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INFRASONIC PASSIVE DIFFERNTIAL SPECTROSCOPY (IPDS) FOR DIRECT DETECTION OF HYDROCARBONS IN EXPLORATORY, PRODUCTION AND DEPLETED FIELDS

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ABSTRACT

Infrasonic Passive Differential Spectroscopy **(IPDS)** Technology was developed in 1995 for detection and monitoring of hydrocarbon deposits for the first time in the history of petroleum Industry. This technology is based on the principles of non linear behavior of fluid systems in porous media. Hydrocarbons in the pore system of reservoirs can be detected as a characteristic deformation of the natural, omnipresent earth noise spectra in the low frequency range between 0.2 and 10Hz. These low frequency seismic signals are recorded at the surface with ultra high sensitive seismometers. The signals are spectroscopically analysed to produce a unique spectral signature which is used as a **direct hydrocarbon indicator**. IPDS has been applied successfully in almost 100 survey campaigns in variety of geological and environmental situations. This is an illustrative tool with high value of information content because it directly indicates the presence of hydrocarbon. It identifies the locations for wild cat wells, delineation wells with greatest chance of success and **drastically reduces the risk of drilling dry wells**. This technology can be integrated into existing seismic data for a better understanding of a potential hydrocarbon accumulation. It is also used for delineation of hydrocarbon pools, identification of oil water contacts and flood fronts for development of a discovered oil field. In a producing field, IPDS is a unique **monitoring tool** because it can detect the presence of movable hydrocarbons, water coning areas and by pass zones. In abandoned fields or in noncommercial fields, this technology can identify the volume of left over oil. This is particularly useful in assercerta-in the **present oil content in old and depleted fields.**

INTRODUCTION

Low frequency Acoustic Spectroscopy, as a scientific principle is well known and has been established in different research fields over the last decades, especially in different military, medical and seismological applications. This science is also the most popular method and frequently used for recording natural events in the earth hazard prediction and Vulcanlogy. In 1995, a small group of scientists, converted the experiences from military industry to oil industry, to apply low frequency acoustic spectroscopy for direct detection of hydrocarbons in the subsurface reservoirs. During the initial experiment in 1997, for the first time in the history of oil industry, it was discovered that, on top of an oil reservoir, the natural earth noise spectra show an increase of magnitude in the frequency range between 0 and 6 Hz. This increase is accompanied with the appearance of several spectral lines. The identification of this phenomenon was subsequently, developed as Infrasonic Passive Differential Spectroscopy (IPDS). This technology is based on the principles of non linear behavior of fluid systems in porous media. Sedimentary rocks contain an enormous variety of microscopic structural features that consist of different size of mineral grains. These grains are bonded in contact with each other in a totally disordered form. Most reservoirs rocks have inter granular cracks and voids, each with different elastic property specific to its own composition. This unique property, of the elastically nonlinear

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behavior of the sedimentary reservoir rocks, where new frequencies are generated that were not present in the primary signals, is effectively used to detect the in-situ reservoir contents. An oil reservoir is such a nonlinear element but with low pass filter characteristics. It is nonlinear only below approx 8 Hz. As a result, the higher incoming frequencies are converted in the reservoir into lower frequencies. These low frequency waves are slow, very slow and it is assumed that the velocity might be below 500m/ sec. Because of their wave length, these are not reflected or refracted from any inhomogeneity in the lithology and so are not absorbed. The signals which are recorded in IPDS, are generated by conversion in the oil reservoir because there is no other multifluid system existing in the reservoir. Traditional seismic methods do not solely depend upon passive, low frequency acoustics and use higher frequency, generally above 20 Hz. Hydrocarbon in the pore system in the reservoir rocks can be detected as a characteristics deformation of the natural earth noise spectra in the low frequency range between 0.2 and 10 Hz (Figure.1). These low frequency seismic signals are recorded passively at the surface with ultrahigh sensitivity seismometers. The signals are spectroscopically analysed to produce a unique spectral signature which is used as a direct hydrocarbons indicator. This method is called 'Passive Technology', because no artificial technical source like vibrator or explosive is used. However, there is a source, and the source is omni present natural earth noise. This seismic acoustic background noise which can be recorded at every location around the globe, is a noise with characteristics spectral peaks at 0.1 – 0.2 Hz caused by the standing waves of the ocean (Aki and Richard, 1980) and by the eigenmodes of the terrestrial crust (Suda et al, 1980) in the millihertz range. The converter response of the reservoir is registered by an ultra sensitive seismometer on the surface.

The patents for the above innovations have already been approved in the US and Europe.

METHOD

Specially designed seismometers are used for recording the low frequency noise. The seismometer is based on the electrodynamics principle and has a proprietary 'inverse loop' magnetic system with an extremely high magnetic influx to avoid any influence from external magneto dynamic fields. (Figure.2). The acoustic recordings acquired in the field are processed through signal processing, cleaning and filtering. The method applied is known as IPDS (Infrasonic Passive Differential Spectroscopy). The recorded signals are transformed from time domain to the frequency domain where spectral signatures are analysed. Usually, 12 spectral lines are picked up after careful preliminary analysis of the spectral signatures of all the recorded points. At the end, a Reservoir Hydrocarbon Index (RHI) map is prepared from the analysis of these spectral lines. This map portrays the hydrocarbon content at each measured data point.

