Hydrocarbon potential assesment of the slope deposits along the SW Dinarides carbonate platform edge

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ORIGINAL SCIENTIFIC PAPER

The peri-platform carbonate clastics extend along the entire Dinarides carbonate platform as slope deposits from Istria offshore in northwest to the offshore Dubrovnik in southeast. These sediments are good potential reservoir rocks of regional extension. This is the first attempt to estimate their hydrocarbon potential.
The mentioned peri-platform deposits extend over 550 - 600 km. Assessment of their reservoir capacity is based on petroleum-geological interpretation of 12 seismic lines crossing transition zone of the Dinarides platform/Adriatic basin. In the studied zone, Tertiary clastics overlay peri-platform slope deposits as regional cap rock while Ladinian-Carnian shales of the Vlasta-1 type represent underlying source rocks, potentially mature in depocenters.
Recent commercial oil discovery in neighboring Rovesti structure at the base of Apulia carbonate platform additionally inspired the authors to make this assessment in the slope zone of the Croatian part of the Dinarides platform. It should be emphasized that our assessment will be in future, most likely corrected by additional interpretation of more cross lines and selected parallel seismic lines.

Key words: Hydrocarbon potential assessment, Peri-platform clastics, Adriatic off-shore

1. INTRODUCTION

This assessment includes 12 interpreted cross sections transverse to Dinarides carbonate platform of Upper Triassic to Middle Eocene age as well as a part of recent offshore Dinarides as a tectonic unit. Along with the interpretation of the mentioned cross sections, a review on characteristics and potential of Friuli and Apulia platforms was performed. The mentioned studies and analysis of several wells drilled for exploration of peri-platform clastics that spread along southwestern margin of Dinarides carbonate platform showed that they represented possible reservoir rocks of regional significance.

Petroleum-geological relations defined by exploration on the neighboring Italian side, in the area of Friuli and Apulia platforms margins that were created under identical paleo-geographic conditions were also analyzed in a separate chapter, thus it has been considered useful to use data from this area for the assessment in Croatian part of the offshore area.

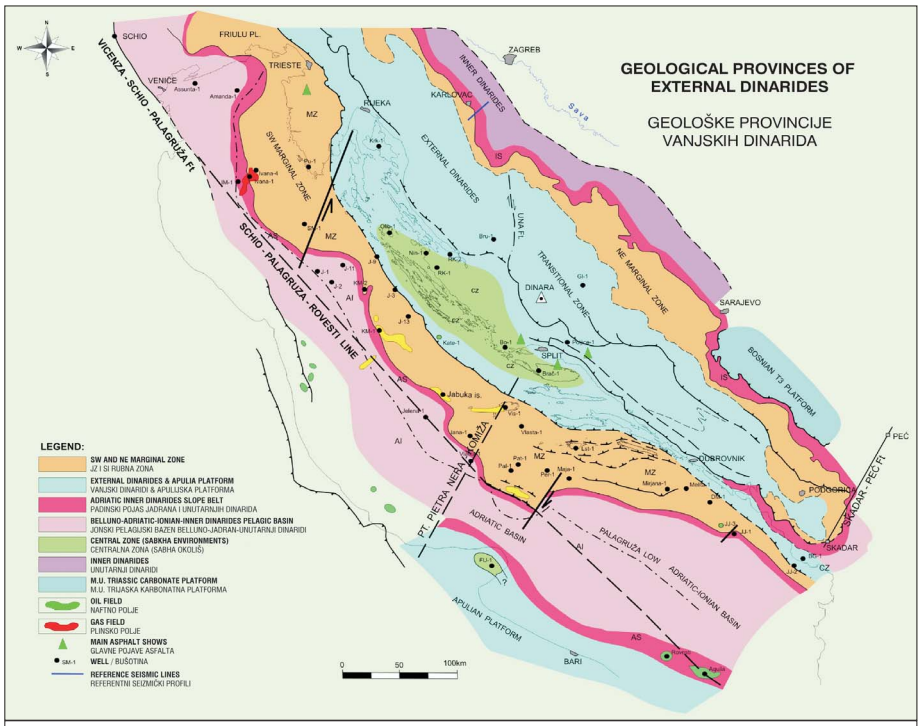


Fig. 1. **This Figure presents regional position of peri-platform clastics belt as a main object of consideration. Also the distribution of other Dinarides exploration units is presented (modified according to Grandić-1974). The position of Južni Jadran-1 well in Monte Negro offshore, coastal area of Gargano peninsula and Rovesti-1 well in Bar-Brindisi offshore are also marked.**

Sl. 1. Slika prikazuje regionalni položaj pojasa periplatformnih klastita kao glavnog objekta razmatranja. Prikazan je i raspored ostalih istražnih jedinica Dinarida i Jadranskog bazena (modificirano prema Grandić-1974). Naznačen je i položaj bušotine Južni Jadran-1 u crnogorskom podmorju, tršćansko-venecijansko podmorje, priobalje poluotoka Gargano i bušotina Rovesti-1 u podmorju Bar-Brindizi.

Figure 1 presents the regional position of peri-platform clastics belt as a main subject of the study. The distribution of other Dinarides exploration units is also presented (modified according to Grandić – 1974). The positions of Južni Jadran -1 and Južni Jadran – 3 wells in Monte Negro offshore are given along with Trieste-Venice offshore, Gargano peninsula offshore and position of Rovesti-1 well in Bar-Brindisi offshore.

In this phase of preliminary assessment, only 12 chosen cross-sections were taken in consideration while in further explorations, successive completing of cross sections grid including the longitudinal seismic cross-sections is planned.

On Figure 2, there is location map of 12 interpreted seismic cross sections which were used for calculation of total reserves of Dinarides platform slope peri-platform clastics. Also the positions of wells that provided data for this study are presented and regional faults tracks which delineate the considered parts of Adriatic sedimentary basin.

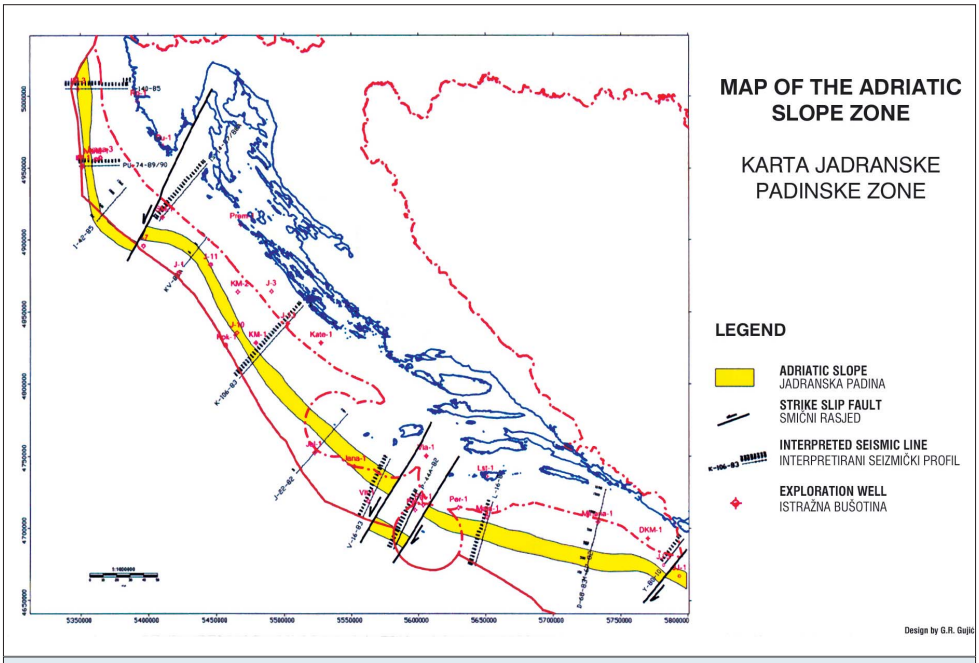


Fig. 2. Index map shows the position of 12 interpreted seismic cross-sections which were used in calculation of total reserves of peri-platform clastics belt from Dinarides platform slope. Positions of wells from which the data were used in this paper are also presented. Several regional faults which bound the considered parts of Adriatic sedimentation basin are also shown.

Sl. 2. Karta lokacija 12 interpretiranih seizmičkih profila koji su korišteni za izračun ukupnih potencijalnih rezervi u periplatformnim klastitima padine Dinaridske platforme. Prikazani su i položaji bušotina korištenih u ovom radu, te trase regionalnih rasjeda koji omeđuju razmatrane dijelove Jadranskog sedimentacijskog bazena.

Istra more – 1 (IM-1), Istra more - 3 (IM-3) and Južni Jadran – 1 (JJ-1) exploration wells need to be mentioned. They were not meant for testing of peri-platform clastics reservoir characteristics but those sediments were partially drilled there. According to project documentation they had a different scope; testing of top carbonates as cap rocs at the base of Tertiary clastics,[4,5] which was the basis for hydrocarbon exploration in the Adriatic basin during earlier exploration period. However, the latest reinterpretation of well and seismic data pointed to uplifted carbonates structures which are, due to frequent emersion phases, less promising. On the other hand, deposits at structures flanks, and especially carbonate clastics as sediments developed by Dinarides carbonate platform weathering, can have better characteristics of potential reservoir rocks of regional spreading. Collectors characteristics were especially confirmed by laboratory research performed on cores from IM-3 well in Istria offshore with determined porosity up to 15% and permeability up to 45 mD.[10] Gas show in Oligocene clastics in JJ-1 well and in South Adriatic also indicated good possibility for hydrocarbon generation and accumulation. However, systematic testing of total peri-platform deposits reservoir potential within their complete spreading in Croatian offshore has not been performed up to now in big interspace from Istria offshore to South Adriatic.

