THE PROXIMAL, SHEET-FLOOD FACIES OF THE CÂNDEŞTI BEDS ALLUVIAL FAN (PRAHOVA RIVER, ROMANIA)

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Abstract. This sedimentological investigation of the Cândeşti Beds (Pleistocene) was carried out on the sediments cropping out on the right bank of the Prahova River (Romania). The study reveals the main textural and sedimentary-structural characteristics of the gravelly deposits and their sedimentogenetic significance. The gravels are the proximal facies, with un-channelized flow and accumulation of grain-supported sediments, of the complex Cândeşti Beds alluvial fan.

Key words: Cândeşti gravels, Early Quaternary, alluvial fan, sheet-flow, sedimentary environment.

1. INTRODUCTION

Goal of the paper. The Cândeşti Beds are one of the most extensive geological formations în Romania, but they have never before been sedimentogenetically investigated. The study presented in this paper offers data necessary to contour a picture of the sedimentary environment responsible for the accumulation of the gravels, the proximal facies of the Cândeşti Beds. This would be a first of the many local scale and detailed sedimentologic approaches necessary to disclose all the aspects of in the very large area of the Cândeşti gravels.

Geological background. The "Cândeşti Beds" denomination was coined by Mrazec şi Teisseyre (1901) for the gravels with the stratotype near the Cândeşti locality, north of Buzău Town. Subsequently Popescu-Voiteşti (1940) favored the stratotype to another Cândeşti locality, north of Târgovişte town. With reference to the deposits cropping out in the sub-Carpathian zone, in the Romanian geological literature other formation names have been also used, mostly the "Cândeşti Gravels" appellation.

A continental fauna of fresh-water gastropods and mammals was described from the Cândeşti Gravels (Motaş, 1956; Damian , 2003 and herein references).

Initially, the Cândeşti Beds were considered of Levantine age (presently renamed as Romanian age) (Protescu, 1932 and herein references). Popescu-Voiteşti (1940) assigned this formation to Late Levantine-Early Quaternary. In the opinion of Liteanu (1961) and Liteanu, Ghenea (1966) the Cândeşti Beds have been accumulated during the Early Quaternary (Villafranchian).

The geological formation of the Cândeşti Beds is developed at a very large scale. The surface extent of the Cândeşti Beds along the mountain border is from the Eastern Carpathians bending to the western part of the Southern Carpathians. In the sub-Carpathian zone the Cândeşti Beds reach hundreds or even several thousand meters in thickness (Damian, 2003). Southward, away from the Carpathian source area, the Cândeşti Beds are thinning out significantly and cease to be, in the area corresponding to the middle part of the Danubian Plain (Liteanu, 1961). The gravels occur only as the northern, sub-Carpathian facies. Along with the thickness decline, the gravelly facies turns into a sandy facies and further on becomes clayey-fine sandy (Liteanu, 1961).

Study area. For the buildup of the first sedimentogenetic information on the Cândeşti Gravels, the investigation was conducted within a limited area with clear outcrops. This area is located on the Prahova River, several kilometers south of

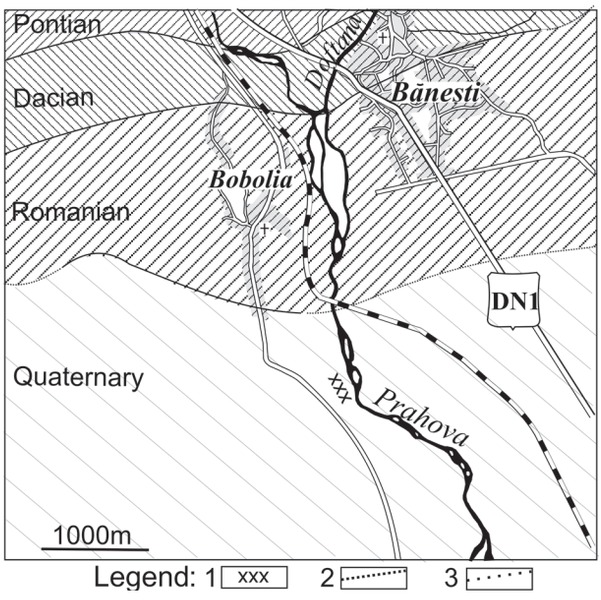


Fig. 1. Location of the investigated gravels (Cândeşti Beds, Early Quaternary), on the right bank of Prahova River, downstream of Bobolia locality. *Legend*: **1**. Investigated outcrops. **2**. Stratigraphic boundary. **3**. Stratigraphic boundary extended beneath recent deposits.

Fig. 2. General aspect of the Cândeşti Beds gravels. As the intercalations of contrasting grain-size sediments are rare, from a distance, the gravels appear like a homogeneous deposit. Prahova River, 500 m downstream of Bobolia locality.

Câmpina town. The Cândeşti gravels crop out on the right bank of Prahova River, 500 m downstream the locality Bobolia (Fig. 1).

2. METHODOLOGY

The investigation of the pebbles textural features was carried out in section, on vertical plane surfaces naturally prepared in the outcrop. Detailed photographs were made at the selected surfaces, downloaded in the computer and the outlines of the pebbles and the larger sand grains were traced. Once drawn, the pebbles outlines were distributed into established classes and the dominant textural characteristics were revealed. Only the pebbles coarser than 4 mm in diameter have been used for the roundness and form analysis. The sandy material finer than 0,5 mm was considered matrix. The matrix and clasts intersects measured along linear sections traced on the detailed outcrop picture, were used to compute the matrix/clasts frequency.

Tracing the grains outlines met with difficulties, due to the small irregularities of the outcrop surface. Some of the pebbles outlines were not entirely visible, due to pebbles partly covered by matrix, or to pebbles appearing in the picture as partially superposed. Consequently, the results of the grain-size or grain morphometry analysis are regarded not as accurate numerical data, but as qualitative appreciation of the main trends.

Power visual comparison chart and Zingg diagram (Blatt *et al.*, 1980) were used to appreciate the roundness degree and the shape of the pebbles.

The investigated gravels of the Cândeşti Beds are almost devoid of finer-grained intercalations, generating difficulties to fully visualize the sedimentary structure. Consequently, the delineation of the large-scale sedimentary structures was made again on outcrop pictures. The visible structure elements have been traced on the photographic image. The entire set of the structure elements was interpreted to point out larger, genetically distinct sedimentary bodies.

3. PRESENTATION OF DATA. CÂNDEŞTI GRAVELS FACIES

3.1. Lithology

Gravel-sand-clay. In the study area the Cândeşti Beds deposits consist almost entirely of gravels. The alternative formation name Cândeşti Gravels can be rightly applied to such deposits.

Observed from a certain distance, the Cândeşti Beds cropping out in the Prahova River area appear as homogeneous gravel deposits, with hardly visible bedding (Fig. 2). The detailed examination points out the presence of sandy intercalations, sometimes more frequent and larger (Fig. 3A), other times scarce and thinner (Fig. 3B). The dominant dimensions of the sandy intercalations are 10-50 cm in thickness and 0,5-5 m lengthways.

