Well log and synthetic seismogram analysis of an oilfield in Assam, India: A 3-C seismic development feasibility study

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ABSTRACT

Well logs from several fields in Assam, India were analyzed to determine the feasibility of a 3-C seismic development study. One of the challenges in the area is to identify sand-rich regions (potential reservoir zones) within a structural geologic setting. We find that representative reservoir sands have an identifiable response; in particular, higher S-wave velocities compared to their surrounding sediments. Synthetic seismograms generated from the logs suggest that these reservoir sands may be detectable with PP and PS seismic techniques.

INTRODUCTION

The Assam province is located in northeastern India (Figure 1) and it constitutes one of the most important onshore petroleum provinces in India. Oil and gas production in the area has been ongoing for more than a century, since the historic Digboi oilfield was discovered in 1889 (Dasgupta, 2007). The NE-SW trending basin has similarly oriented faults which control some of the hydrocarbon traps, with most reservoirs occurring in anticlinal structures and some subtle stratigraphic traps.

Important hydrocarbon-producing strata include: the Paleocene Langpar, Eocene Sylhet and Kopili, the upper Eocene-Oligocene Barail Group, and Miocene Tipam and Girujan facies. The main target in this study is the Barail Group, which was deposited in a deltaic environment. The Barail units can contain interbedded coals, sandstones, and shales.Current oil and gas production in the region occur mainly south of the Brahmaputra River and north of the Naga thrust system (Figure 2).

Elastic properties and rock properties were analyzed using well logs from two wells in the Makum or North Hapjan field (Well A) and the Deohal field (Well B), to evaluate the feasibility of using multicomponent seismic to enhance interpretation in the area. The motivations for acquiring multicomponent (especially, converted P-to-S) seismic data are several-fold, including: improvement of the P-wave sections (via multicomponent filtering techniques), developing new structural details (faults, compartments, closures) using PS images, assisting with defining new stratigraphic features and providing some large-scale lithology (e.g., sand versus shale) information, and help in providing information about fluid distributions.

FIG. 1. Location of the area of study, Assam Province in Northeastern India.
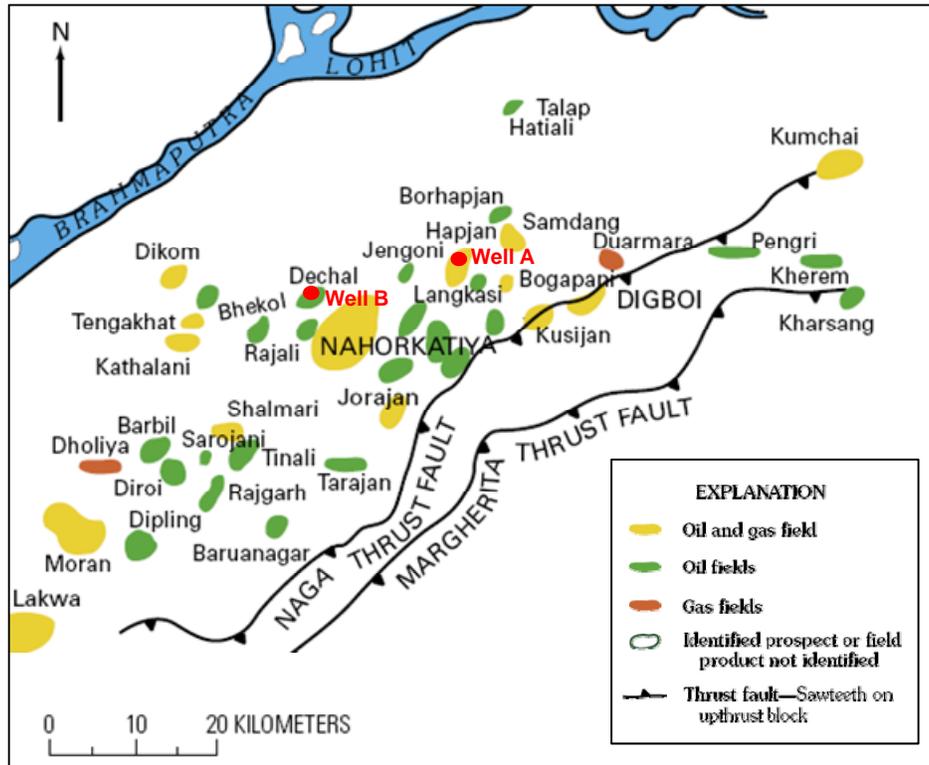

FIG. 2. Distribution of oil and gas fields in the Assam geologic province (From Wandrey, 2004). Red circles indicate location of the two wells used in this study.

