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Review paper

Prospecting for Bypassed Oil and Gas

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PROCEEDINGS

Key words: Prospecting, Bypassed oil, Bypassed gas.

Ključne riječi: istraživanje, preostala nafta, preostali plin.

Abstract

In recent years, it has been increasingly difficult to economically explore for hydrocarbons because of geopolitical uncertainties and low oil prices. In many countries the remaining potential prospects are in areas which are difficult to access because of climate, terrain, offshore water depth, and/or environmental constraints. Also, most of the relatively simple geologic basins have been exploited leaving to explore areas of complex geology. In addition, the probability of finding large fields in mature basins is understandably low.

It is known that substantial amounts of hydrocarbons has been bypassed on a macroscopic and microscopic scale in known fields. This is mainly due to reservoir heterogeneities and complex lithology which result in poor reservoir characterisation. Innovative reservoir management options can reduce the amount of bypassed hydrocarbons. Emerging technologies such as 3-D seismic and horizontal wells facilitate the location of oil and gas which has been bypassed at near-virgin saturation. Sufficiently large amounts of such hydrocarbons could be economically produced in the near term by infill drilling. Innovative improved oil recovery methods can revive reservoirs which were considered depleted by conventional standards. These emerging technologies and methods have the potential of adding bypassed oil to the reserves category at a cost per barrel much lower than the cost of new discoveries.

Sažetak

Isplativo istraživanje ugljikovodika odnedavno je općenito postalo otežano bilo zbog geopolitičkih okolnosti bilo zbog niske cijene nafte. U mnogim zemljama pronalaženje preostalih količina nafte i plina čine zamršenim nepristupačnost terena, surova klima, velike dubine mora i/ili bojazan od onečišćenja okoliša. Brojni bazeni, geološki relativno jednostavni i prividno iscrpljeni, sigurno imaju dijelova složenije građe i sastava koji bi se mogli dodatno istraživati. No, vjerojatnost pronalaženja velikih polja u njima je svakako mala.

Znano je da su stanovite količine ugljikovodika preostale u poznatim poljima kako u makroskopskim tako i u mikroskopskim razmjerima, što uglavnom ovisi o složenosti građe i litološkog sastava ležišta, odnosno o lošijim rezervoarskim značajkama. Novi postupci gospodarenja ležištima smanjuju količinu preostale nafte. Nastupajuće tehnologije kao što su 3-D seizmika i vodoravno bušenje omogućavaju smještavanje nafte i plina koja preostaje u gotovo iskonskom zasićenju. Ona bi se mogla proizvoditi u gospodarski isplativim količinama kao što se to postiže i primjerice utiskivanjem u bušotine. Suvremeni, savršeniji načini otkrivanja nafte i plina mogu učiniti vrlo zanimljivima i ona ležišta koja se prema uobičajenim mjerilima smatraju iscrpljenima. Na osnovi rezultata spomenutih novih tehnologija i metoda preostala bi se nafta mogla uključiti u pridobive zalihe po cijeni nižoj od cijene novootkrivenih količina ugljikovodika.

1. INTRODUCTION

The total world oil and gas resource is classified, according to the degree of geologic assurance, as potentially recoverable discovered, and undiscovered. Part of the discovered resources have already been produced. The distribution of the ultimate resource between these categories differ from country to country. For the United States, a mature oil and gas producer, half of the ultimate resource have been produced. Future production will come from a variety of sources. Reserves in currently proved fields, plus the growth of these fields will contribute half of future production. The other half will come primarily from currently undiscovered resources.

In most mature areas, average inland discovery is becoming smaller and more difficult to find. Deeper prospects present a challenge of operating in high temperature and high pressure, often corrosive, environment. Exploring for undiscovered offshore resources require drilling, completion, and production operations in deep water. The cost associated with offshore environment necessitates the discovery of larger to larger accumulations. A field of 4.8 million m^3 (30 million barrels) may be economically viable inland but the same discovery in 200 meters waters would show minimal return (COX, 1980).

