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HYDROCARBON GAS ACCUMULATIONS IN GREECE AND THEIR ORIGIN*

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ABSTRACT

In the sedimentary basins of Greece are found a lot of hydrocarbon gases that can be distinguished in four categories. Surface gas seeps, gas shows in shallow water-wells, gases in exploration wells and hydrocarbon gas fields. The main gas shows are mainly located inside recent clastic sediments. Hydrocarbon amount varies between a few ppm and several units percent.

Gases are classified in the biogenic gases of Katakolo onshore gas-field, the most surface gas seeps and the gases at shallow depths of exploration wells. Catagenetic are the gases of Katakolo oil field, the Epanomi and South Kavala gas fields, and a lot of gases found in great depths of exploration wells. Metagenetic gases have been identified in Delta Evros and West Thermaikos.

KEY WORDS: Biogenic gas, catagenetic, metagenetic, oil window, gas generation.

ΣΥΝΟΨΗ

Στις ιζηματογενείς λεκάνες της Ελλάδας εντοπίζονται αρκετές εμφανίσεις αερίων υδρογονανθράκων. Σε σχέση με τον τρόπο εμφάνισης διακρίνονται τέσσερις κατηγορίες. Εμφανίσεις αερίων στην επιφάνεια, αέρια σε γεωτρήσεις υδροληψίας μικρού βάθους, εμφανίσεις αερίων υδρογονανθράκων σε ερευνητικές γεωτρήσεις και κοιτάσματα αερίων υδρογονανθράκων.

Τα αέρια κατατάσσονται στα βιογενή του κοιτάσματος της χερσαίας περιοχής Κατακόλου και των περισσότερων επιφανειακών και μικρού βάθους ενδείξεων αερίων. Καταγενετικά είναι τα αέρια των κοιτασμάτων Δυτικό Κατάκολο, Επανωμή και Νότια Καβάλα, και πολλές ενδείξεις αερίων που εντοπίστηκαν σε ερευνητικές γεωτρήσεις. Μεταγενετικά αέρια έχουν εντοπιστεί στον Εβρο και στο Δυτικό Θερμαϊκό.

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Βιογενές αέριο, καταγενετικό, μεταγενετικό, παράθυρο πετρελαίου, γένεση αερίου.

1. INTRODUCTION

Gas shows are often found at surface, but their identification is difficult, especially if they are not accompanied by water. In this case gases can be recognized easier, due to gas bubbles created during their flow. The presence of surface gases is used in the hydrocarbon exploration, by using surface geochemical methods. These methods measure gas accumulations, originating from an oil or gas field, adsorbed in loose sediments or in the ground. If the area is not tectonized, the oil or gas field is possible to be located. But, in highly tectonized areas, the surface gas accumulations are located along the faults (Katsinis, 1994).

Some other gases can also be related to petroleum generation process, like helium (He) and carbon dioxide (CO_2). The CO_2 can be found either like gas, or as carbonate water. It is an indirect indication of petroleum generation, but it is also possible to be generated from inorganic sources.

Hydrocarbon gases in Greece can be distinguished in four categories, related to the way of their occurrence. Surface gas seeps, gases in shallow water-wells, gases in exploration wells and hydrocarbon gas fields. The gas shows are mainly located inside recent clastic sediments. The most significant gas accumulations are located in the Tertiary basins of eastern Greece and in the post-orogenic basins of western Greece (Fig. 1). In this work the three gas fields of Greece will be studied in details, as well as the most significant gas shows detected in other areas.

Hydrocarbons amount in the deep wells varies between a few ppm and several units percent. Chemical composition was identified by the gas chromatograph, which in the well laboratories can usually separate the most light gases, methane (C_1), ethane (C_2), propane (C_3), butane (C_4), and pentane (C_5). The quantity of carbon

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dioxide (CO_2) can also be traced. The hydrogen sulfide (H_2S) can be tested by special instrument. Analyses for higher hydrocarbon gases determination and/or other associated gases were performed in the laboratories of the refineries (ELDA and EKO).

Further to the chemical composition, gas isotope composition allows a better determination of gas origin. The isotopes mainly used are carbon ($\delta^{13}C$) and hydrogen (deuterium - δD) isotopes of methane. These identifications are performed by mass spectrometer. For our gas accumulations were performed just a few isotope measurements, in specialized laboratories outdoor.

All these analyses allow gases classification, in the three main categories of their origin: Biogenic gas from organic mater degradation, catagenetic by the main oil generation procedure and metagenetic by other gases cracking. Distinction is based on the fact that biogenic and metagenetic gases are very dry, whereas the catagenetic are wet gases. As wetness indicators, are used either the ratio $C_1/(C_2+C_3)$ (Waples, 1981), or the C_2+ % (Schoell, 1983), or the ratio $C_1/\Sigma C_n$ (Tissot & Welte, 1984) etc. Furthermore the biogenic gas has very low carbon isotopic values of methane ($\delta^{13}C$), whereas the metagenetic methane is isotopic heavier (Rice & Claypool, 1981). A further categorization is also possible, based on the source rock which generated the gas (Schoell, 1983).