GEOLOGIC SETTING

The Upper Assam basin represents a structurally warped foreland basin between two convergent margins (Mathur et al., 2001). Near-shore to shallow marine conditions prevailed during a major part of the Cretaceous and early Paleogene, as well as during the early and Middle Eocene, changing to deltaic-estuarine conditions during the latter part of the Eocene and Oligocene, and followed by a fluvial setting in the Miocene and younger times (Mathur et al., 2001).

The general stratigraphy of the Assam shelf is shown in Figure 3. The oldest rocks within the basin are Upper Cretaceous and correspond to continental and lagoonal sandstones and interbedded shales of the Dergaon and Disang Formations. These formations are unconformably overlain by over 250 m of massive sandstones of the Tura and Langpar Formations within the Jaintia Group, deposited in a fluvial to marginal marine environment during Paleocene and Eocene times. The overlying Eocene Sylhet Formation is subdivided into the Lakadong, Narputh and Prang members. The basal part of the Lakadong member constitutes more than 350 m of thin sandstones and interbedded shales and coals, deposited in a lagoonal environment. The middle Lakadong consists of thick sands deposited in a strand plain or barrier bar environments, while the upper Lakadong is a calcareous sandstone of restricted shallow water platform (Mathur et al., 2001). The overlying Narputh member consists of claystones and siltstones of a shelf environment, while the Prang member is a shelf carbonate with interbedded siltstones and clay. The Sylhet formation thickens towards the southeast due to contemporaneous platform tilting and basement sourced block faulting.

Unconformably overlying the Sylhet is the Eocene Kopili formation, with as much as 500 m of shallow marine to lagoonal shales and interbedded limestones. The Eocene and Oligocene Barail group comprises as much as 900 m of sands with minor shales deposited in a delta front environment, and as much as 1,200 m of interbedded coals, shales and discontinuous sandstone reservoirs from delta plain environment. The overlying Surma Group is missing on much of the Assam shelf. It is typified by a series of thin siltstones, sandstones and shales deposited in fluvial deltaic to estuarine environments.

The Lower Miocene Tipam Formation sandstone is largely of fluvial origin and the heavy mineral content of the unit indicates derivation from the rising Himalayas, with depositional transport towards the south (Mathur et al., 2001). The overlying Girujan formation consists consists of more than 1300 m of mottled clays containing minor sandstone lenses (Wandrey, 2004) deposited in a lacustrine to fluvial environment. It is unconformably overlain by poorly consolidated fluvial sandstones with interbedded clay and lignite of the upper Miocene Namsang Formation. Quaternary strata in the upper Assam shelf thicken north, where it can exceed 2000 m.

Most hydrocarbon production in the area comes from units above the Oligocene unconformity, mainly from the Barail group and Tipam formation, with quite productive reservoirs found in the Barail and Tipam sandstones, with permeabilities ranging from less than 7 millidarcies to 800 millidarcies, and porosities up to 30%. However, more recent discoveries have been found in the near shore upper Paleocene-lower Eocene

