In the E & P industry, it is teamwork all the way!

*A memoir by Gyanesh Chandra Katiyar**

Mr. Gyanesh Chandra Katiyar is an esteemed veteran of the Indian oil industry, having retired from ONGC in 2017 after a distinguished 38-year career. He began his journey with an M. Tech. degree from the University of Roorkee, now known as IIT Roorkee, before embarking on a diverse and fulfilling career at various ONGC work centers.

His initial role involved seismic data acquisition in Assam, northeastern India, where he dedicated eight years, followed by a seven-year tenure in Dehradun in a similar capacity. He then progressed to E & D, Dehradun, a leading center for seismic data interpretation, where he honed his skills in constructing accurate subsurface models by integrating geological, petrophysical, and engineering data. His next six years were spent in seismic data processing at the Western Offshore Basin (WOB) in Mumbai.

With a solid foundation in seismic data acquisition, processing, and interpretation, Mr. Katiyar naturally transitioned to reservoir characterization, as envisioned by ONGC management. He joined the ONGC Institute of Reservoir Studies in Ahmedabad, where he developed 3D geological models for active fields in the Cambay Basin to enhance hydrocarbon recovery through reservoir simulation. His tenure culminated as the Block Manager of the WOB, where he collaborated with asset teams to tackle exploration and development challenges.

Mr. Katiyar kindly accepted our invitation to pen his memoir, offering an honest reflection on his experiences and the intricacies of his career.

- *Satinder Chopra*

As I settled in to consider the request from GEOHORIZONS' Editor to write my memoir, it initially seemed like a daunting challenge. With nearly four decades of work and a mountain of memories, the idea of crafting a narrative from them was overwhelming. But, had my professional journey ever been devoid of challenges? Certainly not! No one's life is free from them. If it were, life might be quite dull.

Finding solace in these reflections, I mustered the courage to commit to writing. I resolved to start at a propitious moment, perhaps the next morning when I would be mentally prepared. And with that decision, my writing exercise began.

When I started reflecting on the modest start of my career, I quickly found my thoughts emerging from the mist, and my entire work history stood out clearly in my mind. I pick up the threads of my professional life from the time I joined ONGC, the leading national oil company of India. It unfolded in six distinct stages, each one teaching me and bolstering my confidence as a geophysicist.

After earning an M.Tech. in applied geophysics from the University of Roorkee (UOR), presently known as IIT Roorkee, I commenced my tenure with ONGC on November 9, 1979, at the Institute of Reservoir Studies (IRS) in Ahmedabad, taking on the role of Assistant Geophysicist (Surface). My initial assignment was in the 'technical database' section, where I gained knowledge about the operations of IRS's various labs, including the Core Lab, Water Flood Lab, Thermal Lab, Acidization, Artificial Lift, Polymer Flooding Lab, Miscible Flooding Lab, among others, as well as the Field Development Group. As a geophysicist, this presented an excellent opportunity to become acquainted with oil and gas reservoir management techniques.

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Initial phase: Field duty in Assam, northeast India

I had simultaneously interviewed for the positions of Geophysicist (Surface) and Geophysicist (Wells) at the Keshva Deva Institute of Petroleum Exploration (KDMIPE), ONGC, in Dehradun. As luck would have it, I was selected for the position of Geophysicist (Surface) and I soon joined the geoscience division at ONGC, Nazira, Assam. The division, under the leadership of Mr. Rameshwar Nath, sent us new geophysicists to Dimapur for seismic field operation training within the Naga Thrust Belt. As a member of Geophysical Party-23, we operated the analog PT-100 seismic instrument, utilizing Special Gelatine-80 and Seiscord as energy sources. Seiscord, being a line source, necessitated a length equal to a group interval for each shot and was buried about a meter deep. Mr. Nath also organized a series of lectures by senior staff on field parameters design, which proved invaluable to us newcomers. I might also mention that my first-aid training early on at the ONGC Academy in Dehradun came in handy when a field worker suffered a snake bite. We provided first aid and quickly transported him to a hospital in Dimapur, where he received prompt treatment and recovered in a few days.

In 1982, three seismic field parties (GP-8, 9, and 23) from Kolkata, were already operating in Assam under the leadership of Shri M. M. Goswami, head of the geoscience division. The same year, three additional parties, GP-32, 33, and 34, were introduced. I was assigned to GP-34, led by party chief Shri Jaya Prakash Bhargava, tasked with acquiring seismic data in the Sonari-Sapekhati area during the 1982-83 and 1983-84 field seasons. We commenced our acquisition parameter optimization experiment using the new DFS-V seismic instrument. Mr. Bhargava had forewarned us that no reflection events were visible on the seismograms. After suspecting an issue with the instrument settings and after verifying that they were correct, our field supervisor, Mr. Anand Gopal Pramanik, informed us during a visit that our experimental site was located within the pulverized zone of the Naga Thrust, which explained the lack of reflections. We relocated our experiment and successfully completed the optimization process. This was our first problem solving exercise, and a learning experience for us.

