© MIKHAIL N. GUSEV, YURI V. POMIGUYEV
gusevm@list.ru, pmgv@bk.ru

UDC 551.435.1 (282.257.5)

ON THE CHARACTER AND DIRECTION OF THE VERTICAL CHANNEL DEFORMATION OF THE AMUR RIVER (THE ZEYA RIVER MOUTH—KHINGAN GORGE)[*]

SUMMARY. The Amur River is the largest water-stream in the North East Eurasia. The state border between Russia and China runs along its channel. But the river activity has been studied incompletely. It is very important to understand the formation peculiarities of the youngest part of the river valley—River Valley Bottom (RVB) geomorphological system as well as its channel as the most dynamic element. The paper is aimed at the study of the vertical channel deformations of the Amur River in the Holocene at the section of its middle reaches from the Zeya River to Khingan Gorge extending for 410 km. The main attention is paid to the study of conditions of the river valley formation, lithology structure of RVB, morphological and morphometric parameters of the of the water-stream longitudinal profile. It is established that the Amur River (from the Zeya River mouth to Khingan Gorge) is being formed under extremely uneven geological and structural and also very changeable geodynamic conditions. These conditions mainly determine the features of the structure and dynamics of the RVB and its channel.

Basing on the analysis of the water-stream longitudinal profile and its comparison with the calculated "graded longitudinal profile" as well as on the analysis of the BRV lithological structure data (composition, thickness alluvium, distribution of flood-plain and channel alluvial facies), it is established that the vertical deformations of the Amur River in the Holocene are of directional character. The water-stream incises into the underlying rocks with the mean velocity of 0.9–1.1 mm per year. Maximum incises intensity is characteristic of the river at the section of Khingan Gorge and its magnitude is comparable (about 2 mm per year) with the velocity of Khingan Range elevation.

KEY WORDS. The Amur River, river valley bottom, channel, vertical channel deformation, longitudinal profile, alluvium.

The Amur River, one of the main nature components of the Far East, has a huge impact on the development of both natural and social processes in the region. Its activities in substance determine the spatial position of the riverbed, and with it—of the state border between Russia and China. Until recently, there had been no long-term purposeful research of the river valley bottom with its most dynamic element—the riverbed, which within the middle stream, is characterized by high dynamism. The

* *The study was supported by The Russian Foundation for Basic Research, research project No. 11-05-00372-a.*

information on the investigated area of the Amur River we found in 4 papers [1–4]. Despite their importance, information about the dynamics of the river in this area is very scarce. It is obtained mainly through the analysis of the hydrological stations and archival materials that cannot provide a holistic view of the uniqueness and the character of bottom-and riverbed-formation there. Some of the provisions of the published articles do not completely agree with the actual data which we obtained during the geomorphological studies (mainly field, ongoing since 1987) of the bottom of the Amur River valley, including its riverbed. The totality of these circumstances determined the need to publish the results of our research of the river. Its foundation is based on the long-term field studies of the structure and the dynamics of the river valley bottom and the results of the synthesis and analysis of literary and primary sources on this problem. The collection, processing, analysis and synthesis of the factual material were performed with the help of the complex of the traditional research methods to investigate the fluvial topography and the water-streams activity.

Objective—to analyze the data based on the characteristics of the structure and the dynamics of the geomorphological system—The River Valley Bottom (RVB), its basic elements (including the water-stream longitudinal profile) to characterize the vertical deformation of the Amur River in the Holocene from the Zeya River to Khingan Gorge.

Conditions for the river valley bottom formation and structure. In the geological and structural terms the considered 410 km long section of the Amur River, inherits the southern suburb of the Zeya–Bureya (the Low Zeya) hollow along its border with the Small Hinggan mountain structures (Figure 1). Throughout the history of the formation of the river valley, the beginning of which coincides with the onset of the current stage of tectonic activity (Q1) [5], the territory was experiencing the differentiated, predominantly positive sign of movement, especially active from the end of the mid-Quaternary time (Q23) to the present day [6]. As the result, the foundations of the cavity made up of blocks of different sizes, acquired the "keyboards" structure in the form of the individual deflections and elevations (Figure 1). The Amur River cuts them from the right bank of the mountain structures.

