PS Geochemical Characterization, Depositional Environment, and Controlling Factors of β-Carotene - A Case Study of Jimsar Depression, Junggar Basin of China*

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Abstract

Relatively high abundance of β-carotane has been detected in some source rock extracts from Lucaogou Formation (LCG) of Jimsar Depression, Eastern Junggar Basin. A combined investigation of bulk geochemical study and molecular geochemical observation on 31 source rocks samples from LCG were carried out. The LCG is defined as good source rock with high hydrocarbon generation potential, indicated by high TOC (0.27%-13.90%), high hydrocarbon potential index (S1+S2, 0.15–109.01 mg HC/g) and low-maturity to maturity. The biomarkers of LCG source rocks extracts are characterized by short to long chain n-alkanes, a wide range of Pr/Ph (0.74-1.42) and β-Carotane (β-Carotane/Maximum Carbon, 0.16-1.92), high concentrations of C29 sterane, the presence of relatively low tricyclic terpanes and middle gammacerane index values (0.14-0.29). These are consistent with a relatively low oxidizing to low reducing depositional environment of fresh to brackish water conditions, with a major contribution of terrigenous organic matter input and a low contribution of aquatic algal-bacterial organic matter. Based on the correlation relationship between β-Carotane abundance and depositional environment and thermal maturity, it can be concluded that the β-Carotane of LCG is mainly derived from terrigenous organic matter and distributed in the brackish water conditions, low reducing depositional environment, but not affected by thermal maturity. However, β-carotane is mostly associated primarily with anoxic, saline lacustrine environment, and its biological origin was cyanobacteria and algae, historically. This study could provide a new research perspective for geological and geochemical significance of β-carotane and its application in oil-source correlation.

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1. Introduction

Historically, β-carotane is associated primarily with anoxic, saline lacustrine, or highly restricted marine settings, and its biological origin is cyanobacteria and algae (Peters et al., 2005). β-carotane has important significance in geology, geochemical and oil-source correlation, whereas previous studies on the geochemical characterization, deposition environment, and controlling factors of β-carotane within the Lower PermianLucaogou Formation in the Jimsar Sag of Junggar Basin were limited and not known. We have conducted a comprehensive investigation of bulk geochemical and molecular geochemistry on the Lower Permian Lucaogou Formation in the Jimsar Sag of Junggar Basin to reveal that the β-Carotane of Lucaogou source rocks in Jimsar Sag is mainly derived from terrigenous organic matter and mainly distributed in the brackish water conditions and low reducing depositional environment, not affected by thermal maturity.

2. Geologic setting

The Jimsar Sag with the total area of 1278 km^2 is located in the eastern uplift of Junggar Basin (Fig. 1a). The Sag is a dustpan-shaped depression with faulting in the west (Fig 1b) and has been the focus of tight oil exploration and development in China.

