Development of geophysics applications for oil and gas exploration in India – a historical ONGC perspective

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Abstract

In this centenary year of geophysics in India, we piece together the developments in surface geophysics for oil and gas exploration, from an ONGC perspective. We have considered this historical account in two phases, namely, the period prior- and post-independence of India. The developments have been spread over decade blocks, so that a systematic, yet broad stroke development patterns can be brought out. We begin our narration with the first gravity survey that took place in 1923, followed by another two years later, a survey campaign restarted in 1937 that led to the discovery of the Nahorkatiya oil field in Assam. Magnetic and seismic surveys were also introduced in the early part of the twentieth century, but exploration for oil and gas gradually started picking up post-independence of India. Once ONGC was born in 1956, a planned approach towards exploration in the country started, with the acquisition of gravity/magnetic surveys onshore, followed by seismic surveys. The discovery of commercial quantities of hydrocarbons in Cambay encouraged the exploration in other areas, both onshore and offshore. Thus followed the developments in all areas entailing digital recording instruments, and offshore seismic survey vessels, computerization for processing the seismic data, and interactive interpretation of the processed seismic data. The geophysical data formed a large input component of the data that led to the numerous oil and gas discoveries made by ONGC till date. The hard work, knowledge, and vision that the pioneering geophysicists of ONGC had demonstrated, yielded favourable results, interspersed with some setbacks, and again exploring and discovering oil fields. All this has been a fascinating journey for ONGC.

Keywords: geophysical surveys, gravity surveys, magnetic surveys, surface seismic surveys, 3D onland surveys, marine surveys, seismic data processing, interactive interpretation workstations (IIWS)

Introduction

2023 is a landmark year for Indian geophysics as it completes 100 years since the first geophysical survey was conducted on Indian soil. It is a proud feeling for every Indian geophysicist who has worked in India or has been associated in some way with the Indian geophysical journey. SPG has taken the lead in conceiving the idea of recognizing the completion of 100 years of geophysics as well as compiling an article on the historical development of geophysics in India. Writing such an article is not an easy task as there is large amount of information to be collated from outside the professional tenure of one generation of geophysicists. Still, for posterity, it is important to put on record how it all started on a clean slate and progressed thereafter. Such a compilation can serve as an inspiration for the young and upcoming geophysicists, and that is the motivation for compiling this article.

One can trace the earliest use of geophysics in India to a triangulation survey of the Indian peninsula carried out in 1800 (though proposed in 1799) for geodetic application. This triangulation survey was given the official name of 'Great Trigonometrical Survey' in 1818 (Wikipedia, 2023). But for the purpose of this article, we restrict

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our discussion about the historical application of surface geophysics to oil and gas exploration in India. Consequently, other references to geophysics applications have been eclipsed.

Though the first mention of the discovery of oil in India goes back to 1825, during the First Anglo-Burmese War (1824 – 1826), when a British officer reported about the observation of 'great bubbles of gas and petroleum' in the jungles of Assam, it took the British (colonial era) a few decades to finally get a commercial success when oil was struck in Digboi oil well no. 1, on 19th Oct 1889, producing 200 gallons of oil per day. This was the beginning of the oil industry in India.

Historically, the development of the oil industry in India can be considered in two distinct phases, namely, the period prior to independence, and the post-independence period.

Pre-independence period

Gravity surveys

The first geophysical survey for hydrocarbons was carried out in the Indus Valley in 1923 by Burmah Oil Company, a British oil company headquartered in Glasgow at the time. The instrument used for the survey was a torsion balance (Trehan, 2002), and the results indicated an anticline hidden under the alluvium. This was followed by another torsion balance survey carried out in Assam in 1925 at Bordubi, on the plains of Digboi by a two-man geophysical team from the Eötvös Geophysical Institute, Budapest, to study the concealed rocks. Later, similar surveys were also conducted in the Punjab (northern India) plains, which indicated Delhi-Lahore buried ridge considered the cause for water logging in the alluvium planes of Punjab.

After a gap of almost 12 years, these early surveys were followed with gravity surveys conducted by Burmah Oil Company again in the alluvial plains of Assam. A seismic survey was launched in during 1937-38 by a consortium of companies (Burmah Oil Company, British Petroleum (then Anglo-Iranian Oil Company), and Shell), which continued till 1939 in the alluvial areas of upper Assam.

Elephants being used in a seismic survey in Brahmaputra Valley in 1937-38.
(Photo courtesy: Dr. P. Chandrasekaran)

The campaign comprised gravity surveys first to locate more promising areas where seismic surveys (discussed later) were acquired and discovered the prolific Nahorkatiya oil field in 1953, first discovery in independent India (Bhave, 2002).

The outbreak of World War II halted the geophysical activities in India and led to the second lull from 1939 to 1948, i.e., till just a year after India gained independence.

Magnetic surveys

After the invention of the magnetometer by Carl Friedrich Gauss in 1933 (based on the measurement of variations of the Earth's magnetic field), magnetic surveys became useful for a variety of objectives including search for minerals, and oil and gas. The field work of the first magnetic survey in India was undertaken during 1901 to 1913 (Mishra, 2016) with field stations distributed at 30 to 40 miles apart over undivided India, Myanmar (Burma) and Sri Lanka (Ceylon). The results were published in the form of charts, contoured manually and tables. The second magnetic survey was carried out in 1930.

Seismic surveys

The seismic reflection surveying was developed in the US in the early 1920s by Maurice Ewing and his colleagues Reginald Fessenden and John Webb. The method consisted of sending seismic waves into the ground or water and recording the reflected signals from the subsurface rock layers to image geological structures, resulting in the development of the reflection seismograph. These surveys found their application in India after a couple of decades.

Post-independence period

After India gained independence, plans were drawn up by the Standard Oil Company (Stanvac) of USA for oil exploration in the Bengal Basin (both India and East Pakistan). In the early 1950s, both magnetic and gravity surveys were conducted in many areas in West Bengal, and the integrated interpretations were carried out, to verify the indications seen earlier with gravity surveys. In fact, in December 1953, a joint exploration program with 25% participation by the Government of India and 75% Stanvac share was signed, and extensive ground gravity and seismic reflection surveys were signed out during 1954-56 in the Bengal Basin. While the Indo-Stanvac project was going on in the Bengal Basin in 1955, the geophysical department in Geological Survey of India (GSI) sent a gravity-magnetic field party to Jaisalmer, Rajasthan led by Mr. B. S. Negi, an eminent geophysicist (who later became Chairman of Oil and Natural Gas Commission, and in whose name the SPG named its highest honour, the SPG Medal).

