

MACUSPANA BASIN, SOUTHEAST MEXICO: AN EXAMPLE OF A TERTIARY MARINE DELTAIC PETROLEUM HABITAT.

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ABSTRACT – Geochemical and biological marker analyses of oil, rock and gas samples from the Macuspana basin indicate the presence of a Miocene age relate source rock containing abundant reworked higher plant material. This source rock was deposited in a suboxic marine deltaic environment. The origin of gases associated with the oils, based on wetness and isotopic composition of methane, suggest also a Tertiary source rock within the oil window. The light isotopic values of methane, present in some gas samples, probably represent fractionation of thermogenic gas due to long migration through a siliciclastic section.

RESUMEN – Analisis geoquímicos y de biomarcadores efectuados en muestras de aceite, roca y gas provenientes de la Cuenca de Macuspana permitieron identificar una familia de aceites originada por material organico marino y de plantas superiores retrabajadas depositadas en un ambiente marino deltaico del Terciario. Los gases asociados a estos aceites son humedos y con base en su composicion isotopica y contenido de metano puede deducirse que fueron generados por rocas generadoras del Terciario situadas dentro de la ventana de generacion de hidrocarburos. Los gases que muestran valores isotopicos muy ligeros probablemente representan fenomenos de fraccionacion de gas termogenico debido a una migracion de larga distancia a traves de la seccion siliciclastica del Terciario.

INTRODUCTION

The Gulf of Mexico is one of the largest petroleum provinces of the world, containing approximately 9% of the world's known petroleum reserves. The southern half of the Gulf of Mexico alone contains more than 81% of the Gulf's petroleum reserves (Brooks, 1986).

The petroleum resources of southeastern Mexican basins are concentrated in the Campeche Sound area, with 96% of the overall Mexican petroleum production.

Until recently, the Macuspana Basin, has been considered to be the only gas-prone basin of Southeastern Mexico.

In order to evaluate the petroleum resources of the Macuspana basin, southeastern Mexico (Fig. 1), a number of oil, gas and rock samples were analyzed, under a geochemistry approach. This paper aims to classify the oil and gas types and to assess the depositional environments and thermal maturity of their source rocks, using a multidisciplinary approach (geochemical and geological). The purpose is to build a reliable classification of Macuspana oils with respect to their origins, and to understand differences in their composition through molecular geochemistry using GC-MS and GC-MS-MS



Fig. 1. Location map of Mexican Southeastern basins.

techniques (e.g. Moldowan *et al.*, 1985; Mello, 1988; Mello *et al.*, 1988; Peters & Moldowan, 1993; Mello *et al.*, 1993).

In total, five selected oil samples, two seep oils, eight gases and a number of selected rock samples were analyzed. The samples were

recovered from reservoirs and sedimentary units ranging in age from Middle Miocene to Pleistocene. All the oil samples were analyzed for API gravity, carbon isotope, elemental analysis (Nickel, Vanadium and Sulfur), gas chromatography and gas chromatography-mass spectrometry. In addition, representative oil samples were examined by GC-MS/MS.

Total organic carbon, pyrolysis Rock-Eval, organic extraction, carbon isotopic, gas chromatography and gas chromatography-mass spectrometry analyses (GC-MS and GC-MS-MS) were carried out on selected rock samples.

EXPERIMENTAL AND ANALYTICAL PROCEDURES

All oil and rock samples were submitted for bulk, elemental and liquid chromatography analysis according procedures described previously (Mello, 1988).

The GC analyses of alkanes were carried out using a Hewlett Packard 5890A equipped with a splitless injector and fitted with a 30m DB-5 column. The GC-MS/MS technique was performed using a triple-quadrupole Finnigan TSQ-70 instrument coupled to HP 5890A splitless gas chromatography fitted with a 35m DB-5 fused silica column.

The carbon isotope ratios were measured in a Finnigan Delta-E mass spectrometer. The isotopic data were reported in the usual delta notation referenced to the PDB standard.

GENERAL GEOLOGY

The stratigraphic column in the southeastern basins, in which the Macuspana basin is located, comprises a long sedimentary section ranging from Middle Jurassic to Recent in age (Fig. 2). Metamorphic continental basement underlies the sedimentary section comprised of a series of sedimentary rocks ranging in age from Late Triassic-Middle Jurassic (Isthmian Salt) to Pleistocene (Paraje Solo Formation).

During the Late Triassic-Lower Jurassic times, a rift phase associated with the opening of the Gulf of Mexico allowed deposition of salt bodies into the basin.

During the Callovian and the beginning of the Oxfordian, marine conditions prevailed in the basin. Oxfordian times are not represented in the Macuspana basin.

The Kimmeridgian was marked by a

marine transgression in the southeastern basins, represented by shales, which in some areas are bentonitic and sandy with limestone intercalations. In contrast, oolitic carbonate banks, partially dolomitized, with layers of dolomites and anhydrites characterize the upper portion of Kimmeridgian. Maximum flooding of Jurassic marine transgression occurred during the Tithonian. At this time, undisturbed laminated organic-rich calcareous mudstones containing mainly type II kerogen were deposited over most of the area. The Tithonian calcareous shale is the most important source rock in Mexican basins (Gonzalez & Holguin, 1991). These rocks, that extend from east-central to southeastern Mexico, are both very rich in total organic carbon (TOC) and are thermally mature. Their deposition is related to worldwide Late Jurassic oceanic anoxic event.

During the Cretaceous, a sag basin phase represented by a carbonate platform overlaid the Upper Jurassic deposits (Fig. 2). Drowning of the carbonate platform occurred during the Upper Cretaceous. Rocks from this time are represented, in the Chiapas-Tabasco area, by marl and turbiditic sediments accumulated in bathyal conditions. In the Campeche area, Upper Cretaceous deposits are represented by dolomites and shaly limestones containing chert.

