Quaternary Geochronology 36 (2016) 38–54

Contents lists available at ScienceDirect

Quaternary Geochronology

journal homepage: www.elsevier.com/locate/quageo

Research paper

Multiple combustion metamorphic events in the Goose Lake Coal Basin, Transbaikalia, Russia: First dating results

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ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form
26 July 2016
Accepted 5 August 2016
Available online 6 August 2016

Keywords:
Coal fires
$^{40}Ar/^{39}Ar$-ages
Mineralogy
Neotectonic activity
Goose Lake Coal Basin
Transbaikalia

ABSTRACT

Combustion metamorphic (CM) rocks (clinker and paralava) occur in abundance in the eastern and southern margins of the Goose Lake in Western Transbaikalia and form five fields. The sections we studied in natural outcrops exposed in numerous gullies and in quarries comprise the full range of CM varieties from low-grade to fused paralavas and clinkers. The tridymite-plagioclase-cordierite and tridymite-cordierite paralava and clinker have medium to high K/Ca ratios (~2.5–4.5 wt.%) with K restricted to K-rich (~4–6 wt.% K_2O) high-silica glass, making the bulk samples suitable for $^{40}Ar/^{39}Ar$ dating.

Regional-scale combustion metamorphic events were triggered by reactivation of faults in the Goose Lake Basin causing repeated erosion of gently dipping coal-bearing sediments that exposed coal beds to oxidation resulting in their spontaneous ignition. Geological evidence indicates that the earliest natural coal fire and formation of CM rocks occurred at the end of the Early Cretaceous. Geological and preliminary geochronological data indicate that large-scale coal fires occurred in the Early Pleistocene (no later than 1.8 ± 0.4 Ma ago) and in Late Pleistocene (0.02 ± 0.01 Ma and 0.03 ± 0.03 Ma).

1. Introduction

Recently, intensive studies have been made on major subsurface coal fires, especially in Asia, North America and Europe (Zhang et al., 2004; Sokol et al., 2005, 2010, 2014; Sokol and Volkova, 2007; Stracher, 2007; Stracher et al., 2013, 2015), the mineralogy of related combustion metamorphic (CM) rocks (Foit et al., 1987; Cosca et al., 1989; Sokol et al., 2010, 2014; Žáček et al., 2010; Grapes, 2006, 2011; Grapes et al., 2011; Stracher et al., 2013, 2015); temperatures and redox conditions of ancient fires, including buried foci and the regime of CM melt crystallization and cooling (Cosca et al., 1989; Sharygin et al., 2009; Grapes et al., 2011; Sokol et al., 2014). Climate control of large coal fires as landscape-forming phenomena in the Late Cenozoic history of coal basins has been suggested by Zhang et al. (2004), Heffern and Coates (2004), Heffern et al. (2007), and Sokol et al. (2014). Coal fires often arise in warm and dry climate settings (Yavorsky and Radugina, 1932; Usov, 1935; Heffern and Coates, 2004; Heffern et al., 2007; Stracher, 2007), such as during interglacial periods in Siberia (Yavorsky and Radugina, 1932; Usov, 1935; Sokol et al., 2010, 2014), Arctic Canada (Piepjohn et al., 2007), and post-glacial times in the Pamir-Alay mountains (Sokol et al., 2005; Sharygin et al., 2009, 2015). In this respect, CM melt rocks (paralava and clinker) suitable for dating using $^{40}Ar/^{39}Ar$ and U-Th/He methods are a potential indicator of past climate conditions, tectonic and erosional events that have shaped the landscape (Sokol et al., 2014). Large coal fires are inferred to have been recurrent events from studies of CM complexes in the Great Plains, USA, where fires began when coal beds became exposed by erosion (Heffern and Coates, 2004; Heffern et al., 2007). In the Kuznetsk coal basin (southwestern Siberia, Russia) episodic coal fires were restricted to periods of tectonic activity when climate conditions were favorable for coal ignition (Novikov et al., 2008; Sokol et al., 2010, 2014; Novikova et al., 2015).

