



Combining impedance inversion and seismic similarity for robust gas hydrate concentration assessments – A case study from the Krishna–Godavari basin, East Coast of India

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ABSTRACT

Gas hydrate saturations were calculated based on Archie's relation and rock-physics modeling utilizing log measurements of electrical resistivity and P-wave velocity through the gas hydrate stability zone (GHSZ) at two sites in the Krishna Godavari (KG) basin off the East Coast of India. Acoustic impedance inversion was then performed around the well sites for regional extrapolation of the borehole data. Well-log based gas hydrate concentration estimates and core data are in general agreement with the seismic impedance inversion results at the individual well sites. However, the correlation with seismic data and thus the confidence in the extrapolation decreases with distance from the well site. To address the general problem of unknown regional confidence limits in the extrapolation and aid in regional gas hydrate assessment analyses, a new approach is introduced by calculating the running-sum of the seismic similarity attribute across the gas hydrate stability zone. The running-sum of the similarity attribute can be used locally on a 2D seismic line or 3D seismic volume for defining the limit of well-data extrapolation around a given well site. By normalizing the running-sum of the similarity attribute from all available 2D seismic data in the KG basin, a regional map was generated yielding effective confidence limits for extrapolation of well-log data. Such maps of regional confidence limits can be used strategically in basin-wide gas hydrate assessments as they provide a measure of probability to find a given gas hydrate concentration, and may also offer a guide for defining a minimum regional spacing between well-sites to address the overall structural complexity of the basin (which is reflected in the similarity of the seismic data).

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1. Introduction

Gas hydrate is considered as potential alternative source of energy during recent years (e.g. Boswell and Collett, 2011; Boswell and Saeki, 2010). The identification and quantification of gas hydrates have drawn significant global scientific attention due to their world wide occurrences and abundance on continental margins. Reflection seismic imaging methods, being the principal method in hydrocarbon exploration, are extensively used for gas hydrate detection (e.g., Dai et al., 2004; Diaconescu et al., 2006; Ecker et al., 1998; Kvenvolden and Barnard, 1983; Shipley et al., 1979; Xu et al., 2004). The presence of gas hydrate in sediments is frequently inferred on seismic records by the presence of

a bottom-simulating reflector (BSR), marking the base of the gas hydrate stability zone (GHSZ). The presence of gas hydrate in sediments has a large effect on the elastic properties, notably P- and S-wave velocity, and electrical resistivity (e.g., Lee and Collett, 2009). Independent of the physical location of gas hydrate in the sediments, P-wave velocity (and thus P-wave impedance) is strongly increased relative to a gas hydrate free background. S-wave velocity and impedance are especially increased if gas hydrate forms such that it stiffens the overall sediment matrix. However, there are few examples of S-wave data sets to fully assess the ability of S-impedance inversion to delineate gas hydrate occurrences (Riedel et al., 2010). The presence of gas hydrate or a few percent of free gas below the gas hydrate stability field produces no measurable density effects on seismic data. With empirically derived or theoretical relations between gas hydrate concentration and elastic parameters, measurements of seismic velocities can be used to quantify gas hydrate concentrations in sediments.

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In 2006, the first India National Gas Hydrate Program drilling expedition (NGHP-01) completed fifteen sites for the study of gas hydrate in the KG basin. The objective of the program was to collect sediment cores and obtain well logs in area where there was substantial seismic evidence of the occurrences of gas hydrates and thus aid in the verification of exploration models. The NGHP-01 targeted the KG basin slope region at water depths ranging from 800 m to 1500 m. The coring and drilling sites are shown in Figure 1. The KG basin sites have a prominent regional BSR (Collett et al., 2008). The lithologies are dominated by clay and small amount of silt and sand at almost all sites. At Site NGHP-01-15 some sand-dominated lithologies were also observed tied to a prominent channel system (Riedel et al., 2011). At Site NGHP-01-07 we used data from the logging-while-drilling (LWD) campaign, whereas at Site NGHP-01-15 we used results of a wire-line logging program for calculating gas hydrate concentrations. At both sites, coring was performed and measurements of pore-water chlorinity and whole-round core temperatures measured with an automated IR camera system, confirmed the log-derived gas hydrate saturations.

Well-log-information provides a direct means to obtain gas hydrate concentrations by measuring P- and S-wave velocity and other related physical properties (e.g., Guerin et al., 1999). However, the challenge is to extrapolate the well-log information away from the borehole using seismic data to achieve a complete assessment of a gas hydrate deposit. In this paper we first use well-log techniques to quantify gas hydrate concentrations and then apply acoustic impedance inversion on post-stack 2D and 3D data to infer regional gas hydrate concentrations. We finally introduce a new seismic attribute in the form of normalized running-sum of seismic similarity, yielding a map of regional seismic similarity that can be used to define meaningful measures for confidence limits or probabilities in the extrapolation of the inversion results away from the boreholes to aid in more robust resource assessments.

