.4 | 47 | 0.47 | <0.03 | 0.28 | <0.01 | 0.2 | 2100 | 13.5 | 7.1 | 13.8 | 3.8 | 64 | 2.4 | 2.5 | 2100 | 6 | 18990 | 38 | 11.5 | 430 | 96 | 94 | 1.0 | -62.3 | -6.4 |
| 8 | WR-V-300_20220615 | 282.0 | 282.0 | 282.0 | -222.0 | -222.0 | -222.0 | 2022/06/15 | 2022/06/15-8/12 | Wakkanai Fm. | 567688.1 | 4988346.5 | -222.0 | 1300 | | 7.8 | | 2700 | 63 | 62 | 47 | <0.05 | 5.5 | 63 | 0.83 | 0.05 | 0.48 | <0.01 | 0.2 | 3300 | 21 | 11.7 | 43 | 23 | 65 | 1.8 | 5.4 | 2200 | 7 | 2000 | 40 | 12.6 | 460 | 131 | 133 | -0.5 | -52.8 | -4.5 | |
| 9 | WR-V-330_20220615 | 310.0 | 310.0 | 310.0 | -250.0 | -250.0 | -250.0 | 2022/06/15 | 2022/06/15-8/12 | Wakkanai Fm. | 567688.1 | 4988346.5 | -250.0 | 1140 | | 7.4 | | 2500 | 61 | 60 | 40 | <0.05 | 3.8 | 57 | 0.70 | <0.03 | 0.44 | <0.01 | 0.3 | 2900 | 18.9 | 10.7 | 0.7 | <0.1 | 94 | 2.2 | 4.5 | 2200 | 3 | 2000 | 40 | 11.2 | 460 | 124 | 117 | 2.9 | -57.3 | -5.2 | |
| 10 | WR-V-338_20220615 | 310.0 | 310.0 | 310.0 | -250.0 | -250.0 | -250.0 | 2022/06/15 | 2022/06/15-8/12 | Wakkanai Fm. | 567688.1 | 4988346.5 | -250.0 | 1150 | | 7.4 | | 2300 | 57 | 53 | 37 | <0.05 | 5.0 | 69 | 0.72 | <0.03 | 0.45 | <0.01 | 0.2 | 2600 | 17.0 | 11.9 | 7.9 | 0.6 | 86 | 1.7 | 3.5 | 2200 | 3 | 2000 | 40 | 11.5 | 480 | 112 | 110 | 1.1 | -57.3 | -5.3 | |
| 11 | WR-V-348_20220615 | 343.9 | 343.9 | 343.9 | -283.9 | -283.9 | -283.9 | 2022/06/15 | 2022/06/15-8/12 | Wakkanai Fm. | 567688.1 | 4988346.5 | -283.9 | 1320 | | 7.6 | | 3000 | 70 | 41 | 34 | <0.05 | 7.4 | 66 | 0.83 | <0.03 | 0.58 | <0.01 | 0.2 | 3900 | 25 | 27 | 2.6 | 2.0 | 103 | 2.0 | 6.9 | 2300 | 4 | 2100 | 42 | 12.6 | 470 | 144 | 147 | -1.2 | -54.8 | -4.4 | |
| 12 | WR-E-20_20220614 | 27.0 | 27.0 | 27.0 | 33.0 | 33.0 | 33.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | 33.0 | 137 | 136 | 7.7 | 7.6 | 12.3 | 260 | 13.0 | 8.9 | 3.3 | <0.05 | 0.60 | 8.4 | 0.34 | 0.10 | 0.035 | <0.01 | 0.3 | 220 | 1.8 | 0.4 | 5.1 | <0.1 | 12.1 | 3.8 | 23 | 360 | <1 | 310 | 6.1 | 12.1 | 74 | 12.9 | 12.7 | 0.8 | -66.5 | -9.8 |
