Structure of upper crust off Southeast coast of Brazil: Indications for mantle root of a giant hydrocarbon field

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Context of the Present work

Recent discoveries of giant oil fields along the southeast continental margin of Brazil (at depths > 6km and temperatures >150° C) have reopened the debate on the origin of petroleum.

The characteristics of occurrence, generation and preservation of petroleum in pre-salt structures of SE Brazil are known to be NOT fully compatible with the premises set forth in biogenic models.

The model of abiogenic (mantle) origin of petroleum is also found to be unsatisfactory, there being difficulties in identifying specific physical and chemical processes for production and transport of complex molecules of hydrocarbons within the relatively tight mineral structures present in sub crustal layers.

In the present work a new hybrid model of petroleum generation is proposed that can overcome the above mentioned problems encountered in biogenic and abiogenic models.

The limitations of the biogenic model

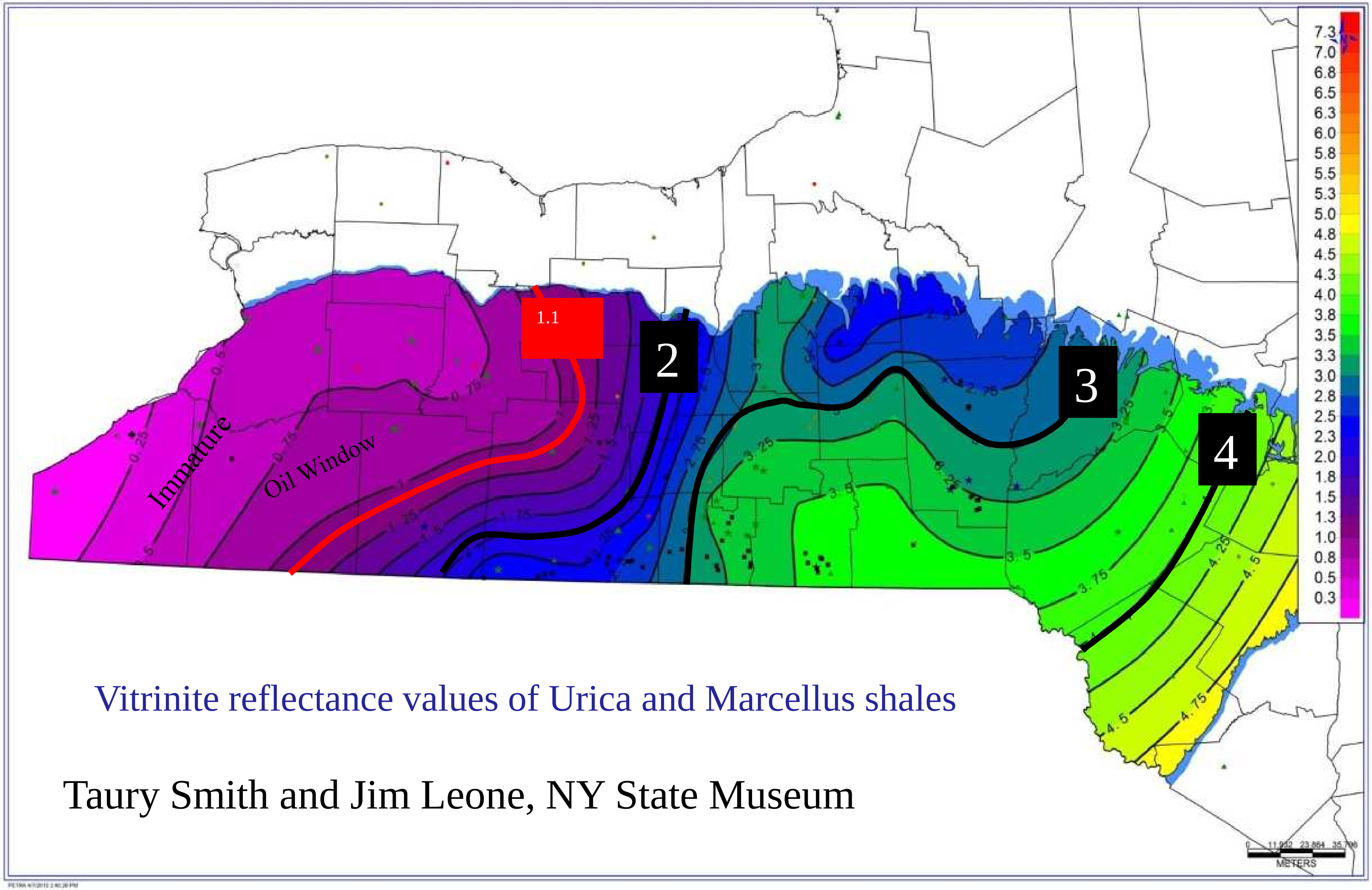
1- The presence of source rocks (bituminous shale) and occurrence of favorable geologic conditions for thermal maturation are not always sufficient for the formation of oil deposits.

