

GEOCHEMICAL STUDY OF BEMOLANGA TAR SAND AND TSIMIRORO HEAVY OIL DEPOSIT IN THE WEST SEDIMENTARY BASIN OF MADAGASCAR.

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ABSTRACT

BEMOLANGA (BML) tar sand and TSIMIRORO (TSM) heavy oil have been subjected to various geochemical studies during the past years. These geochemical data have largely contributed to deeper knowledge of the oil generation in Madagascar sedimentary basins. In fact, oil prone source rocks have been identified along with their maturity level of *lower Cretaceous, middle Jurassic and Triassic* age.

Madagascar tar sands and heavy oil are biodegraded and oil was generated by source rocks of probably *terrestrial* derived organic matter (type III). Moreover, recorded geochemical data are of great importance for the better understanding of oil generation, differential migration as well as hydrocarbons characteristics which are necessary for the future exploration research works within the Madagascar sedimentary basins.

Nevertheless geochemical studies on the tar sands and heavy oil have to be performed in detail for better optimization and rationalization of further exploration works to be carried out in the overall sedimentary basin in general and in the *Karoo (Permo Triassic)* formation in particular.

Keywords: heavy oil, oil generation, geochemical, hydrocarbons, tar sands, migration, sedimentary basins, Karroo, geochemical.

INTRODUCTION

Bemolanga and Tsimiroro are the two largest non conventional hydrocarbon fields in Madagascar. Both deposits are located in northern part of MORONDAVA sedimentary basin, bounded by the crystalline basement of **Bongolava** to the East and the **Bemarahaha** plateau to the West. The sediments belong to I and II group *Permian and Triassic* of the *Karoo* system.

Both fields are located on high structure controlled by major faults mainly in the NNW-SSE direction and the **Ranotsara** fault shown in figure 1. For the oil accumulation, the sandstone formations of the *upper Triassic* constitute the main reservoir rock. [11]

The presence of these two deposits has certainly boosted the hydrocarbon exploration in Madagascar since 1980 and lot of petroleum companies among them some majors (BP oil, Amoco, Total) have acquired licenses for petroleum exploration in west sedimentary basin permits of Madagascar.

For the better understanding of the origin of these oils, several geochemical studies have been undertaken on the BML and TSM deposits and on different formations in the **Majunga** and **Morondava** sedimentary basins.

This paper is based upon the main results of studies mentioned above, and tries to explain the contribution of these results to the hydrocarbon exploration in Madagascar. Data acquired in this paper is a synthesis of analyses carried out at OMNIS (The owned State Company in charge of petroleum research in Madagascar) laboratory and at High School of Polytechnic of Antananarivo laboratory in the framework of collaboration in between of these two laboratories since the beginning of the petroleum exploration.

Thus this paper deals mainly with:

- The various analyses done on the oils and sediments samples of the two deposits and samples from other fields of Madagascar.
- Oil to oil correlation tests of BML and TSM to other oils to source rock correlation tentative to possible source rock throughout the basins.

The study is particularly focused on the formation of Karroo system. The different locations of studied areas are shown in figure 1.

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GEOCHEMICAL EVALUATION [9]

BML – TSM oils are the viscous oils trapped in the anticline structures of the *upper Triassic* sandstones whose reservoir rocks appears on the surface and slightly buried. The physico-chemical properties of these oils are given in table 1.

In comparing the main characteristics of the two oils, we can conclude that:

- The BML oil is heavier than the TSM one
- Their sulfur contents are almost equal and very low
- The very low sulfur content would be a particular characteristic of these Malagasy non conventional crudes.
- The BML oil has more asphaltic compounds and higher metal content than the TSM oil.

CHEMICAL STUDIES [15]

The chemical studies demonstrate the biodegraded nature of Bemolanga and Tsimiroro oils. These studies are mainly focused on the following matters:

- The distribution of the different hydrocarbon (HC) groups (saturates, aromatics, nitrogen, sulfur and oxygen);
- n-alkane signature on gas chromatography;
- Isotopic studies.

DISTRIBUTION OF THE DIFFERENT HYDROCARBON GROUPS [6]

The oil distribution results into different hydrocarbon groups.

The oil distribution results into different HC groups by thin layer chromatography (TLC) are gathered in table-2.

A simple plot of the oil composition in the ternary diagram in figure 2. shows:

- The biodegraded nature of BML and TSM oil;
- The preserved nature of BML AND TSM oil (3, 15, and 16).

n-ALKANE SIGNATURE ON GC [5]

The Gas Chromatography analyses give the chromatograms in figure 4.

These footprints chromatograms allow to state:

- The advanced biodegradation nature of BML and TSM oils with disappearance of the linear alkane and branched hydrocarbon, as well as the pristane and phytane.
- The non degraded or semi-degraded nature of the other oil of the same formation (figure 4, sample 17).