Birth of ONGC

It would be very appropriate to mention here briefly the circumstances that led to the birth of the Oil and Natural Gas Commission (ONGC), and the ideals followed by its founders. In 1851, the Geological Survey of India (GSI) was established at Calcutta (now Kolkata), India. Its prime objective was to conduct surveys for geological mapping and discover economic minerals. The enthusiasm and the far-sightedness of the government of India to find the strategic liquid mineral (oil) in the country led it to create an oil and gas division within GSI in 1955. In August 1955, the short-term geophysical division in GSI became the Oil and Natural Gas Directorate and was set up with headquarters at Dehradun. Mr. A.M.N. Ghosh, who was a senior superintending geologist with GSI was appointed its director. With a small group of officers and staff from GSI, and renting Patiala House (now Tel Bhavan), the Directorate made its humble beginning in Dehradun.

As no interest was shown by the western private oil companies for hydrocarbon exploration in India, a delegation led by Mr. K. D. Malaviya, Mr. A.M.N. Ghosh, Mr. H. R. Dewan, and Mr. M. B. Ramachandra Rao visited the USSR in the year 1955 to study the oil exploration methods being followed there and ascertain the availability of relevant geophysical and drilling equipment. Subsequently, a team of Soviet experts was invited to India, so that the members could study the conditions, have consultations with Indian geoscientists and then suggest a plan for oil exploration in the country. The plan suggested by the Soviet team had some key components that included carrying out exploration in several basins simultaneously, a 5-year plan for exploration consisting of a program for geological, geophysical and drilling investigations, and establishment of a commission in place of the Oil and Natural Gas Directorate, which could effectively and efficiently address the issues related to organization, management, operations and finance. This plan was approved by the Government of India, and the Oil and Natural Commission (ONGC) was set up with Mr. K. D. Malaviya as its Chairman, and Mr. A. M. N. Ghosh as Member (Technical) and Mr. A. C. Bose as Member (Finance).

ONGC was thus born on 14th August 1956. It was charged with the responsibility of working as a government department in recruitment, procurement (machinery and equipment) and following the formalities of Union Public Service Commission (UPSC), Planning Commission and Directorate General of Supplies and Disposal. The first responsibility for ONGC was to recruit competent technical degree holders as apprentices and make them undergo intensive training in India, as well as depute them on appropriate trainings abroad when required.

ONGC also organized three different directorates, for geology, geophysics, and engineering. The engineering directorate recruited experienced drillers from Assam Oil Company and many fresh mechanical engineers, in addition to getting equipped with four drilling rigs.

All the above initiatives taken by ONGC were aimed at acquiring technical knowhow and practical experience for which significant investments were made. Very interestingly, it was resolved not to invest on construction of office space or provide elaborate amenities to employees till oil was found in the country. Such was the vision and wisdom of the founders of ONGC, and their magnanimity to condone mistakes made by the apprentices to inspire them so that the ultimate goal could be achieved. And their foresight paid off well eventually.

The first batch of apprentice geologists and geophysicists for ONGC was recruited through UPSC in 1956. The apprentices received training both in classrooms at Calcutta and in the field. The geophysicists working for Stanvac (later Exxon) in the Bengal Basin helped immensely. The trainees would get real seismic records on paper (wiggle traces) for correlation of reflection events and calculating their reflection times to prepare maps of different geologic horizons. At the end of the first nine months, these trained geophysicists were dispersed to lead and guide operation of geophysical surveys to be carried out. Nine gravity-magnetic and six seismic field parties were raised to begin field operation in different basins of India.

These geophysicists would work in the field for eight or nine months and then return to their headquarters for the off season for data interpretation and writing reports. The gravity-magnetic parties would analyze their acquired data and prepare Bouguer gravity and magnetic anomaly maps providing the basement structural configuration. Some of the equipment being used by the gravity-magnetic field parties were the Russian gravimeters GAK-3M, and later the improved version of highly sensitive astatized Worden gravimeter. Similarly, the initially used magnetometer M-2 manufactured by Geologorazvedka Leningrad, were replaced by Askania vertical magnetometer (Trehan, 2002) which measures vertical intensity of earth's magnetic field with better accuracy.

The historical development of the various types of geophysical surveys carried out in ONGC may be classified into different time spans as follows:

1950 to 1960

After its establishment in 1956, ONGC conducted gravity and magnetic surveys to first understand the regional geological framework of various sedimentary basins in India, wherefrom the potential areas for hydrocarbon exploration could be identified. In those days the role of the gravity and magnetic surveys, as a quick reconnaissance tool was confined to identification of potential basins by providing depth to basement, the sedimentary thickness and the basement structural highs and lows for delineating priority areas for seismic surveys.

Though the seismic reflection surveying was developed in the US in the early 1920s by Maurice Ewing and his colleagues Reginald Fessenden and John Webb, these surveys found their application in India after a couple of decades in 1954 by StanVac in Bengal basin. The seismic surveys were implemented in ONGC in late 1950s with the deployment of analog/optical system (Sharma, 2002). The Soviet chief geophysical trainer, Mr. Yarapolk, trained the ONGC geophysicists and shaped the seismic data acquisition technique in India. The first seismic crew was headed by Mr. A. M. Awasthi, conducted 2D single fold seismic data acquisition using 24 channel CC 26-5 ID analog equipment in the foothills of Jawalamukhi and Janauri areas in Himachal Pradesh. The seismic data were recorded on photo paper with the help of an oscillograph. ONGC drilled its first well in 1958 at Jawalamukhi in the Himalayan Foothills and found a promising but non-commercial gas pool. The single fold split-spread seismic data acquired in 1957 in Cambay basin on interpretation, along with gravity and magnetic survey data, led to the to the first discovery of oil and gas at Lunej-1 (Cambay Field) in 1958. Soon after ONGC also hit a major oil field Ankleshwar to the south close to Gulf of Cambay. This set the stage for the development of the oil industry in Gujarat.

1960 to 1970

The formative years

Analog magnetic seismic data recording on land was introduced in ONGC around 1963-64, with the use of the P-11 and P-12 systems of SIE Inc., USA, and the Soviet systems such as CC-24-л CC-26-51D. These were later replaced with the PT-100 and PMR-20 systems having much higher dynamic range of 120 dB. The deficiencies with the earlier systems was that their dynamic range was about 30/40 dB, whereas the dynamic range of the signal detected at the geophone was as high as 120 dB.

Improvised shallow water seismic survey in Gulf of Cambay

Discovery of hydrocarbons in commercial quantities at Cambay and in Ankleshwar in late fifties, gave impetus to obtain seismic survey data in Gulf of Cambay which lies close to these finds. This Gulf is shallow in most parts and experiences about 9 m of tides daily while during low tides parts of the Gulf are exposed as sand bars. Due to these difficult conditions ONGC found that getting seismic data in this part by contracts was extremely expensive and decided to carry out seismic surveys on its own despite having no prior knowledge and experience of such surveys. The Late T.S. Balakrishnan planned the overall strategy with Mr. Mohan given the charge of operations.

