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Short Communications (Research Advances)

Muscovite $^{40}Ar/^{39}Ar$ isotopic dating of pegmatite veins in the Bieyesamas rare metal deposit in the Altay Mountain, Xinjiang, northwestern China

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1. Objective

The Altay Orogenic Belt in Xinjiang, China is located in the west of the Central Asian Orogenic Belt and in the transition zone between the Siberian Plate and the Kazakhstan-Junggar Plate, extending approximately 500 km in northern Xinjiang, China (Fig. 1a). The Altay Orogenic Belt has undergone two-way accretion of the Paleozoic crust and the Meso-Cenozoic intracontinental orogeny, leading to the formation of large numbers of intermediate-acid intrusions. More than 100000 pegmatite veins have been discovered in the intermediate-acid intrusions, and they constitute an important rare metal metallogenic belt of China (Fig. 1b). The most famous rare metal deposit in the Altay Mountain in Xinjiang is the Koktokay No. 3 pegmatite deposit (Kong HL et al., 2023), which, however, has been shut down due to resource depletion. A batholith-like two-mica monzogranite has developed in the Bieyesamas area, which lies to the northeast of the No. 3 pegmatite deposit. A medium-sized spodumene deposit has been found in the monzogranite. In recent years, dozens of granitic pegmatite veins have been newly discovered in the Altay Orogenic Belt and all show the mineralization of rare metals such as lithium, beryllium, niobium, tantalum, rubidium, and cesium (Fig. 1c). These findings indicate that the Altay Mountain has considerable potential for ore prospecting (Qiao GB et al., 2020, 2021). He HH et al. (2020) constrained the formation time of ore-bearing pegmatites in the Bieyesamas area through U-Pb dating of tantalite-(Mn) in pegmatites. However, they did not determine the duration of the rare metal mineralization of the pegmatites. This study is to constrain the cooling history of the pegmatite melts through $^{40}Ar/^{39}Ar$ dating of muscovite widely distributed in the ore-bearing pegmatites, thus providing new data on the evolution and the diagenetic and metallogenic relationships of rare metals in the Altay Orogenic Belt.

2. Methods

The argon isotopic dating of muscovite was conducted at the $^{40}Ar/^{39}Ar$ chronology laboratory of the Institute of Geology, Chinese Academy of Geological Sciences. The processed samples were placed in channel B4 of the 49-2 reactor of the China Institute of Atomic Energy for fast neutron activation for 24 h, during which the instantaneous and integrated neutron flux of the reactor was 2.65×10^{13} n/cm^2·s and 2.29×10^{18} n/cm^2, respectively. Meanwhile, as control samples, ZBH-25 biotite reference material with a standard age of 132.7±1.2 Ma and K content of 7.6% was also irradiated by neutrons. The samples were heated in a stepwise manner using a graphite furnace. They were heated for 10 minutes and purified for 20 minutes in each step. The mass spectrometric analysis was performed using a multi-collector noble gas mass spectrometer GV Helix MC, with 20 sets of data being collected for each peak value. All the data were processed through regression analysis to obtained their values at time zero before mass discrimination corrections, atmospheric argon corrections, blank corrections, and corrections for interfering isotopes were carried out. The correction factors for interfering isotopes resulting from neutron irradiation were obtained by analyzing irradiated K_2SO_4 and CaF_2, including $(^{36}Ar/^{37}Ar_0)_{Ca}$=0.0002398, $(^{39}Ar/^{37}Ar_0)_{Ca}$=0.000806, and $(^{40}Ar/^{39}Ar_0)_K$=0.004782. ^{37}Ar was corrected through radioactive decay, and the decay constant λ of ^{40}K was set to 5.54310^{-10}/yr. The plateau age can be defined as the age corresponding to a cumulative ^{39}Ar