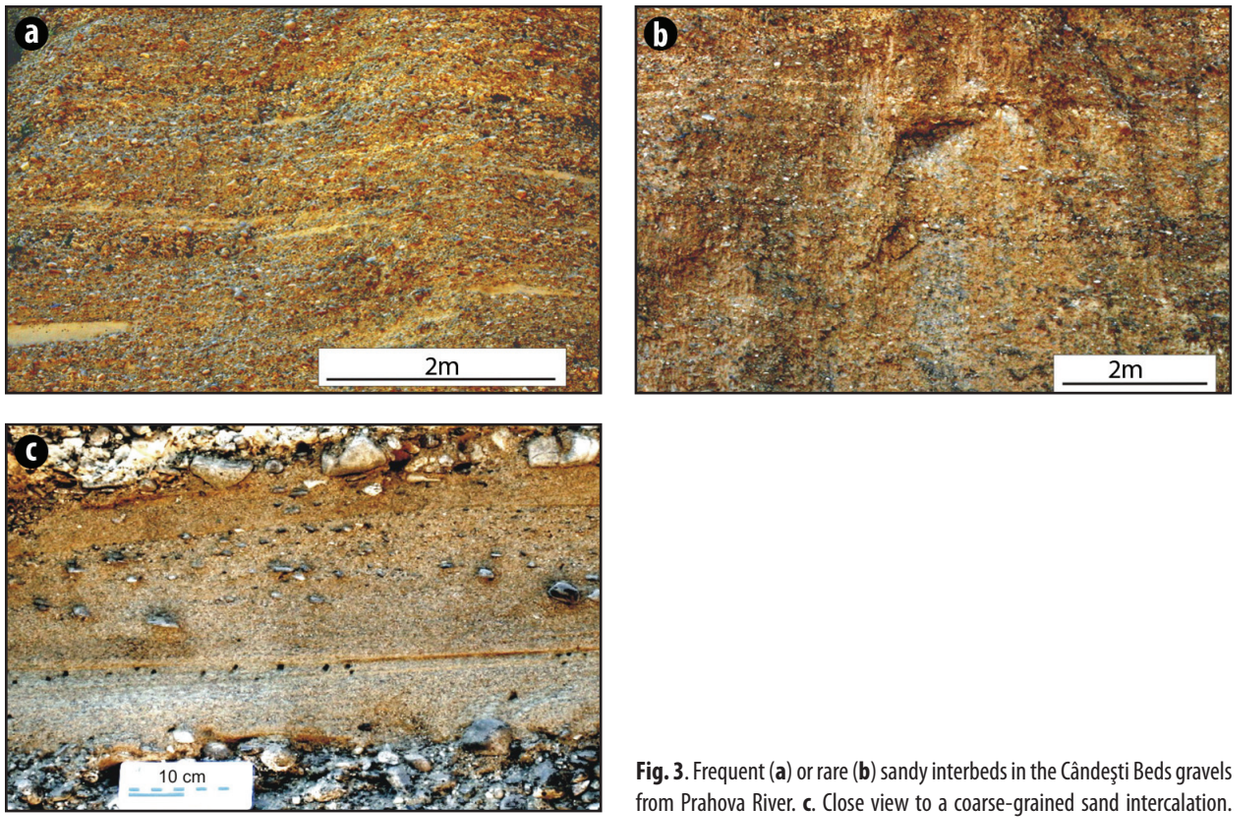


Fig. 3. Frequent (**a**) or rare (**b**) sandy interbeds in the Cândeşti Beds gravels from Prahova River. **c**. Close view to a coarse-grained sand intercalation.

The intercalated sand is coarse-grained, with small pebbles (2 – 5 cm) along the lamination internal structure (Fig. 3C). On the whole, the sandy intercalations make up from 1-3% to 8-10% of the gravelly deposit.

An important feature of the Cândeşti Beds in the investigated location is the complete absence of clay intercalations.

The brown silt marker. A bed of brown silt appears intercalated in the Cândeşti Beds gravel from the Prahova River (Fig. 4A). With 20 to 25 cm thickness, the brown silts extend laterally uninterrupted for 50-75 m. This is the maximal extent visible in the investigated outcrops, where the bedding shows a slight angle southward dip (about 10°). The brownish silt may represent a local marker in the investigated Cândeşti Beds succession.

Evolving gradually from the underlying gravel, in the lower part the brownish silt comes out as a matrix among the pebbles and becomes entirely siltic toward the top (Fig. 4B). The silt limit with the overlying gravel is sharp, largely undulated. Locally the silt-gravel boundary is convex-up, possibly erosional (Fig. 4C).

A yellowish silt, with rare embedded pebbles (Fig. 4D) has been noticed above the brown silt, showing lens-like development.

3.2. Textural Features

Pebbles grain-size. The dominance of the large pebble gravel facies (Fig. 5A) over the units with fine-grained pebbles (Fig. 5B) is obvious in the Prahova River outcrops. The analysis, based on the photographic image processing, indicates the 16-32 mm class as the limit of the grain-size field of the pebbles (Fig. 5). This classifies the investigated deposit as middle-sized gravel, according to the Wentworth grain-size scale. The modal grain-size class is either 8-16 mm or 16-32 mm (Fig. 6).

Taking into consideration the large grain-size domain of the investigated gravels, extending over at least seven grain-size classes, the poor grain-size sorting of the gravels is evident.

Sandy matrix. The gravel elements of the Prahova River Cândeşti Beds are bound by a coarse-grained sandy matrix, moderately indurated. The matrix represents 16% to 48,5% of the gravels volume (mean value 26.5%, out of six measurements).

The matrix is filling intergranular spaces of various sizes, from millimeter pores to centimeter wide spaces (Figs 6 and 10).

Besides the predominant sandy matrix, in the investigated gravels also occurs a silty-clayey yellowish matrix. The silty matrix is locally distributed (Fig. 7) or is selectively extending along lamination structures (Fig. 15), rendering evident the sedimentary structure.

Pebbles roundness. The pebbles in the gravels cropping out along the Prahova River show an advanced roundness condition. The rounded pebbles equally fit in the rounded

