CONSIDERATIONS REGARDING THE OPPORTUNITY TO CONTINUE USING THE SARMATIAN VII OBJECTIVE WITHIN THE ZD STRUCTURE AN UNDERGROUND NATURAL GAS STORAGE DEPOSIT

CONSIDERAȚII PRIVIND OPORTUNITATEA CONTINUĂRII UTILIZĂRII OBIECTIVULUI SARMAȚIAN VII DIN CADRUL STRUCTURII ZD CA DEPOZIT SUBTERAN DE ÎNMAGAZINARE A GAZELOR NATURALE

Costin Viorel VLĂȘCEANU[1] Marius STAN[2]

Abstract: *The ZD structure represents an important accumulation area, constituting a gaseous structure of domal type separated tectonically into two blocks. The gas deposits discovered in the formations belonging to the age of Sarmatian, Buglovian, and Badenian, are arranged over a depth range, between 400 and 2800 meters. The Sarmaţian VII gas complex, on the ZD vault, selected as a candidate to be arranged as an underground gas storage depot, is made up of a succession of porous-permeable layers (sands, sandstones, and marly sandstones), with a thickness of up to at 110 m. The present research represents an update of both the previous works and the model of the deposit on the researched structure. The technical accident from May 2009 at the W7 probe and the partial access of the 3D seismic cube were analyzed on the one hand.*

Keywords*:* reservoir, underground gas storage, injection cycle, extraction cycle.

Rezumat: *Structura ZD reprezintă o zonă de acumulare importantă, constituind o structură gazeiferă de tip domal separată tectonic în două blocuri. Zăcămintele de gaze descoperite în formaţiunile aparţinând ca vârstă Sarmaţianului, Buglovianului şi Badenianului, fiind dispuse pe un interval de adâncime, cuprins între 400 şi 2800 metri. Complexul gazeifer Sarmaţian VII, de pe boltirea ZD, selectat ca şi candidat pentru a fi amenajat ca depozit subteran de înmagazinare gaze, este alcătuit dintr-o succesiune de strate poros-permeabile (nisipuri, gresii şi gresii marnoase), cu o grosime de până la 110 m. Prezenta cercetare reprezintă o actualizare atât a lucrărilor anterioare*

---

[1] Lecturer Ph.D. Eng., Dept. of Petroleum Geology and Reservoir Engineering, Petroleum and Gas University of Ploiesti, Romania, e-mail: viorel.vlasceanu@upg-ploiesti.ro

[2] Associate Professor Ph.D. Eng., Dept. of Mechanical Engineering, Petroleum and Gas University of Ploiesti, Romania, e-mail: mstan@upg-ploiesti.ro

cât și a modelului de zăcământ de pe structura cercetată. Au fost analizate pe de o parte accidentul tehnic din mai 2009 petrecut la sonda W7, iar pe de altă parte accesului parțial al cubul de seismică 3D.

Cuvinte cheie: zăcământ, înmagazinare subterană a gazelor, ciclu de injecție, ciclu de extracție.

1. Introduction

The ZD accumulation area, with an area of about 70 km^2, is a tectonic gas dome-type structure separated into two blocks.

From a geological point of view, the ZD structure is located in the Transylvanian Basin, a basin that was part of and evolved together with the large epicontinental sea Paratethys during the Oligocene-Miocene, extending from Central Europe to Lower Asia. The gas reservoirs discovered in the formations belonging to Sarmatian, Buglovian, and Badenian are arranged on a depth range, between 400 and 2800 meters. The storage activity started in 2004 and lasted until 2009. During this period, 4 cycles of injection-extraction were operated, the storage activity being stopped beginning in 2009, and the installations being preserved. For the first injection-extraction cycle from 2004-2005, 9 existing wells were used, which were converted into storage wells. In the last storage cycle in 2009, 6 of the existing wells were used plus 2 new wells [1].

The existence of gas accumulations in this area was highlighted in 1929, the geological research and exploration work continues even today. Natural gas extraction began in 1954 and gradually developed with the discovery of new gas complexes. About 45 million St.m^3 gases were extracted, the combined production representing 71 % of the initial geological gas resources. The Sarmatian VII gas complex on the ZD vault is made up of a succession of porous-permeable layers (sands, sandstones, and marly sandstones), with a maximum thickness of 110 m, separated by impermeable intercalations, made of marls and clays, with thicknesses of up to 4 m [2].

The extraction rate caused the reservoir pressure to decrease at the beginning of the injection process to about 79 % of the initial one. The value of the gas recovery factor achieved at the end of the gas exploitation stage in the Sarmatian VII field is 86 % and justifies the conclusion according to the elastic expansion of the gases ensured to a large extent the displacement of the extracted fluids.