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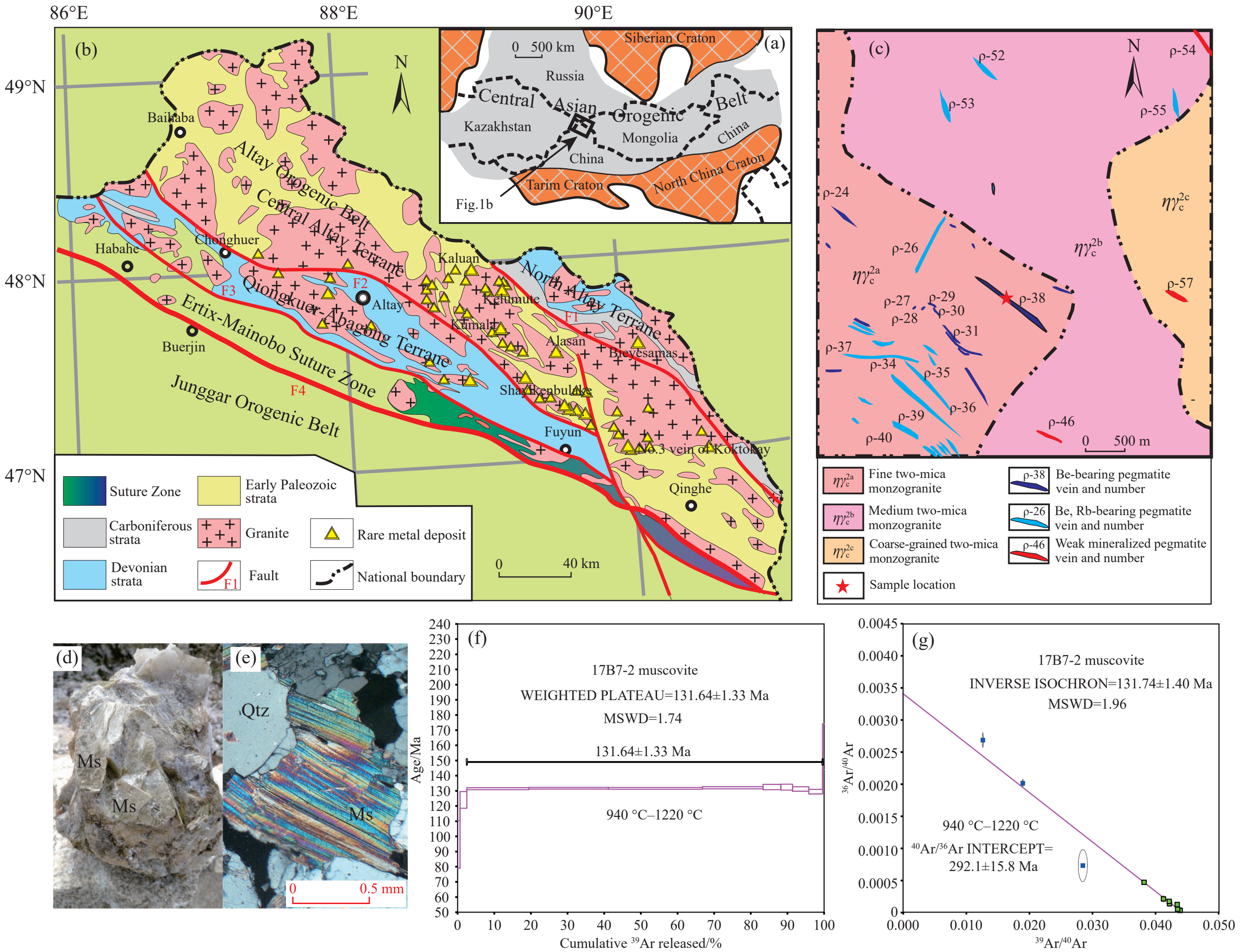

Fig. 1. Geotectonic location (a) and intrusion distribution (b) of the Orogenic Belt of Xinjiang, northwestern China; the geological map (c) of the Bieyesamas deposit; the field photographs (d) and microphotographs (e) of muscovite; $^{40}Ar/^{39}Ar$ plateau age (f) and inverse isochron age (g) of muscovite. Note: F1–Hongshanzui Fault; F2–Abagong Fault; F3–Kezijiaer Fault; F4–Ertix Fault. Ms–muscovite; Qtz–quartz.

release of >50%, and the inverse isochron age can be calculated based on the plateau age using the regression algorithm. The plateau age and the positive and negative isochron ages were calculated using the Ar-ArCALC program. All the data had a 95% confidence interval (2σ).