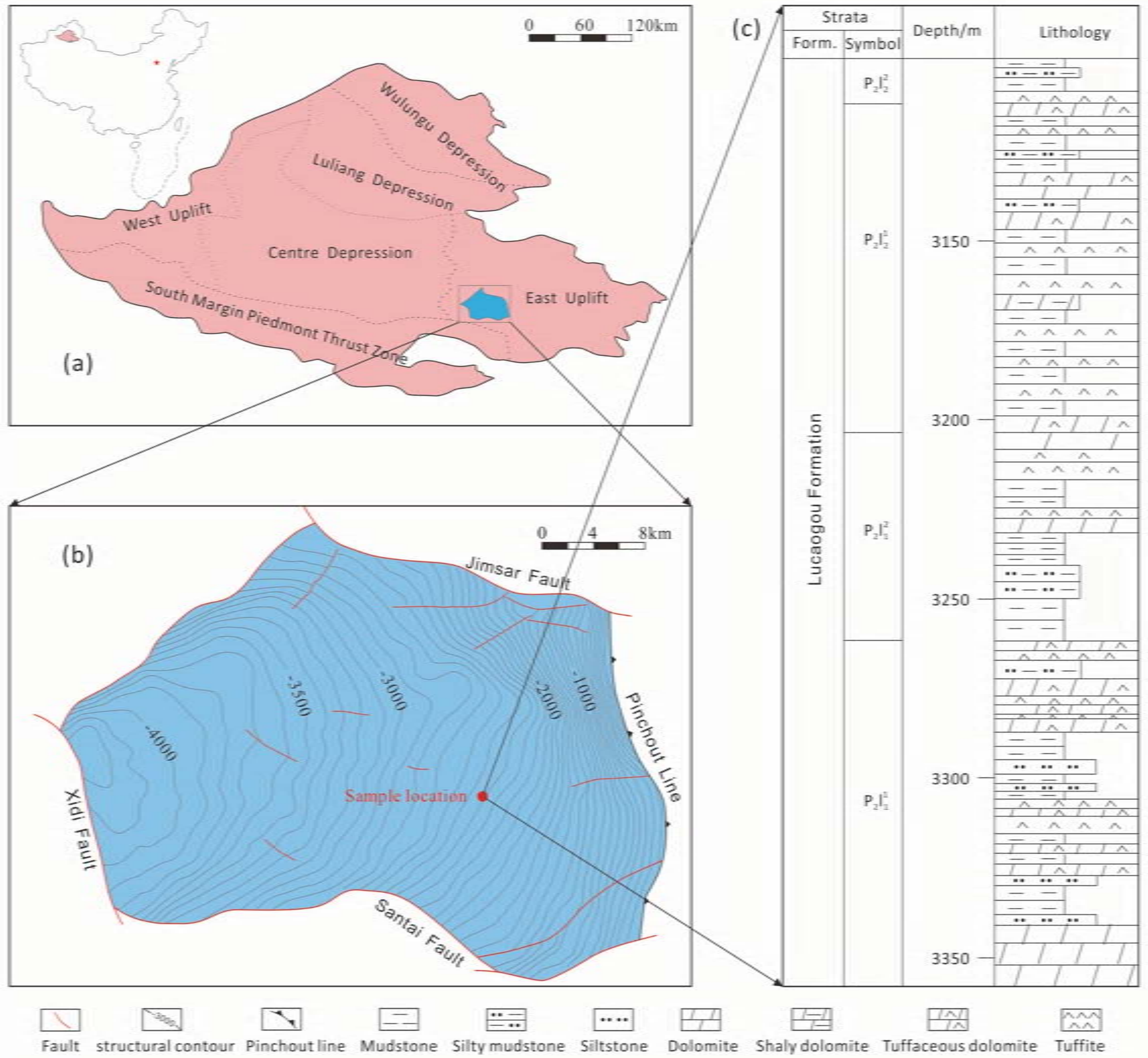

Fig.1 (a) Map of Junggar Basin in Northwestern China, showing the location of Jimsar Sag; (b) Structure contour map of the surface of the Lucaogou Formation of Jimsar Sag, showing well from which samples were taken; (c) The summary of lithological stratigraphy in the Jimsar Sag (Modified after Jiang et al., 2015). Form. =Formation.

In recent years much progress has been made in the Permian Lucaogou Formation, which is the primary exploratory stratum of tight oil reservoirs in the Jimsar Sag. Core and thin section observation and sample analysis show that the Lucaogou Formation is made up of thin lamellate tuffite and tuffaceous dolomite interbedded with mudstone and siltstone, with a thickness of 200~300m

3. Organic matter abundance and Rock-Eval pyrolysis

Lucaogou source rocks exhibit a wide range in TOC contents, laterally from 0.27% to 13.90%, and with average value of 2.63%. The average value of S_1 and S_2 of source rock samples are 1.20mg/g and 10.22mg/g, in the range of 0.01-11.70mg/g and 0.14-97.31mg/g respectively, showing that the source rocks have high organic matter abundance. Most of source rock samples have Rock-Eval T_{max} of 436-451℃, suggesting a low-maturity to maturity

