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Application of the Infrasoinic Passive Differential Spectroscopy (IPDS) for Hydrocarbon Direct Detection and Reservoir Monitoring in Fields of the North-Caspian Basin: Achievements and Challenges

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ABSTRACT

This technique is based on the principles that hydrocarbon reservoirs as a multi-fluids system in porous medium has an unconventional (non linear) transfer characteristics for acoustic waves. Hydrocarbon fluid in porous system can be detected as a characteristic deformation of the natural earth noise spectra in the acoustic low frequency range between 0.2 and 10 Hz. The anomalous absorption/emission of micro-seismic noise is used as source for direct detection of oil/gas accumulation (OGA) trapped in a porous matrix/reservoir.

In these conditions, the OGA passes in generation of its proper infra-acoustic waves. The mechanical energy of hydrodynamic nature is simply transforming in acoustic energy generating the IPDS waves/signals (downward conversion). The spectral amplitude of background micro-seismic emission above the OGA exceeds considerably that of outside the OGA in the frequency range of 0.1-30 Hz. Measuring and processing the characteristic spectral amplitude of this generated and amplified natural micro-seismic noise defines the presence or absence of OGA.

Applying this technology to three important fields in the North Caspian basin has shown that it provides a detailed spatial hydrocarbon distribution, reservoir delineation and monitoring and reliable estimation of hydrocarbon potential reserves or resting un-produced oils. Correlation of field production data with the passive seismic monitoring results shows an enough satisfactory output of the applied technology for reservoir monitoring. This technology could be also promising for EOR/IOR projects, as well as for horizontal and vertical well drilling projects.

However, in faulted disintegrated zones owing to increased heterogeneous stress as factor of both micro- and macro-seismic instability the IPDS signals are somewhat deformed. This fact implies some ambiguities, which have to be clarified and resolved.

INTRODUCTION

Passive seismic technologies for hydrocarbon exploration and reservoir monitoring are considerably developing last years. However this technique is still requiring further investigations as related both conceptual and experimentation elaborations.

This paper reveals the general trends conditioning the reservoir behavior and clarify the correlations between the IPDS survey findings and field production data. A lot of oil and gas accumulations are revealed and detailed reservoir monitoring is provided for all the areas for which production data were available. An attempt is made to clarify the real processes taking place during the field's exploitation and conditioning anomalies manifesting during oil and gas production. These processes are, to large extent, creating some apparent inconsistency between the field production data and the IPDS results, particularly in zones of intensive development of faulted systems in the studied fields.

BASIC CONSIDERATION FOR FORECASTING THE FUTURE OIL AND GAS MARKET

• During around 100 years, the humanity has consumed around one half to one third part of what the nature has produced during more than 800 million years

• Today from each three barrels oil consumed, only one barrel is replaced in world remaining reserves by active exploration

• The needed investment per potential barrel (to be discovered and produced) is in the order of 20 cents (of US $) in North America, 45 in North Sea but only 10 in Russia and CIC and 5 in the middle East and North Africa, where HC potential is considerably higher

• Declared and published hydrocarbon (HC) proven reserves are subject to political and economic manipulation and speculation and are most likely exaggerated:

- OPEC producers are inflating their proven reserves in order to increase their production quotas, defined as a function of reserves,
- International oil companies are also inflating their proven reserves in order to support their stock values in financial markets, being required by the Securities and Exchange Commission to publish yearly their updated reserves

• All these factors imply increasing prices within the real equation offer/demand and consequently the unique rentability of investing in HC industry

PHYSICAL PRINCIPALS OF THE IPDS TECHNOLOGY

Basically for applying this technology, there is no need of any external seismic source. The anomalous absorption / emission of natural micro-seismic noise is used for direct detection of oil/gas accumulation (OGA) trapped in a porous matrix/reservoir.

• The OGA is excited/activated by external artificial or natural field of elastic vibration in frequency range of effective interaction of this field with the hydrocarbons enclosed in porous reservoir matrix.

• In these conditions, the OGA passes in generation of its proper infra-acoustic waves.

The mechanical energy of hydrodynamic nature is simply transforming in acoustic energy generating the IPDS waves/signals (downward conversion).

• This model assumes a capillary-bubble environment and links the described phenomena to evaporation and condensation of fluids in presence of electrical charges.

• The spectral amplitude of background micro-seismic emission above the OGA exceeds considerably that of outside the OGA in the frequency range of 0.1-10 Hz as this is demonstrated on experimentation results shown on figure 1.

Detection and mapping of hydrocarbon accumulations

Measuring and processing the characteristic spectral amplitude of the generated and amplified natural micro-seismic noise defines the presence or absence of OGA. While the IPDS measurements is conducted in the framework of a geometric grid designed to cover in the best way the investigated territory, the survey results generate a map of spatial distribution of the possible HC accumulations in the studied area as shown in figure 2. This figure demonstrates IPDS survey results in an area in West Texas, where 2 drills were performed in oil prospects revealed by IPDS and oil was effectively found in these two locations as this is described in figure 2.

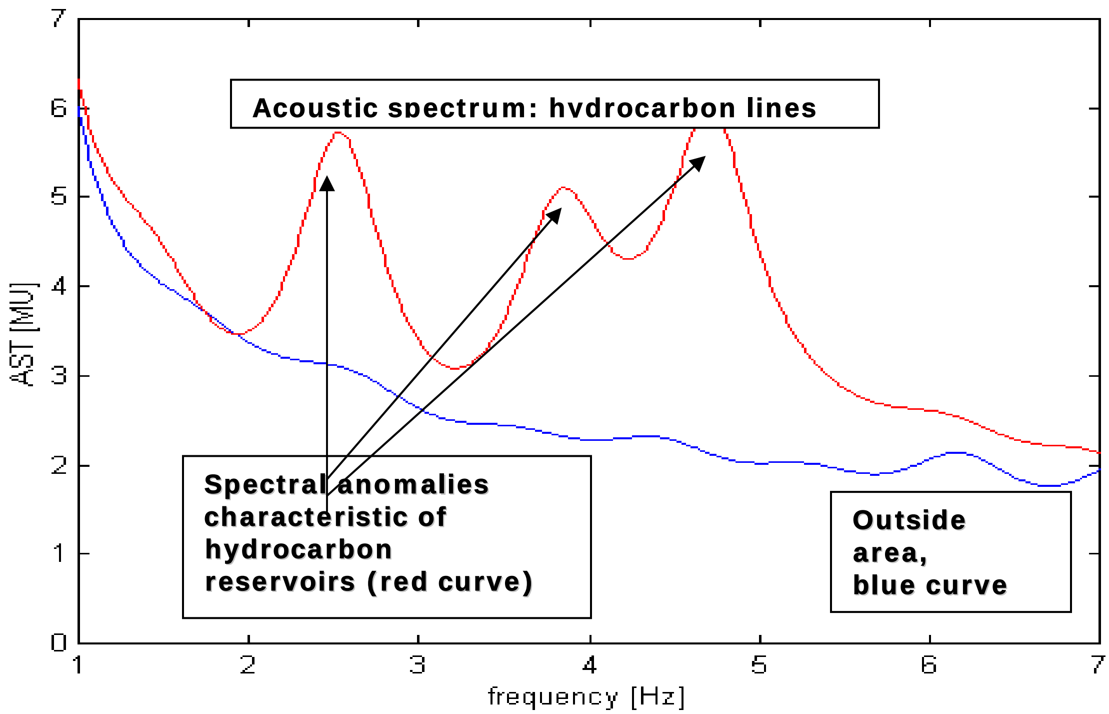


Fig. 1 Comparison of spectra and signals recorded during the IPDS survey. Live Data: Spectral analysis of signals recorded in the northern part of the UAE-Q field

