Role of Seismic Amplitude in Assessment of Oil API

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Keywords

Unconsolidated Sands, Seismic Amplitude, Oil API

Summary

Seismic amplitude is dictated by the lithology and the pore fluid. Presence of oil also causes anomalous seismic amplitude in the Pliocene reservoir of Niger Delta and it looks brighter than conventionally thought. Here a modeling effort has been made to investigate the cause of the seismic anomaly associated with oil. In the rock physics modeling it is found that light oil (API more than 30 deg) causes amplitude anomaly similar to gas and it is further found that even low API oil too produces anomalous amplitude albeit small. The intensity of anomaly increases as oil API increases. The real data study also confirms the finding from model study.

Introduction

In oil and gas exploration, DHIs are commonly thought to be diagnostic of gas. But, oil sands can also generate both bright spots and flat events (Rosa et al., 1985; Hwang and Lellis, 1988).Oil sands of Plio-Pleistocene age in Gulf of Mexico causes seismic anomaly similar to that of gas sand (Clark, 1992).

Pliocene reservoir with depth ranging between 2200-2450m , located in Offshore India, also shows seismic anomaly in presence of normal grade(light) oil (Nanda and Wason, 2013).The API (American Petroleum Institute) gravity used to classify oil as light or normal grade (API > 31.1), medium (API between 22.3 to 31.1), heavy (API<22.3) or extra heavy (API<10).

Area of study is located in the offshore part of Niger Delta (**Fig.1)**. The age of the reservoirs is Pliocene. Presence of oil in a drilled well in the area has caused bright amplitude in the depth range of 2260-2283m. The area is in abundance with light oil (35-40 deg API). Oil driven seismic anomaly has given impetus to carry out detail study. To understand it, a rock physics modelling involving the rock type (consolidated, unconsolidated or poorly consolidated), its texture, and the influence of the pore fluid on the elastic parameters investigated. This study is extended to see the influence of oil on seismic amplitude by varying its API for two types of sands ie clean and Shaly sand which may be prevalent in deltaic reservoir.

Geological History

The Niger delta is situated in Gulf of Guinea on the west coast of Africa The base of the sequence in the delta is massive and monotonous marine shales (Akata Shales) grading upward into shallow marine fluivial sands, silts and clays (Abgada formation-main reservoir rocks).Depositional environment of the area under study is barrier bar which is the cleaner and coarser sands due to longshore currents along the coastline and mouth bars deposited at the mouth of distributaries.

Method

The workflow consists of: 1) Rock physics diagnostics 2) Dry frame modeling followed by 3) Gassmann fluid substitution by varying oil API. Fluid properties were modeled by Batzle and Wand method.

Dvorkin and Nur in1996 introduced theoretical models for clean sands: Friable Sand Model (unconsolidated line) and Contact Cement Model to infer rock type, clay volume, digenetic trend and texture in velocity-porosity plane as shown in Fig.2.

Another theoretical model for moderately compacted sediment is given by Constant Cement Model (Avseth et al. in 2000). In this geological set up, Friable sand model holds good in the area under study. The model assumes that the porosity reduces from the initial sand pack value due to deposition of solid matter away from the grain contact and represented by modified lower Hashin-Shtikmann bound model which connects the critical porosity and the mineral points (Dvorkin and Nur in1996).

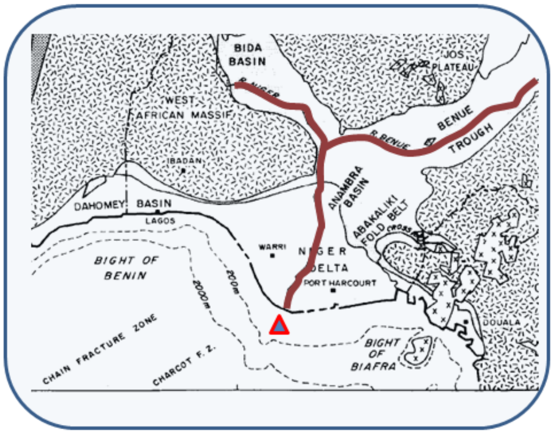

Fig.1 Simplified geologic map of Gulf of Guinea modified from Whiteman, 1982, Allan 1965).The red triangle is the location of study.

