STRATIGRAPHIC INTERPRETATION OF THE BADENIAN FORMATIONS IN THE ROMANIAN PART OF THE PANNONIAN BASIN – THE STEP FROM 2D TO 3D*

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1. INTRODUCTION

The area of investigation is located in Romania in the eastern part of the Pannonian Basin (Fig. 1) which started developing as an intramontane basin during Miocene times. The 3D survey subject to interpretation is located N of the Apuseni Mountains within a system of W–E trending middle and late Miocene grabens (Fig. 2).

Fig. 1 – Regional geological settings (Săndulescu, 1988). 1, Inner Dacides; 2a, Transylvanides and Pienides; 2b, Măgura group; 3a, Middle Dacides; 3b, Serbo-Macedonian massif; 4, External Dacides; 5, Marginal Dacides; 6, Moldavides; 7, Carpathian Foreland; 8, Vardar zone; 9, Inner Dinarides and Hellenides; 10, Outer Dinarides and Hellenides; 11a, basins; 11b, Neogene volcanics. Tr, Transylvanian basin; EEP, Eastern European Platform; SP, Scythian Platform; MP, Moesian Platform; ND, North Dobrogea orogen; EA, Eastern Alps; WC, West Carpathians; EC, East Carpathians; SC, South Carpathians; D, Dinarides; A, Apuseni Mountains.

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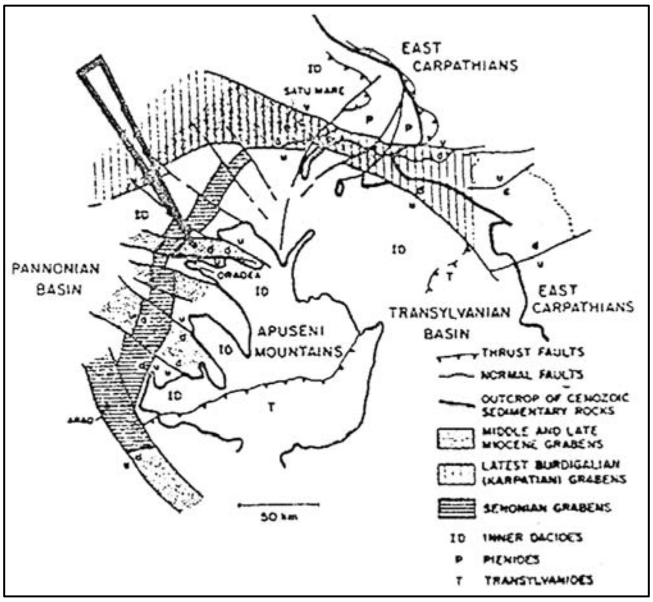

Fig. 2 – Regional structural settings (Săndulescu, 1988).

The sedimentary record starts with Cretaceous rocks directly overlying crystalline basement. With the opening of the grabens and rapid subsidence of the Pannonian Basin the Badenian Formation was deposited consisting of deep marine fans originating from the hinterland which was subject to major erosion. Subsidence and deep marine fan deposition continued throughout the Badenian and Sarmatian. After a minor break deposition of clastic sediments continued during Pliocene times (Table 1).

Table 1

Stratigraphic table for the area of investigation (after Steininger *et al*., 1988)

	MEDITERRANEAN STAGES	CENTR. PARATETHYS, ALP. / CARP. REALM	AREA OF INVESTIGATION
PLEISTOCENE	PLEISTOCENE	PLEISTOCENE	PLEISTOCENE
PLIOCENE	PIACENCIAN	ROMANIAN	PLIOCENE
	ZANCLEAN	DACIAN	
L. MIOCENE	MESSINIAN	PONTIAN	NOT PRESENT
	TORTONIAN	PANNONIAN	
M. MIOCENE	SERRAVALLIAN	SARMATIAN	SARMATIAN
	LANGHIAN	LATE / MIDDLE / EARLY BADENIAN	BADENIAN
E. MIOCENE	BURDIGALIAN	KARPATIAN / OTTNANGIAN	NOT PRESENT
		EGGENBURGIAN	
	AQUITANIAN	EGERIAN	
OLIGOCENE	CHATTIAN		
			CRETACEOUS

The area of investigation was longterm subject to exploration and several minor oil fields were identified. Exploration so far was based on 2D seismic data only which did not allow for accurate delineation of the reservoirs. In 1995 the first 3D survey was acquired within the area. The acquisition size is approximately 60 sqkm, bin size 25 m and sample rate 2 ms (Fig. 3).