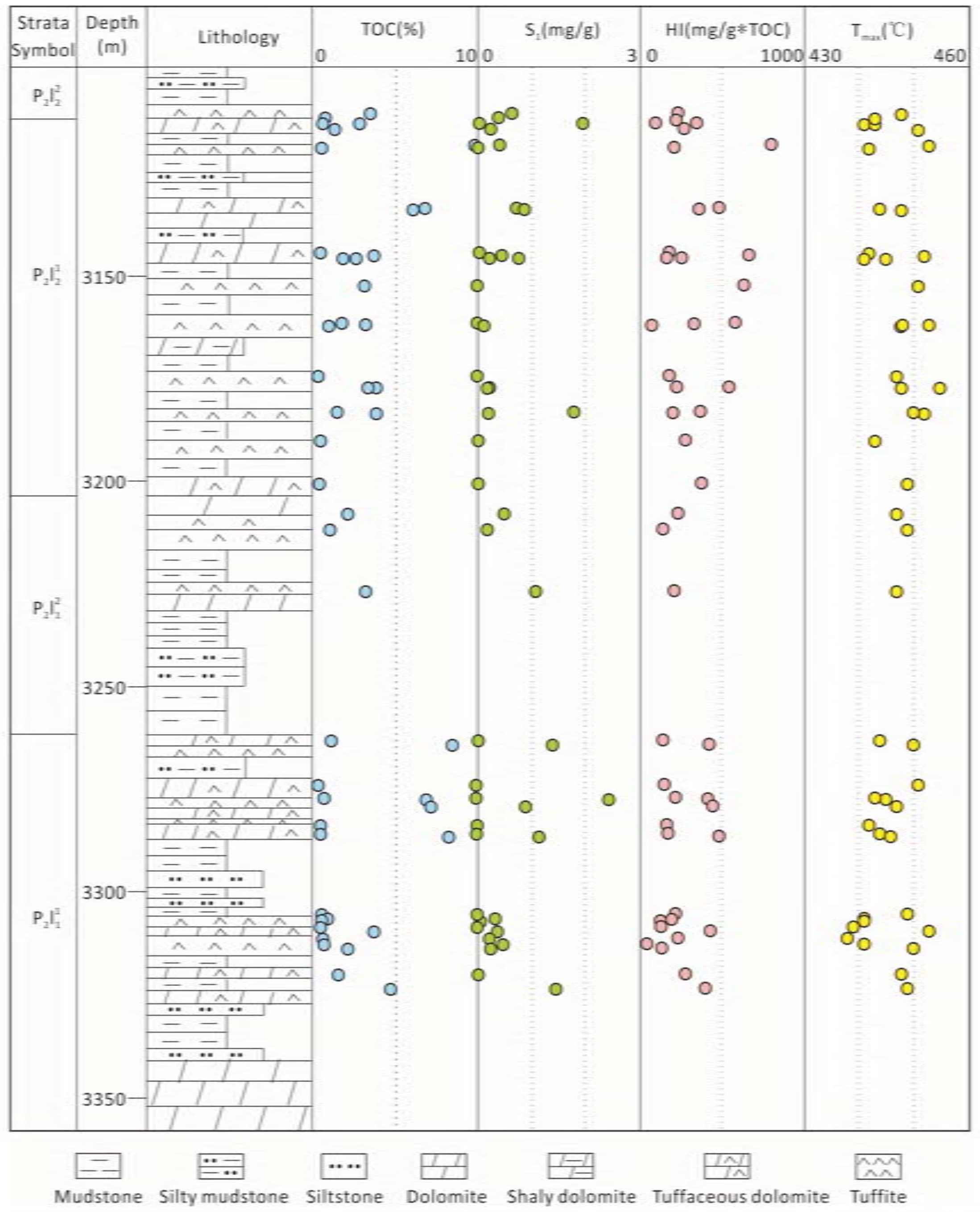

Fig. 2 Vertical variations in TOC, S_1, HI and Tmax data for tuffaceous sediments within the Lower Permian Lucaogou Formation in the Jimsar Sag of Junggar Basin. TOC=Total organic carbon (wt. %); S_1(mg/g), the amount of hydrocarbon of free; HI=S_2/TOC*100, S_2(mg/g), the amount of generated hydrocarbons; T_{max}(℃), the temperature of the maximum generation rate of kerogen cracking.

Plots of Pr/nC_{17} ratio versus Ph/nC18 ratio shown in Fig. 4 can also be used to infer redox condition of the source rock depositional environment (Peters et al., 1999), indicating a low oxidizing to low reducing depositional environment.

The samples show a higher proportion of C_{29} (39%-56%) compared to C_{27} (11%-32%) and C_{28} (29%-37%) steranes , reflecting a low contribution of aquatic algal-bacterial organic matter and major terrigenous organic matter input, as indicated by regular steranes ternary diagram (Fig. 5).

4. Molecular analysis

The source rocks extracts contain a full range of C_{13}-C_{31} nalkanes and isoprenoids, pristane and phytane. And the source rock samples of Lucaogou Formation display wide variation in β-Carotane. Tricyclic terpanes are low in the m/z 191 chromatograms of the Lucaogou Formation source rock extracts (Fig. 3)

