Future exploration challenges for ONGC – some ways to tackle

- N. C. Nanda*

Abstract

The declining hydrocarbon production from brown fields in the country is a matter of concern that necessitates the discovery of new fields for maintaining a reasonable reserve-to-production ratio. Explicably, such initiatives require continuing exploration with more vigour and urgency.

Exploration for hydrocarbons is customarily driven by seismic data, the mundane practice being mapping of the structural and high amplitude anomaly (DHI) prospects, followed by drill-tests after geologic appraisals. However, with passage of time, the dearth of such anomalies to map from the existing seismic data is becoming increasingly critical and poses a big challenge to pursue exploration in the future. Two ways are being suggested here to tackle the challenge.

Revisiting the multitude of multidisciplinary data in the producing and non-producing basins can help find new hydrocarbons. This involves reprocessing of the legacy seismic data through state-of-the art imaging and visualization as well as re-evaluation with the improved knowledge and experience acquired over the past several years. Another way to meet the challenge can be an innovative approach to conceive and generate prospects from the review of legacy data through interlacing of imaginative minds and powerful machines. Novel geologic plays are innovatively conceived from the comprehensive and exhaustive review of multidisciplinary data in the area. This is followed by an animated search for evidence in the seismic data after suitable reprocessing, tailor-made to endorse the play, and to the exercise of generating prospects for drilling. This is likened to a process reverse to that in seismic modelling and could be named "**reverse seismic modeling (RSM)".**

(This article is written exclusively in the context of exploration practices in ONGC, as perceived by the author and is a recreated version of the key-note address presented at the SPG-20 Kochi conference.)

Introduction

Sensibly, oil companies prefer buying or operating proven assets than expending money on rank exploration for managing risk reduction. The motive clearly is to enhance production and maximize monetization by deploying advanced engineering techniques and technologies presently available. However, enhancing production from the depleting fields through secondary and enhanced oil recovery (EOR) processes can be a temporary solution, as the incremental production is unlikely to maintain the desired reserve-to-production ratio (R/P) in the long term. To achieve sustainable R/P in the future, it is *sine qua non* that resources are replenished by adding new reserves continually, which puts emphasis on continuing tireless exploration and with urgency and earnestness.

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Traditionally, explorations for hydrocarbons have been seismic-driven; prospects such as structural and high amplitude anomalies (DHIs) have been mapped from seismic and drill-tested albeit after due geologic appraisal. This expedient approach for finding new hydrocarbons has been holding on so far. But with the passage of time, most of the structural and DHI prospects being drill-tested, and with the seismic anomalies becoming increasingly rarer to map, it raises a mute question as to how exploration is going to be impacted in the near future. Implicitly, if anomalies are not seen on seismic data, is it time to discontinue exploration and surrender acreages? How can one be absolutely sure there are no more hydrocarbons to be found in the area? What if, there are unnoticed potential prospects present but are subliminal in seismic data due to reasons of improper imaging or more radically due to the insentience of the seismic interpreter?

Future exploration challenges

Most of the oil and gas fields operated by ONGC are undergoing depletion, which raises concern about maintaining a sensible R/P. Augmenting production through secondary and enhanced oil recoveries (EOR) will further impact the R/P unless new fields are discovered, and reserves replenished. This compels the explorationist to continually generate new prospects to find more hydrocarbons. Earlier, areas accessible on land were aplenty, and carpet-acquisition of seismic data was continued to generate new prospects. Most of the approachable and geologically preferred areas are covered by seismic surveys by now and prospects mapped and drill-tested leading to the present oil and gas fields. The operationally difficult and geologically assessed 'high risk-low reward' frontier areas are left, some of which have been explored with none-too-encouraging results and with the others under exploration. With the environmental ecosystem becoming increasingly stingier with time, it may be difficult in the near future even to go back to the old prospective areas for acquiring new seismic data. This is an impending problem which will compel the geoscientists to persistently find new prospects from the existing seismic data for continuing exploration in the future.

