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Proceeding Paper

Evaluation of Gas Generation Potential Using Thermal Maturity Modelling—The Katakolo Case: A Probable Pathway to Energy Transition †

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Abstract: It is evident that the increased focus on energy transition, will increase the demand for gas as it is the transitional fuel to the net zero CO_2 emission era. The West Katakolo field is the only oil and gas discovery in Western Greece, and it is operated by Energean. The three offshore West Katakolo wells have defined both the oil and the gas zones, while onshore exploration wells have penetrated biogenic gas-saturated Plio-Pleistocene sands. This study assesses the gas generation potential of the local Plio-Pleistocene and Triassic sources using thermal maturity modelling based on the available legacy data, with limitations being addressed by running several case-scenarios. In conclusion, this study supports the generation of thermogenic and biogenic gas from the Triassic and Plio-Pleistocene sources respectively, demonstrating the importance of maturity modelling in hydrocarbon exploration, applied on the Katakolo case; a potential gas source to facilitate the energy transition in Greece.

Keywords: biogenic gas; natural gas; maturity modelling; energy transition; Ionian; Katakolo

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1. Introduction

Despite the increased focus on energy transition, the demand for oil and especially for gas is expected to remain high beyond 2040 [1]. As energy security remains crucial, the use of lower greenhouse-gas emitting energy forms such as hydrogen and natural gas, are vital, with one of their main feedstocks being methane. This study assesses the gas generation potential of two petroleum systems of the Katakolo area; one of Plio-Pleistocene and one of Triassic age source rocks, for microbial (biogenic) and thermogenic (natural) gas respectively. This is achieved through source rock geochemical analysis and 1D thermal maturity modelling tied to existing wells. It should be noted that the modelling input is based on available legacy data, integrated with results of outcrop sample analysis.

