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Monte-Carlo Modeling of Some Niger Delta Slope Events

[1]M.I. Oladapo, [1]J.S. Ojo, [2]M.O. Olorunfemi and [3]B.A. Adetola
[1]Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria
[2]Department of Geology, Obafemi Awolowo University, Ile Ife, Nigeria
[3]Nigeria Petroleum Investment Management Services, NNPC, Lagos, Nigeria

Abstract: Monte-Carlo modeling has been utilized in this study to simulate seismic P-wave events on four horizons (AA, BB, CC and DD) in a Niger Delta Slope environment with the aim of generating AVO attributes. Monte-Carlo modeling undertaken on a well log from the Gulf of Mexico served as a generic model and control. Trends analysis regressions generated in the environment served as input for the models while default parameter in SAVIOR (fluid method) was used for establishing reservoir fluid properties. Fourier velocity served as velocity function. The results of the modeling are presented as AVO crossplots for brine sand (background), residual hydrocarbon and commercial hydrocarbon. For each event, offset-dependent synthetic seismograms are also generated using Zoeppritz equations. The AA horizon is typified by incoherent orientations of AVO crossplots. The horizon is thus presumed unconsolidated. The synthetic seismogram generated shows no perceptible amplitude variation with offset on all the models. AVO crossplot of the encountered BB horizon show that most of the commercial hydrocarbon plots and some of the residual hydrocarbon plots fall on quadrant III (bright spot quadrant). Synthetic seismic generated for BB horizon exhibits positive AVO response (soft kick) on the commercial hydrocarbon model. A similar but marginal response was obtained on brine saturated BB model. Brine saturated model of the AVO crossplot for CC horizon model plotted mostly on hard sand quadrant. Conversely, presumed commercial hydrocarbon saturated CC is split between the hard sand and soft sand quadrants with low background normal values. The DD horizon is similar to the deep model of the Gulf of Mexico and hence exhibits similar crossplot. Curiously, high background normal (Bn) characterized residual hydrocarbon models while unconsolidated gas sand horizons exhibit anomalous characteristics. The AVO crossplot obtained from the Monte-Carlo model could be a robust tool for mapping reservoirs within the Niger Delta Slope.

Key words: Monte Carlo modeling, Niger Delta Slope, Gulf of Mexico, AVO attributes, residual and commercial hydrocarbon, background normal

INTRODUCTION

The Monte-Carlo simulation of wells (i.e., 1-D stratigraphic profiles with measured physical properties) using a combination of geological knowledge can be used in seismic lateral prediction studies (Wood and Curtis, 2004; De Groot *et al*., 1996). The simulation of realistic synthetic reflection sequences or of lithological sequences has been studied by Sherrif (1992), Barnes and Tarantola (1993), Walden (1993) and Kerner and Harris (1994) because of the potential benefit in seismic reservoir characterization applications (De Groot *et al*., 1996).

The Monte Carlo method is a procedure that involves sampling based on probabilities to approximate the solution of mathematical or physical in a statistical way (De Groot *et al*., 1996; Vazquez-Prada *et al*., 2002). Monte-Carlo models are used for a variety of different problems (Musson, 1999; Yang *et al*., 2000; Santini *et al*., 2004; Przybilla and Korn, 2008). In geoscientific applications, the method is used e.g., for reserves and porosity estimations and for prospect evaluations.

The Monte-Carlo-model utilized in this study is a computer program designed to simulate a two-spike seismic P-wave reflection event and generate seismic amplitude attributes for the event. Three layers consisting of upper bounding shale, laminated sand and lower bounding shale define the model. Average values (and in some instances a statistical variance) of the parameters controlling the elastic properties of each layer are given as

Corresponding Author: M.I. Oladapo, Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria

inputs. The given distribution functions are randomly sampled to generate an ensemble of two-spike events. For each event offset-dependent synthetic seismograms are generated using Zoeppritz equations to model the angle-dependent reflection coefficients and convolving with specified wavelet.

GENERIC MONTE-CARLO MODEL

The geology of the Gulf of Mexico (GoM) deepwater environment is similar to that of the Niger Delta Slope (Fig. 1). Information is presently inadequate on the Niger Delta deepwater environment because few wells are available. The Gulf of Mexico data, where available, could therefore be utilized as a generic model for the understanding of the Niger Delta Slope geology and hence its petrophysical and seismic attributes. In this study therefore, Monte-Carlo simulation of a well log from the deepwater Gulf of Mexico is undertaken as a control to enhance the understanding of the petrophysical crossplots in the Niger Delta Slope. Shallow and deep Monte-Carlo models were generated using SAVIOR™.

The regressions generated in the study area in the Niger Delta Slope environment (Oladapo and Adetola, 2005) were used for the model while Harvie-Braunsdrof fluid method was utilized for reservoir fluid properties. Fourier velocity was also adopted as velocity function for the models. It was observed that salinity, temperature and pressure variations had trivial influence on the model results. The data utilised for the crossplots generated in this study were acquired from Buit-1 well within the Niger Delta Slope. A typical seismic section from the study area showing horizons of interest is shown in Fig. 2.

