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An interpretative approach for gas zone identification and lithology discrimination using derivatives of λ∗ρ and μ∗ρ attributes.

Shubhabrata Samantaray* and Pankaj Gupta.
Reliance Industries Ltd, Petroleum Business (E&P)
e-mail: *shubhabrata.samantaray@zmail.ril.com**, e-mail:*P.Gupta@zmail.ril*.com

Summary

The "λ"term, or incompressibility, is sensitive to pore fluid, whereas the "μ" term, or rigidity, is sensitive to the rock matrix as described in the original paper by Goodway et al(1997) that gives the physical interpretation of the lambda, λ and mu (μ) attributes. As per the theory, it is impossible to de-couple the effects of density from" λ" and "μ"when extracting this information from seismic data. It is therefore beneficial to cross-plot λ∗ρ vs μ∗ρ to minimize the effects of density. Michael Batzle et al (2001) suggested that for Sandstones and Clay rich Sandstones (similar to NEC Setup) the difference of Bulk and Shear modulus (K –μ) may give better result in hydrocarbon identification. In addition to this, Russell et al. (2003) has proposed an attribute IP^2*-C**IS^2 *with C being a function of* $(Vp/Vs)^2$ *where Vp and Vs are the P and S wave velocities.*

This paper describes a case study from North East Coast of India including six wells which encountered gas at Tertiary stratigraphic levels and reservoir of different quality. The study shows use of the above attributes to successfully separate the gas bearing zones from the surrounding medium. Here λ∗ρ – μ∗ρ attribute is equivalent to IP^2*-C**IS^2 *with C being a constant function of* $(Vp/Vs)^2$*. P wave, S wave and Density log from six drilled wells have been used in this analysis with a sample interval of 0.5 m. Lithology logs have been used to discriminate the clay stone from Sandstone. The gas sands, water sands and clay stones have been characterized successfully by the above mentioned attributes and λ∗ρ – μ∗ρ and λ/μ index has been prepared. Results from Prestack Simultaneous Inversion have been included to illustrate the utility of this attribute identifying the gas reservoirs over some other common seismic attributes.*

Introduction

Amplitude is a surface related property whereas Variation in Amplitude can be a reservoir property. This is sometimes the reason for failure of DHI driven exploration campaigns. Mere amplitude contrast may be ambiguous and may be out of several other factors other than hydrocarbon.Prestack Seismic Inversion which is related to Variation of amplitude with offset or angle can generate attributes which are related to bulk and shear modulus whose derivatives in some cases can be an excellent gas zone indicators.

Before a seismic attribute is created for a whole 3D seismic volume as a gas reservoir indicator it is necessary to check whether its sensitivity is significant to resolve the gas zones at the target location from the well logs. Fundamentally if the gas zones are separable in the well derived attribute then only it can be expected to work in seismic volume. If core samples or Sonic, Shear and density logs are available then a Hydrocarbon Separability Index can be generated which will decide the worth of Prestack Seismic Inversion results.

METHODOLOGY

Goodway et al. (1997) proposed a new approach to *AVO inversion* based on the *Lamé parameters* λ and μ, and *density* ρ, or *Lambda-Mu-Rho (LMR)*. The theory is as follows:

$$V_P = \sqrt{\frac{\lambda + 2\mu}{\rho}} \text{ and } V_S = \sqrt{\frac{\mu}{\rho}}$$

$$\text{therefore} : I_S^2 = (\rho V_S)^2 = \mu\rho$$

$$\text{and} : I_P^2 = (\rho V_P)^2 = (\lambda + 2\mu)\rho$$

$$\text{so} : \lambda\rho = I_P^2 - 2 I_S^2$$

Since Lamda-Rho is sensitive to fluid and Mu-Rho is sensitive to Lithology hence crossploting these two attributes has become a powerful technique to detect gas and lithology discrimination.

Batzle et al. (2001) suggest calculation of (K-μ) where K is the Bulk Modulus and μ is the shear modulus that acts as Optimal Hydrocarbon Indicator but it requires laboratory measurements of core samples. A tutorial by *Russell et al (2003)* presents the attribute $I_P{}^2 - C\ I_S{}^2$ where C being a function of $(Vp/VS)^2$. Interestingly

- $\lambda = K - 2/3 * \mu$
- or
- $\lambda\rho - \mu\rho = (K - 5/3 * \mu) * \rho = I_P{}^2 - 3 * I_S{}^2$

This above equation is considered in the current case-study.