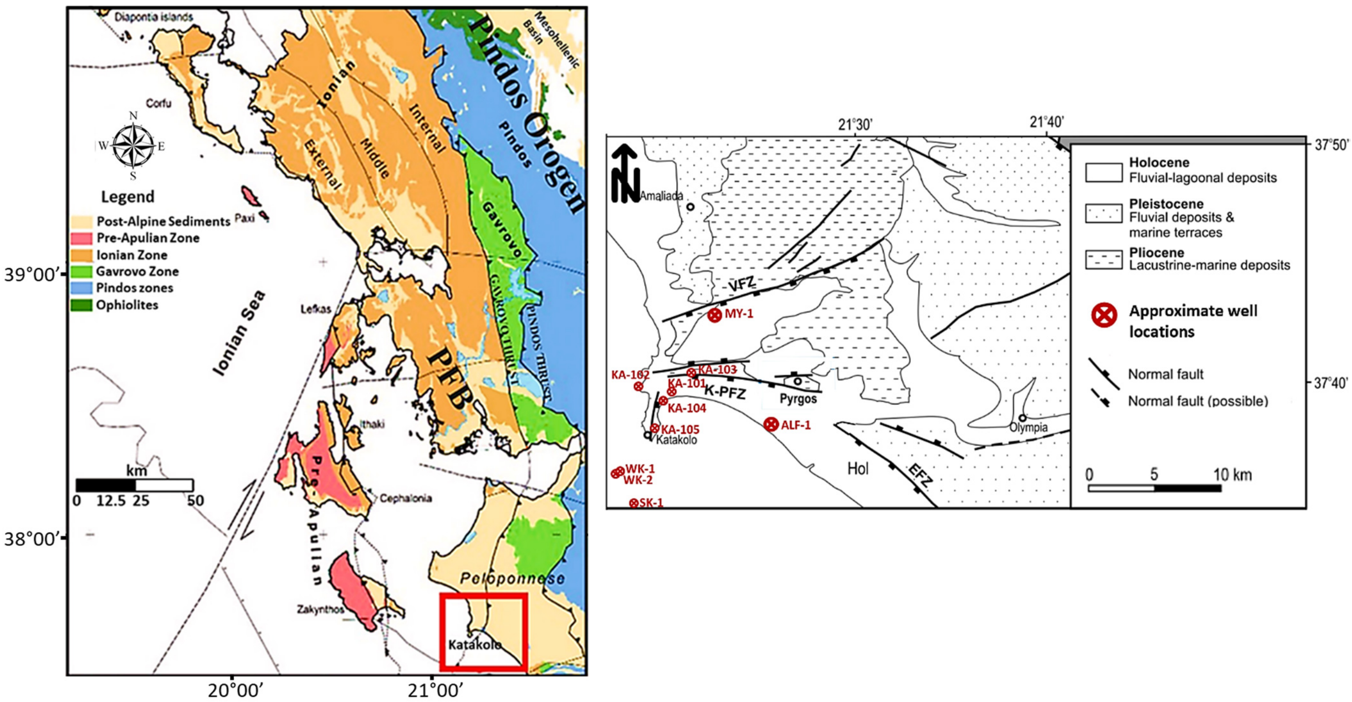
2. Study Area

2.1. Location

The study area is located in the North-WesternPeloponnese, in Greece. Geologically it lays within the Ionian geotectonic zone of the External Hellenides; the southern branch of the Mediterranean Alpine belt [2]. In terms of stratigraphy, a thick Plio-Pleistocene sequence unconformably covers the Mesozoic carbonates and the exhumed Triassic evaporites. The existence of flysch deposits is not confirmed by the wells, yet without excluding the possibility to exist in the surrounding area. Also, tectonic configuration is overprinted by the halokinetic movements, generating promising trapping mechanisms. The general pattern of the Ionian stratigraphic column can be seen in many published works [3–5], yet the Katakolo area exhibits some differences related to the absence of the Jurassic syn-rift formations according to the drilling results [6].

2.2. Katakolo Gas Field

The offshore Katakolo area is the only proven oil and gas field in Western Greece. It is found within Mesozoic carbonate reservoir rocks and is operated by Energean. It is part of the Katakolo license, which incorporates both offshore and onshore areas (Figure 1a,b). In addition, gas shows on the Plio-Pleistocene strata have been tested in some onshore wells, while gas seepages are recorded both offshore and onshore. Studies [7–9] have shown that most onshore gases are associated with a Plio-Pleistocene biogenic source, while gas associated with the Pre-Neogene sequence is catagenetic, or in other words wet natural gas. The thermogenic gas reserves that the West Katakolo structure hosts are 24Bcf [10]. Additionally, the reported gas seepages in Katakolo are regarded as of the biggest thermogenic gas seepages in Europe [7]. The above-mentioned characteristics, make the area a possibly promising candidate for gradual decarbonization and for achieving local energy security by supporting the local economic activities.



(**a**) (**b**)

Figure 1. (**a**) Location of Katakolo within the External Hellenides with the area of interest delineated within a red rectangle, modified after [11]. (**b**) Main tectonic features of the onshore Katakolo area, modified after [12].

3. Model Frames

The drilling results suggest the absence of the typical Jurassic syn-rift sediments, thus that the area has not probably been subjected to rifting. It is rather possible, that it was subjected to uplift and erosion during that period, eroding part of the Lower Jurassic "Pantokratoras" limestones. Considering the legacy well reports (unpublished data from Energean S.A.) and the new outcrop samples which were geochemically analyzed for this study, a gas prone source (type III) was mainly depicted for the onshore Pliocene samples and an oil/gas source (type II-III) for the Triassic samples. The latter is also in line with additional geochemical data [3,7,13] that point towards a type II-S kerogen for the Triassic source rocks in the area. The reports also refer to the presence of Cretaceous Vigla shales as a potential source rock, without being considered however as the main one.

3.1. Onshore Models

Two onshore point locations are examined, tied to the MY-1 and ALF-1 wells (Figure 1b). The analyzed petroleum system is of Plio-Pleistocene age, probably deposited in a lacustrine/lagoonal to shallow marine environment. This is supported by the varying pr/ph, the low nC21-nC35 compared with the high nC15-nC20 alkane concentrations and the suggested gas prone sources illustrating a marine influenced terrestrial environment. A potential problem in such lithostratigraphy, where the Plio-Pleistocene sequence overlays evaporites, is the sulphur ions present within the latter, which may convert the biomethane into H_2S [13]. Yet, minor sulphur is reported within this Plio-Pleistocene sequence [8].

