

An integrated approach for subsurface opportunity mapping in a mature gas field, Assam, India

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ABSTRACT

The Duarmara field, which is situated in the Assam-Arakan Basin of Northeast India, was discovered in 1970 (in three wells) using 2D seismic data, which showed gas and condensate. Geological, petrophysical, and geophysical processes are integrated to create a thorough understanding of the subsurface, which is necessary for opportunity creation in this field. The present study describes a multidisciplinary method that integrates these three areas to more accurately and safely locate and assess hydrocarbon opportunities. Although the structural and stratigraphic foundation is established by the geological workflow, petrophysical analysis uses Vshale (shale volume), porosity (Phie), permeability, and saturation assessment (Sw and So) to offer quantitative insights into reservoir quality. Potential hydrocarbon indications are found and reservoir geometry is improved by geophysical interpretation, which includes seismic inversion, AVO (amplitude vs offset), and attribute analysis. Risk-based opportunity ranking, volumetric estimation, and robust static modelling are all supported by the integration of these datasets. This process improves field development tactics in intricate subsurface settings, facilitates data-driven decision-making, and increases exploration efficiency.

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1. Introduction

Opportunity generation in oil and gas fields combines geological, petrophysical, and geophysical analyses to identify and evaluate hydrocarbon prospects. Geological studies establish the stratigraphic and structural framework, while petrophysical analysis quantifies reservoir properties such as porosity, permeability, and water saturation. Geophysical workflows, including seismic interpretation and inversion, delineate reservoir geometry and fluid indicators. Integration of outputs from these domains enables robust reservoir modelling, volumetric estimation, and risk-based opportunity ranking. This multidisciplinary approach enhances subsurface understand-

ing, reduces exploration risk, and supports effective decision-making for field development and hydrocarbon recovery.

The study area lies within Assam-Arakan Fold-Thrust Belt (AAFTB) one of the most significant petroliferous basins in South Asia, spanning the north-eastern states of India and parts of western Myanmar. This geologically complex region is part of the larger Indo-Myanmar Ranges and is characterized by its intricate tectonic history, diverse stratigraphy, and substantial hydrocarbon reserves. The basin has been a focal point for oil and gas exploration since the late 19th century, with the first commercial oil discovery in Asia occurring in Digboi, Assam, in 1889.

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Over the years, the AAFTB has emerged as a critical hydrocarbon province, contributing significantly to India's energy security and Myanmar's economic development.

2. Exploration History

Assam-Arakan Geological Province has been recognized as petroliferous since the first oil discovery in Digboi in 1889, located in the northeastern corner of India and the subsequent discoveries both in the Assam plains and parts of folded belt within the province. The portion of this province falling in the north-eastern region of Indian Territory has a sedimentary covered area of approximately 1,16,000 km². The Upper Assam Basin is bounded by three major thrust faults viz. Himalayan orogenic belt in the north, Mishmi Thrust in the east and Schuppen Belt in south. Topographically, the Assam Shelf fore-land basin part is a normal flood plain area of the River Brahmaputra and its tributaries (Dutta, 2024). During the last more than five decades, the exploration and exploitation activities of both the national oil companies – Oil and Natural Gas Corporation Ltd (ONGC) and Oil India Limited (OIL) in the Upper Assam Shelf has resulted in the discovery of large, medium and small sized oilfields like, Nahorkatiya, Tengakhat, Moran, Lakwa, Rudrasagar, Geleki and many others. Recent discoveries in the area are of small–medium sizes (Fig. 1).

Duarmara Field was discovered by OIL in 1970. OIL drilled 3 wells in the field DMR-1, 2, 3.

The exploration well DMR-1 was drilled in 1969–1970 on the seismic high of Dumduma, primarily to explore the Tipam hydrocarbon prospects and discovered gas and condensate in the 3,565 m Tipam T-40 sand. Surma sands were also tested in this well, but flowed water with only minor traces of oil. The T-40 sand produced gas at a rate of 1.465 MMSCF/day and condensate at a rate of 125.8 BOPD.