Recalling his experience about seismic data acquisition in this area in the early 1960s, Mr. V. C. Mohan (Mohan, 2023) says a 90 ft flat-bottomed barge was hired and modified for the survey. A floating streamer with noise cancelling hydrophones were ordered, which consisted of a 24-core conductor cable 600 ft long with 4 connectors for hydrophones per channel, and a 200 ft leader sheathed in light weight plastic foam. Hydrophones were to be tied to this streamer and connected externally. Fishing net buoys with elastic ropes were used for additional buoyancy. A separate 45 ft boat by the name Sagar Kanya was used for carrying explosives. Charges were made and dropped near the center of the streamer. This constituted a two-boat split-spread seismic survey operation. Two high-frequency communication sets were ordered for communication and semiautomatic detonation. For location and navigation, the Decca navigation system (from UK) and two dinghies were ordered. The 24-channel analogue tape and photo paper recording was to be used for recording.

With all this equipment underway, the surveys were expected to begin operations in 1962. However, except for the barge and the dinghies, none of the other essential equipment arrived in time for the 1962-63 field season. Instead, the seismic data acquisition was carried out on some of the exposed sand bars utilizing the two- or three-hour low tide times. This was no small task, as drilling shot holes with water jets, laying of seismic cables, and recording were done all in the short time interval.

For the following field season (1963-64), the awaited equipment arrived, and the seismic data acquisition started. Needless to mention, the marine operations were not without challenges. After setting up a large reel for rolling in and out the streamer, diesel engine drive, gear train and brake system on the aft (rear) of the barge (Mahindra), at the first sea trial, the streamer sank instead of floating. Additional flotation and buoys were added to keep the streamer afloat. The communication systems received (from GE) would work in a 20 ft spread and had to be returned for rectification. As a stop gap arrangement, the locally made (BEL, India) wireless equipment was adapted. A fishing trawler was used as a shooting boat in the two-boat survey operation. The commercially available balloons were found to be inadequate for keeping the explosive charges at a depth of 5 ft, instead factory rejects of a surgical glove were found to work for the purpose and was used indigenously.

Another problem encountered at the first sea trial had to do with the observation that while in operation and sailing against the tide, the barge would go back due to the water currents, and when sailing with the tide, it would move too fast to cope with. This led to the operations to be limited to the neap tide days and the period between tide reversals. The survey profiles were oriented along northeast-southwest or northwest-southeast directions. The cross currents would increase the streamer feathering to beyond 70° which was unacceptable and was another limitation.

In the 1964-65 field season, on a good productive day around 100 recordings could be done in a day, while an average day would restrict to 50. This way the operations continued till the 1968-69 fair weather season. Over 1500-line km of 2D seismic data were acquired during this time. Based on the interpretation of these data two interesting structural features were mapped, one at the mouth of the Narmada River off Aliabet Island, and another about 15 km west of the mouth of Tapti River. Exploratory wells drilled on these features exhibited oil and gas shows but were found to be non-commercial. The challenge of carrying up a seismic survey with improvised equipment and accomplishing it indigenously by making use of the meagre available resources is indeed creditable and such were the traits of the ONGC pioneers. In 1964, regular marine surveys along the Indian coasts had started by the Russian vessel Archanghelsk, which worked for ONGC till 1968. Mr. Moolchand was head of the Indian team associated with the operation to provide logistic support, like explosives, etc.

The shooting of a seismic survey in action (1963), with M. V. Mahindra in the foreground and the streamer trailing it. To the right is a waterspout generated by the explosive in water with the shooting boat to the side. (Photo courtesy: Mr. V. C. Mohan)

An inside view of M. V. Mahindra (1963) where a crew member is seen at the steering control. On the left is the console for navigation, with the Decca receiver on top and the audio equipment below. (Photo courtesy: Mr. V. C. Mohan)

Found R & D institutes (KDMIPE)

During this period, a research and development (R&D) institute was also established in 1962, with Dr. Hari Narain, an eminent geophysicist, as its first Director, which was later named as Keshav Deva Malviya Institute of Petroleum Exploration (KDMIPE) to serve as the nodal point for knowledge acquirement and sharing. Thus, during the decade of the 1960s, ONGC laid the foundation for building the exploratory infrastructure comprising assimilation of the necessary technical knowhow, organization of the field crews for geological and geophysical surveys and generating prospects for drilling.

In 1967, ONGC decided to buy its first digital computer, the Honeywell-400, installed at the digital computer center at Dehradun. It was a second-generation computer which had data and program input through punched cards. Honeywell-400 had 2 kilo words of main memory (compared with 16 GB RAM on a laptop these days), with CPU cycle time of one-tenth of a megahertz (compared with an over 3GHz for a laptop these days). It had no disc or drum attached, was connected to four tape drives and one line printer. It rendered valuable service and was phased out after 10 years. Besides the geophysical (non-seismic), reservoir, and other geoscientific data processing, the computer was used extensively for ONGC's business applications. In addition to all such uses, the computer provided a good and early training ground for ONGC geoscientists and managers to learn about computer basics and be prepared for bigger and advanced computer technology applications of the future.

The seismic surveys leading to the early discoveries of oil and gas fields such as Ankleshwar, Kalol (1960-61), Sanand (1962) in Gujarat, and Rudrasagar and Lakwa (1960-61) in Assam provided the initial impetus for its aspiration to become a recognized oil player to discover enough oil and make the country self-sufficient.

1970 to 1980

Intensification of seismic surveys, induction of CDP

Hard pressed by the country's increasing demand for oil, ONGC was mandated to go in for more rigorous exploration. As a result, the beginning of the seventies decade saw the induction of new seismic techniques such as CDP (with PT-100 seismograph and 24 channels), Vibroseis and marine surveys along with sophisticated digital instruments with increased channel capacity (24 to 48),which resulted in better quality subsurface imaging that led to discovering more fields (Sharma, 2002). The concept of the common depth point (CDP) seismic method was introduced by Harry Mayne (Mayne, 1962) in the 1960s and demonstrated a significant improvement in the quality of the subsurface imaging. This method gained popularity in the 1960s and 1970s, and revolutionized seismic exploration, enabling geophysicists to carry out better interpretation and identify potential hydrocarbon reservoirs. The CDP method subsequently led to the development of 3D and 4D seismic surveys and provided more insights into the subsurface.

ONGC during this period accelerated exploration by conducting extensive onland and marine 2D CDP seismic surveys across different regions of India. The interpretation of such data led to the identification of structural and stratigraphic traps and many more potential prospects in different basins such as Cambay, Krishna-Godavari, Cauvery, and the Assam-Arakan. However, much of the seismic data at the time was still being recorded in analog form on six inches wide magnetic tapes.