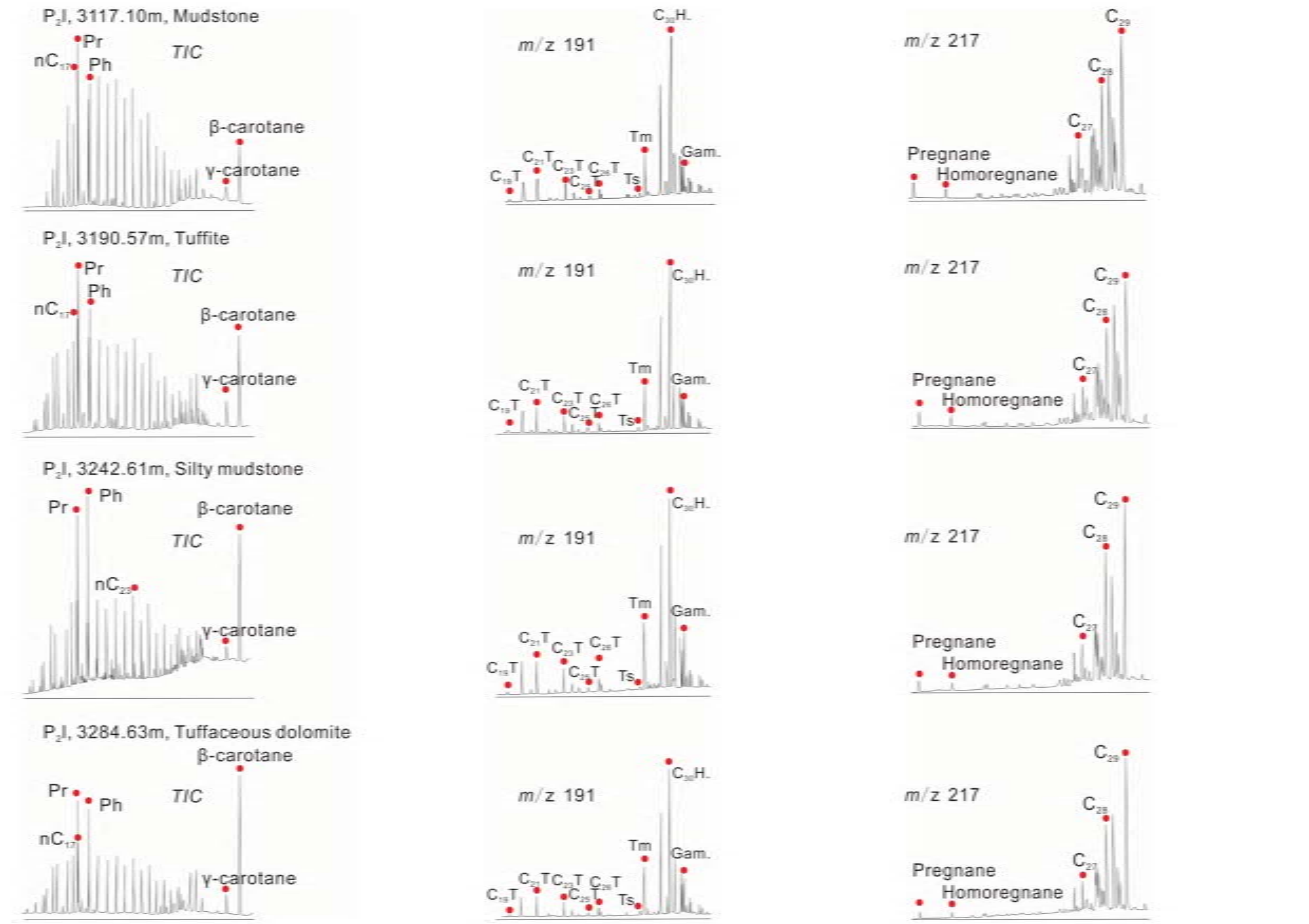

Fig. 3 Biomarker distribution of source rock of Lucaogou Formation in the Jimsar Sag . Show in the sequence of TIC, sterane (m/z 217) and terpane (m/z 191) distribution.