3. Geological Setting and Structural Configuration

The Assam-Arakan Basin is situated in northern Assam, the northeastern region of India (Fig. 2) The northeastern Himalayan foothills and the Assam-Arakan thrust band are separated by the composite foreland basin (Nandy, 2001; Mandal and Dasgupta, 2013; Sahoo and Gogoi, 2009; Hossain et al., 2021).

According to Kumar et al. (2023), the basin is situated in a regional triangle formed by the Naga Thrust (NT) and the Himalayan Frontal Thrust (HFT). The tectonic interaction of the Assam Arakan mountains to the south, the Mishmi thrust to the east, and the Himalayan orogeny to the north has had a significant influence on the basin shape. Its asymmetrical slope gradually slopes towards the Naga Hills in the south and the Himalayan foothills in the north (Nandy, 2001; Sahoo and Gogoi, 2009; Mandal et al., 2011; Mandal and Dasgupta, 2013; Hossain et al., 2021, Gogoi et al., 2022). To the southwest, the Shillong plateau basement uplift partially disturbs the basin, while the Mishmi Thrust terminates the northeast side.

The Indian plate's convergence with the Eurasian plate and subsequent collision with the Burmese plate has caused the basin's core basement to undergo significant flexural and structural changes, resulting in a number of highs and lows (Borgohain et al., 2017; Kumar et al., 2023). With gently extended folds split by faults striking NE-SW or ENE-WSW, the underlying structures and the sedimentary cover above seem to be of the platform type (Nandy, 2001; Mandal and Dasgupta, 2013; Sahoo and Gogoi, 2009). Because of constant collision and convergence over the geologic era, these deposits have experienced severe faulting, folding, and uplift (Borgohain et al., 2017; Kumar et al., 2023).

The basin area is approximately 20,000 km² and has a total sedimentary volume of 110,000 km³. The age of the section ranges from Cretaceous to Recent and rests on Archean granitic basement. Depth to Basement ranges up to 8000 m in the eastern part of the basin. The principal structural units of the Assam basin comprise the Eastern Himalayan Thrust Belt which contain Mesozoic and Tertiary aged rocks; the Upper Assam Valley, a stable, normally faulted fore-land and the thrust belt in the east known as the Belt of Schuppen which contains mainly Tertiary rocks and whose geomorphological expression is known as the Naga Hills. The Mishmi Hills to the north and the Mikir Hills to the west comprise Precambrian gneisses and granites (Fig. 3). The study area Duarmara lies in the Upper Assam Valley and close to Naga Thrust.

4. Generalized Stratigraphy of Assam Shelf

Three factors—tectonic subsidence, sediment supply, and eustasy control the Assam Shelf's strati-

