Modelling Biogenic Gas Generation and Migration – Application on the Levantine Basin*

N. Maurand[1], A. Pujol[1], A. Ravin[1], S. Wolf[1], M. Dubille[2], P. -Y. Filleaudeau[2], and B. Lebreuilly[2]

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[1]IFP Energies nouvelles, Rueil-Malmaison, France (nicolas.maurand@ifpen.fr)
[2]Beicip-Franlab, Rueil-Malmaison, France

Abstract

Methanogenic biodegradation of Sedimentary Organic Matter (SOM) has recently focused the interests of the Oil and Gas industry following the growing demand on natural gas and the discovery of giant biogenic methane accumulations (Levant, Tamar Field, …).

In order to model biogenic gas generation and migration, new functionalities have been developed by IFP Energies nouvelles within basin simulator TemisFlow™. First, the total labile organic matter was split into three distinct fractions: a first fraction that micro-organisms can directly metabolize and controlled by a degradation rate which is a function of microbial activity, a second fraction (labilizable) for which a previous thermal transformation, controlled by an Arrhenius equation, is necessary, and a third fraction, refractory. Consequently, temperature has a strong impact on biogenic methane generation since it controls both the bacterial activity and the transformation rate from labilisable to labile organic matter. The methane produced in the model is allowed to be distributed in three states: 1) adsorbed onto SOM, 2) dissolved in formation brine, and 3) as a free gas phase. The methane is transported in the model by the effects of burial and compaction, whereby the production and distribution of biogenic methane is fully coupled with dissolution and advection mechanisms, and is then allowed to migrate as a dissolved compound in water but also as a free gas phase.

Since the model parameters have been determined at low scale, an upscaling work is essential to use this model at basin scale. The effects of the different generation laws are submitted to a sensitivity analysis. Recommended values are defined based on natural 1D cases corresponding to the geological history of LEG175 (Benguela upwelling, offshore Namibia). Finally, the model of biogenic gas production and migration implemented has been used on a 2D section of the Levantine Basin showing the distribution of adsorbed, dissolved, and free gas along the geological history. A particular focus is made on the effect of the Messinian crisis on the evolution of the gas distribution.

References Cited

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Katz, B., 2011, Microbial Processes and Natural Gas Accumulations: The Open Geology Journal, v. 5/1, p. 75-83. doi:10.2174/1874262901105010075

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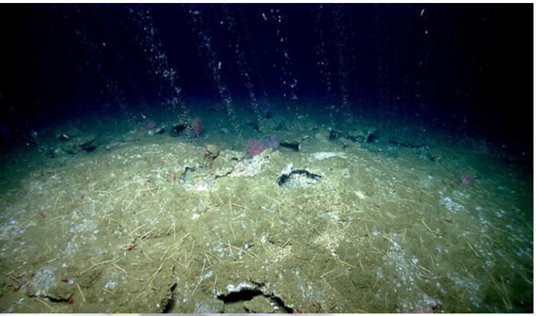
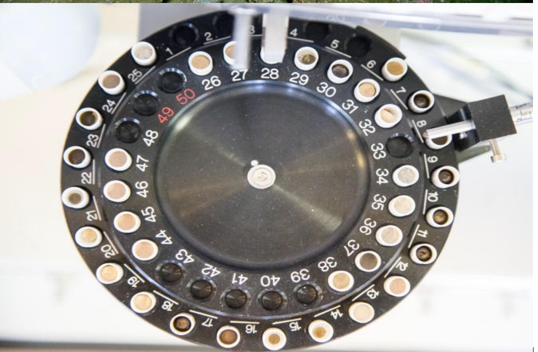
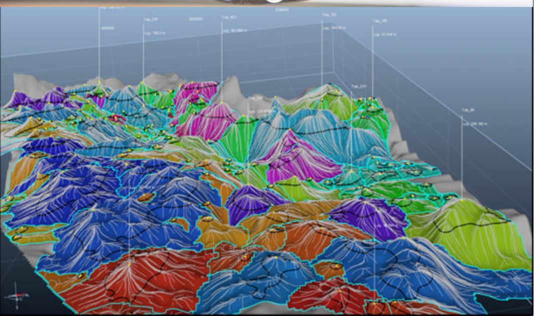






MODELLING BIOGENIC GAS GENERATION AND MIGRATION

APPLICATION ON THE LEVANTINE BASIN

N. MAURAND, A. PUJOL, A. RAVIN, S. WOLF,
M. DUBILLE , P.-Y. FILLEAUDEAU, B. LEBREUILLY

CONTEXT (1/2)
BIOGENIC GAS INTEREST

RESPONSIBLE
OIL AND GAS

Biogenic gas:

- up to 20% of today's natural gas reserves*
- Often shallow reservoirs more accessible than traditional gas

Lost of discoveries done while looking for thermogenic HC

- difficult to predict optimum conditions for Biogenic Gas formation, migration and conservation

The E&P industry is increasingly interested in predicting biogenic gas accumulations

Examples of known giant biogenic gas accumulations (Katz, 2011)	Reserves (Tcf/Bcm)
Agostino-Porto Garibaldi (Italy)	3.5/99 [11]
Antrim Shale Resource Play (Michigan, USA)	~50/1420 [12]
Ballena Field (Colombia)	1.2/34 [13]
Barbara Field (Italy)	1.5/43 [14]
Chuchupa Field (Colombia)	5.7/161 [13]
Kenai Field (Alaska, USA)	2.25/64 [15]
Niengo Field (Indonesia)	7-10/198-283 [16]
Raven Field (Egypt)	4/113 [17]
Sebei-1 Field (China)	95/2690 [18]
Southeast Alberta Gas Field (Canada)	14/396 [19]
Tamar Field (Israel)	8.4/238 [20]
Terang-Sirasun Field (Indonesia)	1/28 [21]
Urengoy (Russia)	220/6230 [22]

**Sources : Rice, 1992; Katz, 2011*

CONTEXT (2/2)
BIOGENIC GAS TECHNICAL CHALLENGES

RESPONSIBLE
OIL AND GAS

Microbial generation processes

- process at the microscopic scale
- organic matter bio-availability heterogeneously distribution in the sedimentary pile.
- biogenic gas production rates variation with depth due to temperature increase and rarefaction of organic substrates.

