

# Identification of Neogene mixed lacustrine carbonate in western Qaidam basin

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**Abstract** Compared with marine carbonate, lacustrine carbonate is limited in distribution globally; moreover, as an unconventional kind of carbonate, it cannot be evaluated and identified with conventional methods, so less attention has been paid and fewer studies have been made on it. However, according to exploration experiences all over the world, lacustrine carbonate can be an important source rock and reservoir rock in some cases. Qaidam basin, a large salt-water lake basin, had the lacustrine mixed deposition setting to form complex carbonate reservoirs. The recently found Neogene lacustrine algal limestone is an exploration target worthy of attention. The author has used drilling and well logging data to identify lacustrine algal limestone. The method is of great significance for the exploration and development of lacustrine carbonate in other areas.

**Keywords** Mixed sediment · Lacustrine carbonate · Algal limestone · Salt-water lake basin

## Introduction

Mixed deposition is a special deposition phenomenon, in which sediments formed by terrigenous clastics and carbonates (including allochemical grains, etc.) can be a set of rock combination, or a combination of rock layer systems (Guo et al. 2003). Consensus has not yet reached about the origins and classification of the mixed

sediments (Feng 1993; Sha et al. 2001; Ma and Liu 2003; Guo et al. 2003; Zhang et al. 2000). Zhang (2000); Wang (2001) believes diamictite is the result of mixing caused by sudden events, gradual changes at facies margin, in-place deposition, erosion and redeposition, and palaeokarst. Modern deposition produces this kind of mixed sediment too, which has some unique features (Zhao 2013a; Wang 2010).

The Neogene salt-water lake deposits in the Qaidam basin have typical features of mixed sedimentation (Ulmishek 1984); Dang and Zhao (2004). The sedimentary source of northwestern Qaidam basin Neogene reservoir mainly came from the Aryan Mountain (Zhao 2013b); Hanson et al. (2001), a far away source area. Developing in an arid-semiarid climate, the Neogene reservoir is a kind of mixed sediment rock formed by alternating chemical and mechanical actions during the phase of lake water turning from slightly brackish water to brackish water (Tuo et al. 1995). According to current understanding of mixed deposition, and studies of the Neogene in the western Qaidam basin, the author identified mixed carbonate by logging and imaging (Fig. 1) (Xu 2007; Yang 2010).

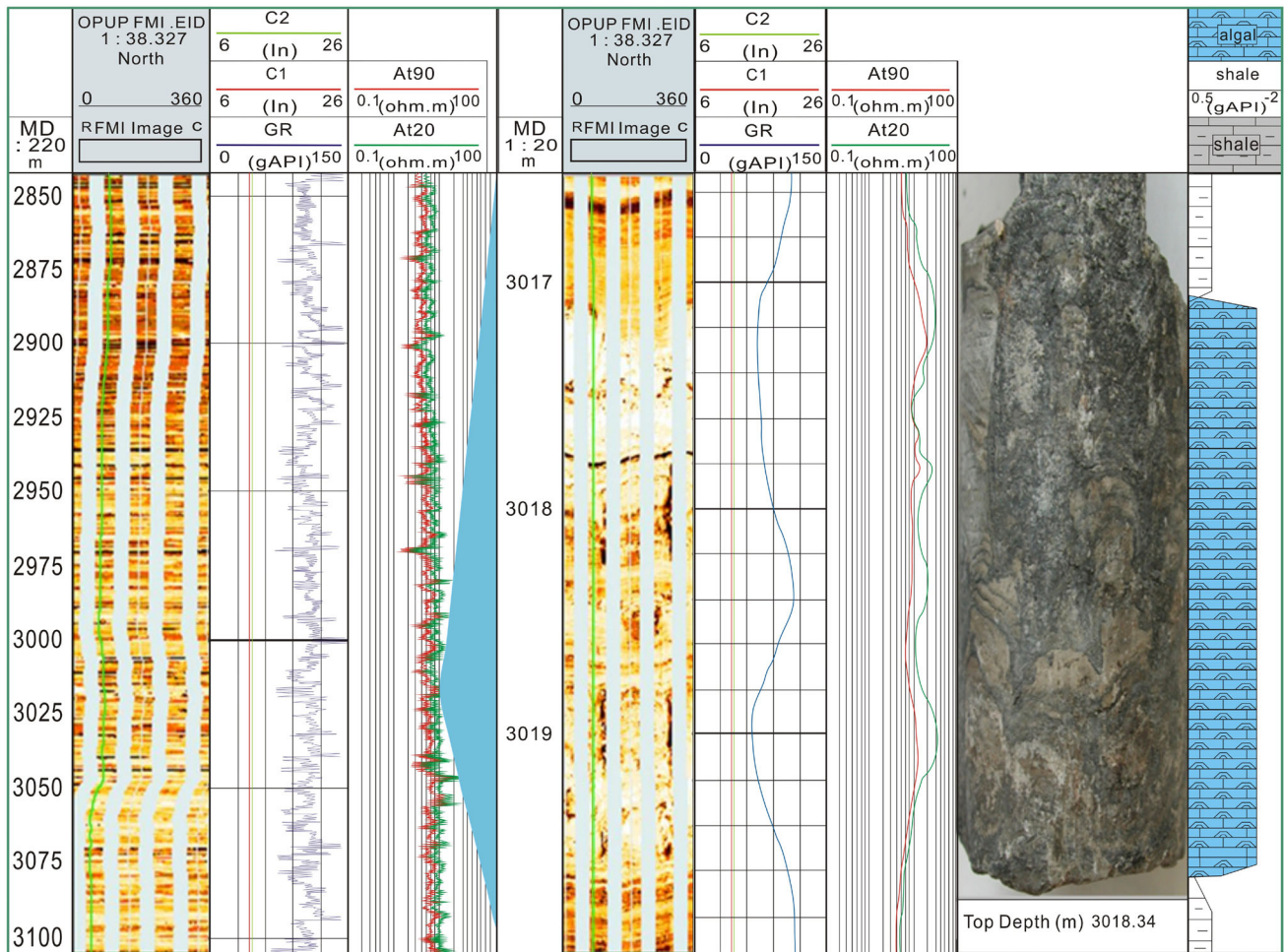
## Lacustrine carbonate of mixed deposits identification methods

