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Origin of Hydrocarbons in the Eastern Part of the Drava Depression (Eastern Croatia)

Zvonimir **HERNITZ**[1], Josipa **VELIĆ**[1] & Gertrud **BARIĆ**[2]

Key words: Hydrocarbons, Source rocks, Genesis, Pannonian Basin, Croatia.

Ključne riječi: ugljikovodici, matične stijene, geneza, Panonski bazen, Hrvatska.

Abstract

Oil and gas in the eastern part of the Drava depression originated from source rocks of very good generating capabilities - dark gray to black marlstones of Ottnangian, Karpathian, Badenian, Sarmatian and partly Pannonian age. During different tectonic regimes, algal-lipid rich kerogen formed in anoxic and suboxic marine environments. The typical terrestrial maceral vitrinite only occurs as traces.

Sažetak

Nafte i plinovi istočnoga dijela dravske depresije vuku podrijetlo iz matičnih stijena - tamnosivih do crnih marlita otnanške, karpatske, badenske, sarmatske i dijelom panonske starosti vrlo dobrih generirajućih sposobnosti. U uvjetima različite tektonske djelatnosti stvarao se algalno-lipidni kerogen vezan za anoksične i suboksične marinske okoliše. Tipni terestični maceral vitrinit javlja se samo u tragovima.

1. INTRODUCTION

Most oil fields and deep wells in the eastern part of the Drava depression are located in the area between Našice and Donji Miholjac (Fig. 1). Their number decreases both E and W, with Bizovac being the easternmost field. The main reservoir rocks are coarse-grained clastic rocks of Miocene age and, partially, magmatic rocks. Previous investigation has also determined the existence of source rocks (locally in relative thick successions).

These rocks have been studied periodically since BÖHM (1940) and OŽEGOVIĆ (1944) stated that the source rocks are thin-bedded, brown bituminous layers of Sarmatian age. Later field evidence, gathered during detailed geological mapping, have confirmed the probable Sarmatian age of the source rocks (PIKIJA & ŠIMUNIĆ, 1978). HERNITZ (1983) discussed the possible occurrence of conditions favourable for hydrocarbon generating prior to the Tertiary, i.e. a wider stratigraphic age of possible source rocks. By the end of the nineteen-eighties numerous papers written jointly by oil geologists and organic geochemists were published (BARIĆ & RADIĆ, 1988; BARIĆ et al., 1989; PUTNIKOVIĆ et al., 1989; ALAJBEG et al., 1990, 1994). They have concluded that all source rocks in the Pannonian Basin are stratigraphically placed between the Pretertiary rocks and well logging marker Rs5 (approximately Lower, Middle and part of the Upper Miocene). All examined oils originated from these source rocks. Migration paths were estimated as short, both the lateral and vertical migration of fluids depending on the free energy level and on the pressure level. Recognition of source rocks on the basis of up-to-date geophysical investigations in wells was presented and elaborated by VULAMA (1994).