Though digital recording of seismic data was introduced in the western world in 1963, in ONGC digital recording of seismic data started in early 1970s by procuring three digital seismic recording systems, DFS III (from Texas Instruments, USA) and SN328 (Sercel Inc., France). The rest of the field parties were still using analog recording units. However, by 1980 all the analog recording units were replaced with DFS IV, or Sercel 338 units.

In 1974, Vibroseis was introduced as the energy source for the first time in ONGC. A seismic crew with vibrators from Prakla with correlator stacker and Summit-VII seismograph with 48 channel capacity was sent for data acquisition to Iraq for data acquisition under a contract in a foreign basin. This experience was quite useful as ONGC went on to carry out more seismic surveys with Vibroseis source in subsequent years.

With the beginning of digital data acquisition, ONGC installed its first dedicated computer for digital seismic data processing at Dehradun in 1971 to handle processing of enormous data acquired by the increased number of seismic field parties by now. It was the Texas Instruments Office Processing System (TIOPS) manufactured by Texas Instruments, USA, with 8 kilowords of main memory, which was later upgraded to 32 GB in steps, a drum (not disc) for mass storage, an FFT (Fast Fourier Transform) box for processes such as convolution, correlation in frequency domain, an analog-to-digital converter for digitizing the analog magnetic field tapes, and a seismic section plotter.

This system had a limited processing capability for single fold seismic data recorded on tape but was found to be slow and not adequate for ONGC needs.

Mr. V. C. Mohan briefing a visiting delegation to the ONGC computer center about the TIOPS components (1972). To the left are the two tape drives, and to the right are the CPU in black, with the FFT box above and the hard disk below. In the foreground is the card reader (left) and teletype printer (right). (Photo courtesy: Mr. V. C. Mohan)

The President of India, Mr. Fakhruddin Ali Ahmed, visiting the ONGC computer center (1974). Late Dr. N. B. R. Prasad, Late Mr. V. V. S. Sastry and Mr. V. C. Mohan are also seen in the photo. (Photo courtesy: Mr. V. C. Mohan)

Late Mr. S. N. Talukdar, Mr. M. A. Ganapathy being briefed about an XY plotter. Mr. V. C. Mohan is also seen (left) in the photo. (Photo courtesy: Mr. V. C. Mohan)

Marine seismic surveys gather speed

The Russian survey mapped the big structural high in the west coast and proposed by Prof. Kalinin of Russia, was drilled in 1972 to discover the giant Mumbai High oil and gas field. Accelerated exploration followed with several companies such as Digicon, GSI, and Prakla Seismos given contracts by ONGC for carrying out marine surveys. These surveys resulted in the mapping of several structures in the Bassein area and a few more to the south of it. At this point ONGC management felt the need to acquire a fully equipped and integrated geophysical survey vessel with seismic reflection and gravity data acquisition capabilities in the offshore areas. With this planning, ONGC awarded the contract for building such a ship to Seismic Engineering Company Inc., S.A. (SEISA) in 1974. The seismic vessel was named M. V. Anweshak and was constructed at Jacksonville, Florida, USA. It was a fully computerised vessel with two computers (Hewlett Packard 2000 and Nova 200) for online real time processing of satellite navigation and gravity data, a 48 channel 2400 m long streamer, and airgun array as energy source. It was also equipped with La Coste Romberg sea gravity meter, magnetometer, and Magnavox satellite navigation system, the first of its kind in India. it reached Mumbai in June 1975 after a sailing of 51 days with two geophysicists on board to monitor the dynamic navigation system twenty-four hours every day to test its operational efficacy and to get acclimatized. In August 1975 it became the first Indian flagship with satellite navigation to operate in Indian waters in the east coast. The vessel used to operate round the year; for most of the period in the west coast and with the onset of southwest monsoon , June –September, when the sea becomes rough, its deployment was shifted to east coast where the northeast monsoon sets in October. Mr. K. N. Bhave was overall in charge of planning and operations.

(The frontal shot of M. V. Anweshak seen docked for maintenance apparently. Photo courtesy: Mr. Arun Goel)

Taking leads from the gravity maps, the areas in the Mumbai offshore basin were prioritized for surveys by Anweshak, which resulted in quick discoveries of a number of oil fields such as the Bassein and South Bassein (named Panna later) and D1 oil fields. The ship also mapped several potential structures on the east coast of India.

(A plan for a seismic survey being discussed by a pioneer group of geophysicists comprising (L to R), Mr. S. K. Gupta, Mr. M. K. Sen, Mr. K. N. Bhave, Mr. D. K. Trehan, Mr. D. K. Soni, and Mr. N. C. Nanda on board the M. V. Anweshak. Photo courtesy: Mr. N. C. Nanda)

As alluded to above, the seismic field data from the increased ONGC land seismic crews that started operating since early 1970s, as well as the large volumes of seismic data that were being acquired by M. V. Anweshak, and some other contract vessels on contract, all started pouring in. ONGC therefore felt the need for acquiring a more powerful computer for processing such large volumes of seismic data. At the time the US government had restrictions on the type and speed of CPUs which can be exported to India and its end users. Consequently, in September 1975, the IBM 370-145 system with array processors was installed at KDMIPE.

After bench marking the available software packages available, Seismograph Services Ltd (SSL) seismic data processing package was ordered. IBM (India) and later Computer Maintenance Corporation (CMC) were assigned for maintenance of the hardware.) This system was installed at a new building within KDMIPE premises at Dehradun. This IBM computer had a RAM of 16 mb and peripherals were a FFT unit, removable disc drive for 100mb hard disc units, 4 half inch tape drives, a card reader and line printer.

1980 to 1990

Accelerated exploration, induction of 3D seismic

Encouraged by the offshore discoveries of the 1970s, the focus on marine surveys was further stepped up by the detailed surveys carried out by Anweshak. This made the decade by far the most productive, marked by a number of medium to large offshore fields in the Mumbai offshore basin on the west coast and in KG and Cauvery offshore basins in the east coast. The surveys brought out a number of structures resulting in middle and large sized discoveries, Mukta (1981), Neelam(1987), CA-CD (1986) oil fields on the west coast and Ravva (1987) and PY-3-2 (1988) oil fields in KG and Cauvery offshore basins on the east coast. In the meantime, improved versions of seismic equipment used onland also yielded discoveries of several more oil and gas fields in Cambay, Assam Arakan, KG and Cauvery basins, the latter gifting the Narimanam and Kovilkallapal (1985) fields.

By this time the need for detailed characterization of the producing reservoirs and several other potential prospects was felt and another seismic vessel named M. V. Sagar Sandhani was inducted by ONGC in 1986 in order to equip itself with the capability of acquiring 3D seismic data in the offshore areas. It was built by Southern Ocean Shipbuilding, in Singapore. This vessel was better equipped in terms of technical capabilities and included a helipad for landing a helicopter in case of emergency.

