Geological Society of Romania
Faculty of Geology and Geophysics
GeoEcoMar

SEDIMENTOLOGY OF FLYSCH AND MOLASSES

Field trip
Guide Book

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Geological setting

The Carpathians represent an orogenic belt with a complex structure, wherein the flysch nappes modify their trend with 200° from the northernmost area (Poland) down to the south, in the bending zone of Romania. The segment of the Alpine belt comprised between the Tisza springs in the north and Dambovita Valley in the south represents the Romanian Eastern Carpathians (Fig. 1).

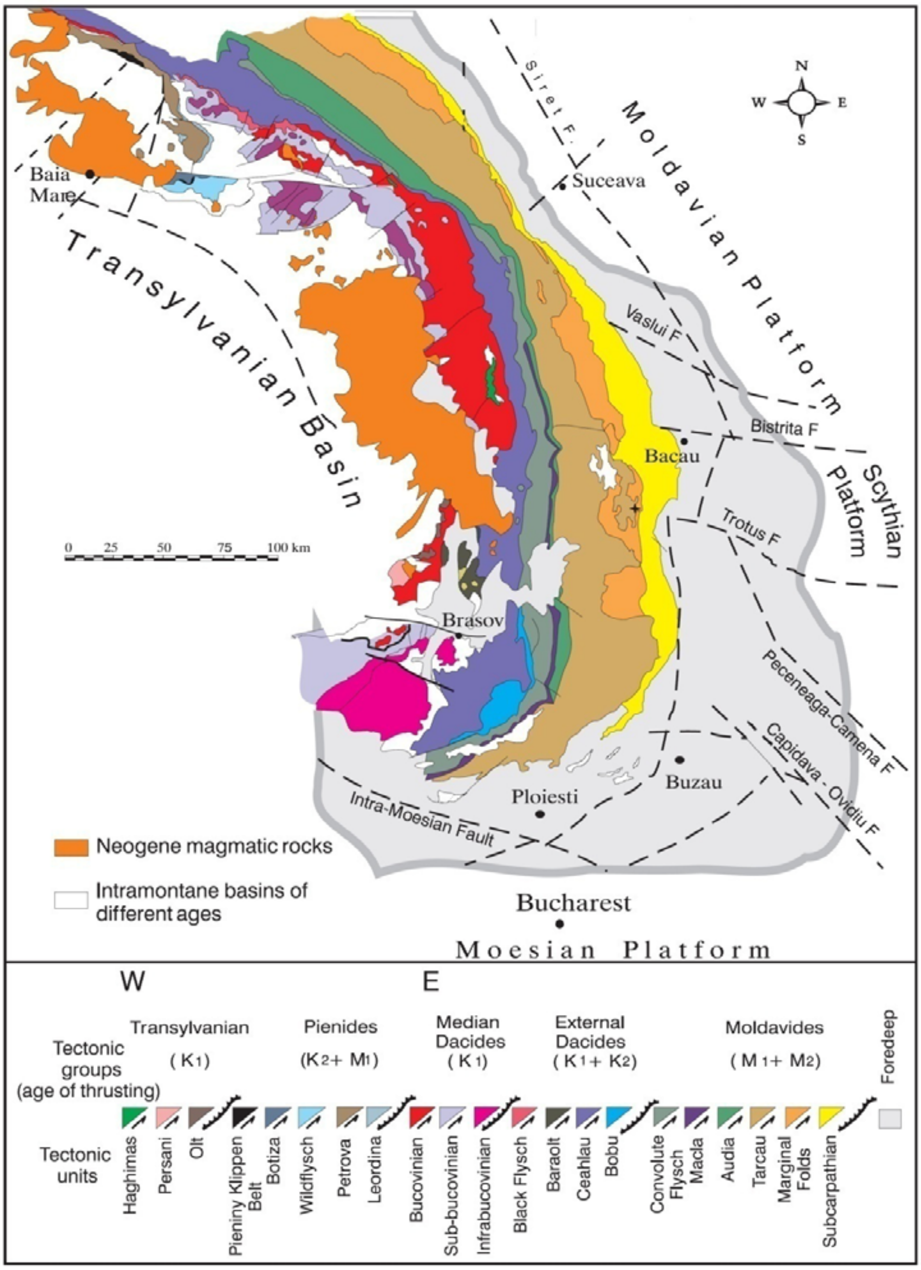

Fig. 1. Geological sketch map of the Eastern Carpathians
(acording to Săndulescu, 1984 and Bădescu, 1998)

The Alpine history of the Carpathians can be divided into an extensional Triassic-Neocomian period followed by a compressional one, Neocomian – Miocene. In the extensional regime two expansion zones were created: an oceanic rift, with passive continental margins in the west and an intracontinental rift, located to the east.

