Source Rock Deposition Controlled by Tectonic Subsidence and Climate in the Western Pearl River Mouth Basin, China: Evidence from Organic and Inorganic Geochemistry*

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Abstract

Lake deposits, which contain significant petroleum resources, are important to understand and predict. The deposition of lacustrine source rocks, unlike marine source rocks, displays strong heterogeneity, which is caused by its small water reservoir size and frequent external environment changes. The strong heterogeneity can be evidenced from wide ranges of salinity, pH, Eh, and marked variation of biota and can be traced by various geochemical parameters. Sometimes these indexes, however, are contradictory and thus restrict source rock evaluation.

In this study GC-MS and trace elements analysis were conducted by using 20 and 51 source rock samples respectively from the western Pearl River Mouth Basin. The co-variation of organic and inorganic indexes indicate the combination is a valid method to reconstruct primary productivity and depositional environment. The synchronous changes in organic matter input, primary productivity, and sedimentary environment were reasonably interpreted by two deposition models, which were controlled by the tectonic subsidence and climate.

During the E_2w depositional stage, the rapid subsidence and low sediment supply led to thick sediments deposited in deep lacustrine environment and resulted in sediment starvation. The low water injection provided little terrigenous organic matter and oxygen. Besides, the small area/depth ratio impeded the water circulation, thus resulting in shallow thermocline and euxinic-anoxic bottom environment. Therefore abundant algae, which contributed to the high AOM content and high productivity, can be preserved. The warm and wet climate gave birth to autochthonous organism, such as dinoflagellates and pavlova gyrans. During the E_3e depositional stage, slow subsidence and sufficient sedimentary supply resulted in expanding, shallow lacustrine environment. The greater area/depth ratio and high water inflow made the environment unstable. Enough TOM was transported to the slope but little to the depocenter. The hot and dry climate led to decreasing autochthonous organism and evaporation environment. The strong evaporation and high water flow resulted in saline, suboxic-dysoxic acid bottom environment and deep thermocline.

Different sedimentary environments resulted in different geochemical features, thus using the various geochemical features can trace palaeosedimentary environments. Furthermore, potential source rock deposition can be predicted by using suitable models when detail data is not available.

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Source Rock Deposition Controlled by Tectonic Subsidence and Climate in the Western Pearl River Mouth Basin, China: Evidence From Organic and Inorganic Geochemistry

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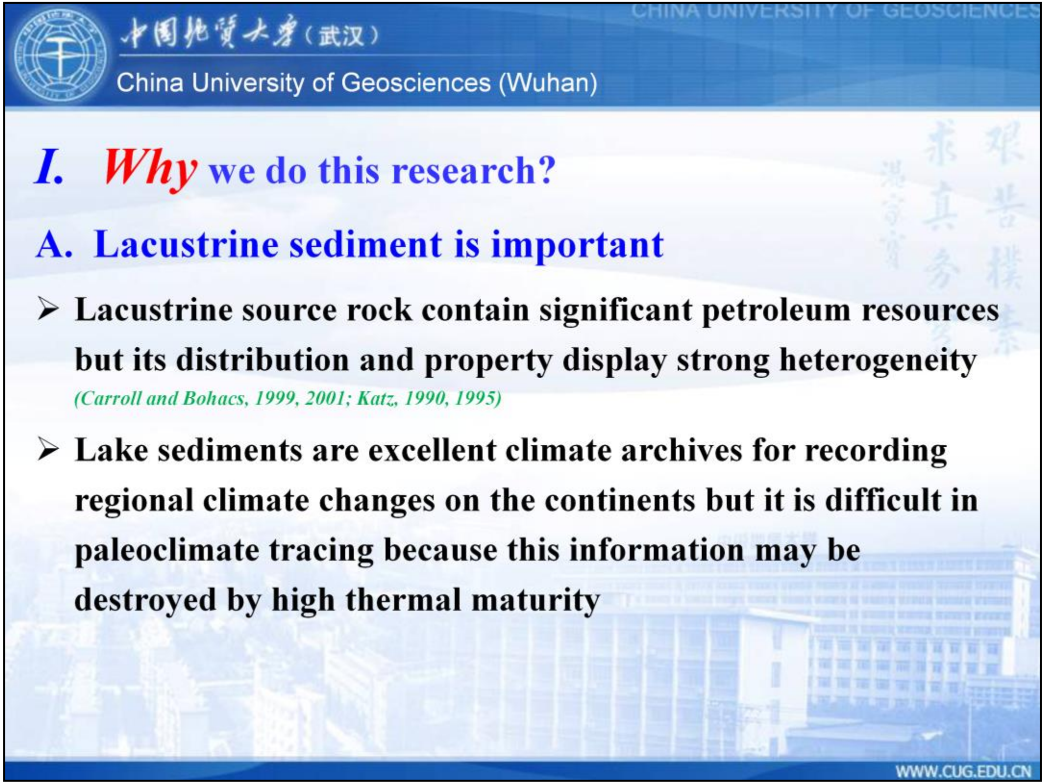
Outlines

