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NMR Logging Application for Complicated Reservoir Formation Evaluation of M Oil Field in Middle East

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Abstract: *There are many carbonate oil fields laying-out in and around Middle-East region, which are the hot productive spot with the huge crude oil reserves. However, these reservoirs also face the challenges of complex lithology, diverse pore configuration, and strong formation heterogeneity to affect the field operation performance. Take Iraq oil companies as an example, before joint operations with overseas oil companies from 2010, only the conventional logging technologies were mainly applied on site, but which can not provide enough support for the development of oil field. After 2010, the advanced logging technologies, such as Nuclear Magnetic Resonance (NMR) logging which are superior to conventional logging in some aspects, are introduced in order to support oil fields development effectively, and which actually makes good performance to direct the identification of non-pay zones, hidden effective zones and micro-fracture distributions. Technical analysis is based on M Oil Field in Iraq to share the experiences of NMR logging application from the view of reservoir engineering in the complicated carbonate reservoir.*

Keywords: *Oil Field in Middle East, Complicated Carbonate Reservoir, NMR Logging, Reservoir Stimulation, Well Logging*

1. Introduction

Carbonate oil reservoirs are commonly distributed in the middle-east region, and the oil reserves are very huge[1-4]. It is of great significance for the sustainable development of world oil resources. The M oil field in Middle East is a large carbonate type, and it is located in the south of Zagros tectonic belts. Due to the sedimentary environment is located in slight slope of carbonate platform, its formation lithology is very complicated and it is composed of gypsum, salt rock, dolostone, limestone, sandstone and so on. Furthermore, the pore configurations are of much diversity, so the formation are extremely heterogeneous. The capability of conventional logging is limited for application in these reservoirs, and it is hard to evaluate formation accurately using only conventional logging technologies. However, NMR logging, electric imaging logging and other logging technologies do have special advantages in evaluation of these complicated carbonate formations, and they are helpful in finding more pay zones and improving the development results of oil fields[5-8].

2. Reservoir Characteristics

M oil field is a multi-layer large oil field mainly composed of Tertiary Asmari reservoir and Cretaceous Mishrif reservoir. The oil formation is located at depth 2800-4300m, low permeable, with middle and low porosity, mainly composed of heavy oil with average gravity 22 API, including H_2S and CO_2. As for Asmari reservoir, its sedimentary environment is marked by restricted platform facies and can be divided into three oil groups including A, B, and C from top to bottom. Furthermore, A oil group is mainly composed of dolostone, and it is also composed of small amount of thin-layer or crumby gypsum. The reservoir space of dolostone is mainly interparticle dissolution pore and intercrystalline dissolution pore (see Figure 1), and there are also coelomopore, moldic pore, and micro pore in matrix. Some pores are filling by the gypsum and high-angle micro fracture is quite common, so the formation is of fracture-pore type [9-11]. B oil group in Asmari reservoir is mainly composed of limestone, there are also dolostone and sandstone in some part, and the pore space are mainly corrosive

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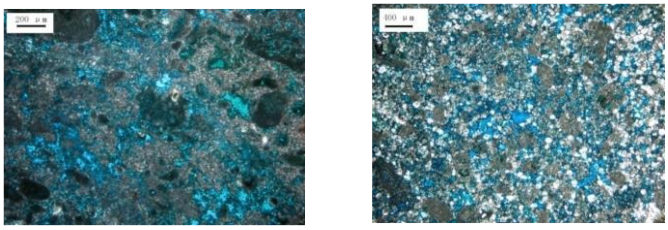
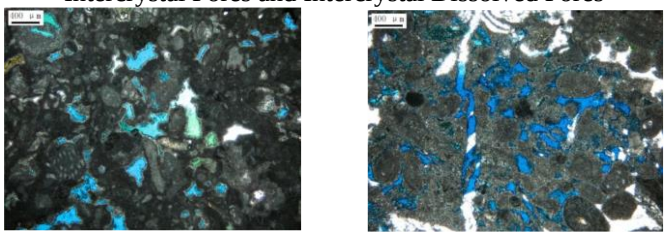
pore and matrix pore(see Figure 2), there are also a slight amount of micro fractures.