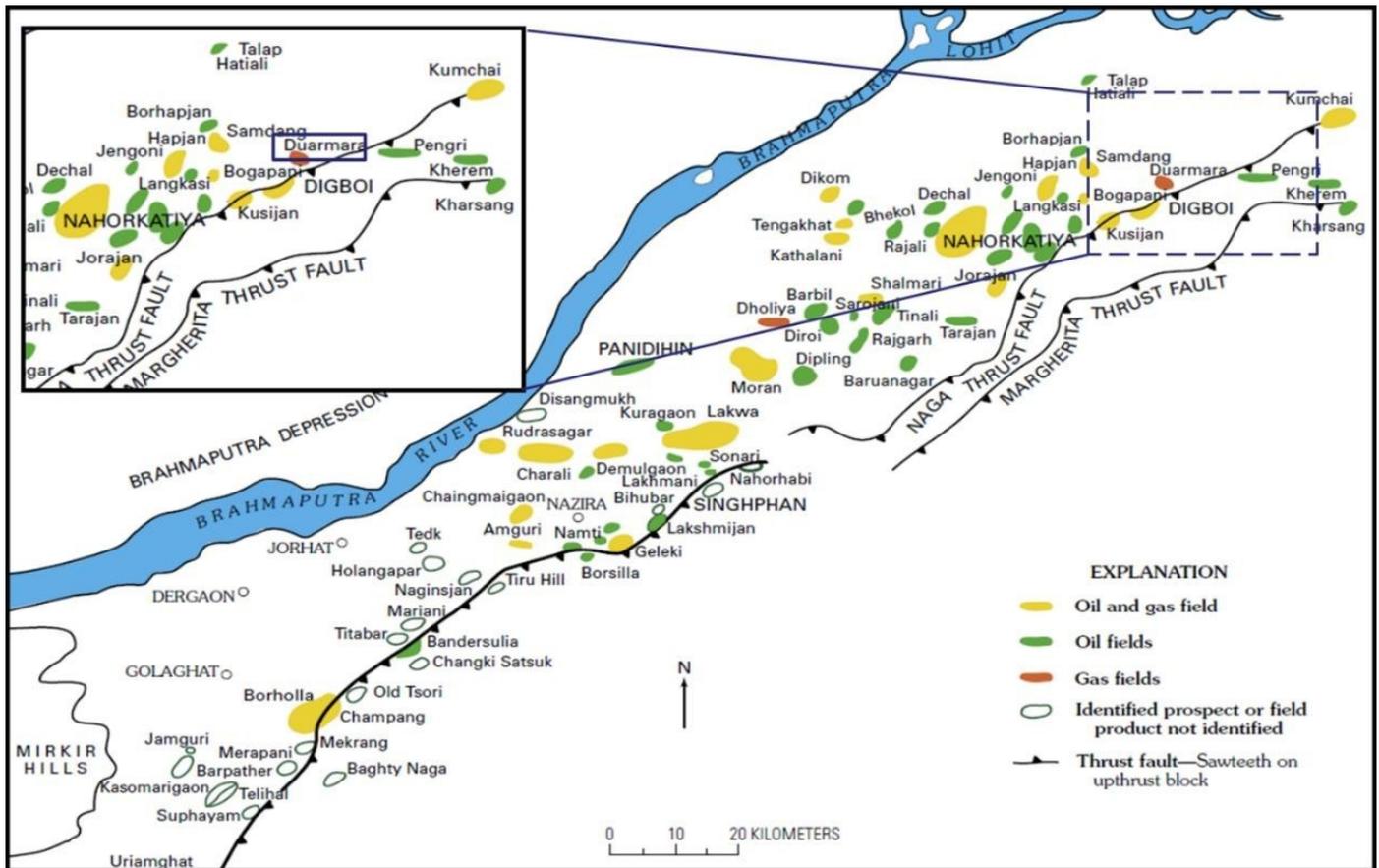


Fig. 1. Oil and gas fields in Assam shelf.

graphic record. The foreland basin receives its sediment supply from the southeast side of the overriding thrust band or from the northwest side of the Himalayan highlands. Paleocene to Holocene sediments are present in this Tertiary basin (Fig. 4). Localized, rifted depressions contain Cretaceous deposits. In front of the Eastern Himalayas are trap volcanics, basal conglomerates, and lower Cretaceous Gondwana deposits. The deeper portions of the basin, close to the Naga Hills, are where Upper Cretaceous fluvial sandstones are found.

Gneisses and granites are among the crystalline metamorphic rocks that make up the basin's Precambrian basement (Bhandari et al., 1973; Nandy, 1980, 1983, 2001). Paleogene, Neogene, and Quaternary deposits cover the basement. These include the Alluvium cover (Pleistocene to Recent), the Langpar, Lakadong/Therria, Prang, Narpuh, and Kopili formations (Paleocene to Eocene), the Barail formation (Oligocene), the Tipam and Girujan formations (Miocene), the Namsang formation (Mio-Pliocene), and the Dhekiajuli formation (Pliocene). These deposits, which include limestones, shales-sandstones,

coal-shale alterations, massive sandstones, mottled and variegated clays, intercalated sands, and thick alluvium cover, were formed in a range of shallow marine, deltaic, and fluvial environments (Bhandari et al., 1973; Raju and Mathur, 1995; Sahoo and Gogoi, 2009; Goswami and Goswami, 2008; Deb and Barua, 2010; Mandal and Dasgupta, 2013; Kumar et al., 2023). The basin now gets sediment from the north, south, and east due to its bordering massive fold and thrust belts (Mandal et al., 2011; Mandal and Dasgupta, 2013; Kumar et al., 2023).