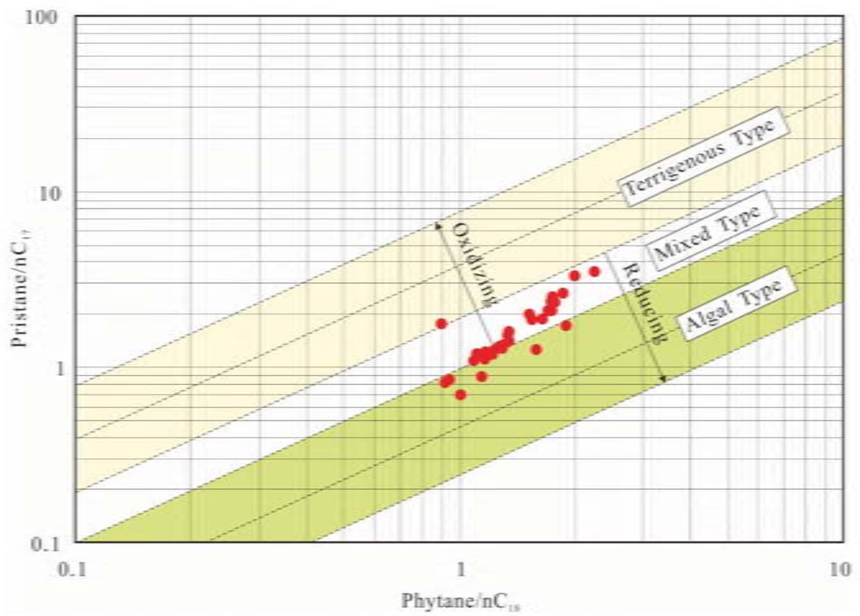

Fig. 4 Relationship between Ph/nC_{18} and Pr/nC_{17} ratio values for samples within the Lower Permian Lucaogou Formation in the Jimsar Sag of Junggar Basin (Modified after Peter et al., 1999).

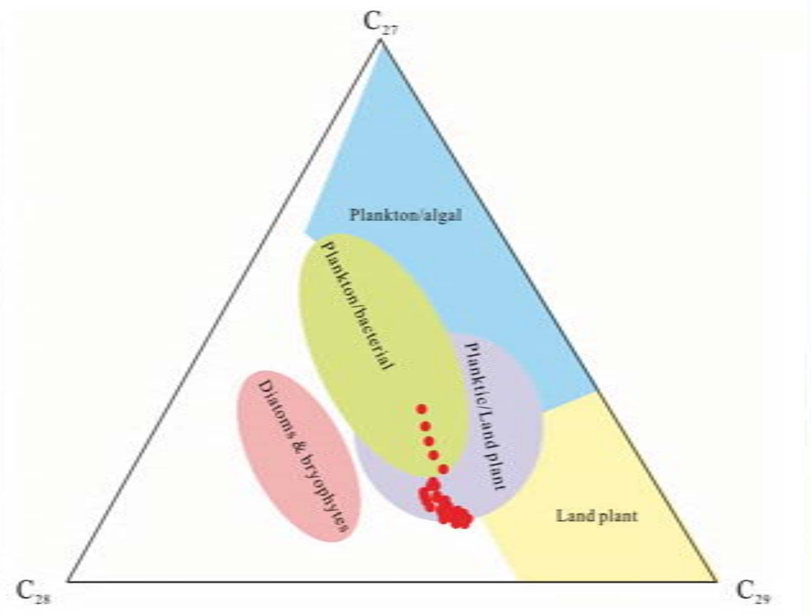

Fig. 5 Ternary diagram of C_{27}-C_{28}-C_{29} steranes for samples within the Lower Permian Lucaogou Formation in the Jimsar Sag of Junggar Basin (Modified after Adegoke et al., 2014).

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5. Relationship between thermal maturity and β-carotane

It is also critical to note that there is no obvious correlation between β-Carotane and the commonly used thermal maturity parameters C_{29}αββ/(αββ+ααα) and C_{29}ααα20S/(20S+20R). Therefore, we can conclude that the wide variations in β-Carotane could not have been caused by thermal maturity in the Jimsar Sag.

