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# Natural coal fires in the Kuznetsk Coal Basin: geologic causes, climate, and age

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**Abstract**

The paper summarizes data on the Pleistocene combustion metamorphic complexes of the Kuznetsk Coal Basin. Paralava and clinker samples are dated by $^{40}Ar/^{39}Ar$ incremental heating. The $^{40}Ar/^{39}Ar$ ages of the combustion metamorphic rocks permit reconstructions of the succession of renewed activity of ancient faults in the Salair zone and age estimates for the evolution of the present-day drainage network. Cross sections of burned rocks from the western margin and center of the Kuznetsk Basin are compared. The geologic factors of coal ignition risks are analyzed. On the western margin of the Kuznetsk Basin, paleofires occurred in steeply dipping thick seams with predominant crushed vitrain–clarain coal, which has a high oxygen and methane adsorption capacity. Highly denuded high-temperature combustion metamorphic complexes are most often localized in the arches of slightly broken anticlines. Oxygen was supplied to the coals during the Late Cenozoic renewed fault activity and the subsequent erosion of the sediments. The natural fires in the area were a result of external rather than spontaneous ignition. The depths of the paleofires (up to 200 m) indicate that they occurred in a warm and dry climate. In the center of the Kuznetsk Basin, dispersed fire foci appeared in seams of self-igniting coals with the erosion propagation of the current drainage network. The combustion metamorphic complexes here are partly eroded and consist mostly of clinkers with a low degree of alteration. The $^{40}Ar/^{39}Ar$ ages and geological data indicate that the earliest large-scale combustion events on the western periphery of the basin occurred in the Eopleistocene (1.3–0.9 Ma). The oldest $^{40}Ar/^{39}Ar$ age of a coal fire episode ($1.7 \pm 0.3$ Ma) might be the upper age boundary of the altitude differentiation of topography, which corresponds to the renewed activity of the Tyrgan and Afonino–Kiselevsk faults. The later synchronous combustion events on the western margin ($0.2 \pm 0.1$ Ma) and in the center of the basin (0.13–0.02 Ma), most probably, occurred during the Kazantsevian interglacial, which gave rise to the present-day drainage network.

*Keywords:* $^{40}Ar/^{39}Ar$ dating; coal fires; combustion metamorphic complexes; climate; paralavas; clinkers; Kuznetsk Basin

## Introduction

In epochs of mass burial of organic matter, caustobioliths were isolated from atmospheric oxygen. During recent tectonic activity, manifested in block movements of the basement of the bottom of sedimentary basins, especially near their edges, huge amounts of organic fossil fuel reached the day surface (Lepezin, 2005; Stracher et al., 2010). The increased erosion of the territory ensured direct contact between oxidizer and fuel, which was the main cause of fires. Coal in the zone of aeration adsorbs oxygen and catches fire or quickly loses its flammability owing to oxidation inactivation (Kukharenko, 1960; Stracher et al., 2010). Therefore, natural coal fires occur as "an immediate response" to tectonic activity and intensified erosion. Consequently, absolute dating of episodes of combustion metamorphism permits numerical reconstructions of the Late Cenozoic history of sedimentary basins (Heffern et al., 2007; Novikov et al., 2008). As coal fires usually take place under warm dry conditions (Heffern et al., 2007; Usov, 1935; Yavorskii and Radugina, 1932), their dependence on climate opens up the possibility of using combustion metamorphic (CM) rocks as new climate indicators.

This opinion has been supported by the dating of CM rocks in the Great Plains, United States (Heffern et al., 2007). It was carried out by the (U–Th)/He and track methods for detrital zircon from clinkers which had formed during coal fires. These methods made it possible to date fires no older than 1 Ma and to reconstruct the stages of development of the present-day drainage network. The results of the dating permitted assigning

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Table 1. Stratigraphy and coal content of the Upper Paleozoic of the Kuznetsk Basin (Kudinov, 2007; Yuzvitskii, 2003)

