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Impact of particle size on gas hydrate occurrence & distribution – A case history from KG Deep Offshore.

Abstract: Gas hydrates are crystalline solids composed of water and gas. Gas hydrate are considered as to store large amount of natural gases and active research is being pursued worldwide on the occurrence and distribution of natural gas hydrates in offshore as well as in arctic regions. ONGC has been playing very active role in the gas hydrate research. This paper presents the results of particle size distribution (PSD) in part of the KG deep water area drilled/cored during NGHP-02 and hydrate distribution in coarse grained reservoir at various depositional systems. The sediments consists of grain size mostly ranging from 63 to 250 µm, generally decreasing from shallow to deeper depths in the NE part (B in Fig. 1). The grains are very fine to fine grained and dominate the sediment core samples (Fig. 3), the hydrate saturation ranges from (50-80%), whereas in the central prospect part (C in Fig. 1) the grains are polymodal in nature varying in size from 35 to >500 µm (i.e., very fine to very coarse grained, occasionally gravel sized) and with hydrate saturation (40-50%) (Fig.4). In the SW part, grain size varies from 5 to 7 µm with hydrate saturation ranges from (30-40%) (Fig.5).

1. Introduction

The Krishna Godavari Basin is a proven petroliferous basin along the east coast of India covering 145,000 km² in the offshore has been one of the primary targets of India National Gas Hydrate Program Expedition 02 (NGHP-02). The basin contains sediments about 5-km thick with several depositional sequences, ranging in age from Late Carboniferous to Pleistocene (Curray et al., 1982). Gas hydrate is a naturally occurring “ice-like” combination of natural gas and water that has the potential to serve as an immense resource of natural gas from the world's oceans and Polar Regions (Collett et al., (2014). India has started its gas hydrate expedition in 2006 by executing NGHP-01 and subsequently in the year 2015 by NGHP-02. During the Expedition-02, 42 gas hydrate wells at 25 sites were completed. Our study area is located at the SW, central and NE part of the offshore basin (Fig. 1) the SW (Area E) lying, in the landward slope, approximately 180 km off Kakinada Coast in KD and GD blocks, central (Area C) lying, in the landward slope, approximately 140 km off Kakinada Coast in D6 blocks and NE (Area B) lying, in the landward slope, approximately 100 km off Visakhapatanam Coast in KGDWN-98/5 block part of the offshore basin. In these areas water depth varies from 1760 to 2814m. Sand deposits are closely linked with channel systems (e.g. Galloway and Hobday, 1996; Posamentier and Kolla, 2003), and sand-rich sediments are the favourable host-type for gas hydrate accumulation. Thus, mapping the architecture of gas hydrate-bearing sediments within channel deposits in the KG Basin has not only local implication on the understanding of the sedimentary systems in the KG Basin, but also further defines the gas hydrate petroleum system, helping to foster the approach and overall understanding of natural gas hydrate occurrences. Here we present a model for how gas hydrate is being accumulated in the coarse-grained fraction of sand-rich sediment sequences, their grain size distribution and with their lateral distribution governed by the channel-geometry. The main objective of this study is to build up a model controlled by sediment study and supported by downhole log signatures.

2. General Geology and tectonic set up of the basin

Krishna Godavari Basin is a typical passive margin characterised by polycyclic evolution history which witnessed its first marine transgression during Albian-Aptian time. The eastward tectonic tilt of the basin facilitated onset of the primary fluvial pathways (Godavari and Krishna) and the two present day delta systems were established during early Miocene time. Structural pattern in the basin thus is typical of passive margin-with loading on the shelf, related phases of growth and formation of frontal toe thrust. The passive continental margins were a result of different rifting episodes during the breakup and dispersion of Gondwanaland. Plate reconstructions place the eastern Indian margin adjacent to Enderby Land in East Antarctica with the northern margin of “Greater India” along the western margin of Australia [Powell et al., 1988]. The sediment thickness reaches a maximum of over 22 km on the Bangladesh shelf and over 2 km of fan sediments are found at 2°S (Curray et al., 1982), over 2500 km to the south. The river has a high sediment transport (Sastri et al., 1981; Biksham and Subrahmanyam, 1988) and the river has built substantial deltas as a result, seismic lines in the show features typical of fans including cut and filled channels and abundant growth faulting. Thus the sediments to be drilled are likely clays with well-defined sand horizons. In the Godavari offshore area, the top of the Miocene shows extensive slumping and erosion as subsequent regression and faulting have scoured this surface. The Plio-Pleistocene is represented by deep marine dark grey claystone that forms the regional seal for basin. The sands are sourced from Godavari river system and deposited on the lower slope (Fig.2).

