Oil and gas bearingness and structural elements of Adriatic islands and peninsulas (Outer Dinarides) with special review of anhydrite – carbonate Mesozoic complex and diapiric belt

V. Spaić

ORIGINAL SCIENTIFIC PAPER

Evaporite deposits of Mesozoic age in the area of Adriatic islands and peninsulas (Outer Dinarides) have been attracting attention of exploration geologists for many years. This paper presents petroleum geological data that provide more certainty for more accurate planning of exploration operations that would result in location of new, very deep exploration wells in certain parts of Adriatic islands and peninsulas (Figures I, 2, 3, 4 and 5).

This is the area of anhydrite-carbonate complex, especially in the part of Mesozoic basin where certain hydrocarbon shows of C_1-C_5 were acquired in Brač-1 ß well and where the pressure of 1 100 bar (15 954 psi) was measured. This confirms the previous knowledge that deposits with anhydrite seal represent closed petroleum geological units with high pressure and temperature and commercially significant hydrocarbon quantities.

The opinion is presented on hydrogen sulfide shows in anhydrite-carbonate complex and its bad impact on human health and on destructive alteration of crystal lattice in steel.

The paper also presents diapirs on the southern edge of Mesozoic basin in the area of southern islands, their impact on formation of certain islands and possible impact on oil and gas bearing relations within this basin (Figure 5).

Keys words: oil and gas bearingness, outer Dinarides, Adriatic islands, anhydrite-carbonate complex

1. INTRODUCTION

The Dinarides sedimentary basin spread from northwestern parts of Slovenia toward southeast in the direction of Albania where it crosses Albanides and Hellenides. Heterogeneous deposits from Paleozoic, Mesozoic and Kenozoic were sedimented in this basin. Their thickness, recognized by geophysical survey is over 15 000 m (49 213 ft). According to their litho-s tratigraphic, tectonic and petroleum geological characteristics, they represent a significant target for oil and gas exploration.

Asphalt and bituminous rock shows from Istria to the end southeastern Dinarides have long time ago triggered discussions on oil and gas exploration as asphalt and bituminous rocks might be an important indication of hydrocarbon presence in deeper parts of the basin.[38,39,63]

Numerous Croatian and foreign geologists have been studying Dinarides presenting in their works different points of view. This is the explanation for different interpretations of Dinarides structure as well as in tectonic regionalization of this area. Differences can be seen in different terminology used in presenting of certain tectonic schemes. [6,11,12,28,29,30, 31,44,45,47,49,55,56,62]

Deep and very deep drilling in the Dinarides area provided new information on deep geological structure of this area. The first exploration of Dinarides deep structure in Croatia started in 1959 by deep exploration well Ravni Kotari – 1 (RK-1) which was drilled northeast of Zadar near Murvica, its total depth being 4 535.10 m (14 879 ft). Anhydrite deposits ($CaSO_4$) were recognized at the depth of 2 000 m (6 562 ft) which followed under younger Cretaceous carbonate ($CaCO_3$) deposits, representing a big surprise. After that, deep exploration drilling continued with shorter or longer interruptions until 1975. In 1975, very deep drilling started in Dinarides by drilling of Nin – 1 (Nin-1) well with total depth of 5 600 m (18 373 ft), followed by Brač -1 beta (Brač-1ß) well with total depth of 6 047 m (19 839 ft). Poljica - l (Polj-1) well with the total depth of 5 515 m (18 094 ft) was drilled in 1981 and this was the last well drilled in the Dinarides area. During exploration drilling period that lasted several years, 17 exploration wells were drilled in the coastal Adriatic area and on Adriatic islands which represents a small number of wells considering the acreage of this exploration area.

Hydrocarbons and hydrogen sulfide (H_2S) shows were registered in certain wells. The most significant ones were found in wells in the area of Ravni Kotari, Dugi Otok, Olib, and Brač in anhydrite-carbonate rock complex. Oil was detected in Ravni Kotari-1 and -3 wells and Dugi Otok -1 well whereas gas shows were detected in

Olib – 1, Nin -1 wells and especially in Brač-1ß well. Source rocks were recognized on the surface in certain wells within deposits of Carboniferous, Permian, Ladinian, Carnian, Malm, Albian, Cenomanian, Turonian and Senonian. Results of geochemical analyses show that source rocks vary from immature ones to those of early maturity, mature ones and over mature source rocks.[8,9,19, 36,38,39, 50,60,61,62]

Source rocks are probably situated even deeper in the Adriatic Sea area in Paleozoic, Mesozoic and Cenozoic rocks from which hydrocarbons could have migrated into the deposits of anhydrite-carbonate complex and especially into the layers beneath. Accordingly, it has been concluded that the coastal area and islands area from Istria to Crna Gora, represent promising area for oil and gas discovery, especially in the area where the complex of anhydrite-carbonate-petroleum rocks of Mesozoic age was recognized.[12,21,26,29,34,37] This was even more obvious after the drilling of Brač-1ß deep exploration well on the island of Brač near place called Milna. The well confirmed the assumption that those rocks formed close petroleum geological systems characterized by high pressures. Pressures within this well were 1 100 bar (15 954 psi).[33,34]

