Rapid petroleum potential assessment of Bantumilli marginal oil field using infrasonic passive differential spectroscopy

E.D. Rode,[1*] S.R. Das[1], S. Ravindran,[2] M.K. Mukherjee,[2] A. Bordoloi[2] and P. Jinagam[2] **show with an Indian case study how application of infrasonic passive differential spectrascopy technology for marginal fields and by-passed oil in brown fields is significant in eliminating the risk of drilling dry holes.**

A field is considered marginal when it has lesser quantity of in-place hydrocarbons and distributed in several layers. Its extent is limited, it is located far from the existing infrastructure facilities, and the economics for the development of the fields are marginal. Bantumilli field possesses all these characteristics and is thus termed a marginal field. Quantifying infill potential in marginal fields often involves several challenges. These include highly heterogeneous reservoir quality both horizontally and vertically, incomplete reservoir databases, a considerably large amount of data involving a number of wells, and different production and completion practices.

Perhaps, the most accurate way to establish infill potential is to conduct a detailed integrated reservoir study, which is often time-consuming and expensive for operators of marginal fields. Hence, there is a need for less demanding methods that characterize and predict heterogeneity and production variability. As an alternative approach, various authorities have used empirical or statistical analysis to model well performances. Many of these methods are based solely on the analysis of well locations, production, and time data. In yet another method, passive sound is used to quantify the total hydrocarbon content, delineate the hydrocarbon contained area, determine the thickness of oil/gas columns at different locations, and subsequently prepare the development plan. Infrasonic passive differential spectroscopy (IPDS) is one such technology that predicts the total oil/gas content in field and later develops the field with minimum cost and time. This method ensures that not a single well turns out to be a dry hole.

Bantumilli field is located in the eastern coast of India in the Krishna–Godavari basin (KG basin). Oil, gas, and condensate have been discovered in two wells in the Bantumilli field. The reservoirs, however, are thin, sporadic, and cannot be discerned in the seismic sections. As a consequence mapping of the reservoirs is riddled with uncertainties. The seismic and electrolog analysis did not help in deciphering the spread of the hydrocarbon containing reservoirs. IPDS technology was executed to ascertain the petroleum potential of the area. The reservoir hydrocarbon index (RHI) map was prepared after calibration of the RHI values in the discovered oil/gas wells. The prospective areas were delineated, petroleum reserves of the field were estimated, and the location of the exploratory wells identified.

Figure 1 *Sedimentary basins of India.*

Bantumilli field

Bantumilli field is situated in the Krishna-Godavari sedimentary basin in the east coast of India (Fig.1.)

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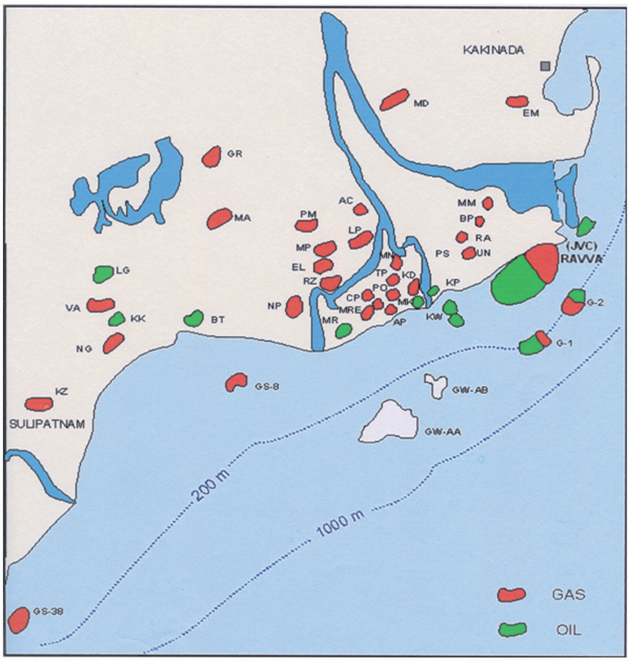

Figure 2 Oil and gas fields of Krishana-Godavari Basin.

Bantumilli field is located in the onshore part near the coast, surrounded by many oil and gas fields (Fig. 2).

The field is a rift fill sequence situated SE of Bantumilli graben and SW of the plunging part of Tanuku ridge. Kaza-Kaikalur horst trending NE-SW separates West Godavari into Gudivada graben on NW side and Bantumilli graben on SE side (Fig.3).