In this work we have tried to estimate their total pore volume based on interpretation of 12 cross sections through peri-platform deposits. The following seismic cross-sections were interpreted:

I-14-89, PU-74-82, I-42-85, KV-86A-81, K-106-83, J-22-82, V-16-83, P-44A-82, L-16-82, D-68-83, M-67-82 and Y-80-10 (locations in Figure 2).

Joint sedimentary body of peri-platform clastics has most often wedge to irregular shape. Within this initial phase, the total volume of this unit was estimated on relatively small number of transverse cross-sections. To increase the accuracy of assessment, assessment on higher number of interpreted transverse and longitudinal cross-sections regarding platform spreading is anticipated.

Along with interpretation of peri-platform clastics sediment body sizes, the special attention was given to determining sedimentation depressions within their environment, where the development of potential source rocks exists which are capable for expulsion and migration of hydrocarbons into the surrounding traps.

The following were separately described:

1. Istrian platform slope;
2. area southwest of Kvarner transverse fault,
3. area southeast of Šolta-Komiža-Pt.Pietra.Nera transverse fault.

Those are parts of the studied area that were from Upper Lias paleo-tectonically completely or partially separated as separate sedimentary basins. However, main considered sedimentation area represents a part southwest of the main Dinarides carbonate platform slope, where, after Upper Lias pelagic and hemipelagic sedimentation took place in Adriatic basin, which resulted in sedimentation of Sciaglia-Biancone formation deposits. Halokinetic structures like KM-1 diapir, Jabuka diapirs, Palagruža diapirs and diapirs in Mljet island offshore regularly appear south of Kvarner transverse fault along Dinarides carbonate platform edge. It is supposed that these diapirs were initiated by reactivation of deep faults that affected to the uplifting of Permian-Triassic evaporite deposits (Fig. 3).

The generalized geological column, presented in Figure 3 (indicated by heavy red line) shows total sedimentary sequence of Dinarides; from Triassic-Paleozoic clastic-evaporite sediments, carbonate-anhydrite sediments of younger Mesozoic to Tertiary clastics. The episode of separation of Dinarides from the Apulia platform is especially marked.

2. Istrian platform slope sector

Studying of petroleum-geological potential started in north Adriatic area and spread up to the most southern part of the offshore belonging to Croatian territorial waters.

Dinarides platform edge in the Istrian offshore is clearly expressed and marked by peri-platform clastics show. Significant gas fields like Ivana, Ika and other are located in this area, however

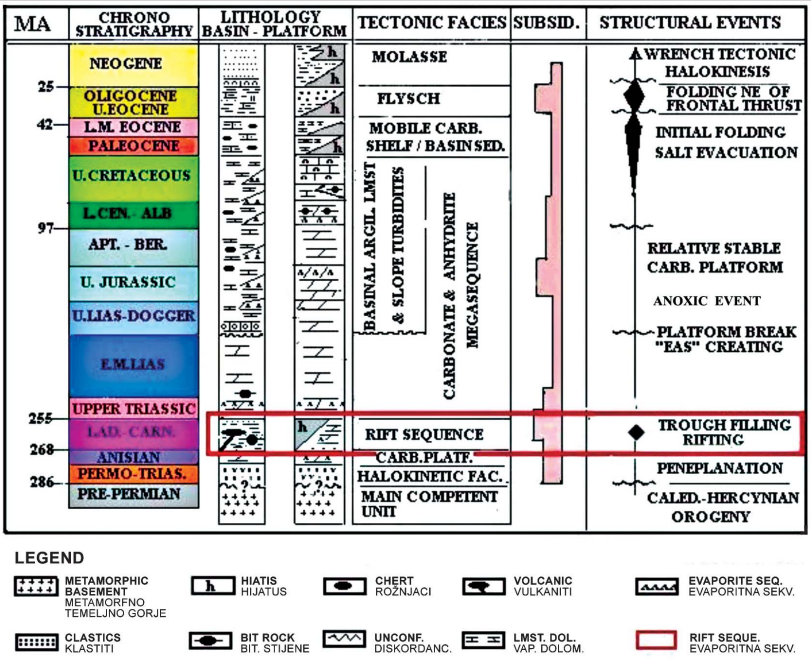


Fig. 3. This generalized geological column presents total Dinarides sedimentation sequence from Triassic-Paleozoic clastic-evaporites deposits, carbonate-anhydrite sediments of younger Mesozoic to Tertiary clastics. Separation episode of Dinarides from Apulia platform is especially marked.

Sl. 3. Na ovom generaliziranom geološkom stupu prikazana je ukupna sedimentacijska sekvenca Dinarida od trijasko-paleozojskih klastično-evaporitnih naslaga, karbonatno-anhidritnih sedimenata mezozoika do tercijarnih klastita. Posebno je označena epizoda odvajanja Dinaridske od Apulijske platforme.

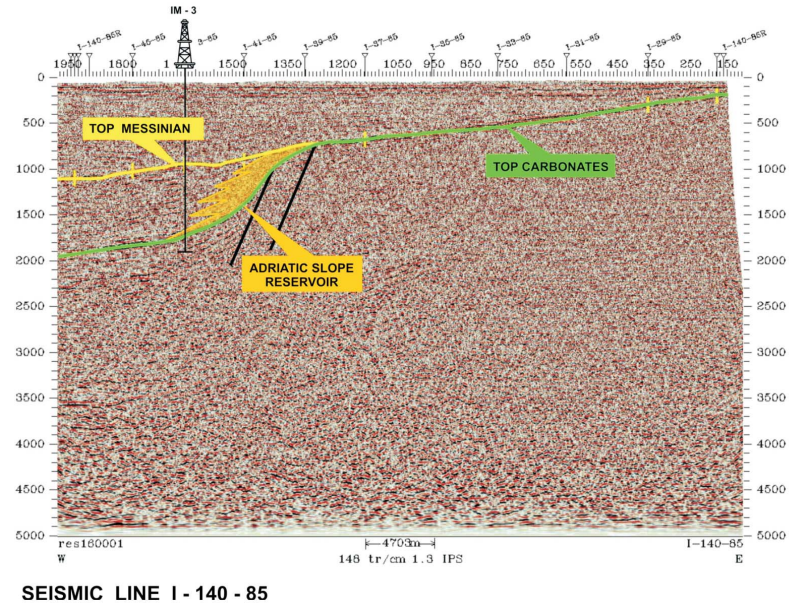


Fig. 4. Relatively narrow spreading of peri-platform clastics in top carbonates and Messinian basement is presented. IM-3 well which includes only the lower part of slope deposits is on I-140 cross-section thus the prosperity of the upper part with clinoform pinch out is not known.

Sl. 4. Na profilu I-140 nalazi se bušotina IM-3 koja je zahvatila samo donji dio naslaga pregiba te nije poznata perspektivnost gornjeg dijela s klinoformnim isklinjenjima. Žutom je bojom označeno razmjerno usko rasprostranjenje periplatformnih klastita u ovom području. Oni se uvijek nalaze u krovini karbonata i u podini mesinskih sedimenata.

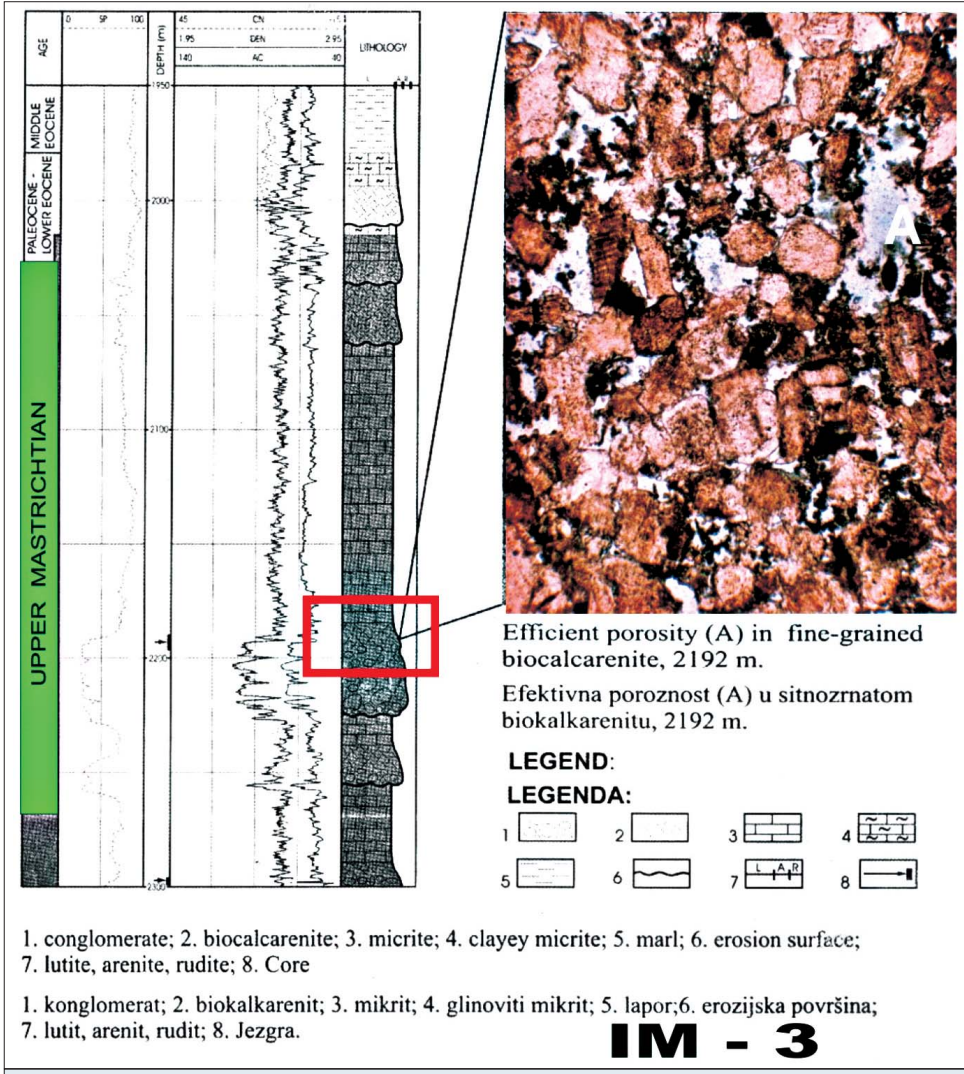


Fig. 5. Detailed porosity on IM-3 well is presented in geological column and the photograph of micro-facies where effective porosity is marked in blue color and by symbol A - effective porosity. This data is taken as orientation one for the whole belt of peri-platform clastics.