There are three pay sands in well X (Fig.3a) namely Sand1 (oil zone), Sand 2 (Gas zone) and Sand 3 (gas zone).Sand1 and Sand 3 being thicker have been selected for rock physics diagnostics to understand their texture and nature whether consolidated, unconsolidated or poorly consolidated. Clays and quartz are the dominant minerals in the area under study.

Friable sand model was made at a differential pressure of 20 MPa close to sand 3. Clay content in making dry rock frame was varied from 0 to 30%.First dry frame bulk and shear modulus at critical porosity (depositional porosity) were made at respective mineral content by Hertz-Mindlin Theory and then effective dry frame moduli at any other porosity were calculated by the interpolation between critical porosity and mineral point with help of Hashin-Shtikmann lower bound model.

Thereafter, Gassmann fluid substitution was performed on the modelled dry frame and consequently saturated Vp, Vs and bulk density at each porosity are obtained. Fluid mixing was done using Reuss average assuming the reservoir is in homogeneous saturation. Bulk modulus of quartz and clay was taken 38 GPa and 20.9 GPa and shear modulus 44GPa and 8GPa respectively. Density of quatz and clay has been taken 2.65g/cc and 2.68g/cc respectively. Critical porosity ranged from 40% to 34% as clay content increases from 0 to 30%.Reservoir temperature and pressure were taken to be 68 deg.cel and 20MPa respectively.

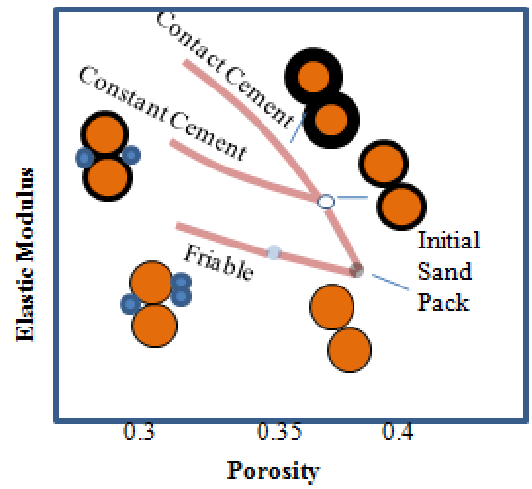

Fig.2 Schematic depiction of three effective-medium models for high-porosity sandstones and corresponding diagenetic transformations (Jack Dvorkin and Amos Nur, 2000)

The hydrocarbon affected zones of the sands under study were brought to 100% water saturated case before cross-plotting. Sand intervals (Sand1=2260m-2283m, sand3=1857m-1929m) selected from well X, when cross-plotted in velocity-porosity plane (Fig.3b), follow the trend of Friable Sand Model (unconsolidated line) having clay volume ranging dominantly between 10-30%.

This shows that the sand intervals under diagnostics are un-consolidated and un-cemented with clay ranging from 10% to 30%.. Fig.3c displays shale interval above Sand3 under study, follow the unconsolidated line and contains almost on average 55% clay and 45% quartz as per diagnostics. It is observed that elastic and reservoir property (porosity) of both the intervals follows same trend. The sands: Sand1 and Sand3 almost 400m apart as seen in the log of well X, overlap each other in velocity-porosity plane.

