CHARACTERIZATION OF A CARBONATE CEMENTED, MIOCENE RESERVOIR, OFFSHORE VIETNAM.

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Abstract

Reservoir quality in sandstones of SE Asia can be strongly influenced by variable levels of carbonate cement in intergranular pores spaces. The distribution of these cements is typically not homogenous. Lower and Middle Miocene texturally-immature tidally-influenced sands, now lie at depths of 2000-3500 m in the offshore North Vietnam. These sediments occur in a tectonic regime of initial extension and escape of compactional waters, followed by a regime of compression and inversion. Sands recovered in cores show numerous intervals of local to pervasive carbonate cementation, which creates an homogenous poroperm distributions. Within a tidal channel and tidal mudflat sediment-host, detailed analysis using a combination of conventional core study, wireline and petrographic techniques broadly defines these cemented intervals, but cannot satisfactorily explain the source of carbonate cement. Wireline analysis, without comparison to equivalent core, does not reliably define zones of cement occurrence.

This study uses a novel application of stable isotopes (carbon and oxygen) in an attempt to better define the origin of the fluids that precipitated the cements, using a cored set of Lower Miocene sands. The resulting C-O cross plot defines two groupings; Group 1 cements occur in mostly in mud-dominated units and show a set of relatively less-negative carbon and oxygen values (0‰ to -3‰ and -5‰ to -12‰, respectively). Group 2 cements, occur in sand units and have a relatively more negative range of carbon and oxygen values (-5‰ to -9 ‰ and -11‰ to -15‰). Group 1 cements are interpreted as derived locally via compactional water cross flows. Group 2 are interpreted as forming in sandstone aquifers that were the foci for the escape of warmer, likely more-basinal, waters. The escape of these waters may be related to the compressional stage in the strike-slip basin that hosts these sands.

Key work: carbonate cement, fluid evolution, depositional environment, reservoir quality.

1.Introduction

Carbonate cement in the reservoir sandstones can have a strong effect on reservoir quality . Zones with carbonate cement tend to have lower porosity and permeability and carbonate cement distribution is typically not homogeneous across a field. The purpose of this paper is to study diagenesis of Miocene sandstones from related wells in the offshore of north Vietnam (figure 1), particularly to; 1) study the effect of carbonate cement on reservoir quality, 2) to define likely distribution of carbonate cements and 3) understand the relationship, if any, between carbonate cement and depositional/ diagenetic environments.

An integration of sedimentological and petrophysical analysis, petrography analysis and stable isotope analysis is done in order to improve the understanding of carbonate cement, reservoir character and likely production behavior of this Miocene sandstone potential reservoir. For the purposes of this study and to evaluate the results of earlier studies, detailed core descriptions were completed in wells 1 and 2. Moreover, 25 samples, in 10 m core of well 1, were taken for stable isotope analysis and some additional samples were taken for petrographic analysis. A seismic profile was made available to the author to allow a broad correlation between the wells and to estimate structural style.

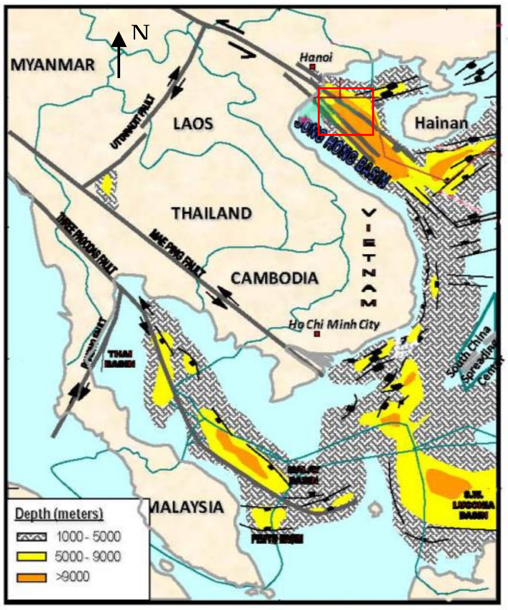


Figure 1. Study area
(Gong &Li, 1997; and Li et.al.,1998)