These grabens comprising a thick prism of Cretaceous rift fill sequence are not present over Kaza-Kaikalur horst. The oldest rift fill sequence is considered to contain non-marine clastics although there is evidence to suggest that the oldest rift fill sequence contains marine clastics.

Bantumilli field is a basement high, draped over the basement and faulted anticlinal structure. The wells drilled in and around Bantumilli area confirm the basement high in this area. This high is the SW extension of the NE-SW trending Tanuku horst. The Tanuku horst slopes towards SW and Bantumilli high forms the SW dip of this horst. The Bantumilli basement high has independent structural relief, with the shallowest position near the Bantumilli-3 well. The high slopes gently towards NE, moderately towards SW and steeply towards NW and SE.

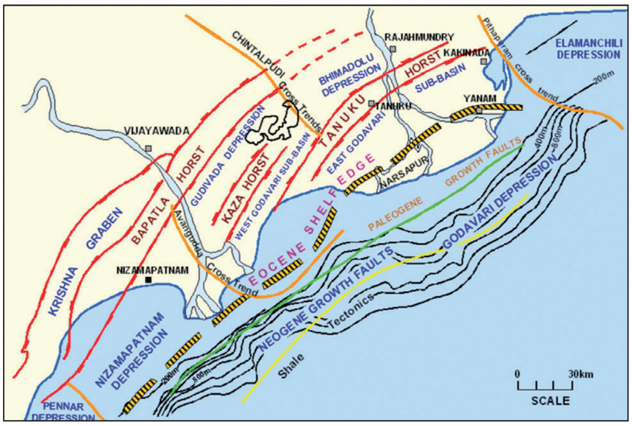

Figure 3 Tectonic framework of Krishna-Godavari Basin.

The wells on Bantumilli structure are drilled up to the Archean basement. The basement is overlain by Cretaceous sediments. The lower part of the Cretaceous section, the Nandigama formation, comprises sandy siltstones and pyritic claystone and shale. The lower part of Nandigama formation increases in thickness away from Bantumilli high in all directions, indicating on-lapping of the bottom part of this section against the basement. Processed dipmeter data in Bantumilli-5 indicates a sharp change in dip at 2910 m dividing the Nandigama formation into two units. The lower unit has dip of 1–8° towards NW and the upper unit has a dip of 2–12° towards SW. The two objects in the well Bantumilli-2 in this on-lap section produced light oil. One sand in the well Bantumilli-5 seems to be oil bearing. The overlying Raghavapuram shale formation is comprised predominantly of claystone /shale with a few intercalations of sand beds. These sand horizons contain oil and gas in Bantumilli field. The upper section , Tirupati sandstone, is characterized predominantly by sandstone. Lower Paleocene is composed of volcanic flows with intertrappeans (Razole formation) and upper paleocene comprised mainly by dolomite limestone with a thin layer of sandstone and claystone. The Eocene to recent section consists of sandstone and claystone (Fig.4).

Exploration prologue

The exploration in Bantumilli field commenced by drilling the first well, BNT-1, on a structural high of 80 km^2. The well however turned out to be dry due to the absence of proper reservoir rock. The subsequent well, BNT-2 was drilled over another structural culmination. Oil and gas were discovered in this well in the two horizons in the Nandigama and Raghavapuram shale formation. In the third well BNT-3 oil and gas were encountered in shallower horizons. Two other wells, 4 and 5, drilled on other structural dispositions were abandoned as dry holes. It was thus surmised that accumulations of oil in Bantumilli area are not controlled by structural entrapment alone. Pursuing further exploration became difficult. The attention thus shifted to ascertain the spread of the reservoirs over the field. The oil and gas bearing horizons in wells BNT-2 and BNT-3 are thin and non-persistent. The electrolog correlation and preparation of depositional model did not result in the identification of prospective locations (Fig.5).

The reservoir being sporadic in character could not be correlated to specific seismic markers. As a consequence, the development of Bantumilli marginal field turned uncertain, difficult, and unattractive. At this stage the operator of the Bantumilli field adopted the non-conventional method of IPDS to characterize the oil bearing area, estimate the reserves, and identify the locations for drilling.

Implementation of IPDS

Principles

IPDS is a technology for direct detection of hydrocarbons. The frequency of the recorded wave is infra or less than normal sound waves. In this method no artificial sound, e.g., explosives or vibration, is used; the record of the passive sound of the earth only is utilized. This technology works only when two differential media, e.g., oil and water or oil/gas and water, are present in the reservoir. Spectroscopy is the processing technique of those signals, interpreting anomalies representing the presence or absence of hydrocarbons. The principle of this method is that a hydrocarbon reservoir is a frequency converter. It deforms the frequencies of the omnipresent natural earth noise (Fig.6).