A large percent of the world's undiscovered resources lies north of the 60th parallel in Arctic Canada and Russia. The costs of exploration, development

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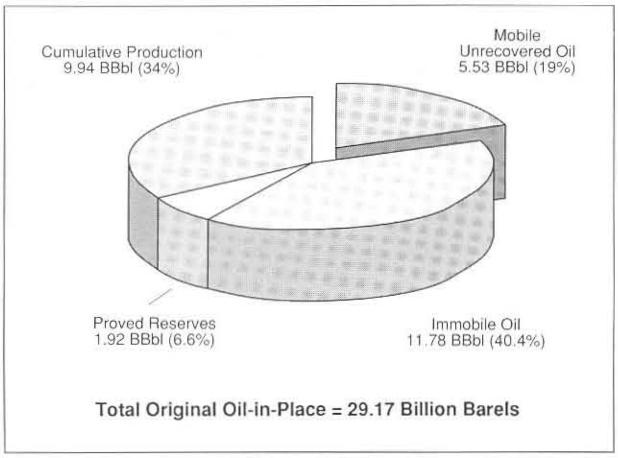

Fig 1 Distribution of original oil-in-place in Federal Offshore Gulf of Mexico, after an ICF report (I.C.F., 1996).

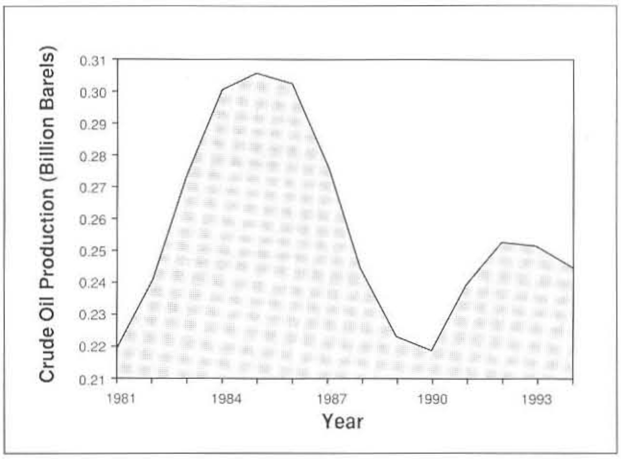

Fig. 2 Crude oil production (1981-1994) of Federal Offshore Gulf of Mexico, after an ICF report (I.C.F., 1996).

and transportation in the Arctic are very high. Higher prices will be required to support further exploration for and development of the Arctic region. Exploring the Arctic and other inhospitable and remote areas such as the rain forest will also require the development of ecologically sound technologies.

The world resource base is largely dependent on three factors: price of oil and gas, cost of exploration and development, and availability of lands for exploration. The surface area yet to be explored is decreasing continuously, and the price of oil is determined by forces external to the petroleum industry. The oil industry forecasts appears to be moving towards using a flat oil price. As the resource base continues to mature, the cost required to explore for and to develop remaining resources is increasing. New technologies will be the key to reducing the cost. These factors and considerations are creating a business climate that is challenging and will necessitate considerable change in priorities, strategies, and management structure.

The industry has then to give more consideration to bypassed oil. This relatively new term refers to the hydrocarbons which have been bypassed on microscopic and macroscopic scale in already discovered and developed reservoirs. Oil bypassed on microscopic scale is the immobile oil trapped in the reservoir pores by viscous and capillary forces and cannot be displaced by water. The immobile oil is the target for number of enhanced oil recovery techniques particularly miscible gas and chemical flooding. Oil bypassed on a macroscopic scale is the mobile oil which remains in the reservoir after conventional recovery for a variety of reasons. The magnitude of bypassed oil is significant. For example, in federal offshore Gulf of Mexico it is estimated that at the conclusion of conventional recovery techniques, nearly two-thirds of the known resources will remain unrecovered. A 878 million m^3 (5.53 billion barrels) or 19% of OOIP is in the category of mobile bypassed oil (Fig. 1). Figure 2 shows that the Gulf of Mexico annual offshore production peaked in 1970 and has since fallen dramatically. The noticeable increase in production starting in 1990 is primarily due to the application of 3-D seismic, horizontal wells, and other technologies which targeted bypassed oil. The different types of bypassed oil and the means for their identification and recovery are discussed hereafter.

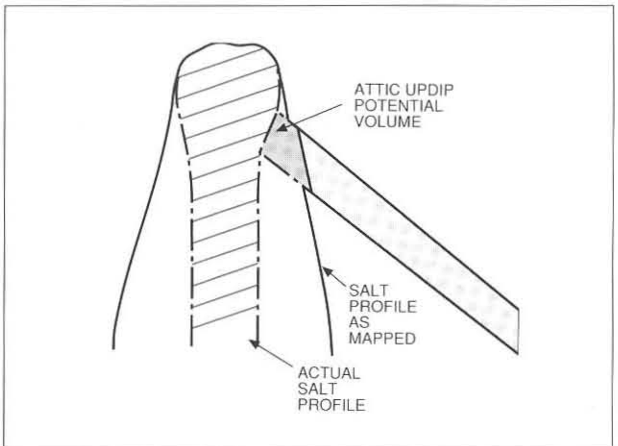

Fig. 3 Bypassed oil due inaccurate detection of salt boundary, after an ICF report (I.C.F., 1996).

