Oil Generation as the Predominant Overpressure Mechanism in the Dongying Depression, Bohai Bay Basin, China*

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Abstract

The Dongying Depression in the Bohai Bay Basin is a young, prolific petroleum-producing basin in China. The mudstones and oil shales of the Eocene Shahejie Formation (Es3 and Es4) are the major source rocks dominated by Type I kerogens with TOC of up to 18.6%. The Es3 member is characterized by a relatively high sedimentation rate of up to 500 m/Ma. Widespread overpressures are present in Es3 and Es4 with pressure coefficients up to 1.99. Among the sonic, resistivity and density logs, only the sonic log displays an obvious response to the overpressure. Acoustic travel time vs. effective vertical stress analysis of more than 300 wells suggests that they are affected by the effective vertical stress with the travel time reducing with increasing vertical effective stress.

Disequilibrium compaction has been previously proposed as the sole cause for the high magnitude overpressures in the Eocene strata of the Dongying Depression citing the rapid deposition of the fine-grained sediments. However, we believe that the overpressures are caused by oil generation from the source rocks in the Es3 and Es4 intervals. The overpressured sediments display a normal compaction as evidenced from the overpressured mudstones exhibiting no anomalous low density, the apparent none-correlation between the mudstone densities and the effective vertical stress, and the overpressured reservoir sandstones showing no anomalous high matrix porosities or anomalous geothermal gradient. The depths to the top of the overpressure intervals range from 2000m to 3000m following closely with the depths of the associated source rocks. All the overpressured reservoirs and source rocks have a minimum temperature of approximately 87 °C. The overpressured source rocks generally have vitrinite reflectance (Ro) values of 0.6% or higher. Overpressures are not found in the strata within which the Ro values are < 0.5%. The overpressured Es3 and Es4

reservoirs are predominantly filled with oil or oil-bearing. Organic-rich source rocks with overpressures are capable of generating hydrocarbons and thus can maintain an abnormal high pressure. The precipitation of calcite in the calcareous mudstones observed in the source rocks may have caused significant reduction in porosity and permeability to form an effective pressure seal. The origin of overpressures in the reservoir rocks may have been generated by the overpressured fluid transmission from the source rocks through active faulting and fracturing.

Selected References

Jiang, F., Z. Jiang, and P. Xiongqi, 2008, Division and quantitative evaluation of petroleum accumulation system in Dongying Sag: Earth Science Journal of China University of Geoscience, v. 33/5, p. 651-660.

Jiang, Q., L. Zhiming, Z. Caiming, W. Qin, and T. Xiaohong, 2008, Characteristics of light hydrocarbons of source rocks in Dongying depression: Geological Science and Technology Information, v. 27/5, p. 87-91.

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2 CSIRO Earth Science and Resource Engineering

Presentation Outline

- Regional setting
- Overpressure in the Dongying Depression
  - Disequilibrium compaction vs oil generation
- Evidence supporting oil generation as the major cause for overpressure
  - Oil saturation of overpressured reservoirs
  - Spatial distribution of overpressured reservoirs
  - Reservoir sandstone porosity
  - Well log response in mudstones associated with overpressure
  - Present day oil generation capability and geothermal gradients
- Conclusions

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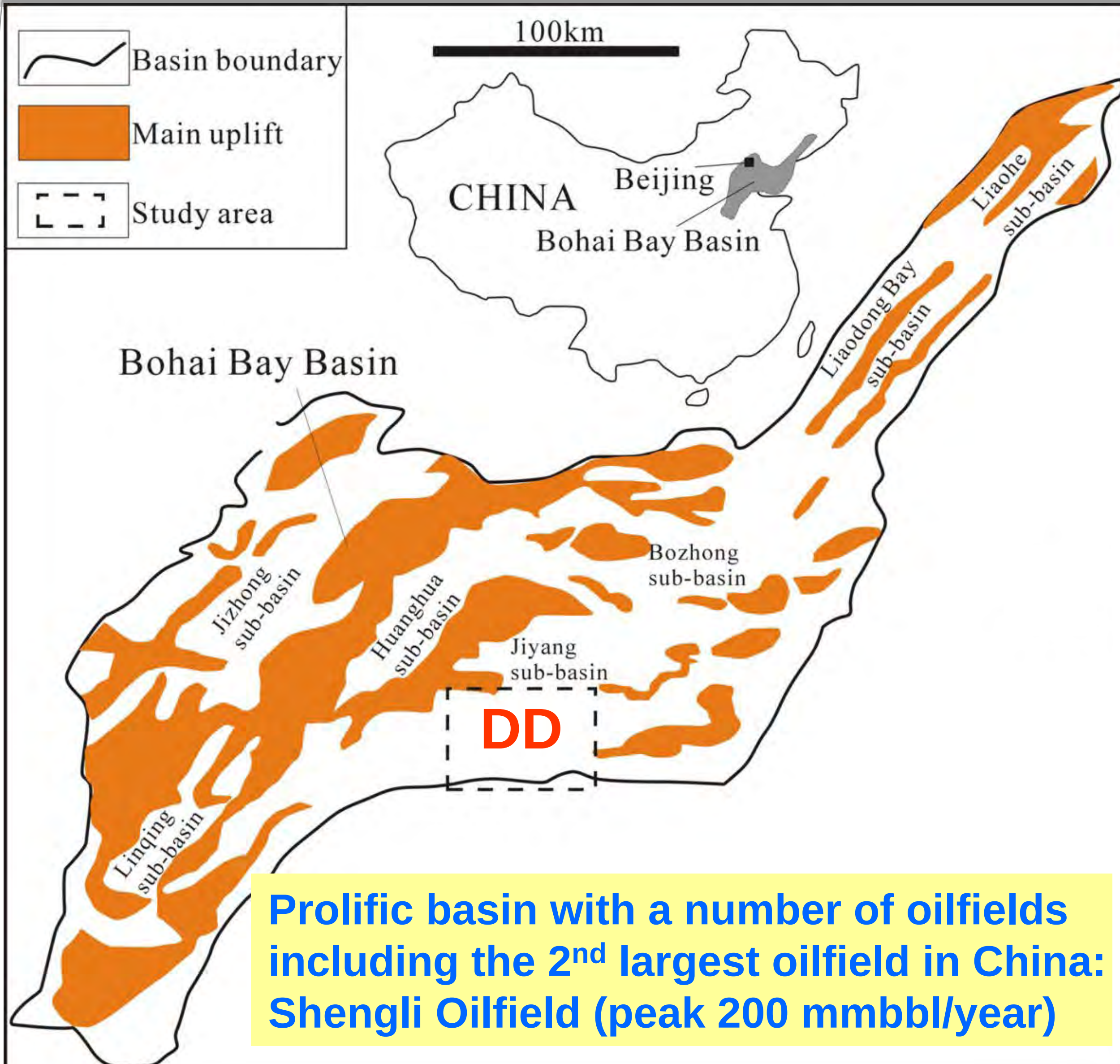
Regional Setting: Bohai Bay Basin



Prolific basin with a number of oilfields including the 2nd largest oilfield in China: Shengli Oilfield (peak 200 mmbbl/year)

200,000 km^2

Rift basin with a L Jurassic-E Tertiary basement

Syn-rift: 65-24.6 Ma (lacustrine deposition in grabens)

Post-rift 24.6 Ma – Present (fluvial deposition)