Soon after, I was transferred to GP-32, led by Mr. Mulk Bahadur Singh, and arrived at the camp on December 2, 1984, coinciding with the Bhopal Gas-Leak Disaster. During the 1984-85 field season, I worked in Nagaland's thrust-and-fold belt in the Merapani area and in the Patharkandi-Neelam Bazar area of Karimganj district in Cachar for the 1985-86 season. In Nagaland, we implemented static corrections based on geomorphological features like valleys, slopes, and hill-tops, supported by small-spread refraction surveys conducted in each zone to determine seismic velocity.

In the Patherkandi-Neelam Bazar area in Cachar, long-wavelength/high-frequency ground-roll was a significant issue due to the presence of higher velocity rocks just beneath the weathering zone. This led to the necessity for longer receiver arrays to cancel out ground-roll, which also resulted in the attenuation of higher signal frequencies. To address this specific type of surface noise, Mr. M. B. Singh implemented the innovative stack-array approach proposed by Nigel A. Anstey. The stack-array method proved effective in areas where higher velocity rocks are located directly below the weathering layer, which causes higher frequency-longer wavelength surface noise. The stack-array approach requires shooting in a straight line without any shot gaps, with the shot-interval being equal to the group-interval, shots placed between successive groups, and the detector array length matching the group-interval centered at the picket.

Another issue in the area was surface noise in the form of multiply-reflected refractions of the first-breaks within the weathering layer's wave-guide. This occurs when there is a high seismic velocity contrast between the weathering and sub-weathering layers, often due to sedimentary rocks situated right below the base of the weathering layer. This type of noise appears on seismograms as multiple trains of noise parallel to the first-breaks. In Cachar, it was noted that when the shot-hole depth exceeded a certain critical point, greater than 30 m, water would infiltrate the Special Gelatin (SG-80) sticks, preventing the explosive from fully detonating, which resulted in a very low-energy/high-frequency signature on the seismograms. This problem was addressed by encasing the charges in polythene bags before loading.

(As President SPG, addressing the delegates during the 2015 SPG Conference in Jaipur)

Additionally, it was found that optimal seismic energy transmission from the charge's blast occurred when it was embedded in clay rather than sand, as the latter likely absorbs more energy due to inelastic deformation within the unconsolidated shallow sand layer, even when this layer is below the base of the weathering layer. It was also noted that occasionally, the seismic reflection intensity in shallow pockets would inexplicably diminish. Upon further investigation, it was discovered that marsh gas, detected during shot-hole drilling in these pockets, was attenuating the reflections. The operational area was situated between the Patharia and Adamtila anticlines to the west and the Chargola anticline to the east, with the Neelam Bazar syncline in between. The anticlines are related to thrusts, featuring steep westerly limbs, necessitating long spreads with smaller group intervals and a high number of channels to capture reflections from steeply dipping reflectors at greater offsets.

It was interesting learning about the practical problems encountered during seismic data acquisition in difficult terrains, which the northeastern part of India is known for. The takeaway from my experience in Assam and Nagaland was that once the problem is identified, investigate the causes, and look for the solution in terms of the subsurface geology or the geophysical equipment being use. This period represented my first stint in the northeastern part of India, which had ended.

Phase two: Northern region office, Dehradun

In July 1987, I was transferred to the northern region office of ONGC in Dehradun, now restructured as one of the Frontier Basins. My assignment was in GP-38, operating in the thrust-and-fold belt of the Himalayan Foothills. Under Party Chief Mr. N.D. Ghildiyal, we surveyed the Dhanaura Anticline during the 1987-88 field season. We aimed to comprehensively map the anticline within one season, aligning strike lines and dip lines at right angles wherever feasible. The seismic system utilized was the SN-328, a telemetry seismic recording system with sign-bit technology. For drilling shot-holes in the Middle and Lower Siwalik formations, as well as the Lower and Upper Dharmsala formations, portable mechanical rigs were employed. Multi-hole shot patterns were implemented in the Upper Siwalik formation, characterized by hard Proterozoic quartzitic boulders within unconsolidated to semi-consolidated clays. In regions with Upper Siwalik formation, we sometimes had to manually dig shallow shot-holes. The following field season in Hamirpur presented the Upper Siwalik formation with calcite-cemented quartzitic boulders, necessitating the use of pneumatic drilling rigs with slow rotation due to the formation's hardness, achieving a drilling rate of only 1 m per hour. In the Himalayan Foothills, we applied the first-break static correction method, adjusting sub-weathering velocity according to the geological formations beneath the weathering layer base, such as unconsolidated clays of the Recent, Upper Siwalik, Middle and Lower Siwalik, Lower and Upper Dharmsala, and even Proterozoic slates beyond the northernmost thrust in the Solan-Sarahan area. Mr. H. S. Gharpure created a program to calculate static corrections on a programmable calculator.