The relatively high tectonic activity of the territory in combination with the other environment, largely determines the nature and the direction of the riverbed deformations (especially vertical) and this is reflected in the structural features of the river valley. The modern bed of the Amur River is developed mainly in the lake and alluvial deposits (usually, clays) of the Tsagayanskaya suite (K2cg), more rare—in the sedimentary (sandstones, soapstones) or volcanic (andesites, dacites) rocks of the Lower Cretaceous (K1) [10]. Partly water-stream cuts through them, forming the bed on the basement rocks—the granites of the Upper Paleozoic Era (PZ3) [10]. During the valley formation the water-stream shaped the asymmetric valley with the complex (from 2–3) of the terraces above the floodplain along the left bank [11]. The presence (in their native ledges) of the radical cap making up the terrace and the small capacity (up to 10–20 m) of the alluvium (mostly gravel) indicates that they are created by the stream at the directed incises into the bedding rocks.

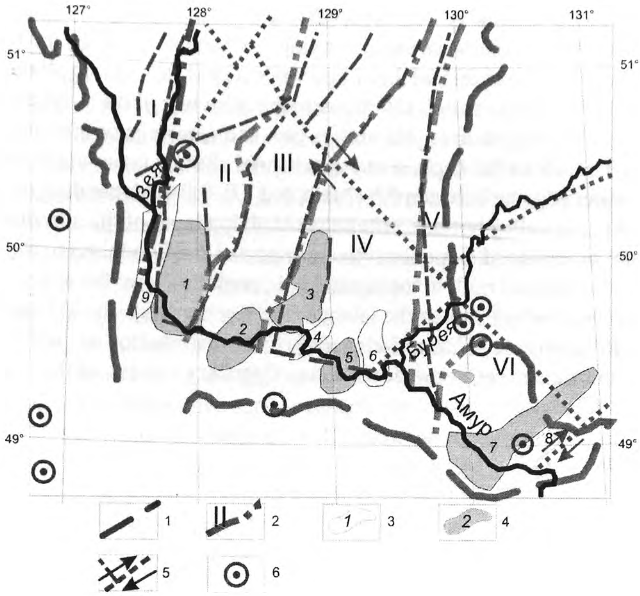

Figure 1: Geological and structural diagram of the Low Zeya (Zeya–Bureya) hollow (according to E. N. Lishnevsky (1968), A. P. Sorokin and V. D. Glotova (1997), M. I. Kopylova (2001).

1 — the border (the 2nd order) of the Low Zeya hollow, 2 — the third order border structures: negative (I — the Amur River area, II — the Zeya–Selemdzha, IV — the Yekaterinoslavskaya, VI — the Arkhara), positive (III — the Zavitaya–Maykurskaya, V — the Tura River area); the 4th oder structures: 3 — deflections (1 — the Lermontovsky, 2 — the Novopetrovsky, 3 — the Mikhailovsk–Poyarkovsky, 5 — the Kupriyanovsky, 7 — the South Arkharsky), 4 — elevations (4 — the Voskresenovskoye, 6 — the Kalininskoye, 8 — the Predhinganskoye, 9 — the Lermontovskoye), 5 — the major foundation breaks; 6 — the earthquake epicenters.

