Types of Stratigraphic Traps in Tertiary Deposits of the Eastern Slovakia

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Abstract

Tertiary sediments of the Eastern Slovakia were deposited in the Eastern-Slovakian Basin, Inner-Carpathian Paleogene Basin and basins of the Outer Western Carpathians represented by Magura and Dukla Units. In the first basin shallow-water conditions prevailed during the deposition and the most common types of perspective hydrocarbon traps are represented by architectural elements of deltaic and shelfal environments. The second and third areas are typical by predominant deep-water sediments forming basic types of the most perspective traps: canyon fills, deep-water distributary channels and lobes comprising basic architectonical elements of turbidite depositional systems. Tapering fan-deltaic fronts on steeply inclined ramps are also valuable from the view point of hydrocarbon prospection.

Key words: *Stratigraphic **T**raps in **T**ertiary **D**eposits, hydrocarbon traps*

Introduction

After discovery and gradual exhaustion of the largest hydrocarbon structural reservoirs the attention of the oil companies turn toward the prospection of small structural-stratigraphic and stratigraphic hydrocarbon traps. This situation, characteristic for many countries of the world, has been analogous in the Slovakia. The first hydrocarbon prospection, aimed at the finding of tectonic structures in the areas of former Czechoslovakia, was realized by Czech Oil Mines. In the framework of this prospection several thousand counter-flash-type boreholes were drilled in the most perspective regions of the country - in the areas of Vienna, Danube and East-Slovakian Basins. The main objective of the boreholes was to obtain knowlege on basic tectonic structure. Based on this deep boreholes were planned resulting in findings of important reservoirs (Jiříček, 1996). New tectonic conceptions, also applied in the Czechoslovakia, development of sedimentology as well as application of new technologies in the geophysical prospection (seismics, electricity logs) resulted in change of the prospection paradigm. Already in 1968 based on biostratigraphy and palaeoecology a deltaic body in the East-Slovakian Basin was identified (Jiříček, 1968). The results of this analysis showed new possibilities in the hydrocarbon prospection. New knowledge from the area of basin tectonics, seismostratigraphy and sequence stratigraphy (e.g. Vail, 1977, Busby and Ingersoll, 1995) deeply changed methodology of the evaluation of the regions from the view point of hydrocarbon prospection.

Tectono-sedimentary position of the Tertiary basins in the Eastern Slovakia

Play concept analysis, used for the prospection of perspective hydrocarbon areas, requires analysis of several factors. One of them is knowledge on basin type, main structural and tectonic events as well as knowledge on basin structure, stratigraphy and main lithological units of basin fill. From the view point of these factors the basins of the Eastern Slovakia may be divided into three basic types: East-Slovakian Basin, Inner-Carpathian Paleogene Basin and basins of the Outer Western Carpathians represented by Magura and Dukla Units. The different tectonic and sedimentary evolution of these basins resulted in different types of perspective stratigraphic traps in their sedimentary fills. According the prevailing sedimentary condition and basin development the basins may be divided into basins with shallow-water conditions and basins with deep-water conditions.

Shallow-water settings: East-Slovakian Basin

The East-Slovakian Basin is a basin with complex tectonic history determined by oblique subduction of an oceanic slab occurring between the North-European Platform and the ALCAPA plate at the onset of its origin and later also combined with the thermal extension induced by rising asthenosphere far away in hinterland. The basin represents an autonomous part of the Transcarpathian Basin extending mostly on the Slovak territory. It is filled by the Neogene clastics, volcanics, caustobioliths and evaporites thick up to 9 km. Genetic type and spatial distribution of deposits varied during the basin evolution depending on tectonics, volcanic activity, sea level

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changes as well as sediment input (Vass et al., 2000). The onset of deposition in the East-Slovakian Basin is closely related to the termination of deposition in the Inner-Carpathian Paleogene Basin (Janočko et al., 1999, Jacko and Janočko, 2004) in the Early Miocene - Eggenburgian. After a period of non-deposition in the Ottnangian, the sedimentary evolution renewed in the Karpatian and continues as long as Romanian.