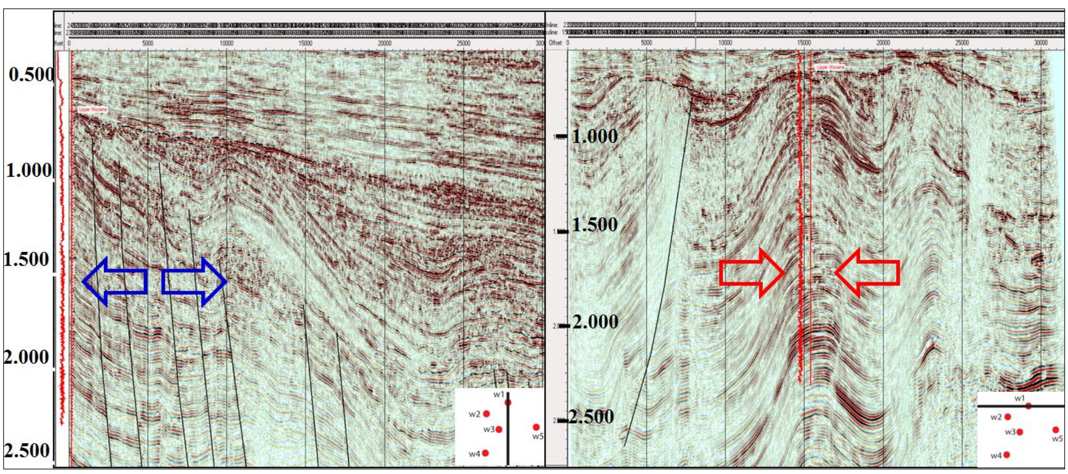
2. Geological setting

The study area lies in an inverted (Oligocene to Recent), with the first phase characterized by left lateral strike slip, second phase by right lateral strike slip, and thermal subsidence since the end of inversion phase. Miocene sediment under study was strongly influenced by inversion after an intial extensional phase. Due to high proportions of muds and labiles, sediments were strongly compacted and were buried to depths of more than 2000-2500m prior to inversion. By the time sediments were tectonically inverted, although they were uplifted to depth around 2000m, the potential reservoir rocks already had low poroperm due to a combination of cementation and diagenesis.

In-line and cross-line seismic though well 1 in the figure 2 show that the sediment style in subsurface is strongly overprinted by extensional and compressional stresses. This phenomenon is the same in other wells in study area. Clearly, extension followed by compression must have influenced fluid flow regime. That is, compactional fluid escape occurred during extension, followed an episode of fluid flow related to compression.

3. Methodology

A detailed sedimentologic description was made and graphic logs constructed to better define depositional environment and reservoir potential. The compiled log also sets up the framework for samples collected for laboratory study (thin sections, XRD and stable isotope analysis). With wireline log data alone, it is often challenging to reliably determine the facies & environment. In this study depositional environment was determined based on the



Extension stress Compression stress

Figure 2. Inline and crossline though well 1.
Sediment was affected by both compaction and extension stress

log shapes tied back to core interpretation results. In addition, petrographic samples were selected from two cut cores, sidewall cores, and cuttings of the 2 wells. This study integrates all existing information including previous petrographic study, as well as the laboratory work done in this study in order to better understand depositional and diagenesis in the two wells under study. Moreover, stable isotopic analyses were done using the sample determinations along cut core well 1. Isotope values can provide importance information about water-rock interactions during diagenesis. The O isotope ratio can give information on the source of fluids (meteoric or marine…) that precipitated the various carbonate cements while the C isotope ratio in cements can be used to infer organic sources such as soil gas or catagenic fluids (Longstaffe, 1983).

4. **Results& discussion**

4.1. Core description

Well 1:

Core in well 1 samples a 6.2m long intersection in Lower Miocene sediments. It includes a 3m thick composite sand body, made up of stacked fining-upward units (figure 3). Grain size in the sands is mostly medium with fine in the upper part. Plant remains are dispersed throughout the sand. Where large enough, they show a coaly aspect. Clay pebbles and clay drapes on ripples, indicate, together with oyster fragments, a tidal/estuarine influence (figure 4). Siderite nodules are commonplace. Trough cross-bedding and oblique bedding are the main current-related sedimentary features. Above and below this sand body are mud-dominated fine sands and clayey micaceous silts. However, bioturbation prevents the observer from fully appreciating the distribution of the original sedimentary structures and layers. Both vertical and horizontal burrows are present (figure4). The latter are more numerous, which indicates less frequent sand influxes in the finer intervals, i.e. a relatively moderate energy setting. Comparing the observed features with wireline log shape across the cored intervals in well 1, we can infer that the muddier layer (inferred from the higher gamma values in the log) is actually made up of thin layers of mud and mud-dominated sand and silts, with a thickness in core of 1m above sand body, and 5 m below sand body. Prior to this study the finer grained intervals