In offshore areas, ONGC also conducted seabed surveys using techniques such as multibeam sonar, sub-bottom profiling, and remotely operated vehicles (ROVs), which helped in the mapping of the seafloor topography, subsurface structures, and gas seepages for identifying shallow water hazards to help safe drilling.

(A shot of M. V. Sagar Sandhani in action on the high seas. Photo courtesy: Mr. Arun Goel)

During this period the seismic acquisition was also improved and augmented in the onland basins. 3D seismic technology was experimented with, with the first survey conducted in North Jotana field (1985-87) in North Cambay Basin with limited 2D seismic accessories available. The first 3D seismic of its regular kind was conducted in ONGC during 1985-86 in the Balol Field in the same basin. The data were acquired with a vibrator source, using a seismograph with 1024 channels, and sign bit recording technology. Simple four-line swath geometry with 192 live channels was used with a bin size of 15 x 60 m. As no 3D seismic processing capability existed inhouse, the data were processed by GSI in Singapore in 1988. The 3D seismic surveys provided better images of the subsurface and thus a more accurate understanding of reservoir characterization, which led to better drilling successes. As a result, ONGC started acquiring 3D seismic surveys as a routine and the number of 3D seismic crews in ONGC increased linearly along with the number of prospects covered.

ONGC also awarded a contract in 1985 to CGG (Companie Generale De Geophysique) for carrying out seismic surveys in the Shahgarh subbasin (western Rajasthan) to speed up exploration in onland frontier areas. CGG brought five Mertz-14/613 model vibrators mounted on offroad buggies and 96 channel SN358 recording seismograph with CS2502 real time summation correlator. 48-fold seismic acquisition was carried out with four vibrators at 12 m spacing, two sweeps per vibrator with 12 s sweep length and sweep frequency (10-65 Hz).

Later in 1987, ONGC acquired the seismic equipment from CGG and raised its own crew. In addition, another seismic crew was raised by procuring four buggy-mounted Prakla vibrators from German and 96 channel SN358 seismic unit with CS2502 correlator stacker from France. These two crew operations continued till the 1991-92 field season in Rajasthan Basins, with the second crew using Prakla vibrators continuing operations up to 1997-98 field season. Transient Electromagnetic (TEM) data were acquired in the trap covered areas of Saurashtra in 1989 by Geometra of Germany in collaboration with ONGC (Trehan, 2002).

Augmenting processing capabilities, installation of IIWS

With the increase in the number of recording channels and 2D and 3D land crews increasing to 45, the bulk of the seismic field data continued piling up and the IBM 370-145 was incapable of handling the data and a lot of seismic data were to be sent abroad for processing. Besides these, the process of migration was also being run routinely after stacking. Thus, to handle such a workload, a VAX 11-780 computer system with 2 MAP-300 array processors was added, with Phoenix seismic processing software running on it.

As can be gauged from the above narration, all the seismic data being acquired by ONGC in India, land or marine, were being sent to Dehradun for processing. To eliminate the need to ship the data outside and between the regions and Dehradun, the ONGC management decided on setting up regional computer centers to curtail processing time. Accordingly, in 1987, two Russian computers were installed at Baroda and Calcutta, a Norwegian computer system installed at Madras (now Chennai), and a Tata Elxsi system with Digicon software was installed at Mumbai. The same year, a mainframe IBM 3083-JX3 computer system with Western Geophysical seismic processing software was installed at Dehradun. This system had 3D seismic data processing capability, introduced the compact cartridge 3480 as the magnetic medium, and had an online interactive interpretation workstation (CRYSTAL) attached. This well-equipped seismic data processing and interactive interpretation center was separated from KDMIPE and housed in a newly constructed building called Geodata Processing and Interpretation Center (GEOPIC). In addition, two standalone GeoQuest interactive interpretation workstations (IIWS) based on MicroVax computers were also installed in GEOPIC under the interpretation section the INTEG (integrated interpretation group). This center became the biggest computing and interpretation facility of ONGC (at the time 75% of the total processing workload of ONGC and all the 3D seismic data acquired annually were being processed and interpreted), where multidisciplinary teams started functioning to solve complex subsurface interpretation problems encountered in exploration and development.

(Geodata Processing and Interpretation Center (GEOPIC) housed within the KDMIPE campus, Dehradun)

1990 to 2000

3D seismic and IIWS, focus on reservoir characterization

Following the acquisition of TEM data in the trap covered areas of Saurashtra in 1989, magnetotelluric data were acquired in the same area by Phoenix of Canada in 1992. Some more magneto telluric data were acquired by the Indian Institute of Geomagnetism (IIG), Mumbai for ONGC in the eastern margin and a few stations inside the southern part of Cambay Basin for estimating the thickness of the Mesozoic/Pretrappen sediments in the area (Trehan, 2002).

The continuing tempo of exploration saw 3D seismic playing a crucial role not only in discovering hydrocarbons but also in field development. Several fields discovered on land and offshore by 2D seismic needed accurate geometry of reservoirs and their parameters for proper development. Many of these were covered by 3D seismic surveys and the interactive interpretation workstations (IIWS) helped in providing more accurate reservoir parameters, crucial particularly for developing offshore fields. Some of the offshore fields such as Raava and PY-3 were offered to foreign companies for development which were expensive and involved foreign exchange. The 3D results in most cases varied from the 2D interpretation and exploration programmes for drilling further delineation/development wells were accordingly modified. An important attainment in the late nineties was a multi-component OBC (ocean bottom cable) 3D survey carried out over Mumbai High field by PGS, Norway, to help address production problems.