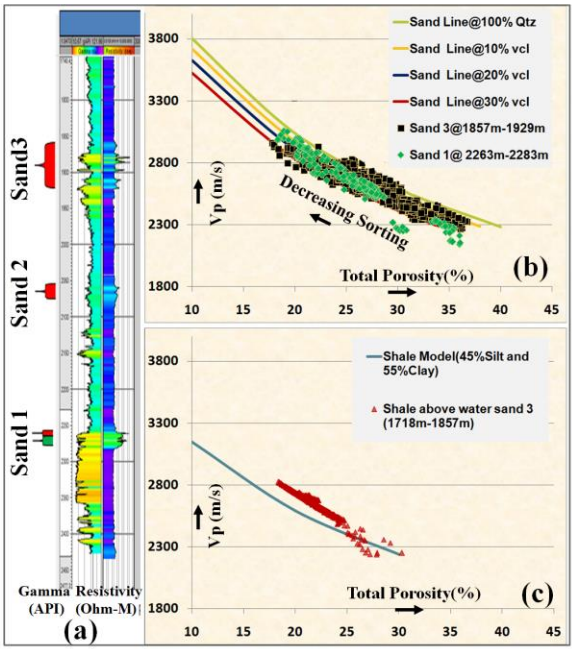

Fig.3(a) is the drilled well X showing three pay zones (b)Friable Sand Model with varying clay content(c) Shale model (appears to be very silty in nature) model using unconsolidated line.

Possible explanation is that the deeper sand (Sand1) has not undergone considerable compaction compared to sand3 and textures and mineralogy are similar. Therefore; rock physics modeling performed at sand3 will also hold good at Sand1 and also in the interval between two sands because no abrupt change in the velocity at the well is observed.

Shale model line was also created using unconsolidated (friable) model (Fig.3c).Shale intervals under study appear to be very silty in nature according to the model.

To analyze fluid effect, two scenarios were considered: 1) clean sand with Φ=26 % Vqtz=90% & Vcl=10% and 2) and shaly sand with Φ=22 %, Vqtz=70% & Vcl=30% overlain by shale (55%clay, 45% qtz and Φ=20%) using friable sand model.The full stack seismic amplitudes for water, oil and gas case were calculated assuming two half spaces (shale/sand interface) by substituting fluids into the modeled frame of sands in lower half space. Polarity was set to peak (hard) as increase of acoustic impedances.Fig.4 and 5 depicts the reflectivity vs. angle plot as well as modeled seismic amplitudes for water, oil and gas for clean and shaly sand respectively. The oil API was varied from 15-40 deg at an interval of 5deg.

In clean sand model, reflectivity due to light oil at any angle between 0-40 deg. is almost half of the gas sand and is close to zero for water sand (Fig.4a). As the oil API decreases, its reflectivity starts moving closer to water case. Corresponding full stack seismic amplitudes were modeled by convolving with a zero phase Ricker wavelet (Fig.4b, c &d).According to the model, anomalous seismic amplitude appears even at 15deg oil API compared to that of water sand and increases with increase in its API.

While in shaly sand model (Fig.5c), seismic amplitude also increases with increase in API but is less sensitive compared to clean sand. Water sand in this case too produces amplitude (hard) but opposite to clean sand case. At 15-40 deg oil API range, seismic anomaly is similar to that of clean sand but with reduced value.

Since the seismic amplitude is not only a function of geology but also a combination of geology and noise. (Hendrickson, 1999; Simm et al., 2000).Therefore, oil with API less than 25 deg. can hide behind the noise in practical dataset and be too difficult to recognize in terms of anomalous seismic amplitude. In both the cases discussed, oil (API > 25 deg) driven seismic amplitude is almost half to that of gas sand and may produce recognizable anomaly.

Real Data Example

Seismic data was converted to zero phase and polarity convention was set to peak (hard) as increase acoustic impedances. At Sand1, the seismic (Fig.6) is showing brightening of amplitude where oil column of 20m has been encountered. Since oil API is not known here by laboratory analysis, therefore, integration of the modeling results in terms of seismic amplitude (Fig.5c, and d) with the real one may give a clue to assess oil API based on amplitude.The real seismic amplitude of oil Sand1 showing 30%-40% less amplitude than that in gas