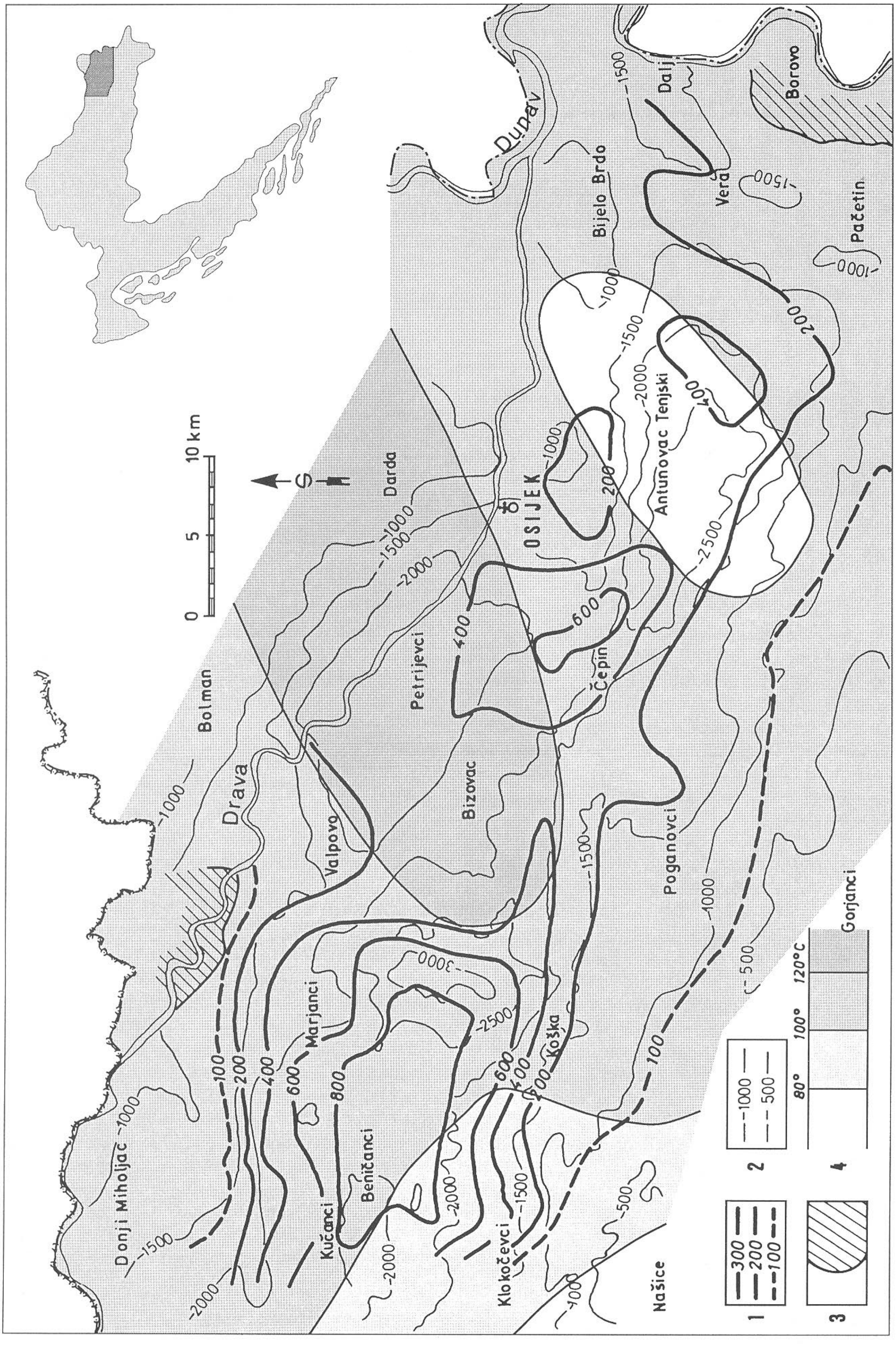
2. GEOLOGICAL COMPOSITION AND STRUCTURE

The geological structure of the study area is complex, comprising a deep depression the elevated parts of which contain oil and gas-oil fields. The deepest parts are oriented WNW-ENE, with palaeorelief at depths of approximately 3,000 m, locally down to 3,500 m (near Beničanci, between Beničanci and Bizovac and southern of Osijek near Antunovac Tenjski). Depression is traversed by numerous structural highs, which are locally mutually connected (Našice, Klokočevci, Beničanci, Ladislavci, Kučanci, Donji Miholjac, Poganovci, Bizovac, Valpovo, Vinkovci, Pačetin, Vera, Bijelo Brdo).

Overlying Badenian or Sarmatian deposits (approximately represented by the marker Rs7) are characterised by similar structural features (Fig. 1), and occur at depths of approximately 2,000 m, increasing from 2,500 m to more than 3,000 m in synforms. The reservoirs are located at depths between 1,600-2,700 m.

Badenian and older sediments in anticlines are from 200-400 m thick increasing to approximately 800-1,000

[1] University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, HR-10000 Zagreb, Croatia.
[2] INA-Naftaplin, Laboratory Dept., Lovinčićeva bb., HR-10000 Zagreb, Croatia.



Dunav
Drava
OSIJEK
Darda
Bolman
Petrijevci
Bizovac
Valpovo
Donji Miholjac
Marjanci
Kučanci
Beničanci
Koška
Klokočevci
Našice
Čepin
Antunovac Tenjski
Bijelo Brdo
Dalj
Vera
Borovo
Pačetin
Poganovci
Gorjanci
0 5 10 km
1
2
3
4
300
200
100
1000
500
80°
100°
120°C

m in synclines (particularly between Bizovac and Beničanci, Fig. 1). This fact is very important, because these deposits comprise a major portion of the source rocks, which have been found in samples from wells located predominantly in the southern parts of depression, e.g. the Klokočevci, Marjanci, Obod and Bokšić wells. In the Kučanci and Ernestinovo wells predominantly gas generating source rocks were determined, their thickness being estimated as 400-500 m (Kučanci) up to 600 m (Obod). These deposits are probably thicker, but more data is required to clarify this assumption.

There are two or three main rock types in the study area. These are coarse-grained clastic rocks (breccias and sandstones), fine-grained clastic rocks (siltstones and marlstones) and Miocene (predominantly Badenian) effusive rocks. This association is an excellent combination from an oil geologist's point of view: representing in one vicinity, almost at the same locality, both possible source rocks and reservoir rocks. Numerous effusive intrusions have led to additional temperature increases, and differential compaction has provided structures favourable for hydrocarbon accumulation.

Coarse-grained clastics are characterised by their very heterogeneous composition and granulometry. Two major types were determined: rock-fall breccia and tectonic breccia. They are composed mainly of Mesozoic carbonates, and secondary older, Palaeozoic magmatic and metamorphic rocks. Rock-fall breccias cover a larger area, lying partially over tectonic breccia, and partially over the eroded palaeorelief; transport was relatively rapid and short. Deltaic and near-shore breccio-conglomerates were found locally, e.g. near Ladislavci and Beničanci (TIŠLJAR, 1993). Hydrocarbon accumulations are characterised by low Gas/Oil Ratio in fields (GOR from 18 to 80 m^3/m^3), as well as the undersaturation of reservoirs. Reservoir rocks are overlain by marls of variable thickness and physical properties.

Magmatic rocks associated with their pyroclastic products have been found at several localities. The most common are neutral to basic andesites, basalts and andesite-basalts occurring at Bokšić, Crnac, Klokočevci, Obod, Obradovci and Štekovica. They were mostly located at depths ranging from 1,800 to more than 3,000 m.

The presence of breccia and evidence of polyphase magmatism indicate very intensive tectonic activity during the Miocene. However, findings of source rocks of Badenian (Bokšić, Kučanci, Obod), Karpathian (Obod) and Ottnangian age (Obod) demonstrate that in some parts of the studied area low-energy environments existed for long periods (HERNITZ et al., 1993).