A passive margin phase is represented by a thick sequence of Tertiary sediments. This phase is characterized by a change in sedimentation marked by a lithological contrast between the Cretaceous carbonates and Tertiary terrigenous. Through the Cenozoic the basin was filled with prograding sequences of shales and sands. The shelf edge was extended to its present position.

In the Macuspana basin, where salt tectonics played a lesser role, the condensates and gas are the most important hydrocarbons produced, up to now. The production is concentrated in Miocene and Pliocene reservoirs. Trapping in the Miocene and Pliocene are both stratigraphic and structural in faulted anticlines (Guzmán-Vega & Mello, *in press*).

RESULTS AND DISCUSSION

Sedimentary organic matter and oils contain complex assemblages of biological markers. It is well established that such components reflect the remains of precursor natural products in organisms, which contributed organic matter at the time of sediment deposition. Biological marker distributions in oils can,

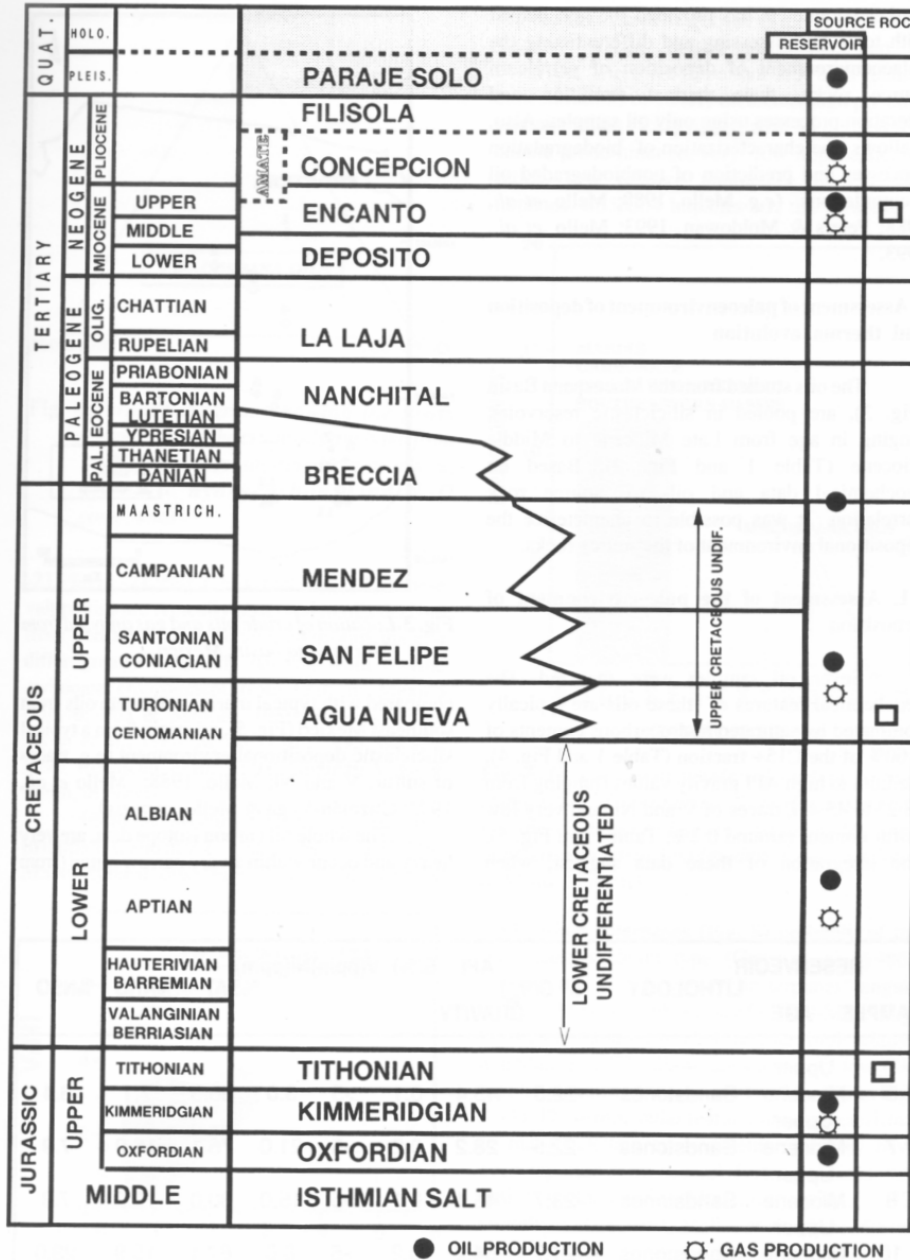


Fig. 2. Stratigraphic column of the Mexican Southeastern basins showing the reservoir and potential source rocks units.

therefore, serve as diagnostic fingerprints, carrying information about the prevailing environmental paleo-conditions (Mello, 1988). Thus, this method assists in ascertaining the

depositional environment of petroleum source rocks via the types of contributing organisms. Recently, a better understanding of the distributions and concentrations of geochemical and biological

marker parameters has provided the geochemist with tools for assessing and differentiating the paleoenvironment of deposition of petroleum source rocks, their thermal evolution and alteration processes using only oil samples. Also, it allows the characterization of biodegradation processes and prediction of nonbiodegraded oil accumulations (e.g. Mello, 1988; Mello *et al.*, 1988; Peters & Moldowan, 1993; Mello *et al.*, 1993).

1. Assessment of paleoenvironment of deposition and thermal evolution

The oils studied from the Macuspana Basin (Fig. 3), are pooled in siliciclastic reservoirs, ranging in age from Late Miocene to Middle Pliocene (Table 1 and Fig. 2). Based on geochemical data and oil- to- source rock correlation it was possible to characterize the depositional environment of the source rocks.