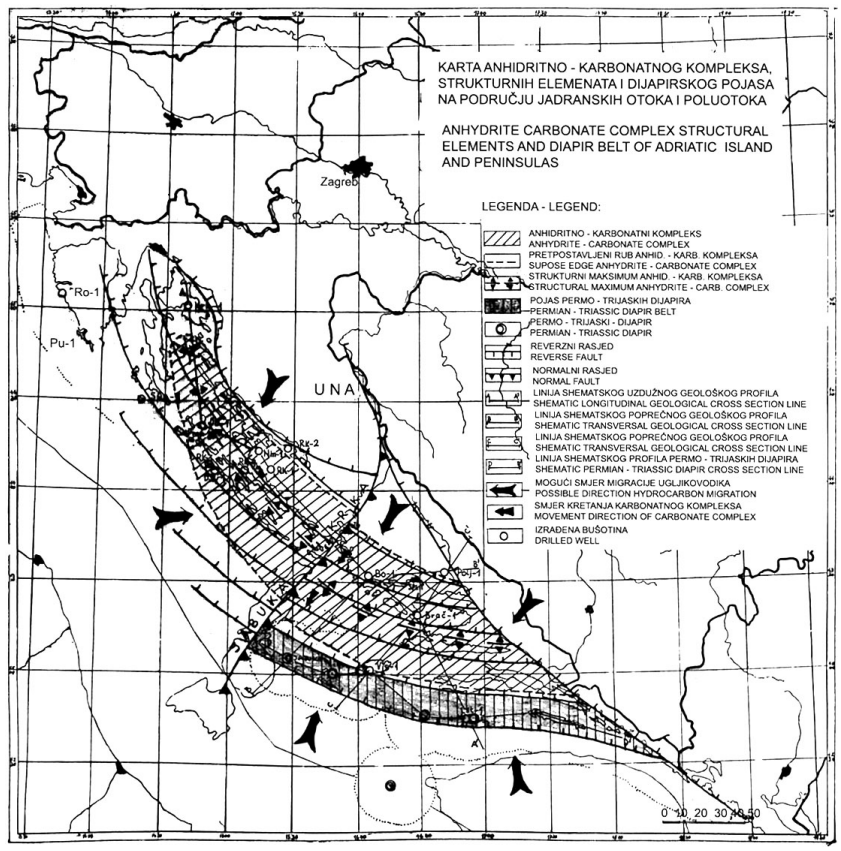

Fig. 1. Map of anhydrite-carbonate complex, structural elements and diapiric belt in the area of adriatic islands and peninsulas

Sl. 1. Karta anhidritno-karbonatnog kompleksa, strukturnih elemenata i dijapirskog pojasa na području jadranskih otoka i poluotoka

The analysis of all geological-geophysical surveys results and analysis of results from deep exploration wells provided a general view of deep geological, tectonic and petroleum geological characteristics of Mesozoic deposits, coastal and island area. These are the characteristics I want to write about and present in this paper.

According to the above, three basic lithological complexes may be separated in this area.[10,14,16,17,19,20,33,34, 35,38,39,40,41,44,49,52,58,59,60,61,66,67,72,73,75]

Those are:

- carbonate complex of Cretaceous rocks,
- complex of anhydrite-carbonate rocks of Lower Cretaceous and Upper Jurassic age,
- complex of clastic-evaporite-carbonate rocks of Permian – Triassic age.

The mentioned complexes of rocks have been explored to different degrees. The reasons are their thickness, depth and technical characteristics of drilling rigs which, in 1975, had capacity to drill up to around 4 000 m (13 123 ft). Diapirs of south Adriatic area are also presented and described.

2. CARBONATE ROCKS COMPLEX

Carbonate rocks complex spreads from the surface to anhydrite carbonate complex and this carbonate rocks complex is the most explored part of Mesozoic deposits. These rocks were discovered on the surface or were drilled in all wells. They are composed of limestone, dolomite, limestone breccia and bauxite. They are of Cretaceous age.

Stronger uplifting occurred in Outer Dinarides at the end of Mesozoic, influenced by Laramian orogeny phase. Main folding, reversed faulting and overthrusting of rock masses occurred during Eocene and until Oligocene in Pyrenean phase, whereas horizontal movement components belong to Middle Miocene.

Reversed faults are longitudinal to NW-SE spreading direction and are typical for tangential pushes from north and northeast. These faulting and pushes caused formation of ovethrust structures. Upright, diagonal, recumbent and plunging folds were created. Repeating of beds occurred, along with flake composure and steep dipping of beds causing significant increase in carbonate sediments thickness. (Figures 1, 2, 3, and 4).

The other fault system consists of faults that are perpendicular to Dinarides NNE-SSW spreading direction. By their origin, they are younger than reversed faults. The opinion is that they originate from Middle Miocene. Those faults have significant horizontal movement components. One of those is also a fault spreading along Jabuka depression which is perpendicular do Dinarides

spreading direction. Further it spreads with Krka River going further into river Una Valley acquiring the characteristics of reversed fault.

Due to tectonic movements from NE, carbonate rocks complex was sliding over anhydrite (decollement) in southern direction and is characterized by tectonic disturbance, carstification and deep infiltration of surface water into underground. Carbonates became folded, flaked, broken and grinded. It resulted in fractures, caverns, cavities and caves where water circulated from surface to anhydrites.