In 1990, Mr. A.G. Pramanik, Head of the Frontier Basins, established the Geo-Technology Cell (GETEC), tasked with disseminating geophysical literature to the region's geoscientists. GETEC was also responsible for designing and optimizing seismic field data acquisition parameters, quality control of seismic data, and conducting in-house training. I was part of this team. Mr. B.V.S.S.R. Murthy and Mr. Sunil Sharma developed a computer program for the automated calculation of static corrections, shot data, and reel information. This program was integrated with the mainframe computer at GEOPIC, the biggest computing facility of ONGC, allowing for automatic data entry, a process further refined in collaboration with Mrs. Pragati Mitra from GEOPIC. The implementation of this computer program significantly reduced the time required to interface field data with the mainframe computer. The Society of Petroleum Geophysicists (SPG) organized a training called '*Computer Application in Seismic Field Data Acquisition*' based on this program. GETEC hosted numerous in-house training programs. Among these was a course titled '*Geological Primer for Geophysicists*,' led by Mr. Jokhan Ram. Following the classroom sessions, he conducted field trips for the participants across two routes, one towards Mussoorie and another around the Mohand area near Dehradun.

In the Frontier Basins, Mr. N. K. Verma, Jr., and I were tasked by Mr. Bal Krishna Verma with interpreting the refraction data of the Satpura basin. Previous interpretations suggested a shallow basement depth of only 500 m, making the basin less attractive for hydrocarbon exploration. Since the refraction data could not be retrieved from the field tapes, we analyzed the first-breaks from the available paper prints of the refraction hodographs.

(At the media interaction during the 2015 SPG Conference; seated from right to left are Mr. D. K. Saraf, the then CMD ONGC, Mr. T. K. Sengupta, the then Director (Offshore), ONGC, Mr. A. K. Dwivedi, the then Director (Exploration), ONGC, and Mr. Katiyar)

We obtained a geological map of Indian sedimentary basins with an overlay of the Bouguer gravity anomaly from Mr. D. P. Verma of the geophysics division at KDMIPE. A detailed examination of the Bouguer gravity anomaly map, particularly of the Gondwana Basin of South Rewa, revealed that the Satpura Basin also exhibited an increasing Bouguer anomaly from south to north (approximately 80 mgal), suggesting that the basin's deepest point was in the north, where it abuts the Narmada-Son lineament. The presence of intra-sedimentary sills was misleading the interpretation of the refraction hodographs, indicating an apparent basement depth of only 500 m. We referenced an SEG monograph on refraction data interpretation, which included a case study from Libya where similar misinterpretations occurred due to intra-sedimentary sills. The monograph recommended calculating the rate of attenuation of the first-breaks per wavelength. In cases with intra-sedimentary sills, this rate was significantly higher due to energy leakage into deeper sedimentary formations, compared to the true basement. Integrating this data, we predicted a basement depth of over 3000 m in the northern part of the basin, which was later confirmed by drilling. The basement in the Satpura Basin is igneous, unlike the common meta-sedimentary Bahraich. After spending twelve years in the field acquiring seismic data, it was time for a change.

Phase three: E & D, Dehradun

In July 1994, I transferred to the Exploration and Development Directorate (E&D), where I worked under the guidance of Mr. Jokhan Ram, Mr. I. N. Pande, and Dr. Pradyut Kumar Bhowmik within the Mumbai and Southern Regional groups. There, I learned manual seismic reflection data interpretation from Mr. Vishambhar Singh and received comprehensive guidance from Mr. Jokhan Ram. The E&D Directorate provided a dynamic environment for the growth of a geo-scientist's knowledge and a synergistic exploration perspective. We mapped the WO-16, B-193, and Ratna structures in India's western offshore region.

In 1995-96, we received a proposal from Mr. B.K. Bose of WOB to conduct an ocean-bottom-node (OBN) 2C-3D seismic survey over the entire Mumbai High field. Mr. Anand Prakash and I reviewed the proposal and recommended it to our group head, Mr. Jokhan Ram, who then informed the Head of E&D Directorate. At that time, as many oil fields globally were entering a rejuvenation phase, a 3D seismic survey became essential for detailed reservoir characterization. The 3D seismic data of the Mumbai High field continues to be used for reservoir characterization and the strategic placement of horizontal wells to tap bypassed oil and identify new exploratory targets.

(With the representatives of various societies at the Global Affairs Committee during the 2015 SPG Conference)

Mr. R. Venkatrangan tasked us with preparing the National Seismic Programme on a fast track. We suggested conducting east-west and north-south reconnaissance grid seismic surveys, using portable bunkers for crew accommodation, vibrators with high peak-force as the energy source, and a hybrid telemetry seismic recording system. These lines were planned to align with east-west offshore seismic lines and supplemented by transition zone seismic surveys.

My six years spent at E & D helped me understand and appreciate interpretation of seismic data and how it aims to construct an accurate subsurface model with the integration of geological, petrophysical, and engineering data. It was then time for me to go to my next phase.

Phase four: WOB, Mumbai

In July 2000, I was transferred from the E&D Directorate in Dehradun to the Western Offshore Basin (WOB), Mumbai.