3. Results

The Bieyesamas two-mica monzogranite extends in the NWW direction and occurs as a batholith, with outcrops covering an area of more than 1000 km^2. It can be divided into an inner medium-coarse-grained and an outward medium-fine-grained lithofacies belt. However, these two lithofacies belts are not separated by a distinct boundary but show a gradual transition (Fig. 1c). Large numbers of rare metal-bearing granite pegmatite veins have developed in the Bieyesamas pluton, and most of them occur in the NW-SE direction. Samples used in this study were collected from ore-bearing vein *ρ*-38 in the Bieyesamas deposit (Fig. 1c). The rare metal-bearing pegmatites in the samples have a massive structure and pegmatitic textures and mainly consisted of spodumene (48%), plagioclase (22%), quartz (18%), and muscovite (10%). Among them, the muscovite is euhedral and flaky in form (Figs. 1d, e), with a flake diameter of 0.3–1.5 mm (size of a hand specimen: 5–15 mm). Moreover, the muscovite in the samples shows a scattered distribution pattern, distinctly bent cleavage, and wavy extinction.

The muscovite sample (No. 17B7-2) used in this study comprised stromatolitic aggregates, which are pure and free of impurities. This sample was heated using 11-step heating (780°C–1400°C). Eight sets of ages that met precision requirements were used for calculation, and the calculated results are shown in Table 1. The sample ages exhibited a stable spectrum, based on which a plateau age of 131.64±1.33 Ma was obtained via averaging (Fig. 1f). The inverse isochron plot of the muscovite sample showed closely correlated data (Fig. 1g), yielding an inverse isochron age of 131.74±1.4 Ma, which is consistent with the plateau age. The initial $^{40}Ar/^{36}Ar$ ratio of 292.1±15.8 Ma was obtained, which is similar to the $^{40}Ar/^{36}Ar$ ratio of the present atmospheric argon (295.5). These data indicate that the muscovite has remained closed relative to the $^{40}Ar/^{39}Ar$ system since it was crystallized and

Table 1. ^{40}Ar / ^{39}Ar **isotopic data of muscovite from pegmatite vein.**

T/°C	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar_k$	$^{40}Ar^*$/%	$^{39}Ar_k$/%	Age/Ma	±2σ
Sample=17B7-2, Material=muscovite, Weight=13.55mg, J=0.00350533±0.00001753.								
940	25.5026	0.0807	0.0134	21.5604	84.54	16.86	131.44	±0.66
970	22.2362	0.0235	0.0021	21.6127	97.19	21.75	131.75	±0.57
1000	22.1765	0.0284	0.0020	21.5955	97.38	25.65	131.65	±0.58
1030	22.3869	0.0757	0.0025	21.6615	96.75	16.54	132.03	±0.70
1060	23.0604	0.2926	0.0045	21.7485	94.29	4.88	132.54	±1.75
1110	23.6067	0.1284	0.0064	21.7344	92.06	3.19	132.46	±1.94
1160	23.0952	0.1846	0.0054	21.5225	93.18	4.43	131.22	±1.46
1220	22.4275	0.0000	0.0041	21.2239	94.63	3.76	129.46	±1.52

was not affected by late thermal events, with no excess argon existing. Therefore, the muscovite ages determined using the mass spectrometric analysis are reliable.

4. Conclusion

As suggested by previous studies, the U-Pb isotopic ages of rare metal minerals represent the emplacement age of pegmatites, while the $^{40}Ar/^{39}Ar$ ages of muscovite represent the cooling age of pegmatites. Therefore, the joint constraints of these two types of ages form the basis for discussing the formation epoch, evolutionary time frame, or cooling history of pegmatites. He HH et al. (2020) carried out the TIMS tantalite-(Mn) U-Pb dating of rare metal-bearing pegmatites in the study area and obtained a weighted average age of 160.1±1.1 Ma (MSWD=0.0057). This age is the crystallization age or the emplacement age of the pegmatites in the study area. In this study, the $^{40}Ar/^{39}Ar$ age of the muscovite in the ore-bearing pegmatites was obtained to be 131.64±1.33 Ma (MSWD=1.74), which represents the cooling age of the pegmatites. These two sets of data suggest that the rare metal-bearing pegmatites in the Bieyesamas deposit underwent differential evolution for approximately about 29 Ma, which resulted from slow crystallization and cooling. The differential evolution was always accompanied by rare metal mineralization, leading to the formation of rare metal mineral resources with zones of multiple mineral structures.

CRediT authorship contribution statement

Geng-biao Qiao and Xiao-hong Wang conceived of the presented idea. Geng-biao Qiao and Ping Wang performed the computations and verified the analytical methods. Jun-Lu Chen encouraged Geng-biao Qiao to investigate the pegmatite veins in Bieyesamas lithium deposit. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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