Due to the basin's asymmetrical slope and the location of the fore bulge, a short-term stratigraphic framework was dominated by eustasy and sediment supply. An upper unconformity developed as a result of tectonic activity, whereas a base unconformity developed as a result of erosion of the gradually moving fore bulge. The sedimentary record of the basin was created during the Paleogene, when the Indian Plate was moving after splitting from the Antarctic Plate, during passive margin setting. Paleocene to Lower Eocene sediments were deposited as coarse clastic sediments in rivers and the ocean. The Middle

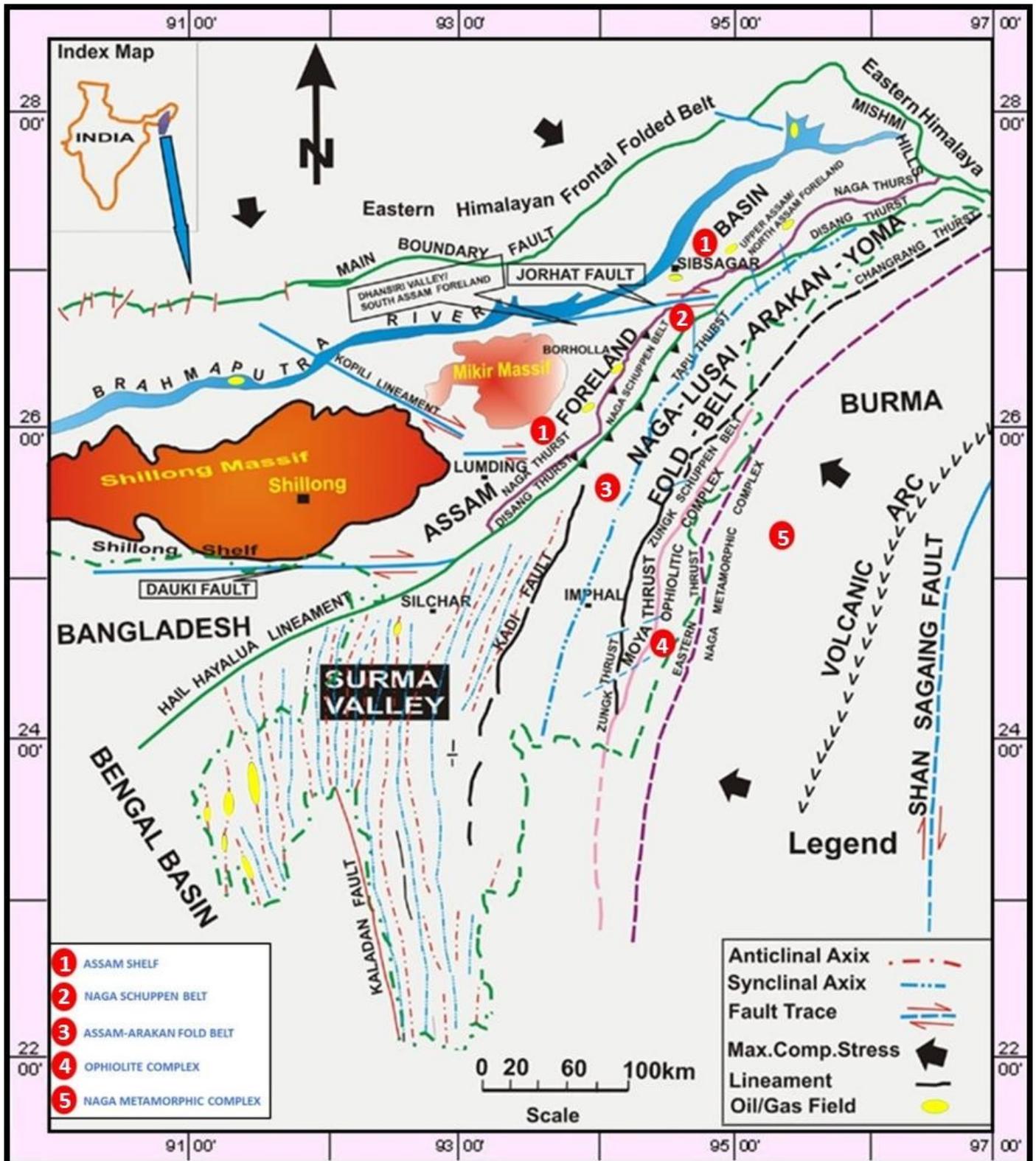


Fig. 2. Major structural elements of Assam-Arakan basin (modified after Singh et al., 2011).

Eocene saw the deposition of carbonate deposits as a result of extensive transgression, whereas the Upper Eocene sees the deposition of shale. The geological uplifts in the region and the declining sea level are re-

sponsible for the increasing fraction of coarse clastics during the Oligocene and Miocene. Unconformable relationships between the Tipam sands and overlaying sediments are indicative of a successive basin-wide

