THE SEDIMENTOLOGY OF THE UPPER CRETACEOUS CONTINENTAL DEPOSITS FROM THE SOUTH-WESTERN PART OF THE TRANSYLVANIAN BASIN, THE ŞARD FORMATION

Izabela MARIS

University of Bucharest, Department of Mineralogy, 1, Nicolae Balcescu Bd, 010041, Bucharest;
e-mail: izabela@contentlogic.ro

Abstract. Continental deposits especially conglomerates have always been a challenge to geologists because of the lack of fauna and of the petrographic diversity of their particles. The continental deposits located in the south-western part of the Transylvanian Basin make no exception. This paper presents the sedimentological and facial features of the Şard Formation, which is cropping out on the right bank of the Ampoi River. Among the various sedimentary formations exposed in this region, the Upper Cretaceous to Lower Tertiary successions are of special interest, marking the sedimentary environment's evolution near the Cretaceous - Tertiary boundary. At this level a reddish continental formation was deposited and its formation is typical for alluvial depositional system (braided rivers). Detailed lithological columns have been logged recording textural parameters like pebbles morphometry and granulometry as well as the sedimentary structures and clast composition, over the 60 m thickness of the outcropping section.

Key words: Transylvanian Basin, Maastrichtian, braided river, red continental deposits.

INTRODUCTION

Transylvanian Basin was formed behind the Carpathian arch and is bordered on the north and east by the Eastern Carpathians, on the south by the South Carpathians and on the west by the Apuseni Mountains (Pătraşcu *et al*., 1994). It is considered to be a post - Cenomanian sedimentary basin, which was developed on top of an overthrust nappe system (Royden, 1985; Tari and Horvath, 1995). The Transylvanian Basin is a semi-circular basin about 150 km wide and 200 km long, containing thick sediments, deposited from the Cretaceous to Upper Miocene, having large lateral and vertical variations, with a variable thickness, ranging from 2.5 to 4 km (Ciupagea *et al*. 1970). The sediments accumulated inside the basin reflect their history from rifting to uplift, inversion and flexure (Sharland *et al*., 2001). On the south-western corner of the Transylvanian Basin, the Upper Cretaceous megasequence is composed of siliciclastic sediments showing an evolution from marine to continental environment. Several formations have been defined: the Bozeş Formation, the Vurpăr Formation and the Şard Formation, separated by erosional events (Codrea and Dica, 2005).

THE ŞARD FORMATION

The Şard Formation is known in literature as a "Red clastic complex" (Ilie and Mamulea, 1958), "Red continental formation" (Dimian and Popa - Dimian, 1963), "Continental complex with reddish variegated deposits" (Bleahu and Dimian, 1967), "Old variegated complex" (Mészáros *et al*., 1969), "Red clastic facies" (Antonescu, 1973), "Bozeş Formation" (Lupu, in Bleahu *et al*., 1981), "Red Clastic Formation" (Antonescu *et al*., 1983) "Upper Maastricthian (continental facies) " (Grigorescu, 1987), "Bozeş Strata (Grigorescu *et al*., 1990), "Vinţu de Jos Strata" (Therrien *et al*., 2002), "Red Continental Strata, Vurpăr" (Therrien, 2005) and was defined in the Şard village, near the city of Alba Iulia (Fig. 1). Geographically, it is located at the border between the eastern flank of the South Apuseni Mountains and the western edge of the Transylvanian Basin.