3.1.1. Model Input and Calibration

Whilst for oil generation a low geothermal gradient (GG) is usually considered to be a drawback, in the case of microbial gas generation is considered to be favorable. Based on temperature measurement on the wells, the GG is approximately 1.56 °C/100 m (unpublished data from Energean S.A.). Additionally, the maximum vitrinite reflectance is less than 0.50%Ro within the Neogene section (unpublished data from Energean S.A.) suggesting an early diagenesis stage. Additionally, the Total Organic Carbon (TOC) content, within coal layers, reaches values up to 33%wt. It should also be noted that the Neogene lithostratigraphy was introduced based on the reported well cutting lithologies (unpublished data from Energean S.A.).

A chief part of the modelling is the boundary conditions. Thus, paleowater depth (PWD) was introduced based on the reported fossilised organisms and lithologies [14], while paleoheat flow was introduced based on many sources [15,16]. Finally, biogenic reaction kinetics were used for the model calibration. This reaction kinetics model is created by the software [17] and describes the generation of hydrocarbons by means of bacterial reactions. All the above mentioned were used for the model calibration, where the tectonic events and the boundary conditions were tuned within a plausible framework, to generate the final model of the finest calibration, the result of which is shown in Figure 2.

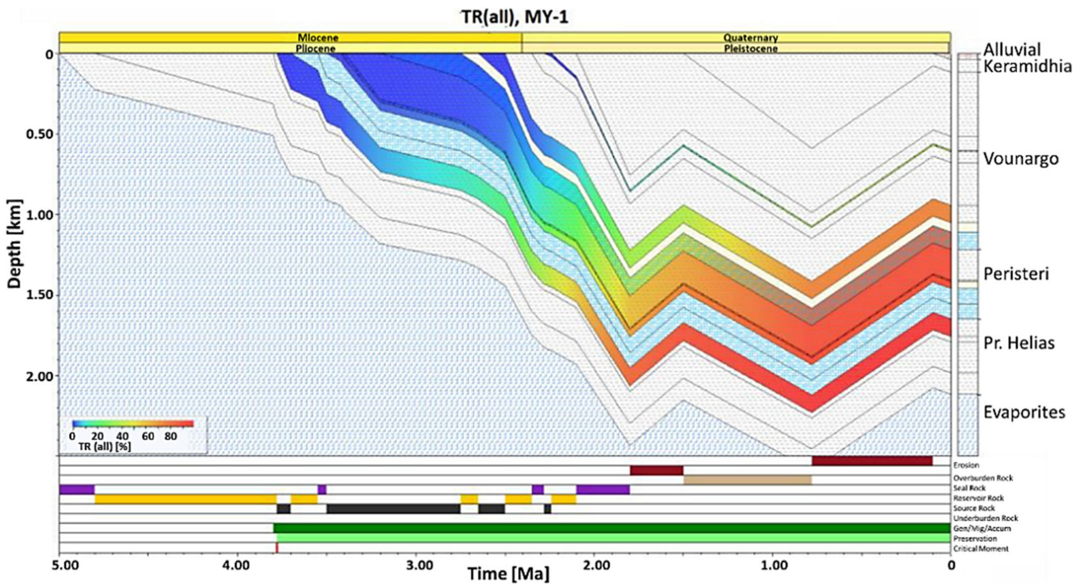


Figure 2. MY-1 1D source rock's transformation ratio (TR%) model, integrated into the burial history of the MY-1 well location.

3.1.2. Model Output and Discussion

The burial histories of the two locations seem to demonstrate some differences, yet with erosion events having occurred within the past 2Ma. According to the final model, the Northern point location (MY-1 1D model) (Figure 2) has undergone higher sedimentation and later erosion, compared with the southern (ALF-1). This is probably related to the active period of the faults surrounding the well and its relative location to the sedimentary basin.

The paleoevnironmental conditions and tectonic evolution seem to favor biogenic gas generation, something also reinforced by the conducted modelling. This study suggests that microbial gas has been generated and is still being expelled, while generation had ceased for a period of time when erosion was taking place. In all cases, tectonic activity seems to be of significance, with areas located within Neogene sedimentary basins, such as ALF-1 and KA-101/104/105 being the most promising in terms of microbial gas generation and expulsion amounts.