ISOTOPIC STUDY [3]

The isotopic study results are shown in table 3.






The biodegradation of the BML and TSM oils is confirmed by a decrease of the isotopic ratio of the saturate fraction, in comparison to the other oils in the same formation. Consequently, the distribution into different HC groups, the chromatograms on GC and the isotopic results are convergent to confirm the biodegraded status of the two oils.

SOURCE ROCK EVALUATION [2, 7]

SAKOA FORMATION [4]

The geochemical characteristics of Sakoa coal samples are shown in table 4.

These results show:

-  The rich organic matters content of coal samples and the presence of a very good hydrocarbon potential (S₂ > 20 mg/g).
-  The kerosene has continental origin, gas prone, type III (HI < 50).
-  The sediments are immature to marginally mature (T max = 431°C - 436°C, CPI > 1).
-  The oxydant environmental deposit (Pr/Ph > 2).
-  The signature of saturate hydrocarbons from Sakoa coal shows the presence of non biodegraded organics as shown in figure 3.

PERMO-TRIASSIC FORMATION

The source rock evaluation was carried out through Rock-Eval analysis, gas chromatography and vitrinite reflectance determination, whose results are given in table 5 and 6

These results indicate that:

- ❖ Although BML and TSM show a good hydrocarbon potential they are still at the stage of immaturity (T max = 424, CPI=1.37, Ro = 0.5) predicting the migrated state of these oils.
- ❖ The other sediments of the same formation are mature, post mature but they have generally a poor hydrocarbon potential.
- ❖ The BML and TSM sediments are deposited in a reducing environment (Pr/Ph < 2, Table 5).
- ❖ The chromatogram trends of BML and TSM oils would have a mixed origin (continental-marine, type II-III) considering the predominance of nC13 – nC19 and HI values < 200 as shown in Figure 4, 5b.

JURASSIC FORMATION

The same previous studies were also undertaken for the Jurassic formation whose results are presented in the Table 7, 8
These results show that:

- The samples from Jurassic formation of different basins present low hydrocarbon potential (S2 > 2mg/g) except for some results showing a moderate potential (Samples 2, 3, 5, 9)
- These samples have moderate to good ratio in organic matter (TOC = 0.1 - 3.3%)
- The samples are marginally mature to post-mature (Tmax = 391°C), however most of them are in oil windows. These results are confirmed by CPI values.
- The gas chromatography demonstrated the presence of non degraded hydrocarbon which is shown in the chromatograms signature of n-alkanes in Figure 6.
- The general feature of some chromatograms shows the predominance of n-C13 - nC19 and reduction of n-alkanes > 25 would show a mixed organic matter, type II-III as shown in Figure 6, 5b.
- Oxidant environment deposit (Pr/Ph > 2) for samples 2, 7, and 9, beside the reducing environment for the others.

CONCLUSION ON THE ORIGIN OF BML AND TSM OILS

SOURCE ROCKS [7, 8]

The question which may arise about the advantage of hydrocarbon exploration is to know what the source of BML and TSM hydrocarbons was. The following explanations and remarks try to answer to this question.

SAKOA Formation

Considering the results represented in the Table 4, the hypothesis of hydrocarbon generation from Sakoa coal could not be excluded.

PERMO-TRIASSIC Formation

The rock study of these formations in BML and TSM areas have shown the immature stage of hydrocarbon. The studies of the same formations of some nearby samples (3, 6) have indicated the same level of immaturity and poor organic matter contents. Thus, the *Permo-Triassic* of the area would not constitute potential sources of BML and TSM oils.

JURASSIC Formation

Generally, sediments of this formation would not be potential source rock except in particular levels of same samples (3, 7, and 10).

CORRELATION STUDIES

The correlation study has to consider several geochemical parameters for a better likeness delimitation of different samples. The BML and TSM oils are considered as generated from the same source rock as shown in the distribution of n-alkane and the isotopic values as well.

The values of the isotopic ratio reported in Figure 7 point out the presence of oils genetically different in one hand, and in the other hand, BML and TSM oils groups seem similar as indicated in the diagram of samples 16 and 20.

Moreover GC results show that oil issued from *Sakoa* coal is different from those of BML and TSM.

The studies showed that the BML and TSM oils are degraded in the *Permo-Triassic* formation. The existence of other types of non degraded oil as reported in Figures-2, 4 in the same formations would mean the good reservoir quality of the Karroo formation in the Northern as well as in the Southern part of the two deposits.

The existence in some oils of series C14+ (sometimes C13+) with well defined phytane and pristane shows the preserved status among these *Karoo* oils. The some like biodegraded state of these oils does not allow easy comparison with oil of *Jurassic* formation.

The comparison would be more difficult as the terrestrial origin of these oils is confirmed whereas those of other formations are of marine or mixed marine-terrestrial origin. Nevertheless, the fact that these oils are supposed to be migrated does not inhibit us to admit the possibility to be the same oils from Jurassic formation.