2000 – 2010

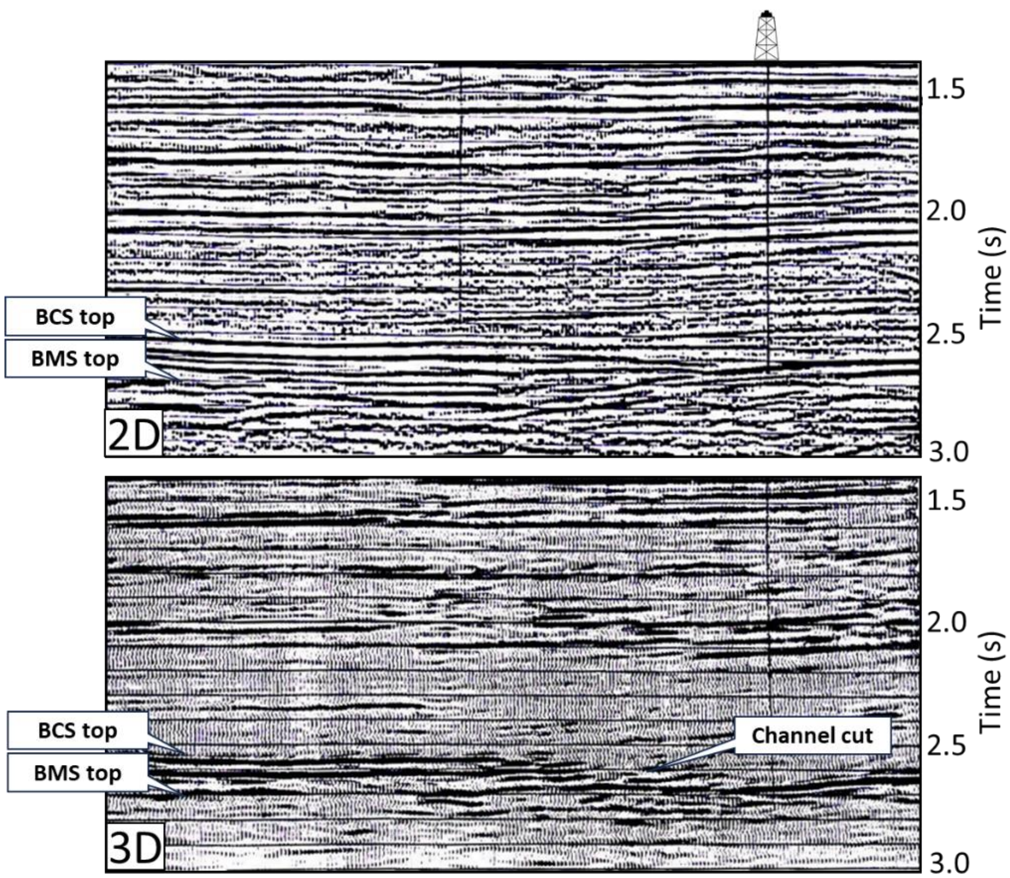
Continued strengthening of seismic API

Encouraged by 3D seismic results ONGC increased the number of 3D seismic crews, and in 2005, there were 19 crews deployed for surveys in different onland sedimentary basins of India. Seismic data acquisition, processing and interpretation (API) tools and technologies were upgraded. Digital geophones and multifold recording channels were used for wide azimuth wide angle 3D surveys. M.V. Sagar Sandhani, equipped with a single streamer and single source at launch, was upgraded to dual streamer and dual source in 2002 to keep up with the accelerated exploration activities. Additional offshore 3D seismic surveys were also carried out by contracting vessels in addition to M. V. Sagar Sandhani.

Around this time a new survey technique called *controlled source electromagnetic* (CSEM) for offshore areas was commercialized which delineates hydrocarbon bearing strata based on resistivity measurements. Also referred to as 'seabed logging (SBL)', CSEM surveys were conducted in ONGC on a few selected profiles in KG and Cauvery offshore basins on trial basis.

This was also the time frame which allowed the integration of the seismic, gravity and magnetic surveys, and efforts at acquiring more advanced technologies, software for processing, interpretation and reservoir modeling were inducted. Over the years more interactive interpretation workstations were added at various work centers of ONGC as the need arose.

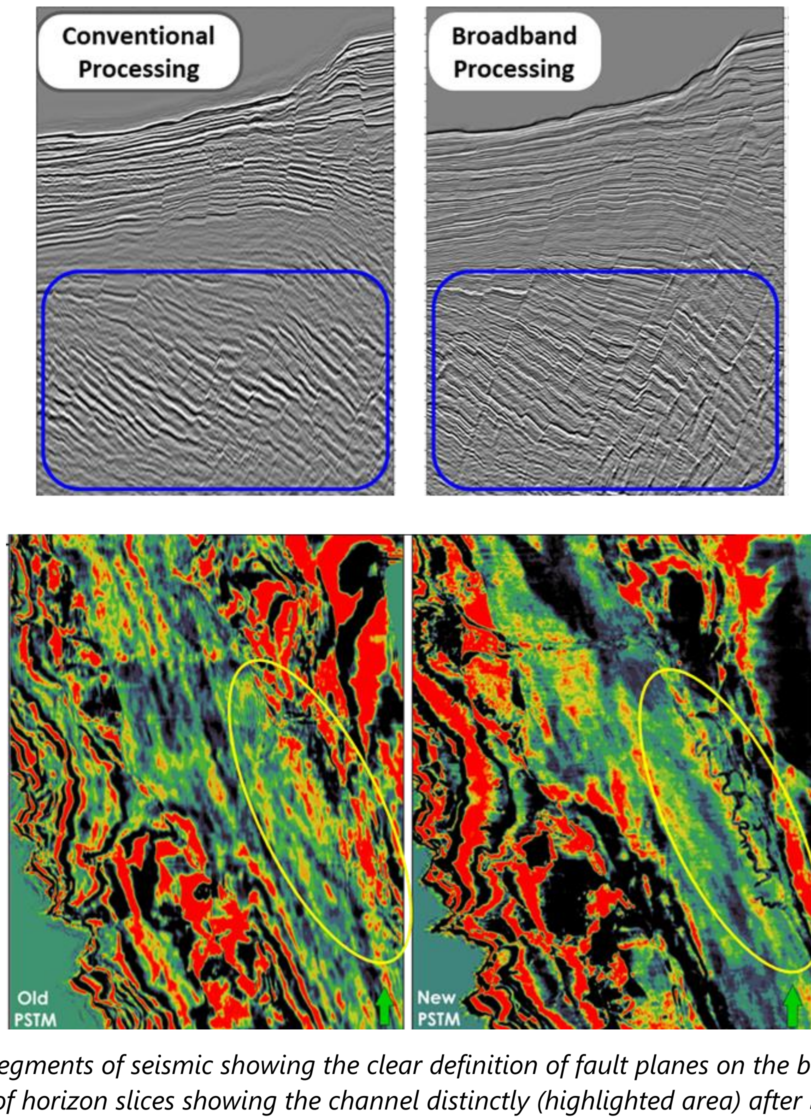
In terms of processing of seismic data some of the salient features included 2D and 3D signal conditioning, advanced processing for foothills and thrust-fold belt imaging, merging of multiple 3D vintages for both land and marine seismic data, high-resolution near-surface and subsurface velocity model building, 2D and 3D updating of tomographic models, depth imaging (both isotropic and anisotropic), prestack gather conditioning for AVO as well as poststack signal conditioning and enhancement.