At WOB, I joined the Special Processing Group at the Seisdata Processing and Interpretation Centre (SPIC), ONGC, Panvel, which specialized in AVO analysis, VSP data processing, and acoustic seismic inversion. The group included Mr. Vinod Kumar Vaid, Mr. Om Prakash Singh, and was supervised by Mr. Ansuya Prasad Pant. Mr. Kishore Jyoti Roy Burman, Chief Geologist at WOB, recommended performing seismic impedance inversion on 2D seismic grid data of the Vasai East area, using data from 4 to 5 drilled wells. Mr. Nagarjuna executed the impedance inversion, applying a strategy that projected the drilled well data onto the nearest seismic line, along the strike direction. The inverted seismic lines were printed at the same vertical scale as the standard seismic lines, facilitating easy comparison of the acoustic impedance response. The integration of these seismic impedance lines with subsequent drilling in the area led to the discovery of the new oil field in Vasai East, east of the existing Bassein gas field.

Additionally, the Special Processing Group tackled the challenge of optimally locating wells in the platform area of the Mumbai High North field. Mr. Vinod Kumar Vaid performed the impedance inversion, and we correlated the acoustic impedance results with core data in collaboration with Dr. Alok Dave at the Regional Geology Laboratory, ONGC, Panvel. This collaboration led to the recommendation of optimal well locations. The success of these wells prompted the assignment of the reservoir characterization of the entire Mumbai High North field to a multi-disciplinary team, which included members from both WOB and the Mumbai High Asset.

In 2002, the SPG International Conference and Exposition took place at Hotel Taj, Mumbai, presided over by Mr. A. G. Pramanik, the second President of SPG. The event showcased virtual reality technology for the oil and gas industry, leading to a decision by the WOB and Asset Management, under the dynamic leadership of the then CMD ONGC, Mr. Subir Raha, to establish two virtual reality centers: one at Vasudhara Bhavan, Bandra East, Mumbai, and another at SPIC, Panvel. Mr. Samiranjan Biswal, Head of SPIC, and I were tasked with setting up these centers. We overcame numerous challenges related to space selection and allocation at both sites, thanks to the supportive higher management and the generous cooperation of our colleagues, completing the centers within the designated timeframe. The Vasudhara Bhavan center was dedicated to G&G studies and the placement of horizontal/deviated development wells for the Mumbai High, Bassein, Satellites, Neelam, and Heera Assets, while the SPIC, Panvel center focused on exploration applications by the WOB.

Intriguingly, during the same year, I served on the subsurface team for the Mumbai High Asset. Mr. Kharak Singh was the Asset Manager, and Mr. J. L. Narasimham was the subsurface manager. My responsibilities included managing the virtual reality center at Vasudhara Bhavan, known as the Third Eye Centre (TEC), organizing expert training for the TEC multi-disciplinary team, and providing geophysical insights through the team of geophysicists in the Mumbai High Asset.

Additionally, we had the 2C-3D seismic data reprocessed by Paradigm Geophysical at their Mumbai center. Mr. Mahendra Pratap, recently transferred from Jorhat, Assam, oversaw quality control for the data processing, while Dr. S. Ramanan led the subsurface team.

The subsurface team at Mumbai High Asset considered using a micro-gravity survey to monitor the progression of injected water for secondary oil recovery. This technique was already employed to track the movement of up-dip injected water in a roughly 80 m thick gas reservoir in Alaska. The Mumbai High field case, with its thin limestone layers containing oil at 0.82 g/cm^3 and injected seawater at a density of 1.025 g/cm^3, showed that the water did not move as a single front. Additionally, the necessity of ship-borne micro-gravimeters in offshore areas could lead to less accuracy due to wave and tide-induced gravimeter height variations.

(While visiting the SPG booth during the 2017 SPWLA-India Symposium and Exhibition at Mumbai with the then Director (E), ONGC, Mr. A. K. Dwivedi, the then President, SPWLA, Mr. R. K. Pandey, the then President, SPWLA, Dr. Luis Quintero, and Mr. Chaman Singh, the then ED. ONGC)

Another concept to check was to assess if a 3C-4D seismic survey conducted in a 100 km^2 pilot project in the Mumbai High North Field could aid in detecting bypassed oil. Various agencies performed seismic modeling to ascertain if the changes in P-Wave and S-Wave impedance due to alterations in oil saturation from initial to current levels would be discernible, especially in thin oil-bearing limestone layers interspersed with shale. Unlike the thick clastic reservoirs in the North Sea where oil moves vertically in response to production, here the oil migration is more lateral. Furthermore, the implementation of a life-of-the-field 4C-3D project in this heavily instrumented offshore field was deemed impractical due to significant ship traffic and field instrumentation. Consequently, a decision was made to execute a pilot OBN-based 4C-3D seismic API over a 100 km^2 area in the Mumbai High North (MHN) field to identify zones of bypassed oil through improved reservoir characterization. This pilot was conducted under Mr. Apurva Saha's leadership as the Asset Manager of the Mumbai High Asset, with Mr. S. K. Verma heading the subsurface team. Subsequently, in 2016, Mr. Uma Shankar Deo Pandey, the Chief of Geophysical Services, and I, serving as the Basin Manager, WOB, commissioned the 3C-3D Processing Group of Western Onshore Basin, Vadodara, to reprocess the acquired 4C-3D seismic data from the MHN pilot project. The 3D-3C Team at WOB, Vadodara, exceeded our expectations by not only providing detailed reservoir characterization but also identifying the zones of bypassed oil, fulfilling the pilot project's initial goal.