The main objectives of this article are:

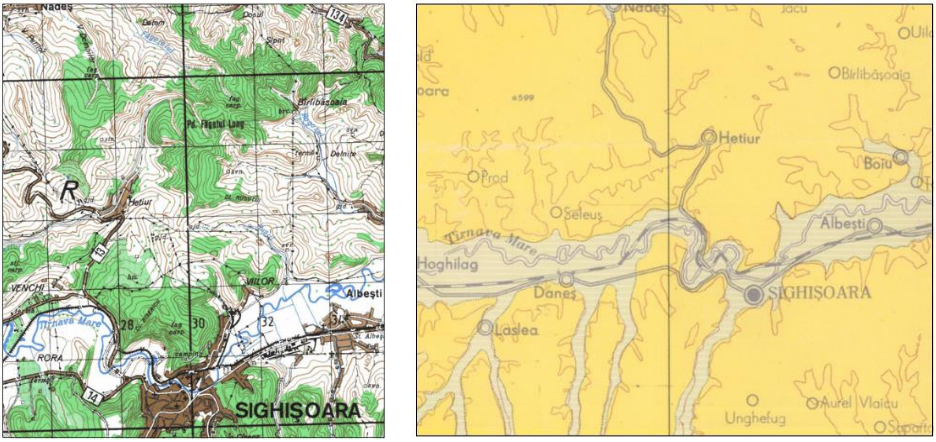
1. creating a geologic model (static) of the reservoir (stratigraphy and lithology, sedimentary tectonic arrangement, initial distribution of fluids);

2. dynamic reservoir model creation and analysis:
3. past injection-withdrawal periods;
4. current reservoir behavior;
5. behavior the operation of the deposit, and performance recording.

2. The geological model of the structure

From an administrative point of view, the ZD structure is located in Mureș County, on the territory of Hetiur, and Seleuș communes (figure 1).

From a geological point of view, the ZD structure is located in the Transylvanian Depression, a basin that was part of and evolved together with the large epicontinental Sea Paratethys during the Oligocene-Miocene, extending from Central Europe to Lower Asia [3].



a) b)

Figure 1 – Localization from the administrative map fragment (a) and geological point of view (b) of a ZD structure, scale 1:200.000 and 1:100.000

Legend: pn - Marly clays, sands [7]

2.1. Stratygraphy and litology

The main gas formation within the ZD structure is the Sarmatian, consisting of an alternation of marls, clay shales, sandstones, and dolomitic limestone with local intercalations of dacite volcanic tuffs. It was divided into several complexes from the shallower complex I (the roof located at a depth of 382 m) to the deep complex XV (the roof located at a depth of 2098 m), a fact confirmed the by W14 well (drill in 1956) which indicated the presence of gas at almost all levels.

From a lithological point of view, the Sarmatian, which presents both fining-up and coarsening-up siliciclastic sequences, suggests a depositional environment dominated by median to external deltaic cones and deep turbiditic deposits of great depth. Only complex VII of Sarmatian was converted into a gas deposit (figure 2), which is considered depleted [4].

In general, the Sarmatian VII complex is isolated from the upper complex VI, respectively lower VIII, by clay layers 10-20 m thick with the role of upper and lower cover. However, in some W17 and W51 probes (figure 3), the upper and lower covers are much thinner (a few meters), which suggests a possible intercommunication between complexes in areas not intercepted by existing wells and where they may be missing.

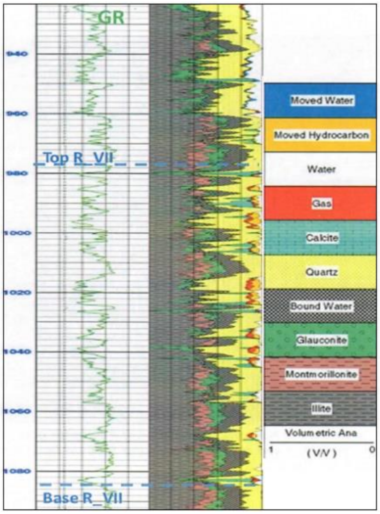


Figure 2 – Petrophysical interpretation of Complex VII (representative well)

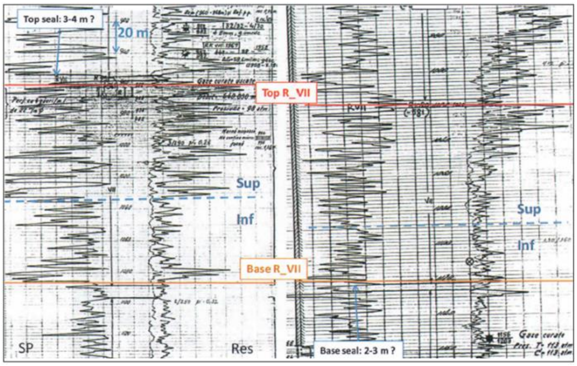


Figure 3 –Examples of low-thickness diagram of the upper and lower covers of Complex VII

Based on the interpretations obtained from the complex geophysical diagrams made in the new wells (W7A and W11A) and correlated with the existing wells, complex VII was divided into 4 subcomplexes marked from top to bottom A-D (figure 4), thus:

– subcomplex A is represented by 4 porous-permeable packages (marked R1-R4), separated by 3 impermeable packages (marked C2-C4);

– subcomplex B is represented by impermeable decimetric packages, with continuous development on the whole reservoir;

– subcomplex C is represented by 3 porous-permeable packages (marked R1-R3), separated by 2 impermeable packages (marked C2 and C3);

– subcomplex D is represented by 3 porous-permeable packages (marked R1-R3) and an impermeable package (marked C3).

