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ScienceDirect

Russian Geology and Geophysics 57 (2016) 434–450

RUSSIAN GEOLOGY
AND GEOPHYSICS

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Thermochronology of Early Paleozoic collisional and subduction–collisional structures of Central Asia

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Received 10 June 2015; accepted 28 August 2015

Abstract

The thermochronology of the Early Paleozoic collisional and subduction–collisional systems and blueschist complexes of the Central Asian Orogenic Belt has been reconstructed by the proposed method of "through" isotope dating. The evolution of these geologic structures is divided into short synchronous stages of active thermal events related to large-scale mantle–crustal magmatism, high-pressure/low-temperature and high-temperature/low-pressure metamorphism, and intense tectonic deformations. The plume activity of different intensities, both in intraoceanic and intracontinental environments, is presumed to be the deep mechanism of synchronization.

Keywords: collisional tectogenesis; metamorphic deformations; U–Pb and ^{40}Ar–^{39}Ar dating; thermochronology; Central Asia

Introduction

Phanerozoic folded orogens are key to the geologic evolution of Central Asia. It is customary to distinguish suprasubductional and collisional orogens (Dobretsov et al., 2001; Lobkovskii et al., 2004; Shengör et al., 1993; Vladimirov et al., 2003, 2005). The estimation of duration of orogenic events, their periodicity, variations in their intensity, and style over time is highly important in the geodynamic modeling of orogeny. Depending on the type of collision (e.g., continent–continent or island arc–continent), the formation of collisional structures can last for 50 Myr or more (e.g., Himalayas) to 18 Myr (Dalradian orogeny, British Caledonides) (Dewey, 2005; Vladimirov et al., 2003; Yin, 2006).

The Cambrian–Ordovician played important role in the evolution of the Paleoasian ocean (Dobretsov, 2011; Dobretsov and Buslov, 2007; Rudnev, 2013). At that stage, early collision terminated; most of the "primary" ocean closed; and "secondary" oceans and island arcs formed, including the Paleouralian and Ob'–Zaisan paleooceans. By analogy with that of the present-day Western Pacific, the evolution of the Central Asian Orogenic Belt (CAOB) is considered by some authors (Badarch et al., 2002; Buslov et al., 2001, 2004; Didenko et al., 1994; Fedorovskii et al., 1995; Khain et al., 2003; Kuzmichev et al., 2001; Laurent-Charvet et al., 2003; Mossakovskii et al., 1993; Wang and Liu, 1986; Yin and Nie, 1996; Zonenshain et al., 1990) in terms of the successive accretion of island arcs, oceanic islands, oceanic plateaus, accretionary prisms and/or microcontinents. Others (Kovalenko et al., 1999; Yarmolyuk et al., 2003, 2013) substantiate the hypothesis that the CAOB Caledonides belong to the accretionary superterrane which formed independently of the Siberian Platform as a result of collision (accretion) of a system of Vendian–Cambrian island arcs, backarc basins, and Precambrian terranes between them with a group of oceanic islands and lava plateaus marking a mantle hotfield. After that event, the superterrane joined the Siberian craton along a strike-slip boundary of the transform-fault type.

The thermochronological approach can be used to obtain unique information on the metamorphic history of indicator rocks during ascent and cooling, the age of medium- and low-temperature tectonic events, and the time of formation of plutonic rocks and their ascent to the surface. Unfortunately, such studies within the CAOB are fragmentary rather than systematic. Pioneering works include studies of UHP metamorphic complexes—Kokchetav and Maksyutov (Dobretsov et al., 2006; Lepezin et al., 2006; Schertl and Sobolev, 2013),

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1068-7971/$ - see front matter © 2016, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.rgg.2016.03.006

complexes of Cordilleran-type metamorphic cores in Transbaikalia (Sklyarov et al., 1997), and blastomylonites of the Irtysh shear zone (Eastern Kazakhstan) (Travin et al., 2001). Results of thermochronological reconstructions for the key Early Paleozoic collisional structures of Central Asia are presented with the use of the approach developed by the author during field studies and the interpretation of the data obtained in integrated expeditions (Baikal region, eastern Tuva, and Kazakhstan) in 1997–2014.