(Examples: Shale rich formations in basins of northeast USA, western Canada and southeast Brazil)

2- The space – time charcateristics of oil fields do not reveal clear correlations with model predictions. Adhoc "processes" are often invoked to "explain" the presence or absence of oil fields.

3- In many cases multiple heat transfer processes operating in complex geometry are necessary to account for the specific thermal features in generation and preservation oil fields. Such processes are frequently incompatible with estimates of paleothermal conditions of sedimentary basins.

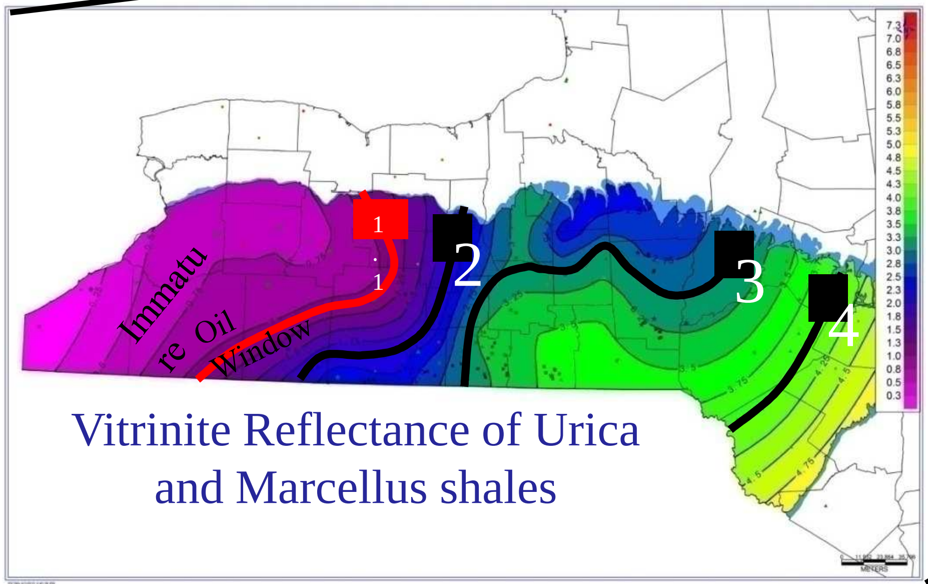
Example: Maturation Levels in shales of the Western parts of New York



