Lithology and Mineral Resources, Vol. 39, No. 6, 2004, pp. 523–529. Translated from Litologiya i Poleznye Iskopaemye, No. 6, 2004, pp. 602–609.

Titanium–Zirconium Placers of the Stavropol Region

N. I. Boiko

Rostov State University,
ul. Zorge 40, Rostov-on-Don, 344090 Russia
e-mail: boiko@geo.rsu.ru

Received February 26, 2003

Abstract—Lithofacies analyses and paleogeographic reconstructions of the middle Sarmatian sequence in the central Ciscaucasus, which hosts the most promising titanium–zirconium placers of the Stavropol region, indicate that ore components (rutile, ilmenite, leucoxene, and zircon) were mainly delivered to the Stavropol placer basin by the paleo-Volga River from a northern land. Bryozoan organogenic edifices played a significant role in the formation of placers. The organogenic edifices appeared under anomalous (for bioherm formation) conditions of terrigenous sedimentation on the western and northwestern slopes of the Stavropol Uplift, hampered the transport of ore material to the deep-water zone of the basin, and promoted its differentiation in the paleouplift.

FORMULATION OF THE PROBLEM

After the breakdown of once single and powerful mineral resource base of the Soviet Union, our country lost the free access to titanium and zirconium placer deposits that now serve as sources for commercial mineral concentrates of these metals in the world. Although Russia has a large capacity for the metallurgical processing of titanium and zirconium ores, we completely depend upon the import of this raw material from the Verkhne-Dneprovsk mining–metallurgical plant (Ukraine) based on the Malyshev (Samotkan) deposit, the sole titanium–zirconium placer exploited in the FSU (*Rossypnye*…, 1997). At the same time, this raw material is essential for different branches of the Russian industry. For example, the metallic titanium industry requires 120 kt/yr of ilmenite concentrate, while the titanium pigment industry requires no less than 600 kt/yr of this valuable raw material. The demand for zirconium concentrate (10 kt/yr) is also fulfilled by import from the Ukraine (Bykhovskii *et al.*, 2001; Korolenko, 2001). Thus, the situation with raw mineral base is rather paradoxical. Russia has a large potential for the development of national titanium and zirconium raw mineral base capable of not only fulfilling the current and perspective industrial demands for these metals, but also providing a significant volume of titanium and zirconium concentrates for export. Nevertheless, our country is one of the largest importers of these materials.

Thus, the adequate provision of Russian industry with titanium and zirconium concentrates is an urgent issue. Therefore, we should primarily assess the titanium–zirconium placer areas known in our country. This type of ore deposit has a high commercial appeal, because its development requires a relatively small investment and the opening of mining plant in such areas will not need much time. Currently, two large provinces of ancient coastal-marine titanium–zirconium placers are available in our country. The first province is located in the Russian Platform, whereas the second province is associated with peripheral structures of the West Siberian Plate. The first province includes the Tsentral'noe and Kirsanov deposits (Tambov district), the Lukoyanov deposit (Nizhegorod district), several promising areas in the Timan–Pechora region, and the Stavropol placer basin (southern Russia).

The Stavropol Basin is confined to the synonymous uplift, a large structure of the Scythian Plate. The placers are localized at four (Chokrakian, Karaganian–Konkian, middle Sarmatian, and middle–upper Sarmatian) stratigraphic levels. The Beshpagir, Kombulat, Tashlin, Grachev, Vysotsk, Tuguluk, and other most perspective placers are characterized by the commercial-grade mineralization with the total content of titanium and zirconium minerals exceeding 50 kg/m^3. The placers are primarily associated with the middle Sarmatian level and mainly composed of fine-grained (approximately 0.1 mm) coastal-marine sands. The heavy fraction of productive sands includes ilmenite, rutile, zircon, and leucoxene associated with tourmaline, staurolite, garnet, and rare grains of other minerals. The light fraction is mainly composed of quartz (90–94%).