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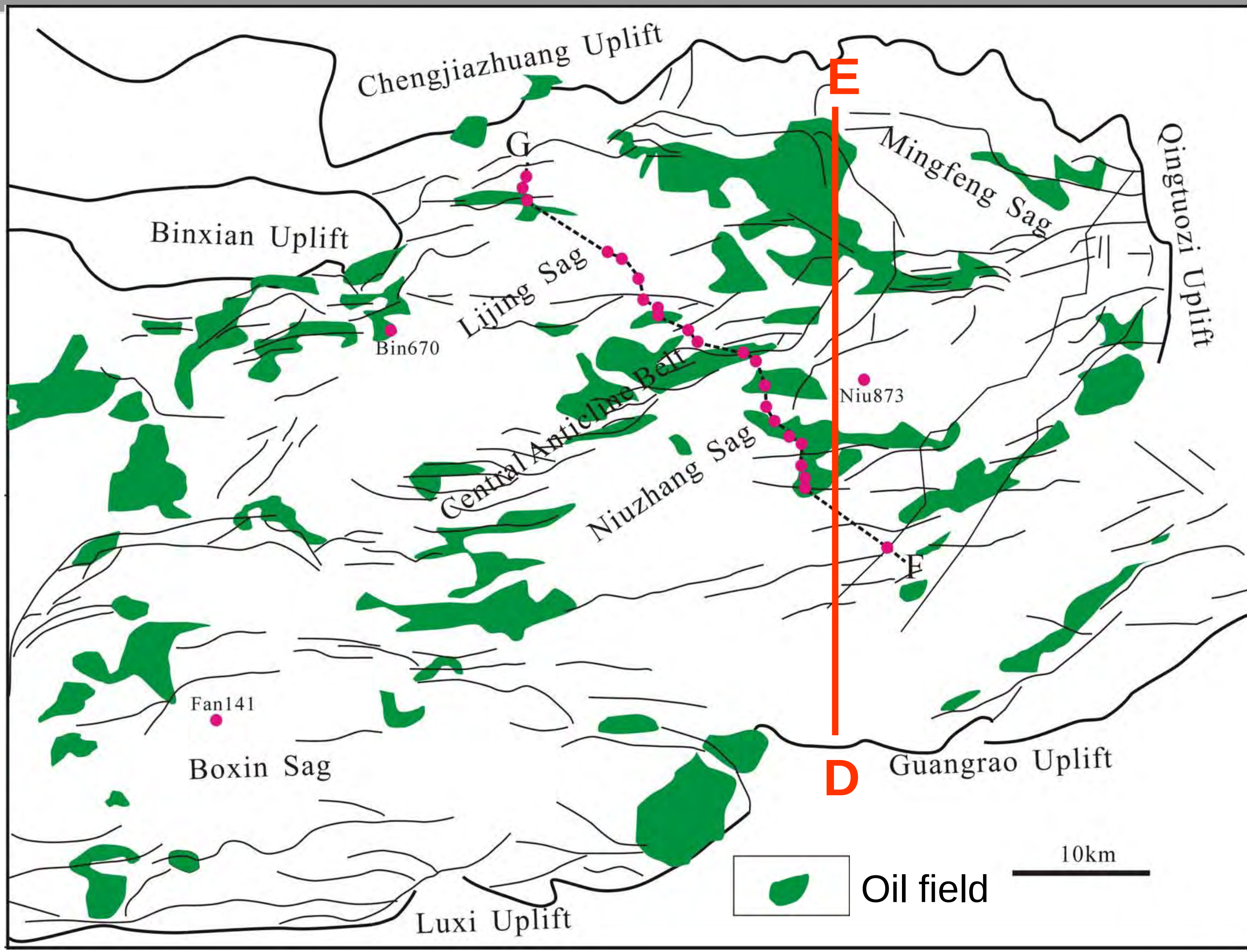
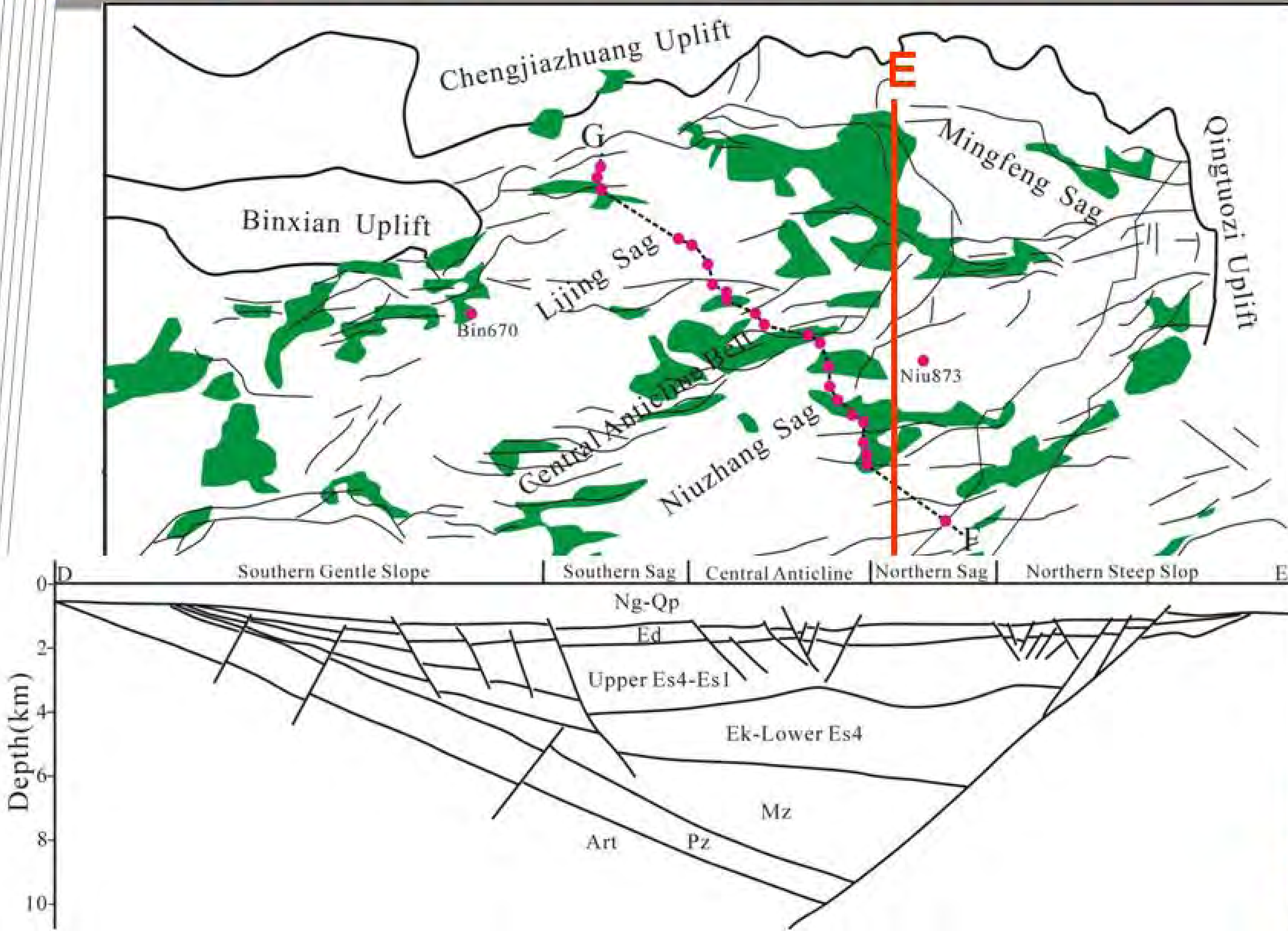
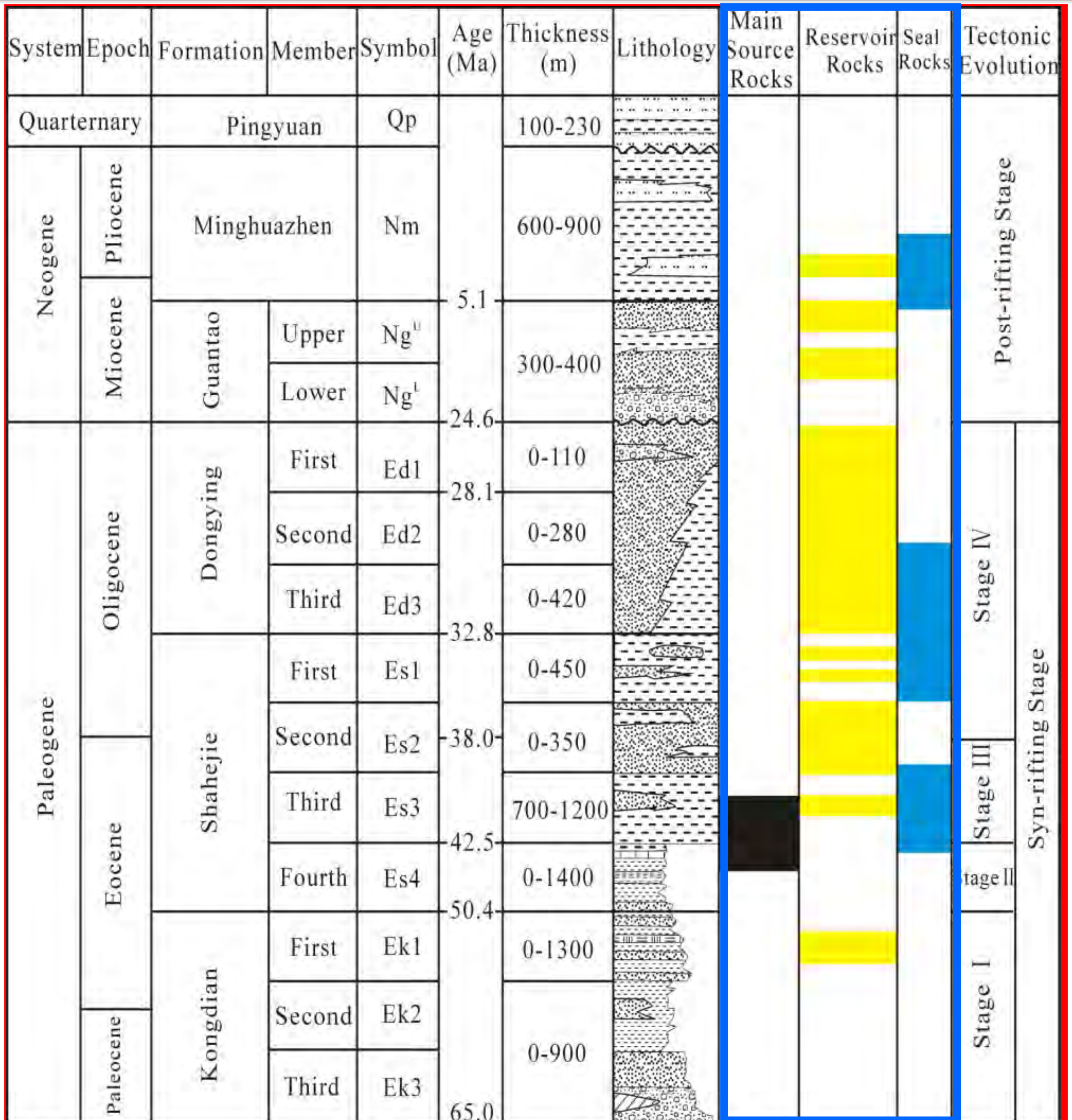
Dongying Depression (DD), Jiyang Sub-basin



Dongying Depression (DD), Jiyang Sub-basin



Stratigraphy and Petroleum System of the Dongying Depression



Source: Es3&Es4
Reservoir: Ek-Nm
Seal: Es3-Nm

Type I kerogens (oil-prone), high TOC (18.6%)

Es3 had a high depositional rate: 500 m/Ma

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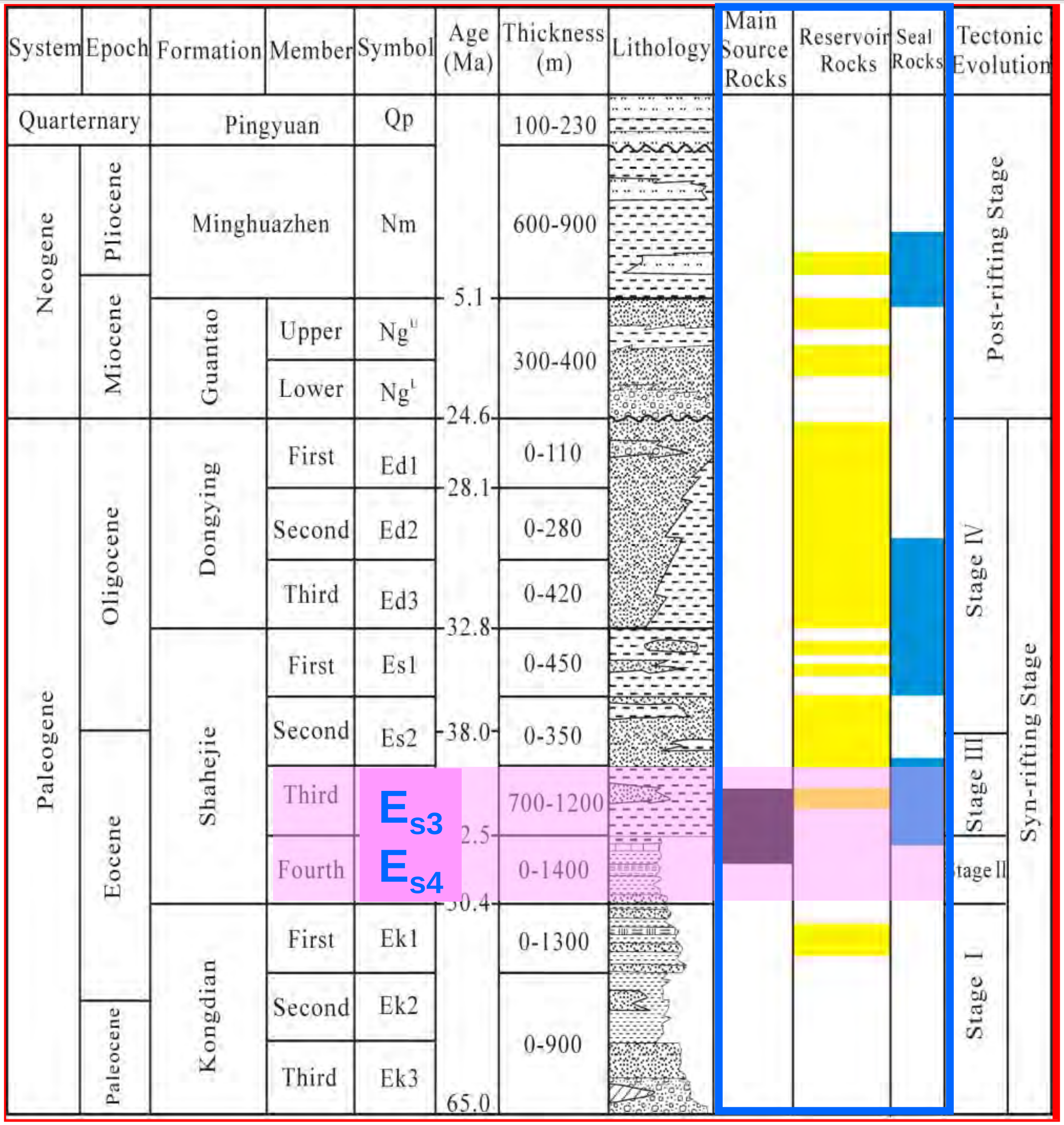
Stratigraphy and Petroleum System of the Dongying Depression



