Geochemistry and Chemostratigraphy of Meso- to Neoproterozoic Sedimentary Rocks of the Yenisei Ridge (Siberia, Russia)

Irina Vishnevskaya, Natalia Pisareva, Artem Proshenkin and Nadejda Kanygina

Abstract Here we report the results of a study of the sedimentary rocks of the Yenisei Ridge, located on the south-western margin of the Siberian Platform. We investigated geochemical data on Meso- to Neoproterozoic terrigenous rocks and the isotopic (Sr, C, O) characteristics of carbonate rocks (the Sukhoi Pit, Tungusik, and Shirokino groups). The data show that the Sukhoi Pit, Tungusik, and Shirokino groups were deposited more than 850 Myr ago. The absence of tillite deposits and the occurrence of positive $\delta^{13}C$ values indicate that the deposition took place before the occurrence of the Cryogenian global glaciations. The distributions of rare and trace elements in these rocks indicate that they were formed by the erosion of very mature (highly differentiated) rocks of the Siberian Platform.

Keywords Carbonate · Cryogenian · Chemostratigraphy · Strontium · Rare and trace elements

The Proterozoic was the most extensive period of sedimentary rock development. One of the largest Proterozoic sedimentary basins in Russia is around the Siberian Platform. This study focuses on a part of these deposits, that is, the Meso- to Neoproterozoic sedimentary rocks of the Yenisei Ridge, located on the south-western margin of the Siberian Platform.

The Mesoproterozoic rocks of the Sukhoi Pit Group are divided into the terrigenous Kordin, Gorbilok, Uderey, and Pogoruy formations, which are covered by the carbonate Kartochki and Alad'in formations (Fig. 1). These sediments formed in continental margin environments with source areas situated mainly on the Siberian Platform. The lower part of the Sukhoi Pit Group is intruded by granitoids of the Teya and Kalamina massifs, with a U–Pb age (dated by zircons) of around

I. Vishnevskaya (✉) · N. Pisareva · A. Proshenkin
Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
e-mail: vishia@igm.nsc.ru

N. Kanygina
Novosibirsk State University, Novosibirsk, Russia

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866–875 Ma (Nojkin et al. 1999; Vernikovskaya et al. 2004). These sediments are overlain by Neoproterozoic sediments of the Tungusik Group. The group is divided into a set of carbonate–terrigenous formations, which from bottom to top are the Potoskui, Djursk, Seriy Klyuch, and Dadikta. The youngest of the studied rocks are the carbonate deposits of the Goreva Formation (Shirokino Group). These sediments were formed in a passive continental border environment.

The chemical compositions of sedimentary rocks reflect the compositions of protoliths eroded from source rocks (Taylor and McLennan 1985). The relationships between REE, Th, Sc, and some other elements with high nuclear charge can indicate various facets of a basin's geological evolution. During a basin's geological history, Rb, Sr, Ba, Th, U, Y, Hf, Zr, and Sc contents tend to increase, as does the Th/Sc ratio, whereas the contents of Cr, Co, and Ni, and the ratios of Zr/Y, La_N/Yb_N, Cr/Th, Cr/Sc, La/Th, and Cr/V decrease. Most of these impurity elements arrive at the sedimentary basin with rock fragments and have almost the same concentrations as are found in the crust (Taylor and McLennan 1985). Thus, the study of the geochemical characteristics of sedimentary rocks allows us to reconstruct source-area composition and to estimate the age of the eroded crust. Condie (1993) used ratios of Cr/V–La/Th, Y–Zr, and Cr/Th–Co/Th and some other parameters to determine the average composition of early Archean (>3.5 billion years old), late Archean (3.5–2.5 billion years) and Palaeoproterozoic (2.5–1.8; 1.8–1.6 billion years) upper crust. A comparison of the chemical composition of the Kordin Formation (Sukhoi Pit Group) (Maslov et al. 2008) with these data shows that sediments of the Sukhoi Pit Group were formed as the result of erosion of old continental crust that was already highly geochemically differentiated during the late Archean (Nojkin and Turkina 1993). This is confirmed by the fact that the Kordin Formation and post-Archaean Australian shale (PAAS) (Fig. 1) have similar compositions and by the high Th contents in the studied rocks.

