LOOK ACADEMIC PUBLISHERS
OPEN ACCESS

INTERNATIONAL JOURNAL OF ENVIRONMENTAL & SCIENCE EDUCATION
2016, VOL. 11, NO. 18, 11375-11383

Formation Conditions and Metal Content of the Late Triassic Deposits in the Kular-Nera Slate Belt (Northeastern Russia)

Lena I. Polufuntikova[a] and Valery Y. Fridovsky[b]

[a]North-Eastern Federal University Named after M.K. Ammosov, Department of Prospecting and Exploration of Mineral Deposits, Yakutsk, RUSSIA;
[b]Diamond and Precious Metal Geology Institute SB RAS, Yakutsk, RUSSIA.

ABSTRACT

This research investigated the prevailing conditions in the bottom water of the sedimentation basin and the degree of their effect on the authigenic mineralization of the Upper Triassic terrigenous deposits in the Kular-Nera slate belt (Northeastern Russia). The analysis of the distribution of rare and trace chemical elements in the studied sample showed significant variations of their composition and the presence of a number of elements in amounts that are higher than the bulk Earth values. Increased, in respect to sandstone, concentration of Li, B, Sc, V, Ni, Zr, Nb, and Mo was discovered in siltstone. A small deficit of Be, Nb, and Mo was discovered in the Late Triassic deposits on average; the concentration of these elements in individual samples exceeded the bulk Earth values by 1.5-2 times at that. Variations of the ΣCe/ΣY index (from 2.4 to 6.2) are indicative of either changes in the facies environment (coastal-marine to deep-water) or changes in the composition of the source area. The Sr/Ba¤0.5 ratio and the increased content of boron are typical for lagoon and highly desalted deltaic deposits. In most cases, the Mo/Mn values do not exceed 0.01; V/Cr_{mean} = 1.09, Ni/Co –7.0, while V/(V+Ni) – from 0.23 to 0.85, which is indicative of a prevailing oxygen environment with short-term decreases of the oxygen content and an increasing role of reduction processes. Due to changes in the sea level during the formation of the Late Triassic deposits, the anoxic environment changed to a moderately anoxic one.

KEYWORDS
Northeastern Russia, Upper Triassic, gold fields, metal content, redox environment.

ARTICLE HISTORY
Received 6 June 2016
Revised 1 October 2016
Accepted 18 October 2016

Introduction

The Verkhoyansk-Kolyma orogen includes several stratigraphic sequences with prevailing gold fields (Aquarelle Inc., 2010; Goldfarb et al., 2014; Goryachev & Pirajno, 2014). The Upper Carboniferous sequences include deposits of the Yurskoe-Brindakit and Bular-Onocholokh ore fields; the Permian sedimentary rocks include the large Natalkinskoe and Nezhdaninskoe deposits; the Upper

CORRESPONDENCE Lena Polufuntikova pli07@list.ru

Triassic sedimentary rocks include the Maly Taryn, Drazhnoe, Bazovskoe, and Badran deposits (Astakhov et al., 2010; Grinenko & Prokopiev, 2016; Fridovsky et al., 2015; Fridovsky et al., 2014). An important factor for the formation of large gold fields is the enrichment of individual stratigraphic sequences with ore elements, which creates conditions for a staged mobilization of gold during orogenic metamorphic and magmatic events (Polufuntikova & Fridovsky, 2016; Prokopiev et al., 2008; Voroshin et al., 2014). The Upper Triassic section of the Verkhoyansk zone (southeastern flank of the Kular-Nera slate belt) deposits is characterized by the presence of claystone, siltstone and rare sheets of sandstone (Polufuntikova & Fridovsky, 2016). Facies of deposits of a downslope apron and alluvial cone have been discovered in this area, which change to more distal medium-grained and fine-grained turbidites of alluvial cone in the northeast. Turbidite sequences accumulated in the distal part of the Verkhoyansk passive continental margin, while the debris was brought to this part of the sediment basin by large rivers – paleo-Lena and paleo-Aldan (Grinenko & Prokopiev, 2016; Prokopiev et al., 2008). The research investigates the geochemical features of the Upper Triassic deposits by the example of the central part of the Kular-Nera slate belt, which is located east of the structures of the passive continental margin of the Siberian (North Asian) craton (Figure 1). The Upper Triassic facies-variable clastic deposits accumulated in the deep-water alluvial cones on the slope and foot of the continental margin (Polufuntikova & Fridovsky, 2016).

