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## **Tertiary Oil-Prone Coals and Carbonaceous Shales Identified as the Potential Source Rock of the Caracara Sur Oil Field in the Llanos Basin, Colombia\***

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Search and Discovery Article #20386 (2017)\*\*

Posted April 3, 2017

\*Adapted from extended abstract based on oral presentation given at AAPG/SEG International Conference and Exhibition, Barcelona, Spain, April 3-6, 2016

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### **Abstract**

The Caracara Sur oil field is located in the Llanos Basin, one of the largest and most prolific sedimentary regions of Colombia. The field produces 21°API oil from the Carbonera C7 formation of Paleogene age, located at a depth ranging from 4,500 to 5,500 ft below ground level. The reservoir consists of multilayered and compartmentalized sandstone packages, intercalated with shales and thin beds (1 to 5 ft) of high volatile bituminous coals and carbonaceous shales deposited in a deltaic environment. The Carbonera C7 section (Paleogene age) exhibits excellent source rock potential, showing vitrinite reflectance values ( $R_o < 0.55\%$ ) and  $T_{max} (< 435^\circ\text{C})$  below the conventional threshold for oil generation. Multicomponent kinetic analyses in Carbonera C7 samples indicates oil generation onset at  $80^\circ\text{C}$ , close to the present day temperature in the Caracara Sur field ( $65\text{--}75^\circ\text{C}$ ). It is suggested that the oils are early generated from a low-activation kerogen in a nearby region where the Carbonera C7 is found deeper and more mature, probably some 10-50 km westwards.

### **Introduction**

The Caracara Sur oil field is located in the Llanos Basin, one of the largest and most prolific sedimentary regions of Colombia ([Figure 1](#)). The field produces 21°API oil from the Carbonera C7 formation of Paleogene age, located at a depth ranging from 4,500 to 5,500 ft below ground level ([Figure 2](#)). The reservoir consists of multilayered and compartmentalized sandstone packages, intercalated with shales and thin beds (1 to 5 ft) of high volatile bituminous coals and carbonaceous shales ([Figure 3](#)) deposited in a deltaic environment.

### **Analyses and Interpretation**

Recent geochemical analyses have evidenced that Caracara Sur oils may have been generated by a source rock of Tertiary age, as suggested by the oleanane index value ( $>20\%$ ), in contrast with a largely claimed Late Cretaceous source rock. The geochemical analyses of carbonaceous

shales and coals intercalated within the producing sandstones of the Carbonera C7 exhibit an excellent source rock potential (TOC 20-55%, HI 300-400 mgHC/gTOC), containing type I/III oil-prone kerogen deposited in a lacustrine-terrestrial to fluvio-deltaic environment (Figure 3). These organic-rich beds are considered as an excellent candidate to source the Caracara Sur oil. However, these rocks appear immature for oil generation at the field location, as indicated by Rock-Eval data ( $T_{max} < 435^{\circ}\text{C}$ ) and measured vitrinite reflectance values ( $\%R_o < 0.55$ ). The pyrolysis gas chromatogram (Figure 4) from an extract of a Carbonera C7 core sample is comparable with samples of boghead coal, which are exemplary for lacustrine oil shales (Type I source rock). Most of the petroleum type organofacies for the organic-rich Carbonera C7 cores ( $\text{TOC} > 3\%$ ) is a P-N-A oil with high wax content to a paraffinic oil with high wax content (Figure 5).

Multicomponent kinetic analyses of rock samples were carried out to further investigate the Carbonera C7 potential as source rock (Figure 6). The transformation ratio and generation rate curves derived from the activation energies by applying a geologic heating rate of  $3^{\circ}\text{C}/\text{Ma}$  show the oil generation onset at  $80^{\circ}\text{C}$  with a maximum temperature at  $140^{\circ}\text{C}$  and the 90% transformation ratio reached above  $160^{\circ}\text{C}$  (Figure 7). The present-day reservoir temperature at Carbonera C7 in Caracara Sur field ranges from  $65$  to  $75^{\circ}\text{C}$ , which supports the hypothesis that oil generation and expulsion could take place from the Carbonera C7 organic-rich beds from a nearby region where they are deeper and considerably more mature, probably some 10-50 km westwards.

Finally, oil-to-source rock correlation has been attempted to ensure the Carbonera C7 coals and carbonaceous shales may be the Caracara Sur oil source, but it was not conclusive. Most source rocks are immature, while oil samples show a different degree of maturity, which makes difficult the oil-source rock correlation (Figure 8). Concerning the depositional environment, there is an overlap of the produced oil and the rock samples for lacustrine shale (Zone 3 in Figure 9) as indicated in the Pr/Ph versus DBT/P plot. Therefore, more than one source rock could be active in the system.

## Conclusions

The Carbonera C7 section (Paleogene age) exhibits excellent source rock potential, showing vitrinite reflectance values ( $R_o < 0.55\%$ ) and  $T_{max} (< 435^{\circ}\text{C})$  below the conventional threshold for oil generation. Multicomponent kinetic analyses in Carbonera C7 samples indicates oil generation onset at  $80^{\circ}\text{C}$ , close to the present day temperature in the Caracara Sur field ( $65$ - $75^{\circ}\text{C}$ ). It is suggested that the oils are early generated from a low-activation kerogen in a nearby region where the Carbonera C7 is found deeper and more mature, probably some 10-50 km westwards.