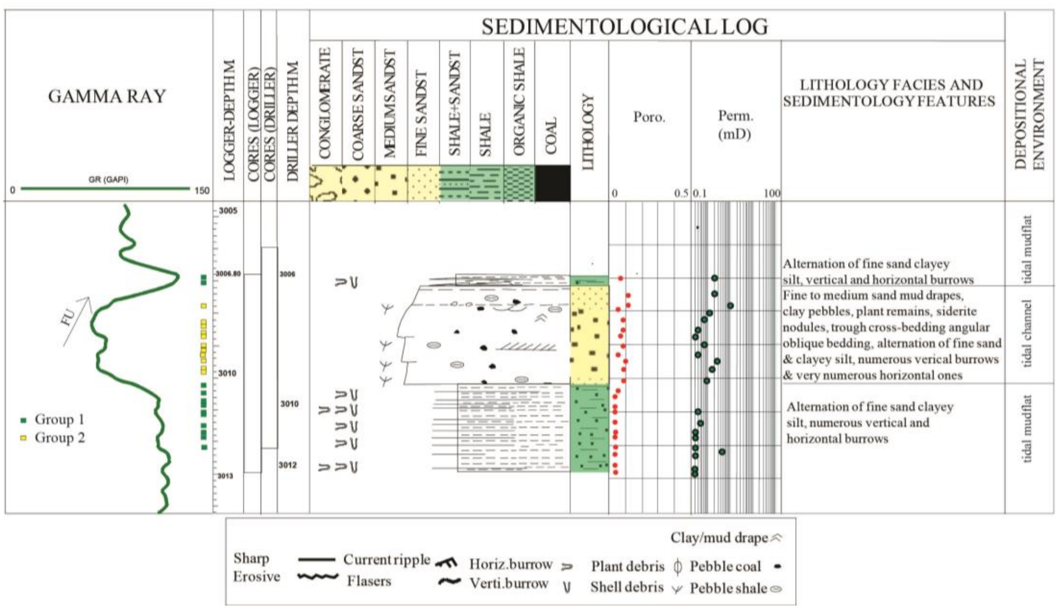


Figure 3. Core description& interpretation, lower Miocene, well 1

at this depth in well 1 had been interpreted as prodelta. The tidal influence seen in the core makes this unlikely and in my opinion, sands in this core interval were likely deposited in tidal channel and the finer grained intervals are likely tidal mudflats (figure 3).

Stable isotope samples in cored interval of well 1taken from mud dominated layer were assigned to group 1, others from the sand layer to group 2.

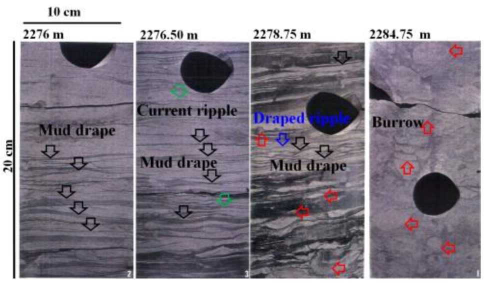


Figure 4. Mud drape indicates a sandy tidal environment,with burrows in the mud dominated unit, lower Miocene, well 1.