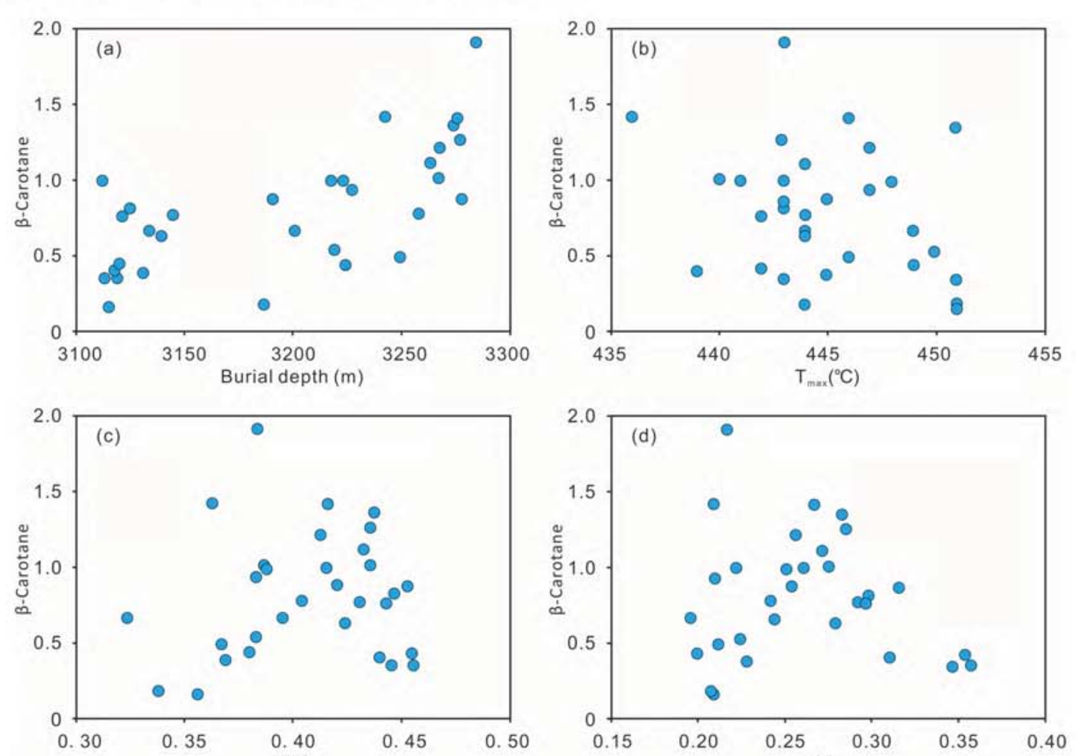

Fig. 6 Correlation between depth, Tmax, 20S and ββ reflecting organic matter maturity and β-Carotane in the Jimsar Sag.

6. β-carotane depositional environment

The β-Carotane decreases with increasing Pr/Ph and increase with increasing C_{35}/C_{34}, G/H and ETR. The correlation of β-Carotane with Pr/Ph, C35/C34, G/H and ETR indicate that the high abundance of β-Carotane is mainly distributed in the brackish water conditions and low reducing depositional environment, although low β-Carotane content is existed in the fresh water and oxic depositional environment.

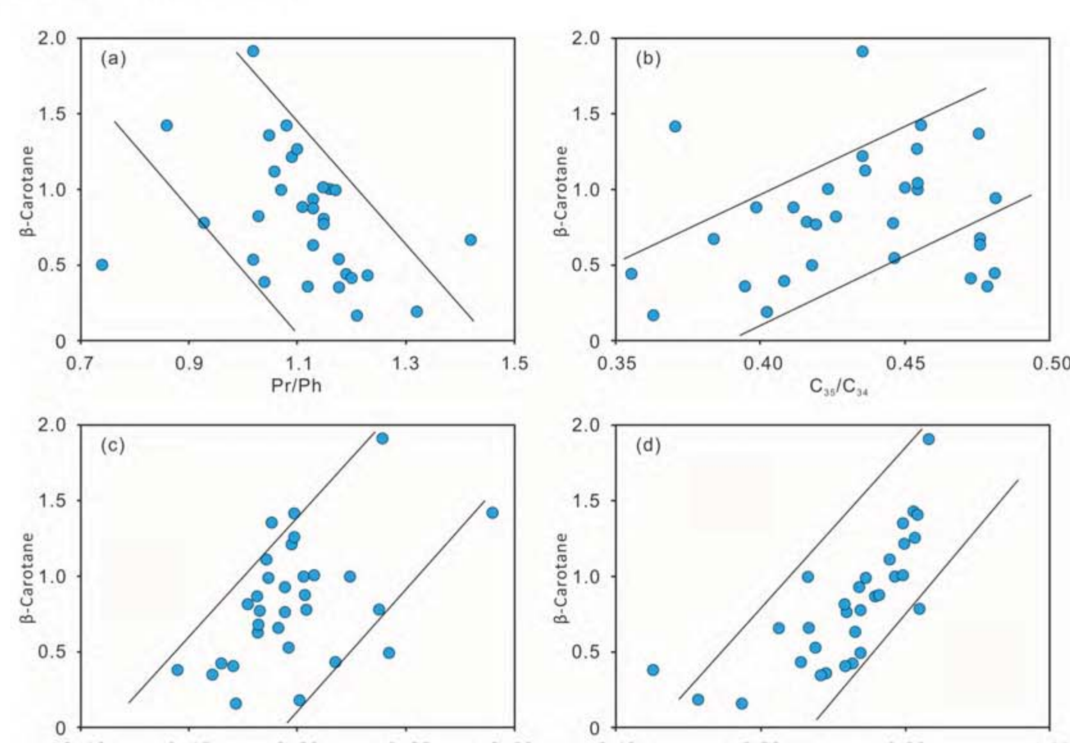

Fig. 7 Correlation between Pr/Ph, C_{35}/C_{34}, G/H, ETR and β-Carotane reflecting depositional environment of Lucaogou Formation of the Jimsar Sag, showing the relationship between redox conditions, salinity and β-Carotane.