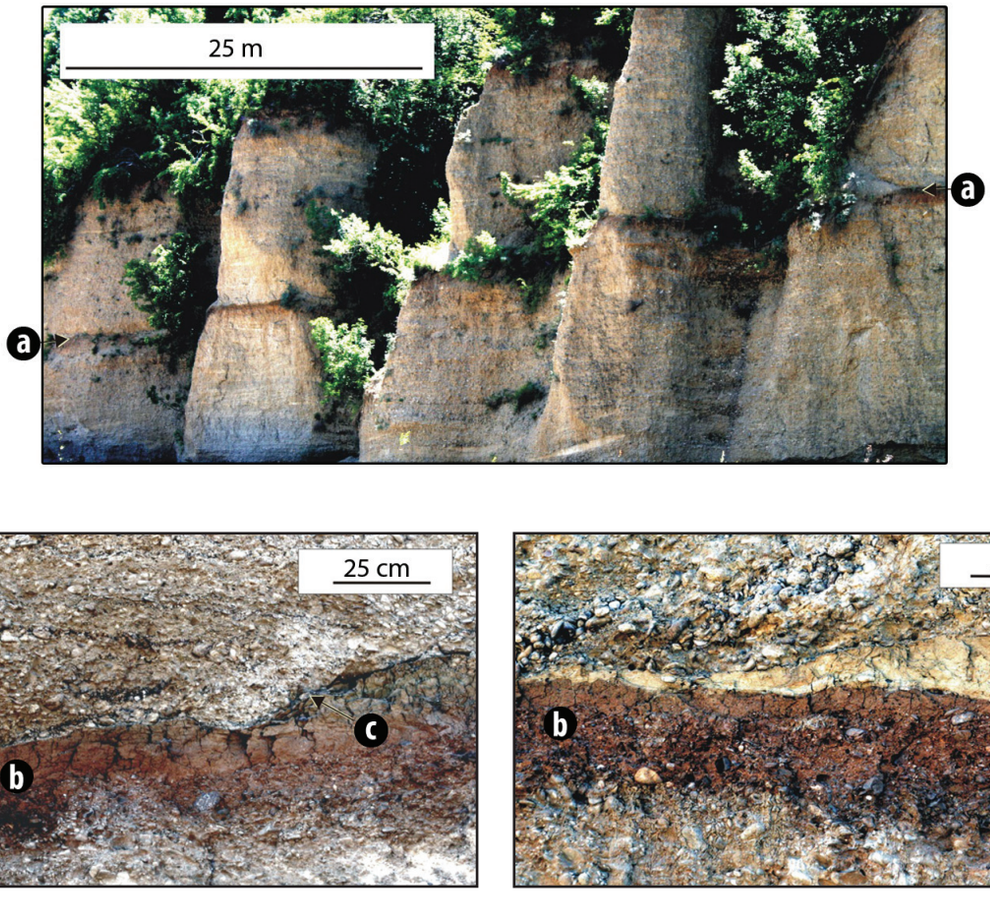


Fig. 4. Brown silt bed (**a**) with significant lateral extension in the Cândeşti Beds gravels. **b**. Brown silt evolving gradually from the underlying gravel deposit. **c**. Erosion surface at the top of the silt bed. **d**. Lens-like yellowish silt with embedded gravels, overlying the brown silt bed. Prahova River, 500 m downstream of Bobolia locality.

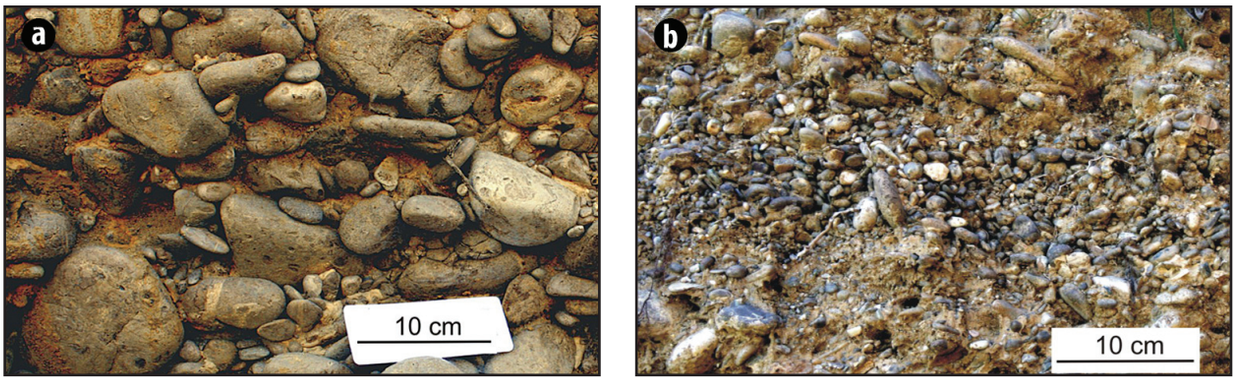


Fig. 5. The grain-size variation range (from **a** to **b**) of the Cândeşti Beds gravels, cropping out on Prahova River. The two images are at the same scale, in order to permit the direct comparison.