## Recommendations

Further geochemical analyses and geochemical modeling are still required to better assess the origin of the Carbonera C7 oils in the Caracara Sur field. Should the hypothesis of the Carbonera shales acting as source rocks be confirmed, it would have an exciting implication for future oil exploration in the Llanos Basin.

### **Reference Cited**

Horsfield, B., 1989, Practical criteria for classifying kerogens: Some observations from pyrolysis-gas chromatography: *Geochimica et Cosmochimica Acta*, v. 53, p. 891-901.

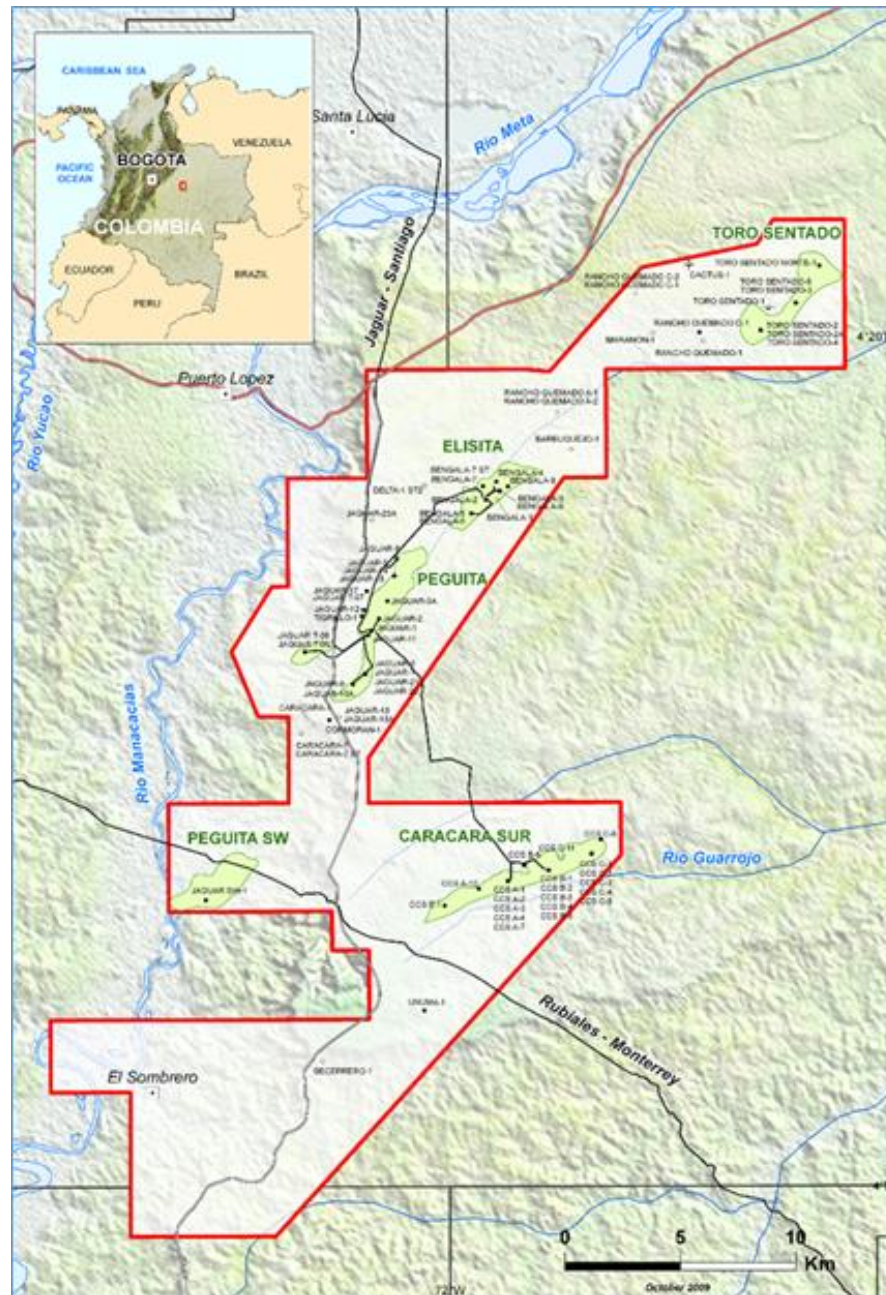


Figure 1. Location map of Caracara Sur oil field (Llanos Basin, Colombia). The field is situated in the SE part of the Caracara Concession (red polygon). Other oil fields within the Concession (Peguita, Elisita, Toro Sentado) are also producing from the Carbonera C7 section.