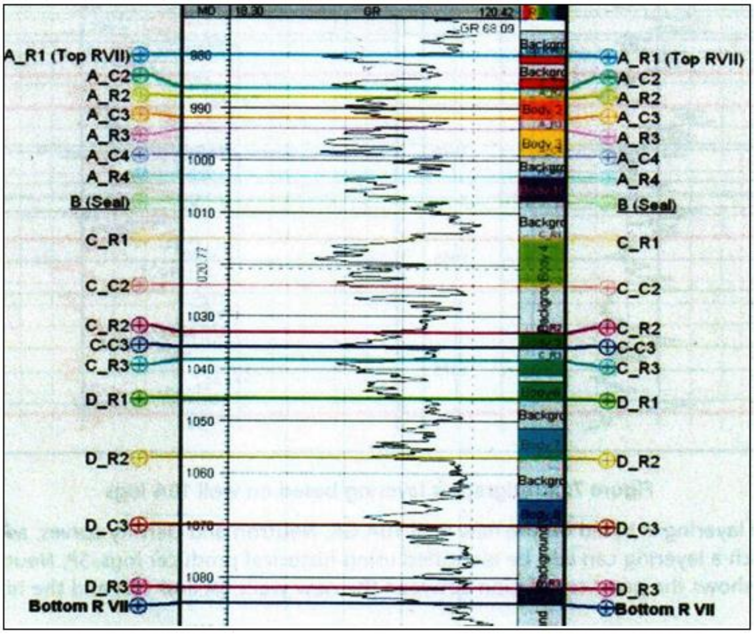
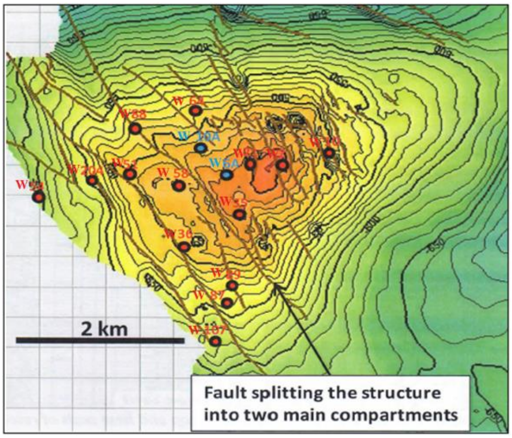


Figure 4 – Stratigraphic division of a well-Complex VII

2.2. Structure tectonic

Compared to the previous structural image (untectonized), the interpretation of the 3D (figure 5) seismic based on which the new geological image was made, indicates the presence of a fault system with NV-SE orientation. The new structural-tectonic image represents a domed structure affected by a main fault (marked F), considered leaky, and with a jump between 10 and 20 m (figure 6), which divides the structure into two areas-western and eastern [6].

In general, at the level of the Transylvanian Depression, the traps are structural and generated by the Badenian salt movement. The ZD gas structure is a good example of this type of trap. The gas interest targets were identified in the Badenian, Buglovian, and Sarmatian formations, of which the Sarmatian VII target with a high degree of depletion became a storage reservoir.



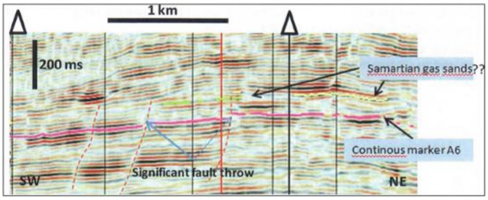


Figure 5 – Structural map (upper hypothesis) at complex head VII

Figure 6-Seismic cross-section interpretation indicating amplitude fault F

2.3. Initial distribution of fluids (the dynamic model)

For the initial distribution of fluids in the Sarmatian VII complex, which proved to be productive, an average saturation limit was estimated at 610 meters below sea level.