Sl. 5. Tip poroziteta na bušotini IM-3 prikazan je na geološkom stupu i fotografiji mikro-facijesa na kojem je naznačen plavom bojom i simbolom A. Riječ je o efektivnom porozitetu koji se može identificirati i na karotažnim dijagramima na lijevom dijelu slike, po obliku krivulja spontanog potencijala, neutronske karotaže, karotaže gustoće i zvučne karotaže. Ova interpretacija uzeta je kao ogledna za cijeli pojas periplatformnih klastita.

up to now there were no oil shows. One of the possible reasons is the lack of oil generating centers and also the fact that certain wells were not drilled on place of pinch out and closing of potential traps as presented in Fig. 4 and Fig. 6.

Figure 4 shows seismic cross-section I-140 and its IM-3 well which included only lower part of slope deposits; thus the potential of upper part with clinoform pinch out is not known. Yellow color marks relatively narrow spreading of peri-platform clastics in this area. They are always situated in carbonate top and in the basement of Messinian sediments.

Istrian platform slope, as well as the whole Dinarides platform, is paleo-tectonically conditioned. According to Del Ben[2] interpretation, this is the case of deep faults which spread up to "MOHO" horizon. This is a lineament which caused, southwest of Dugi Otok, intrusion of Triassic batholiths and Permian-Triassic evaporites and development of structural uplift of Palagruža Island.

In the area of Istrian slope of carbonate platform, west of Rovinj-1 (Ro-1) well, Istra more-3 (IM-3) well was drilled at shot-point 1700 on seismic cross section I-140-85. By its smaller part, the well included peri-platform clastics at the depth of 2 200 – 2 225 m (Fig. 5). Laboratory measuring data are significant and confirmed good porosity of 15% and permeability of 45 mD. As on the remaining part of the slope there was no such measuring, this data is taken as reference data for the whole explored belt of peri-platform clastics.

Figure 5 shows porosity type on IM – 3 well, presented in geological column and on the photograph of micro facies, marked in blue and by symbol A. This is effective porosity that can be identified on well logging diagrams on left part of the figure. By the curve shape it has spontaneous potential, neutron well logging, density well logging and sonic well logging. This interpretation is considered as a model for the whole peri-platform clastics belt.

According to the presented interpretation of PU-74-82 (Fig. 6) it is obvious that the drilling should have been performed closer to vertical projection of shallow gas well Ivana-4A which was stopped in Plio-Quarternary clastics at the depth of 925 m, while possible oil shows are much more likely to occur in peri-platform clastics of Pre-Oligocene age. The distance between IM-1 and Ivana-4A is 6.5 km, which is probably too big distance. From the example of oil positive well Well-1 JI from Gargano peninsula it is possible to estimate that the optimal distance would be 3.0 km (Figl. 11). According to regional exploration results it is known, however, that separation of Dinarides and Apulia platform began in

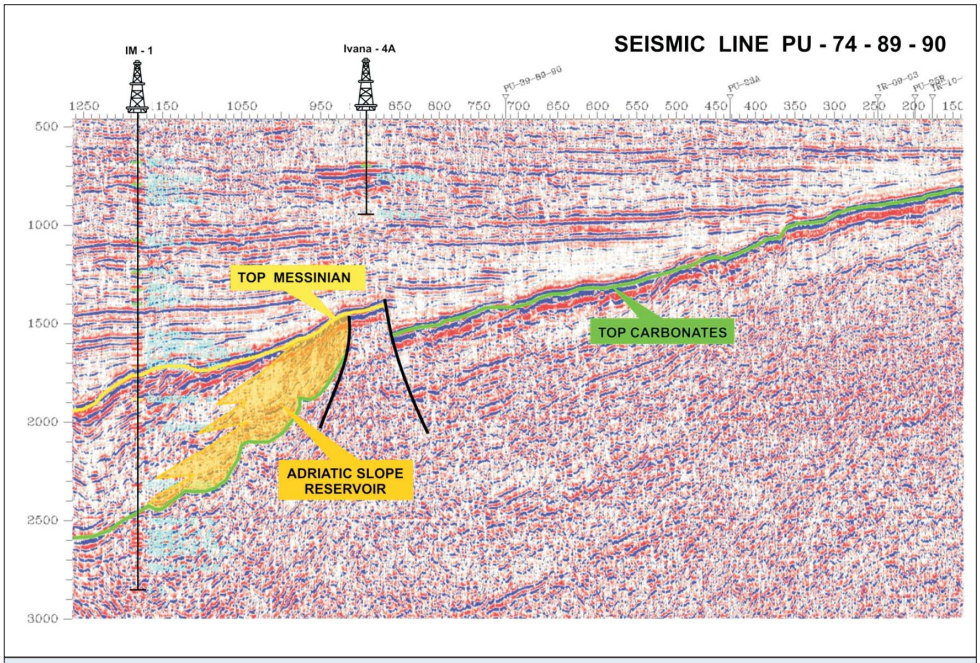


Fig. 6. Pinch out of peri-platform clastics in the direction of Istrian carbonate platform is clearly pointed out in the presented PU-74-82 cross-section. Pinch out is visible in "upward clinoforms" show of Upper Cretaceous to Oligocene age as possible petroleum-geological traps of structural-stratigraphic type which were, unfortunately, not tested by exploration drilling.

Sl. 6. Na prikazanom profilu PU-74-82 jasno se ističe isklinjenje periplatformnih klastita u smjeru Istarske karbonatne platforme. Isklinjenje se očituje u pojavi "uzlaznih klinoformi" gornjokredne do oligocenske starosti kao mogućih naftnogeoloških zamki stratigrafskog tipa koje još nikad nisu bile testirane istražnim bušenjem.

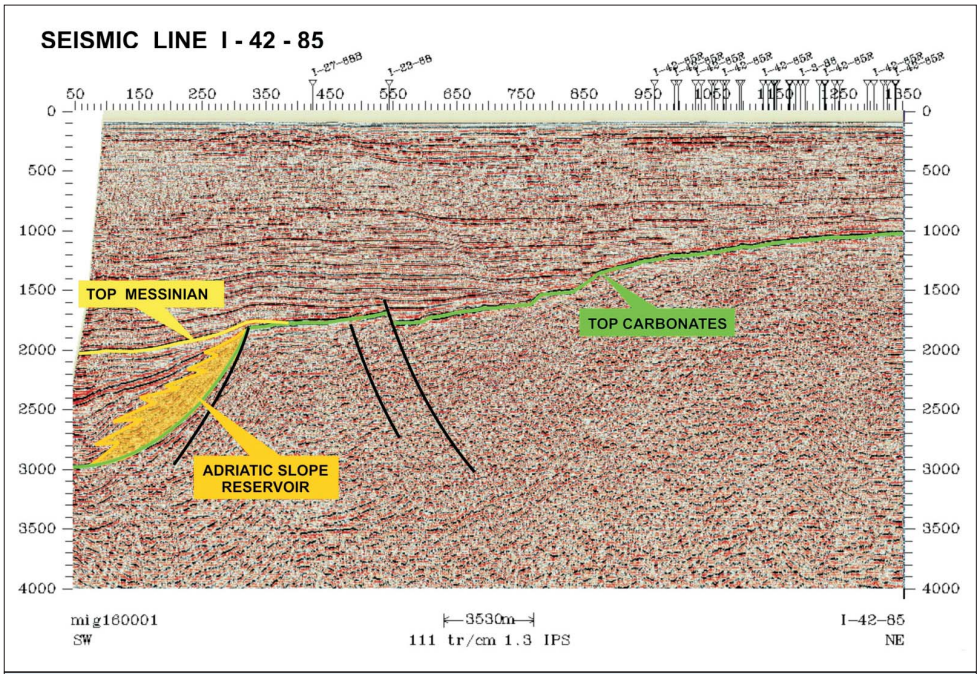


Fig. 7. Seismic cross-section I-42-85 covering southern part of Istrian platform where it is crossed by "Kvarner transverse fault" which spreads from SM-1 to Barbara gas field in Italian offshore.

Sl. 7. Seizmički profil I-42-85 obuhvaća južni dio istarske platforme na mjestu gdje ju presijeca kvarnerski transverzalni rasjed koji se proteže od bušotine SM-1 do plinskog polja Barbara u talijanskom podmorju.

Upper Lias when peri-platform clastics were formed as well as potential reservoir rocks.

Clear pinching out of peri-platform clastics in direction of Istrian carbonate platform is shown on presented cross-section PU-74-82, Fig. 6. Pinching out is expressed in "upward clinoform" show of Upper Cretaceous to Oligocene age as possible petroleum geological traps of structural stratigraphic type that were unfortunately not tested by exploration drilling.

As mentioned before, the data from IM-3 well were used as reference for cross-section processing in central and south Adriatic, i.e. for the whole belt of peri-platform clastics spreading.[9] Euxinic depocenters were not recognized as starting points of possible expulsions into described clinoforms in southwest direction, i.e. toward northern part of the Adriatic Basin. Authors propose the interpretation of cross-sections grid of the considered area to check the possibility of the existence of such depocenters and after that the reinterpretation of migration paths.

Figure 7 presents seismic cross-section I-42-85 which includes southern part of Istrian platform where it is crossed by "Kvarner transverse fault" which spreads from SM-1 to Barbara gas field in Italian offshore.

