Analele Universităţii din Oradea – Seria Geografie Year **XXI**, no. **2/2011** (**December**), pp. **222-232**
ISSN **1454-2749**, E-ISSN **2065-1619** Article no. **212107-527**

DOWNSTREAM VARIATION IN PARTICLE SIZE: A CASE STUDY OF THE TROTUŞ RIVER, EASTERN CARPATHIANS (ROMANIA)

Dan DUMITRIU*
„Alexandru Ioan Cuza" University of Iaşi,
B-dul Carol I, no 11, 700506, Iaşi, Romania, e-mail: dndumitriu@yahoo.com

Daniel CONDORACHI
„Alexandru Ioan Cuza" University of Iaşi,
B-dul Carol I, no 11, 700506, Iaşi, Romania, e-mail: condordan@yahoo.com

Mihai NICULIŢĂ
„Alexandru Ioan Cuza" University of Iaşi,
B-dul Carol I, no 11, 700506, Iaşi, Romania, e-mail: mn_geogr@yahoo.com

Abstract: In order to analyze Trotuş river bed deposits granulometry 21 sampling point were chosen, located at about 7 km each other. After field and lab analysis it was noticed that there is a general downstream reduction trend for clasts size, but only if we consider extreme sampling points (headwaters and outflow). Trotuş midcourse display a downstream coarsening phenomenon, influenced by tributaries and slope processes that deliver much coarser materials than the ones stacked within river bed deposits.

Keywords: bed sediment, grain size, median grain size, downstream fining, downstream coarsening

* * * * * *

INTRODUCTION

The nature of river bed sediments, also bank sediments have an important influence on rivers' morphological and hydro-dynamic characteristics. Also is involved in rivers' solid flow formation and components. In this context, grain size analyses may bring significant information regarding solid flow, sediment sources, their behavior at river bed deposits fluvial processing, etc. That's why reports and studies on river bed sediments size have a long tradition perhaps of their practical nature. First reports were linked of *downstream fining* (Leonardo da Vinci, 1504 - 1506; Guglielmini, 1697; Frisi, 1762) (Gomez et al., 2001). These reports and the next ones founded the law stated by Sternberg (1875) according which grain size decrease exponentially with the travel distance.

Starting from this finding, many studies focused on this process of river bed particle size decrease known as downstream fining. Was considered that this phenomenon has as main cause one of the following processes: *fine particle selective transport or selective sorting* (Paola et al., 1992; Ferguson et al., 1996; Wilcock, 1997; Gasparini et al., 1999; Hoey and

* Corresponding Author

Bluck, 1999; Montgomery et al., 1999); *abrasion* (Krumbein, 1941; Bradley, 1970; Schumm and Stevens, 1973; Parker, 1991a, 1991b, 1991c; Kodama, 1994; Malarz, 2005); *in situ clast weathering during storage* (Bradley, 1970; Heller et al., 2001), and *the spatial distribution of sources for resistant lithologies* (Pizzuto, 1995).

In certain cases a deviation from the normal trend of downstream fining called *downstream coarsening* was reported, and some factors were responsible for this: tributaries influence (Miller, 1958; Knighton, 1980; Rice, 1998, 1999); direct river channel inputs of materials by slope processes where floodplain is missing (Benda, 1990; Grant and Swanson, 1995; Grimm et al., 1995; Lambert et al., 1996; Rice and Church, 1996; Church, 2002; Brummer and Montgomery, 2003; Attal and Lavé, 2006). Recent studies focused on the grain size and shape within river beds insist on relationships between source area characteristics and river bed sediments characteristics (Desloges, 1990; Mikoŝ, 1994; Ichim et al., 1998; Moussavi-Harami et al., 2004; Farrow and Sklar, 2005; Malarz, 2005; Stanley et al., 2006; Attal and Lavé, 2006; Lindsey et al., 2007; Rengers and Wohl, 2007; Rădoane at al., 2007, 2008; Mureşan, 2009; Miao et al., 2010; Pike et al., 2010; Venditti et al., 2010).

STUDY AREA

Trotuş drainage basin is located in central-eastern part of Eastern Carpathians and Moldavian Subcarpathians and has about 4,350 sqkm and a length of about 160 km (figure 1). Between headwaters and Siret confluence, the altitude difference is about 1,290 m (from 1,360 m altitude at headwaters to 70 m altitude at confluence). Trotuş River is of VIIIth order in Strahler classification. The catchment area lies on four distinct structural and lithological units: marginal syncline, carpathian flysch, pericarpathian molasse and the platform.

Petrographically, in the four litho-stratigraphical units dominate the following lithology: 40% clayey silty rocks; 35% sandstones of different types; 18% quaternary deposits (gravels, sands, loams, clays); 5% crystaline schysts, limestones and dolomites; 2% menilites, disodiles etc.

Average annual rainwater spans from 722 mm / yr in Trotuş Valley and almost 1,000 mm/yr in higher mountains. These values drop down about 100 mm/yr in central part of Dărmăneşti Depression and towards the subcarpathians limit. Average annual discharge for Trotuş River, recorded at Vrânceni hydrometric station, is of 33 ^{3}/s while maximum was of 3,720 m^3/s, recorded in 29th of July 1991.