3.2. Offshore Models

Although Western Greece source rock studies focus on the Vigla shales and the syn-rift shale formations, this study aims to analyse the generation potential of the Triassic, in light of the wet natural gas reported in the wider Katakolo area. The oil and gas zones of the West Katakolo field are located within Mesozoic carbonate reservoir rocks, trapped and sealed by a Miocene pseudo-anticline covered by a Plio-Pleistocene sequence.

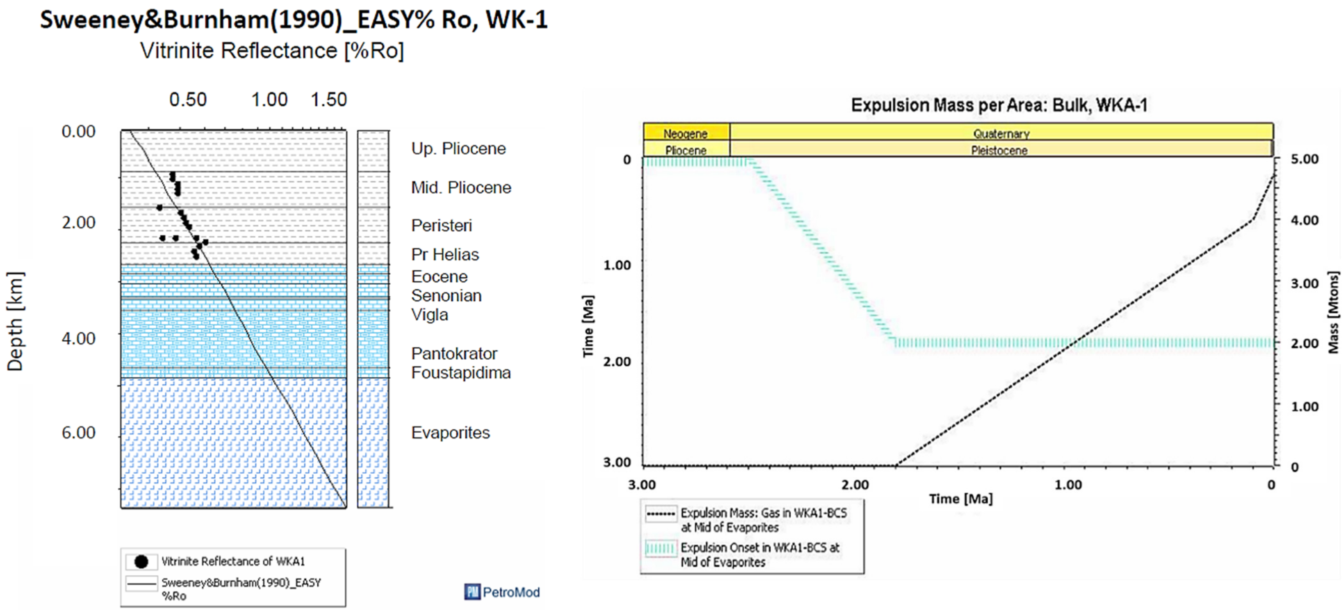
3.2.1. Model Input and Calibration

Given that the Triassic evaporites have not been entirely drilled, case scenarios were created based on the WK-1 and WK-2 wells, namely the Best (BCS), Mean (MCS) and Worst (WCS) case scenarios (Table 1). A low geothermal gradient of 1.65 °C/100 m was introduced, consistent with the bottom hole temperatures (unpublished data from Energean S.A.). Kerogen seems to be of type II-III based on WK-1 geochemical analyses [3], yet with H_2S content indicating a type more alike to the II-S type. Lithology has been introduced according to SK-1 well cuttings (unpublished data from Energean S.A.), with Triassic intercalations incorporated into the general lithology mixture. Also, the evaporites were assigned with source, reservoir and seal rock potential per interval from the bottom to the top, and the boundary conditions are considered to be similar to the onshore ones, yet differing from the present day water depth.