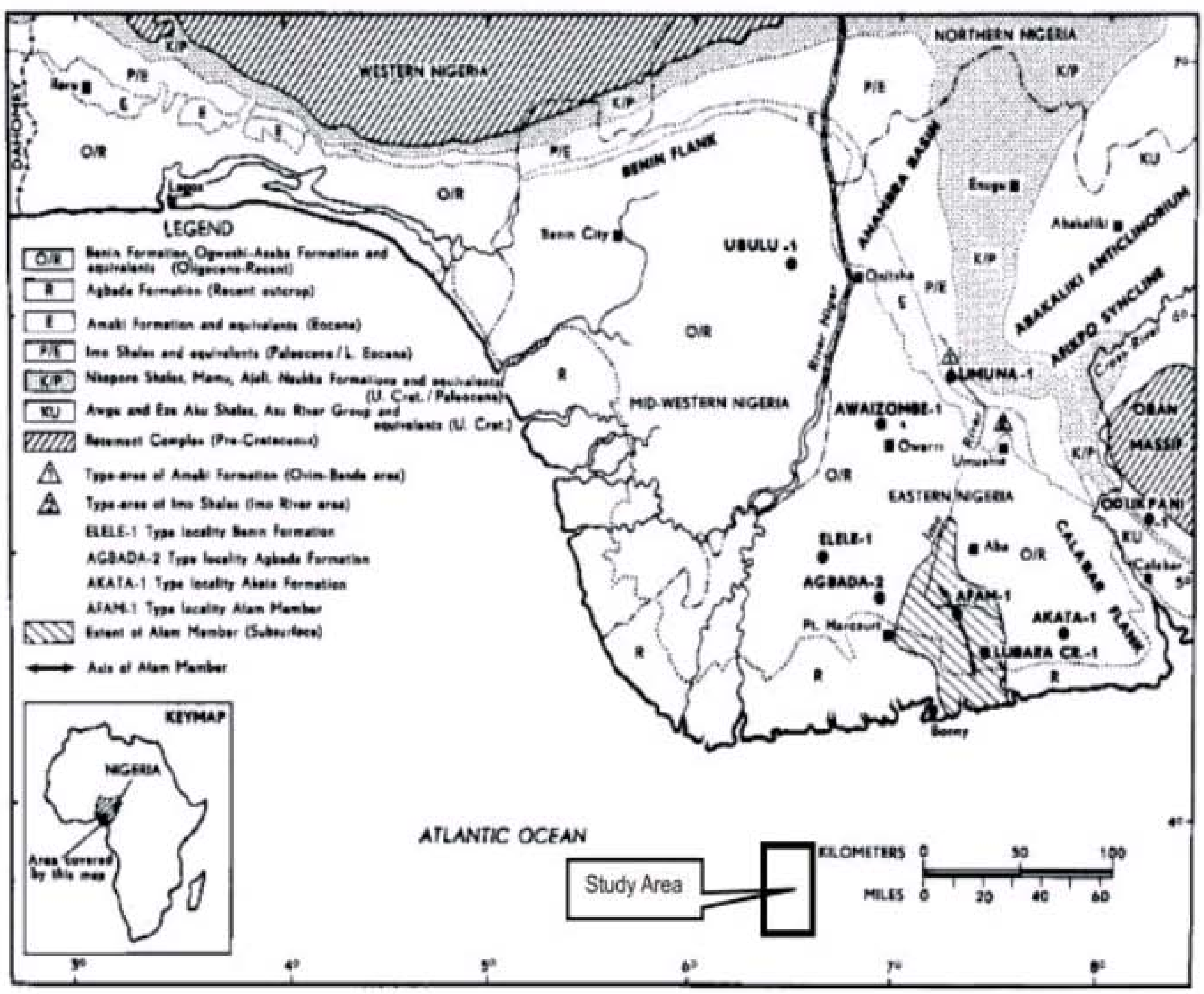

Fig. 1: Geological sketch map of Niger Delta complex (Short and Stauble, 1967) showing the deepwater location of the study area