2. Geology and tectonic setting of the KG basin

The eastern continental margin of India evolved as a consequence of rifting and subsequent drifting of the Indian plate away from the rest of East Gondwanaland in the Late Jurassic and Early Cretaceous (Ramana et al., 2001). The KG basin, situated in a classic

passive-margin setting and proven petroliferous basin, has a lateral extent of ~500 km and extends more than 200 km from the coast into the deep sea (Bastia, 2006; Gupta, 2006; Max, 2000). Sediment thickness in the KG basin varies from 3 to 5 km in the onshore region and may exceed 8 km in the offshore region (Prabhakar and Zutshi, 1993). The basin is characterized with horst and graben systems, which are filled with thick sediments of Permian-to-Recent age and emerged as one of the frontier areas for future hydrocarbon exploration (Gupta, 2006). Discovery of conventional gas and large deposit of gas hydrates in recent years (Bastia, 2006; Collett et al., 2008) attract the scientific community to study the basin in greater detail. The basin has significant hydrocarbon potential both in the Tertiary delta as well as in the channel-levees and overbank play types in the deepwater region. The delta fronts also exhibit mass-transport deposits (MTDs), scars and irregular topography features formed by sliding/slumping (Forsberg et al., 2007; Ramana et al., 2009). The sediments of widespread MTDs and submarine canyons over the modern upper continental slope in KG basin are shale dominated (Shanmugam et al., 2009). Major delta systems with thick argillaceous and arenaceous facies have prograded basin-ward after the rifting of the basin during the Late Cretaceous. Large canyons of different magnitude have also contributed to the total sediment accumulations. The fast rate of deposition on the slope-intraslope basins has led to the development of fault extensions (Bastia, 2006).

Hydrocarbons were found in the KG Basin in 1979, and the first commercial gas discovery was in 1980 (Gupta, 2006). The deeper sections of the KG deltaic system are one of the most favorable areas for gas hydrate occurrence in the Indian passive-margin as they are characterized by thick sediment accumulation with a substantial potential to generate hydrocarbons (Max, 2000). The deeper part (>800 m water depth) of the KG deltaic system shows significant deformation in forms of normal faults and toe-thrusts (Bastia and Nayak, 2006; Ramana et al., 2009). Deformation progressively changes from a typical regional normal (growth) fault environment to a thrust–fault regime (Riedel et al., 2011). The sediments around the thrust–faults are severely deformed resulting in regional apparently blank seismic sections. These toe-thrusts can be the preferred pathway for the migration of deeper fluids into the gas hydrate stability zone (Riedel et al., 2008). Deep mini-basins form between the individual thrust faults trapping significant amounts of sediment. Within one of these mini-basins a channel system was discovered near Site NGHP-01-15, which extends south for about 10 km until it is lost across the outcrop of another toe-thrust fault (Riedel et al., 2011).

3. Material and method

3.1. Gas hydrate saturation (S_h) estimation from logs

Gas hydrate saturations can be estimated from well-log data using different techniques as shown by Collett et al. (1984, 1999), Collett (2001), Collett and Lee (2004), Kleinberg et al. (2003, 2005), Lee and Collett (2008, 2009), Mathews (1986), Guerin et al. (1999), and Hyndman et al. (1999). The most commonly used well logs for gas hydrate saturation estimates include electrical resistivity and P-wave velocity. Below, we discuss the gas hydrate concentration estimates based on resistivity and P-wave velocity measurements at the sites NGHP-01-07 and NGHP-01-15. These estimated results are then compared with the prediction from the post-stack impedance inversion results.

3.1.1. S_h estimates from electrical resistivity logs

Gas hydrate bearing sediments exhibit relatively high electrical resistivity values in comparison to water-saturated sediments,

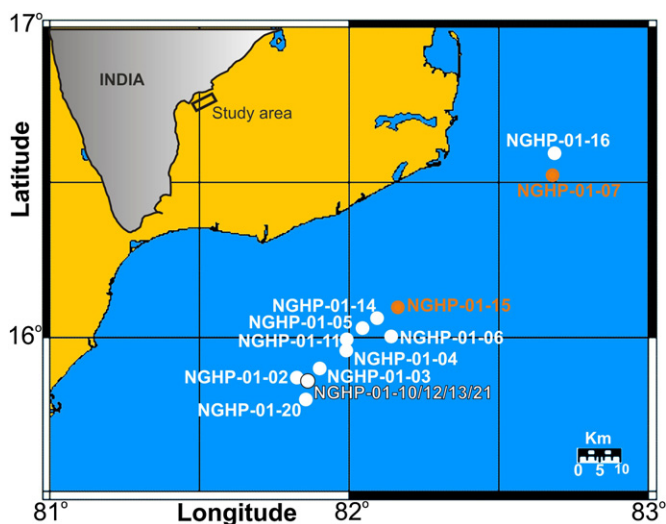


Figure 1. Map of the study area in the Krishna Godavari Basin, eastern continental margin of India. Locations of drill sites used in this study area are shown in orange with circles and site name. All other locations visited are shown in white. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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