The data of the lithology structure of RVB eloquently testify to the nature of the vertical riverbed deformations of the river in the Holocene. The general alluvium capacity within the floodplain varies from 9–16 m and 20–24 m (usually in the rear) and within the bed is not more than 8–9 m, often—no more than 4–5 m. Considering that the Amur River depths reach 12–14 m (at high waters up to 20 m), the maximum relative elevation of the floodplain—8.10 m and the normal capacity of the alluvium (by E.V.Shantsera's technique [12]) makes 20–24 m, we get the capacities of the modern alluvium within the RVB, as a rule, to be less, less often to be equal to normal capacity. The exception is made by the data of the separate wells drilled on the left-bank of the floodplain in the area from the middle of the Arkhara River to the middle of the Ganukan River, where the alluvium capacities increase up to 26–30 m (Figure 2).

Consequently, the dynamic state of the RVB is described as instrative, although close to equilibrium (in V.V. Lamakin's understanding [13]) and achieved by the slow incises of the water-stream. The results of the properties study of the modern alluvium, being characterized rather rough structure, similar to the alluvium of the floodplain terraces, testify to the prevailing incises. Numerous pits and clearings within the floodplain reveal the contact of the flood-plain and the channel alluvial facies at the levels above the present water edge by between 0.5–2.0 m and 7.0–8.0 m, depending on the spatial position within the valley bottom. Often the overlying layer of the alluvium riverbed facies has the pronounced slope from the rear part of the floodplain to the river bed. Everywhere it is opened both in the coastal ledges of the Amur River (up — 2.5–4.5 m above the water edge) and of the islands (the Krestyansky, the Telyushinsky, the Urilsky, the Peschany etc.). These facts testify that the formation of the RVB happens in the inherited mode, i.e. in the conditions of primary incises of the water-stream into the bedding rocks.

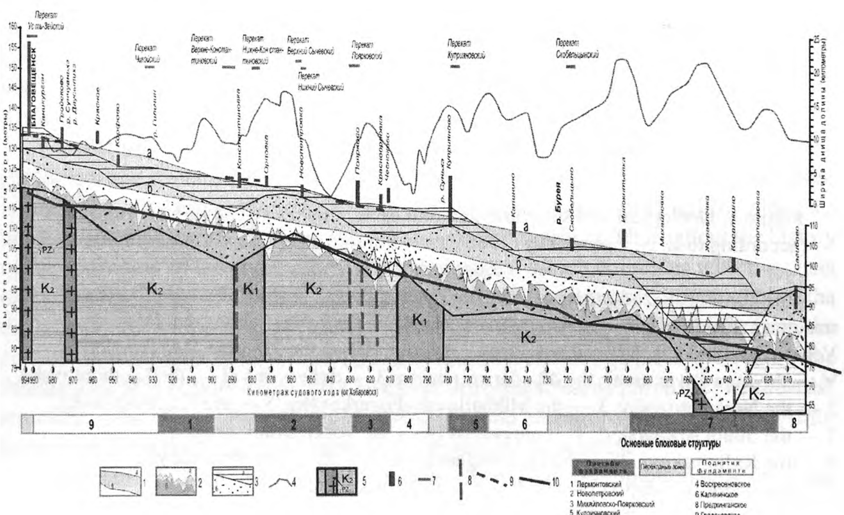

Figure 2: The change of the biases in the different phases of the water regime (1: a — in the high water period 1928, b — in the dry-weather period 1980), of the bottom surface of the channel (2: a — 1957,b — 1980) and the capacity of floodplain alluvium (3: a — of the floodplain facies, b — of the riverbed facies), of the width of the valley bottom (4), of the rock bedrocks (5); of the hypsometric position of the settlements (6) in relation to the longitudinal profiles (the upper limit of icons - the maximum altitude, the lower limit of icons — the minimum altitude), of the major rifts (7), of the disjunctive violations (8) the high-rise flood level position in 1984 (9), the calculated longitudinal (drawn) profile of the Amur River in the area from the mouth of the Zeya River to the Hingansky Gorge (10).