3. Methodology

Data available for this study include core visual observations and LWD logs from three areas (Area B, C and E). Downhole logs are used for facies analysis establishing a relationship between lithofacies associations and curve shapes. The log parameters were further used to identify log facies signatures (finning up and blocky patterns). Finally, the recognized well-log facies were correlated with the core data in order to understand the geological significance of the log facies, as well as to construct potential links lithology, gas hydrate occurrence, and log facies to build a depositional model. Multiwavelength laser particle analyser (Beckman Coulter, model LS13320) to measure the grain size of core sediments. Laser particle analysis is based on the principle that particles of a given size diffract light at a given angle, which increases with decreasing particle size. The laser particle analyzer can provide measurement of sediment grain size ranging from 0.375 μm to 2 mm in size in ~10 min.

4. Result and Discussion

Based on the seismic data analyzed during the expedition to identify suitable sand facies as reservoir for hydrates are correlated with the LWD/wireline logging and sediment data. The seismic data were correlated with the well logs by identifying finning up and blocky log signature patterns. Turbidite sand and debris flow were identified within the available suite of downhole logs, core based sediment studies and grain size analysis. Post drilling analysis of well log curve patterns and seismic data was used to identify the sand facies that are hosting the discovered gas hydrate accumulations. As reviewed below, the lithofacies identified in each of the areas shown to host gas hydrates as established during NGHP-02 have identified.

4.1 AREA: B

The well taken for study is shown as “B” (black arrow) (Fig. 1) located in Area B along the northern margin of the KG-Basin. Based on the lithologic characteristics of cores recovered from sediment at this site can be divided into four main lithostratigraphic units: Unit I (0–150.20 mbsf), Unit II is not recovered in this well, because it gets thinner and fainter and apparently tapered out at this site, III (150.20–271.00 mbsf), IV (271.00–316.17 mbsf), and V (316.17– 346.85 mbsf) (Fig. 3). Unit I is characterized by an abundance of hemiplegic deposits. These sediments are composed mainly of terrigenous silty clay. Unit II, which corresponds to the upper high Natural Gamma Radiation interval at other sites, was not identified at this site. Unit III consists mainly of dark olive-gray to olive-black silty clay and greenish gray clay. These finer components contain large amounts of sponge spicules and diatoms. Large amounts of mica/wood fragments and very few biogenic components characterize this unit. Unit IV is composed of gray calcareous nannofossil–rich silty clay. The lower part of Unit V is characterized by MTDs composed of silty clay clasts in sandy matrixes.

The sediments consists of grain size mostly ranging from 63 to 250 μm, generally decreasing from shallow to deep depths; however, the mean grain size is 125μm in the NE part (B in Fig. 1), which contain high saturation of the hydrate occurrence. More than 95% of the grains are 125μm, indicating that very fine to fine grains dominate the sediment core samples (Fig. 3), are of the hydrate saturation ranges from (50-80%). Most of the major gas hydrate zones associated with Reflector R1 in the eastern transect and Reflector R2 in the western transect are layered type. Fracture-type gas hydrate zones are also commonly developed above Reflector R1 (Fig. 3). Fracture-type gas hydrate zones are developed in borehole images recorded from this area with abundant vertical fractures. Also, the spatial distribution of the fracture-type gas hydrate zone is possibly related to the anticlinal structure and the grain size distribution in the area. Gas hydrate saturations in this area follow the trend. i.e., coarser the sediments in fractures has higher saturation.

4.2 AREA: C

The well taken for study is shown as “C” (black arrow) (Fig. 1) located in the central part of the KG-Basin. Based on lithologic characteristics, recovered from Early Pleistocene to Late Pleistocene sediments are divided into two lithostratigraphic units: Units I (0–251.23 mbsf) and II (251.23–337.03 mbsf). Unit I composed mainly of carbonate grain–bearing terrigenous organic matter–rich olive-black silty clay and muddy-matrix mass transport deposit (MTD). Unit II consists predominantly of coarse-grained sediment such as gravel, coarse to fine sand, gravelly mud/sand, and silty clay. The grains are polymodal in nature varying in size from 35 to >500 μm (i.e., very fine to very coarse grained, occasionally gravel sized) and with comparatively low hydrate saturation (40-50%) (Fig. 4). A fracture-type gas hydrate zone developed in this area. The hydrate saturation is better because of the fractured dominated hydrate system. The grain size variation is responsilbe for the well-developed hydrate bearing fracture system. It is again observed that the gas hydrate saturation and occurrence is largely guided by the particle size distribution and coarser grains accommodate higher saturations of gas hydrates.

