Study on the Recorded Highest Paleotemperature and Thermal Maturity Evolution of the Lower Paleozoic Marine Shales in the West of Middle Yangtze Region, Central China*

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Abstract

The Lower Paleozoic shales of marine strata in the western region of the middle Yangtze of central China are considered high degrees of thermal evolution. It is, however, very difficult to determine their thermal maturities (vitrinite reflectance, Ro) due to no vitrinite in organic material in the marine shales of the Lower Paleozoic formations. The objective in this study is to determine the highest paleogeotemperature and then to reconstruct thermal maturity evolution history of the Lower Paleozoic marine shales in the western central Yangtze area using basin modeling technology with the data from thermo-acoustic emission experiments, bitumen reflectance measurements, kerogen FTIR (Fourier transform infrared spectroscopy) analysis. The results of thermo-acoustic emission experiments illustrate that the Lower Paleozoic marine shales have a good thermal Kaiser effect and the rock thermo-acoustic emission signals regularly vary with geotemperatures. The experienced highest paleogeotemperatures of the Lower Cambrian strata change from 293.3 degrees Celsius to 324.4 degrees Celsius, and the highest paleogeotemperatures of the Upper Ordovician-Lower Silurian strata change from 210.4 degrees Celsius to 256.5 degrees Celsius. Furthermore, the sensitivity of thermal Kaiser effect has been tested by reheating the rocks experiments, suggesting the thermo-acoustic emission can be applied to the measurements of the marine shale experienced highest paleogeotemperatures. Combined with the measured highest paleotemperatures and referred to the bitumen reflectance values as the constraints, the thermal maturity modeling of Lower Paleozoic marine shales has been carried out, the results of the thermal maturity modeling demonstrate that the modeled values of vitrinite reflectance (Ro) for the Lower Cambrian and Upper Ordovician-Lower Silurian marine shales range between 3.5% and 4.0% and 2.5% to 3.0%, respectively. The organic matter maturations in the Lower Cambrian and Upper Ordovician-Lower Silurian marine shales are in the stage of high thermal evolution with over-maturities, consistent with the characteristics of kerogen FTIR analysis in the Lower Paleozoic marine formations.

Selected Reference

Ganz, H., and W.D. Kalkreuth, 1991, IR classification of kerogen type, thermal maturation, hydrocarbon potential and lithological characteristics: Journal of Southeast Asian Earth Sciences, v. 8/1-4, p. 19-28.

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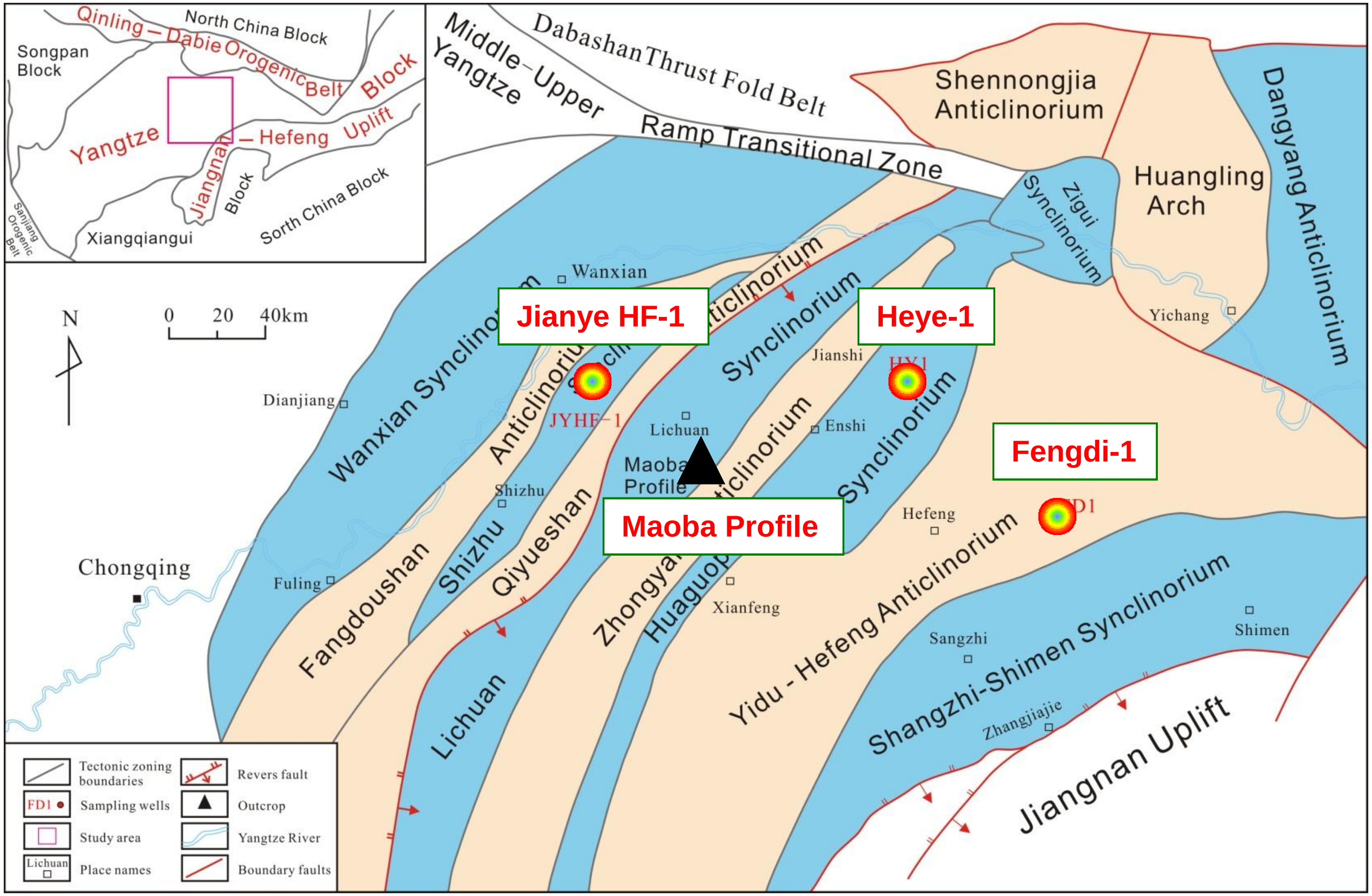
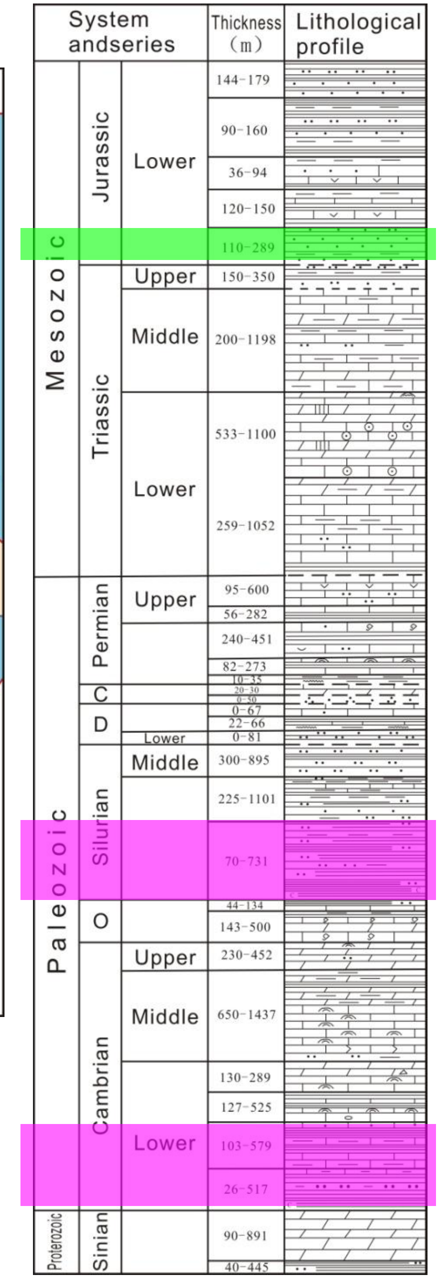
Outline