Complex tectonic and sedimentary evolution of the basin resulted in formation of numerous tectonic and stratigraphic hydrocarbon traps. The most potential stratigraphic traps in the sedimentary fill of the East-Slovakian Basin are represented by deltaic and shoreface sandstone bodies sandwiched by surrounding shales. The most perspective, but also active reservoirs, occur in the Upper Badenian and Lower Sarmatian Klčovo Formation and Lower and Middle Sarmatian Stretava Formation. The first formation represents mostly deltaic sediments often known as "Sečovce delta" (Jiříček, 1968, Janočko, 1992, Řeřicha, 1992), the second one is mostly represented by inner- and outer-shelf deposits (e.g. Janočko, 1992). However, new results based on sedimentological research, seismic and sequence stratigraphy suggest also other stratigraphic units of the sedimentary fill as highly perspective.

The most perspective stratigraphic traps include two main architectural elements recognized in the deltaic sedimentary system of the East-Slovakian Basin - distributary channels and mouth bars. Both of them may be defined both from the outcrops and their subsurface analogues recorded by seismic lines and electricity well logs.

The distributary channels comprise fill of erosive features visible on seismic profiles as curved lines cutting the underlying reflectors. The reflectors are laterally restricted (Fig. 1). The channel fill is well visible on SP curves - typical is box-like shape of the curves with flat base and top (Fig. 2).

The mouth bars are depicted on the seismic profiles as prograding reflectors with striking downlap geometry (Fig. 1). The progradation is also confirmed by SP curves where the mouth bar are defined as turn bell-shaped forms (Fig. 2).

The shoreface deposits, developed mainly in Lower - Middle Sarmatian Stretava Formation, are typical by three main types of responses: 1, box-like shape of curve with flat base and top intepreted as thick massive sand beds without mud drapes. The thickness of these beds is up to 10 m; 2, a succession of closely-spaced pointed responses where SP is not pull all the way back to the shale baseline. The values of SP decreases upward suggesting upward-fining thin-bedded sand beds interfingered by mud drapes. The described intervals are up to 20 m thick; 3, pointed responses interpreted as thin sand beds, the thickness of beds is up to 3 m.

The box-like shaped responses of SP logs (type 1) occur only in boreholes located closer to the basin margin. In these boreholes they usually pass or they are alternating with closely-spaced pointed responses (type 2). The upper part of the logs consists of pointed responses (type 3). The succession of the response types is interpreted as transgressive delta where interdistributary channels (type 1 and 2 responses) pass into sand bars of nearshore (type 3 response). The interpretation is consistent with the interpretation of depositional environment inferred from the outcroping deposits on the basin margin (Janočko, 2004). The pace of high SP values ranges from 20 - 30 m in the lower part of logs and 30 - 40 m in upper part of the logs suggesting lower order cyclicity than observed on deposits outcroping on basin margin. This cyclicity is probably caused by allocyclic mechanism, however, the main reason (fluctuation of sediment input?, sea level?, tectonic activity?) is not clear. The boreholes situated basinward only show pointed responses (type 3) suggesting thin sand bodies enveloped by basinal shale. The cores responding to the intervals of pointed readings show ripple-cross laminated, medium-grained sandstone interpreted as nearshore bars originated by wave action (Janočko, 2004).

Deep-water settings: Inner-Carpathian Paleogene Basin and Outer Western Carpathians basins

The largest Slovakian Paleogene basin developed south of the Klippen belt is Inner Carpathian Paleogene Basin. Initial evolutionary stage of the basin is assumed in the conditions of oblique convergence during retreating subduction boundaries, when the thrusting velocity of the upper plate was lower than the velocity of retreat of the lower plate (e.g. Royden, 1993, Janočko, 2002, Janočko et al., 2003). The retreating subduction boundary resulted in prevailing compressional regime at its front (the area of the Outer Carpathians) and extension in the tail. Based on large foraminifera analyses (e.g. Kohler, 1998) found in the sedimentary basin fill, the beginning of the extension is assumed in Middle Eocene – Lutetian. Sediment distribution and N-S asymmetry of the basin clearly indicated by seismic profiles and boreholes suggest initial opening of the basin close to the subduction zone today indicated by the Pieniny Klippen Belt position. The basin fill consists of terrestrial, shallow- and deep-water deposits with total thickness over 3 km.