| 13 | WR-E-68_20220614 | 63.8 | 63.8 | 63.8 | -3.8 | -3.8 | -3.8 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -3.8 | 830 | 860 | 7.4 | 7.5 | 11.7 | 1790 | 67 | 41 | 26 | <0.05 | 4.2 | 69 | 0.51 | 0.13 | 0.33 | <0.01 | 0.1 | 1770 | 12.6 | 7.6 | 41 | 1.7 | 80 | 1.3 | 1.1 | 1980 | 3 | 1840 | 37 | 19.6 | 420 | 89 | 83 | 3.3 | -57.5 | -6.5 |
| 14 | WR-E-132_20220613 | 132.0 | 132.0 | 132.0 | -72.0 | -72.0 | -72.0 | 2022/06/13 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -72.0 | 1510 | 1560 | 7.9 | 7.9 | 13.9 | 3500 | 121 | 45 | 37 | <0.05 | 9.7 | 131 | 0.78 | 0.57 | 0.54 | <0.01 | 0.1 | 3800 | 26 | 10.1 | 0.7 | 1.9 | 116 | 10.0 | 3.9 | 3300 | 12 | 2900 | 58 | 64 | 670 | 167 | 163 | 1.0 | -46.7 | -2.6 |
| 15 | WR-E-136_20220613 | 132.0 | 132.0 | 132.0 | -72.0 | -72.0 | -72.0 | 2022/06/13 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -72.0 | 1420 | 1450 | 8.0 | 7.9 | 12.8 | 3200 | 112 | 44 | 31 | <0.05 | 8.6 | 110 | 0.83 | 0.21 | 0.68 | <0.01 | 0.1 | 3600 | 24 | 10.6 | 6.5 | 1.5 | 99 | 1.6 | 4.6 | 3000 | 11 | 2700 | 53 | 28 | 610 | 153 | 151 | 0.7 | -45.8 | -2.2 |
| 16 | WR-E-170_20220614 | 169.0 | 169.0 | 169.0 | -109.0 | -109.0 | -109.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -109.0 | 1220 | 1260 | 7.8 | 7.7 | 14.8 | 2800 | 92 | 11.8 | 21 | <0.05 | 13.5 | 94 | 0.58 | 0.08 | 0.43 | <0.01 | 0.1 | 2800 | 19.0 | 16.4 | 9.5 | 8.0 | 92 | 1.6 | 8.2 | 2900 | 7 | 2600 | 52 | 27 | 590 | 132 | 129 | 1.1 | -49.2 | -2.5 |
| 17 | WR-E-202_20220614 | 202.0 | 202.0 | 202.0 | -142.0 | -142.0 | -142.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -142.0 | 1030 | 1050 | 8.1 | 8.0 | 14.5 | 2400 | 79 | 27 | 24 | <0.05 | 5.7 | 88 | 0.42 | 0.15 | 0.32 | <0.01 | 0.1 | 2100 | 14.2 | 15.3 | 26 | 1.1 | 94 | 1.4 | 6.6 | 2900 | 14 | 2600 | 53 | 29 | 590 | 116 | 108 | 3.3 | -53.2 | -3.9 |