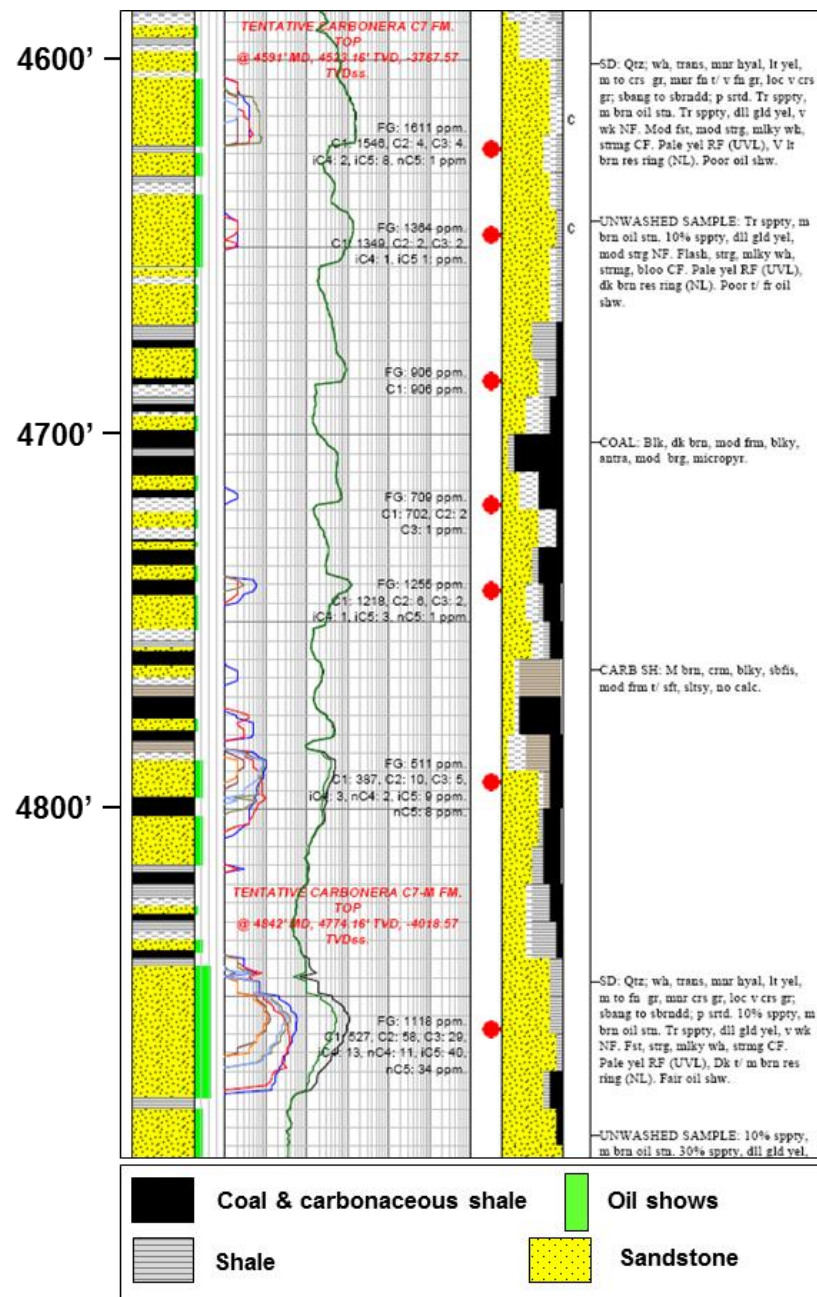


Figure 2. Formation evaluation log of the Carbonera C7 section from a well of the Caracara Sur field. Reservoir section consists of oil producing sandstones intercalated with shales, coals and carbonaceous shales.