Carbonate rocks complex characteristics are tangential and radial faults, overthrust structures, deep carst, relatively lower temperatures and pressures and mud loss and generally loss of circulation during drilling. Rocks of that complex are abundant with natural phenomena typical for carst areas.

Those are the following:

- Fractures, caverns and cavities of various size and shapes;
- Their areal connection;
- Fractures, caverns and cavities ties at the depth with surface parts
- Water filled fractures, caverns and cavities ;
- Water flow through the "network" of fractures, caverns and cavities
- Loss of mud, sea water and cement slurry during drilling;
- Low geothermal gradient as a result of underground water flow and relatively good thermal conductivity of carbonate rocks.

Disturbance of carbonate deposits, repetition, fractures, caverns, cavities, caves and steep bed dip cause great difficulties during drilling. This has negative impact on drilling progress. Complete losses of mud or water are frequent, along with stuck and broke drillpipes.

Carstification depth and related surface water infiltration are not the same in the whole coastal area. It depends on anhydrite position, which is situated at various depths as e.g. in Olib-1 well at 1 664 m (5 459 ft), in Ravni Kotari-1 well at 2 000 m (6 562 ft) and in Brač-1ß well at the depth of 3 850 m (12 631 ft) (Figures 2, 3 and 4). Surface water flow through the system of fractures, caverns and cavities, relatively good thermal conductibility of carbonate deposits and absence of clasts, resulted in low geothermal gradient (1.5 °C/100 m = 10.6 °F / 100 ft). Measured temperature in this rocks complex is 40 °C (104 °F).

According to determined indicators in carbonate complex, there are no signs of oil and gas reservoir formation.[30,33,58,59,60]

Only several asphalt shows of different sizes along with traces of gaseous hydrocarbons and traces of hydrogen sulfide and carbon dioxide were recorded.[37,60,61]

In this paper we would like once again to reflect on possible genesis of arching of Adriatic islands and peninsulas and on so called "Hvar direction" spreading direction of south Adriatic islands.60 Further research has determined that this spreading direction had significant impact on tectonic break going along Jabuka depression line and river Krka valley of NNE-SSW spreading direction while being perpendicular to Dinarides. Along this fault, carbonate and anhydrite-carbonate rocks were lowered in relation to Ravni Kotari block whereas carbonate rocks complex slid over anhydrites (decollement) along the fault in the direction south (Figure 1). This is one of numerous proofs of arching that lead to so called "Hvar direction" spreading of south Adriatic islands.

3. ANHYDRITE – CARBONATE COMPLEX

Anhydrite-carbonate rocks complex spreads from the island of Rab, over Ravni Kotari and south Adriatic islands and then subsides below Dinarides. Its length is about 300 km (186.4 mi) and average width around 60 km (37.3 mi) which make a total of 18 000 km² (6 950 mi²) (Figure 1). Olib-1, Ravni Kotari-1, -3 and -4, Dugi Otok-1 and Nin-1 wells have drilled anhydrite-carbonate complex on Ravni Kotari block whereas Brač-l ß and Vis-1 wells drilled this complex on "block" south Adriatic islands (Figure-1). Pula-1, Susak-1, Premuda-1, Ravni Kotari-2, Poljica-1 and Lastovo-1 wells did not encounter calcium sulfate deposits as they are probably situated on the edges of those deposits. According to the mentioned wells, this rocks complex was defined and its assumed edge was entered on the map.

Structural maximum goes approximately through the central part of the complex. Northwestern Ravni Kotari block is structurally higher than southeastern block of south Adriatic islands, whereas the southeastern one is lowered along Jabuka-Krka fault, which can be seen on longitudinal schematic profile (Figure 2) and also from well data of wells drilled on those blocks.

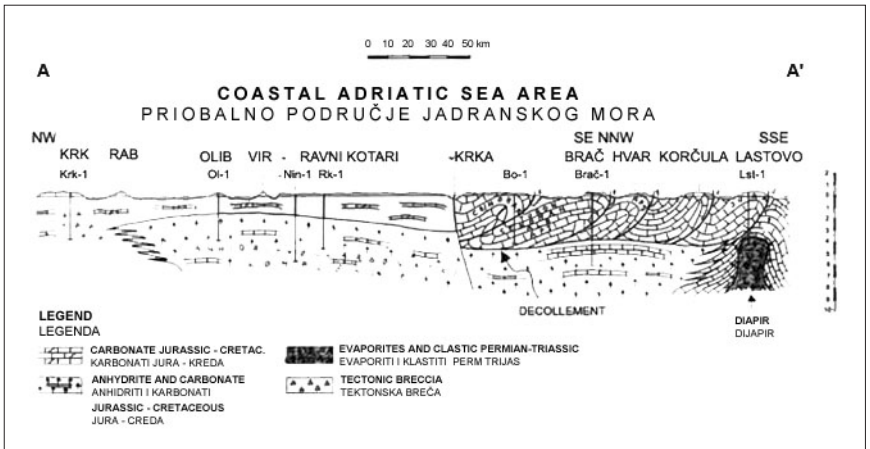

Fig. 2. Shematic longitudinal geological cross section profile from Krk-1 well to Lst-1. A-A'

Sl. 2. Shematski uzdužni geološki profil od bušotine Krk-1 do Lst-1. A-A'

Olib-1 well on the island of Olib encountered the shallowest top of anhydrite-carbonate complex at the depth of 1 664 m (5 459 ft), whereas Brač-1ß well on the island of Brač encountered the deepest anhydrite top at the depth of 3 850 m (12 631 ft).