IPDS has been applied successfully in almost 100 survey campaigns in variety of geotectonic conditions. This is an illustrative tool with high value of information content because it directly indicates the presence of hydrocarbons. Since the source of the sound is from the crust of the earth, this technology works effectively in any geographic location, geological condition, or tectonic setup, and independently of lithological barriers (below basaltic rocks, coal beds or intrusive) and environmental limitations.

RESULTS

Exploration & Delineation:

Small lease holding oil companies that cannot afford costly seismic surveys to ascertain the oil potential of their acreage, resort to IPDS technology. In such cases, the key task is not to drill a dry hole. In one such case, as in West Texas, no precise data were available except the position of a dry hole and a producing well (Figure. 3). IPDS technology was executed in this field. The Reservoir Hydrocarbon Index map, indicated the presence of a number of independent oil pools. The wells drilled on such identified oil prospects, produced oil @ 80 bopd and 150 bopd.

An IPDS survey was recently carried out in an oil field of Cambay basin of India for locating delineation wells. Delineate of this field was riddled with many uncertainties. These uncertainties involve the limitations in the display of reservoirs in seismic sections, undecipherable reservoir trends, inconsistent petrophysical characters and uncertain structural disposition. The reservoirs are overlain by thick horizons of coal, coal-shale intercalations and underlain by basaltic rocks. A new well drilled just 20 m from an existing old well, recorded the presence of an additional oil bearing horizon. The evaluation of all the existing data could not justify the necessity of any additional delineation or development well. Under these limitations, IPDS was carried out to ascertain the petroleum content of the field. The RHI map prepared from this survey, shows the oil content at different locations. The maximum oil content is shown in red colour indicating a RHI value of 1 and no oil in white colour indicating a RHI value of 0. This map showed close correspondence with the tectonic alignment and structural trend of the oil field. The south eastern part, indicated the presence of only marginal oil, which is corroborated by the presence of a depleted well at this place. The oil water contact is also located close to this well. The survey also revealed the presence of oil in the northern portion of the area. This was confirmed by the presence of flowing oil wells. The survey further displays that, the accumulation of oil increases towards the western part. A transition area, containing a thin rim of oil is present in the western limb of the field. The RHI map delineated the oil bearing limit of the field and indicated the present status of the existing wells. It was concluded from this survey, that this oil field has limited areal extension and does not contain much additional oil. More wells may not be needed to drain out the existing oil from the field. The survey saved the cost of drilling of an envisaged additional well in this field.

The most significant feature of the RHI map is the identification of a prospect, located about1 Km. west of the oil field. The oil accumulation area may be much larger, extending towards northwest. The IPDS survey further indicated the presence of considerable amount of oil in the west, south and north west of the field. Such oil accumulated areas are confirmed by the presence of existing oil wells (Figure. 4).

IPDS in virgin areas as a precursor to seismic survey:

On the basis of regional geological setups, many unexplored areas are initially identified to have some petroleum potential. In such areas, an IPDS survey in the commencement of exploration stage, can locate the prospective areas that may contain oil. Before carrying out a conventional and costly regional seismic survey, it is economical to execute an IPDS survey in a wider grid to identify the area of interest. 2D or 3D seismic surveys, if necessary may be carried out subsequently, in the prospective areas. Further, in areas where, conventional seismic surveys cannot be conducted due to intense urbanization, it is best to resort to IPDS survey. Example of one such situation is the exploration in an area of U.A.E.

The acreage is located between two well explored areas. The terrain to the NW contains many gas fields and the areas in SE have giant oil fields. However, this intervening area is presently under intense urbanization. No Conventional seismic survey is possible in this area. Only a gravity map of the area was available. This gravity map shows the presence of a N-S oriented high with possible presence of some faults in NE –SW direction in the north western portion of the area. Another small gravity high is also observed near the northeastern portion. The petroleum potential of this area was unknown.

An IPDS survey was conducted initially over the entire area. Three major prospects were identified from the survey. (Figure. 5). The RHI map prepared from IPDS shows very good correspondence with the tectonic configuration, revealed from the gravity map. The RHI map shows presence of another fault in the eastern side of the block, aligned in NW –SE direction, separating the central prospect from the northeastern prospect. Another N-S trending prospect in the eastern part of the area was also depicted from the IPDS survey. The subsequent IPDS survey was conducted in detailed scale with closer grid. This survey further confirmed the spread of the petroleum prospects and delineated the oil containing area. (Figure. 6). The regional alignment of the prospect together, reflect a NE –SW orientation. This prospect is restricted in the SE, by a NE-SW aligned fault. Further, this prospect is located between two lows, one in the SE and the other in the NW. These lows may be the depressions containing adequate source rock. The overall configuration, indicates, excellent petroleum potential of this prospect.

Identification of drilling location after initial seismic survey:

The seismic map reflects a ESE –WNW aligned structural high with associated lows in the south and north (Figure.7). A well, drilled in the NW part was abandoned as a dry hole. Another location was released in the crestal portion of the structural high. However, before drilling the proposed well, the Company carried out IPDS survey to confirm the correct position of the proposed hole.