Well 2:

Core data in well 2 comes from an 18.4 m long core (2271 to 2289.4 m) in the middle Miocene section. The core contains fine to medium-grained sand, with abundant horizontal and vertical burrows (figure 5). Some silts, and clays with sand segregations, both with numerous borrows were deposited between sand units. The lower part of the cored section is mainly made up of medium-grained sand layers, that are bioturbated, micaceous, with plant debris, with pebbles of shale, and occasional shell fragments. The upper part of the cored section is mainly fine-grained sand with more clay influx compared to the lower section. Sediments in this lower part are mostly alternations of rippled layers of fine sand with clay drapes, variably bioturbated with plant remains and grey clays, silty in varying proportions (figure 6). Especially in muddier layers there draped sand ripples (figure 6) which are good indicators of tidal mudflat environment. The uppermost part of the cored section is a fine sand, bioturbated, with current ripples, mud drapes and pebbly coaly intervals. Based on these observations, the cored interval in well 2 is interpreted as being deposited in a tidal channel and tidal mudflat setting (figure 5).

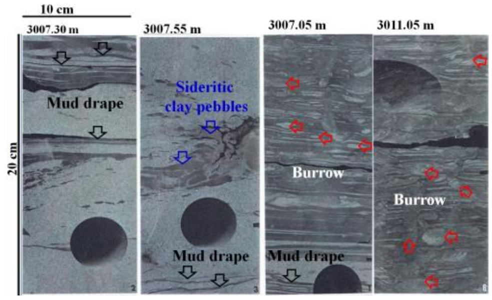


Figure 6. Mud drapes & draped ripples indicate a tidal environment with burrows in the mud dominated unit, well 2

4.2. Wireline Log constructions and comparisons

Fining-upward successions are seen in the wireline log signatures of all two wells, over stacking thicknesses and shapes, which when tied back to core in wells 1 and 2 indicated a tidal-influenced set of sands, likely deposited in a more regional deltaic environment (figure 3, 5). Even so, it is very difficult to separate tidal and non tidal environment based only on log shape as a variety of depositional settings can have similar vertical trends (fluvial point bar passing up into floodplain versus tidal channel passing up into mudflat). Therefore, without core, depositional interpretations from log shape are tentative.