Identification of lacustrine carbonate lithology with conventional log

Carbonate deposited in lacustrine mixed sedimentary environment is principally made up of sandstone, carbonate, mudstone the mixture of the three, in which reservoirs are dominated by algal limestone and sandstone (Fig. 2).

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**Fig. 1** FMI logging identification on lithology in western Qaidam basin

**Determination of rock composition with three porosity logging**

Based on lithology-physical model, the lithology components are determined. On the basis of three porosity logs, the contents of mudstone, carbonate and sandstone are calculated with petrophysical methods like material balance equation.

$$\begin{aligned}
 V_1 + V_2 + V_3 + \Phi_f &= 1 \\
 V_1 \times \rho_1 + V_2 \times \rho_2 + V_3 \times \rho_3 + \Phi_f \times \rho_f &= \rho_b \\
 V_1 \times CN_1 + V_2 \times CN_2 + V_3 \times CN_3 + \Phi_f \times CN_f &= CN_b \\
 V_1 \times T_1 + V_2 \times T_2 + V_3 \times T_3 + \Phi_f \times T_f &= T_b
 \end{aligned}$$

where  $V_1, V_2, V_3, \Phi_f$  are the framework volume of component one, component two, component three and pore fluid space in the rock;

$\rho_1, \rho_2, \rho_3, \rho_f$  are the framework density response of component one, component two, component three and pore fluid in the rock;

$CN_1, CN_2, CN_3, CN_f$  are neutron framework response of component one, component two, component three and pore fluid in the rock;

$T_1, T_2, T_3, T_f$  are acoustic framework curve of component one, component two, component three and pore fluid in the rock;

$\rho_b, CN_b, T_b$  are log response value of density, neutron, acoustic;

