PS Effects of Pore Geometry Changes on Velocity Anisotropy on Chalks*

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Abstract

Chalks are deep-water pelagic sediments consisting largely of stable low-magnesium calcite with high critical porosity. Progressive diagenesis reduces their initial porosity and makes changes in their pore geometry. Reduction in the porosity implies velocity increment, while changes in the pore structure may cause the velocity to increase or decrease. Pore geometry changes toward stiffer pores (intra-particle porosity) results in higher velocities compared with the changes toward compliant pores (inter-particle porosity). Pore-model stiffness (PMS value) is a parameter which was introduced by Saberi et al. (2009) and was used to incorporate porosity and pore types into velocity interpretation. The self-consistent approach (SCA) to make a link between velocity, porosity, and lithology changes in chalks. The PMS value is an attribute of this link which is governed by both velocity and porosity. In theory, for a given porosity, velocity increases with increasing PMS value. Therefore, PMS values contain information about velocity, porosity, and pore types, and may be assigned for different lithofacies (ooze, chalk, and limestone). We investigated the relationship between PMS value and Observed Velocity anisotropy at some drilled wells during deep sea drilling program (DSDP) and ocean drilling program (ODP).

Many authors analyzed and modeled chalks physical properties (porosity, density, velocity anisotropy, pore geometry etc.), using these programs in different diagenetic phases. A dataset from some sites of the DSDP/ODP located in the Ontong Java Plateau (western equatorial Pacific) were selected and used to interpret the horizontal and vertical velocities using PMS values to analyze the effects of pore geometry changes on velocity anisotropy.

Our results show that velocity anisotropy is very small for ooze intervals, while it increases with depth by passing through chalk and limestone intervals. The PMS value follows almost the same trend for different lithofacies and decreases from ooze to limestone intervals. This indicates the role of compliant pores (intercrystalline porosity) on velocity anisotropy: rocks with soft pore system (lower PMS values) are more susceptible for velocity anisotropy although they may have gone through digenesis and become indurate. However, soft rocks with a stiff pore system (high PMS value) do not necessary show an anisotropic velocity.

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Effects of pore geometry changes on velocity anisotropy on chalks

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Introduction

Chalks are deep-water pelagic sediments consisting largely of stable low-magnesium calcite with high critical porosity. Progressive diagenesis reduces their initial porosity and makes changes in their pore geometry. Reduction in the porosity implies velocity increment, while changes in the pore structure may cause the velocity to increase or decrease. Pore geometry changes toward stiffer pores (intra-particle porosity) results in higher velocities compared with the changes toward compliant pores (inter-particle porosity). Pore-model stiffness (PMS value) is a parameter which was introduced by Saberi et al. (2009) and was used to incorporate porosity and pore types into velocity interpretation. They self-consistent approach (SCA) to make a link between velocity, porosity and lithology changes in chalks. The PMS value is an attribute of this link which is governed by both velocity and porosity. In theory, for a given porosity, velocity increases with increasing PMS value. Therefore, PMS values contain information about velocity, porosity and pore types, and may be assigned for different lithofacies (ooze, chalk, and limestone). We investigated the relationship between PMS value and observed velocity anisotropy at some drilled wells during Deep Sea Drilling Program (DSDP) and Ocean Drilling Program (ODP).

The study area is located within the Ontong Java Plateau (Fig. 1). The Ontong Java Plateau in the western equatorial Pacific is a broad mid-oceanic submarine plateau striking northwest and parallel to the Solomon Islands to the south. It covers an area of ca 2x106 km^2 with a thick column of pelagic carbonates which holds no accumulation of hydrocarbons. The collision of this plateau with the old Solomon arc resulted in uplift of the Ontong Java Plateau's southern margin.