The research addressed a series of issues related to the alteration of the chemical composition, enrichment or impoverishment of rocks with rare and trace elements. The analysis of geochemical data enables assessing the primary specialization of sedimentary complexes and determining their role in the formation of increased concentrations of ore components.

Aim of the Study

This study aims to determine the prevailing conditions in the bottom water of the sedimentation basin and their effect on the potential metal content of terrigenous deposits.

Research questions

Can the climate, basin salinity, and redox conditions be changed in the bottom water during the accumulation of the Upper Triassic deposits in deep-water alluvial cones on the slope and foot of the continental margin?

Does the lithological type of rocks affect their degree of enrichment with ore components?

Method

The research investigates the geochemical features of the Upper Triassic deposits by the example of the central part of the Kular-Nera slate belt, which is located east of the structures of the passive continental margin of the Siberian (North Asian) craton (Figure 1). The Norian samples of sandstone and siltstone were taken for geochemical studies. Spectral analysis of rocks was conducted using a mass spectrometer at the laboratory for geochemical methods of mineral deposit exploration of the North-Eastern Federal University Geological Exploration Faculty. The research investigated the distribution of a series of indicator elements in sandstone and siltstone, their correlation, migration mechanisms and conditions.

The theoretical framework of the study included a set of methods relevant to the set goal, namely: analysis, synthesis, and formal logical research methods. The study generalized the experience of Russian and foreign researchers on the subject at hand.