After having been exposed to impedance inversion and reservoir characterization exercises, setting up and managing virtual reality centers, and overseeing the reprocessing/reservoir characterization of multicomponent (4C-3D) seismic data for the MHN field, it was now my chance to explore more that was in store for me.

Phase five: IRS, Ahmedabad

In 2009, I was transferred to the Institute of Reservoir Studies (IRS) in Ahmedabad, marking my second tenure there. As the head of the Geology and Geophysics Group (G&G Group), I worked alongside Mr. Rajiv Banga, GM (Geology). The IRS was led by Dr. Rajendra Vitthal Marathe, who proposed in a meeting that our group should undertake seismic impedance inversion of the Limbodra field in the Cambay Basin, which had over a hundred drilled wells. I delegated this task to Dr. Ashok Chandra Gupta, advising him to compile all drilling and production data from the existing wells. Our analysis of facies variations, which influence production, guided the placement of future development wells in the field. Likewise, Mr. Naresh Kumar Khatri and his team's seismic inversion work in South Limbodra effectively distinguished between the non-reservoir cemented sands and reservoir-quality sands, thereby preventing the drilling of unproductive development wells.

The primary focus of the IRS's G&G Group was to create 3D geological models of active fields to support reservoir simulation and their further redevelopment, aiming to maximize ultimate recovery.

An excellent example of synergy in exploration and development is the new discovery east of Gandhar field. During an Asset Development Board meeting for the Ankleshwar Asset, Mr. Onkar Nath Gyani of IRS was set to propose two development locations. I was also present in the meeting where Mr. Gyani briefed Dr. Marathe about these locations, and Dr. Marathe suggested Mr. Gyani consult with me. Mr. Gyani expressed his intention to propose the locations based on reservoir simulation, yet he had reservations about the accuracy of the reservoir facies. Dr. A. C. Gupta performed a rapid seismic impedance inversion to delineate the facies, suggesting a slight relocation of the southern site to a region with better facies and to abandon the northern site due to potential shaly facies. This process unexpectedly revealed sandy facies extending eastward, past the known boundary of the pool. Mr. Harjinder Singh, Ms. Bhumija Agrawal, and their team conducted a thorough analysis of this eastern region, which led to the proposition and approval of an exploratory site. The drilling of this site yielded a significant oil flow upon testing, and Mr. A. K. Gupta, the Asset Manager for Ankleshwar, swiftly transitioned the well to production within a week. The success of this discovery can be attributed to the collaborative approach championed by Dr. Marathe.

The Balol-Santhal fields, located in the North Cambay basin, are known for their heavy oil reserves. In the early 1990s, Mr. U. S. D. Pandey pioneered the first 4D-seismic survey in the Balol field. Subsequently, Mr. Asit also worked on the Balol field while he was in the G&G Group of IRS. The Santhal field, currently producing heavy oil, employs up-dip in-situ combustion. The flue gases generated from burning the heavy oil propel the oil down-dip towards the eastern production wells. Understanding the combustion front's down-dip progression is crucial for positioning new production wells. To achieve this, Mr. Naresh Kumar Khatri and Ms. Archana Sharma performed seismic impedance inversion on the base 3D seismic data, gathered before production started, and on additional 3D seismic data collected after a significant period since the commencement of oil production and in-situ combustion.

(Presenting a bouquet to Mr. Satinder Chopra while delivering the Continuing Education Course during the 2015 SPG Conference at Jaipur)

Biot-Gassmann modeling revealed a 20% change in acoustic impedance pre- and post- in-situ combustion, making it an exemplary case for 4D-seismic monitoring of the reservoir. However, executing a 4D-Seismic project is challenging due to the need for consistency in field geometry, detector placement, and data acquisition and processing hardware/software. Given the region's agricultural focus on cash crops and the substantial compensation demands for crop damage from vehicle traffic and drilling/blasting activities, a more feasible approach was to perform seismic inversion on two separate seismic data sets and compare the resulting impedance volumes to track the combustion front's progress, which should be evident as the acoustic impedance in the production zone decreases by 20% following in-situ combustion.

Monitoring the movement of an in-situ combustion front can also be achieved by conducting a micro-gravity survey over the heavy oil field. This is due to the reservoir's density change of approximately 0.25 g/cm^3. Assuming the heavy oil has a density of 0.90 g/cm^3, connate water a density of 1.03 g/cm^3, connate water content of 11%, porosity of 30%, and post in-situ combustion, the conversion of all heavy oil and connate water within the 30% pore space to flue gas with a density of 0.1 g/cm^3, this change should be detectable by the survey. Micro-gravity surveys are environmentally friendly and can be conducted in areas where logistical issues prevent seismic surveys. The technique relies on a significant density contrast between the target and its surrounding environment, which can be identified by the survey. The Santhal micro-gravity survey project was executed by Mr. Prabhakardu and his team from the geophysics division of KDMIPE, ONGC, Dehradun.