The greatest thickness of this calcium-sulfate complex was measured by Nin-1 well and it was 3 790 m (12 434 ft). However, even with the total depth of 5 600 m (18 373 ft) this rocks complex was not drilled completely. The real thickness of this anhydrite-carbonate complex has not yet been determined. Its big thickness was most probably caused by orogenic movements which lead to steep beds and partly it might have been influenced by diapirism.[34,35,58,59,60]

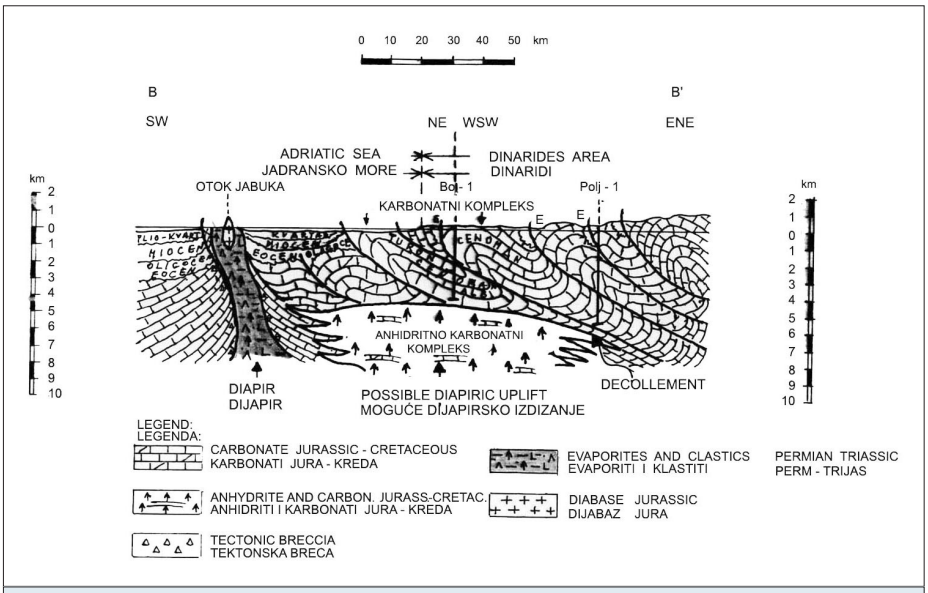

Fig. 3. Shematic transversal geological cross section Adriatic Sea – Dinarides. B-B'
Sl. 3. Shematski poprečni geološki profil Jadransko more - Dinaridi. B - B'

Their very steep dip of 70° was measured in Nin-1 well at the depth of 4 600 m (15 092 ft). The most reliable data are acquired by dipmeter from Brač-1ß well, interval 1 775-1 870 m (5 823 - 6 135 ft) where bed dip of 50° was measured. Dip of those beds in these wells was recorded at the depth of 5 824 m (19 108 ft) and was even 70-80°.

All other sedimentary rocks shall follow anhydrites overthrust movements more easily and that is the reason why my opinion is that anhydrite represents sliding surface (decollement) where carbonate rocks complex was sliding, folding and overthrusting which was proved in Boraja-1 and Brač-l ß wells (Figures 2, 3 and 4).

In the period between Upper Triassic and Upper Cretaceous, the Outer Dinarides area was represented by relatively stable carbonate shelf with exclusive calcium-sulfate and carbonate sedimentation regime. Recognized age of anhydrite-carbonate complex is Upper Jurassic and Lower Cretaceous. Calcium-sulfate Mesozoic rocks complex is composed mainly of anhydrites whereas carbonate rocks (limestone and dolomite) appear in the shape of intercalations of millimeter, centimeter and meter thicknesses.

When drilling tools enter this complex, carst phenomena disappear and there is almost no mud loss. They depend on thickness and secondary porosity of intercalations of carbonate rocks within anhydrites.[14,16,17,44,49,50,59,60,61,62,63,66]

The most significant oil and gas shows were recorded within anhydrite-carbonate complex.

The highest temperature was measured in Dugi Otok-1 well. It was 71 °C (159.8 °F) at the depth of 3 950 m (12 959 ft). Temperature gradient was 1.06 °C/100m (10.34 °F / 100 ft) which relates to geothermic degree of 94 m/1 °C (9.1 / 1 °F). Such low temperatures were caused by thick sedimentary series of carbonates where there are no rocks that could be relatively good thermal isolators like clay and marl. Temperature gradient in Brač-1ß well increases slowly and remains low up to 5 140 m (16 864 ft). It starts to rise from this depth especially in anhydrite-carbonate complex. This confirms previous knowledge that rocks with anhydrite cover represent closed petroleum geological units with high pressure and temperature. Temperature in Brač-1ß well recorded at the depth of 5 000 m (16 404 ft) was 60 °C (140 °F) with the tendency of increasing toward further depth.[49]

Temperature in Brač-l ß well was continuously growing with depth. However, due to stuck and broken drillpipes it was not possible to measure it at the well bottom.