1.1. Assessment of the paleoenvironment of deposition

Seven oil samples were analyzed. The geochemical features of these oils are typically dominated by saturated hydrocarbons contents of < 60% of the C15+ fraction (Table 1 and Fig. 4), medium to high API gravity values (ranging from 28.2° to 45.4°), traces of V and Ni, and very low sulfur content (around 0.2%; Table 1 and Fig. 5). The integration of these data suggest, when

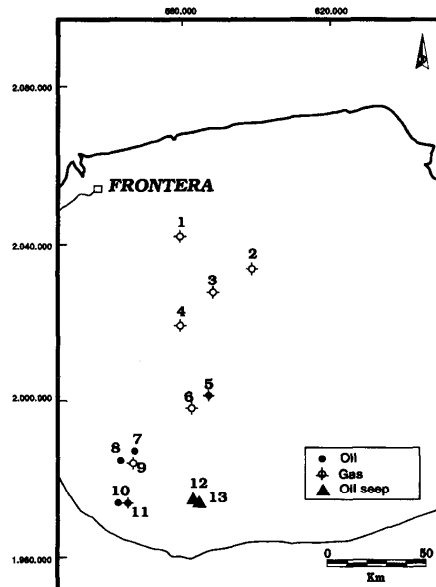


Fig. 3. Location of crude oils and gas analysed from Macuspana basin, Mexico

compared with typical marine carbonate oils from southeast Mexico (Fig. 5), an origin from a typical siliciclastic depositional environment (e.g. traces of sulfur, V and Ni; Mello, 1988; Mello *et al.*, 1993; Guzmán-Vega & Mello, *in press*).

The whole oil carbon isotope data, are very heavy and occur within a very narrow range (from

SAMPLE	RESERVOIR		$\delta^{13}C(\text{‰})$	API GRAVITY		S(%)	V(ppm)	Ni(ppm)	%SAT	%ARO	%NSO
	AGE	LITHOLOGY									
5	Upper Miocene	Sandstones	-22.5	45.4	0.1	>5	3.0	86.5	7.1	6.4	
7	Upper Miocene	Sandstones	-22.5	28.2	0.2	>5	21.0	76.1	16.0	7.9	
8	Upper Miocene	Sandstones	-23.7	45.1	0.1	>5	15.0	80.0	12.2	7.8	
10	Upper Miocene	Sandstones	-21.7	54.2	0.2	>5	6.0	67.1	15.9	23.0	
11	Upper Miocene	Sandstones	-22.6	30.5	0.0	>5	>1	68.4	16.6	15.0	
12	Seep		-21.9	20.3	0.3	>5	73.0	67.6	17.9	14.5	
13	Seep		-22.3	25.8	0.3	>5	34.0	72.5	15.8	11.7	

Table 1. Bulk and geological data for oil samples from Macuspana basin, Southeast Mexico.

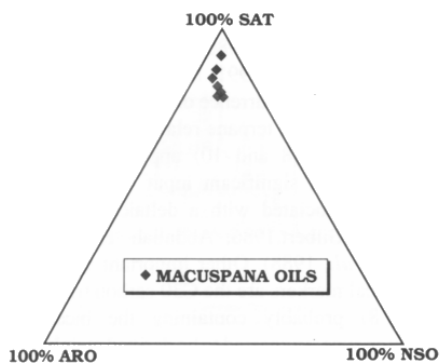


Fig. 4. Ternary diagram showing the gross composition of the crude oils analysed from Macuspana basin: saturated hydrocarbons, aromatic hydrocarbons and NSO compounds

-23.7‰ to -21.9‰; Fig. 6 and Table 1). These values also are typically observed in oils derived from Tertiary marine deltaic environments and differ greatly from oils derived from marine carbonate environment from Gulf of Mexico (Fig. 6; Poa & Samuel, 1986; Brooks, 1986; Mello *et al.*, 1988; Mello *et al.*, 1993; Sassen, 1990; Kennicutt *et al.*, 1991; Guzmán-Vega & Mello, *in press*).

From the gas chromatogram and m/z 191 (triterpanes) and m/z 217 (steranes) and GC-MS-MS of typical oils (Figs 7-10), a number of

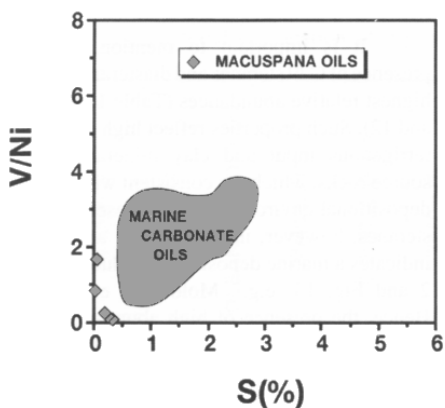


Fig. 5. Vanadium/nickel ratio vs. sulfur content (%) of oils analysed from Macuspana and marine carbonate oils from others Mexican Southeastern basins (modified from Guzmán-Vega & Mello, *in press*).

molecular features diagnostic of oils sourced from Tertiary marine deltaic sediments, can be observed. The most important are: high relative concentrations of 18 (H)-oleanane, high pristane/phytane ratios ($>>1$) linked with an odd/even n-alkane predominance, very low hopane/sterane ratios, low relative abundance of extended hopanes, C35/C34 hopanes <1 , the presence of

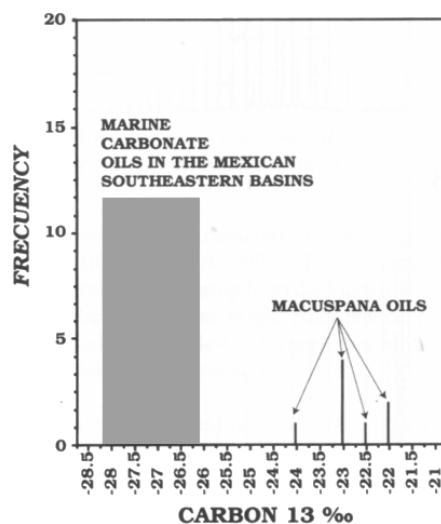


Fig. 6. Frequency of whole oil carbon isotope composition of oils analysed from Macuspana and marine carbonate derived oils from Mexican Southeastern basins (modified from Guzmán-Vega & Mello, *in press*).