clastic sequence, with Eocene reservoirs constituting more than 50% of crude oil production by Oil India Limited (Mathur et al., 2001).
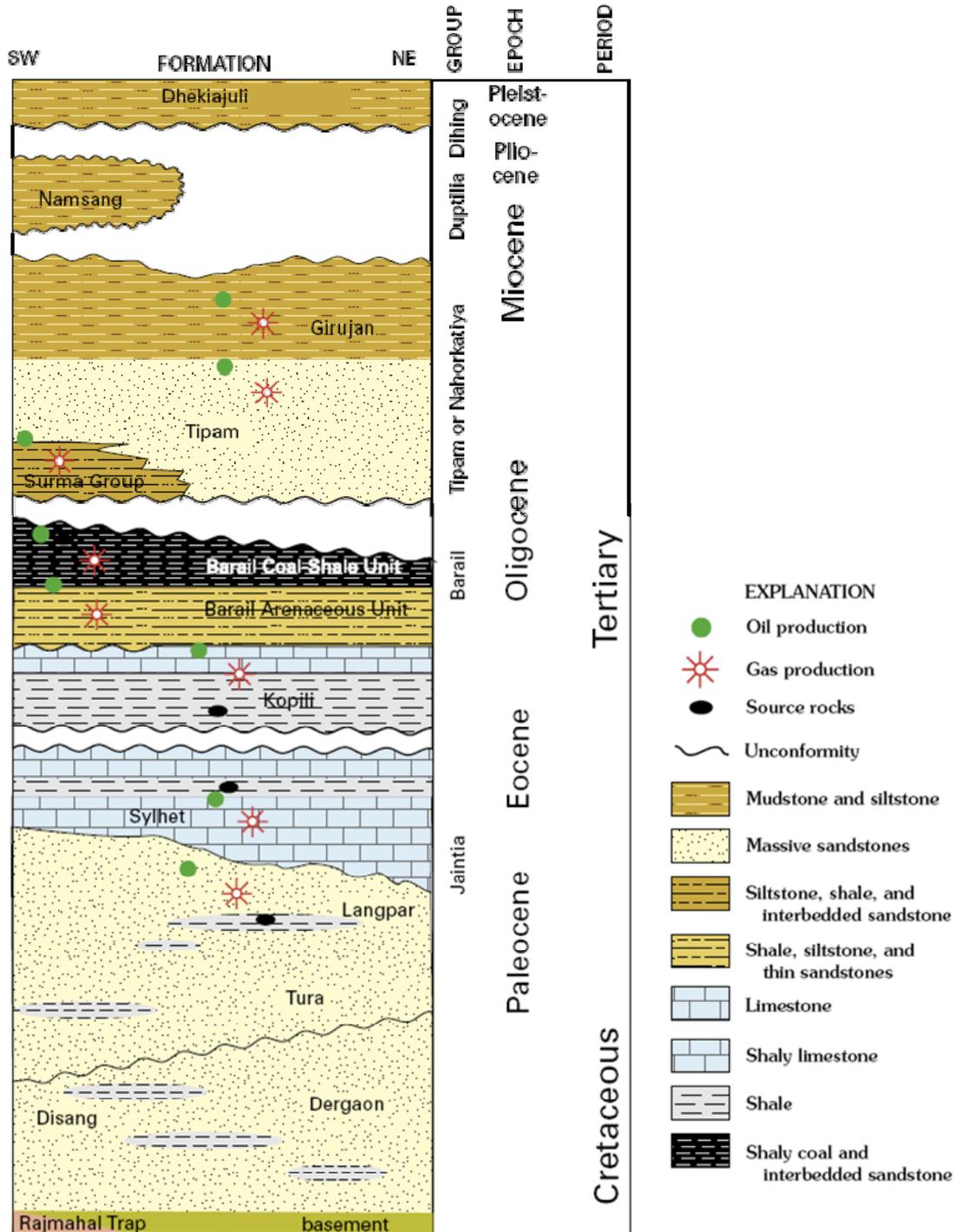

FIG. 3. Generalized stratigraphy of the Assam shelf, India (From Wandrey, 2004).

LOG ANALYSIS

An example of a suite of logs from well B in the Deohal field, is given in Figure 4. Most logs available have a depth range from 1,200 to 2,900 m. Well A from the Makum field is shown in Figure 5. Note that there are distinct S-wave velocity (Vs) anomalies in the Barail sands, with Vs generally increasing with sand quality. This is an important observation for the future use of converted (P-to-S) waves as the PS reflection coefficient is a function of the change in Vs across the interface. In general, good sands are indicated by a lowered SP, low gamma ray (~50 API), 30% porosities, lowered densities, resistivities between 10 and 20 ohms, and high Vs. The good reservoir sands generally plot (on a V_p versus V_s chart) below V_p/V_s=2 and below the mudrock line (See Figure 6).