1. Geological setting
2. Thermo-acoustic emission experiments
3. The model of thermal maturity evolution
4. Kerogen FTIR analysis
5. Conclusions

1. Geological setting





Structural sketch map of the west of middle Yangtze region and the locations of wells & field profile

1. Geological setting

Shuijingtuo and Wufeng-Longmaxi strata are the two main sets of marine shales in the Lower Paleozoic Formations.

Shale characteristics:

Net thickness:

100~400m.

TOC:

Equals 2%~6%, upmost to 14.1%

Types:

Mainly Type Ⅱ$_1$

Maturity:

R_o equals 2%~6%

Buried depth:

700~6000m.

Shuijingtuo Formation

Net thickness:

20~70m

TOC:

Equals 1.5%~3.5%, upmost to 5.28%

Types:

Mainly Type Ⅱ$_1$

Maturity:

R_o equals 1.8%~4. 9%

Buried depth:

471~6000m.

Wufeng Formation –Longmaxi Formation

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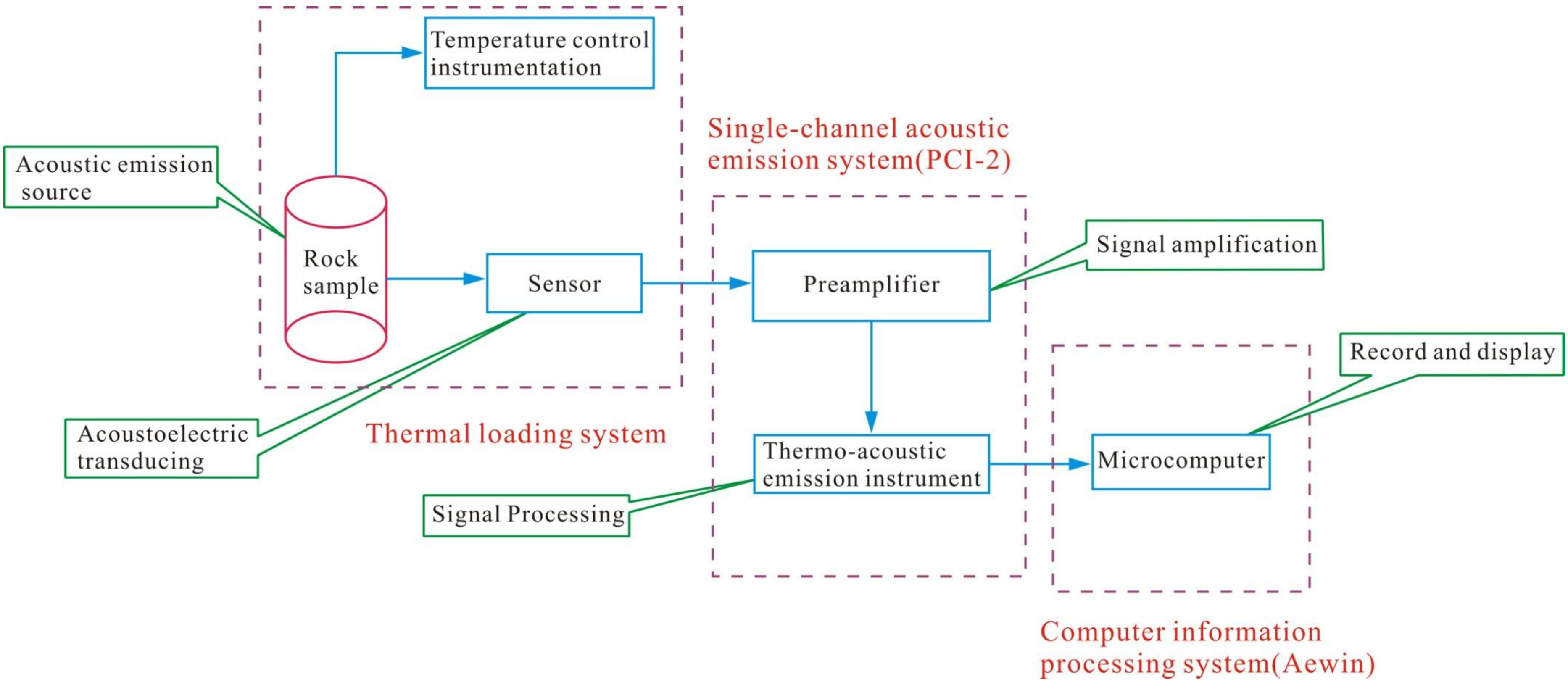
2.1 Experimental equipment

Due to the different expansion coefficients within the mineral grains, the accumulated elastic strain energy of rock is released as a stress wave under thermal loading. – thermo-acoustic emission (Yuan Z M et al, 1991).



Flowing chart of the thermo-acoustic emission instrument

2. Thermo-acoustic emission experiments

2.2 Experimental samples

15 samples collected:

- siltstone
- fine-grained sandstone
- argillaceous siltstone
- Mudstone
- a small amount of coquina and calcareous mudstone.