This is the case of two parallel faults with tectonic trough formed between them. Considering the data from Susak more-1 (SM-1) well, in the deeper part of this trough, Middle Triassic euxinic deposits were developed with TOC up to 4.5%. This trough is crossed by J-1-J-7-83 seismic cross-section which presents the platform slope.

3. Area Southeast of Kvarner Transverse Fault

Central Adriatic area is different from Central Adriatic basin. The difference is in fact that here, southeast of paleo-tectonic line Čabar-SM-1-J-7 (Kvarner transverse fault), Permian-Triassic evaporite deposits were developed which caused halokinetic movements and structures forming which had impact on sedimentation along Dinarides carbonate platform slope southeast of the mentioned line. The mentioned tectonic line has most probably transcurrent character which is reflected on differential shift of western from eastern wing. This fault with shift, according to its spreading is also possible good migration corridor.

On seismic cross-section KV-86A-81, Fig. 8, there is considerable thickness of over 1 000 m and width of 10 km of peri-platform clastics as potential reservoir rocks. Possible traps make pinch outs that stand out on this seismic cross-section.

Movements along the slope have most probably intensively affected the sedimentation of slope deposits. Changes are clearly expressed on cross-section K-105-82, D-10, D-8 and especially on J-22-82 i.e. in the area of diapirs of Jabuka island (Fig. 10). On this cross-section, structural depression between Jabuka diapir and Jelena-1 structural uplift is pointed out. Considering the intense subsidence, Ladinian-Carnian and Carnian euxinic shale as good and mature source rocks, are anticipated in the mentioned depression. From these potential source rocks, it is possible to forecast migration into traps on flanks of the mentioned Jabuka and Jelena struc-

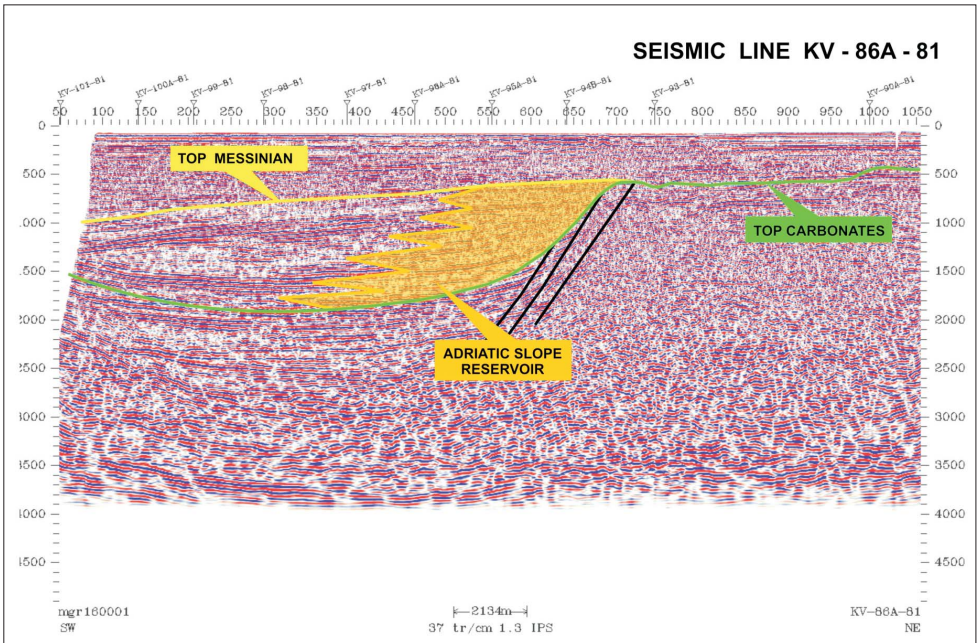


Fig. 8. The considerable thickness of over 1 000 m and width of around 10 km of peri-platform clastics as potential reservoir rocks stands out on KV-86A-81 seismic cross-section. The possible traps make pinch outs which are clearly visible on this seismic cross-section.

Sl. 8. Na seizmičkom profilu KV-86A-81 ističe se znatna debljina od preko 1 000 m i širina od 10 km periplatformnih klastita kao potencijalnih ležišnih stijena. Najznačajnije moguće zamke čine isklinjenja u smjeru sjeveroistoka.

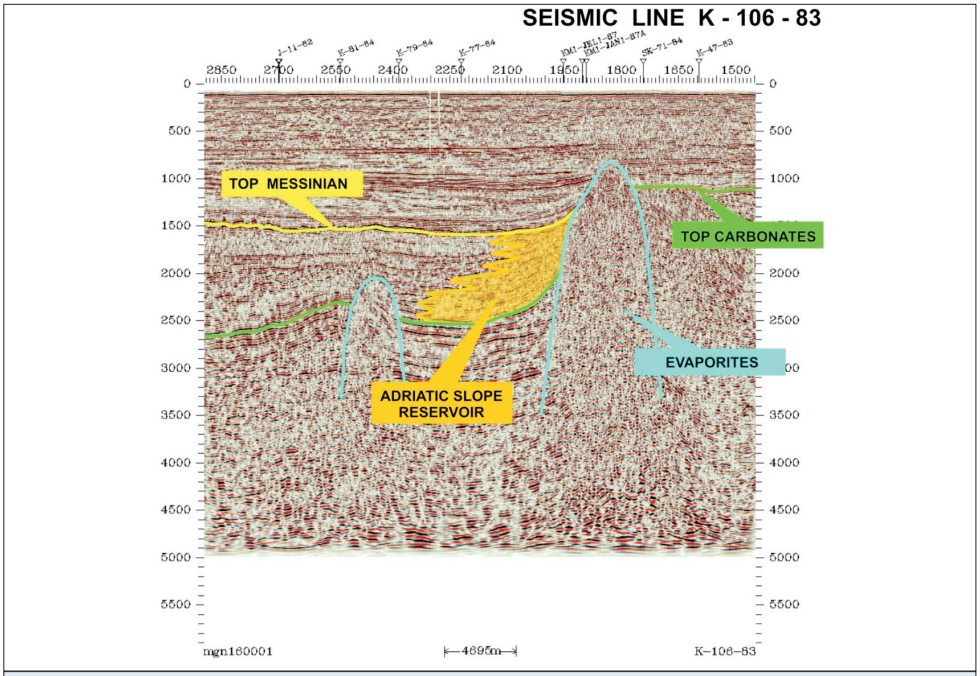


Fig. 9. Seismic cross-section K-106-82 shows protrusion of evaporates at the very transition of platform into Adriatic basin with younger Mesozoic pelagic deposits and Tertiary clastics and peri-platform clastics in Messinian deposits base.

Sl. 9. Na seizmičkom profilu K-106-82 prikazan je proboj evaporita na samom prijelazu platforme u Jadranski bazen s mlađim mezozojskim pelagičkim naslagama i tercijarnim klastitima i periplatformskim klastitima u podini mesinskih naslaga.

tures. These traps are proposed as good plays for further exploration.

Seismic cross-section K-106-82, Fig. 9, shows protrusion of evaporites at the very transition of platform into Adriatic Basin with younger Mesozoic pelagic deposits and Tertiary clastics and peri-platform clastics in Messinian deposits base.

The mentioned Jelena-1 well confirms strong emersion phase after Upper Lias when Miocene sediments discordantly overlie deposits of "Ammonitico Rosso" type, and the logical assumption is that possible reservoir and seal rocks could have been eroded and degraded at the vertex of this structure. According to the stated above, it is possible to conclude that main potential should be expected at the northeastern flank of Jelena structure where it is possible that hydrocarbon accumulations are situated in upward clinoforms as structural-stratigraphic traps. Migration is here expected from the deep depocenter south of Jabuka island where Ladinian-Carnian deposits were lowered at a very big depth i.e to the maturation level of potential euxinic deposits of "Vlasta-Komiža" type. According to seismic interpretation, this is the case of depression where "E" horizon is situated at the depth of 10 km.

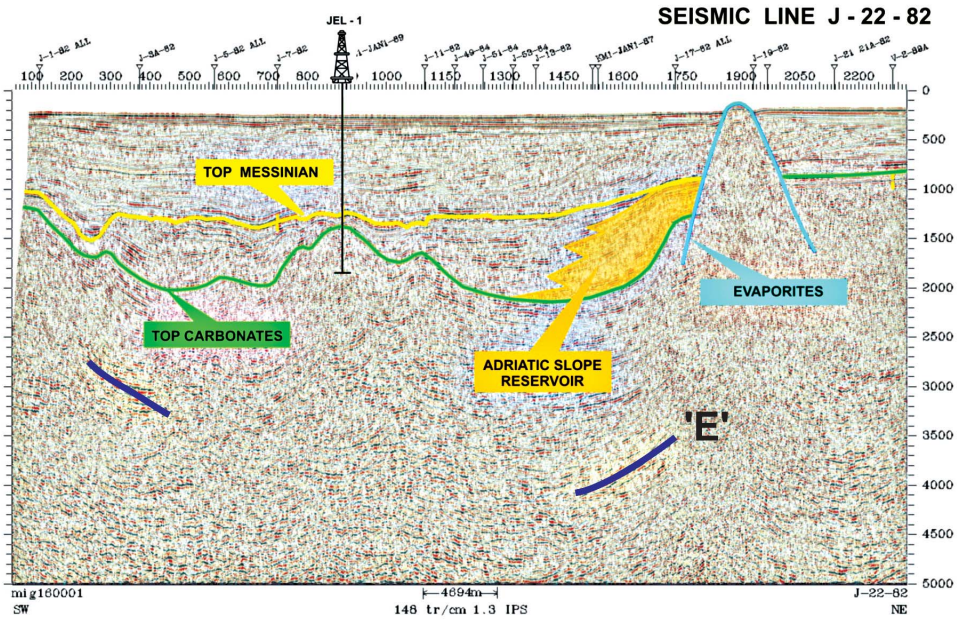


Fig. 10. Seismic cross-section J-22-82 clearly shows relations between Jabuka island structures (evaporites) and Jelena-1 structure and inter-depression with potential source rocks. Depression depth, i.e. burial of potential source rocks of Vlasta-1 type in most part of the profile is sufficient for their maturation which makes this cross-section prosperous for further hydrocarbon exploration.