Similarly, in the vast offshore areas east and west of the country, cherry-picking of the prospects in the shelfal parts has been done and drilled resulting in the present offshore oil and gas fields. This leaves only the deep-water offshore areas for exploration but drilling results of several superdeep and ultra-deep prospects, unfortunately, was not too encouraging. Under the restraining circumstances, the exploration to discover new hydrocarbons inland and offshore poses a real and a big challenge. Clearly, new inventive exploration strategies are to be mulled by the geoscientists to meet the challenge.

However, with little newly acquired seismic data forthcoming, the geoscientist is bound only by available existing data to find new prospects to drill. Fortunately, with tremendous recent advances in seismic processing as well as imaging algorithms and visualization, the legacy seismic data can be greatly improved and re-evaluated (Chopra et al., 2005; Yan et al., 2017; Dutcher et al., 2021). In such cases, the desired processing needs to be geology-specific, as envisaged by the interpreter and it is of utmost importance that the synergy between the interpreter and the processor should be intense to bring out the best results. Goal-oriented imaging of seismic data by optimum parametrization followed by cognitive reinterpretation through the experience and knowledge gained by the geoscientists over the years is expected to unravel hidden anomalies that were missed earlier. Data mining and data analytics would play a vital role in re-evaluating the multitude of multidisciplinary geoscientific and engineering data in 1) finding new oil/gas in the existing petroliferous basins of India through reprocessing and remapping, and 2) generating new prospects by conceiving innovative novel geologic plays. The bottom line is, until the seismic data are evaluated to explain the geologic plays sufficiently, the opportunity for finding new hydrocarbons in those areas remains to be explored.

1) Finding new oil/gas in the petroliferous basins

(a) The Mumbai Offshore Basin carbonate tract:

Eocene and Miocene limestones in the Mumbai Offshore Basin host the major oil and gas fields. However, several sizable structures in the limestones on drilling were found dry due to lack of porosity. This poses the problem of identifying porous limestone reservoirs from seismic. Though a vast provenance of limestones with thick large structures exists in the basin, often a single dry well drilled on the crest of a structure proving tight has been the bane of further exploration. A stark example is the Eocene limestone reservoir of Ratna field consisting of a large structure. While three wells drilled in the axial part of the structure flowed a good amount of oil from different parts of the thick Eocene limestone, a development well drilled within the structural closure, 500 m away from the crestal well, surprisingly tested dry with little porosity. Carbonate reservoirs are known for their complexity and mapping of porosity pods from seismic within the limestone has been a relatively stiff task (Neuman and Kuznetsov, 2009; Zhang et al., 2010, Zhou et al., 2018; Chopra et al., 2022). Nevertheless, the Ratna example underscores an important message. Should a dry well drilled on the highest part of a big structure justify the entire structure to be devoid of porosity and abandoned without further probe? Arguably, one cannot rule out the presence of probable porous zones elsewhere within the structure, away from the crest, due to the complex nature of facies changes in limestones as in the above instance. Evidently, it calls for finding ways to predict porosity in limestones from seismic.

Much work has been carried out and published on seismic rock physics for clastic reservoir rocks all over the world, but relatively much less is known about carbonate reservoirs (Ruiz et al., 2012; Sun et al, 2015; Mur and Vernik, 2020). More studies on rock-fluid properties of carbonates and their seismic responses are required for better understanding of porosity prediction in limestones. It requires systematic and organized analyses of multitude of multidisciplinary data available from drilled wells in the oil/gas fields to help seismic rock physics modelling and provide important insights to rock-fluid properties of limestone reservoirs. Identification and mapping 'porosity pods' from seismic in the extensive tract of thick limestones particularly in the Mumbai Offshore Basin can be highly rewarding. A study plan for this may be on the following lines.

i) Collating the data on the petrophysical properties measured/determined in the wells/labs for various types of carbonates of different ages (Paleocene, Eocene, and Miocene) and depositional environments.

ii) Extensive seismic rock physics modelling using rock-fluid properties such as lithology, V_P, V_S, bulk density, Poisson's ratio, porosity, and fluid saturation, etc., to calibrate seismic response.

iii) Analyzing seismic multiattributes of porous and non-porous limestones with varying fluid saturation to establish empirically the discriminant to identify hydrocarbon reservoirs in the limestones.

iv) Exhaustive reprocessing of seismic data would aid predicting hydrocarbon bearing porous pods in the limestones, albeit specific to the area-geology and would lead to opening up limestone explorations in the other areas of the country.