18 core plugs prepared:

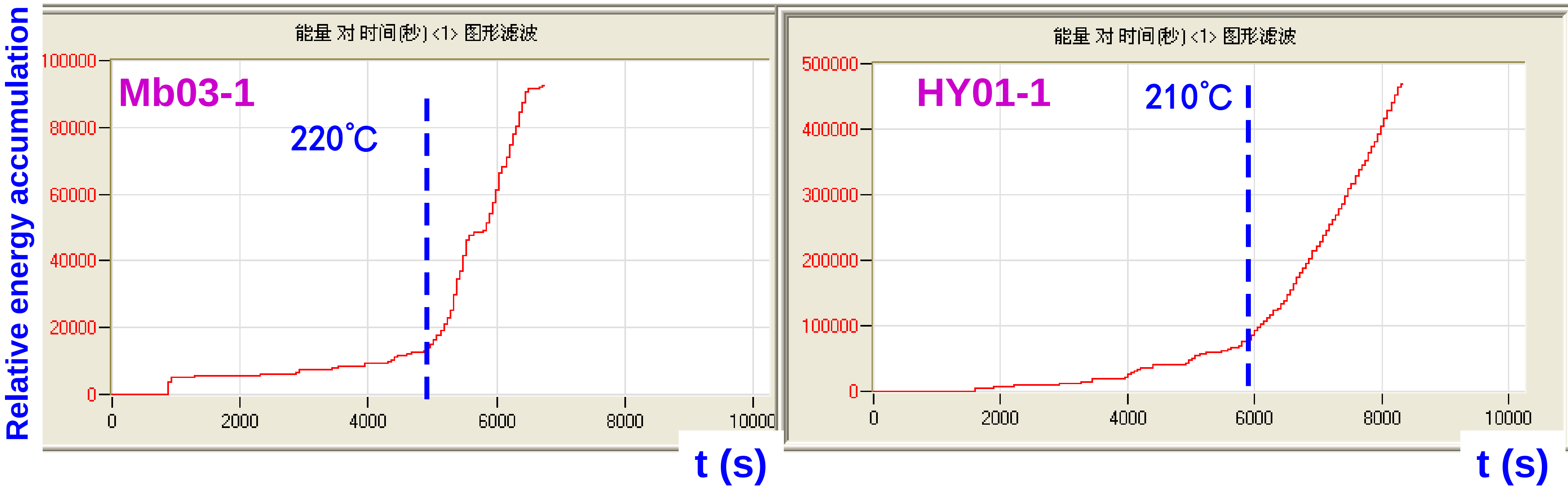
- 2.5cm in diameter, 2-4cm in height, top and bottom flat and smooth, no cracks.

Siltstone， Well Heye-1, 1992.16m

Core plugs

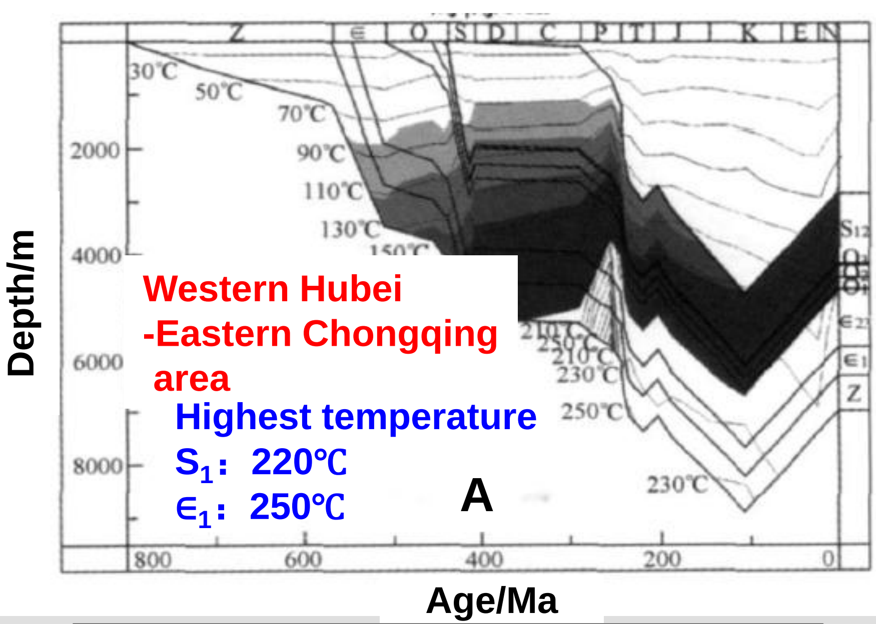
2.3 Experimental scheme

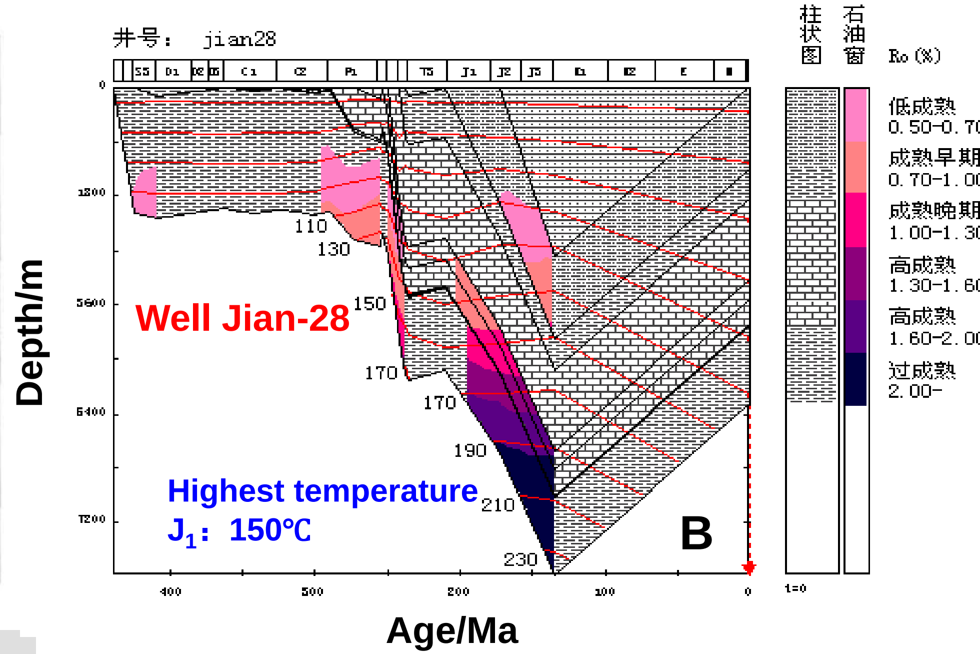
Relative energy accumulation is employed to measure the thermal Kaiser effect and points in this experiment. Heating rate is 2℃/minute, and initial temperatures range from room temperature to 50℃.