C30 carbon triterpanes (Fig. 8) probably of the bicadinane skeleton type (Cox *et al.*, 1986), presence of Des-A tetracyclic terpanes ranging from C23 to C27 (Table 2; see GC/MS-MS in Figs 8-10), a dominance of C29 steranes, high relative abundance of C29 diasteranes and very low C30 regular steranes (Table 2; see GC/MS-MS in Figs 8-11). These molecular features are characteristics of marine deltaic environments and they have been reported from several Tertiary sedimentary basins in the world (Ekweozor *et al.*, 1979; Grantham *et al.*, 1983; Mello, *et al.*, 1988; Murray *et al.*, 1994).

The main molecular features which characterize the oils as derived from Tertiary sediments lies in their terpane distributions, which include biological markers diagnostic of higher plants input, notably high abundances of 18 (H)-oleanane (e.g. Figs 8 and 12). This compound was first identified (Hills & Whitehead, 1966) in an oil

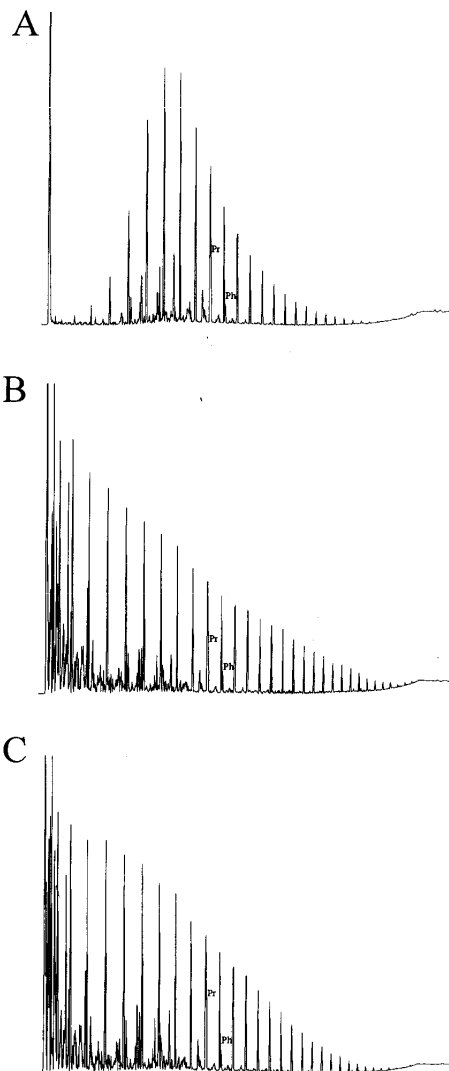


Fig. 7. Representative whole oil gas chromatograms for oils from Macuspana basin.

from the Niger delta. Further work by several authors has suggested an origin from precursors in higher plants of the angiosperm family (Ekweozor *et al.*, 1979). More recently, it has been reported to occur in a large number of oil samples, but always appears to be linked to terrestrial inputs in Tertiary basins (Taranaki delta, New Zealand; Beaufort-Mackenzie delta, Canada; Po Basin, Italy; Niger delta, Nigeria; Amazonas delta, Brazil; Mississippi delta, USA, and several basins around the world;

Grantham *et al.*, 1983; Philp & Gilbert, 1986; Riva *et al.*, 1986; Brooks, 1986; Mello *et al.*, 1988; Kennicutt II *et al.*, 1991, Moldowan *et al.*, 1991 and 1994). The occurrence of the Des-A and Des-E C24-tetracyclic terpane relative to the tricyclic terpanes (Figs 8 and 10) appears also, to be indicator of a significant input of higher plant material associated with a deltaic environment (Philp & Gilbert, 1986; Abdullah *et al.*, 1988; Mello *et al.*, 1988). Other important age related biological markers are the C30 carbon triterpanes (Fig. 8) probably containing the bicadinane skeleton type, suggested to be derived mainly from sesquiterpenoid Tertiary angiosperm resins (Grantham *et al.*, 1983; Robinson, 1987; Czochanska *et al.*, 1988; Murray *et al.*, 1994).

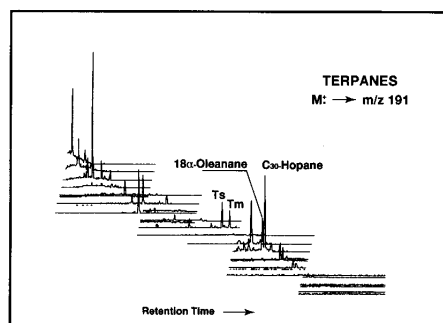


Fig. 8. Representative GC-MS/MS analysis of tricyclic, tetracyclic and pentacyclic terpanes in the saturate fraction of an oil from Macuspana basin.