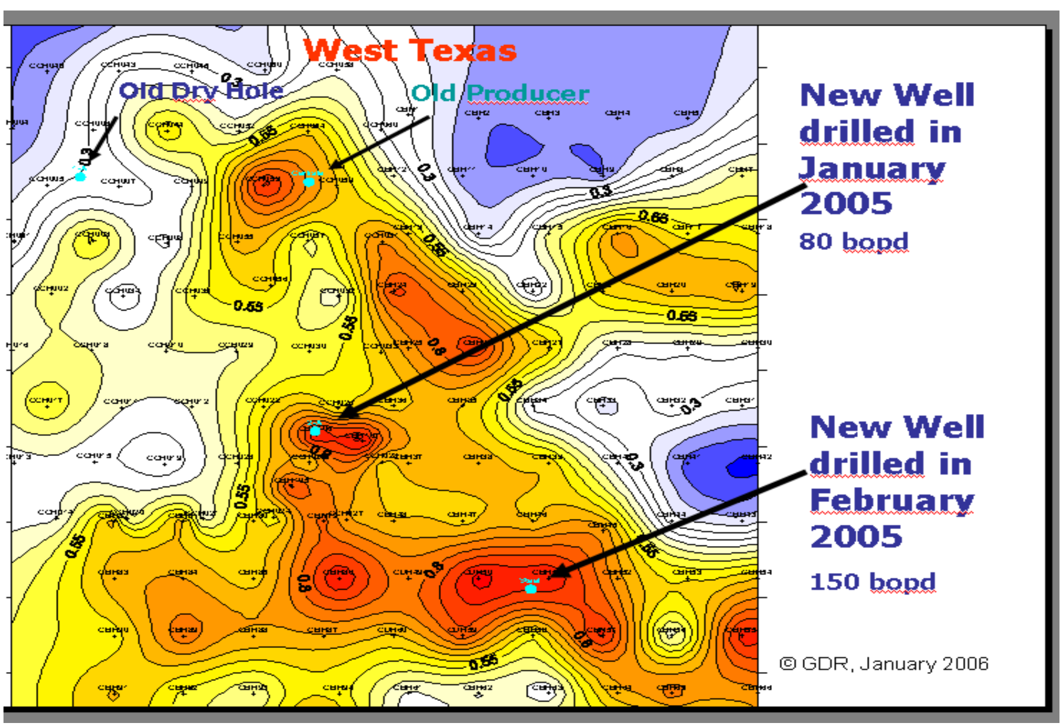


Fig. 2 Detection and mapping of spatial and depth distribution of hydrocarbon accumulations in West Texas. Red to yellow figures represent oil accumulation zones where isolines represent net oil pay zone thickness; whereas blue figures present water- saturated zones (See color scale captions in Fig. 8, which represents direct hydrocarbon indicator, as function of cumulative net oil pay zone thickness)

The IPDS field experimentations in many studied areas, particularly in the United Arab Emirates have established a direct correlation between GEOSPECTRA hydrocarbon indicator and net oil pay zone thickness as shown on the example of the UAE field B (figure 3), allowing for the moment to define the cumulative thickness of oil-bearing strata.

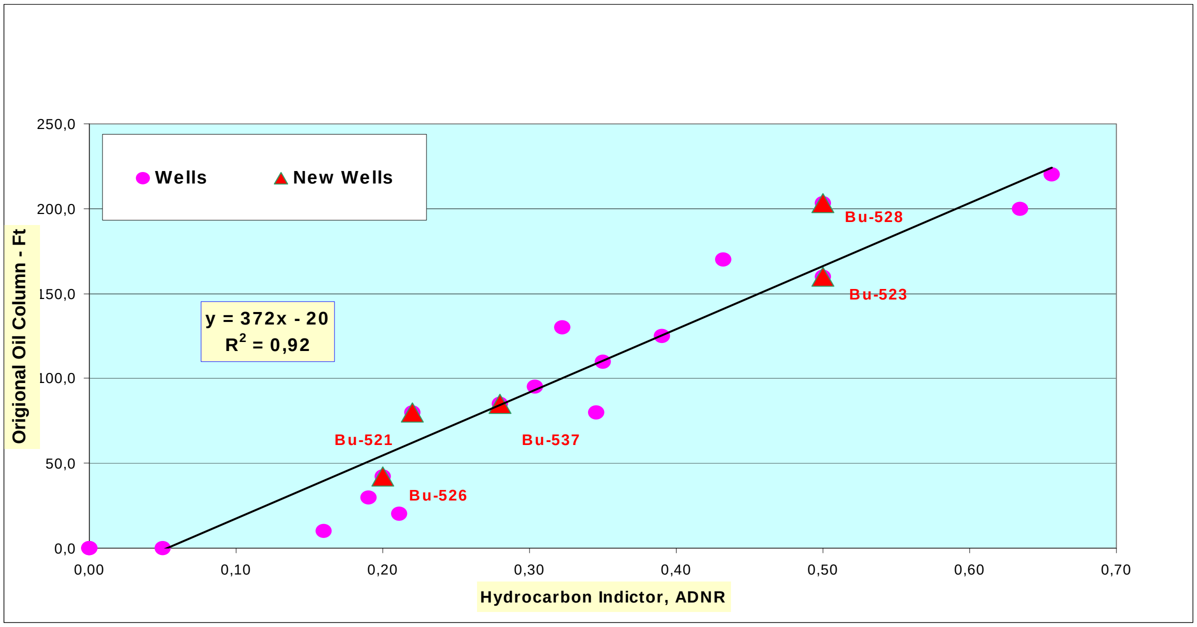
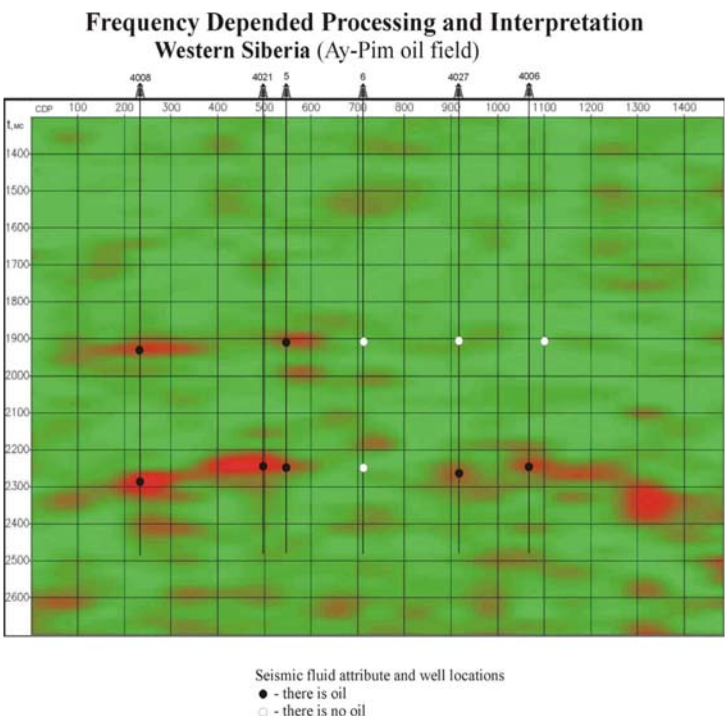