The area of *Outer Western Carpathians* in the Eastern Slovakia has a typical folded and thrusted structure of an accretionary wedge consisting of Magura and Dukla Units mainly composed of Late Cretaceous - Oligocene siliciclastic, deep-marine sediments. Originally, the units represented sedimentary areas of the northern Tethys, isolated in certain evolutionary stages by elevation structures (Golonka et al., 2000). The primary Middle-to Late-Jurassic rifting (Pescatore a Slaczka, 1984) evolved into post-rift stage of thermal basin disintegrations commenced during the Lower Cretaceous, remnant oceanic basin and finally, foreland basin in the Oligocene (e.g. Oszcypko, 1999). The main mechanism triggering the basin subsidences was the crust flexure due to subduction processes and related formation of the accretionary wedge, which loaded the crust. The basin fill, tectonically intensively deformed, is up to 9 km thick.

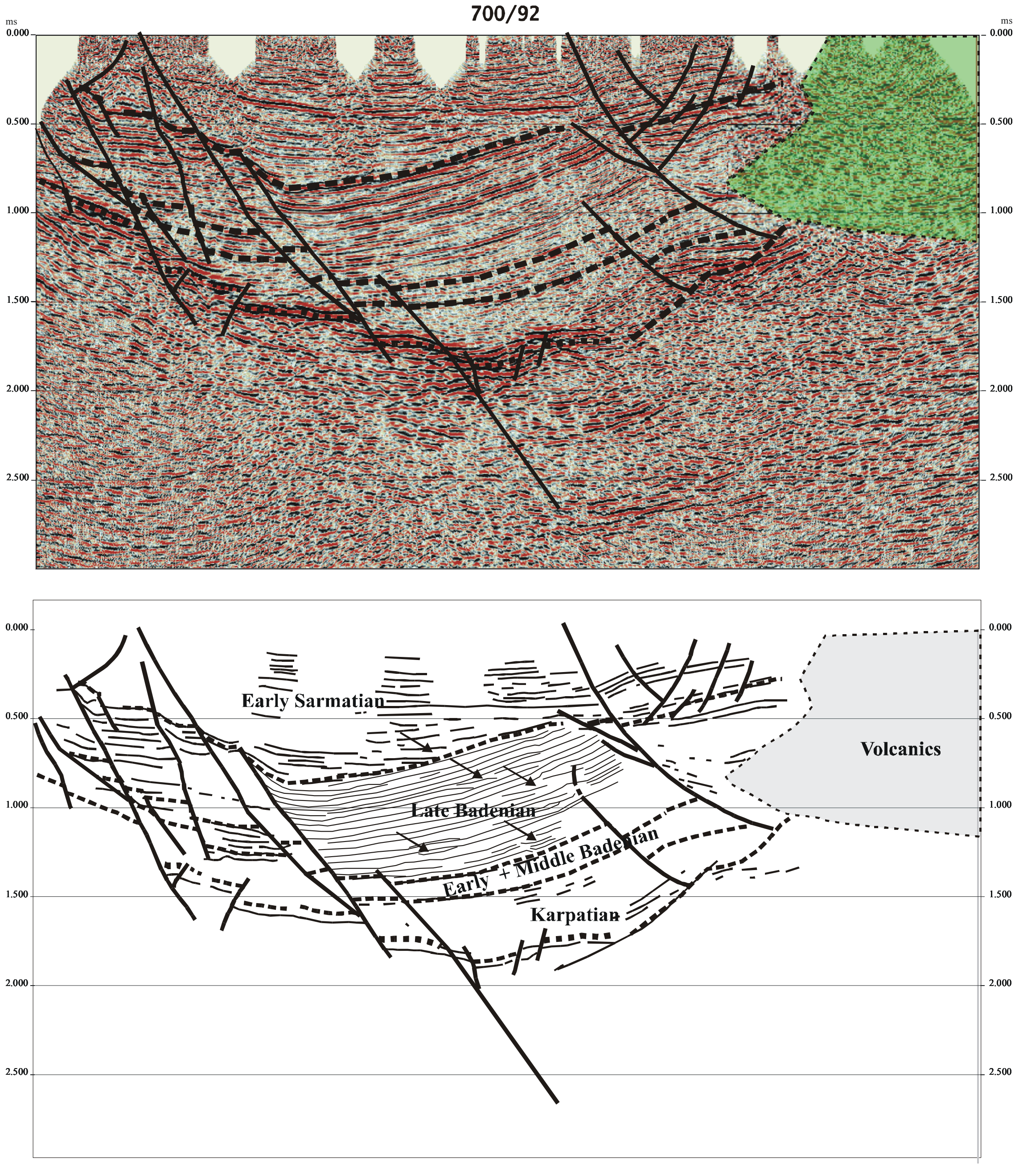

Fig. 1: Seismic profile 700/92 and the interpretationn of the Late Badenian part. Note the downlap of reflectors interpreted as mouth bar deposits indicators and reflectors suggesting erosion of distributary channels.