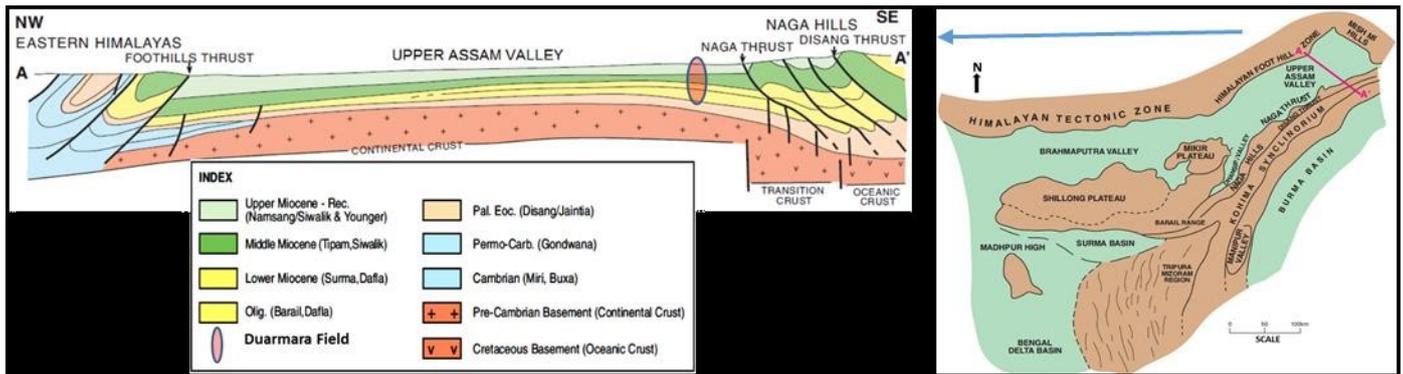


Fig. 3. NW-SE cross section from the eastern Himalayan foothills to Naga Hills.

compressive orogenic phase from the Upper Miocene to the Pliocene that led to the formation of landforms and subsequent erosion.

5. Event Chronology

The chronology of events indicates favorable timing of generation and migration of hydrocarbon during Eocene from a source rock of Eocene age. Oligocene witnessed deposition of reservoir rocks and formation of many traps that together helped accumulation of the oil and gas (Wandrey, 2006) (Fig. 5).

6. Integrated Subsurface Workflow for Opportunity Generation

The integrated subsurface workflow for opportunity generation in oil and gas fields encompasses three critical domains: geological, petrophysics, and geophysics (Fig. 6). Each domain provides unique insights that, when combined, enable a comprehensive evaluation of hydrocarbon potential and the identification of new exploration and development targets.