The deformation of the natural earth noise spectra is characteristic in the very low frequency range between 0.2–10 Hz. These deformed signals on spectroscopic analysis produce unique spectral signatures. These spectral signatures are used as direct hydrocarbon indicators. Generally, there are three categories of passive seismic. These are passive acoustic spectroscopy, passive reflection seismic, and passive micro-event monitoring. IPDS deals with passive acoustic spectroscopy and it detects the presence or the absence of a petroleum containing reservoir. The reservoir in this method is described as a multi-fluid system in porous material. The nature of the very low frequency emitted wave is that it does not suffer any absorption, because of no reflection and no refraction. Any inhomogenity in the travel path of the signal does not have any effect. The reason for the formation of such signals has similarity with radio modulation systems or signal amplifliers. Any non-linear transmission element in the signal transmission system will create sub-waves and harmonics from the signal elements.

A petroleum reservoir is such a non-linear element, but with low-pass filter characteristics. It is non-linear only below 8 Hz, and as a result, higher incoming frequencies are converted in the reservoir into lower frequencies (differential products). But these products only exist in the frequency range below 8 Hz and they have a totally different behaviour compared with other seismic waves which are normally dealt with. These low frequency waves are slow, very slow, and the velocity might be below 500 m/sec. Because of their wavelength they are not reflected and not refracted from any incongruous lithology and so not absorbed.

Instruments

Patented sensors measure the sound waves. These sensors are seismometers with sensitivity of 30,000–120,000 V Sec/m

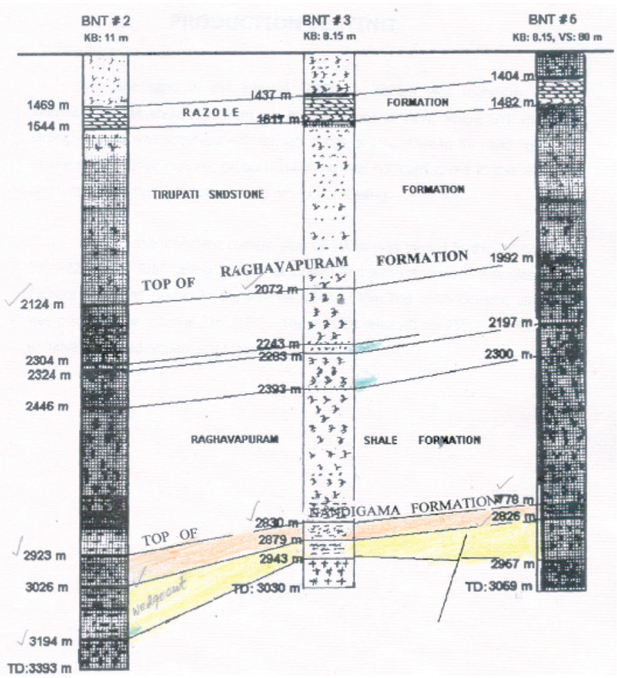

Figure 4 Stratigraphy of Bantumilli field.

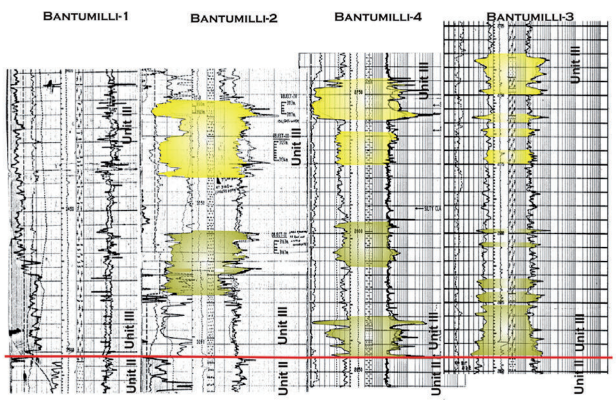

Figure 5 Electrolog correlation of the reserves containing horizons.