7. Relationship between organic matter origin and β-carotane

The β-Carotane increases with increasing CPI, C_{29} sterane, $C_{26}T/C_{25}T$ and decreases with increasing C_{27} sterane and $C_{22}T/C_{21}T$. The correlation of β-Carotane with CPI, C_{29} sterane, $C_{26}T/C_{25}T$, C_{27} sterane and $C_{22}T/C_{21}T$ indicate that the biological origin of β-Carotane is mainly terrigenous organic matter input in Jimsar Sag, not aquatic algal-bacterial and algae organic matter.

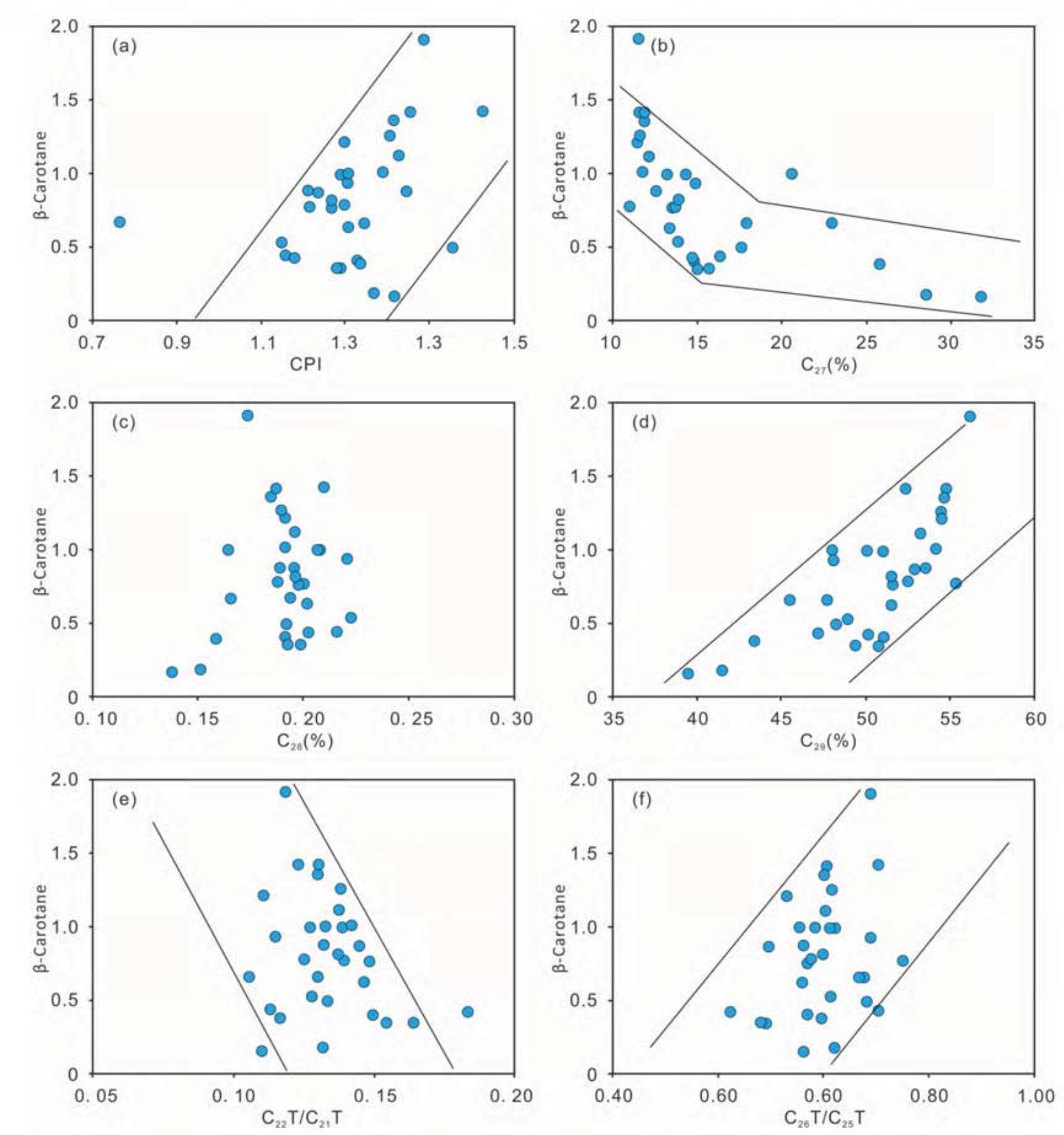

Fig. 8 Correlation between CPI, C_{27} sterane, C_{28} sterane, C_{29} sterane, $C_{22}T/C_{21}T$, $C_{26}T/C_{25}T$ and β-Carotane reflecting terrigenous organic matter input and primary productivity in the Jimsar Sag, showing the different organic matter's contribution to origin of β-Carotane.

8. Conclusions

Based on our bulk geochemical study and molecular geochemical observation on 31 source rocks samples, we inferred the geochemical characteristics, depositional environment and controlling factors of β-carotane within the Lower Permian Lucaogou Formation in the Jimsar Sag of Junggar Basin, the following conclusions can be drawn:

(1) The source rock in the Lucaogou Formation are defined as good and with high hydrocarbon generation potential, indicated by high TOC (0.27%-13.90%), high hydrocarbon potential index (S_1+S_2, 0.15–109.01 mg HC/g) and low-maturity to maturity.

(2) The biomarkers of Lucaogou source rocks extracts are characterized by short to long chain n-alkanes, a wide range of Pr/Ph (0.74-1.42) and β-Carotane (β-Carotane/Maximum Carbon, 0.16-1.92), high concentrations of C_{29} sterane, the presence of relatively low tricyclic terpanes and middle gammacerane index values (0.14-0.29). Which is consistent with a relatively low oxidizing to low reducing depositional environment of fresh to brackish water conditions, with a major contribution of terrigenous organic matter input and a low contribution of aquatic algal-bacterial organic matter.