3. SOURCE ROCKS

Source rocks are mainly dark gray to black, seldom light gray, very compact marlstones. These dense rocks are predominantly composed of cryptocrystalline calcite; hydromica and siliciclastic material composed of grains of silt and fine sand size (mostly angular quartz and feldspar grains and muscovite) are subordinate. The rocks contain kerogen, in some places in the form of ribbons, laminae or disseminated within the mineral matrix. Kerogen-rich marlstones are mostly homogeneous in composition, and are up to 1 m thick, seldom more. However, there are also intervals characterised by the alternation of light and dark coloured laminae. In some places, where cores were sampled continuously and are well preserved, numerous sequences are clearly visible of intervals up to 300 m thick (e.g. in Obod-7 well). Each couplet is composed of a few centimetres of coarse or fine-grained sandstone passing over several centimetres into dense marlstones. At the contact of the sandstone and underlying marlstone there is occasional evidence of submarine erosion e.g. load casts. Flaser structures and bioturbation are infrequent. The marlstones are locally stylolitised and tectonically fractured, with sliding surfaces and joints filled with either calcite or oil.

Source rocks occur both above and below the well logging marker Rs7. In some places similar environmental conditions were maintained for rather long time after deposition of this marker bed, as indicated by a several hundred metre-thick continuous succession of overlying marlstones. The Marjanci-1 well is a typical example: petrographic analysis of a rock sample 300 m above Rs7 describes a kerogen rich marlstone, i.e. source rock.

Numerous geochemical analyses of source rocks from the eastern part of the Drava depression were used for correlation with geophysical measurements in the wells, as well as for calibration of instruments (VULAMA, 1994). Spiderweb and steeped diagrams of geophysical and geochemical parameters gave recognisable results. The following average values were measured: total natural radioactivity (GR) - 180 API; interval transit time (Δt) - 40 μsec/m; electric resistivity (R) - 90 Ohmm; apparent neutron porosity (Φ_N) - 30%; bulk density (ρ_b) - 2.25 g/cm^3; uranium U^{238} contents (SL) - 13 ppm; spontaneous potential (SP) - 70 mV; total organic carbon contents (Corg) - 6.5%. By means of crossplots, e.g. electric resistivity (R) versus vitrinite reflectance (Ro), it has been determined that values of 32 Ohmm and 0.51% of vitrinite reflectance represent a boundary between mature and immature source rocks,

Fig. 1 Legend: 1) isopach of Lower and Middle Miocene impermeable rocks (predominantly marlstone and siltstone); 2) structural contours of well logging marker Rs7 (H); 3) area without marker Rs7 (H); 4) isotherms at 2,000 m depth.

Sl. 1 Legenda: 1) izopahe donjo- i srednjomiocenskih nepropusnih stijena (pretežno marliti i siltiti); 2) stratoizohipse repera Rs7 (H); 3) granica rasprostranjenosti repera Rs7 (H); 4) izoterme na dubini od 2000 m.

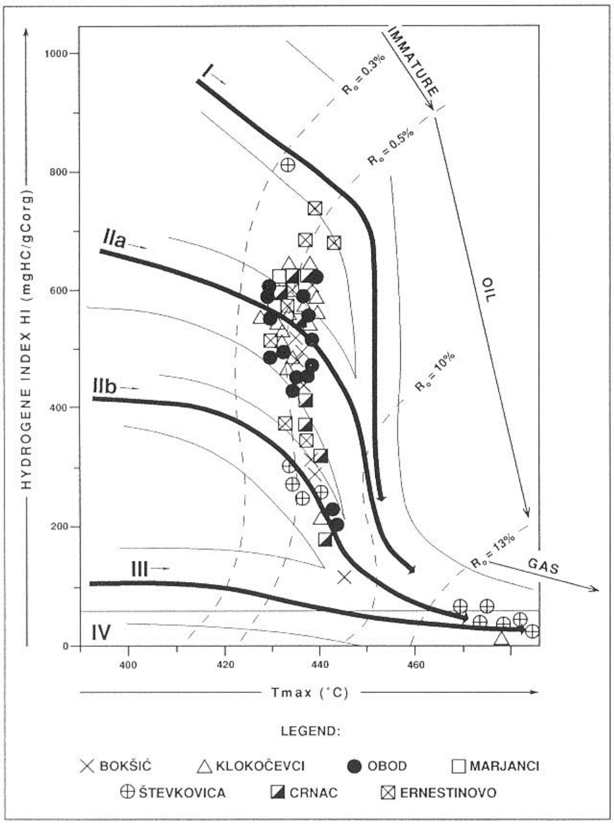


Fig. 2 HI-T_{max} diagram showing types and maturity of kerogens (after ESPITALIÉ et al., 1977).

Sl. 2. Tipovi i zrelost kerogena u HI-T_{max} dijagramu (prema ESPITALIÉ et al., 1977).

i.e. boundary values for the beginning of oil and gas generation.

Determination of source rocks was performed using conventional geochemical analyses and methods. A large number of cores, drill cuttings, oils and gases from more than 30 wells were investigated. Total organic carbon varies from 0.6% to 6.0%. Sequences shallower than 2,000 m are characterized by low TOC values, with partially oxidized organic matter. The increased concentration of organic matter was observed in carbonate-rich pelitic deposits. The results showed an average organic matter content of 1.3 percent. Rock Eval analyses indicate good source rock sections with a high potential for petroleum generation (genetic potential $S_1 + S_2$), reaching more than 30 mg HC/g rock.