| 18 | WR-E-246_20220614 | 239.0 | 239.0 | 239.0 | -179.0 | -179.0 | -179.0 | 2022/06/14 | 2022/06/15-8/12 | Koetoi Fm. | 567724.0 | 4988286.5 | -179.0 | 840 | 860 | 8.1 | 8.1 | 15.0 | 1990 | 62 | 16.5 | 14.5 | <0.05 | 5.0 | 69 | 0.23 | 0.08 | 0.182 | <0.01 | 0.2 | 1600 | 10.2 | 13.3 | 21 | 18.8 | 47 | 1.5 | 17.4 | 2600 | 15 | 2300 | 46 | 23 | 510 | 93 | 89 | 2.4 | -59.1 | -5.2 |
| 19 | WR-E-276_20220614 | 276.0 | 276.0 | 276.0 | -216.0 | -216.0 | -216.0 | 2022/06/14 | 2022/06/15-8/12 | Wakkanai Fm. | 567724.0 | 4988286.5 | -216.0 | 1000 | 1040 | 7.4 | 7.5 | 16.7 | 2100 | 50 | 39 | 27 | <0.05 | 4.8 | 57 | 0.51 | <0.03 | 0.35 | <0.01 | 0.2 | 2200 | 14.9 | 29 | 1.6 | 0.6 | 71 | 1.6 | 8.1 | 2100 | 3 | 2000 | 40 | 12.0 | 450 | 102 | 99 | 1.3 | -58.0 | -5.6 |
| 20 | WR-E-310_20220614 | 310.0 | 310.0 | 310.0 | -250.0 | -250.0 | -250.0 | 2022/06/14 | 2022/06/15-8/12 | Wakkanai Fm. | 567724.0 | 4988286.5 | -250.0 | 810 | 840 | 7.7 | 7.8 | 16.7 | 1960 | 57 | 19.6 | 14.1 | <0.05 | 5.3 | 58 | 0.24 | 0.06 | 0.159 | <0.01 | 0.3 | 1580 | 10.3 | 6.6 | 0.5 | 0.6 | 56 | 1.9 | 64 | 2400 | 7 | 2100 | 43 | 21 | 490 | 93 | 86 | 4.0 | -59.6 | -5.6 |
| 21 | WR-E-340_20220614 | 340.0 | 340.0 | 340.0 | -280.0 | -280.0 | -280.0 | 2022/06/14 | 2022/06/15-8/12 | Wakkanai Fm. | 567724.0 | 4988286.5 | -280.0 | 1210 | 1250 | 7.7 | 7.7 | 16.4 | 2700 | 65 | 47 | 37 | <0.05 | 6.2 | 69 | 0.76 | <0.03 | 0.43 | <0.01 | 0.2 | 3100 | 19.8 | 34 | 35 | 22 | 61 | 1.8 | 5.9 | 2400 | 5 | 2100 | 43 | 13.4 | 490 | 128 | 126 | 0.7 | -53.4 | -4.4 |
| 22 | WR-W-136_20220613 | 136.0 | 136.0 | 136.0 | -76.0 | -76.0 | -76.0 | 2022/06/13 | 2022/06/15-8/12 | Koetoi Fm. | 567654.1 | 4988285.4 | -76.0 | 1630 | 1660 | 7.5 | 7.6 | 10.9 | 3400 | 103 | 79 | 71 | 0.23 | 9.6 | 95 | 1.90 | 0.10 | 1.37 | 0.02 | 0.3 | 4600 | 34 | 12.4 | 56 | 1.2 | 152 | <0.3 | 136 | 2900 | 5 | 2200 | 44 | 25 | 600 | 170 | 181 | -3.0 | -48.9 | -3.5 |
| 23 | WR-W-156_20220614 | 156.0 | 156.0 | 156.0 | -96.0 | -96.0 | -96.0 | 2022/06/14 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