Gas migration physics

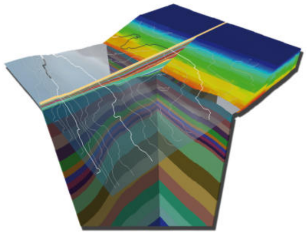
- Fast migration
- Strong effect of dissolution/exsolution in/from water

Timing

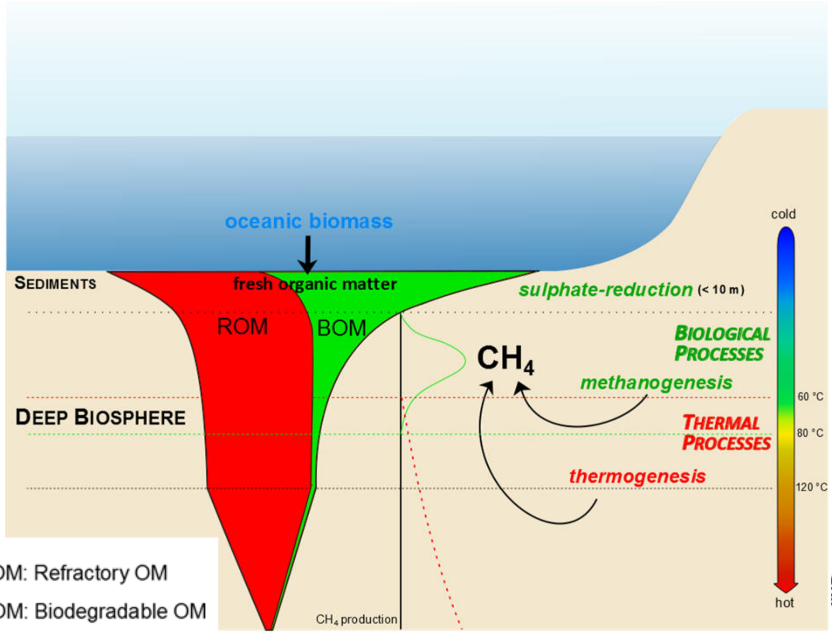
- Subtle synchronisation between early generation and trapping

Challenge to accurately simulate biogenic gas generation and migration processes at the basin scale

Diagenetic scale



Sedimentary basin scale

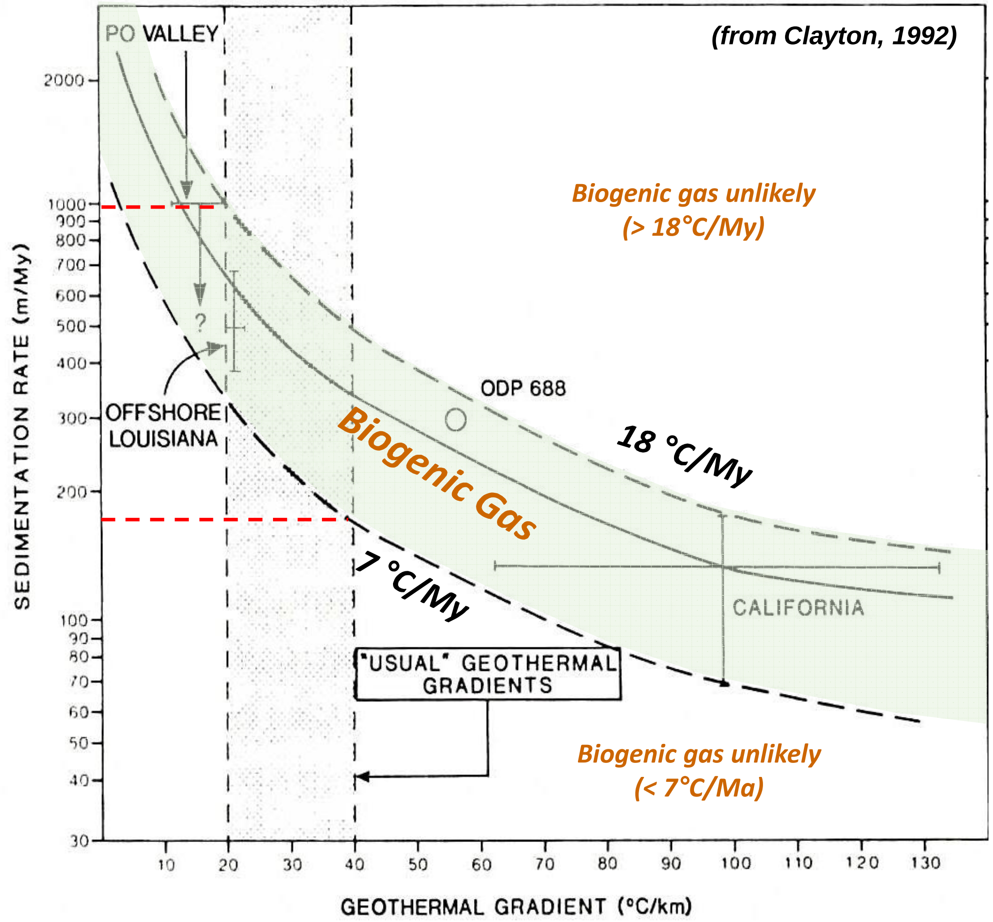


ROM: Refractory OM
BOM: Biodegradable OM

CLAYTON'S CONCEPT (1992)

RESPONSIBLE OIL AND GAS

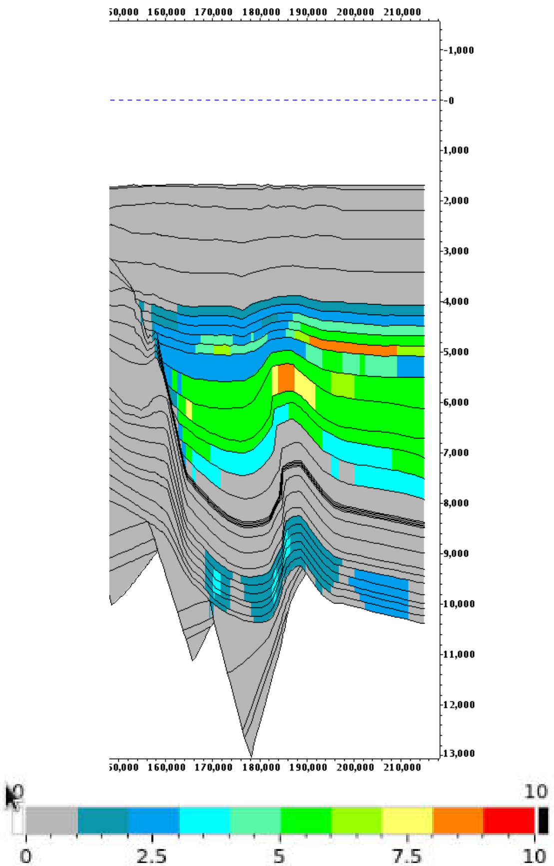
- The biogenic gas potential definition is based on Clayton's Concept:
  - Clayton (1992) proposed a characterization of biogenic gas basins (1ary type) in function with the **geothermal gradient** and the **sedimentation rate**.
  - The biogenic gas generation occurs at low temperature, T< $T_{pasteurization}$ (80°C).
  - Usually the biogenic gas system is efficient for a **Heating Rate** (temperature increase rate) between +7°C/My and +18°C/My.