CONCLUSION

The geochemical studies carried out on BML and TSM deposit led to the following conclusion:

- The advanced biodegradation of these two oils have not made the origin comparisons easier as with the same formation oil and of the Jurassic formation.[14]
- Possible source rocks of these oils were exposed and have shown that the SAKOA formation and some level in the *Permo-Triassic* and the *Jurassic* formations may constitute potential source rocks. However, the geodynamic structure of the basins with high bottoms and depressions does not allow a precise delineation of the possible source rocks sequences.
- Finally, geochemical studies undertaken on BML and TSM led to some remarks on the hydrocarbon exploration in the *Karoo* formation particularly and on the entire two basins in general.
- The studies were mainly focused on *Karoo* formation, nevertheless with the gas index discovery in the middle cretaceous formation, detailed advanced geochemical studies in the *Cretaceous* formation may eventually bring over explanations for the genesis of those non conventional oils, even though, none was exposed in this present paper.

Table 1. Physico-chemical characteristics of Bemolanga and Tsimiroro oils [8]

CHARACTERISTICS	Bemolanga oil	Tsimiroro oil
Density (15° C)	0.9921	0.9585
°API	11.06	16.10
Sulfur (% weight)	0.51	0.40
Viscosity cSt at 70° C	9735	863
100° C	1038	150
121° C	543	56
Softening point (°C)	+36	+12
Asphaltènes C5 (% weight)	16.10	7.52
Residual carbon Conradson (% weight)	13.30	8.31
Ni (ppm)	180	55
V (ppm)	18	2

Table 2. Extraction results of different oils on TLC

SAMPLES*	SAT	ARO	NSO
BML 1	49.10	13.80	37.10
BML 2	47.70	15.60	34.70
BML 3	38.90	11.90	49.20
BML 4	52.20	13.90	33.90
TSM 1	27.00	8.30	64.70
TSM 2	25.00	25.00	50.00
TSM 3	24.70	18.80	56.00
TSM 4	26.10	20.10	55.40

SAMPLE*= representative sample from surrounding areas

Table 3: Isotopic ratio of the saturates, aromatics (% Peedee Belemnite Standard*) [10, 12]

SAMPLE	13C SAT*	13C ARO*
BML 10	-34.92	-32.45
BML 11	-34.95	-32.30
BML 12	-35.14	-32.43
TSM 4	-35.96	-32.47
TSM 13	-33.96	-31.86
TSM 17	-34.79	-32.79
Core sample 20.3	-29.21	-27.96
Core sample 20.4	-29.28	-28.09
Core sample 20.5	-29.38	-28.03
Core sample 20.6	-29.60	-28.26
Core sample 20.7A	-29.81	-28.25
Core sample 20.7B	-29.38	-27.94
Core sample 16.8	-29.71	-28.19
Core sample 16.9	-29.99	-28.36

*(% Peedee Belemnite Standard= % PDB

13C SAT*= Isotopic value of saturates

13C ARO*= isotopic value of aromatics.

Table 4. Geochemical characteristics of Sakoa coal samples [7]

Sample	Ro	T max (°C)	TOC (%)	S2 (mg/g)	HI	CPI	nC17	nC18	Pr/Ph
Coal 1	0.80	436	64.10	135.99	-	-	2.97	0.27	8.75
Coal 2	0.55	431	64.41	30.87	48	1.52	4.00	0.38	7.20

Whereas: Ro = Vitrinite Reflectance, T max = Maximum temperature of pyrolysis at the top of S2, S2 = potential Source-Rock. nC17, nC18 = normal saturates, TOC = Total Organic Carbon, HI = Hydrogen Index, CPI = Carbon Potential Index.