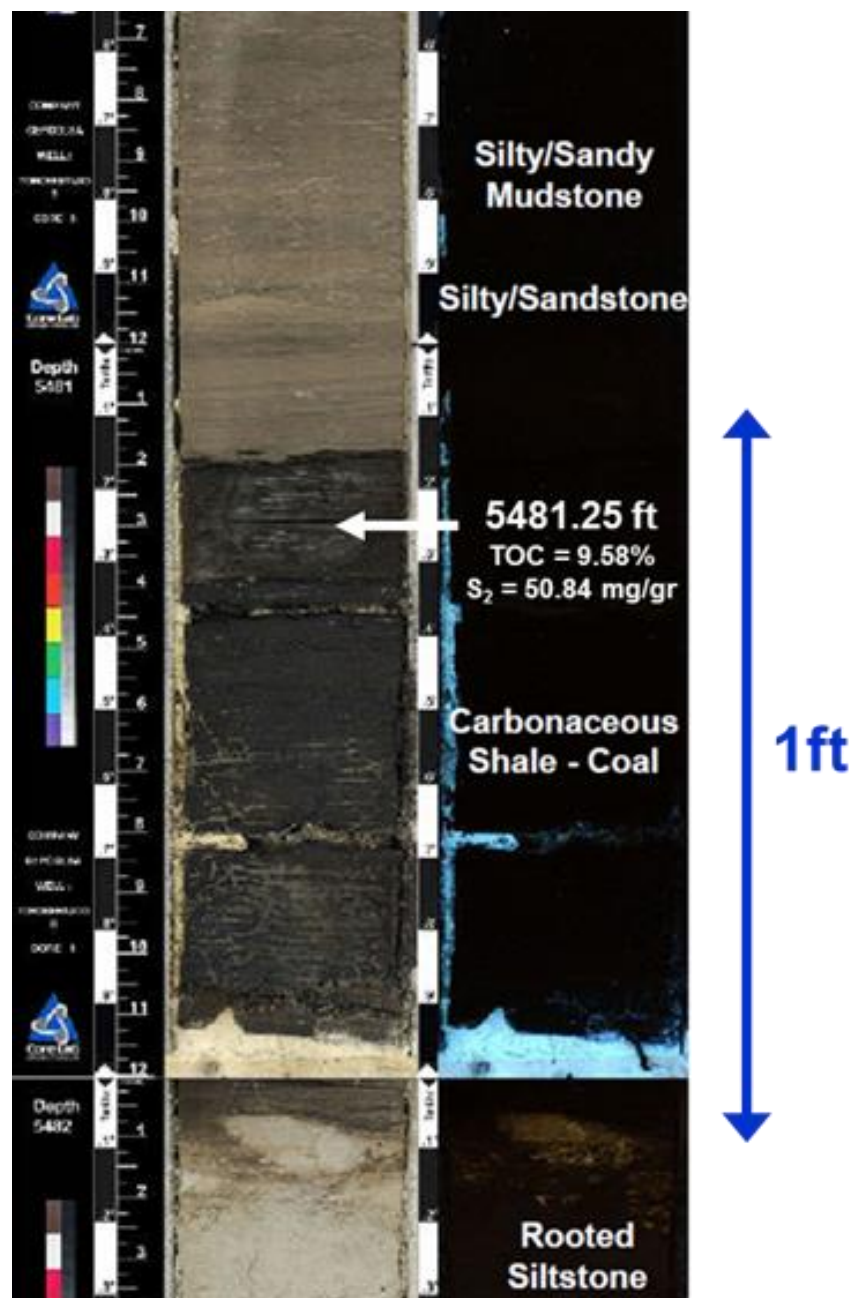


Figure 3. Core photo of a carbonaceous shale/coal bed from the Carbonera C7 section that exhibits high TOC (9.58%) and S<sub>2</sub> (50.84 mg/gr) values. These organic-rich beds are considered as the potential source rock for the Caracara Sur oils.

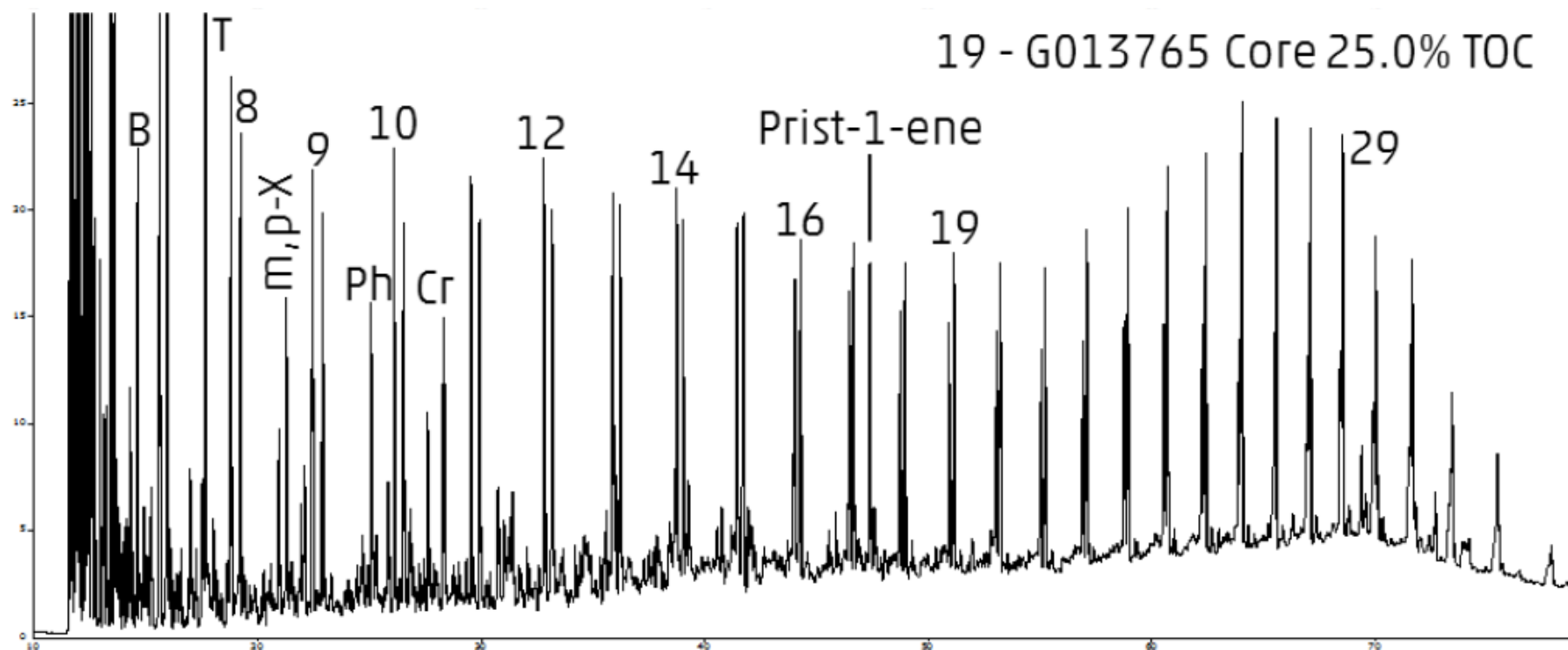


Figure 4. Pyrolysis gas chromatogram from an extract of a core sample of the Carbonera C7 section in the Caracara Sur field (B=benzene, T=toluene, numbers=chain length of alkene/-ane doublets, m, p-X=meta- plus para-xylenes, Ph=phenol, Cr=cresols). This pyrolysate is dominated by normal hydrocarbon doublets of n-alkenes and n-alkanes (see the peaks of 8, 9, 10, 12, 14, 16 and Prist-1-ene) and extends to a long chain with maxima at n-C26 to n-C29 (see peaks before number 29, where another “hump” is situated). This is very similar to a boghead oil sample.