PRELIMINARY BIOGENIC GAS MODELS
TIME OF RESIDENCE WITHIN THE “BIOGENIC WINDOW”

- If $T > T_{pasteurization}$:
  - If the cell just got deposited, the index is set to 0.
  - Otherwise, the index stays the same as the previous event.
- If $T < T_{pasteurization}$:
  - If the cell experienced a pasteurization phase (i.e. if the index at the previous age does not correspond to the time since the deposit of the cell), the index stays the same as the previous event.
  - Otherwise:
    - If the heating rate is between 7 and 18°C/My, the index corresponds to the time since the deposit of the cell.
    - Otherwise, the index stays the same as the previous event.

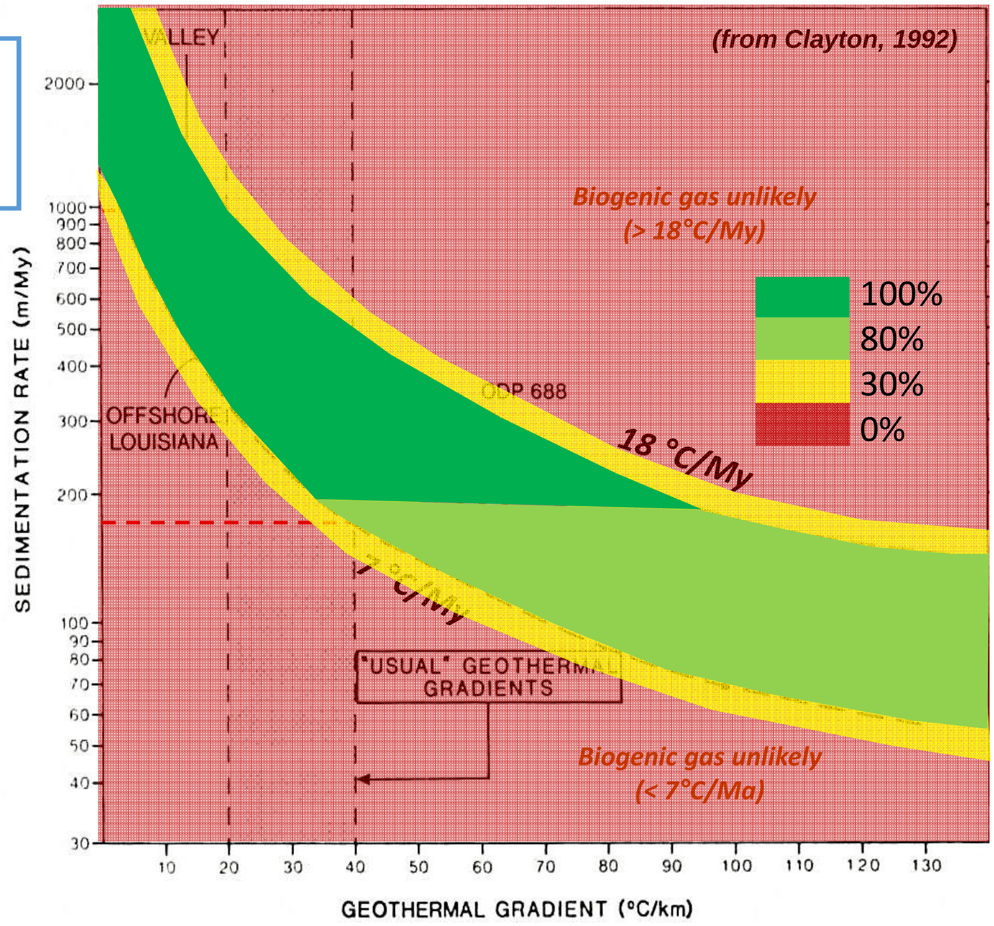
time of residence within the “biogenic window” (Ma)



PRELIMINARY BIOGENIC GAS MODELS
BIOGENIC GAS POTENTIAL INDEX

Heating rate map at deposition time (°C/My)
=
Thermal gradient map(°C/m) x sedimentation rate map (m/My)

- A biogenic gas potential index map is obtained for each layer, according to Clayton's observations:
  - If HR < 6°C/My or HR > 20°C/My or SR < 50m/My
    ➔ TOC_{lab} = 0%
  - If 6 < HR < 7°C/My or 18 < HR < 20°C/My
    ➔ TOC_{lab} = 30% TOC
  - If 7 < HR < 18°C/My and SR > 200 m/My
    ➔ TOC_{lab} = 100% TOC
  - If 7 < HR < 18°C/My
    ➔ TOC_{lab} = 80% TOC
- The Effective labile TOC are obtained by the multiplication of the labile TOC maps by the biogenic gas generation and preservation potential index maps.
- Dedicated kinetic parameters within the biogenic window



BIOGENIC GAS MODEL

CHARACTERISING AND MODELING BIOGENIC GAS IN SEDIMENTARY BASINS

RESPONSIBLE
OIL AND GAS

A **biogenic gas generation and migration prototype** plugged on TemisFlow™

1 Parametric model

Resulting from laboratory measurements

2 Flexible model

Allowing to test different generation scenarios

3 Complete model

Taking into account complexes biological and physical interactions

➔ Getting a better prediction of the biogenic gas potential in exploration

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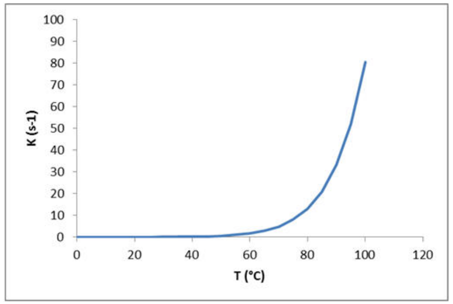
BIOGENIC GAS MODEL

1 A PARAMETRIC MODEL - A LINK WITH LABORATORY

Biogenic gas production formulation:

1. Split of Organic Matter into **refractory**, **thermolabilisable** and **labile** fractions
2. Reactivity decrease with time using published models
3. Degradation rates function of Temperature
4. Kinetic thermal source of labile compounds (Thermal activation)



Refractory Organic Matter

$$TOC_{total} = TOC_{ref} + TOC_{zlab} + TOC_{lab}$$

(Burdige *et al.*, 2011)

$$\frac{\partial TOC_{zlab}}{\partial t} = -k(T) \cdot TOC_{zlab}$$

$$-k(T) = A \cdot e^{-\frac{E_a}{RT}}$$

(Middlebourg 1989)