A density-porosity log was calculated using default sandstone parameters, with a matrix density of 2.65 g/cm^3 and a brine density of 1.09 g/cm^3. Note the slight crossover of the neutron and density porosity at the top of the Barail4 and 5 intervals on well A, indicating a gas cap might be present. However, Mathur et al. (2001) note that interpreting porosity logs can be complicated, at least at the Eocene level, as neutron and density porosity crossovers have been found to not be necessarily associated with gas effects in the area. Mallick et al. (1997) attributed these anomalous crossovers to the lower density of amorphous silica relative to quartz in the reservoir sand, and concluded that the density-neutron crossover should only be used to identify sands within comparatively clean sandstone reservoirs. This problem can be partially resolved by changing the matrix convention used to calculate the porosity logs from limestone scale (2.7 g/cm^3) to actual matrix scale (2.55 g/cm^3). In general, for oil-bearing zones the crossover magnitude is less than 3 porosity units in the actual matrix scale, compared with more than 6 porosity units on the limestone scale, with crossover being greater than six for gas-bearing zones in the actual matrix scale (Borah et al., 1998).
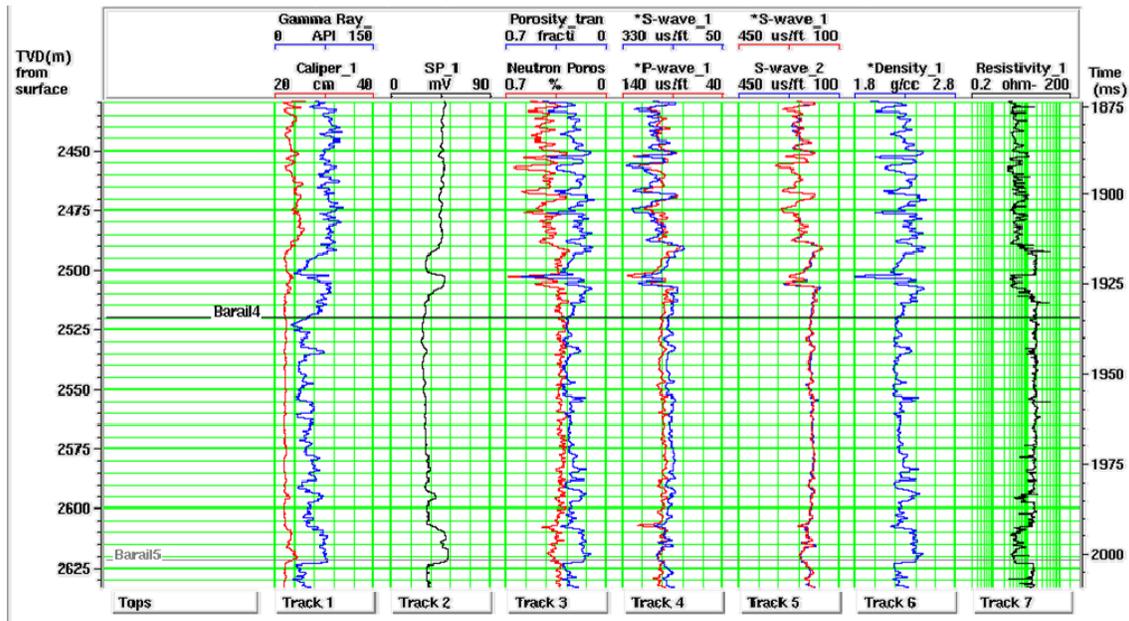

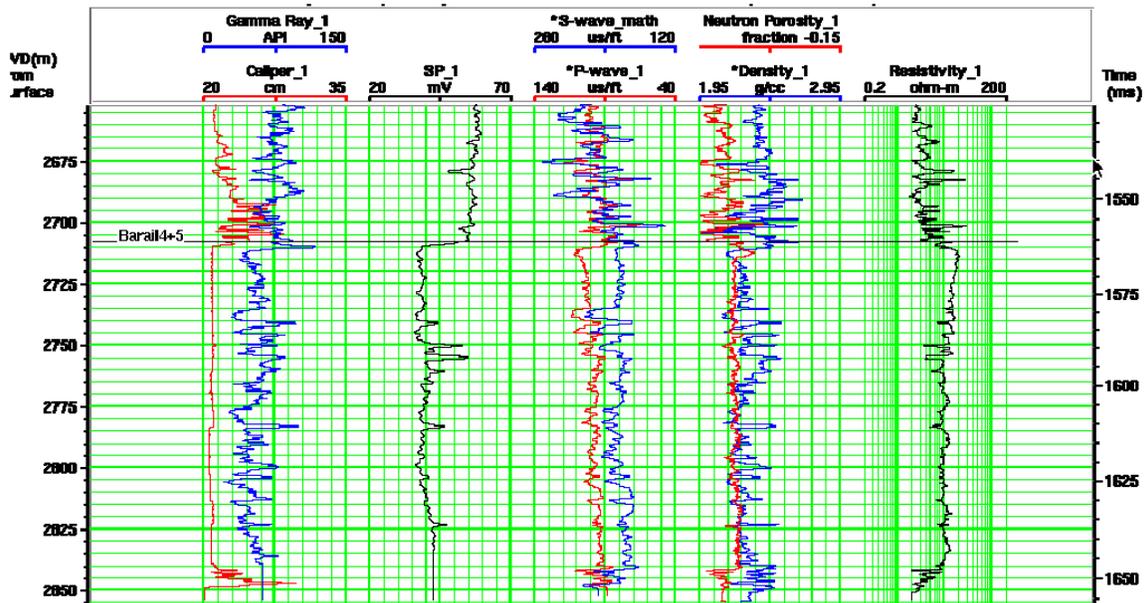FIG. 4. Suite of logs for well B (Deohal field) at the Barail4 productive interval.