Depending on the intensity of the deformations, two major compression periods could be distinguished, which generally affected different orogenic areals: Dacidic period, characterized by two deformational paroxysms (Middle Cretaceous and Late Cretaceous) and the Moldavidian period, generally Miocene, but also within it, recognizing some tectogenetic phases: intraburdigalian and intrasarmatian. The two compression periods are responsible for setting up melting paleoplanes, oceanic and/or continental crust shields and tectonic "nappes" structuring (fig. 2).

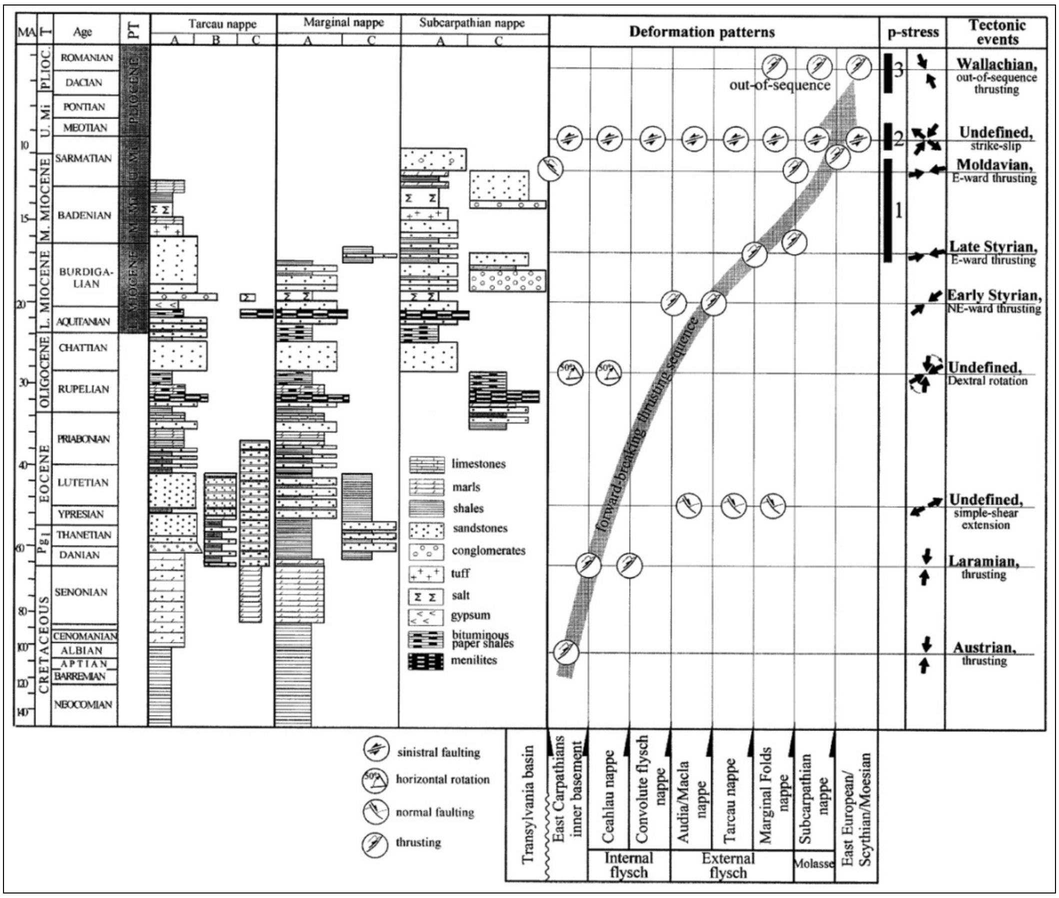

Fig 2. Stratigraphic columns in the external Moldavides units and the main tectonic events
(according to Maţenco and Bertotti, 2000)

The goal of this field trip is to visit some outcrops of tertiary deposits witch belong to Moldavides nappe complex and to the foredeep.

The Moldavides

The Moldavides complex (Fig.1) is a succession of N-S trending imbricated thrust nappes and which consist of Cretaceous-Tertiary sedimentary rocks. The nappes of the Moldavidic complex are:

i) Teleajen (Curvicortical), Macla and Audia Nappes – all consisting of Cretaceous rocks;

ii) ii) Tarcău and Marginal Folds (Vrancea) Nappes – they consist of both Cretaceous and Tertiary rocks;

iii) Subcarpathian Nappes exclusively consisting of Tertiary rocks.

The Foredeep

The formations younger than the last tectonogenesis of the Moldavides, namely Neosarmatian – Pleistocene molasses, were assigned to the Foredeep. The Foredeep was divided in two zones: an unfolded and a folded one.

The folded Foredeep deposits are developed in the Bend Area ("Diapiric Folds Zone"). They overlay the Subcarpathian Nappe and partialy, the outer margin of the Tarcau Nappe.