The determination of the ages of Precambrian sedimentary rocks is very difficult, and Sr isotope chemostratigraphy appears to be the only approach for establishing the ages of carbonate sequences. We have studied the sediments of the Sukhoi Pit, Tungusik, and Shirokino groups for Rb–Sr and C–O isotope system integrity. The main criteria for integrity were the correlations of impurity elements (Mn, Fe, and Sr) with stable isotopes ($\delta^{13}C$ and $\delta^{18}O$). The primary $^{87}Sr/^{86}Sr$ ratio in rocks of the Sukhoi Pit Group is 0.7057–0.7061 and the $\delta^{13}C$ values of this group range from −1.0 to +1.5 ‰. The less altered rocks of the Tungusik Group are characterized by an $^{87}Sr/^{86}Sr$ ratio of 0.7055–0.7058 and wide variations in $\delta^{13}C$ values from 0 to +5 ‰. The $^{87}Sr/^{86}Sr$ ratio in less altered rocks of the Shirokino Group is 0.7055–0.7059 and the $\delta^{13}C$ values are generally between +3.5 and +5.2 ‰ (Vishnevskaya et al. 2012) (Fig. 1). The analysis of isotope data of the studied carbonate rocks and variations in the Sr isotope composition of Proterozoic seawater (Kuznetsov et al. 2003; Halverson et al. 2010) shows that the $^{87}Sr/^{86}Sr$ ratio of 0.7053–0.7061 for carbonates from the Sukhoi Pit and Tungusik groups is typical of the broad age interval from 1070 to 750–770 Ma. However basement of the Sukhoi Pit Group was pierced by Teya and Kalamin granite batholiths at around 866–875 Ma, and therefore group had formed by this time. All

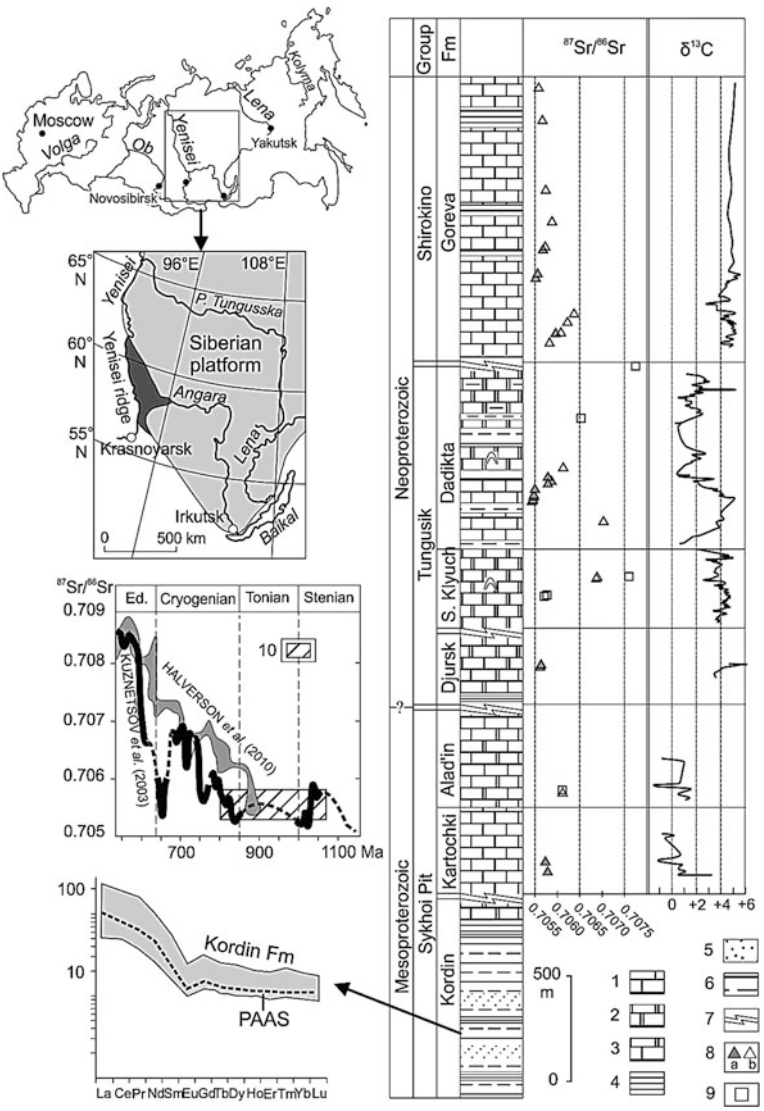

Fig. 1 Geochemical and chemostratigraphic features of Meso- to Neoproterozoic rocks of the Yenisei ridge. *1* limestone; *2* dolomite; *3* limestone with interlayers of dolomite and dolomitized limestone; *4* black shale; *5* sandstone; *6* siltstone; *7* section intervals not considered; *8* rock samples of **a** stratified and **b** nonstratified limestone; *9* rock samples of dolomite; *10* the $^{87}Sr/^{86}Sr$ ratio in less altered carbonate rocks of the Shirokino, Tungusik, and Sukhoi pit groups; Fm, formation; S. Klyuch, Seriy Klyuch; Ed., Ediacaran

studied carbonate rocks had accumulated prior to global glaciations occurring during the Cryogenian. This is confirmed by the absence of tillite in the studied groups (Melnikov et al. 2005). $\delta^{13}C$ values in the reviewed sections vary from +0.4 to +5.3 ‰ (Fig. 1), which is evidence for the absence of a cold period.

Geochemical data of terrigenous rocks, the isotope compositions of carbonate rocks from the Sukhoi Pit and Tungusik groups, and geochronological data together show that these groups were formed as the result of the erosion of old deposits from the Siberian Platform. Sedimentation of carbonate rocks started no later than 850 Myr ago, before the first glaciations took place during the Cryogenian.

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