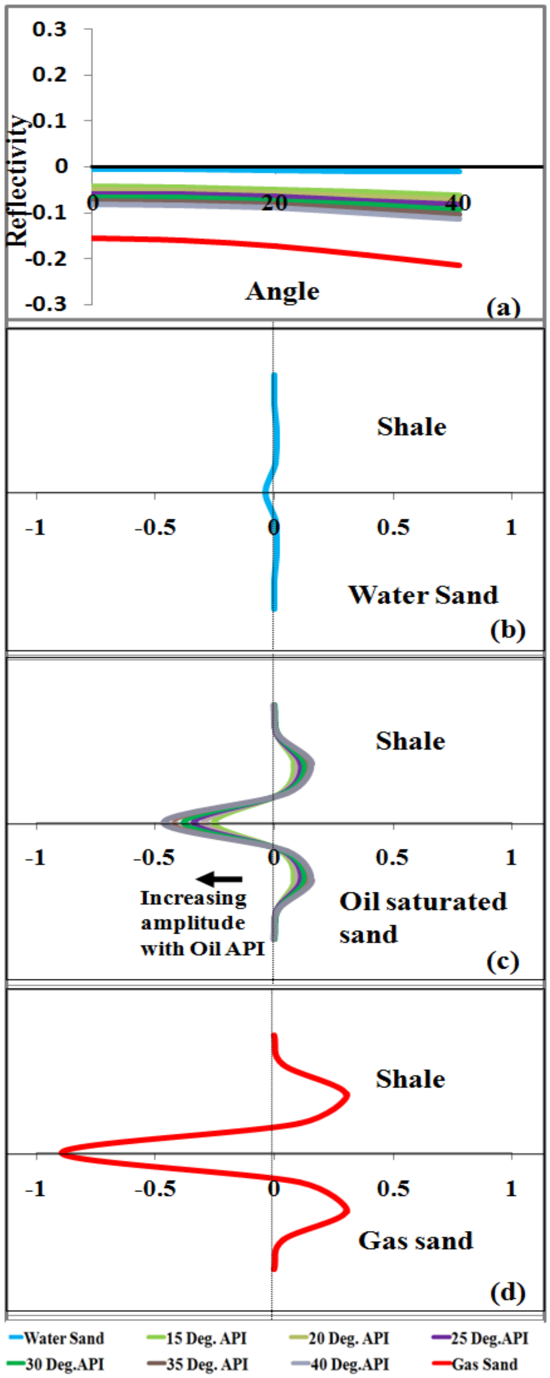

Fig.4 Clean sand model (a)reflectivity vs angle for water, oil(varying API from 15-40Deg.) & gas (b) amplitude for water sand (c) amplitude for varying oil APIs as in (a) and (d) amplitude due to gas sand.