GEOLOGICAL BACKGROUND

The area under study lies on the shelf and continental slope offshore of the East-Coast of India, in North East Coast basin. The North East Coast basin is a passive margin basin which evolved along the NE-SW rifted continental margin of Eastern India when India separated from Antarctica during Jurassic-Early Cretaceous time.A basin wide transgression during late Paleocene–middle Eocene time caused the deposition of thick shale – limestone units in the block. Oligocene sediments are seen to wedge out against the Eocene shelf edge. Oligocene and Eocene are around 5.5 to 6 km deep in the northern part of the block (proved HC area).Middle to Lower Miocene sediments seems to have deposited in deep water-basinal part. Canyon cuts and deltaic progradational clastic deposits originated due to coastal river systems like Ganges-Brahmaputra, Subarnarekha, Baitarani, Brahmani, and Mahanadi dominate Upper Miocene and Pliocene sequences. Canyon cuts are steep sided, sharp, narrow to wide and at times 1.5 to 2km deep. These canyons have created localized deep water depositional condition within the shelf. Channels bringing in sands within these canyons can be mapped clearly from 3Dseismic data using attributes like coherency and spectral analysis. The course of these channels is governed by the course of the canyons. The delta deposits are manifested as parallel laminations with progradational sequences in high-resolution seismic sections. It is seen that canyon cuts in eastern and western part of the 3D area has caused the formation of a central stable area of the delta sediments. The gas discoveries in Well-A, Well-B, Well-C and Well-D wells are found in this stable part. Well-E and Well-F have encountered canyon fills in the shallower part and deltaic and progressively deepwater clastics in the deeper part.

CASE STUDY:

WELL-A

Two gas bearing sand/silt reservoirs have been encountered in well-A which are categorized as Gassand1 and Gassand2 .GasSand1 is a silty sandstone reservoir and GasSand2 is a sandstone reservoir. Here both the gas sands have been considered for gas reservoir characterization.

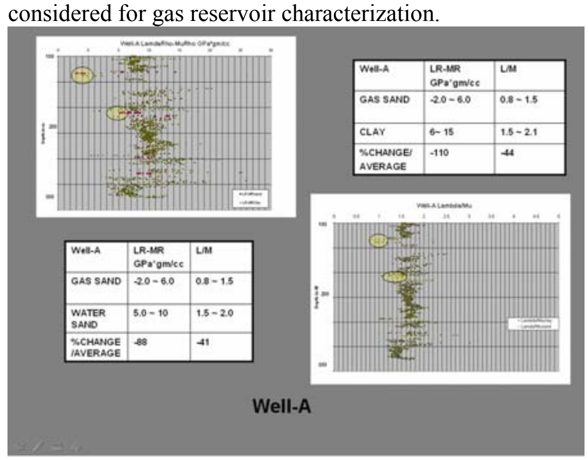

Fig.1 Gas Reservoir characterization and Lithology discrimination by λρ – μρ and λ/μ for Well-A. Depths values are in fictitious units.

WELL-B

Three gas bearing silt/sand reservoirs have been encountered in the deviated Well-B .These gas reservoirs named GasSand1, GasSand2 and GasSand3 have been encountered in the Upper Miocene level.

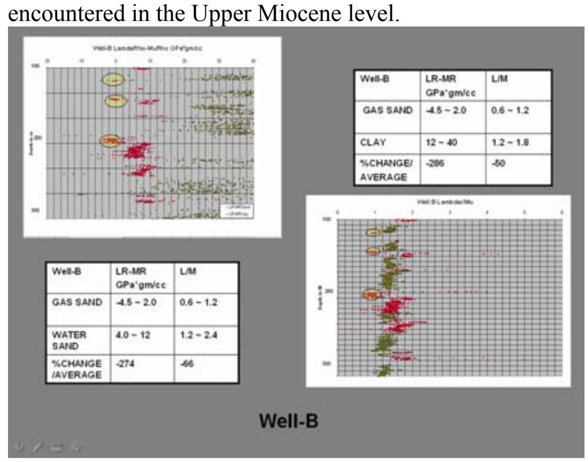

Fig.2 Gas Reservoir characterization and Lithology. discrimination by λρ – μρ and λ/μ for Well-B. Depths values are in fictitious units.