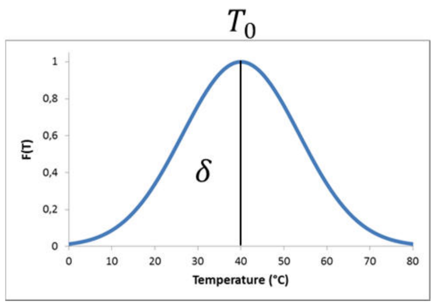
(Wallman *et al.*, 2006)

$$\frac{\partial TOC_{lab}}{\partial t} = -r_{bio} F(T) \cdot TOC_{lab} - \frac{\partial TOC_{zlab}}{\partial t}$$

$F(T)$ = Table

Labilisable Organic Matter ⇩ Produce TOC_{lab}

Labile Organic Matter ⇩ Produce CH_4

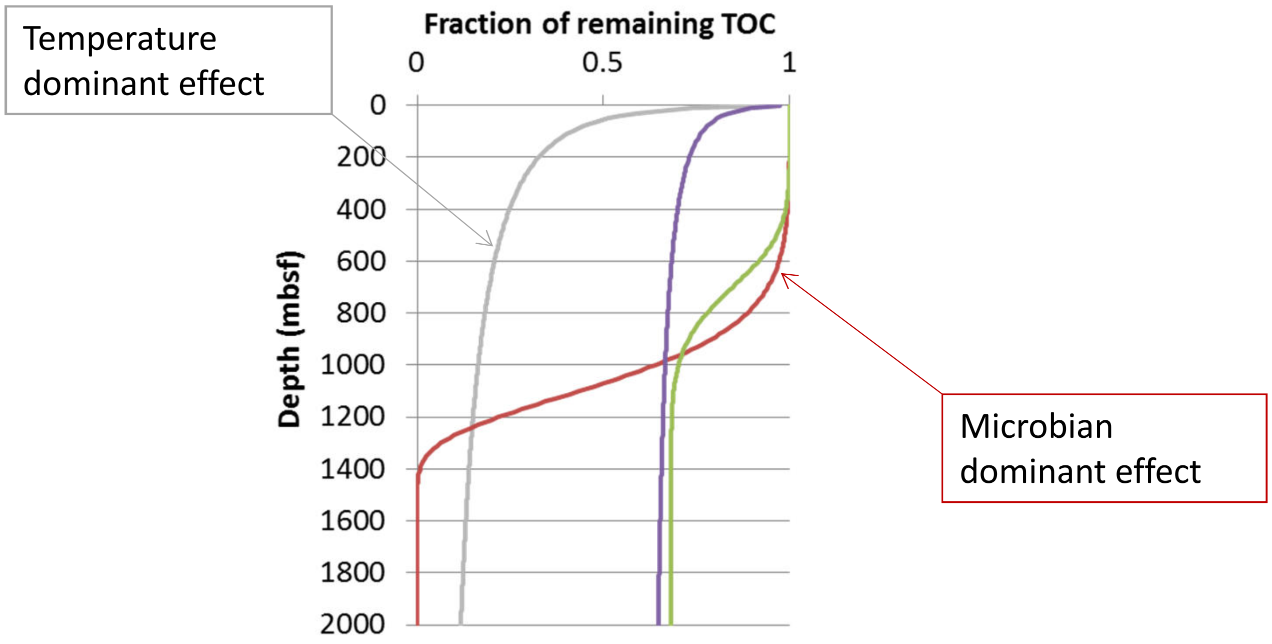


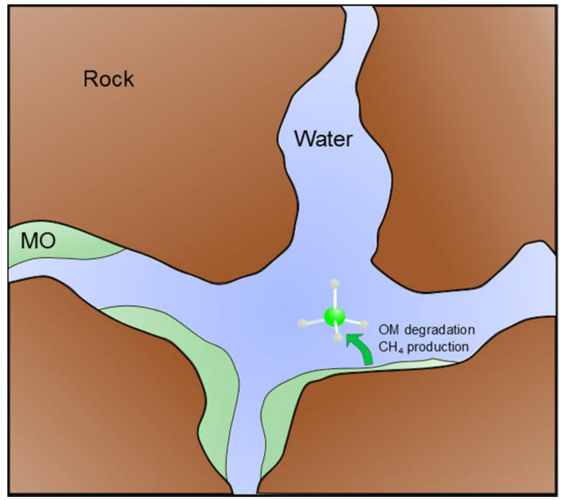
BIOGENIC GAS MODEL

2 A FLEXIBLE MODEL - TESTING DIFFERENT GENERATION PROCESS

RESPONSIBLE
OIL AND GAS

Biogenic gas production as a function of temperature and bacterial activity

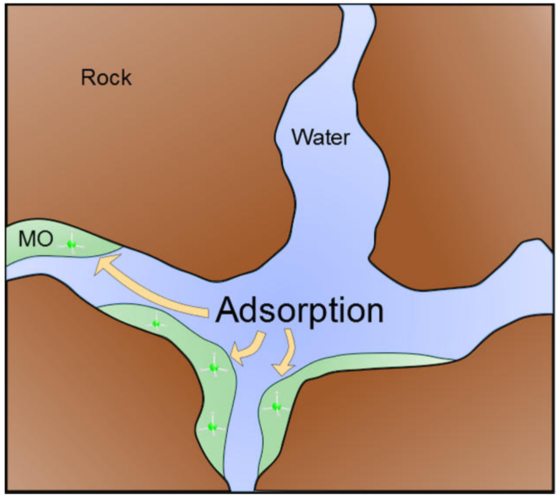


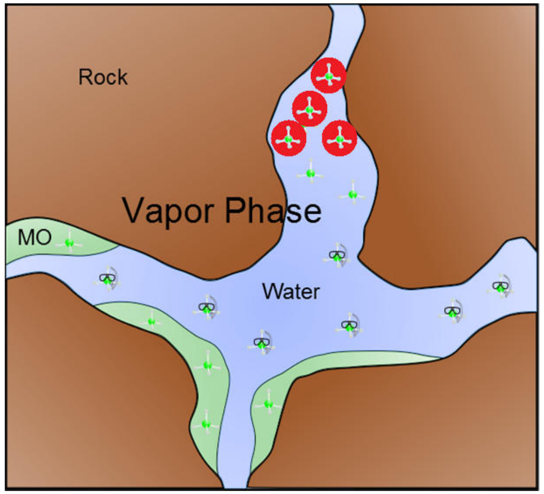


BIOGENIC GAS MODEL

3 A COMPLETE MODEL - BIOLOGICAL AND PHYSICAL INTERACTIONS

Biogenic gas transport physics		
Gas adsorption using a langmuir equation	Gas solubilization in formation water following the model of Duan and Mao	Gas migration according to Darcy formulation