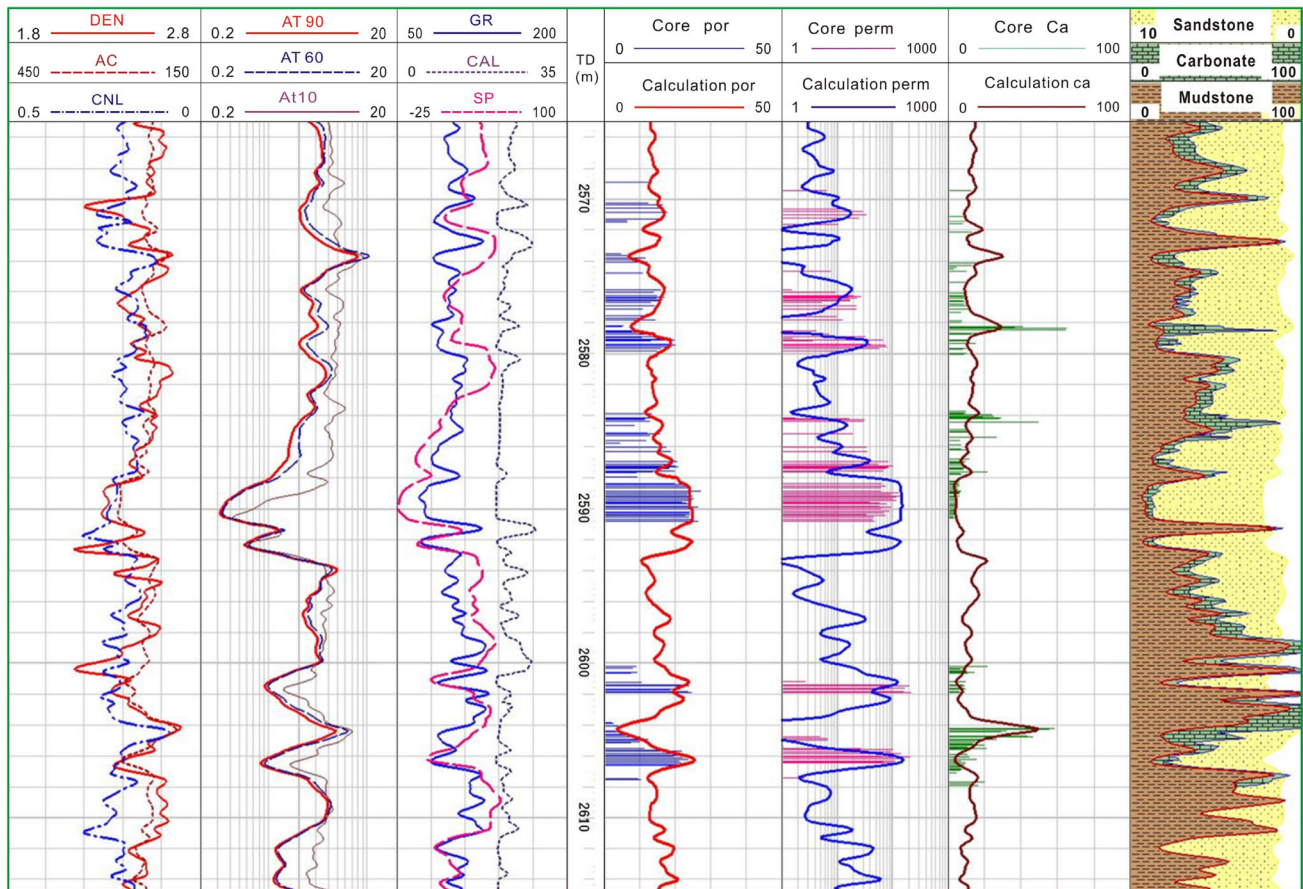
$\Phi_f$  is volumes of pore fluid;

1 is the total volume;

Component one is the contents of mudstone, component two is the contents of carbonate, component three is the contents of sandstone (Fig. 2).

**Calculation of clay content with core calibration logging**

In shale content calculation, shale content from core analysis and relative gamma ray are used to build a calibration model. When spectroscopy gamma ray is available, gamma



**Fig. 2** Logging identification on lithology in western Qaidam basin

ray value free of uranium is used in calculation. The calculation model is as follows:

$$V_{sh} = 68.832 \times \Delta_{GR}^2 + 5.3058 \times \Delta_{GR} + 5.466$$

where  $V_{sh}$ —shale content, %;  $\Delta_{GR}$ —relative value of gamma ray.

Calculation of carbonate content by using flush zone resistivity

Carbonate components usually exist in cement or cementation state, so cementation degree is closely related to carbonate content (Fig. 3).

$$R_{xo} = \frac{a \times b \times R_{mf}}{\phi^m \times S_{xo}^n} \approx \frac{C}{Q^m}$$

where  $C$ —wellbore environment,  $\phi$ —porosity data, obtained by acoustic logging,  $M$ —pore cementation exponent, affected by carbonate content, porous structure exponent,

$$m = f(R_{xo}).$$

For shallow lake sedimentary environment, the variation in cementation degree can be reflected by carbonate

content, and displayed on shallow lateral resistivity in the end, flushed zone resistivity can be obtained by core calibration logging, which will then be used to calculate carbonate content:

$$V_{ca} = f(R_{xo}, \phi) = f(R_{xo}, \Delta t).$$

Carbonate reservoir physical properties parameter determination

To reduce influence on porosity by shale, generally, use acoustic logging curve, porosity obtained by empirical formula:

$$\text{Por} = 0.131596 \times T - 21.6897$$

( $R = 0.838; N = 138$ )

where, Por logging calculating porosity (%) (Fig. 2).  $T$  acoustic logging value,  $R$  Relation coefficient,  $N$  Number of samples.