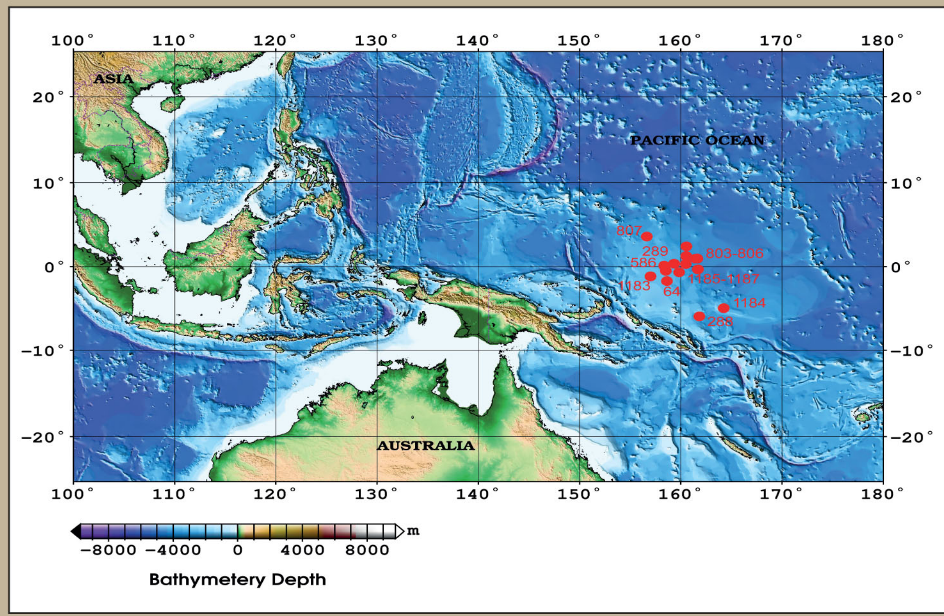

Fig. 1 Location map

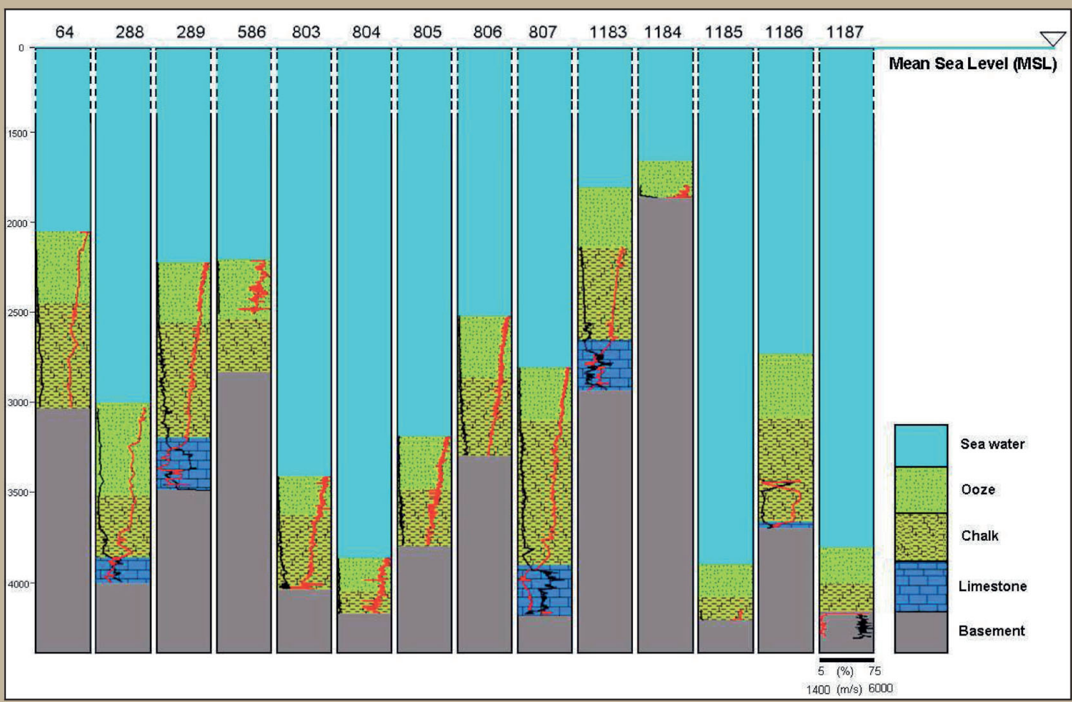

Fig. 2 Cross section of the drilled wells during the deep sea drilling and ocean drilling projects on the Ontong Java Plateau. The location of the area is given in Figure 1. Available plug velocity (black line) and plug porosity measurements (red line) shown for each well.