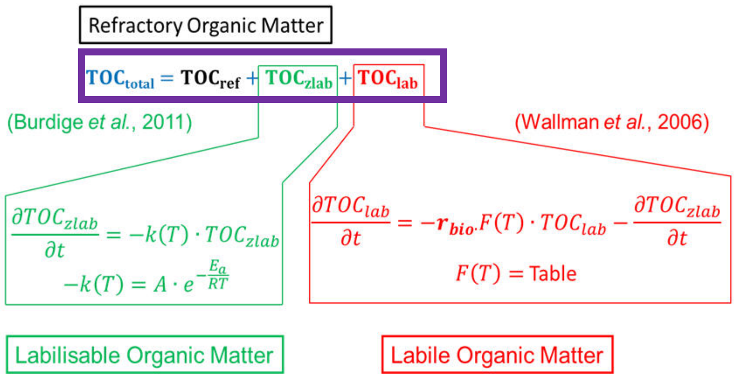
WORFLOW
COMBINING LABORATORY AND MODELING

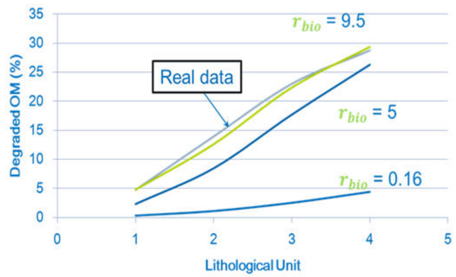
RESPONSIBLE
OIL AND GAS

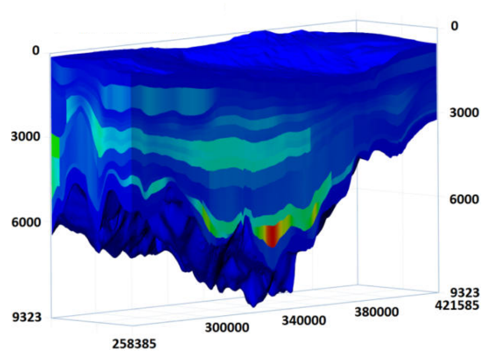
1 Experimental characterisation of Organic Matter (OM) labile fractions

2 Calibration of the diagenesis degradation law

3 Full scale implementation of organic diagenesis







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WORFLOW – PART 1
EXPERIMENTAL CHARACTERIZATION OF ORGANIC MATTER (OM)

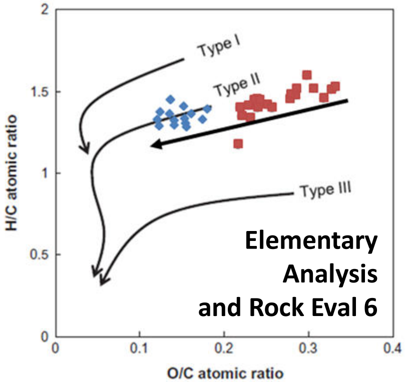
RESPONSIBLE
OIL AND GAS

Definition of initial OM distribution in space and its reactivity in time

- Determination of the paleo/initial TOC
- Combination of geochemical methods to characterize the evolution with depth/time of the 3 fractions

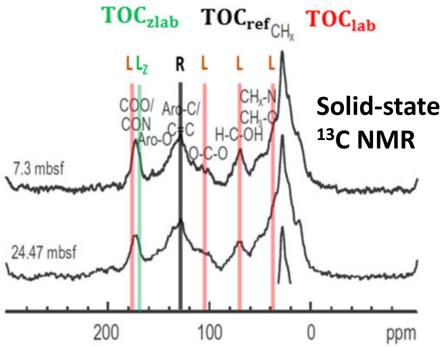
Core samples from company/IODP well and Kerogen extraction

+



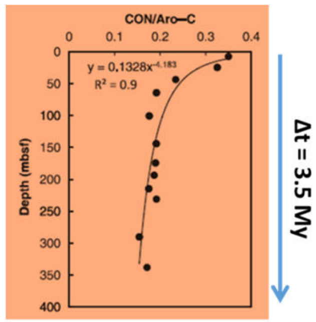
Diagenetic path of Carbon
Actual biogenic potential
Spatial distribution of the OM

+



Quantify the distribution of carbon among various functional groups

=



Determination of degradation and biogenic gas production rates

WORFLOW – PART 2
CALIBRATION OF THE DEGRADATION LAW

RESPONSIBLE
OIL AND GAS

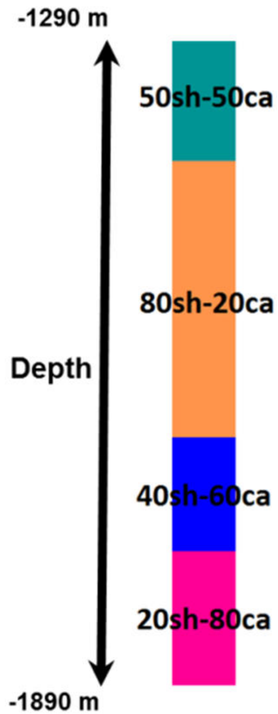
Fit experimental data with SOM reactivity model

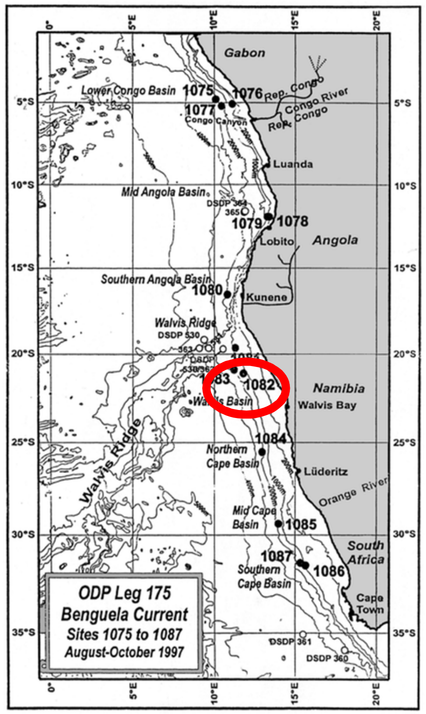
- Investigation of various model representation
- Carried out mainly on 1D model

Input data (from *Part 1*):

- Initial TOC for depositional environment derived from *Rock Eval 6* data
  - ➔ Estimated from present day TOC
- Distribution of different OM fractions derived from ^{13}*C NMR* data
  - $TOC_{ref,init}$ (aromatic+aliphatic)
  - $TOC_{zlab,init}$ (lipids)
  - $TOC_{lab,init}$ (carbohydrates, proteins)