The oil-producing shallow sands in the Ankleshwar area, located approximately 150 m below the surface, present an intriguing challenge. Initially discovered through traditional surface hydrocarbon seepages, these sands are now actively producing and have sparked exploratory interest. To delineate these sands, one could either employ a micro-reflection seismic survey with a small spread-length, group interval, shot interval, and charge size, coupled with high-frequency geophones and a higher seismic signal sampling rate, or alternatively, a more cost-effective micro-gravity survey could be utilized. This approach is similar to the high-resolution seismic surveys used for coal seams and is viable because the shallow oil-bearing sands have a lower density due to the reduced density of the sands compared to the surrounding clay layers and the replacement of water by lighter hydrocarbons in the pore spaces. Mr. Prabhakardu and his geophysics team at KDMIPE also undertook this project.

With the increasing maturity of exploration and production (E&P) in the Cambay basin, the focus has shifted to the thick, tight silty reservoirs. The potential of methane gas within thick coal seams is also being considered as a coal bed methane (CBM) resource. These coal seams could serve as oil reservoirs, especially over the crestal parts of structural highs where they exhibit significant fracture porosity, as evidenced by oil flow from fractured coal in the WOB.

(Presenting a bouquet to Dr. Jessie Davey, a G & G and Reservoir expert from Australian School of Petroleum, University of Adelaide, at Mumbai in April 2016)

Additionally, the exploration for Mesozoic reservoirs on the eastern flank of the Cambay basin is gaining interest, as they are expected to be found at relatively shallow depths beneath a thinner trapping cover. The Mesozoic sandstones, known for their excellent sorting, porosity, and friability, are visible in Pavagarh, where they have been used to construct monuments with intricate carvings.

My tenure at IRS helped me learn and appreciate firsthand how a collaborative approach to seismic reservoir characterization can be effectively used for successful drilling. In areas where seismic surveys cannot be acquired due to logistic issues, micro-gravity surveys could be utilized. Perhaps, after this very useful experience, it was time for me to move on.

Phase six: WOB, Mumbai

As it unfolded, phase six of my ONGC career comprised my role in different positions, all in the WOB.

In early 2012, I was assigned to WOB as the Block Manager for the Western Offshore Block, with Mr. Pradyut Kumar Bhowmick serving as the Basin Manager. Discovered in 1976, the NBP (N B Prasad-D1) field in the WOB is located about 200 km from Mumbai in water depths of about 85-90 m. This field is characterized by a distinctive reservoir structure where thin, reefal porous carbonate layers are oil-bearing, capped by tight carbonate layers. Conversely, thick, porous carbonate layers typically lack oil, likely due to the absence of an up-dip seal. Mr. D. K. Dasgupta, the Area Manager, proposed that a vertical well scheduled for drilling in the NBP field by the Bassein and Satellites Asset be extended by an additional 100 m to test the lower pay zone, which he believed to be oil-bearing based on nearby well logs. After consulting with Dr. Mahendra Pratap Singh, the surface manager of the Bassein and Satellites Asset, who concurred with the idea, we forwarded the approved proposal from Mr. Bhowmick. The drilling into the lower pay zone revealed continuous oil-bearing strata, leading to an additional 200 m of drilling and comprehensive advanced logging. This resulted in a significant increase in the yield from the lower pay zone.

Mr. K. Vasudevan and his team re-evaluated the basal clastics overlaying the basement in the Mumbai High field, identifying it as a new and significant prospect. The Mumbai High basement is a patchwork of granitic and metamorphic rocks, with granitic inclusions contributing clean sand to the basal clastics. For oil to be present in basement fractures, certain conditions must be met: the location should be a pronounced high at the basement level, as seen in the eastern Mumbai High North and B-119/121 areas, and there must be an effective seal overhead. In other regions, oil from basement fractures migrates into the basal clastics when no effective seal is present.

In July 2013, I was appointed as the Block Manager for the Cambay-Tarapur Block in Vadodara. The Cambay basin offers geoscientists an excellent learning environment with its diverse geological features, ranging from shallow sands to oil in fractured igneous rocks, heavy oil in the north, light oil in the south, and unconventional reservoirs including oil in fractured shales, tight formations, coalbed methane, and shale oil. At that time, Mr. S. K. Das served as the Basin Manager. I proposed to the Regional Geology Laboratory (RGL) in Vadodara to carry out a geochemical survey in two NELP blocks, one at the northern edge and the other on the western flank of the Cambay basin, to support 3D-seismic interpretation through the integration of geochemical anomalies. We recommended implementing a 3C-3D seismic survey in the Kalol and Gandhar fields to enhance reservoir characterization. This approach proved beneficial in identifying productive channel sands and preventing the drilling of non-productive wells. 3C-3D seismic data, by integrating P- and S-wave information with DSI logs, offers superior reservoir characterization. Utilizing this method, a non-productive development well in the Ahmedabad Asset was successfully redirected in near real-time into a channel sand formation.