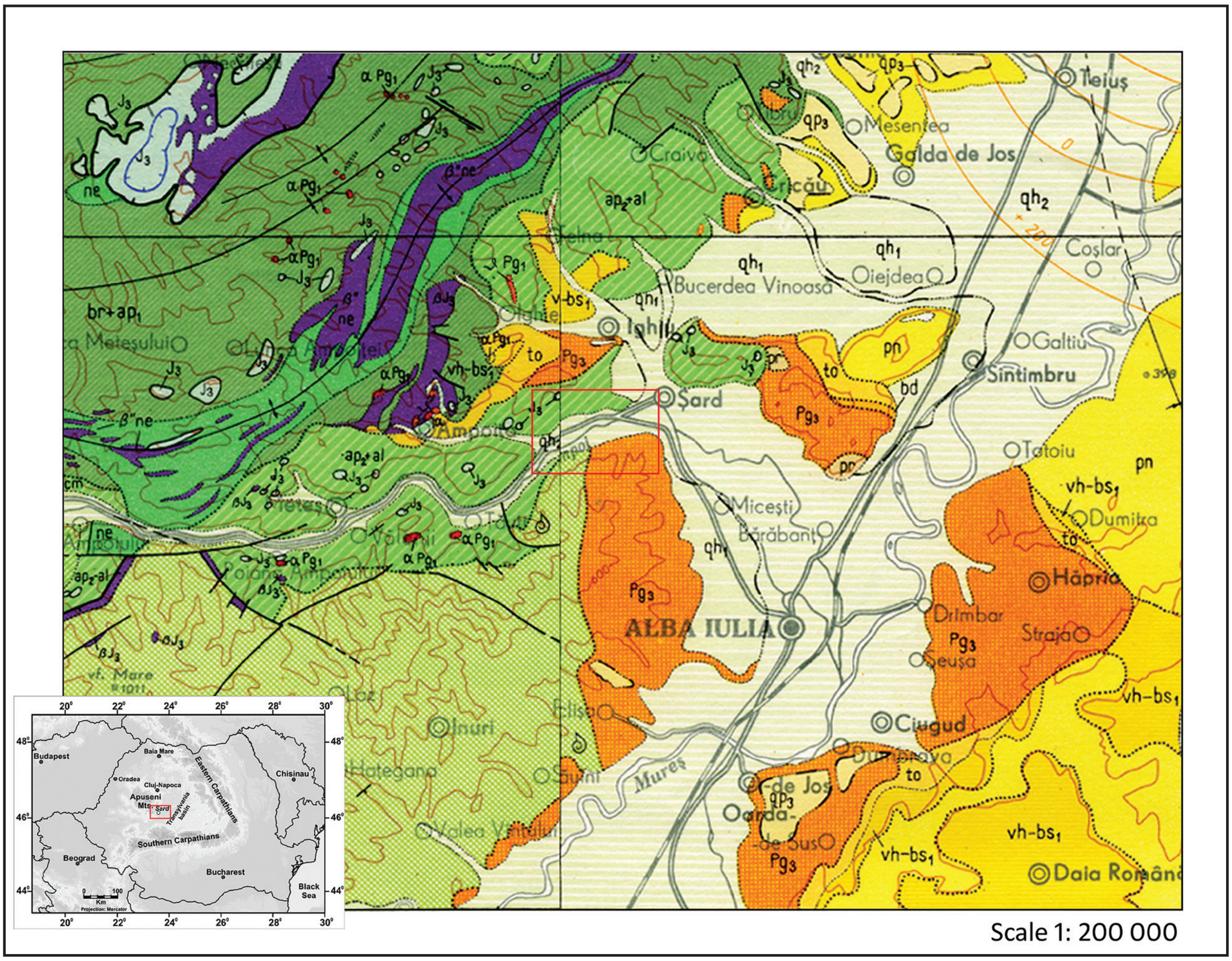

Fig. 1 Geological map of Alba Iulia area (after Geological Institute, Lupu *et al*., 1967)

This formation is cropping out on the right bank of the Ampoi valley (Fig. 2) and is composed of continental sediments made of alternating conglomerate, sandstone and silt (Fig. 3). The faunal content is scarce and is dominated by the presence of bone fragments of vertebrates of the Upper Cretaceous age (Maastrichtian): dinosaurs, crocodilians, turtles (Nopcsa, 1905; Weishampel *et al*., 2003; Codrea and Dica, 2005). The fauna association of this formation is similar to the Cretaceous fauna from the Haţeg Basin, which may lead to a correlation of deposits of both sedimentary basins (Transylvanian Basin and Haţeg Basin) (Codrea and Dica, 2005). The sedimentary evolution of the Şard Formation begins in the late Maastrichtian and continues until the Priabonian, when the sedimentary regime changed from continental to marine sedimentation (Codrea and Dica, 2005).