3. Past injection-withdrawal periods

3.1. Reservoir pressure

The gas production stopped at the end of August 2009. The first injections started in June 2004 and almost 40 MNm^3 were extracted from gas involving 9 wells. It can be stated that:

– restated pressures measured on each well increased continuously between August 2003 and April 2004 following almost the same gradient (+ 1.5 bar/5 months);

– in April 2004 reservoir pressures varied from 20.5 bar (wells W36T, W88) to 27.2 bar (well W10) showing the geological heterogeneities/ compartmentalization of the Sarmatian VII reservoir. A common average reservoir was not measured after 8 months without any production;

– calculated average reservoir pressure in April 2004 is 23.5 bar with at least variations of +/- 16.5 %;

The reported average at the end of the reservoir depletion is 21.5 bar, 2 bar less than the one calculated in April 2004 based on well measurements. Such difference could be due to the calculation method (from wellhead to downhole) or to possible aquifer support effect between the "end of production" and April 2004.

3.2. Well productivity/injectivity

From June 2004 until October 2006, 9 wells participated in injection/production activities. In March 2006, wells W64 and W88 were followed by well W89 in November 2006 (peripheral location and with very low production/injection contributions-around 5 % per well) [6].

6 "historical" wells were still involved in storage activities until May 2009 with the following contribution ratios.

It can be appreciated that:

– Main historical producer contribution to storage came from wells W58 and W35 with 40 to 50 % of the overall injected/withdrawn gas.

– Wells W7, W35, and W204 should be considered as mean producers/injectors in terms of gas volumes and compared to other wells.

– Well W10, the most peripheral one, showed a very low capacity.

The well productivity depends on the well locations: the longer the distance between the well and the top/center of the structure, the lower the well production/injection.

Such relationship a is also established when comparing perforated interval and well productivity from 1957 until 2003 (considering all well tubing diameters (2" $^{1/2}$ to 2" $^{7/8}$) are the same).

The perforated interval was based on reservoir quality and reservoir thickness above G.W.C. (*Gas-Water-Contact*).

Historical working gas volumes are around 50 Mm^3 which represents less than 1 % of the Gas Initially In Place:

– there is a very low chance that gas injected on a given well could be produced via another one considering the historical well spacing.

– Moreover, the reservoir is heterogeneous/partitioned supported by well pressure regimes that vary from one well to the other.

In this way, peripheral wells W64, W204, W10, and W36T showed a negative injected/produced gas balance (at Working Gas = 0 m^3). They had probably produced some residual cushion gas.

Wells W35 and W7 showed a positive injected/produced gas balance and had therefore contributed to the local replacement of cushion gas. Overall the injected/produced gas balance is close to zero.

4. Current reservoir behaviour

4.1. Pressure gradient

There were not many valid reservoir pressure measurements since the beginning of the reservoir conversion, as the reservoir is heterogeneous and stabilized pressures can not be obtained with short reservoir build-up. The best dataset originates from the very early times of the reservoir conversion with [6]:

– the first set of measurements in April-May 2004 before the first injection;

– the second set of measurements in October 2004 just after the end of the injection program.

– the third set of measurements in May 2005, 8 months after the end of the first injection.

As already mentioned, there were noticeable variations in measurements from one well to another and such discrepancies were still obvious even after 8 month period without any gas movements.

There is a high degree of uncertainty about the average reservoir pressure gradient mainly due to the reservoir pressure evolution from April to May 2004.

Consequently, reservoir pressures before and after injection of 37.8 MNm^3 are respectively:

– 23.5 bar and 29.7 bar when considering initial pressure in April 2004;

– 25.8 bar and 29.7 bar if considering the initial pressure in May 2004 leading to a gradient range of 1.03 bar/10 MNm^3 (first case) to 1.64 bar/10 MNm^3 (second case).

The current pressure gradient appears to be very high compared with the gradient deduced from the field depletion period: 0.18 bar/10 MNm^3 (assuming an 80 bar decrease when producing 4 400 MNm^3).

This is not surprising considering the low reservoir permeability (5-300 mD) and the sand body discontinuities (compartmentalization).

Moreover, recent reservoir pressure measurements performed on the new wells W6A and W10A clearly suggested strong local heterogeneities that can partially isolate sand bodies and create fluid cross-flows in the well vicinity.

Table 1 summarizes the measured pressure on well W6A one month after the drilling operations. Initial wellhead shut-in pressure of 51 bar resulted from a major interval (upper one) put in communication with less depleted intervals. Vertical pressure equilibrium through the reservoir formation (final mean wellhead shut-in pressure in line with the initial one measured in the main interval 1015-1086 m) was restored during a really short period meaning that over-pressured intervals were of negligible volumes. Such pressure re-equilibrium was interpreted with cross-flow mechanisms illustrated by a production profile survey during well shut-in phase.