2. HYDROCARBON GAS ACCUMULATIONS IN THE SEDIMENTARY BASINS OF GREECE

2.1 South Kavala gas field

In the taphrogenetic Prinos basin, further to the Prinos oil field, the South Kavala gas field (Fig. 1) was discovered in 1972, by the SKA-1 well, drilled by Oceanic Company. The reservoir is located between two evaporitic horizons and consists mainly of sandstone fine to coarse and microcon-glomeratic in alternation with claystone, marl and conglomerate in clay matrix, all of turbiditic origin (Proedrou, 1979, Proedrou & Sidiropoulos, 1992). The reservoir top is located at 1656m and the gas-water contact at 1723m. Net thickness is 10m avg., porosity ranges between 20 and 24% and permeability is up to 400md. The in place reserves are estimated 1 x 10^9 m^3. The up today production (Xenopoulos, 2000) is 660 x 10^9 m^3 of gas plus 0.6 x 10^6 bbls of light oil (65 API). Gases are also detected in the oil wells of Prinos oil field.

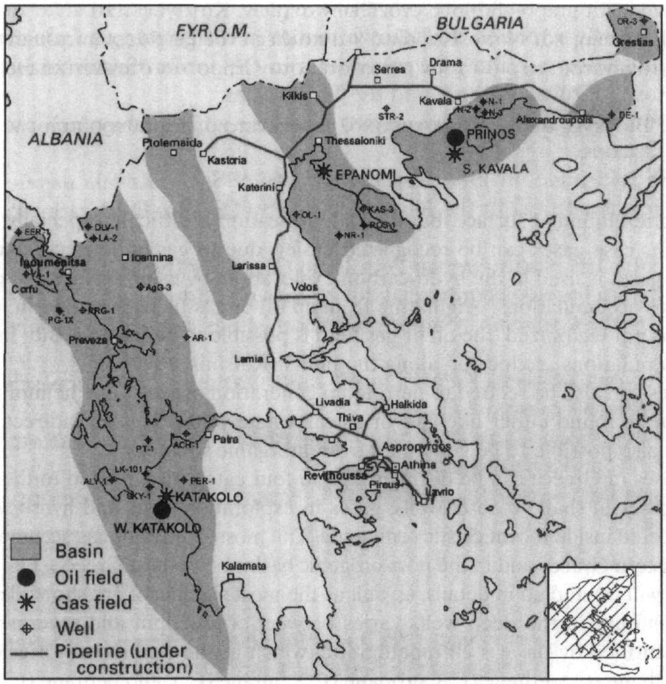

Fig. 1: Gas fields and most significant gas wells in the sedimentary basins of Greece

South Kavala gas is a wet (catagenetic) gas, as concluded by all the wetness indicators (App. 1) and it is associated with condensate (Fig. 2a). The absence of H_2S from its composition differentiates this gas from associated with condensate (Fig. 2a). The absence of H_2S from its composition differentiates this gas from Prinos gases, which are rich in H_2S (App. 1). Prinos gas is probably associated with Prinos oil, which is generated from a source rock deposited in carbonate-evaporitic environment of Upper Miocene age (Parassis et al., 1995), before the main evaporite formation. Gas is very mature as concluded from the high amount of H_2S (Connan & Lacrampe-Couloume, 1993) and its isotopic data as well (Fig. 2b). This gas is generated from marine euxinic sediments that can be the early pre-evaporitic marine horizons. These sediments are buried in great depth in the Prinos graben, so their maturity is very high. South Kavala gas is less mature than Prinos gas (Fig. 2b). It is H_2S free, so it is probably generated from humic organic matter. Its possible source is the pre-evaporitic continental horizons of Middle Miocene age that in the South Kavala area are not buried deep, so their maturity is not high.

2.2 Epanomi gas field

In Epanomi area, the Epanomi gas field (Fig. 1) was discovered in 1988. In 1989 the production test of Epanomi-2 well gave 19 MCFD of gas and small quantities of light oil. The structure is a paleoerosional surface of U. Jurassic-L. Cretaceous limestones with 1% average porosity and the reserves are estimated to be 500x10^6 m^3 of natural gas (Roussos, 1993).