Conglomerate strata have thicknesses ranging from 0.5 to 2.7 m and contain pebbles of various origins: volcanic rocks (andesite, rhyolite, dacite, basalt and volcanic tuffs), metamorphic rocks (sericite schist, quartzite, gneiss, phillite) and sedimentary rocks (radiolarite, cherty limestone, pure limestone, sandstone, microconglomerate and muddy rip-up clasts). Conglomerates are poorly sorted and have a red clayey matrix. In terms of sedimentary structures, parallel stratification, cross tabular stratification and massive structures have been identified. The ratio between particles and matrix is highly variable throughout the sequence, therefore both matrix and grain supported conglomerates were separated.

The sandstone strata are thinner (thickness range 0.3 to 0.7 m) and consist of coarse, medium and fine grained lithic sandstones with angular, sub-angular and sub-rounded particles. The sorting degree of the arenite fraction ranges from moderate to well sorted. Parallel, tabular and trough crossed bedding have been found in the arenitic strata.

The siltstone strata consist of massive brick-red to yellowish-red siltstones which represent paleosol levels. Their thickness varies between 10 – 90 cm. Bioturbation is caused by the plant and small animal traces (krotovinas and cervotocinas) (Plate 1). These appear as thinner or thicker channels within the paleosol matrix. The density of the bioturbation in the paleosols is low, their presence is especially emphasized in the upper part of the formation, whilst, in the lower part, they are replaced by carbonate nodules and a continuous hard carbonate crust. Carbonate accumulations are of a rhizoliths type (Fig. 4), nodular calcrete and caliche. They are the result of the dry climate when the evapo-transpiration exceeds the

Fig. 2 The Sard Formation outcrop

precipitation, which is insufficient to remove soil carbonate minerals (Retallack, 2001; Therrien 2005).

METHODS

The lithological units of the Şard Formation were described in sedimentological terms, considering the textural parameters (granulometry and morphometry of pebbles), the structural features of litons (parallel, cross-stratification, pebble imbrication, etc.), the bed thickness and the degree of bioturbation. The paleocurrent flow directions were measured using pebbles imbrication and cross stratification. The sedimentological study has been completed by the petrographic laboratory investigation of thin sections.

Facies and Sequences in the Şard Formation

According to the grain size data in conjunction with structural analysis, the Şard Formation consists of 12 types of facies: four ruditic facies - represented by polymictic para- and orthoconglomerate; four arenitic facies - medium and fine grained, poorly cemented sandstones; one red siltic facies - incipient paleosol and three of paleosol facies (*Bk , Bt and K horizons of paleosol*). All these facies are shown in Table 1.

Facies assemblage

In the Şard Formation seven facies assemblages were identified, which define the geometry of depositional units, with fining upward, blocky or coarsening upward features. These facies associations have been interpreted as channel deposits, gravelly bars, gravelly sheets, sand lenses, lateral accretion forms - point bars; crevasse splays and alluvial sheets.

(1) Channel deposits

Channel deposits are represented by depositional sequences composed of facies Gp, Gh, Sh, Sp and Sr (Mial, 1996) (Table 1). The thickness of these associations is variable (1.2 - 3 m). Finning upward sequences can be distinguished, with erosional and concave - up base, marked by the presence of large rip-up clasts (Fig. 5).

(2) Gravel bars and bedforms

This type of sediment is dominant in the Şard Formation. It has in its composition the Gh, Gp, Sh, Sp facieses (Table 1). Facies associations which compose the gravel bars are 5 to 15 m in thickness, coarsening upward, blocky and fining upward sequence geometry type. The association suggests several overlapping plastic debris flows, with high viscosity and viscous laminar or turbulent flow, interpreted as depositional structures, evidenced in lateral or longitudinal bars, with great lateral continuity (Fig. 6 and Fig. 7). Their growth is explained by aggradation and progradation. The lower-order architectures (lens, lobes and sheets) appear delimited by discontinuities caused by seasonal events like floods (Cant and Walker, 1976, 1978; Singh, 1977; Cant, 1978; Miall, 1985, 1996, 2000).