Vitrinite reflectance values of Urica and Marcellus shales

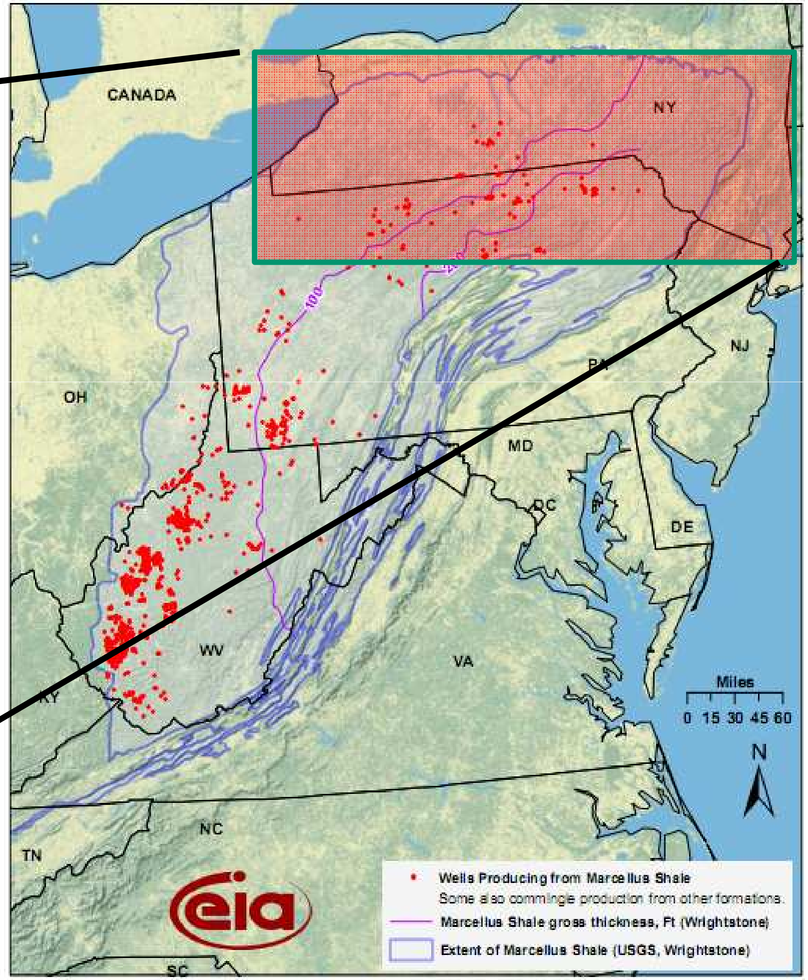
Taury Smith and Jim Leone, NY State Museum

Widespread occurrence of gas fields point to the presence of gas reservoirs, but oil fields are absent.



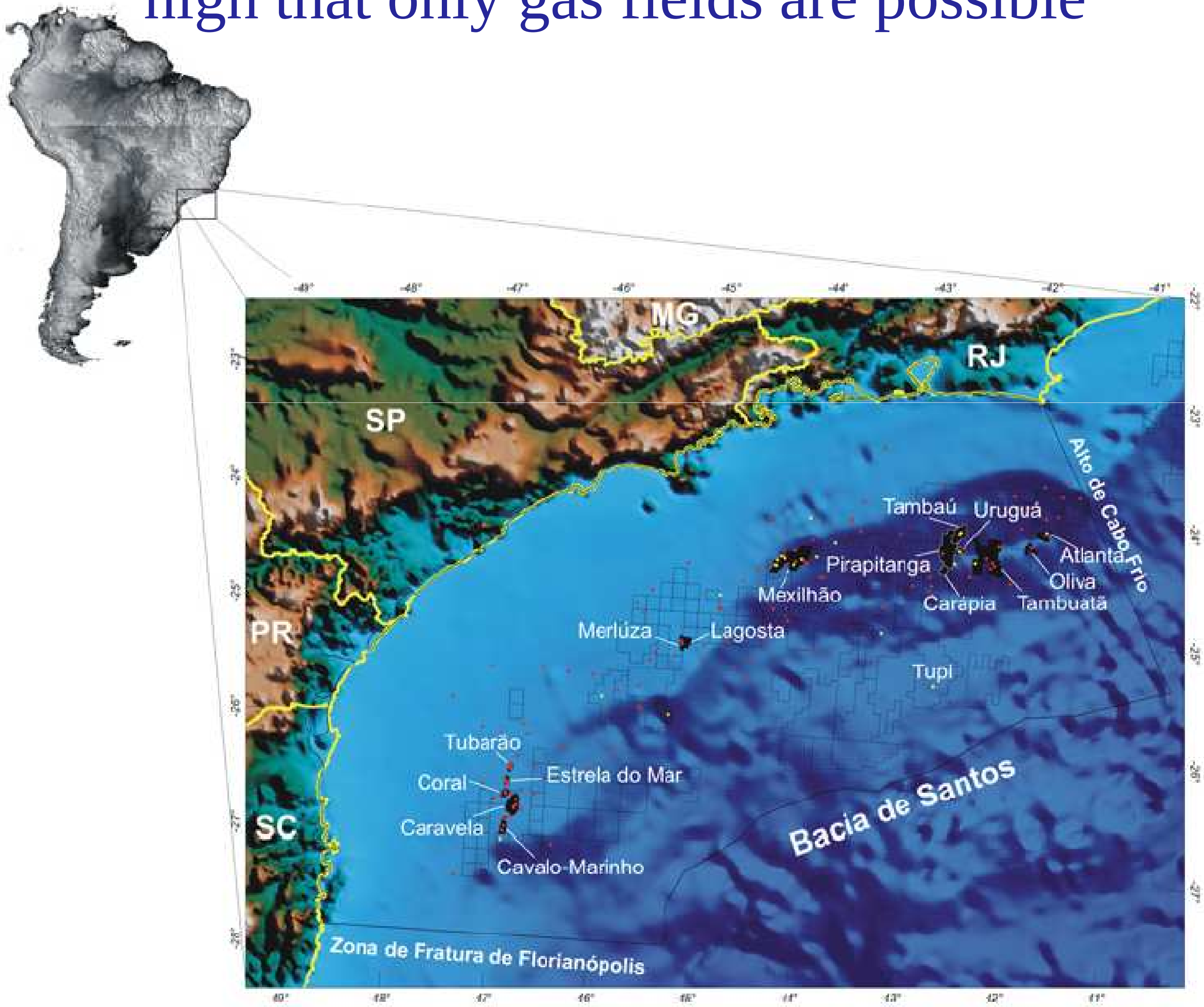
Vitrinite Reflectance of Urica and Marcellus shales