WELL-C

Two gas bearing silt/Sand reservoirs are there in Well-C out of which the deeper gas reservoir gas been considered for characterization**.**

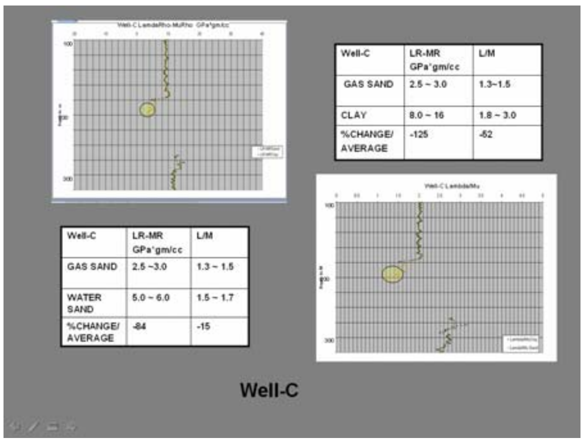

Fig.3 Gas Reservoir characterization and Lithology discrimination by $\lambda\rho - \mu\rho$ and λ/μ for Well-C. Depths values are in fictitious units.

WELL-D

Four Gas Reservoirs of various thicknesses have encountered in Well-D but only top and bottom gas reservoirs could be resolved in the current analysis.

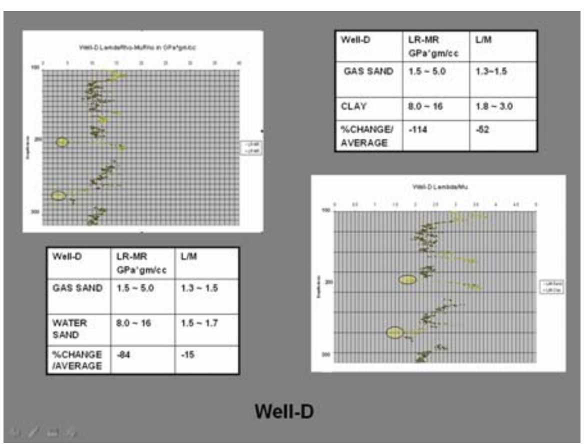

Fig.4 Gas Reservoir characterization and Lithology discrimination by $\lambda\rho - \mu\rho$ and λ/μ for Well-D. Depths values are in fictitious units.

Well-E

Well-E encountered three gas bearing sand/silt reservoirs .One of the gas zone is not seismically visible though it is resolved using the above attributes.

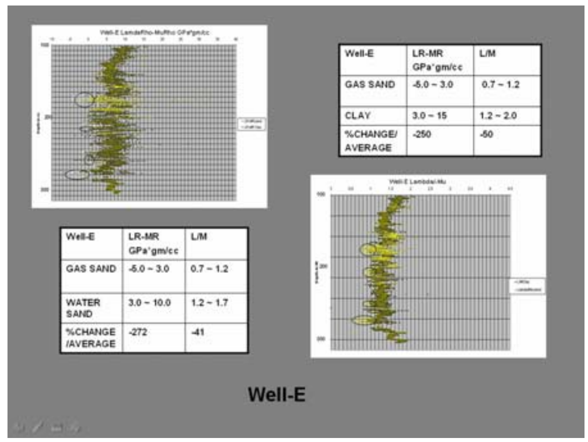

Fig5 Gas Reservoir characterization and Lithology discrimination by $\lambda\rho - \mu\rho$ and λ/μ for Well-E. Depths values are in fictitious units.

WELL-F

Well-F which is the deepest of all six wells encountered two gas reservoirs, one was a shallower sandstone reservoir and another one is a silty reservoir deeper level.