It is important to mention, also, the presence of C29 steranes and diasteranes with the highest relative abundances (Table 1 and Figs 9 and 12). Such properties reflect high amounts of terrigenous input and clay minerals in their source rocks, which are consistent with a deltaic depositional environment. The presence of C30 steranes, however, in relative low abundances, indicates a marine depositional influence (Table 2 and Fig. 13; e.g. Moldowan *et al.*, 1985). Hence, the presence of high abundances of 18 (H)-oleanane, C30 carbon triterpanes, diasteranes, and C24 Des-A and Des-E tetracyclic terpanes (Figs 8-11) and C30 steranes indicates a Tertiary marine siliciclastic deltaic origin. Well-documented examples of oils derived from deltaic environments include those from Tertiary Niger delta (Hills & Whitehead, 1966; Ekweozor *et al.*, 1979), Mahakam delta in Indonesia (Schoell *et al.*, 1983; Grantham *et al.*, 1983;

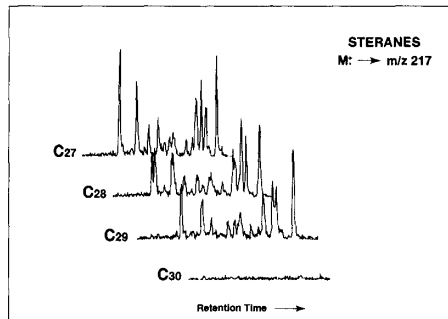


Fig. 9. Representative GC-MS/MS analysis of steranes, in the saturate fraction for the oils from figure 8.

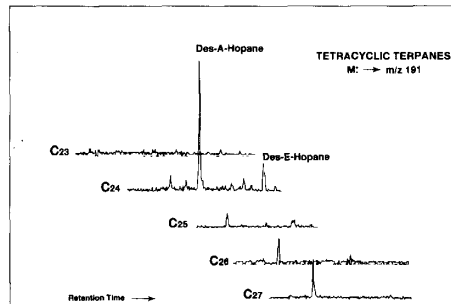


Fig. 10. Representative GC-MS/MS analysis of tetracyclic terpanes for the oil from fig. 8.

Beaufort-Mackenzie delta in Canada (Brooks, 1986), Amazon Delta (Mello *et al.*, 1988), Mississippi Delta (Kennicutt II *et al.*, 1991), and deltas in SE Asia, Southern China and New Zealand (Murray *et al.*, 1994).

The trend observed in the cross-plots from Fig. 12 (oleanane/C30 Hopane vs. C30 regular sterane/C29 regular steranes ratios) of the oils could be associated to sea level variations during the sedimentary deposition of their respective source rocks. Nevertheless, a quantitative study should be necessary to test this hypothesis (Mello, *et al.* 1994).

Very low sterane/hopane ratios, when compared with data from marine carbonate oils from the Gulf of Mexico (Fig. 13; Guzmán-Vega & Mello, *in press*), suggest a major bacterial contribution to these oils, probably related to reworking and bacterial degradation of organic

matter derived from remnants of terrestrial higher plants (Killops *et al.*, 1991). In summary, the geochemical data arising from the Macuspana oils are indicative of an origin from source rocks deposited in a siliciclastic, Tertiary, marine deltaic depositional environment.

1.2. Thermal evolution of oils and gas samples

Data from key maturity-related biomarker parameters (Table 2) from the oils show a thermal evolution stage ranging from the early stage to the peak of oil generation (Figs 14-15). Therefore, their putative source rocks were submitted to a medium to low thermal stress, being equivalent to a vitrinite reflectance value (Ro %) ranging from 0.5% to 0.9% (Mello, 1988).

The gases studied in the Macuspana basin, are wet (methane abundance ranging from 73% to

SAMPLE	C ₂₉ /C ₃₀ (a)	C ₃₀ /C ₃₁ (b)	OLEANANE INDEX (c)	24/4/26/3 (d)	C*30/C29 Ts (e)	Ts/Tm (f)	DIAINDEX (g)	%C ₂₇ (h)	%C ₂₈ (h)	%C ₂₉ (h)	C ₂₇ /C ₂₈ (i)	STERANES/HOPANES (j)	Pr/Ph (k)
5	0.6	0.3	0.6	1.1	0.4	1.3	0.9	31.2	32.3	36.6	0.9	0.1	3.2
7	0.6	0.5	0.6	0.9	0.3	1.0	0.6	30.0	35.4	34.5	0.9	0.1	-
8	0.6	0.4	0.8	0.9	0.6	1.1	0.7	28.4	35.5	36.1	0.8	0.1	3.4
10	0.5	0.6	0.7	0.5	0.3	1.1	0.4	23.6	36.6	39.8	0.6	0.1	2.1
11	0.6	0.6	0.6	0.6	0.3	0.9	0.5	26.4	37.5	36.1	0.7	0.1	2.1
12	0.5	0.6	0.6	0.8	0.3	0.7	0.8	30.6	33.2	36.2	0.8	0.1	-
13	0.6	0.3	0.6	0.8	0.4	0.9	0.6	27.6	35.4	37.0	0.7	0.1	-

Table 2. Source-Dependent Parameters for oils from Macuspana basin, Southeast Mexico.

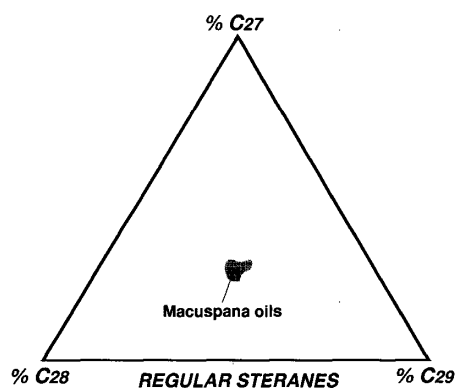


Fig. 11. Ternary diagram showing the C_{27} , C_{28} and C_{29} steranes of the crude oils analysed from Macuspana basin.