I. ***Why*** **we do this research**

II. ***Ways*** **to finish this research**

III.***Results*** **of this research**

IV. Source rock depositional models

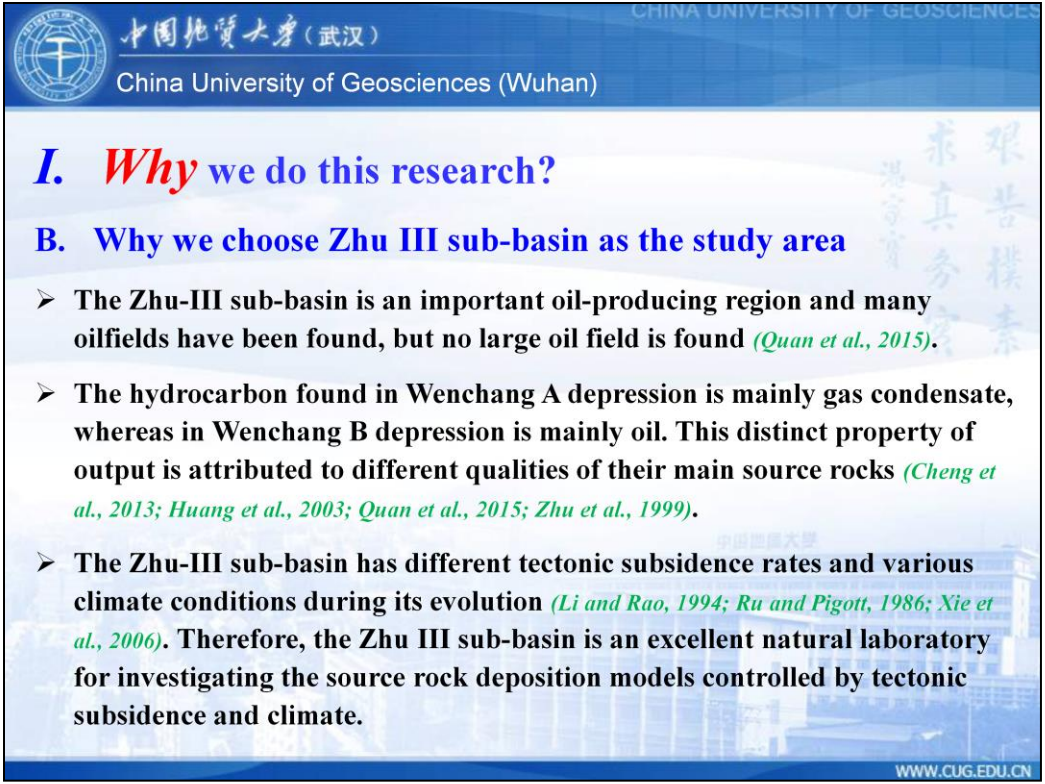


Presenter’s notes: First one, why do we this research?

Lacustrine source rocks are very important in China because they contain a lot of petroleum resources. But their distribution and property show strong heterogeneity, which restrict exploration.

Besides, lake sediments are excellent climate archives for recording regional climate changes on the continents. It can help us better understand the source rock depositional mechanism and where we can find other high quality source rocks.

But it is difficult in paleoclimate tracing because this information may be destroyed by high maturity.



Presenter's notes: Many oilfields have been found in the study area, Zhu III sub-basin, and it is believed to be an important oil-producing region. However no large oil field is found.

The most important hydrocarbon kitchen in the Zhu III sub-basin is Wenchang A and Wenchang B depressions. The hydrocarbons found in Wenchang A depression is mainly gas condensate, whereas in Wenchang B depression is mainly oil. This distinct property of output is attributed to different qualities of their main source rocks. Previous studies indicated fresh water, reducing and middle-deep lacustrine facies environment during the Eocene; saline, oxidic and swamp facies environment during the Oligocene. However, the reason why the two source rocks exhibit such distinct properties is rarely reported. Therefore, a better understanding of source rock deposition is needed.