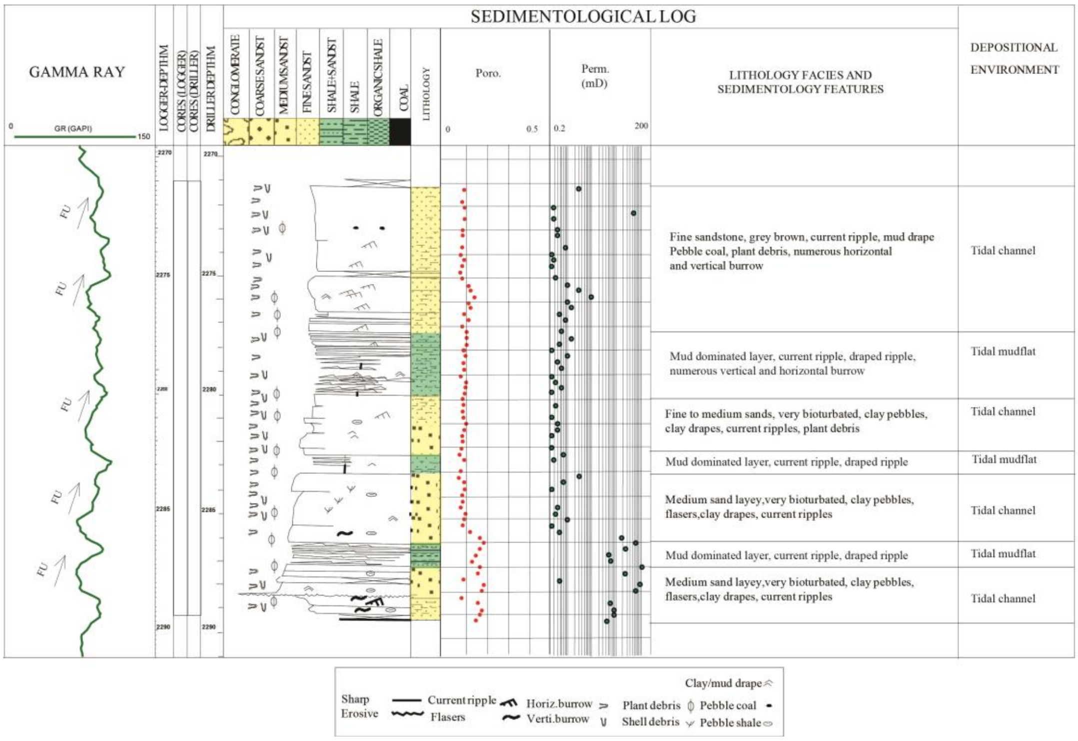


Figure 5.Core description, middle Miocene, well 2

4.3.Petrographicresults

In all cored intervals carbonate cement is present and makes up the highest volume of the authigenic components. And so it has a strong influence on reservoir quality in both the Middle Miocene and Lower Miocene sandstones. Zones that are intensely cemented in core are defined both by nodules and dispersed patchy to pervasively cemented bands. In some thin sections from better cemented intervals, the effect of local carbonate cement replaces near totally the primary porosity. As mentioned earlier, group 1, 2 in cored interval of well 1 (figure 7, 8) show different dominant carbonate cement styles in each group. Redox spots of carbonate cement dominate cements in group 1 and indicate early diagenesis (figure 6). No late stages of carbonate cement filling voids were seen in group 1. In contrast, in group 2, most of the carbonate cement fills residual porosity and postdates secondary silica cement overgrowths (figure 7). Carbonate cement tend to have blocked pores and is mostly related to later diagenesis. As we shall see in the next section, two carbonate cement styles in both groups can be related to the stable isotopic signatures.

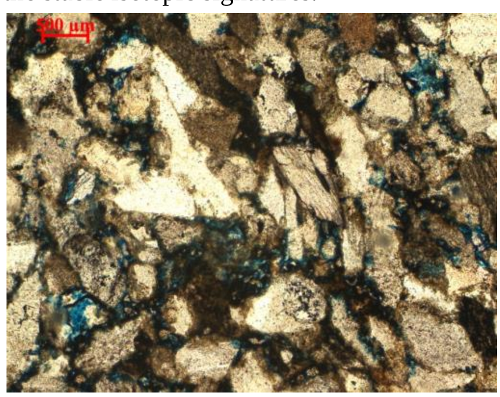


Figure 7. Thin section in Group 1, mud dominated layer, 3011.7m, well 1

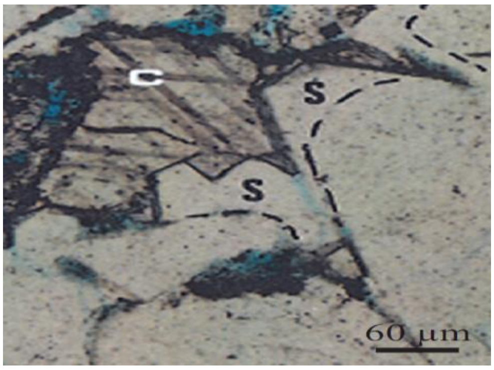


Figure 8. Thin section in Group 2, sands layer, 3008.96 m, well 1

4.4. Stable isotope results

Results of stable isotope analysis in cement samples from well 1 are shown in figure 9. All of these samples in well 1 were taken in lower Miocene sediments. Carbon, oxygen isotope values range from 0‰ to -9‰ and -5‰ to -15‰, respectively. Carbon-Oxygen covariant plots quite clearly define two groups with greater separations along the carbon axis.

Group 2 has more negative carbon values, with oxygen with ranging from -5‰ to -9 ‰ and -11‰ to -15‰, whereas group 1 has carbon, oxygen with more positive values ranging from 0‰ to -3‰ and -5‰ to -12‰, respectively.

When the two isotope groupings are tied back to the core logs it is clear that Group 2 characterizes cements in medium-grained sandstone intervals, with good sorting, no bioturbation and higher porosity, permeability compared to group 1. Group 1 is mud dominated with more organic matter, abundant bioturbation and little porosity, permeability.