FIG. 5. Suite of logs for well A (Makum field) at the Barail4 and 5 productive interval.

Dipole sonic logs from well B show little difference between fast and slow shear waves, suggesting small azimuthal anisotropy at this location. However, the area does have faulting and fracturing, so on a larger scale azimuthal anisotropy may be present. With the vertically layered strata, we would expect some vertical transverse isotropy or variations of seismic velocity with angle from the vertical.

CROSS-PLOTS

It is useful to plot various log values against each other to investigate the relationships between rock properties. We are searching for properties and their values that will isolate the sands of interest. Cross-plots from these two wells (Figures 6 and 7) show significant scatter of the different elastic properties. Using the GR as a lithological indicator for sands and shales, it is possible to note that P-wave velocities for these two lithologies overlap significantly, suggesting that conventional P-wave exploration will not be sufficient to delineate the prospective reservoir. Density and Vp/Vs appear to be better lithological indicator, with lower densities and Vp/Vs values below 2 corresponding to sands.

There appears to be a linear relationship between P- and S-wave velocity, and it also shows the good sands plot below the line for Vp/Vs=2. Cross-plots with respect to resistivity did not show any evident relation between saturating fluid and density or velocity.

Summarizing, we see that the sands of interest (as indicated by low gamma ray values and high resistivity), have fairly high S-wave velocities, average P-wave velocities, Vp/Vs values around 2, and somewhat lowered densities (2.15 – 2.3 g/cc).
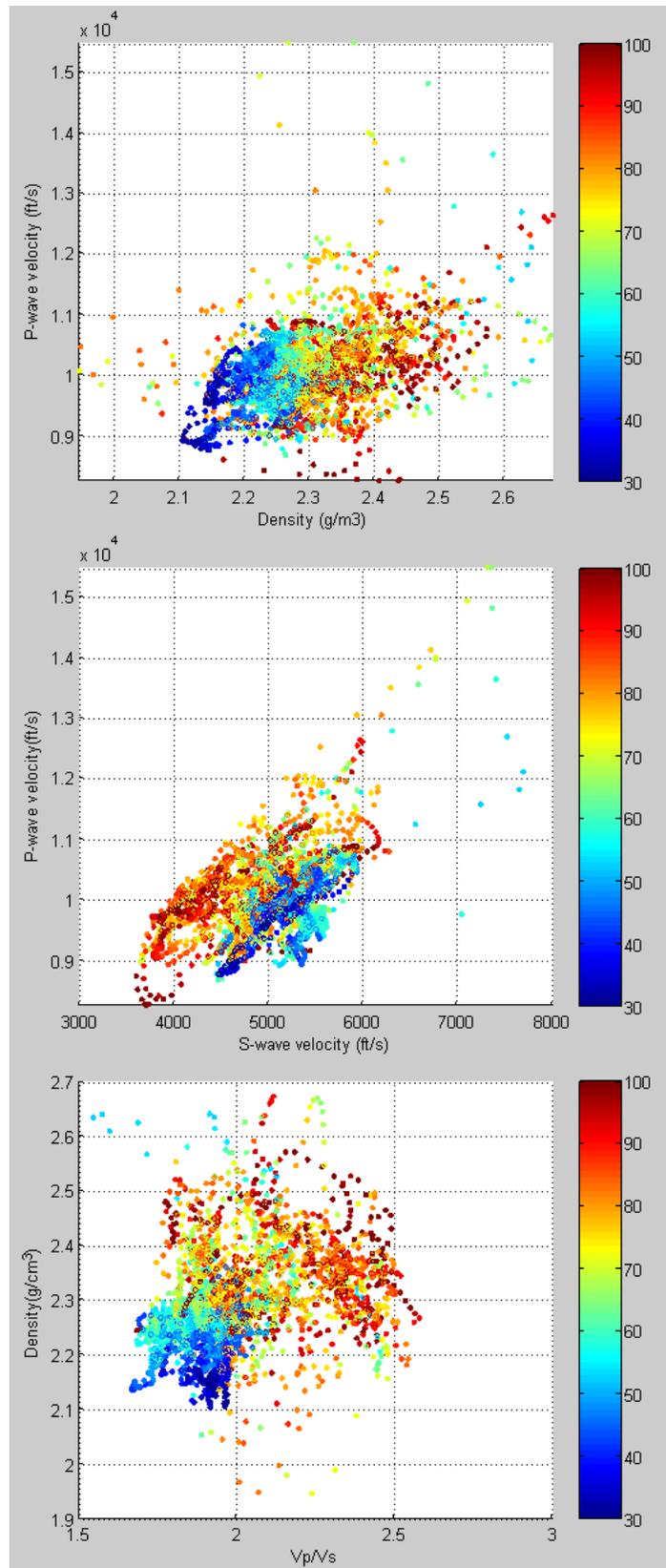
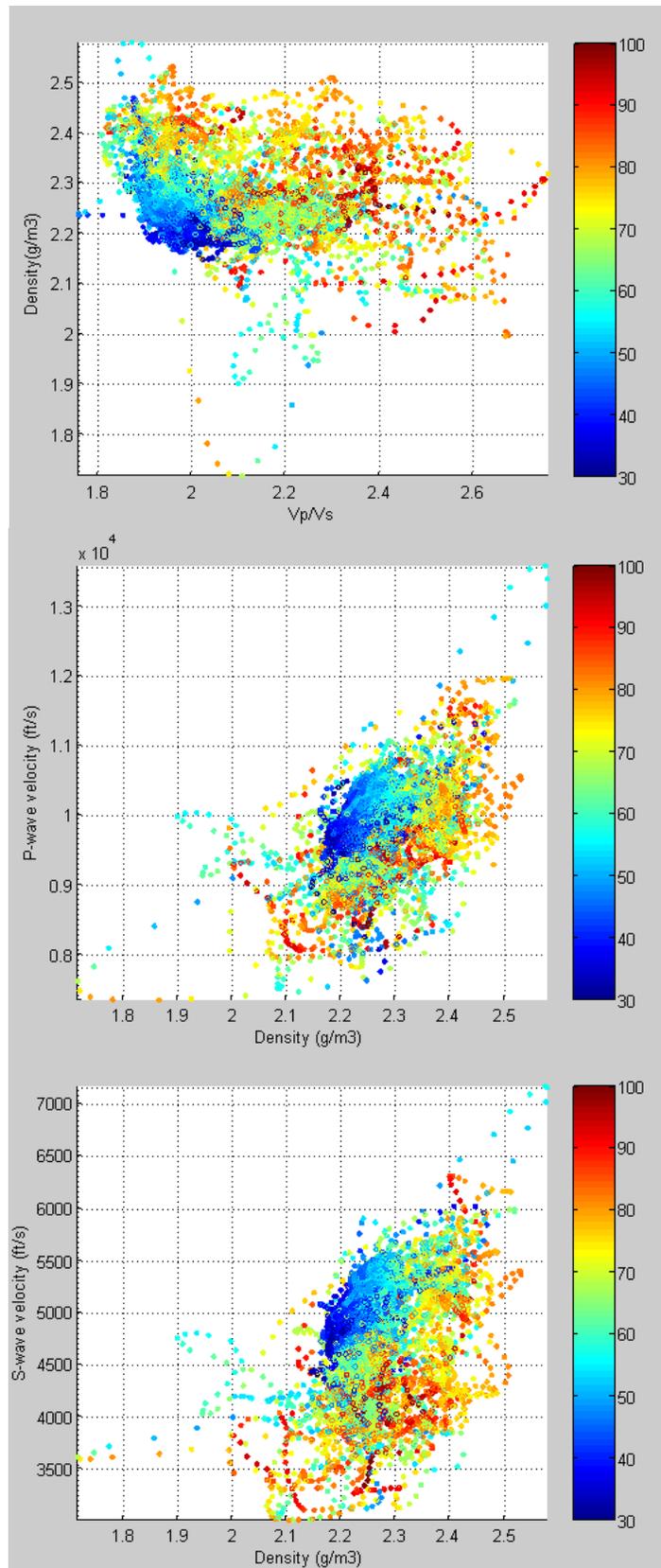FIG. 6. Cross-plots for well A within the reservoir interval (2500-2800 m). Color bar indicates GR values.