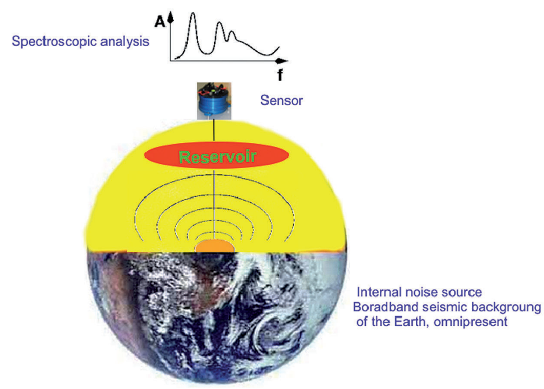

Figure 6 Schematic acoustic spectroscopic signature of a subsurface hydrocarbon reservoir.

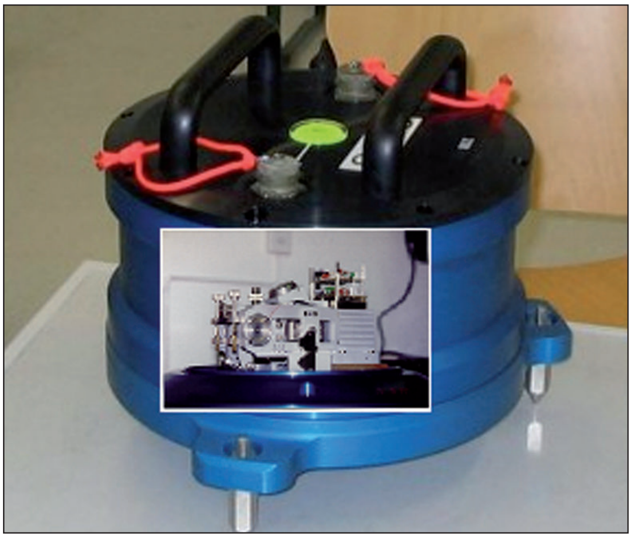

Figure 7 Ultra-sensitive seismometer with inset of internal view.

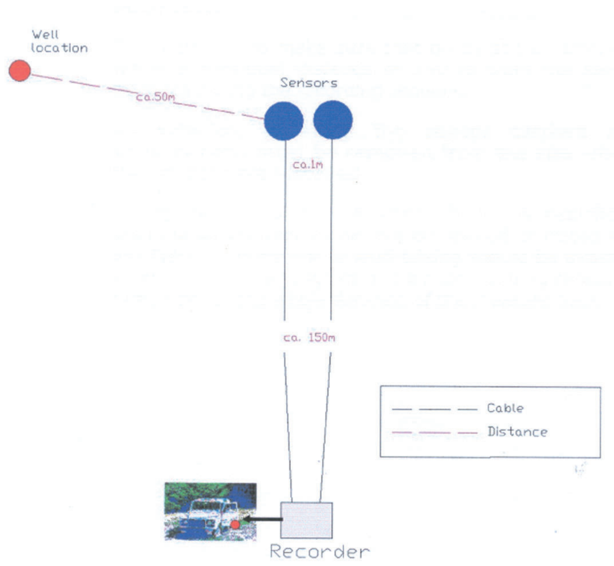

Figure 9 Acquisition set-up at well locations.

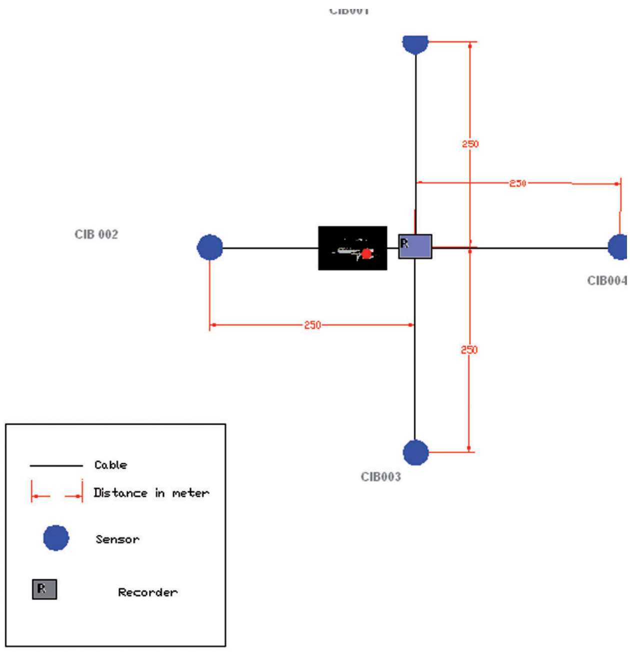

Figure 8 Acquisition set-up at data points.

(a normal I/O geophone shows in this frequency range a sensitivity of 28 V Sec/m). This instrument weighs about 15 Kg, can record frequency between 0.1–40 Hz., is an electrodynamic, inverse loop magnetic system which is self-calibrating (Fig.7).