The calculating permeability use conventional way for the marl limestone, algal limestone empirical formula:

$$\text{Perm} = 77.625 \times \text{Pro}^{3.855} \times V_{sh}^{-0.929} \times 10^{(3.855 \times |1 - R_s/R_d|)}$$

where, Perm logging calculating permeability (Fig. 2). Por logging calculating porosity,  $V_{sh}$  clay content (%),  $R_s$  shallow resistivity,  $R_d$  deep resistivity.

Use Archie equation to obtain the oil saturation (Fig. 4),

$$S_w = \sqrt[n]{\frac{abR_w}{\phi^m R_t}}$$

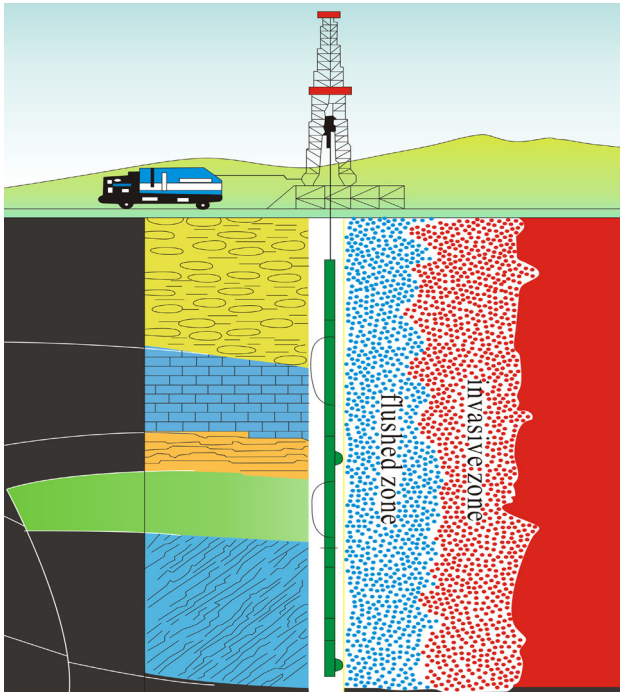
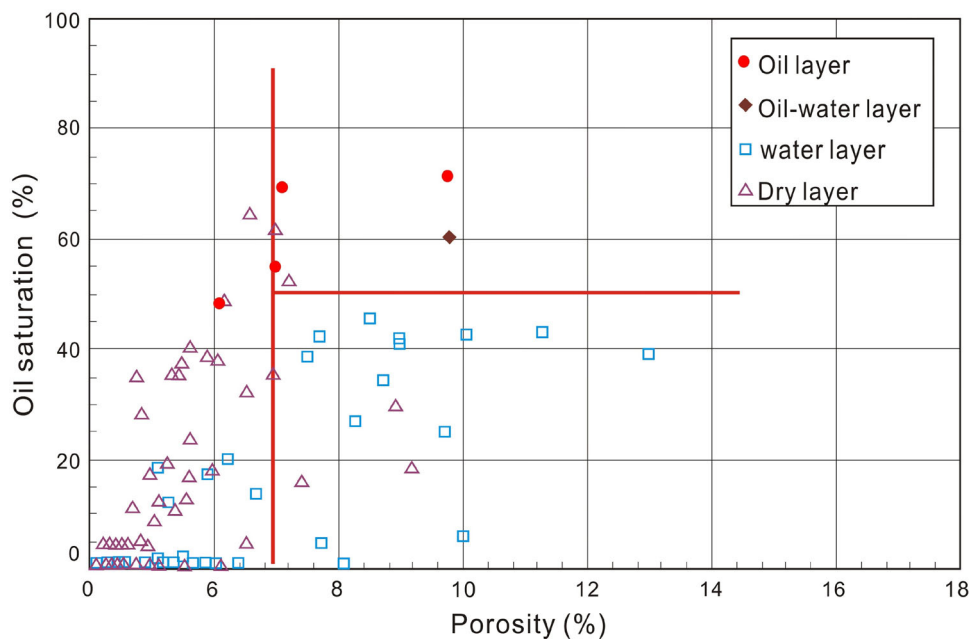


Fig. 3 Logging borehole analysis sectional view

Fig. 4 Porosity and oil saturation crossplot of logging interpretation in western Qaidam basin



Imaging identify lithology of lacustrine carbonate

Formation micro-resistivity imaging (FMI) plays a crucial role in the lithology identification of lacustrine carbonate and the understanding of special geologic phenomena.