4.3 AREA: E

The well taken for study is shown as “E” (black arrow) (Fig. 1) located in southern portion of the KG-Basin. Two distinct lithounits are identified based on LWD data analysis and correlation with seismic data (Fig. 5). Unit-1 (200-250m) showing high resistivity and low gamma exhibiting finning up sequence with inter bedded sand/silt/clayey-sized sediments. Unit-2 (250-300m) showing low resistivity and high gamma exhibits blocky pattern. Two representative lithologic types were also recognized in this succession one is coherent organic matter–rich silty clay supported with muddy matrix and the other is a mixture of sand/silt/clay with sand dominated matrix. The grain size varies from 5 to 7 μm with hydrate saturation ranges from (30-40%). The grain size pattern ranges from very fine silt to silt grade and the hydrates are more concentrated in potential fractures as identified at 112.5–155.7 mbsf above the channel system and possible layered-type gas hydrate zone was identified in the channel system (222–239.2 mbsf) (Fig. 5). This is because the available gas migration was limited, due to the fine grain size of the sediments and therefore occupies the available fractures/fissures present thus having lower saturations. The hydrate occurrence in the fine grained sediments have very less dispersed hydrate saturation since, the surface areas of the silt sized sediments limits the hydrate saturation.

5. Conclusion

Based on integrated log, core and seismic studies, two well-developed gas hydrate system has been identified in deep offshore in the KG-Basin and hydrates are distributed in sand dominated facies. Turbidite sand and debris flow were identified from the log and sediment studies. Turbidity current mechanism is the main geological process responsible for the deposition of gas hydrate bearing reservoirs facies. The near-seafloor gas hydrate-bearing sediments in this study are dominated by fine-grained turbidites, fine-grained muddy sediments, including hemipeligic sediments, debrites (mud with breccia). These fine-grained sediments might be extensively modified by slumping and associated gravity flow processes. Which are finally re-deposited in the forms of slumps, debrites and turbidites as shown in the model (Fig.-6). Such fine grained sediments are known to be housing the fracture dominated gas hydrates with higer saturations and the dispersed hydrates in these sediments exhibit lower saturation levels. The SW parts of our study area are mainly sand-silt-clay sequences, like massive graded very fine sand, laminated sand/silt-clay. These sedimentary features indicate the presence of fine-grained turbidities. The hydrate bearing sediments in middle part of study area are mainly thinly laminated sand-silt-clay with presence of scattered gravel grains in a channel-levee system. In the NE part of the study area, excellent reservoir facies sediments are encountered. These are very fine sand/silt sediments deposited by turbidite channel.

6. Acknowledgment

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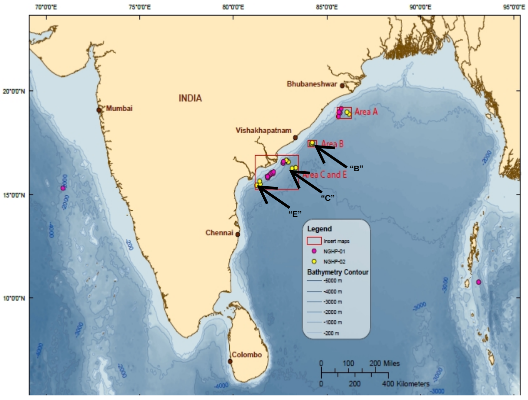


Fig.1: Location Map in study area showing drilled wells

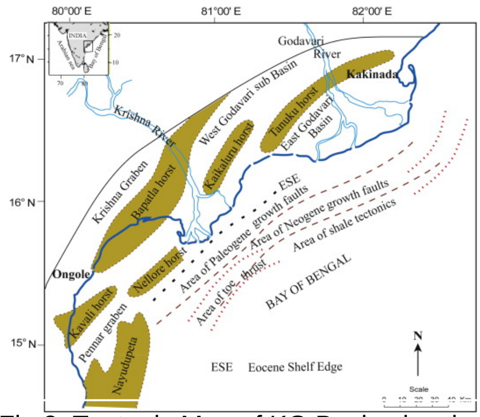
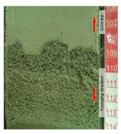
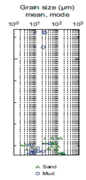


Fig.2: Tectonic Map of KG Basin showing major tectonic activities.