Marcellus Shale Gas Play, Appalachian Basin

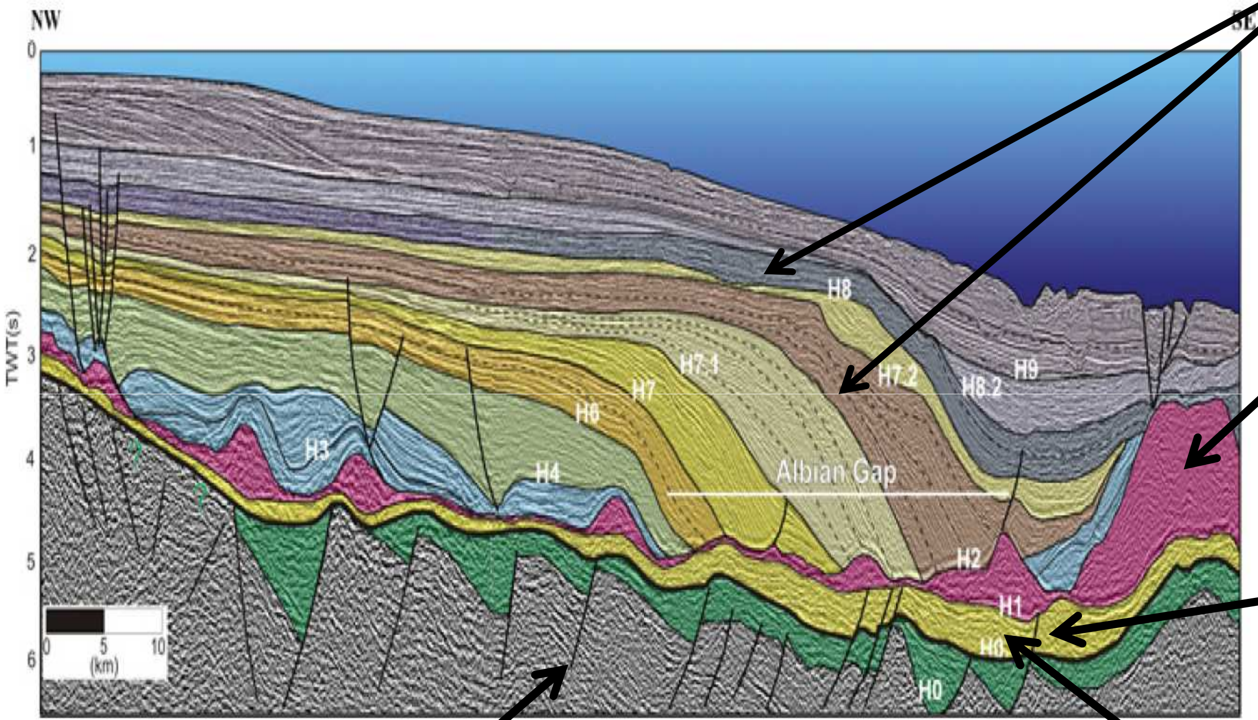


Source: Energy Information Administration based on data from WVGES, PA DCNR, OH DGS, NY DEC, VA DMME, USGS, Wrightstone (2009). Only wells completed after 1-1-2003 are shown. Updated March 17, 2010

Santos basin, offshore SE Brazil
According to biogenic models maturation levels are so high that only gas fields are possible



Stratigraphic sequences (northern sector)



Oil accumulations occur in sand sequences of Eocene age.