Figure 3 Correlation between the IPDS hydrocarbon indicator and net oil pay zone thickness in the UAE field B. Correlation coefficient is in the order of 90%

Other original investigations of passive seismic capability for direct detecting and mapping of hydrocarbon accumulations were also documented by other researchers in West Siberia. (Goloshubin et al., 2006). Reflections from an oil-saturated layer have increased amplitude and delayed travel time at low frequencies if compared with reflections from a gas-saturated layer. This effect was observed for both ultrasonic lab data and seismic field data (figures 4 and 5). One set of field data revealed high correlation of low frequency processed image for two different production horizons represented by fractured shale and sandstone. Another set was processed for the purpose of contouring of oil/water contact, and reveals very good correlation with available well data. Thus the frequency dependent amplitude and phase reflection properties can be used for detecting and monitoring HC saturated layers.



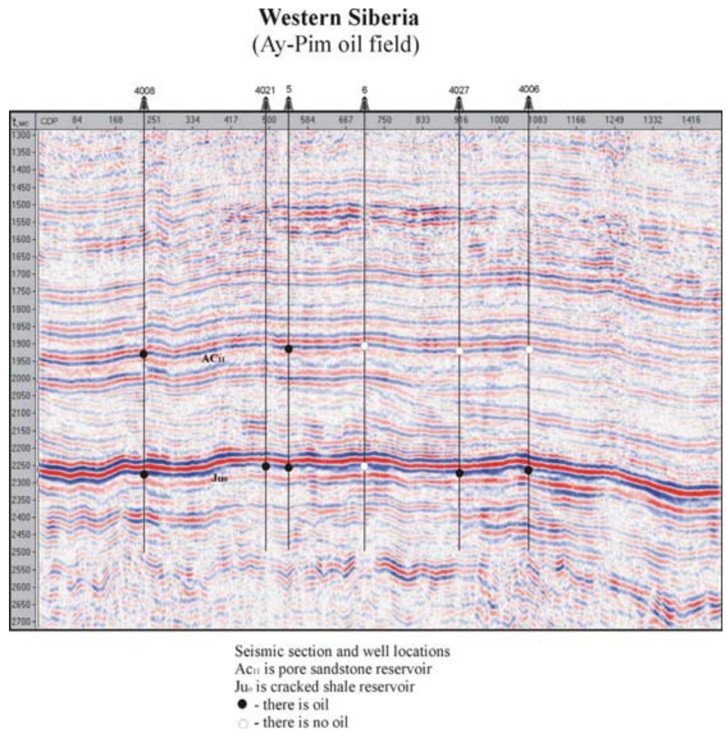


Fig. 5 Seismic profile for the same area (Goloshubin et al., 2006)

Fig. 4 Passive low-frequency seismic profile showing detected oil accumulation and their correlation to well production data (Goloshubin et al., 2006)

SUB-SALT EXPLORATION

Geological setting and particularities of the Pre-Caspian basin

General feature

The Pre-Caspian basin is one of world's deepest troughs making locally up to 25 km depth. This basin is distinguishing by an original geological structure consisting of two geologic structural stages: Paleozoic and Mesozoic separated by a thick (up to few thousands meter thick) of salt deposits (Figures 6 and 7).
Today's HC production is almost exclusively concentrated within the Cretaceous, Jurassic and Triassic beds. This fact is mainly conditioned by the shallow depth of HC-bearing horizons of Cr, J and T making in some areas no more than 300-400 m depth. As to Paleozoic (mainly Carboniferous and Devonian) prospects, they are generally enough deep varying between 3000 and 8000 to 10000 meters. As long as there are still HC accumulations not explored and produced yet, petroleum investors are not going to spend more expensive exploration and production investments targeting Paleozoic prospects under the salt beds and domes.
However, many of the HC accumulations under production today are depleted to great extent and within a short and middle term feature, there should be no other choice other to go explore and produce HC from Paleozoic horizons. From the petroleum system point of view, every thing points to occurrence of huge oil and gas accumulations in the Carboniferous and Devonian reservoirs. In this province, we have an extremely organic-rich and maturated source rocks of regional extension, clastic and especially carbonate reservoirs with satisfactory to good petrophysical characteristics, which are moderately compacted owing to the low density of the upper lying salt horizons. Last are ensuring a high quality seals besides to other seals like faults, discordances and other tectonic sealing features. Timing of hydrocarbon generation and traps formation looks also enough favorable in the most of the studied provinces.

Evaporates features and implications for the petroleum system

Salts beds and domes present a big problem for reflection seismic surveys and make prospecting probable geological oil-bearing structures very difficult and even impossible in some areas in the sub-salt sections. This is a great advantage for the passive seismic (IPDS) technology enabling not only direct hydrocarbon (HC) detection

independing of the trap type, structural or not, but functioning there where the seismic is almost not able to map even the structures, nothing to say about detecting oil occurrence within them.
As regarding petroleum system criteria for defining HC prospects, such thick salt beds play an extremely favourable role for the formation and conservation of HC accumulations and fields:

- Salts are recognized as one of the best caps for preservation of generated HC accumulations, because of their perfect sealing proprieties (negligible porosity and permeability).

- The salt density is sensibly lower that other sediments such as shales, carbonates sulphates, sandstones, volcanic and intrusive formations and others. This implies that sub salt formations, including clastic or carbonate reservoirs would be considerably less compacted under the sediment load as compared to the same reservoirs being located under other sediment type with higher density. This situation is extremely important for preserving good porosity and permeability even at great depths in presence of thick salt formations as a result of moderate mechanical reservoir compaction under load. This is precisely the case in this area, similarly to other petroleum provinces in the world such as Africa, the Mexican Gulf basins and many other salt-bearing provinces where we could discover HC pools at depths exceeding 5000 m and even 7000 m depth.