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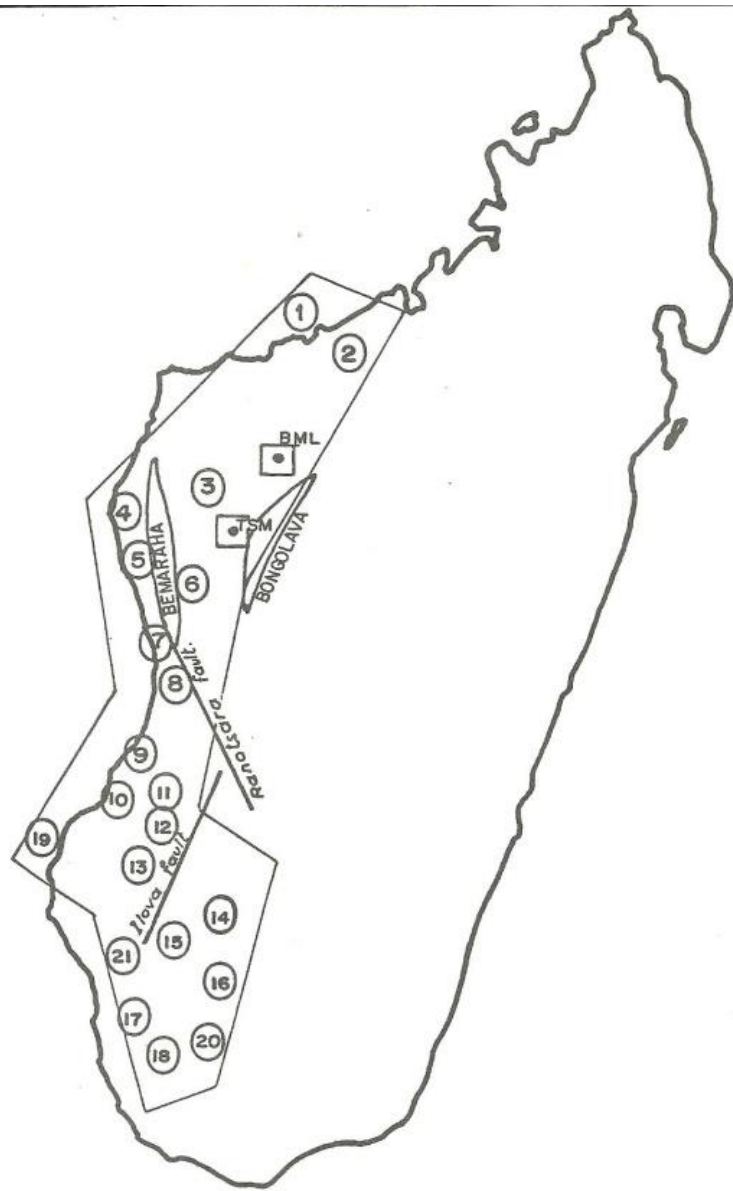
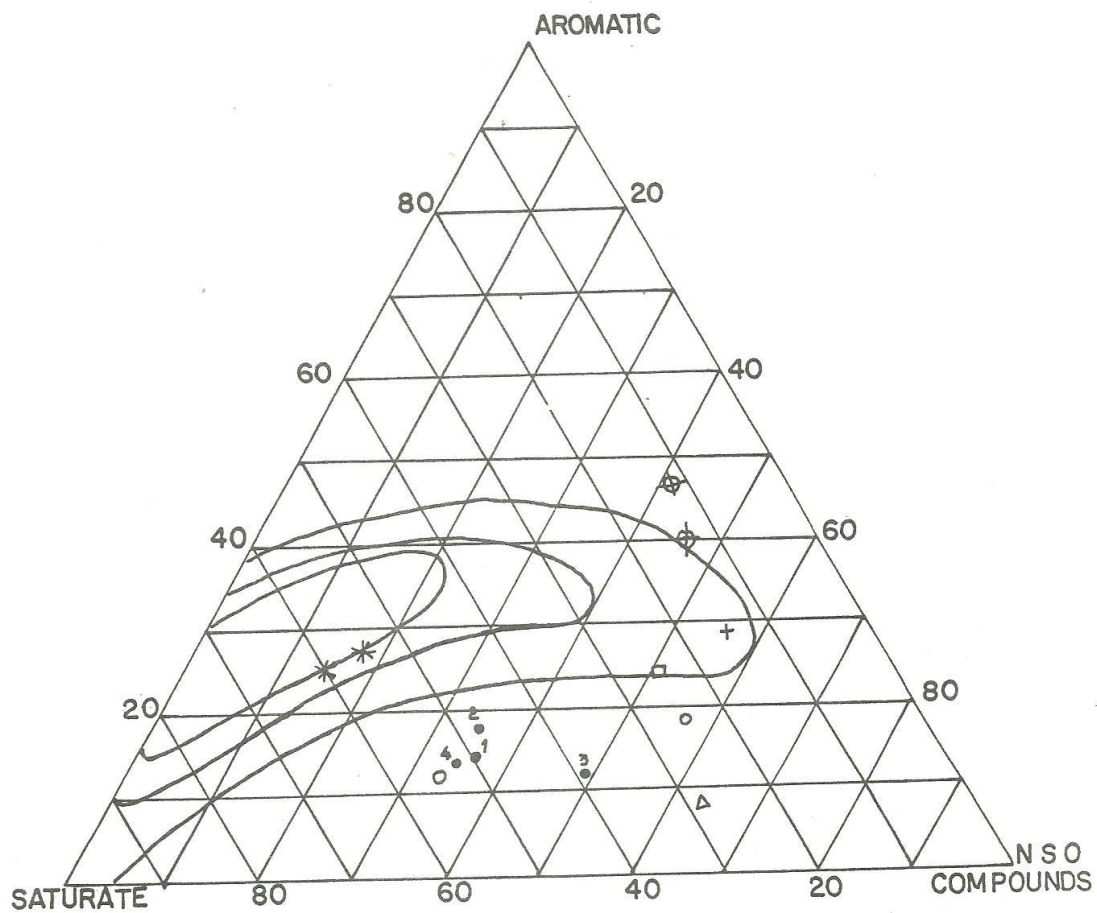