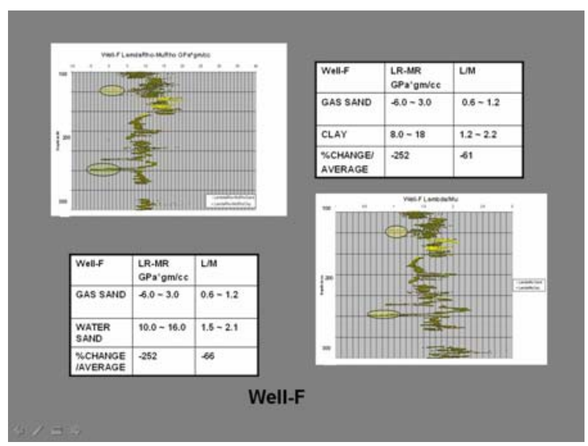

Fig6 Gas Reservoir characterization and Lithology discrimination by $\lambda\rho - \mu\rho$ and λ/μ for Well-F. Depths values are in fictitious units.

	λρ −μρ Gas Sand GPa*gm/c	λρ −μρ Water Sand GPa*gm/c	λρ −μρ Clay GPa*gm/c	λ/μ Gas Sand	λ/μ Water Sand	λ/μ Clay
WellA	-2.0~6.0	5.0~10.0	6.0~15.0	0.8~1.5	1.5~2.0	1.5~2.1
WellB	-4.5~2.0	4.0~12.0	12.0~40.0	0.6~1.2	1.2~2.4	1.2~1.8
WellC	2.5~3.0	5.0~6.0	8.0~16.0	1.3~1.5	1.5~1.7	1.8~3.0
WellD	1.5~5.0	8.0~16.0	8.0~16.0	1.3~1.5	1.5~1.7	1.8~3.0
WellE	-5.0~3.0	3.0~10.0	3.0~15.0	0.7~1.2	1.2~1.7	1.2~2.0
WellF	-6.0~3.0	10.0~16.0	8.0~16.0	0.6~1.2	1.5~2.1	1.2~2.2

Table: 1 λρ −μρ and λ/μ attributes Ranges for Gas Sand, Water Sand and Clay stone for six wells

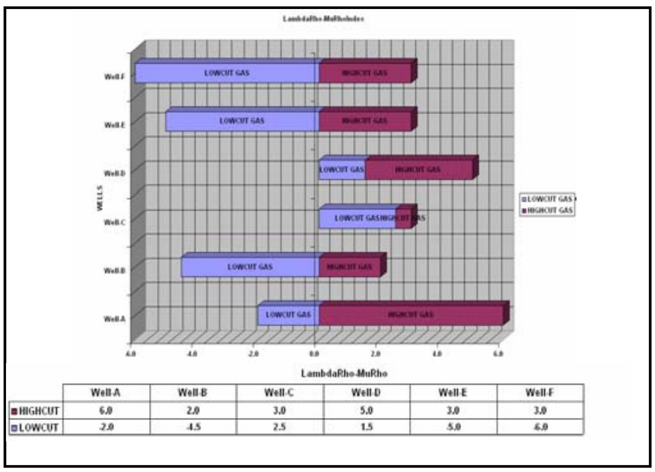

Fig.7 LambdaRho-MuRho Gas Separability Index for six wells.

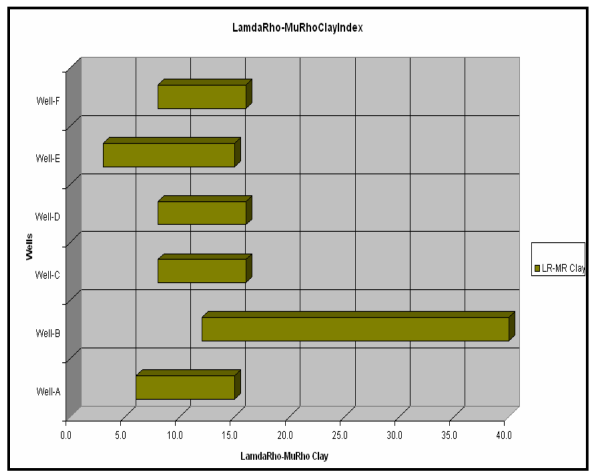

Fig.8 LambdaRho-MuRho Clay Index for six wells.