The RHI map from IPDS indicated the presence of a number of independent oil accumulation centres. The overall trend of these centers is in NE –SW alignment. It was further revealed that the proposed location(BH-2 old) falls in a non prospective area. A new proposed location(BH-2 new) was

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subsequently identified for drilling (Figure. 7). The RHI map additionally reflected that the area is affected by a number of fault blocks. A new prospect viz. Hanifa potential was discovered from the IPDS survey (Figure. 8)

Monitoring of Petroleum Fields:

In another task to monitor the shift of a gas water contact(GWC), the IPDS measurements were carried out in a gas field of UAE. The initial RHI map prepared in 2001, showed the gas bearing areas of the field and the existing (GWC) at that time (Figure. 9). The map revealed that the central portion of the area contains most of the gas. Gas accumulations were also observed in the western, eastern and northern part of the area. The southern part of the area was devoid of any hydrocarbons. These revelations were confirmed by the actual status of the wells. In order to monitor, the present condition of the gas bearing wells, another IPDS survey was conducted after 3 years, in 2004. The survey indicated the progressive GWC from the East to the West. It additionally confirmed the presence of remaining gas bearing areas over the field (Figure. 10).

Finding more oil in abandoned & depleted fields:

Two oil fields located in Caspian region were surveyed with IPDS technology to find out present oil content in the depleted and partly abandoned fields. Caspian oil and gas bearing provinces are generally hosted by extended salt dome structures as well as persaline deposits. The HC fields generally consist of multiple vertically separated horizons. Both the fields Surveyed, are well explored but are presently considered to be depleted. These are penetrated by more than 200 production and injection wells. Further field developments with new wells remain a major challenge, despite the fact that many of the reservoir units, depositional facies and production parameters are already relatively understood.

The resultant IPDS RHI map indicated that for field A (Figure.11), the oil is swept almost completely in the central part of the field contrary to the east sides of the field. On the east side, a local variation of the RHI map indicates the difference of hydrocarbon occurrence based on variation in local depletion. The major portion of the eastern side of the field is almost totally depleted. This finding was confirmed by the Operator Company from the current production from the field. In the north eastern side of the field, because of high density of wells, local lateral depletion can be observed. Two areas in this area are not depleted completely as seen in the IPDS map. To the south east part of the field, a large area with high IPDS values can be attributed to the presence of HC in “a stratigraphic trap”. The existing wells were abandoned after these failed to produce oil from the shallower horizons . Further, these wells were not drilled deep enough to penetrate the lower Triassic pay horizons . As a result , this high potential area remains unexplored. The Operator explained that in the early life of the field, it was not expected that the Triassic would have productive zones. However, the Company has now started to produce oil from the Triassic in that area with good daily production rates. The higher values in the north western part of the field also indicated presence of significant amount of oil. This area is presently abandoned, after depletion of many wells. The Operator confirmed that Triassic horizons might have HC which have not been investigated before.

For field B, the IPDS map (Figure.12) shows very good correspondence with the actual location of the oil producing and water injection wells. The prospective area, containing oil is found in the eastern area of the survey; where as the lowest values are concentrated in the central part of the field. These observations were confirmed by the Operator Company.

In this area, salt tectonics is the main element responsible for the creation of geological structures. The IPDS survey results strongly indicate that, the surrounding area of the main salt dome of the field B structure has good petroleum potential. In the south and south east of the structure, there is a great potential in the sub-salt formations. Conventional seismic methods in such complex structures would be very costly. Several costly and deep wells would be required to prove the hydrocarbon accumulations in the sub-salt reservoirs in the periphery of this field.

CONCLUSION

Passive low frequency seismo acoustic spectroscopy (IPDS) has been proven in more than 90 projects, worldwide, to be a reliable Direct Hydrocarbon Indicator Technology. It is complementary to traditional geological and geophysical exploration methods. The passive nature of this technology opens new dimension of information. This technology is extremely flexible and environmental friendly. It reduces the cost and risk both in exploration and production. At the current situation of world wide energy aspects, the most pertinent thing is to reduce the risk in exploration, because the 'easy' reserves are already discovered. The most pertinent function is to achieve growth in reserves, in explored and producing oil fields. For this purpose and under all relevant aspects, passive acoustic spectroscopy like IPDS seems to be the most effective exploration and monitoring tool. It is effective in green field delineation in virgin areas, exploration to locate most prospective drilling location, field development for the delineation of the hydrocarbon pool, identification of oil water and gas water of contacts, oil field monitoring and finding more hydrocarbons in depleted – abandoned fields.

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REFERENCES

Aki, K. and Richards, P.G. [1980] Quantitative Seismology, Theory and Methods. Freemann.

Akrawi Karim , Ernst D. Rode [2007], Application of Direct Hydrocarbon Indication based on Passive Seismic (IPDS) Surveys In Middle East, Petrotech-2007,New Delhi, India, Abstracts vol-2, P 30

Biot, M.A. [1956] Theory of propagation of elastic waves in a fluid-saturated porous solid – 1. Low frequency range. J. Acoust.Soc.Am., 28, p168-178

Dangel, S. et.al. [2003] Phenomology of tremor-lie signals observed over hydrocarbon reservoirs. Journal of Volcanology and Geothermal Research, 128, p135-158

Earnst D. Rode , Passive Seismic ,Simposio Brasilerio de Geofisica, Simposio Brasilerio da SBGF, Natal 21-23, de setembro de 2006.