The Epanomi gas field is composed (App. 1) of 71.8% hydrocarbon gases and 26.6% non-HC gases (CO_2=22.6%). In the EP-B1 well, east of the Epanomi field, the gas is composed mainly of carbon dioxide (CO_2=93.5%). The hydrocarbon gases are wet gases since they have a significant percentage of C_2+ compounds, ranging from 3.2 to 4% (App. 1). This percentage is combined with the carbon isotope of methane, (App. 2) in the diagram of Fig. 2a (Schoell, 1983). The plot indicates that gases are of catagenetic origin. Furthermore, they are produced from a mixed source, from sapropelic-liptinitic and humic organic matter. This source could be either one-source rock containing either component, e.g. algae and lignite, or two different sources. The Epanomi oil is also originated by two sources (Rigakis et al., 1995). One of the possible sources is the Eocene shales drilled in POS-1 well (Fig. 1). The organic matter of these shales has double origin, from algae and higher plants. Since gas is thermogenic, in combination with the geological setting led us to conclude that, gas and oil have the same sources: the Eocene shales and a second source probably from deeper-unknown horizons, as concluded by the high maturity level of the gas (Fig. 2b).

The carbon dioxide (CO_2), as concluded by carbon isotope data ($\delta^{13}C$) has not the same origin with the

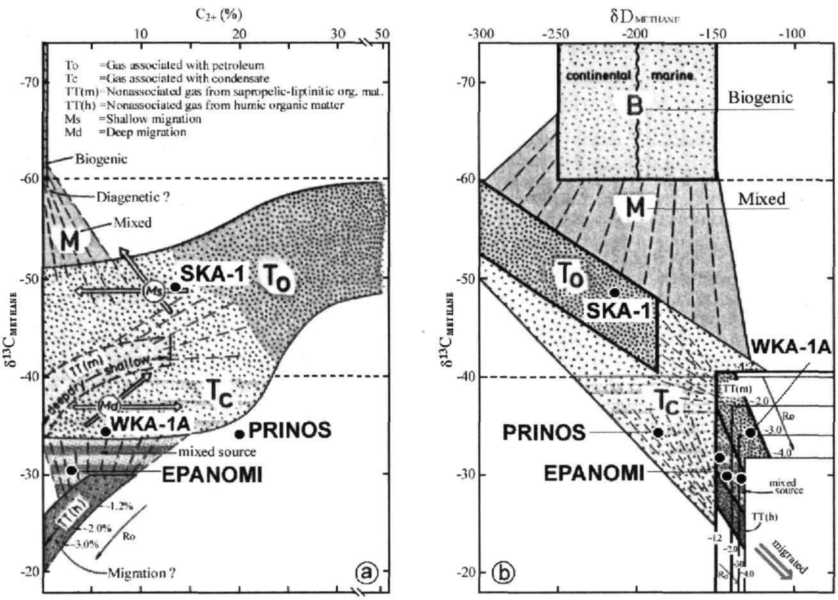

Fig. 2: Classification of Greek hydrocarbon gases by compositional and isotopic variations (evolution paths after Schoell, 1983).
a. C_2+ hydrocarbon gases vs. $\delta^{13}C$ of methane.
b. Methane isotopes, $\delta^{13}C$ vs. δD (deuterium).

hydrocarbon gases. It is originated by the evolution of the dolomitic limestones of Mesozoic age (Rigakis et al., 1995), since during the process of dolomitization it is also produced CO_2. The inorganic origin of the CO_2 is a positive fact for the area, indicating that the source rocks products are mainly hydrocarbons, or in other way, the whole potential of the source rocks can be calculated as hydrocarbon potential.

2.3 Katakolo gas field

In Katakolo onshore area a small gas field was discovered in 1980. A horizon at 1230m of KA-101 well gave 4 MCF of gas, with 42 bars pressure. Even higher surface pressures, up to 150 bars, have been reported at 1760m of KA-102 well. These very promising gas horizons can be used for local consumption (industries, greenhouses, etc.), but additional studies are needed, like detailed seismic work etc., in order to evaluate the adequacy of the reserves.

Hydrocarbon gas shows, mainly methane, appeared in most of the other wells drilled in NW Peloponnessus. The main gas concentrations are found in Neogene clastic horizons, medium to fine-grained sands, of Vounargo or Peristeri formations. Furthermore surface gas seeps, located on a normal fault, are known in two places: Faros (known as "Volcano") and Katakolo port.

The NW Peloponnessus gases can be distinguished in two major categories (App. 3): The dry gases having a $C_1/(C_2+C_3)$ ratio greater than 1000 and the wet gases having a $C_1/(C_2+C_3)$ ratio less than 100. Three gases with a ratio between 270 and 600 (App. 3) are possible of mixed origin. Dry are most of the gases found in late Cenozoic clastic sediments, and in Mesozoic carbonates of some wells. Wet gases are the surface gas seeps, all the gases found inside the evaporites, the West Katakolo oil field associated gases, as well as the gas shows found in clastic sediments of KA-105 well.