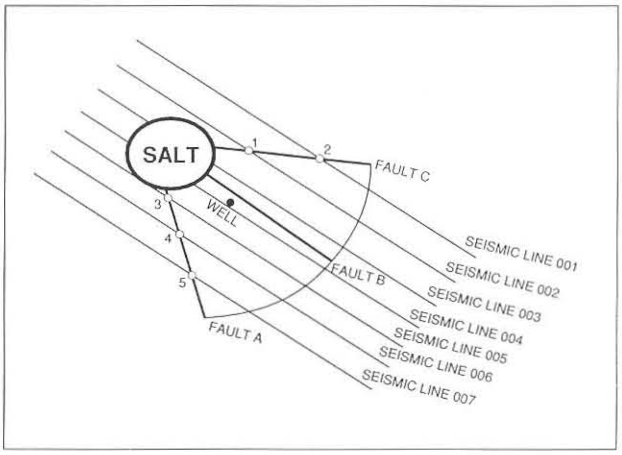

Fig. 4 Bypassed oil due to faulting, after an ICF report (I.C.F., 1996). The recently developed 3-D seismic technology can provide the necessary information to properly map the reservoir.

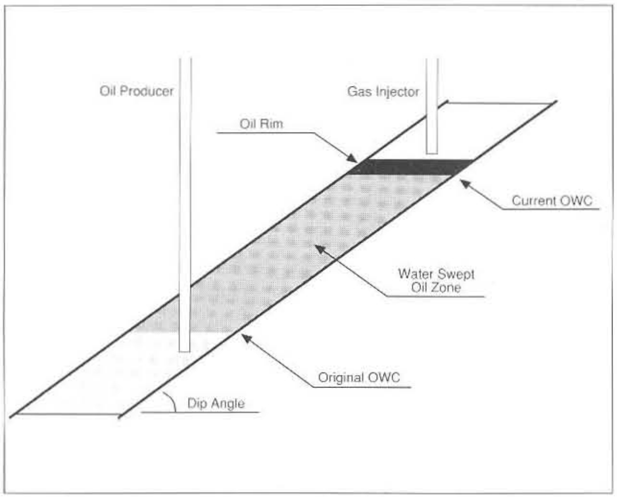

Fig. 5 Schematic of the double displacement process (after LEPSKI et al., 1995).

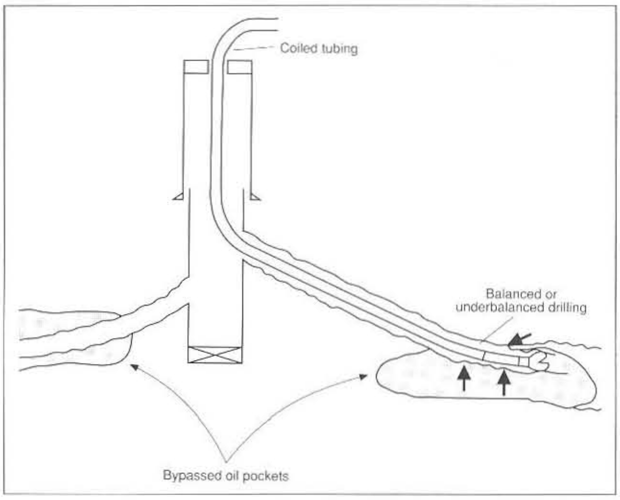

Fig. 6 Combining advanced drilling technologies to reach bypassed oil pockets, after PEDEN & TWEEDIE (1995).

2. BYPASSED OIL DUE TO INACCURATE DELINEATION OF RESERVOIR BOUNDARIES

One example of inaccurate delineation of geologic structures is that of salt intrusions (Fig. 3). Optimum selection of drilling locations around salt intrusions is hampered by refraction of the seismic waves as they pass through the salt body. This refraction tends to distort the seismic images making it difficult to pinpoint the salt boundary. Much oil has been bypassed because the salt boundaries were not clearly visible in seismic imaging. Another example is that of faults which are not detected by conventional 2-D seismic technology (Fig. 4). As a result oil in an isolated fault block is bypassed.