Khan Tawassul , McGuire Sofia , Elastic Nonlinearity measurements help map permeability, pore fluids,Oil and Gas journal, July 15, 2002, p 32

Lesurf Jim, Mixer diodes Coherence, University of St. Andrews, fife KY 16 9SS, Scotland Mukherjee M.K., E.D. Rode, Singer J.M.,[2002],ADNR Explorer : Acoustic detection of hydrocarbon reservoirs , Society of petroleum geophysicists on 4th Conference & Exposition on Petroleum Geophysics ,Mumbai ,India p302

Serdar Kaya, Ernst Rode, Dylan Kier, Integrated Application of Passive Seismic Technology For Trapped Oil Detection in Mature Fields and Hydrocarbon Discoveries in Adjacent Compartments, 19-22 November 2007, 10th International Congressof the Brazilian Geophysical Society, Rio debJaneiro, Brazil.

Singer J. et.al [2002] Spectroscopic identification of tremor phenomena over hydrocarbon reservoirs. EAGE 64th Conference & Exhibition – Florence, Italy, 27-30 May 2002

Suda, N., Nawa, K.,Fukao, Y., [1998] Earth's background free oscillations. Science 279, p2089-2091

Westervelt, P.J.[1963] Parametric Acoustic Array. The Journal of the acoustical society of America, Volume 35, Number 4, p535.

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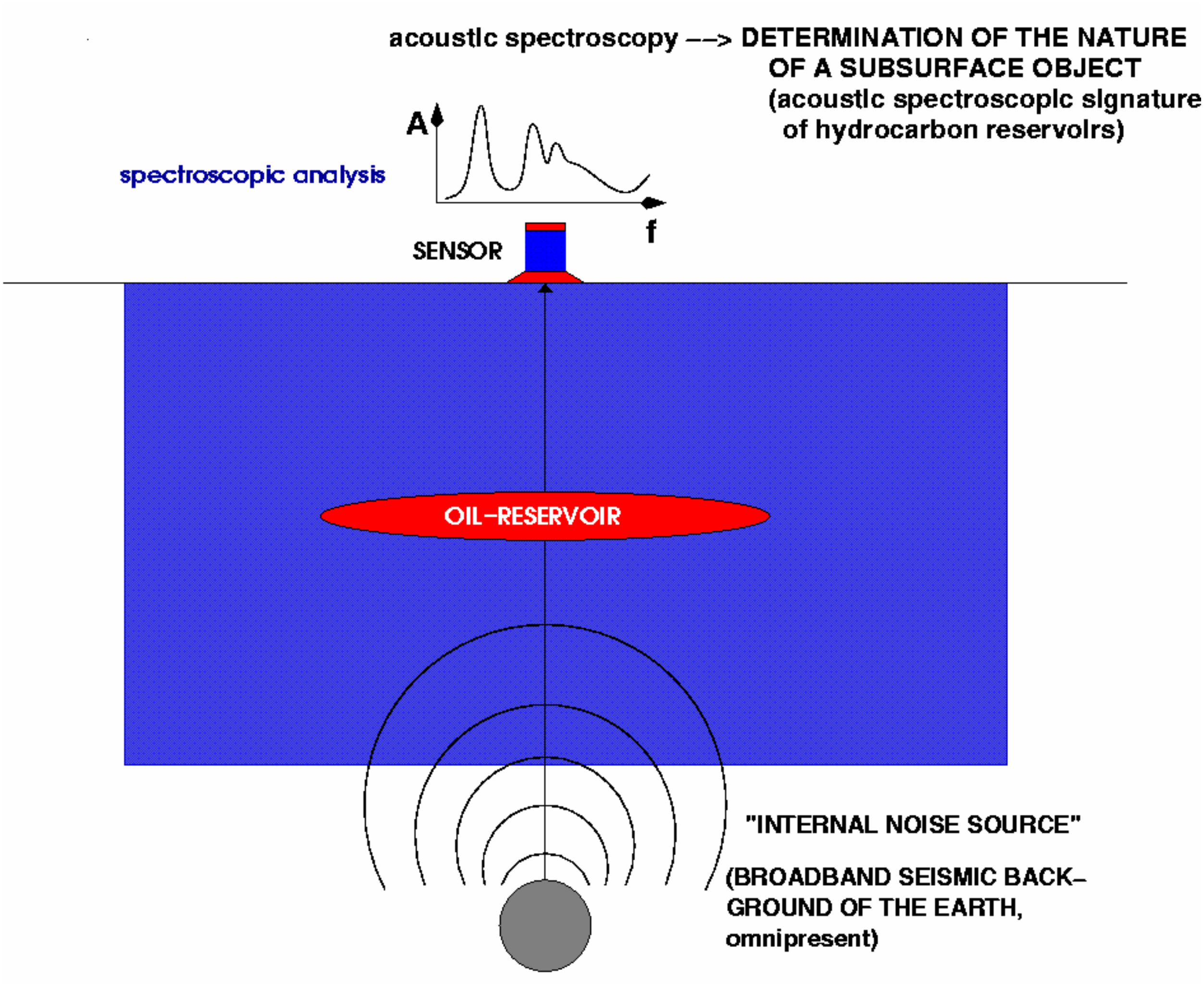