Gases of the West Katakolo oil field (offshore), tested by the wells WKA-1, -1A and -2, are catagenetic, associated with condensate. Classification is based on the WKA-1A gas data, the crossplot of C_2+ hydrocarbons vs. $\delta^{13}C$ of C_1 (Fig. 2a). All the other wet gases, found inside the evaporites but also in flysch and sometimes in Neogene sediments, are also characterized as catagenetic. So, catagenetic gases are found either in the pre-Neogene basement, or in Neogene sediments, in areas where the basement is located near the surface, or it is joined by fault with the surface.

Classification of the dry gases is more difficult. For these gases isotopic data are needed, that are not available, to separate biogenic from metagenetic gases. In the absence of these data, the NW Peloponnessus gases can theoretically be classified either as biogenic or as metagenetic gases. In fact, based on geological data the gases can be characterized as biogenic, because:

1. Gases are mainly found in very young sediments of Plio-Pleistocene age.
2. They are located in shallow depths, usually less than 2000m.
3. The temperature gradient of the area is not high, ranging from 1.15 °C/100m in evaporites to 2 °C/100m in clastics and carbonates (Rigakis, 1999), favoring the generation of biogenic gas even in depths greater than 2000m. In this depth temperature is only 60 °C, much lower than 75 °C, the upper limit for biogenic gas generation (Rice & Claypool, 1981).

The genesis of the biogenic gases was also favored from the rapid deposition of the sediments in anoxic and sulfate deficient environment (Claypool & Kaplan, 1974, Rice & Claypool, 1981). These conditions were obtained in the continental to near shore environment where the clastic sediments of NW Peloponnessus were deposited (Kamberis et al., 1992). A negative factor could be the presence of the Triassic evaporites that underlie the clastic sequence. The sulfur ions coming from these evaporites can create problems in hydrocarbon gas production, by converting CH_4 to H_2S (Rice & Claypool, 1981). Instead of this, most of the biogenic gases in that area are located above the evaporitic dome, e.g. the significant amounts of gas in the Katakolo area wells. In order to define the area of sulfur action, the diagrams of Fig. 3 were constructed, showing the presence of gas above the evaporites in the wells with remarkable amount of gas. From the diagrams it is concluded the following.

The longer distance from the evaporitic dome, with significant reduction of the methane quantity, is 760m measured in KA-102 well. It is probably because in great depths the biogenic gas generation is getting less. This distance is sorted in the rest of the wells, 630m in KA-101 well, 520m in KA-104 well, 280m in PER-1 well, and less than 200m in the wells MY-1 and KA-103. According to this, the influence of sulfur ions is limited in a narrow area above the evaporitic dome, probably due to the late evaporitic movement (Kamberis et al., 1998), that did not allow the extended sulfur action. So, the existence of the evaporites can not exclude the presence of gas fields in the area. Furthermore, this diapir can help the gas accumulation, favoring the trap generation during its uplift movements. The gas accumulation is also favored in this area by the sediments type, characterized by the extensive shale strata constraining adequate seals, and also by the high deposition rate (Rice, 1993).

These biogenic gases are related to some lignite horizons drilled by deep ter is immature for oil generation, but high quantities of biogenic gases can be produced in these low maturities (Rice & Claypool, 1981).