3. BYPASSED OIL DUE TO RESERVOIR HETEROGENEITY

Oil reservoirs are produced either by natural or artificial drive mechanism, in which oil is pushed to the producing wells by the expanding gas and/or the invasion of water into the reservoir. The spatial reservoir heterogeneity will leave considerable volumes of oil bypassed in isolated pockets. If the bypassed pocket is large enough, it could be produced economically in the near term simply by drilling a new infill well without the need for more complex and costly enhanced oil recovery processes. In a homogeneous system, infill drilling accelerates production. In a heterogeneous system it also results in incremental recovery. The recovery is the result of improved reservoir continuity, improved areal and vertical sweep. Infill drilling is not without risk and requires detailed reservoir description to improve chances of success (GOULD & SAREM, 1989).

4. ATTIC OIL AND OIL BYPASSED IN THE WATER-SWEPT ZONES

Attic oil is that oil trapped updip from the highest well in a reservoir. Attic oil is usually limited in size to justify drilling new wells. This bypassed oil is the target of side-tracking or updip gas injection. The updip gas injection process for recovering attic oil can be expanded into a Double Displacement Process (DDP) to recover the oil bypassed behind the water front. The DDP involves updip gas injection into a water-invaded oil column in order to produce incremental oil. The incremental oil results from the mobilisation of a fraction of the residual oil left behind in the water-swept zone. Gravity-stable gas displacement causes the formation of an oil bank which builds up progressively as it migrates down the reservoir towards the producing wells. A simplified schematic of a dipping reservoir subjected to DDP is shown in Fig. 5. Incremental oil recovery depends on the amount of gas injected and the location of a down-dip wells. Favorable conditions may result in the recovery of up to 40% of the initial oil-in-place (LEPSKI et al., 1995).

Waterflooded reservoirs of Louisiana were screened to determine the potential of recovering incremental oil by CO_2 injection. Of the 197 waterflooded reservoirs screened, 39 look economically attractive. The potential incremental recovery from these reservoirs is about 11.3 million m^3 (71 million barrels) (DIAZ et al., 1996).

5. WATER CONING

Whenever a well is producing from an oil layer overlaying a water layer, the pressure gradients may deform the horizontal water-oil contact into a cone shape contact. The cone height above the horizontal

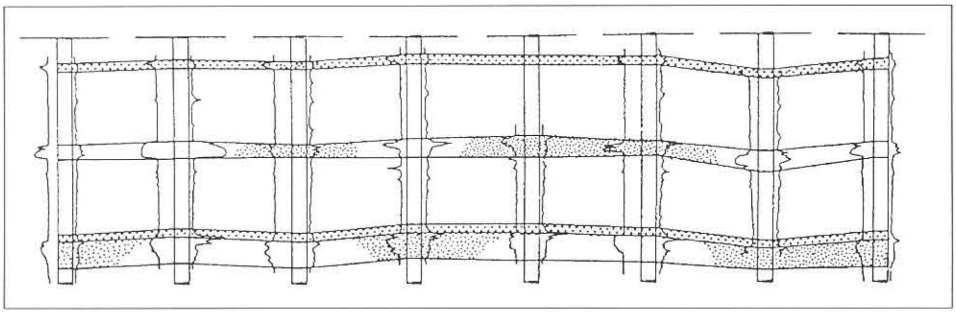

Fig. 7 Shaded Areas Indicating Possible Bypassed Oil in a Nearly Depleted Reservoir in Louisiana, after BOURGOYNE & KIMBRELL (1994).

contact depends on the production rate. Above a certain critical rate water will enter the well bore. The water coning phenomenon may cause the oil cut to reach its economic limit prematurely leaving a significant amount of mobile oil unrecovered. Producing at a rate below critical may be uneconomical. A horizontal side track or lateral may present an economic option as a much higher flow rate can be realised without deforming the horizontal contact. Additional well technologies, namely coil tubing drilling, and under-balanced drilling can be combined with horizontal and lateral drilling to achieve large improvement in hydrocarbon recoveries in such cases (PEDEN & TWEEDIE, 1995) (Fig. 6).

