New Perspective of Stratigraphic Sequences in Gandak Depression, Ganga Valley Basin, India

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Abstract

Basin analysis is one of the most significant and complex tasks in the field of oil and gas exploration. In the stage of basin analysis, it needs to establish the necessary boundary conditions that should be present in the basin for hydrocarbons to occur in rocks and their accumulation. Certain conditions must be met e.g., presence of a source rock, reservoir rock, with adequate porosity and permeability, traps (structural, stratigraphic or combination), overlain by adjacent to an impermeable layer (cap rock or seal) within the basin. To estimate such conditions geophysical tools such as seismic, gravity, and magnetic are used for surveying. Therefore, this study is conducted by the use of integrated seismic and well data in the Ganga Valley basin, which is one of the major sedimentary basins in the Indian subcontinent adjacent to Himalaya. A quantitative interpretation of seismic and well data has been summarized along the seismic sections A, B & C in the Gandak depression of Ganga Valley basin. General overview results, from the seismic section, shows stratigraphic and structural, and structural-cum-stratigraphic traps are observed all over the Ganga Valley basin. The central Gandak depression indicates better tectonic and depositional conditions for structural traps in the Neoproterozoic sequences of upper Vindhyans. However, the seismic section also shows a deep granitic Bundelkhand basement with some intruded body and hidden features. To identify these bodies data, need to be further correlated with several well logs. This geophysical study will help to quantify the potential source, reservoir,cap rocks, and petroliferous traps in the Ganga Basin.

Introduction

Physiographically, India is classified into three main divisions, the Himalaya, the Peninsula, and the Indo-Gangetic Plain. Indo-Gangetic plain was by the deposition of terrigeneous clastic sediments brought down by the rivers of the Indus, Ganges and the Brahmputra river systems into the basin created as an aftermath of the upliftment of Himalayan orogeny during the Pliocene-Pleistocene time. The Indo-Gangetic Plain has further been categorized into the following basins: the Indus basin, the Brahmaputra basin, the Punjab basin, the Ganga basin, and the Bengal basin. This study is mainly focused on the Ganga basin which is a major component of the Indo-Gangetic plain. The Ganga basin originated as a result of the formation of a depression in front of the uplifted Himalayas due to intensive orogeny of the Pliocene-Pleistocene age. The Ganga plain originated due to the subsidence of the crust due to compression forces on the peninsula. Subsequently, the depression was filled with terrigeneous sediments brought down by river system, flowing from the Himalayas to the peninsula India. Hence, Ganga basin is an example of a peripheral foreland sedimentary basin where oil and gas discoveries are still waiting for study. Therefore, this study is mainly focused on the Ganga valley basin which is a dominant component of the Indo Gangetic plain. Consequently, the Ganga basin is extensively discussed.

Study Area

Ganga Basin (GB) and Punjab Plain (PP) are the essential part of the Indo-Gangetic (IG) Plain covering 3,04,000 sq. km area. The basin extends over an area of 2,000 kilometers (1,200 mi) in length and 450 kilometers (280 mi) in width, located within Long.

77°E and 88°E and Lat. 24°N and 30°N (Figure1) (Padhy & Das, 2013).

The present study accounts for the seismic delineation in the east Ganga basin (Gandak Depression) for hydrocarbon prospectivity. The east-west elongated Ganga basin is the largest Quaternary alluvium sedimentary terrain in the northern part of India. The basin, which is the major unit in the geology of the Indian subcontinent, was brought down by rivers draining the Himalayan range. The Ganga basin provides a present-day example of a peripheral active foreland basin (Sastri et al., 1971). The Ganga Basin covers an area of about 2,42,444 sq.km, which is more than half of the Indo-Gangetic (IG) Plain. It consists of alternate beds of sand and clay with intermittent calcareous poorly consolidated interbeds down to the bedrock.

The basin's basement is characterized by multiple buried faults and ridges. The Delhi-Haridwar ridge, for example, is the Aravalli Mountains' expansion into the Himalayas via Haridwar. Faizabad ridge and Munger-Saharsa ridge represent the continuation of the Bundelkhand and Satpura massifs, respectively. Faults and tectonic extensions from the Indian shield run through all of these ridges (Gorain et al., 2023; Sinha et al., 2005).