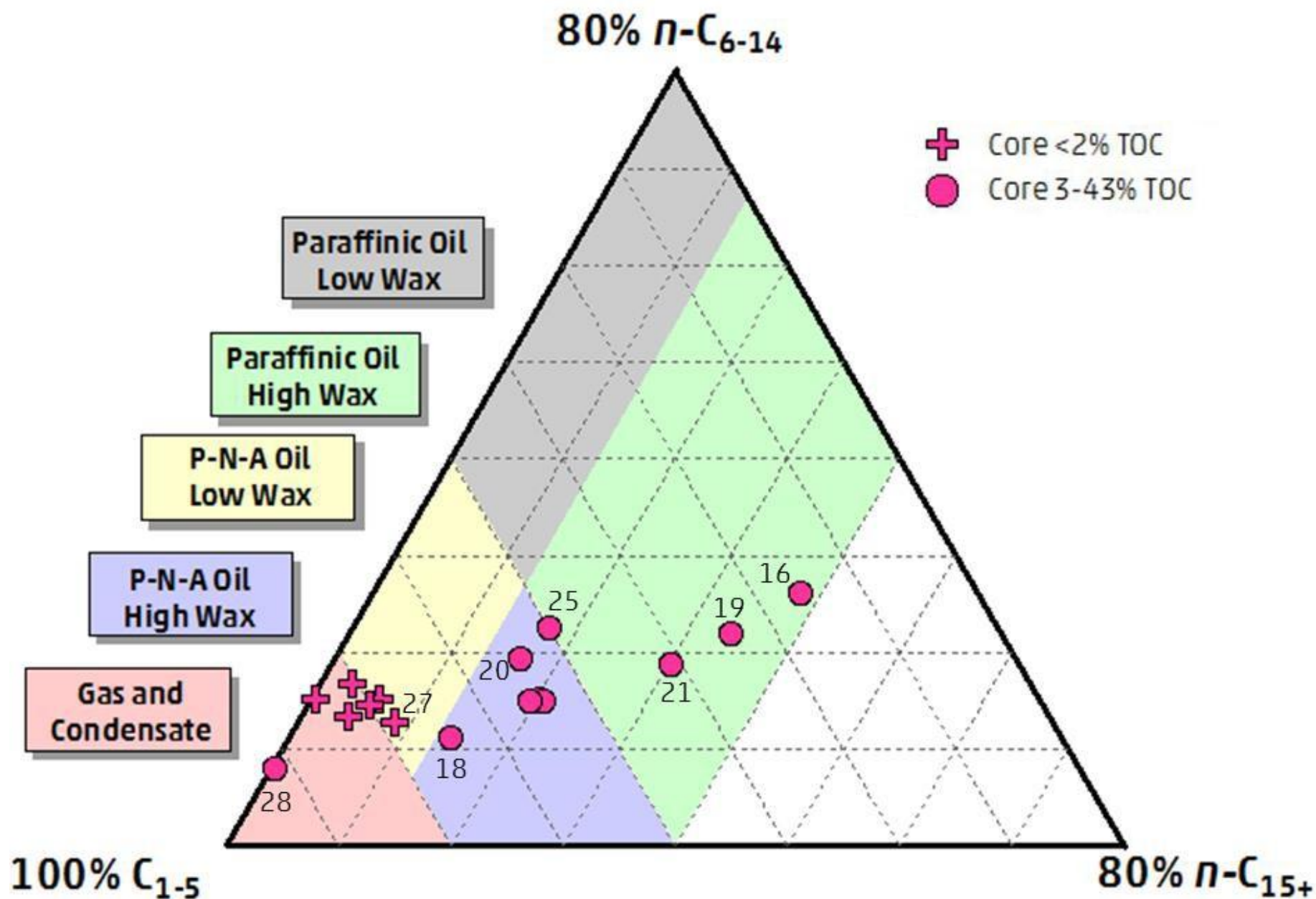


Figure 5. Organofacies ternary plot (Horsfield, 1989) showing extracts from core samples of the Carbonera C7 section. Most of the organic-rich (TOC=3-43%) samples lie in the zones P-N-A Oil High Wax and Paraffinic Oil High Wax.