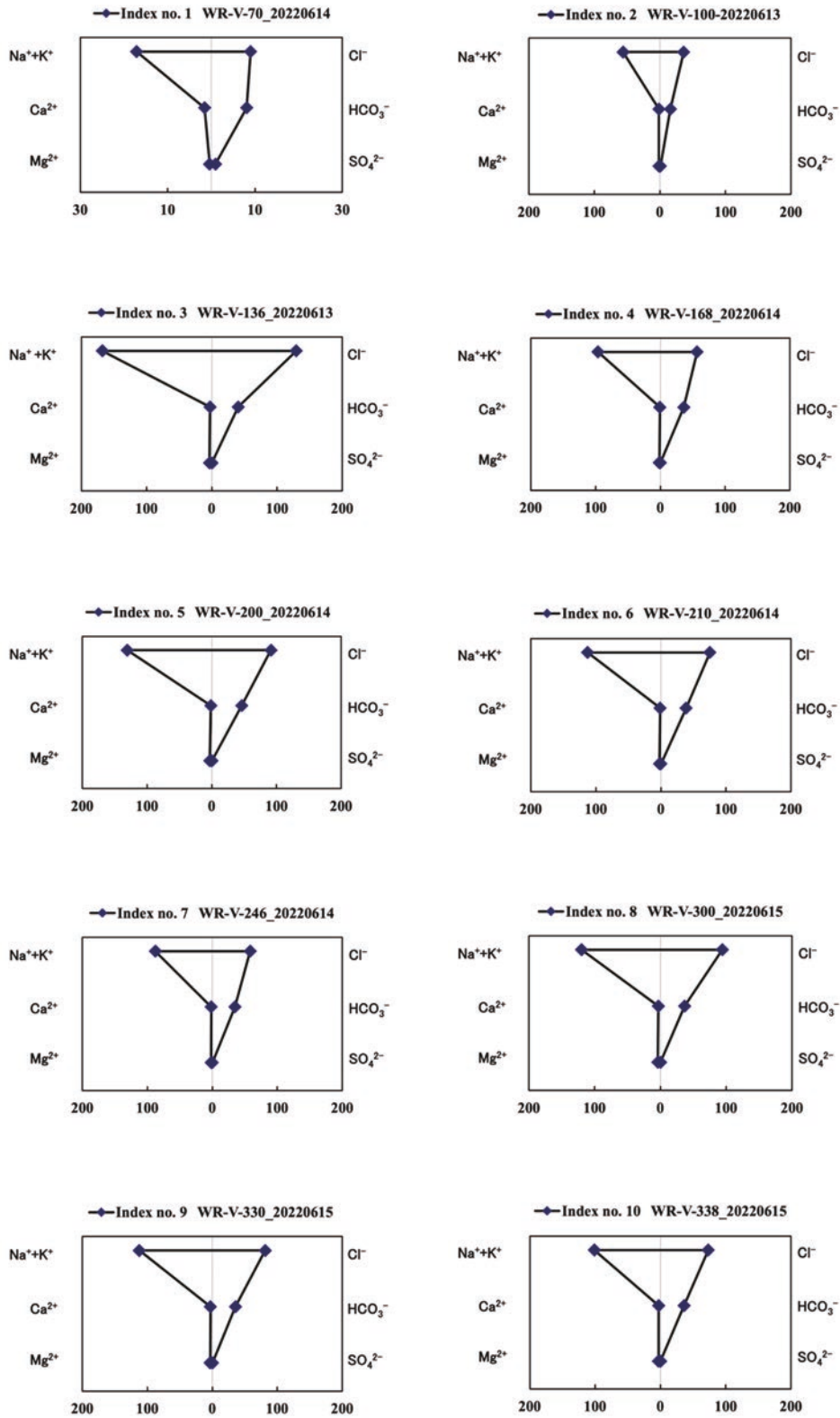


Fig. 3a Stiff diagrams for the data of index no. 1–10

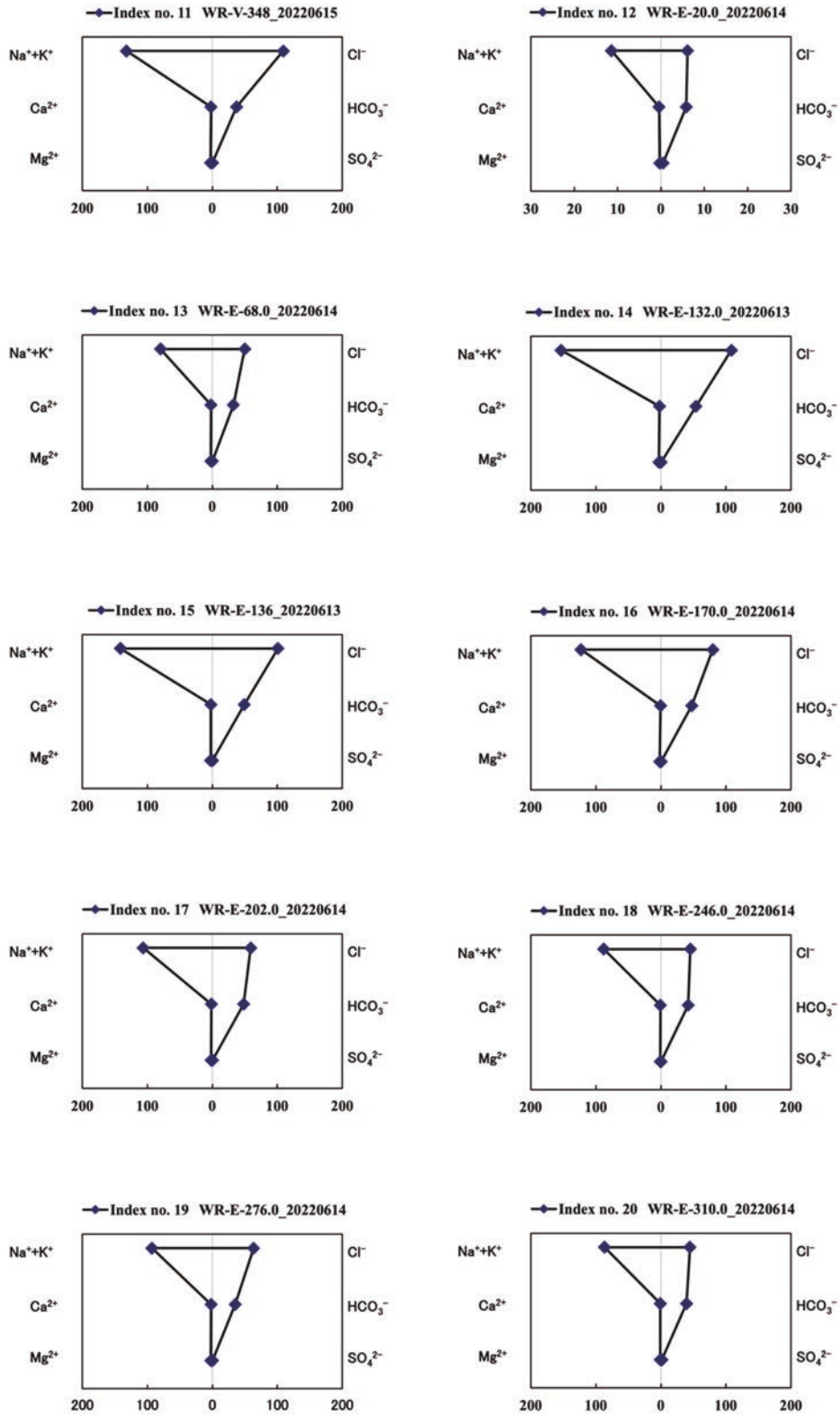


Fig. 3b Stiff diagrams for the data of index no. 11–20

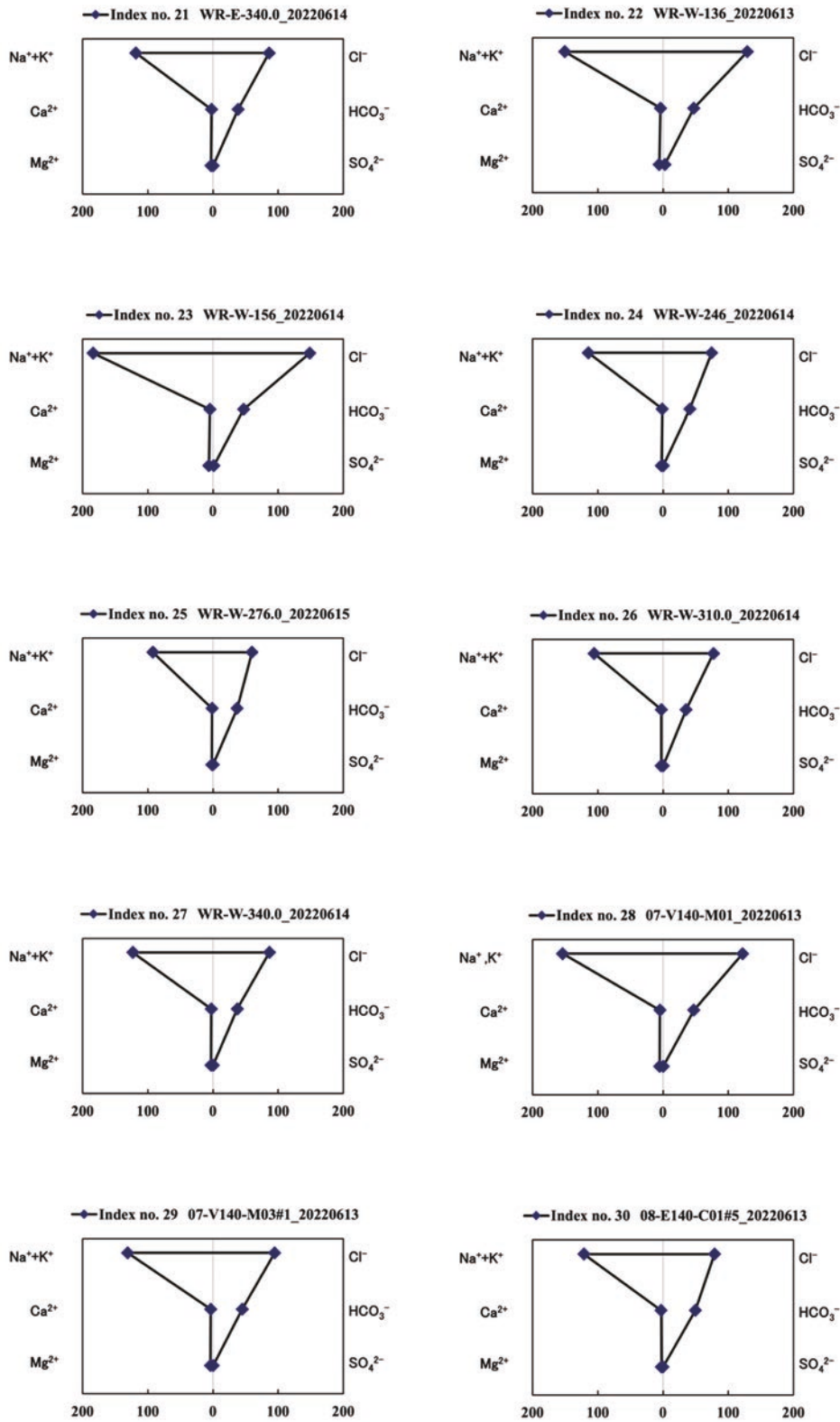


Fig. 3c Stiff diagrams for the data of index no. 21–30

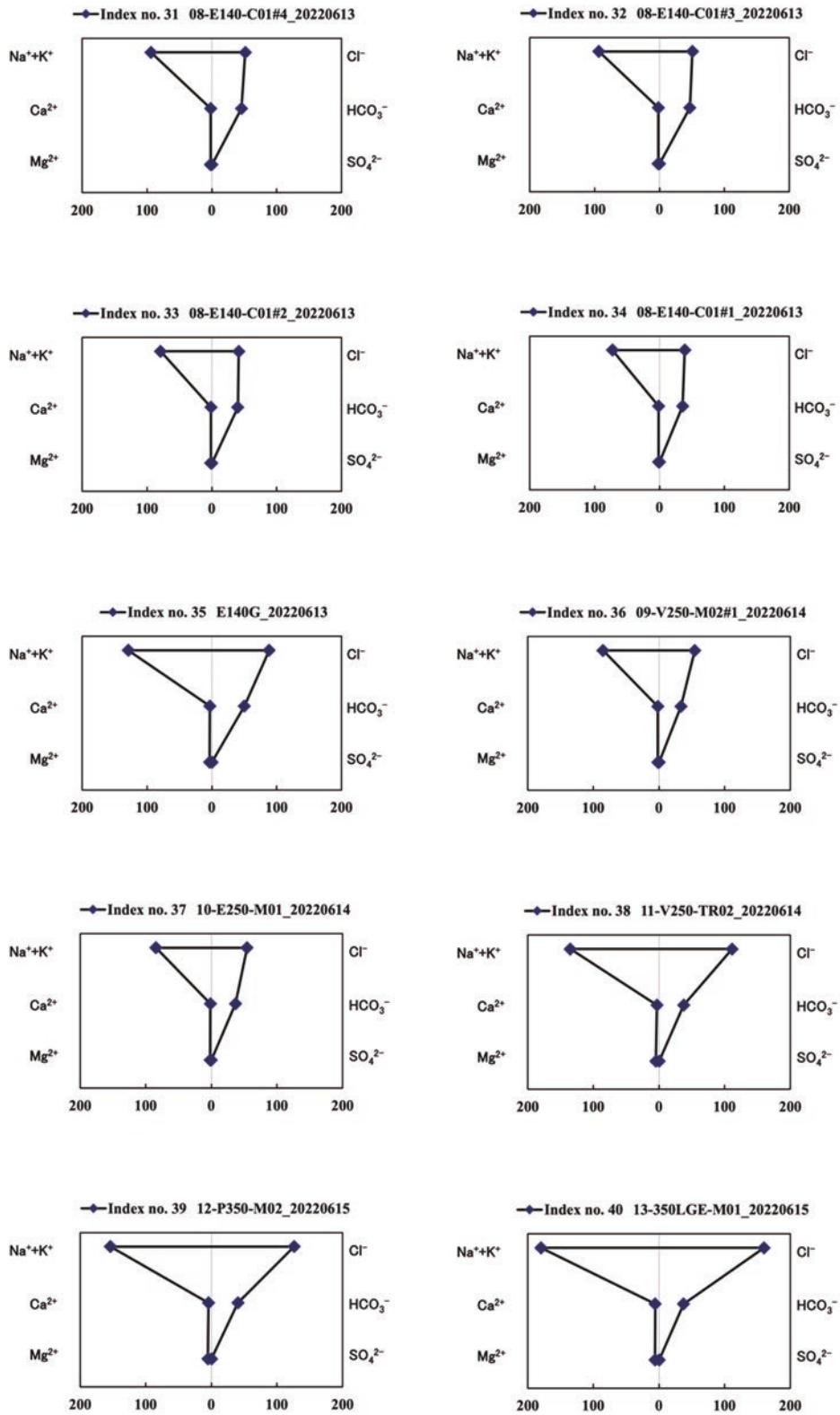


Fig. 3d Stiff diagrams for the data of index no. 31–40