The folding of this part of the Foredeep took place in the Wallachian (intra-Pleistocene) phase, and was characterised by the halokinetic processes involving the Lower Miocene salt deposits.

Buzau Geopark

The Geopark is located in the Carpathian band zone, covers a teritory 1100 sq km, a population of about 45000 inhabitants and endorse unique geological places and phenomenon, a high biodiversity and a well preserved cultural heritage (fig. 3).

The geopark area comprises faulted and folded sedimentary deposits of the Tarcau Nappe (Sennonian – Lower Miocene), marls, sandstone, salt and gypsum of mollase type deposits belonging to the Subcarpathian Nappe (Lower – Middle Miocene) and sandstone, marls of marine, lacustrine, deltaic and fluviatile environments of the thrusted internal foredeep (Upper Miocene – Holocene). Associated fauna of invertebrate's fossils and sedimentary structures are characteristic for the last part of Tethys Basin evolution, transition to Paratethys (Dacic Basin) and the intermittent connections with other basins. A well documented sedimentary record of Messinian salinity crisis (event) and of the Miocene / Pliocene boundary in Paratethys are well represented along the Slanicul de Buzau Valley. The area is well known for its comprehensive sedimentation of Pontian, Dacian and Romanian deposits and also for few outstanding geological assets like Colti amber, salt diapirs and mud volcanoes.

Geopark biodiversity was shaped by the geological and climatic evolution of the Carpathians in connection to neighbouring areas and especially North Dobrogea and Black Sea. The geopark territory is covering three biogeographic regions: steppic, alpine and continental.

More than 80 habitats types were identified, a great number of species listed in different national and European directives for nature conservation and few endemic species like *Euscorpius carpathicus, Nitraria shoberi and Artemisia santonicum.*

