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ScienceDirect

Russian Geology and Geophysics 55 (2014) 629–648

RUSSIAN GEOLOGY AND GEOPHYSICS

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# Sedimentology and isotope geochemistry of Riphean carbonates in the Kharaulakh Range of northern East Siberia

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Received 14 November 2013; accepted 26 November 2013

**Abstract**

Stable carbon isotope variations in primarily offshore Proterozoic carbonates of the Eselekh, Neleger, and Sietachan Formations in the Kharaulakh Range of northern East Siberia provide important information on the depositional history of the Riphean complexes and allow an age estimate to be made for potentially petroliferous Precambrian strata in the northeast of the Siberian Platform. The results of petrographic, geochemical, and isotopic studies of the measured samples demonstrate that the carbonates are recrystallized without substantial postdepositional alteration of the carbon isotope system and that the acquired $\delta^{13}C$ values are accurate and can be used for the purposes of chemostratigraphy. The Riphean strata of the Kharaulakh Range are characterized by mostly high (5.5–8.6‰) $\delta^{13}C$ values. Based on carbon isotope data, the studied section could not be correlated with Mesoproterozoic strata of the Anabar and Olenek Uplifts but occupies a rather higher stratigraphic position. It can be correlated with the Baikal Group of the West Pre-Baikal Area and the Dal'nyaya Taiga Group of the Patom Upland; specifically, the negative shift in the uppermost Sietachan Formation possibly corresponds to the Zhuya negative excursion. Comparison with the model curve of carbon isotope evolution in the Precambrian ocean suggests that the age of the studied section does not exceed 820 Ma. Most likely, the studied strata are younger than 635 Ma (i.e., postdate the Marino glaciation) but older than the Gaskiers glaciation (580 Ma).

*Keywords:* carbon isotopic composition of carbonates; Riphean; Vendian; Neoproterozoic; stratigraphy; sedimentary environments; Kharaulakh Range of northern East Siberia

## Introduction

Interest in geology of the subarctic regions of Siberia and the adjacent continental shelf seas has grown significantly in recent years. In this context, the study of stratigraphy and sedimentology of potentially fossiliferous depositional sequences, specifically the Upper Precambrian strata cropping out along the flanks of Anabar Anticlise and within the Udzha and Olenek Uplifts and the Kharaulakh Range (Fig. 1), is of particular importance (Dobretsov and Kontorovich, 2013; Kontorovich, 2008; Kontorovich et al., 2013; Surkov et al., 1991).

The Riphean (Meso-Neoproterozoic) depositional sequence of the Kharaulakh Range comprising the Ukta, Eselekh, Neleger, and Sietachan Formations was extensively studied during the 1960s through 1980s (Komar, 1966; Korobov, 1963; Krylov et al., 1971; Mokshantsev, 1979; Semikhatov and Serebryakov, 1983; Shpunt et al., 1982). The results of these studies as well as the correlation with sections in the Pre-Anabar Region and Olenek Uplift were summarized in a set of correlation charts, where the Ukta and Eselekh Formations (and occasionally the Neleger Formation) were regarded as Middle Riphean, whereas the Neleger and Sietachan Formations were assigned to the lowermost Upper Riphean (Mokshantsev, 1979; Semikhatov and Serebryakov, 1983). The stratigraphic position of these formations has remained essentially unchanged (Mel'nikov et al., 2005), and the information on Riphean lithology and stratigraphy in the Kharaulakh Range and adjacent territories of the Siberian Platform has been widely used in both regional and global geological reconstructions (Pisarevsky et al., 2008; Sears et al., 2004; Vernikovsky et al., 2013). In terms of sedimentology, the Riphean section of the Kharaulakh Range consists of primarily offshore carbonates with no significant hiatuses (lasting more than a few dozen million years); therefore, it is highly unlikely that this essentially continuous depositional sequence represents over 200 million years of geological history. To our opinion, the depositional history of the

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http://dx.doi.org/10.1016/j.rgg.2014.05.008

succession can be resolved using stable carbon isotope chemostratigraphy.

Variation in primary stable carbon isotopic composition ($\delta^{13}C$ value) in marine carbonates has been shown to be the result of partitioning of carbon between organic carbon and carbonate carbon reservoirs and used for recognition of different-scale geological events and resolution of various stratigraphic problems. In Precambrian research, where traditional methods of stratigraphy are limited in application, chemostratigraphy is particularly important.

A change in $\delta^{13}C$ values from near zero to variations between –2.0‰ and +2.0...+3.0‰ is recorded worldwide in Proterozoic rocks younger than ca. 1300 million years (Bartley et al., 2001; Derry et al., 1992; Halverson et al., 2005, 2007, 2010; Jones et al., 2010; Kah et al., 1999; Kaufman, 1997; Khabarov and Ponomarchuk, 2005; Knoll et al., 1995; Lindsay and Brasier, 2002; McKirdy et al., 2001; Melezhik et al., 2001; Pokrovskii et al., 2006; Walter et al., 2000). Neoproterozoic rocks 1000–800 Ma old are characterized by much greater variations of $\delta^{13}C$ values ranging from –3.0...–2.0‰ to +4.0...+6.0‰. There is an additional increase in the amplitude of $\delta^{13}C$ variations (from –10.0...–5.0‰ to +8.0...+12.0‰) in even younger Neoproterozoic strata. The end of Neoproterozoic is marked by somewhat smaller variations. Carbon isotope record can also be affected by regional and local processes (Kah et al., 1999; Knoll et al., 1995); therefore, stable isotope studies are typically accompanied by basin research and analyses of possible postdepositional modifications in the primary isotope systems.