The geological workflow involves the systematic analysis of regional geology, well logs, cores, and biostratigraphic data to establish a robust stratigraphic and structural framework. This includes facies interpretation and depositional environment analysis, leading to the construction of static reservoir models and gross rock volume (GRV) estimations.

The petrophysical workflow focuses on well log quality control, core-log integration, and advanced interpretation techniques to quantify porosity, permeability, water saturation, and net pay. These parameters are essential for assessing reservoir quality and volumetric calculations, supported by uncertainty quantification and rock typing.

The geophysical workflow integrates seismic acquisition, processing, and interpretation, including seismic inversion, attribute analysis, and depth conversion. These processes help delineate reservoir boundaries, identify direct hydrocarbon indicators (DHIs), and enhance reservoir characterization.

The final integration phase merges outputs from all three domains to generate and risk-rank subsurface opportunities. This multidisciplinary approach ensures a technically robust and data-driven strategy for optimizing resource identification, reducing exploration risk, and enhancing field development planning.

7. Play Types and Future Outlook of Duarmara Field

The major play types in the Assam Basin are as follows (Table 1):

- Pre-Cretaceous: Basement play
- U. Paleocene–M. Eocene: Basal Tertiary Sylhet-Kopili play
- Oligocene: Barail Play
- Miocene: Tipam Play
- Miocene–Pliocene: Girujan play

Duarmara field is located in the Assam Shelf in the vicinity of the producing Digboi fields. The play types can be summarized as follows:

- Play 1: tilted fault blocks, anticlinal closures and fluvial stratigraphic traps of Barail Group (Oligocene age).