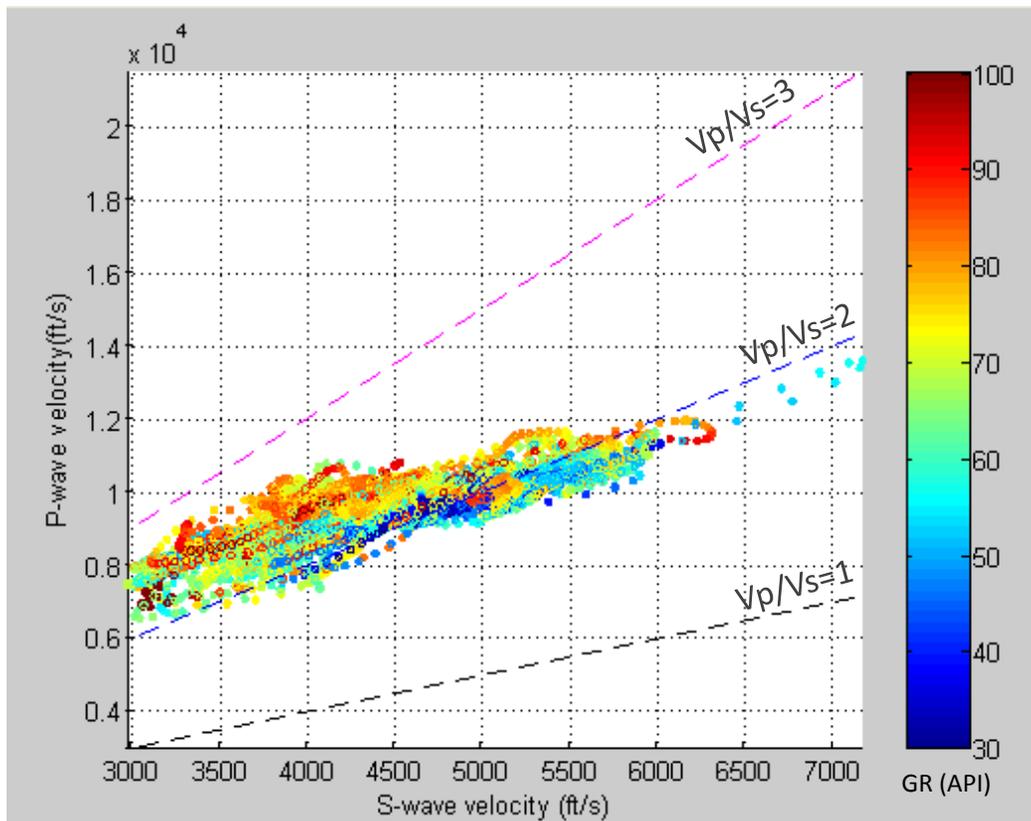FIG. 7. Cross-plots for well B from 2200-2800 m depth. Color bar indicates GR values.

FIG. 8. Vp versus Vs cross plot for well B.

SYNTHETIC SEISMOGRAMS

   PP and PS synthetic seismograms were generated for the two wells to evaluate the seismic response at the top of the reservoir. None of the synthetics image the Eocene targets as sonic logs were not available for that interval. The surface seismic data indicate that there is a signal frequency band from about 10-60 Hz for the P-waves. This suggests that we should expect a PS band from about 5-30 Hz. The PP synthetics were calculated using a Ricker wavelet with a dominant frequency of 40 Hz, while the PS synthetics used a 20 Hz Ricker wavelet.