2.4 Tertiary basins of eastern Greece

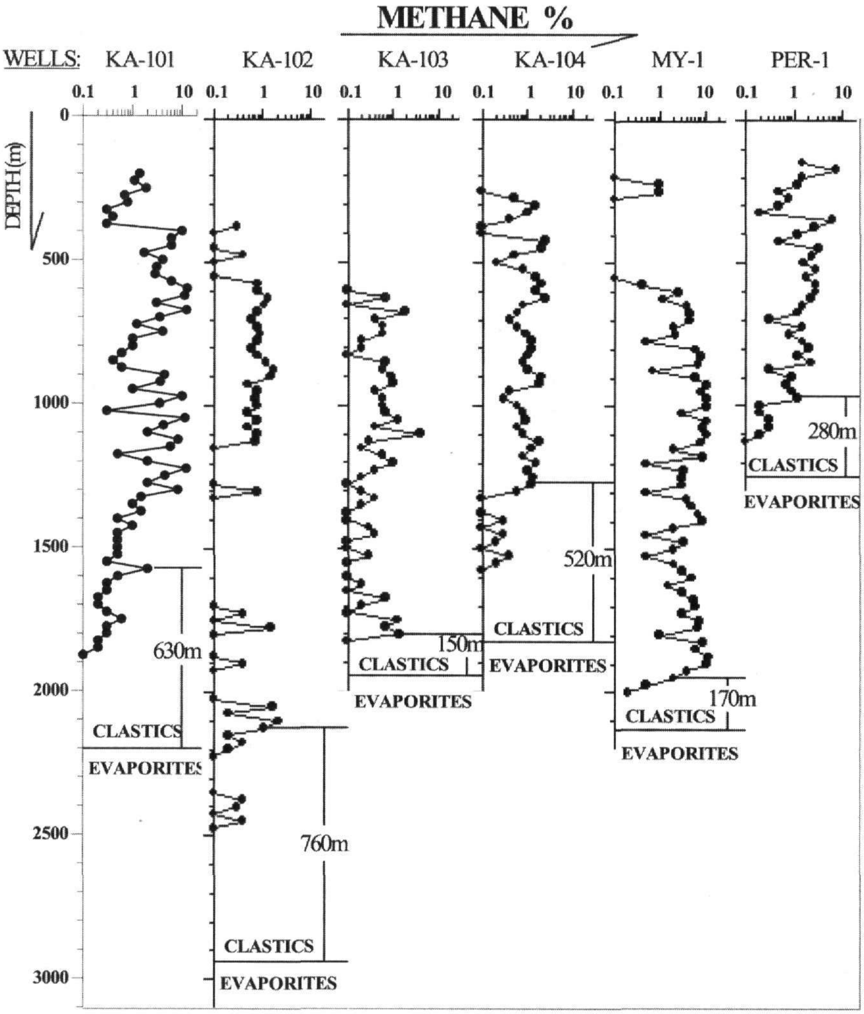

Fig. 3: Hydrocarbon gas accumulations in Katakolo area wells with evaporitic basement, indicating the limited influence of sulfur ions in the Neogene clastic sediments overlying the evaporites.

In Evros-Orestias basin gas shows have been identified by all the exploration wells. Gases at shallow depths are composed of methane, obviously of biogenic origin (App. 1). In greater depths of Orestias sub-basin the whole series of gaseous hydrocarbon (up to C_5) were detected. At 2170m depth of Orestias-3 well, inside Oligocene sandstone, heavier hydrocarbon gases (C_2 and C_3) are first identified. It is important that, these gases are found just after the onset of oil generation. The upper limit of oil window in this well is located at 2100m depth, as concluded by maturity models. Higher gas presence has been tested in two horizons at 2250 and 3050m (App. 1). These are catagenetic gases as concluded by the ratio $C_1/(C_2+C_3)$.

In the Delta Evros sub-basin the gas shows are limited and are consisted only by methane. In the shallow horizons these gases are of biogenic origin and are located nearby lignite horizons of Oligocene age. The methane of the deeper horizons (App. 1), can't be of biogenic origin, since biogenic gases are usually generated up to 1000m depth, and anyway in a temperature lower than 75°C (Rice & Claypool, 1981). In this area the geothermal gradient is 3°C/100m, higher than the other sedimentary basins of Greece, due to the magmatic intrusions. The organic matter of the sediments, because of the rapid heating due to sudden thermal transfer, passed quickly through the catagenesis to the metagenesis stage. The oil window is restricted in the narrow interval 1200-2400m. So, the methane of the deeper horizons is considered as metagenetic.

Three deep wells (Nestos-1, -2, -3), drilled in Nestos Delta for petroleum exploration, identified very promising gas horizons inside sandstone layers of Miocene age (App. 1). Most of these gases are related to lignite horizons of significant thickness, drilled by these wells. At shallow depths gases are composed of methane, obviously of biogenic origin. But, the most significant gases are found deeper and are of catagenetic origin, as concluded by the ratio $C_1/(C_2+C_3)$, that is less than 100 in all cases. In Nestos-1 and Nestos-2 wells, C_2+ gases appeared at 2200m and 1820m depth respectively. These gases should have been migrated from deeper layers, since the oil window starts at 2450-2500m in this area. In Nestos-2 well C_2+ gases are first detected at 2775m, just after the onset of oil generation. No gases have been detected after 3500m, the lower limit of oil window. Very promising gas concentrations have been reported in the production tests of Nestos-2 well (App. 1), but the pressure was generally low and the gas flow negligible, due to the restricted lateral extend of the reservoirs. The best results (0.5-1.5 bars pressure and 160 m^3/hour gas flow) are reported in the test No 5 at 3364-3370m depth. But, even these are considered as very low.

Gas shows are limited in Strymon basin. In the shallow horizons the only compound of gas is methane, of biogenic origin. In some cases this gas is directly related to lignite horizons. In the deeper horizons heavier (catagenetic) gases are found, but in low quantity as well (App. 1). It is very interesting that in STR-1 and -2 wells, C_2+ gases are detected at 2380m and 2186m depth respectively, just after the onset of oil generation (2330m in STR-1 and 2000m in STR-2).

In Kassandra area, low amounts of gas have been found by some deep wells (App. 1). Gases at shallow depths are of biogenic origin. At 3467m depth in Possidi-1 well, just after the onset of oil window (3300m), was first detected heavier hydrocarbon gases (App. 1) of catagenetic origin.