Table 1 – **Wellhead shut-in pressure evolution in well W6**

Reservoir	**Well W6**	**WHSP (barr) 27/10/ 08**	**WHSP (barr) 27/10 /08**	**WHSP (barr) 31/10 /08**	**WHSP (barr) 26/11 /08**
SarmatianVII	Interval 1 1015 – 1086	37	51	47	37.5
	Interval 2 1111 – 1113	71			
	Interval 3 1127 – 1131	60			

4.2. Behavior of the reservoir in operation, recording performance obtained (2004-2009)

a) Injection-extraction cycle

After the exploitation as a free gas field stopped, in 2004 the use of the Sarmatian VII geological formation as an underground gas storage and extraction depot through 9 existing wells in production began (W8, W11, W36, W37T, W59, W65, W89, W90, and W205).

Gas storage operations began in 2004 and involved 9 wells W8, W11, W36, W37T, W59, W65, W89, W90, and 205).

The activity started with 40.2 million Stm^3/cycle (2004 cycle) reaching in 2008 to exceed 50 million Stm^3/cycle (figure 7). Well injection flow rate varies between 10*103 Stm^3/day and 160*103 Stm^3/day (figure 8), with tubing pressures ranging from 22 to 37 bar (figure 9).

The quantities extracted per cycle varied from 58 million Stm^3/cycle (the year 2005-2006) to 7 million Stm^3/cycle (the year 2009-2010), (figure 10), and the flow per well varies between 5*103 Stm^3/day and 90*103 Stm^{3}m^3/day (figure 11), on 11÷18 mm nozzles, with tubing pressures between 12-25 bar (figure 12). Depending on the needs, on calendar months, the quantities of gas extracted in storage, with the exception of the 2008-2009 cycle, vary between 5 and 17 % of the total load per cycle, in the 2008-2009 cycle, these being between 14 and 26 %, the largest being held in November, December, and January.

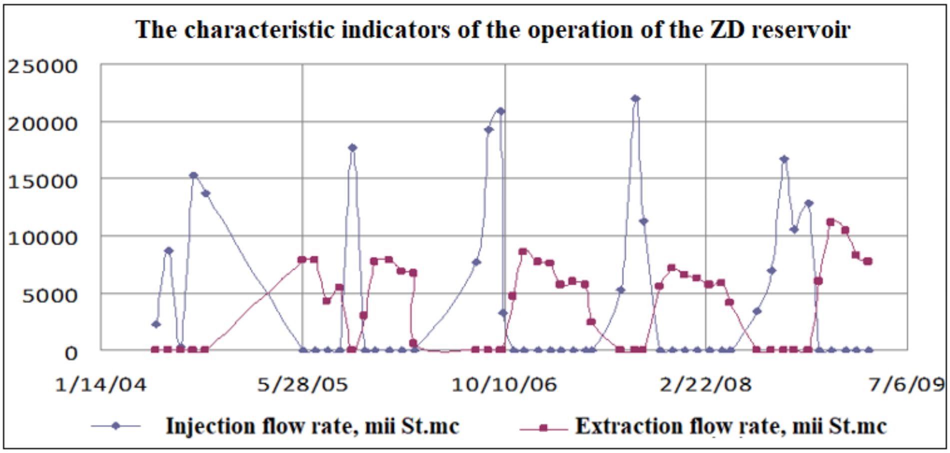


Figure 7 – The simulation of the daily evolution of the gas flow in the reservoir

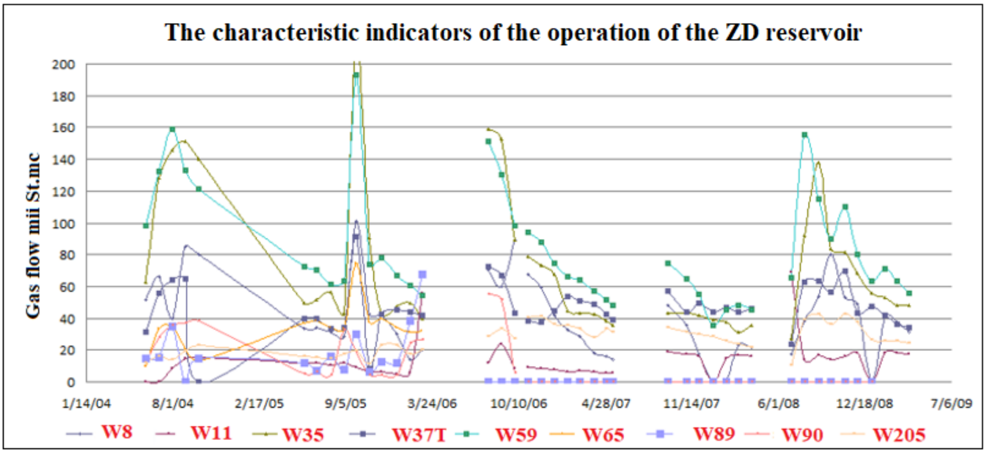


Figure 8 – The simulation of the daily evolution of the gas flow on the wells

Table 2 indicates that wells W8, W36, W37, and W59 make a much larger contribution to the injection-extraction process than other wells. (figure 7) indicates that the wells that contributed the most to the injection-extraction process are positioned in the apex area of the structure, while the probes positioned on the flanks had a weaker contribution.