Tectonic Setting and Stratigraphy

Ganga basin is one of the largest sedimentary basin of India located in the northern boundary of the Indian shield, formed due to the collision of the Indian and the Asian plates and underthrusting of the Indian plate. In the east, basin is limited by subsurface Monghyr–Saharsa ridge and Delhi–Haridwar ridge in the west. In the north, it is bounded by the outermost Siwalik foothills of the Himalayas by the Himalayan Frontal Thrust (a series of reverse faults) which extends parallel to the Himalayas from west to east. The exposed Purana sediments or Vindhyan group and Bundelkhand granites/gneiss massif limit the basin in the south (Sahu & Saha, 2014). Based on the study of Gravity-Magnetic, Aeromagnetic & seismic surveys, earlier researchers, structurally segmented the Basin into three important depressions namely Sharda, Gandak, and Madhubani depression (Figure1). All of these depressions are said to be separated from one another by interceding basement ridges.

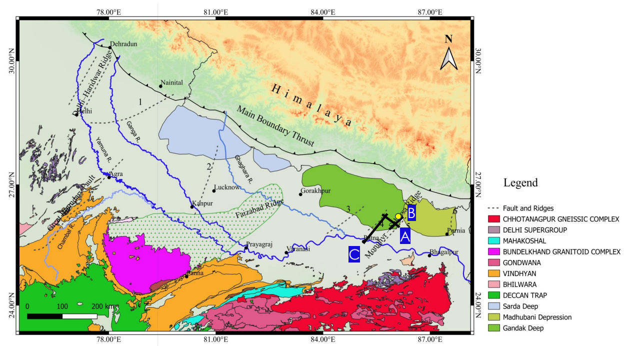

Figure 1:Map depicts lithology and tectonic structures of the Ganga Valley basin; numbers represent the major subsurface faults identified by the use of geophysical methods. 1. Delhi Moradabad Fault, 2. Lucknow Fault, 3. West Patna Fault, 4. East Patna Fault, 5. Monghyre-Saharsa Ridge Fault, 6. Malda-Kishanganj Fault; R. River (modified from Sastri et al 1971; Rao 1973; Sinha 2005; Srinivas et al., 2014)

The chrono-geological section of the Ganga basin in the study area consists of Archaean Paleoproterozoic Bundelkhand granite basement rocks and Mesoproterozoic to Quaternary deposits of the fluvial sedimentary cover. The development of each sedimentary sequence occurred in different genesis and the history of subsidence and upliftment. The deposition of terrigenous sedimentary cycles are identified in three major time period followed by
1)Mesoproterozoic - Bahraich group
2)Neoproterozoic-Paleozoic Ujhani, Tilhar and Madhubani Formations
3)Tertiary sediments – Siwalik group and Quaternary Alluvium

The basin's stratigraphy includes Bundelkhand granites at the basement sequence which was later on faulted by tectonics**.** The lowermost formation of the lower Vindhyan group (Bahraich group) is identified, which is overlain by three units of the upper Vindhyan group (Ujhani, Tilhar, and Madhubani Formations). The Tertiary deposits are split into five formations, three of which are part of the Siwalik group.

The Siwalik Group is a coarsening upward siliciclastic succession in the foreland basin that has the thickest concentration of debris sourced from the Himalayas. The deposits are continental and mostly indicate deposition in floodplains, meandering rivers, and braided rivers. Since the early 1900s, the Siwalik Group has been classified into Upper, Middle, and Lower Siwalik based on vertebrate fossil markers. The Siwalik Group begins with the Lower Siwalik. The Lower Siwalik began to take shape around the Middle Miocene. The Lower Siwalik is distinguished by alternating sandstone and mudstone facies deposited in river and floodplain settings. From the upper Miocene through the Pliocene, the Middle Siwalik was deposited. Sandstone beds dominate this unit, interrupted by thin mudstone to siltstone horizons.

The Upper Siwalik, which was deposited from the Pliocene to the Quaternary, is thought to be a sedimentary record of the last phase of Himalayan orogeny. In the upper layers of the Upper Siwalik, conglomerate facies predominate, with sandstone, mudstone, and conglomerate in the lower strata. The generalized stratigraphic sequence of the Ganga basin is given in Table 1.