Lithostratigraphy

The terms ooze, chalk and limestone, which will be used subsequently, simply give three different names to the same deposit as it passes through a continuous spectrum of diagenetic stages. Thus, they discriminate between soft, firm and indurate sediments (Fig. 3).
Four wells (288-289-807 and 1183) have been selected for this study as 1) they have complete data set (porosity, velocity, carbonate content etc.); 2) they penetrated deep enough (especially for site 807) into the sediments to have cores from different diagenetic realms (ooze, chalk and limestone); and (3) ooze, chalk and limestone transitions are more distinct for these sites (especially for site 807).

Leg 30/SITE 288
Unit1 - This unit composes of foram-nannofossil ooze and chalk. It is divided into two sub-units: 1A (0-82 mbsf) and 2B (82-500(?) mbsf).
Unit 2 - This unit composes of chalk and limestone with chert, clay, and siltstone. It is divided into sub-units: 2A (533-737mbsf), 2B (737-775mbsf), 2C (775-814mbsf), 2D (814- 908 mbsf) and 2E (908-988.5mbsf).

Leg 30/SITE 289
Unit 1 - This unit composes of nannofossil-foram ooze and chalk.
Unit 2 - This unit composes of radiolarian bearing limestone, siliceous limestone, chalk, limestone, chert, and tuff. It is divided into two sub-units: 2A that consist mainly of radiolarianbearing limestone, siliceous limestone, nannoforam chalk, nannoforam limestone, and nodular chert, and 2B that consists mainly of limestone and tuff.

Leg 30/SITE 807
Unit 1 - This unit composes of ooze and chalk with. It is divided into subunits 1A (0-293mbsf) and 1B (293-968mbsf), based on the degree of induration.
Unit 2 - This unit composes of limestone, chert, and chalk. It is divided into subunits 2A (968-1098mbsf) and 2B (1098-1351.4mbsf), based on the transition from chalk to limestone.
Unit 3 - This unit composes of claystone and siltstone with varying amounts of radiolarians, and limestone. It is divided into subunits 3A (1351.4-1369.7mbsf) and 3B (1369.7-1379.7mbsf), at transition from claystone to limestone.

Leg 192/SITE 1183
Unit 1 - This unit consists of foram-nannofossil ooze to chalk. It is divided into subunits 1A (0-337.6mbsf) of ooze, 1B (337.6- 444.83 mbsf) of chalk with minor amounts of siliceous microfossils and sponge spicules, and 1C (752-838.6mbsf) of nannofossil foraminifer chalk and limestone with volcanic ash layers. There was no sample recovery for the Interval between (0-328mbsf), therefore lithology assumed from other sites.
Unit 2 - This unit composes of limestone, chert, and zeolitic chalk. It is divided into two subunits of 2A (838.6-958.3 mbsf) of limestone and chert and 2B (958.3- 986.6 mbsf) of limestone and zeolitic chalk. Unit 3 - This unit composes of limestone. It is divided into subunits 3A (986.6- 1088.8 mbsf) of white limestone and 3B (1088.8-1130.4 mbsf) of gray and pinkish white limestone.

Methodology

Saberi et al. (2009 and 2010) divided chalk porosity spectrum into three classes according to their potential influence on seismic velocities (Fig. 2) named as: (1) Grain porosity, (2) Matrix porosity, and (3) Crack porosity. They considered depositional environments responsible for defining the initial spectrum which will be modified later by diagenesis. A simple sketch of chalk diagenesis is given in Figure 2. Furthermore, self-consistent approach (SCA) was used to define the initial pore aspect ratio spectrum and the enforced modification through diagenesis. The results of our study show a clear relationship between chalk depositional environments and diagenesis with a parameter named as pore-model stiffness (PMS value). PMS value is defined as the average between different pore aspect ratio concentrations and implicitly related to the porosity and velocities, as a change in porosity usually infers the pore geometries to alter, thus, the seismic velocities. During this study we will investigate more the effects of pore geometry changes on the observed seismic anisotropy on core-plugs. Four sites (288, 289, 807 and 1183) have the complete dataset for such study. The core-plugs retrieved from these sites are provided with horizontal and vertical velocities. Simply, the difference between these two types of velocity should refer to anisotropy. The pore-model estimation also has been done on the same core-plugs.