Anhydrite, in petroleum geological sense represents excellent seal (cap) rock whereas carbonates within anhydrites, considering their secondary vuggy porosity, might be excellent hydrocarbons collectors, as was proved in certain wells. Thesis that hydrocarbon reservoirs might have been formed in anhydrite-carbonate rocks complex is based on significant oil and gas shows recognized in certain wells. This is especially confirmed by gas discovery in very deep Brač-l ß well on the island of Brač near Milna. Brač-l ß well reached the total depth of 6 047 m (19 839 ft). Gaseous hydrocarbons were recognized in anhydrite- carbonate rocks complex at the depth of 6 014 m (19 731 ft) at very high bed pressure of around 1 100 bar (15 954 psi). Hydrocarbons C_1-C_5, water, H_2S and CO_2 were recognized.

This proves the existence of closed hydrodynamic systems within this rock complex as well as the existence of conditions for forming of hydrocarbon reservoirs within them.[17,19,35,36,40,42,46,60,61,62]

The thickness of Mesozoic deposits where wells were drilled is considerably great. It reached 6 047 m (19 839 ft) in Brač-l ß well. Carbonate complex deposits constitute 3 850 m (12 631 ft) whereas anhydrite-carbonate series deposits constitute 2 197 m (7 208 ft). Even the final depth of 6 047 m (19 839 ft) of Brač-l ß well did not en-

counter beds that would indicate change within sedimentation cycle.

Great bed thickness, and especially carbonate complex, was most probably caused by orogenic movements which caused folding, reversed faulting and thrusting of beds, ones over others, which caused the steepness and repetition of beds, and at the same time also the thickness increase.[34,35,58,59,60]

Diapiric uplifting is probably partly represented in this area.

Evaporite deposits are found on all continents and their age varies from pre-Cambrian until today. Most parts of main and oil and gas bearing areas are related to those deposits.

According to the above mentioned data on gas and high pressure in Brač-1â well we can say that forming of oil and gas reservoirs might have occurred in carbonates within anhydrites in the anhydrite-carbonate rock complex of south Adriatic islands.

Possible mature source rocks might occur in deep Mesozoic and Paleozoic beds in the Adriatic offshore, from where hydrocarbons might have migrated into anhydrite-carbonate and clastic-evaporite-carbonate deposits complex. The existence of hydrogen sulfide was determined in almost all the wells of Outer Dinarides in carbonate complex and also in anhydrite-carbonate-complex of Mesozoic age. Its highest concentration was recorded in anhydrite-carbonate complex of Ravni Kotari-3 well and on Dugi Otok, whereas especially high quantities were recorded in Brač-l ß well on the island of Brač. Hydrogen sulfide was registered within 2 713 - 3 013 m (8 901 - 9 085 ft) interval in Ravni Kotari-3 well. During drilling, its concentration in mud was 280 to 600 ppm, whereas during testing it was over 1 500 ppm. Such high hydrogen sulfide concentration has caused intense "corrosion" of drilling equipment and testing tools. Hydrogen sulfide also posed great hazard for people as was proved by two cases of poisoning. However, the biggest hydrogen sulfide show with extremely high pressure of 1 100 bar (15 954 psi), at the depth of 6 047 m (19 839 ft) in Brač-l ß well, was the first such show in the Outer Dinarides in the area of southern islands. During the drilling of Brač-lß well, only insignificant hydrogen sulfide shows were notice. However, from 5 800 m (19 029 ft) in anhydrite-carbonate rock complex and deeper, those shows become more significant, causing the working conditions to be more complex. This is the first well where high pressures appeared that enabled fluid influx from rocks into bore channel at the depth of 5 800 to 6 047 m (19 029 - 19 839 ft). Those were C_1-C_5 hydrocarbons, water, H_2S and CO_2. Hydrogen sulfide appeared in increased quantities and at the depth of 6 047 m (19 839 ft), more than 4 000 ppm was measured on vibrator by toximeter.

The drilling of very deep Brač-l ß well was suspended at the depth of 6 047 m (19 839 ft). It was caused by high pressure in gaseous hydrocarbons saturated rocks and by high concentration of hydrogen sulfide which represented great danger for workers on the drilling rig but also for residents of Milna. Breaking of drillpipes at the depth of 100 m (328 ft) added to the above.

Hydrogen sulfide is colorless, very toxic gas, with the smell of rotten eggs and combustible. It changes your blood count and is very toxic due to its destructive impact on hemoglobin. Hydrogen sulfide is very toxic even at small concentrations of only 100 ppm, and can cause death within only 4 hours of exposure. At concentration of 800 ppm the death is instantaneous. It also destroys complete flora and fauna, and also causes destructive alteration of crystal lattice in steel, making steel to loose its elastic properties and to become fragile. This is so called structural corrosion and not superficial which appears as a result of oxidation. Hydrogen sulfide is mostly related to sulfate minerals and can be expected in all of the following wells of Outer Dinarides, i.e. in places where anhydrite occurs, which has already been proved by the drilled wells. It appears on the surface in Splitske Toplice and on the island of Pag. Due to high pressures and high hydrogen sulfide concentrations, it is necessary to drill the future very deep exploration well in anhydrite-carbonate rock complex of Mesozoic age in Outer Dinarides in technically perfect manner.