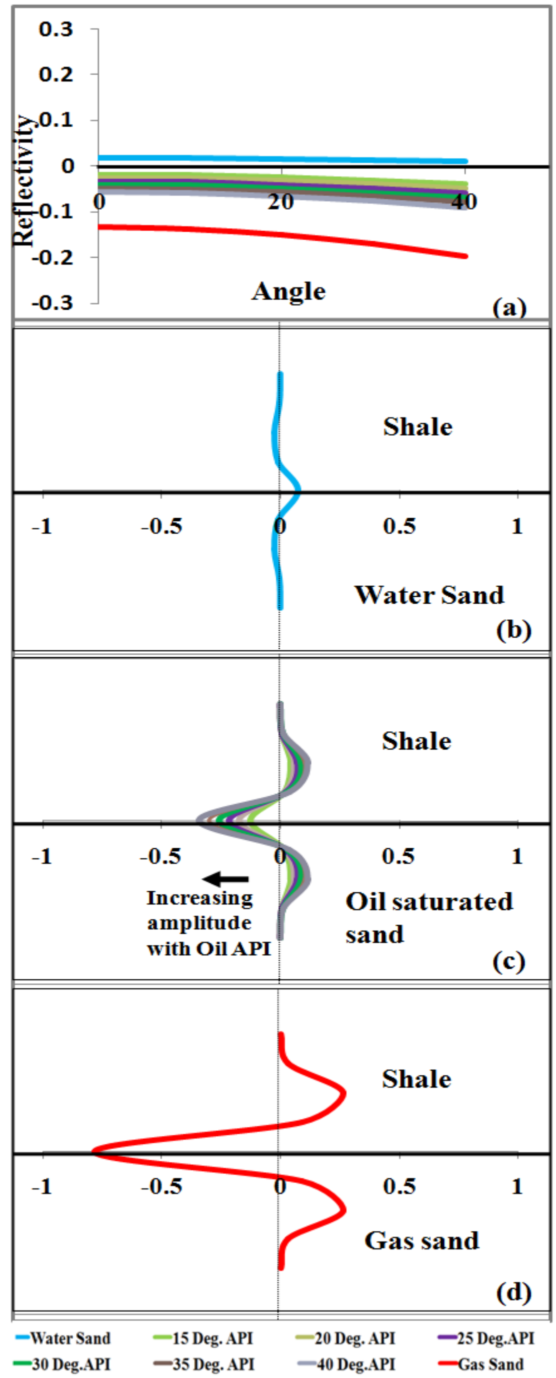

Fig.5 Shaly sand model (a)reflectivity vs angle for water, oil(varying API from 15-40Deg.) & gas (b) amplitude for water sand (c) amplitude for varying oil APIs as in (a) and (d) amplitude due to gas sand.

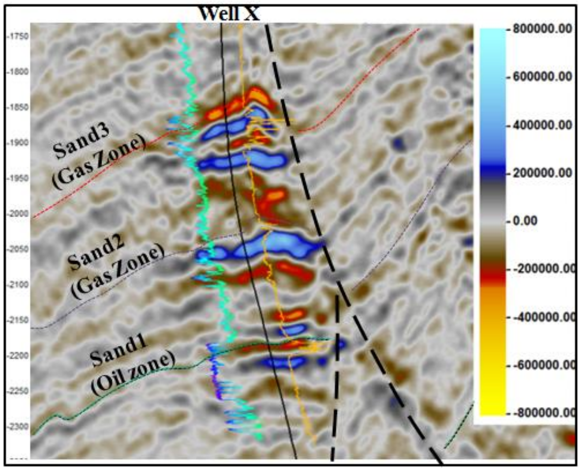

Fig.6 Full stack seismic showing amplitudes in drilled oil and gas zones. Amplitude shows up in oil zone but less than that in gas zones. The log in green is gamma and in orange is deep resistivity.

sand3 (scale bar) can be said to have not only anomalous amplitude but also this amplitude is building up because of higher API oil. The caveat is the amplitude at the top of the oil zone may be affected by the gas cap, but base (hard-positive reflectivity) is not having this problem because it is oil water contact (OWC). The OWC is also showing increase of amplitude.

Sand2 (23m net pay) having very thin sand and shale alterations is a gas charged body. The sand being very shaly in nature has gradational top and base into shale. Therefore, sand2 does not show amplitude at its top and even at the base .The amplitude seen just below it is because of the interference of the wavelets arising from the bottom of the sand2 and top of the another water charged clean sand just below it. That is why polarity of the events at sand2 is not the same as the top of Sand1 and 3 have in spite of being gas sand.

Care must be taken because the results are based on the reservoir parameters. It may change if reservoir parameters vary i.e. mineralogy, pressure, temperature even in the unconsolidated sediments.

Conclusions

The sands under analysis were found to be unconsolidated. In unconsolidated sands, seismic anomalies can appear not only due to gas but also due to oil. This was observed in both the real and synthetic data. Synthetic data was generated by rock physics modelling (friable sand model) and Gassmann fluid substitution. Furthermore, oil API was also varied from heavy to normal grade (i.e. 15-40 deg.) to analyse its effect on seismic amplitude. Oil driven amplitude increases with increase in its API and is almost half of gas sands for normal grade oil. In the modelling part, two types of sands namely shaly and clean sands were considered. Seismic amplitude appeared more sensitive to oil in unconsolidated clean sand than that in shaly sand.

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