(Comparison of 2D seismic segments of the same subsurface. Superior 3D imaging reveals the subtle stratigraphic prospects not seen in 2D. Data courtesy: ONGC; image courtesy: Mr. N. C. Nanda, 1990)

As with all computer equipment, once its prime life period is over, replacement is necessary, coupled with the advancement in computing power and capacity that needs to be embraced. Consequently, by 2002, more powerful 3D processing and interpretation systems were installed at Jorhat, Mumbai, Baroda, Chennai and GEOPIC, Dehradun. More accurate interactive interpretation on prospect, basin-scale could now be carried out using 2D and 3D seismic data using modern and vintage surveys. Advanced image visualization tools helped enhance the delineation of structural and stratigraphic subsurface features. State-of-the-art interactive interpretation software packages such as Petrel and Kingdom, etc. were installed at different work centres.

In view of the increasing processing workload, the SGI Origin 2000 high-end server computer with 20 CPUs, manufactured by Silicon Graphics (SGI), was installed at GEOPIC in the year 2000. The machine was upgraded to 32 CPUs in 2002 for achieving better throughput of data. Paradigm software was used for processing seismic data on the Origin 2000 computer. For the first time prestack time migration could be initiated in the production environment. Disk-based processing was introduced replacing tape-based processing, which tremendously helped in increasing the throughput, though it demanded large disk space.



(Above) Comparison of segments of seismic showing the clear definition of fault planes on the broadband processed data. (Below) Comparison of horizon slices showing the channel distinctly (highlighted area) after broadband processing. (Source: GEOPIC, ONGC)

In 2007, this machine was supplemented with two new machines, namely the SGI Altix with 64 CPUs running Linux as a single system image with a Linux distribution called SGI Advanced Linux Environment, as well as the IBM P690, 30 CPUs, high-end UNIX-based server. The following year (2009-10) saw the installation of the IBM PC-cluster system with 640 high-performance dual core CPUs, which gave GEOPIC enough throughput capacity at the time. With the installation of new hardware and software also came the challenge of getting conversant with them and yet ensuring the high production of processed data to come through. At this stage GEOPIC acquired major commercial processing software from WesternGeco, CGG, and Paradigm. Time and depth domain prestack migration became viable with the introduction of high-performance PC cluster system. GEOPIC also got equipped with 300 TB of disk space and a robotic tape library with 2600 (each of 500 GB) slots.

In a very short period of time, ONGC acquired much knowledge and experience with a large well-skilled workforce and the focus had shifted more to exploration of subtle stratigraphic traps and detailed characterization of reservoirs. This was accomplished by using integrated analysis of multidisciplinary data sets comprising gravity and magnetic surveys, 3D seismic surveys, well log data, petrophysical, geochemical, reservoir and production engineering data. Advanced versions of microgravity surveys were carried out to help identify delicate density variations in the subsurface to complement seismic data. In-depth synergistic evaluation of data of EM surveys to help explore sub-trappean Mesozoic sediments in the onland Kutch and Saurashtra areas, and 3C 3D P-SV survey in Cambay basin for characterizing fractured reservoirs, were carried out. Notably, a a baseline 3D (2003) and two timelapse 3D surveys (4D) in 2004 and 2005 were carried out in the Balol heavy oil field in Cambay Basin to monitor the sweep efficiency of the *in-situ* combustion front was conducted to address production problems.

Besides the commendable efforts by ONGC mentioned above, continual collaborations with geophysical service providers led to the upgradation and acquisition of the latest technologies.

2010 and after

Era of continued developments in data processing

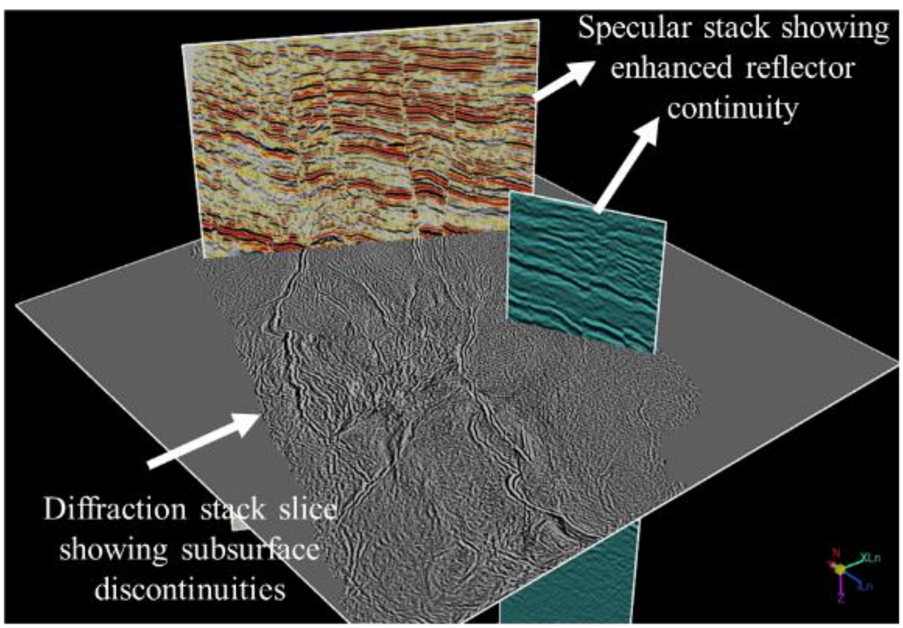
This is an era when advanced and the then state-of-the-art processing techniques and technologies were introduced in ONGC.

ONGC adopted broadband technology in 2014 and ocean bottom node (OBN) technology in 2018. Broadband seismic data acquisition and processing helped enhance the bandwidth leading to better imaging of the subsurface features including fault planes, compared with conventional data processing. ONGC has acquired more than 24,000 km^2 of broadband streamer data along east and west coast of India, and 2,300 km^2 of OBN data over two campaigns. OBN multicomponent data with large offset, rich azimuth, and relatively less noise yielded superior vertical and spatial resolution bringing out better details of the subsurface structural and stratigraphic anomalies. More recently (2022), ONGC has acquired node based seismic data acquisition system for its onland deployment.

With newer exploration challenges, technological developments, and hardware obsolescence ONGC's resource upgradation continued. Common Reflection Angle Migration (CRAM) software was introduced in 2012-13. GeoTomo software was acquired for processing 2D seismic data in hilly terrain for continued exploration in frontier areas. The existing PC cluster system after serving its useful life was replaced with a more powerful high performance PC cluster system with 250 compute node dual CPUs, 12 cores per CPU, 256/385 GB RAM per node, 650 TB storage in 2015 at GEOPIC. Disk storage was further augmented to 3000 TB in 2018. The system had 4 GPU nodes to cater to high compute prestack depth migration jobs.