Depths of the drilled wells in Dinarides show the technical success of the performed operations. Accordingly, for future exploration activities, the drilling of very deep wells at the depths of 6 500-7 000 m (21 325 - 22 966 ft) is planned. The following requirements need to be met for future operations in such great depths, under great pressures, gaseous hydrocarbons and hydrogen sulfide shows: casing, drillpipes, wellhead, spools, valves and preventers must be made of hydrogen sulfide resistant steel. Drilling rig must be equipped with bentonite, baryte, various additives, water etc. It must be equipped also with safety equipment and technical protective equipment like hydrogen sulfide indicators, inhibitors etc.[34,38,62,63]

4. CLASTIC – EVAPORITE – CARBONATE COMPLEX

This deposits complex is situated below anhydrite-carbonate complex and is composed of limestone, dolomite, marl, sandstone, anhydrite, gypsum and salt. Chronostratigraphically, this rock deposits complex most probably belongs to Permian-Triassic. Depth position and supposed multiple alteration of permeable and impermeable rocks indicate the possibility of closed petroleum geological systems and high temperatures and high water salinity, whereas high pressures might be expected in beds.

Probably the most favorable conditions for hydrocarbon accumulation exist below anhydrites in clastic-evaporite-carbonate rock complex. Oil and gas reservoir of commercial value might have been formed in this deposits complex in case the source rocks exist there.

There is a possibility that Brač-lß well has already entered into this deposits complex, however this has not been proved.

Considering the great depth where we can expect clastic-evaporite-carbonate complex, it can be reached by very deep well of 6 500 to 7 000 m (21 325 - 22 966 ft). With the advanced drilling technology, the conditions for

exploration of clastic-evaporite carbonate sediments in the coastal and islands area of Outer Dinarides are fulfilled.

5. DIJAPIRIC BELT

Diapirs are the result of vertical intrusion of certain bodies – deposits toward surface. Such movements occur often in salt, gypsum, anhydrite and other rock reservoirs under influence of mostly tectonic forces. Recently, there were discussions on magmatic diapirs.

The most common one is salt diapirism. Salt has different characteristics than other sediments as it is relatively light and plastic. Usually top sediments present obstacle, resistance and they are uplifted by diapires. In this case diapiric folds develop (Figure - 5). At the contact of diapires with other rocks, during intrusion tectonic breccias are formed. Diapires are created, occurring in every area of the Earth during all geologic time periods, from Paleozoic until today. In Croatia there are over thousand islands of different geological composure. Most of the islands are composed of sediment, carbonate rocks (limestone and dolomite). One island is composed of eolian deposits, so called loess and that is the island of Susak. Two Adriatic islands in the south (Jabuka and Brusnik) are composed of volcano rocks; diabase. This is the results of diapiric activity. Diapires have pushed (uplifted) Jabuka and Brusnik to the surface (Figures 3 and 5). According to the seismic survey of Adriatic offshore, it has been determined that Jabuka has no "roots", however it lies on diapir. The island is composed of volcanic diabase rock of Jurassic age which was proved by samples analysis.

Diapir, probably of Permian-Triassic age, composed of evaporates and clasts, has on its way upward brought to surface a diabase boulder in Jurassic deposits and simply pushed it –brought it to the surface (Figures 3 and 5). I suppose that the same scenario occurred in the case of Brusnik Island which is also composed of diabase of Jurassic age.

Jabuka, Sveti Andrija (Svetac), Brusnik, Biševo, Vis, Sušac, Lastovo and Mljet islands are situated in diapiric belt 20 km (12.4 mi) wide with spreading direction west-east. Over the Elafiti islands the belt sinks below Dinarides. Along with Jabuka and Brusnik, the islands of Svetac, Biševo, Vis, Lastovo and Mljet lay on diapirs. (Figure 5).

The proof for the above are clastic-evaporite deposits of diapirs of Permian-Triassic age which were broken and deformed by anhydrite-evaporite complex. It has also deformed top carbonate beds of Jurassic-Cretacesous age near Komiža and on the island of Vis (Figure 4). This was proved by Vis-1 deep exploration well which was drilled near Komiža. The well first drilled clastic- evaporite deposits of Permian-Triassic age, then it entered anhydrite-carbonate rock complex of Lower Cretaceous whereas the drilling was completed in Upper Jurassic limestone due to small capacity of the drilling rig (Figure 4). Bay near Komiža on the island of Vis has round shape shaped by diaper and later by erosion.