Table 1. Dividing data of the case scenarios concerning the offshore models. The BCS and WCS were introduced based on cutting samples of a neighboring well (SK-1), and the MCS from the Rock Eval analysis performed on the outcrop samples.

Case Scenario	TOC (%)	HI (mgHC/gTOC)
BCS	3.85	189
MCS	1	50
WCS	0.5	25

Maintly due to the high sulphur content, the so-called "Pepper&Corvi (1995) TII-S(A)" [18] kerogen kinetic model was used, after careful comparison with other models. Its validity was verified by the correspondance between the source rock lithologies, while it was the only kinetic model with which a proper calibration fit was achieved. More specifically, given the model input, the vitrinite reflectance data were primary used to calibrate both the onshore and offshore models (Figures 2 and 3a).



(a) (b)

Figure 3. (a) Final maturity calibration fit of the WK-1 model, based on Vitrinite Reflectance (%Ro) data (unpublished data from Energean S.A). (b) Expulsion Mass and Onset of the Triassic evaporites of the WK-1 model.

Multiple model iterations were run with different tectonic, lithological and heatflow characteristics alongside different kinetic models in order to achieve the best calibration fit of the vitrinite reflectance curve. It should be noted that the tuning of these characteristics was performed within coherent for the area frameworks. As a result, the finest tuning for the offshore models was achieved using the previously mentioned kinetic model, the given vitrinite reflectance data (unpublished data from Energean S.A) as well as the tectonic events, and it is thoroughly described in [14].

3.2.2. Model Output and Discussion

According to the utilized scenarios, BCS and MCS are the only probable scenarios for in situ gas generation and expulsion. Given that, thermal maturity modelling suggests three gas generation phases and two expulsion phases for the WK-1 and three for the WK-2. For both 1D models, the latest expulsion onset was estimated to be at around 2 Ma (Figure 3b) and the earliest between 140–170 Ma.

Based on the prevailing paleoenvironmental conditions described in [14], the presence of a Triassic source rock is highly plausible, with its latest expulsion being related to a catagenesis stage with thermogenic gas presence and its earliest to an early oil-related thermogenic gas phase. Thus, the gas entrapment should have been achieved, with the trap formation preceding the second expulsion phase.

4. Discussion

Regarding the Katakolo microbial gas, the different thermal maturity histories of the two onshore 1D models, reflect the local effect of tectonism, leading into continuous gas generation in the depocenter (ALF-1) and limited in the flank (MY-1) and intra-basinal horst locations. With respect to the offshore models, the Triassic evaporites turn out to uphold the previous studies, which associate the existing gas in the West Katakolo field with Triassic evaporitic source rocks.

The prevailing paleoenvironmental conditions along with the tectonic evolution have led to both microbial and natural gas generation and expulsion. Although areas with systematic gas releases have been reported in the area around the Katakolo peninsula (offshore and onshore), this study has shown that certain conditions exist that favor the generation of gas. Both gas types are expected within the Plio-Pleistocene sequence, while natural gas is also expected in traps surrounding the West Katakolo field.

As stated by [19,20], Greece had an Energy dependency rate of around 75% in 2019, relying mainly on imports for its living. Therefore, given the time it takes to build up new renewables and to implement energy efficiency improvements, this scenario represents a potential quick win for energy production, emission reductions, and autonomy.

5. Conclusions

In a nutshell, it appears that Katakolo has a unique gas potential which might be beneficial towards the direction of energy security in the energy transition period of Greece. It is thus crucial to firstly understand the importance of thermal maturity modelling to improve our understanding of the subsurface conditions and verify the existing geological models and concepts. The current study gives an insight into the gas generation potential that the wider area of Katakolo has.

Given the study location and the amount of the 24Bcf [10] of gas reserves, gas production could potentially support the local urban and agricultural energy needs. Should a local gas distribution grid be developed, this amount could assist the local agricultural production (greenhouse) during the winter period, with the CO_2 by-product being used for the growth of plants. The gas could also support the increasing energy demands during summer, with the touristic peak occuring during that period. The agricultural sector will be supported, the associated greenhouse gas emissions will be controlled, and the energy supply will be supported with an additional energy source. As such, the Katakolo case could represent a pilot project for the energy transition and the energy security of Greece.

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