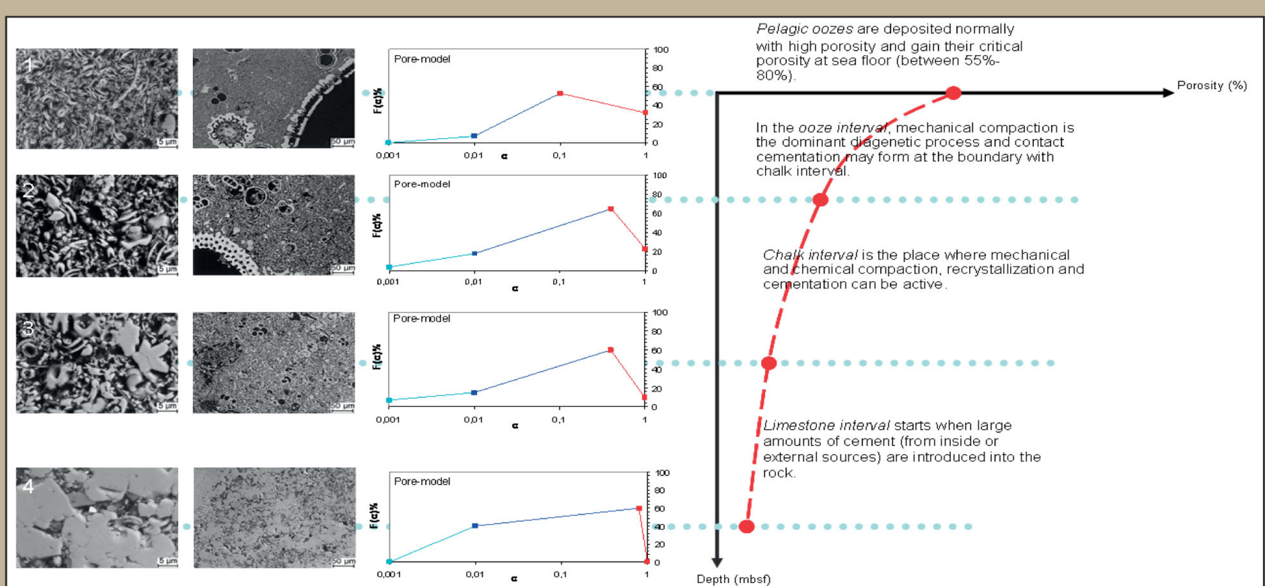

Fig.3 Chalks porosity and diagenesis model.

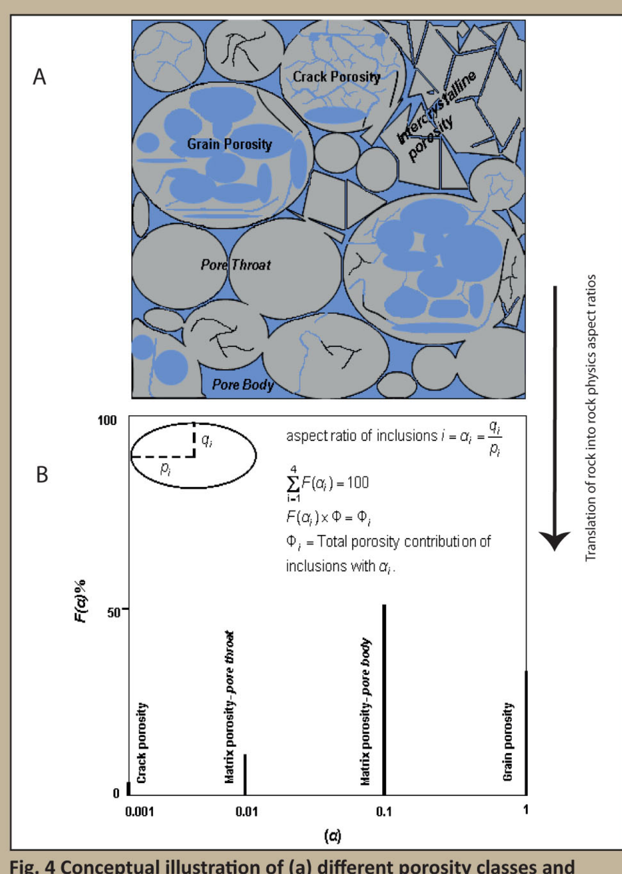

Fig. 4 Conceptual illustration of (a) different porosity classes and (b) related pore-model in chalks considered in this study.