- The thermal conductivity of salts is considerably higher that of other sediments or rocks: again the shales, carbonates sulphates, sandstones, volcanic and intrusive formations and others. Excessive heat flow coming from the deep horizons of the lithosphere contributes often during the geological history to destruction of huge accumulations of HC already trapped in reservoirs in old and/or deeply buried horizons. Excessive heat flow implies also over-cocking of organic matter in source rocks and disturbs oil generation process. The cited above higher thermal conductivity of salts favours largely the dissipation of over heating of the geological section including the occurring within it organic matter and/or the HC accumulations.

This implies again better preservation of oil and gas pools in deeply buried horizons suffering higher heating, resulting from deep burial and/or closer lithosphere. Evaporate high thermal conductivity largely favours dissipation of excessive heating and over-cocking of CH and organic matter in Source rocks, impedes diagenetic processes degrading reservoir petrophysical proprieties, particularly quartz pressure solution in classic reservoirs.

All of this is another asset for the IPDS (having no reflection, no dispersion and no adsorption), being favour to operate in an environment of petroleum system including salt deposits, there where reflection seismic is very disappointed for functioning correctly, particularly for revealing HC prospects in the sub-salt formations. As we have clarified above, highly promising HC prospects could be expected at considerable depths in the Pre-Caspian basin.

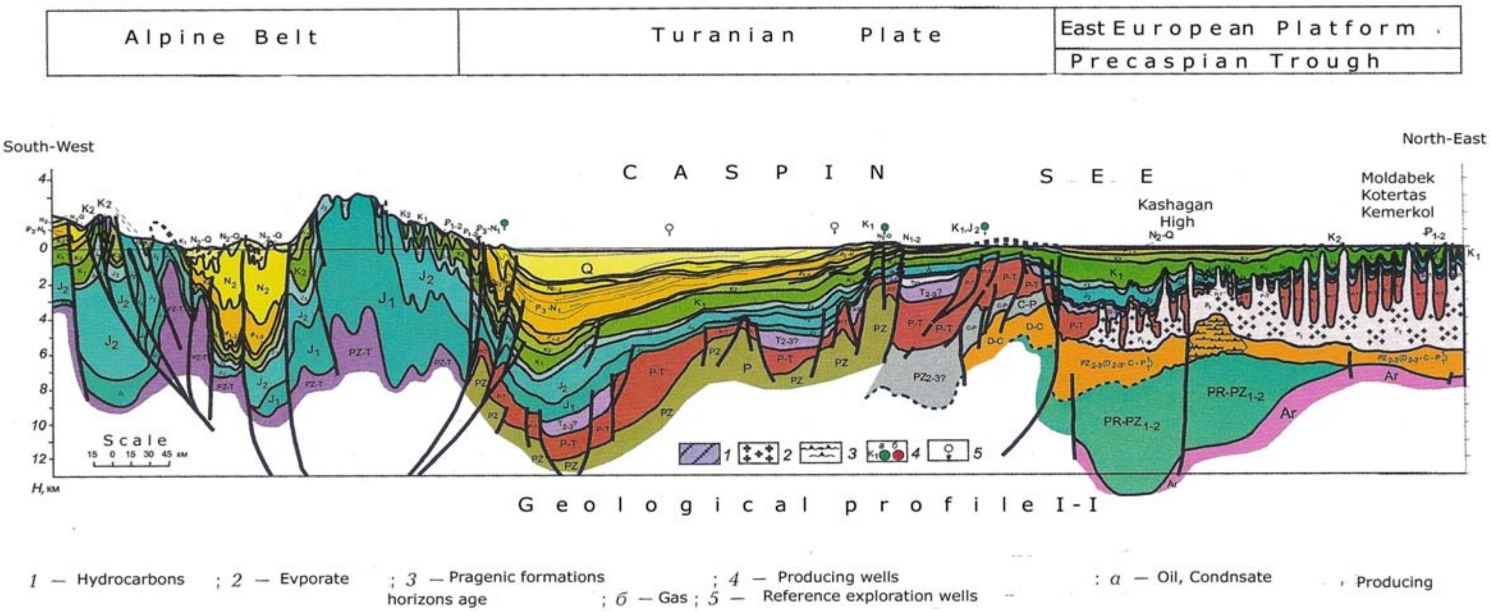


Fig. 6 Regional geological profile in the Pre-Caspian basin where the right part of the figure is presenting the North Caspian basin, related to the East European platform. Here, an IPDS survey for HC exploration and reservoir monitoring was carried out in Moldabek, Kutertas and Nurzhanova fields in 2006-2007

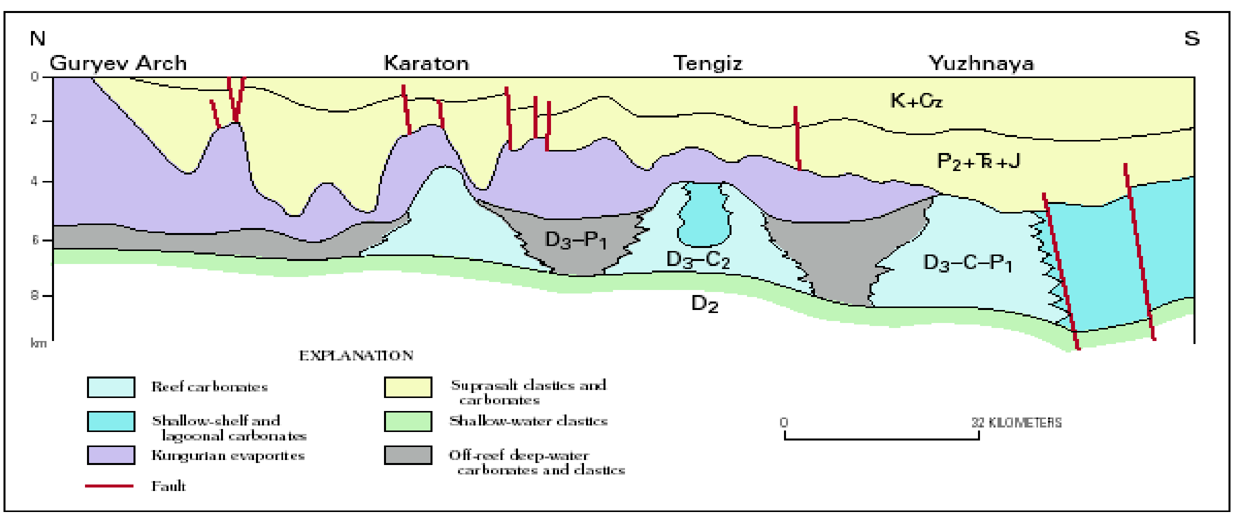


Fig. 7 Simplified schematic profile of the Pre-Caspian basin, showing the Two-stage geological structure (Paleozoic and Mesozoic systems separated by salts) as one of the World's most important HC-bearing provinces, including the Tengiz Super-giant oil field in Kazakhstan

Infrasonic passive differential spectroscopy (IPDS) survey: Detection of huge HC accumulations, mainly in the sub-salt Carboniferous and Devonian formations in the North-Caspian basin

An IPDS survey was shut here in 2007 covering the Moldabek and Kutertas fields and the surrounding areas as well as Nurzhanova field with the surrounding areas. The results of these surveys are shown in figures 8 and 9.