Earlier (Gur et al., 1995) has been successfully carried out and (Sokol et al., 2010, 2014) followed them implemented an algorithm for $^{40}Ar/^{39}Ar$ dating of bulk samples of CM rocks because separation of K-rich phases (mainly K-Al high-silica glass) from these ultrafine-grained and vitreous rocks is almost impossible. Therefore, special criteria for the selection of CM rock specimens suitable for $^{40}Ar/^{39}Ar$ dating are required. In this study we report the first

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http://dx.doi.org/10.1016/j.quageo.2016.08.001
1871-1014/

$^{40}Ar/^{39}Ar$ ages of high-temperature CM rocks around Goose Lake (*Lake Gusinoye* in Russian), eastern side of Lake Baikal, Western Transbaikalia, together with documenting their mineral and chemical compositions, a knowledge of which is essential for the successful dating of these rocks. The $^{40}Ar/^{39}Ar$ ages provide constraints on the timing of neotectonic activity within the southeastern flank of the Goose Lake coal basin.

2. Geological setting

2.1. Geology of the Goose Lake Basin

Early Cretaceous basins east of Lake Baikal (western and eastern Transbaikalia) belong to the west to northwest-trending 1300 km long and up to 600 km wide Trans-Baikal rift system. Mesozoic rifts in western Transbaikalia are East African-type extension structures formed in the continent interior (Samoilov and Yarmolyuk, 1992). Rifting began locally in the Early Jurassic, affected large areas in the Early Cretaceous, and ceased in the latest Early Cretaceous (Tsekhovsky, 2013). Chains of Mesozoic rift valleys follow old fault zones. Most of the basins are half-grabens or more rarely grabens, are within a few tens of kilometers long, and merge into large synclinal structures. They are cut by faults to form sub-basins separated by horsts (Samoilov and Yarmolyuk, 1992; Tsekhovsky, 2013) (Fig. 1).

Goose Lake, 15-18 × 70-75 km, located 65 km southeast of Lake Baikal at 51°5′ − 51°20′ N; 106°9′ − 106°38′ E, occupies a typical Early Cretaceous basin (Goose Lake Basin) in the Transbailakian rift system lying upon Paleozoic granitic basement cut into fault blocks. It is fault-bounded and flanked by the Monostoi and Khambin uplifts in the southeast and northwest, respectively, and consists essentially of two sub-basins (Northeastern and Southwestern) separated by the Zagustai uplift (Bulnaev, 2006; Lunina and Gladkov, 2009).

The Goose Lake Basin originated in the Berriasian in the area of several small, <2–2.5 km wide and 5–25 km long, grabens and evolved until the second half of the Aptian. It reached its maximum extension in the middle-late Valanginian and earliest Hauterivian and became filled with silt, sand, and coarse sediments (Ubukun Formation; K_1g ub). In middle-latest Hauterivian and earliest Barremian, the area of subsidence reduced but the rate of subsidence became notably faster. In the second half of the Barremian and in earliest Aptian, new graben-like sub-basins were formed and accumulated organic-bearing clastics of the Selenga K_1g-br sl (below) and Kholboldzhin K_1br-a hlb (above) formations which became the source of a large coal deposit in the Kholboldzhin sub-basin. The Lower Cretaceous Gusinoye Ozero Group (K_1g) filling the basin are interpreted as a coal-bearing clastic fan unit deposited in hilly plain (Fig. 1). Rifting ceased in the second half of the Aptian, and the coal-bearing sediments first experienced denudation landscapes (Tsekhovsky et al., 2005; Tsekhovsky, 2013).

A long period of denudation between the Mesozoic and Cenozoic rifting events produced peneplain and thick weathering profiles, which are locally preserved on some ridges (Ochirov, 1964; Florencov, 1965; Rezanov, 1988). Neogene tectonic activity, controlled mainly by the Baikal rifting, was the last stage of tectonism in the Goose Lake Basin history. Cenozoic activity included Oligocene, Early Pliocene, Middle-Late Pliocene, and Quaternary events (Radziminovich et al., 2013). Neogene-Quaternary evolution of fault blocks in the basin and its surroundings inherited Mesozoic patterns. The latest seismic activity is evidenced by faulting (Monostoi Fault) and soft-sediment deformation (seismites) of Upper Cenozoic sediments (Lunina and Gladkov, 2009). The northeastern and southeastern borders of the basin provides evidence of Cenozoic faulting including Holocene events. In the Quaternary, tectonic activity waned markedly judging by deposition patterns and the smooth appearance of present-day topography (Lunina and Gladkov, 2009).