2971m 3017m

Intercrystal Pores and Intercrystal Dissolved Pores



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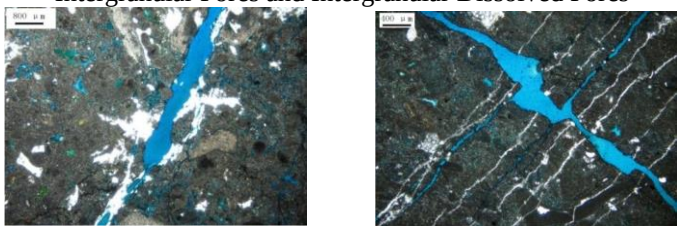
Intergranular Pores and Intergranular Dissolved Pores



2791.31m 2985.26m

Micro-fractrures of Asmari Reservoir

2976 m 2986m 2982m

Matrix Micropores, Coelompores and Modic Pores

Figure 1: Pores types and configuration of upper zones of Asmari Reservoir.

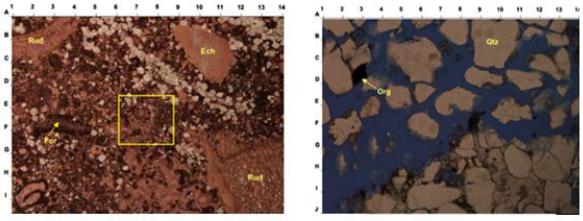


Figure 2: Pores types and configuration of lower zones of Asmari Reservoir

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3. Reservoir Formation Evaluation by NMR logging

This oil field is firstly developed at 1970's, and nearly 70 wells are drilled during the first more than 30 years of development. During that period, only conventional well logging data is available because other well logging techniques are not applied in this oil field at that time. As for carbonate oil reservoir in this oil field, it is influenced by both complicated lithology and pore configuration; some good potential formations are easily to be missed and undeveloped due to the incorrect use and judgment of conventional well logging data. There are mainly two problems in the application of only conventional well logging data [12-16]: some reservoir formations showed good porosity and permeability in conventional well logging but they only produced none or little oil in reality (see layer 1-4 in Figure 3 below); some reservoir formations showed low porosity and permeability in conventional well logging but they have high oil production in reality (see layer 5 in Figure 3 below). The oversea oil company took over this oil field since 2011, and introduced the advanced well logging techniques such as NMR logging, electric imaging logging and so on. Therefore, the reservoir evaluation level is largely improved and the result of oil field development becomes much better.

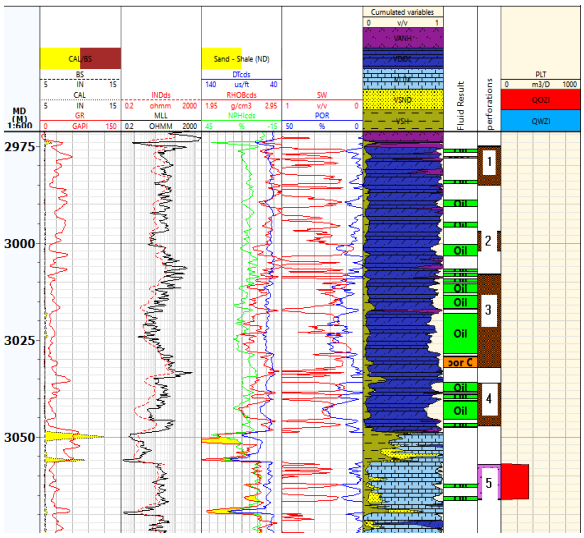

Figure 3: Conventional logging results in complicated carbonate formation evaluation.

3.1. Identification of Non-productive Formation

Actually, improving the evaluation accuracy of formation property and fluid production index is very important for the long-term steady production of oil fields. It can have positive influence for pay interval design in well completion, for pump sizing and power capacity design of Electric Submersible Pump artificial lift, and so on. The following is an authentic example in M oil field development by introduction of NMR well logging technique.