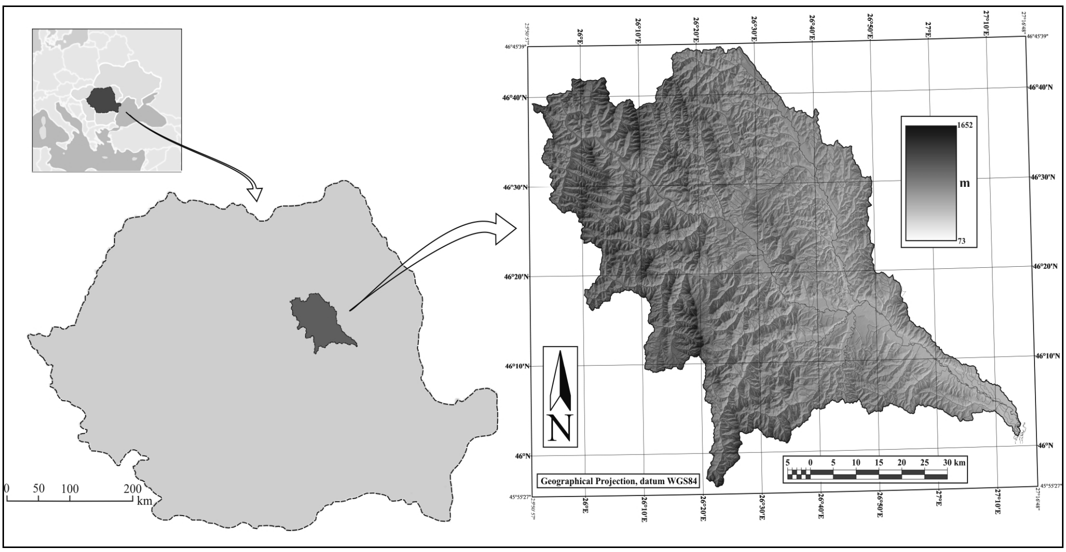

Figure 1. Study area location

MATERIALS AND METHODS

In this study was used volumetric sampling for river channel sediments that uses sampling for surface layers or pavement layer and subsurface layer or subpavement layer (Mosley and Tindale, 1985; Church et al., 1987; Ichim et al., 1992) (figure 2). This sampling method consists in drawing of three sampling categories: *surface sample* (from the layer called hydraulic layer or pavement of which thickness is equal with the diameter of the largest clast); *subsurface sample* (or subpavement - material located under hydraulic layer); a *global sample* (obtained by summing up the previous sampling categories).

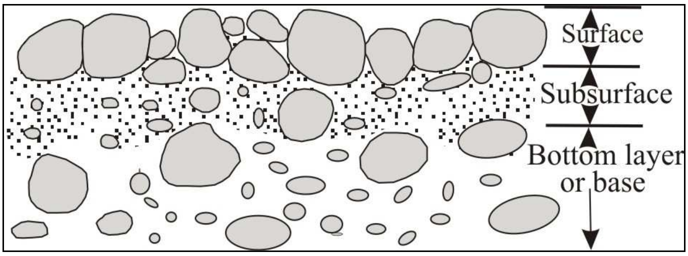

Figure 2. The illustration of the arrangement mode of the bed deposits

After setting up the sampling method and sampling points (21 channel sections at a distance of 7 km of each other) (figure 3) topometric measurements were made, for each sampling point, to precisely assess the slope of the river channel and floodplain. Then, using the method proposed by Mosley and Tindale (1985), that states that the weight of the largest clast from sampled area is 5% from total weight of the sample, the clast with the largest diameter was identified. This was weighted to know the quantity of the sampled probe area. One square meter area was chosen as being representative for the entire section, out of which were collected surface and subsurface gravel. Some of granulometric fractions were sieved directly in the field using a set of sieves with holes having diameters according to the Wentworth scale. Sieving holes were of 64 mm (-6 phi), 32 mm (-5 phi), 16 mm (-4 phi), 8 mm (-3 phi). The clasts with diameters between 128 - 256 mm were measured and weighted using a special calliper. For the ones larger than 256 mm, more difficult to be weighted in the field, a diameter-weight scale conversion was used (Church et al., 1987; Ichim et al., 1992) built on the basis of the river clasts that were investigated by evaluating the weight of the biggest clasts on the basis of the *B* axis.