| Group | Subgroup | Formation | Thickness of sediments, m | Number of coal seams | Total thickness of coal seams, m | Coal content, % (range of coal contents, %) |
|---|---|---|---|---|---|---|
| Kol'chugino ($P_2$kl) | Erunakovo ($P_2$er) | Tailugan ($P_2$tl) | 1900–2580 | 105 | 101.5 | 3.6 (0.7–16) |
| | | Gramoteino ($P_2$gr) | | | | |
| | | Leninsk ($P_2$ln) | | | | |
| | Il'inka ($P_2$il) | Uskat ($P_2$usk) | 1000–1600 | 64 | 12.6 | 1.4 |
| | | Kazankovo-Markina ($P_2$k-m) | | | | |
| | Kuznetsk ($P_2$kz) | Mitino ($P_2$mt) | 500–1200 | 6 | 0.5 | 2.5 |
| | | Staryi Kuznetsk ($P_2$skz) | | | | |
| Balakhonka ($C_1$-$P_1$bl) | Upper Balakhonka ($P_1$bl) | Kemerovo ($P_1$km) | 825–1275 | 68 | 98.6 | 4.0 (1.3–21) |
| | | Ishanovo ($P_1$is) | | | | |
| | | Promezhutochnaya ($P_1$pr) | | | | |
| | Lower Balakhonka ($C_{2\text{-}3}$bl) | Alykaeva ($C_3$al) | 290–1045 | 3 | 2.1 | 1.8 |
| | | Mazurovo ($C_2$mz) | | | | |
| | Ostrog ($C_{1\text{-}2}$os) | Kaezov ($C_2$ks) | 100–600 | – | – | <1 |
| | | Evseeva ($C_1$ev) | | | | |

the paleofires to Pleistocene interglacials. This approach to dating CM events could have been acknowledged the best one, but its applicability is strictly limited by the paleogeographic conditions of formation of coal-bearing sediments, because zircon accumulates only in littoral sediments. Thus, there is a need for different methods for dating CM rocks, which would be applicable to a wider spectrum of sedimentary protoliths.

A fundamentally different technique for dating molten CM rocks, based on the conventional $^{40}Ar/^{39}Ar$ method of stepwise heating, was developed by us for the Pleistocene CM rocks of the Kuznetsk Basin. The oldest ages (~1.2 Ma) were obtained for CM rocks from the Kuznetsk Basin–Salair Ridge junction (Novikov et al., 2008). Along with the K–Ar method, the $^{40}Ar/^{39}Ar$ method is widely used in dating fresh mafic rocks (Karlstrom et al., 2007; Perepelov et al., 2010).

The objectives of the present work are (1) to reconstruct the detailed geologic structure of CM complexes of different ages; (2) to define the main factors of risks (tectonic, structural, and compositional) of natural coal fires in the Kuznetsk Basin; and (3) to date CM rocks and to reconstruct the age intervals of extensive coal fires on the western margin and in the center of the Kuznetsk Basin.

## Geologic structure of coal-bearing rocks and the CM complexes of the Kuznetsk Basin

Kuzbass, Russia's largest coal basin, is also considered the basin with the highest potential for the recovery of sorbed methane from coal seams (Karasevich et al., 2001). Structurally, it is confined to the Kuznetsk Depression, which consists of thick (up to 10 km) sedimentary units belonging to the interval $D_2$–$J_2$ (Table 1). The Upper Paleozoic–Mesozoic sediments at the basin periphery were disturbed by the revived activity of ancient faults in the Late Cenozoic. The sediments show the strongest deformation on the northwestern and southwestern margins of the basin (Yavorskii, 1969; Yuzvitskii, 2003). Traces of ancient coal fires are found throughout the Kuznetsk Basin. However, most of the paleofires are concentrated in four areas: Kemerovo, Prokop'evsk–Kiselevsk, Kondoma, and Erunakovo. In 2005–2009, we studied the CM (burned) rocks of the strongly deformed western margin (Prokop'evsk–Kiselevsk area, or Salair complex) and the slightly deformed central part of the Kuznetsk Basin (Erunakovo area, Sokolovo, Kamushek, Inya, and Karakan complexes) (Fig. 1). When the geologic situation and structure of the CM rocks were analyzed, data from holdings (Mednikova and Zhdanova, 1967; Zhdanova et al., 1970) and large-scale maps (Fot'eva, 1984; Luppov, 1964, 1965; Yuzvitskii, 1998, 2000) were used along with the authors' field data.

## The Salair complex

**Geological setting.** The western margin of the Kuznetsk trough was strongly deformed by the overthrusting of the Salair block under near-horizontal compression (Kudinov, 2007; Yavorskii, 1970; Yuzvitskii, 2003). The block structure of the region is determined by a series of subparallel reverse–overthrust faults with a general amplitude of vertical displacements of up to 2000 m. The largest ones are the Tyrgan, Taiba, Afonino–Kiselevsk, and Kiselevsk. They mark off three altitudinal steps. The altitudes of the upper step are 440–460 m; those of the middle one, 380–400 m; and those of the lower one, 320–370 m (Fig. 2). The middle altitudinal step includes the Western and Central tectonic zones (Kudinov, 2007). The Western zone is dominated by compressed linear