   Synthetic seismograms for well A show shallow AVO effects, from 1.55 s to 1.8 s, which are probably related to problematic Vs logs. The logs look more reliable deeper in the section. There is also a strong AVO response at the top of the Barail4 and 5 in the PP synthetic. The PS synthetic seismogram shows a response at the top of the Barail as well as at the deeper Barail 4 and 5 horizons. The PS synthetic seismograms from well B (Figure 3) show an amplitude increase with offset at the top of the Barail sand, which is not evident in the PP section. Also note that out to offsets of about 3500 m there are little or no changes in polarity. This suggests that an offset-to-depth ratio of about 1.5 is useful.
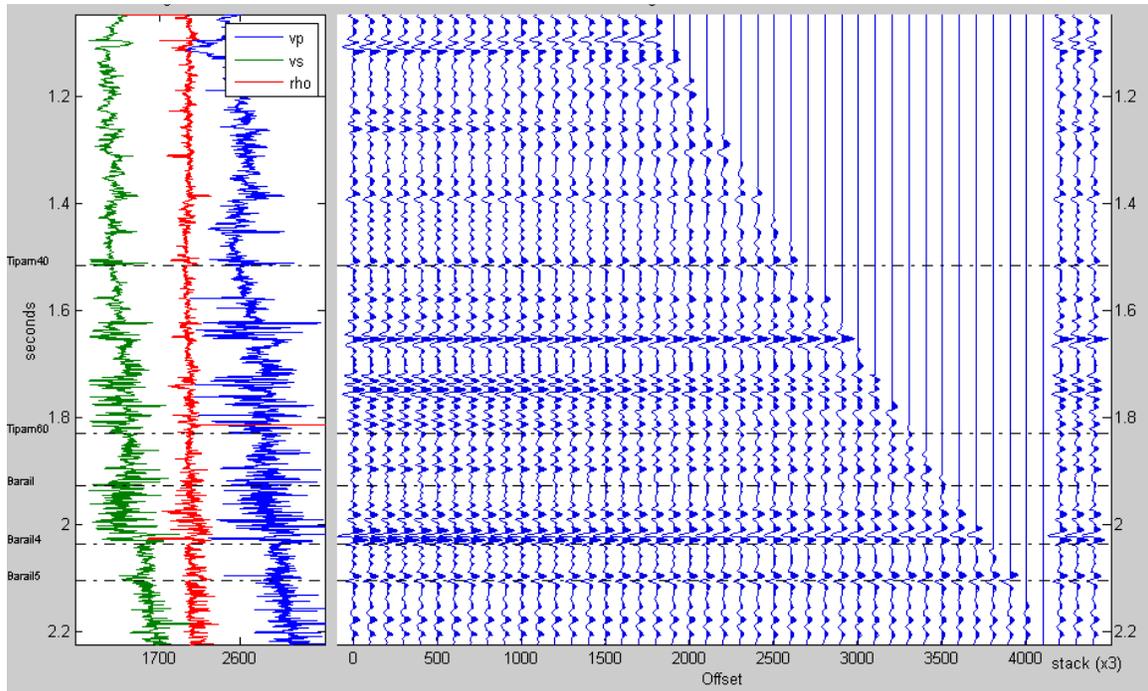
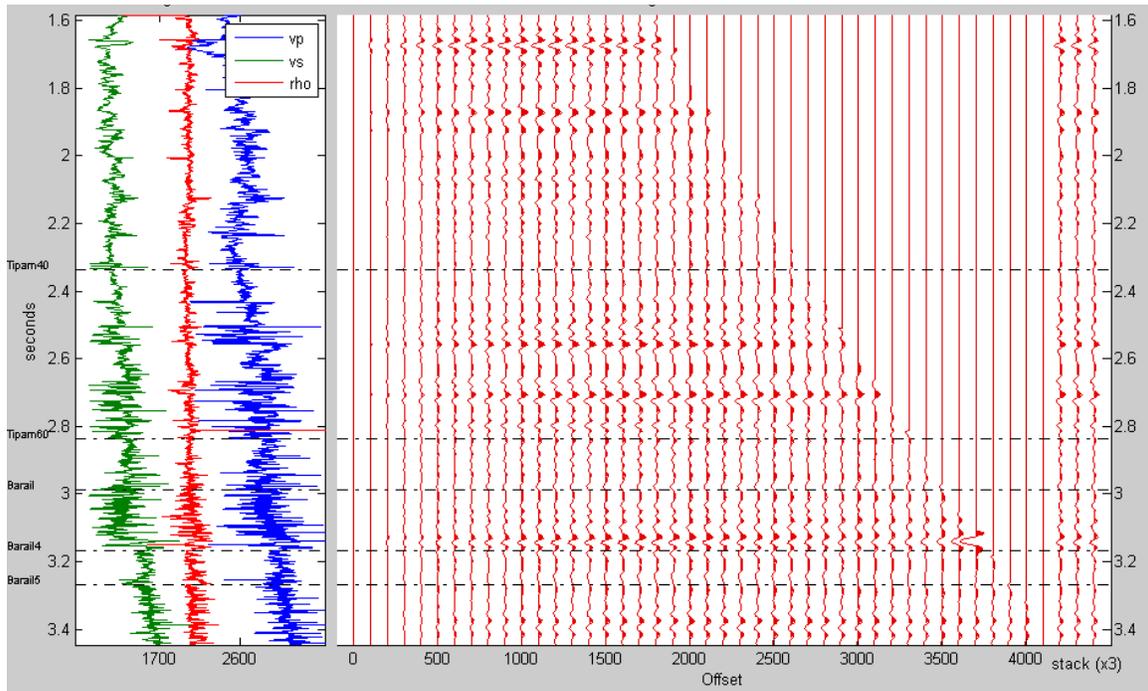FIG. 9. PP synthetic seismogram for well B (Deohal field).

FIG. 10. PS synthetic for well B (Deohal field).

CONCLUSIONS

The reservoir sands appear to have anomalous S-wave velocity character that may be detectable using converted-wave methods. Petrophysical analysis and synthetic seismogram modeling show the often distinctive character of the reservoir sands. In general, crossplots from different wells show that good sands are indicated by $Vp/Vs \leq 2$, Vs in the range between 1400 and 1800 m/s, Vp between 2650-3300 m/s, densities between 2.15-2.35 g/cm_3, and high resistivities.

ACKNOWLEDGEMENTS

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