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Physical Geography

The Genesis, Transportation and Accumulation of the Bed Drift of Mountain Rivers

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(Presented by Academy Member Tamaz Tchelidze)

ABSTRACT. The genesis, transportation and accumulation of the mountain rivers bed drift in time and space, are casual processes, which depend on such values, as river water discharge (Q, m^3/sec), river inclination (I, ‰), geology and other parameters of the basin. The genesis and amount of the river drift is a function of a climate and depending on its cycles, is more intense in warm periods and reduces when it gets cold. The major drift-forming natural factors are glaciers, erosion, landslides and torrents. Drift transportation, i.e. the process of the drift transfer is a function of many variables, which is mainly described by the laws of Chezy-Maning and Airy. In the upstream of the reservoirs, this process, besides the said laws, is subject to the regularities of the ratio between the drift with the greatest diameter (d_{max}) and velocity of the river (*V, m/sec*). At some locations, a river may cross an uplifting ridge, or "epirogenic border" and subsiding plain. Such a border is sawn down by the river bed to form so called "balance bed" with relevant properties. If the speed of the threshold elevation is more than the bed cutting speed, a depression is formed, in which the river permanently precipitates the drift to form the bed of the right inclination, or "balance" bed. Some rivers use a significant portion of drift to compensate the stagnations formed by a torrent talus train, the "torrent dam". The result of these processes is the formation of Chiori floodplain and Saglolo and Chrebalo plain-accumulative terraces in the river Rioni basin and Tianeti Plain in the upper reaches of the river Iori and many other events. A significant portion of the drift is used to form the drift prisms of water reservoirs. The river, uses a portion of the remained bed drift to form a balance bed located on the subsiding plains and neutralize the sea eustasy effect. Another part of the drift is used to form a delta, permanently fill the coastal beaches and create the accumulative forms in the sea. A mountain water reservoir conflicts with the sea coastal protection and safety of the upstream population and infrastructure. Therefore, when selecting its location, the genesis of the riverbed drift, sites of natural accumulation and grain size of the drift must be considered. An optimal site to build a reservoir dam is epirogenic borders, as the dam rises higher there and consequently, the exploitation phase of the dam is longer. *© 2017 Bull. Georg. Natl. Acad. Sci.*

Key words: bed drift, debris, epeirogenic threshold, mudflow barrier, equilibrium channel

Highly energetic, communal and irrigation designation of the mountain rivers constantly increases in the background of the demographic explosion and current climate changes. The most efficient means to use the mountain rivers, particularly in tandem of helio- and wind energy, is water reservoirs despite the fact that they have a major deficiency as they do not transfer the river bed drift towards the sea. Solid mater accumulates in the water reservoirs, as a silting prism and gradually deteriorates its exploitation properties. In order to minimize this deficiency, when selecting the location for building a water reservoir, the diameter of the largest drift (d_{max}) and terms of drift transportation, as well as the time needed by the river to take such drift downstream, i.e. to restore the original mode of drift transportation, must be identified along the section adjacent to the dam [1, 2].

The regime of mountain river bottom sediments is the most poorly studied processes of river hydrology. His research significantly intensified after the building of reservoirs [3, 4], since these structures accumulate the bottom sediments in the form of a silting prism and thus create an acute shortage of beach forming material on the sea beaches. Simultaneously, they lift the tributaries bed and increase the probability of catastrophic flooding within the propagation of the plume of the silting prism.

The necessity to eliminate these negatives necessitates a significant expansion of field observations, experimental and theoretical studies of the genesis and transport of river sediments, as well as the accumulation forms created by bed drift.

Materials and Methods

The field data and laboratory studies of the rivers of the Caucasus (Andis Koysu, Kuban, Rioni, Enguri, Tergi, Iori, etc.) accomplished in 1980-2016, as well as geological, hydrological and geomorphological study results published in special and scientific literary sources were used to solve the problem [4, 5].

The observations of the sections of the rivers, which are perspective to build the water reservoirs, were accomplished with a particular care. The visual field studies were more efficient in low-water periods, while the study of the terms of transportation of the bed drift was more efficient during the floods and freshets [6, 7].