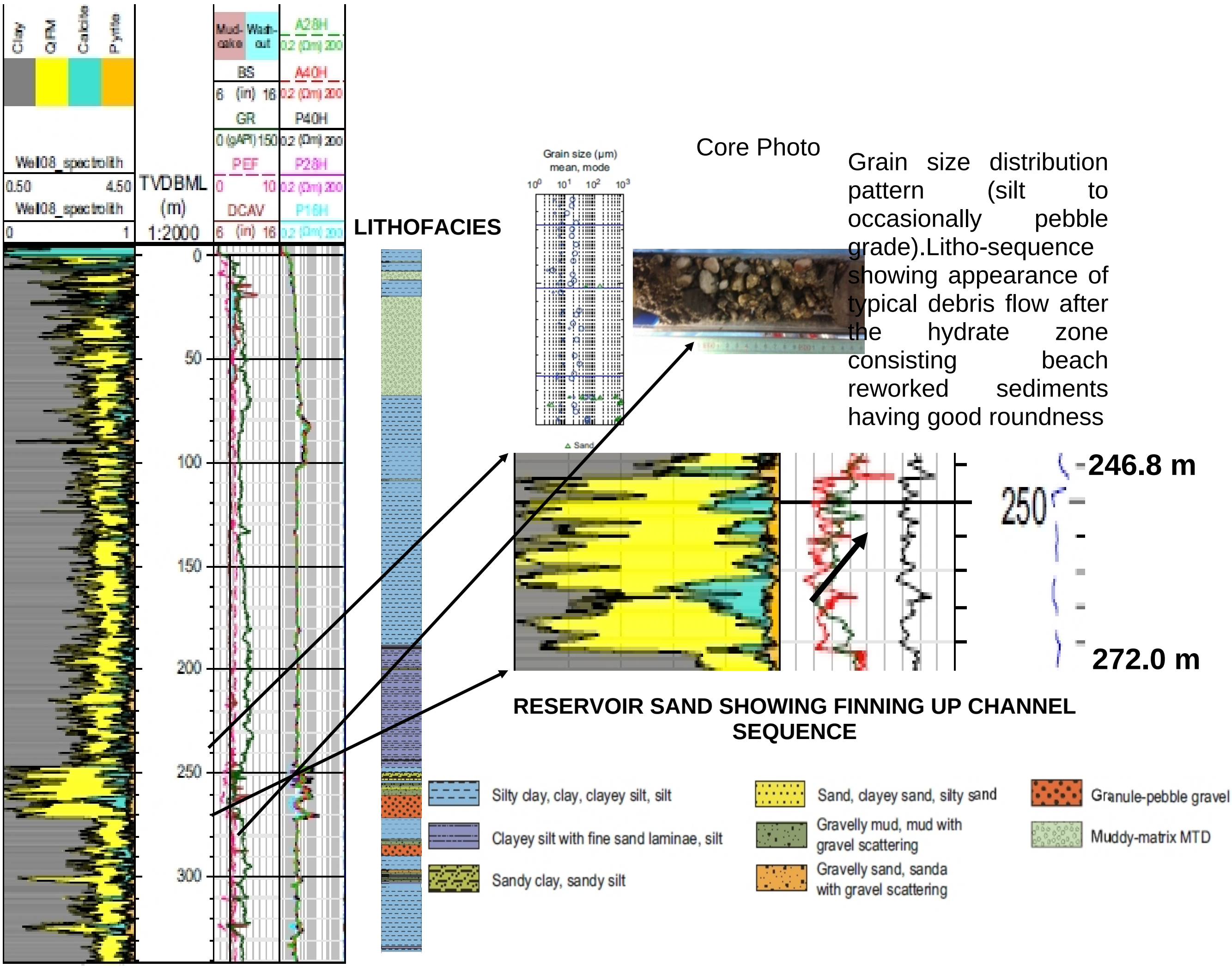


Fig. 4- Log motif correlated with well exhibiting finning up pattern (black arrow, typical turbidite)

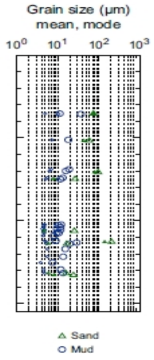


Fig.5: Log motif correlated with seismic section showing evidence of slope failure, exhibiting serrated pattern (typical turbidite) and blocky pattern (typical Mass Transport Deposit) with grain size distribution pattern.