Sl. 10. Seizmički profil J-22-82 jasno prikazuje odnose između struktura otoka Jabuka (evaporiti) i strukture Jelena-1 te depresije između njih ispunjene potencijalnim matičnim stijenama. Dubina depresije, odnosno zalijeganje potencijalno matičnih stijena tipa Vlasta-1 na većem djelu profila je dovoljna za njihovo sazrijevanje što čini ovo područje perspektivnim za daljnja istraživanja ugljikovodika.

Seismic cross-section J-22-82 in Figure 10 clearly shows relations between Jabuka island structures (evaporites) and Jelena-1 structure and depression between them which is filled with potential source rocks. Depression depth, i.e. burial of potential source rocks of Vlasta-1 type on the most part of the cross-section is sufficient for their maturation which makes this area promising for further hydrocarbon exploration.

However it is necessary to mention that also Posidonia deposits which were recognized in Jelena-1 well at 1 440 m represent also potential source deposits just like in the Ionian Basin area, where, in Kurveleshi zone they contain up to 15% of TOC.

Lately, as well as in the Ionian Basin area, intense exploration is performed south of the island of Vis and these results shall be studied in the next period and included in this preliminary assessment of peri-platform clastics pore volume. The important thing is that oil show has been determined in Vlasta-1 well. Testing has acquired 16.0 m^3 of medium heavy oil while the Ladinian-Carnian shale at this depth contained 4.2% of TOC.

4. Area Southeast of Šolta – Komiža - Pt. Pietra Nera Transverse Fault

4.1 Area South of Šolta - Komiža Fault to Mljet Island Offshore

Cross-sections V-16-83, Vls-Pat-82, L-16-82 and Vlatka-1, Vlasta-1, Lastovo-1 and Maja-1 wells were chosen as typical for this area. Results are illustrated in Figures 8, 9, 10 and 11. Cross-section V-16-83 was chosen as especially significant one. This cross-section crosses halokinetic structure at shot point 1 650. This structure on its southern side separates sedimentation depression which was filled with peri-platform clastics from southwestern flank of Dinarides carbonate platform.

As on the previous seismic cross-section, cross-section V-16-82, Fig. 11 also shows diapiric evaporites protrusion at platform edge and deep subsidence of potential source rocks of Vlasta-1 type. Especially visible are structures at the southwestern part of depression where traps in "upward" clinoforms can be expected.

One of the possible interpretations is that along this structure there is a deep fault which makes path for hy-

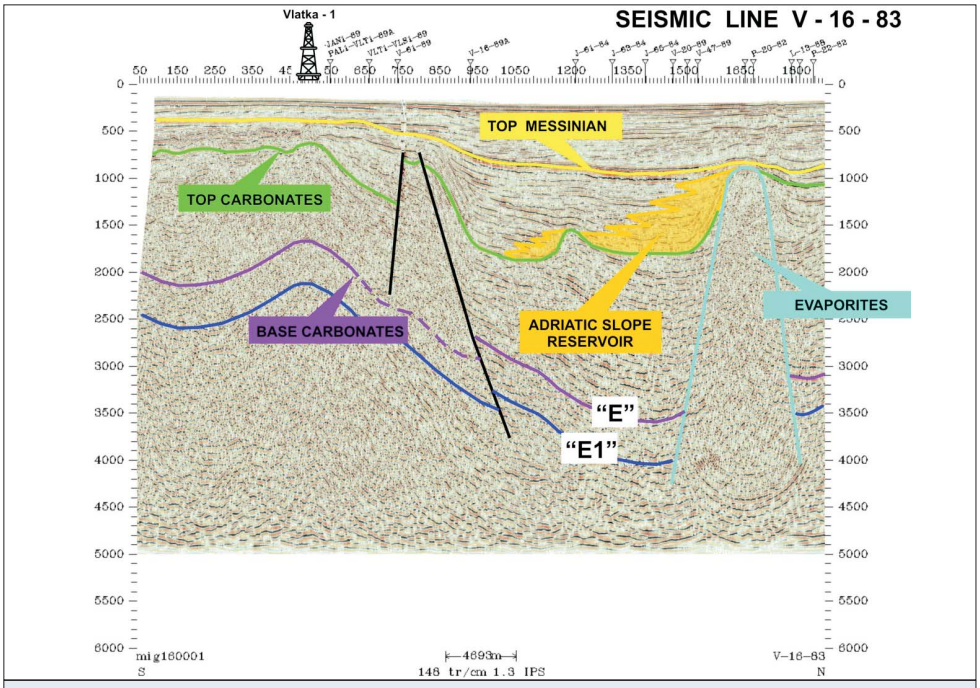


Fig. 11. The previous seismic cross-section V-16-82 shows diapiric evaporites protrusion at platform edge and deep subsidence of potential source rocks of Vlasta-1 type. Especially visible are structures at the southwestern part of depression where traps in "upward" clinoforms can be expected.

Sl. 11. Kao i na prethodnom seizmičkom profilu i na profilu V-16-83 ističe se dijapirski proboj evaporita na rubu platforme i duboka subsidencija potencijalno matičnih stijena tipa Vlasta-1. Posebno se ističu strukture na jugozapadnom dijelu depresije gdje se mogu očekivati zamke u "uzlaznim" klinoformama.

drocarbon migration from deep depression where burial of "E" horizon is supposed i.e. top of Ladinian-Carnian shale as potential source rocks at the depth of 3.5 seconds of two way time or approximately at 4 000 m. Thus subvertical hydrocarbon migration from these Ladinian-Carnian shale in peri-platform clastics clinoforms is supposed and then their accumulation in stratigraphic traps and clinoforms of upward type. Considering the very close location of Vlasta-1 well, where oil was discovered in the same Ladinian-Carnian euxinic shale and according to the mentioned interpretation of petroleum-geological relations, the mentioned trap was proposed by the author as a very significant lead, i.e. potential hydrocarbon accumulation.

Paleo-tectonically significant cross-section V-16-83 is within the domain of well known Pt. Pietra Nera fault north of Gargano peninsula. According to study of A. Del Ben2 and later processing of deep CROP cross-sections of the mentioned locality near Pescara all the way to Šolta intense transverse fault is marked. This fault is parallel with "Kvarner" fault and can also have a function of good migration corridor (Fig. 1). As already noted on Fig. 13, migration from euxinic deposits of Vlasta-1 facies is supposed. Unfortunately neighboring Vlatka-1 well was drilled on paleo-structural uplift which was several times in emersion and is prone to incision and resedimentation, thus the forming of clastic sediments occurred with potential traps on the flank of uplifted structure. Due to the mentioned reason, the complex of peri-platform clastics is proposed to be more prosperous. Favorable conditions are forecasted also on the flanks of the marked structure (TP 700) where clinoform sedimentation shapes are well developed as possible traps.

4.2 Palagruža Slope

In the deeper part of seismic cross-section P-44A-82 (Fig. 12) top of Middle Triassic has been interpreted ("E1" horizon) with potential source rocks of "Vlasta-Komiža" type of Ladinian-Carnian age which are buried in Patricija-1 well area at the depth up to two seconds of two way time, which should, according to maturation diagram,[6] be sufficient for the maturation (late mature) of mentioned source rocks. It should be mentioned again that in Vlasta-1 well 16 m^3 of oil were determined in mentioned Triassic rocks at 5 402 m.

The purpose of interpretation of seismic cross-section P-44A-82, presented on Fig. 12, is to present more completely the sedimentation basin with pelagic development of younger Mesozoic deposits southwest from Palagruža structural uplift. Potential source deposits of Ladinian-Carnian, southwest of the structure were lowered over 5 sec. of two way time i.e. to maturation level. The migration into traps within peri-platform Cretaceous-Paleogene clastics is supposed.

Platform-basin transition is, like in the other parts of Dinarides platform slope, conditioned by reactivated Triassic faults which brought to surface carbonate deposits near Palagruža and Galiola Triassic and Jurassic where older Permian-Triassic evaporites are most probably in the uncovered basement. Specific structural characteristic in this area, southeast of Vis island, is significant intensity of tectonic vertical shifts along Dinarides carbonate platform slope and according to this, more intense development of sedimentation depressions as potential oil-generating centers (southwest of Palagruža-1 (Pal-1) and Patricia-1 (Pat-1) wells or from Palagruža slope uplift). Dinarides carbonate platform was moved by Šolta-Pt.Pietra Nera strike-slip fault and by parallel fault on the eastern part of Palagruža island in the direction of Adriatic pelagic basin central part. Proofs for this are seismic cross-sections P-40A-82 to P-2-82 southwest of Palagruža island and Gargano Mare E-1 well which encompassed the pelagic deposits of younger Mesozoic.