The fulfilled survey has aimed two principal goals: Monitoring reservoirs under production and exploration other possible HC accumulations in areas, which were not studied and/or drilled yet, surrounding the fields under production. Figures 7 and 8 show the detected huge HC accumulations occurring particularly in the peripheral areas of Moldabek, Kutertas and Nurzhanova fields: to the South, South-East and North-East of the Moldabek and Kutertas fields (fig. 8); and to the East, South-East and North-East of the Nurzhanova field (Fig. 9). These accumulations could be entrapped in both Mesozoic (Cr, J, T) and Paleozoic reservoirs (C, D), but mostly in the Paleozoic reservoirs under the salt horizons. Probably that is the main reason why these areas were not targeted yet, insofar as seismic surveys are suffering difficulties to reveal possible promising structures under so thick evaporates horizons. And that is the outstanding advantages of the passive seismic IPDS technology to operate successfully in such environment as it was clarified above.

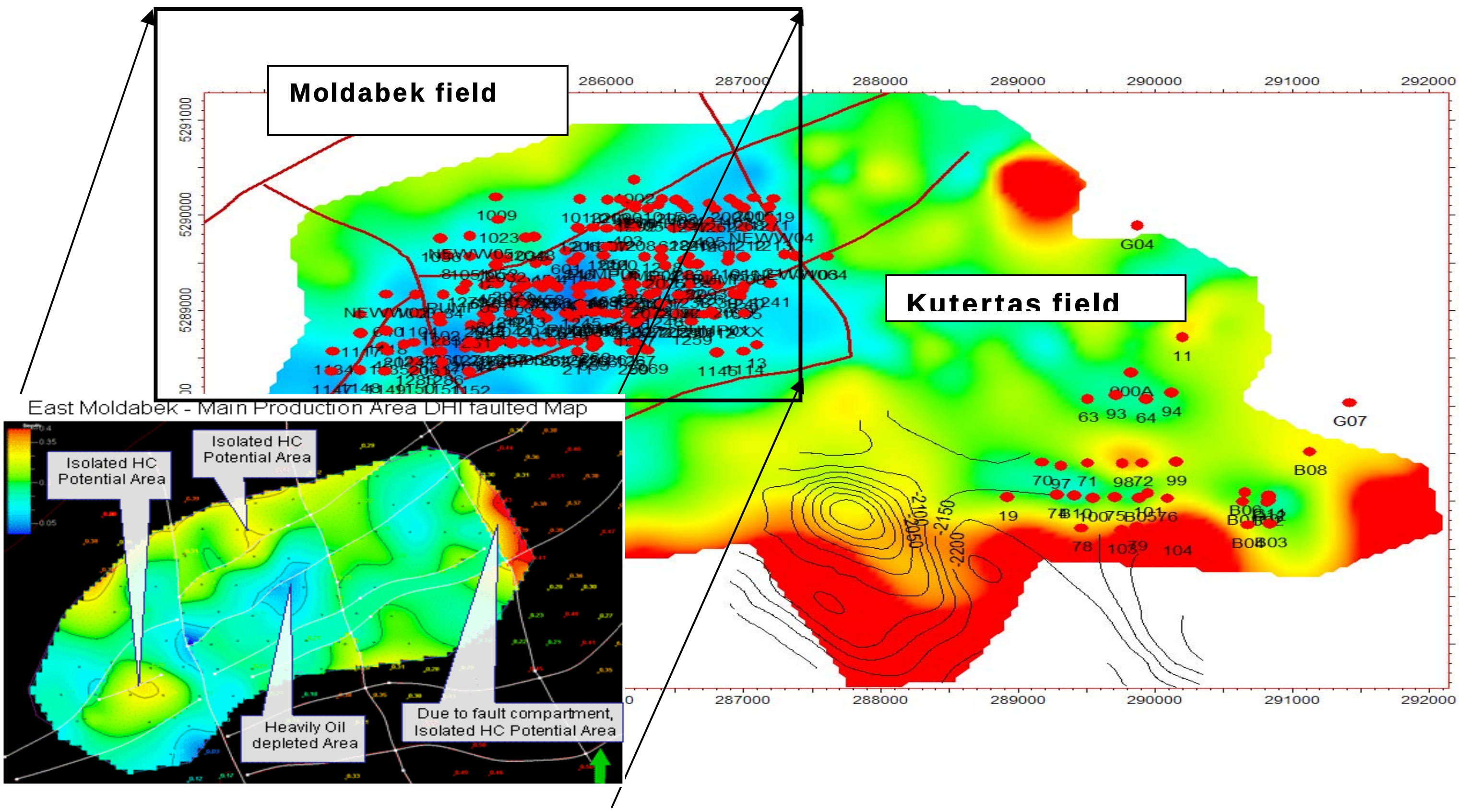


Fig. 8 Map of spatial distribution of hydrocarbon accumulations in the Moldabek and Kutertas fields in the North Caspian basin.
(See color scale captions in Fig. 8, which represents direct hydrocarbon indicator, as function of cumulative net oil pay zone thickness)

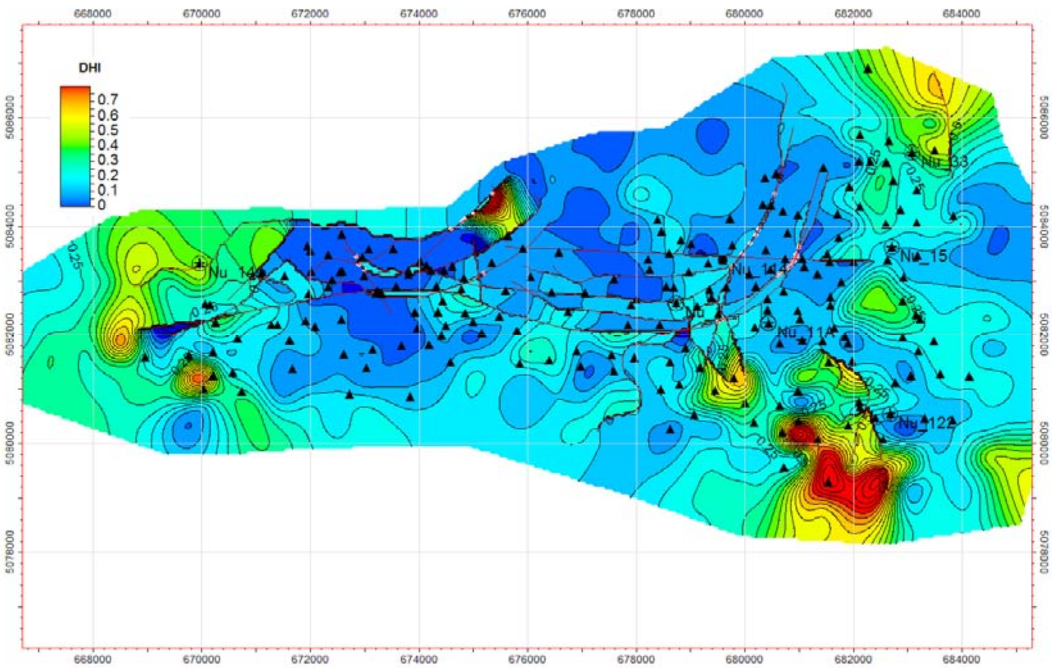


Fig. 9 Map of spatial distribution of hydrocarbon accumulation in the Nurzhanova Field. Color scale represents direct hydrocarbon indicator, as function of cumulative net oil pay zone thickness.