5. Discussion - integrating core, wireline and rock property measurements

Comparing the core-defined properties from well 1 and 2 we can see that the mudstone-dominated layers have similar sets of sedimentary features, both with abundant burrows. Burrows in well 2 are more numerous and larger than in well 1. In terms of sands, these are once again similar, both are fine to medium grained sands with current ripples, mud drapes (figure 4), shell debris, pebbly coal and clay pebble layers. So the main differences are related to intensity of bioturbation. Whereas the sandstone in well 1 was not bioturbated, sandstone in well 2 has numerous burrows of different sizes and orientations (vertical, horizontal, subhorizontal). Sediment associations and features in sands from both wells indicate a tidal influence and hence were deposited in waters no more than a few metres deep, as

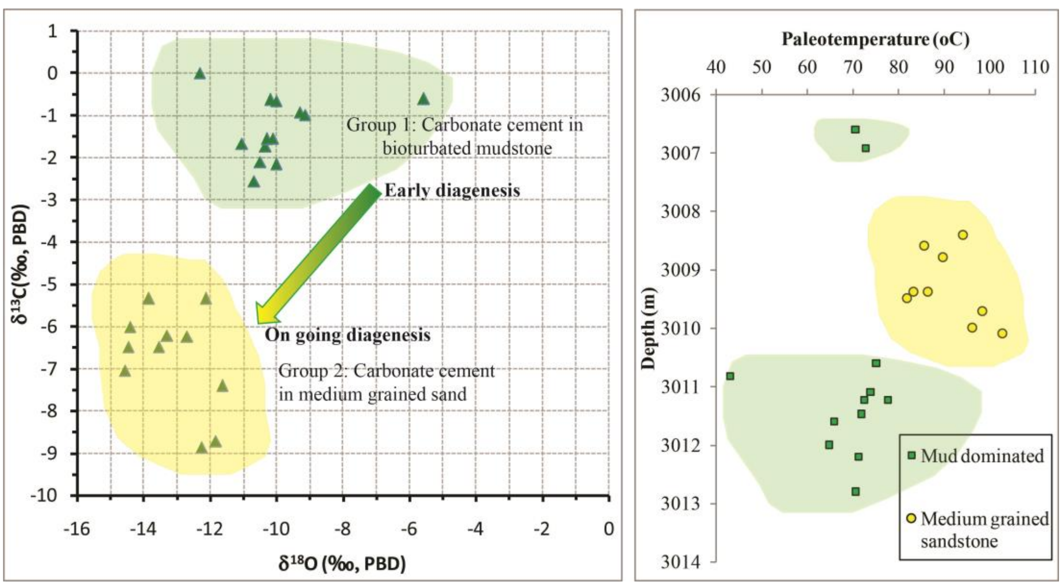


Figure 9. Stable isotopic resultsin the sandstone, Lower Miocene, well 1

were the associated mudflats. If these sediments were deposited as prodelta muds and sands, waters are typically tens of meters or more deep. At such depths we we will not see any sedimentary features indicating tidal environments. Therefore, finer grained sediment units in both cored intervals were deposited in tidal systems, not as prodelta muds.

Low porosity and permeability in lower and middle Miocene sands in the cores are associated with a high content of shale/flaser beds, high levels of compaction and cementation. Sediment was deposited in delta to shallow marine environment, influenced by tidal currents.

When this happened some mud and shale was deposited within the sand body. Poroperm values in the sandstone reservoir are lower in diagenesis, typically because sediment was strongly compacted.

Moreover, petrography results show high volume of siderite and calcite in each sample in lower Miocene well 1(figure 10), middle Miocene well 2 (figure 11) and possible differences in diagenetic evolution. Unfortunately, the high volume of carbonate cement, which was determined from petrography analysis, cannot be seen directly based on log curves across cored interval (figure 12, 13).