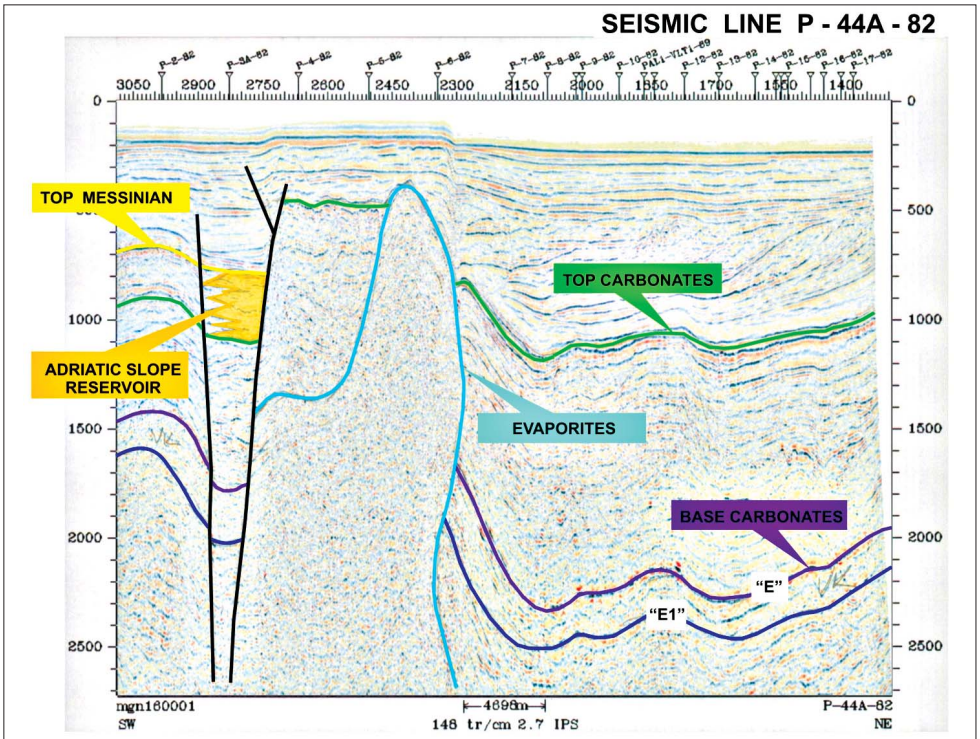


Fig. 12. The purpose of P-44A-82 seismic cross-section interpretation is to present more completely the sedimentation basin with pelagic development of younger Mesozoic deposits southwest of Palagruža structural uplift. Potential source deposits of Ladinian-Carnian southwest of the structure were lowered over 5 sec. of two way time to maturation level. The migration into traps within peri-platform Cretaceous-Paleogene clastics is supposed from this depression.

Sl. 12. Namjena je interpretacije seizmičkog profila P-44A-82 da prikaže potpunije sedimentacijski bazen s pelagičkim razvojem mlađih mezozojskih naslaga jugozapadno od strukturnog izdignuća Palagruža. Potencijalno matične naslage ladinika-karnika jugozapadno od strukture spuštene su preko 5 sek. dvostrukog vremena tj. na nivo maturacije. Iz ove depresije se pretpostavlja migracija u zamke unutar periplatformnih kredno-paleogenskih klastita.

4.3 Vis – Lastovo – Mljet Sector

Sector south of the island of Visa, which nicely illustrates the transition from platform into South Adriatic Basin is visible on interpreted seismic cross-section L-16-82 (Fig. 13).

Seismic cross-section L-16-82, Fig.13, includes a part of Dinarides platform on the transition into the Adriatic Basin. Transition is characterized by development of slope deposits, i.e. peri-platform clastics as potential reservoir rocks of considerable thickness.

Intense eroding-abrading of Upper Cretaceous rudist limestone is very typical northeast of Maja-1 well. Detritus of these sediments is resedimented in the direction of Adriatic basin. "Upward" clinoform shapes were created in these peri-platform clastics as potentially promising petroleum-geological traps, which are especially expressed at shot point 800 - 900 of this cross-section. Traps are situated at the depth two seconds of two way time, i.e. approximately at 3 500 m. In this study they were studied as promising plays for further exploration. It is especially important that they are situated near "Palagruža east" depocenter which can be considered as potentially oil generative center for migration into mentioned peri-platform clastics. Reservoir characteristics are supposed in the deposits similar to the previously described ones on IM-3 well which were created in identical paleo-geographic conditions. In their top, these deposits have good seal sediments of younger Tertiary age of considerable thickness. Considering the favorable petroleum-geological conditions, seismic cross-section V-16-83 and especially cross-section L-16-82 and maturation diagram (Fig. 14), indicate especially favorable conditions for oil and gas generation and accumulation, thus the mentioned area is considered to be very promising within the domain of stated cross-sections. According to the mentioned above it is considered as the most suitable one for further petroleum-geological exploration.

Fig. 14 shows maturation diagram for the selected point A which is close to shot point 1000 of seismic cross-section L-16-83 and confirms that Ladinian-Carnian deposits have been for 60 million years at the depth of over 7 500 m where their average maturity of 0.7-1.0 (%Ro) can be expected.

According to the constructed maturity diagram for this part of South Adriatic, deposits older than Norian and Rhaetian at the depth of over 8 000 m should be situated in the main maturation phase with 0.1 to 1% Ro. Two ways time of 5.5 seconds undoubtedly proves that Ladinian-Carnian deposits are situated below that depth. Geothermal map also proves that the considered area is situated in favorable geothermal conditions for source rock maturation with temperatures up to 80 °C (Fig. 15).

Fig. 15 shows regional map of geothermal relations (map of isotherms) where it is visible that in the area of South Adriatic there are favorable conditions for maturation of potential source rocks such as Ladinian-Carnian euxinic shale. The map indicates the potential migration direction toward northwest.

One of especially favorable conditions is the existence of good potential source rocks such as the ones drilled in Vlasta-1 well, where the thickness of Ladinian-Carnian shale is 1 360 m, TOC up to 4.2% with oil show at the depth of 5 402 m, where 16 m^3 of oil were acquired. This

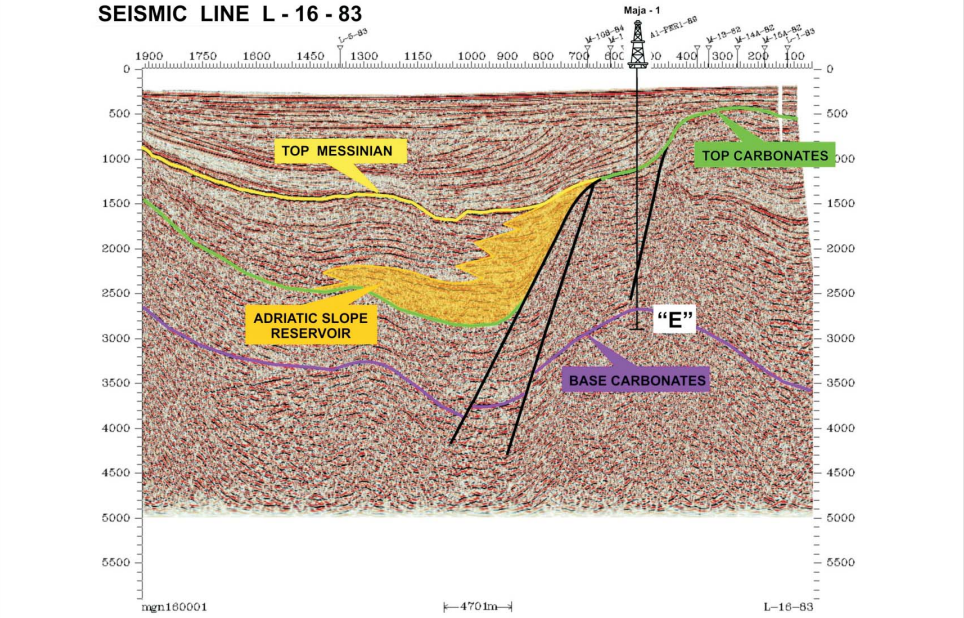


Fig. 13. Seismic cross-section L-16-82 includes part of Dinarides carbonate platform on the transition into the Adriatic Basin. Transition is characterized by development of slope deposits, i.e. peri-platform clastics as potential reservoir rocks of considerable thickness.

Sl. 13. Seizmički profil L-16-82 obuhvaća dio Dinaridske karbonatne platforme na prijelazu u Jadranski bazen. Prijelaz je karakteriziran razvojem pregibnih naslaga, odnosno periplatformnim klastitima kao potencijalnim ležišnim stijenama značajne debljine.

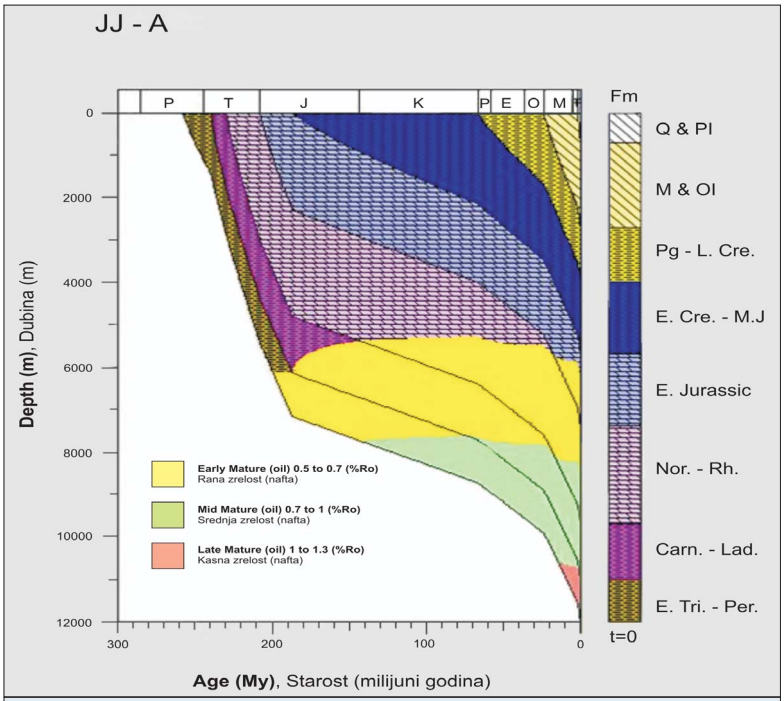


Fig. 14. Maturation diagram for the selected point AA which is close to shot point 1000 of L-16-83 seismic cross-section confirms that Ladinian-Carnian deposits are situated at the depth of over 7500m where their average maturity of O.7-1.0 (%Ro) can be expected.