The changing tectonic subsidence rates and varying climate conditions makes the Zhu III sub-basin an excellent natural laboratory for investigating source rock deposition models controlled by tectonic subsidence and climate.

I. Why we do this research?

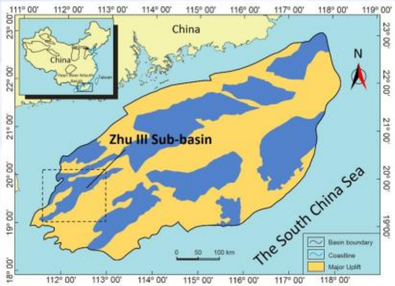


Fig. 1. Map showing the structural divisions of the Pearl River Mouth Basin, China and location of the Zhu III sub-basin *(modified from Zhu and Mi, 2011)*.

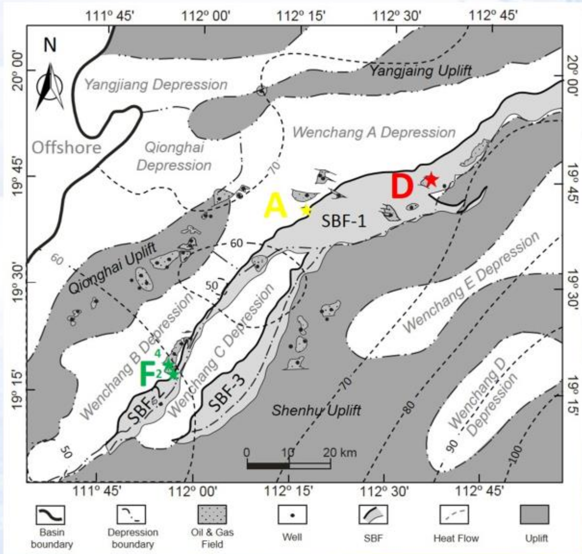


Fig. 2. Location map showing the South Boundary Fault, heat flow distribution and sampled boreholes *(modified from Quan et al., 2015; Yuan et al., 2009)*.

Presenter’s notes: The Pearl River Mouth Basin is located on the northern shelf of the South China Sea and this is the study area for Zhu III sub-basin. These are the mentioned hydrocarbon kitchen, Wenchang A and Wenchang B depression. The SBF represents the South Boundary Fault. Samples used in this study are from wells A and D in the Wenchang A depression and well F in the Wenchang B depression. Well D is located in the depocenter and well A in the slope.

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I. Why we do this research?

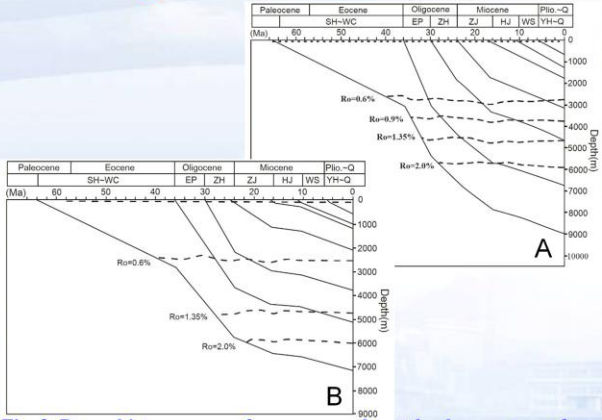


Fig. 3. Burry history curves for source rocks at the depocenters of the Wenchang A depression (A) and Wenchang B depression (B) *(from Huang et al., 2003)*.

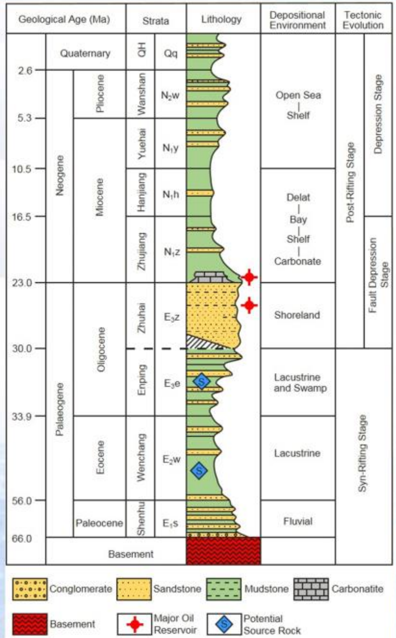


Fig. 4. Generalized stratigraphy of the Pear River Mouth Basin *(modified from Chen et al., 1991 and Jiang et al., 2009)*. **Possible source rock and major reservoir intervals are marked. QH= Qionghai Formation.**

Presenter's notes: The main source rocks of this area are the Eocene Wenchnag Formation and Oligocene Enping Formation. The depocenter was in the Wenchang B depression in the Eocene, then migrated to the Wenchang A in the Oligocene. Due to the deep buried depth, the Eocene Wenchang Formation has exhausted its potential. So all the Wenchang Formation samples are from well F in the Wenchang B depression.