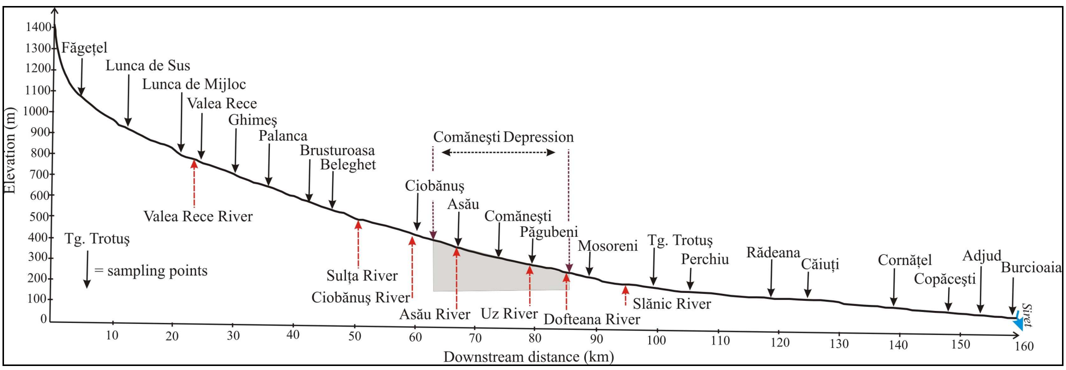

Figure 3. Sediment sample point distribution

After all the sampled material was weighted, from each class (piles of gravel were made on each class) sample clasts were taken from each class. It was randomly picked 100 clasts from classes of 16 - 32 mm and 32 - 64 mm for morphometrical and petrographical lab analysis. For the material smaller than 8 mm, sieving was continued in the lab using sieves of smaller diameter (6; 5; 2; 1; 0.5; 0.2; 0.1 mm). From the obtained results there were made assessments on differences from pavement and subpavement, on median diameter of river bed deposits, on the percentage of each granulometric fractions, clasts morphometry, lithology etc. Global samples (by summing pavement and subpavement samples) were separated in 14 granulometric classes, at 1 phi interval, on five dimensional steps, according with Wentworth scale (Church et al., 1987), as follows: *a) silt + clay* (< 4 *phi* or 0.063 mm); *b) sand* (between 4 *phi* or 0.063 mm and - 1 *phi* or 2 mm); *c) gravel* (between - 1 *phi* or 2 mm and - 6 *phi* or 64 mm); *d) cobble* (between - 6 *phi* or 64 mm and - 8 *phi* or 256 mm); *e) boulder* (over - 8 *phi* or 256 mm).

RESULTS AND DISCUSSION

MEDIAN DIAMETER OF BED MATERIAL

Regarding median diameter of Trotus River bed particles was noticed a general tendency of grain size reduction between the extreme two sampling points (from 38 mm at Făgețel, located at 7.1 km from headwaters, to 27 mm at Burcioaia, at 160 km distance from headwaters). Out of this general tendency, among main confluences or where Trotus valley becomes narrower, positive and negative deviations were recorded. Second polynomial function fitted at best general variation tendency for median diameter that helped to separate four sectors (figure 4). Therefore, upper course (downstream confluence with Valea Rece) average median diameter is around 62 mm, then down to Ciobănuş confluence to be around 92 mm. A slight reduction was reported downstream Ciobănuş confluence, but not of great importance for general features of river bed deposits from this short section between Ghimeş and Asău. Median diameter grow tendency in midcourse reach a maximum downstream Asău, after which a reduction is reported within Comăneşti Depression.

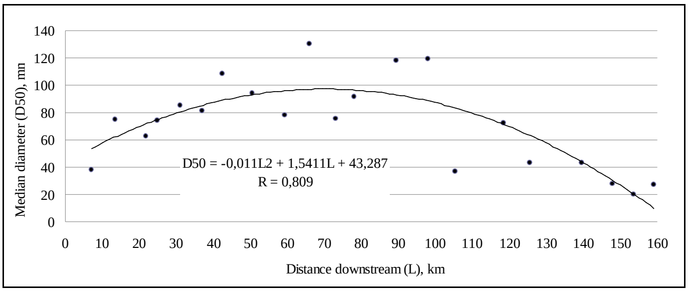

Figure 4. Downstream variation in the median diameter of the bed material

A second maximum is reported in the exit sector from Depression and entrance in subcarpathian area. Downstream Perchiu section median diameter variation records a constant reduction except a small increase after Tazlău confluence. Concluding, three sectors were separated that have the lowest median diameter (Făgețel - Valea Rece; inside Comăneşti Depression; lower course downstream Tazlău confluence) and another one in mid course, in which D_{50} values are, in average, above 90 mm. These high values for median diameter may be caused by sediments inputs from the short tributaries and high longitudinal slopes that deliver coarse material in Trotuş channel, on one hand, and slope feeding, on the other hand, as this sector is located in an area where is a valley narrowing at the entrance and exit from Comăneşti Depression. In this narrow areas slopes have an important role in feeding the river channel with coarse materials.

SURFACE BED MATERIAL GRANULOMETRIC SPECTRUM

This has a variation tendency that, in general, is close to perfect, with a downstream increase share for small gravel size, where boulders and cobbles are replaced by gravel. It cannot be said that is an ideal distribution, as the competition is just between cobbles and gravels. Usually, in river bed deposits classes of grain size particles becomes smaller and their share increase exponentially downstream. In this particular case grains from silt, clay and loam classes do not record any increase in share, on the contrary, their share display a reduction. This anomaly is present for certain clasts dimension in river bed deposits. For Trotuş River, boulder and cobble clasts are not specific, in particular, for upper course, but for midcourse sectors (figure 5).

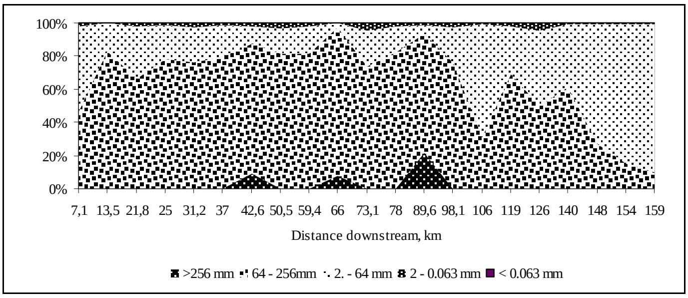

Figure 5. Downstream variation in the grain size distribution of the surface channel deposits

Cobbles (64 - 256 mm) is the granulometric class with the largest share within pavement. In certain sampling sections (especially in the midcourse) this class share is about or over 80% (Valea Rece, Palanca, Beleghet, Ciobănuş, Asău, Păgubeni, Târgu Trotuş). As in the case of median diameter, the function that better adjusts variation tendency for cobbles along longitudinal profile is the polynomial one, that identifies almost the same sectors, but with a small value for Comăneşti Depression. Cobble class has a constant increase after Făgețel sampling point (46.67%) until Trotuş entrance in Depression (Asău - 89.44%) and after a decrease of about 15% at Comăneşti, a new sharp increase is reported downstream Uz confluence (82.1%). In subcarpathian and plateau areas cobble class loses its significant chare, but a significant anlomaly is recorded downstream Trotuş confluence with Oituz, Caşin and Tazlău (figure 6).