RESERVOIR MONITORING

Tens of producing wells were checked as regarding the IPDS survey findings versus production data as an approach for reservoir monitoring. The calculated net oil pay zone thickness (NOPTZ) for the great part of the checked wells in the studied area is in a satisfactory agreement with the production data provided by the field operator (compare figures 8 and 10). However, for some wells located directly in heavily faulted zones, the NOPTZ does not match the production data. This situation would be analyzed and clarified in the following section.

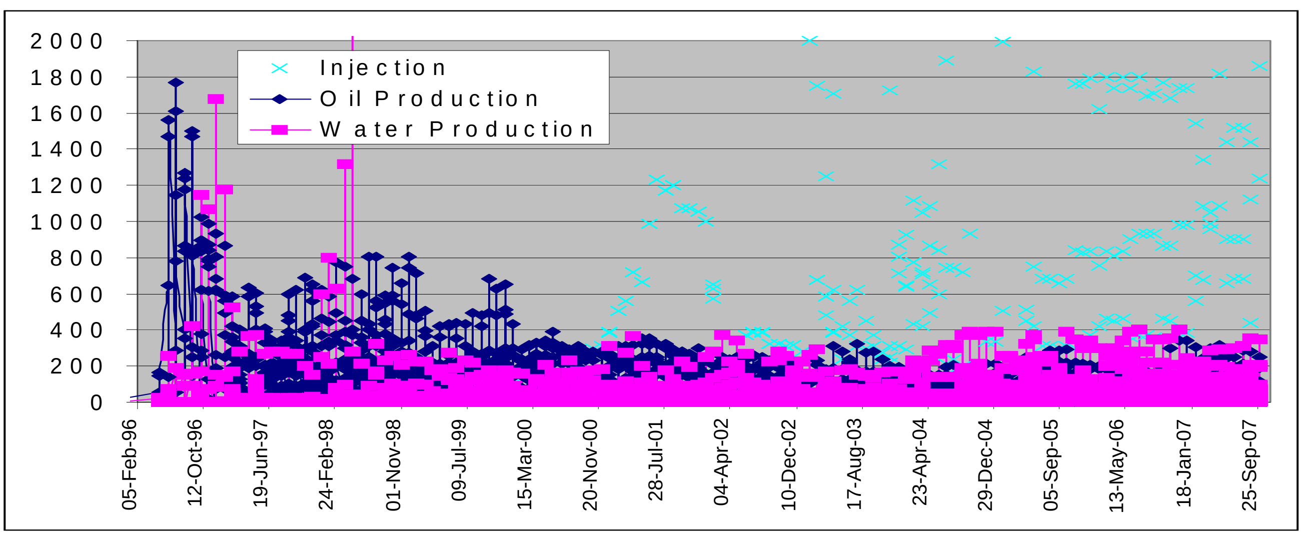


Fig. 10 Production history of Moldabek field. It is well seen in this figure that these fields are producing mainly water and are depleted to great extent since 2000. This fact is perfectly matching the pattern of hydrocarbon spatial distribution as revealed by IPDS survey (Figures 8 and 9). The lasts show that the studied fields are mainly presented in blue color reflecting prevailing water cut production rather than oil. Oil and water production data are expressed in tons.

Here we provide as an example the correlation carried out for the CVP_105 well in the Nurzhanova field (Fig. 11). The CVP_105 well occurs at the peripheral of an important oil-bearing zone but slightly touching a faulted zone as shown on the IPDS map here (Fig.11). Its production history shows two long interruptions: 1964-1970 and 1982-2000. The average production rate from 2000 up to day makes around 250 T/M. This situation could be considered as confirmation of the field production data to the IPDS results.

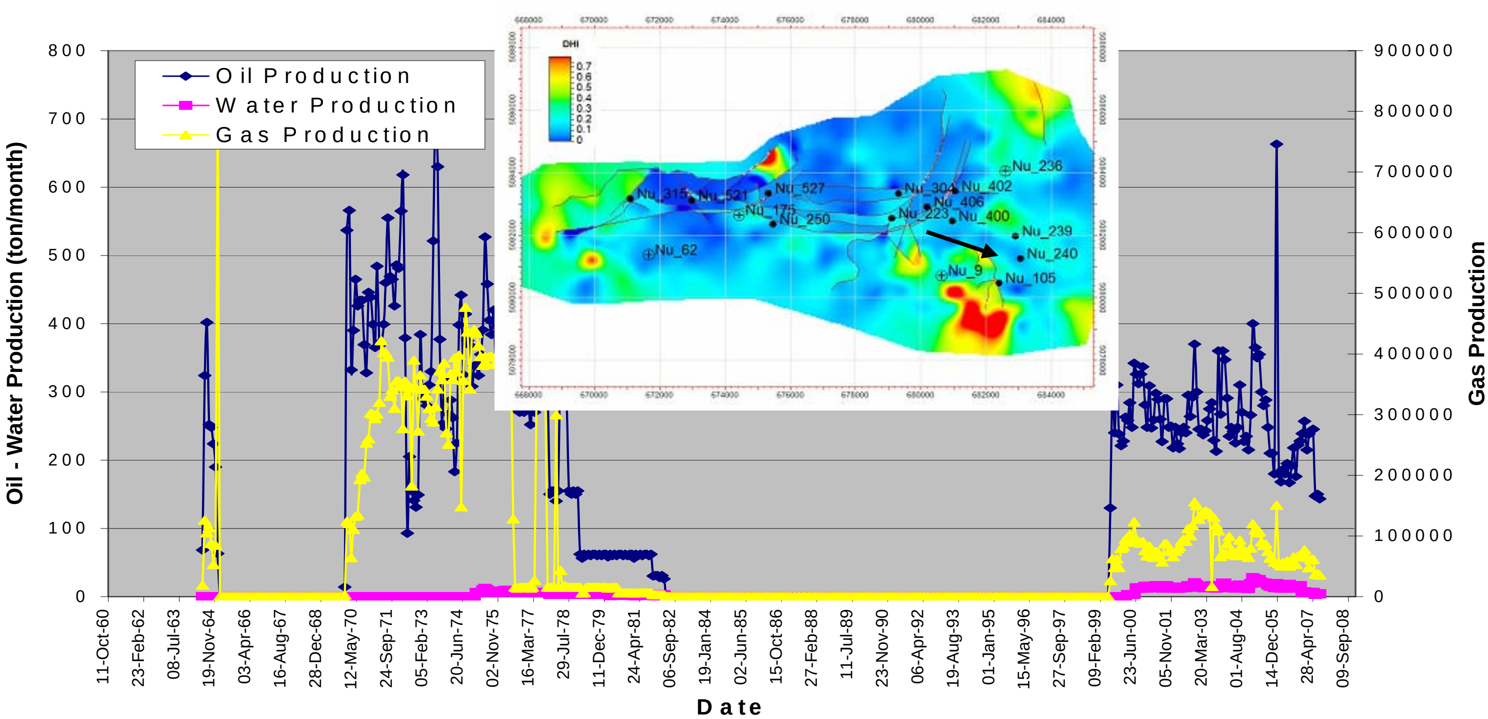


Fig. 11 Correlation of production data and IPDS survey results for well CVP_105:J3_II-CE-1. Oil production data are expressed in tons; gas production data are expressed in M^3