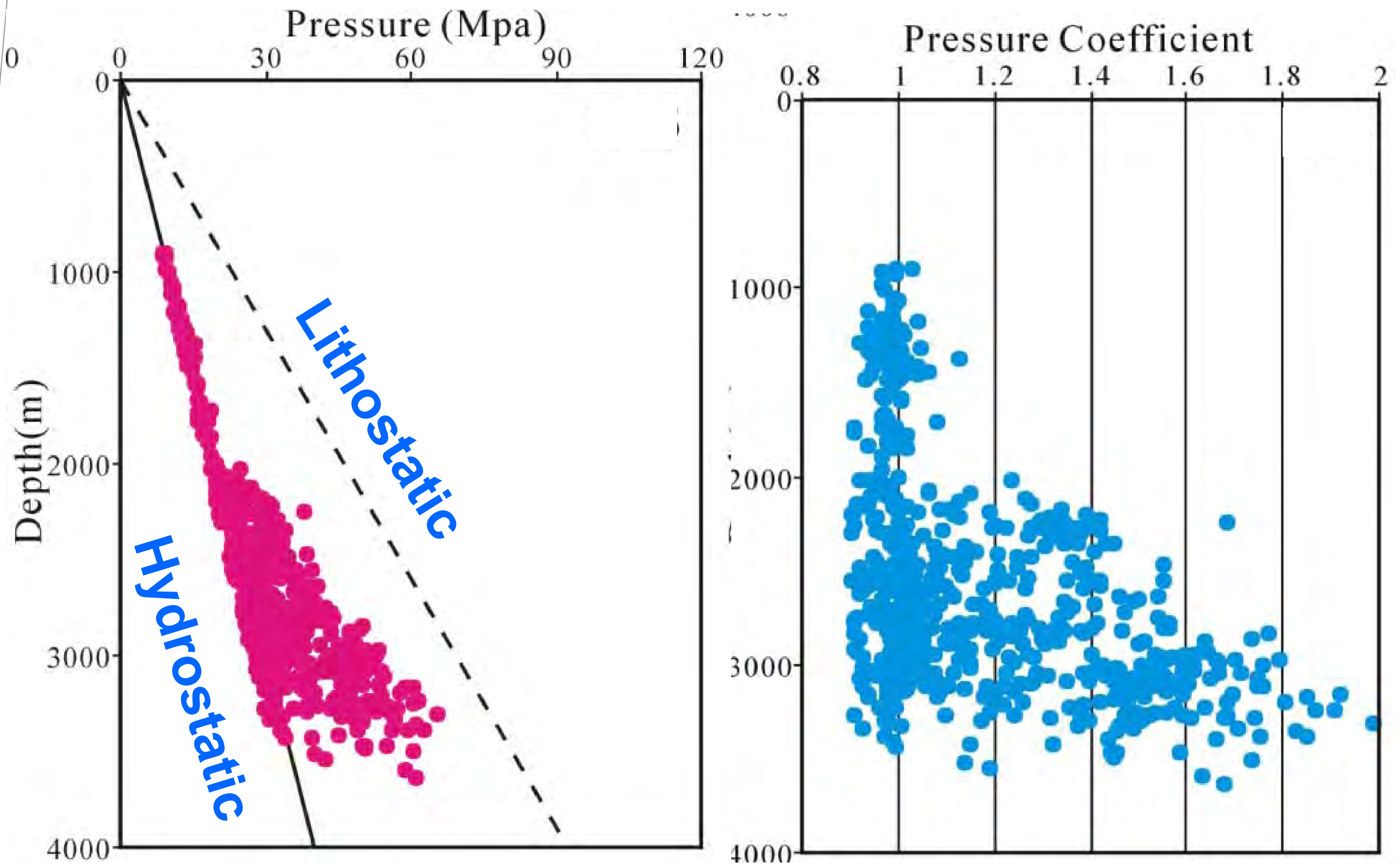
Source: Es3&Es4
Reservoir: Ek-Nm
Seal: Es3-Nm

Type I kerogens (oil-prone), high TOC (18.6%)

Es3 had a high depositional rate: 500 m/Ma

Es3 and Es4: a complete petroleum system with source, reservoir and seal

Overpressure in the E_{s3} and E_{s4} Reservoirs



Pressure Coefficient up to 2.0

Overpressure Mechanisms

- ❑Disequilibrium Compaction
- ❑Oil Generation
- ❑Aqua-thermal
- ❑Dehydration
- ❑Tectonic compression
- ❑Lateral pressure transmission

In the Dongying Depression overpressure within the Tertiary siliciclastic lacustrine sequences has been previously considered to be caused primarily by Disequilibrium Compaction