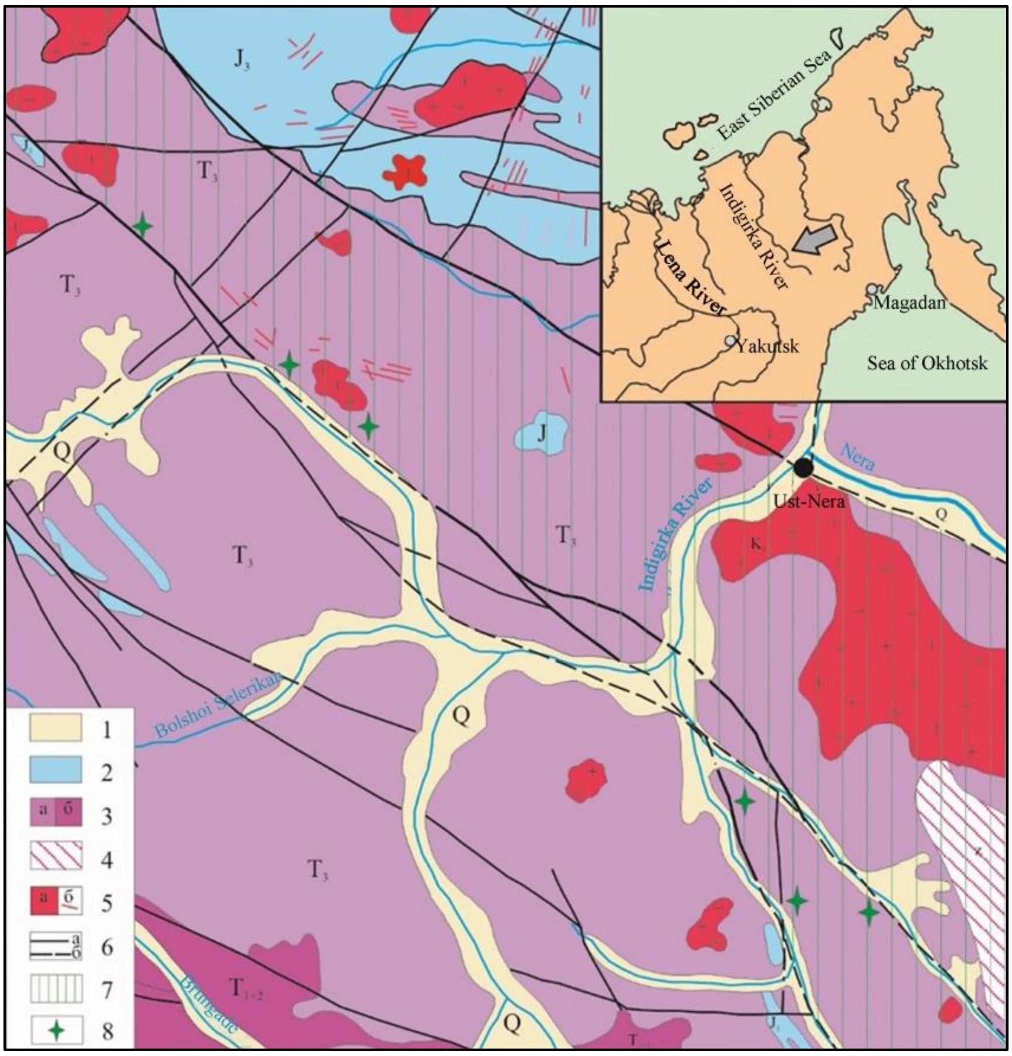

Figure1. Geological map of the central part of the Kular-Nera slate belt and adjacent territories.

1 – Quaternary deposits; 2 – Jurassic deposits; 3 – Triassic deposits: a – late; b – early and middle; 4-5 – magmatic formations: 4 – Early and Late Cretaceous subvolcanic bodies, 5 – Early Cretaceous: a – granite, granodiorite, b – granite-porphyry and dacite-porphyry dikes; 6 – faults: a – proved, b – assumed; 7 – Kular-Nera slate belt; 8 – sampling stations.

Data, Analysis, and Results

The analysis of the distribution of rare and trace chemical elements in the studied sample showed significant variations of their composition (Figure 2) and the presence of a number of elements in amounts that are higher than the bulk Earth values (Nedra Inc., 1977). The content of cobalt varied significantly in sandstone varieties (CCo from 0.8 to 25.1 ppm) and was relatively consistent in siltstone (CCo from 12 to 28 ppm). On average, the content of cobalt in the studied rocks was close to the bulk Earth values. Rocks had an increased content of Cr, with greater variations of its content being characteristic of sandstone (from 22.3 to 580.5 ppm). Siltstone had increased, in respect to sandstone, content of Li, B, Sc, V, Ni, Zr, Nb and Mo. A small deficit of Be, Nb, and Mo was discovered in the Upper Triassic deposits on average; the concentration of these elements in individual samples exceeded the bulk Earth values by 1.5-2 times at that (Table 1).

Table 1. Concentration of elements (ppm) and values of some geochemical indices in the Upper Triassic sedimentary rocks from the central part of the Kular-Nera slate belt