RESERVOIR MONITORING CHALLENGES: DISCUSSIONS

A. Pressure features

The most obvious evidence of reservoir compartmentalization is possibly the observation of different pressure decline trends in different wells, or groups of wells. Figure 11 shows an example, relative to some pressure history during the exploitation of the fields studied.

It can be noticed that most of the wells follow a different pressure decline trend with respect to the others. The geophysical interpretation of the area showed a complex system of intersecting faults, with 3 major visible trends, E-W, NE-SW and NW-SE fault blocks in both Nurzhanova and Moldalbek fields, thus proving that the separating faults are scaling. The exception of the some wells that follow the same decline trend should also be noted, which indicates that in fact not all the faults are sealing.

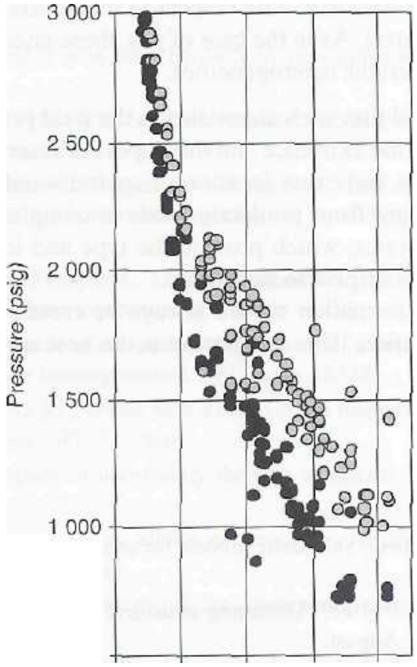


Fig. 12 Pressure decline trends in the presence of a stratigraphic boundary

Reservoir compartmentalization is illustrated in the figure, which shows the pressure data collected during the over 40 years of production history of fields. Here, <u>after a few years of rapid pressure decline, data start grouping into two distinct families, which follow different trends.</u> This pressure behavior was unexpected and the subsequent revision of the stratigraphy of the area, highlighted that a zone of thinning of the reservoir was present in the region between the two main areas of the Moldabek and Kutertas field at least. It is to be concluded that, even though no wells had tapped a completely shaly section, a stratigraphic boundary had to exist in order to justify the observed pressure behavior.

The described pressure history development complicates not only the hydrocarbon drainage features during the field's exploitation but also the hydrodynamic equilibrium in the fields, which in turn affects considerably the Geospectra IPDS survey. <u>This situation explains some cases of inconsistency between field production data and IPDS results.</u>

One more feature that can be noted is that the pressure difference between the various fault blocks can be significant, which proves that the scaling mechanism is extremely strong. In other contexts, the sealing potential of the faults could be overcome by the pressure differentials imposed by the viscous forces related to production. <u>This very important circumstance affects considerably the hydrodynamic equilibrium within the field and consequently the IPDS signals involving thus some inconstancies between the field production data and the IPDS survey results</u>

B. <u>Oil rate, water cut and gas/oil ratio (GOR)</u>

All the commonly recorded production parameters are related in some way to the prevailing average pressure and saturation conditions in the reservoir. Therefore, even in the absence of direct pressure measurements, parameters like oil and gas rates, water cut, and gas or condensate oil ratio can be used to infer information about reservoir compartmentalization.

The use of this kind of data is in some way obvious, however attention must always be paid to accurately distinguish the behavior of the reservoir from anomalies related to well completion problems. The following typical field performance may flag the existence of reservoir discontinuities:

- *Hydrocarbon rates* Declining rates; observed in many clustered wells may be the consequence of a declining average pressure level, related to an isolated compartment. Such situation affects again the hydrodynamic equilibrium trends of the field depending on the compartments features, architecture and structuration in terms of the general reservoir trends, and subsequently the IPDS signal.

- *Gas-oil ratio (GOR)* Rising GOR's, not in line with the general field trend, may be due to the depletion of isolated portions of the reservoir, where the pressure has fallen below the bubble point. This fact is well reflected in the contrasted features of our IPDS map where it is clearly seen the different color-scaled compartment in the fields and testifies in favor of the accuracy of our results though some apparent inconsistency with production data. Likewise, early gas breakthrough in the producing wells may be related to the existence of high permeability paths.

- *Water cut* Water breakthrough may happen early or, conversely, with significant delay in some parts of the fields, with respect to the general advance of the water front (aquifer or injected water). As in the case of gas, these anomalies are frequently related to the existence of reservoir heterogeneities. Lasts are omnipresent in the studied fields; they are well reflected in the contrasted and discontinued features of the production history and in turn amplify some false inconsistency again between production data and IPDS results.

Finally, it should be noted that such anomalies in the field's production performance allow us to ascertain the existence and the impact of reservoir heterogeneity, but does not permit the identification and exact location of such discontinuities. From this point of view, the information coming from production data is complementary to the one derived from static data like geophysics, which provide the type and location of the heterogeneity but not its effectiveness with respect to fluid flow.
Therefore, production information should always be cross-checked and integrated with independent source information. This integration is the best approach to a real effective reservoir characterization.

At the microscopic scale, the water-oil relative permeability is by far the most important factor, since it defines the relative mobility of the 2 phases at various saturation conditions, as well as the residual oil saturation for a water flooding process. Important properties like rock wettability are also strongly related to the microscopic displacement process. The microscopic efficiency also defines the highest recovery factor attainable for a water-oil system, in the case of 100% volumetric displacement efficiency.

At the macroscopic scale, represented by the areal and vertical displacement efficiency, the most influencing factor is reservoir heterogeneity. Large-scale reservoir features like shale streaks, faults, and fractures and in general all those features that represent barriers or, conversely, high conductivity paths to fluid flow impair the homogeneity of the displacement process.

To conclude, all the internal dynamic changes in reservoir features especially those related to pressure evolution, reservoir heterogeneities, oil/gas ratios, water cut displacement, fluid physical behavior are all affecting the reservoir hydrodynamic and geodynamic (related to charge change) equilibrium. This is a fundamental key conditioning the IPDS signals. Geological features such as faulting, fractures, dislocations, lithology, stratigraphy and others should be also taken into consideration. Consequently, production information should always be handled with great care, cross-checked and integrated with independent source information particularly when correlating them with such sensitive and physically sensed criterion as the IPDS signals. This is the best approach to a real effective reservoir characterization.