II. Ways to finish this research

A. Organic Geochemistry

- TOC and Rock-Eval pyrolysis

  ——22 samples were collected from F2 well and 42 from F4 well

- Organic petrography

  ——47 samples from F4 well

- Gas-chromatography (GC) and GC-mass spectrometry (GC-MS)

  ——14 samples from E_3e source rock and 6 from E_2w source rock

B. Inorganic Geochemistry

- Trace element

  ——50 samples from F2 well

Presenter's notes: Section II, Ways to finish this research. In this study we used conventional techniques to finish this research. The organic and inorganic data agree with each other, which makes its more reliable in source rock characterization.

III. Results of this research

A. Source Rock Heterogeneity

- The E_2w have a higher TOC contents and hydrogen index (HI) than the E_3e
- The E_2w show a strong heterogeneity

Table 1
The TOC and Rock-Eval parameters of the source rocks for the F2 and F4.

Well/Strata	TOC	S_1	S_2	S_3	T_{max}	HI
F2 well						
Mean values for E_3e (23)	1.23	0.11	2.87	0.54	433	201.88
Mean values for the E_2w_1 (11)	0.36	0.04	0.59	0.37	437	171.11
Mean values for the E_2w_2 (8)	2.05	0.79	13.26	0.57	443	638.44
F4 well						
Mean values for E_3e (7)	0.69	0.13	1.20	0.76	426	205.57
Mean values for the E_2w_1 (4)	0.31	0.06	1.04	0.39	440	334.98
Mean values for the E_2w_2 (11)	2.69	1.85	13.48	4.68	447	499.18

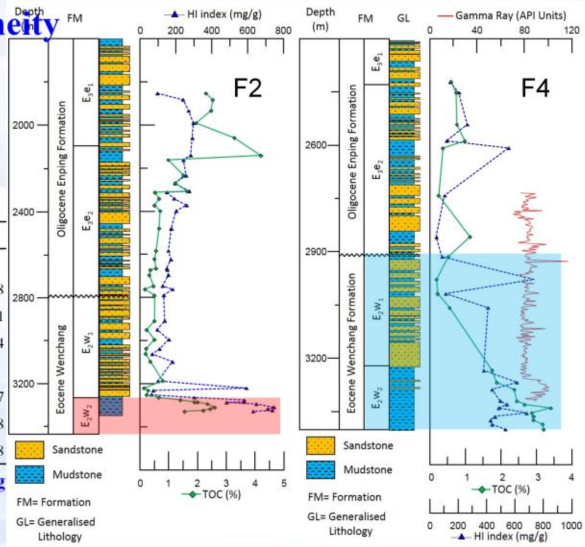


Fig. 5. Difference between the Eocene Wenchang Formation and Oligocene Enping Formation in lithology, organic matter abundance and type.

Presenter's notes: Section III, Results of this research. Source rocks display strong heterogeneity. The E_2w have a higher TOC contents and hydrogen index (HI) than the E_3e. Therefore, the E_2w has abundant oil-prone organic matter, the E_3e has less rich, gas-prone type organic matter. In addition, the E_2w shows a strong heterogeneity. Both the TOC contents and HI in the second member of the Eocene Wenchang Formation (E_2w_2) are dramatically higher than the first member of the Eocene Wenchang Formation (E_2w_1). Besides, as the Eocene Wenchang Formation has higher thermal maturity, we believe its original potential is greater.