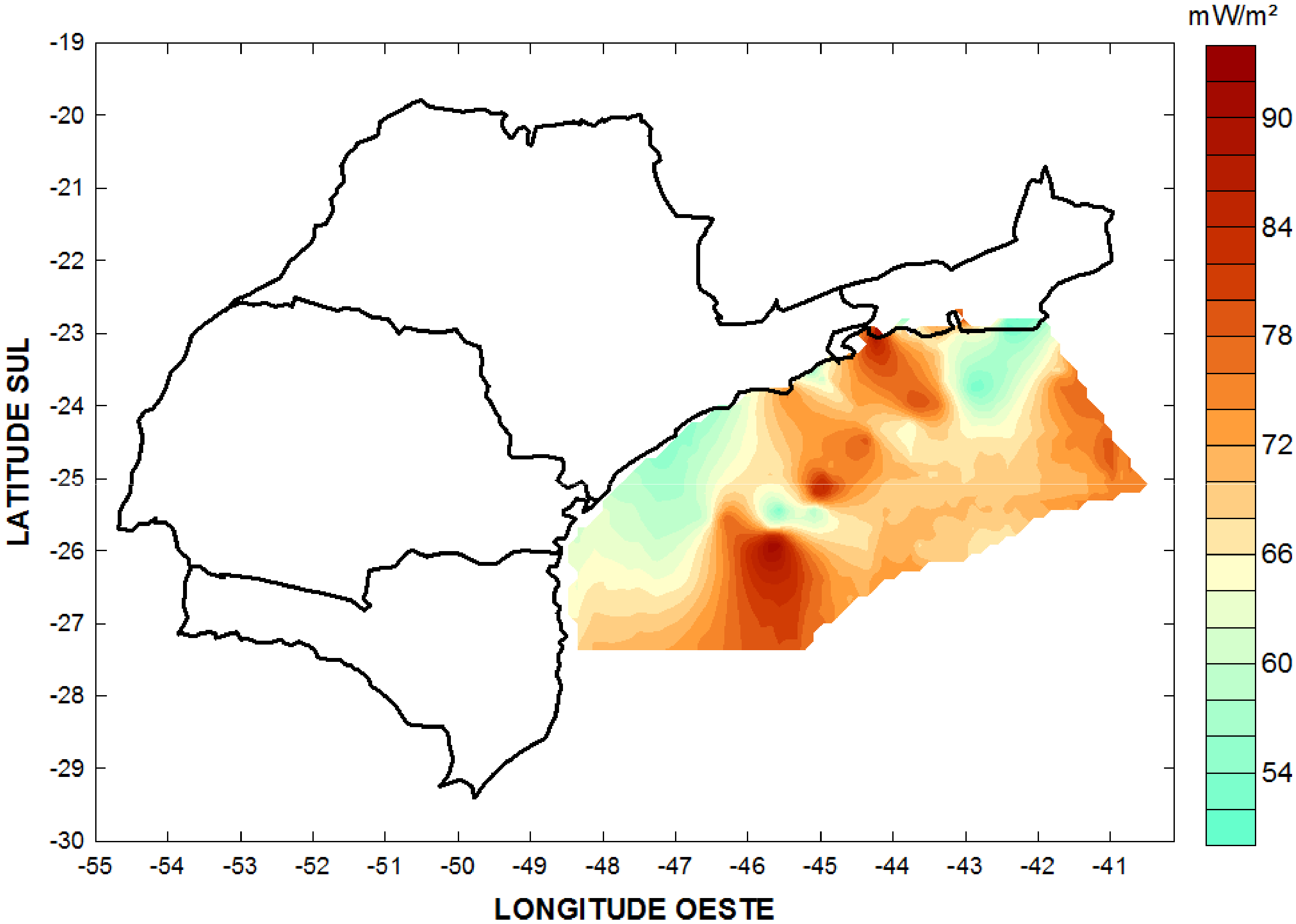
Thick Salt covers act as cap rocks

Giant oil deposits occur in pre-salt sand sequences of Guaratiba formation.