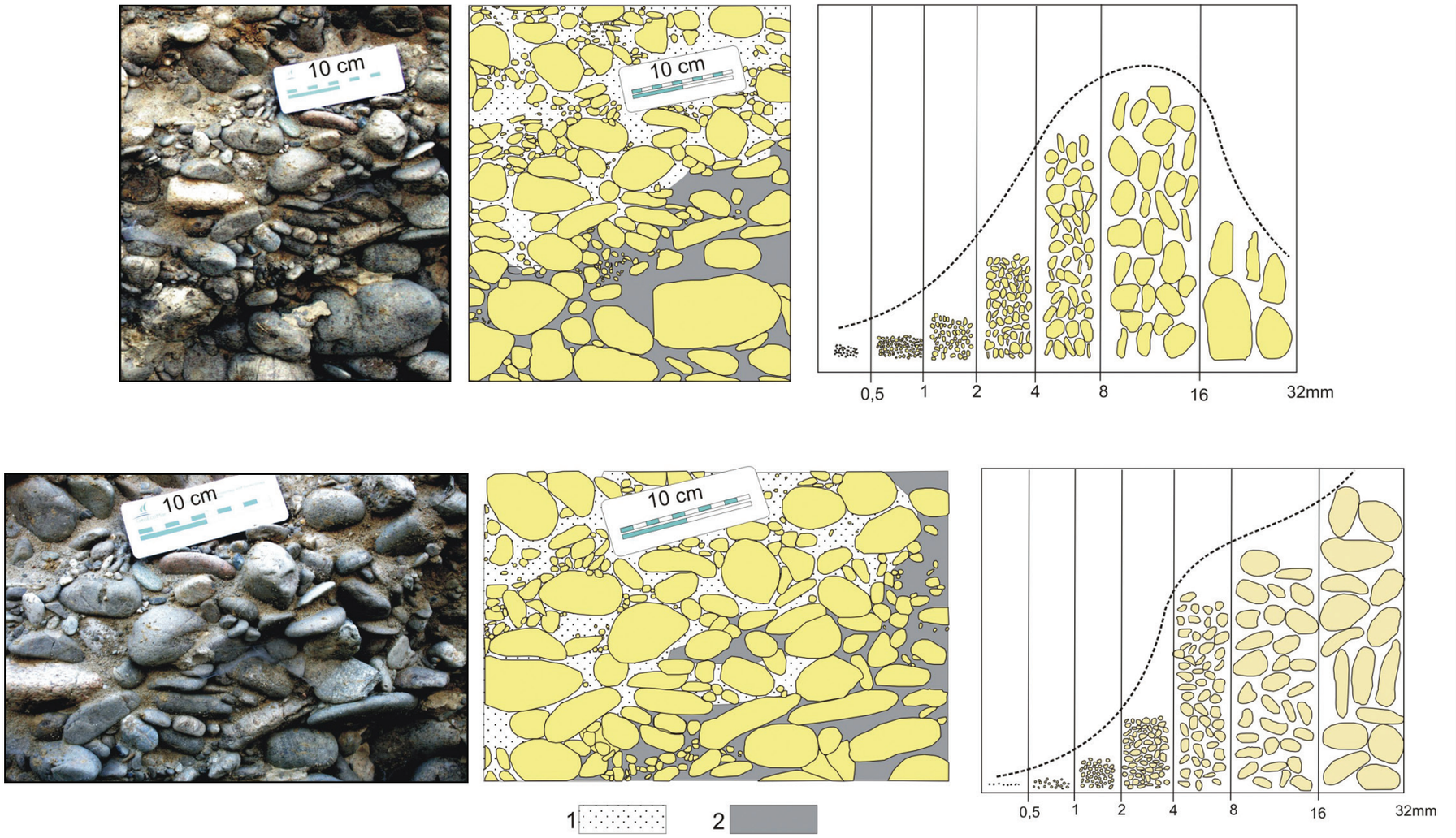


Fig. 6. Grain-size distribution of the Cândeşti Beds gravels. The estimation of the grain-size (also roundness and shape) characteristics is based upon the examination of the pebbles (and larger sand grains) outlines, traced on outcrop pictures. The graph showing the distribution on dimensional classes, expresses only the frequency trend. *Legend*: **1.** Sandy matrix. **2**. Unclear fill of the intergranular space.

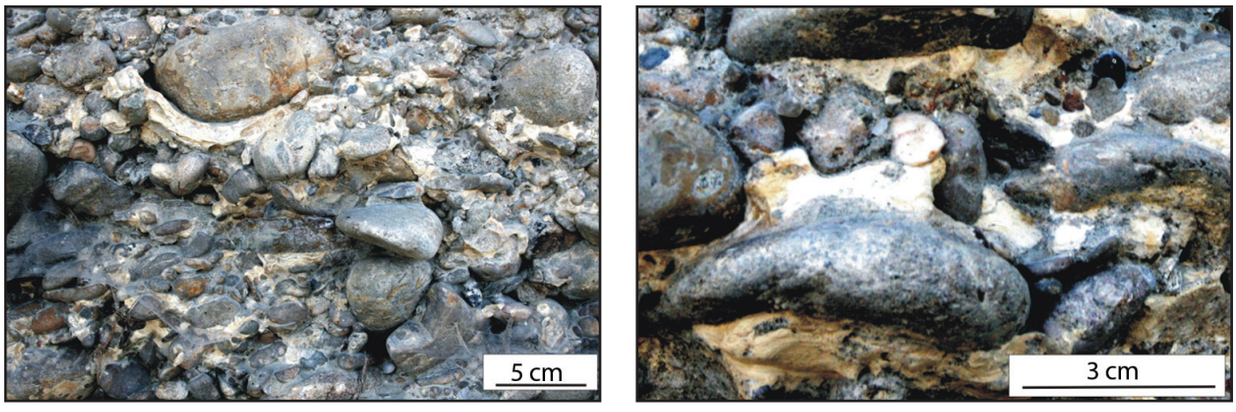


Fig. 7. Silty matrix in the Cândeşti Beds gravels cropping out on the right bank of Prahova River.

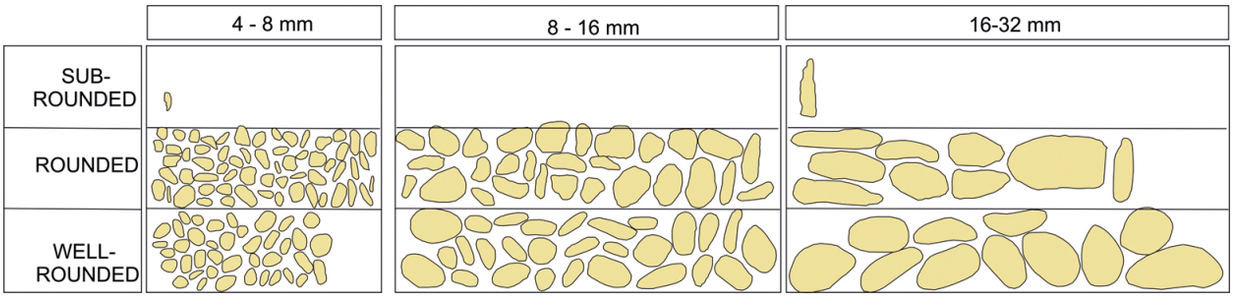


Fig. 8. Roundness *vs* grain-size in the Cândeşti Beds gravels. Outcrops on the right bank of Prahova River, downstream of Bobolia locality.

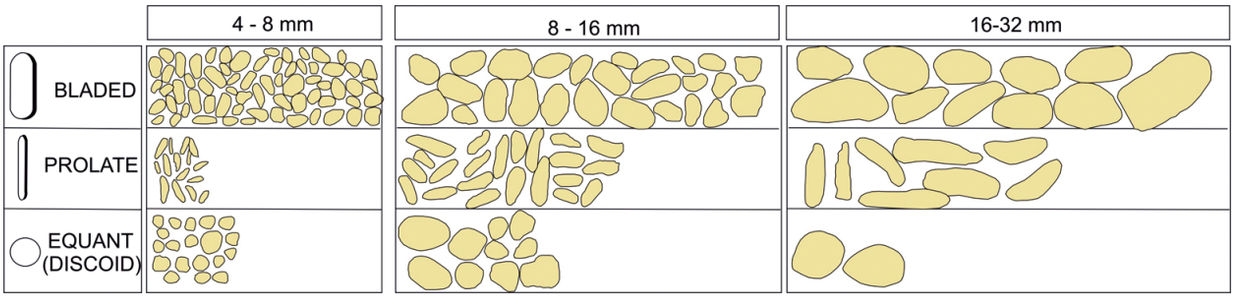


Fig. 9. Pebbles form in the Cândeşti Beds. Prahova River, right bank, 500 m downstream of Bobolia locality.

and well rounded classes (Fig. 8). The largest pebbles (16-32 mm) are slightly more frequent in the well-rounded class, while the smaller ones belong a little more frequently to the rounded class. Few pebbles are subrounded; the less advanced roundness is due to their siliceous nature (Fig. 13C).

Pebbles form. The relation between the three dimensions determine the equidimensional, elongated or flat of a pebble. To explore the shape distribution of the pebbles in the Cândeşti Beds gravels, the pebbles outlines traced on photographic outcrop images have been distributed into the form categories defined by Zingg (in Blatt *et al.*, 1980). Since our section investigation cannot differentiate between equant and discoid/oblate, these form types were introduced into the same class.

The textural analysis indicated the bladed pebbles are the most common (Fig. 9). In decreasing order of frequency are the prolate and equidimensional (equant and oblate) pebbles. The order of frequency of the equant/oblate and prolate forms is reversed for the smaller (4-8 mm) pebbles.

Packing. The arrangement of the pebbles in the Cândeşti Beds gravels was examined in section. As results from the processing of the outcrop pictures (Figs 6 and 10), clast supported gravel is typical of the investigated Cândeşti Beds. Most of the times, a pebble is supported by two or three other pebbles. The large pebbles surrounded by small pebbles can show many more intergranular contacts (up to ten contacts have been observed).