III. Results of this research

A. Source Rock Heterogeneity

I. E_3e (2248m)
- Coaly: 40.2%
- Woody: 21.3%
- Herbaceous: 35.1%
- AOM: 3.4%

II. E_2w_1 (2912m)
- Coaly: 51.1%
- Woody: 17.3%
- Herbaceous: 31.6%
- AOM: 0%

III. E_2w_2 (3346m)
- Coaly: 2.5%
- Woody: 11.9%
- Herbaceous: 16.4%
- AOM: 69.2%

◆ **The E_2w is oil-prone kerogen type**

◆ **The E_3e is gas-prone kerogen type**

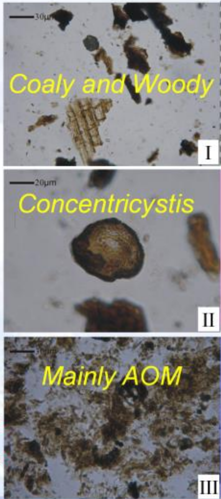
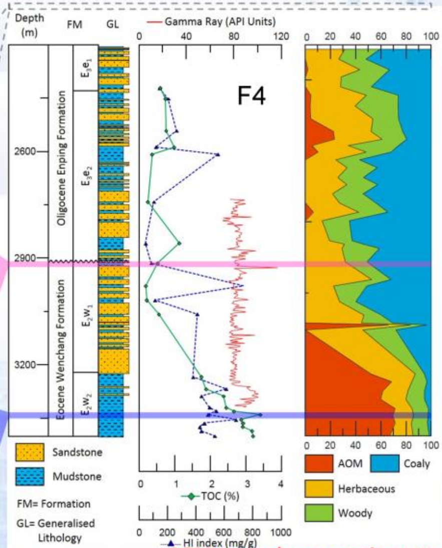


Fig. 6 Difference between the Eocene Wenchang Formation and Oligocene Enping Formation for well F4 in maceral



AOM: amorphous organic matter

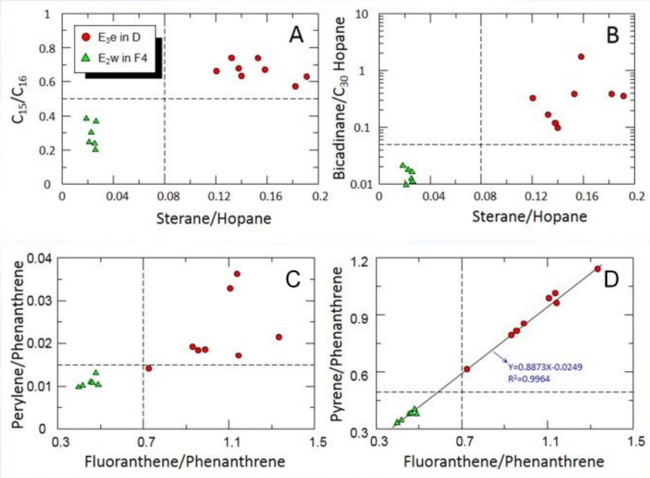
Presenter's notes: The organic petrography study reveals the Oligocene Enping Formation is composed mainly of coaly and woody maceral. On the contrary, the second member of the Eocene Wenchang Formation is mainly amorphous organic matter (AOM). So, the Wenchang Formation is oil-prone kerogen type and the Enping Formation is gas-prone kerogen type.

GC-MS: Saturated and Aromatic Hydrocarbon

III. Results of this research

B. Sources of Organic matter

◆ The E_3e received more contribution from terrestrial organic material



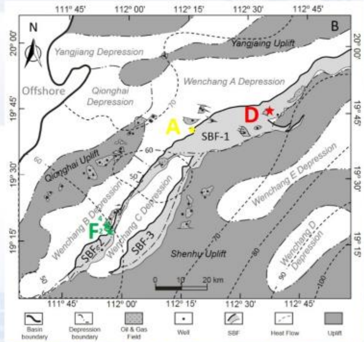


Fig. 7. Correlation between various biomarker parameters reflecting organic matter input in the Zhu III sub-basin, showing the differences in biomarker compositions

Presenter's notes: Sources of Organic Matter. The GC-MS measurement of saturated and aromatic hydrocarbon indicates that the Oligocene Enping Formation received more contribution from terrestrial organic matter.