Fig. 1 : LOCATION MAP OF DIFFERENT STUDIED AREAS



LEGENDS :

- BML
- △ TSM
- 3
- + 15
- ⊕ 16
- * 17
- 18

FIG.2 : TERNARY DIAGRAM (ARO, SAT, NSO)

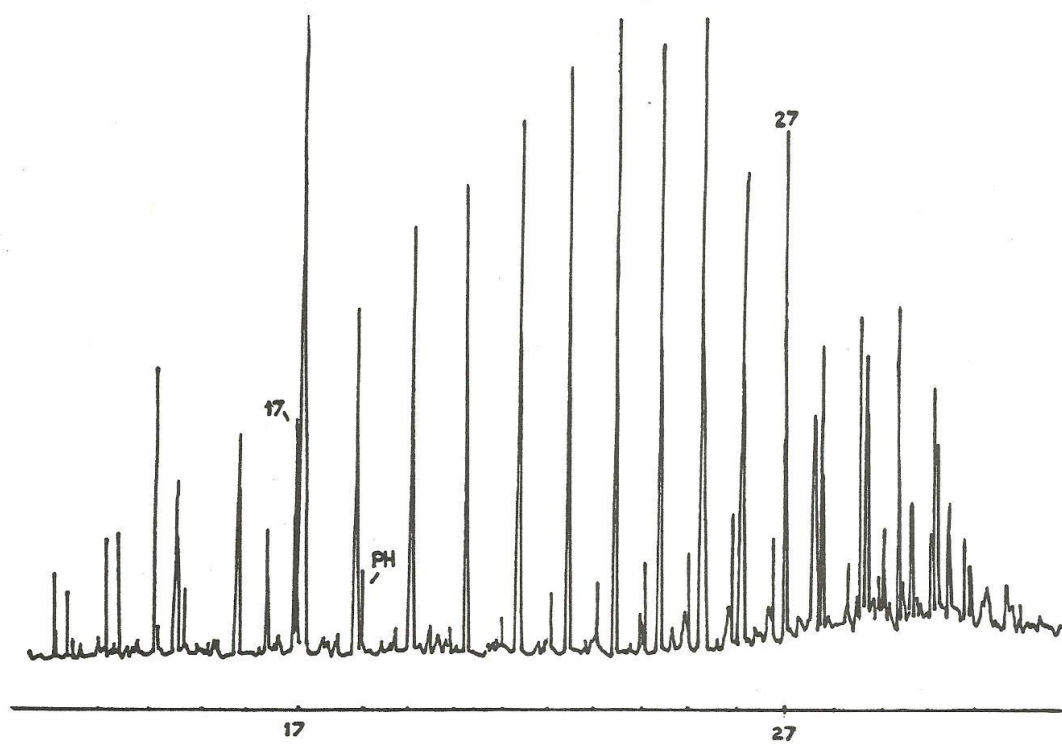


Fig 3: SAKOA COAL : nC_{15}^{+} CHROMATOGRAMS.