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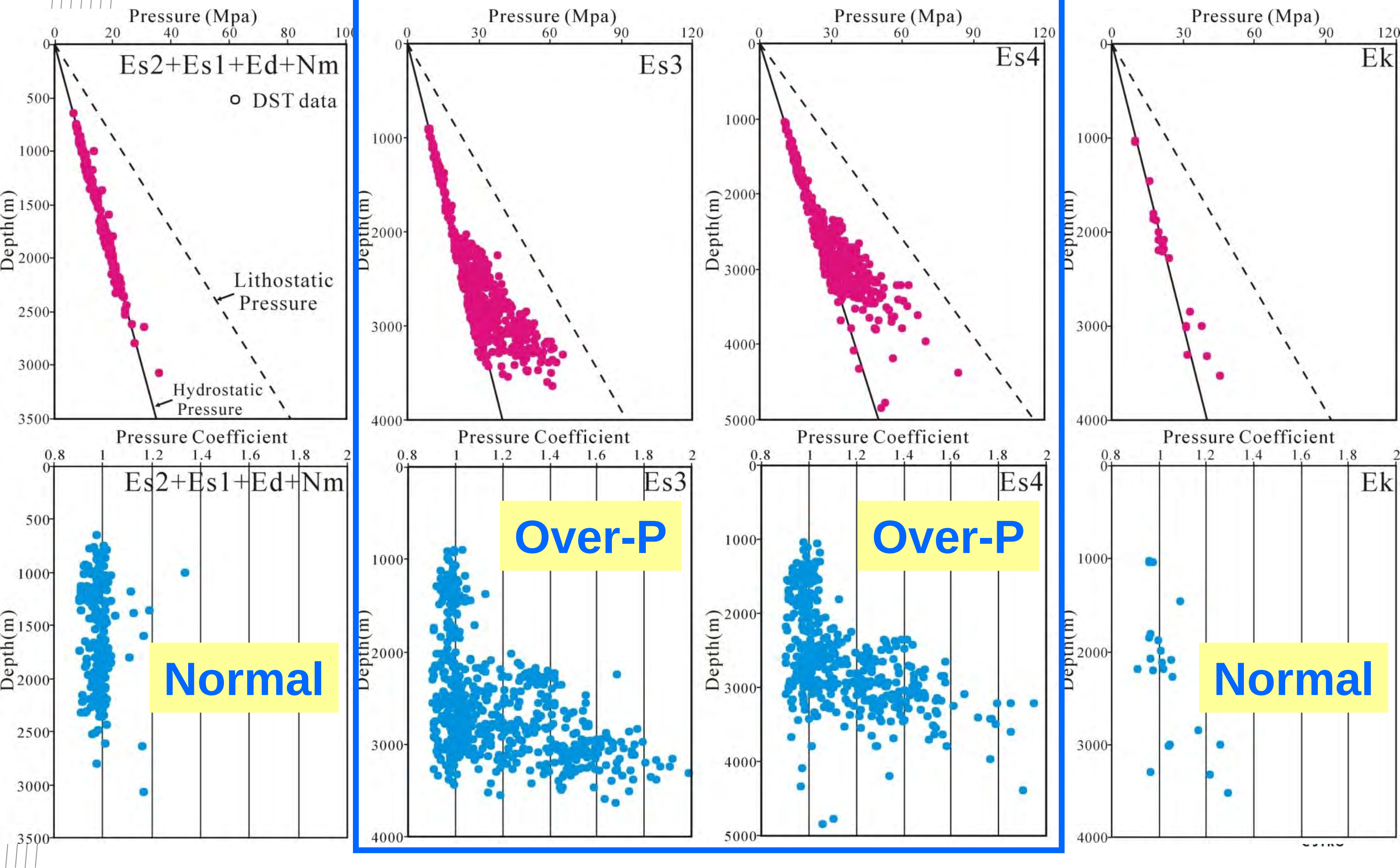
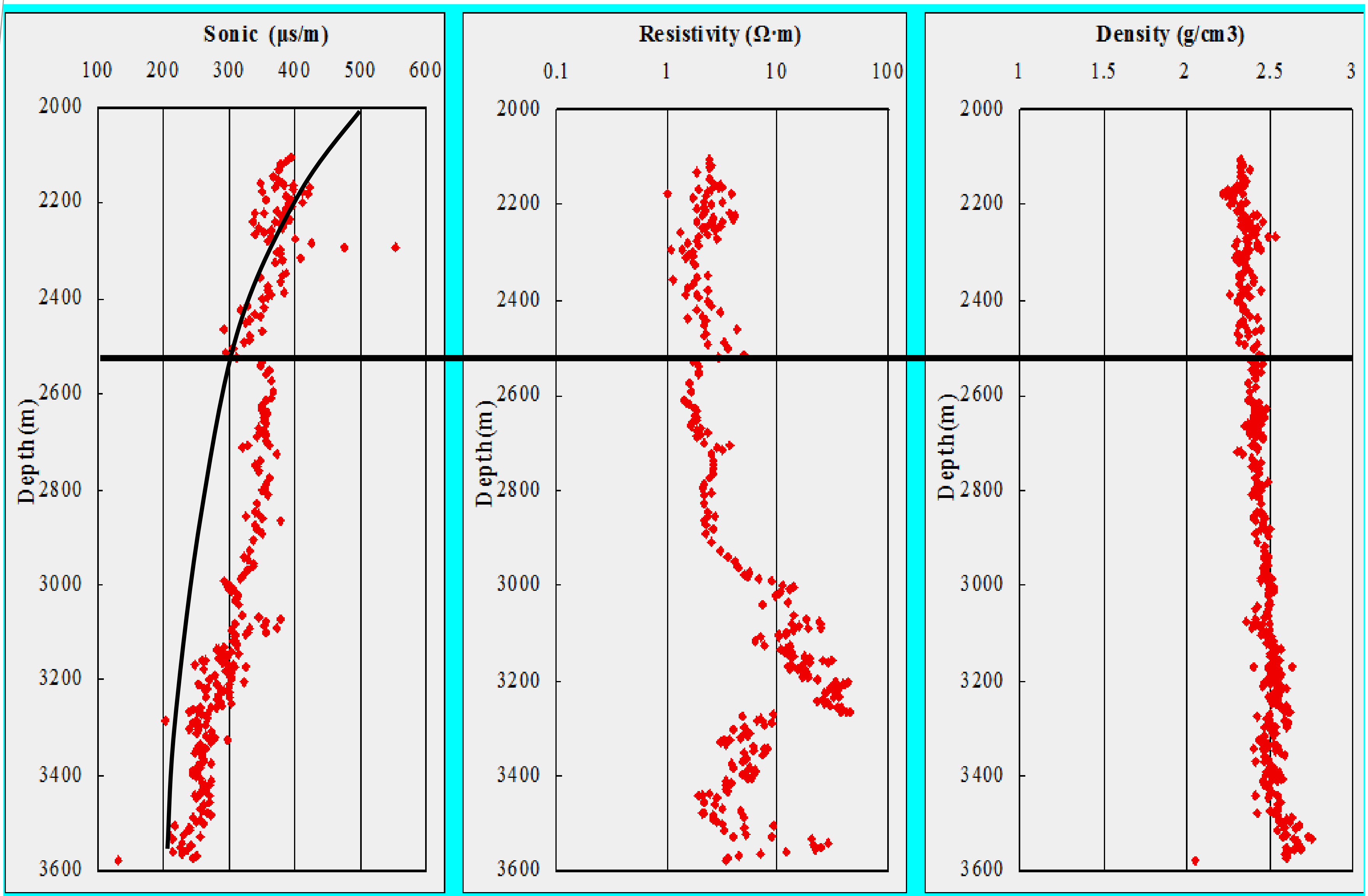
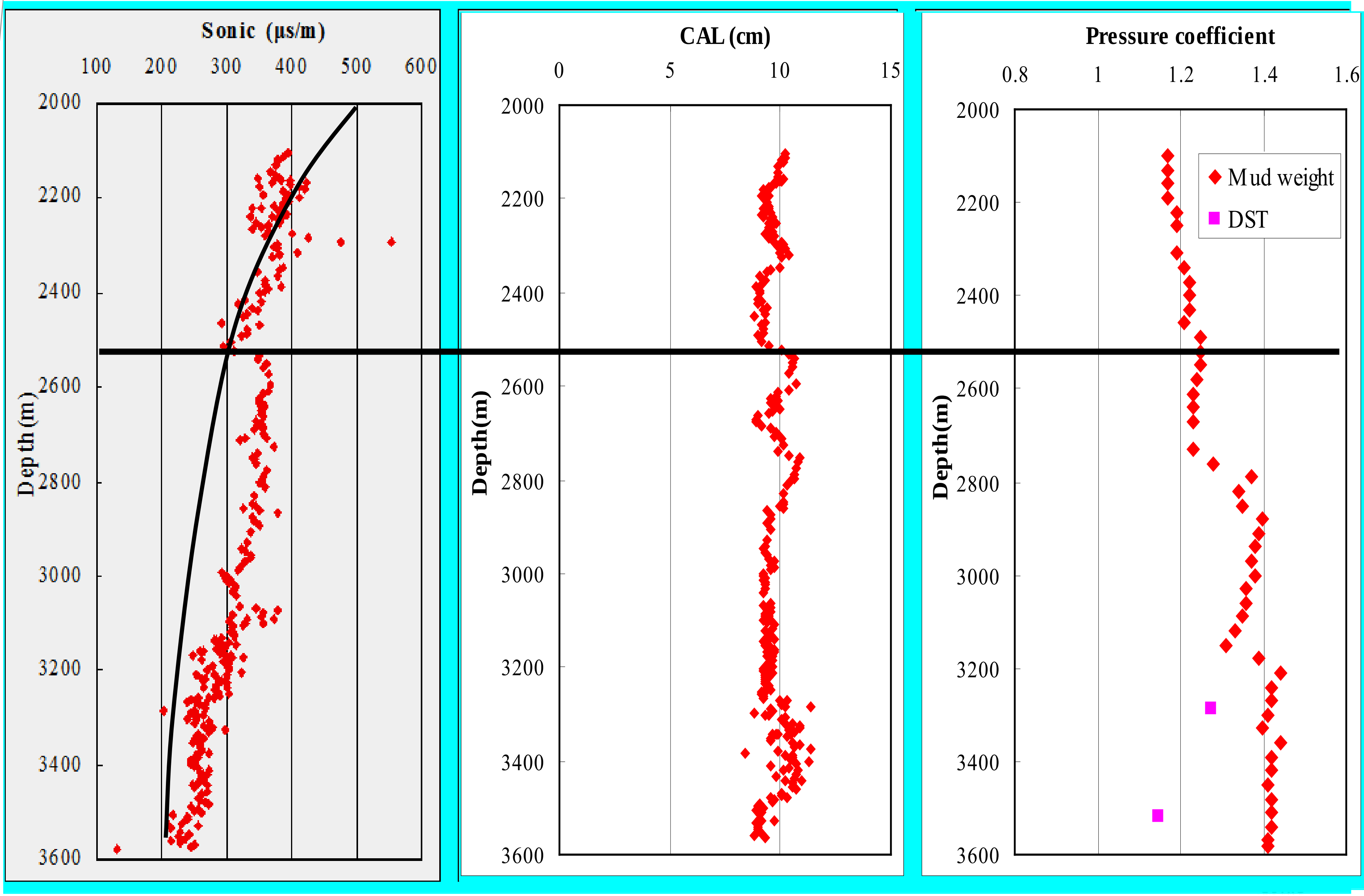
Overpressure in Es3 and E4 Sandstones



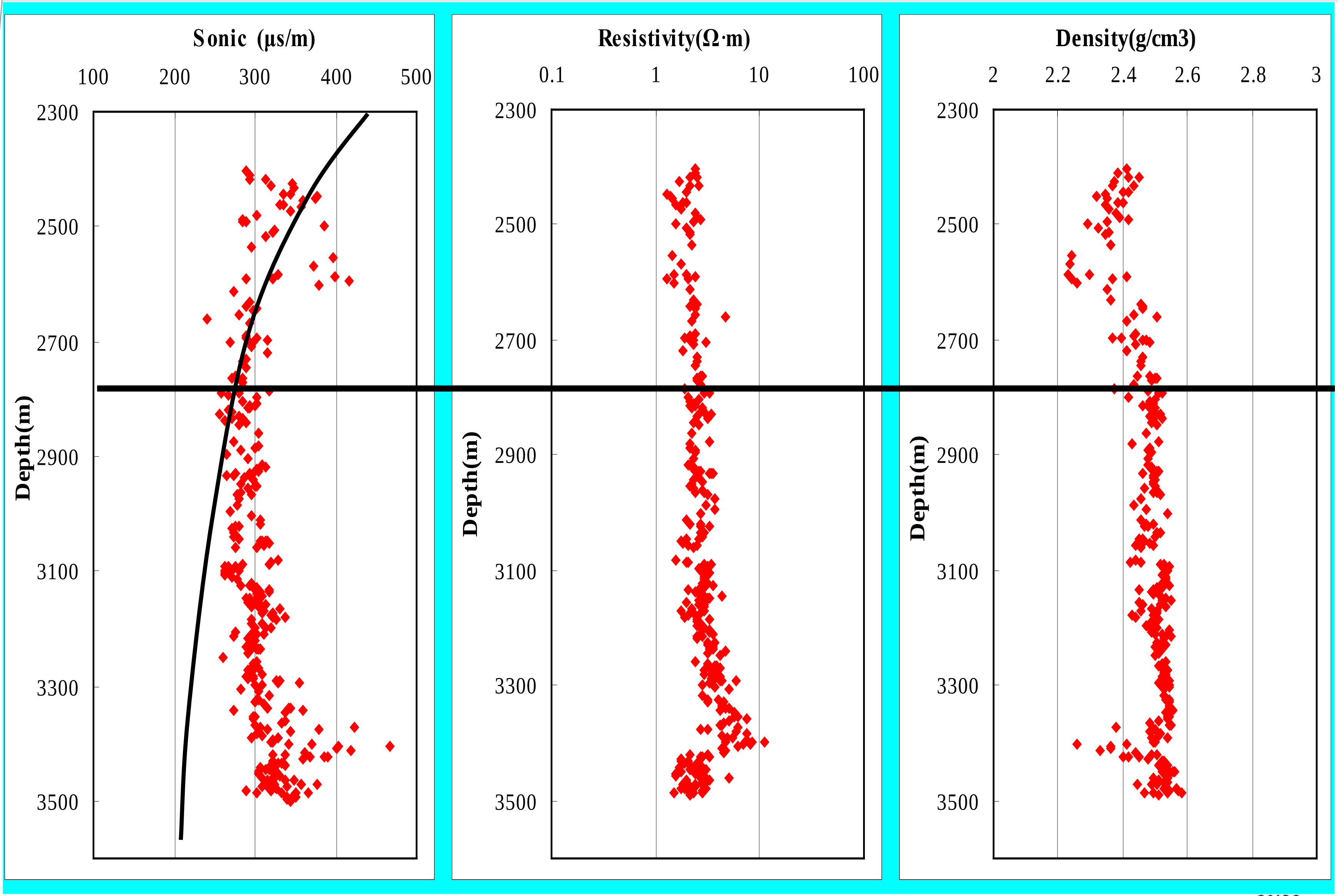
Log Response of the Overpressured Es3 and Es4 Reservoir Intervals (Well Bin 670)



Log Response of the Overpressured Es3 and Es4 Reservoir Intervals (Well Bin 670)



Log Response of the Overpressured Es3 and Es4 Reservoir Intervals (Well Niu 873)