GC-MS: Saturated and Aromatic Hydrocarbon

III. Results of this research

B. Sources of Organic matter

- The elevated S/H ratios for the E_3e are caused in part by the C_{28} sterane rather than C_{29} sterane
- The E_2w source rock received significant input of plankton and metazoan
- The property of E_3e in depocenter is similar to that of the E_2w but different from the E_3e in the slope
- The terrestrial organic matter is probably transported from the slop to the depression

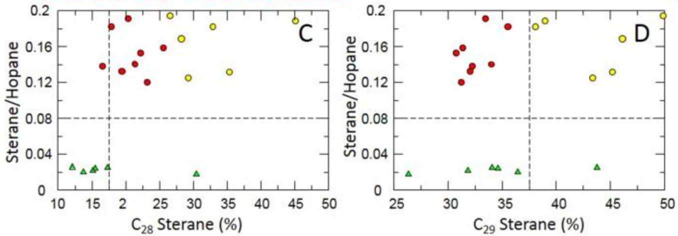


Fig. 8. Variation of Sterane/Hopane with C_{28} sterane and C_{29} sterane

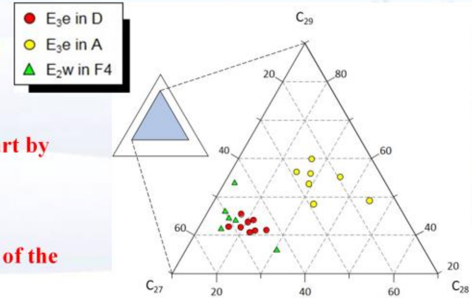
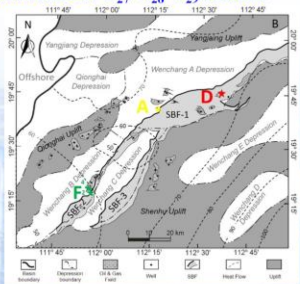


Fig. 9. Ternary diagram of the relative abundance of C_{27}-C_{28}-C_{29} sterane



III. *Results* of this research

C. Water Salinity

- The water salinity increased from the Eocene to Oligocene
- The water salinity correlated well with sedimentary cycle

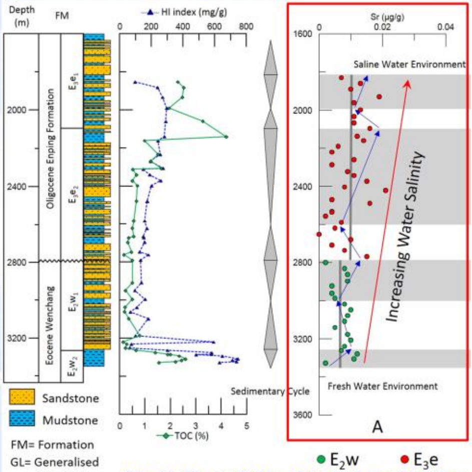


Fig. 10. The variation of trace elements with sedimentary cycle and lithology for well F2 which encounters both the E2w and E3e, showing the different water salinity during the Eocene and Oligocene.

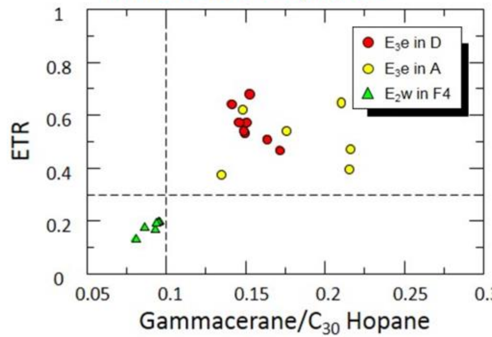


Fig. 11. Cross plot of ETR and Gam/C30 Hopane reflecting the different water salinity during the E2w and E3e source rock deposition

III. Results of this research

D. Redox Conditions

- **The environment is more reducing when the Eocene;**
- **Reducing environment is the precondition of the preservation of AOM. In other words, the presence of AOM indicates the water environment is reducing;**
- **The redox condition is stable during the Eocene but unstable during the Oligocene;**

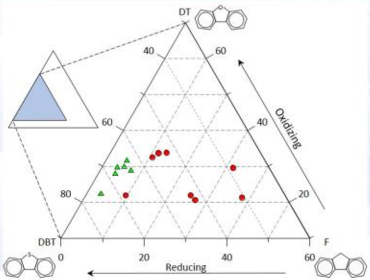


Fig. 12. Ternary diagrams of the relative abundance of F-DT-DBT (B) showing the redox conditions

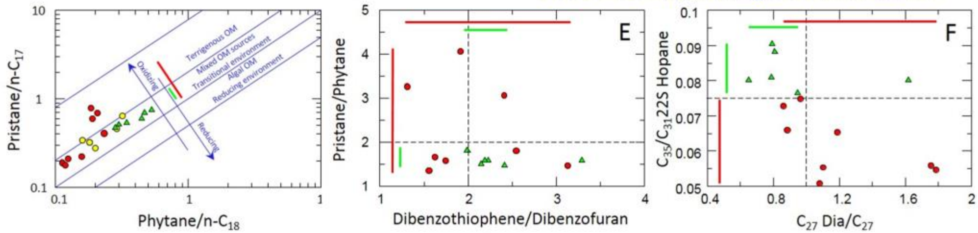


Fig. 13. Correlation between various biomarker parameters reflecting redox conditions in the Zhu III sub-basin. Pay attention to the scatter of the E_3e samples.