Monitoring of the reservoir pressure between August 2003-April 2004 (figure 11) and December 2009-January 2012 (figure 12), periods in which no oil operations were carried out in the deposit, after the last phase of production, showed a continuous increase in pressure.

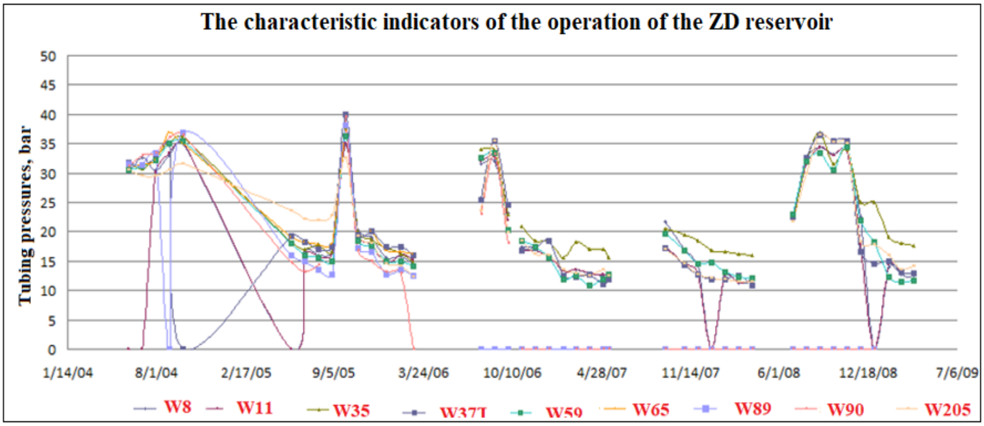


Figure 9 – The simulation of the evolution of the dynamic pressure at the eruption head, on the wells

Table 2 – **Coefficient of the contribution of wells to production and injection in the period 2004-2009**

Period	**Wells**	**W8**	**W11**	**W36**	**W37T**	**W59**	**W205**	**W65**	**W89**	**W90**	**W7A**	**W11A**	**Volume Mm^3**
		%											
2004	injection	15	2,2	26,1	11,6	26,2	3,50	5,3	3,6	6,5	-	-	37,9
2005	production	12,5	4,3	17,7	13,9	25,3	5,90	13,2	5,6	1,7	-	-	-18,5
2005	injection	14,6	1,2	25,5	12,8	25,9	2,70	9,6	5,1	2,6	-	-	17,7
2005 2006	production	12,3	2,1	19,9	16	24,5	7,70	13	3,2	1,3	-	-	-32,5
2006	injection	15	1,9	26,8	14,3	26,8	7,90	-	-	7,2	-	-	51,1
2006 2007	production	12,7	2,9	22,4	19,2	27,4	15	-	-	0,4	-	-	-48,4
2008 2009	production	11	5,2	17,6	12,5	21,4	8,80	-	-	-	10,2	13,3	38,1*

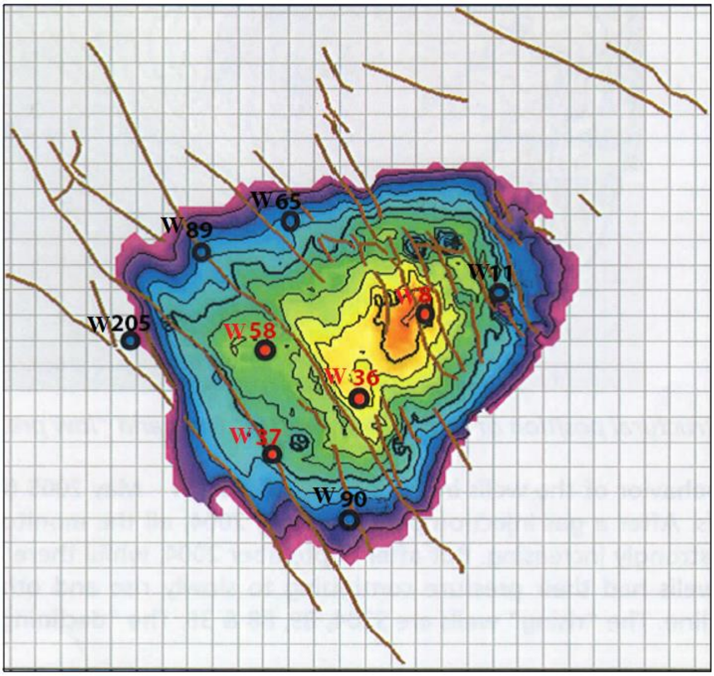


Figure 101 – The simulation of the position of the contributory wells of the reservoir (wells with significant contribution in red; wells with low contribution in blue)