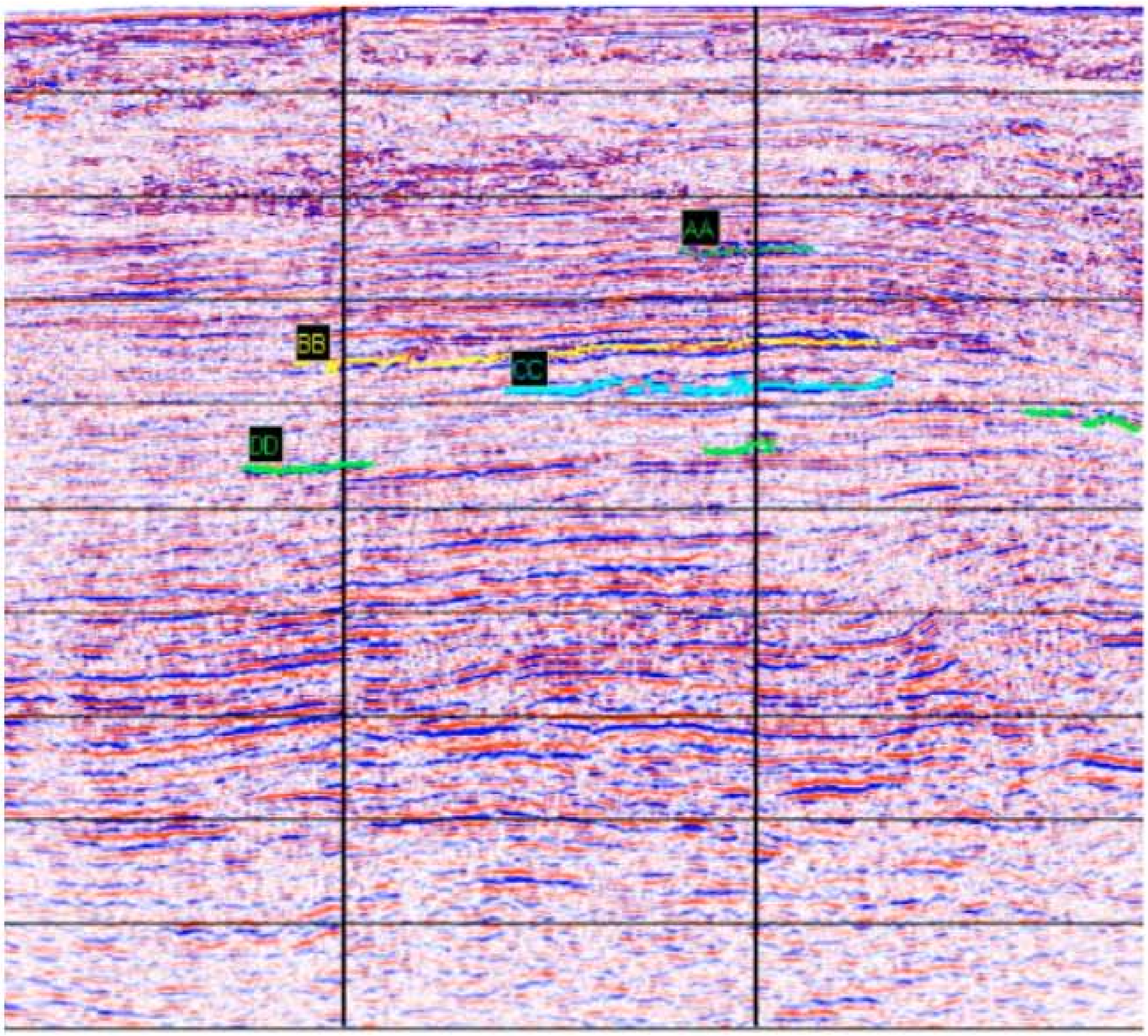

Fig. 2: A seismic section from the Niger Delta Slope

The generic model obtained from Gulf of Mexico well log generated for the combined horizons evaluated include AVO L-M (or A-B) (Bortfeld, 1961; Shuey, 1985) crossplot shown in Fig. 3a. The L-M crossplots are typical of brine sand (pink plots), residual hydrocarbon (light orange) and commercial hydrocarbon (red) models. The brine model forms the background trend. Abnormally high background normal (Bn) values characterised the residual hydrocarbon models. Unconsolidated gas sand formations may exhibit such abnormal characteristics. Similar AVO crossplots may therefore typify the shallow reservoir sand formations of the Niger Delta Slope.

The 1-D composite synthetic section generated from the AVO crossplot of Fig. 3a is presented in Fig. 3b. This plot shows three models i.e., brine, residual hydrocarbon and commercial hydrocarbon. All the three models are characterised by decrease in V_p and density as hydrocarbon saturation increases. In contrast the V_s, stack amplitude, intercept (L) amplitude and half gradient (M/2) values show increase in value as hydrocarbon saturation increases. The synthetic seismogram exhibits amplitude increase with offset on residual and commercial hydrocarbon models while no amplitude variation was displayed on the brine model.

The composite AVO crossplot of Fig. 3c reveals that AVO crossplot could be a robust tool for mapping deep reservoirs. The background normal vectors for the residual hydrocarbon models are very low compared with similar reservoirs at shallow levels. In contrast the background normal values for the commercial hydrocarbon are much higher than for the residual hydrocarbon. Such results could enhance interpretation of AVO analysis. However, the depth adopted for this model may not exist within the Niger Delta Slope.