98.4%), thermogenic ($\delta^{13}C$ values from -66.7 to -41.5‰), and genetically associated with the oils (Fig. 16 and Table 3). Using the classical Schoell's diagram (Fig. 16), the heavier gases ($\delta^{13}C$ values from -41.2 to -43.1‰) would be of thermogenic origin, while the other ones ($\delta^{13}C$ values from -62.3 to -66.7‰), would correspond to mixing of thermogenic and bacterial methane. However, the very consistent evolution of the isotopic ratios with the distance from the oil kitchen, allows to interpret these gases as altered by migration fractionation effect. Such hypothesis, should allow gas compositions with a random distribution

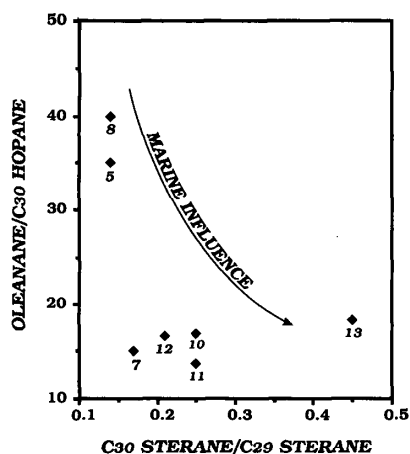


Fig. 12. Oleanane/ C_{30} hopane ratio vs. C_{30} regular steranes/ C_{29} regular steranes ratio for oils from Macuspana basin.

along the migration pathway. Experimental evidence and natural case studies have shown that methane may be solubilized in the formation waters, and diffuse through it, with chemical and isotopic fractionation effect. The diffuse gases would be chemically drier and isotopically lighter (e.g. Pernatou *et al.*, 1995).

1.3. Rock samples and oil-source rock correlation

The Miocene rock samples from Costero-1 and Vernet Sur-1 well present TOC up to 2%, S_2 up to 20 mg HC/g. rock, HI up to 670 mg HC/g. COT, and predominance of amorphous Kerogen.

Petrographic data from selected samples from the Costero-1 well show a large organic matter variation. Some Miocene samples are dominated by amorphous organic matter. In contrast, most of the Tertiary samples are characterized by an abundance of woody organic matter (Fig. 17).

Tertiary core and cuttings samples from the Macuspana basin were analyzed (Table 1). These

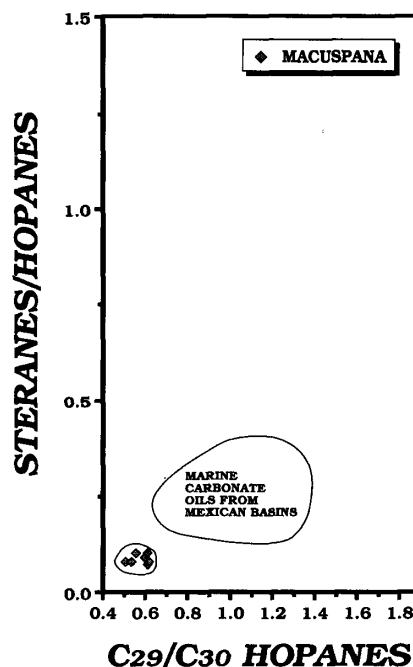


Fig. 13. Steranes/hopanes ratio vs. C_{29}/C_{30} pentacyclic terpanes of oils analysed from Macuspana basin.

rocks are organic-poor (TOC 1%, S₂ < 5 mg HC/g. rock and HI < 300 mg HC/g. TOC, type III kerogen) and can be considered as poor source rocks for liquid hydrocarbons. These features suggest that relatively oxygenated conditions prevailed in their paleoenvironment of deposition. Petrographically, they are shales composed essentially of woody organic matter (>60%), and their reflectance values indicate an immature stage (R_o < 0.5%, Table 1).

Figure 18 illustrates the attempt of an oil-source rock correlation using an oil recovered

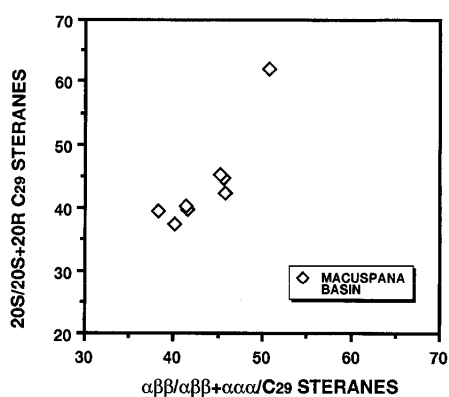


Fig. 14. Relative thermal maturity of oils based on proposed isomerization reactions among the C₂₉ steranes ($\alpha\beta\beta/\alpha\beta\beta+\alpha\alpha\alpha$ and $20S/20S+20R$) of oils analysed from Macuspana basin.

from the Jose Colomo 22 well and an Miocene organic extract. The molecular features related to gas chromatograms and m/z 191 and m/z 217 mass chromatograms show a good match although the rock sample is of a lower thermal evolution stage. On the other hand, there is a

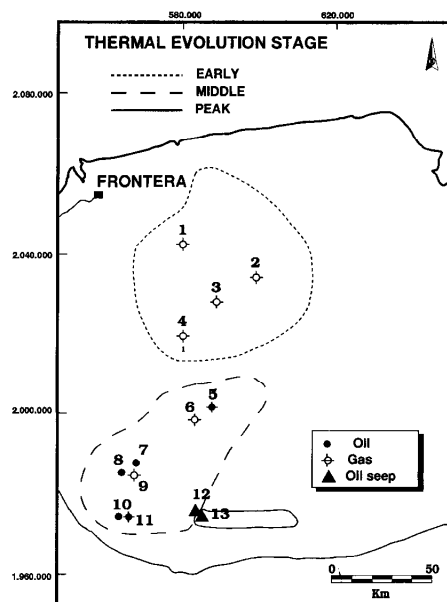


Fig. 15. Thermal evolution map for oils and gases analysed from Macuspana basin.

correlation for most of the diagnostic biological marker features arising from an Tertiary siliciclastic marine deltaic depositional environment.