Some pilot studies may be initiated in the offshore fields as a good mix of types of limestone reservoirs having different fluid saturations of oil, gas and brine. The reservoirs also occur at shallow to moderate depths with relatively good quality seismic data and provide large amounts of geological, petrophysical data for analysis. Of particular interest would be the application of Poisson's impedance and AVO attributes for limestone reservoirs which are till date are not adequately studied. The possibility of identifying hydrocarbon-bearing porous pods ("sweet spots") from seismic can stimulate limestone exploration in other areas such as in Upper Assam Shelf and in the east and west offshores areas of India which could open up massive scopes for limestone exploration in future.

(b) The Cambay Basin

Many oil and gas fields in the basin consist of thin oil-bearing Eocene sands (~5-12 m) associated with the overlying thin coal (Kalol) strips (~5-10 m) deposited in the fluvio-deltaic environment. The oil sands located within structural closures are underlain by shales with no visible oil-water contact and are believed to be structural traps. Dry wells drilled off structural closures often delineate the fields limited to these dry wells. However, uncertainty in correlation of the sands in the well logs in many cases indicate the sands as discontinuous and diachronous, a strong likelihood considering the fluvio-deltaic depositional setting, where frequent facies changes are common. Occurrence of discrete oil sands as stratigraphic plays beyond the structural closures, thus has a high probability which needs to be further investigated. Unfortunately, the resolution of the existing seismic data does not allow mapping of thin stratigraphic sand reservoirs which can be of diverse types associated with the depositional style. The seismic response of the thin target sands is generally contaminated by interference of the strong reflections from the overlying coals resulting in composite reflections that lead to poor resolution. The log motifs of two nearby wells, separated by a mere 350 m and the 3D seismic segment through the wells succinctly illustrate the points mentioned above (Figure 1). It is expected that advanced processing techniques can help separate the coal reflections and improve resolution to enable proper mapping of the thin stratigraphic oil sands.