Organic facies determination based on visual kerogen analyses showed a predominance of amorphous kerogen and higher exinite content. These results are in agreement with hydrogen indices (HI) of 400 to 650 mg CH/g TOC. According to the chemical classification of kerogen, the organic matter is oil prone, type II kerogen. Vitrinite as the typical terrestrial maceral, was found only in traces, although some terrigenous influences can be attributed to hydrogen-rich lipids - sporinite and resinite.

The hydrocarbon potential of the source rocks is not uniform. The causes of variations in organic matter content can be linked to the reduced production of biomass and to the alteration of the depositional environment, as confirmed by the presence of thinner layers of highly oxidized sediments. The results of carbon isotope measurements performed on kerogens confirmed the type of organic facies and depositional conditions. Carbon isotope ratios ranging from $\delta^{13}C$ -22.4‰ to -25.9‰ indicate algal-lipid (hydrogen-rich) facies associated with anoxic and suboxic environments (SCHOELL, 1984). The availability of maturity parameters (T_{max}, TAI and colour of fluorescence) enabled the preparation of a maturity profile and estimates of maturity (Fig. 2). The catagenetic phase i.e. the onset of the oil window begins at depths from 2,100 m to 2,200 m.

Abundant organic matter and a high geothermal gradient (> 5°C/100 m) caused the generation and increased expulsion of hydrocarbons at a lower level of thermal maturity (YUKLER, 1987), as confirmed by increased quantities of bitumens in identified source rocks. Bitumen content averages 2,000-4,000 ppm, but rises to 10,908 ppm (Bokšić-13 well, 2,691.5 m).

Oils from this area are characterized by 30° to 34° API gravity; sulphur contents of 0.18-0.60%; up to 16.4% of resins and asphaltenes; and carbon isotope ratios of approximately $\delta^{13}C$ -25.0‰. Gas chromatograph profiles of "whole" oil are characterized by relatively regular hydrocarbon distributions (Fig. 3) with molecular ratios Pr/C_{17}, Ph/C_{18} and Pr/Ph less than 1 and CPI ~ 1. Oils are characterized by the reduction of light hydrocarbons in the gasoline fraction. All parameters indicate that oils originate from hydrogen-rich lipid kerogen, which has reached the mature phase of thermal alteration.

The properties of investigated oils indicate high levels of similarity in the original facies but the differences in migrational phenomena, different levels of precursor maturity and tectonic disturbances have caused variations in hydrocarbon composition in certain localities, such as the Crnac field. The aforementioned differences are here also conditioned by unfavourable physical characteristics of the cap rocks which enabled migration of the lighter hydrocarbons and thereby reduction of their content.

The regional distribution of determined source rocks is especially important. Variable depths of burial and tectonic fragmentation resulted in the specific characteristics of this area. The 50-60 m thick succession of source rocks in the Crnac field 2,500 m deep represent cap rocks above the hydrocarbon reservoirs. Lateral equivalents of these source rocks at the Števkovica and Klokočevci fields represent reservoir rocks, due to their secondary fracture porosity (BARIĆ & RADIĆ, 1988; BARIĆ et al., 1989).

Gases in this region are classified into three groups: biogenic-diagenetic, thermogenic and mixed gases (Fig. 4). In the majority of the fields gases generated with oils are "wet", thermogenic gases with average isotope values of $\delta^{13}C$ -46.3‰ and δD -170‰ (SCHOELL, 1983). Accumulations of biogenic-diagenetic gas (the western part of the Bokšić field, and certain localities of

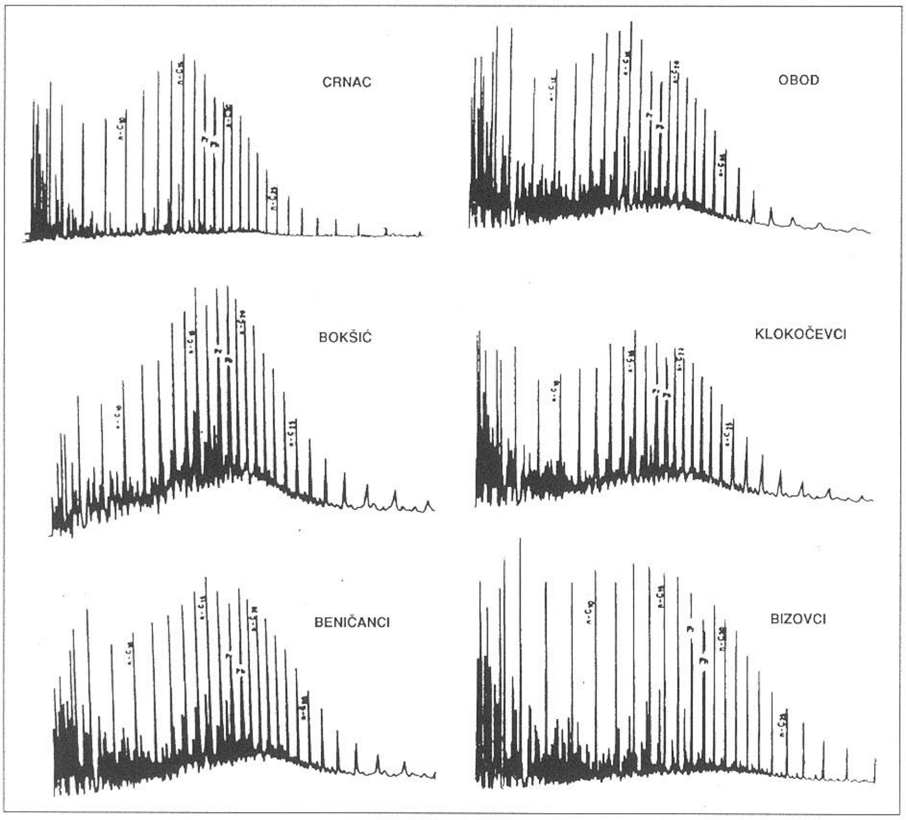


Fig. 3 Gas chromatograms of whole oils from eastern part of the Drava depression.