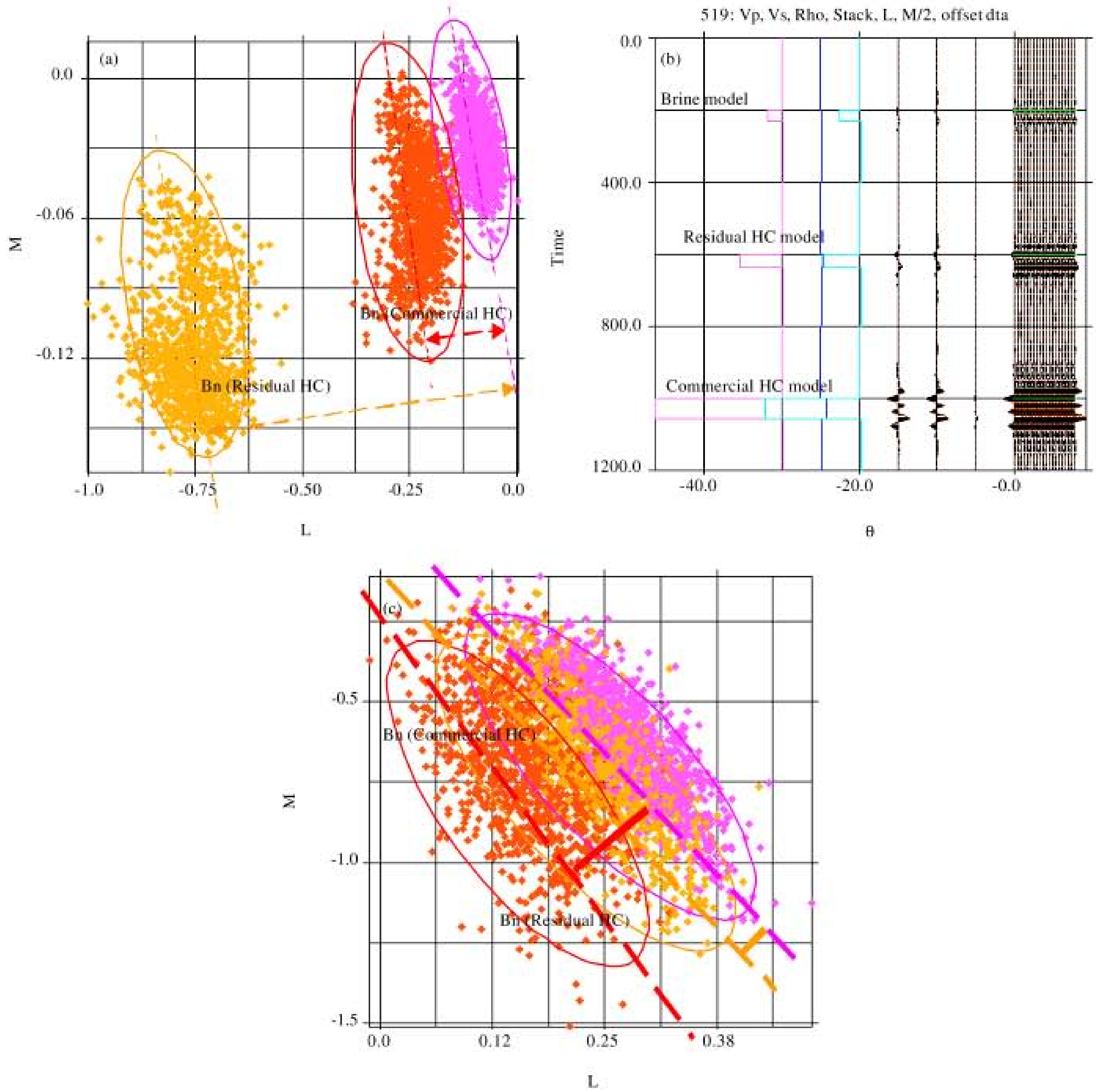

Fig. 3: (a) AVO crossplot of GOM shallow reservoir model, (b) 1-D synthetic seismogram from AVO crossplot of shallow Gulf of Mexico model and (c) AVO crossplot for the Gulf of Mexico deep model

MONTE-CARLO MODEL WITHIN THE STUDY AREA

AA horizon: The Monte-Carlo model of AA horizon resulted in the generation of AVO crossplots (L-M) and synthetics. In brine saturated AA model, separation of residual and commercial HC on L-M crossplot could not be achieved (Fig. 4a, b). In the residual hydrocarbon model of Fig. 4c, little separation of residual and commercial hydrocarbon models was obtained on the class III quadrant (Rutherford and Williams, 1989; Castagna *et al*., 1998). Variation in background normal vector also characterised the crossplot. The much desired AA model is presented in Fig. 4d where commercial (red plots), residual (yellow plots) and brine (pink) are assumed present in the presence of whitening noise. The separation is well defined with a near-constant background vector for residual and commercial hydrocarbon.

The AA horizon L-M crossplot real model is shown in Fig. 5a. The incoherent orientations of the crossplots point to the fact that the AA horizon is possibly