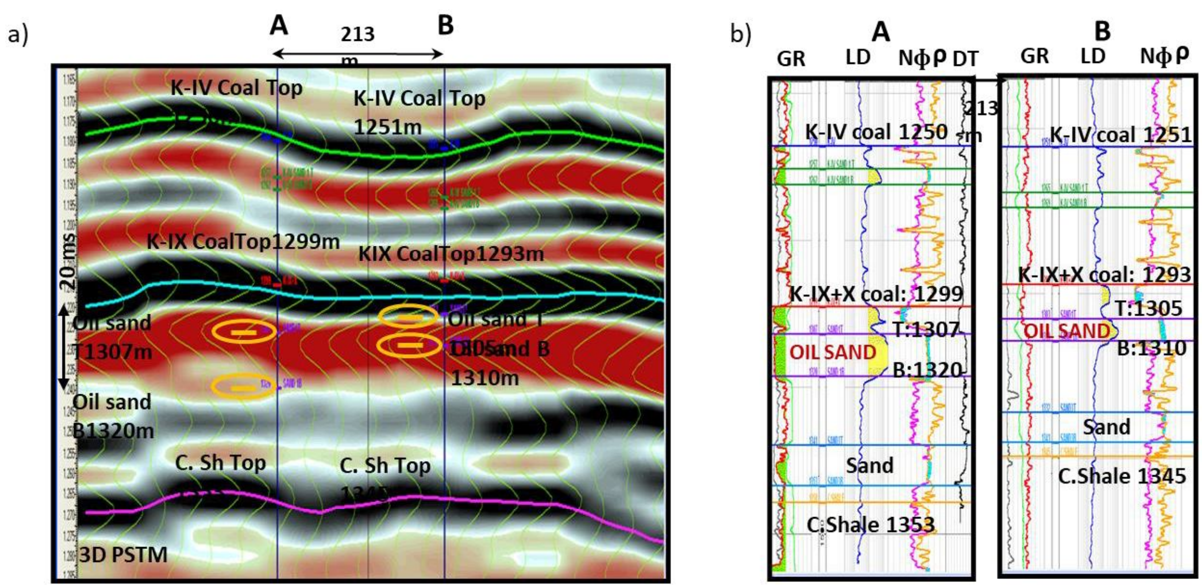

Figure 1: (a) Seismic response of the oil sands and (b) their log motifs. The log motifs (b) of the oil sands in the closely spaced wells, 213m apart, suggest facies changes. The tops and bottoms of the oil sands marked on the seismic section in (a) also show phase inconsistencies and correlation problems for accurate mapping of the pays. (*Courtesy ONGC, India)*

(c) The Upper Assam Shelf

This highly petroliferous basin is unique in having hydrocarbon reservoirs of almost all ages, from Precambrian basement to Permian to Miocene with multiple petroleum systems. However, the Barail and the Tipam sands deposited in fluvio-deltaic environments constitute the main hydrocarbon-bearing reservoirs in the producing fields. Seismic reflections from the oil-bearing Barail sands occurring at large depths suffer (similar to that in Cambay basin), interference of strong reflections from overlying coal-shale (BCS) units. This makes it difficult to map accurately the geometry of the hydrocarbon bearing sands, particularly the sinuous channel sands in the Barail coal shale (BCS) formation. The other important oil reservoirs of the Miocene Tipam sands occurring at moderate depths though show better resolution but are affected by a multitude of younger faults, which are suspected to have complicated the process of migration and accumulation of oil and gas. The faults need to be mapped more accurately to better characterize the reservoirs for producing more hydrocarbons.

Acoustic and shear impedances are widely used to differentiate lithology and fluid content. Supplementing the attributes with the Poisson's impedance in analysis would help in better identification and prediction of type of sands (matrix) and fluid content in the Cambay and Assam basins.

2) Generating new prospects by conceiving innovative novel geologic plays

A novel conceptual interactive interpretative approach is evoked to help generate prospects from the existing data through reviewing and reprocessing by interlacing creative minds and powerful machines. Extensive coverage of seismic (2D/3D) and numerous wells drilled in the basins over the last several decades have provided enormous amounts of geoscientific and engineering data. These massive volumes of multidisciplinary data generated so far, however, need to be rewardingly re-analyzed by utilizing the knowledge and wisdom gained over the years.

The reverse seismic modelling (RSM) approach

Fast and powerful computers, sophisticated image processing and interactive interpretation techniques driven by experiences and creative imaginations of analysts offer tremendous scope for reevaluation of the wealth of exploration data gathered over the last several years. Reviewing the data differently can help nebulize innovative geologic plays apart from the prevailing ones. The perceived plays, however, would need seismic support that can be provided by high-quality data, reprocessed with tailor-made object specific parameters. The innovative play model remains unchanged, and the seismic data undergo iterative reprocessing till the final image evinces support for the play for considering upgradation to a prospect for drilling. This is a process reverse to that of the usual forward modelling where the geologic model is changed repeatedly till it matches the field seismic and used to interpret the geology from the seismic. The conceptual approach may be named, "reverse seismic modeling (RSM)". RSM is intended to change the contours of the continuing ideas on geologic plays in the area and instead conceive innovative novel plays/prospects from the existing data for exploration. The approach essentially consists of two steps, a) conceiving innovative play models from reanalysis of existing multidisciplinary exploration data, and b) finding evidence in optimally reprocessed seismic data for upgrading the play(s) to prospect for drilling.