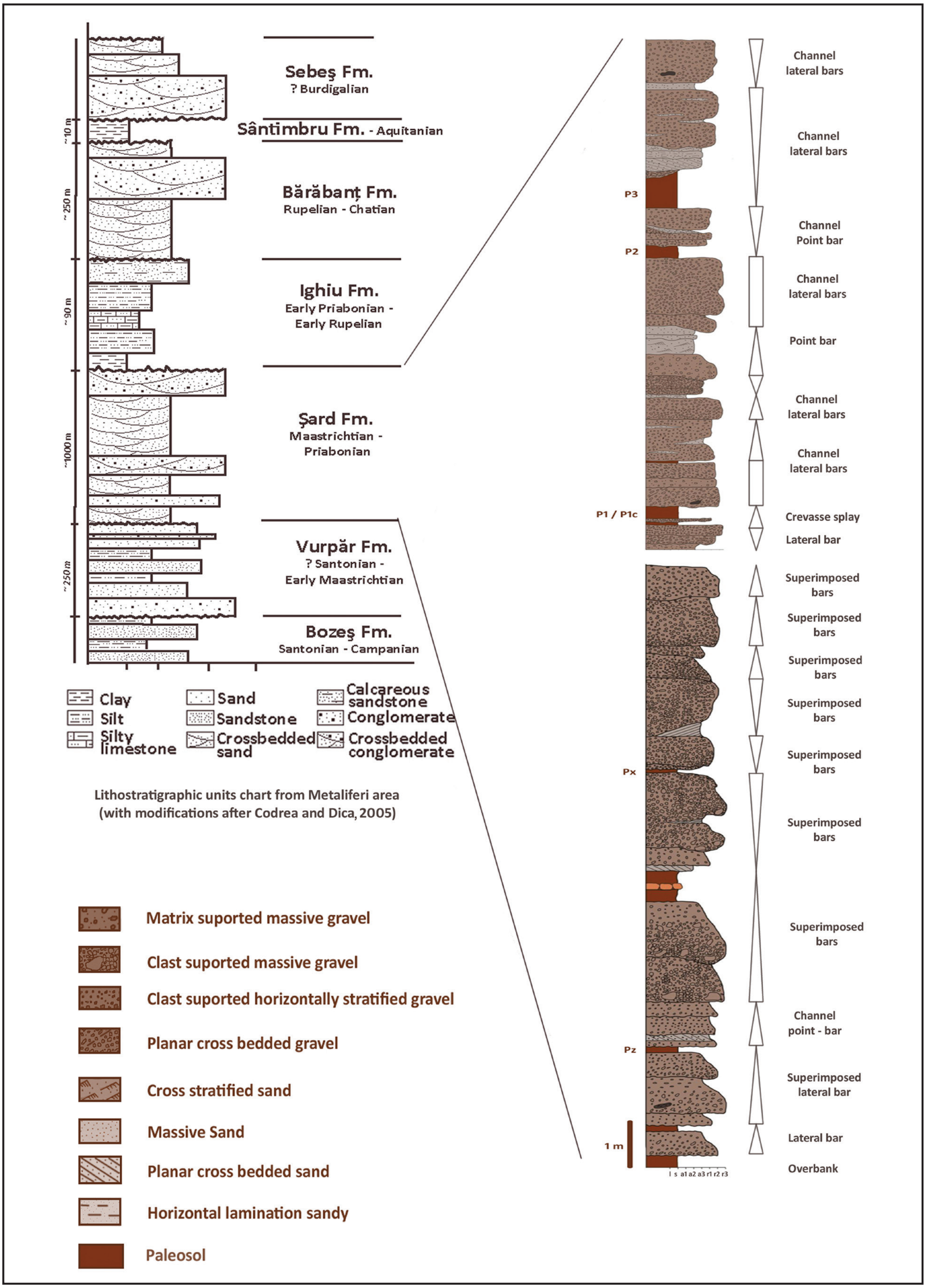

Fig. 3 Detailed geological column of Şard Formation

Table 1. Textural and structural facies characterization of the Sard Formation

Facies	Facies Code (Mial, 1996)	Thickness (cm)	Composition	Textures			Structures	Bio-turbation	Climate	Interpretation
				Particle size (mm)	Particle form	Sorting				
Matrix supported massive gravel	Gmm	50 - 120	Polymictic matrix suported conglomerate	10 - 140 (pebbles)	Rounded and subrounded	Very poorly sorted	Massive structure; poor grading; diffuse imbrication of pebbles	Absent	Subhumid with alternating wet and dry periods	Plastic debris flow deposits in channel and pre-existing alluvial settings Gravelly bars
Grain supported massive gravel	Gcm	85 - 240	Polymictic grain supported conglomerate	40 - 150 (pebbles)	Rounded and subrounded	Very poorly sorted	Massive structure	Absent	Subhumid with alternating wet and dry periods	Pseudoplastic debris flow Coarse gravelly bars; tabular bodies with erosional bases; gravel bedforms
Grain supported horizontally stratified gravel	Gh	20 - 145	Polymictic grain supported conglomerate	20 - 145 (pebbles)	Subrounded to very well-rounded	Very poorly sorted	Parallel stratification; diffuse pebble imbrication	Absent	Subhumid with alternating wet and dry period	Coarse gravelly bars; lag deposits or sieve deposits Tabular bodies with erosional bases; gravel bedforms
Planar cross bedded gravel	Gp	80- 120	Polymictic grain supported conglomerate	20 – 125 (pebbles)	Rounded and very well-rounded	Very poorly sorted	Oblique stratification and normal grading	Absent	Subhumid with alternating wet and dry period	Channel deposits, longitudinal bars or transversal bars Coarse gravely bars; tabular bodies with erosional bases; gravel bedforms