Figure 1 – Schematic presentation of Spectral Signatures of a subsurface reservoir

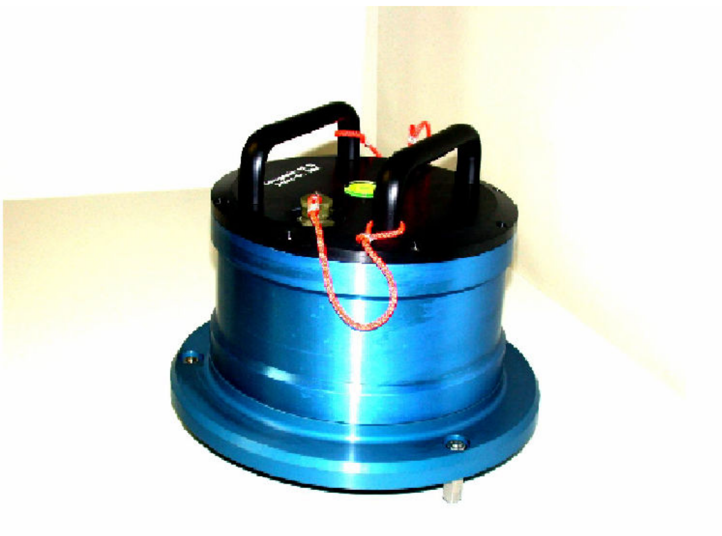

Figure 2 – Passive Seismic Seismometer

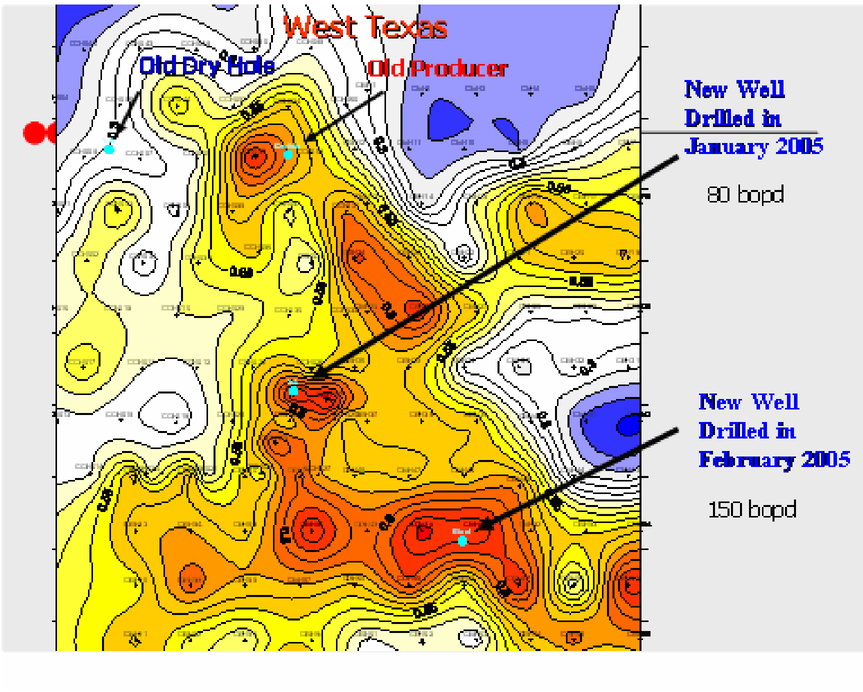

Figure 3 – IPDS survey over West Texas (After E.D. Rode)

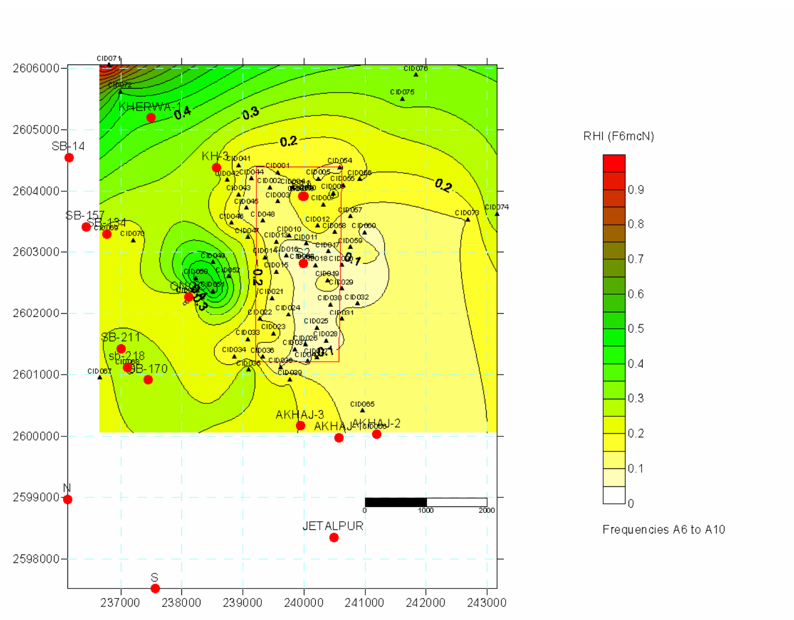

Figure 4 – Hydrocarbon Index Map, Sanganpur, Cambay Basin, India.