In the Thermaikos offshore basin very significant gas accumulations were identified, by the wells Olympia-1 and Nireas-1 drilled in 1986 (App. 1). The shallow dry gases of OL-1 well are of biogenic origin, related to lignite horizons of Miocene age. Gases at deeper horizons are wet gases (App. 1), with a ratio $C_1/(C_2+C_3)$ less than 20, indicating a catagenetic origin. Inside the Eocene horizons of OL-1 well the gas shows were very limited, composed of methane. This methane is considered as metagenetic, since the Eocene horizons of this well are overmature, as concluded by maturity models. In NR-1 well even higher gas quantities were detected (App. 1). Shallow dry gases inside Plio-Pleistocene sands are biogenic. In deeper Miocene horizons the gases are wet-catagenetic ($C_1/(C_2+C_3)$ between 70 and 92), related to Miocene lignites. Gases detected inside Eocene horizons are generated from Eocene sources. These are wet-catagenetic gases ($C_1/(C_2+C_3) \sim 60$) having similar composition and probably the same origin with the Epanomi hydrocarbon gases. According to that, high quantities of CO_2 are not expected to be found in Thermaikos offshore area. Four production tests performed in the most significant gas layers of NR-1 well gave remarkable gas concentrations (App. 1), but with low pressure and gas flow.

In the wells, drilled for hydrocarbon exploration in the Mesohellenic trough, were detected negligible gas shows, in sandy horizons of Tsotili formation (Aquitanian-Burdigalian age). The quantity of these gases could be much higher, if the drilling mud was not so heavy (grater than 1.15, in some cases even grater than 1.3 gr/cm^3). Nevertheless in this basin have been identified very prosperous source rocks, capable for generation of great amounts of gaseous hydrocarbons (Kontopoulos et al., 1999).

2.5 Western Greece basins

Remarkable gas shows were detected in the deep wells, drilled for petroleum research in NW Greece, (App. 4). Most significant are the gases of Archagelos-3 well, composed of methane, obviously of biogenic origin. Near these gases, lignite layers were drilled. Gases filled a conglomerate reservoir of Pliocene age, with 22-30% porosity. All other gases, found inside flysch or the Eocene-Mesozoic carbonates, were catagenetic as concluded by the low ratio $C_1/(C_2+C_3)$. Most remarkable are the gases found in dolomite breccias, inside the Triassic evaporites of Delvinaki-1 well. These catagenetic gases are obviously generated by the Triassic source rocks that are present in this area (Karakitsios & Rigakis, 1996). NW Greece is not so promising for gas reserves. On the other hand this area is very promising for oil, since there have been identified very prosperous oil source rocks (Rigakis & Karakitsios, 1998, Rigakis, 1999).

Some good gas horizons have been detected by deep wells drilled in Ionian sea-Ionian islands, as indicated in App. 4. In shallow depths, inside Plio-Pleistocene sediments, the gases are of biogenic origin. Catagenetic are the gases found at 2225m depth of Parga-1 well (L.-M. Pliocene), the gases of Alykes-1 well (868m) inside limestones of U. Cretaceous age and all the gases of Paxi-Gaios-1x well, found inside the carbonates of U. Jurassic to Triassic age.

3. CONCLUSIONS

Significant hydrocarbon gas accumulations have been identified inside recent clastic sediments in the sedimentary basins of Greece, mainly in the Tertiary basins of eastern Greece and in the post-orogenic basins of western Greece.

Gases are related to lignite horizons in many cases and they are classified in three main categories.

- ✓ Biogenic gases derived from organic mater degradation. This group contains the gases of Katakolo onshore gas-field, the most surface gas seeps and the gas shows found at shallow depths in exploration wells.
- ✓ Catagenetic gases, generated by the main oil generation procedure, are the gases of Katakolo oil field, the Epanomi and South Kavala gas fields, and a lot of gas accumulations found in great depths in exploration wells.
- ✓ Metagenetic gases, originated by other gases cracking, have been identified inside overmature sediments in Delta Evros and West Thermaikos.

In most of the wells, the heavier hydrocarbon gases (C_2+) are first detected just after the onset of oil generation, while these gases are extremely limited after the lower limit of oil window. After that, the presence of C_2+ gases can be used as a first estimation of the oil window limits.

The CO_2 in Epanomi-Thermaikos area is of inorganic origin, so the whole potential of the source rocks can be calculated as hydrocarbon potential.

The influence of sulfur ions, in the biogenic gases of the Neogene clastic sequence in NW Peloponnessus area, is limited in a small area above the evaporitic dome, due to the late diapiric movement.