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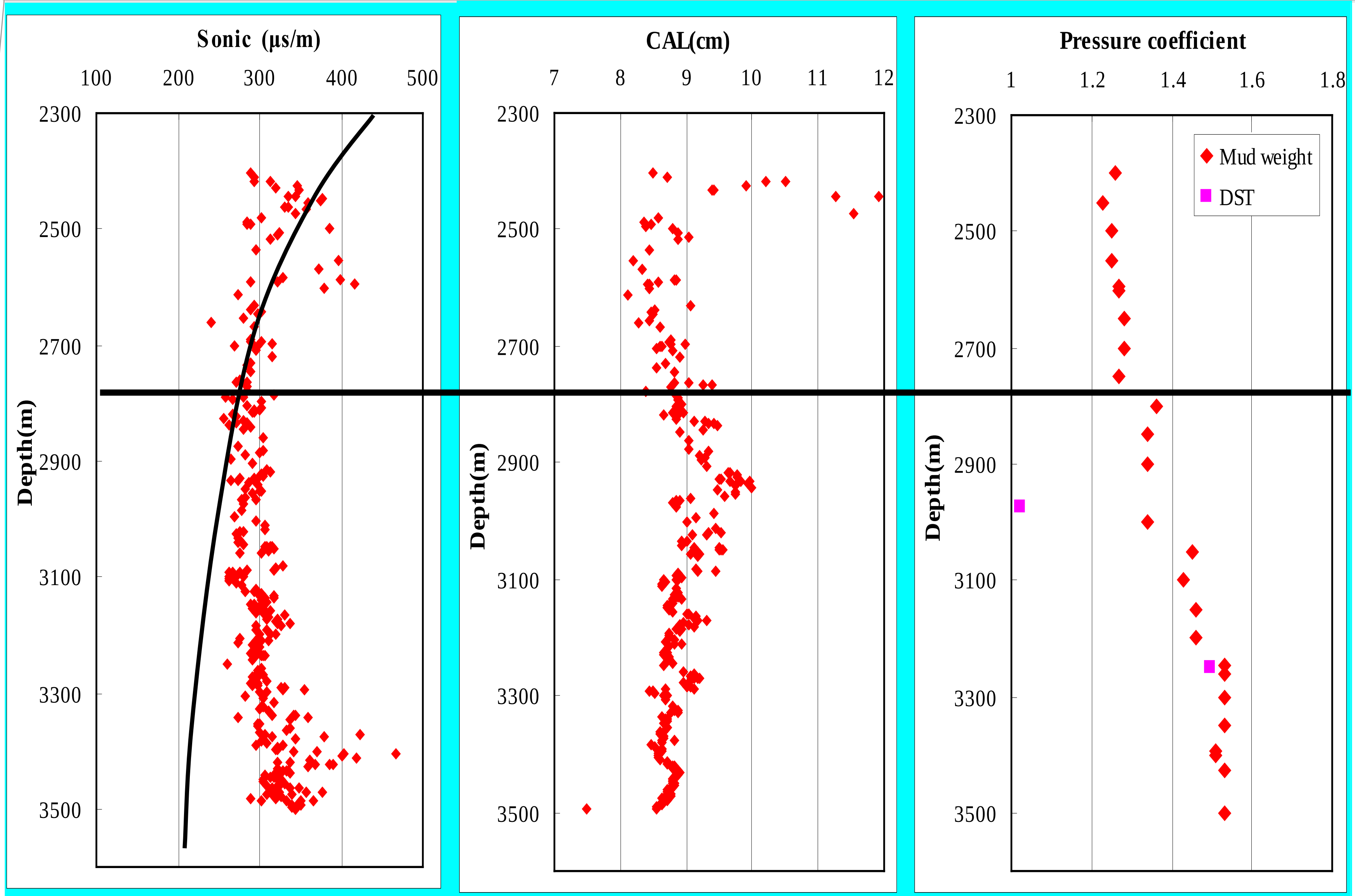
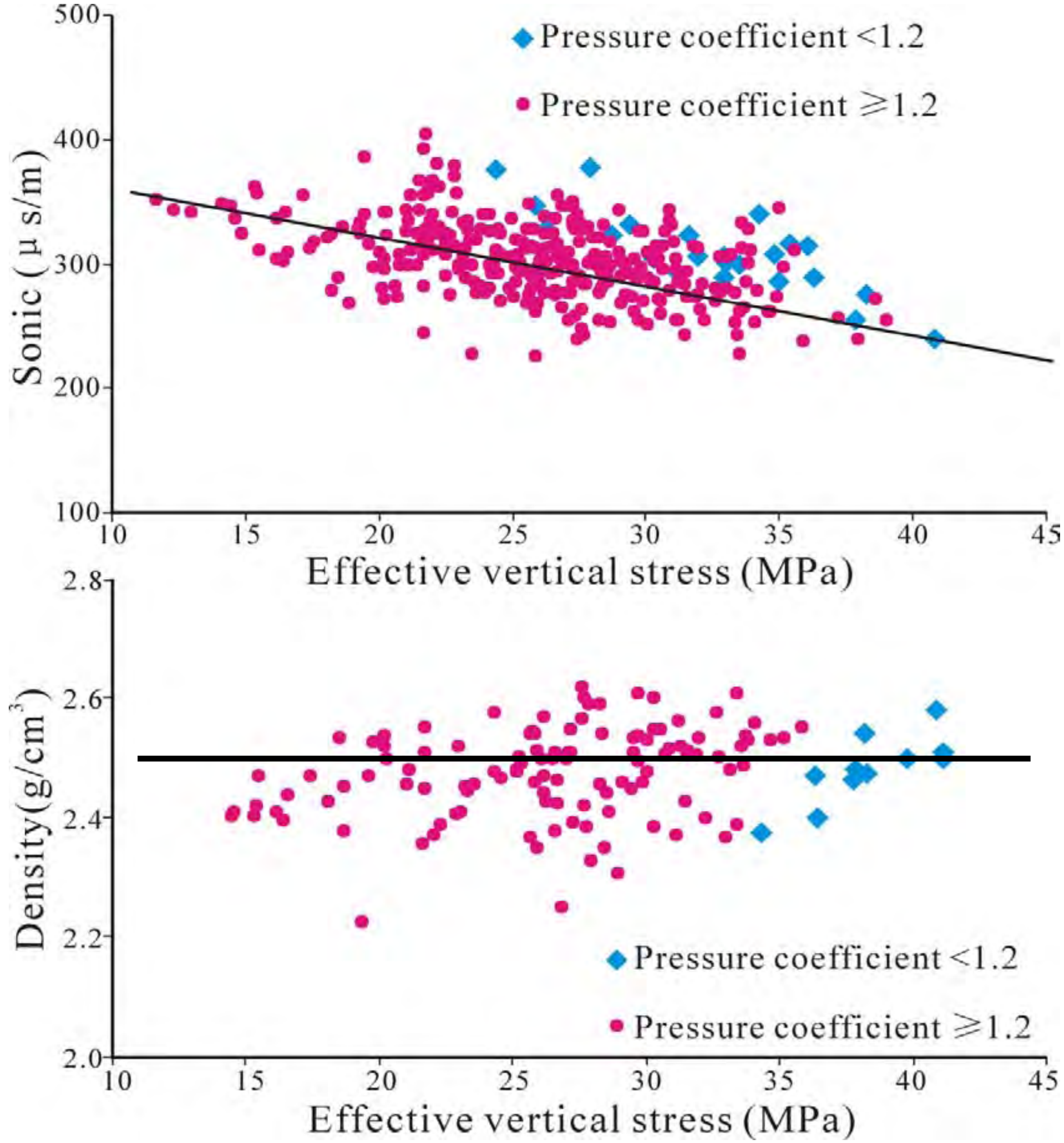
Log Response of the Overpressured Es3 and Es4 Reservoir Intervals (Well Niu 873)



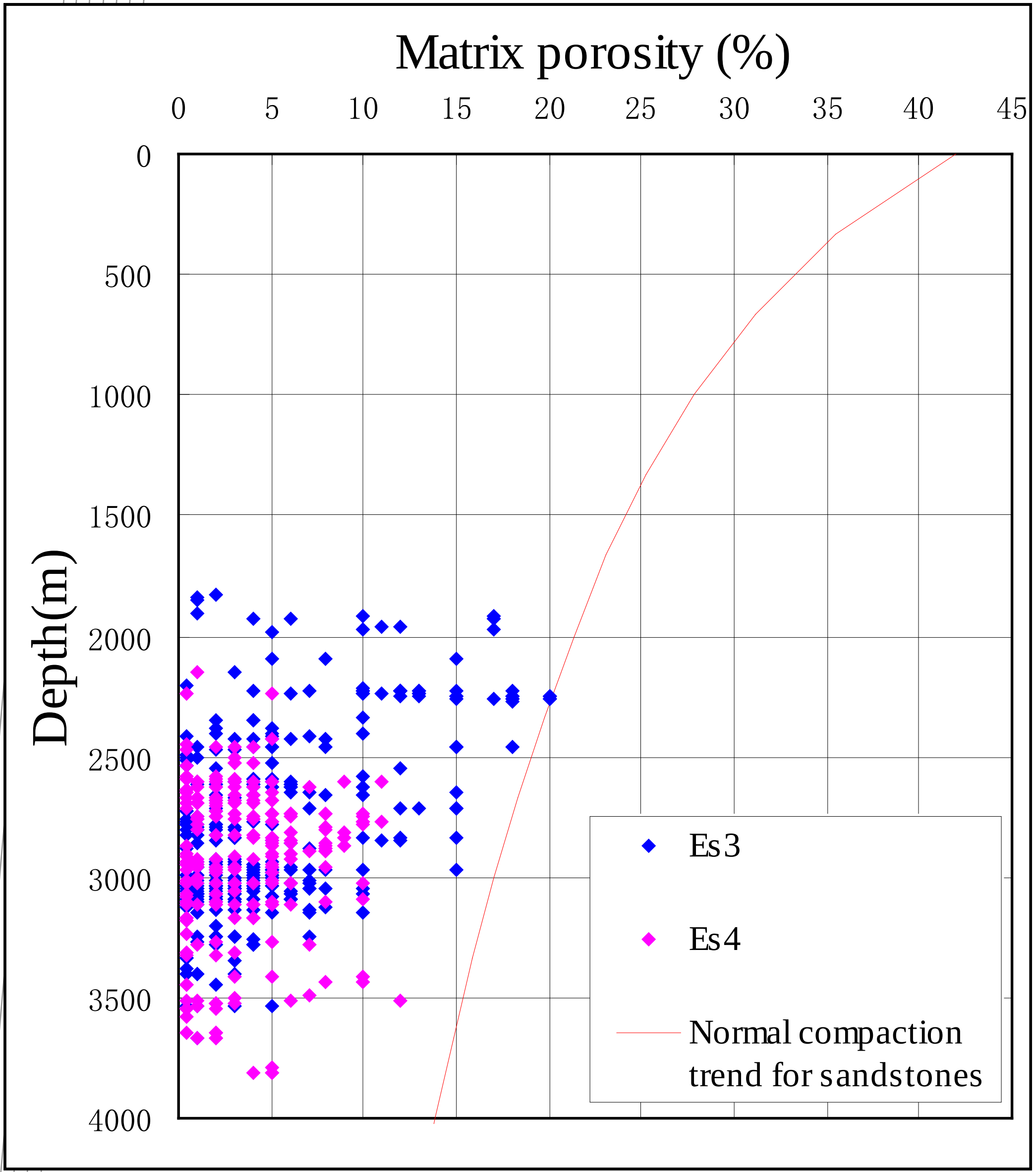
Sonic velocity and Density vs Effective Vertical Stress for Es3 and Es4 Mudstones

The acoustic travel-time of the overpressured mudstones is affected by the vertical effective stress while the densities show no changes compared with the normally pressured mudstones.



