A new perspective of the forming of calcareous layers above oil sand through the analysis of paleo-environment

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Abstract. Lithology and architecture of alluvial fans can become too complicated, influenced by rapid deposition of sediments near the provenance. The paleo-environment of oil sand can be often better observed through drilling cores and well loggings, rather than outcrops and seismic attributes, for the outcrops are usually covered by modern deposition and not allowed to be exploited while seismic waves often cannot detect layers too shallow above 200m. Reservoirs are mostly buried at extremely shallow depths from 0 to 500m. Oil is mostly found within a mixture of oil sand and carbonates. The calcareous layer, which is steady and widespread with a thickness of 0.5~2m, is found above the oil sand layer in all wells. The limestone above oil sand layer shows a significant change of facies and paleo-environment. Only sandstone with abundant oil can easily form the carbonates above oil sand, which means the calcareous content is a result of temperature and pressure change at the edge of oil layers. As a vivid description, the calcareous content is similar to the environment of calculus, which also underwent a change of pressure & temperature with a concentration of CO2. These phenomena can also be observed in micro-level or use chemical reactions to explain why both calculus and calcareous can form after they underwent temperature and pressure change accompanied with oil.

1. Introduction

Oil reservoirs associated with carbonate rocks have always been the research focus nationwide. As for most oil sand regions, carbonate rock usually only accounts for the minor amount, but they show great significance to serve as a more perfect trap for all oil reservoirs. Relative positions of different layers in space is often called architectures [1], which refers to a more specific sedimentary facies and their space distribution. Oil reservoir heterogeneous is greatly influenced by architectures [2], and all following research about its origin is based on it. As for the study area, the architecture is generally within humid fan facies. A humid fan is usually on a gradual slope covering a large area. It is considered that this kind of fans has its own sedimentary system and characteristics, which is quite...
different from common fans for it accumulate much more quickly in a small region. Fan root is at the top of the oil sand layer and slowly broadened. Gravel dams form some connected bodies in sheet flow. In mid-fan subfacies, sheet flow becomes braided flow. Sheet-flood fine grains usually deposit in channels. As for the edges of fans, grain size is most fine with slowest fluid. The sediment surrounds the fan in circular belts with inter-layers [3] or vertical barriers. From root to edge in a fan, flow units change with the sequence of channel, braided, and cross flow.

CH is a large oilfield discovered in 2008. It is located at the slope of the fault zone, between Junggar Basin and Hoxtolgay Basin [4] (Figure 1). Reservoirs in the oilfield are mostly buried at extremely shallow depths, from 0 to 500m. Thus the high oil viscosity is formed naturally [5], but not through man-made ways like water-drive and gradual oil production [6]. Due to the complicated distribution of sand bodies, the geological conditions need to be investigated. They are near-provenance humid fans with rapid change of thickness and depth from north HQ-1 Block to its south in southwestern Hala’ alta Mountain. More than ten cored wells were drilled in this region, targeting oil sand and shallow oil layers. The study aims at analyzing these wells to find out favorable facies and regions to exploit.

2. Change of facies at outcrop

Layers of Jurassic group are buried within shallow depths. Outcrops can be easily seen in many areas, mainly from the depth of 500m to outcrop. However, they cannot be simply studied with traditional geochemical methods. In addition to conventional well log correlation, outcrops can also be correlated and described. As shown in Figure 2a and 2b, the boundaries at outcrops are found. J1b is divided into three parts, which are all normal graded. Based on its outcrop and logging data, the lower part of J1b1 layer is mainly humid fans, the mid-fan is braided river, and the top is river delta. J1b2 is mainly shallow lake, with a transition of braided river at the top and bottom. J1b3 is covered by delta sedimentation again, thus forms braided river delta, and shallow lake. The calcareous layers we focus on are widespread at outcrops.

![Figure 1. Position of the Oil Play in Zhunggar basin, Xinjiang.](image)
Figure 2. Facies boundaries observed at the outcrop of Hashan Mountain Region; braided-flow mid-fan and mudstone edge-fan boundary (left), sandstone mid-fan and gravel root-fan boundary (right); photos taken in 2014, Xinjiang.