According to materials of the North Caucasian Regional Division of the All-Russia Institute of Economics of Mineral Resources and Utilization of the Earth's Interior (VIEMS), potential resources of titanium and zirconium in the Stavropol Basin are as much as 38522.4 kt. In terms of the geological setting and investment appeal, the Stavropol Basin is among the most promising titanium–zirconium placer areas in the European part of Russia. However, geology of this placer basin is rather insufficiently clear for the com-

0024-4902/04/3906-0523 © 2004 MAIK "Nauka/Interperiodica"

prehensive appraisal, much less for the commercial development.

The strategy of further geological prospecting for titanium–zirconium placers in the Stavropol region primarily depends on the completeness and reliability of available materials concerning the geological setting of the middle Sarmatian rocks. The knowledge of their lithofacies features and formation constraints, which significantly governed the genesis of ore deposits (source of ore minerals and mechanism of their transport, mobilization, and conservation), is also essential. Therefore, our work is mainly devoted to the lithofacies analysis of placer-hosting rocks and paleogeographic reconstruction of their timing as a basis for mineragenic modeling.

LITHOFACIES FEATURES AND FORMATION CONSTRAINTS OF THE MIDDLE SARMATIAN PLACER-HOSTING ROCKS

The middle Sarmatian rocks outcrop over a wide zone in southern areas of the central Ciscaucasus. They were recovered by boreholes in oil exploration areas in the unexposed northern part of the Stavropol Uplift and adjacent structures.

One can readily recognize the middle Sarmatian rocks in the majority of exposed sections and subdivide them into two lithological sequences. The lower sequence is mainly composed of clayey (Cryptomactra) beds, whereas the upper sequence consists of primarily sandy and calcareous beds with the typical middle Sarmatian fauna (*Geologiya…*, 1968). The substage base locally contains an intercalation of carbonate and clayey rocks known as the Mamaika Beds (*Stratigrafiya…*, 1986). Recently, a new detailed stratigraphic scheme was proposed for the Sarmatian rocks of the Stavropol region (Rudyanov, 1995). However, rock formations (suites) defined as the main stratigraphic unit in this work does not correlate with each other. They often lack any faunistic substantiation and reliable correlation with the general chronostratigraphic scale.

Analysis of the composition, structure, and formation constraints of the middle Sarmatian rocks in the central Ciscaucasus makes it possible to identify two major (coastal-marine and shallow-water shelf) types of lithofacies complex (figure).

Coastal-Marine Lithofacies Complex

Rocks of the costal-marine lithofacies are most abundant in the Stavropol placer basin. One can divide them into the sandy, pelitic–sandy, psephitic, and organogenic edifice subcomplexes.

The *sandy subcomplex* is widespread in the central and eastern areas of the Stavropol Basin. This subcomplex unconformably overlies the early Sarmatian sequence and includes the following units (from the bottom to top):

(1) Greenish gray calcareous and silty sediments up to 3.0 m thick.

(2) Gray or yellowish gray, cross- and wavy-bedded, sandy sequence (up to 208–210 m) with the beach-type bedding, friable fine-grained structure (grain size ~0.1 mm), monomineral (quartz) composition, and micaceous admixture. The sequence includes up to 21-m-thick interbeds and units of dark gray (with bluish tint), massive, medium- to coarse-grained, quartz sandstones with mica. The sandstones, in turn, occasionally include up to 5-cm-thick layers of compact pelitomorphic and clayey limestones with coalified plant remains.

(3) Yellowish gray, horizontal- and cross-bedded, medium-grained clayey sands with oolite-type structure. This unit encloses lenses and intricate inclusions of sandstones with a variable calcareous admixture. Its thickness is as much as 50.5 m in Borehole K-1-B on the left bank of the Tomuzlovka River 7.2 km north of the Settlement of Aleksandrovka. The thickness is maximal (82.0 m) at the Settlement of Kalinovka and gradually decreases in the northern direction.

(4) Yellowish or brownish gray, bedded, friable or slightly cemented, fine-grained sequence of quartzose, clayey, and calcareous sand (up to 43 m). This unit includes numerous lenses and separate interbeds of sandstones with a variable amount of calcareous admixture, coquina-containing limestones, and sandy clays. This section includes Ti- and Zr-bearing minerals.