(3) Cross-plots of biomarker parameters and β-Carotane show that the β-Carotane of Lucaogou source rocks in Jimsar Sag is mainly derived from terrigenous organic matter and mainly distributed in the brackish water conditions and low reducing depositional environment, not affected by thermal maturity.

9. Acknowledgements

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Appendix

TOC, Total organic carbon (wt. %);
S_1(mg/g), the amount of hydrocarbon of free;
S_2(mg/g), the amount of generated hydrocarbons;
T_{max}(℃), the temperature of the maximum generation rate of kerogen cracking.
Pr/Ph, Pristane/Phytane;
Pr/C_{17}, Pristane/C_{17}n-alkane;
Ph/C_{18}, Phytane/C_{18}n-alkane;
CPI, $2(C_{23}+C_{25}+C_{27}+C_{29})/[C_{22}+2(C_{24}+C_{26}+C_{28})+C_{30}]$;
γ-carotane, γ-carotane/Maximum Carbon;
β-carotane, β-carotane/Maximum Carbon;

$C_{19}T$, C_{19} tricyclic terpanes;
$C_{21}T$, C_{21}tricyclic terpane;
$C_{23}T$, C_{23}tricyclic terpane
$C_{25}T$, C_{25}tricyclic terpane;
$C_{26}T$, C_{26}tricyclic terpane;
Ts, 18α (H)-22,29,30- trisnorneohopane;
Tm, 17α(H)-22,29,30-trisnorhopane;
$C_{30}H$, C_{30}hopane;
Gam., Gammacerane;
C_{27}, C_{27}sterane 20R;
C_{28}, C_{28}sterane 20R;
C_{29}, C_{29}sterane 20R;

C_{27}(%), C_{27} steranes/(C_{27} steranes +C_{28} steranes +C_{29} steranes);
C_{28}(%), C_{28} steranes/(C_{27} steranes +C_{28} steranes +C_{29} steranes);
C_{29}(%), C_{29} steranes/(C_{27} steranes +C_{28} steranes +C_{29} steranes);
20S(%), C_{29} sterane ααα20S/(20S+20R);
ββ(%), C_{29} sterane αββ/(αββ+ααα);
$C_{22}T/C_{21}T$, C_{22} tricyclic terpane/C_{21} tricyclic terpane;
$C_{26}T/C_{25}T$, C_{26}tricyclic terpane/C_{25} tricyclic terpane;
G/H, Gammacerane/C_{30} hopane;
C_{35}/C_{34}, C_{35}22S/C_{34}22S hopane;
ETR, $(C_{28}T+C_{29}T)/(C_{28}T+C_{29}T+Ts)$.

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