	V	Co	Cr	Ni	Mo	Mn	Ce	V/Cr	Ni/Co	V/(V+Ni)	Mo/Mn
Sandstone											
Bz-P-3	27	1.5	328.2	10.4	2.9	2810.07	24.7	0.08	6.93	0.72	0.001
Bz-P-2	41.5	1.9	449.6	16.2	3.8	379.3	31.4	0.09	8.53	0.72	0.010
Bz-P6	142	12.9	129.6	22.9	2.5	370.01	58.5	1.10	1.78	0.86	0.007
Bz-P-4	26.1	8.1	291.1	22.9	3.9	153.25	19.3	0.09	2.83	0.53	0.025
Bz-P-8	85.1	7.6	379.9	28.2	3	296.13	53.1	0.22	3.71	0.75	0.010
Bz-P-7	106.8	13.3	520.2	24.1	3.6	391.54	107.9	0.21	1.81	0.82	0.009
Bz-P-13	87	8.8	580.5	24.6	3.6	201.5	64.9	0.15	2.80	0.78	0.018
Bz-P-10	42.5	3.5	317.4	21.5	3.4	355.84	28.6	0.13	6.14	0.66	0.010
Mr-6	177.2	3	99.9	16	2.4	450.39	66.8	1.77	5.33	0.92	0.005
Mr-5-	61.3	5.9	378.6	23.6	2.9	588.23	43	0.16	4.00	0.72	0.005
Mr-12	95.1	8	248.7	28.9	2.6	204.83	50.6	0.38	3.61	0.77	0.013
Mr-11	90.1	8.7	290.7	32.2	2.7	537.51	51.8	0.31	3.70	0.74	0.005
Mr-4	92.1	10.8	226.6	32.4	2.9	608.99	50.1	0.41	3.00	0.74	0.005
Mr-7	67.2	7.5	124.6	36.9	2.3	1727.38	37.2	0.54	4.92	0.65	0.001
Mr-1	93.9	11.6	262	41.5	2.7	246.57	52.1	0.36	3.58	0.69	0.011
Mr-2	54.2	5.8	221.6	21.5	3	2128.21	37.2	0.24	3.71	0.72	0.001
Mr-3	68	7.6	352.1	26.3	3.7	869.57	42.1	0.19	3.46	0.72	0.004
Mt 1-8	41.3	3.2	22.3	12.2	2	696.96	64.03	1.85	3.81	0.77	0.003
Mt 1-9	42.1	3.9	28.4	18.2	2.1	4646.4	62.58	1.48	4.67	0.70	0.000
Ap 1	76	16.4	63.3	44.8	1.5	542.08	86.56	1.20	2.73	0.63	0.003
M 167	90.2	25.1	63.1	46	1.2	232.32	65.96	1.43	1.83	0.66	0.005

Table 1. (*Continued*)

	V	Co	Cr	Ni	Mo	Mn	Ce	V/Cr	Ni/Co	V/(V+Ni)	Mo/Mn
Siltstone											
Bz-P-5	32.7	2.1	434.2	16.4	3.5	300.08	24.3	0.08	7.81	0.67	0.012
Bz-P15	98	12	248.5	29.3	2.8	270.65	69.2	0.39	2.44	0.77	0.010
Bz-P-1	162.2	12.7	159.7	42.1	2.5	289.08	89.1	1.02	3.31	0.79	0.009
Bz-P-9	163.5	19.1	322.5	49	4.4	359.32	96.5	0.51	2.57	0.77	0.012
tr-2	366.30	28.97	173.50	85.54	4.39	1270.79	44.24	2.11	2.95	0.81	0.003
tr-3	214.70	19.75	164.20	53.73	4.10	214.51	42.27	1.31	2.72	0.80	0.019
tr-6	282.90	22.17	159.90	66.23	3.60	336.09	31.14	1.77	2.99	0.81	0.011
tr-9	213.90	26.76	163.10	93.52	2.60	373.26	39.09	1.31	3.49	0.70	0.007
tr-12	233.00	20.40	227.70	73.66	3.47	145.59	43.8	1.02	3.61	0.76	0.024
tr-15	234.30	17.64	179.80	72.78	11.84	281.88	41.47	1.30	4.13	0.76	0.042
tr-18	245.20	18.05	201.20	79.13	3.73	367.84	22.33	1.22	4.38	0.76	0.010
tr-21	280.70	20.47	206.20	102.00	4.51	450.70	45.22	1.36	4.98	0.73	0.010
tr-25	233.40	28.89	195.40	99.32	3.84	550.60	32.39	1.19	3.44	0.70	0.007
tr-28	123.00	12.15	399.20	38.80	2.47	339.20	49.02	0.31	3.19	0.76	0.007
tr-34	224.90	21.20	160.80	87.90	2.34	629.60	52.86	1.40	4.15	0.72	0.004
tr-35	233.50	24.50	177.30	88.86	4.81	297.40	58.91	1.32	3.63	0.72	0.016
Ku-6	182.3	18.3	189.5	76.5	1.7	232.32	56.6	0.96	4.18	0.70	0.007
E-1	114.7	17.8	274.1	57.1	2	619.52	52.1	0.42	3.21	0.67	0.003
E-2	133.9	16.1	248.9	56	3	232.32	61.7	0.54	3.48	0.71	0.013
Ms-2	101	19.7	312	135.4	2.3	2555.52	49.2	0.32	6.87	0.43	0.001
G-24	132.1	23.9	376.2	66.3	3.7	309.76	53.7	0.35	2.77	0.67	0.012
P 90	154.8	28.1	126.3	79.9	1.4	619.52	47.43	1.23	2.84	0.66	0.002
P 96	148.9	26.7	160.1	102.9	1.6	542.08	43.87	0.93	3.85	0.59	0.003
D-60	153.5	20	167.8	72.5	2.7	619.52	63.4	0.91	3.63	0.68	0.004
V-9	95.6	16.7	303.6	54.3	4.1	247.808	49.2	0.31	3.25	0.64	0.017
Z-28	219.3	17.1	159.2	76.5	2.7	271.04	58.3	1.38	4.47	0.74	0.010