(5) Yellowish or brownish gray, fine-grained quartzose sands with oblique, wavy, and horizontal bedding and lenses of sandstones and clays. The sandstones are represented by gray or light gray, cross-bedded, quartzose and calcareous varieties. The gray or greenish gray, fine-bedded clays (up to 0.3–0.5 cm) contain calcareous and sandy admixtures. The wavy- and cross-bedded sands nearly always contain Ti- and Zr-bearing minerals. The most typical section of this subcomplex can be observed at the southwestern periphery of the Settlement of Beshpagir. Therefore, some geologists identify this sequence as the Beshpagir Formation. The thickness of the productive sandy sequence is 14.4 m in the Beshpagir area and increases to 44.0 m in the northeastern direction.

The *pelitic–sandy subcomplex*, mainly developed in the western and southwestern areas of the coastal-marine lithofacies complex, includes the following units (from the bottom to top):

(1) Greenish (or brownish) gray or dark gray, sandy and silty, laminated clays with up to 3.0-cm-thick jarosite interlayers with a spacing of 0.1–0.5 m. The clays include up to 10.0-cm-thick interlayers of gray fine-grained clayey sand. Interlayers of gray fine-grained sandstones with lenses of gypsum and inclusions of coalified plant remains are less common. The roof of the clayey sequence encloses massive pelitomorphic clayey limestones known among the geolo-