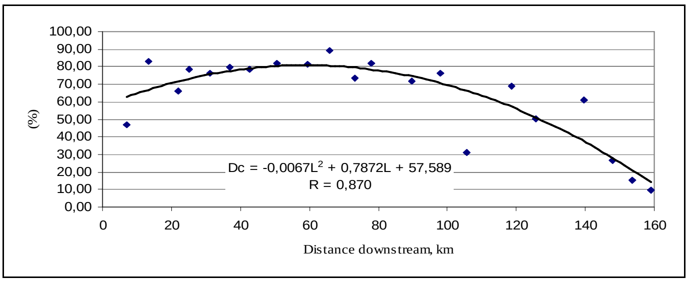

Figure 6. Cobble variation share within pavement along Trotuş River

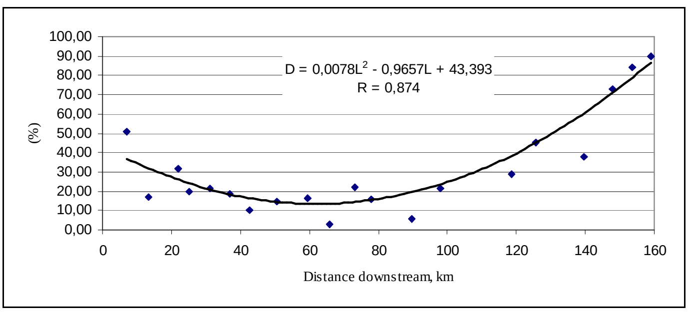

Figure 7. Gravel variation share within pavement along Trotuş River

Gravel class (2 - 64 mm) within pavement displays an inverse relation with cobble class along longitudinal profile. In the upper course has about 50% then decreases slowly downward to Asău (2.58%) and Mosoreni (5.66%). Outside mountain area, correlated with cobble share decrease, there is a constant increase for gravel clasts with a maximum value of 84.41% at Adjud (figure 7).

Blocks class (over 256 mm) are specific only to pavement in Trotuş midcourse, where the valley has many narrow sectors and slope materials feed directly the river channel.

Sand class (2 - 0.063 mm) has a small share of only 4% in Comăneşti Depression, upstream Uz confluence, which is explained by river slope reduction that allow *„graded"* gravel formation.

SUBPAVEMENT DEPOSITS GRANULOMETRIC SPECTRUM

This is characterized by gravel (2 - 64 mm) and sands (2 - 0.063 mm) dominance. In the sampling sections located downstream Tazlău confluence, these two classes can hold over 90% from river bed deposits granulometric spectrum (figure 8). Out of mountain area Trotuş has no important tributaries that can significantly influence river bed deposits granulometry. Also proximity slopes to river channel and river banks deliver only fine materials and the decrease of river slope determines a grain sorting that trigger downstream fining. Of course, in the river midcourse gravel and sand share decrease on cobble favour (50% at Ghimeş, 52.6% at Brusturoasa, 70% at Asău, 50% at Mosoreni and Târgu Trotuş). In this sector, tributaries and slopes constantly feed Trotuş river bed with much coarser materials that in most cases cannot be transported and were stocked and has undergone in situ processing.

From figures 8 and 9 it can be said that, finally, for sub-pavement deposits it can be reported an ideal distribution, which is disturbed in river midcourse, like all other river bed deposits qualitative characteristics. Second polynomial functions describe at best variation tendencies for gravel and cobble share within pavement deposits (i.e. certain gradual *„vanishing"* for clasts with larger size).

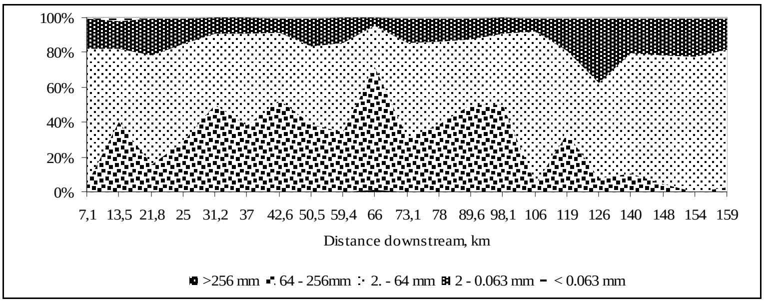

Figure 8. Subpavement granulometric spectrum

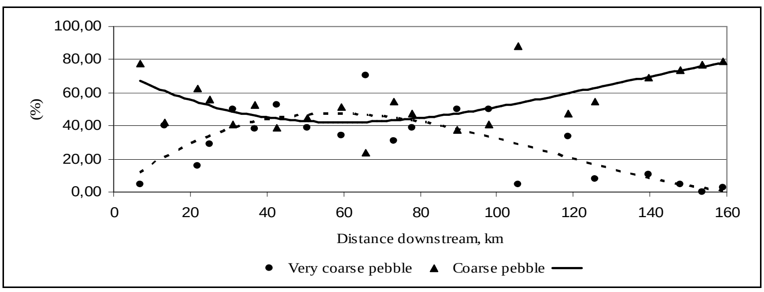

Figure 9. Cobble (64 - 256 mm) and gravel (2 - 64 mm) variation share within subpavement deposits, along Trotuş River

RIVER BED DEPOSITS GLOBAL GRANULOMETRIC SPECTRUM

River bed deposits global granulometric spectrum reflects both pavement and sub-pavement characteristics. The dominance of cobbles and boulders in pavement materials gibes Trotuş deposits a coarse facies, from headwaters to outflow, while sub-pavement sands make some *„enhancement"* of materials sizes, as fine materials share are increasing downstream (figure 10).