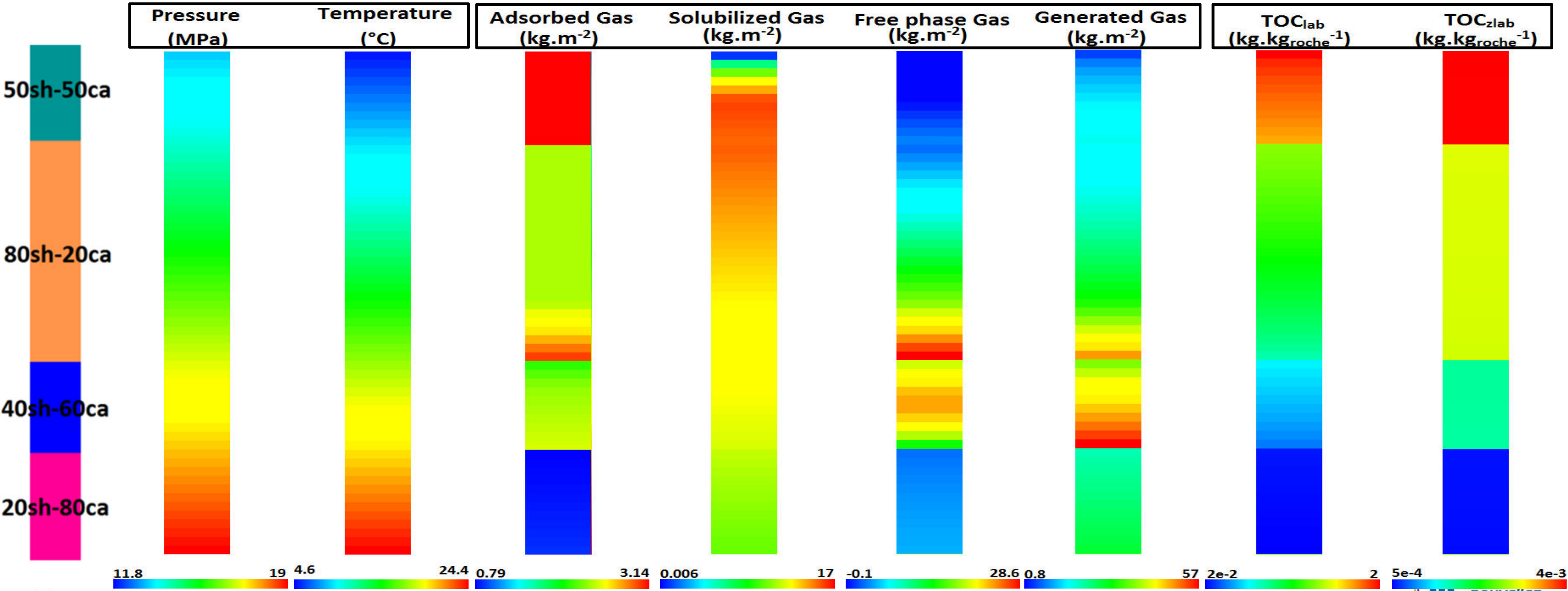
Objective: fit diagenesis degradation law on data





WORFLOW – PART 2
CALIBRATION OF THE DEGRADATION LAW

RESPONSIBLE
OIL AND GAS

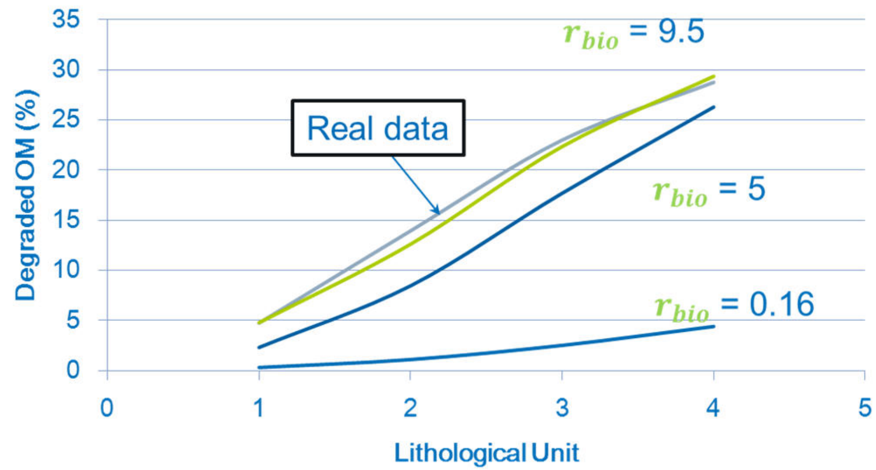


WORFLOW – PART 2

CALIBRATION OF THE DEGRADATION LAW

RESPONSIBLE OIL AND GAS

Lithology	Degraded TOC (%) (data)	Degraded TOC (%) (simulation)	Error (%)
50sh-50ca	4.7	4.8	**0.83**
80sh-20ca	13.9	12.6	**9.6**
40sh-60ca	23	22.3	**2.8**
20sh-80ca	28.8	29.4	**2.1**

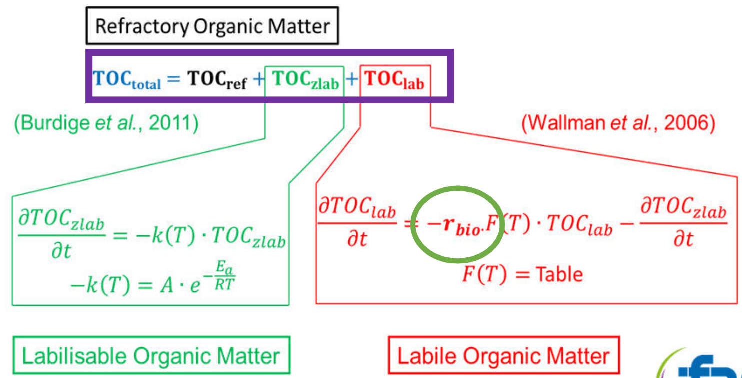


Results:

Home made degradation law used

Value of r_{bio} that fits the data

This calibration can now be used for a 2D/3D model

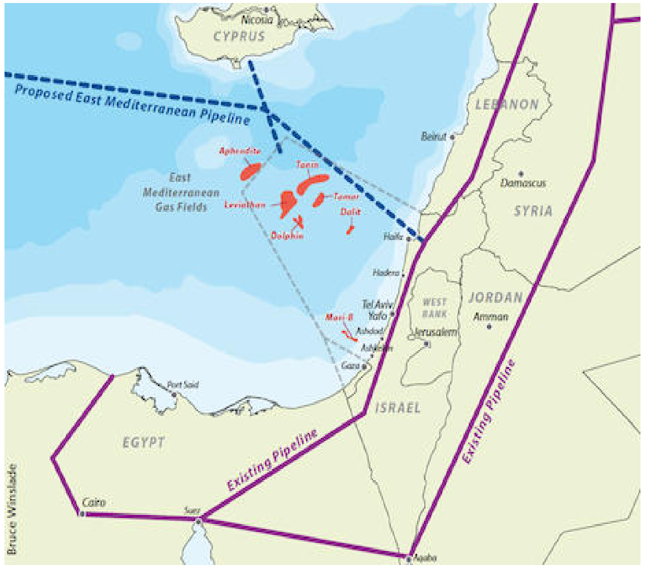


WORFLOW – PART 3
FULL SCALE IMPLEMENTATION - GEOLOGICAL MODEL

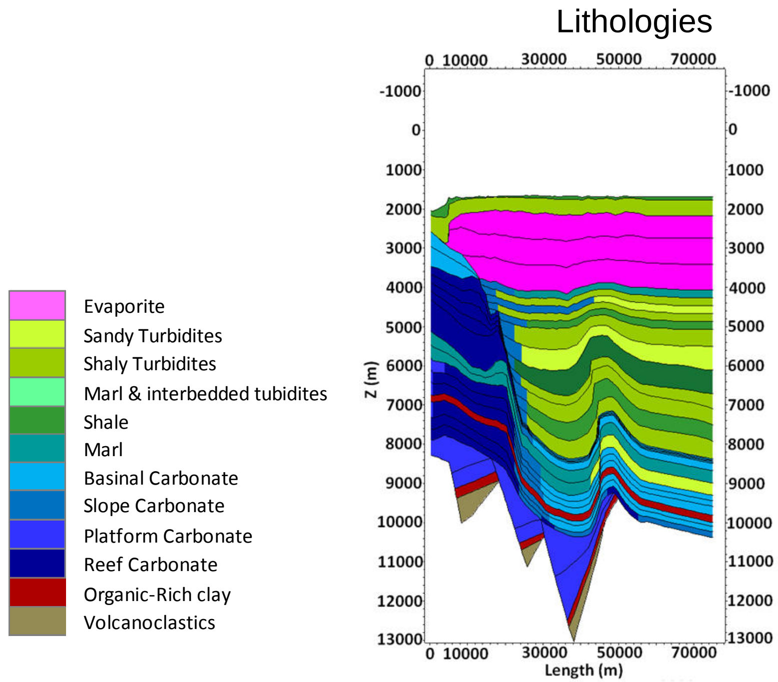
RESPONSIBLE
OIL AND GAS

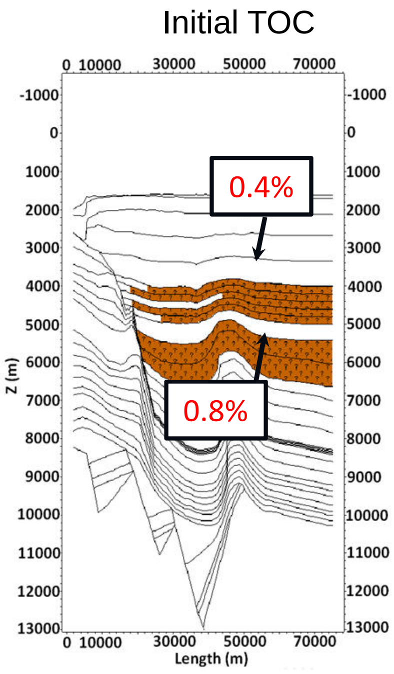
Use calibrated data within studied sedimentary basins

- Benefit from Platform tools to construct geological model



Source: Bruce Winslade
http://www.geoexpro.com/articles/2013/09/the-levantine-basin-prospects-and-pitfalls





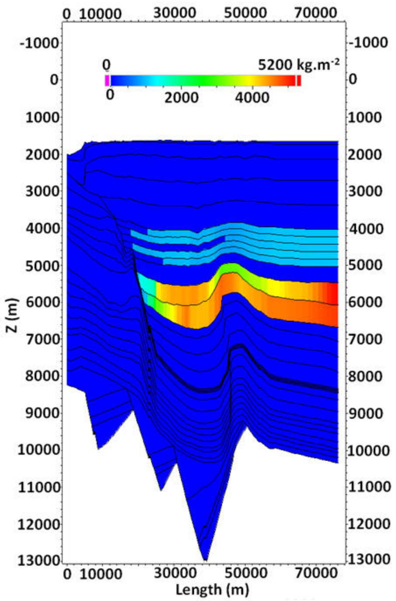
Case STUDY: aphrodite (levantine basin)

WORFLOW – PART 3
FULL SCALE IMPLEMENTATION - SIMULATION RESULTS

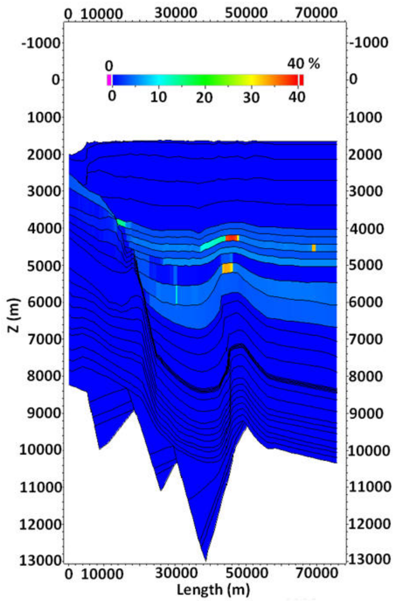
RESPONSIBLE
OIL AND GAS

Modelisation of the generation and migration of biogenic gas by using advance prototype
Integration of results within TemisFlow TM