In this contribution we report the results of sedimentological, petrographic, geochemical, and isotopic studies of carbonates of the Kharaulakh Range, together with the resolved trend in the evolution of carbon isotope composition, and discuss possible applications of the new data for stratigraphic correlation of the studied section.

## Regional geological setting and stratigraphy

The Kharaulakh Range is located at the boundary between the northeastern part of the Siberian Platform and the Verkhoyansk Fold Belt. The Riphean strata of the Kharaulakh Range crop out in the Chekurovka and Bulkur anticlines of submeridianal extension. Sections were studied in the northestern flank of the Chekurovka Anticline in coastal cliffs of the left bank of Lena River downstream from the Chekurovka settlement (Fig. 1). The strata are moderately dislocated, with different-scale isoclinal folds with overturned northwestern limbs, penetrated by several thick (up to 60 m) dolerite sills and complicated by small amplitude faults (normal faults, strike-slip faults, and thrust faults). The Riphean rocks of the Kharaulakh Range became dislocated together with Vendian, Paleozoic (Cambrian and Permian) and Mesozoic (pre-Aptian) strata during formation of the Verkhoyansk Fold Belt and are traditionally included into the latter (Mokshantsev, 1979).

The Riphean primarily carbonate complexes reach 1000 m in observed thickness and comprise the Ukta (>150 m), Eselekh (380–400 m), Neleger (150–160 m exclusive of the dolerite sills) and Sietachan (310–320 m) Formations (Mokshantsev, 1979; Semikhatov and Serebryakov, 1983). The Sietachan Formation is conformably overlaid by the Upper Vendian Kharayutekh Formation (Fig. 2).

The Ukta Formation consists of tuffaceous shales with lenticular interbeds of quartz sandstones; in addition, the uppermost Ukta Formation includes dolostones, particularly stromatolitic dolostones (Mokshantsev, 1979; Shpunt et al., 1982). We did not study the Ukta Formation and the lower part of the Eselekh Formation.

The Eselekh Formation is divided into three members. The Lower Member comprises mostly gray and light gray stromatolitic dolostones. Diverse stromatolites (conophytons, yakutophytons, baicalia) form large bioherms (up to a few dozen meters in diameter) separated by lumpy and intraclastic dolostones. The rocks are heavily recrystallized and often represented by clearly crystalline varieties, with relicts of stromatolitic (banded clotted pattern) and lumpy intraclastic structure. The upper part of the Lower Member is dominated by recrystallized grainy dolostones, with lenticular lamination and wave ripple marks, interpreted as proximal storm deposits (tempestites). The dolomitic tempestites become thinner up the section and are changed to limestones of the Middle Member.

The Middle Member of the Eselekh Formation consists of mostly gray, dark gray, micritic-siltitic, fine lumpy to intraclastic limestones with thin lenticular bedding, occasionally with graded bedding, interpreted as storm deposits (tempestites). The limestones are recrystallized, contain abundant pyrite, and have high organic carbon content. The rocks are organized into three shallowing-upward sequences ca. 15 m thick. Each sequence is composed of small, meter-scale shallowing-upward cycles (Fig. 3*A*). The meter-scale cycles in the lower part of the sequences consist of fine laminated, sometimes muddy, often graded micrite-siltite couplets with dark gray thinly laminated shale interbeds deposited in distal shelf setting (below storm wave base) overlain by dark gray, micritic-siltitic, fine lumpy to intraclastic limestones with wave-ripple lamination (tempestites) deposited in mid-shelf setting (between fair weather and storm wave base). Lumpy to intraclastic limestones with wave-ripple lamination deposited in mid-shelf, occasionally shallow water settings (above fair weather wave base) increase in importance in the meter-scale cycles in the upper part of the sequences).

In the Upper Member of the Eselekh Formation, the same lithologic types interstratify with packages (15, 20 and 3–5 m thick) of light gray stromatolitic dolostones containing large conophytons and colonnela (Fig. 3*B*). Meter-scale shallowing-upward cycles consist of limestones, with increased contribution of lenticular-bedded, lumpy to intraclastic storm deposits of mid-shelf and shallow water settings. The limestones are locally dolomitized.

The lower part of the Neleger Formation comprises mostly dolostones, whereas limestones dominate in the thicker upper part of the formation. Dolostones are gray and dark gray, yellowish gray on weathered surfaces, often contain cherts (Fig. 3*C*, *D*). Several meter-scale shallowing-upward cycles