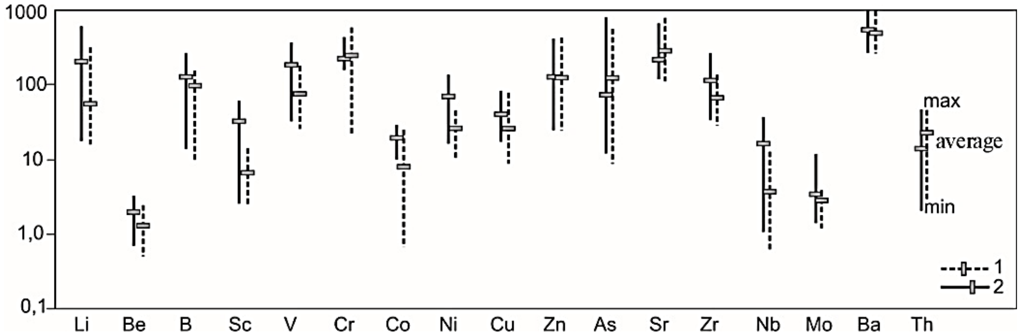

Figure 2. Content of elements in the Norian deposits.
1 - sandstone; 2 - siltstone. The range of changes is shown (min; max; average content).

The ΣCe/ΣY ratio – a rare earth element differentiation index in various climatic conditions of sediment genesis – was used as a geochemical indicator of the paleoclimate (Maslov et al., 2016). In the studied sample, ΣCe/ΣY>2.3 at value variation from 2.4 to 6.2. The paleo-salinity index Sr/Ba does not exceed 0.5 in 76% of the sample with increased concentration of B (CB/Ck=10-100) (Figure 3).