6. BYPASSED OIL DUE TO MISINTERPRETATION OF WELL LOGS

Potential hydrocarbon-bearing formations are identified from well log data. Misinterpretation of these data, due to the complexity of the rock-fluid system, may lead to the bypassing of complete intervals. Such cases are the target for reinterpretation of original open hole logs using newly established petrophysical models. Cased hole logs, such as the Thermal Decay Time (TDT) and the Gamma-Ray Spectrometry Tool (GST), can also be used to investigate the current fluid content in old wells. The reinterpretation of old logs was

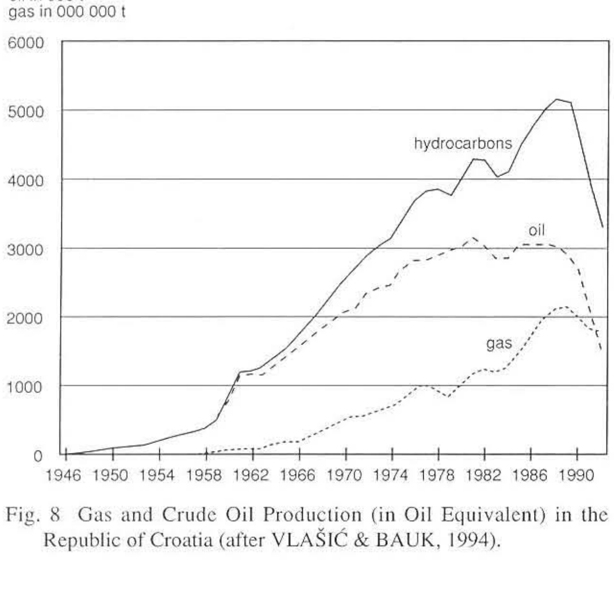

Fig. 8 Gas and Crude Oil Production (in Oil Equivalent) in the Republic of Croatia (after VLAŠIĆ & BAUK, 1994).

attempted in a Louisiana field near primary depletion (BOURGOYNE & KIMBRELL, 1994). Several possibilities of bypassed oil were identified and indicated by the shaded areas on the cross-section of Fig. 7. The top sand is thin and shaly and was not tested for hydrocarbon production. New interpretation indicated much higher oil saturation than was indicated by initial interpretations. This thin sand could be a good candidate for horizontal well application. The other two sands were selectively completed. Pockets of mobile oil were bypassed due to uneven advance of water and/or absence of perforations. Some of these pockets could be the target of infill drilling and/or recompletion of old wells.

7. BYPASSED OIL POTENTIAL IN THE REPUBLIC OF CROATIA

Oil and gas production supplies more than half the energy need of the Republic of Croatia. All present oil and gas production comes from the Pannonian Basin. As of 1994, the Croatian part of the Pannonian Basin has produced 78 million tons of oil and 30 billion m^3 of gas (VLAŠIĆ & BAUK, 1994). Production history is shown in Fig. 8. The sharp drop in oil production in the late eighties is due to occupation of fields in Eastern Slavonia, and reduction of exploration activities. To remedy this critical situation INA is considering more aggressive exploration policy which will open domestic areas for foreign companies. This option is limited by the relatively small area available for exploration. INA is also considering acquisition of discovered reserves abroad especially in the Mediterranean area, and the application of enhanced oil recovery processes (VLAŠIĆ & BAUK, 1994).

In addition to the above mentioned options, reserves could also be increased by prospecting for bypassed oil. The potential of this option can not realistically be determined before a detailed study is undertaken. The Croatian part of the Pannonian Basin contains 54 reservoirs. The eight largest of these fields account for 83% of total recoverable reserves. Prospecting for bypassed oil should target this manageable number of reservoirs.

Awaiting such a study, we can point to few possibilities. Analysing primary recovery indicated that an inefficient solution gas drive was predominant in most of the fields. Only few fields, with 27% of initial recover-