In the freshet phases, quite frequently, when the rivers Rioni and Enguri used to throw the blocks with their diameter of approximately 0.5 m onto the 1.2-meter-high dikes and gabions, the naturalistic studies of the types of the drift transportation and parameters of the accumulative formations were carried out with Jvari, Sioni, Gumati and other water reservoirs. The drift grain size was studied by using field and laboratory methods [4, 5].

Results

The studies showed that the major drift-forming factors in the river beds are glaciers, erosion, landslides, mud torrents and slide and fall of the blocks from the steep gorge slopes. At some places, the blocks with a diameter of more than 5.0 m (with the weight of over 10 tons) are slid or drifted by a glacier in the riverbeds. Their parameters and movement trajectory are relevant to the historical time, and when selecting the location for building the reservoirs, are considered in one respect only, in particular, a dam must be located at a distance from them excluding any impact on its stability or exploitation quality.

Drift genesis is a casual process, which is a function of a climate and like the climate, has a clear cyclicity [8]. In moderate latitudes, the ongoing climate warming cycle started in the 1860-1880s and is expected to continue to the end of the present century. In this period, the glaciers retreated for many tens or hundreds of meters [9].

As a result, the moraine mass has liberated and gets into the rivers ultimately increasing the amount of drift significantly. In addition, an increasing humidity in the mountainous regions leads to the increased volume of erosive material and activated torrents and landslides [10]. All these processes were aggravated by stronger anthropogenic factors as a

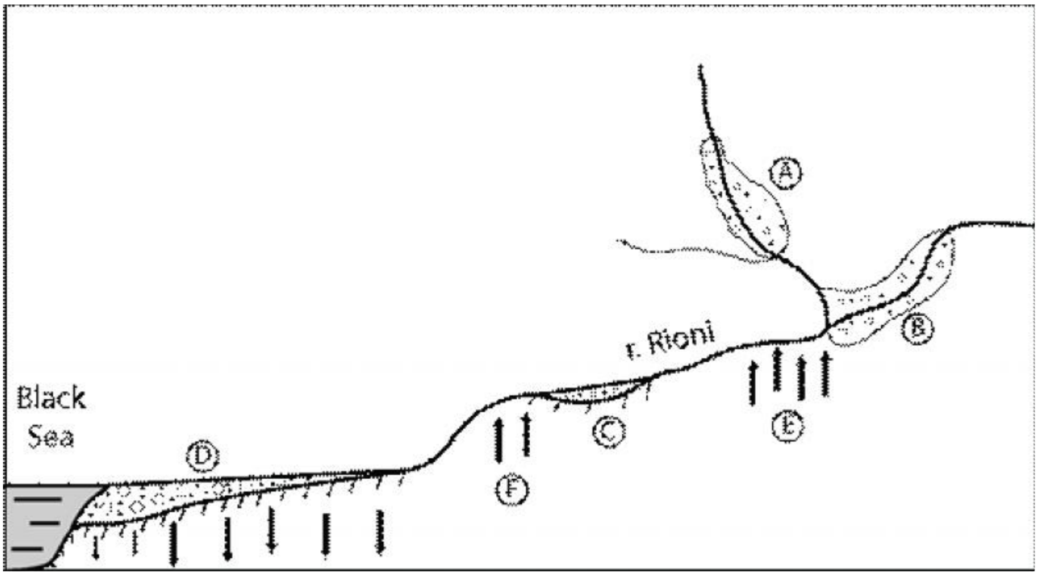

Fig. Longitudinal profile of Rioni River
Accumulation planes: A-Tchiora; B-Palolo; C-Tchrebalo; D-Kholtketi
Epigenetic thresholds: E-Shoda-Kedela range; F-Sairme massive.

result of a demographic explosion.

The grain-size and chemical composition of the drift in the Mountain Rivers are diverse. The drift in the mountainous regions is formed by a volcanogenic mass, such as granites, diorites, andesite, etc.; it is formed with sandstones and clay slates in the middle-mountainous zones, while limestone and sometimes gypsum also get into the play in the low-mountainous zones, depending on the chemical composition of the drift, the degree of their wear and transformation and factional content change. Limestones, clay slates and other soluble and soft rocks wear swiftly, solve in water and most of them reach the border only as a solution, fine sand, dust or clay particles.