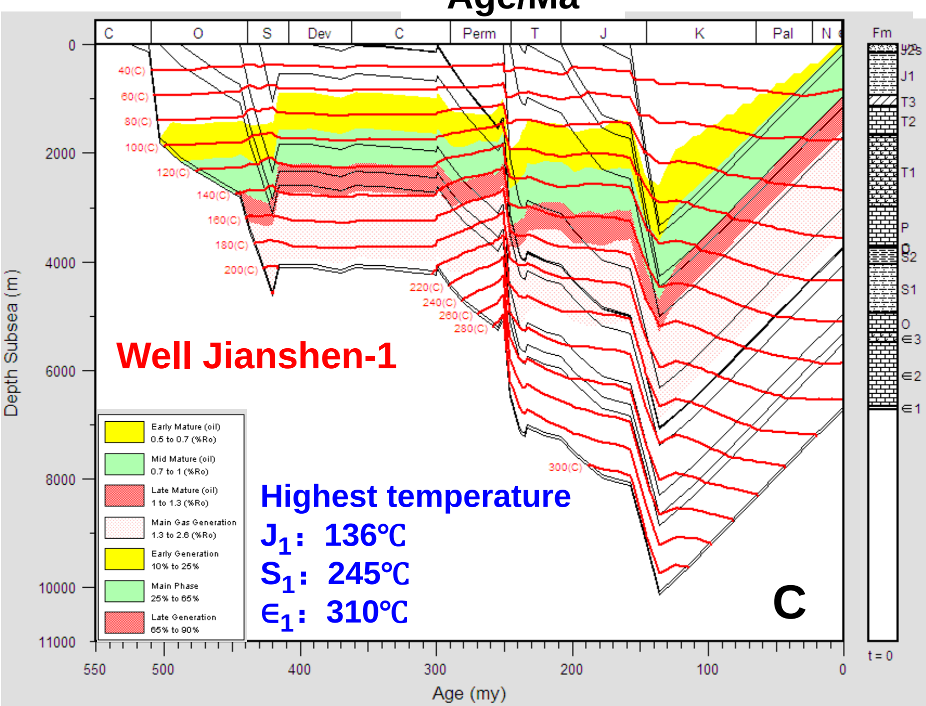


The relationship between thermo-acoustic emission characteristics and temperature

2.4 Final temperatures setting







Final temperatures：

Dongyuemiao Member: 220℃/232 ℃

Wufeng Formation: 320℃

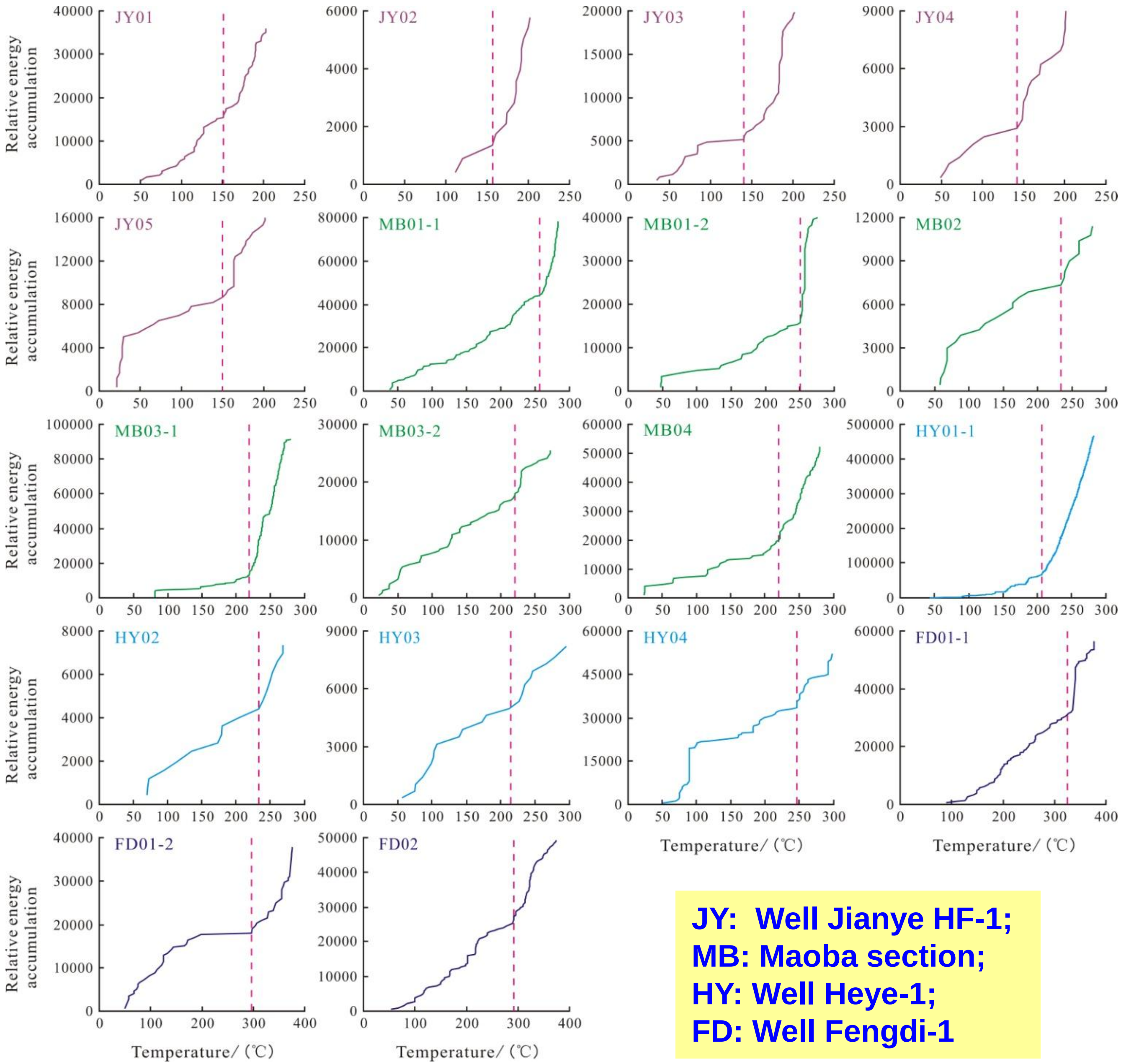
Longmaxi Formation: 300℃

Shipai Formation: 400℃

A: Tao s et al, 1999; B: Hu S B et al, 2005; C: He S et al, 2008

2.5 Test results

The experienced highest paleogeotemperatures



Lower Cambrian strata: 293~324℃;

Upper Ordovician-Lower Silurian strata : 210~257℃;

Lower Jurassic: 142~157℃, in accord with other scholars' research results of fission track and thermal maturity evolution modeling.