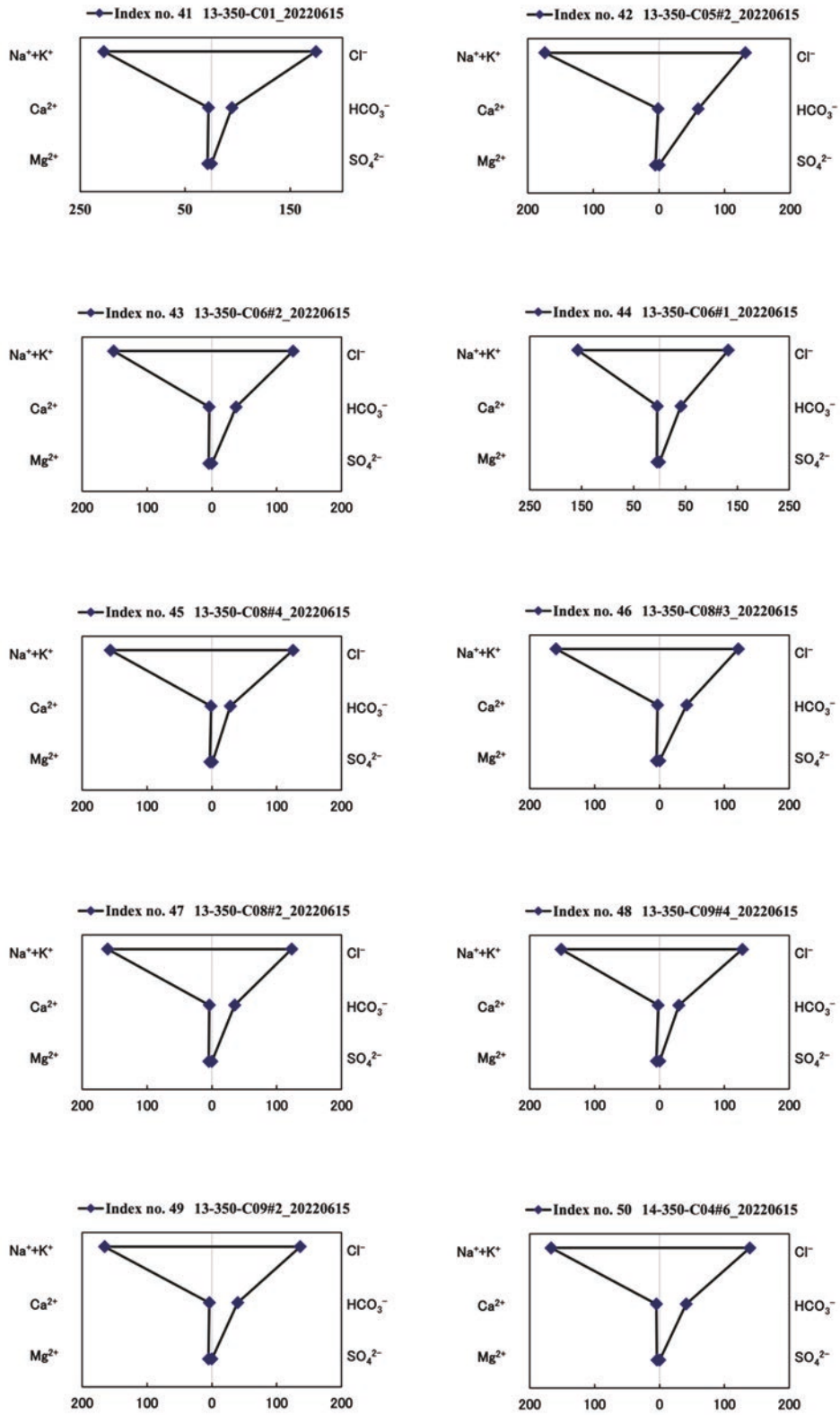


Fig. 3e Stiff diagrams for the data of index no. 41–50

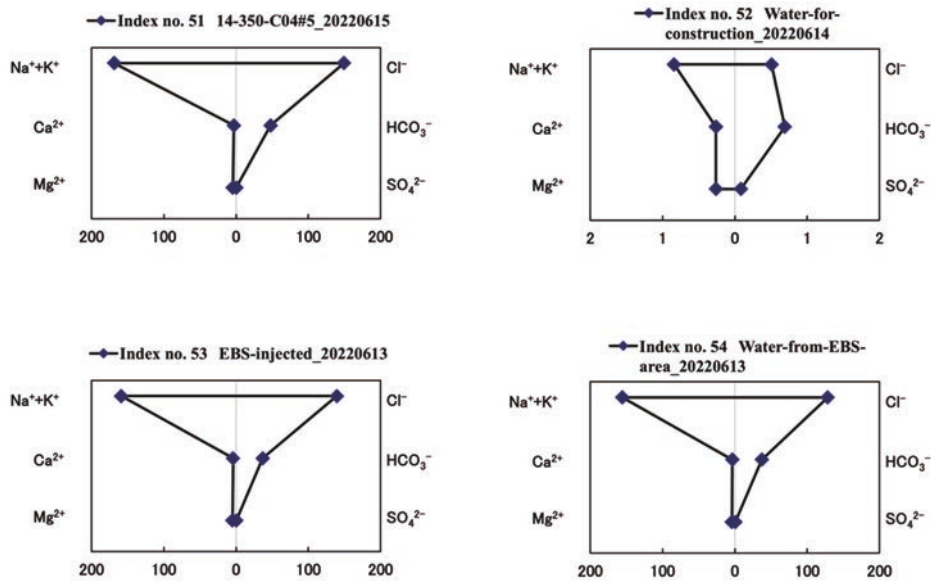


Fig. 3f Stiff diagrams for the data of index no. 51–54

5. Summary

This report summarizes the results of the chemical analysis of 54 groundwater samples collected in the Horonobe URL in 2022. Analytical results include groundwater chemistry such as pH, electrical conductivity, dissolved