On 1st January 2014, I took over as the Basin Manager for the Cambay Basin.

Regarding the Aliabet field in the Gulf of Khambat, which was initially identified using 2D seismic data, we advised conducting a 3D seismic survey as part of the field development strategy to characterize the reservoir more precisely before commencing the drilling of development wells, thereby avoiding the expense of non-productive wells. 3D seismic reservoir characterization provided a clearer understanding of reservoir heterogeneity, leading to more effective field development and the avoidance of non-productive wells.

In the Gandhar West area, some sands exhibited high electrical resistivity, which could indicate oil-bearing sands. However, production testing yielded fresh water at a prolific rate. The presence of this fresh meteoric water in Gandhar west area suggested that the basement high from which these sands are derived exists further to the west of the Gandhar west field.

During 2014, three NELP Blocks were brought into production in the Cambay Basin. Multidisciplinary teams, including members from the basin, the IRS, and the Institute of Oil & Gas Production Technology (IOGPT) in Panvel, were assembled to expedite the development plans for these newly discovered fields.

The Cambay Basin contains thick siltstones with low electrical resistivity, yet they contain oil. Advanced logging suites are necessary to identify the presence of oil within these reservoirs. Hydro-fracturing with appropriate power is essential for production from these formations. The existence of natural fractures can significantly enhance production. To determine the density and orientation of these natural fractures, 3C-3D seismic surveys are beneficial.

The 3D seismic spread geometry was planned as an asymmetric split-spread to ensure clear imaging of both shallow and deeper reflectors. This approach aims to detect the presence of potential Mesozoic rocks beneath the relatively thinner traps on the eastern flank of the Cambay Basin.

In April 2015, I was transferred from Vadodara to WOB to assume the role of Basin Manager.

At WOB, during my visits to SPIC in Panvel, I stressed the importance of integrating the processing center with the Virtual Reality Centre at SPIC. This integration is crucial for thorough quality checks of the 3D velocity volume before depth migration. Collaborative efforts at the Virtual Reality Centre, Priyadarshini, were routine. An example of the success of this strategy is the reopening of a NELP exploratory block.

Regarding the recording of advanced log-suite in exploratory wells, our philosophy at WOB was to selectively record the necessary advanced logs to ensure that critical information was gathered during the exploratory phase itself. This method not only saves time and money but also lays the groundwork for future exploratory leads by enhancing the understanding of the factors influencing the absence or presence of hydrocarbons in a specific exploratory well and incorporating advanced log data into reservoir characterization.

(In discussion with Mr. U.S.D. Pandey, HGS-WON, and Mr. P. B. Pandey, the then ED, ONGC, during the Joint Annual Technical Meet organized by SPG-APG in November 2014)

Employing this strategy, we discovered gas in an exploratory well located at the westernmost edge of the Mumbai High field, within a NELP block, at a shallow depth interval of 932-938 m. In this well, despite the direct fluid sampler failing to recover any gas, the P-wave and S-wave logs exhibited textbook behavior indicative of a probable gas zone, namely a significant reduction in P-wave velocity without a corresponding decrease in S-wave velocity. Based on this observation, the zone at 932-938 m was conventionally tested and yielded commercial quantities of gas! Similarly, commercial gas and condensate were produced in a well NNE of Mumbai High, in the Kutch NELP block, following well testing directed by full-wave sonic log analysis. In fact, full-wave seismic impedance inversion becomes feasible with the availability of full-wave sonic logs. The full-wave sonic log from a well provides a complete elastic characterization of the formations, and trendline analysis of the Poisson ratio enables explorationists to identify the pore fluids present in various lithologies, such as siltstones and complex carbonate reservoirs, where the rock's compactness depends more on the original facies and diagenetic episodes than on the geological age of the formation. For instance, in one of the drilled wells, the Lower Bassein limestone showed a Poisson ratio as low as 0.12, akin to that of gas-charged sandstone. Upon production testing, the formation yielded oil with a 25% lime sand grain content, indicating that the productive Lower Bassein formation was almost equivalent to loose lime sand.

In the B-193 field, it was necessary to determine if two compartments, separated by a fault, were in communication. This was resolved by analyzing the fingerprints of oil samples from both compartments, which were found to be identical, confirming their communication.

Likewise, geochemists at RGL, Panvel identified three active source kitchens for hydrocarbons: the Tapti-Daman Low, an area to the NNW of Mumbai High, and a low between Mumbai High and NBP field.

RGL, Panvel installed a cutting-edge whole core CT scanner with 5-micron resolution to produce high-resolution 3D digital images of cores. These images were analyzed for sedimentary features, pore size, pore-throat distribution, porosity, permeability, and possibly diagenetic episodes.

Drilling beyond 3000 m poses the risk of formation damage, such as fractures within the potential reservoir and the intrusion of drilling mud clays, leading to a permanent loss of the formation's permeability. Consequently, the formation may not respond during production testing. Another issue is the solidification of drilling mud-clay at the higher temperatures found at greater depths, which can be mitigated by adding suitable additives to the drilling mud.