The punctual contacts between pebbles are the most frequent (Figs. 6 and 9). Planar contacts occur between flat pebbles, involving no deformation. No concave-convex contacts were detected.

Outcrop examination on small surfaces usually evidences pebbles with random orientation (Fig. 10). In few occasions pebbles with preferential orientation (imbrication) were noticed (Fig. 11A). Frequently, the pebbles are preferentially stacked along lines of primary sedimentary structure (Figs 11B and 14B), the most common way to figure out the internal sedimentary structures.

Pebbles surface texture. Small pits, of circular or slightly elongated shape, with millimeter dimensions, occur on the pebbles surface (Fig. 12). More than ten marks of this kind can be discerned on one side of the large pebble in figure 12. The shape of the marks leads to the supposition that they result through the pressure applied at the contact between pebbles.

Broken pebbles. Occasionally there have been noticed well rounded flat pebbles with a highly irregular side (Fig. 13). The aspect of these irregular surfaces suggests they occurred through the breaking of the pebbles, after they were rounded. No traces of rounding subsequent to the rupture process were detected on the broken parts.

3.3. Sedimentary structures

The sedimentary structure in the Cândeşti Beds gravels from the Prahova River zone are usually difficult to see, due to a certain degree of homogeneity of the deposits. When sand is abundant the details of the sedimentary structures are evident (Fig. 14). The architecture of the sedimentary structures is more difficult to understand if sandy laminae or intercalations are not present. Only the careful inspection of the individual pebbles orientation and of the differentiation between larger and smaller pebbles allow the visualization of the sedimentary structures elements.

Current lamination. All the primary sedimentary structures observed in the investigated Cândeşti Beds gravelly deposits belong to the category of current, cross-lamination. They are trough cross lamination units.

At small scale investigation, the conchoidal attitude of the cross-laminae is evident (Fig. 14) as well as the erosional relationships between the trough cross lamination bodies.

The size of the trough cross-lamination units is variable, depending on the scale considered. At middle scale the range of their width is 80-90 cm to 2-2,5 m (Fig. 15). The current-laminated units show thickness between 15-20 cm (Fig. 15) and 40-60 cm (Fig. 13).

Large-scale current-lamination bodies. The graphic interpretation of the current structure elements (Fig. 16) point out the integration of the cross-lamination visible in the outcrop into much larger tabular-shaped, current-laminated bodies. The large-scale sedimentary structure of the investigated Cândeşti Beds consists of smaller trough-cross units (4-9 m wide and 0,9-1,5 m thick) and larger developed tabular bodies with metric thickness (1,5-2,5 m) and several tens of meters lateral extension.

4. INTERPRETATION OF DATA

Cândeşti gravels proximal sedimentation environment

The published paleontological data clearly indicate the Cândeşti Beds gravels cropping out in the sub-Carpathian zone accumulated in a continental, fresh-water environment (Motas, 1956; Liteanu, Ghenea, 1966 and others). Integrating surface and subsurface data, the Cândeşti Beds researchers of the 20th century realized the sub-Carpathian gravels are replaced southward by sand deposits and farther to the south by alternating clay and fine-grained sand (Liteanu, Ghenea, 1966).

Since the beginning of the last century, due to the regional areal extension, the gravelly facies and their continental fauna, the Cândeşti Gravels have been interpreted as sediments accumulated in vast fluvial cones. Presently, also taking into account the large-scale facies variation, we are following this interpretation, only we use the modern term alluvial fan complex.

The study whose results we are describing, accumulated data based on sedimentological observations and analysis for a documented image of the sedimentary processes and environments of the Cândeşti Beds gravelly deposits.

The cross-lamination/bedding is the omnipresent sedimentary structure in the Cândeşti Gravels from Prahova River zone. Together with the continental faunal association, the presence of this structure indicates the fluvial currents as the major transport and sedimentation agent of the gravel.

The large pebbles (up to the 16-32 mm grain-size) of the Cândeşti Gravels deposits (Fig. 7) mark the high energy of the sediment transport agent. The broken pebbles (Fig. 13) could be a consequence of the vigorous transport, but the syn-sedimentary timing of the pebbles breakage was not demonstrated. The high roundness degree of the pebbles also implies energetic transport, mostly in the mountain rivers, but also in the alluvial fan area (possibly through successive transport cycles).

The Cândeşti Beds data pointing out high energy sediment transport as opposed to poor grain-size sorting, express a contradiction valid for all fluvial gravelly deposits. In our opinion a fluvial gravel sedimentary unit, the way we see it today, includes particles accumulated at diverse moments corresponding to various transport energy levels. Consequently, the finer-grained particles, transported by a weaker flow, will infiltrate between coarse-grained particles, earlier deposited during a phase of stronger water flow; which will lead to a poor sorting of the accumulated sediment.