JY: Well Jianye HF-1;
MB: Maoba section;
HY: Well Heye-1;
FD: Well Fengdi-1

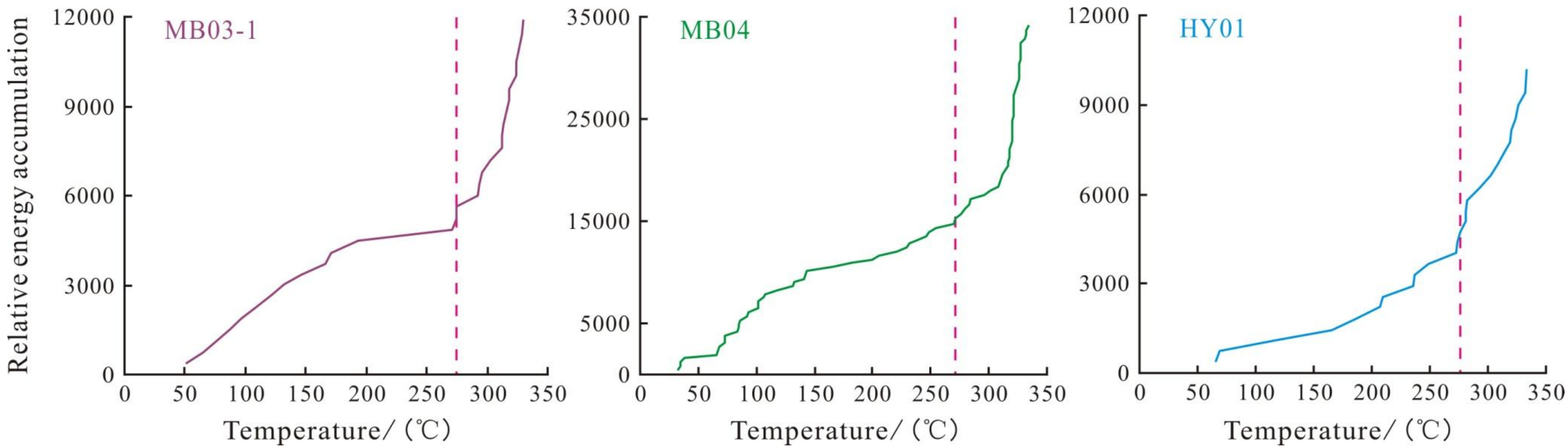
2.5 Test results

Well/Field profile	Stratigraphy	Sample ID	Lithology	Depth (m)	Initial temperature(℃)	Final temperature(℃)	Measured temperature of columns(℃)	Highest Paleo-temperature (℃)
JYHF-1	J_1dy	JY01	Mudstone	571.02	44	220	202.9	151.5
JYHF-1	J_1dy	JY02	Calcareous mudstone	601.57	49	232	216.7	156.5
JYHF-1	J_1dy	JY03	Coquina	622.82	34	220	202.6	144.1
JYHF-1	J_1dy	JY04	Mudstone	627.43	50	220	204.5	141.8
JYHF-1	J_1dy	JY05	Mudstone	644.07	25	220	202.6	150.2
MB	S_1l	Mb01-1	Fine sandstone	/	36	300	283.5	256.5
MB	S_1l	Mb01-2	Fine sandstone	/	48	300	280	250.3
MB	S_1l	Mb02	Siltstone	/	48	300	278.3	234.3
MB	S_1l	Mb03-1	Siltstone	/	49	300	279.7	219.5
MB	S_1l	Mb03-2	Siltstone	/	24	300	279.4	220.9
MB	S_1l	Mb04	Siltstone	/	23	300	280	219.8
HY1	S_1l	HY01	Siltstone	1992.16	43	300	281.9	210.4
HY1	S_1l	HY02	Mudstone	2157.5	50	300	278.9	233.8
HY1	S_1l	HY03	Mudstone	2159.5	20	300	279.3	214.5
HY1	O_3w	HY04	Mudstone	2161	50	320	297.7	246.8
FD1	ϵ_1sp	FD01-1	Argillaceous siltstone	1663.97	29	400	377.1	324.4
FD1	ϵ_1sp	FD01-2	Argillaceous siltstone	1663.97	25	400	375.3	296.5
FD1	ϵ_1sp	FD02	Siltstone	1664.67	51	400	374.7	293.3

2. Thermo-acoustic emission experiments

2.6 Thermal Kaiser effect tests

Sample name	Initial temperature (℃)	Final temperature of temperature control instrumentation (℃)	Highest measured temperature of the second heating (℃)	Highest test temperature of the second heating (℃)	Highest measured temperature of the first heating (℃)	Temperature difference (℃)
Mb03-1	42	360	334.5	274.8	279.7	4.9
Mb04	23	360	334.8	270.9	280	9.1
HY01	68	360	334.2	275.6	281.9	6.3