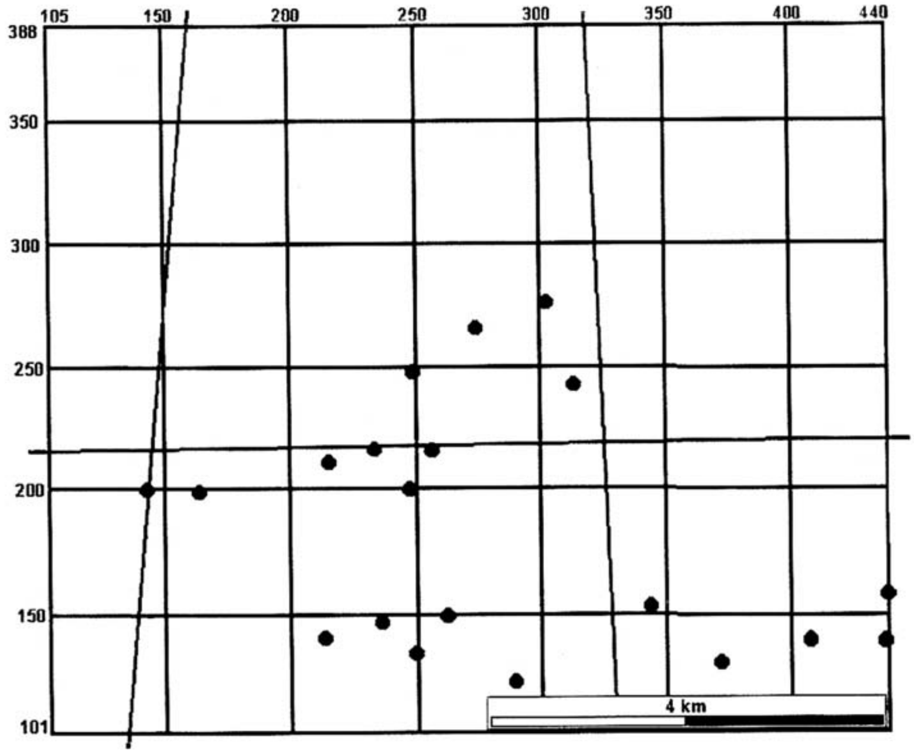

Fig. 3 – Location map.

The first part of this paper focuses on the comparison of 2D vs 3D, the second part deals with the structural and stratigraphic interpretation of the 3D survey and describes the methodology applied. The interpretation methodology and the results are highlighted using two examples from the stratigraphic sequence.

2. COMPARISON OF 2D vs 3D SEISMICS

In order to discuss the differences between 2D and 3D random lines were extracted from the seismic cube along existing 2D lines and were compared from the interpreters point of view. Two out of these lines are running approximately S–N following the general dip direction, the third one is a strike line running in E–W direction (Fig. 3).

When comparing the dip-line in the western part of the area (Fig. 4) it is obvious that both vertical and lateral resolution are strongly enhanced in the 3D section. Still in principle the main unconformities identified from 3D seismics are comparably well imaged in the 2D data. Major differences are related to the Top Cristalline (BSMT) which is not at all imaged in the 2D section but is very predominant in the 3D data. The anticlinal structure visible on the 2D line around CDP 800 is no longer visible on the 3D section. This might either be interpreted as a 3D effect, or, taking into account the E–W running line (Fig. 5) rather as a problem related to static corrections which was better resolved in the 3D data by applying an improved weathered layer model for the static corrections.

The dip-line in the eastern part of the area (Fig. 5) proves in general the statements of the previous section, i.e. an improvement of resolution and better imaging of the basement in the 3D data. In addition the Badenian internal reflections are better resolved in the S allowing for better definition of discontinuities in this area. The reverse fault in the S cannot be interpreted from the 2D data.

Finally the strike line (Fig. 6) highlights the overall advantages of 3D vs 2D besides the ones already mentioned above: 3D migrated data do not suffer from side effects like information from updip which of course cannot be resolved by 2D migration. Such side effects result in a drastic decrease of vertical resolution and overall poor reflection continuity. A reasonable correlation of events is not possible in the 2D data. Normal and reverse faults clearly imaged in 3D are not imaged on the 2D section.

The following conclusions summarize the review of 2D vs 3D data:

- Vertical and lateral resolution is better in the 3D data which is to be expected due to 3D migration.
- Dip-lines allow in principle for identification of the main surfaces of discontinuity in both 2D and 3D, however the internal reflection configuration is better imaged in 3D.
- 3D effects downgrade the use of 2D data in strike direction. It is not possible to reliably correlate the surfaces of discontinuity based on 2D data. Thus a reliable delineation of potential updip pinchouts is not possible.
- The given data density of the 3D with a bin size of 25 m allows for extraction of seismic attributes in order to support the stratigraphic interpretation and to establish a depositional model.

3. INTERPRETATION

3.1. METHODOLOGY

The interpretation started with the correlation of the main unconformities in the seismic cube based on the existing correlation of well markers. The picking of such surfaces of discontinuity, e.g. onlap and downlap surfaces of course required mainly manual picking of such events over the entire survey. The final correlation could be used to locally update the well marker correlation if required. This resulted in the general framework for the entire survey which formed the basis for further interpretation work (Fig. 8). In addition these results allow for discussion of the structural setting and the structural development of the area.