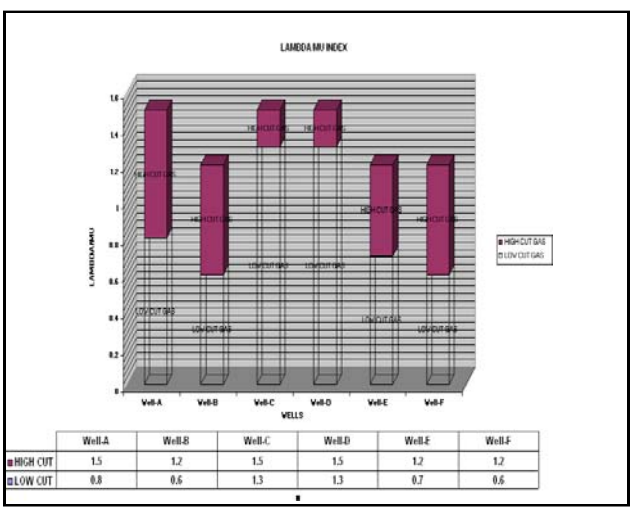

Fig.9 Lambda/Mu Gas Separability Index for Six wells.

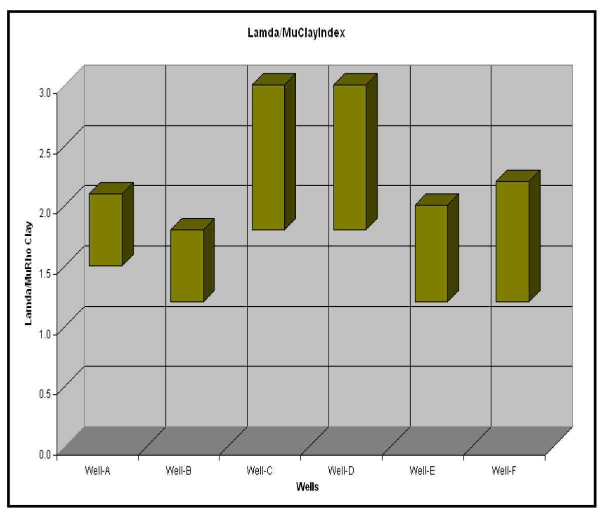

Fig.10 Lambda/Mu Clay Index for Six wells.

Petrophysical Characteristics of Main Gas Zones

Petrophysical Characteristics of Main Gas Zones	lr -mr Gas Sand GPa*gm/cc	l/m Gas Sand	Avg Phi		Avg Sg
Well-A	-2.0~6.0	0.8~1.5	GS2	0.22	0.70
			GS1	0.22	0.60
Well-B	-4.5~2.0	0.6~1.2	GS3	0.24	0.54
			GS2	0.21	0.55
			GS1	0.21	0.58
Well-C	2.5~3.0	1.3~1.5	GS1	0.19	0.40
Well-D	1.5~5.0	1.3~1.5	GS4	0.15	0.81
			GS3	0.15	0.60
			GS2	0.22	0.72
			GS1	0.16	0.82
Well-E	-5.0~3.0	0.7~1.2	GS3	0.10	0.17
			GS2	0.10	0.21
			GS1	0.11	0.16
Well-F	-6.0~3.0	0.6~1.2	GS2	0.11	0.53
			GS1	0.10	0.16

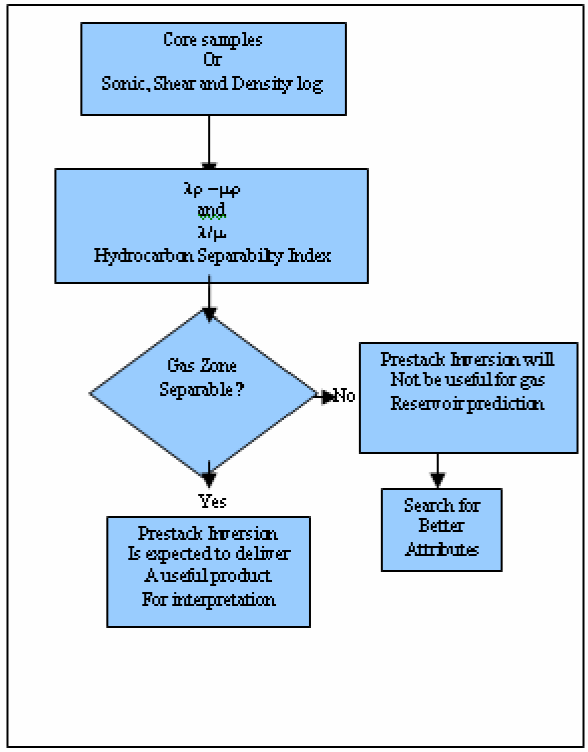

Fig 11 Flow chart for Interpretative Hydrocarbon Separability Index Calculation and its use in Prestack Inversion Process.