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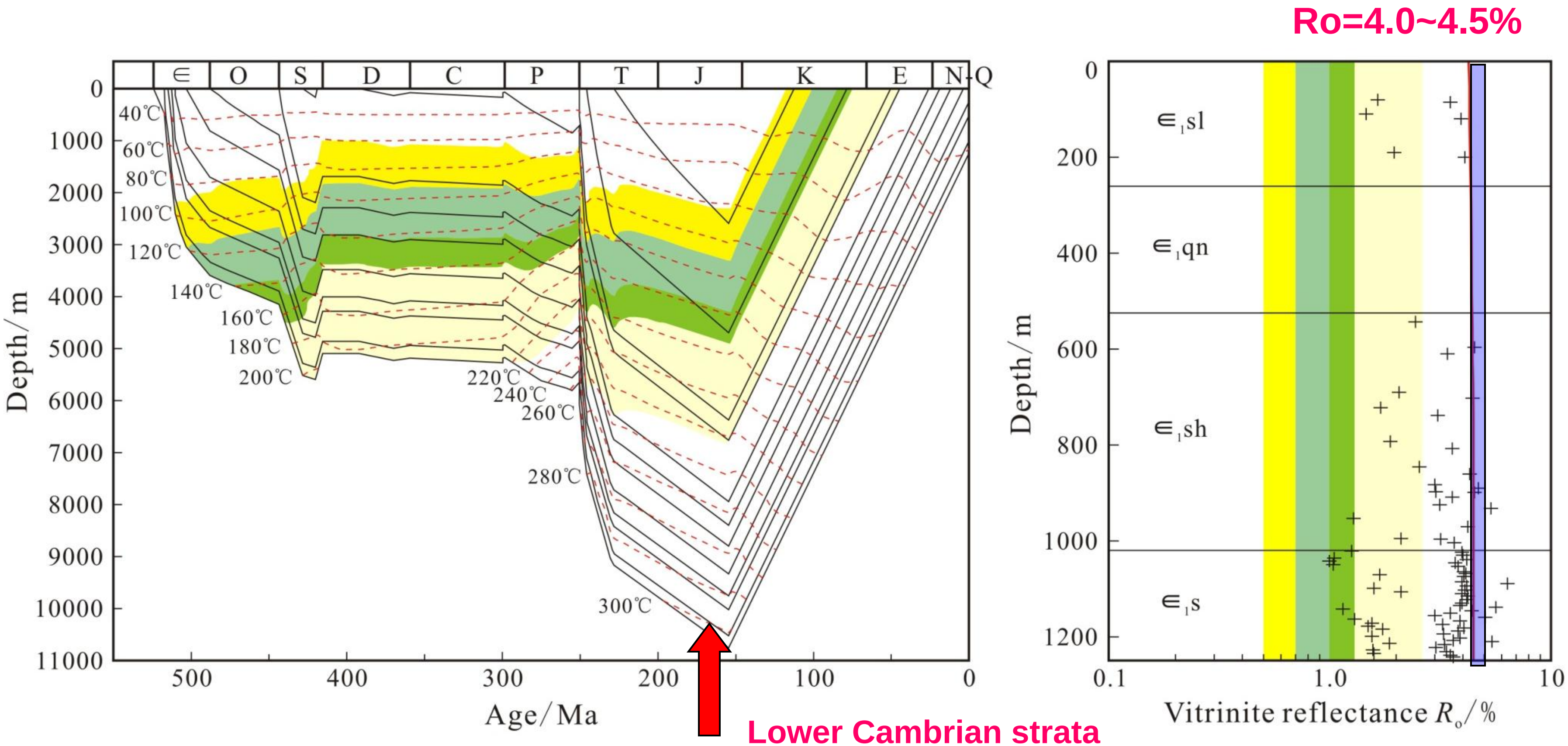
3. The model of thermal maturity evolution

3.1 Well Fengdi-1

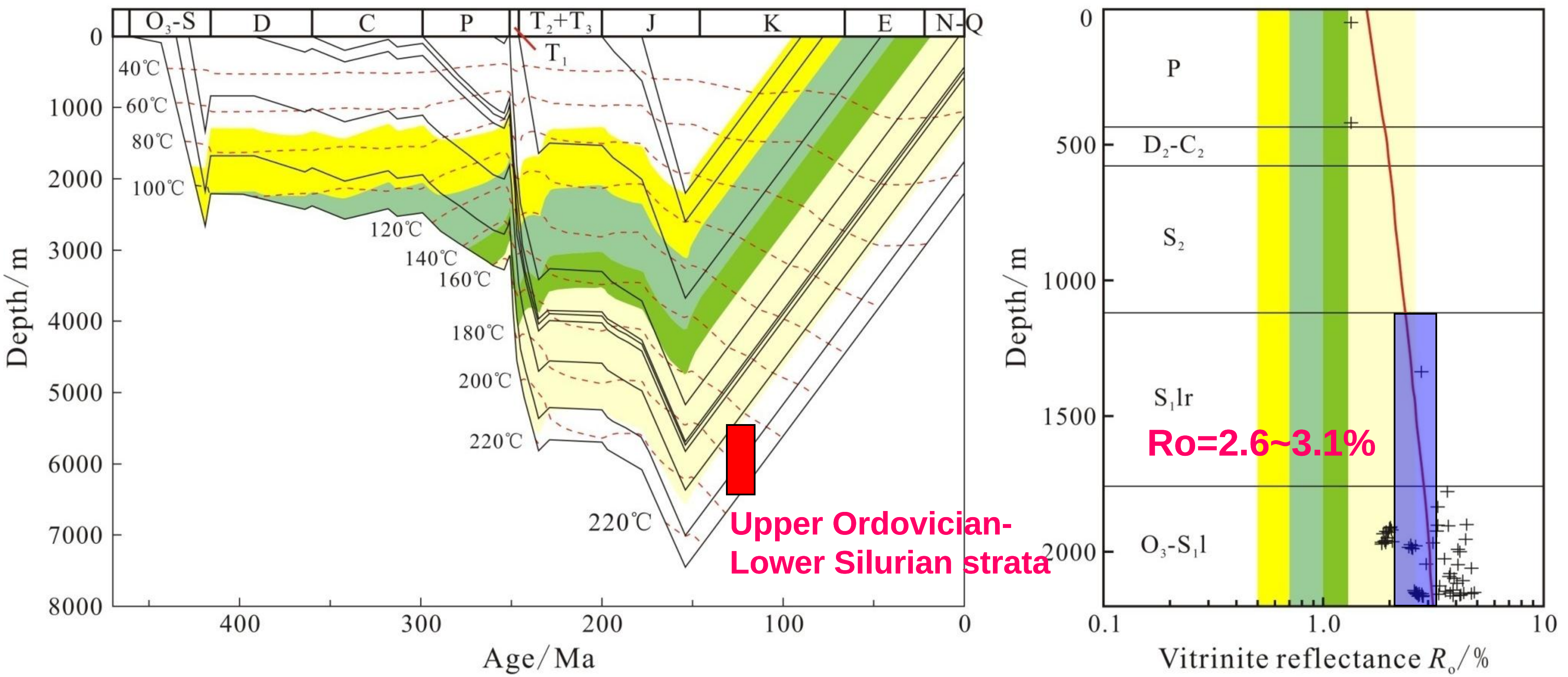
The modeling values of vitrinite reflectance (R_o) in the Lower Cambrian strata change from 4.0% to 4.5%, beyond the maturation threshold of gas generation(3.0%).