No evidence of Disequilibrium Compaction

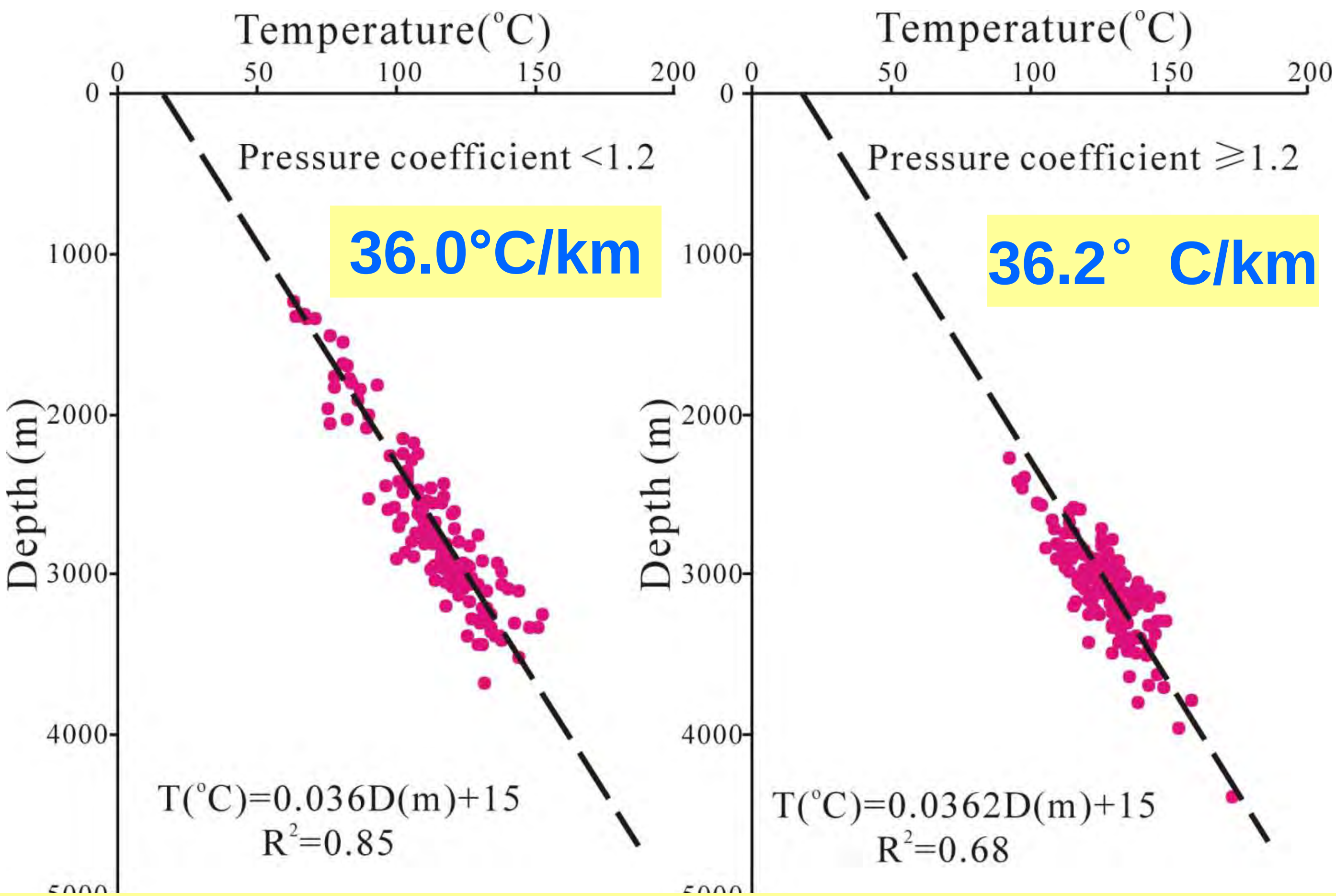
Depth profiles of the matrix porosity for Es3 and Es4 Reservoir Sandstones



The matrix porosities were estimated from thin-sections. The sandstones do not have anomalously high porosities.

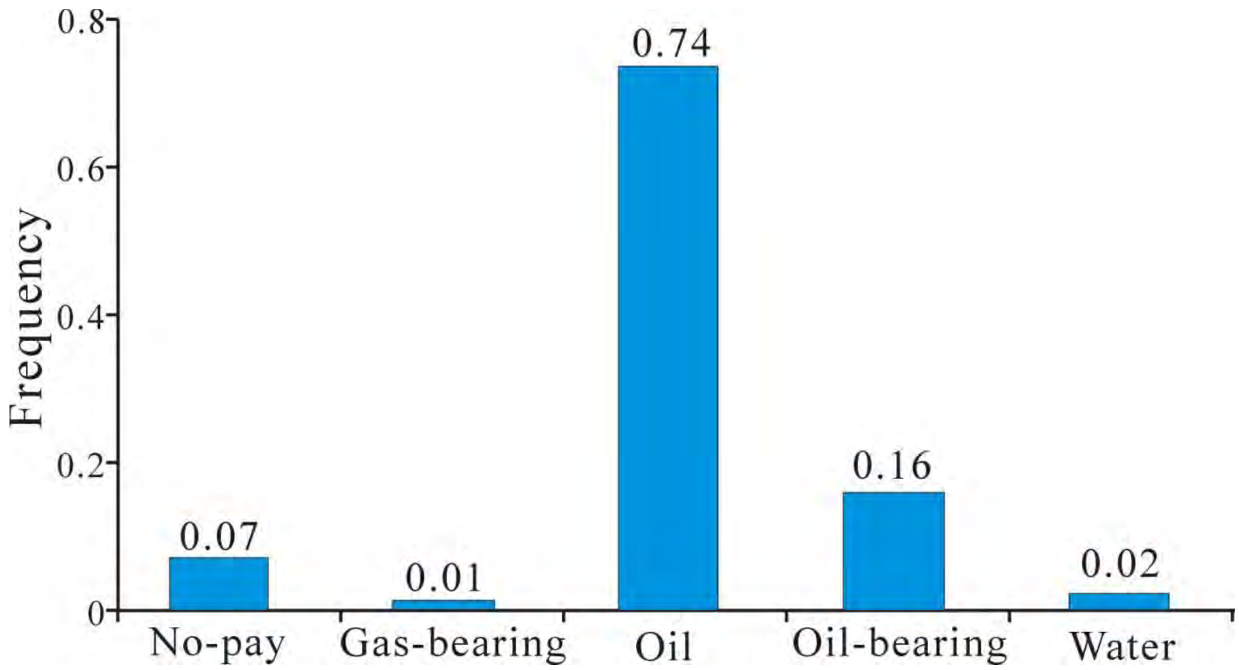
No evidence of Disequilibrium Compaction

Measured Temperature Depth Profiles for Over-pressured and Normally Pressured Reservoirs



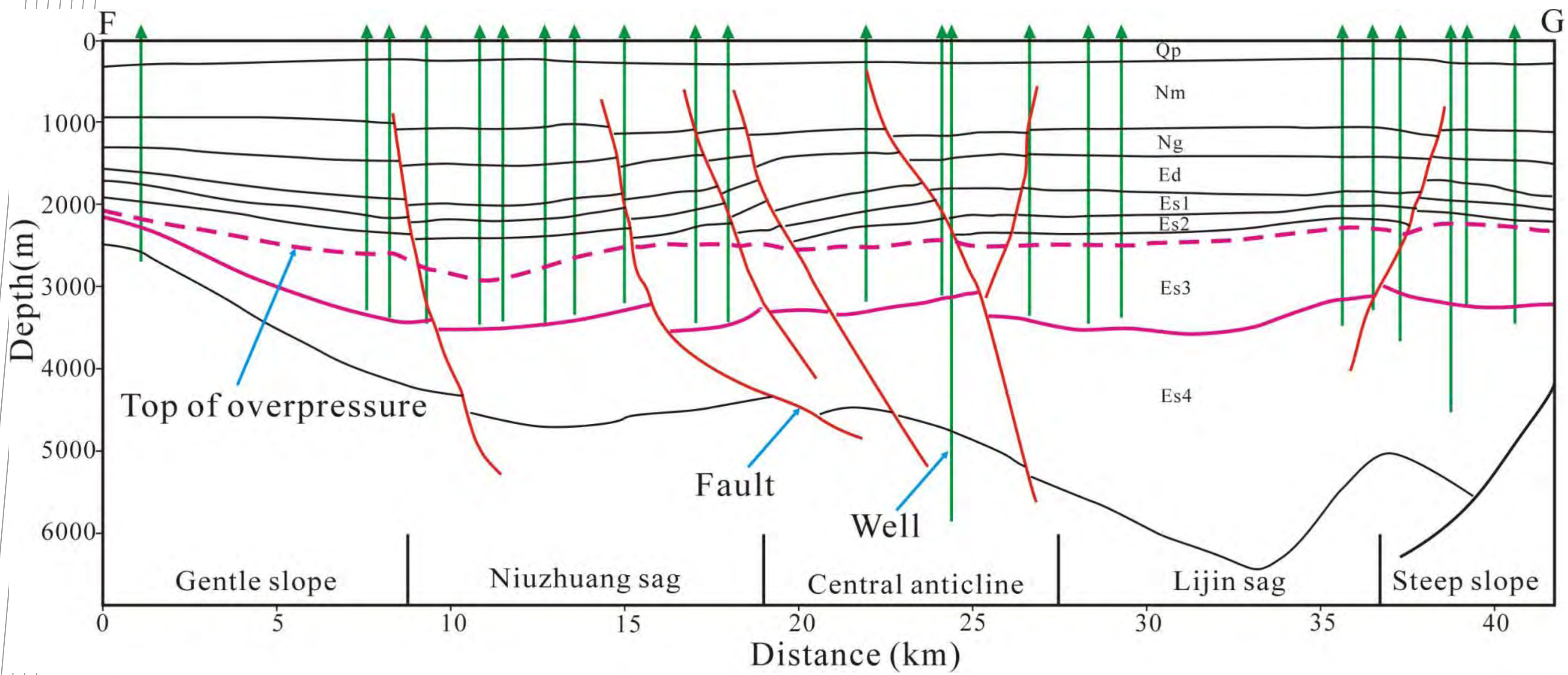
The similar geothermal gradients suggest that the over-pressured sandstones do not have anomalously high porosities as compared with the normally pressured sandstones