Guaratiba formation in the rift sequence is considered the source rock of both shallow and deep oil accumulations.

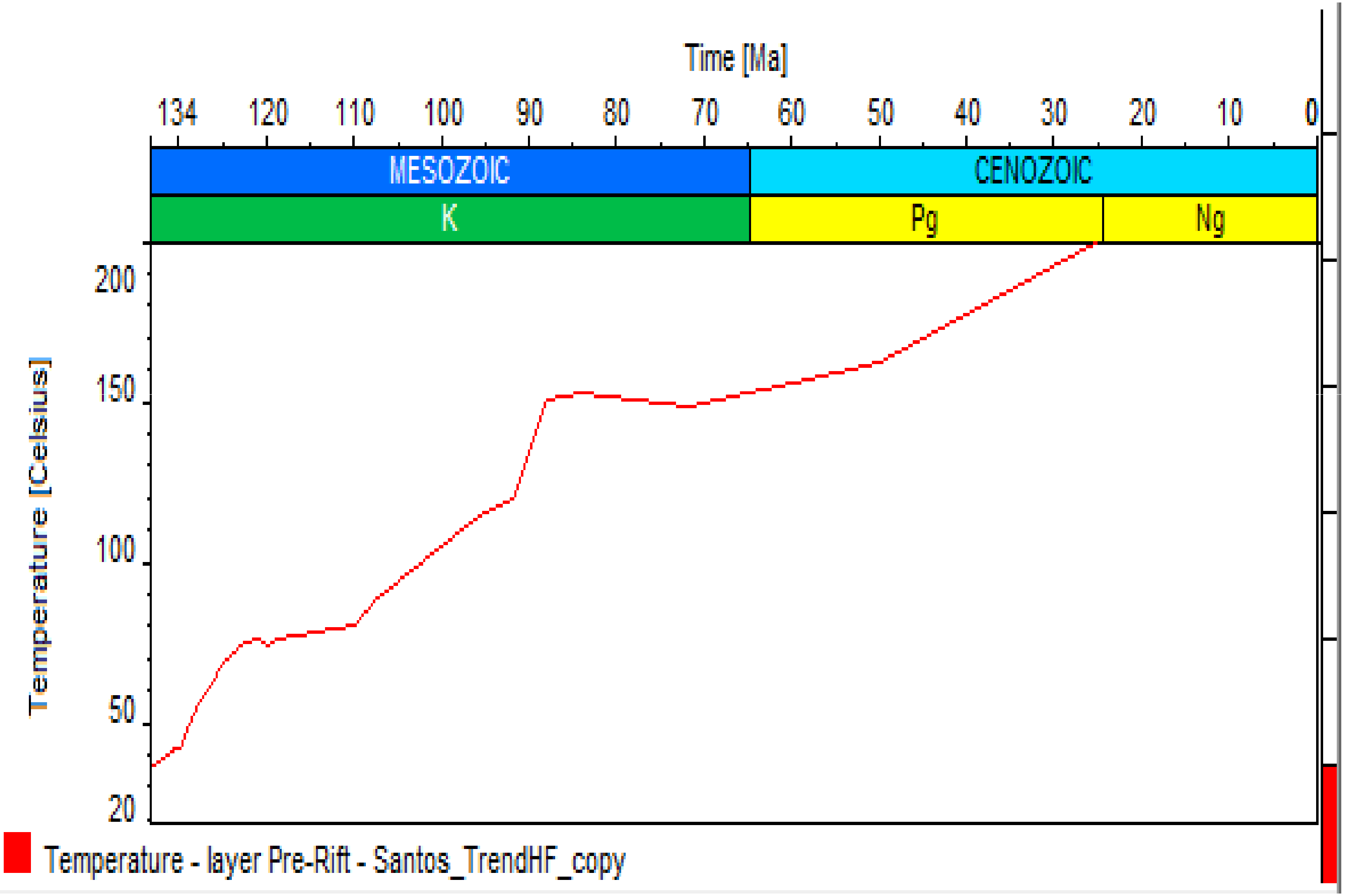
Basement rocks are mesozoic Volcanic sequences.