Based on the maximum height (7–8 m) of the overlying layer location of the alluvium riverbed facies above the modern water edge in the Amur River and considering the second bottom age—7500 years [14], the maximum intensity of the Amur River incises on the stretch of stream under consideration is 0.9–1.1 mm/year. The incises along the river, however, has been uneven. For example, taking into account the leveling works of the roof hypsometric position of the alluvial riverbed facies within the floodplain array in the area between Kalinino and Kupriyanovo settelemts, it was found that the incision intensity on the average makes 0.83 mm/year 0.83 mm/year. This value is comparable to the incision speed data of the the Amur and Zeya Rivers Plain (the Dep River) during the Quaternary—0.58 mm/year [14].

The longitudinal profile of the river and the vertical channel deformations. Another reliable source of the information on the vertical riverbed deformations is the longitudinal profile build on the results of the geodetic works (Figure 2). The nature of the biases changes of the water-stream free surface reflects the losses of the kinetic energy on the length [15–17] because of the changing conditions of the development—both the internal and the external ones. Therefore, our research methodology is based on the analysis of the slope changes of the water-stream longitudinal profile, which interfaces with the analysis of the riverbed forming alluvium distribution along the river of the average diameter, the capacity of the alluvial formations of the valley bottom according to the geological and structural conditions. We also considered the various signs of the riverbed deformations, manifested in the valley bottom structure elements and in the formation peculiarities. The data were obtained during the field studies of 1987–2012.

The water content in the Amur River increases regularly from 3486 m^3/s (Grodekovo village) to 4500 m^3/s (Innokentyevka village) and up to 4893 m^3/s (Pompeyevka village) [18]. In accordance with this, the transporting ability of the river grows. This is confirmed by the data of the field observations of 1959–1961 [19] and 1987–1989 [18] for the runoff of the sediments within the Upper and Middle Amur.

It is known [15–17] that the water-streams activity is primarily determined by their internal properties, in particular, by their water availability. Under the growth of the water content the longitudinal profile takes the form of the concave curve with the directed reduction of the biases along the river. Such a form is typical for the longitudinal river profiles not only in general, but also for the considerable length fragments, when the external riverbed forming process conditions (lithological, tectonic, geomorphological initially, climatic) remain relatively unchanged.

For the Amur River considered stretch, despite the significant increase (30%) of the water content, the regular reduction of the slopes along the river is not marked. The slopes vary in their size only slightly (on the average 0.00009–0.00012), remaining practically constant (except for the local channel segments) (Figure 2). Moreover, in the high waters the water-stream biases before the Hingansky Gorge increase most nearly 2-fold (up to 0.00017), that creates the convex bend in this segment of the longitudinal profile free surface (Figure 2). The absence of the corresponding changes of the usual water content and the longitudinal profile form indicates that the formation of the riverbed within the area under consideration is not so much influenced by the internal stream properties (especially by its water content), but by the external conditions of the riverbed shaping. Which of the external conditions have the decisive influence on the Amur River riverbed formation within the considered area? How does their action show itself on the vertical deformations of such a powerful water-stream as the Amur River?

These features of the Amur River longitudinal profile shape indicate that, as approaching the Small Khingan ridge, the river is "forced" to spend some of its energy to commit the extra work that is not committed on other sites located up the river. The additional energy consumption is caused by the tending of the water-stream to level the transportation ability along the river as directed by the changing external conditions. For the additional work it is necessary for the water-stream to change the corresponding parameters and to compensate for the loss of the energy to overcome the resistance to the stream flow due to the changing external conditions. According to the modern theoretical representations [15–17] the greatest riverbed energy costs are associated with the water-stream resistance to the fast flow, which causes the insertion of the steady against the erosion massive rocks into the course, the insertion of the additional rough fragments increasing the granularity of the channel forming alluvium, and the obstructions in the form of uplifting geological structures.