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Results and Discussion

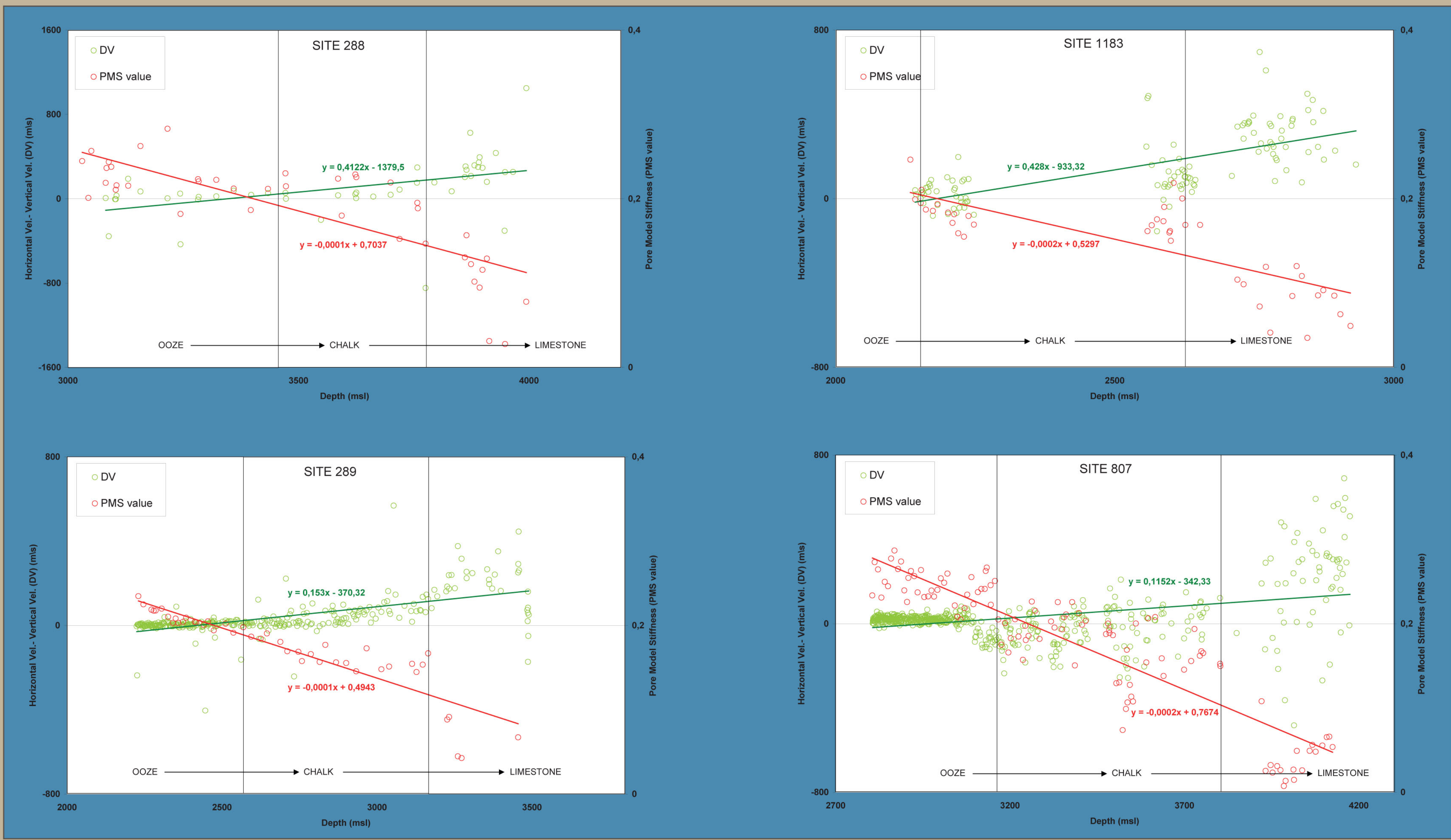

Fig.3 Comparison between velocity anisotropy and PMS value for the studied wells.