Table 1: Generalized stratigraphic sequence of Ganga basin(modified from Srinivas et al., 2014).

Era	Period		Age (Ma)	Group/Formation	Thickness(m)	Lithology
Cenozoic	Quaternary		1.5 - Recent	Alluvium	200-426	Loose sand, Kankar, Gravels, and Pebbles
	Tertiary	Neogene	5.5 - 1.5	Upper Siwalik	200-1300	Interbedded Sandstone, Silty Claystone
			10.8 - 5.5	Middle Siwalik	250-1970	Sandstone, Claystone, and Siltstone
			18.3 - 10.8	Lower Siwalik	130-1540	Sticky clay, Sandy claystone, and hard siltstone
		Paleogene	35 - 28	Matera	400	Grey to black silt shale alternation, occasional sandstone
Regional Unconformity (Major Upliftment)						
Mesozoic	Cretaceous		145 - 66	Erosion		
	Jurassic		201 - 145			
	Triassic		251 - 201			
Paleozoic	Ordovician to Permian		485 - 251			
	Cambrian		?	Kamapur	50-450	Dominantly arenaceous with fissile shales, Claystone
Proterozoic	Neo-Proterozoic		700 - 635	Tilhar	210-380	Argillaceous Limestone, Dolomitic at base with Shale
			700 - 800	Ujhani	130-850	Quarzitic Sandstone with Shale and Claystone
			?	Madhubani	2430+	Dolomite, limestone, shale, siltstone
	Unconformity (Major Upliftment)					
	Meso-Proterozoic		1550-1350	Bahraich	527+	Quarzitic Sandstone, Limestone, Basic Rocks, Phyllites, and Schists
Archean Basement (Bundelkhand Granite/Gneiss)						

Methodology

2D seismic lines, section A, section B and section C are utilized for seismic data interpretation in the Ganga Basin to identify the potential deeper hydrocarbon reservoir in the Proterozoic sequence. A seismic section A (Figure 2) extends about 160 kilometers, elongated in NW to SE in the Ganga basin acquired under NSP (National Seismic Program). In contrast, seismic section B extends about 90 kilometers in NE and SW directions. Both lines are crossing to each other (Figure 4). The formation tops (horizons) were correlated with the Well located at seismic section B (Figure 3). These horizons were further extended in section A and section C.

Seismic data interpretation

Seismic sections A, B and C are showing fluvial deposition of strong reflectors for upper siwalik, middle siwalik and lower siwalik, which are dipping towards north . A major Regional Unconformity (RU)

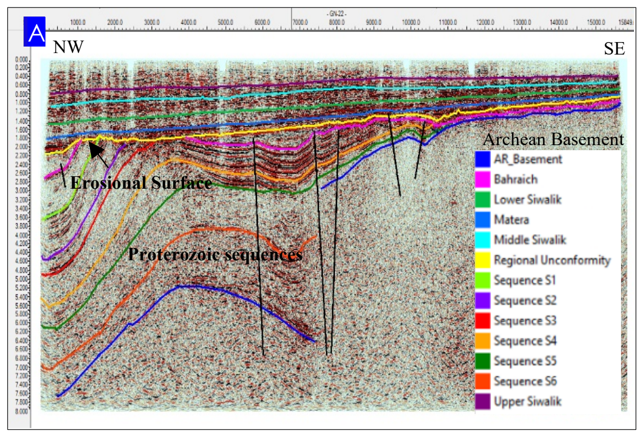

Figure 2: 2D seismic section (Section A) in the NW-SE direction showing deeper stratigraphy in the Ganga Basin.