Acquisition

IPDS data acquisition is done by placing the sensors as planned in the measurement set-up. Normally measurements are taken at 4–6 recording points (data points) at the same time, using one or two six channel recorders. The recording time is not less than 40 minutes (standard). The distance between the sensors is not critical but spacing below 90 m makes no sense economically and technically because mostly the resolution is not better than 50 m. The set-up depends upon what is already known from the field. In a virgin area where one looks for indication of hydrocarbons, the spacing may be some kilometers. Once the target has been identified, the spacing may be 150 m or less. This method is mobile and flexible, it can be iterated, and can approach the project in different phases. The sensors are mostly placed 150–250 m from the data recorder.

Processing

The recorded signals are transformed from the time domain to the frequency domain where their spectral signatures are analyzed. Usually 12 spectral lines are picked after careful preliminary analysis of the spectral signature of all recorded points. This is done for each field as there is always a difference in the spectral characteristics from survey to survey. Subsequently only six or seven lines are chosen and used to ultimately generate the reservoir hydrocarbon indicator (RHI) map. The raw signal recorded is strongly dependent on environment noise and on stochastic variation of the white earth noise spectra. For this reason, the raw signals are filtered before and after transformation in the frequency domain. Different kinds of filter are applied; which one is most appropriate is generally a process of iteration and comparison with existing data. Attention to the status of the wells (producing, abandoned, observation) during the campaign is necessary. Prior to data processing the recorded files are edited to remove the most obvious noise events. Most of the artificial noise effects have frequencies greater than 10 Hz.

Application

The technology has been widely used in over 100 field application, e.g. the Qushwahira, Bu Hasa, Marghan and Shag oil and gas fields of ADCO, UAE; the East Moldavek and Nurznanov fields of Kajumunaygaz, Kazakhstan; the Tanehill prospect, Young County, Texas and other fields in the USA; OML-277, Nigeria; Bantumilli, K-G Basin, Indiad; and Sanganpur, Cambay Basin, India.

IPDS is a method of direct detection of hydrocarbons before drilling and is complimentary to other exploration methods. It identifies the presence and amount of hydrocarbons in the subsurface. It can be used in virgin areas to detect the presence of petroleum. In oil field monitoring, it screens the oil/gas producing areas, determines the locations of infill wells, identifies the OWC or GWC, identifies the bypass or attic oil, uneven flood fronts, and ineffective draining. In abandoned and depleted fields, this technology has been used to ascertain the presence of leftover oil in the field. It is a giant cost saver in exploration, field development, field monitoring, and in depleted-abandoned fields.

Rapid assessment of Bantumilli field using IPDS technology

Bantumilli field spreads over an area of about 54 km^2. Seismic data under various campaigns have been obtained in successive years. The subsurface structural configuration changed with the acquisition of new 2D and 3D seismic data. Five wells were drilled on the structural culmination. Two wells produced oil and gas. All the wells were later abandoned. The reservoir are thin, sporadic and cannot be mapped from the seismic data. The petrophysical data did not help in deciphering the reservoir characteristics. Due to these limitations, it was decided to execute IPDS survey in the area to locate the prospective areas.

The measurement configuration consisted of a square lay-out, with sensors placed at each corner and the recording vehicle in the centre. The distance between the sensor and recorder measured 250 m (Fig.8).

For the measurement at drilled wells, the set-up was configured as in Fig.9.

The measurements were carried out at 240 data points (DP) including the calibration at the five drilled wells (Fig.10).

The acoustic recordings acquired in the field were processed allowing quality control, signal processing, cleaning, and filtering.. For quality assessment of all sensors, three calibrations were performed throughout the measurement. The processing method used for this survey involved analyzing the spectral characteristics of the signal in the frequency domain and determining the (RHI) reservoir hydrocarbon indicator (F7 mc N parameters) from six spectral lines. The data were processed in GeoMat software.