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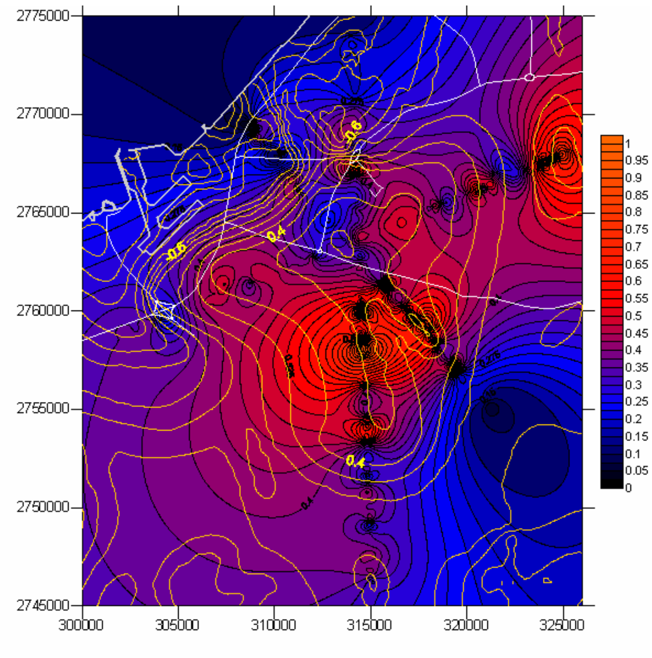

Figure 5 – Hydrocarbon anomaly map, UAE (After E.D. Rode et al.)

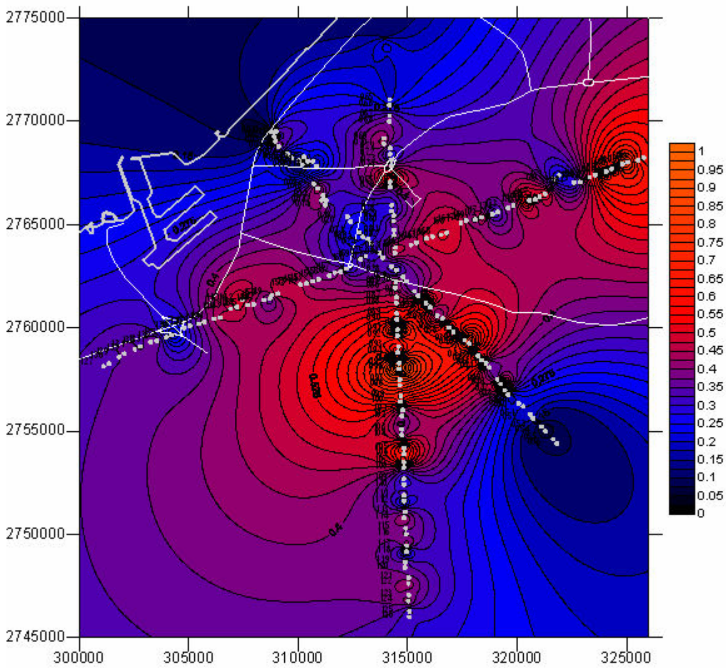

Figure 6 – Petroleum propects identified from IPDS, UAE (After E.D. Rode et al.)

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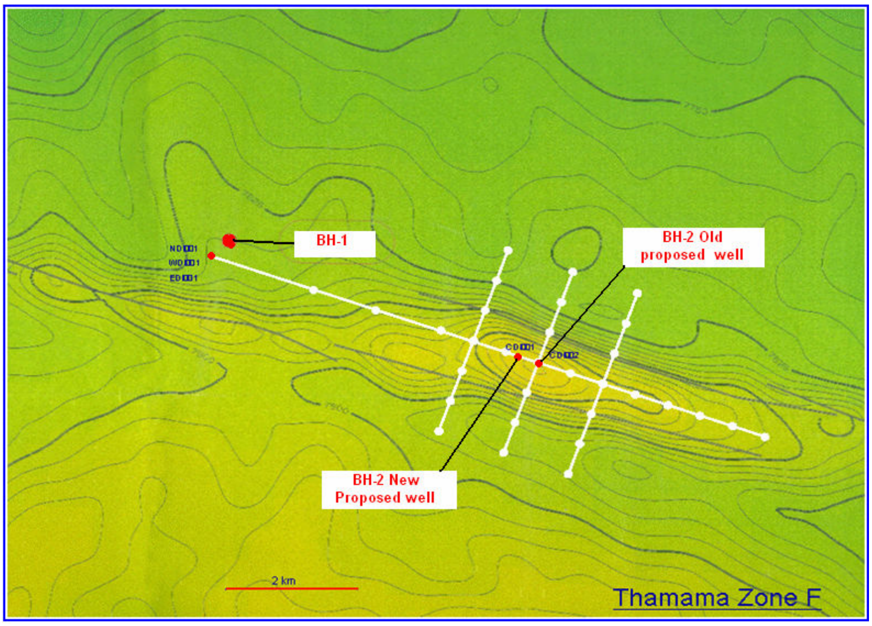

Figure 7 – Identification of drilling location through IPDS survey (After E.D. Rode et al.)