In offshore operations, even highly productive exploratory wells may be abandoned after production testing. Initially, the total reserves must be evaluated before developing a plan. Reusing a producing exploratory well necessitates installing equipment like the mud line suspension system (MLS) at the start of drilling. Adopting this system has led to significant savings in time and money. These advancements in drilling technology, testing, and completion were actively researched and implemented by Mr. A. K. Vinod, Head-Geology, and his team at WOB.

Exploratory wells are monitored in real-time from a base office 24/7. This system detects drilling issues as they occur, allowing for immediate corrective actions, which leads to smoother drilling operations and prevents costly delays and overruns due to drilling complications. Particularly, the stress profile for a well about to be drilled is prepared based on the stresses encountered in nearby wells. This provides advanced knowledge for maintaining safe mud density to prevent formation fracturing and subsequent mud loss. Real-time monitoring of the drilling process can also help mitigate formation damage to some degree. However, drilling engineers often avoid under-balanced drilling due to the risk of blowouts. For this reason, non-damaging drilling fluids (NDDF) have been introduced for high-pressure, high-temperature (HPHT) wells as both drilling and completion fluids.

Significance was also placed on S-1 sand, equivalent to the sand deposited extensively in the Western Offshore during a regressive phase in the Miocene, as well as various limestone layers younger than L-II over the Mumbai High field.

The Ratna field was returned to ONGC in 2016 for the overhaul of rusted/damaged surface facilities, drilling of development wells, and resumption of production. A broadband 3D seismic survey covering an area of over 1000 km² was prioritized to ensure improved reservoir characterization and to increase the success rate of development wells.

For producing fields like the NBP, an Ocean Bottom Node (OBN) 3D seismic survey was planned to enhance reservoir characterization, guide the placement of new development wells, and explore deeper prospects.

In the Kutch offshore area, a gas discovery was made in a Jurassic formation within a NELP block during Mr. S. V. Rao's tenure, at a depth of approximately 5000 m. Drilling through over 2000 m of basalt to reach hydrocarbons in the Mesozoic rocks below required a firm belief in the project's potential. This discovery was confirmed by a second well drilled in 2015-16. However, it was necessary to drill through a trap thickness of over 2000 m, situated beneath a Tertiary sedimentary layer of about the same thickness. Drilling through basalt rock is a slow process, averaging about 1 m per hour, meaning only about 24 m could be drilled in a day, significantly increasing the cost of the well. An experimental deployment of a newly developed drilling bit in this well increased the drilling rate from the previous 1 m per hour to 2.5 m per hour, achieving a total depth of approximately 5500 m. In this well, commercial quantities of gas were discovered at a rate of about 450,000 cubic m per day in the Cretaceous formation, revealing a new viable play. Later, a drilling rate of about 4 m per hour in basalt was attained with improved drill bit technology, which has opened up extensive sub-trappean and within-trap territories for exploration, both offshore and on land.

In the Kutch offshore region, the trap top at the base of the Tertiary sequence was also targeted as an exploratory play. The preferred method for drilling this formation is using NDDF (Non-Damaging Drilling Fluid) mud to prevent formation damage and to conduct tests with clear fluid. Hydrocarbons discovered in this setup have unveiled a new play.

The Ministry of Petroleum and Natural Gas (MoPNG) in India commissioned a significant resource appraisal exercise for the producing basins, which was undertaken by ONGC. For both the Kutch offshore and onland, as well as the Kerala-Konkan region, gravity modeling was employed to determine the location of depositional centers and the thickness of source rock intervals, in coordination with available 2D regional seismic lines. The gravity modeling was conducted by the geophysics team at KDMIPE in Dehradun. It was revealed that, in addition to the existing data, the Gulf of Kutch has a sizable thickness of source rock interval.

Thus, as the experts in exploration consistently emphasize, the secret to success in exploration and production, especially in a mature basin, lies in the close collaboration among geologists, geophysicists, geochemists, reservoir engineers, drilling engineers, production engineers, and all other disciplines involved in the E&P sector. Theoretical bases, technology, concepts, modelling techniques keep growing, and therefore, more and more remote, and subtle exploratory plays become amenable to exploration and production. No one-up manship works in the E&P industry, it is teamwork all the way!!

I retired from ONGC in July 2017 after 38 years of service. My professional journey was filled with fascinating experiences, as previously mentioned, where I encountered challenges related to subsurface characterization of oil and gas reservoirs. I sought solutions through collaborative discussions, and we incorporated new technologies as needed, which brought additional value.

The oil sector is volatile, and the business carries inherent risks, yet my tenure at ONGC was unaffected by these factors. We stayed committed to our duties, executing them with dedication and teamwork. It goes without saying that I had the opportunity to work alongside outstanding colleagues, leaders, and mentors, whose confidence in me enhanced my capabilities as a geoscientist.

Reflecting on my career, I feel a sense of contentment, achievement, and joy.