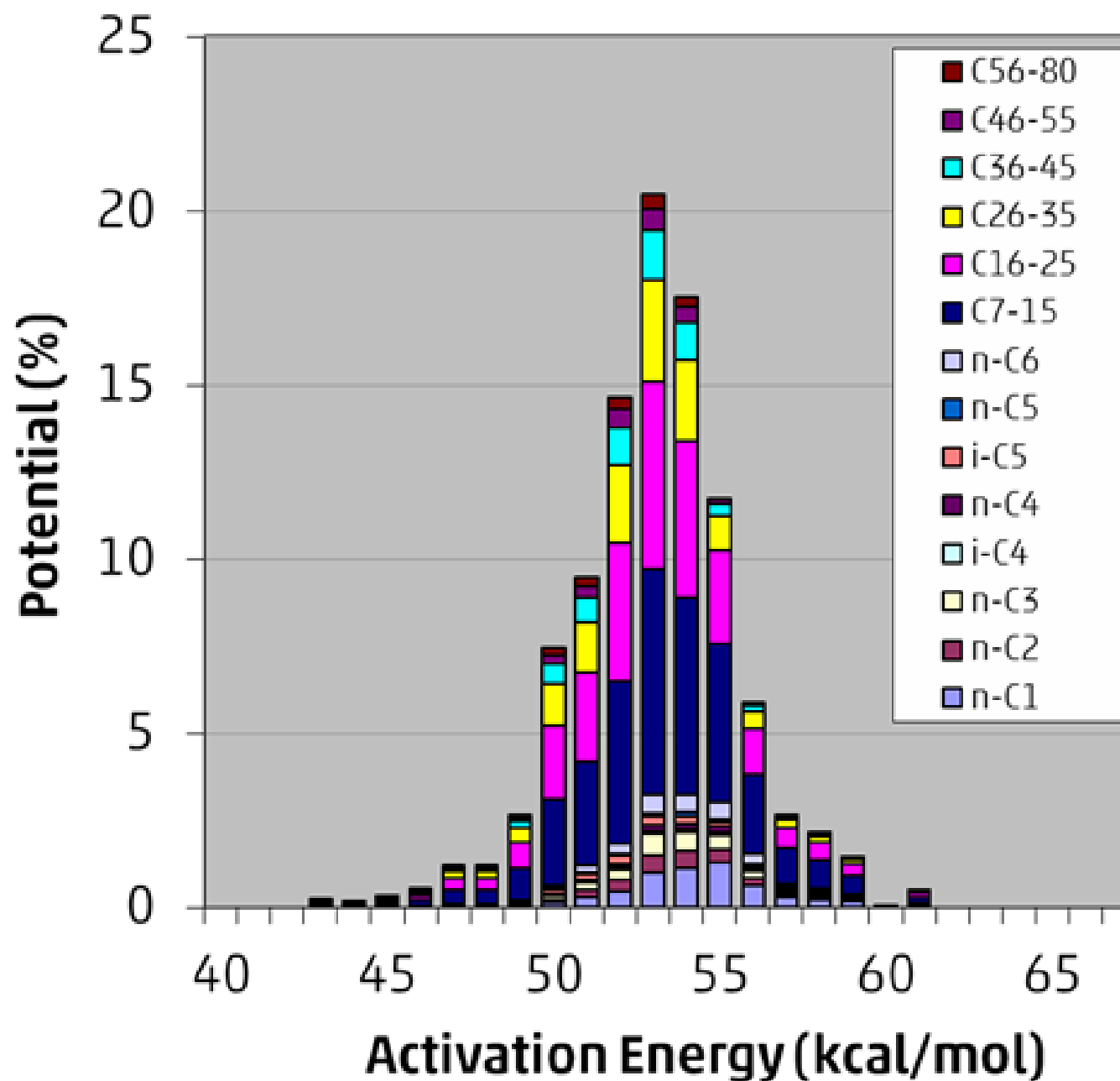


Figure 6. Multicomponent kinetics of an organic-rich rock from the Carbonera C7 section. The activation energy has its highest generation potential at 53 kcal/mol and accounts for 20% of the total reaction.