For the formation of dolostone and limestone, due to its specific sedimentary and diagenetic process, it usually has good porosity but poor connectivity between reservoir pores. Conventional well logging techniques can identify the existence of pores but cannot help to judge the flow ability of pore fluids. Figure 4 and table 1 showed the data of some well in M oil field(see the fifth column from the left in Figure 4, the region with purple color showed the porosity decrease interpreted by NMR well logging compared with conventional well logging). For the zone marked with NO.1, it should be superior zone by regional and geological analysis, and its interpreted porosity is also very good by conventional well logging analysis. However, its hydrocarbon show is poor in mud logging during the well drilling process. If analyzing by NMR well logging, NO.1 zone has low movable fluid porosity and low permeability, and NO.2 zone has little difference between conventional well logging interpretation and NMR well logging interpretation.

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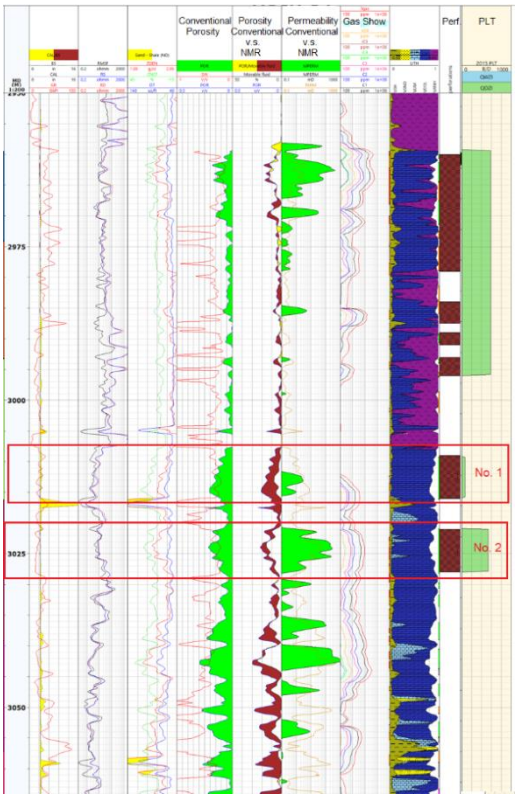

Figure 4: Comparison between conventional logging and NMR logging of Well A-34.

After perforation operation, production profile testing shows that NO.1 zone has poor fluid production and it can produce fluid only at 10m^3 per day. This result is inconsistent with the interpretation of conventional well logging results. However, if compared with the interpretation results of NMR well logging, the production profile testing result is consistent, which shows that the static data has good consistency with dynamic production data. This circumstance also happens in some other wells of M oil field.

Table 1: Data comparison among conventional, NMR logging and production profile test of Well A-34.

Layer	Porosity interpreted by conventional well logging	Movable fluid porosity interpreted by NMR well logging	Permeability interpreted by NMR well logging	Production profile testing results
	%	%	mD	m^3/d
No 1	20.5	7.5	3	10
No 2	21	16	300	85

3.2. Identification of Hidden Productive Formation

Fail of identification for productive good formation, especially for oil zones at the bottom of reservoir, will increase the difficulty for finding potential in the later stage of oil field development, because the distribution of oil and water will become extremely complex when the water cut is high. NMR well logging can solve this problem easily, because it can do good identification for some hidden productive formation which cannot be found by interpretation of conventional well logging.

In the interpretation of conventional well logging, oil zone with high GR value is usually identified as shale, because the interpreted porosity is low after shale correction. Actually, some zones may be good production zones with high gamma activity, if only conventional well logging is used, these hidden (which means cannot be identified by conventional well logging) zones will be missed. For example, based on the interpretation theory of conventional well logging, pay zone marked with NO.1 in Figure 5(the fifth column and the sixth column are the interpretation results of porosity and permeability respectively by both conventional well logging and NMR well logging, the region marked with red color are the difference between them) is not an effective zone due to its thickness is not enough. NMR well logging shows that this interval has good porosity and permeability, and it should be a rich oil zone in this well. In mud logging during the drilling process, gas show value is high which also supports the interpretation results of NMR well logging. In well completion, NO.1 zone is

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perforated, and the actual production perspective is very good. Based on the operation experiences of M oil field, the productivity of this well can highly exceed the interpretation results of conventional well logging. Furthermore, with reference to the production profile testing results of adjacent well, this zone is confirmed as a very productive pay zone.