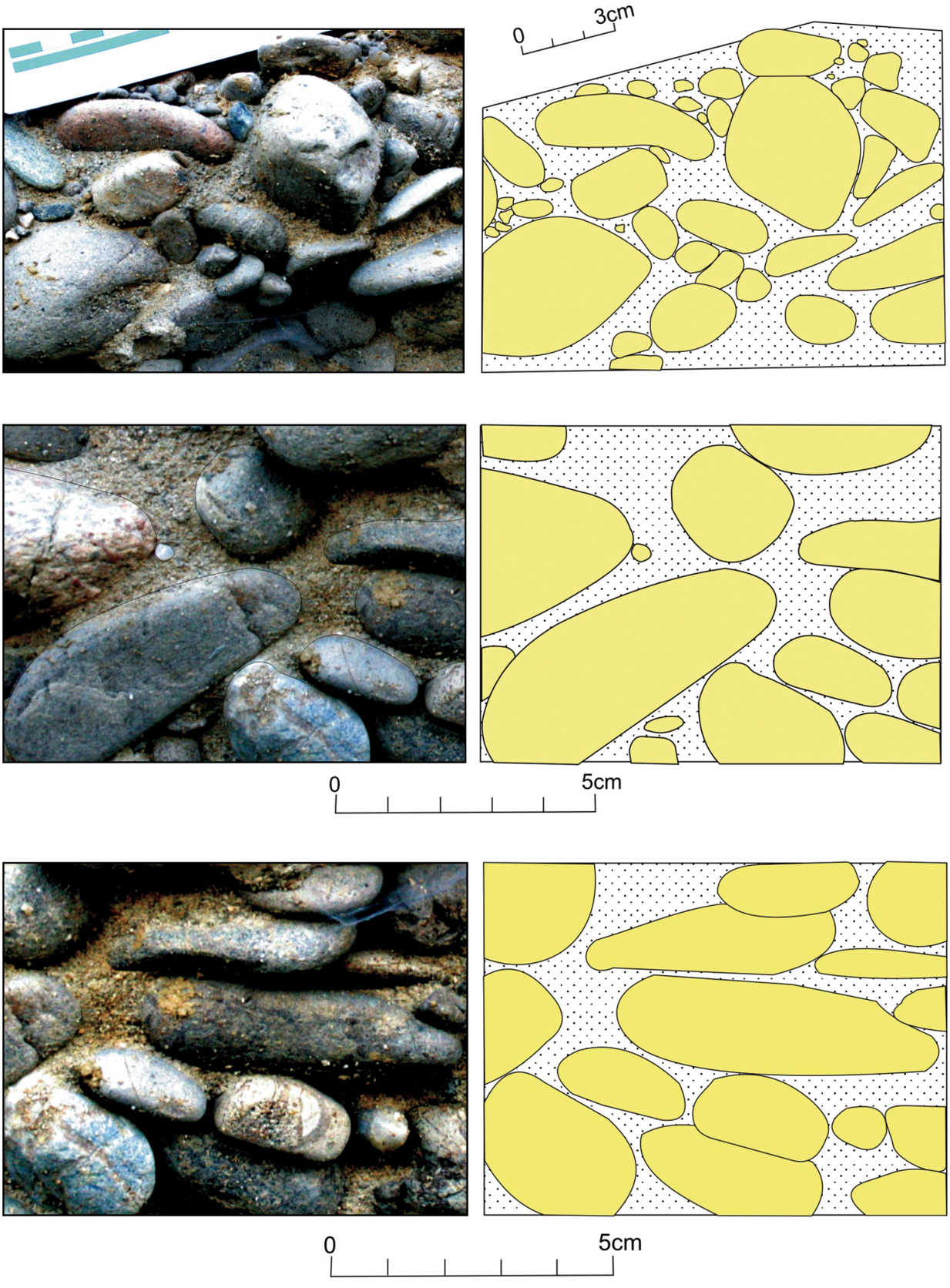
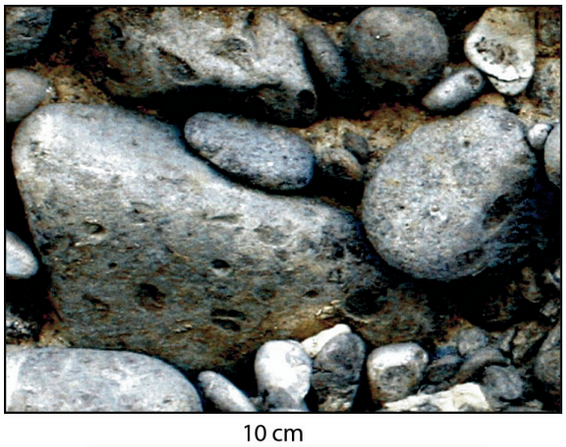


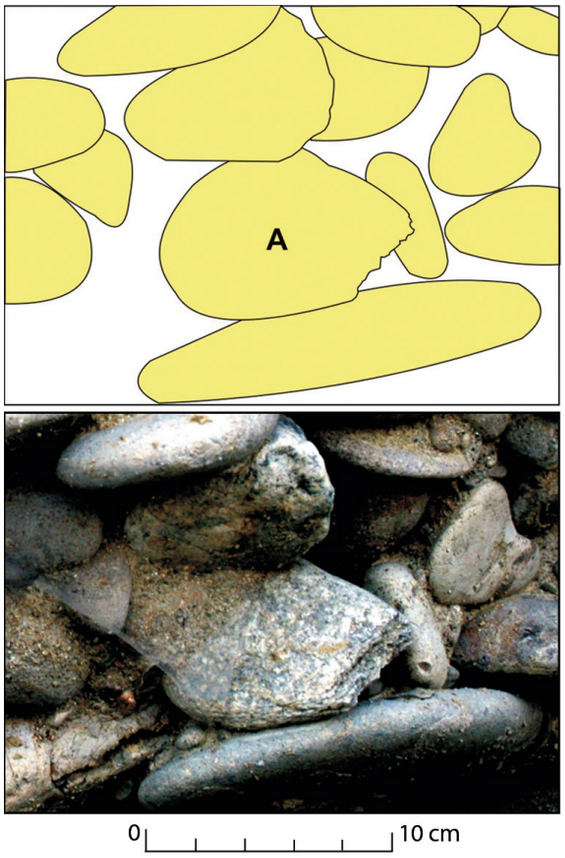
Fig. 10. Pebbles packing in the Cândeşti Beds. Sand matrix filling the spaces between pebbles. Pebbles are dominantly in contact (grain-supported type of packing). Lack of preferential orientation in the pebbles arrangement, except the lower figure where elongated pebbles are in contact. Prahova River, 500 m downstream of Bobolia locality.

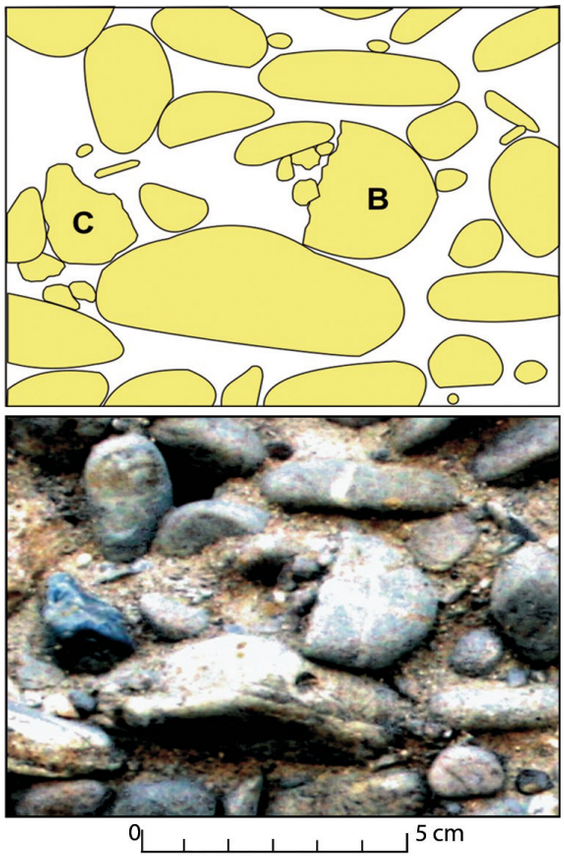
▲ **Fig 11**. Pebbles preferential arrangement in the Cândeşti Beds. **a**. Imbrication. **b**. Larger pebbles marking the lower limit of a trough cross-lamination unit. Cândeşti Beds in outcrops on the right bank of Prahova River, downstream of Băneşti and Bobolia localities.



◀ **Fig. 12**. Marks on the pebbles surface, probably generated by the pressure exerted at the contact points between gravel elements. Note the numerous marks on the surface of the larger pebble. Cândeşti Beds, outcrops on the right bank of Prahova River.

▼ **Fig. 13**. Broken pebbles (**A** and **B**) in the Cândeşti Beds cropping out on the right bank of Prahova Valley. **C**. Subrounded green chert.