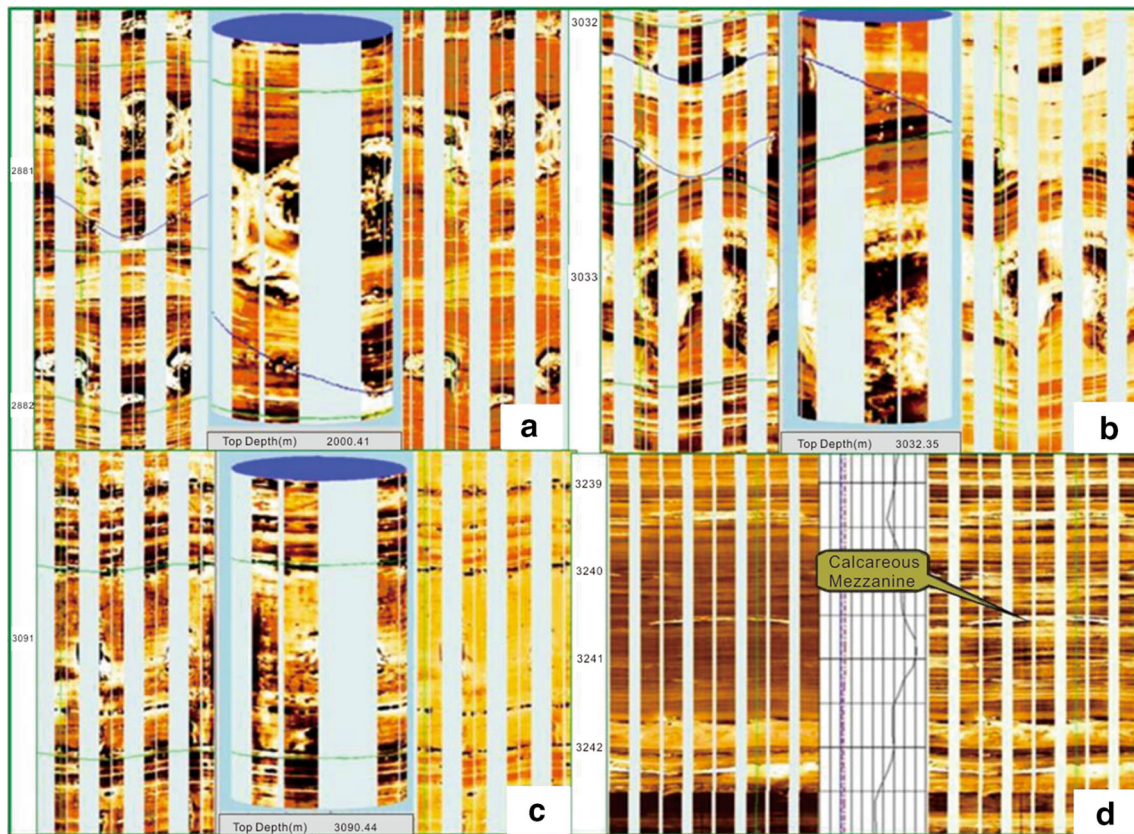
Carbonate in lacustrine mixed sediments is primarily the product of algal organism deposition and generally includes algal limestone mass (Fig. 5a), laminated algal limestone (Fig. 5b), and algal micritic limestone (Fig. 5c).

Mudstones in lacustrine sediments take on black parallel bands on FMI image. Calcareous mudstone is black mudstone with small amount of bright calcic. Marl is black and white bands on dynamic image, and marl differs from mudstone in that it is bright on a static image (Fig. 5d).

### Conclusions

Different from simple marine carbonate and continental sandstone, the lacustrine carbonates of mixed sediments in western Qaidam are complex and without pure carbonate, siltstone or mudstone.

Sedimentary modes involve mechanical deposition, chemical deposition and biological deposition. Carbonate, siltstone and mudstone principally form distinctive interbeddings, with small thickness (at millimeter scale in general), reflecting frequent alternation of depositional differentiation in vertical direction, short depositional cycle, and fast change, which may be related to the sea-



**Fig. 5** FMI significant characteristics of algal limestone reservoir. **a** Algal limestone mass and nuclear. **b** Laminated algal limestone. **c** Algal micritic limestone. **d** Calcareous mudstone

sonal climate changes in this area. The sediments are mainly carbonate and mudstone in an arid climate on the whole.

Mixed deposition in lake facies makes study of lacustrine carbonate more difficult; this study introduces the lacustrine carbonate identification method with logging and imaging, which has achieved good results in exploration.

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