Although the biomarker features have a good correlation, there are significant differences when their respective carbon isotope compositions are compared (Fig. 18). Carbon isotopic values of the oils range between -24 ‰ to -22 ‰ (Fig. 6). In contrast, the extract of Vernet Sur-1 has values around -26.55 ‰ (Fig. 18). These isotopic differences among the pooled hydrocarbons and the organic extracts could be explained by expulsion/migration processes (Leythaeuser & Poelchau, 1991).

SAMPLE	RESERVOIR AGE	LITHOLOGY	$\delta^{13}\text{C}$ (‰)	METHANE CONTENT(%)	C2+ CONTENT(%)
1	Lower-middle Pliocene	Sandstones	-65.4	98.1	1.9
2	Lower-middle Pliocene	Sandstones	-66.8	98.0	2.1
3	Lower-middle Pliocene	Sandstones	-64.0	98.5	1.5
4	Lower-middle Pliocene	Sandstones	-62.3	98.4	1.6
5	Lower-middle Pliocene	Sandstones	-41.2	73.6	26.4
6	Lower-middle Pliocene	Sandstones	-42.0	74.5	25.5
9	Lower-middle Pliocene	Sandstones	-41.5	87.8	12.2
11	Upper Miocene	Sandstones	-43.1	73.0	27.0

Table 3. Geological and geochemical data of gas samples from Macuspana basin, Southeast Mexico.

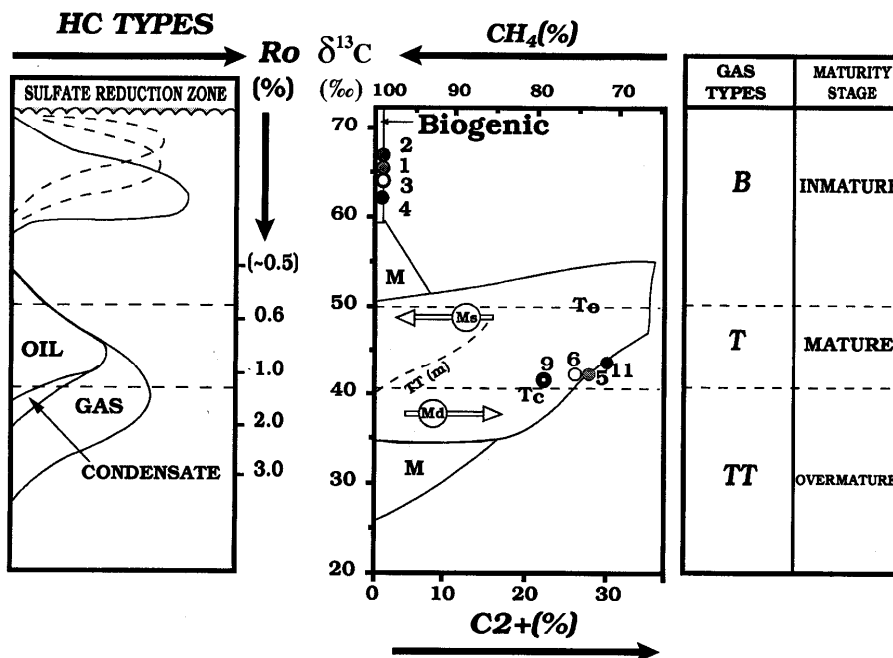


Fig. 16. Relationship between carbon isotopic composition of methane and C₂+ content (wetness) from Macuspana basin gas fields in genetic diagram after Schoell et al. (1983).

As suggested by their molecular features, the source rocks of the Macuspana oils were deposited under hypoxic marine conditions in a prodelta area during Miocene time. These sub-environments received mainly land-derived organic matter. The interlayered, mixed sands and shales of the paralic sequence of the associated

delta, can provide reservoir opportunities and sealing cap rocks in the direct neighborhood of the front delta. Furthermore, young deltas during their progradation undergo comparatively strong subsidence. This is in turn essential for source rock maturation, generation and preservation of hydrocarbons in the deeper parts of the basin.

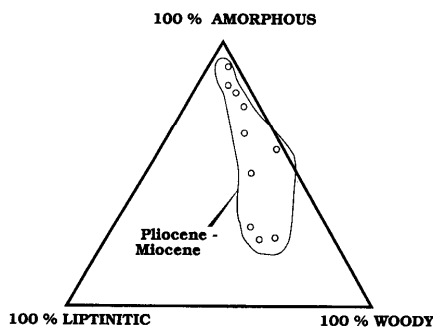


Fig. 17. Ternary diagram showing the relative abundances of main organic matter constituents from the Pliocene-Miocene section of the Costero 1 well Macuspana basin, Mexico.

CONCLUSIONS

1- Geochemical and biological markers analyses of oil, gas and rock samples were used to identify Tertiary marine deltaic-sourced oils. They can be recognized by their ¹³C values between -23.6‰ to -21.7‰, low sulfur content, pristane/phytane ratios >>1, low hopane/sterane ratios, low relative abundance of homohopanes, C35/C34 <1, high relative concentrations of oleanane, presence of Des-A tetracyclic terpanes ranging from C23 to C27, and the presence of C30 regular steranes.