The transportation and accumulation of drift in the rivers flowing in different geological, geomorphological and hydrological conditions is of a particular interest. The drift transportation, i.e. the process of drift transfer is a function of many variables, which is mainly described by the laws of Chezy-Manning and Airy [8, 11]. This process, in the upstream of the reservoirs, besides the said laws, is the function of the ratio between the drift with the greatest diameter (d_{max}) and velocity of the river (*V*, m/sec) [1].

An example is Gumati water reservoir with 97.5% of its conservation zone occupied with drift, while the process of silting up is ongoing. The blocks and larger drift (d>0.3m) here, on the train of the drift prism are accumulated along the river section with a less inclination. Below them, there follow boulder ridges, while downstream, the river transfers only fine (d<5.0 mm) bed drift.

Some rivers cross several tectonic zones and fault lines and catch mud torrents. In these zones, some sections of the earth’s crust as ridges and massifs, gain the height at different speeds. For a river, such ridges are a constantly uplifting border to be sawn by it to form a bed. If the river cutting speed (*V*, mm/century) is less that the uplift speed (*V*, mm/century):

$$(V-\nu)=P, \text{ mm/century} \qquad (1)$$

a depression is formed, which is constantly filled with drift by the action of the river creating an accumulative plain (Figure), which has a shape of a basin at some places.

Sairme carbonate massif creates such an accumulative formation in the middle course of the river Rioni as Chrebalo basin is, which is uplifting and is therefore, an “epirogenic border” for the river. In the geological time, the river develops its bed in this border. Besides, in order to preserve the necessary current speed, the river permanently deposits the drift in this depression and builds the bed with a sufficient inclination.

A similar plain is sometimes formed by some mud torrents when they block the river periodically with the dam-barrier created with the chunks of large blocks and cliffs. The river has cut such a barrier what needs certain time and necessary water discharge. Before that, the river sediments the drift in the upstream of the given dam creating an accumulative relief form in the upstream of the "torrent dam". An example is Chiora Plain known as "Chiora Floodplains" among the local people.

A common type of an anthropogenic factor is a water reservoir used to distribute the flow in time and space. Together with the water, the reservoir accumulates drift as well, and a drift prism is created, which is formed as a terrace plain at the final stage of the river development.

Some rivers flow across an accumulative plain. If such kind of the relief is located in a negative tectonic zone (Colchis, Dunai, Parana Plains, etc.), the river must raise its bed to the point as to neutralize the plain subsiding effect and give its bed sufficient inclination [12]. One such river in Georgia is the Rioni. As the Rioni flows onto Colchis lowland (Figure.), it has to neutralize the plain subsiding speed $V_d = 0.6$m/century and the Black Sea elevation, i.e. modern eustasy effect, which is $E=0.2$ m/century at the river mouth.

Consequently, the river Rioni must raise the bed by 0.8 m/century at its mouth:

$$V_d + E = 0{,}8 \text{ m/century,} \tag{2}$$

while at the beginning of the plain, near Vartsikhe, this value is $h=0{,}7\ m$, as the land subsidence speed at this point is less ($V_d<0{,}5$ m/century). Such bed inclination, I is calculated with the following expression:

$$I=[h-(V_d+E)]/L \text{ m/km,} \tag{3}$$

where L is the distance from Vartsikhe to Poti.

It is clear that the river with such an inclination is not capable of transferring large drift (d>5 mm), but must use it to fill Colchic depression and elevate its bed. In addition, the size of the deposited material decreases towards the mouth. The visual examinations prove that the size of the drift of the river Rioni does not exceed 2 mm near the city of Poti. Finally, the river carries the remained drift into the Sea and by taking it across the underwater canyon created by it, sediments it on the sea shelf and slope.

Particularly interesting is the river Chorokhi, as its bank is built with its bed drift with the city of Batumi and some other settled areas built on it. A 24-reservoir cascade with total volume of 4.0 km^3 is being intensely built across the river. This cascade will hold 6.0 km^3 drift [1,2]. This means that Batumi coast will not receive Chorokhi drift for at least 500 years.

This negative effect is further aggravated by the fact that another river, the Ajaristskali, which could alleviate the severe lack of the bank-constituent drift, will be closed with a water reservoir in the near future blocking the drift transportation towards Batumi coastline for many tens of years.