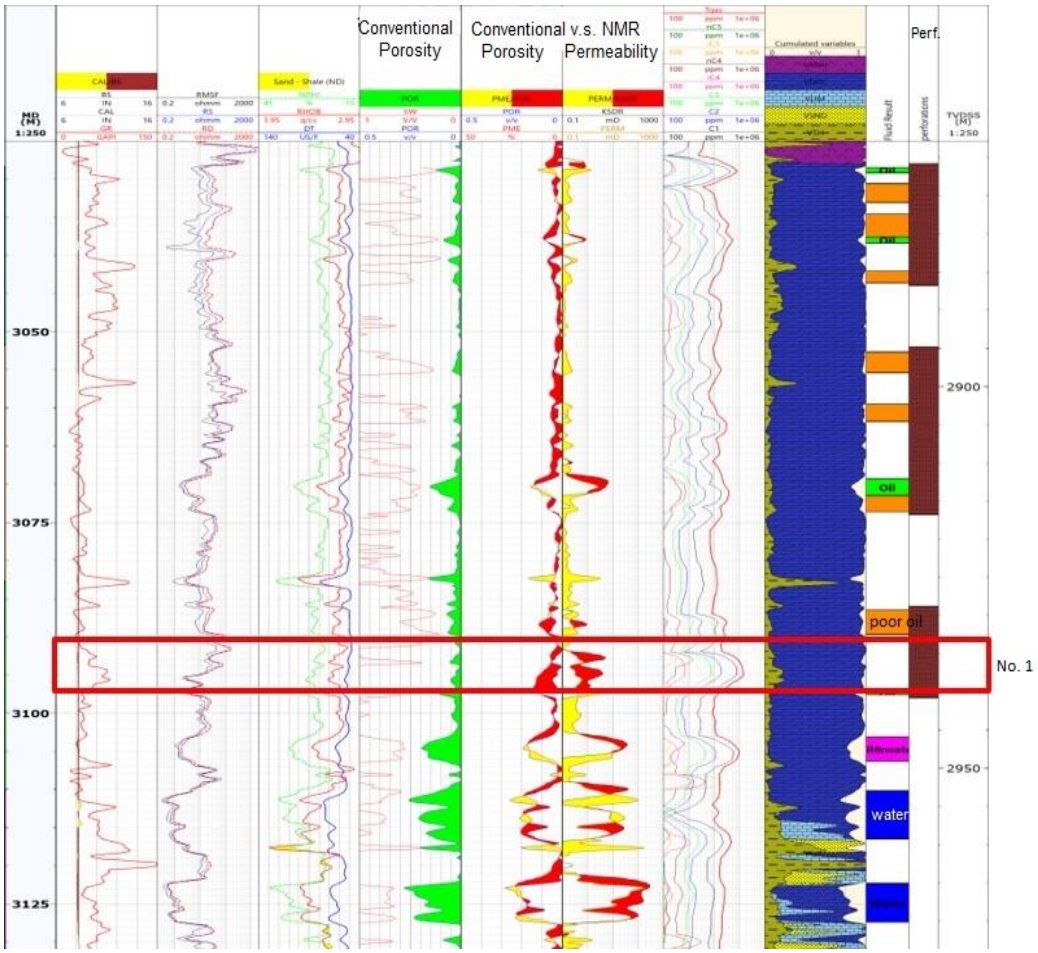

Figure 5: Comparison between conventional logging and NMR logging of Well A-19.

3.3. Identification of Micro-fracture Formation

Based on the development experiences of carbonate oil reservoir, micro fracture is commonly distributed due to the squeezing in diagenetic process, due to the weathering-erosion effects and so on. In the zones with limestone, micro fracture is also distributed occasionally with low density. The distribution details of micro fracture are usually hard to conclude, either in forecasting before well drilling or evaluation after well drilling. However, the zone with much micro fracture distribution is zone of high productivity, and it is one of the most important target zones in oil field development.

