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A methodology of porosity estimation from inversion of post-stack seismic data

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A R T I C L E I N F O

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A B S T R A C T

Post-stack inversion of seismic data is routinely carried out to derive acoustic impedance (AI) and, hence petrophysical properties in an area. We have been introducing here an uncommon methodology of inverting post-stack seismic data into porosity from porosity log. The post-stack inversion for estimation of direct porosity is performed by utilizing an estimated porosity wavelet, low frequency model and model based inversion. This methodology is implemented on two types of 2D post-stack seismic dataset; (a) deep water Mahanadi (MN) offshore containing gas hydrate sediments and (b) clay rich, shaly sediments in Krishna–Godavari (K–G) shallow offshore. The total porosity (φ) estimated from density log for the depth interval of 1725–2032 m ranging from 49 to 75% has been used as input for porosity inversion from the seismic data of unconsolidated sediments at 1701 m bathymetry in MN basin. The total porosity for the depth interval of 410–1494 m ranging from 5 to 45% has been used as input for porosity inversion from the 2D post-stack seismic data of shallow offshore sediments at 31 m bathymetry in K–G basin. This prediction is applied to dataset having good (for MN) and poor correlation (for K–G) between AI and porosity. In MN basin, the porosity along 2D multichannel seismic ranges from 53 to 65% in the gas hydrated zone with maximum value of 70% at the free gas filled unconsolidated sediment below the bottom simulating reflector (BSR). The water bearing silt/clay sediments indicates porosity of about 60–65% below the seafloor. In K–G basin, the porosity in Raghavapuram shale varies from 13 to 30% with maximum value of 52% is observed in Paleocene sediments.

1. Introduction

Acoustic impedance (AI) mapping is a common approach for inversion of post-stack seismic data to delineate reservoir properties. Nowadays, pre-stack seismic inversion techniques are used for computation of impedances: P-impedance, S-impedance and density. These are further used for estimation of porosity, shale volume, lithofacies and water saturation from seismic data. Well information are available at hundreds of metres apart, therefore the objective of seismic inversion method for reservoir characterization is to delineate petrophysical properties for the interwell region or adjacent to the wells.

Quantitative measurement of the porosity of any rock is important. The presence of dispersed shale leads to porosity anomaly in the reservoir rock. Porosity of rocks is measured in various ways such as: from core samples in laboratory; from log data, from interval velocities of seismic traces as well as from mathematical modelling. Observations on sonic log data provide good vertical resolution of geological strata, but are at sparse locations. In contrast, seismic method provides usual areal sampling but with noticeably lower vertical resolution. The integration of 2D seismic data of any area with porosity measurement at wells can significantly improve the porosity distribution in space. The petrophysical parameters are generally predicted from seismic inversion properties such as acoustic impedance (AI) using multivariate statistics modelling, non-linear methods including neural network (e.g. Hampson et al., 2001; Leiphart and Hart, 2001; Walls et al., 2002; Pramanik et al., 2004; Calderon and Castagna, 2007; Singha and Chatterjee, 2014; Singha et al., 2014). Objectives of this paper are to (a) develop the relation between porosity and acoustic reflectivity, (b) estimate the porosity wavelet and (c) perform direct inversion of post-stack seismic data to predict porosity from well log. The methodology is applied to 2D post-stack data of shallow offshore of Krishna–Godavari (K–G) and deep

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water of Mahanadi (MN) basin.

2. Study area

2.1. Mahanadi basin

The MN and K–G basins along the eastern continental margin of India are developed due to rifting and break-up of Gondwana land during Jurassic time. The MN basin is located between hydrocarbon producing K–G basin to the southwest and Bengal basin to the northeast (Fig. 1). The basin is separated from K–G basin by 85° E Ridges. The present study area belongs to one of the deep water blocks of MN basin, close to the present day shelf.

Deep water blocks of MN basin witnessed the confluence of sedimentation by the two rivers: The Ganga and the Mahanadi. Interpretation of data reveals the presence of horst-graben structures trending ENE-WSW, located to the northwest of continental shelf break (Das et al., 2010). A thick pile of sediments (about 8 km) of Upper Cretaceous to recent age is deposited in deeper water portion of MN basin (Jagannathan et al., 1983; Fuloria et al., 1992; Fuloria, 1993; Bastia, 2006). A general geology and hydrocarbon prospect of MN basin is comprehensively dealt by Fuloria (1993). A basaltic lava flow (known as Rajmahal trap) is present in between Lower and Upper Cretaceous sediments. Carbonate, a well-known litho-marker is present in Middle Eocene. Overlying Neogene sequence consists of clastics in the type of channel–levee complex, alluvial fans and mass transport systems in a deep-sea setup. Channel-levee complexes in Mio-Plio sediments are observed pervasively throughout the basin (Das and Datta, 2012).