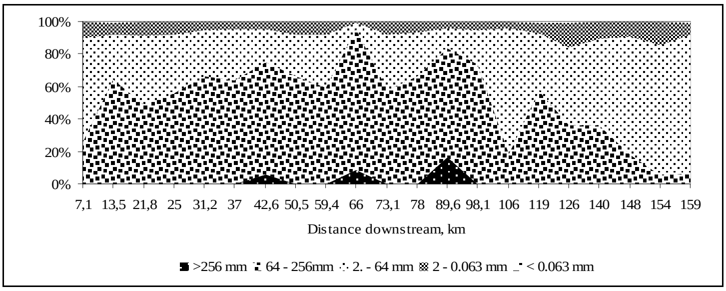

Figure 10. Trotuş River bed deposits global granulometric spectrum

In spite of this, sands barely succeed to have over 10% in several sampling sections, while silt and clay have less than 1%. In this way, cobbles and gravels, from most sampling points, hold toghether over 90% from granulometric spectrum, which allow us to put Trotuş River in the category of gravel bed river.

TROTUŞ RIVER BANKS SEDIMENTS GRANULOMETRY

River banks sediments (sampled in 17 out of 21 cross sections for floodplain geomorphological complex) have median diameter between 0.04 - 0.35 mm (figure 11).

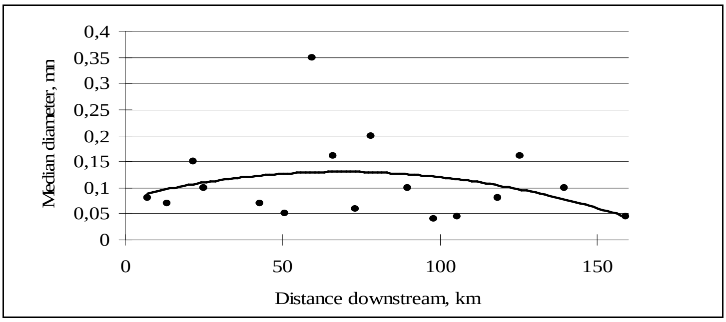

Figure 11. Trotuş River banks deposits median diameter variation

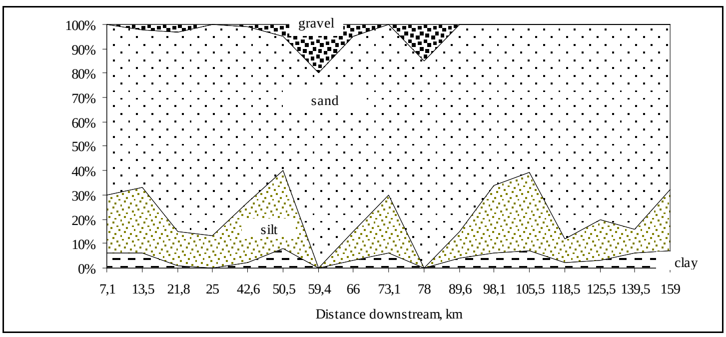

Figure 12. Trotuş River banks deposits granulometric variation

Gravels are reported sporadically, as lenses that indicate either former river channels, or some influences made of some tributaries (Ciobănuş, Slănic).

Along river longitudinal profile, confluences and local petrographic facies disturb the tendency of granulometric size decrease. Most important influences are reported at Ciobănuş and Slănic confluences.

Trotuş River banks are, in general, sandy (in most cases over 70%), but between confluences is was reported an increase of silt and clay share (40% at Beleghet and Perchiu, 32% at Burcioaia, 30% at Comăneşti) (figure 12).

MODALITY OF THE GRAIN SIZE DISTRIBUTIONS

Granulometric distribution can be analysed by graphics interpretation for each sampling point along the river. In this way, from graphics shape it can be assessed if granulometric distribution is *unimodal*, which means that the material is quasi-unifom regarding particle size (in this case can be composed only of gravel cobble blocks, or only by sand and other fine sediments) or *bimodal* (and in some cases poly-modal) when are present gravel and sand deposits. Linked with composition share of the two most important classes to form mixes it is considered that the ideal mix would be 70% gravel and 30% sand, which is identical with the ones proposed by Ibbeken (1983) and Ibbeken and Schleyer (1991) for river bed deposits in their lower course for Calabrian rivers. Rădoane et al. (2001, 2006, 2008) indicate that, for the Romanian studied rivers, bimodality is determined by under 25% for 1 - 20 mm fraction, which is considered a fundamental element in river deposits distribution formation.

For Trotuş River the modality of the grain size distribution was analysed separately for surface, subsurface and for the global sample. Based on individual share for cobbles, gravels, sands and silty-clayey particles that compose river bed deposits, histogram distributions were calculated. Based on these graphs was settled that the distribution is unimodal (was noted as modality 1) or bimodal (modality 2). From figure 13 histograms one can notice that:

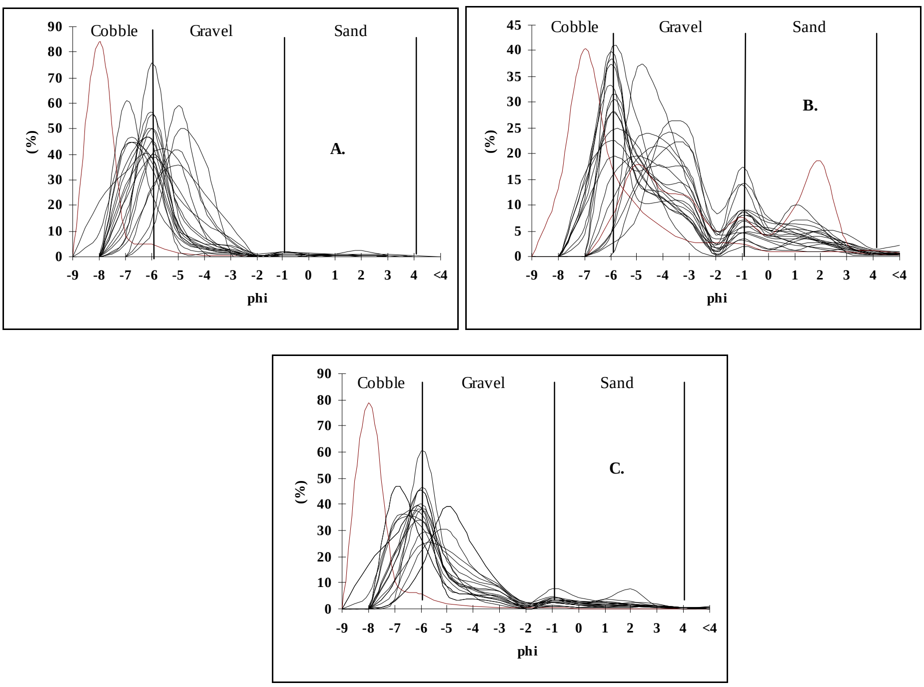

Figure 13. Histogams of the grain size distribution along the Trotus River, swowing contribution of the subsurface sediments to bimodality: **A**. surface bed sample; **B**. subsurface sample; **C**. global sample.

- *bimodality has a very slight increase downstream Trotuş River* and has a correlation coefficient of 0.222. For the rivers of which river bed deposits are made of materials with very different sizes, was reported, as a general rule, that for the upper course is specific a unimodal distribution, and in lower course a bimodal distribution (Ibbeken şi Schleyer, 1991; Kodama, 1992; Sambrook Smith, 1996; Ichim et al., 1998; Rădoane et al., 2001, 2006, 2008). Bimodal distribution is reported in only one section (Căiuți) and only for sub-pavement and global sample;

- *bimodality has an inverse relationship with Trotuş River channel slope*. As the river slope reduces itself (within Comăneşti Depression and after Trotuş exits from mountain area) a weak bimodal distribution was reported;

- *bimodality has an indirect relationship with median diameter variation* for river bed deposits. For Trotuş River bimodality is manifest together with D_{50} decrease, explained by share reduction for cobble and gravel and increased share for fine sediments (sand and silt);

- *bimodality is in direct relationship with the percentage* of sand, gravel and 1 - 20 mm fraction;

- *bimodality of granulometric distribution is different from the pavement and sub-pavement samples.* Trotuş granulometric distribution for pavement deposits is exclusively unimodal. Sub-pavement samples, along with an increase of fine sediments display a slight bimodal tendency.

CONCLUSIONS

The obtained results have the same consistency with the ones reported by other authors that studied different Romanian rivers (Ichim et al., 1998, Maria Rădoane et al., 2001, 2006, 2008). Their main conclusion, and verified on Trotuş River, was that *large geological and geomorphological units that east Carpathian rivers cross them diagonally has as a result certain granulometric clustering along river drainage channel.*

This phenomenon was well emphasized by using a triangulated diagram which display a clear discrimination among cobble (> -6 phi), gravel (-6 phi -1 phi), sand (-1 phi -4 phi), silt and clay (< 4 phi). From figure 14 some conclusions can be drawn:

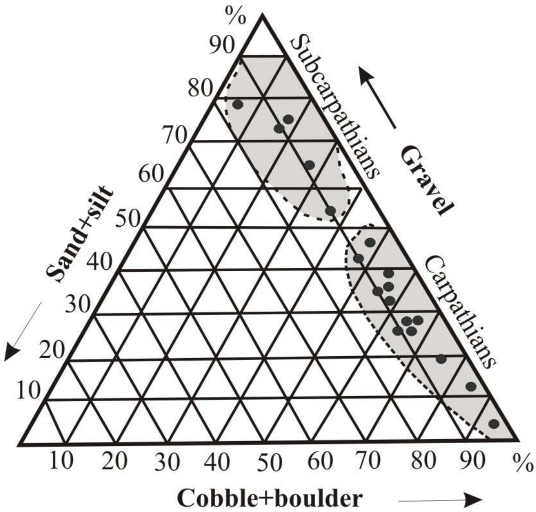

Figure 14. The change of Trotuş granulometric spectrum in relationship with geomorphological units

- *carpathian area* groups the sampling sections in which cobbles and boulders have a large share in river bed sediments composition of about 60 - 80%. The cluster from Carpathian area is well shaped in the right corner;

- *subcarpathian area* is composed by sections where dominates gravel, and the cluster is located in the upper center part of the diagram.

River bed materials orting was done in a long competition process between sorting and sediment abrasion during fluvial transport. Fluvial processing rock resistance, river channel slope and the strength of fluvial transport individualized each river (Ichim et al., 1998, Maria Rădoane et al., 2001, 2006, 2008).

ACKNOWLEDGMENT

This work was supported by CNCSIS - UEFISCSU, project PNII - IDEI number 436/2007.