It is clear that a coast left without the filling drift will be subject to the abrasive action of the Sea in the coming years, and intense beach washout will start. Such a course of events is typical for any mountain river in case it is closed with a water reservoir.

Therefore, when selecting the water reservoir location, the peculiarities of the basins described above and the role of the drift transportation and accumulation formations must be taken into account.

By considering the factors affecting the drift genesis and transportation, the balance equation of the bed drift originated in the mountain river basin during a certain period (a century) can be presented as follows:

$$B = \Sigma T + \Sigma C + JW + D + E + O \tag{4}$$

where B is the amount of bed drift formed in a unit time (year, century), ΣT is the drift precipitated in the depressions formed with uplifting borders, ΣC is the material accumulated in the stagnations formed with torrent barriers, ΣW is the drift caught in the drift prisms of the water reservoirs, D and E are the bed material used to neutralize the plain subsidence in the negative tectonic zone and modern sea eustasy effect, respectively and *O* is the drift taken into the sea.

Conclusions

The principal results of the study can be generalized as follows:

- The genesis and volume of river drift is a causal process, which is the function of a climate and like the climate, is characterized by the cyclicity of grain size and volume.

- The drift transportation is a function of many variables, mainly described by the laws of Chezy-Maning and Airy. This process, in the upstream of the reservoirs, besides the said laws, is the function of the ratio between the drift with the greatest diameter (d_{max}) and velocity of the river (*V*, m/sec).

- A certain amount of the bed drift is used to fill the depressions formed by the action of the ridges and massifs elevating against the river current. A significant portion of the drift is used to form a silting prism of the plains and water reservoirs formed by mudflow, as well as to fill and to mud the plains found in tectonic depressions and neutralize the sea eustasy effect.

- It is recommended to select an efficient location for the water reservoir by considering the diameter of the largest bed drift, as the water reservoir functions as long as it is capable of transferring the drift of the said size downstream, i.e. before it restores the original conditions of drift transportation.

- A mountain water reservoir is in conflict with sea coastal protection and safety of the upstream population and infrastructure. In order to adapt to this negative effect, when building the hydraulic buildings, the genesis of the drift, the sites of their natural accumulation and grain size of the drift, and particularly, the peculiarities of the relation between the drift with particularly large diameters (d_{max}) and water current, must be considered.