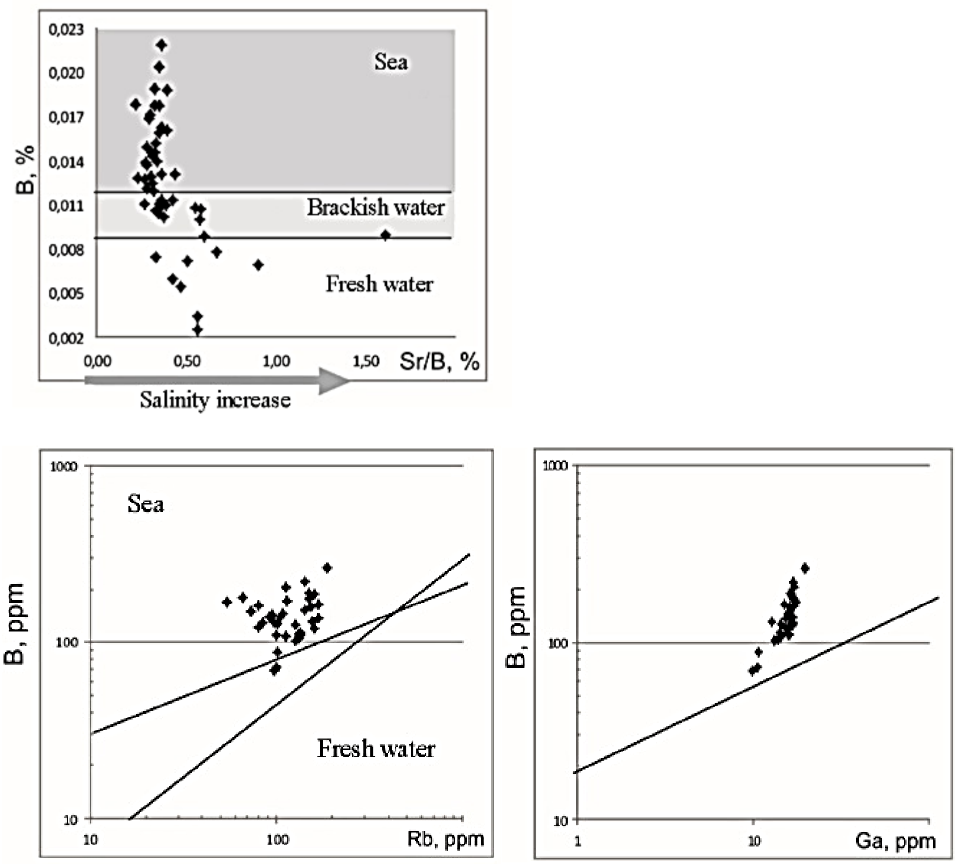

Figure 3. Reconstruction of the paleo-salinity of the sedimentation basin. Deposition environments according to Suslov G.A.; Rb-B and Ga-B diagrams (Maslov, 2005).

The Mo/Mn, Ni/Co, V/(V+Ni), and V/Cr ratios were used to assess the redox environment of bottom water (Maslov, 2005; Kholodov, 2002; Hatch & Leventhal, 1992; Jones & Manning, 1994; Ross et al., 2011). The anoxic environment of sedimentation or hydrogen sulfide contamination is shown by a Mo/Mn value from 0.01 to 0.1, with lower values being typical for well-aerated waterbodies (Kholodov, 2002). Somewhat increased Mo/Mn indices (from 0.011 to 0.032) were found for a part of the analyzed sample; however, the Mo/Mn value did not exceed 0.01 in most cases. V/Cr<1 is indicative of an oxide environment, while V/Cr>2.0 is indicative of an anoxic environment (Jones & Manning, 1994). During the formation of the Upper Triassic deposits in the sedimentation basin, the oxidizing conditions (V/Crmean=1.09) were preserved with short-term decreases in the oxygen content and an increasing role of reduction processes. The Ni/Co values (from 1.83 to 6.87) do not exceed 7.0, which is also indicative of a prevailing oxygen environment (Jones & Manning, 1994). In different parts of the Upper Triassic rock cross section, V/(V+Ni) ranges from 0.23 to 0.85 with a mean value of 0.71±0.09. This indicator is indicative of low oxygen content in certain parts of the sedimentation basin (Figure 4).

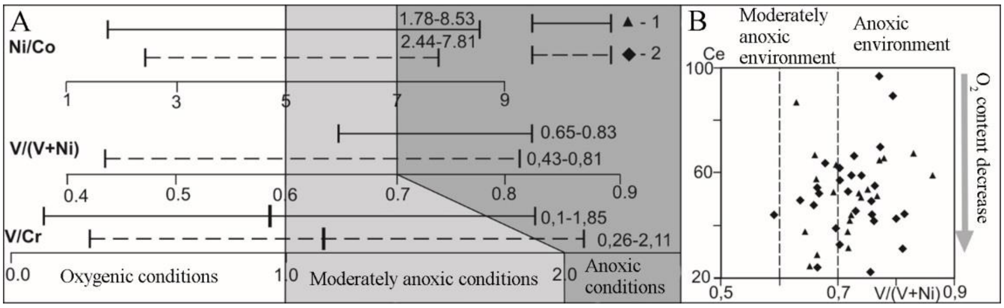

Figure 4. Variations of redox environment indices for the Upper Triassic deposits in the central part of the Kular-Nera slate belt.