Massive sand	Sm	7 - 15	Fine to coarse grained sandstone	Fine to coarse grained arenite	Subangular - subrounded	Moderately and well-sorted	Massive structure	Absent	Subhumid with alternating wet and dry period	Sediment - gravity flow deposits
Horizontal lamination	Sh	7 - 35	Fine to coarse grained sandstone	Fine to coarse grained arenite	Subangular - subrounded	Well- sorted	Horizontal parallel lamination	Absent	Subhumid with alternating wet and dry periods	Hyperconcentrated flows Sandy sheets or gravelly sheets; point - bars
Planar cross bedded sand	Sp	33 - 92	Fine to medium grained sandstone	Fine to medium grained arenite	Subangular -subrounded	Well- sorted	Oblique lamination	Absent	Subhumid with alternating wet and dry periods	Longitudinal bars, linguoid bars and sandy bedforms Sandy sheets or gravely sheets; point - bars
Cross stratified sand	Sr	25	Medium to coarse grained sandstone	Medium to coarse grained arenite	Subangular - subrounded	Moderately to well- sorted	Cross stratification	Absent	Subhumid with alternating wet and dry periods	Longitudinal bars, linguoid bars and sandy bedforms Sandy sheets or gravely sheets; point - bars
Mud	Fr	40 - 120	Siltite	Medium to fine grained silt		Very well-sorted	Massive structure	Present	Subhumid with alternating wet and dry periods	Overbank deposits : (levees, muddy sheets, crevasse splays); Incipient soil
Carbonate paleosoil	P	15 - 70	Carbonate nodules and calcrete				Nodular structure	Present	Subhumid with alternating wet and dry period	Overbank deposits; paleosols with chemical precipitation

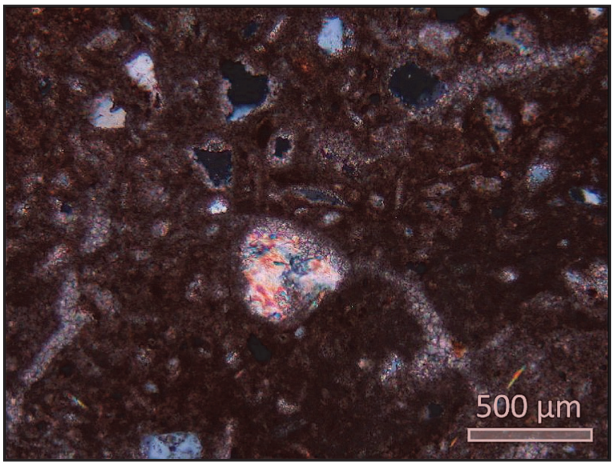

Fig. 4 Red Palleosol thin section.The thin section shows micritic matrix with multiple sparitic and microsparitic filaments, which represent plant traces