III. Res

D. Redox C

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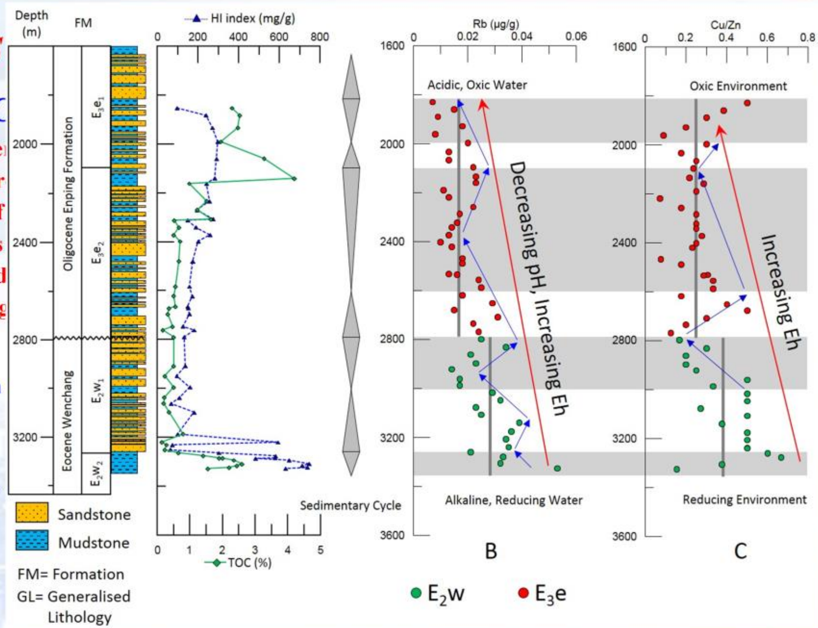
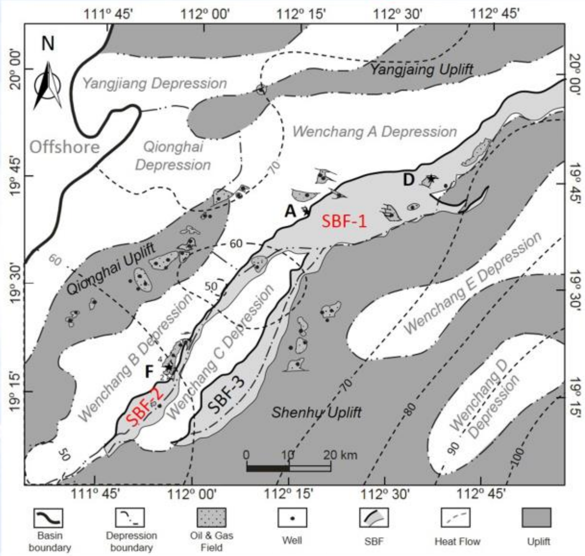


Fig. 14. The variation of trace elements with sedimentary cycle and lithology for well F2 which encounters both the E_2w and E_3e, showing the different redox conditions during the Eocene and Oligocene.

III. *Results* of this research

	Geochemical characteristic	Geological implication
E_3e	• Low TOC contents and hydrogen index; • Low AOM contents but high coaly material; • High S/H, Bicadinane/C_{30}H, C_{15}/C_{16}, C_{28}%, C_{29}%, fluoranthene, perylene, pyrene; • High Gam/C_{30}H, ETR, Pr/Ph, C_{27}Dia/C_{27}; • Low DBT and C_{35}/C_{31}; • Samples are scattered;	• Gas-prone kerogen type; • Significant terrigenous higher plants input; • High eukaryotic organisms input which is contributed by chlorophyll-c containing phytoplankton and some special higher plant species; • Saline and less reducing water column; • Unstable depositional environment;
E_2w	• High TOC contents and hydrogen index; • High AOM contents but low coaly material; • Low S/H, Bicadinane/C_{30}H, C_{15}/C_{16}, C_{28}%, C_{29}%, fluoranthene, perylene, pyrene; • Low Gam/C_{30}H, ETR, Pr/Ph, C_{27}Dia/C_{27}; • Low DBT and C_{35}/C_{31}; • Samples are agminated;	• Oil-prone kerogen type; • Low terrigenous higher plants input; • High prokaryotic organisms input; • Fresh and reducing water column; • Stable depositional environment;