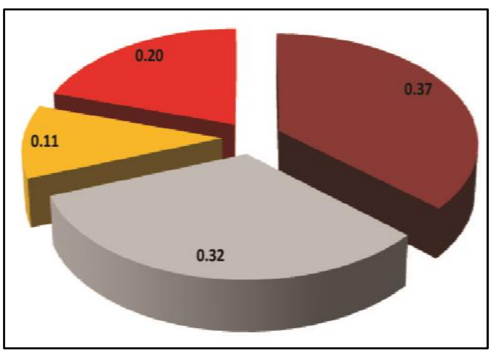


Figure 10. High volume of calcite and siderite cement in Lower Miocene well 1

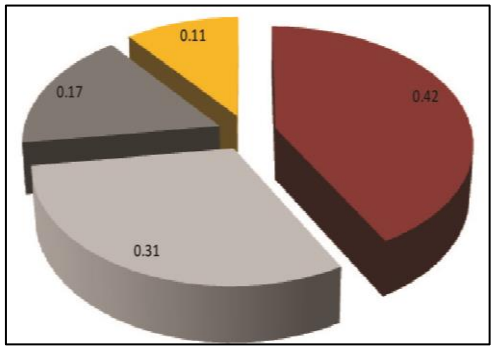


Figure 11. High volume of calcite and siderite cement in Middle Miocene well 2

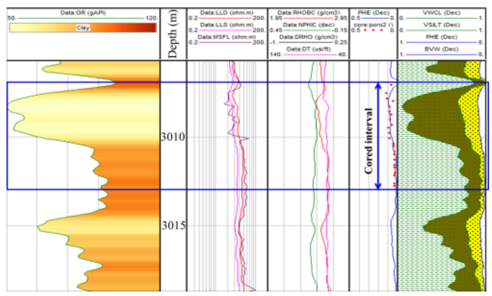


Figure 12. Log shapes support a tidally-influenced channel interpretation (as seen in core), but cannot see carbonate cement, cored interval, well 1

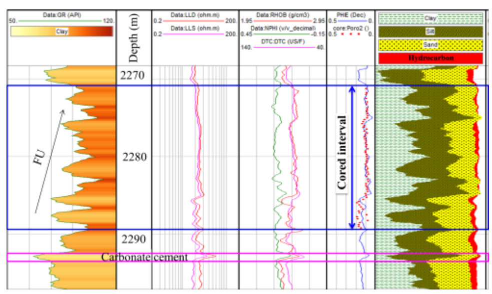


Figure 13. Log shapes support a tidal channel, tidal mudflat interpretation (as seen in core), cannot see carbonate cement seen in sands of cored interval,well 2

Wireline log can give some indirect information about the presence of possible carbonate cement along well (not all), but we do not see cement style based on it. Petrography results can give a very clear understanding of cement style in each sample, but it cannot explain what was the fluid source for the carbonate cement. Stable isotopes can.

In terms of stable isotopic signatures, the change in O isotope values can indicate changes in temperature of formation fluids across the time the cements precipitated; more negative O isotope values typically indicate warmer temperatures in the burial (mesogenetic) environment. I attempted to determine fluid paleotemperatures for this area, based on an equation from Anderson &Authur (1983). In this study I do not have a measured oxygen isotope value for Miocene seawater, therefore I assume that $\delta^{18}O_w$ was 0‰.

$$T\ (°C) = 16.0 - 4.14\ (\delta^{18}O_{cc} - \delta^{18}O_{sw}) + 0.13\ (\delta^{18}O_{cc} - \delta^{18}O_{sw})^2$$

Where $\delta^{18}O_{cc}$: oxygen isotope of calcite in PDB standard;$\delta^{18}O_w = 0$ ‰: oxygen isotope of seawater.

So the temperate results give a value around 70ºC for carbonate cement in the lower Miocene sands, which are indicative of mesogenetic, rather than eogenetic fluid temperatures. However the temperature results are poorly constrained as the fluids precipitating the various carbonate cements are not necessarily marine. Crossflowing waters were likely from mixed sources; meteoric and compactional with some seawater or connate and basinal influences.

The Carbon-Oxygen covariant plot (figure 9) show the Carbon and Oxygen isotope ratios of carbonate cements in Well 1 in the2 groups, as defined earlier. This suggests that carbonate cement was likely formed from two types of pore water. There are some processes which may influence contribution of the lighter δ^{18}Ovalues, for example: carbonate cements were formed in meteoric incursions (Hudson, 1978; Prosser et al., 1993), or the cements were recrystallized at higher temperature (Morad and Eshete, 1990) or they were related to oxidation of the organic matter in sulphate-reduction conditions (Morad and Eshete, 1990). Based on my observations, comparing isotope values with thin section observations and SEM, I can see organic matter in those samples that are mudstone dominated. Therefore, I think carbonate cement in the mudstone is relatively early (less negative oxygen compared to Group 2) and related to redox interfaces with organic matter and sulphate reduction conditions as these waters moved through and ultimately escaped from the compacting shales.