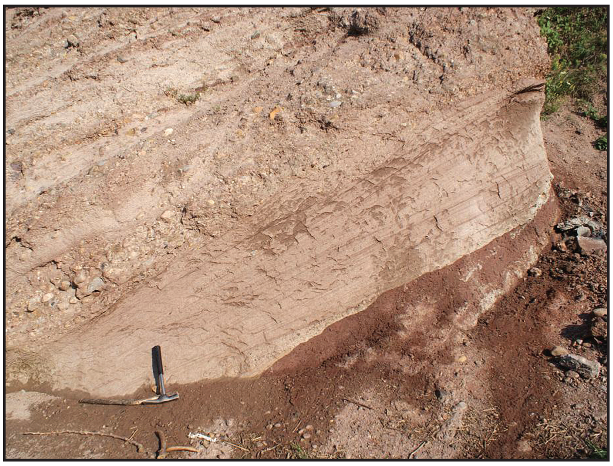

Fig. 5 Channel deposits

Fig. 6 Polymictic grain supported conglomerate with parallel stratification. Coarse gravelly bars

Fig. 7 Polymictic grain supported conglomerate with oblique stratification and normal grading. Longitudinal or transversal bars

(3) Gravelly sheets

These sequences consist of Gmm and Gcm type facies associations placed in superposed bodies with the geometry of sheet and large lateral extension. Individual units have thicknesses ranging between 0.5 and 3m. Basal units show irregular boundaries, with a non-erosional shape, which follow the irregularities of the substrate. This architecture is related to debris flow processes (Miall, 1985, 2000). Often, the gravelly sheets are associated with sandy lenses or sheets and gravelly bars (Fig. 8).

(4) Sand lenses / Sandy sheets

The facies association that constitutes the sand lenses / sandy sheet architectural element gathers Sp, Sr and Sh facies type, that are associated with the facieses Gp and Gh (Table 1). The sandy sheets have a decimetre-thick tabular geometry and show horizontal, tabular or trough cross-stratification structures (Fig. 9). Lateral expansion is large, covering tens of meters. The sandy lenses thicknesses is 10 to 20 cm and the lateral extensions are limited to 0.2 – 1.5 m. They are specific architectural elements associated to channels, filling in depression forms. Such sequences are deposited during the fall of the basic hydrostatic level of the river, after major hydrodynamic events, giving a fining upward character to the sequence (Mial, 2000).

(5) Lateral accretion - point bar

This type of facies assemblage includes units with geometries of wedges and lobes or sandy sheets that is reduced to a thickness between 1.2 - 2.5 m and widths of 3-5 m, without lateral continuity (Fig. 10). Facies components are: Gh, Sp, Sm, Sr (Table 1). They represent deposits sedimented by lateral accretion which generated arched bodies, with a reactivation surface, occurring as a result of changes in the base level of the river.

(6) Crevasse splays

Facies association that defines the architecture of crevasse channels and crevasse splays is given by facies Gh and Fr (Table 1). It has a fairly rare occurrence across the Şard Formation. The association's thickness is relatively small - 1.2 m, approximately tabular in geometry with a fining upward sequence trend indicating a progradation phase (Mial, 1996).