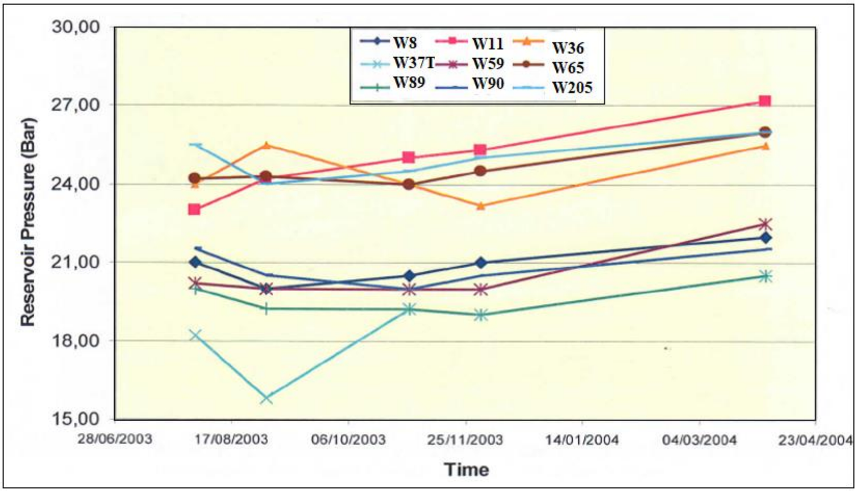


Figure 11 – The simulation of the evolution of reservoir pressure (August 2003-April 2004)

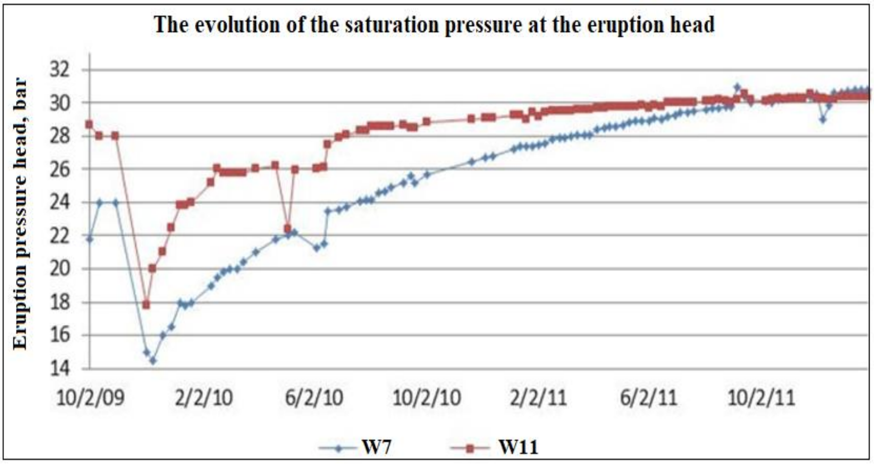


Figure 12 – The simulation of the evolution of the static pressure at the eruption head (December 2009-January 2012)

The increase in reservoir pressure can be attributed to the circulation of gases behind the columns in conditions of inefficient cementation and in the area of wells with columns cut by landslides where gas insulation operations were not effective (including well 8 damaged during the process injection) [5]. Gas emanations are also manifested on the surface of the structure. It is also possible to break the separating screen between complexes VII and VI, respectively VII and VIII during the operation process, by creating differential pressures at the two complexes. No aquifer activity has been shown to contribute to increased reservoir pressure.

Assuming that the monitoring was accurate, the behavior of the wells pressure between August 2003 and April 2004 indicates two distinct groups of wells:

– a "*high pressure*" group (W11, W205, W65, W36);

– a "*low pressure*" group (W59, W8, W90, W89, W37).

By positioning these wells on the structural map, it follows that all "high pressure" wells, less than one (W205) are located in the eastern structural block, while all but one "*low pressure*" well (W8) is located in the western compartment (figure 13).

This suggests that the eastern area was generally less depleted than the western area. The main NV-SE fault could create a partial permeability barrier.

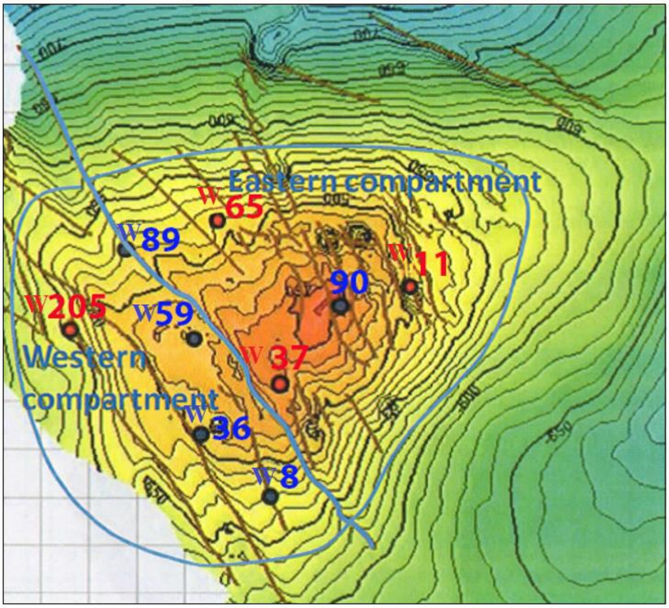


Figure 13 – Structural position of wells with „high pressure” (red) and „low pressure” (blue)