Sl. 3. Plinski kromatogrami nafti u istočnome dijelu dravske depresije.

the Sječe, Ladislavci and Obod fields) are somewhat specific with regard to the origin of hydrocarbons and the present reservoir temperature. The fermentational origin of methane is deduced from the low content of deuterium; δD -252‰ to -244‰ (after SCHOELL, 1988). The bacterial activity and formation of methane are both low-temperature processes, while the present temperature of the reservoir reaches 100°C (Fig. 1, RAVNIK et al., 1990). The aforementioned cases are explained by the rapid subsidence of sediments containing already formed biogenic gas (MATTAVELLI & NOVELLI, 1987). Mixed gases are formed by dismigration of hydrocarbons from oil reservoirs and their mixing with biogenic gases in shallower structures (Beničanci, Obod). Gases from the Bizovac field are specific. Reservoir rocks are hydrothermally altered basalts, at depths from 1,600-1,750 m and contain mature, migrated oils and gases with approx. 13% of higher hydrocarbons. However, the results of isotope measurements of carbon and deuterium (from $\delta^{13}C$ -62.3 ‰ to -63.4‰ and δD from -203‰ to -209‰) indicate their biogenic origin. Such examples are not unusual, and are explained as consequences of migration of thermogenic and biogenic gases and their entrapment in reservoir rocks (MATTAVELLI et al., 1983).

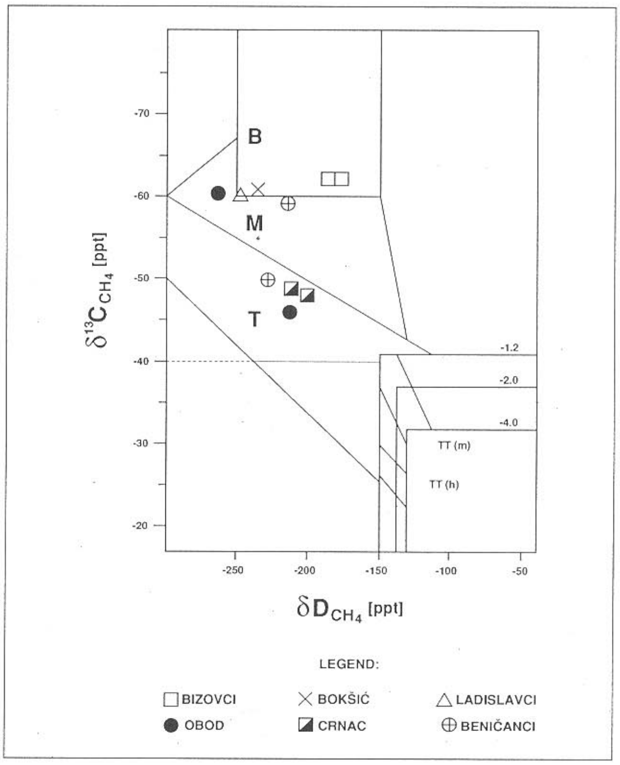


Fig. 4 Isotope ratios of natural gases (genetic zonation after SCHOELL, 1983): B - microbial gases; M - mixed gases; T - thermogenic gases.

Sl. 4. Izotopne vrijednosti prirodnih plinova (genetske zone definirane prema SCHOELLU, 1983). Legenda: B) biogeni plin, M) miješani plin, T) termogeni plin.

4. CONCLUSION

The results of geological and geochemical investigations indicate the presence of source rocks, mostly Badenian marlstones, with high potential for petroleum.

The organic facies of the source rocks is determined as hydrogen-rich lipids, i.e. type II kerogen, which is oil-prone. The specific thermal characteristics of this region ensured the maturation of kerogen and increased expulsion of hydrocarbons. Genetic characteristics of the reservoir hydrocarbons indicate a high level of similarity with the determined source rocks, which can be assumed to be the source of existing accumulations. Certain deviations in oil composition can be primarily attributed to migrational phenomena, but also to the physical characteristics of the reservoir and cap rocks.

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Podrijetlo ugljikovodika u istočnome dijelu dravske depresije (istočna Hrvatska)

Zvonimir **HERNITZ**, Josipa **VELIĆ** i Gertrud **BARIĆ**

1. UVOD

U istočnome dijelu dravske depresije najveća se koncentracija naftnih polja i dubokih bušotina nalazi približno između Našica i Donjega Miholjca (Sl. 1). Smjerom istoka i zapada njihov se broj smanjuje. Najdalje istočno je polje Bizovac. Glavni su naftonosnici miocenski krupni klastiti i djelomice magmatiti. Dosadašnjim je istraživanjima ustanovljena prisutnost i matičnih stijena, mjestimice u relativno velikim debljinama.