Oil Saturation in Overpressured Es3 and Es4 Reservoirs—Evidence 1



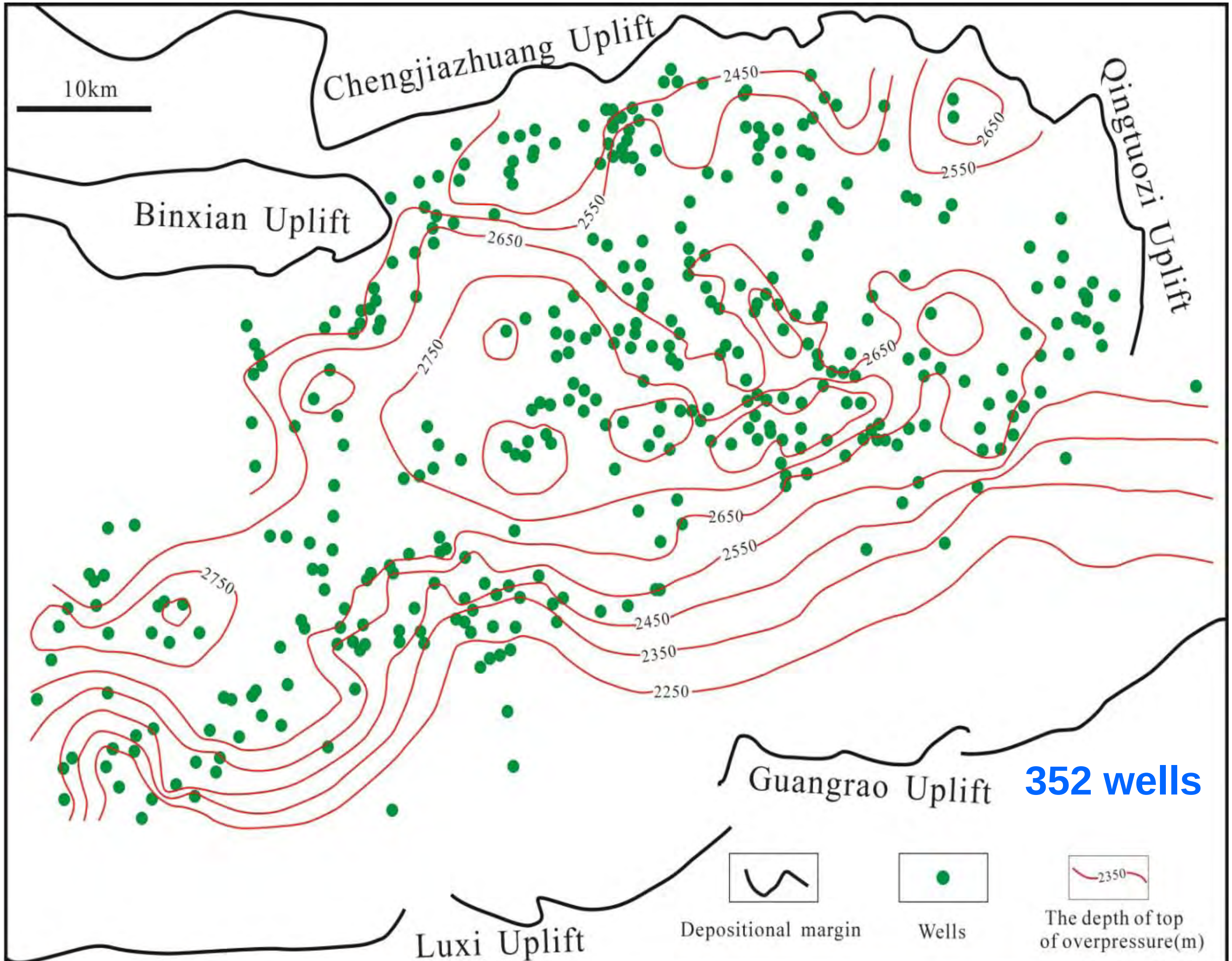
The overpressured reservoirs are dominated by either oil saturated (74%) or oil-bearing (16%) reservoirs.

Top of Overpressured Reservoirs vs the Top of the Source Rocks (Es3)—Evidence 2



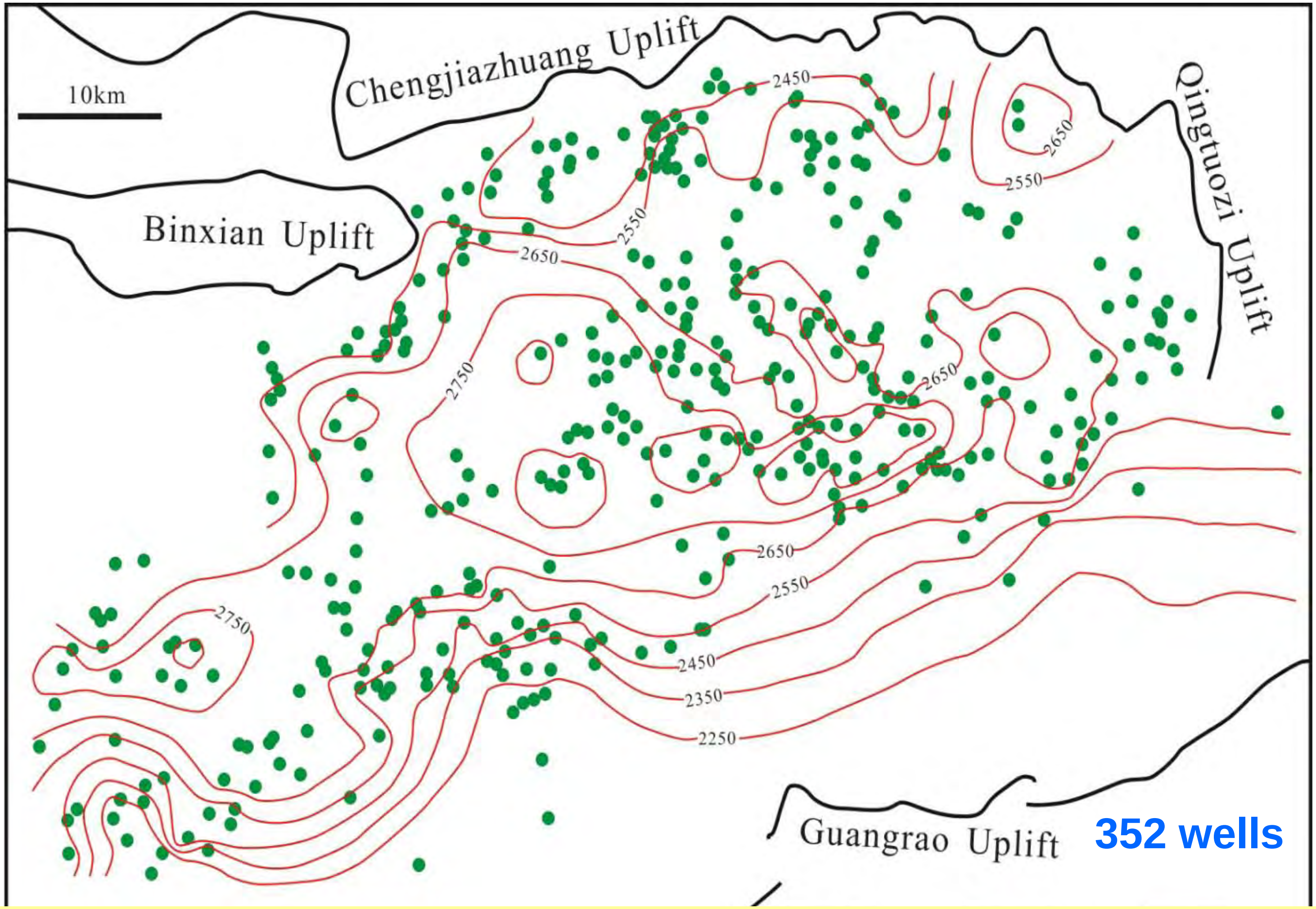
The top of the overpressure zone ranges from 2200 m to 3000 m and increases with the burial depths of the source rocks. The temperatures for the top of overpressure zone are *ca* 87-123°C corresponding to estimated vitrinite reflectance (Ro) of 0.5-0.75%.

Top of Overpressured Reservoirs vs the Top of the Source Rocks (Es3)—Evidence 2



352 wells

Top of Overpressured Reservoirs vs the Top of the Source Rocks (Es3)—Evidence 2

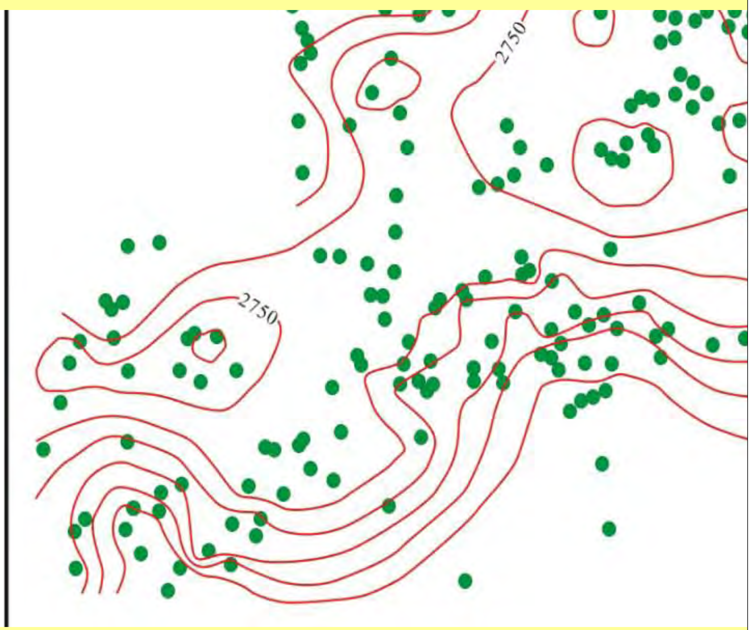


352 wells

The top of the overpressure zone ranges in depths from 2200 m to 3000 m closely mimicking the depths of the source rocks.

Top of Overpressured Reservoirs vs the Top of the Source Rocks (Es3)—Evidence 2

Measured vitrinite reflectance (R_o %) and EqVR (Equivalent vitrinite reflectance) using FAAM versus depths.