1 – sandstone; 2 – siltstone. Ni/Co and V/Cr indices (Jones & Manning, 1994); V/(V+Ni) (Hatch & Leventhal, 1992).

Discussion and Conclusion

In the studied sample, the Ce/Y>2.3 value is indicative of a humid climate during sediment genesis. Variations of the Ce/Y index (from 2.4 to 6.2) are indicative of either changes in the facies environment (coastal-marine to deep-water) or changes in the composition of the source area (Maslov, 2005). The unstable conditions of sedimentation are shown by a series of paleo-salinity indices of the sedimentation basin (Figure 3). The concentration of salt in seawater has a significant effect on the migration capacity of certain elements, such as boron, strontium, barium, rubidium, gallium, and vanadium. Sr/Ba≤0.5 in 76% of the studied sample, which is typical for lagoon and highly desalted deltaic deposits. Variations in the boron content with unchanged paleoclimate and source area composition are also indicative of changes in the sedimentation environment from sea to fresh (Maslov, 2005; Maslov et al., 2016).

The 0.65–0.7 value of the V/(V+Ni) index is typical for sediments that formed in a moderately anoxic environment, while increased values (up to 1.0) are typical for anoxic environments (Hatch & Leventhal, 1992).

Somewhat increased Mo/Mn indices (from 0.011 to 0.032) were found for a part of the analyzed sample, which may be indicative of an unstable oxygen content in the water environment; however, the Mo/Mn value did not exceed 0.01 in most cases. This indicator is also indicative of low oxygen content in certain parts of the sedimentation basin. Increased cerium content in sedimentary rocks is indicative of an oxidizing environment during the regression period, while its decreased content is indicative of reduction or anoxic conditions that formed during the transgression period. The analysis of these indicators in the Norian deposits allowed concluding that the anoxic environment changed to a moderately anoxic one due to changes in the sea level (Figure 4).

Distribution spectra standardized on rare earth element chondrite in rocks of the Kular-Nera belt are considerably homogenous. Rocks include Eu-anomaly, high content of light rare earth elements; rare earth element spectrum has direct type of distribution. These data are indicative of debris accumulation in conditions of passive continental margin, where acidic rocks are the main provenance.

Implication and Recommendation

The analysis of rare and trace elements, as well as the set of geochemical indices showed that during the formation of the Upper Triassic deposits in the territory of the Kular-Nera slate basin, in a humid climate, the facies sedimentation environments changed from coastal-marine and lagoon to deep-water ones with a varying concentration of salt. The salinity of seawater affected the migration capacity of a series of chemical elements and the formation of their anomalous concentrations. During the accumulation and formation of sedimentation masses, an unstable oxygen content was found in the bottom water, alongside changes of oxygen environments to dioxide and, partially, anoxic ones, which was a favorable factor for the authigenic mineralization and enrichment of terrigenous deposits with ore components. Considering that the terrigenous material from the source area was already enriched with a series of ore elements, the conditions of formation of sedimentation masses created prerequisites for their further concentration during epigenetic and orogenic pluton metamorphic processes. Further comprehensive mineralogical and geochemical investigation of sedimentation masses enriched with ore elements will enable assessing their efficient metal content and their significance in the formation of large gold fields.

Disclosure statement

No potential conflict of interest was reported by the authors.

Acknowledgement

This work was supported by the Russian Science Foundation (project no. 14-17-00465).

Notes on contributors

Lena Polufuntikova holds a Candidate of Geological and Mineralogical Sciences, Associate Professor, head of the Department of prospecting and exploration of mineral deposits, North-Eastern Federal University named after M.K. Ammosov, Yakutsk, Russia.