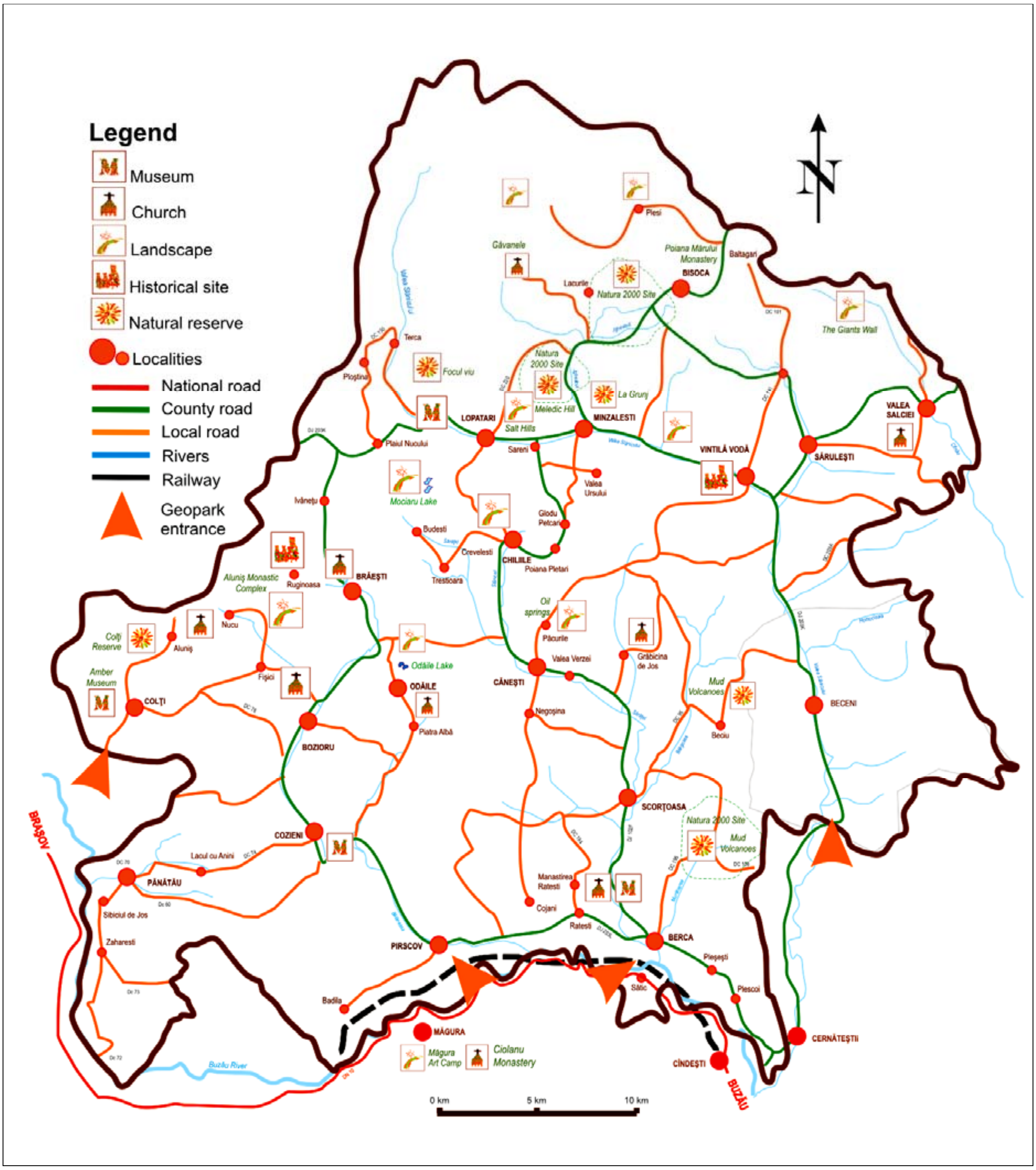

Fig. 3. Buzău geopark map

One of the most impressive historical and archeological characteristic of the geopark area is done by the old 40 monk caves and churches, dug since VI century (?) by orthodox Christians. For this reason the area is also known as the „Romanian Athos".

The geopark development is based on an initiative of the Buzau County Council in partnership with University of Bucharest and supported by 18 mayoralties and other local and national bodies and institutions. Interdisciplinary research studies were the key points to establish the optimal territory of the geopark and to set-up clear objectives for sustainable use of local resources and to generate partnerships for national and international projects in tourism, education and research.

Field trip itinerary (fig. 4)

- *Departure, Bucharest Students' House Gr.Preoteasa, Calea Plevnei, no. 61 - 07,30*
- *Bucharest - Urziceni - Buzau – Nehoiu- Siriu Dam: 7,30 – 11:00*
- *Stop 1 Nehoiu- Siriu Dam, Tarcău Sandstone, Eocene: 11,00- 12,30*
- *Siriu- Chirilesti-Valea Rea: 12, 30-13,00*
- *Stop 2 Chirilesti-Valea Rea: 13,00-13,30*
  Upper Kliwa Outcrop - (Oligocene -Lower Miocene)
- *Chirilesti-Valea Rea – Berca, Mud Volcanoes: 13,30-14,30*
  Paclele Mari: 14, 30-15, 45
  PacleleMici: 15, 45 – 16, 30
- *Paclele Mici – Buzău - Bucharest: 16:30-18:45*