IV. Source rock depositional models



◆ South Boundary Fault (SBF) controlled the formation and evolution of Wenchang A and B depression

➢ E_2w:

Sedimentary supply rate<fault active rate

➢ E_3e:

Sedimentary supply rate>fault active rate

IV. Source rock depositional models

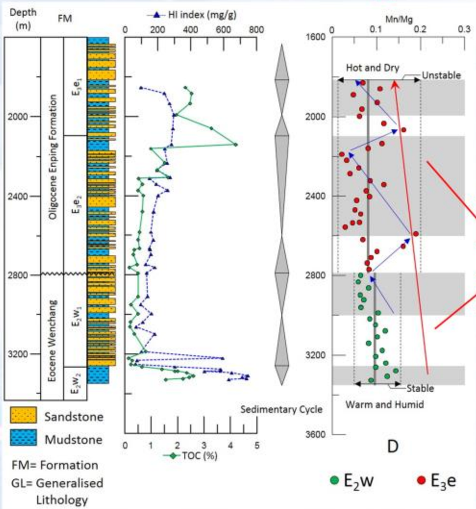
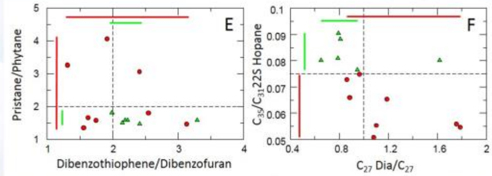
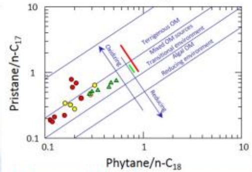


Fig. 15. The variation of trace elements with sedimentary cycle and lithology for well F2 which encounters both the E_2w and E_3e, showing the different weather conditions during the Eocene and Oligocene.



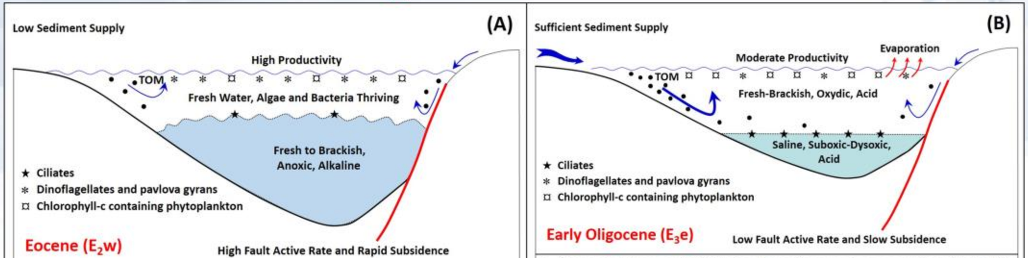
Water is shallow

Water is deep



- During the Oligocene, the weather became more hot and dry as can be evidenced from the variation of Mn/Mg ratios
- The Mn/Mg ratios of the E_3e samples are more scattered than the E_2w
- The shallow water column may makes it sensitive to external environment

IV. Source rock depositional models



(A)
- Rapid subsidence and low sediment supply result in sediment starvation.
- Low water inflow provide little terrigenous organic matter.
- High primary productivity, thriving of dinoflagellates and pavlova gyrans.
- Strongly bacteria re-work on organic matter (?).
- Shallow, unstable thermocline, euxinic and anoxic bottom conditions.

(B)
- Slow subsidence and sufficient sedimentary supply, progradational basin-fill.
- High water inflow provide massive terrigenous organic matter.
- Moderate primary productivity, thriving of chlorophyll-c containing phytoplankton.
- The strong evaporation leads to saline water environment.
- Deep, stable thermocline.

- **Tectonism controls sediment accumulation potential**
- **Climate controls water column property and source of organic matter**
- **Two source rock depositional models are put forward to explain their depositional process, which is primarily caused by the coevolution of tectonic subsidence and climate**
- **The primary productivity and depositional environment exhibit notable differences between the two potential source rocks horizons and show an obvious variation from the depocenter to the slope**
- **The co-variation of organic and inorganic indexes indicates the combination is a valid method in reconstructing source rock depositional models.**

Thank You for Watching