Valery Fridovsky is a Doctor of Geological and Mineralogical Sciences, Professor and Director of Diamond and Precious Metal Geology Institute, Siberian Branch of the Russian Academy of Sciences, Yakutsk, Russia.

References

Aquarelle Inc. (2010). Gold ore deposits in Russia. Edited by M.M. Konstantinov, 349.

Astakhov, A.S., Goryachev, N.A. & Mikhalitsyna, T.I. (2010). On the conditions of formation of gold-rich horizons in ore-containing black-shale masses (by the example of the Permian and recent marine deposits in the Northeastern Asia). Proceedings of the Academy of Sciences, 430(2):212-217.

Fridovsky, V.Y., Gamyanin, G.N. & Polufuntikova, L.I. (2014). Gold-quartz and antimony mineralization in the Maltan deposit in northeast Russia. Russian journal of pacific geology, 8(4):276-287.

Fridovsky, V.Y., Gamyanin, G.N. & Polufuntikova, L.I. (2015). Structures, mineralogy, and fluid regime of ore formation in the polygenetic Malo-Taryn gold field, northeast Russia. Russian journal of pacific geology, 9(4):274-286.

Goldfarb, R.J., Taylor, R., Collins, G., Goryachev, N.A. & Orlandini, O.F. (2014). Phanerozoic continental growth and gold metallogeny of Asia. Gondwana Res., 25(1):48-102.

Goryachev, N.A. & Pirajno, F. (2014). Gold deposit and gold metallogeny of Far East Russia. Ore Geology Reviews, 59: 123-151.

Grinenko, V.S. & Prokopyev, A.V. (2016). Black-shale geological generations of the Verkhoyansk terrigenous sequence and their efficient metal content. Science and Education, 1:31-40.

Hatch, J.R. & Leventhal J.S. (1992). Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) Stark Shale Member of the Dennis Limestone, Wabaunsee County, Kansas, USA. Chern. Geol, 99:65-82.

Jones, B. & Manning, D.A.C. (1994). Composition of geochemical indicesused for the interpretation of paleoredox condi¬tions in ancient mudstones. Chem. Geol, 111:111–129.

Kholodov, V.N. (2002). The role of hydrogen sulfide basins in sedimentary rock formation. Lithology and Mineral Resources, 5:451-473.

Maslov, A.V. (2005). Sedimentary rocks: research methods and interpretation of obtained data. Study Guide., Yekaterinburg: Ural State Mining University Publishing House, 289.

Maslov, A.V., Podkovyrov, V.N., Gareyev, E.Z. & Graunov, O.V. (2016). Paleoclimate changes during the Late Precambrian (based on the study of the Upper Precambrian cross section of the Southern Ural). Lithology and Mineral Resources, 2:129-149.

Nedra Inc. (1977). Geochemistry quick-reference book. 2nd Edition, Revised and Enlarged, 184.

Polufuntikova, L.I. & Fridovsky, V.Y. (2016). Lithological features, reconstruction of redox setting, and composition of the provenances of the Upper Triassic Kular–Nera shale belt. Russian Journal of Pacific Geology, 10:218-229.

Prokopiev, A.V., Toro, J., Miller, E.L. & Gehrels G.E. (2008). The paleo-Lena River - 200 m.y. of transcontinental zircon transport in Siberia. Geology, 36(9):699-702.

Ross, R.L., Stuart, W.B. & Maslennikov, V.V. (2011). A Carbonaceous Sedimentary Source-Rock Model for Carlin-Type and Orogenic Gold Deposits. Economic Geology, 106:331–358

Schultz, R.B. (2004). Geochemical relationships of Late Paleozoic carbon-rich shales of the Midcontinent, USA: a. compendium of results advocating changeable geochemical conditions. Chemical Geology, 206:347–372.

Voroshin, S.V., Tyukova, E.E., Newberry, R.J. & Layer P.W. (2014). Orogenic gold and rare metal deposits of the Upper Kolyma District, Northeastern Russia: Relation to igneous rocks, timing, and metal assemblages. Ore Geol,62:1-24.