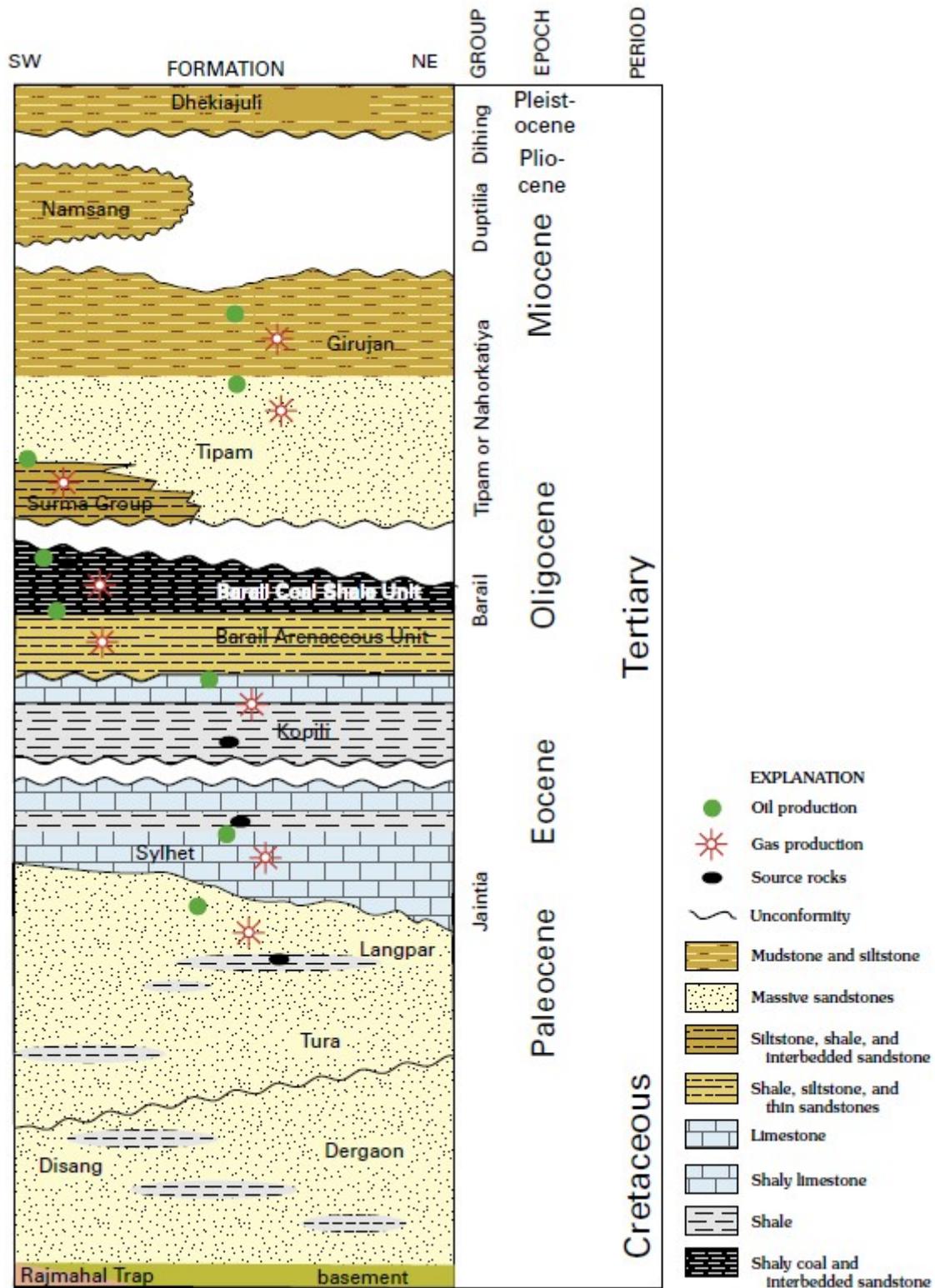


Fig. 4. Litho-stratigraphy of Assam shelf (modified after Mathur et al., 2001).

- Play 2: anticlinal closures and stratigraphic traps of Tipam Group (Miocene age).
- Play 3: unconformity trap, pinch-out/wedge-outs of Girujan Fm. (Mio-Pliocene age)

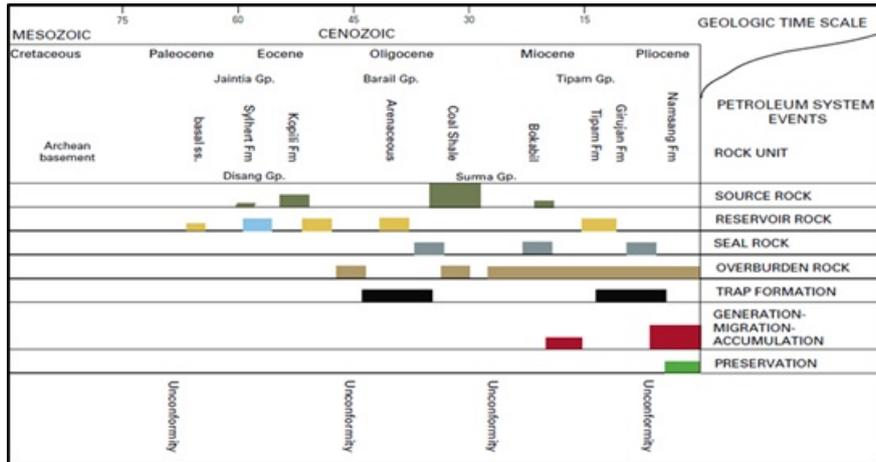


Fig. 5. Petroleum systems events chart for the various elements (modified after Wandrey, 2006).