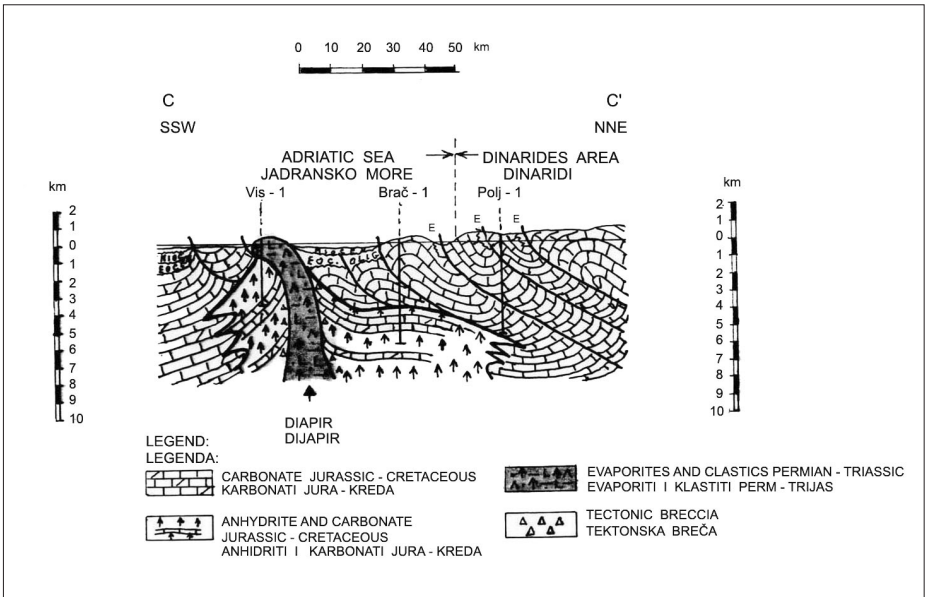

Fig. 4. Shematic transversal geological cross section Adriatic Sea – Dinarides C-C'
Sl. 4. Shematski poprečni geološki profil Jadransko more - Dinaridi C-C'

Palagruža Island is composed of limestone and clastic-evaporite deposits so probably this island is diapirically uplifted.

At its basement, Lastovo-1 well has encompassed similar type of facies and these data show that this might be a case of diapir (Figures 1 and 5).

In the process of diapirism in the area of south Adriatic islands, gypsum diapirism had also great impact especially in the southern part where diapiric belt "touches" anhydrite carbonate complex, especially in the area of Vis Island. Here, the anhydrite hydratization might have occurred and its transition into gypsum.

My opinion is that gypsum diapirism had lower intensity in the area of diapiric belt and could not have affected significantly the shaping of diapirs. Diapirs' height in diapiric belt varies depending on the thickness of Mesozoic deposits situated above. The highest diapirs are the ones that uplifted Palagruža, Vis, Jabuka and Brusnik. Lower are the ones with overlying Jurassic deposits like those on the island of Lastovo whereas the lowest one is overlain by Jurassic and Cretaceous deposits like on the island of Mljet where Mesozoic deposits acquired the shape of a fold (Figure 5). Along the southern margin of mentioned islands, in the diapiric belt a reversed fault was recorded which played a significant role in the development of the described diapirs and their protrusion to the surface. (Figure 1). As the wideness of Komiža bay is approximately 3 km (1.9 mi), I suppose that our diapirs might be 3 to 5 km (1.9 to 3.1 mi) in diameter, maybe even more (Figure 5).

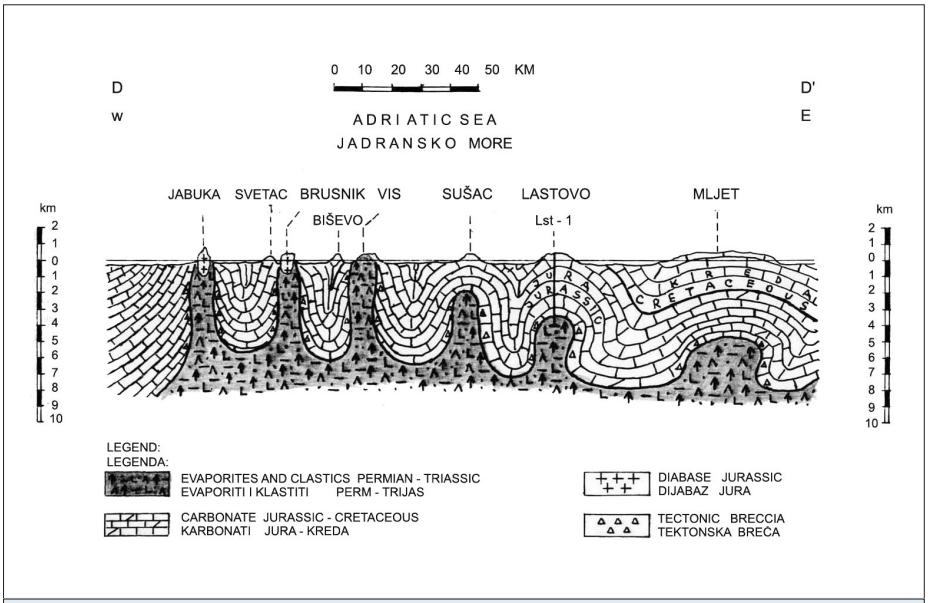

Fig. 5. Shematic cross section of Permian – Triassic diapirs of South Adriatic D-D'
Sl. 5. Shematski profil, permo - trijaskih dijapira južnog Jadrana D - D'

What can be said about main tectonic movements in creation of those diapirs. Probably they are, just like reversed faults, related to tangential movements during Eocene-Oligocene.