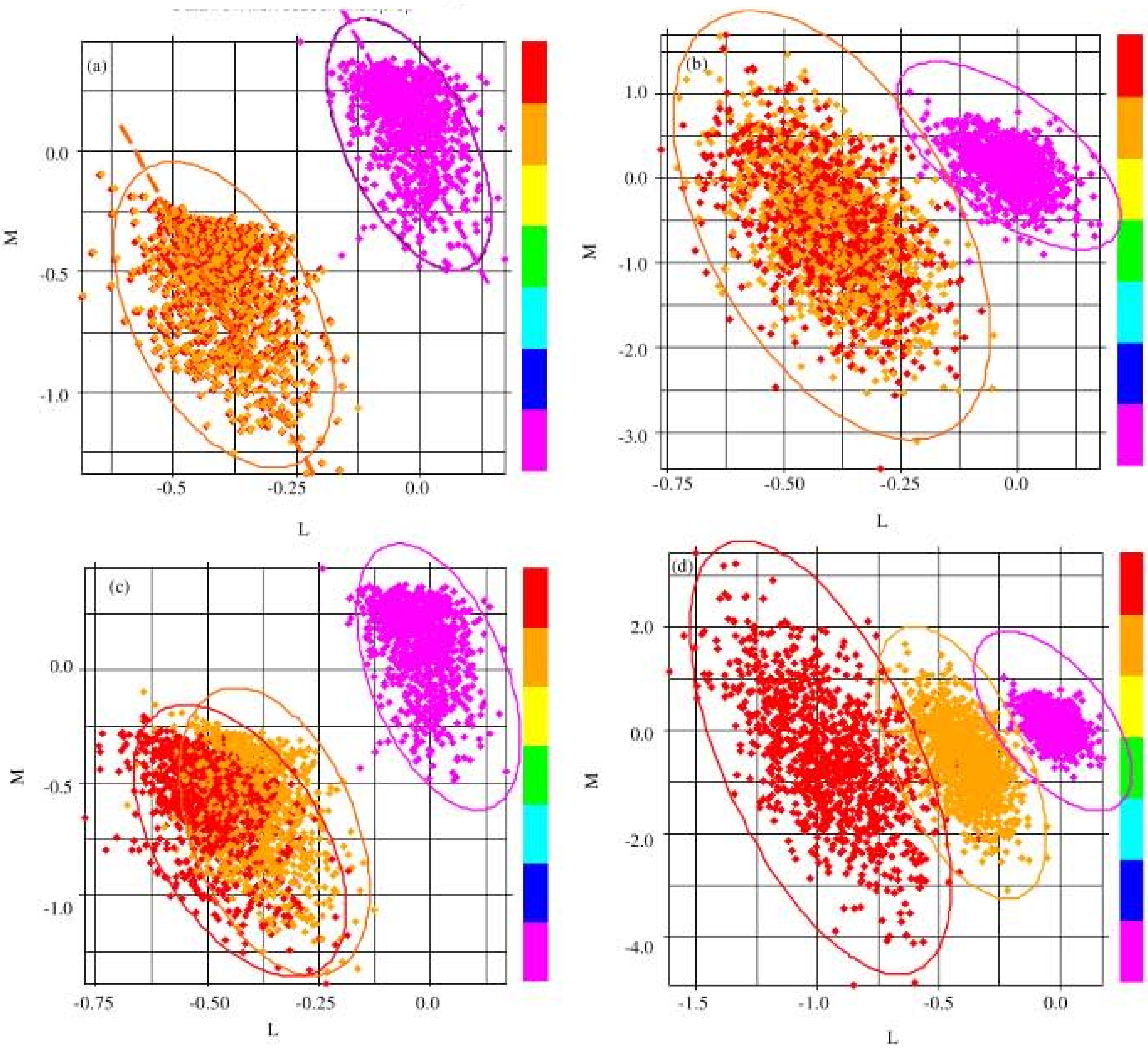

Fig. 4: (a) AVO crossplot of Buit AA brine sands model, (b) AVO crossplot of Buit AA brine sands model + noise, (c) AVO crossplot of Buit AA residual HC sands model and (d) AVO crossplot of Buit AA commercial hydrocarbon sands model

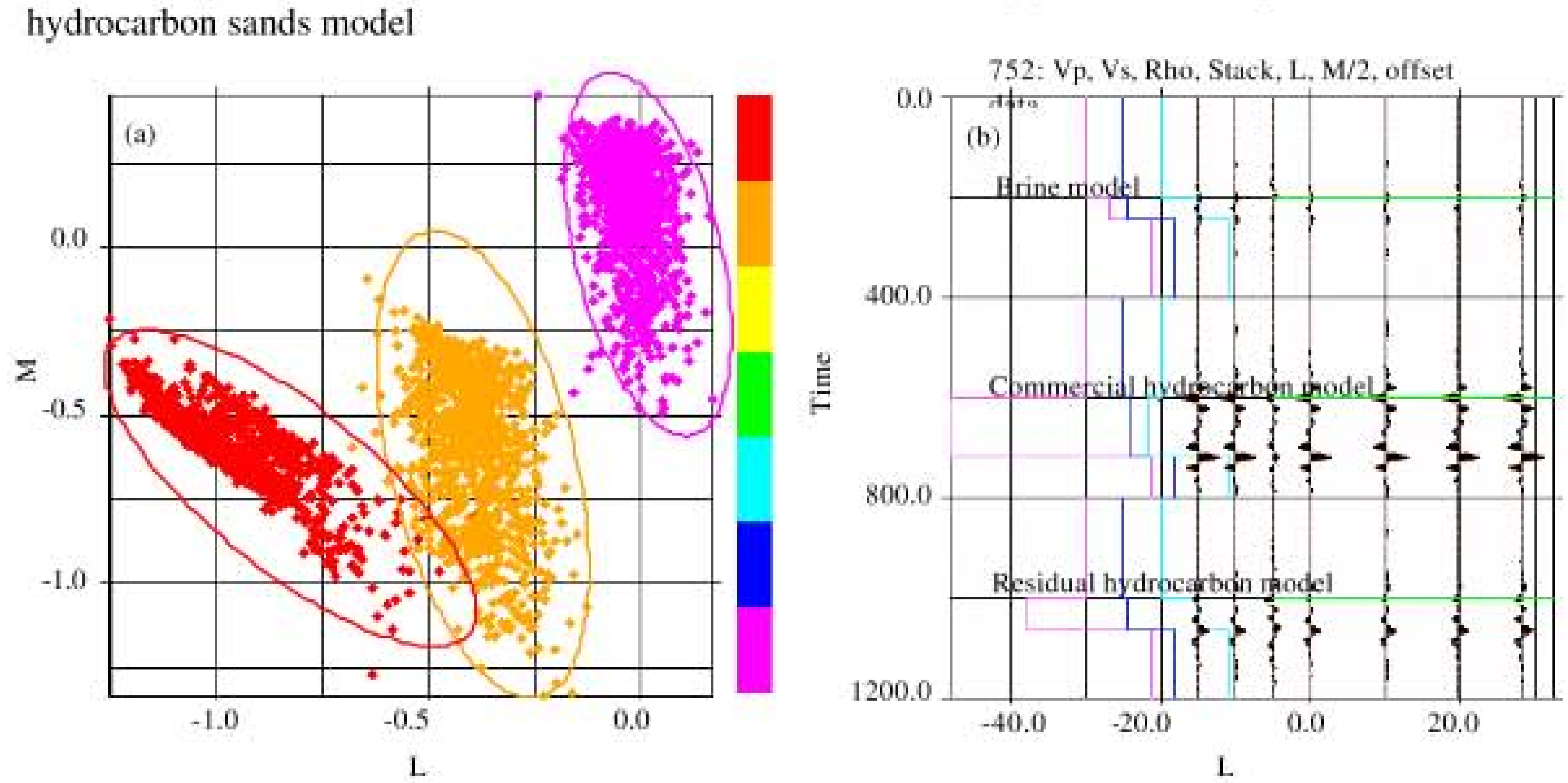

Fig. 5: (a) AVO crossplot of Buit AA as encountered and (b) AVO synthetic of Buit AA generated from AVO crossplot