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AREA	WELL	DEPTH m	AGE	C_1 %	C_2 %	C_3 %	C_{4+} %	H_2S %	CO_2 %	C_2+ %	$C_1/(C_2+C_3)$
Orestias	OR-3	1135	Oligocene	0,6	–	–	–	–	–	<0,001	>640
Orestias	OR-3	2255	Oligocene	1,1	0,35	0,10	0,04	trc	–	0,49	2,4
Orestias	OR-3	3050	Eocene	1,0	0,65	0,43	0,17	trc	–	1,25	0,9
Evros	DE-1	2200	Oligocene	0,8	–	–	–	–	–	<0,001	>800
Nestos	N-1	2100	Miocene	4,0	–	–	–	–	–	<0,001	>4000
Nestos	N-1	2480	Miocene	8,5	0,12	0,08	trc	–	–	0,203	41,9
Nestos	N-1	2720	Miocene	8,0	0,39	0,36	0,05	–	–	0,80	10,7
Nestos	N-2	2110	Miocene	3,0	–	–	–	–	–	<0,001	>3000
Nestos	N-2	3364	Miocene	64,0	10,0	10,0	6,00	–	–	26,0	3,2
Nestos	N-2	3413	Miocene	72,0	12,0	12,0	1,50	–	–	25,5	3,0
Nestos	N-2	3451	Miocene	75,0	12,0	10,0	1,00	–	–	23,0	3,4
Nestos	N-2	3491	Miocene	75,0	12,0	12,0	trc	–	–	24,0	3,1
Nestos	N-3	1815	Miocene	8,0	–	–	–	–	–	<0,001	>8000
Nestos	N-3	2800	Miocene	10,0	0,2	0,15	0,05	–	–	0,40	28,6
Nestos	N-3	3180	Miocene	14,0	1,3	0,42	0,17	–	–	1,89	8,1
Nestos	N-3	3450	Miocene	8,0	0,08	0,02	trc	–	–	0,10	80,0
Prinos-Kavala	PR-2	2560	Miocene	21,47	6,96	7,21	5,87	51,9	7,5	20,04	1,5
Prinos-Kavala	SKA-1	1656	Miocene	86,1	7,0	4,40	2,50	–	–	13,9	7,6
Prinos-Kavala	SKA-2	2180	Miocene	82,9	7,4	5,15	3,70	–	0,36	16,3	6,6
Strymon	STR-2	2040	Miocene	1,2	0,025	0,01	trc	–	–	0,035	33,1
Epanomi	EP-1	2605	Mesozoic	70,4	1,7	0,80	0,50	–	22,6	3,00	28,2
Epanomi	EP-B1	2473	Mesozoic	0,4	0,005	trc	trc	–	93,5	0,01	80,0
Epanomi	EP-2	2800	Mesozoic	67,2	1,8	0,80	2,00	–	23,1	4,60	25,8
Kassandra	KAS-3	1710	M-U Eocene	0,8	–	–	–	–	–	<0,001	>800
Kassandra	POS-1	3467	U. Eocene	0,5	0,18	0,06	0,20	–	–	0,44	1,9
Thermaikos	OL-1	1176	Miocene	12,5	–	–	–	–	–	<0,001	>12500
Thermaikos	OL-1	1656	Miocene	8,0	0,27	0,13	0,05	–	–	0,45	20,0
Thermaikos	OL-1	2180	Miocene	9,6	0,46	0,17	trc	–	–	0,63	15,2
Thermaikos	OL-1	2425	Eocene	0,6	–	–	–	–	–	<0,001	>600
Thermaikos	NR-1	1020	Pliocene	3,5	–	–	–	–	–	<0,001	>3500
Thermaikos	NR-1	1480	Miocene	37,0	0,28	0,12	0,22	–	–	0,62	92,5
Thermaikos	NR-1	1624	Miocene	89,0	0,11	0,03	trc	–	–	0,137	649,6
Thermaikos	NR-1	2775	Miocene	78,0	0,75	0,37	0,51	–	–	1,63	69,6
Thermaikos	NR-1	3192	Eocene-Olig.	78,0	0,9	0,40	0,35	–	–	1,65	60,0
Thermaikos	NR-1	3503	Eocene-Olig.	8,2	0,1	0,03	trc	–	–	0,13	63,1

Appendix 1: Chemical composition of eastern Greece natural gases, identified by exploration wells.

AREA	WELL	DEPTH m	AGE	LITHOLOGY	$\delta^{13}C_{METHANE}$ ‰	$\delta^{13}C_{ETHANE}$ ‰	δD ‰
Prinos-Kavala	PR-2	2560	Miocene	Sandstone	-34,2	-42,2	-185
Prinos-Kavala	SKA-1	1656	Miocene	Sandstone	-48,6	-55,5	-210
Epanomi	EP-1	2605	Mesozoic	Limestone	-30,4	-24,7	-133
Epanomi	EP-B1	2473	Mesozoic	Limestone	-30,3	-	-143
Epanomi	EP-B1	2702	Mesozoic	Limestone	-31,3	-	-148
Katakolo	WKA-1A	2376	Senonian	Limestone	-34,4	-26,5	-124

Appendix 2: Carbon and hydrogen isotopic composition of Greece natural gases.