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ფიზიკური გეოგრაფია

მთის მდინარეების ფსკერული ნატანის გენეზისი, ტრანსპორტი და აკუმულაცია

გ. მეტრეველი*, ლ. მაჭავარიანი*, დ. სვანაძე*, მ. ალავერდაშვილი*, ა. მეტრეველი*

**ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტი, გეოგრაფიის დეპარტამენტი, თბილისი, საქართველო*

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

მთის მდინარეების ფსკერული ნატანის გენეზისი, ტრანსპორტი და აკუმულაცია დროსა და სივრცეში ისეთი შემთხვევითი პროცესებია, რომელთაც მდინარის წყლის ხარჯი (Q მ^3/წმ), კალაპოტის დახრილობა (I‰), აუზის გეოლოგია და სხვა პარამეტრები განსაზღვრავს. მდინარეთა ნატანის გენეზისი და რაოდენობა კლიმატის ფუნქციაა და მისი ციკლების შესაბამისად – დათბობის პერიოდში მეტია, აცივებისას, პირიქით, მცირდება. ძირითადი ნატანწარმომქმნელი ბუნებრივი ფაქტორებია მყინვარი, ეროზია, მეწყერი და ღვარცოფი. ნატანის ტრანსპორტის – ნაკადის მიერ ნატანის გადატანის პროცესი მრავალი ცვლადის ფუნქციაა, რომელიც ძირითადად შეზი-მანინგის და ერის კანონებით აღიწერება. ეს პროცესი წყალსაცავების ზემო ბიეფში, გარდა აღნიშნული კანონებისა, უდიდესი დიამეტრის ნატანის (დმახ) და მდინარის სიჩქარის (V მ/წმ) დამოკიდებულების კანონზომიერებასაც ექვემდებარება. ზოგან, მდინარე აზევებად ქედს, ე.წ. "ეპიროგენეტურ ზღურბლს" და დაძირვად დაბლობს გადაკვეთს. ასეთ ზღურბლს მდინარე თავისი ნატანით ხერხავს, რომ შესაბამისი მახასიათებლების მქონე, ე.წ. "წონასწორული კალაპოტი" შექმნას. იმ შემთხვევაში თუ ზღურბლის აზევების სიჩქარე კალაპოტის ჩაჭრის სიჩქარეზე მეტია, ზღურბლ ზემოთ წარმოიქმნება დეპრესია, რომელშიც მდინარე ნატანს პერმანენტულად ლექავს, რომ საკმარისი დახრილობის, ანუ „წონასწორული" კალაპოტი შექმნას; ზოგან მდინარე ნატანის მნიშვნელოვან ნაწილს სელის გამოზიდვის კონუსის, "სელური კაშხლის" მიერ შექმნილი პერმანენტული შეგუბებების ამოვსებაზე მოიხმარს. ასეთი პროცესების შედეგია მდ. რიონის აუზში ჭიორის ჭალის, საგლოლოს და ჭრებალოს აკუმულაციური ვაკე-ტერასების, მდ. იორის ზემო წელში თიანეთის ვაკის შექმნა და სხვა. ნატანის მნიშვნელოვანი ნაწილი წყალსაცავების მოსილვის პრიზმების ფორმირებაზეც იხარჯება. მდინარე, დანარჩენი ფსკერული ნატანის ერთ წილს, დაძირვად დაბლობებზე მდებარე წონასწორული კალაპოტის შექმნასა და ზღვის ევსტაზიის ეფექტის განეიტრალებაზე მოიხმარს. ნატანის მეორე წილი დელტის ფორმირებაზე, სანაპირო პლაჟების პერმანენტულ შევსებასა და ზღვაში აკუმულაციური ფორმების შექმნაზე იხარჯება. მთის წყალსაცავი კონფლიქტურ ურთიერთობაშია ზღვის ნაპირდაცვასთან, ზემო ბიეფის მოსახლეობის და ინფრასტრუქტურის უსაფრთხოებასთან. ამიტომ მისი ადგილის შერჩევისას მდინარის ფსკერული ნატანის გენეზისი, ბუნებრივი აკუმულაციის ადგილები და ნატანის გრანულო-მეტრიაც უნდა იყოს გათვალისწინებული. ეპიროგენეტური ზღურბლები წყალსაცავის კაშხლის მშენებლობის ოპტიმალური ადგილია, რადგან იქ კაშხალი ზემოთ იწევს და, შესაბამისად, მისი ექსპლოატაციის პერიოდიც შედარებით ხანგრძლივია.

REFERENCES

1. Metreveli G., Matchavariani L. (2016) Research method of silting the mountain reservoirs under the current climate change. *Journal of Water Resources and Ocean Science.* **5**, 2: 22-27.
2. Matchavariani L., Metreveli G., Alaverdashvili M., Lagidze L., Svanadze D., Gulashvili Z. Bregvadze G. (2016) Results of field experiments of reservoirs' siltation for harmonious realization of hydropower and coastline problems. *Second International Conference on Science, Engineering & Environment*, Osaka City, Japan, 639-644.
3. Gvelesiani L.G. (1973) *Rezhim osadkonakoplenia gornykh rek i sedimentatsiia vodokhranilishch. Gidrologia ozer i Vodokhranilishch*. part 2: 38-49 (in Russian).
4. Shamov G.I. (1959) *Gidrologicheskoe soprativlenie rechnykh kanalov*. Leningrad, 378s. (in Russian).
5. Znamenskaya N.S. (1976) *Gidrologicheskoe soprativlenie rechnykh kanalov.* Leningrad, 191s. (in Russian).
6. Alaverdashvili M., Grigolia G., Kvirkvelia B., Kerdikoshvili J., Svanidze G. *et.al*. (1981) savinidze. *Gidrologia reki Bzip (inzhinerno-geologicheskoe opisaniia, stok vodi i osadkov)* Tbilisi, 144s. (in Russian).
7. Stephens T. (2017) Study shows how river channels adjust to large sediment supplies. Santa Cruuz. University of California. Newscenter, 4.
8. Barishnikov N., Samuseev E., Simonov A. (2004) Gidrologicheskoe soprotivlenie rechnykh kanalov. *VI konferentsia - dinamika i termika reck, vodokhranilishch i morskoi pribrezhnoi zoni"*, M. 12-13 (in Russian).
9. Kordzakhia G., Shengelia L., Tvauri G., Dzadzamia M. (2017) Impact of modern climate change on glaciers in Georgia. *Bull. Georg. Natl. Acad. Sci*. **10,**4: 56-63.
10. Mohajeri S.H., Righetti M., Wharton G., Romano G.P. (2016) On the structure of turbulent gravel bed flow: Implications for sediment transport. *Advances in Water Resources*, Elsevier, 92: 90-104.
11. Metreveli G.S., Kereselidze D.N., Rekhviashvili Sh.D. (2004) *Dinamika prizm zalivania rezervuarov.* RAS EMU, *VI Konferentsiia dinamika i termika rek, vodokhranilishch i morskoi pribrezhnoi zon*, M: 69-74 (in Russian).
12. Cienciala P., Pasternack G.B. (2017) Flood plain inundation response to climate, valley form, and flow regulation on a gravel-bed river in a Mediterranean-climate region. *Geomorphology*. Elsevier, **282**: 1-17.