PRESTACK SIMULTANEOUS INVERSION RESULTS

A Simultaneous Inversion on a test area including Well-A, Well-B and Well-D has been carried out and derivatives of LamdaRho and MuRho are available for further interpretation.

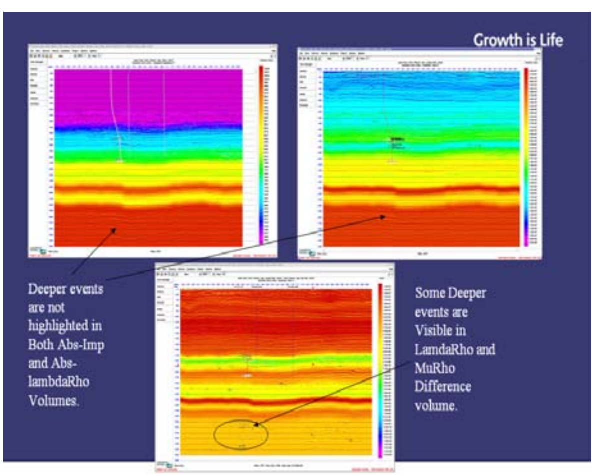

Fig.12 The deeper section in the LamdaRho-MuRho volume shows some anomalous features which were not seen in P-Impedance and LamdaRho volumes

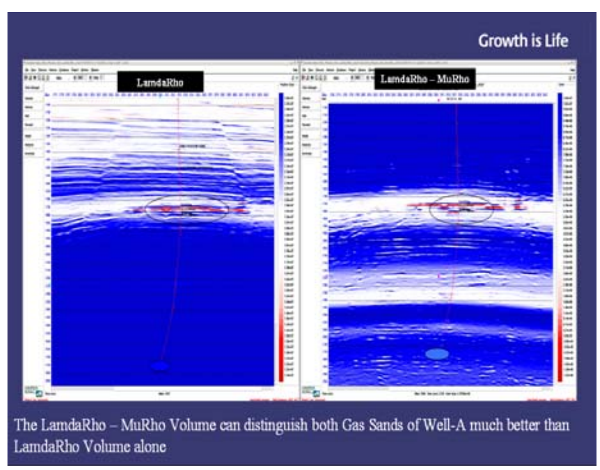

Fig.13 The Prestack Simultaneous Inversion results comprising the WellA, WellB and WellD have been used to compute a volume of LamdaRho-MuRho and the attribute was significant in comparison to Lamda-Rho Volume in identifying the gas reservoirs.

INTERPRETATION

In this paper Lamda-Rho–MuRho and Lambda/Mu attribute has been considered for Gas reservoir characterization and lithology discrimination. The observation is that the attribute is variable from well to well and has a wide variation in its range. The wide variation of the attribute range is due to varying stratigraphic levels of gas reservoirs that have been encountered in different depth ranges. An index has been created for each attribute which will be useful prior to doing any Prestack simultaneous inversion whether to expect the gas reservoirs to be highlighted in the Inverted Volume but calibration to be done with in similar stratigraphic level. .The gas zones are separable from the background but there are exceptional cases of siltstone reservoirs with gas and good quality non hydrocarbon bearing reservoirs. A limitation here in this analysis would be the inability to link this sensitivity of the attribute with gas saturation since this attribute may not distinguish fizz water reservoirs. This may be taken care in improved attributes derived from further analysis and case studies.

CONCLUSION

This study led to following conclusions

1. The above attributes can differentiate Gas Zones from surrounding but cannot quantify the uncertainty associated with Reservoir quality and Dissolved or Fizz water.
2. These attributes will be more predictable and reliable with availability of sufficient core samples as it will give accurate dry Bulk and Shear Modulus values.
3. Understanding the relationship of above attributes with non-DHI gas reservoirs or transparent sections is still a tough task.

Lastly, if Well logs can differentiate the gas zones with these attributes only then Prestack Seismic Inversion is expected to be a useful product for interpretation. After all if well logs can't separate gas zones then Seismic attributes may not be able to do that.

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