C. Reservoir dynamic features

All these factors are playing major roles in the production history of the studied fields and some times they are obscuring the real picture of hydrocarbon accumulation and evolution in the fields under study and thus the production data should be handled with attention while correlating them to the IPDS result.

The abrupt, discontinuous and fluctuation in hydrocarbon and water cut output in the production history of many wells is rather due to internal phenomena and features described above or external production specifications like production regulations (such as pressure manipulation at the head of a well including production stop and restart, water injection activity or drilling in a surrounding area….).

It is obvious that production discontinuous and contrasted history reflects the occurrence of significant events whatever their nature was. The influence of these events on the hydrodynamic equilibrium of the field and consequently on the IPDS measured signals is obvious. A big issue is that we do not know exactly which kind of events was taking place: was the interruption/restarting due to well closure by the field authorities and for which reason? Or, these events were due to internal to the field factors: reservoir heterogeneity, reservoir damage, plugging, changing perforation, well reparation, hydrodynamic features and others.
These possible events and reservoir behavior in the production history are necessarily to be taken into consideration for any correlation between production data and IPDS results.

FAULTING SYSTEM AS GEOLOGICAL BODY: A MODEL FOR DEVELOPMENT OF LARGS SCALE BRITTLE BREAKDOWN AND SEISMIC IMPLICATIONS, INCLUDING LOW-FREQUENCY DOMAIN (IPDS SURVEY)

A new physical model is suggested. Structural material transformation into deforming fault body is analyzed. This model includes a breaking up and faulting dilatation of fluidizing rock by shearing deformation and also fast dehydration reactions. These processes create a heterogeneous structure of fault body as combination of soft and strong domains. Strong decreasing of mylonites rock and increasing of heterogeneous stress are factors of both micro- and macro-seismic instability of the fault body.

Tectonic stress and the fluid pressure occurring in the fractured-porous rock on the earth seismicity, including the earthquakes are of determining role. Of particular influences is that the magnitude of the seismic phenomena is directly linked to the linear extension of the fault involved.
However, a fault is not simply a contact surface of two adjacent geological blocks. A fault in itself is a 3D geological body, considerably distinguishing from surrounding consolidating blocks not only by structural features but also by material composition.
The rocks of faulted systems present some kind of modification of mylonite rocks which is not a result of mechanical wear of grains but a consequence of their re-crystallization – dispersion taking place in the dislocation zone in the conditions of high fluid content, very proper for faults. Rock dispersion and dilatation processes, as well as fluid pressure change take place on the background of physical and chemical change of the fault’s rock material. Last changes are determined by rock metamorphic transformations which occurre in the conditions proper to faulted systems and changes are governed by other rules specific to traditional petrochemistry.

High levels of deviation strain as well as high all-around tectonic compression lead the mineral crystal lattice into activated state, which promotes the transformation of the mechanical energy directly in chemical one. In these conditions of immediate fluid jet in the porous space, such processes induce a sharp change of fluid chemical composition and medium electrical resistance as a source of electromagnetic emissions. These emissions are themselves depending on electrical, electromagnetic and radiometric fields.

All these features could perfectly explain how the typical IPDS signal for porous reservoir matrix saturated with hydrocarbon accumulations would be disturbed, at least partially, in a faulted zone. The IPDS signal is determined as a result of transformation of mechanical energy emitted from elastic vibration of external natural field in low frequency range into acoustic energy. However, in a faulted medium the typical mechanical energy or at least a main part of it is transformed to chemical energy as it was demonstrated above.

During the realization of high-rate dehydration reaction in a tough inclusion zone, the initial kinetic impulse induced by plastic and quasi-plastic deformations could involve brittle destruction of the nearest ordered and energetically saturated domains. If this process of brittle destruction would extend to other neighboring ordered domains then it could lead to creation of an *expanded seismic break*. Another variant of continuation of destruction process of tough inclusions could be the ceasing of break development with its intrusion in soft inclusion domain of great volume

The development of destruction process due to spatial heterogeneities of faulted zones determines these domains as zones of meta-stable state.

So, finally we could conclude that in the faulted zones rocks are subjected to a lot of various structural, physical and chemical transformations inducing formation of both soft and consolidated zones and thus creating additional heterogeneities. The main trend is that we have generally a disintegrated and decompacted area within the faulted blocks owing physical, chemical and structural features completely different from those in the surrounding environment. This situation implies necessarily different medium for the seismic behavior of the area in general and for the IPDS signals of low frequency range in particular with increasing of heterogeneous stress as factor of both micro- and macro-seismic instability of the fault body.

CONCLUSIONS AND RECOMMENDATIONS

The IPDS technology:

1. The IPDS technology is to be considered as outstanding technology for the direct detection of HC accumulations independing of the trap type: structural or not.

2. This technology is also an efficient tool for reservoir monitoring

3. Economically, The IPDS survey is less expensive for an order of magnitude as compared to 3D seismic survey for the same territory. However, the IPDS is to be handled as a complementary tool to the geophysical investigations, rather than an alternative approach.

4. The IPDS technology could appear as efficient tool to evaluate the remaining HC potential to be subjected for any enhanced oil recovery project.

The IPDS findings regarding the Pre-Caspian fields

1. The correlation of the Geospectra IPDS results with the field production data testifies in general of enough satisfactory output of the fulfilled IPDS survey in Moldabek, Kutertas and Nurzhanova fields. The production data fits well with the IPDS findings for the grand majority of wells as it was demonstrated in detail for all the wells for which we were provided with production data.

2. One of the biggest finding is that the IPDS survey discovered a big area to the south of Moldabek and Kutertas fields with huge hydrocarbon accumulations. The discovered hydrocarbons are occurring in Mesozoic (Cr, J, T) and/or Paleozoic (P-T, C, D) sub-salt horizons, being mostly promising.

3. Also the IPDS survey brings in force the presence of three major important hydrocarbon-bearing areas to the east, to the northeast and to the southeast of Nurjhanova field. Other less important areas inside the Nurzhanova field are also brought in force, where there still oil and gas accumulations in other non-exploited Jurassic and /or Triassic horizons.

4. Moldabek field looks as being almost depleted.

5. Nurzhanova Field looks also depleted to large extent but still have more important oil and gas potential as compared to Moldabek field, as it is shown on the IPDS maps.

6. There is apparently some inconstancy between production data and some of the IPDS results. A number of wells, particularly in Nurzhanova field appear in the water zone of the IPDS map while production data show that there still some production even that one could note a dropping trend of hydrocarbon production rates in many of these wells.

A careful examination of the geographic location of the wells in question shows clearly that almost all of these wells are located directly in a faulted zone or they are somewhere very close to the faulted zone. This situation was well analyzed and clarified on the basis on seismic (including low-frequency/acoustic) instability in the faulted zones.

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