I believe that Mesozoic basin of southern islands has higher underground temperature than other parts of anhydrite-carbonate complex as there is a diapiric belt at the margin of this basin which implies temperature increase. On diapirs' margins, there are also tectonic breccias. Oil and gas stratigraphic reservoirs are usually developed on diapirs' flanks. [40,67]

6. CONCLUSION

In this paper, the following topics were studied:

- carbonate rock complex of Cretaceous age,
- anhydrite-carbonate rock complex of Lower Cretaceous and Upper Jurassic age with hydrogen sulfide shows,
- clastic-evaporite-carbonate rock complex of Permian-Triassic age,
- diapiric belt from Jabuka Island to Mljet Island,
- conclusion.

Carbonate rock complex is composed of limestone, dolomite, limey breccias and bauxite. Carbonate complex movement over anhydrites, which represents decollement in south direction under the influence of tangential forces from north, caused development of various types of folds in this complex, like upright folds, diagonal folds, overturned folds, recumbent folds and plunging folds. Reversed faulting and formation of flake composure occurred, repetition and with that also thickening of the complex. Great disturbance of carbonate complex causes difficulties during drilling of deep and very deep wells when total loss of circulations occurs along with broken and stuck drilling tools. As this rock complex is intensively disturbed, accumulation of hydrocarbons was not possible, there were only asphalt and hydrogen sulfide shows.

Anhydrite-carbonate rock complex is composed of anhydrites and carbonates (limestone and dolomite). When a well enters this deposits complex, carst phenomena disappear and mud loss does not occur again. This deposits complex appears to be the most promising hydrocarbon discovery up to now. Gas C_1-C_5, hydrogen sulfide and CO_2, were recorded here under high pressure of 1 100 bar (15 954 psi). It has been determined that closed petroleum-hydro-geological units with high pressure and temperatures exist there. Accordingly, commercially significant hydrocarbon quantities might have been accumulated there. This complex is also related to bigger hydrogen sulfide shows. Hydrogen sulfide is colorless and extremely toxic gas, smells like rotten eggs, it is air combustible, can cause poisoning, causes blood count changes destroying hemoglobin. Hydrogen sulfide causes destructive alteration of crystal lattice in steel causing steel to loose its elastic properties and to become fragile and breakable.

Clastic-evaporite-carbonate rock complex is situated below anhydrite. It is probably of Permian-Triassic age, composed of limestone, dolomite, marl, sandstone, anhydrite, gypsum and salt. It is supposedly ruled by closed petroleum-hydrogeological systems; temperature and salinity are high and high pressure might be expected in beds. Oil and gas reservoirs migh have been created in this complex.

Diapiric belt, 20 km (12.4 mi) wide spreads from Jabuka island to Mljet island. It has a sequence of diapires that affected the development of certain islands by the force of their uplifting from the underground.

Exploration activities and collected data provided new facts that offer possibilities and certainty to plan exploration operations, based on petroleum geological data, aimed to drill new very deep exploration wells in certain areas of Adriatic islands and peninsulas wider area, i.e. the area of south Adriatic islands.

The most promising for oil and gas discovery seem to be the complex of anhydrite-carbonate rocks of Jurassic-Cretaceous age and complex of clastic-evaporite-carbonate rocks of Permian-Triassic age. There is a possibility that in those parts of underground, the preservation of appropriate and required petroleum-geological conditions like source rocks, reservoir and seal rocks, pressure and temperature, are the most favorable.

Accordingly, there is a need for new, modern geophysical survey, especially seismic survey that is a requirement for successful data collection and their geological interpretation for better oil and gas exploration activities. During seismic survey, the attention should be put on possible relation between the drilled wells and seismic cross sections. This would enable their more realistic and better correlation and interpretation.

If we suppose that hydrocarbon reservoirs are situated even deeper and below anhydrite carbonate deposits in Permian-Triassic, well drilling must be performed with technical perfection due to possible high pressures and hydrogen sulfide.

As the drillpipes were broken at the depth of 100 m (328 ft), it is not possible to study completely the gas shows in Brač-lβ well. Thus in further exploration another very deep well of 6 500 m (21 325 ft) should be drilled on the island of Brač, which would reach the basement of anhydrite – carbonate rock complex and would enter potential older oil and gas bearing sediments of Permian-Triassic age and would test confirmed gas quantities from the underground of Brač island. The recommendation is to keep the well location further away from populated area due to hydrogen sulfide.

Lithofacies content of anhydrite-carbonate and clastic-evaporite-carbonate rock complex, their structural position, spreading surface, thickness of deposits, possible source rocks, reservoir and seal rocks, C_1 - C_5 gas, pressure of 1 100 bar (15 954 psi), indicate the possibility of commercial discovery of hydrocarbon quantities in the area of south Adriatic islands.

Map of anhydrite-carbonate rock complex of Mesozoic age (Figure 1) and schematic geological cross sections (Figures 2, 3, 4 and 5) may be useful in complex evaluation of the discussed area.

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Author
Vjekoslav Spaić, N. Nalješkovića 27/V, 10000 Zagreb, Croatia
Phone: +385 1 611 62 80
Cell: +985 99 722 29 97