In respect of the lithological modern alluvium the main bottom of the Amur River is most often like the unconsolidated rocks of the Tsagayan suite (K2cg), which limits the water-stream and the basement rocks interaction. They are covered with the alluvial stratum (4–7 m), limiting the direct interaction between the water course and the rocks of the river bed. Therefore, the changes in the lithology of the bedrock cannot be considered the main reason to determine the shape of the longitudinal water-stream profile.

The additional sources of the sediments in the area of the Bureya River mouth to the Khingansky Gorge are the tributaries of the Amur, the intensely eroded banks and the high (above 35–40 m) rock ledges leaning on the floodplain close to the water edge in the mainstream. However, the largest tributaries of the Amur (the Ganukan, the Urilov, the Gryaznaya, the Mutnaya, the Uyunhe, the Tszelekhe, etc.) are relatively low-powered streams with the range to be no more than 5–6, being much inferior to the Amur in the amount of the transported sediments. Predominantly, they take out into the main course the gravel and the sandy material, which compared to the stream forming alluvium of the Amur, has a smaller structure. For this reason the material coming from the tributaries is not able to have a decisive influence on the riverbed formation and to define the shape of the longitudinal profile of the main water-stream in the area of its considerable length. There is also no reason to associate the morphology of the water-stream longitudinal profile with the clastic material "supply" into the riverbed during the erosion of the river terraces. The intensely eroded banks are limited in their distribution and confined mainly to the upper part of the considered area of the Amur. The erosive material is not able to increase significantly the alluvium stream-forming fineness, as its elements size is not more than of the modern stream alluvium of the Amur. The Rocky ledges at the base of the ad watershed slopes, linked with the course directly or through the narrow (no more than a few tens of meters) alluvial mass appear to be the major source of the coarse sediment. Their role in the delivery of the aggregative material in to the Amur riverbed is more significant. The results of the study of the modern riverbed alluvium properties showed that its fineness below those outputs increases. However, because of the local occurrence the impact of the rock outfalls is limited to the relatively short sections (less than 1–2 km). The total length of which is about 2% of the coastline. A very weak correlation between the average diameter of the alluvium and slope of the river (| r | <0.1) shows a little influence of the alluvium riverbed forming fineness on the form of the water-stream longitudinal profile, as a factor in general. For this reason the makrofragmental material coming into the mainstream from the bed-rock slopes cannot be considered to be the main reasons for the main water-stream longitudinal profile change.

Consequently, the sediment yield cannot be considered to be the main reasons for additional energy spending within the lower half of the considered channel reach. Therefore, it remains to acknowledge that the observed changes in the riverbed formation are due to the tectonic development of the area. They have the structural and the geological nature.

The value of the changes in the gradient surface on which they occur [15–17], primarily effects on the rivers erosion capacity, along with the water debit and the sediment grain size. This value depends on the nature of the local geodynamic conditions. Obviously, in the context of high and specific geodynamic activity (as mentioned above) the erosion should clearly express itself in the longitudinal profile morphology, as well as in the distinctive changes of the water-stream free surface slopes.

On the considered reach, the Amur River consecutively intersects the geological structures, experiencing at present mainly active uplift—the Khingan area and especially—the Small Khingan geoblocks [7], [20] and [21]. At their intersection the river cuts into the rock bed. This is indicated by the small alluvium fineness (less than normal) within the valley bottom. At that the speed of the geoblocks uplift is likely somewhat larger than the water- stream incises speed. That factor in the area of these structures intersection keeps under the forming the drawn profile with the shape approximate to the concave curve fragment (such a profile can be generated only at the incises speed being considerably higher than the speed of the tectonic uplift of the territory or under the equality of these values).