Within the second step surfaces of discontinuity were identified and correlated in between previously mapped main unconformities for the reservoir intervals. Again this required detailed manual picking over the entire area.

These cycles identified were subject to AB/C-code mapping which was mainly done based on seismic attribute maps extracted using the mapped surfaces of discontinuity. The essential step here is to compare the features identified on the attribute maps with the actual reflection terminations and configurations on the vertical sections. Basically three different seismic attributes were used for these investigations (Figs. 7a, 7b, 7c).

The resulting maps formed the basis for the interpretation of the depositional environment, delineation of depositional bodies e.g. fans and the interpretation of the direction of the sediment influx.

Finally a curve of relative sea-level variations was established for the area of investigation, and play concepts for the entire area were developed. Based on such concepts new leads for exploration could be delineated and recommendations for further exploitation of existing fields could be given.

3.2. STRUCTURAL INTERPRETATION

The overall structural settings are discussed based on the depth contour maps of the main unconformities identified (Fig. 9). All maps show in principle a structural high in the southern part of the area (red colours) and a more or less continuous dip to the N.

Top Basement, mapped as a trend surface only, shows a WSW–ENE trending reverse fault separating the basement high in the S from the northern depression. This reverse fault is supposed to be related to rotational movements resulting in local compression. The reverse fault intersects the Top Cretaceous as well and approximately forms the southern boundary for the deposition of the lower Badenian Formation.

The isopach maps (Fig. 10) highlight the structural development of the area. The Cretaceous is thickest developed in the northern part of the area, drastic thinning S of the reverse fault (red colours) is related to erosion on the basement high. This is supported by erosional truncation of reflections and by the presence of Cretaceous rocks within the early Badenian fan deposits in the basin. Lower Badenian generally thins towards S, uplift and reverse faulting however are supposed to have occurred synsedimentary. Main depocentre of the lower Badenian was the NW of the area of investigation. N–S trending normal faulting in Cretaceous, lower and middle Badenian is interpreted to have occurred synsedimentary during the entire Badenian based on the thickness distribution of these intervals, while the reverse faulting/uplift of the basement high decreased. There was however slight relative uplift still during upper Badenian and Sarmatian indicated by a thinning of these intervals along the reverse fault trend. The NE remained the area of main subsidence during Sarmatian. The Sarmatian Formation onlaps on the Top Badenian in the S and is restricted to the northern part of the area after increasingly southward extension of the previous intervals. In addition Sarmatian was partly subject to erosion during the subsequent period of non-deposition.

3.3. STRATIGRAPHIC INTERPRETATION

The intervals in between the main unconformities of the Badenian Formation as well as the Sarmatian Fm were subject to a more detailed stratigraphic investigation. As an example in terms of procedures and results the upper Badenian will be discussed in the following in detail.

In line 250 (Fig. 11) shows the general settings of the area of investigation. Based on reflection terminations the intervals of interest can be further subdivided, e.g. the middle Badenian downlaps on the top lower Badenian (yellow marker in section). The upper boundary is defined by toplap reflection terminations, overall resulting in an internal sigmoid reflection patterns in this part of the section for the lowermost section of the middle Badenian.

The upper Badenian shows onlap reflection terminations on the Mid_Bad_HST marker at CDP 240, further to the S downlap reflection terminations (CDP 140–180) are visible. The onlapping events are interpreted to represent lowstand fan deposits, whereas the progradational pattern is regarded as deposits of the highstand systems tract.

Further subdividion of the fan deposits into two different fans is based on thicker sections in the deeper part of the basin (crossline 310, Fig. 12), where such subdivision based on onlapping and toplapping reflections becomes obvious. After correlation of these events over the entire area amplitudes were extracted 10 ms above the basis of both fans. The resulting amplitude map (Fig. 13) shows the onlapping of the fans onto the basis in both easterly and southerly direction. The lateral distribution of the lower fan is marked by the red line, with in general almost parallel reflection configuration at the basis (blue colours) and only one onlap position indicated by white/red colours cloe to the overall border of extension of the fan. The younger fan shows further onlap positions trending N–S perpendicular to the axis of the basin indicating sediment influx from the east along the basin axis.