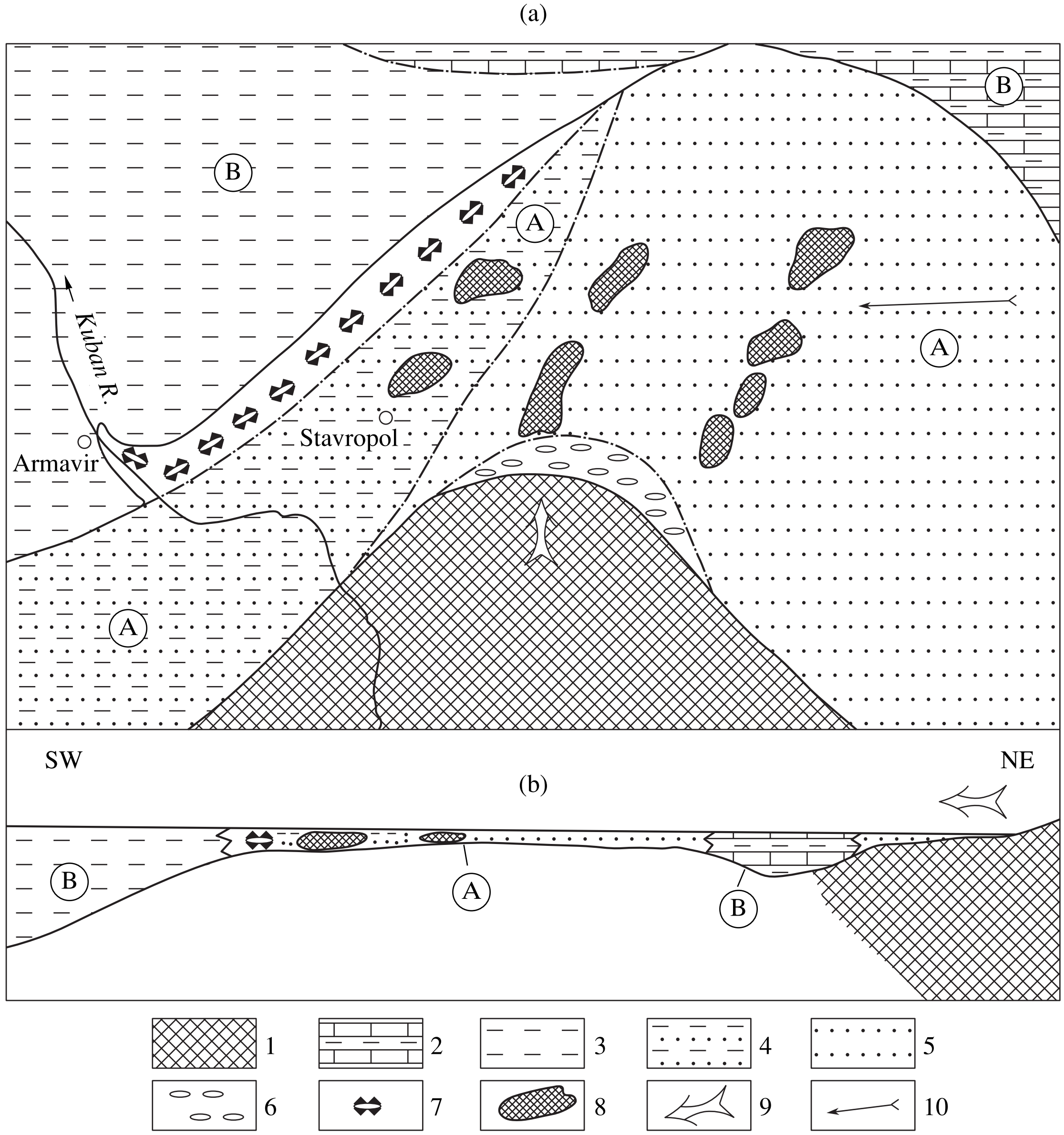

Fig. 1. (a) Paleogeographic scheme and (b) lithofacies profile of the central Ciscaucasus in the middle Sarmatian (based on unpublished materials of E.M. Velikovskaya, A.A. Steklov, L.N. Kazarinov, *et al.*). (1) Land; subcomplexes: (2) pelitic–calcareous; (3) pelitic; (4) pelitic–sandy; (5) sandy; (6) psephitic; (7) organogenic edifice; (8) major titanium–zirconium placers; (9) direction of sediment transport from the denudation zone; (10) direction of marine currents. Lithofacies complexes: (A) coastal-marine; (B) shallow-water shelf.

gists as the Mutnyan marl unit. The clayey sequence has a total thickness of 90 m.

(2) Analogous clays with a higher content of sandy interlayers (particularly, at the sequence roof) with a total thickness of 87 m. The sand is represented by the gray fine-grained quartzose variety.

(3) Alternating sands and clays gradually replacing Unit 2. The gray or yellowish gray, wavy- and cross-bedded, fine-grained sand often encloses detritus. The yellowish gray laminated clay contains silty and sandy admixture, as well as lenticular or powdery aggregate of yellow and grayish yellow fine-grained micaceous sand. The roof of Unit 3 is composed of sands with dissemination of Ti- and Zr-bearing minerals and millimeter-sized interlayers enriched in these minerals. The thickness of this unit varies from a few meters to 50–52 m.

(4) Up to 30-m-thick sequence composed of gray or yellowish gray sands with different types of bedding (horizontal, cross, wavy, and so on), clayey and calcareous admixtures, as well as gray clayey interlayers with a thickness of 5–7 mm and lenses with a spacing of 0.3–0.9 m.

The *psephitic subcomplex* is subordinate and only developed at upper reaches of the Kalaus River as a narrow rim of the middle Sarmatian land in the northern part of the Mineral'nye Vody Uplift. The sequence consists of gray or yellowish gray, cross-bedded conglomerates with different-sized pebbles. The quartzose and cherty pebbles are cemented by carbonate material. They are commonly well rounded and occasionally flattened. The conglomerate often contains lenticular interlayers of massive, gray or yellowish gray, fine-grained sandstones (3–5 cm). The total thickness of conglomerates is as much as 7.5–8.0 m.

The *organogenic edifice subcomplex* rims the middle Sarmatian coastal-marine zone of the central Ciscaucasus on the western and northwestern slopes of the Stavropol Uplift. The edifices make up a virtually continuous band extending along the right bank of the Kuban River from the northwestern Armavir area to the southeastern Settlement of Ubezhenka. Further, the band turns to the northeastern Settlement of Kamennyi Brod and reaches the Settlement of Trunovka (Volkova, 1951). The organogenic edifices incorporate bioherm buildups and massifs mainly composed of bryozoans. The edifices are confined to terrigenous–clayey rocks. They usually make up bands up to 300–400 m long and 20–25 m thick. The organogenic edifices were the structures that significantly governed not only processes of the middle Sarmatian sedimentation, in general, but also the formation of titanium–zirconium placers, in particular.