This ratio of the tectonic uplift rate and the Amur incision is supported by the special purpose structural and geological research. The results of the re-leveling of the Khingan area and the Small Khingan geoblocks territory indicate that the crust within these structures is experiencing the raising at the rate of up to mm 2.0–3.6/year [7], [20]. Moreover, the value of the raising is maximum for the structures traversed by the river in this area. The deviation of the water-stream longitudinal profile from the concave curve (the approximation to the straight or even the convex curve) shows that the speed of the river modern incises within these structures should be assessed by the value slightly less than the rate of the uplift (2.0–3.6 mm/year) of these structures, but higher than in the whole on the Middle Amur. Otherwise, the longitudinal profile slopes on this stretch of the river would be either more (at a much lower rate of the stream incises compared with the rate of the blocks rise) or less (at a faster than the speed of the lifting blocks, the water-stream incises). It is thanks to the commensurable quantities of the Amur crossing structures rise and the stream incises into the bedrock of the uplifting structures, the *antecedent* valley reach with the transverse profile in the form of a clough is formed. The directed reducing of the width of the valley bottom and its main elements indicates, besides, the prevailing incises of the Amur River before the Khingan Gorge. So in the area of 633–580 km the narrowing of not only the channel (s ¬ 1285–1385 m and 575–750 m) is marked, but the the valley bottom as a whole (from 12–14 to 7–8 km). This increases the average size of the riverbed forming alluvium from 7.5 mm (635 km) to 18.8 (605 km) and 20.5 mm (583 km), which indicates the increased transport capacity of the water-stream as it approaches the ridge due to the growth of the longitudinal profile slopes.

We can also assess the nature of the vertical deformation if we compare the desired longitudinal profile of the water-stream with the calculated one answering the worked out profile (within the meaning of N.I. Makkaveyev, [15]), which is constructed in accordance with the formula I = k Fn [22], where I—the slope; F—the flood basin in the river station; n—the statistical index (for the considered reach of the Amur it varies from -0.5 to -1. The real profile in whole is close to the worked out (Figure 2), the maximum depth elevations tend to coincide with the marks of the calculated profile, which demonstrates the stream to lower the bed elevations, that is, its incises.

Conclusion:

1. Our data on the conditions of the formation of the valley bottom and the Middle Amur river bed and the course deformation features complement the results and clarify the findings of the previous studies [1-4].

2. The results of the dual analysis of the water-stream longitudinal profile and the major riverbed forming factors suggest that the Amur River bed formation is influenced not only and not so much by the intrinsic properties of the water-stream, as by the external (to the flow) conditions of the riverbed forming, among which the leading role is played by the changes in the geological and the structural conditions in the form of the transverse neotectonic uplifts in particular—the Small Khingan River. They in the main determine the distinctness of the riverbed deformations that develop in the mode of the primary reduction of the high-rise elevations of the river bed, due to the high geodynamic area activity.

3. The vertical deformations of the Amur River in the Holocene have the directed character, due to the prevailing reduction of the elevations down the river bed at the average speed of 0.9-1.1 mm/year. The maximum increases intensity is characteristic of the river at the reach of the Khingan Gorge, which size is comparable (about 2 mm/year) to the speed of the mountain construction raising.

REFERENCES

1. Antropovsky, V.I. Morphology and Deformation of the Middle Amur River bed. *Geography and Natural Resources. № 3.* (1996): 93–103.

2. Ivanov, V.V., Makhinov, A.N., Chalov, R.S., Chernov, A.V. Vertical Channel Deformations in the Middle Amur. *Moscow State University Bulletin. Series 5. Geography. № 5.* (2000): 32–37.

3. Makhinov, A.N., Chalov, R.S., Chernov, A.N. Offshore Motion of Sediments in the Middle Amur. *Geomorhology. № 2.* (2001): 72–81.

4. Ivanov, V.V., Zavadsky, A.S. Channel Processes in the Amur Marginal Area. *Moscow State University Bulletin. № 4.* (2012): 50–56.

5. Ufimtsev, G.F. Relief Tectonic Analysis (on the basis of the USSR East). Novosibirsk: Nauka. Siberian Branch (1984): 183.