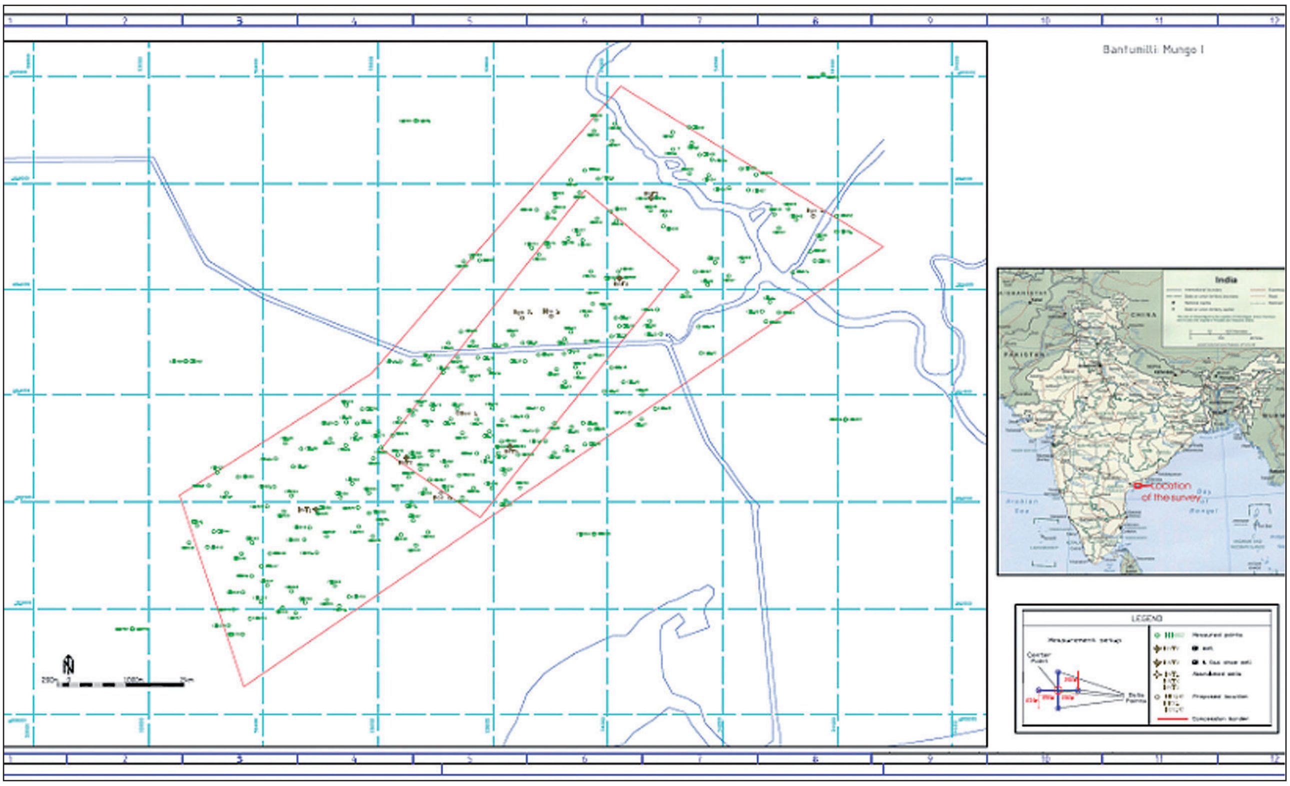

Figure 10 *IPDS data acquisition map, Bantumilli.*

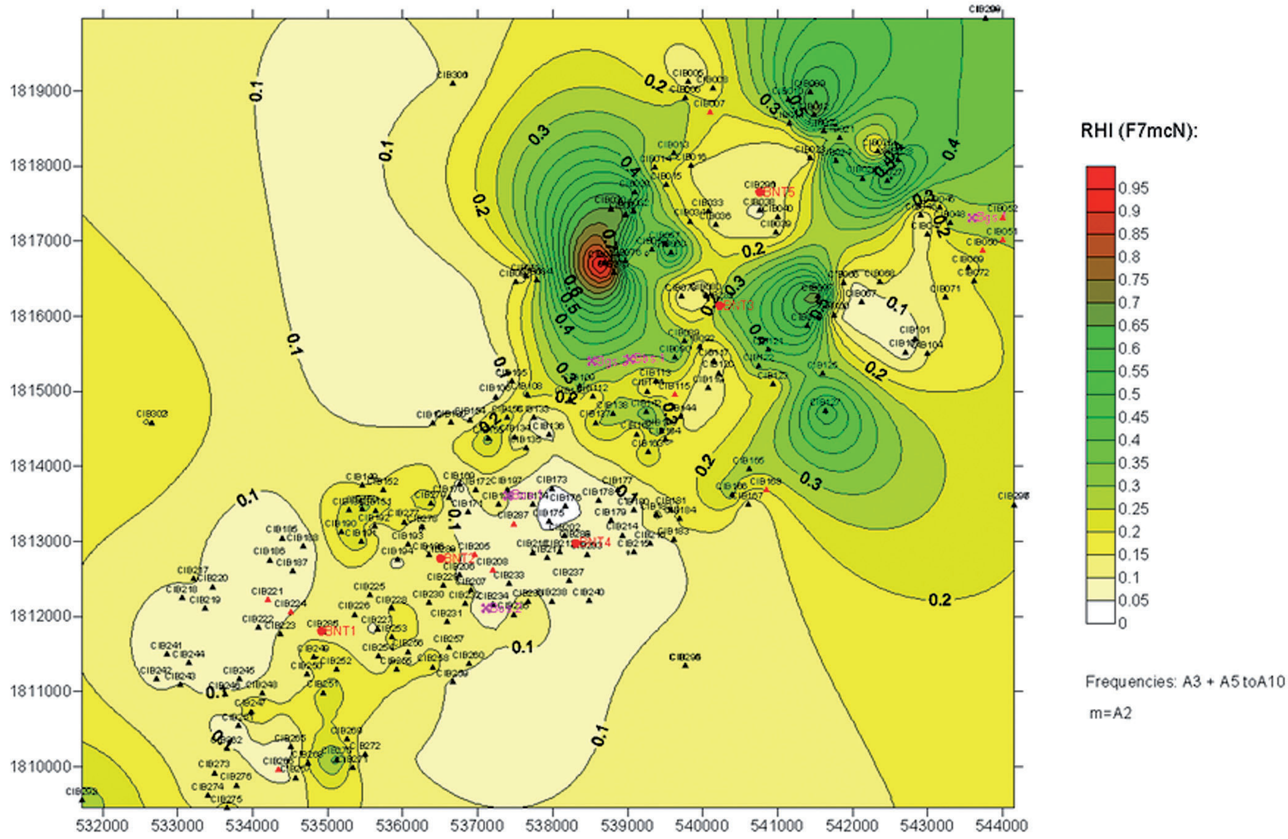

***Figure 11** Hydrocarbon indicator map of Bantumill field.*

The RHI map (Fig.11) presents the presence of hydrocarbon at the different measurement locations. The maximum concentration of hydrocarbon represented by a value of 1.00 (red colour) and the absence of hydrocarbon represented by 0.00 value (white colour) shows that the northern part of the field contains more hydrocarbons than the southern portion. The dry wells in the southern part (BNT-1, BNT-4) confirm this prediction. The other well BNT-5 (a dry hole) is also located in the area devoid of oil. The map revealed the presence of five petroleum prospects. The prospect H seems to possess maximum potential. It spreads over an area of about 8 km^2 and indicates the presence of maximum hydrocarbon column. It is enclosed by 0.3 RHI value and in the centre, it shows a value of 0.95 providing the possibility the thickest oil column. Smaller cumulations towards the eastern portion of this prospect are also present. The sudden crowding and flaring of the contours indicate the presence of the faults dissecting this prospect. The prospect Y and D are found in the eastern part of the area. The prospects together are aligned in NW-SE direction with an intervening low potential area between prospect Y and D. The well BNT-3 is situated in this comparatively low potential area. This well initially flowed oil, gas, and condensate. The constriction of the contours between prospect H and Y and D indicates the possible presence of another fault, aligned in the NE-SW direction. The prospects R and O are identified near the northern part of the field. These are enclosed by 0.5 RHI value and cover more than 1.5 km^2 each. The intervening low between the prospects D and R is represented by 0.2 RHI value. The dry well, i.e., BNT -5, is situated in the intervening low prospective area between the prospects H and Y,D,R and O. All the RHI identified prospects indicate close correspondence with the structural highs i.e., C, A, R, B, O, and N identified from the 2D seismic interpreted map (Fig.12).

The oil generation locales as interpreted from the palaeo analysis and tectonic evaluation have been examined. All the prospective structural and IPDS-identified RHI highs are located very favourably with respect to the oil generation centres and path of migration. Even the faults envisaged from the RHI map are corroborated from the seismic map.