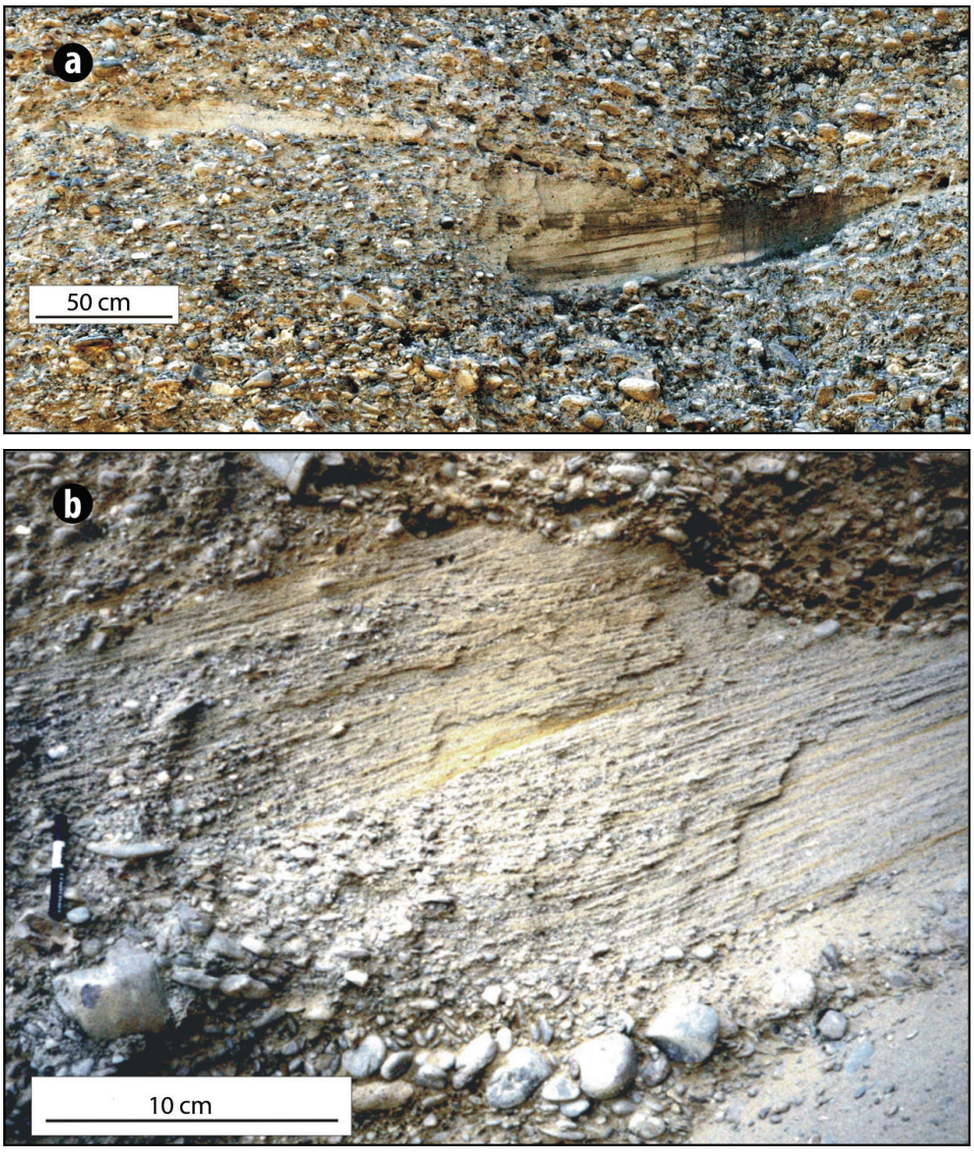


Fig. 14. Current lamination units in the Cândeşti Beds gravels. **a**. Internal lamination very clear in the sand, becomes obscure (still recognizable) in the gravel part. **b**. Complex trough cross-lamination structure and erosional boundaries between overlapping units.

The absence of channel fill structures and the non-existence of clay intercalations in the gravel investigated sediments from the Prahova area are diagnostic for understanding the process of Cândeşti Gravels accumulation. These demonstrate the fluvial flows where un-channelized, and that it did not exist a flooding plain with clayey sedimentation.

The evidenced large-scale tabular bodies with current structure (Fig. 16) represent a positive indication of the transport and sedimentation processes responsible for the accumulation of the Cândeşti Beds gravels cropping out along Prahova River. In correlation with the absence of channel-fill structures, the tabular current bodies indicate the gravelly material was transported as sheet-flood bodies, not constrained in fluvial channels.

The brown silt intercalation (Fig.4), apparently with important lateral extension, is interpreted as the indication of a break of the gravelly sedimentation, possibly of local importance. The brown silt deposit is possibly influenced by an incipient soil development episode.

On the whole, the information provided by our study show that the Cândeşti Beds alluvial fan belongs to the wet type. In the area corresponding to the present-day Prahova River zone on the surface of the alluvial fan migrated un-channelized sheet-like bars, composed of smaller dunes with trough cross-lamination. The sheet bars are probably a flood events product, when the high flood sediment discharge overcame the transport capacity of a channelized system. Only grain-supported sediments occur in the studied area of the Cândeşti Beds alluvial fan. No debris flow sediments have been noticed.