Heat Flow in Santos Basin (Vieira e Hamza, 2010)

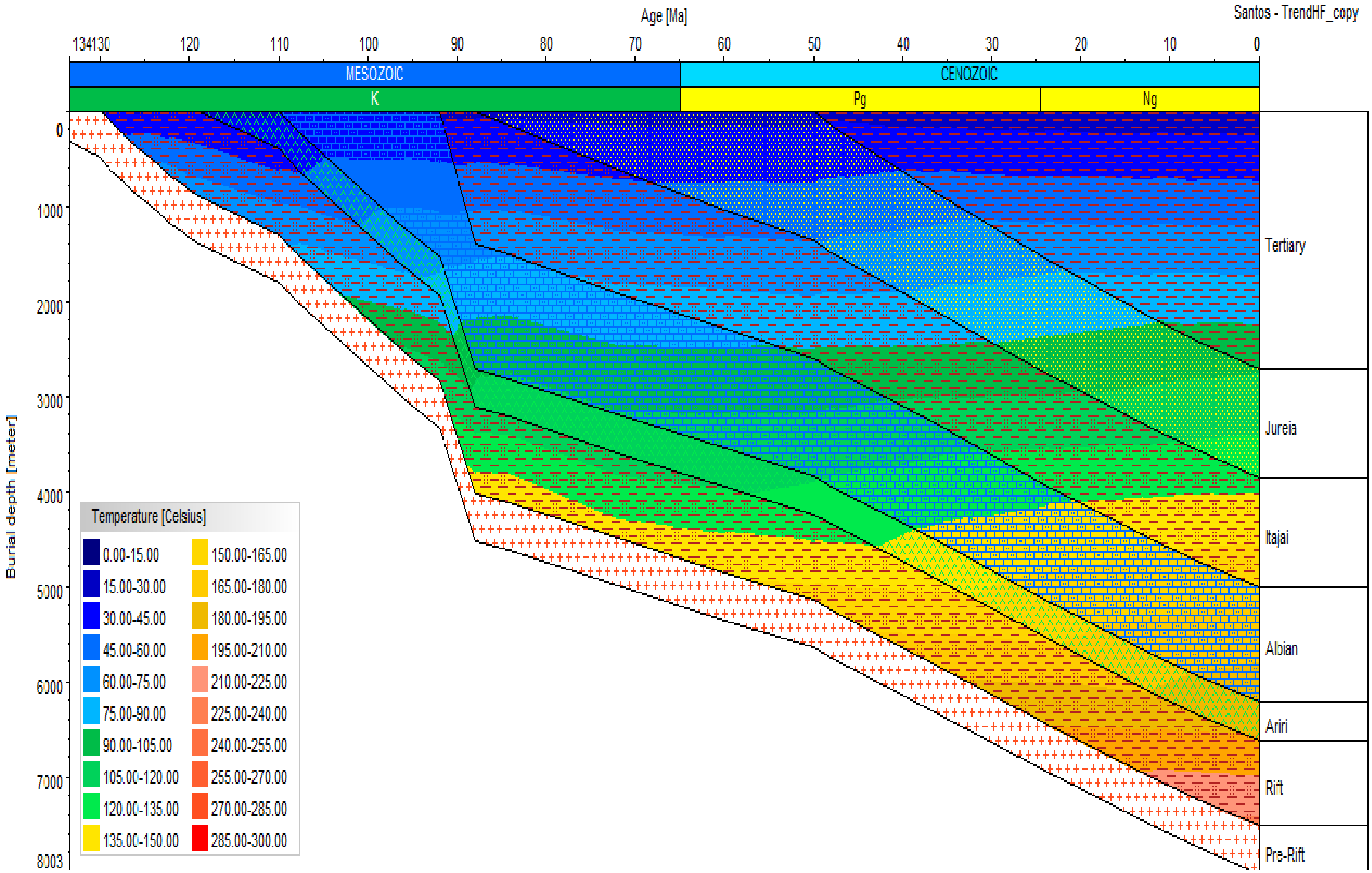


Mean Heat Flow determined using BHT data from 36 oil wells is 70 +/- 15 mW/m²

Evolution of basal temperatures in the rift sequence
(simulation using PETROMOD)