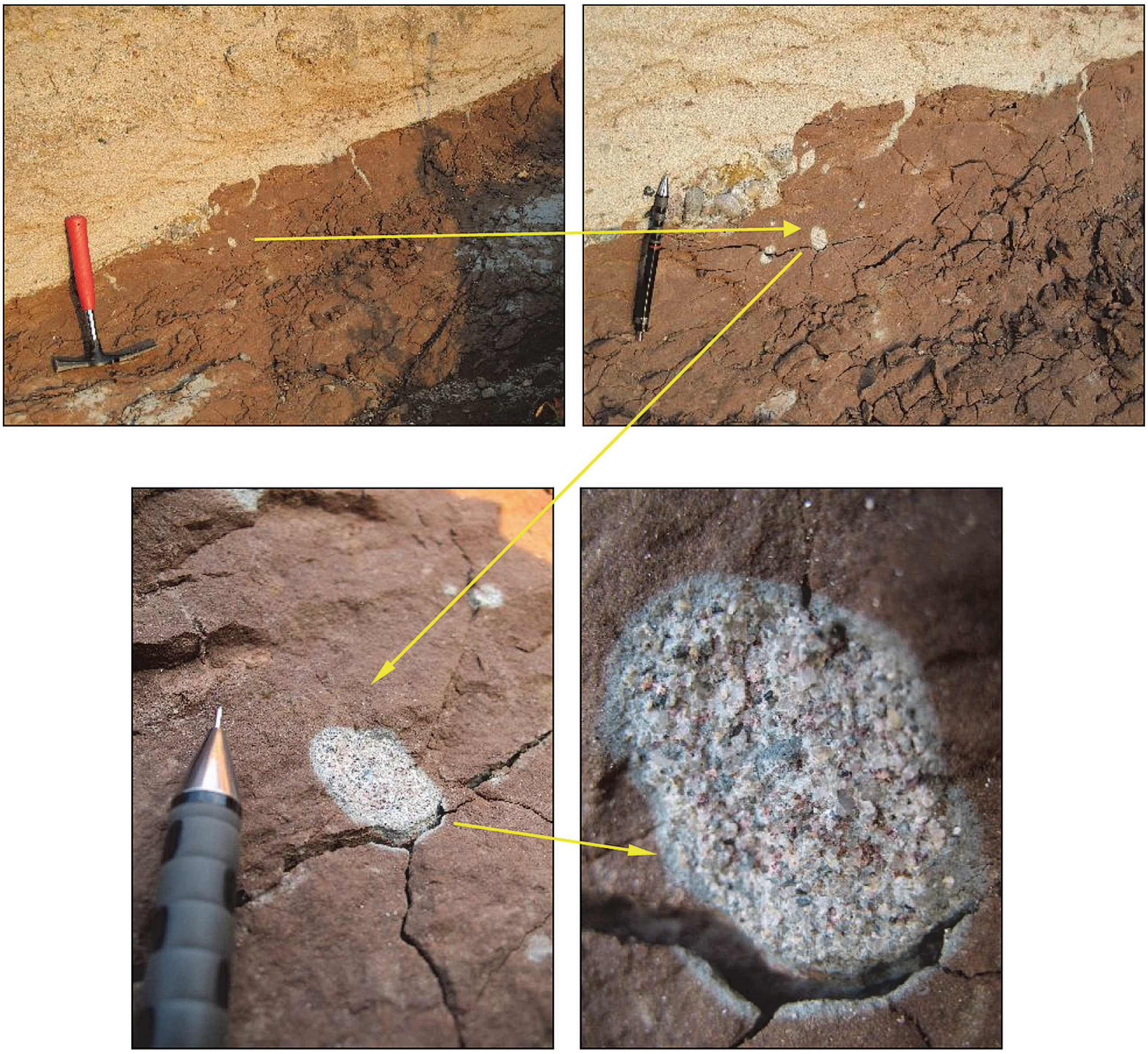

Plate 1 Trace fossils cervotocinas type, developed on different directions filled in with coarse sand material from the adjacent layer

Fig. 8 Polymictic matrix supported conglomerate with diffuse imbrication

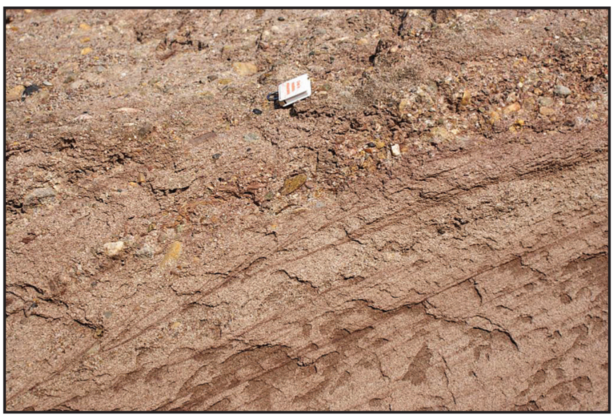

Fig. 9 Cross stratificated sandstone. Sandy sheets

Fig. 10 Point bar deposits. Horizontal parallel and oblique lamination

(7) Alluvial sheets

They consist of facies associations: Fr and P (Table 1). The associations are 0.5 - 1.2 m thick, and show large lateral extensions. The alluvial sheets are built in conditions of low energy flow (Mial, 1996). In these architectures, pedogenetic disrupted bedding and carbonate crusts modified the original structure of deposits, indicating seasonal fluctuations of the hydrographic basin (Fig. 11) (Miall, 1985; Therrien, 2004, 2006; Rettalack, 2001).