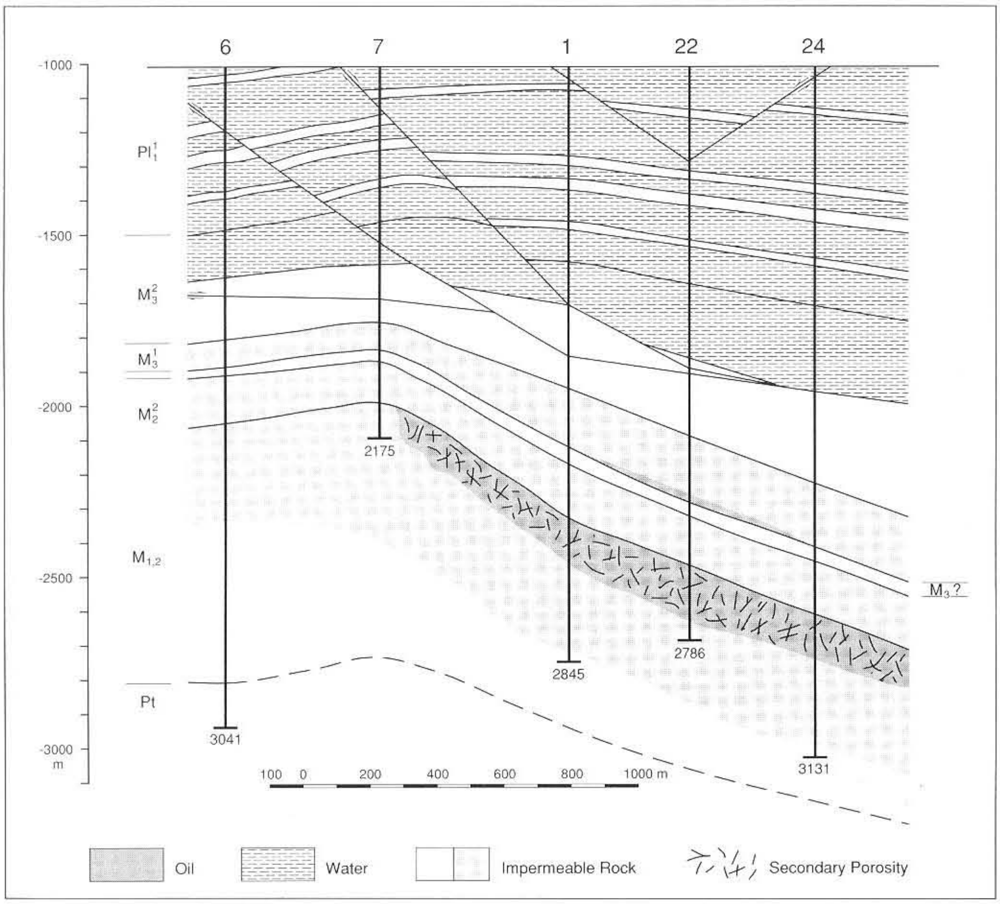

Fig. 9 Cross section of Obod reservoir, Croatia (after TURAJLIĆ et al., 1979).

able reserves are producing under efficient water drive. To increase the sweep efficiency of the encroaching water the present spacing design of production and injection wells could be modified by infill drilling of vertical or horizontal wells. Innovative improved oil recovery methods such as the double displacement process may also contribute to the recovery of bypassed oil in the watered-out zones. Even an average increase of 20% in the ultimate recovery from these reservoirs will result in about 7% increase in the ultimate recovery of Croatia.

Another possibility of the existence of bypassed oil is in reservoir like the Obod reservoir. As shown in Fig. 9, oil exists in zones with secondary porosity embedded in an impermeable rock (TURAJLIĆ et al., 1979). The characterisation and delineation of reservoirs in such environment is rather difficult. The application of new technologies such as 3-D seismics coupled with improvements in formation evaluation could enhance the geologic picture provided by the lower resolution 2-D seismic surveys. An improved picture should result in additional recovery.

The most important gas fields in Croatia are Molve, Kalinovac, and Stari Gradac (HORVAT, 1995). The remaining recoverable reserves of gas in the three fields represent more than 80% of the total discovered gas reserves in Croatia. These gas accumulations exist in reservoirs of complex lithology, various porosity types and generally low permeability. The reservoirs are also characterised by high pressure and high temperatures, and the presence of corrosive and toxic gases, such as CO_2, H_2S and HgS. Because of these difficulties, the existence of significant amounts of bypassed gas is a distinct possibility.

8. CONCLUSIONS AND RECOMMENDATIONS

Croatia needs to characterise and evaluate its bypassed hydrocarbon potential reserves. This include remaining unrecovered mobile oil and gas associated with complex heterogeneous reservoirs, and additional recovery potential and related economic benefits that could result from the application of innovative improved technologies. An analytical system needs to be developed for the characterisation and evaluation of bypassed hydrocarbons. The system would consist of comprehensive database containing detailed rock and fluid properties, geologic information, and production and development history for the Pannonian Basin reservoirs. Continuation of research and development efforts are needed in the areas of directional drilling and completion, 3-D seismic imaging, improved integration of logging and seismic data, and development of geologic models for complex environment. The research and development could effectively be met through collaborative effort between INA, the university, and government.

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