WELL/ AREA	DEPTH m	AGE	LITHOLOGY	C_1 %	C_2 %	C_3 %	C_{4+} %	H_2S %	CO_2 %	C_2+ %	$C_1/(C_2+C_3)$
ACH-1	430	Neogene	Clastics	0,60	-	-	-	-	-	<0,001	>600
KA-101	600	Neogene	Clastics	12,50	-	-	-	-	-	<0,001	>12500
KA-101	2420	Triassic	Evaporites	0,20	0,044	0,017	trc	-	-	0,061	3,28
KA-102	875	Neogene	Clastics	1,70	-	-	-	-	-	<0,001	>1700
KA-103	1100	Neogene	Clastics	4,00	-	-	-	-	-	<0,001	>4000
KA-103	1974	Triassic	Evaporites	1,20	0,07	0,078	0,043	-	-	0,191	8,11
KA-104	625	Neogene	Clastics	2,50	-	-	-	-	-	<0,001	>2500
KA-105	600	Neogene	Clastics	3,20	0,095	0,07	0,10	-	-	0,265	19,4
LAS-1	784	Neogene	Clastics	1,00	-	-	-	-	-	<0,001	>1000
LKY-101	586	Neogene	Clastics	1,40	-	-	-	-	-	<0,001	>1400
LKY-101	874	L.Jurassic	Limestone	0,39	-	-	-	-	-	<0,001	>390
MY-1	925	Neogene	Clastics	11,00	-	-	-	-	-	<0,001	>11000
MY-1	2174	Triassic	Evaporites	1,40	0,085	0,049	trc	0,003	-	0,134	10,4
PER-1	350	Neogene	Clastics	6,20	-	-	-	-	-	<0,001	>6200
PER-1	633	Oligocene	Flysch	7,20	0,48	0,168	-	-	-	0,648	11,1
PER-1	1340	Triassic	Evaporites	2,00	0,20	0,052	trc	-	-	0,252	7,94
PT-1	850	Neogene	Clastics	1,35	0,005	-	-	-	-	0,005	270
SKY-1	870	Up.Jurassic	Limestone	0,60	-	-	-	-	-	<0,001	>600
WKA-1	2543	Eocene	Limestone	10,5	2,00	0,4	0,7	-	-	3,1	4,38
WKA-1A	2376	Senonian	Limestone	73,8	3,60	0,8	1,00	0,8	14,0	5,4	16,8
WKA-2	2513	Up.Jurassic	Limestone	70,4	2,25	0,63	0,54	10,6	12,3	3,42	24,4
FAROS	0	Pleistocene	Clastics	80,0	1,15	0,56	0,156	trc	-	1,87	46,8
KAT.PORT	0	Neogene	Clastics	95,0	1,40	0,2	0,09	trc	-	1,69	59,4

Appendix 3: Chemical composition of NW Peloponnessus natural gases.

Appendix 4: Chemical composition of western Greece natural gases, identified by exploration wells.

AREA	WELL	DEPTH m	AGE	C_1 %	C_2 %	C_3 %	C_{4+} %	C_2+ %	$C_1/(C_2+C_3)$
Arta	AR-1	1100	Pliocene	75,0	-	-	-	<0,001	>75000
Arta	AgG-3	2800	L. Cretaceous	0,3	0,04	0,023	-	0,06	4,8
Ioannina	LA-2	850	Oligocene	0,9	0,41	0,39	0,018	0,82	1,1
Ioannina	DLV-1	652	Triassic	90,0	3,40	0,83	-	4,23	21,3
Ioannina	DLV-1	682	Triassic	55,0	1,40	0,56	-	1,96	28,1
Ioannina	DLV-1	744	Triassic	50,0	0,34	0,22	-	0,56	89,3
Ionian sea	PRG-1	1400	U. Pliocene	9,3	-	-	-	<0,001	>9300
Ionian sea	PRG-1	2225	L-M. Pliocene	7,3	0,33	0,02	0,01	0,36	20,8
Ionian sea	YA-1	465	L. Pliocene	0,9	-	-	-	<0,001	>900
Ionian sea	EER-1	744	Miocene	7,6	-	-	-	<0,001	>7600
Paxi	PG-1X	1584	M-U. Jurassic	3,7	1,00	0,15	trc	1,15	3,2
Paxi	PG-1X	1986	M-U. Jurassic	1,3	0,20	0,10	trc	0,30	4,3
Paxi	PG-1X	2867	L. Jurassic	5,0	2,60	1,90	trc	4,50	1,1
Zakynthos	ALY-1	868	U. Cretaceous	0,7	0,02	0,014	0,01	0,04	21,9