Conclusion

The IPDS data has identified the location of the areas containing petroleum. The RHI values have been calibrated with the various oil and gas columns encountered in BNT-2 and BNT-3 wells. The oil bearing areas of the different prospects have been delineated and reserves of hydrocarbons have

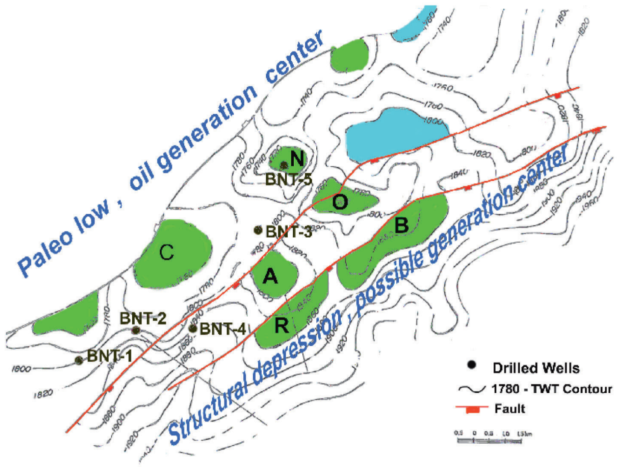

Figure 12 *Structural configuration of BNT-3 producing horizons.*

been estimated accordingly. The delineation wells on these prospects should be drilled and then a development plan can be prepared.

The five abandoned wells on Bantumilli field, erratic play of the reservoirs, uncertain entrapment conditions, and poor response to seismic survey have created uncertainty about the potential of this field. IPDS has identified the various prospects and the limits of the field. In the present situation, it is perhaps the only method to rapidly assess the potential of the Bantumilli field.

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References:

Aki, K. and Richards, P.G. [1980] *Quantitative Seismology: Theory and Methods Vols 1-2*. W.H. Freemann.

Biot, M.A. [1956] Theory of propagation of elastic waves in a fluid-saturated porous solid – 1, Low frequency range. *Journal of the Acoustic Society of America*, **28**, 168-178.

Dangel, S. [2003], Phenomology of tremor-lie signals observed over hydrocarbon reservoirs. *Journal of Volcanology and Geothermal Research*, **128**, 135-158.

Karim, A. and Rode, E. D. [2007] Application of Direct Hydrocarbon Indication Based on Passive Seismic (IPDS) Surveys in Middle East. *Petrotech*, New Delhi, India. Abstracts 2, 30.

Kaya, S., Rode, E. and Kier, D. [2007] Integrated Application of Passive Seismic Technology For Trapped Oil Detection in Mature Fields and Hydrocarbon Discoveries in Adjacent Compartments. *10th International Congress of the Brazilian Geophysical Society*, Rio de Janeiro, Brazil.

Khan, T. and Sofia, M. [2002] Elastic nonlinearity measurements help map permeability, pore fluids. *Oil and Gas Journal*, 15 July, 32.

Mukherjee, M.K. [2009a] Direct Detection of Hydrocarbon in any geological condition by using Infrasonic Passive Monitoring Technology. *IATM, Society of Indonesian Petroleum Engineers*, Bandung, West Sumatera, Indonesia.

Mukherjee, M.K. [2009b] Reservoir Management of Fracture of Basement Through Infrasonic Passive Monitoring Technology. *IATM, Society of Indonesian Petroleum Engineers*, Bandung, West Sumatera, Indonesia.

Mukherjee, M.K., Rode, E.D., Singer, J.M. ADNR Explorer: Acoustic detection of hydrocarbon reservoirs, Society of petroleum geophysicists on 4th Conference & Exposition on Petroleum Geophysics, Mumbai, India, 2002, 302.

Rode, E.D. [2006] Passive Seismic. *Simposio Brasilerio da SBGF*, Natal, Brazil.

Rode, E.D., Mukerjee, M.K., Bordoloi,A. and Pydiraju, J. [2008] Direct detection of hydrocarbons by using IPDS technology. *Petroview*, **2**, 4, 3-12, DGH, Noida, India.

Rode, E.D., Mukerjee, M.K., Das, S.R., Ravindran S., Nandy S.K., Venekataraman E., Bordoloi, A. and Pydiraju, J. [2009] Infrasonic passive differential spectrascopy (IPDS) for direct detetction of hydrocarbons in exploratory production and depleted fields. *Indonesian Petroleum Association*, Indonesia, IPA-09-G-011.

Singer, J. [2002] Spectroscopic identification of tremor phenomena over hydrocarbon reservoirs. *64th EAGE Conference & Exhibition*, Florence, Italy.

Suda, N., Nawa, K. and Fukao, Y. [1998] Earth's background free oscillations. *Science*, **279**, 2089-2091.

Westervelt, P.J. [1963] Parametric Acoustic Array. *The Journal of the Acoustical Society of America*, **35**, 4, 535.