Sl. 14. Dijagram maturacije za odabranu točku A koja se nalazi u blizini TP-1000 seizmičkog profila L-16-83 potvrđuje da se ladiničko-karničke naslage već 60 milijuna godina nalaze na dubini većoj od 7 500 m gdje se može očekivati njihova srednja zrelost od 0,7-1,0 (%Ro).

data is especially encouraging because the spreading of euxinic deposits of Vlasta-1 type has been determined on the wider area especially in the direction of the designed Popovići-1 well in Ravni Kotari.

We propose the exploration drilling on the position of shot point 900 where "upward" clinoforms were interpreted as favorable petroleum-geological traps from the depocenters mentioned in the previous column.

4.4 Mljet – Rt oštra (Boko kotorski zaljev)

Bitumen traces were recognized on Mirjana-1 well. The drilling was performed at the vertex of uplifted structure. Interpretation showed that also here, due to frequent emersions, main collector and seal rocks were destroyed by erosion.

Interpretation of cross sections D-68-83 and M-67-82, Fig.16 showed intense erosion and resedimentation on Dinarides carbonate platform margin and sedimentation down the platform slope. This is very steep and tectonically conditioned slope where tectonic leap is over 4 000 m and where it is possible that the peak of paleo-tectonic structure is rotated in the direction of Adriatic basin.

Similar procedure was proposed by Grandić and Veseli already in 2002.[5] It was clearly stated in the mentioned work that the possible reason for lack of oil discovery on Kate-1 structure was the fact that this structure has been, after initial development in Laramian phase and additional shaping in Pyrenean phase, rotated in counterclockwise direction. The mentioned rotation most probably moved a potential reservoir of this structure in the direction of Dugi Otok Basin 1.5 km. Kate-1 well confirmed only numerous oil traces instead of commercial reservoir. From the top of Eocene foraminifera limestones which is situated at 2 000 m up to final depth at 5 800 m, shows of oil were determined which has most probably laterally migrated from "missed" reservoir toward vertex of Kate structure.

Potential traps are primarily expected at structure flanks in peri-platform clastics spreading zone which are marked on the map. According to the above described conditions, this is the case of great thickness and mass of

peri-platform clastics which, according to seismic cross-section (TP 700-800) can have thickness even bigger than 2 000 m. This geological model represents also an interesting exploration play as on the neighboring JJ-3 well oil has been confirmed and it can be concluded that also this is the case of very promising petroleum-geological play (Fig. 17).

Cross-section Y-80-10, in Fig. 17, includes pointed out structure on carbonate platform margin. Medium heavy oil show was determined on marked JJ-1 well.

Significant quantities of "wet" gas were confirmed on JJ-1 well which is situated 15 km from JJ-3 well in Oligocene peri-platform clastics (C4 - C7).

The described petroleum-geological relations in central Adriatic area and especially of south Adriatic area pose the need for thorough interpretation. It is necessary to adjust the exploration concept of certain structures to new acquirements. That especially concerns negative impacts of emersion processes and it is important to determine complete evolution of certain structural traps from initial structuring phase to first emersions or covering by seal rocks.

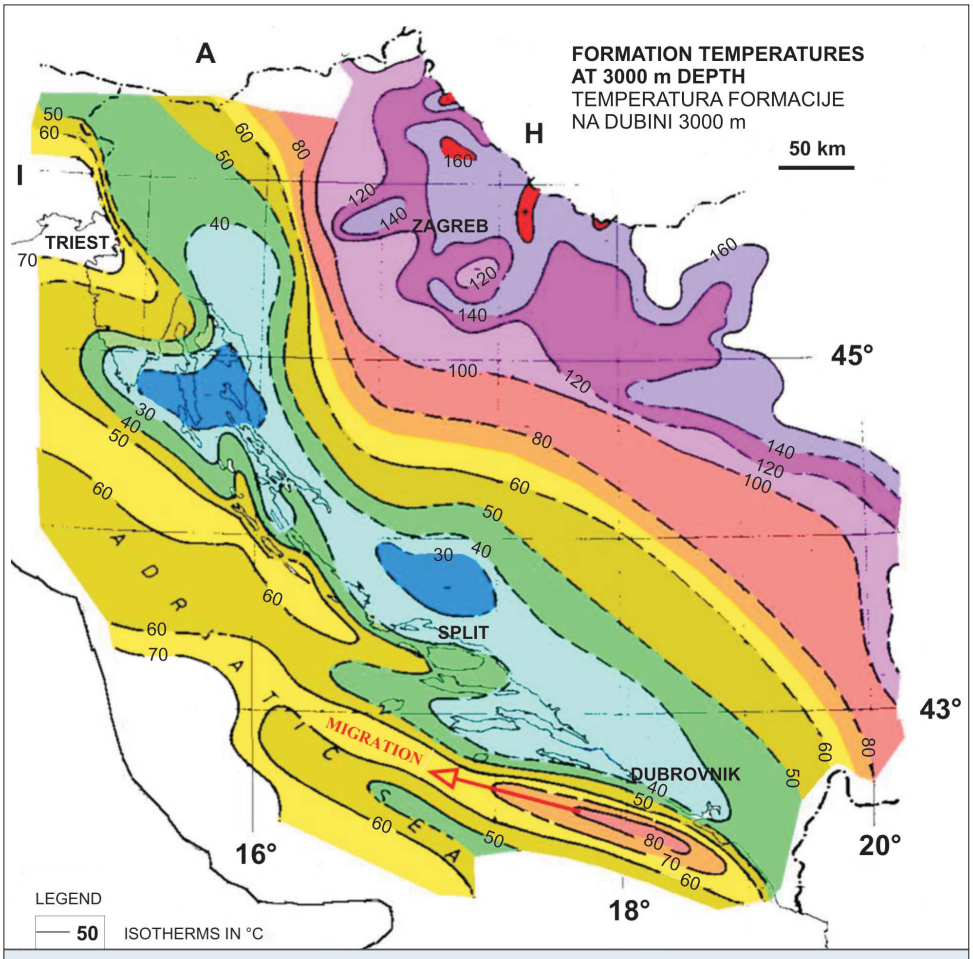


Fig. 15. Regional map of geothermal relations (map of isotherms) shows that in South Adriatic area there are favorable conditions for maturation of source rocks like Ladinian-Carnian euxinic shale. Potential migration direction toward northwest is marked on the map.

Sl. 15. Regionalna karta geotermalnih odnosa (karta izotermi) prikazuje da u području Južnog Jadrana postoje povoljni uvjeti za sazrijevanje potencijalno matičnih stijena kakovi su ladiničkokarnički euksinski šejlovi. Na karti je označen potencijalni smjer migracije prema sjeverozapadu.

5. Preliminary hydrocarbon potential assessment of peri-platform deposits

Based on 12 interpreted cross-sections of North, Central and South Adriatic, a preliminary assessment of potential reserves was made. It is supposed that this is only the first phase of this assessment which should be continued by cross-sections interpretation.

Additional significance of peri-platform clastics petroleum-geological potential was acquired by oil discovery on Rovesti structure on the Italian side of Adriatic where in 2007, commercial oil quantities were discovered. Transverse seismic cross lines where their cross-section was marked were used for assessment of total volume of reservoir rocks. Naturally that it is very difficult to assume that along the whole edge of carbonate platform the same sediments were almost continuously saturated with hydrocarbons but it can be assumed that there is bigger or smaller number of possible accumulations that would contain significant quantities. For potential reservoir it is also necessary or lateral pinching out of reservoir rocks (clastics) toward impermeable deposits or faults which serve as barrier. If we assume that those conditions exist, we can try to determine the total volume of reservoir rock and assess regional potential of hydrocarbon accumulation.

Using the average surface of reservoir rocks calculated from transverse cross-section profile and longitudinal spreading of peri-platform sediments, the total volume was approximately calculated. Considering the expressed great uncertainty in the assessment of parameters for calculation, stochastic (Monte Carlo) simulation was applied for acquiring the most realistic value possible and due to the same also the other parameters were observed in a very strict manner. Figure 18 shows Monte Carlo simulation results.

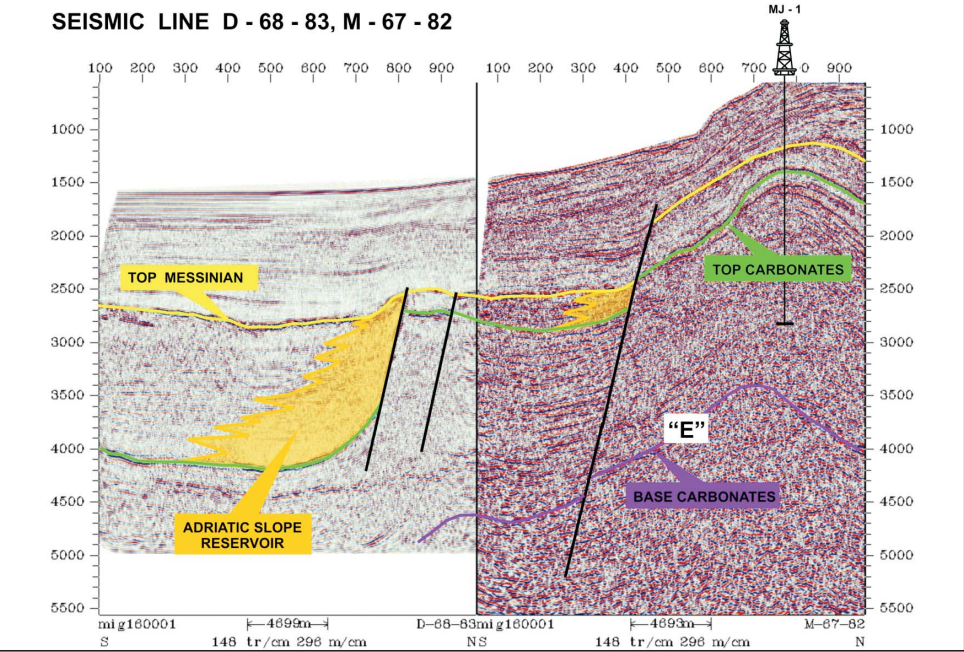


Fig. 16. Interpretation of D-68-83 and M-67-82 cross-sections shows intense erosion and resedimentation on Dinarides carbonate platform margin and sedimentation down the platform slope. This is very steep and tectonically conditioned slope where tectonic leap is over 4000m and where it is possible that the peak of paleo-tectonic structure is rotated in the direction of Adriatic basin.