6. Zhukovsky, S.Ya., Podkaminer, O.S. Preliminary Engineering-geological Zoning of the Middle Amur Valley in Connection with Field Investigations in the Upper Amur. *Problems of Engineering Geology in the Upper Amur.* M.: Lomonosov Moscow State University Publishing (1962): 164–172.

7. Kashin L.A. Map of Modern Vertical Movements with Geodetic Data on the USSR Territory. M.: State Department of Geodesy and Cartography (1989): 4.

8. Miroshnichenko, A.I., Sorokin, A.P., Sankov, V.A., at al. Space Geodesy in the Tasks of Geodymamics: Present-day Motion in the Zeya–Bureya River Basin. *The Pacific Ocean Geology. № 1.* (2008): 71–80.

9. Sankov, V.A., Lukhnev, A.V., Miroshnichenko, A.I., at al. Space Geodesy in the Tasks of Geodymamics: Present-day Motion in the Zeya–Bureya River Basin. *DAN. Vol. 389. № 1.* (2003): 100–103.

10. Kuzmenko, S.P. State Geologic Map of the USSR at 1:200,000 Scale. The Amur–Zeya. Page M-52-XIV: Explanatory note. M.: USSR Ministry of Geology (1983): 82.

11. Gusev, M.N., Pomiguyev, Ju.V. Channel Activity of Main Rivers in the Amur Region under the Conditions of Modern Economic Management. *Geography and Natural Resources. № 2.* (2008): 45–50.

12. Shantser, E.V. Alluvion of Lowland River in Temperate Zone and its Role in the Perception of Structure and Alluvial Measures Formation Regularities. *Institute of Geological Research of the USSR Academy of Sciences,. Issue 135. Geology (№ 55).* (1951): 274.

13. Lamakin, V.V. On Residual River and Other Residual Superficial Deposit. *Proceedings of the USSR Academy of Sciences. Geology. № 2.* (1943): 79–87.

14. Kostomakha, V.A. Experimental Rate Calculation of Relief Forming Processes at the Late Stages of Quaternary for Amur–Zeya Lowland. *Earth Surface, Multilevel Relief and the Rate of Relief Forming. Works of Irkutsk Geomorphologic Seminar (Irkutsk, 9–14 September 2007).* Irkutsk: Institute of Earth Crust, Siberian Branch, Russian Academy of Sciences (2007): 126–127.

15. Makkaveyev, N.I. River Bed and Erosion in its Basin. M.: Academy of Sciences Publishing. (1955): 346.

16. Chalov, R.S. River Bed Studies: Theory, Geography, Practice. *Channel Processes: Factors, Mechanisms, Ways of Manifestation and Conditions for River Beds Formation. Vol. 1.* M.: LKI (2008): 608.

17. Makkaveyev, N.I., Chalov, R.S. Channel Processes. M.: Moscow State University Publishing (1986).

18. Joint Russian–Chinese Scheme of Complex of Water Resources Use in Marginal Areas of the Argun River and the Amur River. *Vol. 5. Climate and hydrology.* Moscow–Zhen Huan Zhuan: Sovintervod, Sunlyaokomvodhoz (1998): 227.

19. Resources of Surface Waters in the USSR. *Vol. 18. Far East. Issue 1: Upper and Middle Amur.* Leningrad: Hydrometeoizdat (1966): 781.

20. Lishnevsky, Ye.N. On the Structure of Basement Surface in Low Zeya Cavity. *Geotectonics. № 5.* (1968): 62–71.

21. Korchagin, F.G. Geodynamics of Amur Geological Unit. *Problems of Geodynamics and Earthquake Forecast. First Russian–Japan Seminar (Khabarovsk, 26–29 September 2000)).* Khabarovsk: FEB RAS (2001): 18–39.

22. Voskresensky, S.S., Voskresensky, K.S. Generated River Longitudinal Profile (Slopes as Watercourse Function). *Geomorphology. №1.* P. 14-22.