The potential stratigraphic traps in the deep-water setting are represented mainly by canyon fill deposits, deep-water fan distributary channels and deep-water lobes. On the steeply inclined ramps on the basin margins, wedging out lobes of fan deltas may also play role as significant traps for hydrocarbons.

Canyon fill deposits are characterized by thick, coarse-grained succession sandwiched by basinal mudstones. Such deposits, reported from the Spišská Magura region (Janočko and Jacko, 1999) may be up to 200 m thick and have complex internal structure. In seismic sections they form distinctive reflectors cutting down into the underlying reflectors.

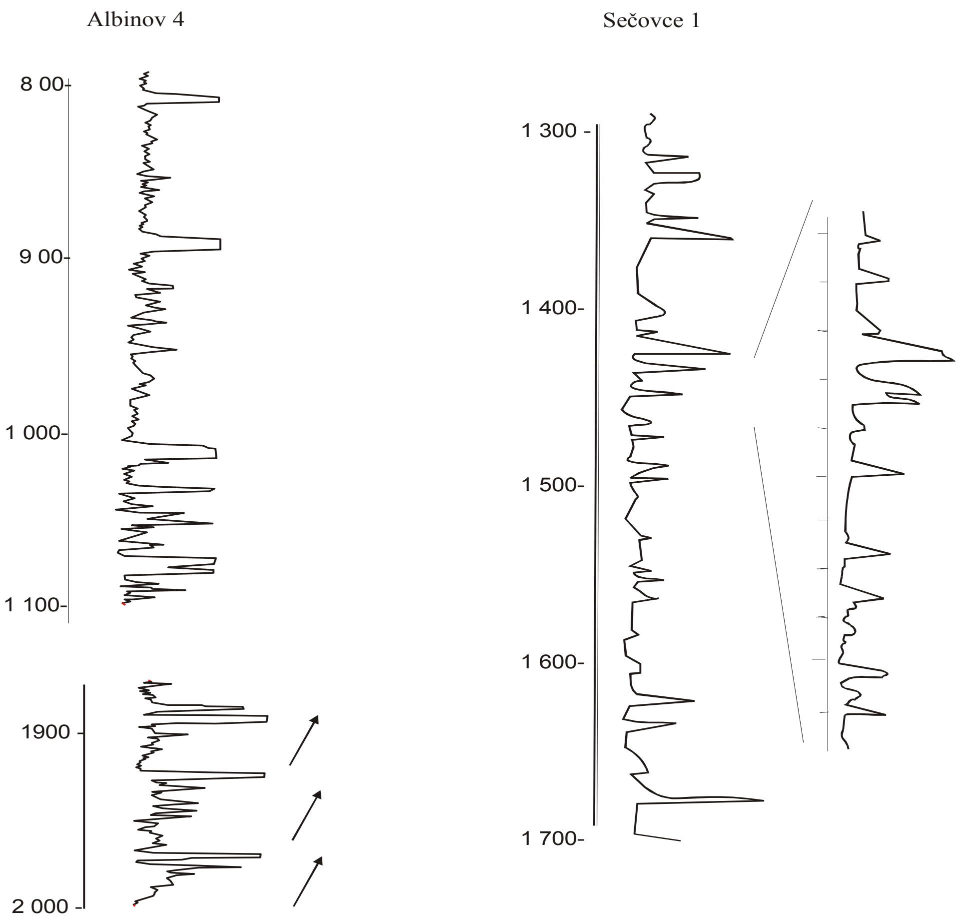

Fig. 2: SP responses of deltaic and shoreface deposits. On the upper left side SP response suggesting distributary channels of Upper Badenian delta. The lower left side shows SP response for mouth bars of this same deltaic system. On the right side of the figure SP responses of shoreface bars are shown.

Deep-water distributary channels belonging to turbidite systems represent linear structures enveloped by interdistributary heterolithic facies. Inspite their linear structure, superimposed channels may be successfuly recognized in the seismic profiles and electricity well logs. Typical is their box-like shape with flat base and top. The thickness of individual channels usually do not exceed 10 m (Fig. 3).