Te su stijene proučavane različitim intenzitetom počevši od polovice ovoga stoljeća, kada se u radovima BÖHMA (1940) i OŽEGOVIĆA (1944) navodi da su "matične kami za zemno ulje" tanko uslojeni smeđi, bituminozni škriljavci sarmatske starosti. Kasnija zapažanja s terena prigodom detaljnih geoloških kartiranja aktualiziraju gledišta o matičnim stijenama kao sarmatskom faciesu (PIKIJA & ŠIMUNIĆ, 1978). O postojanju uvjeta pod kojima je bilo moguće stvaranje ugljikovodika i prije tercijara, odnosno u širem rasponu od sarmata pisao je HERNITZ (1983). Krajem osamdesetih godina javljaju se brojni zajednički radovi naftnih geologa i organskih geokemičara (BARIĆ & RADIĆ, 1988; BARIĆ et al., 1989; PUTNIKOVIĆ et al., 1989; ALAJBEG et al., 1990, 1994). Njihov je zaključak da sve matične stijene u Panonskome bazenu leže između predtercijarnih stijena i elektrokarotažnoga repera Rs5 (približno donji, srednji i dio gornjega miocena). Analizirane nafte potječu upravo iz njih. Migracijski su putovi ocijenjeni kratkim, a lateralno i vertikalno kretanje fluida ovisno je o stupnju slobodne energije i tlaku. Ideju o "prepoznavanju" matičnih stijena uz pomoć suvremenoga sustava geofizičkih mjerenja u bušotinama izložio je i dokumentirao VULAMA (1994).

2. GEOLOŠKI SASTAV I GRAĐA

Geološka građa nije jednostavna. Radi se o dubokoj depresiji s izdignućima na kojima se nalaze naftna odnosno naftnoplinska ležišta. Najdublji se dijelovi depresije protežu pravcem zapad/sjeverozapad - istok/jugoistok s najvećim dubinama paleoreljefa od oko 3000 m, a mjestimice i do 3500 m (kod Beničanaca, između Beničanaca i Bizovca, južno od Osijeka kod Antunovca Tenjskog). Depresiju presijeca niz uzdignuća koja se mjestimice nastavljaju jedno na drugo (Našice, Klokočevci, Beničanci, Ladislavci, Kučanci, Donji Miholjac, Poganovci, Bizovac, Valpovo, Vinkovci, Pačetin, Vera, Bijelo Brdo).

Krovina badena, odnosno sarmata (približno elektrokarotažni reper Rs7) pokazuje podjednake strukturne odlike (sl. 1). Dubine su uglavnom oko 2000 m. U sinklinalama sežu do 2500 m, a mjestimice premašuju 3000 m. Naftna se ležišta nalaze na dubinama između 1600 m i 2700 m.

Debljine badenskih i starijih taložina u antiklinalnim predjelima iznose 200 m do 400 m, a u sinklinalnim oko 800 m, ali i 1000 m (sinklinala između Bizovca i Beničanaca, sl. 1). Ova činjenica ima svoje iznimno značenje, jer se unutar tih naslaga nalazi glavnina matičnih stijena. Debljine im se mogu procijeniti na preko 400 m do 500 m (Kučanci), pa i 600 m (Obod). Nepriјeporno su i veće, ali za tu odredbu nismo raspolagali odgovarajućim podacima. Nađene su u uzorcima jezgara iz bušotina uglavnom južne polovice depresije. To su Klokočevci, Marjanci, Obod, Bokšić, Ernestinovo, dok se polje Kučanci ističe svojim posebnostima. Ondje postoje naftne matične stijene, ali u nekim su bušotinama utvrđene plinske, primjerice u Ku-10 na 2541 m.

S litološkoga stajališta dominiraju dva, odnosno tri tipa stijena. To su krupni klastiti (breče i pješčenjaci), sitni klastiti (siltiti i marliti) te miocenski, najčešće badenski efuzivi. S naftnogeološkoga stajališta te stijene predstavljaju sretnu kombinaciju. U blizini, odnosno gotovo na istome su se mjestu našle matične stijene i krupni klastiti kao mogući naftonosnici. Brojni su proboji efuziva uvjetovali dodatno povišenje temperature, a diferencijalnom kompakcijom su stvoreni oblici povoljni za nakupljanje ugljikovodika.

Temeljno je obilježje krupnih klastita da su izrazito heterogenoga sastava i granulometrijskih značajki. Prisutna su dva osnovna tipa breča: siparne i tektonske. Sastoje se od mezozojskih karbonata, ali i starih, paleozojskih magmatita i metamorfita. Najveću rasprostranjenost zauzimaju siparne breče koje mjestimice leže na tektonskim brečama, a mjestimice na erodiranom paleoreljefu. Transport fragmenata bio je brz i kratak. Ponegdje se nalaze deltni i priobalni brečokonglomerati kao kod Ladislavaca i Beničanaca (TIŠLJAR, 1993). Nizak plinski faktor u poljima (GOR 18-80 m^3/m^3) kao i podzasićenost ležišta karakteristika je ugljikovodičnih akumulacija. Pokrovne stijene predstavljene su laporima nestalnih debljina i fizičkih svojstava.

Magmatske stijene sa svojim piroklastičnim produktima javljaju se na brojnim mjestima. Najčešći su neutralni do bazični andeziti, bazalti i andezitbazalti (Bokšić, Crnac, Klokočevci, Obod, Obradovci, Števkovica). Dubinski im je raspon uglavnom od oko 1800 m do preko 3000 m.

Prisutnost breča i višefazni magmatizam govore o izuzetno intenzivnoj tektonskoj aktivnosti tijekom miocena. Međutim, nalaz matičnih stijena badenske starosti (Bokšić, Kučanci, Obod), karpatske (Obod), te otnanške (Obod) govori da su u pojedinim predjelima kroz duga razdoblja vladali uvjeti mirnoga taloženja (HERNITZ et al., 1993).