The highstand systems tract defined based on the progradational patterns visible on the basement high in the S of the area is highlighted in more detail in the following figures. The reflection pattern in Fig. 14 shows at the basis onlaps to the SW and downlaps to the NE changing in the upper part of the section into a rather toplap/downlap pattern. Regarding the amplitude map (Fig. 15) extracted 10 ms above the basis of the highstand systems tract two lobes shedding from S to N are visible. The seismic line intersects the western lobe perpendicular to the direction of sediment transport, further to the N it rather follows the direction of sediment influx. A very much comparable picture is visible on the second dip-line (Fig. 16) with a rather complex reflection pattern at the basis and to the top a more progradational pattern. The eastern lobe is comparably intersected by this line as the western one was by the other line. This is highlighted on the correlation map (Fig. 17) extracted within the lowermost 20 ms of the interval. The correlation map basically shows the same feature of two lobes being shedded into the basin from S to N.

The top of the interval is generally marked by toplaps in the S of the area (Fig. 18). The amplitude map extracted 10 ms below the top of the interval (top upper Badenian) shows like the maps representing the basal section two lobes shedding into the basin from the S (Fig. 19). Like the maps of the basal section the northern part of the area shows almost uniform colours indicating a more or less parallel reflection configurating at both, top and basis of the interval. The more or less linear N–S trending element in the center of the area of the top section amplitude map is related to an incised channel removing the overlying Sarmatian Formation in parts of the area. The position of the channel appears to be related to a minor depression between the two lobes deposited during the upper Badenian.

3.4. RESULTS

The interpretation of the 3D seismic data allowed for establishment of the stratigraphic framework for the Badenian Formation (Fig. 20). It was possible to subdivide the Badenian into three cycles each consisting of lowstand fans and slope fans being restricted to the basinal area in the N of the area of investigation and overlain by highstand systems tract deposits covering almost the entire area. The fall of sea level at the end of each cycle resulted in formation of major unconformities prior to restart of sedimentation in the deeper part of the basin with onlapping fan deposits. The highstand systems tract terminating the lower Badenian cycle was not correlatable over the area due to the fact that it was beyond seismic resolution. Top Badenian forms another regional unconformity, a comparable cycle of rising sea level of however minor extend occurred during the Sarmatian.

The structural interpretation did not result in any structural closures, thus based on the stratigraphic framework established the following stratigraphic play concepts were identified:

- Updip pinchout of fan deposits against regional unconformities, i.e. highstand deposits which in the deeper part of the area anticipated to consist of fine grained, low porosity and permeability deposits. Optimum position is given in case these highstands are overlain by deposits of the subsequent highstand (Fig. 21a).
- Incised channels on the basement high in the southern part of the area. These channels were incised during times of low sea level and filled with coarse grained sediments during transgressive/highstand systems tract. The channels are overlain by highstand deposits forming the seal. In addition an updip pinchout of such channel deposits is required (Fig. 21b).

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INTERPRETAREA STRATIGRAFICĂ A FORMAȚIUNILOR BADENIENE ÎN ZONA ROMÂNEASCĂ A BAZINULUI PANONIAN – EVOLUȚIA DE LA 2D LA 3D

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(REZUMAT)

În explorarea pentru hidrocarburi din România, prospecțiunea seismică 3D nu a avut un rol fundamental până în 1989. Totuşi, în condițiile absenței accesului la tehnologia de vârf, a existat preocuparea pentru introducerea seismicii 3D atât pe uscat, cât şi pe mare. I.P.G.G. a găsit soluții adaptate dotărilor existente în cadrul întreprinderii. Pe uscat, la achiziție s-au proiectat geometrii de teren ce foloseau echipamente de înregistrare de 48 şi 96 de canale, cuplate, la prelucrare s-au scris softuri speciale etc.

Primul proiect seismic 3D, executat cu tehnică modernă, s-a realizat de către Petrom în anii 1995, 1996 în Bazinul Panonic. Proiectul a fost executat în zona Chişlaz – Pocluşa, obiectivul geologic fiind formaţiunile badeniene şi sarmaţiene, în principal fiind depozite de tip conuri submarine.

Capcanele sunt de tip stratigrafic, efilări pe pantă, de granulometrie grosieră, conuri submarine regresive, prisme de nisip regresive, bine sortate în cadrul secvenţelor de nivel inferior, şi văi formate în perioada căderii nivelului mării şi colmatate ulterior.

Lucrarea prezintă comparativ atât calitatea superioară a datelor seismice 3D faţă de cele anterioare 2D, cât şi principalele concluzii rezultate din interpretarea stratigrafică a cubului de date.

Interpretarea stratigrafică a condus la identificarea a trei secvenţe depoziţionale, la conturarea unui cortegiu de “lowstand system tract” şi transgresiv/ “highstand system tracts” în interiorul acestor secvenţe.

S-a investigat, în detaliu, istoria structurală şi depoziţională a bazinului. Contextul stratigrafic a dus la identificarea zonelor cu potenţial de hidrocarburi şi la recomandări privind dezvoltări viitoare în explorarea şi conturarea zonelor cu potenţial de hidrocarburi.

Key words: inline, crossline, 3D imaging, side effect, seismic attribute, lowstand, highstand.