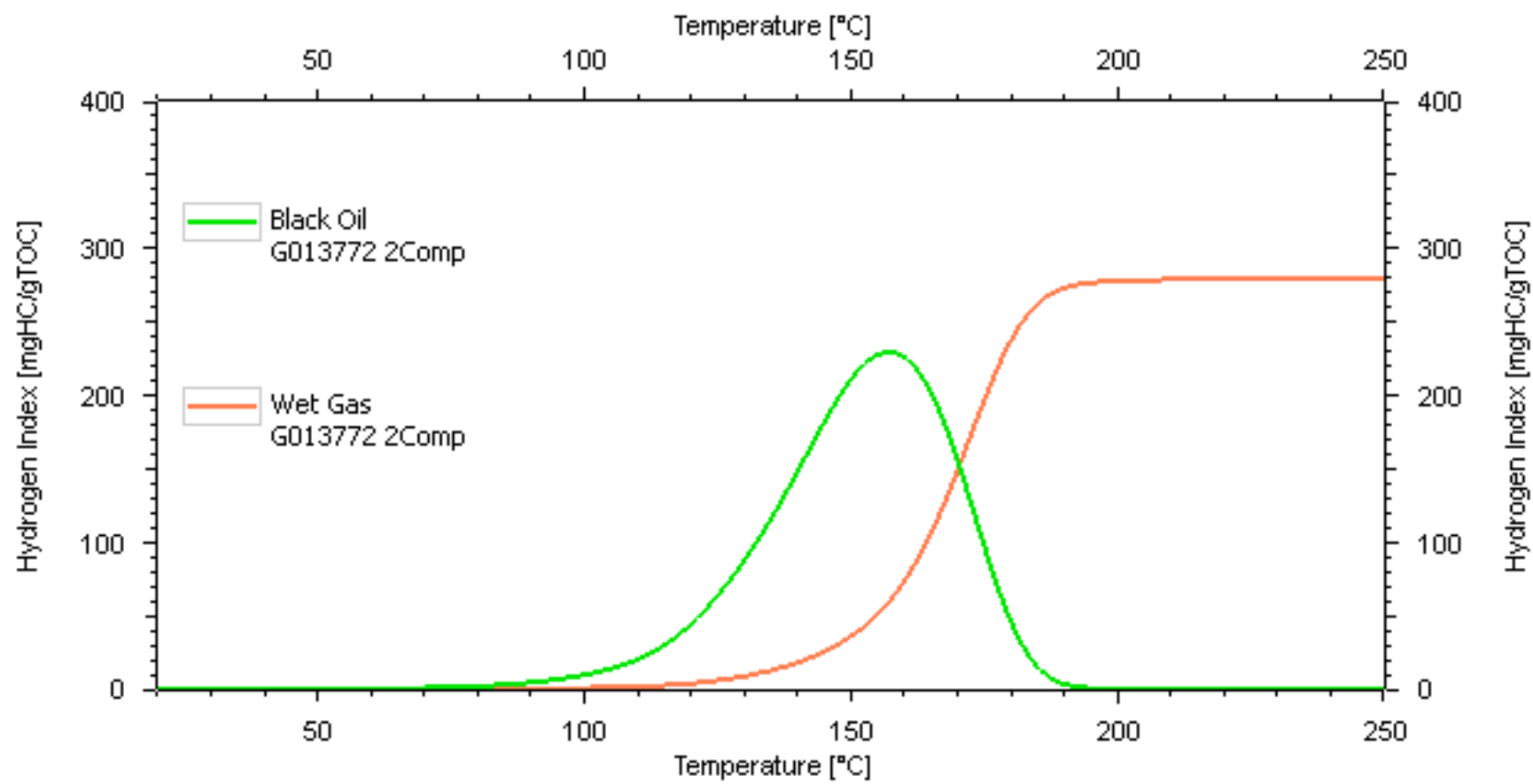


Figure 7. Simplified plot of Hydrogen Index / Temperature for the Carbonera C7 source rock kinetics. The onset of oil generation is around 80°C and reaches the peak at 155°C.