Cross plots in Figure 3 show comparison between velocity anisotropy (DV) and pore model stiffness (PMS) from different wells. The PMS values are calculated according to Saberi et al. (2009) and velocity anisotropy is obtained from core plugs velocity measurements in horizontal and vertical directions (IODP/ODP data). As shown in all studied wells PMS values decrease with depth, although rocks become indurated. This effect reduces porosity related to increase of velocity with depth. According to Saberi et al. (2009 and 2010) the velocity anisotropy (horizontal-vertical velocity) increases with depth from ooze to limestone interval. The comparison between velocity anisotropy line and PMS line indicates a direct relationship between them. This suggests that the main factor controlling the velocity anisotropy is represented by PMS changes and in turn changes in the pore geometry. Therefore it is reasonable to expect no velocity anisotropy if there are no changes in the pore geometry. This also indicates that cracks play an important role in creating velocity anisotropy in rocks. Furthermore, the result of this study can be used to define a seismic attribute in order to discriminate among ooze, chalk and limestone and even velocity anisotropy intervals away from well control based on the relationship derived at well locations. In this case study cross plots for all studied wells (Figure 3) show that the intersection between PMS and velocity anisotropy trend lines occurs at 0.2 value for PMS which almost coincides with the boundary between ooze and chalk. This boundary can be mapped using a 3D seismic cube and applying PMS values as attribute.

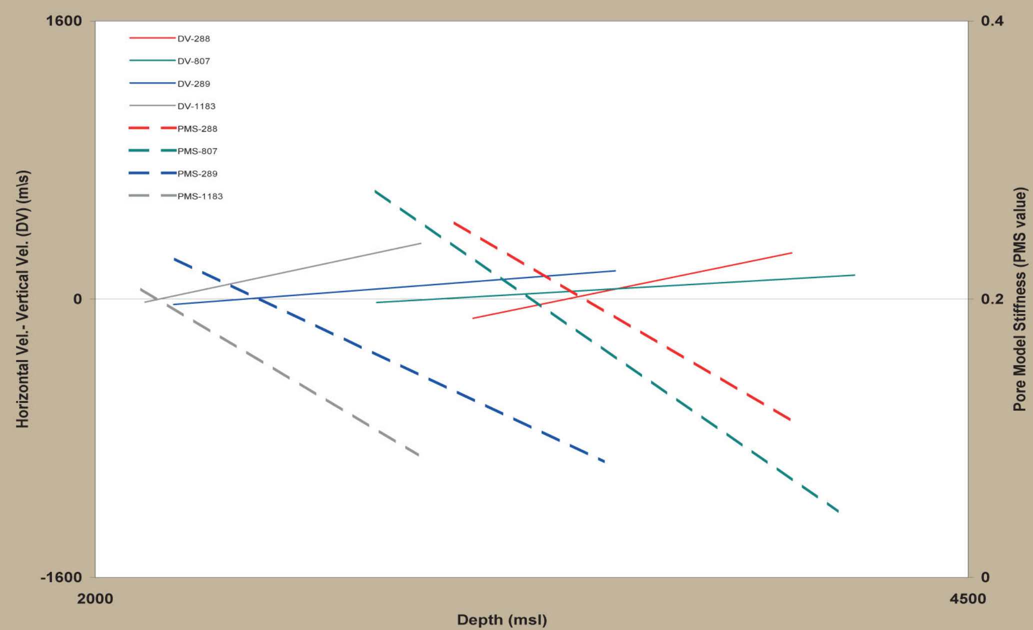

Fig.4 comparison between PMS values and velocity anisotropy for all the wells

Conclusions

Our results show that velocity anisotropy is very small for ooze intervals, while it increases with depth by passing through chalk and limestone intervals. The PMS value follows almost the same trend for different lithofacies and decreases from ooze to chalk to limestone. This may indicate the role of compliant pores (intercrystalline porosity) on velocity anisotropy: rocks with soft pore system (lower PMS values) are more susceptible for velocity anisotropy although they may have gone through digenesis and become indurate. However, soft rocks with a stiff pore system (high PMS value) do not necessary show an anisotropic velocity. This study also shows an indirect relationship between PMS value and velocity anisotropy and changes in lithofacies. Using such relationship enable us to model anisotropic trends in an area and as a result borders for different lithofacies (ooze, chalk and limestone) using seismic data.

References

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