One can very well study the composition and structure of organogenic edifices in their exposures extending along the right bank of the Kuban River from Armavir to the Settlement of Ubezhenka. The edifices are characterized by a spotty distribution of bioherm constituents. Some sectors are composed of bryozoan limestones, while other sectors consist of serpula limestones. Usually, the bryozoan limestones overlie the uneven surface of the serpula limestones. Both varieties include cavities filled with the fine-grained sand or clay containing fragments of bryozoans and molluscan shells (mainly, Pelecypoda). Faunal fragments are distributed as aggregates or patches. The patches occasionally consist of different species, but *Modiola* frustules are more widespread. Bryozoan limestones are often overlain by the layered coquina lenses of *Cardium inflatum* and *C. avicular.*

The bryozoan limestones overlie the sandy sequence between the settlements of Vyselka and Noven'kii. Here, one can see that the lower rounded-wavy surface of organogenic edifices is enveloped by green layered clays with frustule detritus interlayers 0.1–0.2 m thick. The detritus interlayer at the boundary with the underlying sandy sequence encloses poorly rounded flat sandstone fragments (up to 6 cm in size) with a coating of *Microporella.* The light-colored fine-grained sandy sequence beneath the bryozoan edifices includes nodules of gray massive sandstone. The sands are gradually replaced downsection by clays with *Tapes naviculatus.* Holes and numerous cavities in the bioherm limestones are filled with layered sandy clays with coquina (*Hydrobia*) interlayers.

The bryozoan edifices are separated by sandy–clayey sediments with the basal layer usually containing friable frustule detritus analogous to the underlying bryozoan limestone. The detritus includes slightly rounded fragments of bryozoan limestones and sandstones. The detritus fauna appreciably differs from that in the bryozoan limestone bioherms and is more similar to that in the middle Sarmatian sands of the Urup River. The detritus interlayer is overlain by gray layered sandy clays with friable or compact interlayers of detritus and sand, the abundance and thickness of which gradually increases upward the section. The sandy–clayey sequence grades upsection into the yellow fine-grained sands with the typical shallow-water middle Sarmatian fauna (*Mactra seducta, M. subvitalina, Modiola incrassata, Cardium fittoni, Gibbula robur*, and *Hydrobia pseudocaspia*). The sandy sequences separate and locally overlap the bryozoan limestone bioherms. The roof of sandy sequences is eroded and overlain by the compositionally similar sands with the upper Sarmatian fauna.

The bryozoan limestones in the northern organogenic edifices (e.g., at the Settlement of Kamennyi Brod) are compact and silicified. They are marked by a lesser abundance and diversity of fauna relative to those at the southern outcrops. The edifices extend from the Settlement of Kamennyi Brod further to the northeast. Here, the bioherms are not more than 10 m high, while the bioherm bands and chains are up to 400 m long.

Shallow-Water Shelf Lithofacies Complex

Rocks of the shallow-water shelf lithofacies are mainly developed along the western and northern framing of the Stavropol placer basin. In terms of composition and formation constraints, they can be subdivided into the pelitic and pelitic–calcareous subcomplexes.

The *pelitic subcomplex* is most widespread in the eastern area of the western Ciscaucasus. Rocks of this subcomplex were found in boreholes drilled on the wall of the East Kuban Depression. Here, the middle Sarmatian sequence is composed of nearly homogeneous clayey rocks with limestone and sand strata. The basal section includes strongly lithified greenish gray and yellowish brown clays. They grade upsection into the less lithified dark gray clays with a minor admixture of sandy material. Sand in the strata is represented by the dark gray fine-grained variety with a clayey admixture. The similar sand is observed as a powdery coating along bedding planes in the clays. Limestone in the strata is represented by the light gray fine-platy, often silicified, variety with a compact cryptomerous texture and clayey admixture. The maximal thickness of the middle Sarmatian sequence is 250–280 m in the East Kuban Depression and 120–150 m in the Armavir area.