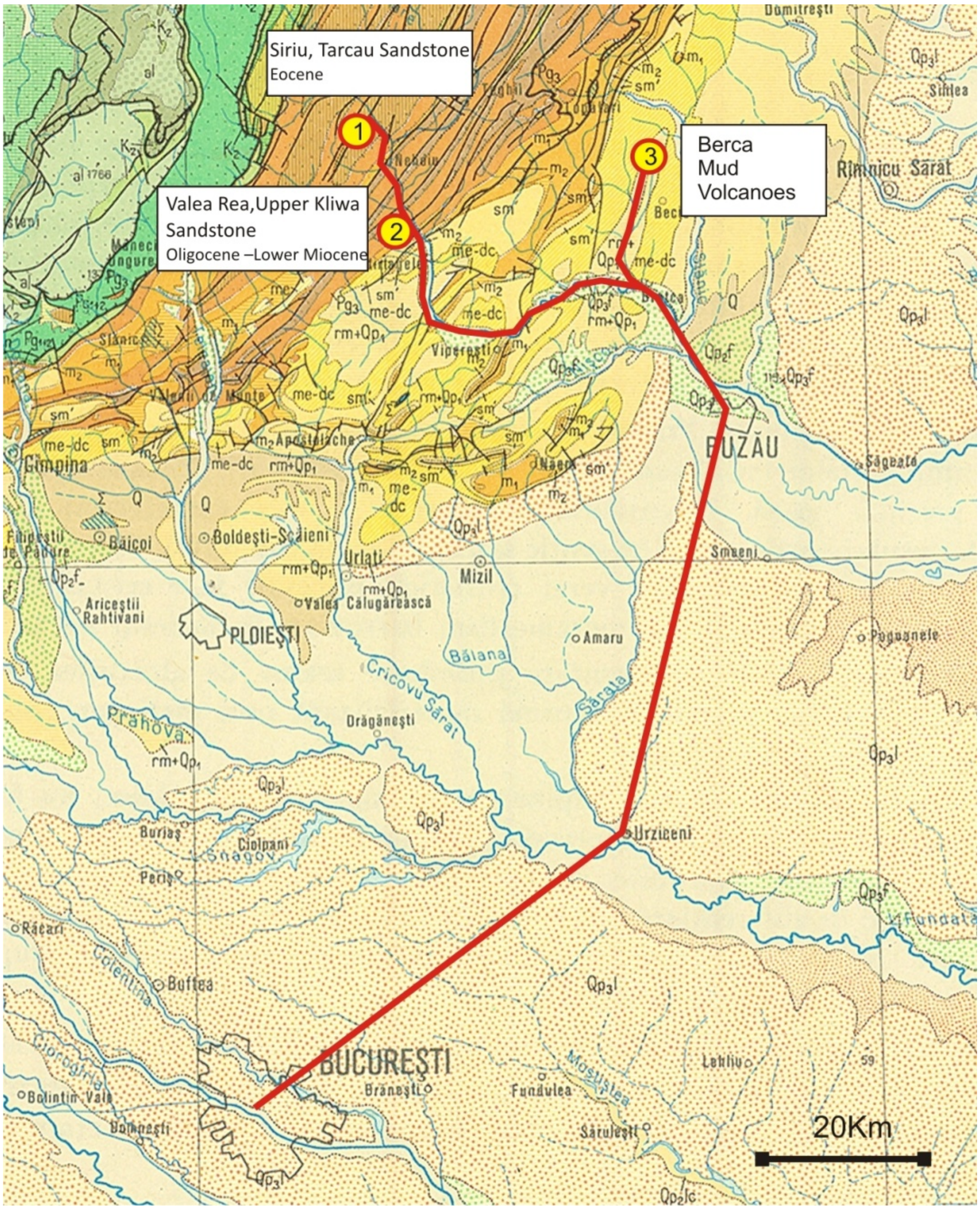

Fig. 4 Field trip itinerary. Geological map, 1: 1 000 000 (GIR)

Stop descriptions

Stop 1: Siriu - Tarcău Sandstone, Eocene

Tarcau Sandstone an almost 1500 m thick sanstone-rich unit which, outcrops in the Buzau Valley next to Siriu dam. However, the outcropping thickness in the study area is about 600 m. The measured section belongs to the upper part of the Tarcau Sandstone Formation and is more than 300m thick. Tarcau Sandstone is Eocene in age. At the base, there are Horgazu Beds, whereas at the upper part there are the Podu Secu Beds.

Lithology: facies and their hydrodynamic interpretations

Seven major facies types (F1 - F7) were recorded based on the following criteria: grain size, physical sedimentary structures and sand/shale ratio. F1 represents the coarsest facies and F7 the finest one (Table 1).

Table 1. Relation between facies types, transport and depositional mechanisms as referred here.

Facies	Flow type	Deposition	Flow behavior rheology
F1: megabreccia (chaotic deposit)	Cohesive Debris flow; laminar flow	Freezing	Plastic
F2: mudstone rafted clasts	Residual flow	Freezing	Plastic - Fluidal
F3: amalgamated, clast supported - graded conglomerates and sandstones	Hyperconcentrated flow	Freezing	Plastic - Fluidal
	Gravelly high density turbidity current	Settling from gravely turbulent suspension	Fluidal
F4: massive - graded conglomerate and coarse sandstones	Gravelly to sandy high density turbidity current; traction carpet	Settling from gravely turbulent suspension	Fluidal
F5: current-rippled fine-grained sandstones	Low density turbidity current (highly efficient - Mutti 1979, 1992, Mutti& Ricci Lucchi 1981, Reading & Richards 1994)	Settling from mud rich turbulent suspension	Fluidal
F6:thin bedded sandstone - mudstone couplets	Low density turbidity current	Settling from dilute turbulent suspension	Fluidal
F7: laminated red & green mudstones	Hemipelagic and pelagic deposition		

Sequence and facies model: The above mentioned facies (F1 to F7) represent depositional units and their association build the facies sequences that allow us to recognize depositional elements (Table 2).

The overall succession can be divided into two packages, each of them consisting of a finning and thinning upward turbidite sequence (system)(Fig. 5).

Table 2. Facies tract associations and depositional elements

Facies associations	Depositional elements
F3\F6\ (F4)	Channel (- overbank) complex
F4\F5\ (F7?)	Channel - lobe transition
F5\F6	Lobe complex (lobe - interlobe)
F7\F6	Basin plain