The model of thermal maturity of Well Fengdi-1

3.2 Well Heye-1

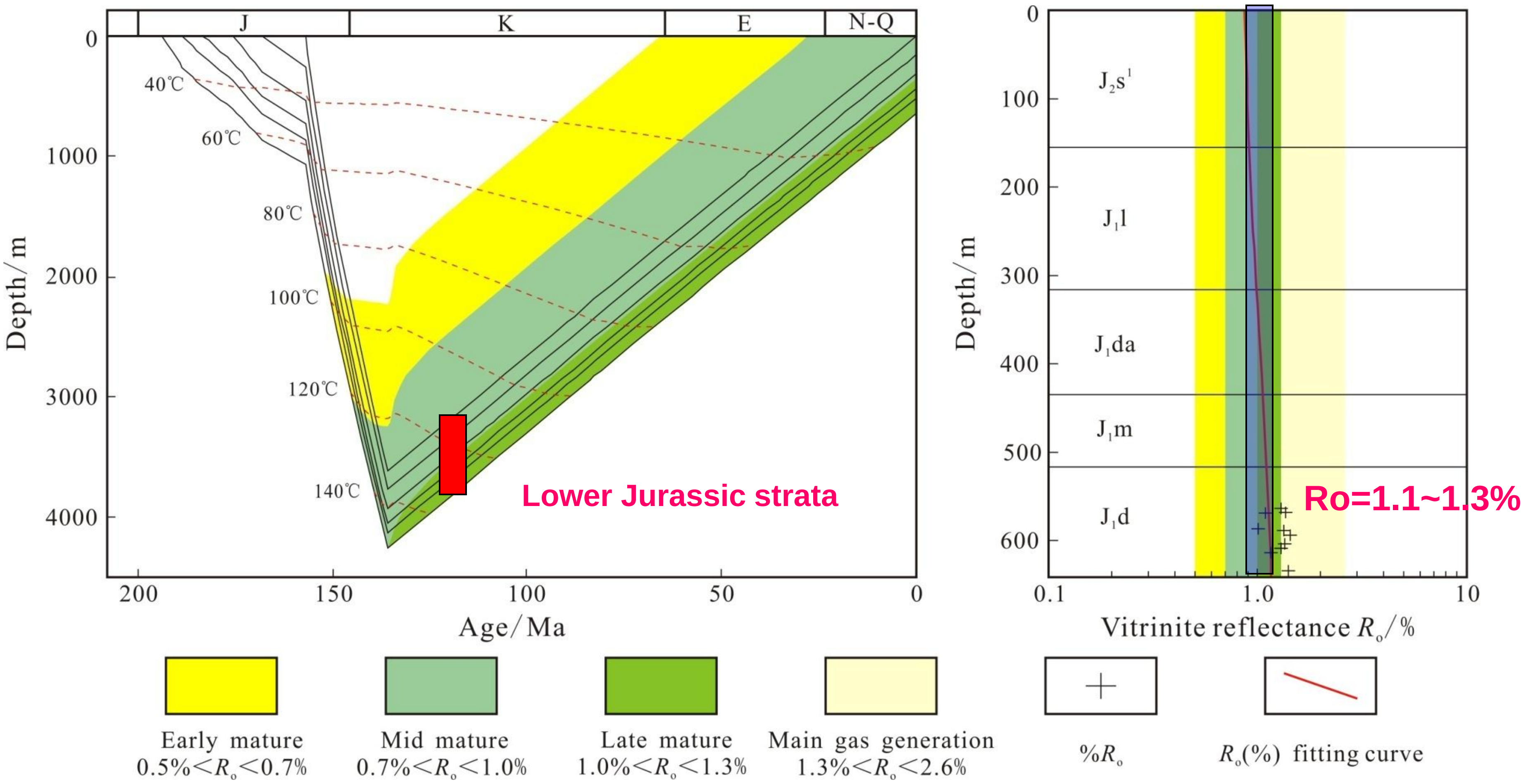
The modeling values of vitrinite reflectance (Ro) in the Upper Ordovician-Lower Silurian strata range between 2.6% and 3.1%. Part of them are beyond the maturation threshold of gas generation.



The model of thermal maturity of Well Heye-1

3.2 Well Jianye HF-1

The modeling values of vitrinite reflectance (Ro) in the Lower Jurassic strata change from 1.1% to 1.3%, within the range of the measured values (1.0%-1.4%).



The model of thermal maturity of Well Jianye HF-1

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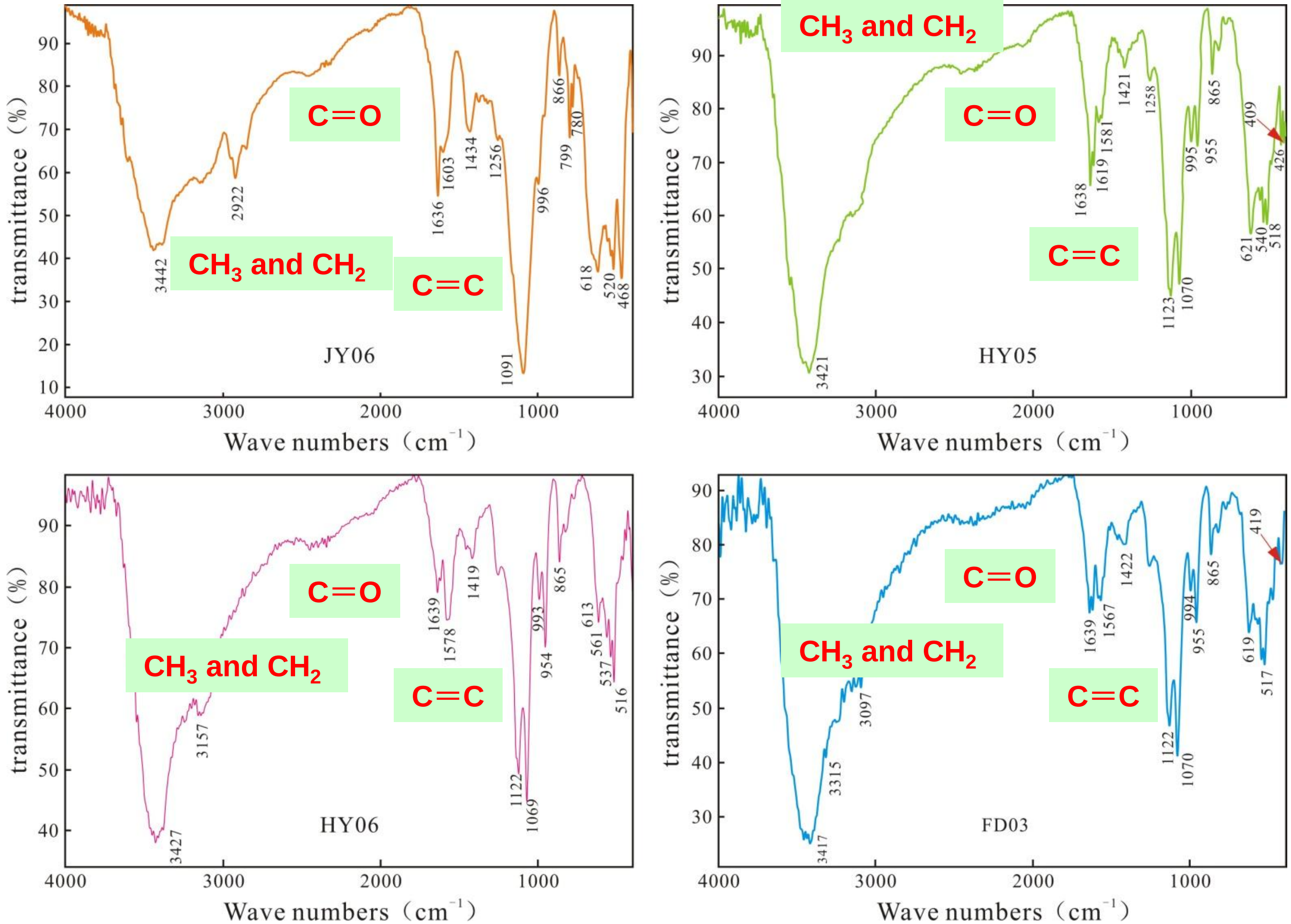
4. Kerogen FTIR analysis