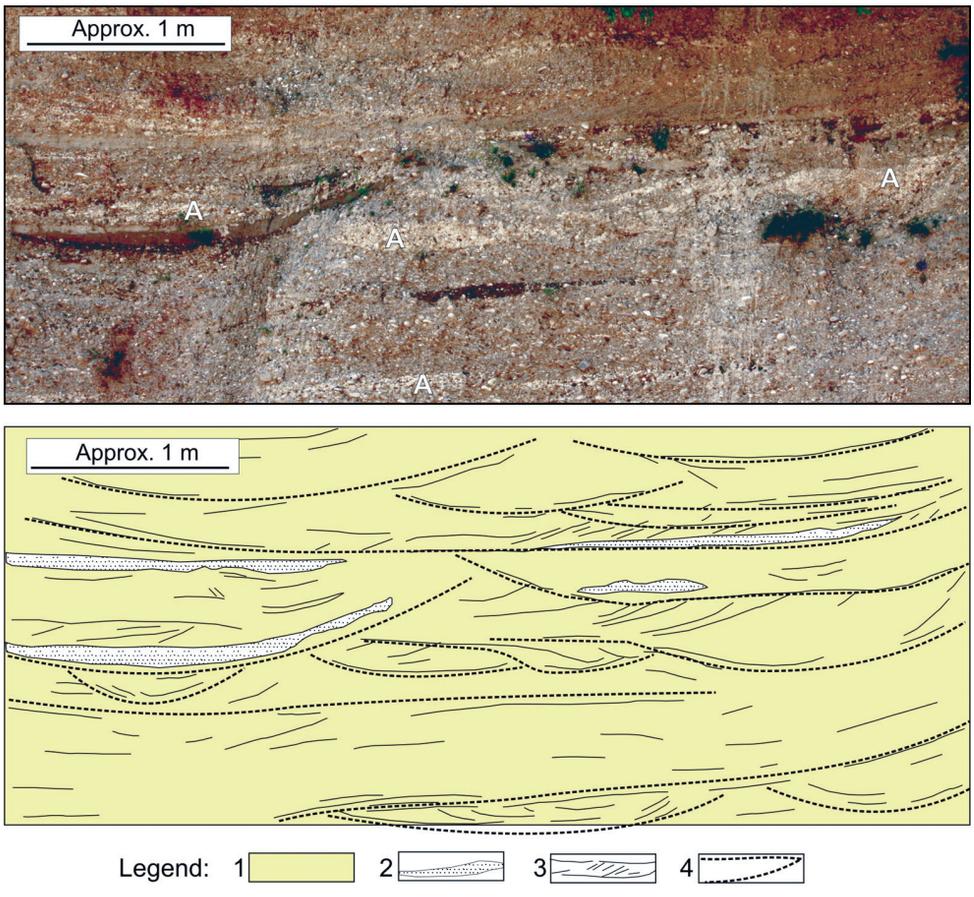


Fig. 15. Medium-scale trough cross-lamination units in the Cândeşti Beds. Section orientation: NE to SW. **A**. Lamination structure revealed through siltic matrix distribution. *Legend*: **1**. Gravel. **2**. Sand. **3**. Current lamination visible in the outcrop. **4**. Interpretation lines, traced to outline the genetic units.

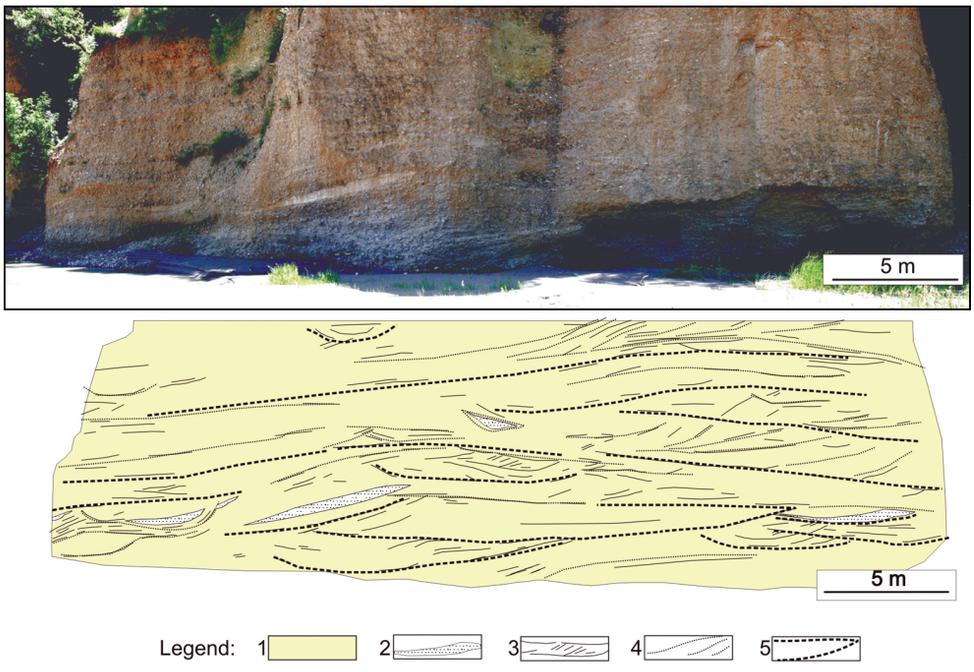


Fig. 16. Large-scale internal current structure in the Cândeşti Beds. The general structure (lower image) obtained through the interpretation of the visible structure lines on the upper image. Section orientation: NE to SW. *Legend*: **1**. Gravel. **2**. Sand. **3**. Current lamination visible in the outcrop. **4**. Lower rank interpretation lines traced within the current units. **5**. High rank interpretation lines countouring large scale tabular current bodies.

In the general picture, the pebble-sized facies of the Cândeşti Gravels (like the Prahova River facies) is the sheet-flood, proximal part of the alluvial fan complex. Southward it could be replaced by the sandy facies of a braided alluvial plain (Rust, 1978). Further to the south, the clayey-sandy distal facies might stand for a meandering alluvial plain. The continental part of the Hayward (1983) depositional model is probably applying to the architecture of the Cândeşti Beds alluvial fan complex.

5. CONCLUSIONS

The sedimentological study of the Cândeşti Beds (Pleistocene) cropping out on the right bank of the Prahova River, highlighted the main textural and structural features of the gravels and their sedimentogenetic significance.

The result of the investigation presents the studied deposits as poorly sorted, medium coarse-grained gravels, with well rounded and elongated shape pebbles and coarse-grained sandy matrix (about 25% of the gravels volume).

The frequent occurrence of trough cross-lamination/bedding points out the fluvial currents as the sediment transport agent. The current laminated, large-scale tabular bodies, with lateral extension to several tens of meters, represent the prominent sedimentary structure feature of the studied gravels. No channel-fill structures and clay intercalation have been noticed in the gravelly sediments.

The investigated Cândeşti Bed gravels are the proximal facies of a Pleistocene complex alluvial fan, characterized by sheet-flood sediments, with grain-supported texture.

REFERENCES

Blatt H.,Middleton G. V., Murray R. C., 1980. Origin of sedimentary rocks, 2nd ed. Prentice-Hall, Englewood Cliffs, 782 pp.

Damian, R., 2003. Geologia depozitelor Neogen superioare dintre Dâmbovița și Prahova. Interpretări geochimice. Ed. Universității din București, 111 pp.

Galloway, W. E., Hobdday, D. K, 1983. Terrigenous clastic depositional systems. Applications to petroleum, coal, and uranium exploration. Springer-Verlag, 423 pp.

Hayward, A. B., 1983. Coastal alluvial fans and associated marine facies in the Miocene of S. W. Turkey. Spec. Publs Int. Ass. Sediment., 6, 323-336.

Liteanu, E., 1961. Aspectele generale ale stratigrafiei Pleistocenului și ale geneticei reliefului din Câmpia Română. Studii Tehnice și Economice, Seria E, Hidrogeologie, 5, 37-59.

Liteanu, E., Ghenea, C., 1966. Cuaternarul din România. Studii Tehnice şi Economice, Seria H, Geologia Cuaternarului, 1, 1-118.

Motaș, I., 1956. Observațiuni cu privire la sedimentația Pliocenului din regiunea Pralea. D. S. Com. Geol. XL, 13-20.

Popescu-Voitești, I., 1940. Sur la présence des galets des roches porphyrique à quartz dans les graviers continentaux du Levantin supériéur- Quaternaire inférieur de l'Olténie occidentale. C. R. Inst. Sci. Roum. (Acad. Sci. Roum.), IV/3-4, 337-339.

Ramos, A., Sopeña, A., 1983. Gravel bars in low sinuosity streams (Permian and Triassic, central Spain). Spec. Publs Int. Ass. Sediment., 6, 301-312.

Rust, B.R., 1978. Depositional models for braided alluvium. In Miall, A.D. ed., Fluvial Sedimentology, Can. Soc. Petrol. Geol. Mem., 5, 605–625.

Protescu, 1932. *Privire generală asupra rezervelor de cărbuni din România*. Stud. Tehn. Econ., III/8.