was encountered underlying lower siwalik & Matera formations. Below Regional Unconformity (RU), major Protreozoic sequences were identified, named as sequence S1, S2, S3, S4, S5, S6 (Figure 2) . These sequences are highly faulted, folded and fractured, and resulted in structural and stratigraphic traps in the Ganga basin. These traps are associated with Paleozoic and Proterozoic intervals, along the Regional Unconformity surface. Indicates favorable zones for hydrocarbon trapping, in Tilhar, Ujhani & Bahraich formation. Probable structural traps (Anticline and Syncline) can be confined to separate local highs ridges, which are well observed in the section A & B. Stratigraphic traps are presumably associated with pinching out zones. Some of the traps can be probably restricted by faults. Section C shows the different direction of sediment deposition for marked as regional sequences 1, 2, 3 and 4. where sequence 2 takes place after the erosion of sequences 3 & 4 both. Section C indicates the depocenter changes throughout the depositional history. There are three Pre-Tertiary sequences in Gandak depression (Figure 5). It cannot be excluded at all, that probable prospects can be associated with the upper part of the Bahraich deposits under favorable conditions, connected with the presence of fracture zones. However, foreland sediments (Siwalik and alluvium) deposited on a fairly uniform surface, and are sloping towards Himalaya. Basement faults (below regional unconformity) identified in this study, did not affect Siwalik sedimentation and the faults are not visible on the surface.

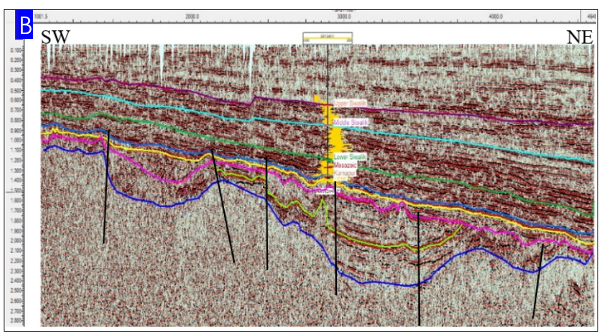

Figure 3: 2D seismic section B in the NE-SW orientation in the Ganga Basin. The seismic section correlated with well.

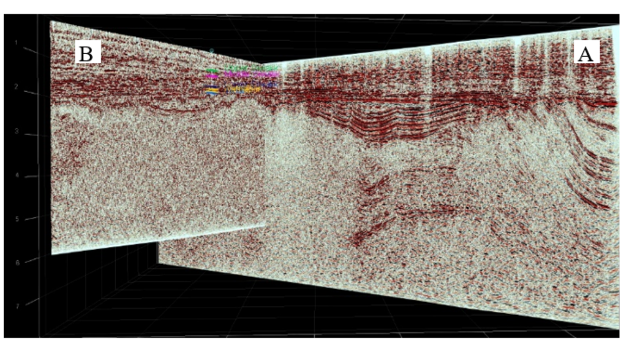

Figure 4: 3D view of seismic section A & B revealing the deeper stratigraphy.

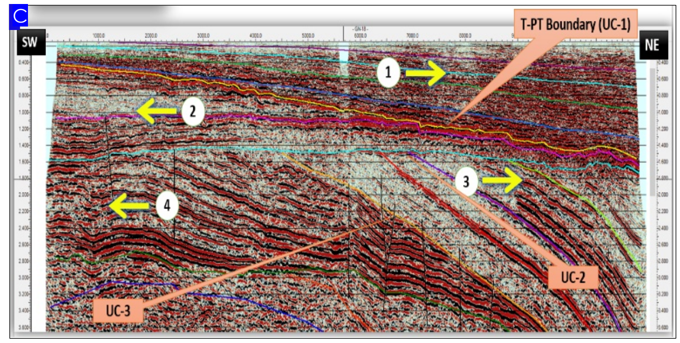

Figure 5: 2D seismic section C shows different directions of sediment deposition.

Conclusions

By observing upliftments and fauts seismic study shows that the Ganga basin was active during the Late Proterozoic sedimentation. The initial phase of sedimentation took place under the conditions of intracratonic rift in the Mesoproterozoic, when the Bahraich group was initialy deposited. A regional unconformity indicated hiatus of missing Mesozoic sediments. Afterword, significant amount of sediments inputs into the Siwalik formation brought down by rivers, flowing from the Himalayan range to the peninsula India.

In the basin, structural, stratigraphic and structural-cum-stratigraphic traps are expected all over the basin. The central part of the Gandak depression indicates better tectonic and depositional conditions for structural traps in the Neoproterozoic sequences of upper vindhyans.

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