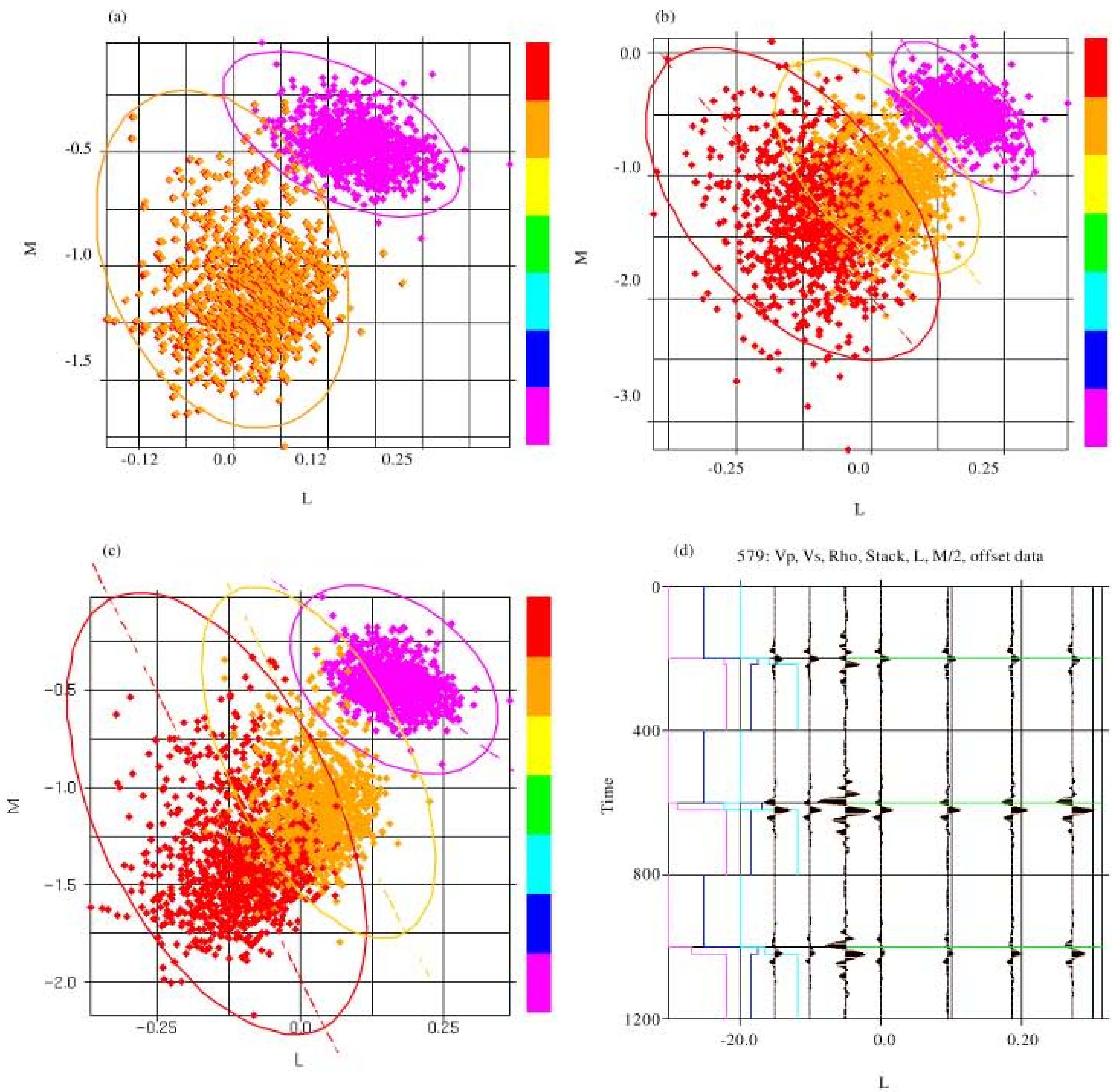

Fig. 6: (a) AVO crossplot of brine saturated Buit BB model, (b) AVO crossplot of Buit BB commercial hydrocarbon model, (c) AVO crossplot of Buit BB horizon as encountered and (d) AVO synthetic of Buit-BB horizon as encountered

unconsolidated. The synthetic seismogram generated from the L-M plot is shown in Fig. 5b. The plot shows three models in one plot: brine, residual hydrocarbon and commercial hydrocarbon. Figure 5b shows no perceptible amplitude variation with offset on all the models.