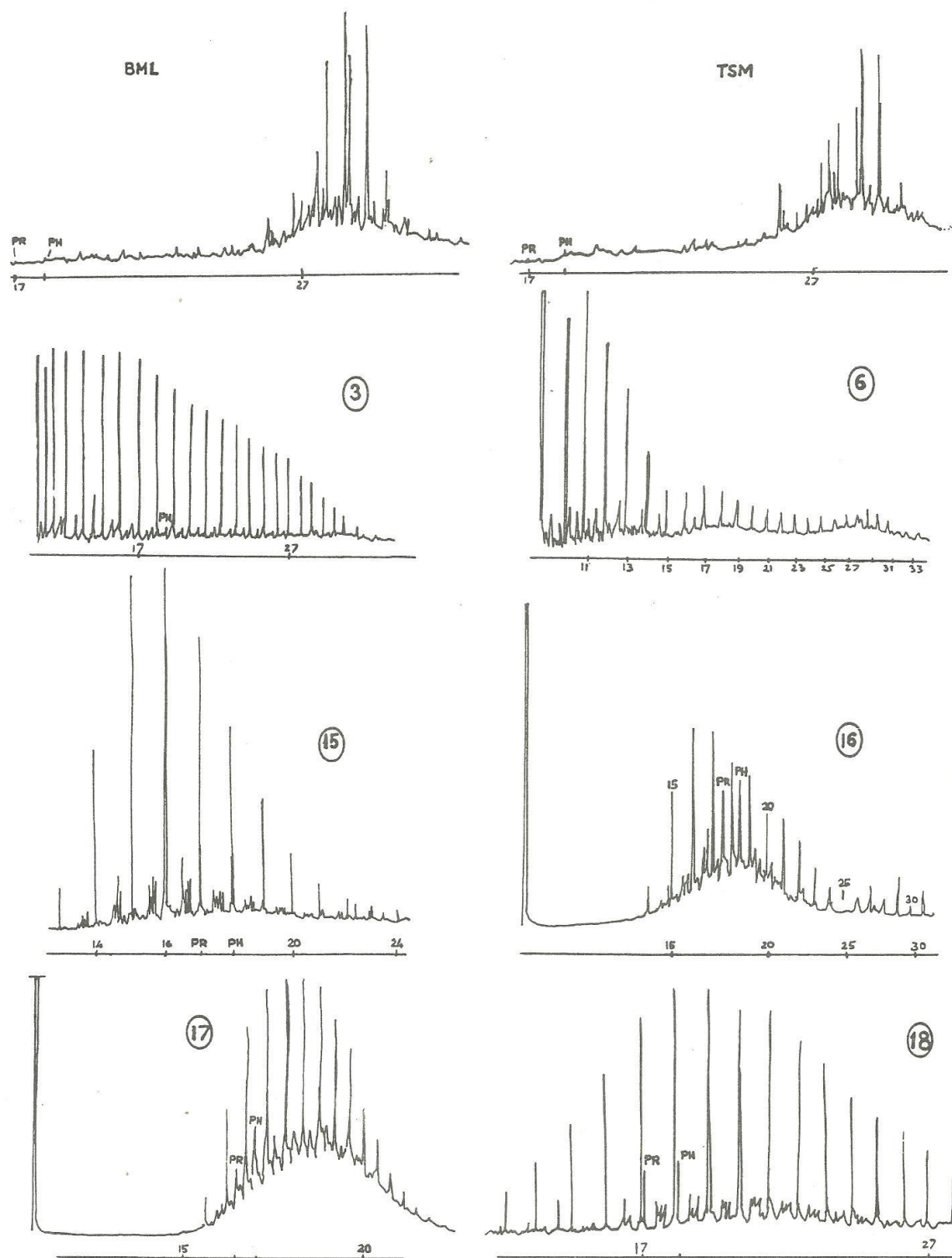


Fig 4: PERMO-TRIASSIC nC_{15}^{+} CHROMATOGRAMS.

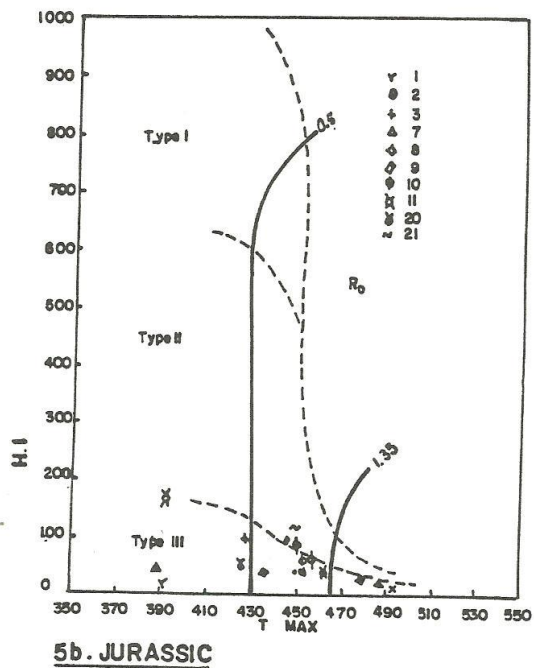
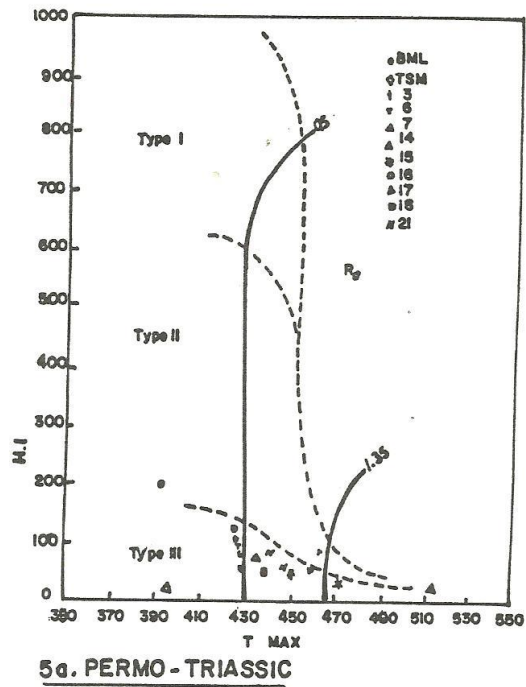