3. MATIČNE STIJENE

Matične su stijene vrlo čvrsti marliti, jedri, tamnosivi do crni, katkada i svijetlosivi. Guste su, sastavljene od kriptokristalastoga kalcita, a mogu sadržavati hidrotinjce, siliciklastične materijale sa zrncima dimenzije silta i nešto sitnoga pijeska, uglavom zastupljenoga uglastim zrnima kvarca, feldspata i listićima muskovita. Ispunjene su kerogenom, koji se mjestimice pojavljuje i u obliku traka, lamina ili je kerogen raspršen unutar mineralnoga matriksa. Marliti obogaćeni kerogenom uglavnom su jednoličnoga sastava u debljinama do jednoga metra, ali i većim. Mogu, međutim, biti laminirani s izmjenom svijetlih i tamnih lamina. Ponegdje su jasno vidljive brojne sekvencije, ako su jezgre uzimane kontinuirano i ako su dobro očuvane u velikoj dužini, kao npr. tristotinjak metara u bušotini Obod-7. Svaka započinje sitno- ili krupnozrnatim pješčenjakom, koji nakon nekoliko centimetara prelazi u guste marlite. Na dodiru pješčenjaka i podinskoga marlita katkada su uočljivi tragovi podvodne erozije ili utiskivanja većih zrna. Poneki su puta vidljive flazerske strukture i bioturbacije. Marliti su mjestimice stilolitizirani i tektonski raspucani s plohama smicanja i pukotinama ispunjenim kalcitom ili naftom.

Matične se stijene javljaju iznad i ispod repera Rs7. Mjestimice se iznad toga repera taložni uvjeti nisu bitno promijenili, jer se kerogenski marliti nastavljaju kontinuirano po nekoliko stotina metara iznad Rs7. Najkarakterističniji je primjer bušotine Marjanci-1. Ondje je petrografski analizirani uzorak, oko 300 m povrh Rs7, određen kao matična stijena, odnosno marlit bogat organskom tvari (smolnjak).

Veliki broj geokemijskih analiza matičnih stijena istočnoga dijela dravske depresije poslužili su za korelaciju s geofizičkim mjerenjima u bušotinama te za kalibraciju mjernih uređaja (VULAMA, 1994). Zvjezdasti i stupnjeviti dijagrami geofizičkih i geokemijskih parametara dali su prepoznatljive oblike. Izmjerene su sljedeće prosječne vrijednosti: ukupna prirodna radioaktivnost (GR) 180 API, brzina zvučnoga vala (Δt) 40 μsec/m, električna otpornost (R) 90 Ohmm, prividna neutronska poroznost (Φ_N) 30%, volumna gustoća (ρ_b) 2,25 (g/cm^3), sadržaj radioaktivnog urana (U^{238}) (SL) 13 ppm, spontani potencijala (SP) 70 mV i količina organskog ugljika (Corg) 6,5%. Pomoću križnih dijagrama, kao npr. električne otpornosti (R) i vitrinitne refleksije (Ro) utvrđeno je da vrijednosti od 32 Ohmm i 0,51% vitrinitne refleksije predstavljaju granice razdvajanja zrelih od nezrelih matičnih stijena što su i granične vrijednosti početka generiranja nafte i plina.

Determinacija matičnih stijena provedena je korištenjem standardnih geokemijskih analiza i tehnika. Ispitivanjem je obuhvaćeno više od 30 bušotina, a analizirani su uzorci krhotina iz isplake, mehaničke jezgre, te nafte i plinovi. Rezultati su pokazali da sedimenti sadrže organsku tvar u vrlo promjenljivoj koncentraciji. Slojevi koji se nalaze pliće od 2000 m sadrže manju količinu organske tvari, a jedan je njezin dio oksidacijski izmijenjen. Do rasta vrijednosti organskog ugljika (Corg) dolazi u pelitnim taložinama povećane karbonatnosti. Sadržaj organske tvari je u granicama od 0,6% do 6,0%, a prosječna vrijednost Corg iznosi 1,3%. Primjenom pirolitičke, Rock-Eval analize na velikom broju uzoraka, utvrđeno je da su matične stijene uglavnom vrlo dobrih generirajućih sposobnosti u kojima naftni potencijal (genetski potencijal $S_1 + S_2$) dostiže vrijednost i veću od 30 mg HC/g stijene.

Organski facijes determiniran na bazi optičkih ispitivanja maceralnog sastava pokazuje predominaciju amorfnoga kerogena i povećani udjel egzinita, što je u suglasnosti s vrijednostima vodikovih indeksa od 400 do 650 mg HC/g Corg. Prema kemijskoj klasifikciji navedena svojstva odgovaraju tipu kerogena II (sl. 2), koji se smatra dobrim naftnim izvorom. Tipni terestični maceral, vitrinit, javlja se samo u tragovima, iako se određeni kopneni utjecaji mogu pripisati vodikom bogatim terigenim lipidima - sporinitu i rezinitu.