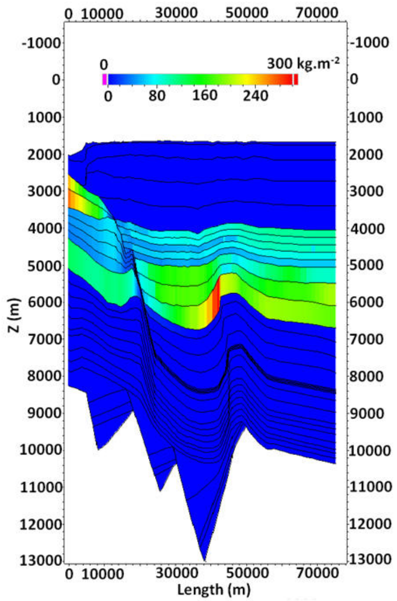
Generated biogenic gas



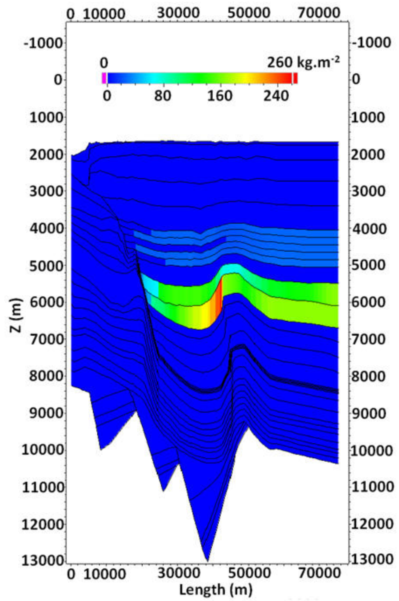
Gas saturation



Dissolved Gas



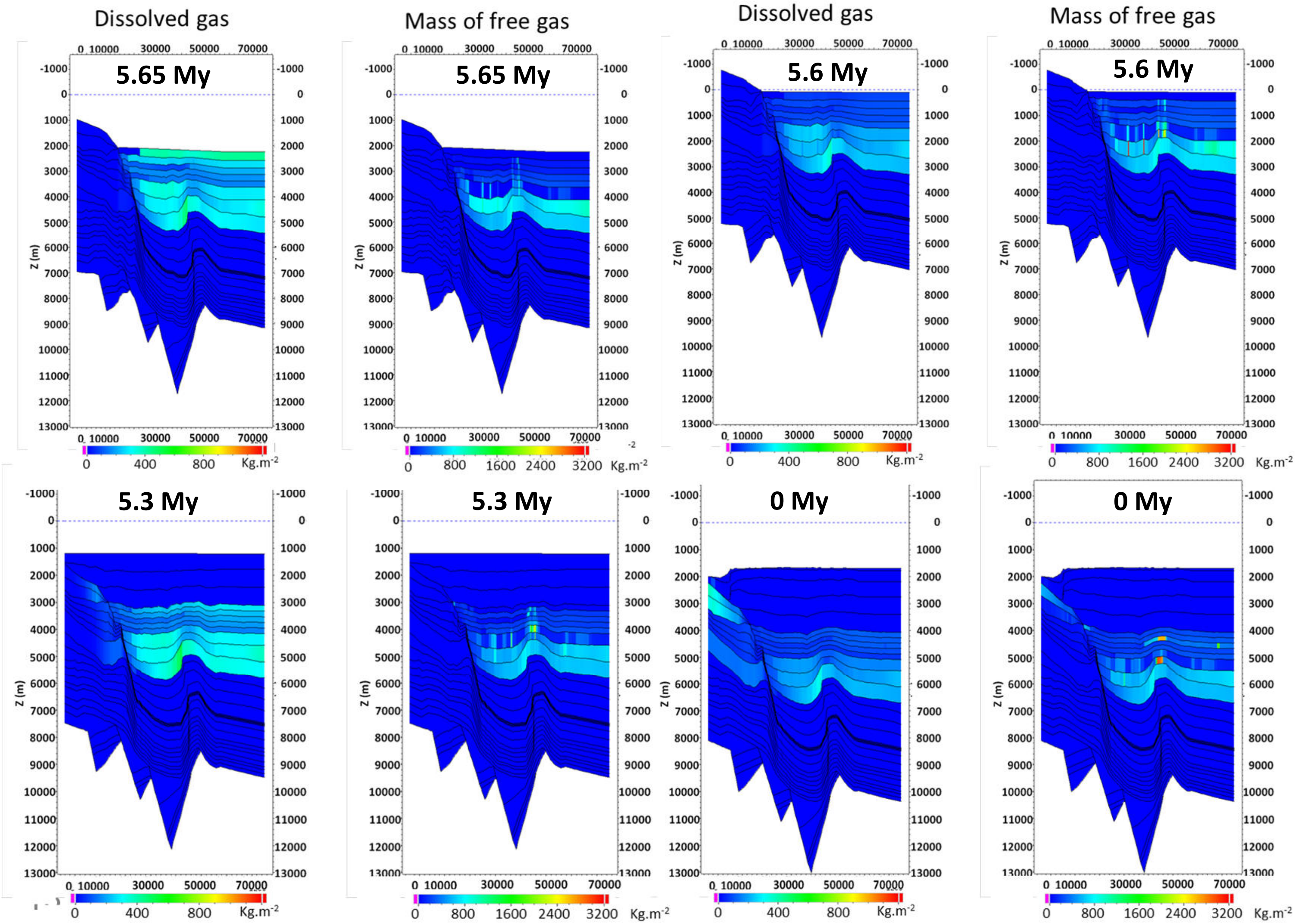
Adsorbed Gas



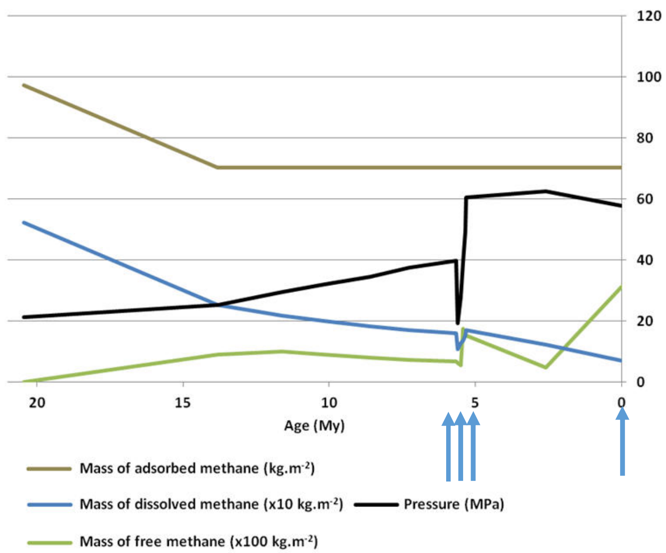
Case STUDY: aphrodite (levantine basin)

WORFLOW – PART 3

TASK 3 : MODELING OF GAS DISSOLUTION/EXSOLUTION



Messinian Crisis



CONCLUSIONS

- Validation of biogenic gas model on several field cases
  - ➔ Innovative and comprehensive model
  - ➔ 3 possibilities of methane storage
- Integrated experimental and modeling Workflow
  - Improve prediction of biogenic gas accumulation
  - Better understanding of structures filling history
- Model can be coupled with:
  - Classic thermogenic processes
  - Biodegradation of the Hydrocarbons

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