Sl. 16. Interpretacija profila D-68-83 i M-67-82 svjedoči o intenzivnoj eroziji i resedimentaciji na rubu Dinaridske karbonatne platforme i taloženju niz -pregib platforme. Radi se o vrlo strmom i tektonski uvjetovanom pregibu gdje je tektonski skok preko 4 000 m i gdje je moguće da je vrh paleotektonske strukture rotiran u smjeru Jadranskog bazena.

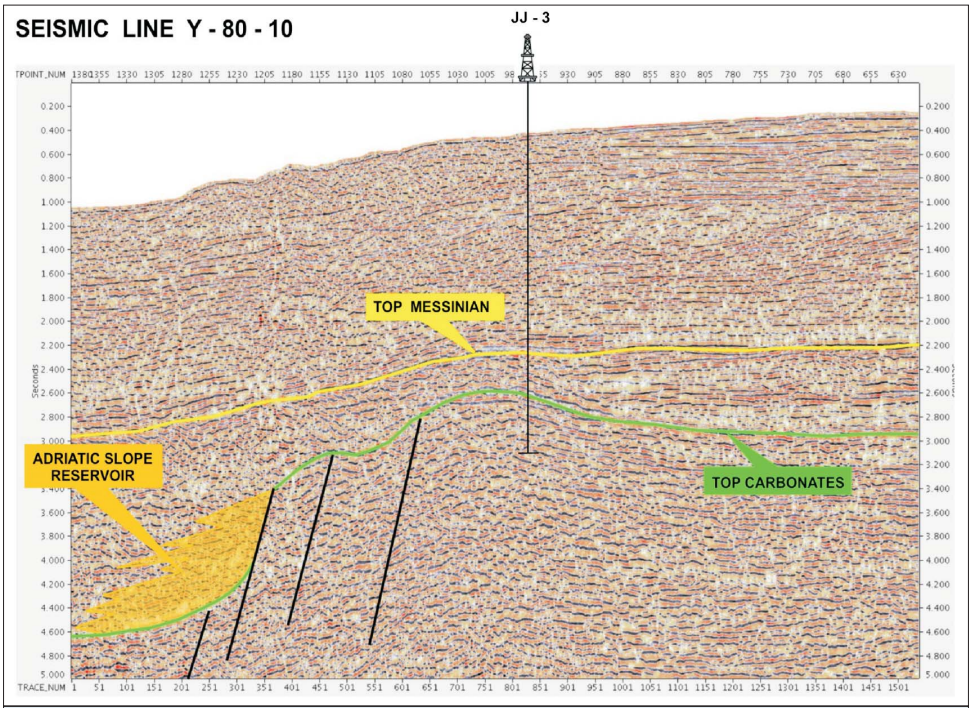


Fig. 17. Cross-section Y-80-10 includes pointed out structure on carbonate platform margin. As already mentioned, heavy oil was confirmed on the well drilled on this structure.

Sl. 17. Profil Y-80-10 obuhvaća istaknutu strukturu na rubu karbonatne platforme. Na označenoj bušotini JJ-1 utvrđena je pojava srednje teške nafte.

From the figure it is visible that the total petroleum-geological potential can be assessed from 2 – 3.3 billion m^3 of oil equivalent, i.e. 386 - 524 million m^3 conditionally recoverable reserves. Naturally these values are without expressed geological risk and they show maximal values that can be expected. In the attempt to assess the size of certain "lead", the risk of 95 - 99% was calculated which is the adopted value considering poor percentage of exploration of the considered "play" and unproved hydrocarbons. Thus the value of 5.3-21.2 million m^3 of conditional oil as an assumption for the range of certain "lead" is in fact boundary value for undertaking exploration by exploration drilling regarding the associated price and risk.

Determining exploration plays and their feasibility are still far from realization as other geological parameters need to be determined first.

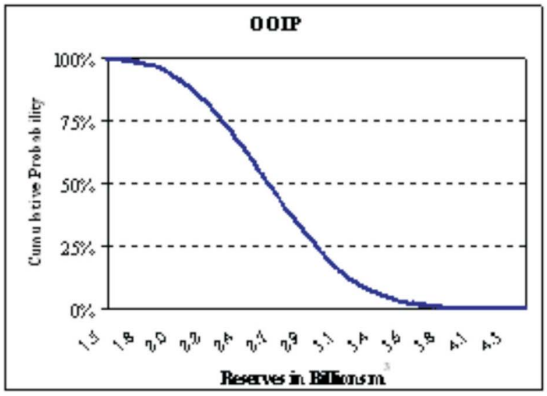
6. Conclusion and recommendations

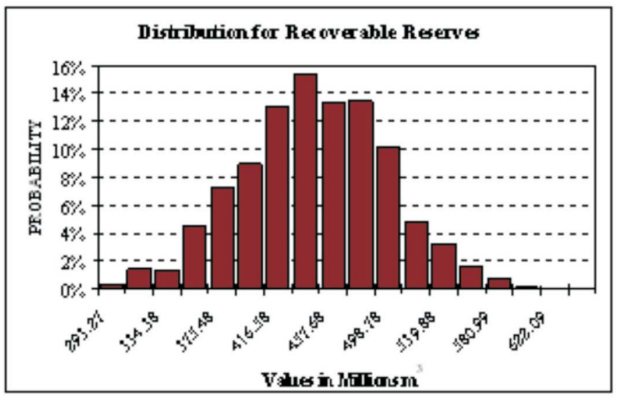
Petroleum-geological potential of certain area is usually assessed on the basis of conditions for hydrocarbon reservoirs and those are: (1) existence of source rocks, (2) existence of depocenters with good geothermal conditions for TOC maturation, (3) conditions for migration into favorable traps, (4) existence of reservoir rocks with good collector characteristics and (5) existence of seal deposits of regional spreading.

The existence of these basic petroleum-geological conditions shall be described more precisely herebelow.

1. Source rocks. As we have previously mentioned, Ladinian-Carnian euxinic shale of "Vlasta-Komiža" type deposits were taken in consideration as most important source rocks. in these deposits in Vlasta-1 well, TOC up

INPUT PARAMETERS	UNIT	DISTRIBUTION	VALUES		
Cross section area	Sq. meters	Constant	8,232,188		
Lenght	Meters	Triangular	100,000	200,000	400,000
Volume	Cub. meters	Triangular	823,218,750,000	1,646,437,500,000	3,292,875,000,000
Net/gross vol	Fract.	Triangular	0.02	0.05	0.10
Porosity	Fract.	Triangular	0.05	0.08	0.13
Water saturation	Fract.	Constant	0.45		
Form. volume factor	p.p.u.	Normal	1.80		st. dev. 0.03
Recovery factor	Fract.	Triangular	0.15	0.17	0.20





Estimated OOIP	m³	Estimated recoverable reserves	m³
Min	2,066,907,264	Min (90% conf.)	385,973,536
Mean	2,648,752,289	Mean	454,714,580
Max (10% conf.)	3,258,987,520	Max (10% conf.)	523,825,696

Estimated recoverable reserves average lead

	m³
Min (90% conf.)	5,326,753
Mean	2,648,752,289
Max (10% conf.)	3,258,987,520

Fig. 18. shows the results of Monte Carlo simulation
Sl. 18. Rezultati Monte Carlo simulacije

to 4.2% was determined as well as medium heavy oil show. These deposits, which in the mentioned well have thickness of 1 300 m and in the direction of Ravni Kotari, according to seismic cross-sections can reach thickness even up to 2 000 m. They were also interpreted in the area of seismically confirmed depressions from Palagruža to depressions in Mljet island offshore.

2. The existence of oil generating depocenters. The mentioned depressions were considered as generative depocenters which were related to Kurveleshi trough in Albania and are genetically related to oil fields in Vlora port area. In the present exploration phase, oil generative depressions are not so expressed as in Central and North Adriatic.

3. Distance of potential generative centers. Depocenters Palagruža and Mljet from 4.5 to 5,5 seconds of depths are situated at the distance that can provide good connection for hydrocarbon migration. The example of discovery on the structure indicates the possibility that hydrocarbon accumulation was result of migration from depocenters of central part of South Adriatic Basin and Albanian part of Ionian Basin which is well known for numerous source rock horizons. Especially known is Kurveleshi belt where five horizons of Reth-Lias, Toarcian (Posidonia beds), Dogger ("green beds"), Oxfordian-Tithonian ("upper chert") and argillaceous deposits of Albian age. The mentioned horizons are important also for prosperity of Croatian part of Adriatic basin considering the possibility of migration in direction of Lastovo and Palagruža islands.

4. Peri-platorm clastics as potential reservoir rocks. According to interpretation of seismic cross-sections L-16-82 and M-34-82 at the southwestern flank of Dinarides carbonate platform slope, good possibilities for hydrocarbon accumulation into statigraphic traps were anticipated. Mostly those are "upward clinoforms" which pinch out opposite of platform slope or toward fault plane which has caused the creation of the slope. Porosity and permeability were graded according to laboratory data on IM-3 well core analyses as there are no other wells in peri-platform clastics with laboratory data.

5. Seal rocks. According to seismic and well data, good seal rocks are made of Tertiary deposits of argillaceous – marl content with impermeable characteristics. Analogy with Rovesti-1 well shows that those are Lower Miocene deposits of Bisciario formation type. Seal rocks are situated in Rovesti well at the depth of 970 m and according to interpretation of seismic cross-sections, somewhat lower depths can be expected in the Croatian part of Adriatic.

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