BB horizon: Two Monte-Carlo models generated for the BB horizon are brine saturated model and commercial hydrocarbon saturated model. The brine saturated model typically plotted on the hard sand (hard kick) quadrant (Fig. 6a). In contrast, the commercial hydrocarbon model (Fig. 6b) is plotted on quadrant III (soft kick). Complete separation of oil sands from gas sands seems unfeasible in the model. Net to gross associated problems may be responsible for any scatter in the real plot as seen in the model.

Figure 6c is the L-M crossplot of the encountered BB horizon. Most of the commercial hydrocarbon plots

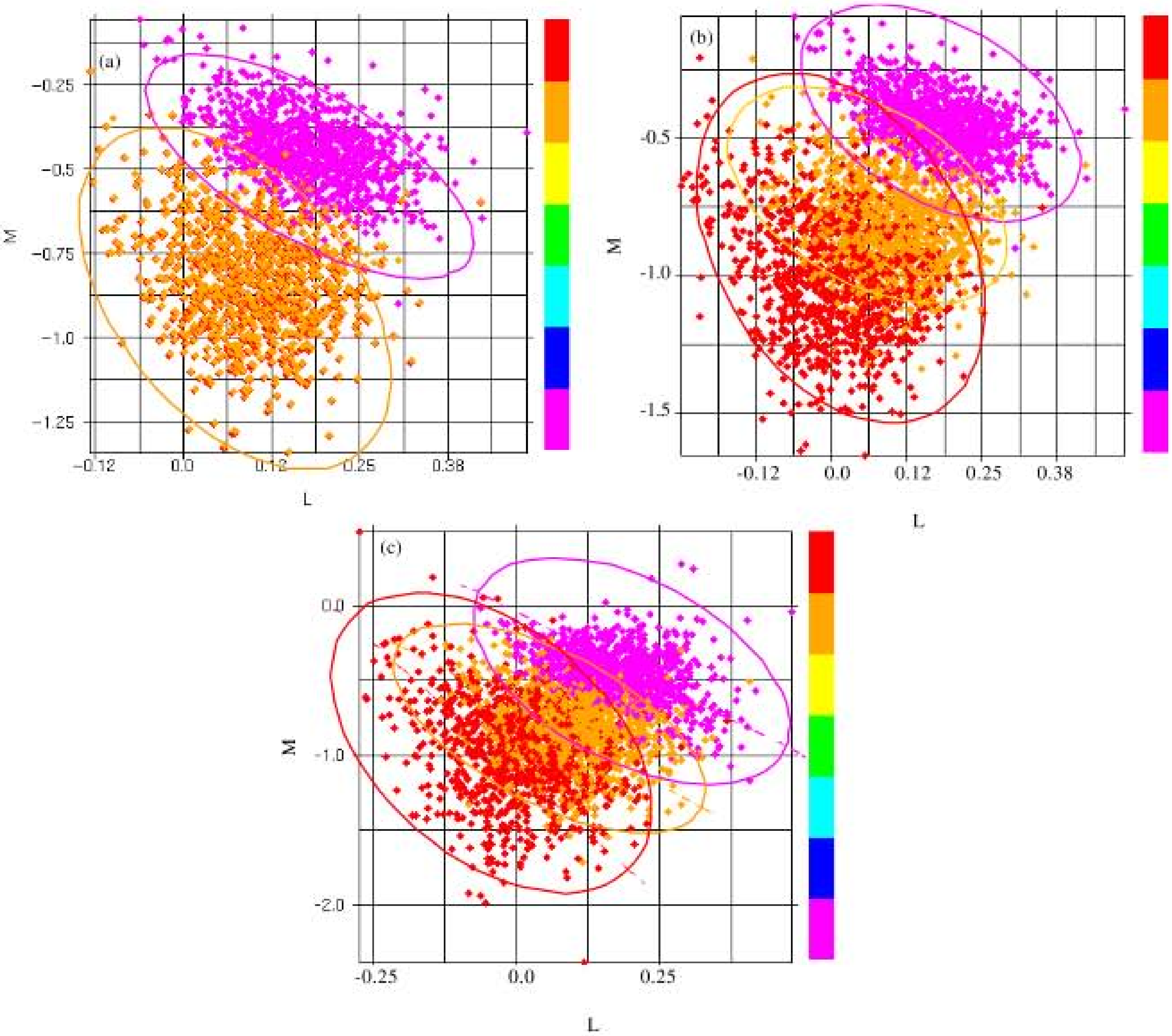

Fig. 7: (a) AVO crossplot of brine saturated Buit-CC model as encountered, (b) AVO crossplot of commercial hydrocarbon saturated Buit-CC model and (c) AVO crossplot of commercial hydrocarbon saturated Buit-CC model + noise