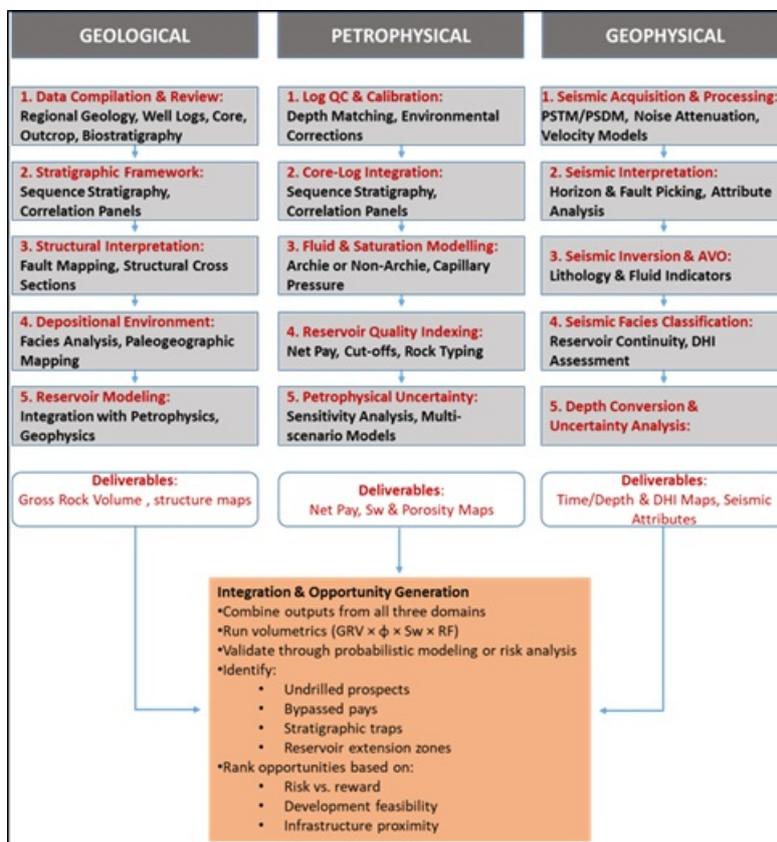


Fig. 6. Integrated subsurface workflow.

Table 1. Major oil and gas fields and play type distribution.

S. No.	Plays	Formation	Major fields
1	Mio-Pliocene	Girujan	Kharsang, Kumchai, Dirok
2	Miocene	Tipam	Hapjan, Digboi, Geleki, Charali
3	Oligocene	Barail	Nahorkatiya, Lakwa, Lakhmani, Rudrasagar, Demulgaon, Sonari, Amguri, Hapjan, Shalmari, Kusijan, Laiplinggaon, Geleki
4	Mid-Upper Eocene	Kopili	Geleki
5	Lower Eocene	Lakadong + Therria (Sylhet Fm.)	Dikom, Kathaloni, Baghjan, Panidihing, Tamulikhat, Tengakhat
6	Archean	Fractured Granitic Basement	Borholla, Champang

The existing wells DMR-1, DMR-2 and DMR-3 were drilled during 1970 using the primitive technology available at that time. Currently, drilling of new wells are planned to prove the hydrocarbon prospectivity and play concept of deeper Barail and Kopili formation. There are plans to acquire the latest well logs, core/side wall core data and detailed analysis of the cores for a sequence stratigraphic analysis, which will help in better delineation of plays. Use of the latest state of the art technology for deep drilling and formation evaluation will result in the latest data set for petrophysical analysis, sequence stratigraphic analysis. Establishing new hydrocarbon bearing zones will be added to the reserves portfolio resulting to upgrade the small field to a sizable oil and gas field.

8. Summary

This study presents an integrated subsurface approach for oil and gas field optimization, combining geological, petrophysical, and geophysical analyses. Geological workflows include stratigraphic correlation, structural interpretation, and static reservoir modelling to define field architecture. Geophysical processing enhances reservoir characterization via seismic data interpretation and inversion, refining fluid and structural features. While petrophysical analysis quantifies porosity, permeability, saturation through log evaluation and rock typing. By unifying these domains, the approach enables comprehensive reservoir modelling, volumetric assessments, and opportunity identification—reducing risks while optimizing hydrocarbon recovery and field development strategies.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. No financial, personal, or professional relationships have influenced the content or findings presented in this study.

CRedit statement

SD:, writing original draft, review & editing, Data curation, formal analysis, methodology, visualization, investigation, validation. DSP: Conceptualization, supervision, review & editing

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