3. Architectural unit
Not only at outcrops, but also inside drilling cores, the architectures of humid fans can be identifiable with better permeability and conductivity in shallow oil layers. Then these data can be classified into 6 sedimentary sub-facies, i.e. channel and sheet-flood sub-facies at fan root, braided belts and sheet flood at mid-fan, run-off belts and widespread swamps at fan edge. As shown in Figure 3, on the basis of grain sizes shown by SP, GR, resistivity logs, or drilling cores, sheet flood sub-facies can then be further divided into fine sediments and sand bodies in the 4th architecture grade. Among them, sheet flows and braided channels can be then further subdivided. Though most micro-facies need no further specific subdivision, a few micro-facies can then be identified if the layer is thick enough to be further divided. For instance, the channel sheet facies can be divided into channels and gravel dams; braided river channels can be further divided into channels and sand dams. Generally, these alluvial fans in Hashan Mountain can accumulate fast near their provenances and usually appear multi-phased.

![Figure 3. Typical architecture units of fans in Chunhui Oilfield.](image-url)
4. Lithofacies of shallow oil reservoirs

Lithofacies is the rock combination that reflects specific sedimentary environment. In the study area, it is divided into several types. Based on regional sedimentary background, through observation of cores and outcrops, it is found that Jurassic fan deposition with water regressive ancient background in humid climate. The major provenance is from northeast. Other two provenances exist when there is adequate material supply. The fans become smaller upward due to less supply, in which it is the thickest layer. Secondary high is gravels and silts with oil. Test results show this kind of oil layers counts for 46% of oil sand layers[7-8]. Oil layers are usually accompanied with calcareous aggregation. There is an area that calcareous form later than silicate, but mostly, calcareous can form earlier than siliceous aggregation, as shown in Figure 4, which is the same around the world. The calcareous part formed before silicate is well-known as carbonate buried hills[9].

![Figure 4](image)

**Figure 4.** Test results of siliceous and calcareous aggregation (Bamonte and Gambarova, 2016; Khaliq and Kudur, 2011).

During the carbonate-silicate cycle, the silicate weathering is expected to undergo following process:

\[2 \text{CO}_2 + \text{H}_2\text{O} + \text{CaSiO}_3 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- + \text{SiO}_2\]

Then there is a process called carbonate precipitation.

\[\text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}\]

The oil can provide sufficient CO\(_2\) during the long geological history. That is how the calcareous layers are formed above the oil layer with many changes in lithology and sub-facies. Some other specific changes and outcomes can both be detected in drilling cores and logging curves in following descriptions.

5. General architecture model

5.1. Architecture of subfacies

The layer with highest oil saturation is studied more specifically in the aspect of reservoir architectures. As shown in Figure 5, from top to bottom, the mid-fan is expanded by braided rivers. Root-fan and braided channels in middle fan are expanded. Sheet-flood in middle fan moves southward. The lithology of mid-fan braided channels is fine sandstone and pebbled sandstone, which are favorable to reserve hydrocarbons in drilling cores, because 14 cored wells in this region show that they are the best rock types to trap oil.
As for the oil conditions of different subfacies, root-fans are better and most cores are oil-saturated. The second best is mid-fan and cores are mostly oil-immersed or oil-flecked. The oil conditions of most fan edges are oil-flecked or fluorescent.

Figure 5. Reservoir architecture model of shallow fans in Chunhui Oilfield (Le et al, 2018, modified).

5.2. Architecture of oil reservoirs

Mid-fan is some connected sand bodies consist of many braided flow channels, which are braided-flow deposition. The channel changes from broad bands gradually into narrow strips. These channels are partially separated by mud barriers. Most barriers are horizontally continuous.

Edge-fan reservoir units are sand bodies in channels or overflows. The seal layers are always fine-grained sediments. Channels become narrower in the edge, which are separated by mud. The reservoir units are in the shape of river strips.