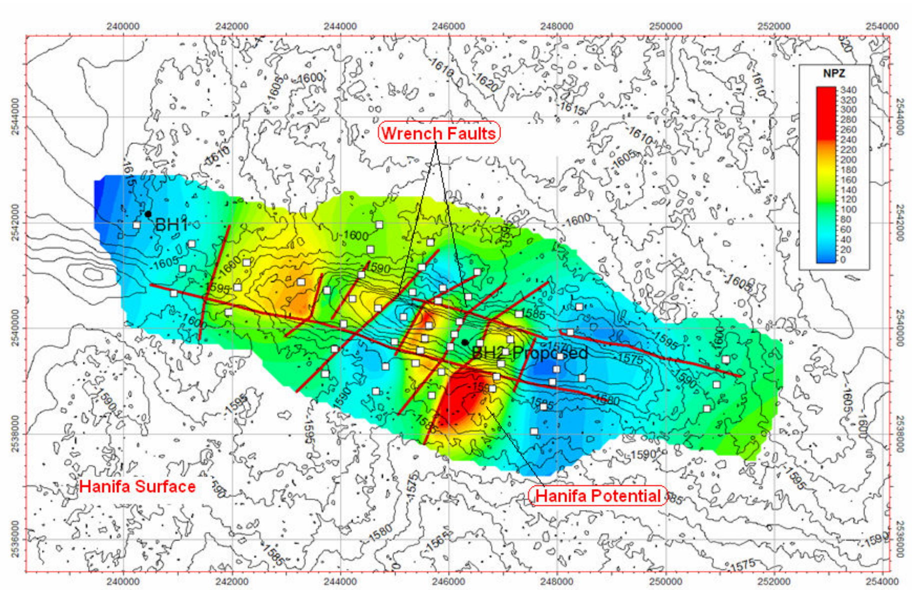

Figure 8 – RHI map showing Wrench Faults and Hanifa Seismic structure (After E.D. Rode et al.)

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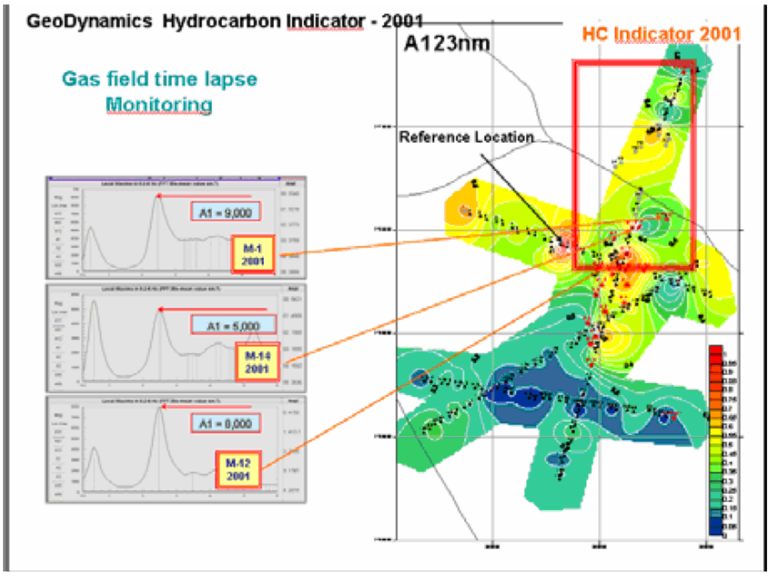

Figure 9 – Hydrocarbon indicator map, a gas field, UAE (After E.D. Rode)

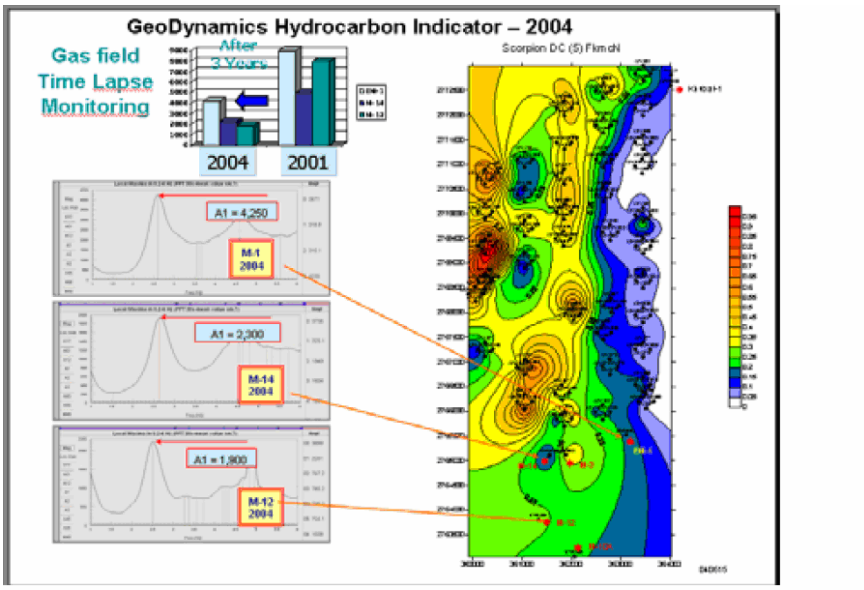

Fig. 10 Progressive HI map of a gas field, UAE (After E.D. Rode)