REFERENCES

Attal M., Lavé J. (2006), Changes *of bedload characteristics along the Marsyandi River (central Nepal): Implications for understanding hillslope sediment supply, sediment load evolution along fluvial networks, and denudation in active orogenic belts.* In Willett, S.D., Hovius, N., Brandon, M.T., and Fisher, D., eds., Tectonics, Climate, and Landscape Evolution: Geological Society of America Special Paper 398, 143 - 171;

Benda L. E. (1980), *The influence of debris flows on channels and valley floors in the Oregon Coast Range, U.S.A. Earth Surf. Process.* Landforms, 15, 457- 466;

Bradley W. C. (1970), *Effect of weathering on abrasion of granitic gravel, Colorado River (Texas).* Geol. Soc. Am. Bull., 81, 61- 80;

Brummer C. J., Montgomery D. R. (2003), *Downstream coarsening in headwater channels.* Water Resour. Res., 39, 10, 1294, 14 p;

Church M.A., McLean D.G., Wolcott J.F. (1987). *River bed gravels: sampling and analysis.* In Sediment Transport in Gravel-Bed Rivers, Thorne, CR, Bathurst, JC, Hey RD (eds). Wiley: Chichester; 43 - 79;

Church M. (2002), *Geomorphic thresholds in riverine landscapes.* Freshwater Biol., 47, 541 - 557;

Desloges J. R. (1990), *Sources for valley-fill alluvial sediments: Bella Coola river basin, British Columbia.* Canadian Geographer , 34, 2, 98 - 109;

Farrow J. W., Sklar L. S. (2005), *Lithologic influence and experimental variability in gravel abrasion. Implications for predicting rates of downstream fining of river bed sediments.* Geological Society of America, 37, 4, 40, 101st Annual Meeting (April 29 - May 1, 2005) San Jose, California;

Ferguson R., Hoey T., Wathen S.J., Werritty A. (1996), *Field evidence for rapid downstream fining of river gravels through selective transport.* Geology, 24, 2, 179 - 182;

Gasparini N. M., Tucker G. E., Bras R. L. (1999), *Downstream fining through selective particle sorting in an equilibrium drainage network.* Geology, 27, 12, 1079 - 1082;

Gomez B., Rosser B. J., Peacock D. H., Hicks D. M., Palmer J. A. (2001), *Downstream fining in a rapidly aggrading gravel bed river.* Water Resour. Res., 37 (6), 1813 - 1823;

Grant G. E., Swanson F. J. (1995), *Morphology and processes of valley floors in mountain streams, western Cascades, Oregon*. Natural and Anthropogenic Influences in Fluvial Geomorphology: The Wolman Volume, Geophys.Monogr. Ser, 89, edited by John E. Costa et al., 83 - 101, AGU, Washington, D. C;

Grimm M. M., Wohl E. E., Jarrett R. D. (1995), *Coarse-sediment distribution as evidence of an elevation limit for flash flooding, Bear Creek, Colorado*. Geomorphology, 14, 199 - 210;

Heller P. L., Beland P. E., Humphrey N. F., Konrad S. K., Lynds R. M., McMillan M. E., Valentine K. E., Widman Y. A., Furbish D. J. (2001), *Paradox of downstream fining and weathering-rind formation in the lower Hoh River, Olympic Peninsula, Washington*. Geology, 29, 971- 974;

Hoey T. B., Bluck B. J. (1999), *Identifying the controls over downstream fining of river gravels*. Journal of Sedimentary Research, 69, 1, 40 - 50;

Ibbeken H. (1983), *Jointed source rock and fluvial gravels controlled by Rosin's law: a grain size study in Calabria, South Italy.* Journal of Sedimentary Petrology, 53, 1213 - 1231;

Ibbeken H., Schleyer R. (1991*), Source and sediment. A case study of provenance and mass balance at an active plate margin (Calabria, Southern Italy).* Springer Verlag, Berlin, 285 p;

Ichim I., Radoane Maria, Radoane N. (1992), *Eşantionarea depozitelor de albie formate din pietrişuri şi bolovănişuri. Metode şi analiză.* Lucrările celui de-al IV-lea Simpozion PEA, Piatra Neamț, 30 - 47;

Ichim I., Rădoane Maria, Rădoane N., Grasu C., Miclăuş Crina (1998), *Dinamica sedimentelor. Aplicație la râul Putna-Vrancea*. Editura Tehnică, Bucureşti, 191 p;

Knighton A. D. (1980), *Longitudinal changes in size and sorting of stream-bed material in four English rivers*. Geological Society of America Bulletin, 91, 55 - 62;

Kodama Y. (1992), *Effect of abrasion on downstream gravel-size reduction in the Watarase River, Japan: Field work and laboratory experiments.* Environmental Res. Center Papers, 15, 88p;

Kodama, Y. (1994), *Downstream Changes in the Lithology and Grain Size of Fluvial Gravels, the Watarase River, Japan: Evidence of the Role of Abrasion in Downstream Fining.* Journal of Sedimentary Research, 64, 1a, 68 - 75;

Krumbein W. C. (1941), *The effects of abrasion on the size, shape, and roundness of rock fragments.* J. Geology, 64, 336 - 368;

Lambert B. C., Jones J. A., Grant G. E. (1996), *The transition from hillslope to fluvial process controls on stream bed particle size in a fifth order mountain stream*. Eos Trans. AGU, 77, 46, 250 - 251;