Conventional well logging techniques are not sensitive to identify zones with good micro fracture distribution. In practice of oil field development, there are usually three ways for identification of micro fracture. Firstly, based on the adjacent well data before drilling, to forecast whether there is potential great micro fracture distribution. Secondly, during the drilling process, to forecast the existence of micro fracture through the leakage amount of mud. Thirdly, to forecast the distribution details through advanced well logging techniques such as NMR well logging and so on, thus well completion plans can be optimized accordingly. Furthermore, these three ways can also be verified during following production periods through reservoir dynamic analysis, reservoir potential discovering and so on. Take the demonstration in Figure 6 as an example, the formation within the red frame line is of low permeability through interpretation of conventional well logging, and it is not perforated in the initial stage. NMR well logging demonstrated that this zone has relatively good permeability. In combination with development experiences, this zone is judged as a zone with good micro fracture distribution. Actually, in the following production practice, this zone is also perforated due to the well is hardly natural flowing, and this well turned into a highly productive flowing well

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with high wellhead tubing pressure as well from then on.

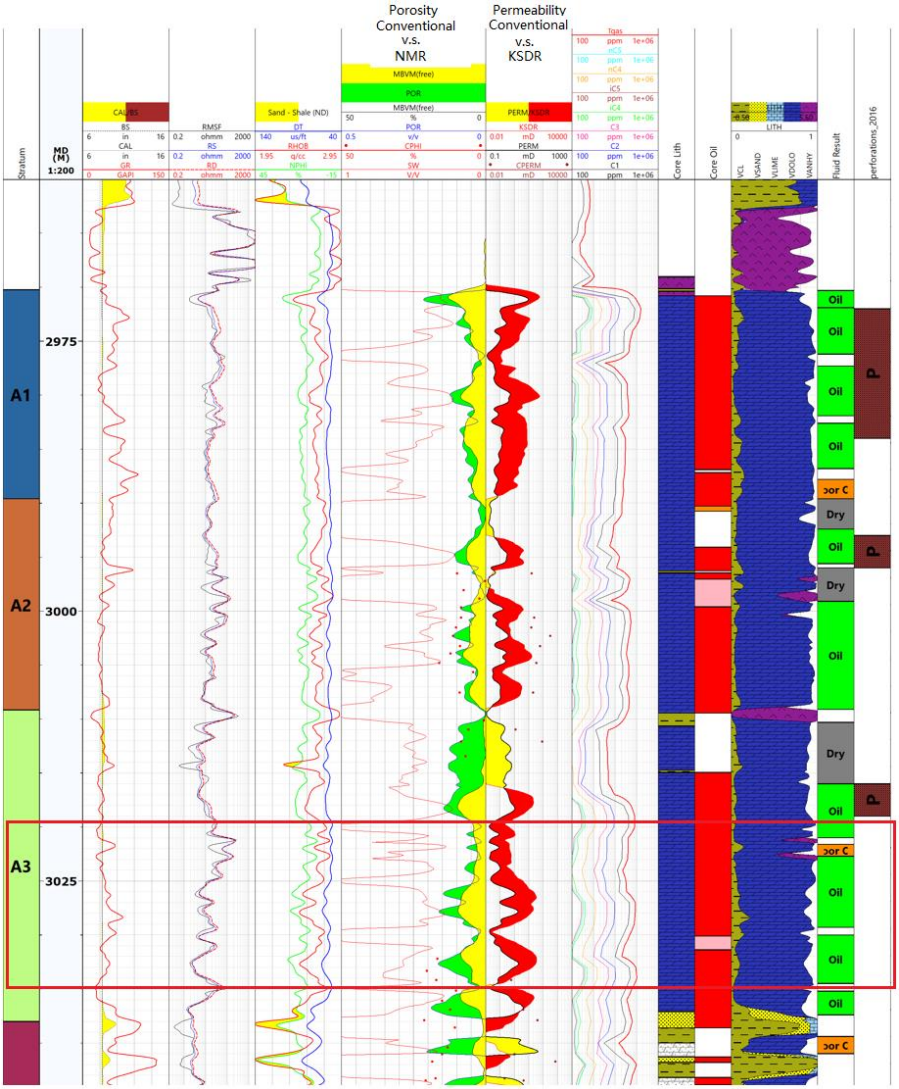

Figure 6: Micro-fracture response for conventional logging and NMR logging in Well A-24.