2- The gases associated with the Macuspana oils are wet, with methane abundance ranging from 73% to 98.46% and ¹³C values from -66.7‰ to -41.5‰. According to abundance and

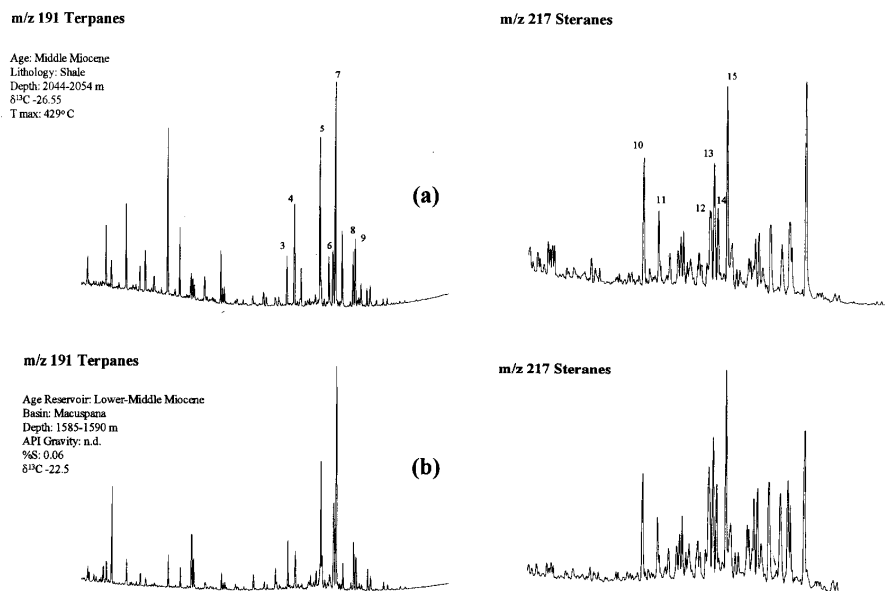


Fig. 18. Oil- source rock correlacion.

a) m/z 191 and m/z 217 mass chromatograms for the Vernet Sur 1 extract

b) m/z 191 and m/z 217 mass chromatograms for the Jose Colomo 22 oil

isotopic composition of methane, the origin of most of them is associated with Tertiary source rocks within the oil window. The samples showing very light isotopic values ($\delta^{13}C$ values < -60 ‰) also have a thermogenic origin, both with compositional and isotopic values altered due to migration fractionation effect.

3- From all the rock samples analyzed, only a few are organic-rich (TOC $> 2\%$, S₂ > 5 mg HC/g. rock and HI > 300 mg HC/g. TOC-type II Kerogen) and can be considered as potential source rocks for liquid hydrocarbons. The oil-source rock correlation shows a good match, suggesting that these rocks were deposited in a marine deltaic hypoxic siliciclastic environment during Miocene times.

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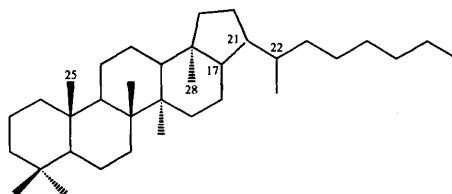
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APPENDIX 1

Terpanes



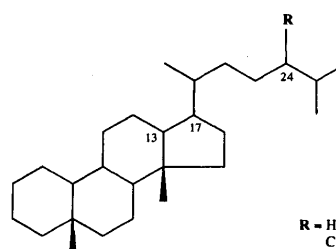
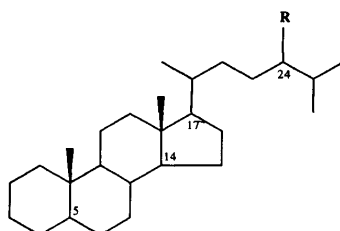
Terpanes

- 1 - C₂₄ Tetracyclic terpane (des-A-hopane)
- 2 - C₂₄ Tetracyclic terpane (des-E-hopane)
- 3 - 18 α (H),22,29,30-Trisnorhopane (Ts)
- 4 - 17 α (H),22,29,30-Trisnorhopane (Tm)
- 5 - 17 α (H),21 β (H),30-Norhopane
- 6 - Oleanane
- 7 - 17 α (H),21 β (H)-Hopane
- 8 - 17 α (H),21 β (H)-Homohopane (22S)
- 9 - 17 α (H),21 β (H)-Homohopane (22R)

Mol.F. M.W.

C ₂₄ H ₄₂	330
C ₂₄ H ₄₂	330
C ₂₇ H ₄₆	370
C ₂₇ H ₄₆	370
C ₂₉ H ₅₀	398
C ₃₀ H ₅₂	412
C ₃₀ H ₅₂	412
C ₃₁ H ₅₄	426
C ₃₁ H ₅₄	426

Steranes



R = H C₂₇
 CH₃ C₂₈
 C₇H₅ C₂₉
 C₃H₇ C₃₀

Steranes

- 10 - 13 β (H),17 α (H)-Diacholestane (20S)
- 11 - 13 β (H),17 α (H)-Diacholestane (20R)
- 12 - 5 α (H),14 α (H),17 α (H)-Cholestane (20S)
- 13 - 5 α (H),14 β (H),17 β (H)-Cholestane (20R) +
13 β (H),17 α (H),24-ethyl-Diacholestane (20S)
- 14 - 5 α (H),14 β (H),17 β (H)-Cholestane (20S) +
13 α (H),17 β (H),24-methyl-Diacholestane (20R)
- 15 - 5 α (H),14 α (H),17 α (H)-Cholestane (20R)

Mol.F. M.W.

C ₂₇ H ₄₈	372
C ₂₇ H ₄₈	372
C ₂₇ H ₄₈	372
C ₂₇ H ₄₈	372
C ₂₉ H ₅₂	400
C ₂₇ H ₄₈	372
C ₂₈ H ₅₀	386
C ₂₇ H ₄₈	372