***LA-ICP-MS zircon U-Pb isotope analysis***

Five specimens were chosen for the zircon study, diorite samples (SD-1, SD-5, SD-6, and HD-1) and one gabbro sample (SD-9). Zircon grains were manually selected and purified under a binocular microscope after being extracted from hosting rocks, diorites and gabbros by applying heavy liquid separation techniques in the Hebei Geological Surveying and Mapping Institute laboratory. The cathodoluminescence photographs were captured using a JSM 6510 scanning electron microscope attached to a 10 kV Gatan CL detector.

Zircon's U-Pb dating and trace element concentration analyses were conducted using LA-ICP-MS at Micro-Macro Geochemistry Technology (Lang Fang) Co., Ltd., China. Laser ablation (LA) utilizes the New Wave UP-213 Nd: YAG solid-state laser from New Wave Company, ICP-MS refers to the Agilent 7900 plasma mass spectrometer from the Agilent Company of the USA. Helium is used as a carrier gas, while argon is employed as a compensating gas to calibrate sensitivity during the test. The samples are combined and attached to an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) with a tee junction. The laser's spot size was adjusted to 30µm. The energy intensity and frequency have been adjusted to 10 J/cm2 and 10 Hz, respectively. NIST SRM610 suggested excellent sensitivity, less oxidation and background interference, and a consistent signal for achieving the perfect environment. Collected background time for 20 seconds, followed by a 40-second sample, and concluded with a 30-second sample purge.

The peak skipping technique is used to gather data, with 10 ms specified for 202Hg and 232Th collection duration. Assigning 20 ms to 204pb and 206pb, 30 ms to 207Pb, 15 ms to 208Pb and 238U, and 6 ms to the other elements. Zircon 91500 was used as the experimental standard to adjust isotope ratios (Wiedenbeck et al., 1995), and conventional zircon plesovice (337ma) was used to control the blind specimen (Sláma et al., 2008). The global standard model NIST SRM610 is the external standard for adjusting trace element concentrations (Pearce et al., 1997). Apply the GLITTER 4.0 program to estimate the isotope ratio and element composition. Isoplot 6.0 (Ludwig, 2008) generated the weighted average age and the harmonic graph.

***Whole-rock geochemical analyses***

The studied samples (SD-1, SD-5, SD-6, and SD-9) were analyzed for major elements at Wuhan Sample Solution Analytical Technology Co., Ltd. in Wuhan using X-ray fluorescence (XRF) on a ZSX Primus II spectrometer made by RIGAKU in Japan. The preparation of samples for major element analysis involved the melting method. A mixture including lithium tetraborate, lithium metaborate, and lithium fluoride in a ratio of 45:10:5 was used, along with ammonium nitrate as an oxidizing agent and lithium bromide as a releasing agent. The melting process was carried out at 1050 ℃ for 15 minutes. The X-ray tube was a 4.0Kw end window Rh target, running at 50kV voltage and 60mA current, with all significant element analysis lines being kα. The standard curve was created utilizing national standard materials, including the rock sample GBW07101-14, soil sample GBW07401-08, and stream sediment sample GBW07302-12. The theoretical α coefficient approach was used for data adjustment, resulting in a relative standard deviation (RSD) of less than 2%.

Whole rock specimens were analyzed for trace elements using an Agilent 7700e ICP-MS at Wuhan Sample Solution Analytical Technology Co., Ltd. in Wuhan, China. The detailed procedure for sample digestion is outlined here: (a) the sample powder (200 meshes) underwent a drying process at 105 ℃ for 12 hours. (b) A precisely measured 50 mg of sample powder was inserted into a Teflon bomb. (c) Gradually, 1 ml of nitric acid (HNO3) and 1 ml of hydrofluoric acid (HF) were introduced into the Teflon bomb. The Teflon bomb was placed in a stainless-steel pressure vessel and heated to 190 ℃ in a microwave for more than 24 hours. After cooling, the Teflon container was opened and placed on a hotplate at 140 ℃ until it evaporated almost completely. Then, 1 ml of nitric acid was added, and the mixture was evaporated until dry once again (f) To the Teflon bomb, 1 ml of nitric acid HNO3, 1 ml of MQ water, and 1 ml of a one ppm internal standard solution were included. The Teflon bomb was resealed and then heated to 190 ℃ in the oven for over 12 hours. (g) The final solution was moved to a polyethylene bottle and diluted to 100 grams, including 2% nitric acid (HNO3).

***Electron probe micro-analysis***

A total of eighty sampling points (minerals) were selected from sulfide-bearing quartz veins in the Danyore Valley, comprising Chalcopyrite (64 points), pyrite (10 points), and Bornite (6 points), an electron probe micro-analyzer (EPMA) is being used for the analysis of these study minerals. The investigations were performed at Beijing Zirconia Navigation Technology Co., Ltd., in Beijing, China, utilizing a JEOL EPMA-8230. The procedure involved checking the cleanliness of the probe piece's surface upon sample reception, placing it in the sample table card holder, creating a vacuum in the instrument, confirming the energy spectrum point of the mineral to be tested, and then employing spectrum testing to analyze with a beam diameter of 1 μm for sulfides, utilizing a voltage of 15-20 kV and a current of 3nA. Before the testing, all thin polished elements were coated with carbon, and natural minerals, namely pyrite, chalcopyrite, and bornite, were employed as standards for calibration. The testing adhered to the following standards:

* GB/T15074-2008 (General Rules for Electronic Microanalysis).
* GB/T 15617-2002 (Method for Electronic Microanalysis of Silicate Materials).
* GB/T 15246-2002 (Method for Electronic Microanalysis of Sulfides (20 kV)).
* GB/T 15245-2002 (Method for Electronic Microanalysis of Rare Earth Oxides).
* GB/T 17359-1998 (General Rules for the Method of X-Radix Energy Analysis of Electronic Microanalysis and Transmission Microanalysis).
* GB/T 17359-2012 (Microbeam Analysis, Energy Analysis).
* SY/T 6189-1996 (Method for Rock and Energy Analysis).

Specific testing parameters included:

1. Acceleration Voltage: 15.0-20.0 kV. 2. Probe Diameter: 5 μm. 3. Current (A): 2×10-8 (A).