Fig 5: VAN KREVELEN DIAGRAM

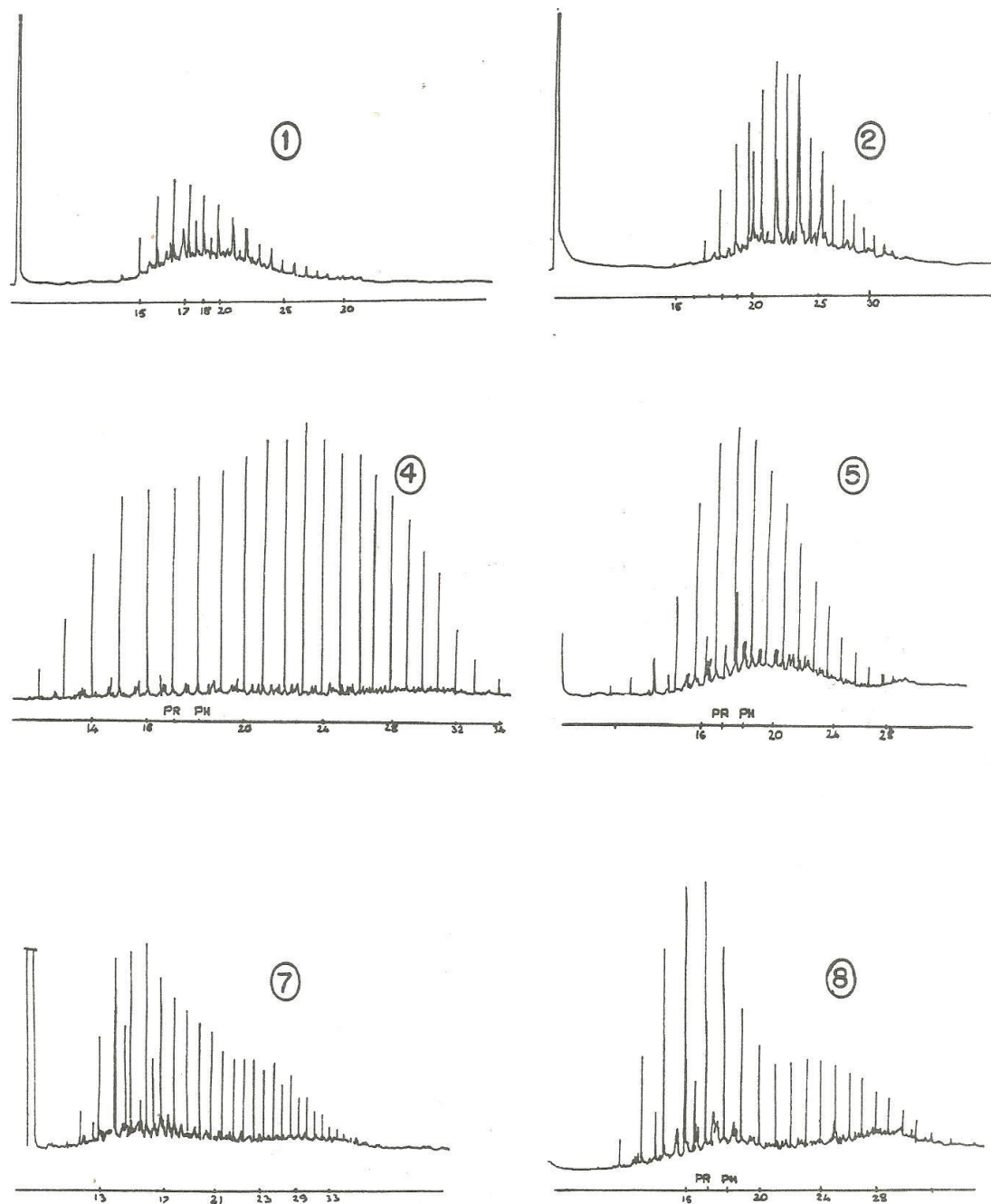


Fig 6 : JURASSIC nC_{15}^{+} CHROMATOGRAMS

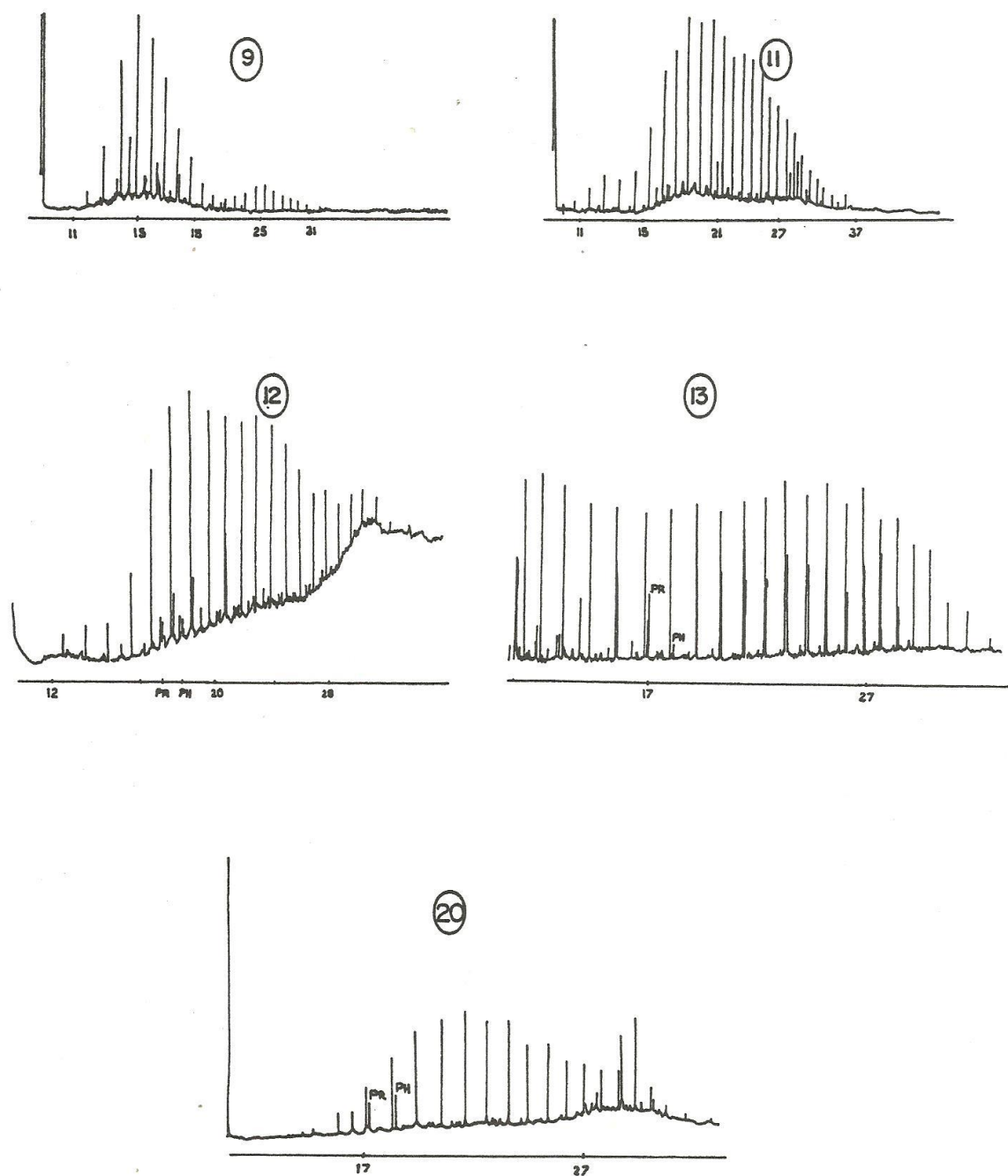