Deep-water lobes with sheet-like geometry represent one of most potential hydrocarbon reservoir type. The thickness of individual lobes is about 10 m (Fig. 3). Typical is their upward-thickening trend as a result of compensation cycles (e.g. Nilsen, 1995). The lobes have reverse bell-shaped form in the SP curve record and concave geometry of reflectors in seismic profiles.

The last, most common type of the hydrocarbon trap is comprised by tapering lobes of fan-deltaic fronts usually developed on steeply inclined ramps. The coarse-grained, mostly gravelly and sandy lobes of Markušovce fan delta show alternation with shoreface deposits in several cycles reflecting mostly climatic oscillation (Janočko and Prekopova, 2004). The lobes gradually pass into outer shelf deposits where they alternate with shelfal mudstones representing good sealing rocks.

Conclusion

Tertiary deposits in the Eastern Slovakia, fill the Eastern Slovakian Basin, Inner-Carpathian Paleogene Basin and comprise the Magura and Dukla Units of the Outer Western Carpathians. The first basin is characterized by shallow-water conditions during its evolution while in the second and third ones mostly deep-water deposition prevailed during the Tertiary.

The most perspective stratigraphic hydrocarbon traps in the East-Slovakian Basin are represented by sandstone bodies of deltaic and shoreface origin. From the deltaic environment these are mostly distributary channels and mouth bar bodies. The channels may be recognized by their erosive features in the seismic profiles and by box-like shape recorded by SP curves. The mouth bars are typical by their upward-coarsening and upwar-thickening trend recorded on the SP curves as reverse bell-shape forms and on the seismic profiles as downlapping reflectors. In the sequence-stratigraphy framework, the mouth bar evolve mostly during the highstand system track while the distributary channels are characteristic for lowstand system track.

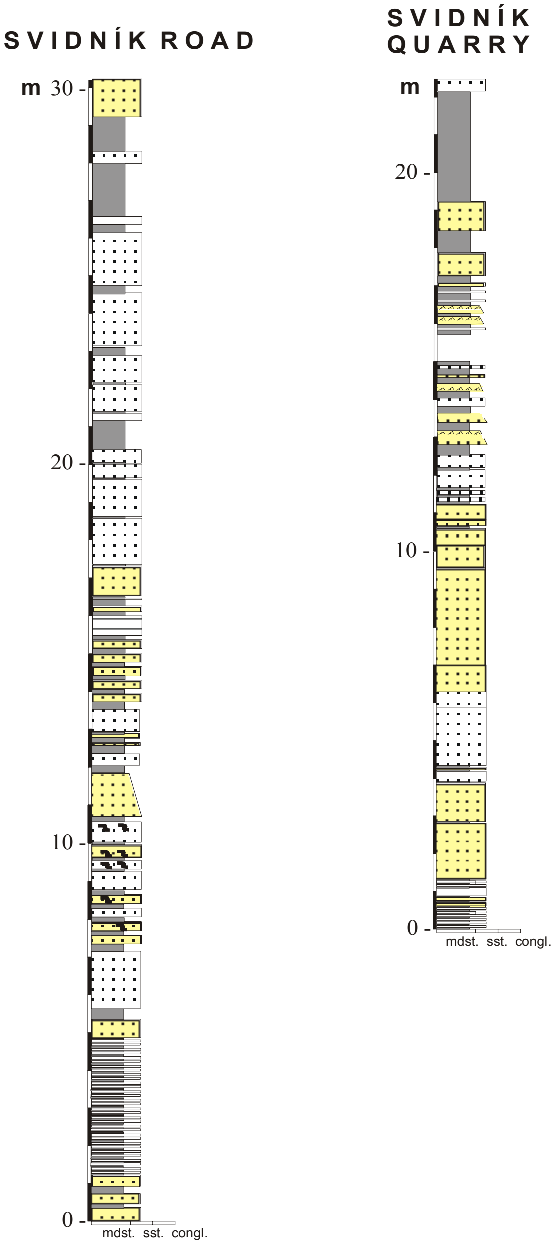

Fig. 3: Vertical succession of channel-and-levee deposits (left) and distributary channels (left) belonging to the deep-water turbidite system.

The most perspective stratigraphic traps in the deep-water settings are represented by tapering fan-deltaic fronts on the steeply-inclined ramps (e.g. Markušovce area near Spišská Nová Ves) as well as canyons, distributary channels and lobes of turbiditic systems.

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