Fig. 11 Red paleosoil with carbonate crust and nodular calcrete

ASSOCIATED DEPOSITIONAL SYSTEM, PALEOCURRENT FLOW DIRECTIONS AND SOURCE AREA

Specific architectural elements (channels, longitudinal and lateral bars, beds and sheets, prisms, lenses and lobes), dominant rudite granulometry, poor sorting, rounded and well-rounded pebble shapes suggest that the sedimentary deposits accumulated in a continental environment specific to a braided fluvial depositional environment.

The multitude of gravelly sheets and their overlapping at the bottom of the sequence, suggest a river system with multiple channels characterized by low sinuosity and currents with a high energy (Cant and Walker, 1976, 1978; Diemer, 1992; Bentham *et al*., 1993). Channel deposits are dominated by Gp, Gh facies associated with the Sh, Sp, Sr arenite facies (Table 1) displaying a fining upward trend. The lateral accretion forms (point bar) are poorly represented at this level. All these suggest an irregularly braided fluvial system (Cassiliano, 1998, Mial, 1985, 2000).

Towards the top of the sedimentary section, there is a change of flow regime so that it passes from a braided system to an irregular meandering one (Mial, 1985). In that part, the gravelly sheets are represented only sporadically, being replaced by point bars, sandy channels and lateral gravelly bars. The sinuosity of the river became higher, current energy decreased and multiple channels concentrated in single channels (Mial, 1985). The laterally accreted sediments started to dominate.

Periodically, the vertical continuity of bars is interrupted by quiet depositional moments. These discontinuities are marked by thick layers with the relatively small tabular geometry of fine deposits, accumulated after major hydrodynamic events during the decrease of river base levels. The fine deposits, red colour, the presence of carbonate nodules and carbonate crusts represent the installation of pedogenetic processes (Therrien, 2004, 2006; Rettalack, 2001).

Some internal sedimentary structures like the tabular cross lamination, trough cross stratification and the imbrications of pebbles preserved in the channel deposits of the Şard Formation, allowed the determination of the paleocurrents flow's direction (Tucker, 2003). At the bottom of the section, the current shows a general tendency to flow on the NW – SE direction, the sinuosity of the river being very low, which suggests the presence of North - North West source areas. Towards the top of the section the flow's direction remains NW - SE, but the sinuosity of the river became higher.

The petrographic analyses of seven sandstone samples revealed the presence of lithic and sublithic sandstone, with numerous fragments of volcanic, metamorphic and sedimentary clasts. Sandstones are moderately to poorly sorted. The sandstone average composition is 68% quartz, 7% feldspar and 25% lithic fragments of which 12% volcanic rocks (rhyolite, andesite, pyroclastic tuff), 9% metamorphic rocks and 4% fragments of a sedimentary origin (limestone and sandstone). All of them have the source area in the surrounding mountains (South Apuseni Mountains).

CONCLUSION

The Şard Formation is typical for a braided river depositional system. Based on particle size distribution and sedimentary structures, 12 types of facies have been identified: four gravelly facies (ortho- and para- polymictic conglomerate), four sandy facies (fine to coarse grained sandstones), one silt facies and three paleosol facies (Bk, Bt and K horizons). Facies have been grouped into 7 facies associations that define the specific architecture of the channels, longitudinal and lateral bars, sheets, prisms, lenses and lobes.

The specific architectural elements, domination of gravel granulometry, high degree of pebble roundness, the poor sorting and relatively compact sedimentary deposits are the main arguements for interpreting the Şard Formation as formed in a braided river environment. The petrographic composition of sandstones and paleocurrent directions, indicate as source area the South Apuseni Mountains.

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