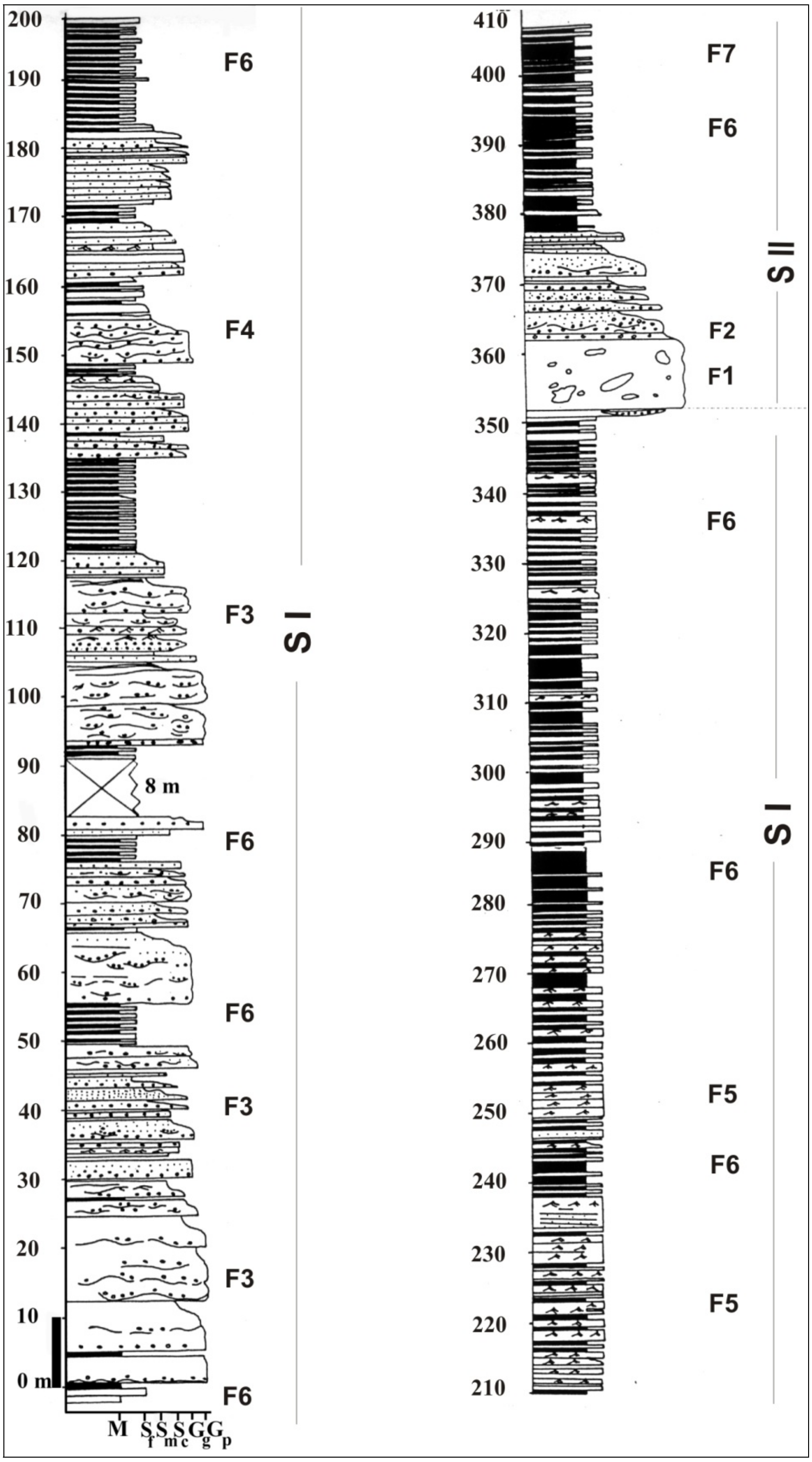

Fig. 5. Interpretation of the gradual vertical stacking pattern recorded in the measured section. Each system (I & II) has a general fining up (muddier - up) trend expressed as a progressive change in facies.

Stop 2 Chirilesti-Valea Rea: Upper Kliwa, Oligocene –Lower Miocene

In Chirilesti locality, on the left of the nr.10 National Road (Buzau – Brasov), the Upper Kliwa Sandstone outcrops in an abandoned quarry.Geotectonic setting is represented by Eastern Carpathians, TarcauNappe, Colti- Rea Valley Facies. Upper Kliwa Sandstone is Aquitanian in age. At the base, there are PoduMorii Strata, whereas at the upper part, the Dysodile Shales and Upper Menilites.

Lithology: On the reverse flank of a fold dipping southwards, there are sandstone sequences displayed in thick layers (sandy facies) and thin interbeds of dysodilicshales, (dysodilic facies), thin silts and sandstones.

Sandy Facies: Beds are of decimetre and meter thickness. The lateral continuity is good. Grain-sizing belongs to the arenites' range. Fine arenites are dominant, however, medium and coarse arenites are also encountered occasionally or even fine rudites in the base of some of the fining upward strata. The inner built structures are massive, fining upward and parallel laminated. Within the base of the depositional units, there are linear vectorial structures of flute casts type which points out an eastern source of the clastic material. The lower limits of the beds are net and flat as well as erosional, accompanied by mud clasts. The upper limits are graded towards silts and dysodile interbeds. Cases have been encountered when the lower limits are graded from fine dysodilic facies. Petrographically, the arenites are quartzite and subquartzose sandstones (>90% quartz), (Grasu, 1988,Anastasiu et al., 1999), (fig. 6)Subordinately, there are encountered lithic sandstones within the base of some graded beds where the coarse arenites and fine rudites (granules) prevail consisting of anchimetamorphic lithoclasts of "Dobrudja-type" green schists.