components (Na⁺, K⁺, Ca²⁺, Mg²⁺, Li⁺, NH₄⁺, F⁻, Cl⁻, Br⁻, NO₃⁻, NO₂⁻, PO₄³⁻, SO₄²⁻, Total-Mn, Total-Fe, Al, B, Sr, Ba, I, alkalinity, dissolved organic carbon, dissolved inorganic carbon, CO₃²⁻, HCO₃⁻, Fe²⁺, sulfide), and δ¹⁸O, δD. In the Horonobe URL Project after FY2020, we will continue to conduct groundwater investigations to obtain data on groundwater geochemistry, which is essential for the Horonobe URL Project, and will compile and publish the obtained results as appropriate.

Acknowledgment

Mr. Nobuhiro Isozaki of the Horonobe Underground Research Center assisted us in analyzing the samples by ion chromatography. Dr. Shuji Tamamura of the Horonobe Research Institute for the Subsurface Environment assisted with the titration for alkalinity and DOC and DIC analysis. For the isotope analysis, we are grateful to CERES Corp. for their assistance. We would like to take this opportunity to express our deepest gratitude. This study was carried out as a part of R&D supporting program titled "Development and Improvement on Groundwater Flow Evaluation Technique in Rock" under the contract with Ministry of Economy, Trade and Industry (METI) (Grant Number: JPJ007597).

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