The *pelitic–calcareous subcomplex* consists of alternating limestone and clay beds in the northern framing of the Stavropol placer basin. Limestone is represented by the yellow compact pelitomorphic variety with a sandy admixture. The content of clastic material of the psammite dimension reaches 35–45%. Clay is represented by the light gray or greenish gray calcareous and sandy varieties. The total thickness of the pelitic–calcareous sequence is 19.5 m.

Analysis of the lithology, structure, and distribution of middle Sarmatian lithofacies complexes and subcomplexes suggests their formation in a relatively shallow-water zone controlled by the Stavropol Uplift (figure). This zone divided the middle Sarmatian Ciscaucasus sedimentary basin into the relatively deep-water western Azov–Kuban and eastern Terek–Caspian depressions. Terrigenous sediments accumulated in these depressions under the impact of an intense water current flowing from the east to west. Previous researchers believed that this current delivered a large amount of clastic material related to destruction of the Caucasian land and probably promoted the formation of organogenic edifices along the western framing of the Stavropol Uplift. The current also created a favorable hydrodynamic environment for the formation of bioherms and provided a sufficient amount of nutrients for benthic organisms. As will be shown below, this current also promoted the formation of placers in coastal-marine areas.

The southern areas of the central Caucasus were characterized by the accumulation of coastal-marine sediments as a result of drastic change in the hydrodynamic regime owing to the presence of prominent organogenic edifices and progressive uplift of the Mineral'nye Vody Uplift in the middle Sarmatian time. This episode was also marked by the formation of the major placers of the Stavropol region mainly in the form of beach deposits extending in the submeridional direction.

Although sediments of the shallow-water shelf lithofacies accumulated relatively near the shoreline, they were strongly affected by the intense current from the Stavropol Strait and Terek–Caspian Depression. Therefore, primarily clayey sediments accumulated in the western and southwestern areas of the Stavropol placer basin behind the organogenic buildups that hampered the outflow of clastic material. In contrast, mainly carbonate and clayey sediments accumulated in the northern areas characterized by the absence of barrier for terrigenous material. The clastic material was delivered through this transit zone to the western Azov–Kuban Depression.

DISTRIBUTION AND FORMATION CONSTRAINTS OF THE MIDDLE SARMATIAN TITANIUM–ZIRCONIUM PLACERS

Lithofacies features and formation constraints of the middle Sarmatian rocks in the central Ciscaucasus discussed above can serve as the basis for the genetic reconstruction of titanium–zirconium placers therein, because the placers formed as a result of the transportation and precipitation of sedimentary material. The placers are related to the manifestation of partial (specific) features of sedimentogenesis. It is very difficult and, probably, impossible to decipher them without the consideration and analysis of general sedimentation trends in the middle Sarmatian basin of the central Ciscaucasus.

At present, we do not have a general unbiased model of titanium–zirconium placer formation for the Stavropol region. According to the available few works devoted to this issue (Miroshnikov, 1995; Rudyanov, 2001; and others), the placers formed in the middle Sarmatian coastal-marine sedimentation basin controlled by the Stavropol Uplift, and the Caucasian land served as the provenance. Since regional weathering crusts were absent in the Greater Caucasus in the Sarmatian and pre-Sarmatian times, the Tortonian (primarily, Chokrakian) sediments relevant to redeposited weathering crust are usually considered the source of ore material for the middle Sarmatian placers. The redeposited crust, in turn, was derived from older weathering crusts of the Russian Platform that are generally accepted as the source for Ti- and Zr-bearing minerals.

Thus, results of the lithofacies and paleogeographic reconstructions of the middle Sarmatian rocks in the central Ciscaucasus indicate that the ore material was delivered by river currents from the north rather than (and, possibly, not only) the Tortonian redeposited weathering crust. Results reported in our previous work (Boiko, 2003) have proved that the Ti- and Zr-bearing minerals were delivered by the paleo-Don River. Hydrodynamic conditions in the middle Sarmatian sedimentary basin (primarily, the presence of western water current from the Terek–Caspian Sea) suggest that the ore material transported by the paleo-Don River, probably, did not participate in the formation of placers in the Stavropol region.