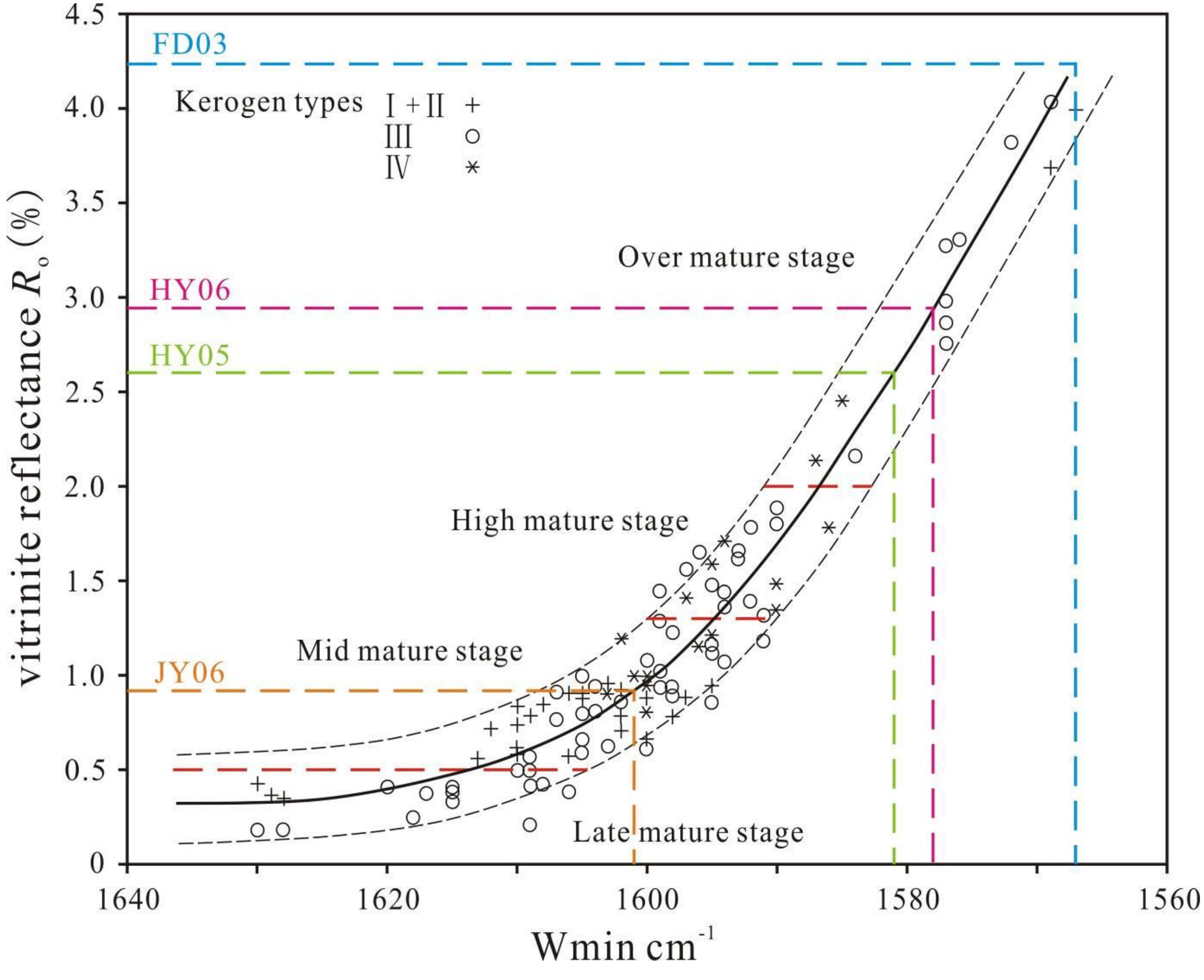
Kerogen FTIR characteristics

Wmin: FD03=1567cm^{1};HY06=1578cm^{-1}; HY05=1581cm^{-1}; JY06=1603cm^{-1}.



JY06: Dongyuemiao Member of Ziliujing Formation, 574m; HY05: Longmaxi Formation, 2152.9m; HY06: Wufeng Formation, 2164.98m; FD03: Shuijingtuo Formation, 2425.99m

R_o: FD03 is 4.2%, HY06 is 2.9%, HY05 is 2.6%, and JY06 is 0.9%.



Correlation between R_o and the minimum wavenumbers of the aromatic C=C bands(Wmin)
(Ganz and Kalkreuth, 1991, revised)

5. Conclusions

- **The experienced highest paleogeotemperatures of the Lower Cambrian strata change from 293 to 324℃, and the highest paleogeotemperatures of the Upper Ordovician-Lower Silurian strata range from 210 to 257℃.**
- **The modeling values of vitrinite reflectance (R_o) for the Lower Cambrian and Upper Ordovician-Lower Silurian marine shales range between 4.0% and 4.5% and 2.6% to 3.1%, respectively.**
- **The characteristics of kerogen FTIR analysis demonstrate that the Lower Paleozoic marine shales have reached over-mature stage. Their vitrinite reflectances are 4.2%, 2.9% and 2.6% from Shuijingtuo Formation to Longmaxi formation, consistent with the results of the thermal maturity modeling.**

Acknowledgements

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