Generirajući potencijal matičnih stijena nije ujednačen. Variranja količine organske tvari moguće je vezati uz smanjenu produkciju biomase, kao i izmjenu taložnih uvjeta, što potvrđuje prisutnost manjih proslojaka visokooksidacijskih sedimenata. Tip organskog facijesa kao i uvjete tijekom depozicije potvrdili su i rezultati izotopnih određivanja ugljika na izdvojenim kerogenima. Vrijednosti ugljikovih izotopnih odnosna od $\delta^{13}C$ -22,4‰ do -25,9‰ su značajke algalno-lipidnog, odnosno vodikom bogatoga facijesa vezanog za anoksične i suboksične okoliše (SCHOELL, 1984). Parametri zrelosti (T_{max}, TAI i boja fluorescencije) omogućili su izradu zrelosnoga prognoznog profila. Katagenetska faza tj. ulaz u naftni prozor nastupa na dubini između 2100 m i 2200 m. Bogatstvo organske tvari, kao i visoki geotermički gradijent (>5°C/100 m) uzrokovali su generiranje i povećanu ekspulziju ugljikovodika kod nižeg nivoa termičkih promjena (YUKLER, 1987), što pokazuju i povećane količine bitumena u ispitivanim matičnim stijenama. Sadržaj bitumena kreće se između 2000 ppm i 4000 ppm, ali doseže i 10908 ppm (Bokšić-13, 2691,5 m).

Za nafte ovoga dijela depresije znakovita je gustoća od 30° do 34°API, sadržaj sumpora od 0,18% do 0,60%, udjel rezina i asfaltena dostiže 16,4%, a izotopni odnos ugljika je približno $\delta^{13}C$ -25,0‰. Plinsko-kromatografski profili "whole" nafti imaju relativno pravilnu ugljikovodičnu distribuciju (Sl. 3) s molekularnim odnosima Pr/C_{17}, Ph/C_{18} i $Pr/Ph < 1$ i CPI ~ 1. Posebna karakteristika ispitivanih nafti očituje se u smanjenoj količini laganih ugljikovodika u gazolinskoj frakciji. Ovi parametri pokazuju da nafte potječu iz vodikom bogatog, lipidnog kerogena koji je dostigao zrelu fazu termičkih pretvorbi.

Svojstva ispitivanih nafti pokazuju visoki stupanj sličnosti izvornoga facijesa, međutim, različitost migracijskih fenomena, neujednačena zrelost prekursora, tektonska poremećenost prostora, uzrokuju izmjene sastava ugljikovodika na određenim lokalitetima. Ovdje na spomenute razlike također utječu i nepovoljne fizičke značajke pokrovnih stijena, jer migracijom dolazi do gubitka lakših ugljikovodika, što je primjerice slučaj na polju Crnac.

Posebno značenje ima rasprostranjenost determiniranih matičnih stijena. Promjenljiva dubina zalijeganja kao i tektonska izlomljenost, uzrok su nekih specifičnosti. Matične stijene u polju Crnac debljine 50-60 m su na dubini od cca 2500 m i čine cjelinu s ležištima ugljikovodika, jer imaju i ulogu pokrova. Istovremeno u ležištima Števkovica i Klokočevci ovi sedimentni zbog sekundarne pukotinske poroznosti predstavljaju rezervoarske stijene (BARIĆ & RADIĆ, 1988; BARIĆ et al., 1989).

Plinove u ovom prostoru, moguće je klasificirati u tri skupine: biogeno-dijagenetski, termogeni i miješani plinovi (Sl. 4). U većini polja plinovi nastali s naftama su "vlažni", termogeni plinovi s prosječnim izotopnim vrijednostima $\delta^{13}C$ -46.3‰ i δD -170‰ (SCHOELL, 1983). Akumulacije biogeno-dijagenetskog plina (zapadni dio polja Bokšić i pojedine bušotine u polju Sječe, Ladislavci, Obod) odlikuju se nekim specifičnostima s obzirom na podrijetlo i današnju temperaturu ležišta. Osiromašenost metana deuterijem (δD -252 do -244‰) prema SCHOELLU (1988) upućuje na prevladavajuće fermentacijsko podrijetlo metana. Bakterijska aktivnost i nastajanje metana su nisko temperaturni procesi, međutim današnja temperatura ležišta dostiže i 100°C (sl. 1, RAVNIK et al., 1990). Navedene slučajeve MATTAVELLI & NOVELLI (1987) tumače brzim tonjenjem sedimenata u kojima je prethodno bio formiran biogeni plin. Miješani plinovi nastaju dismigracijom ugljikovodika iz naftnih ležišta, a ulaskom u pliće strukture, zapunjene biogenim plinom dolazi do njihovog miješanja (Beničanci, Obod). Posebne značajke pokazuju plinovi polja Bizovac. Ležišne stijene, hidrotermalno izmijenjeni bazalti, na dubini od 1600 m do 1750 m sadrže zrele, migrirane nafte i plinove s udjelom viših ugljikovodika od cca 13%. Međutim, rezultati izotopnih određivanja ugljika i deuterija ($\delta^{13}C$ -62,3‰ do -63,4‰ δD -203‰ do -209‰) upućuju na biogeno podrijetlo. Ovi slučajevi nisu neuobičajeni, a tumače se migracijom termogenih i biogenih plinova i njihovim zaustavljanjem u zamkama (MATTAVELLI et al., 1983).

4. ZAKLJUČAK

Rezultati geoloških i geokemijskih ispitivanja pokazali su prisutnost matičnih stijena, pretežno badenskih marlita, dobrih generirajućih sposobnosti. Organski facijes matičnih stijena su vodikom bogati lipidi, tip kerogena II, koji je dobar izvor naftnih ugljikovodika. Specifične termičke karakteristike ovog prostora osigurale su zrelost kerogena kao i povećanu ekspulziju ugljikovodika. Genetska svojstva ležišnih ugljikovodika pokazuju visoki stupanj sličnosti s determiniranim matičnim stijenama i moguće je zaključiti da predstavljaju izvor postojećih akumulacija. Određena odstupanja u sastavu nafti rezultat su u prvome redu migracijskih fenomena, ali i fizičkih značajki ležišnih i pokrovnih stijena.

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