Sediments in study area after the initial extension (and compactional fluid escape) are caught upin inversion tectonics, with left lateral strike-slip in the first phase, right lateral strike-slip in the second phase and thermo-subsidence typifying the end of the inversion phase. Therefore the fluid system in the sediment pile in the study area was strongly affected by both extensional and compressional stresses. The stable isotopic signature of the carbonate cements may related more to structural evolution rather than to depositional environment. A possible structure-related model of fluid evolution for lower Miocene sediments can be seen figure 14. Fluids moving in sediments are first driven by early compaction as fluid in the compacting shale was drained into the sand. Calcite C-O values in group 1 probably indicate cements formed at this time, via bacterial and archaeal metabolisms, perhaps dominated by methanogenesis (hence the more positive carbon values). During the subsequent compressional stage, warmer fluids were driven up and out of the deeper part of the succession and precipitated as the pervasive warmer late-stage carbonate cements in the sandstone aquifers in a plot field that now defines group two. It is highly likely that these same fluids were capable of carrying hydrocarbons and may also have driven some of the secondary porosity features hosted in the siliciclastic fabrics, as seen in wells 1, 2. Thus, fluid in the sands of well 1 have experienced two types of fluid crossflow; one from early shale compaction, where much of the carbonate cementation occur at redox spots in adjacent mudstones, and then a subsequent fluid that was focused into sandstone aquifers, precipitating carbonate cements with a more thermally-evolved signature (Group 2).

confirm a hypothesis of a relationship between tectonic events and sources of carbonate

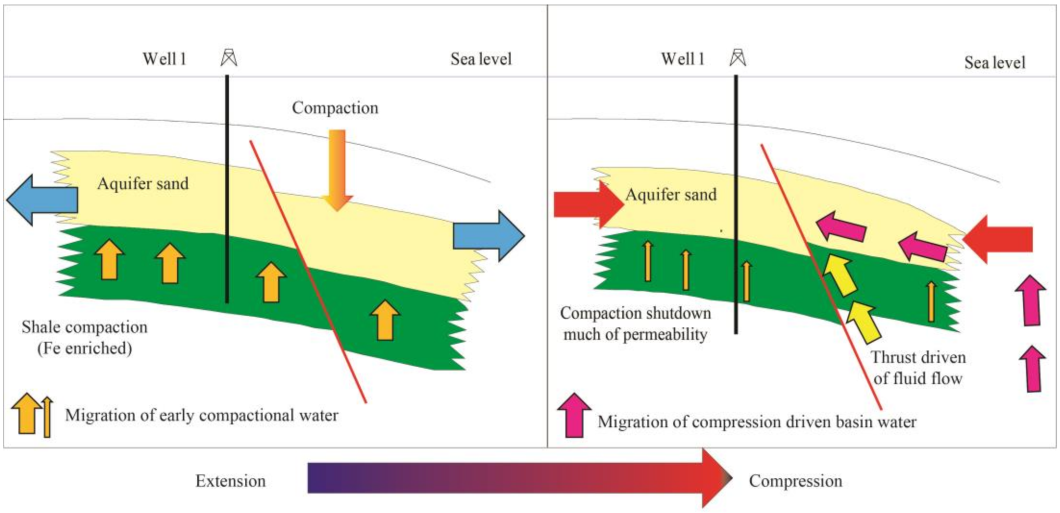


Figure 14. Schematic fluid flow evolution in sediment in cored interval, Lower Miocene, well 1

Summary

Potential sandstone reservoir in the cored intervals in well 1 and well 2 were deposited in tidal channels. Reservoir quality is variable because high volume of mud and clay, which reflects a combination of deposition with tidal influences, high compaction due a high content of mud and labiles and rapid subsidence, followed by tectonic inversion, and a resultant high volume of carbonate cement.

Stable isotope results indicate calcite cement was formed both during early diagenesis and ongoing burial diagenesis. Stable isotopic signatures also provide fluid flow information. The fluids likely come from two sources: the first driven by migration of compactional waters and then the second driven by subsequent compressional flow that also drove the formation of inversion features.

Recommendation

1) Expand the application of stable isotope techniques to all cored wells with carbonate cements in the current study area. This approach will better define fluid evolution and perhaps allow us to understand and predict zones of porosity occlusion in a more regional framework.

2) Expand the application of isotopic analysis to other regions and fields in Vietnam to cement. This should be supplemented by fluid inclusion studies of the various cements.

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