4. Field Application Results of NMR Logging

Actually, as for the development of complicated carbonate oil reservoir, NMR and other advanced well logging techniques play a very important technical guidance role in identification of productive oil zone, movable fluid porosity judgment, and detailed characterization of formation permeability and so on.

Take the producer in Figure 6 as an example, oil group A and oil group B are drainage together at the initial stage of development, and fluid production profile shows that the oil group A contributes little for the total production. However, at the bottom of oil group A in this well, the permeability interpreted by NMR logging is obviously larger than that of conventional well logging. At the same time, the movable fluid porosity interpreted by NMR logging is also higher which shows that there is likely great micro fracture distribution in this zone. In year 2018, some supplementary perforation measures are implemented at oil group A interval. Before these measures, the oil pressure at wellhead and the production rate are both very low, and the natural flowing nearly stopped. After the measures of perforation, the oil production increased 104m^3 per day, and the oil pressure at wellhead increased from 1.8MPa to 3.7MPa. As demonstrated in Figure 7, the oil production is greatly improved and the flowing production period is promptly and effectively prolonged. This achievement also intensified the knowledge of technologist for the geological characteristics in this region, which contribute valuable reference to infilled well location selection and geological design of drilling in following oil field development stages.

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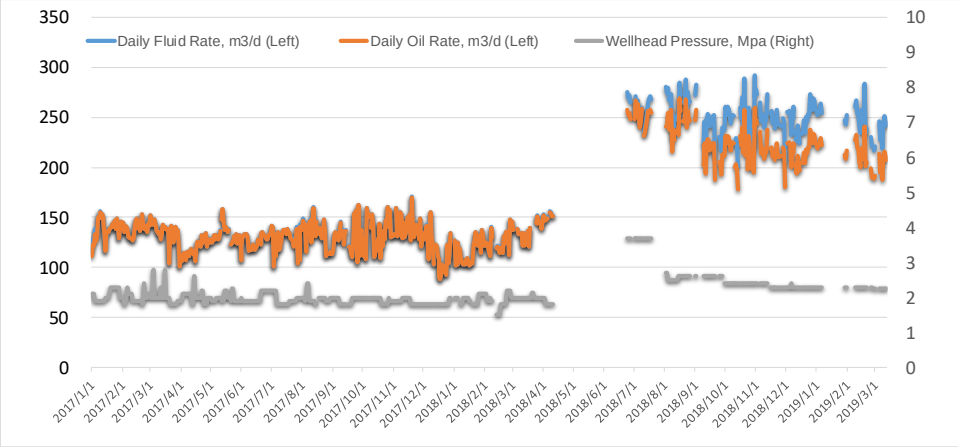

Figure 7: Reservoir stimulation application of Well A-24 with micro fracture identification.

Similarly, either in high productive zone identification and production zone design during the new well completion process, or in the residual oil finding process during the production of old well, NMR well logging both has its unique technological advantage. In recent years, through the advanced logging data in newly drilled wells, combined with geological and production data in adjacent wells, lots of work is launched to find the residual oil. The oil production rate is increased greatly by 50,000 barrels per day due to the supplementary perforation measures only since the year 2016 to 2018, therefore, the production of whole oil field is rapidly increased with relatively low cost.

5. Conclusions

1) For formation with complicated lithology, pore configuration and high heterogeneity in M oil field, NMR logging and other advanced well logging techniques can help to provide more detailed reservoir characterization, which play a unique advantage in oil field development.

2) Based on the actual data and cases recognized from M oil field, the inconsistency between reservoir property in conventional well logging and production performances is interpreted professionally, which is helpful for knowledge enlargement to the regional geological reservoir.

3) Especially for complicated carbonate oil reservoir with much micro fracture distribution, in addition to conventional well logging, it is better to apply for NMR logging, electric imaging logging and other advanced well logging techniques in oil field development process. In this way, the potential of old wells can be more easily found, and the micro-fracture distribution in adjacent regions can be forecast. Therefore, the adjacent new wells with highly productive zones can be much better located.

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