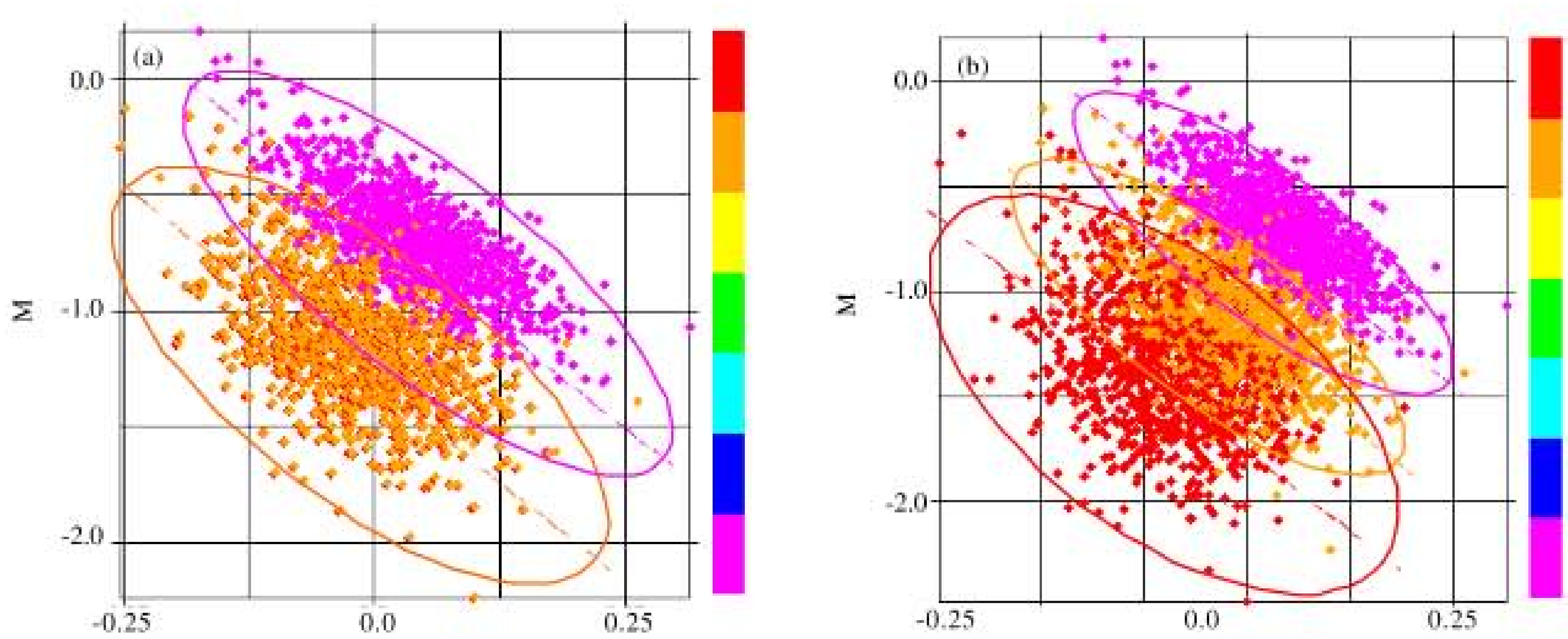

Fig. 8: (a) AVO crossplot of brine saturated Buit-DD model and (b) AVO crossplot of commercial hydrocarbon saturated Buit DD model

and some of the residual hydrocarbon plots fall on quadrant III (bright spot quadrant). In essence, the BB L-M crossplot is diagnostic of hydrocarbon-saturated horizon with some lithology variations within the horizon.

The synthetic seismic generated for the BB horizon (real model) (Fig. 6d) exhibits positive AVO response (soft kick) on the commercial hydrocarbon model.

CC horizon: The brine saturated model of the L-M crossplot for the CC horizon model plotted mostly on hard sand quadrant (Fig. 7a). Conversely, presumed commercial hydrocarbon saturated CC is split between the hard sand and soft sand quadrants with low background normal values (Fig. 7b, c). Distinction between commercial hydrocarbon and residual hydrocarbon AVO attributes is somehow difficult to obtain, as the cloud of crossplots does not enhance good separation.

DD horizon: The DD horizon is similar to the deep model of the Gulf of Mexico and hence exhibits similar crossplot. For gassmann substituted brine sand DD model, the crossplot (Fig. 8a) typifies a general background trend that would exist for the petrophysical crossplot of the horizon. The brine sand in these instances the yellow and pink plots, forms the background trend plot for the horizon. Any deviation from the trend may have been caused by the presence of a lighter fluid presumably hydrocarbon. Lithology changes may also cause such difference.

A commercial hydrocarbon model is shown in Fig. 8b. A separation is observed in the plots of commercial hydrocarbon (red), residual (yellow) and brine (pink). However, the separation is not as distinctive as what obtained at the shallower levels. Notwith standing, the red plots still appeared clearly on quadrant III (bright spot possible). Even in the presence of noise (Fig. 6c) the distinction still persists.

CONCLUSIONS

The AA horizon is typified by incoherent orientations of AVO crossplots. The horizon is thus presumed unconsolidated. The synthetic seismogram generated shows no perceptible amplitude variation with offset on all the models.

AVO crossplot of the encountered BB horizon show that most of the commercial hydrocarbon plots and some of the residual hydrocarbon plots fall on quadrant III (bright spot quadrant). Synthetic seismic generated for BB horizon exhibits positive AVO response (soft kick) on the commercial hydrocarbon model. A similar but marginal response was obtained on brine saturated BB model.

Brine saturated model of the AVO crossplot for CC horizon model plotted mostly on hard sand quadrant. Conversely, presumed commercial hydrocarbon saturated CC is split between the hard sand and soft sand quadrants with low background normal values.

The DD horizon is similar to the deep model of the Gulf of Mexico and hence exhibits similar crossplot.

Curiously, high background normal (Bn) characterized residual hydrocarbon models while unconsolidated gas sand horizons exhibit anomalous characteristics. The Monte-Carlo models obtained from the Gulf of Mexico well MC-522wc and the variety of models generated from Buit-1 well data of Niger Delta Slope can aid in understanding the AVO attribute crossplots. The AVO crossplot obtained from the Monte-Carlo model could be a robust tool for mapping reservoirs within the Niger Delta Slope.

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