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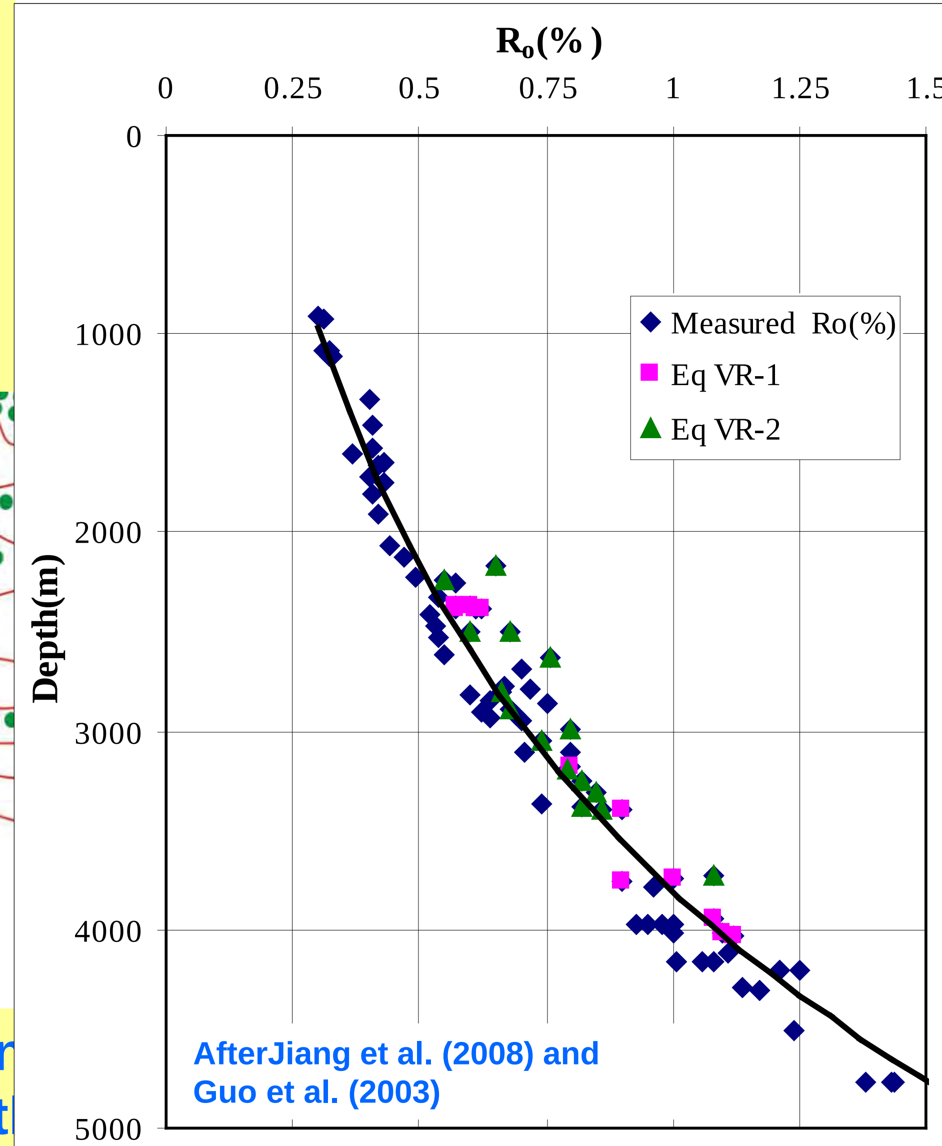
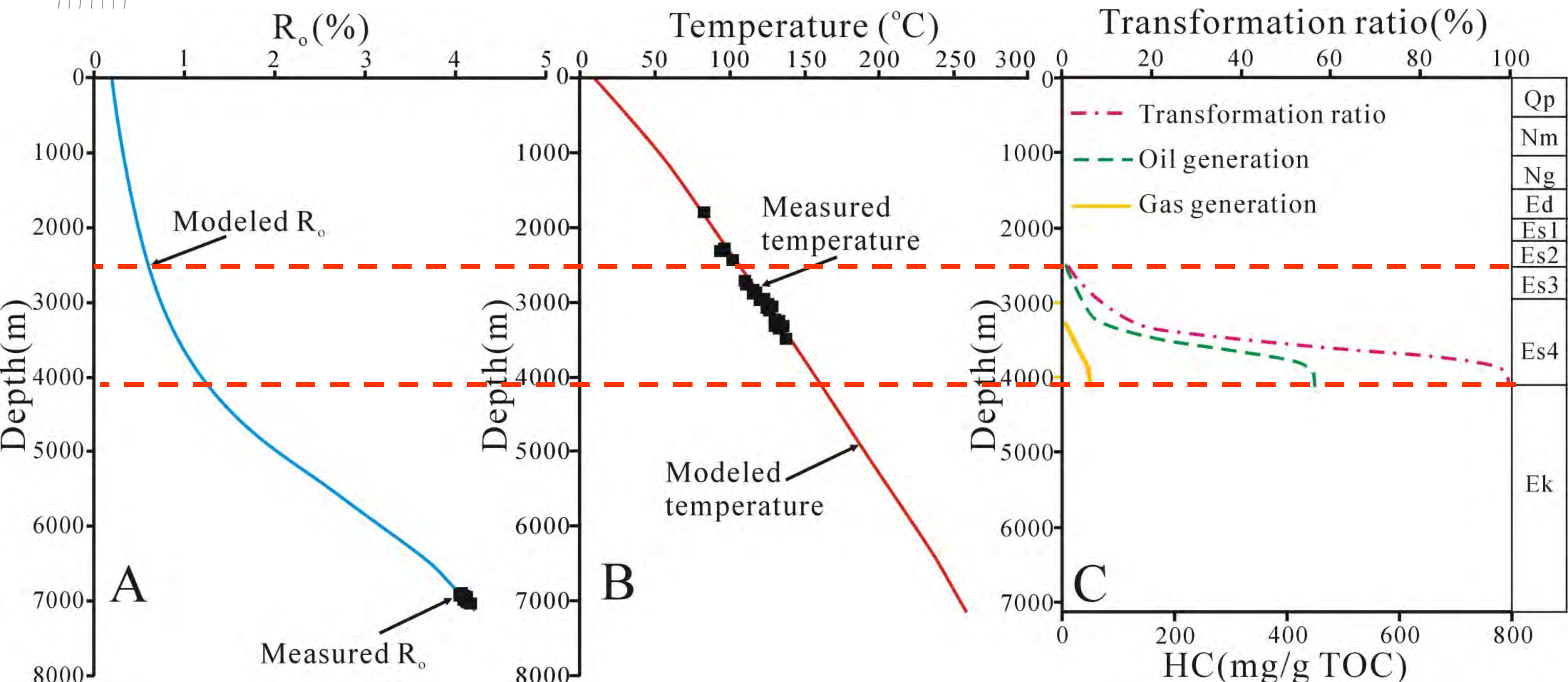


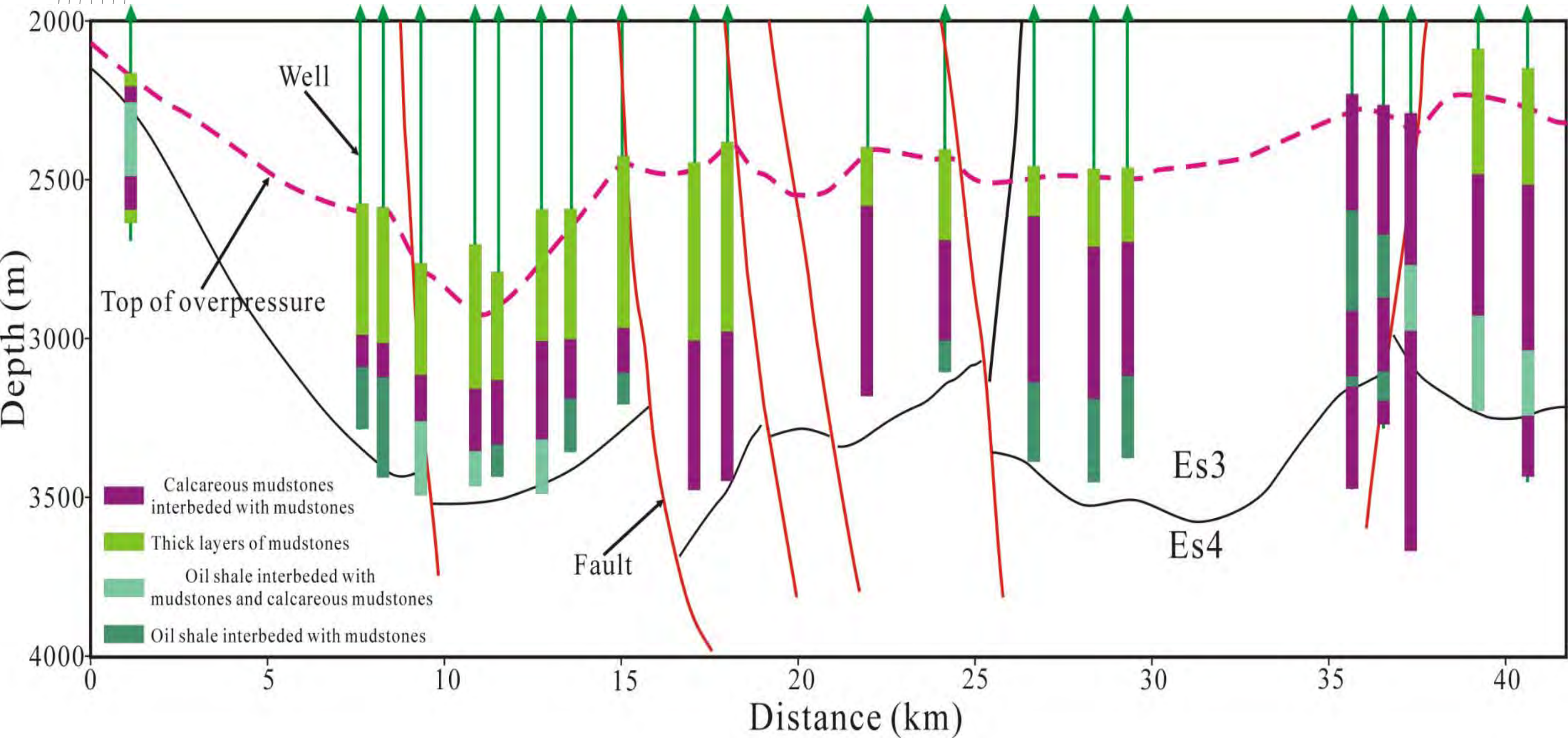
Oil and Gas Generation Capability of Es3 and Es4 at present day —Evidence 3



Modelling results at present day for Well Shengke-1 showing transformation ratio, oil generation and gas generation in the Es3 and Es4 intervals at present day .

Click to View Notes by Presenter

Presence of an Effective Seal in Es3 and Pressure transmission conduits—Evidence 4



The top of the overpressure zone is associated with thick layers of mudstones/calcareous mudstones. Internal fractures and vertical faults are present in Es3 and Es4.

Notes by Presenter (for previous slide):

The main lithology of the lower part is oil shales interbeded with mudstones or oil shales and calcareous mudstones interbeded with mudstones. In the middle part, it comprises calcareous mudstones interbeded with mudstones. In the upper part, the main lithology is thick layers of mudstones. The top of the overpressure zone is associated with the thick layers of mudstones or calcareous mudstones interbeded with mudstones.

Oil Generation as the Predominant Overpressure Mechanism

- High oil generation capability of Es3 and Es4 source rocks and their prolonged generative duration to maintain the pressure regime
- Fractures and faults as pressure transmission conduits to the interbedded Es3 and ES4 reservoirs (short migration distance)
- Effective seal of the Es3 calcareous mudstone cap the overpressure zone
- The timing of the initiation of the overpressure is post the early hydrocarbon charge as suggested by fluid inclusion data (in progress)

Conclusions

- The overpressures in the Es3 and Es4 members in the Dongying Depression was not caused by disequilibrium compaction:
  - absence of anomalously low density in the overpressured mudstones,
  - non-correlation between the density response and effective stress of overpressured mudstones,
  - absence of anomalously high matrix porosities in the sandstones and unusual high geothermal gradients.
- Oil generation is the predominant cause for overpressure:
  - intimate relationship between oil saturation-overpressured reservoirs
  - spatial correlation between the source rock and overpressured zone
  - source rock generation capability at present
  - presence of an effective seal immediately above the overpressure zone and the pressure transmission conduits within Es3 and Es4
- Sonic (log) response appears to be a reliable pressure indicator in the Dongying Depression

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Thank you

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