Methods

As ^{40}Ar/^{39}Ar dating of a set of minerals covers a narrow range of closure temperatures (from 200 to 550 °C), the application of two dating methods (U–Pb dating of zircon and ^{40}Ar/^{39}Ar dating of amphibole, mica, and feldspar) permits a more complete reconstruction of the thermal evolution of igneous and metamorphic rocks, from formation to ascent to the upper crust. An original system with a quartz reactor with an external fast-response furnace for ^{40}Ar/^{39}Ar studies by incremental heating was developed in the laboratory of isotope–analytical geochemistry of the Sobolev Institute of Geology and Mineralogy (Novosibirsk) (Fig. 1) (Travin et al., 2009). One of the main advantages of the device is the possibility of removal of processed samples from the reactor with the use of a magnet after incremental heating to 1300 °C, because melt remains within a nickel cover. On the one hand, this permits minimizing the blank level (no more than 5×10^{-10} ncm^3 ^{40}Ar/20 min at 1200 °C); on the other, this increases the reactor work resource by an order of magnitude. Temperature is controlled using a TXA thermoelectric converter immediately adjacent to the sample in the zone of the maximum heating (Fig. 1). The temperature of each step is controlled with an accuracy of ±5 °C, which is much higher than that in "double-vacuum" systems, which are used in most of the laboratories worldwide.

When results of ^{40}Ar/^{39}Ar incremental heating are interpreted as age and Ca/K spectra, the generally accepted method is the plateau method, in which the average weighted age for several (at least three) successive temperature steps is considered reliable. The plateau steps have to meet the following requirements (Fleck et al., 1977): The age difference between any two of them cannot be significant; they are characterized by consistent Ca/K ratios; and at least 50% of ^{39}Ar released corresponds to them.

As the framing rocks emanate radiogenic ^{40}Ar which accumulated in them at great depths in the crust when temperature increases during metamorphism or melt emplacement, the isotope composition of Ar trapped by the forming minerals can have a considerably higher value than that of atmospheric argon. To identify it and take its presence in the mineral into account, an isochron correlation diagram is most often used. Nevertheless, in the presence of all the above-mentioned intrinsic criteria for the reliability of ^{40}Ar/^{39}Ar age (plateau and isochron regression), the dating disagrees sometimes with geological data or dating by other methods.

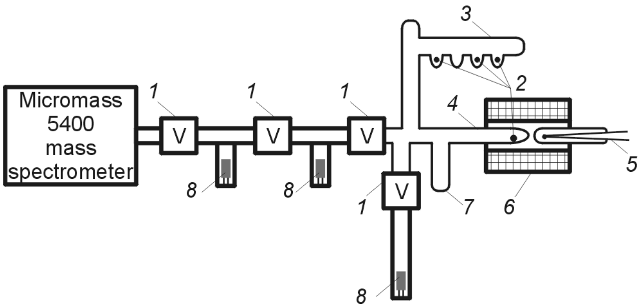

Fig. 1. Schematic diagram for the apparatus for argon extraction, purification, and measurement with a Micromass 5400 mass spectrometer. *1*, vacuum valve; *2*, sample wrapped in Ni foil; *3*, glass herringbone unit for preliminary degassing of samples at 150 °C; *4*, quartz reactor; *5*, TXA thermoelectric converter; *6*, furnace for the external heating of the sample; *7*, nitrogen trap for the preliminary purification of argon; *8*, SAES (Zr–V) getters for argon purification.

Multistage metamorphic, magmatic, and tectonic processes with long time intervals are typical of the collisional structures of Central Asia. Therefore, the isotopic ages of minerals and systems of different stabilities will be distributed over the time scale depending on thermal history and the intensity of superposed deformations and hydrothermal effects. More intense events (superposed heating, dramatic temperature decrease, rapid ascent to the surface, etc.) will yield a larger number of different ages, because complete age rejuvenation and the closure of the isotope system become more likely during such events. Coincidence between the ages of different minerals and isotope systems considerably increases the chance that they correspond to the age of a real geologic event and are reliable. This is what "couple criteria" are based on (Morozova and Rublev, 1987; Shanin, 1979).

"Through" isotope dating has shown high efficiency in thermochronological reconstructions of collisional structures (Lepezin et al., 2006; Travin et al., 2003, 2006). This approach consists in the comparative study of a set of samples: (a) of the same geochemical composition and of primary (magmatic and metamorphic) origin, with different parameters of superposed alterations, or (b) of different compositions (including different mineral phases) but with the same thermal history. Generally, the final criteria for the validity of the obtained isotopic ages are (a) consistency of their relative succession with the series of closure temperatures of isotopic systems (Hodges, 2004) and (b) consistency with the succession of formation of the studied rocks from geological and petrographic data.

Thermochronological reconstructions require thorough selection of parageneses corresponding to the indicator complexes of these systems (Table 1). The formation of collisional structures can be modeled adequately as a result of consistent interpretations of the thermochronological trends obtained for the objects of study and the trends of pressure and temperature evolution of metamorphic complexes, because the character of rock heating depends on geodynamic settings. The Ol'khon (western Baikal region) and Kokchetav (Northern Kazakhstan) regions were the main territories for developing the above-mentioned approach in long-term studies.