Lindsey D. A., Langera W. H., Van Gosena B. S. (2007), *Using pebble lithology and roundness to interpret gravel provenance*

in piedmont fluvial systems of the Rocky Mountains, USA. Sedimentary Geology, 199, 3 - 4, 223 - 232;
Malarz R. (2005), *Effects of flood abrasion of the Carpathian alluvial gravels*, Catena, 64, 1 - 26;
Miao X., Lindsey D. A., Lai Z., Liu X. (2010), *Contingency table analysis of pebble lithology and roundness: A case study of Huangshui River, China and comparison to rivers in the Rocky Mountains, USA.* Sedimentary Geology, 224, 1 - 4, 49 - 53;
Mikoŝ M. (1994), *The downstream fining of gravel-bed sediments in the Alpine Rhine River.* Earth and Environmental Science. Dynamics and Geomorphology of Mountain Rivers. Lecture Notes in Earth Sciences, 52, 93 - 108;
Miller J. P. (1958), *High mountain streams: Effects of geology on channel characteristics and bed material*. N. M. Inst. of Mining and Technol., Socorro, 53 p;
Montgomery D. R., M. S. Panfil M. S., Hayes S. K. (1999), *Channel-bed mobility response to extreme sediment loading at Mount Pinatubo*. Geology, 27, 271 - 274;
Mosley N. P., Tindale D. S. (1985), Sediment variability and bed material sampling in gravel-bed rivers. Earth Surf. Process. Landforms, 4, 465 - 483,
Moussavi-Harami R., Mahboubi A., Khanehbad M. (2004), *Analysis of controls on downstream fining along three gravel-bed rivers in the Band-e-Golestan drainage basin NE Iran.* Geomorphology, 61, 143 - 153;
Mureșan A. (2009), *Relationship between the bed material size and the amount of metamorphic and volcanic rocks in the hydrographic basins regarding two rivers from Maramureş Mountains (Eastern Carpathians-Romania).* Carpathian Journal of Earth and Environmental Sciences, 2009, 4, 1, 19 - 29;
Paola C., Parker G., Seal R., Sinha S. K., Southard J. B., Wilcock P. R. (1992), *Downstream fining by selective deposition in a laboratory flume*, Science, 258, 1757 - 1760;
Parker G. (1991a), *Downstream variation of grain size in gravel rivers: Abrasion versus selective sorting*. Fluvial Hydraulics of Mountain Regions, Lecture Notes in Earth Sciences, 37, 345-360;
Parker G. (1991b), *Selective sorting and abrasion of river gravel. I: Theory*. J. Hydraul. Eng., 117, 131 - 149;
Parker G. (1991c), *Selective sorting and abrasion of river gravel. II: Applications*. J. Hydraul. Eng., 117, 150 - 171,
Pike A. S., Scatena F. N., Wohl E. E. (2010), *Lithological and fluvial controls on the geomorphology of tropical montane stream channels in Puerto Rico*. Earth Surf. Process. Landforms, 35, 12, 1402 - 1417;
Pizzuto J. E. (1995), *Downstream Fining in a Network of Gravel-Bedded Rivers*. Water Resour. Res. 31, 3, 753 - 759;
Rădoane Maria, Rădoane N., Dumitriu D., Miclaus Crina (2006), *Bimodality origin of fluvial bed sediments. Study case: East Carpathians Rivers*. Carpth. J. of Earth and Environmental Sciences, Vol. I, No. 2, 13 - 38;
Rădoane Maria, Rădoane N., Ichim I., Dumitriu D., Miclăuş Crina (2001), *Granulometria depozitelor de albie în lungul unor râuri carpatice*. Revista Geografică, t. VIII, 70 - 77;
Rădoane Maria, Rădoane N., Dumitriu D., Miclaus Crina (2008), *Downstream variation in bed sediment size along the East Carpathian rivers: Evidence of the role of sediment sources*. Earth. Surf. Process. Landforms, 33, 674 - 694;
Rengers F., Wohl Ellen (2007), *Trends of grain sizes on gravel bars in the Rio Chagres, Panama*. Geomorphology, 83, 282 - 293,
Rice S. (1998), *Which tributaries disrupt downstream fining along gravel-bed rivers ?* Geomorphology, 22, 39 - 56;
Rice S. (1999), *The nature and controls on downstream fining within sedimentary links*. Journal of Sedimentary Research, 69, 1, 32-39;
Rice S., Church M. (1996), *Bed material texture on low order streams in the Queen Charlotte Islands*, British Columbia. Earth Surf. Processes Landforms, 21, 1 - 18;
Sambrook Smith G. (1996), *Bimodal fluvial bed sediments: origin, spatial extent and processes*. Progress in Physical Geography, 20, 4, 402 - 417;
Schumm S. A., Stevens M. A. (1973), *Abrasion in place: A mechanism for rounding and size reduction of coarse sediments in rivers*. Geomorphology, 1, 37 - 40;
Stanley J., So V. L. (2006), *Inconsistent grain roundness and sphericity trends and the valley wall influx factor: between Alpine source and lake shore, SE France,* Journal of Coastal Research, 22, 3, 547 - 560;
Sternberg H. (1875), *Untersuchungen über längen-und querprofil geschiebeführender flüss. Zeitschrift für Bauwesen*, 25, 483 - 506;
Venditti J. G., Dietrich W. E., Nelson P. A., Wydzga M. A., Fadde J., Sklar L. (2010), *Effect of sediment pulse grain size on sediment transport rates and bed mobility in gravel bed rivers.* J. Geophys. Res., 115, 19 p;
Wentworth C. K., (1922), *A scale of grade and class terms for clastic sediments*. J. Geology, 30, 377 - 392;
Wilcock P. R. (1997), *The components of fractional transport rate*. Water Resour. Res., 33, 247 – 258.

Submitted: May 12, 2011 | Revised: July 18, 2011 | Accepted and published online August 27, 2011