a) Conceiving innovative plays from review of existing multidisciplinary data

Multidisciplinary data sets, geological, geophysical, petrophysical, geochemical, reservoir and production and engineering, including drilling are collected and collated to create a robust organized data base as the starting template. Key wells in the area are chosen and long composite regional seismic segments (2D and 3D) traversing through (or near) the wells are created for critical regional analysis. The key wells may include the hydrocarbon-bearing, the dry and the water bearing wells, and more importantly the exceptional wells that have shown unanticipated or incompatible results. Multi-set and multidisciplinary data reviewed in a different way by imaginative and experienced geoscientists with open minds and deliberately on the lookout for innovative ideas can help invent novel geologic concepts. Often, in data analysis, convergence for a solution satisfying all evidence from the multi-set data is problematic with some data favoring and others against the inference. Typically, the common tendency is to accept the data that support the intended conclusion and disregard the negatives. In the RSM approach, somewhat based on the principles of *lateral thinking,* however, instead of ignoring the incongruent or incompatible evidence, the negative evidence is given more credence and investigated to get a reasonable explanation as to why things happened or did not happen the way they were expected to. Interpretation based on such inductive logic can gain more insight to providing crucial clues to conceive alternate novel geologic plays Advanced techniques such as 'data mining' and 'data analytics' would be extremely useful in the reanalysis, revealing patterns that could lead to conceptualization of new geologic models from the existing data.

b) Finding evidence in reprocessed seismic data

The conceived geologic play would, however, need seismic evidence to upgrade it to a prospect for drilling. It requires cognitive search for evidence in the improved seismic images that are achieved by reprocessing the data using advanced processing/imaging techniques. Depending on the type of play model conceived, the reprocessing is customized suitably with object-specific parameterization to bring out the best image that endorses the conceived play.

Seismic interpretation essentially deals with visualization of images that depends largely on one's perception. Visualizations and perceptions are co-linked; one often perceives what the brain visualizes. A familiar example of this is river channels and subtle faults, claimed 'clearly seen' by one interpreter may be barely noticeable to others. Evidently, image visualization and perception differ with individuals (mind) and even by the same individual when reviewed after time lapses. For this reason, seeking evaluation of the data by different agencies to get a 'second-look' opinion is at times practiced in the industry. Visualization is also impacted significantly by display modes, plotting scales and colors. Colors particularly influence visualization to a great extent and extensive use of colors in seismic attributes are known to be widely and commonly used for improving perception. Predictably, seismic images, improved with goal-oriented reprocessing parameters can lead to perceived anomalies that were missed initially. Seismic reprocessing, however, may need several attempts to achieve this by experimenting with varying parameters and algorithms to bring out the best of the images requiring close interactions between the interpreter and the processor.

Remarkable technological and technical advances in the fields of artificial intelligence (AI), data science, and interactive processing and visualization technologies provide means and hopes to skillfully exploit the RSM conceptual approach to encounter the exploration challenges. Optimization of geologic goal-oriented processing parameters delivering improved images can unravel subtle traps to explore for more hydrocarbons. Figure 2 is an example of this and underscores the need for reprocessing of seismic data on a massive scale. Renewed analysis of such large amounts of reprocessed data in a holistic manner by experienced and imaginative interpreters is expected to find more hydrocarbons from the areas and more significantly from the producing basins.

The key to successful application of RSM, however, depends essentially on the level of imagination, astuteness, experience and creativity of the interpreters and the skill and expertise of the processors. Interpretation of seismic images needs liberal imagination, but confined to a reality framework, limited to viable geologic models. The initial hunch for conceiving apposite geologic plays and the tenacity to convert plays to prospects by exploiting available powerful software packages through improved seismic images is the challenge for real application of the mind. The RSM approach, planned properly and executed, can meet the challenges by generating new prospects from the existing data and turn out as the game changer in future exploration. More notably, the approach is self-reliant; all activities are doable in-house, and inexpensive, entailing no additional cost. It can also gainfully engage the young geoscientists to learn and acquire knowledge and skill.

Summary

1. Extensive seismic rock physics modelling based on well logs and laboratory data could enable full understanding of the rock-fluid properties particularly of limestones for future exploration.