However, the mineralogy of middle Sarmatian clastic rocks in the central Ciscaucasus indicates the presence of an additional riverine source of the terrigenous and ore materials. We have established that the heavy fraction of productive sands is enriched in epidote group minerals (22–54%), garnets (20–30%), kyanite (10–13%), and hornblende (up to 2%) in the eastern areas of the Stavropol Uplift. Data on the geological structure of the inferred provenances, on the one hand, and the mineralogy of terrigenous material, on the other hand, rule out the involvement of the Caucasian land. For example, garnets and kyanite are typical of Paleogene rocks in the Volgograd area (Vlasov, 1959). High contents of hornblende and epidote suggest their relation to magmatic rock fields, the nearest magmatic fields being located in the Urals. Indeed, the mineral composition of alluvium in the Kama River supports this assumption. According to Baturin (1937), the alluvium of this river contains epidote group minerals (80%) and hornblende (up to 1%).

Thus, the facts discussed above suggest the presence of an additional large river in the middle Sarmatian in the study region. Presumably, the river originated in the Ural Range, flowed across the middle and lower plains of the Volga River basin, and entered the Stavropol Strait somewhere near the southeastern Ergeni area. This river, arbitrarily called the paleo-Volga River, delivered the epidote group minerals and hornblende from the Ural Range. Erosion of Paleogene and Maikopian rocks in the lower reaches contributed garnets, kyanite, and ore minerals. Terrigenous material delivered by the paleo-Volga River to sedimentation basin was redistributed by water currents from the eastern zone to the western Stavropol Uplift area, where hydrodynamic conditions were favorable for the formation of placer deposits.

Results of the lithofacies and paleogeographic reconstructions also indicate an essential role of bryozoan organogenic edifices in the formation of the middle Sarmatian titanium–zirconium placers. Sedimentation environment in the middle Sarmatian was anomalous for the development of bioherms on the western and northwestern slopes of the Stavropol Uplift. The bryozoan organogenic edifices hampered the communication between the Azov–Kuban and Terek–Caspian seas. Thus, they served as a biological barrier and hampered the removal of terrigenous and ore materials by sublatitudinal water currents flowing from the Terek–Caspian Sea to the Azov–Kuban Sea. At the same time, they promoted the differentiation of material in the placer formation zone. In other words, the organogenic edifices served as a specific, highly efficient lithostructural trap (Patyk-Kara, 2002) and provided a very high concentration of valuable minerals. Terrigenous and ore materials were delivered to the Terek–Caspian Sea owing to both the abrasion of its southern coasts composed of the redeposited (Chokrakian and Karaganian) weathering crusts and the delivery of northern materials by the paleo-Volga River. The presence of a second source of ore components is supported by the mineralogy of sediments transported by currents from the east to west across the Stavropol Uplift that served as the placer formation zone. The proposed mechanism of placer formation explains the confinement of all known placers in the Stavropol Uplift to the eastern side of the reef zone.

CONCLUSIONS

The proposed mechanism of middle Sarmatian placer formation in the Stavropol Basin supplements the previous model of reefogenic ore formation (Boiko, 1998; 1999; 2000; and others). The results reported in these works demonstrate that ore formation trends in organogenic edifices should be utilized in the prospecting for both native and placer deposits. Their distribution is primarily governed by the hydrodynamic regime, which, in turn, is controlled by processes of the syngenetic and, occasionally, older bioherm formation.

The distribution trends and formation constraints of titanium–zirconium placers in the central Ciscaucasus can provide insights into the genesis of placers in the Stavropol Basin. Moreover, these trends can also foster the elucidation of new promising areas in the Rostov district and, particularly, Krasnodar, Adygeya, and Karachai–Cherkess regions. The inherited development of the Azov–Kuban Depression over a prolonged episode of the Neogene Period suggests that the placers can equally be related to terrigenous rocks of different (Tortonian–Kimmerian) ages.

ACKNOWLEDGMENTS

This work was supported by the “Integratsiya” Federal Program, project no. E 0227/807.

REFERENCES

Baturin, V.P., *Paleogeografiya po terrigennym komponentam* (Paleogeography Based on Terrigenous Components), Baku, Moscow: Otd. Nauchn. Tekh. Inform., 1937.