The well W205 could be isolated from the rest of the probes in the western area by a fault.

6. Conclusions and proposals

The following conclusions can be drawn from the analysis of the researched structure:

1. The Sarmatian VII gas complex, from the ZD structure, was converted into a natural gas storage in September 2003 and leased for the execution of oil operations;

2. The activity of storage extraction started in 2004 and was carried out in 5 cycles through a total number of 11 wells;

3. The activity of injection extraction was stopped in 2009, after the technical injury of well 8 due to landslides;

4. During the process,198 mil.Stm^3 gases were stored and extracted;

5. The “*pillow*” of about 725 million Stm^3 gas existing at the end of the extraction activity was not affected by the injection-extraction process carried out;

6. After stopping the injection-extraction activity, an increase in the field pressure was found. The possible causes of this phenomenon are of a technical and/or structural tectonic nature and have been analyzed in the paper, being due to the communication between the complexes of the structure;

7. The initial geological resources evaluated by material balance, were verified and confirmed both by the volumetric method and by the Monte-Carlo method in the current paper, obtaining differences of less than 5 %;

The following proposals are made:

1. In the current conditions of knowing the geological-physical model of the deposits of the structure, which generates uncertainties regarding the intercommunication between complexes, due to some technical deficiencies in the wells, it is not opportune to continue the storage process in this deposit;

2. The Sarmatian VII complex is to be preserved with an existing geological gas resource of about 725 million Stm^3 until the eventual specification of the geological-physical model of the deposit and the reanalysis of the storage conditions or the resumption of the exploitation process;

3. Documentation for the conservation of W7A and W11A wells shall be prepared, the only ones at the bottom of the wells.

REFERENCES

[1] Batistatu M.V., Vlășceanu V. – *Geologia zăcămintelor de hidrocarburi*-suport de curs IFR, Ploiești 2015.

[2] Beca C., Prodan D. – *Geologia zăcămintelor de hidrocarburi*, Editura Didactică și Pedagogică, București, 1983.

[3] Mutihac V., Mutihac G. Ge*ologia României în contextul geostructural central-est European*, Editura Didactică și Pedagogică, București, 2007.

[4] Vancea A. – *Neogenul din Bazinul Transilvaniei*, Editura Academiei Române.

[5] Vlășceanu C.V. – *Înmagazinarea subterană a gazelor naturale*, Editura Universitas, 2022.

[6] Vlășceanu C.V. – *Studiu privind înmagazinarea subterană a gazelor naturale-Sarmațian VII.*

[7] Institutul Geologic al României (*www.igr.ro*) – *Fragment hartă geologică, sc. 1:200.000.*

Acknowledgments

I would like to thank all the people who helped me to prepare this work.

Authors' biographies

Costin Viorel VLĂŞCEANU holds a Ph.D. in Mines, Oil and Gas and is a Lcturer Ph.D. Eng. of Reservoir Engineering at Petroleum Geologiy and Reservoir Engineering Departament within Petroleum and Gas University of Ploiesti. He is the author of numerous articles published in the country and abroad and of 5 specialized books.

He also has over 10 years of experience in Designing the Exploitation of hydrocarbon reservoirs.

He received from the CNR-CME the prize for paper "*The hydrocarbons displacement by water in a non-uniform reservoir*" at the FOREN conference (Costinesti 2022).

This year he received the Medal and the certificate for special merits for increasing the prestige and affirmation in the country and abroad of the Association of the Romanian National Committee of the World Energy Council (CNR-CME).

Email: viorel.vlasceanu@upg-ploiesti.ro

Marius STAN holds a Ph.D. in Petroleum Equipment and is a Associate Professor of Mechanical Engineering Departament within Petroleum and Gas University of Ploiesti.

He received from the CNR-CME the prize for paper "*The hydrocarbons displacement by water in a non-uniform reservoir*" at the FOREN conference (Costinesti 2022).

He is the author of numerous articles published in the country and abroad and of 5 specialized books.

This year he received the Medal and the certificate for special merits for increasing the prestige and affirmation in the country and abroad of the Association of the Romanian National Committee of the World Energy Council (CNR-CME).

Email: mstan@upg-ploiesti.ro