2. Goal-oriented reprocessing of vast amounts of existing seismic data providing improved images followed by cognitive re-evaluation, is likely to sustain future exploration for hydrocarbons.

3. The RSM conceptual approach utilizing principles of inductive logic, can help generate novel prospects in the under-explored/relinquished as well as in the over-explored/matured acreages and can be a likely solution to the future exploration problems.

4. The RSM approach is inexpensive and doable in-house, entailing no additional cost and can gainfully engage the young geoscientists to learn and develop imaginative skills and acquire knowledge.

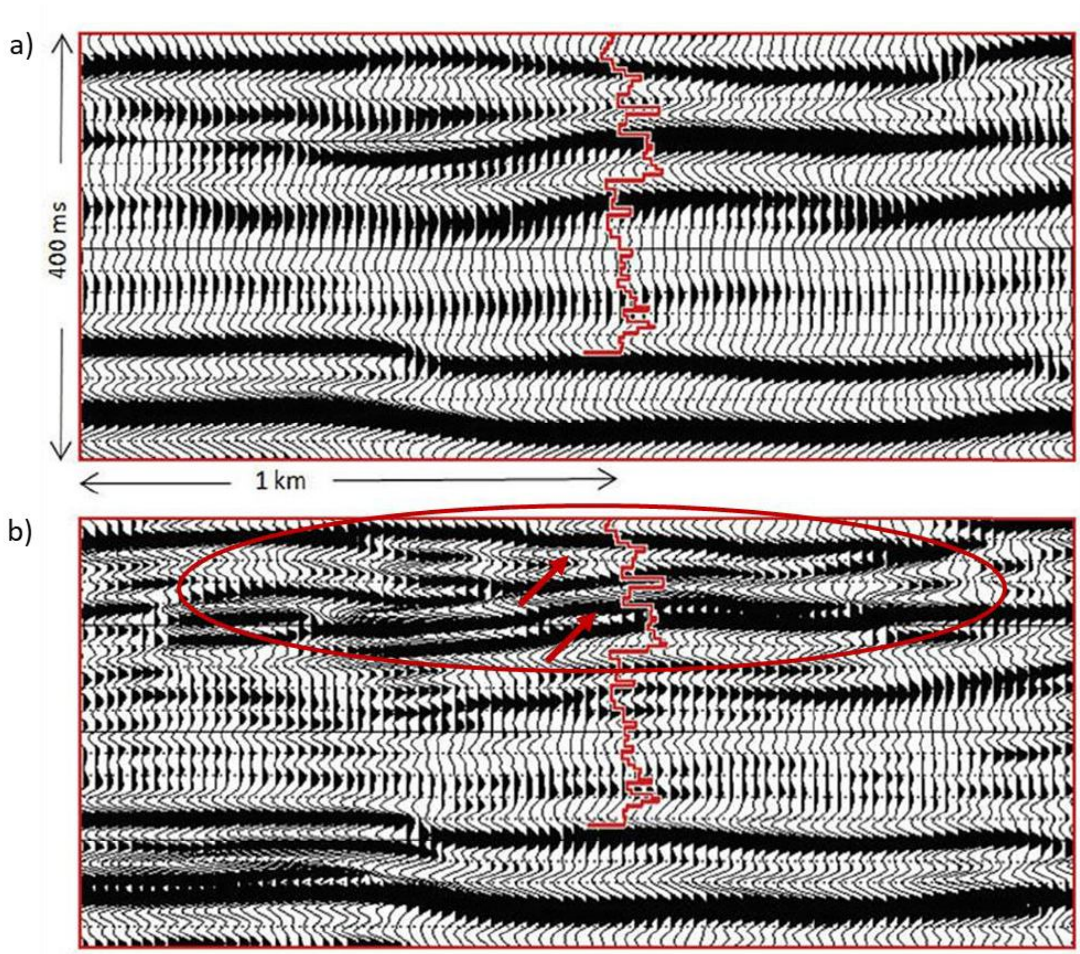

Figure 2: Comparison of segments of seismic sections (a) before, and (b) after customized processing. Notice the overall improved image seen after customized processing. The marked red arrows in the ellipse highlight two potential prospects for exploration that were not visible in original version. *(Courtesy, Satinder Chopra, Calgary)*