Boiko, N.I., Geochemical Features of Reef Formation, *Litol. Polezn. Iskop.*, 1998, vol. 33, no. 2, pp. 145–152 [*Lithol. Miner. Resour.*, 1998, vol. 33, no. 2, pp. 126–132].

Boiko, N.I., Metallogeny of the Reef Complexes, *Rudy Metally,* 1999, no. 6, pp. 18–25.

Boiko, N.I., Gold Mineralization in Upper Jurassic Reef Rocks of the Northern Caucasus, *Dokl. Akad. Ross. Nauk*, 2000, vol. 370, no. 3, pp. 350–352 [*Dokl. Earth Sci.*, 2000, vol. 370, no. 1, pp. 37–38].

Boiko, N.I., Distribution Trends and Formation Conditions of Titanium–Zirconium Placers in Southern Russia, *Rudy Metally,* 2003, no. 1, pp. 17–23.

Bykhovskii, A.Z., Tigunov, L.P., and Zubkov, L.B., Exploration and Development of Titanium Resources: A Pressing Issue in Mining Industry, *Mineral. Resursy Ross. Ekonom. Upravl.*, 2001, no. 4, pp. 25–36.

Geologiya SSSR (Geology of the USSR), vol. IX (Northern Caucasus), part 1 (Geological Description), Moscow: Nedra, 1968.

Korolenko, N.V., Resource Base of Ferrous Metallurgy in Russia: Titanium, *Razved. Okhr. Nedr*, 2001, no. 11/12, pp. 24–28.

Miroshnikov, A.M., Titanium–Zirconium Placers in the Stavropol Region: Mechanism and Depositional Conditions, *Materialy VIII yubileinoi konferentsii po geologii i poleznym iskopaemym* (Proc. of VIII Jubilee Conf. on the Geology and Mineral Resources), Essentuki, 1995, pp. 340–341.

Patyk-Kara, N.G., Placers in the System of Sedimentogenesis, *Litol. Polezn. Iskop.*, 2002, vol. 37, no. 5, pp. 494–508 [*Lithol. Miner. Resour.*, 2002, vol. 37, no. 5, pp. 429–442].

Rossypnye mestorozhdeniya Rossii i drugikh stran SNG (minerageniya, promyshlennye tipy, strategiya razvitiya mineral'no-syr'evoi bazy) (Placers in Russia and Other CIS Countries: Mineralogy, Industrial Types, and Strategy of the Development of Mineral Resource Base), Laverov, N.P. and Patyk-Kara, N.G., Eds., Moscow: Nauchnyi Mir, 1997.

Rudyanov, I.F., Stratigraphy of Middle–Upper Miocene Rocks in the Stavropol Uplift, *Materialy VIII yubileinoi konferentsii po geologii i poleznym iskopaemym* (Proc. of VIII Jubilee Conf. on the Geology and Mineral Resources), Essentuki, 1995, pp. 190–192.

Rudyanov, I.F., Depositional Conditions of the Titanium–Zirconium Placers in the Stavropol Placer Region in *Problemy geologii i geoekologii Yuzhno-Rossiiskogo regiona* (Geology and Ecology Problems in the South Russian Region) Novocherkassk: NABLA, 2001, pp. 159–169 (Tr. Yuzhno-Ross. Gos. Tekhnich. Univ.).

Stratigrafiya SSSR (Stratigraphy of the USSR), vol. 1 (Neogene System, Moscow: Nedra, 1986.

Vlasov, D.F., Facies of Middle Sarmatian Rocks in the Tanais Bay, *Uchenye zapiski Rostovskogo gosudarstvennogo universiteta* (Scientific Transactions of the Rostov State University), Rostov-on-Don: Rostov. Gos. Univ., 1959, vol. 44, issue 8, pp. 33–41.

Volkova, N.S., *Gosudarstvennaya geologicheskaya karta SSSR masshtaba 1 : 200000* (State Geological Map of the USSR. Scale 1 : 200000), Explanatory Note to Sheet L-37-XXX (Stavropol), Moscow: Gosgeoltekhizdat, 1951.