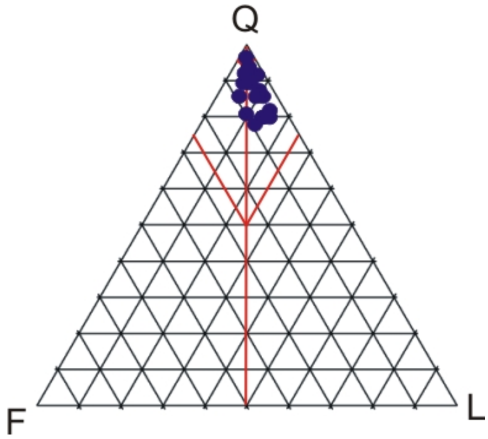

Fig. 6. Petrofacies of Kliwa Sandstone: Quartzose and subquartzose sandstone (Grasu, 1988, Anastasiu et al., 1999)

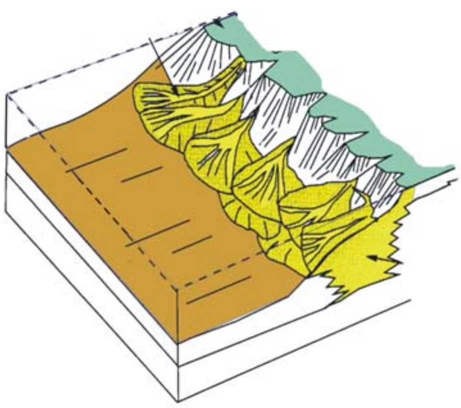

Fig. 7. Facies Model proposed for Kliwa Sandstone, arenitic turbiditic system, with eastern linear source in Anastasiu, et al., 1994

Dysodilic Facies: Interbeds of centimetre and decimetre thickness, consisting of parallel laminated bituminous shales, millimetre-thick silts and centimetre-thick sandstones with asymmetric ripples at the top. There are cases when the whole dysodilic microsequence displays syn-depositional deformations, of convolute lamination type. The arenitic interbeds are also quartzite and subquartzose sandstones.

Hydrodynamic interpretations: The massive sandy structures suggest gravity flows of densely concentrated flows type where the clasts-supporting mechanism is mainly the particle collision and subordinately the turbulence. In case when the turbulent component prevails, the normal graded beddings and flute marks are formed at the bed base. The shales were formed by suspension settling, while the fine thin silts and arenites with top ripples resulted from traction processes. They can represent facies at the end of turbidity currents. The fact that there are *load casts* in the base of coarse sandstone strata points out a very high rate of sedimentation. The convolute laminations in the dysodilic facies suggest syn-depositional deformations along the slope - *slumping*.

Sequence and facies model: The sequences are of a CUS (*coarsening upward sequence*) type, in case when progressive grading from dysodilic facies to sandy facies takes place. The former are interpreted in the terms of turbidite lobes deposited at the slope base. The FUS (*fining up*) sequences, with an erosional base, suggest channel facies which supplied the turbidite lobes (Fig. 7). Due to the very good lateral extension, these sequences have been interpreted in the terms of the arenitic turbidite systems having a linear source with the eastern source supported by both the paleocurrents measurements (Contescu et al., 1966) and the petrographic studies, given by the existence of lithoclasts of "Dobrudja-type" green schists (Anastasiu, 1984).

Economic Bearings: The high degree of lobes and channels connectivity provides for a good quality of hydrocarbon reservoir rock. This quality is strengthened by good values of porosity (22-29%) and permeability (100-400 mD). As a matter of fact, the Kliwa Sandstone represents the main hydrocarbon reservoir of Tarcau Nappe. The hydrocarbon source is represented by the stratigraphic units of the Lower and Upper Dysodiles, with high organic matter content.

Stop 3 - Berca – Arbanaşi Oilfield – Mud Volcanoes

The structural Berca – Pâcle - Beciu – Arbanasi alignment is developed along approx. 30 Km within the Subcarpathian Nappe and it is constituted of an anticline fold longitudinally and transversely tectonized through a fault system which makes that the relation between the structure flanks differs from one zone to another.

In the axial zone of the fold, Meotian and Sarmatian sedimentary deposits outcrop. The drilled wells (the deepest is over 3330m) cross a succession of beds belonging to the Sarmatian, Meotian, Pontian, Dacian and Romanian (Fig. 8). The lithological bed succession comprises more arenaceous levels than the adjacent areas (Moreni, Boldesti); the Meotian includes 27 sand levels among which most of them are productive. The Meotian hydrocarbon accumulations are accommodated in a number of sand beds different from one block to another. The nature of the fluids in the accumulations and their distribution within the alignment are different; the eastern flank is productive in all sectors of the structure (with oil, with or without primary gas cap and more rarely free gas), while the western flank is producing only at Pacle and Beciu (oil with primary gas cap and free gas).