Multichannel stacked and migrated seismic reflection records illustrate the presence of bottom simulating reflector (BSR) in the MN offshore area (Fig. 2). BSR inferred from the seismic section in MN offshore satisfy the criteria of seafloor mimics, opposite polarity with respect to seafloor and cross-cutting of sediment layer. High sedimentation rate (20–40 cm/kyr) is observed in the Bay of Bengal suggesting the hydrate occurrence in the Pleistocene sediments of MN basin (Ramana et al., 2006, 2007). Seismic section is typically selected from National Gas Hydrate Project (NGHP) site NGHP-01-08 at 1701 bathymetry. The BSR is observed at depth of 250 m below sea floor (mbsf) at this site of MN offshore (Collette et al., 2008). Gas hydrate is associated with clay/silt sediments and fractures zones of Pleistocene age.

Fault, free gas seepage through vents/chimney, gas hydrate bearing sediments, free gas zone and channel sand are identified in the seismic section of MN basin. Davies and Clarke (2010) and Yang et al. (2013) interpreted chimneys as the gas migration pathways into the hydrate system. Recently Yang and Davies (2013) proposed that faults caused by creep processes on passive continental margins could act as pathways of gas migration after the upward resetting of the base of hydrates.

2.2. K–G basin

The pericratonic rifted basin is holding multiple petroleum system ageing Mio-Pliocene to Cretaceous age. The shallow offshore area located at the north–eastern part of K–G basin is considered for porosity prediction from 2D post-stack seismic data. The study area contains sediments of Gollapalli Sandstone, Tirupati Sandstone and Raghavapuram Shale formations of Cretaceous age. The sands are deposited during the Upper Cretaceous by a prograding deltaic system that spread out into shelf and slope environments. The shallow marine environment with very slow rate of sedimentation, shallow bathymetry and the nearness to the provenance result the deposition of high gamma-high resistivity shale (HG-HR) sequence known as Raghavapuram Shale (Manmohan et al., 2003). The sequence is carbonaceous, organic rich, silty and with high radioactive: thorium and potassium content. The porosity estimation of Raghavapuram Shale in shallow water is very critical in reducing the drilling risk in this trend. Because the sandstones present in this formation tend to be thin and interbedded with shale, the high reflectivity has a dimming effect on the reflection images of sand-shale boundaries in this zone.

The seismic section belonging to shallow offshore of K–G basin show the geological horizon with its age (Fig. 3). The sand filled channel, faults are identified in the seismic section. The Paleocene top is observed at 230 ms. Seismic reflections are mainly attributed to unconsolidated silty sand/shale/mudstone occurring 230–620 ms of Paleocene age. Top of Raghavapuram Shale is observed at 780 ms from seismic section of K–G basin. Top of Cretaceous and basement of Permian age are observed around 500 ms and 1580 ms respectively. The penetration of seismic energy into the underlying basement is significantly reduced. The basement top stands out as a prominent reflector between the overlying bedded sediments and underlying noisy section of the basement.

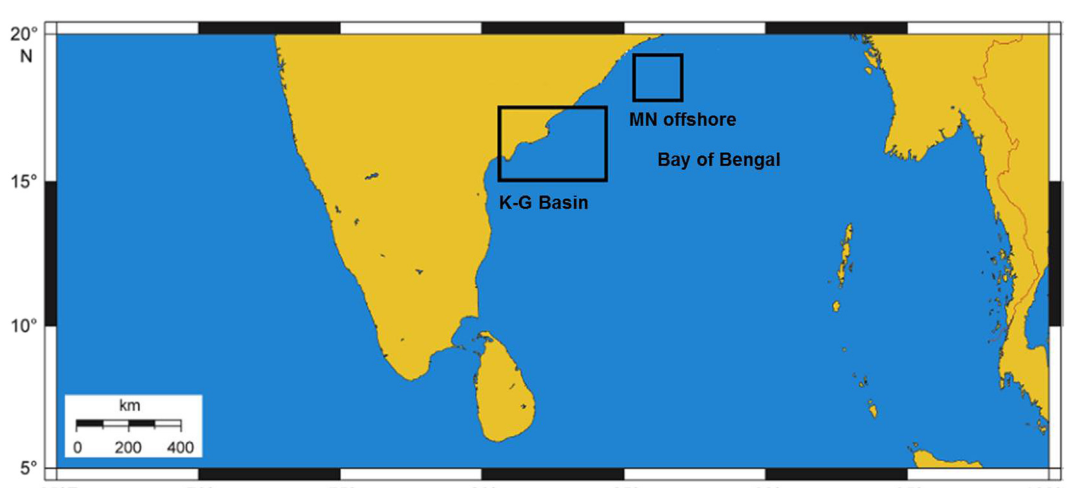

Fig. 1. Location map of Mahanadi basin (MN) and Krishna–Godavari (K–G) basin along eastern continental margin of India (after Collett et al., 2014).