The newly upgraded processing capability enabled the seismic data processors to follow integrated workflows at different stages for land and marine seismic data. Typically, for a raw shot gather obtained from the field, the processor would generate different outputs such as conditioned shot gathers, prestack time migrated and prestack depth migrated stacks. For depth-domain imaging and velocity modeling, local angle domain (LAD) imaging (ES360) coupled with 3D angle azimuth grid tomography could be performed to obtain accurate subsurface imaging. The LAD technique is a ray-based migration algorithm that maps the energy recorded on the surface to subsurface full-azimuth local angle configuration. The LAD gathers can be used to obtain specular as well as diffraction stacks by applying specular and diffraction filters. Similarly, exploiting azimuthal anisotropy present in the LAD gathers, fracture characterization could be carried out.

Processing features such as 4D/5D regularization of seismic data which resulted in filling data gaps, mapping of velocity and amplitude variation with azimuth (allowing determination of fast and slow directions) and diffractions (hence fault related information) extracted directly from the gathers (which are generally captured from post stack volumes through coherency and discontinuity attributes) started getting utilized. This latter prestack process capturing information allowed minor fracture details to be mapped which sometimes is not possible with poststack data. The display of the image below shows a time slice from diffraction stack exhibiting subsurface discontinuities, which are correlated with seismic signatures as seen on segments from specular stacks. All these advanced processing facilities (including reverse time migration) are today available with fully equipped processing centres of ONGC.



Time slice from diffraction stack shown correlated with seismic signatures as seen on segments of sections from specular stack. (Source: GEOPIC, ONGC)

The better processed high resolution seismic data allows extraction of various seismic attributes including variance and discontinuity, seismic inversions and AVO analysis. All these have become an integral part of today's interactive interpretation workflows in helping characterize the reservoirs better and reducing exploration and production risks.

Miles to go....

As one looks back at the almost seven-decade-long geophysical journey, it is indeed satisfying. The dreams and aspirations of the founder geophysicists of ONGC, starting from scratch and progressing under challenging circumstances, have gradually been realized. The hard work, knowledge, and vision of its pioneering geophysicists that led to the opening up of new basins, plays, and discovery of many fields need to be acknowledged.

India aspires to be amongst the top three economies of the world, and an enormous amount of energy is required to realize such an aspiration. Geoscientists in general, and geophysicists, in particular, have an onerous task in this endeavor. It is incumbent upon the present generation of young geophysicists to keep the ONGC flag flying high and shoulder the responsibility reposed on them by the country. While it is a time for celebration during the 'centenary year of geophysics', it is also the time for reflection, perseverance, and rededication. The conscientious geophysicist knows that there are "miles to go before we sleep!". G

Acknowledgements

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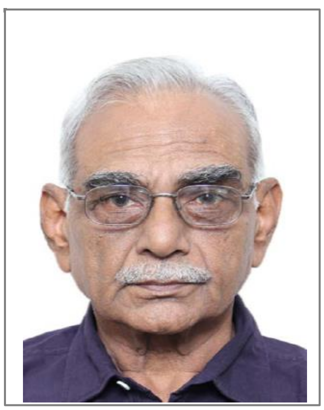
Mr. Satinder Chopra is the founder and President of SamiGeo Consulting Ltd., based in Calgary. He has 38 years of experience as a geophysicist specializing in processing, special processing, and interactive interpretation of seismic data. His research interests focus on techniques aimed at characterization of reservoirs. He has published eight books and more than 500 papers and abstracts. His work and presentations have won several awards from international professional societies the most notable ones being the **2021 Roy O. Lindseth CSEG Medal Award (2021)**, **AAPG Distinguished Service Award (2019), EAGE Honorary Membership (2017), CSEG Honorary Membership (2014), Meritorious Service (2005) Award, 2014 APEGA Frank Spragins Award, the 2010 AAPG George Matson Award,** and the **2013 AAPG Jules Braunstein Award**. He has been the *2010/11 CSEG Distinguished Lecturer*, the *2011/12 AAPG/SEG Distinguished Lecturer*, and the *2014/15 EAGE e-Distinguished Lecturer*.

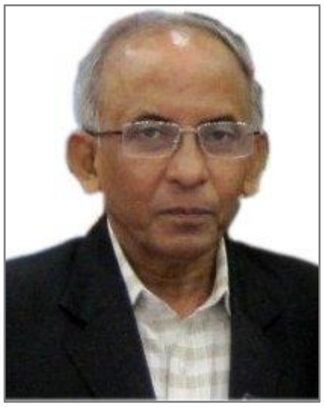


Shri Niranjan Chandra Nanda post graduated in geophysics from Benaras Hindu University, Varanasi, India, in 1959 and soon after joined Oil and Natural Gas Commission (ONGC) where he worked till his superannuation in 1996. Thereafter, as a freelance petroleum geophysicist consultant, his association with ONGC continued as a member of the Advisory Council Committee for reviewing E&D projects in R&D institutes and work centers.

Apart from consulting several E&P companies, Shri Nanda was a visiting faculty to Andhra and M.S universities where he taught seismic interpretation to post-graduate students of exploration geophysics and petroleum geology. He also conducted several training courses a nd workshops in seismic interpretation for industry professionals in and outside ONGC.

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

He has published several papers and authored the book titled "*Interpretation and evaluation of seismic data for hydrocarbon exploration and production-a practioner's guide*", published in 2016 by Springer and a second edition in 2021.



Mr. Subrata Kumar Das is an alumnus of IIT, Kharagpur and a former Executive Director at ONGC. Mr. Das has more than four decades of rich experience in the petroleum industry. His high level of technological sophistication across all the areas of petroleum exploration – acquisition, processing, and interpretation of seismic and geo-scientific data at working as well as in key managerial levels makes him a valuable team member. In ONGC his professional accomplishment embrace heading "GEOPIC", a premier R & D Institute and leading the overall exploration activities of ONGC's largest onland "Cambay" Basin. Post superannuation he provided consultancy on E&P services. Currently he is the promoter Director of a G&G service providing company, named DLBARG Petroleum Private Limited (DDPL).

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5. One of the earliest 2D vintage seismic lines.
6. Offshore Seismic data acquisition. Source: Article: "ONGC fires up huge offshore seismic drive in Mumbai and Andaman basins, Upstreamonline.com, 2021". (https://www.upstreamonline.com/exploration/ongc-fires-up-huge-offshore-seismic-drive-in-mumbai-and-andaman-basins/2-1-1106300)
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8. India's first offshore drill ship Sagar Samrat stuck oil in Bombay high in 1974.
9. Seismic focal mechanisms at Himalayas. Source: "Faulting structure above the Main Himalayan Thrust as shown by relocated aftershocks of the 2015 Mw7.8 Gorkha, Nepal, earthquake, 2015, Ling Bai et al., Geophysical Research Letters, 43, 2, 637-642".
10. Slice showing paleo channels from KG offshore.
11. Section showing modelled Pore Pressure.
12. 3D view of Geo-Cellular model.
13. Hydro-fracking well stimulation
14. Full Waveform Inversion (FWI) Seismic section from Gulf of Mexico (Source: CCG.com).
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