Figure 10 – Progressive HI map of a gas field, UAE (After E.D. Rode)

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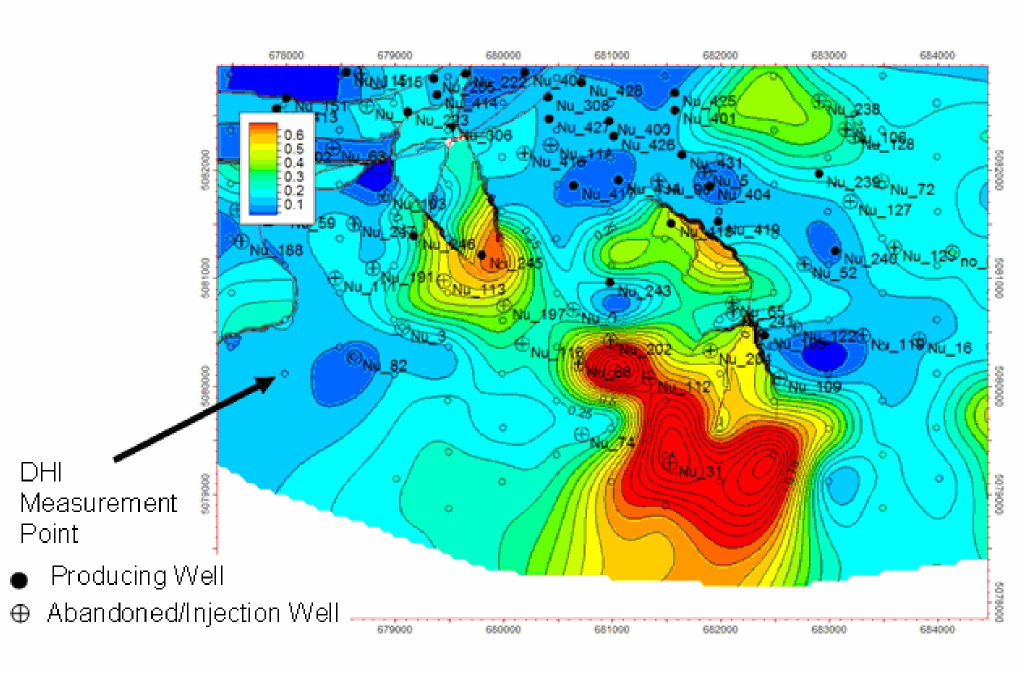

Figure 11 – RHI map of field A, Caspian region. (After Serder Kaya, et al.)

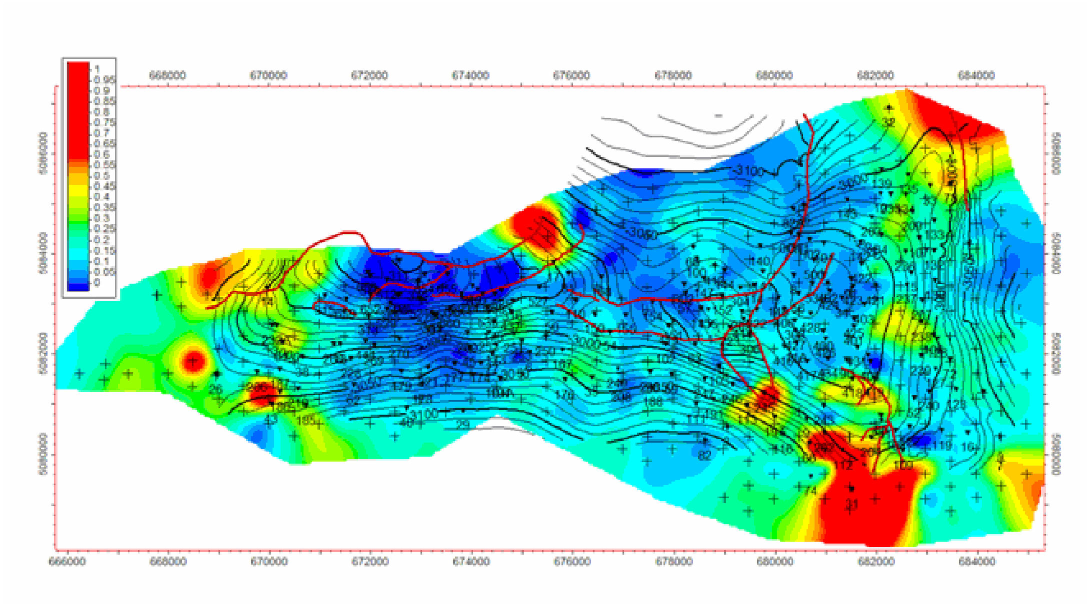

Figure 12 – RHI map of field B, Caspain region (Serder Kaya, et al.)