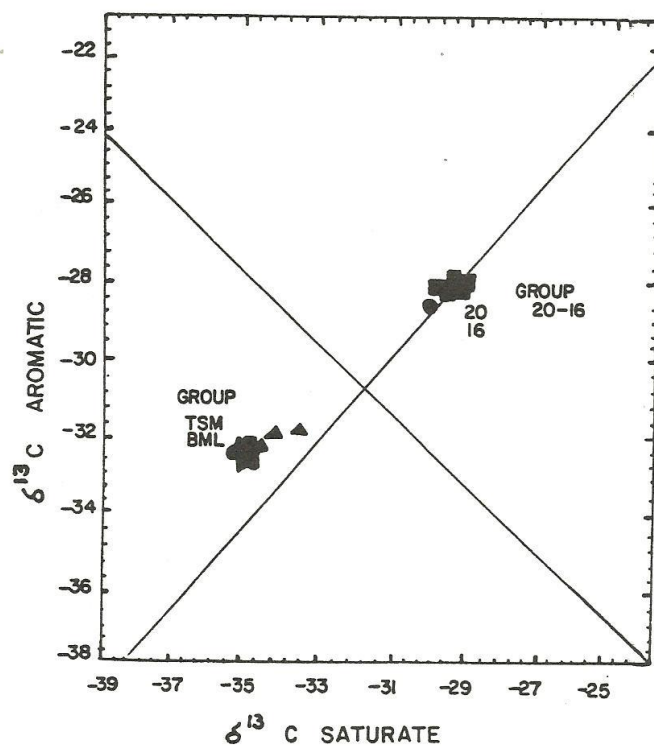


Fig.6 : JURASSIC nC_{15}^{+} CHROMATOGRAMS



SAMPLE KEY :

- 20
- 16
- ◆ BML
- ▲ TSM

Fig. 7: ^{13}C ARO. / ^{13}C SAT. DIAGRAM .