Received May, 2017

REFERENCES

1. Metreveli G., Matchavariani L. (2016) Research method of silting the mountain reservoirs under the current climate change. *Journal of Water Resources and Ocean Science.* **5**, 2: 22-27.
2. Matchavariani L., Metreveli G., Alaverdashvili M., Lagidze L., Svanadze D., Gulashvili Z. Bregvadze G. (2016) Results of field experiments of reservoirs' siltation for harmonious realization of hydropower and coastline problems. *Second International Conference on Science, Engineering & Environment*, Osaka City, Japan, 639-644.
3. Gvelesiani L.G. (1973) *Rezhim osadkonakoplenia gornykh rek i sedimentatsiia vodokhranilishch. Gidrologia ozer i Vodokhranilishch*. part 2: 38-49 (in Russian).
4. Shamov G.I. (1959) *Gidrologicheskoe soprativlenie rechnykh kanalov*. Leningrad, 378s. (in Russian).
5. Znamenskaya N.S. (1976) *Gidrologicheskoe soprativlenie rechnykh kanalov.* Leningrad, 191s. (in Russian).
6. Alaverdashvili M., Grigolia G., Kvirkvelia B., Kerdikoshvili J., Svanidze G. *et.al*. (1981) *Gidrologia reki Bzip (inzhinerno-geologicheskoe opisaniia, stok vodi i osadkov)* Tbilisi, 144s. (in Russian).
7. Stephens T. (2017) Study shows how river channels adjust to large sediment supplies. Santa Cruuz. University of California. Newscenter, 4.
8. Barishnikov N., Samuseev E., Simonov A. (2004) Gidrologicheskoe soprotivlenie rechnykh kanalov. *VI konferentsia - dinamika i termika reck, vodokhranilishch i morskoi pribrezhnoi zoni"*, M. 12-13 (in Russian).
9. Kordzakhia G., Shengelia L., Tvauri G., Dzadzamia M. (2017) Impact of modern climate change on glaciers in Georgia. *Bull. Georg. Natl. Acad. Sci*. **10,**4: 56-63.
10. Mohajeri S.H., Righetti M., Wharton G., Romano G.P. (2016) On the structure of turbulent gravel bed flow: Implications for sediment transport. *Advances in Water Resources*, Elsevier, 92: 90-104.
11. Metreveli G.S., Kereselidze D.N., Rekhviashvili Sh.D. (2004) *Dinamika prizm zalivania rezervuarov.* RAS EMU, *VI Konferentsiia dinamika i termika rek, vodokhranilishch i morskoi pribrezhnoi zon*, M: 69-74 (in Russian).
12. Cienciala P., Pasternack G.B. (2017) Flood plain inundation response to climate, valley form, and flow regulation on a gravel-bed river in a Mediterranean-climate region. *Geomorphology*. Elsevier, **282**: 1-17.

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