2.2. Lithology of Mesozoic sediments

Coal-bearing sediments of the 1850–2050 m thick Gusinoyeozero Group (K_1g) are poorly lithified freshwater continental clastic rocks comprising boulder conglomerate, lacustrine-fluvial and lacustrine-marsh sediments (Datsko, 1973). The group consists of the Murtoi Formation of coarse clastics (K_1b-g mr) at the base overlain by fine clastic sediments of the Ubukun (K_1g ub), Selenga (K_1g-br sl), and Kholboldzhin (K_1br-a hlb) formations (Skoblo et al., 2001). The Selenga and, especially the Kholboldzhin formations, have high coal contents. Seventy coal beds have been mapped in the Goose Lake Basin (Fig. 1; Table S1).

The Murtoi Formation coarse clastics are mainly angular, unsorted, and chaotically distributed debris or blocks of colluvial facies with sporadic lenses or interbeds of layered fine clastic rocks and conglomerates (Tsekhovsky, 2013). The Selenga and Kholboldzhin coal-bearing formations are composed of fine conglomerate, fine to coarse sandstone cemented to different degrees, siltstone, mudstone, and organic-rich mudstone; the percentage of fine-grained rocks in the section is <50%. The Selenga rocks are mostly of fine grained; the formation is thinner and contains fewer coal seams (16 producing coal seams, 11.6 m being the thickest) than the more sandy sediments of the Murtoi Formation. Seventeen 2–4 to 30–53 m-thick coal beds of the Kholboldzhin Formation occur in siltstone and silty sandstone (Ochirov, 1964; Datsko, 1973). Coal-bearing sandstone, conglomerate, and scree are typically poorly sorted and reflect low-energy stream deposition. These sediments sometimes coexist with layered, well-sorted fine conglomerate, sandstone, and siltstone.

The Monostoi Conglomerate overlies eroded coal-bearing rocks, with a thick layer of blocky conglomerate at base indicating an abrupt change in deposition environment. Faunal evidence indicates a late Early Cretaceous age (Ochirov, 1964) that cannot be older than Late Aptian when the coal-bearing sediments first became exposed to denudation (Tsekhovsky, 2013). The Monostoi Conglomerate is exposed on the eastern side of Goose Lake in gullies and in the Kholboldzhin quarry, where small pebbles of CM rocks have been found.

The Goose Lake coals are transitional from brown to black grades (Florencov and Larina, 1937; Ochirov, 1964; Datsko, 1973). Most are semi-dull or semi-bright coals consisting of clarain, durain, and clarain-durain components, with an ash content of 5–41% (average ~25%). Ash content and coal grade increase downward, with long-flame coal occurring in the lower part of the section. The coal is prone to spontaneous ignition (T = 128–149 °C). It becomes friable immediately after being exposed, oxidizes, heats up and often ignites spontaneously in quarries, stock piles, and dumps (Florencov and Larina, 1937; Datsko, 1973). The present-day coal oxidation zone extends to depths of 12–15 m. Coal with lower oxidation potential also easily self-ignites at 185–350 °C. Small foci of smoldering shale are common in gully walls. Large foci of high-temperature smoldering coal occur locally at abandoned sites in the Kholboldzhin quarries, and are marked by ground subsidence, fumarolic mineralization, and the generation of sulfuric dioxides.

2.3. Provenance of coal-bearing sediments: effect on mineralogy

Clastic transport into the Goose Lake Basin, all over its history, has been from the areas of the present-day Monostoi and Khambin ridges composed mainly of Dzhida complex igneous rocks (Sagaluev, 1962; Ochirov, 1964). In the *Monostoi Ridge*, these rocks