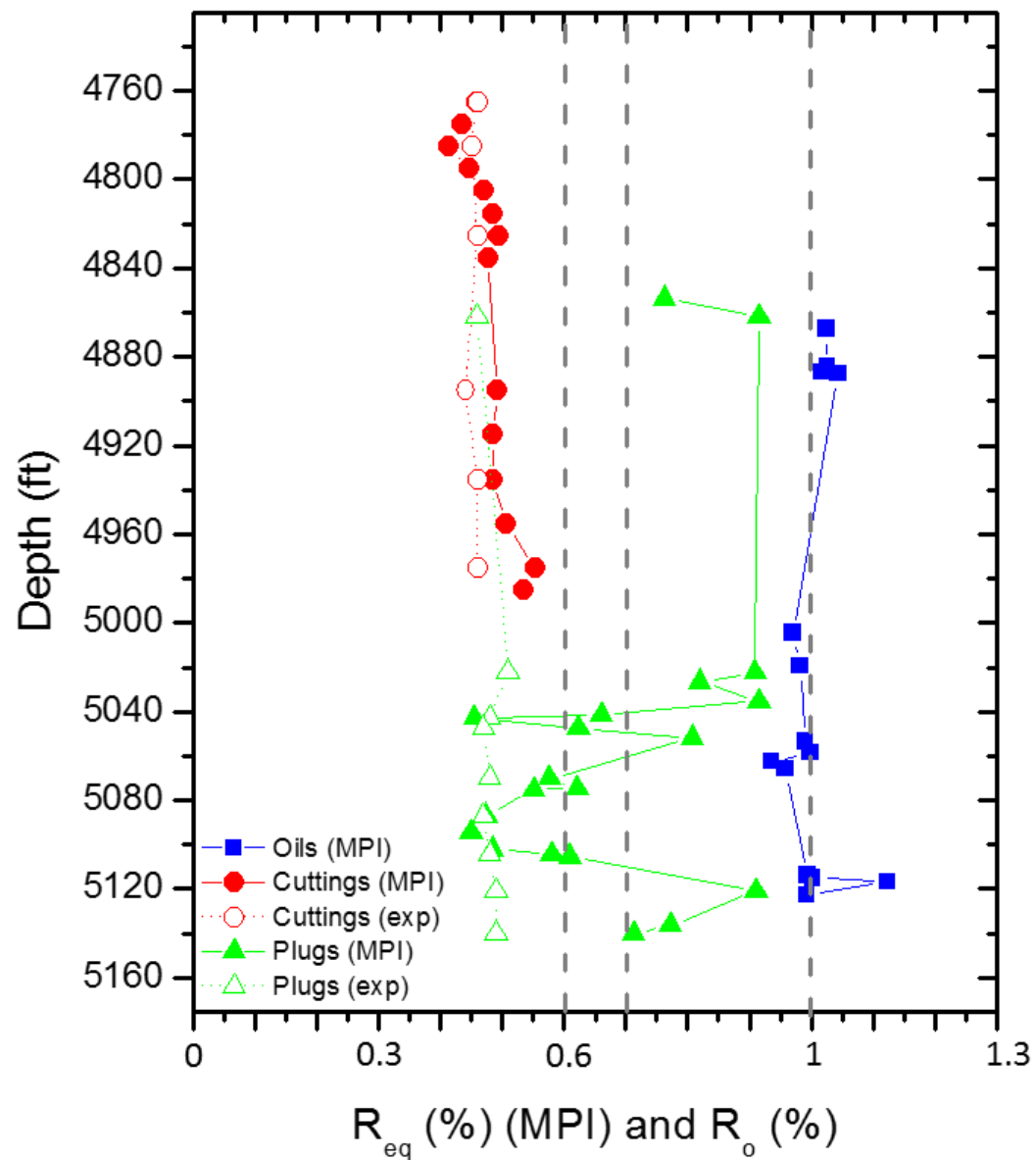


Figure 8. Vitrinite reflectance versus depth diagram, showing the calculated Req (%) with MPI=methylphenanthrene index and the experimental or measured Ro (%). The Req (%) in oil samples plot clearly in the area of main to late mature (even above 1.0 %Ro). The measured %Ro in cuttings and core plug samples show immature (below 0.6%Ro). Calculated Req (%) with MPI from extracts of cuttings have values close to the ones experimentally measured, whereas those of core plugs show higher mature values (maximum of 0.9 %Ro).

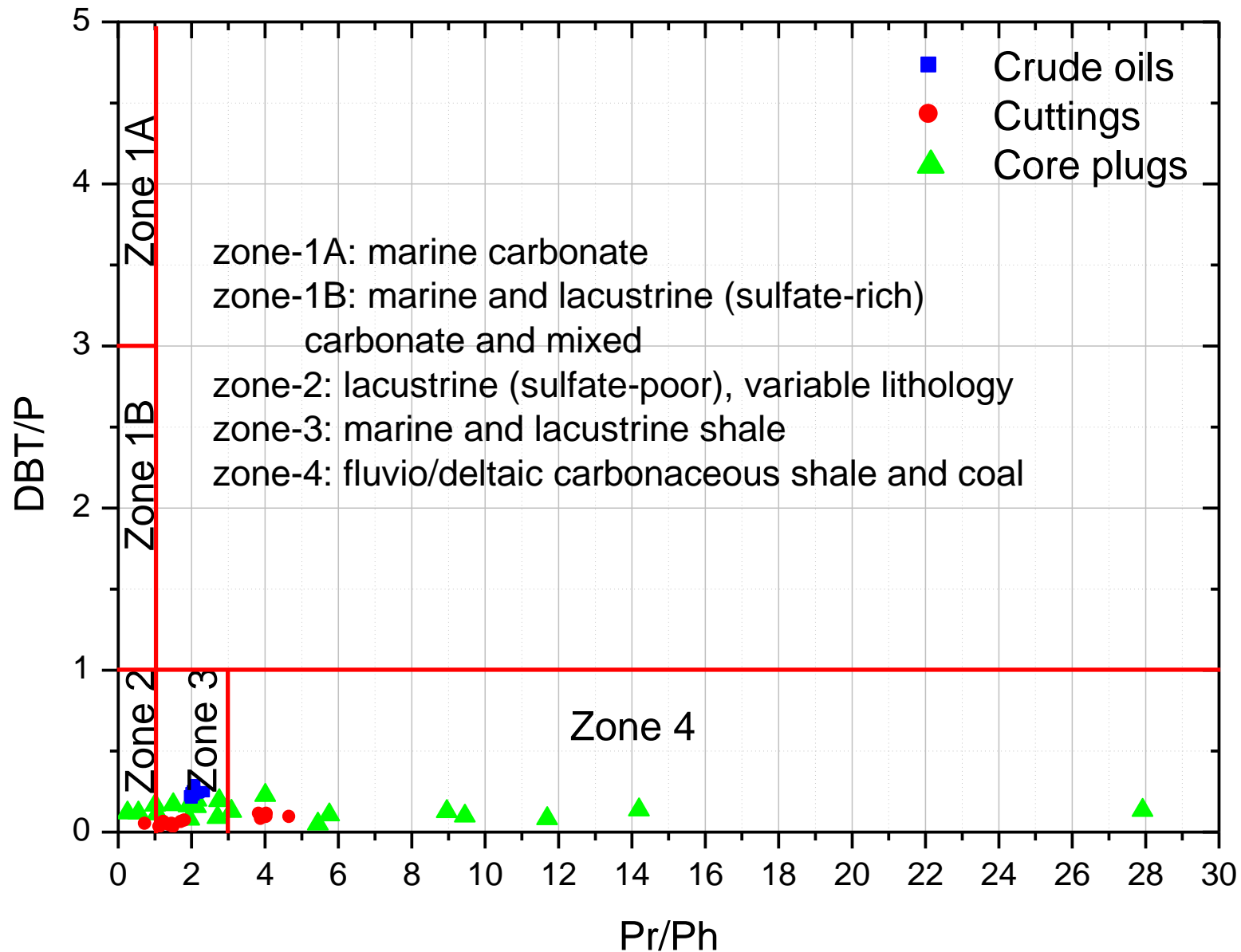


Figure 9. Pristane/Phytane ratio (Pr/Ph) versus Dibenzothiophene/Phenanthrene (DBT/P) plot. The plot reflects overlaps and differences in the depositional environment conditions of the extracts from the source rocks (cuttings and core plugs) and the Caracara Sur crude oils. The crude oil samples plot in the zone of marine and lacustrine shales like some cuttings and core samples do.