The existence of numerous faults as well as the outcropping or the very high structural position of the hydrocarbon-saturated Meotian deposits led locally to the partial deterioration of the conditions of fields sealing. The longitudinal and transverse fault system created pathways of hydrocarbon (especially gas) migration to the surface, what brought about the occurrence of the spectacular phenomenon of Muddy Volcanoes. Along their way to the surface, the gas and the formation water drive the pelitic material and form mud which “erupts” in the area, in a few spots.

The phenomenon of the Mud Volcanoes crops up in a striking way close to Berca, at Paclele Mari and Paclele Mici. This area has been included in the list of the areas protected in Romania.

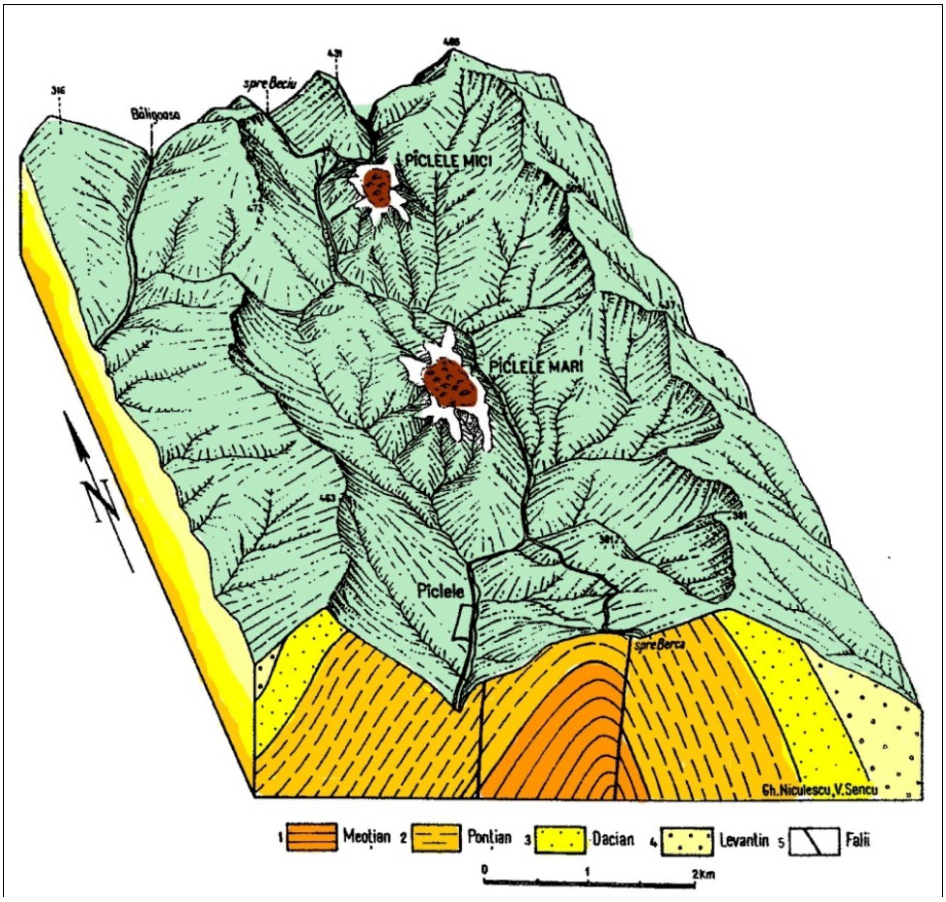

Fig. 8. Berca – Arbanaşi structure. Mud Volcanoes

The geological and botanical reservation *Mud Volcanoes* covers an area of approx. 30 hectares and comprises two areas: Paclele Mici and Paclele Mari.

The Paclele Mici plateau represents a 9.4 ha natural reservation ever since 1924. The object of the protection is the landscape displayed by the relief and the presence of two halophile plant species – *Nitraria schoberi* and *Obione verrucifera*.

At Paclele Mici, there is the largest number of volcanoes having cones, craters with highly varied sizes as well as complex morphology, on the one hand resulted from the mud accumulation and on the other hand by rain water streaming.

The volcanoes occur in groups of 3-5 units being of 2-8m high, with craters of 10-100cm diameters wherefrom viscous mud comes out, flowing as tongues which reach 20-50cm in length.

Pâclele Mari is situated at a few kilometres to the north-east. The name is connected to the very large sizes of three main volcanoes having diameters of over 100m, which are lying in the centre of the plateau. The flanks of the cones are very widely spread, several cones of secondary volcanoes and long violet-blue mud tongues occur onto the former. The external half of the plateau is fragmented by ravines, torrents, developing scenery of badlands. The natural reservation covers an area of 19.6ha.

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