Side note - Inductive logic in seismic interpretation

Inductive logic is like 'lateral thinking' which is often deployed in brainstorming sessions where all options for solution are given credence including negative information. It is an imaginative and provocative way of thinking by looking at things sideways to get different perspectives. Traditionally, interpretation of seismic data uses mostly deductive logic, a top-down approach which starts with the premises of available information and facts to come to an inference. Inductive logic, on the other hand, is the inverse of deductive logic with a 'bottom-up' approach and an indirect and creative way for solutions. It starts with the inference, and reasoning begins with observations based on behavior or patterns and trends of things to provide a result (Heckmann, 2021). For example, in the RSM approach, the inference is made that more hydrocarbons remain in the area to be explored and proceeds with deviating/conflicting patterns/trends observed in data analysis which were discarded as negatives earlier in the deductive-based interpretation. Applying inductive logic in interpretation of seismic data is expected to promote imaginative ideas for creating new prospects from the available legacy data. The two logical approaches are opposite to each other but applied jointly, the interpretation results can be extremely effective and fruitful.

Lateral thinking is a skill to be learned and practiced by exploration geoscientists as a tool to conceive and reveal uncanny plays. Presently, most seismic interpretations are focused on 3D seismic data with rapt attention on extraction of attributes for reservoir characterization. Propensity of young interpreters focused tenaciously on the study of machine-based interpretive software packages may also be limiting the scope for development of skill for imaginative thinking, which is an important element in the art of cognitive interpretation for inventing new geologic concepts. Exploiting men and machines lucratively needs development of both, the human mind (brain) in front of the workstation and the software behind it. Rapid evolution in the sophistication of software, without commensurate progress made in the thinking process can be a drag on the realization of exploration goals. *G*

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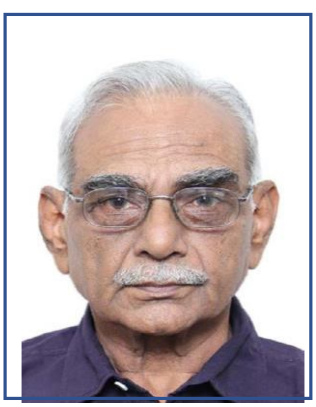

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Thereafter, as a freelance petroleum geophysicist, his involvement in the hydrocarbon upstream industry continues, building more than six decades of varied experience in diversified geologic basins, both in India and abroad. He has been a consultant to many E&P companies in India such as, Essar Oil, Mumbai, Hardy oil, Chennai, BPCL, New Delhi, GSPCL, Ahmedabad, and Germi, Gandhinagar. He has also been a member of the Advisory Council of KDMIPE, ONGC, Dehradun.

Apart from consulting, Shri Nanda has been a visiting faculty to the Delta Institute, Andhra University, Visakhapatnam, and MS University, Baroda, where he taught classes on interpretation and evaluation of seismic data to post-graduate students of exploration geophysics and petroleum geology. He has conducted several training courses and workshops in seismic interpretation for industry professionals at different work centres of ONGC, GERMI, Gandhinagar and at **Society of Petroleum Geophysicists** (SPG) biennial international conferences.

In 1987, he was honoured with the **National Mineral Award** by the **Government of India** for his pioneering contribution in the field of reservoir seismic**.** He received an **Honorary Life Membership** from **SPG**, India, in 2006 and an **outstanding geophysicist** award from **GEOINDIA** in 2008. In 2013, he was awarded the **B. S. Negi gold medal** for lifetime contribution in petroleum geophysics by **SPG, India.**

He has published several papers and authored a book entitled **"Interpretation and evaluation of seismic data for hydrocarbon exploration and production-a practioner's guide"**, published by Springer in March 2016. A second edition of this book containing additional topics, including **"Exploration and exploitation of unconventional reservoirs – role of seismic"** was published by Springer in April 2021.