Generally, as shown in Figure 6, the root-fan channels are at the top of a fan and broadened downward. After flood leaves the channel, gravel dams quickly form a connected gravel body in sheet flow. In the mid-fan, sheet flow becomes braided flow, thus braided channels form. Among the channels, sheet-flood fine grains deposit. In the fan edge, grain size is the most fine with lowest fluid energy. The sediment surrounds the fan in a circular belt. From fan root to fan edge, the flow forms are found to be in the sequence of channel flow, sheet flow, braided flow, and cross flow.

In the inner part of a fan root, gravel accumulates quickly into a connected body. Buried hills are on the side of a fan root. Channel flow gradually changes into sheet flow. Sand bodies are in the sheet stacks vertically. There are some barriers in some regions, such as fine-grain sediments in sheet flow. In the gravel-sand bodies, barriers are mostly unstable with fine-grained sediments.

Humid-fan is large-scaled and widely distributed due to its gradual slope. In a wet and warm environment, the sediment is mostly limestone with coals. Sand channels move less frequently, so sand dams are occasionally formed. Most fan facies consist of multiple positive cycles, and it is overall retrograding deposition.

As for the characteristics of logging response, sand channels generally have the characteristics of low electrical resistance, with high SP and GR. On the contrast, gravel dams usually have high R25, low SP and low GR. Sheet flood have medium logging response between them. Middle fan have relatively low resistance, and its SP and resistance display two positive cycles. The fan edge has the high resistance, low SP and low GR due to cementation. In Figure 7, the complex reservoir architecture profile can thus be concluded based on logging.
6. Conclusion

The paleo-environments of alluvial fans are the mixture of oil sand and carbonates. The calcareous layers, with a thickness of only 0.5~2m, were formed above the oil sand in almost all cored wells. This is not simply a change of facies, but rather a supplement to the theory that the limestone above oil sand shows a change of temp&pressure, facies and paleo-environment with a concentration of oil or CO₂. The calcareous layers are formed during the carbonate-silicate cycle, which are common in both East and West China. The forming of calcareous content is also similar to that of the calculus, which underwent a significant change of environment with oil and CO₂. This phenomenon gives a vivid explanation and comparison to why both calculus and calcareous can be formed more easily under changing pressure and temperature accompanied with oil.
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References
[1] Khalid Al-Ramadan, Ardiansyah Koeshidayatullah, Dave Cantrell, et al 2019 Impact of basin architecture on diagenesis and dolomitization in a fault-bounded carbonate platform: outcrop analogue of a pre-salt carbonate reservoir, Red Sea rift, NW Saudi Arabia Petroleum Geoscience 26 448-461
[2] G Yildiz, İO Yilmaz 2020 Reservoir heterogeneity of orдовician sandstone reservoir (Bedinan Formation, SE Turkey): Diagenetic and sedimentological approaches Marine and Petroleum Geology 118 1-25
[3] Wu Y., Xu S., Wu Z., et al 2017 Heating Oil Sand and Effects on the Interlayers Petroleum Science and Technology 35 9-15
[4] Wu Z., Xu S.Y., Liu X.L., et al 2016 Quantitative lithology identification technology of complex sand-conglomerate bodies 28 114-118,126
[5] Wu Z., Zha Ming, Gao Changhai, et al 2016 Characteristics and Densification Mechanisms of Shallow Oil in Chengbei Terrace Area Petroleum Science and Technology 34 123-129
[6] Wu Z., Zhai L., Wu Y., et al 2019 Favorable Effects on the Densification of Water-driven Oil and Its Residual Oil Enrichment Geological Journal of China Universities 25 93-98
[7] Bamonte and Gambarova 2016 High-Temperature Behavior of SCC in Compression: Comparative Study on Recent Experimental Campaigns Journal of Materials in Civil Engineering 28 04015141
[8] W. Khaliq, V. R. Kodur 2011 Thermal and mechanical properties of fiber reinforced high performance self-consolidating concrete at elevated temperatures Cement and Concrete Research 41 1112-1122
[9] X. Lan, H. Liu, X. Lü, et al 2020 Geological and geochemical implications of the complicated carbonate diagenetic process in the Lower Ordovician buried hills of the eastern Tazhong Low Rise, NW China, using Well M1 as an example Carbonates and Evaporites 35 1-15