History of subsidence and Temperatures
(Simulation using PETROMOD)



Problems with Biogenic Model of Oil generation in Santos Basin

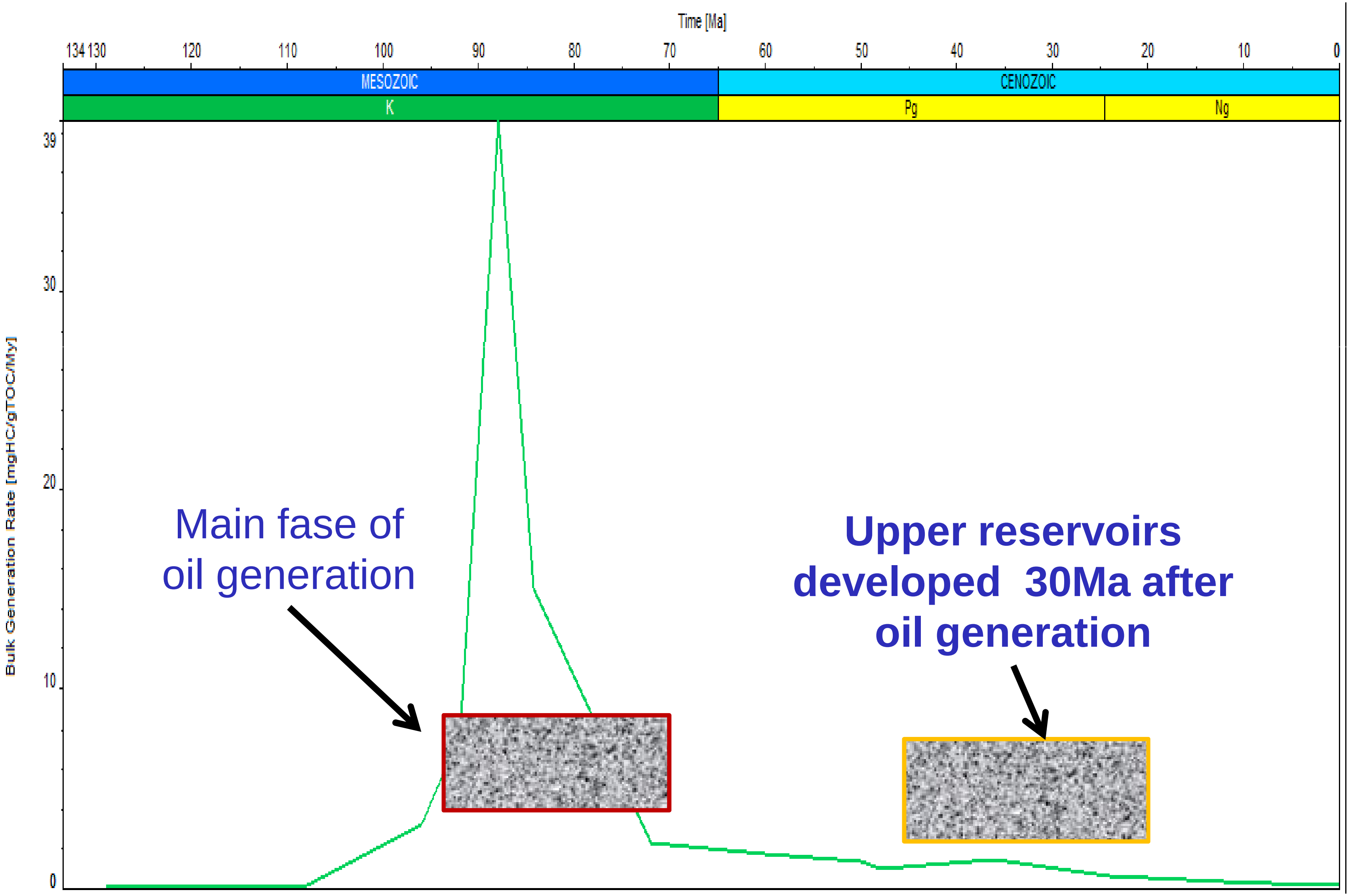
1- The main fase of oil generation (70-90 Ma) PRECEDES formation of shallow turbidite reservoirs

2- The maturation levels (Ro and TTI) in pre-salt formations are ABOVE the limits oil generation.

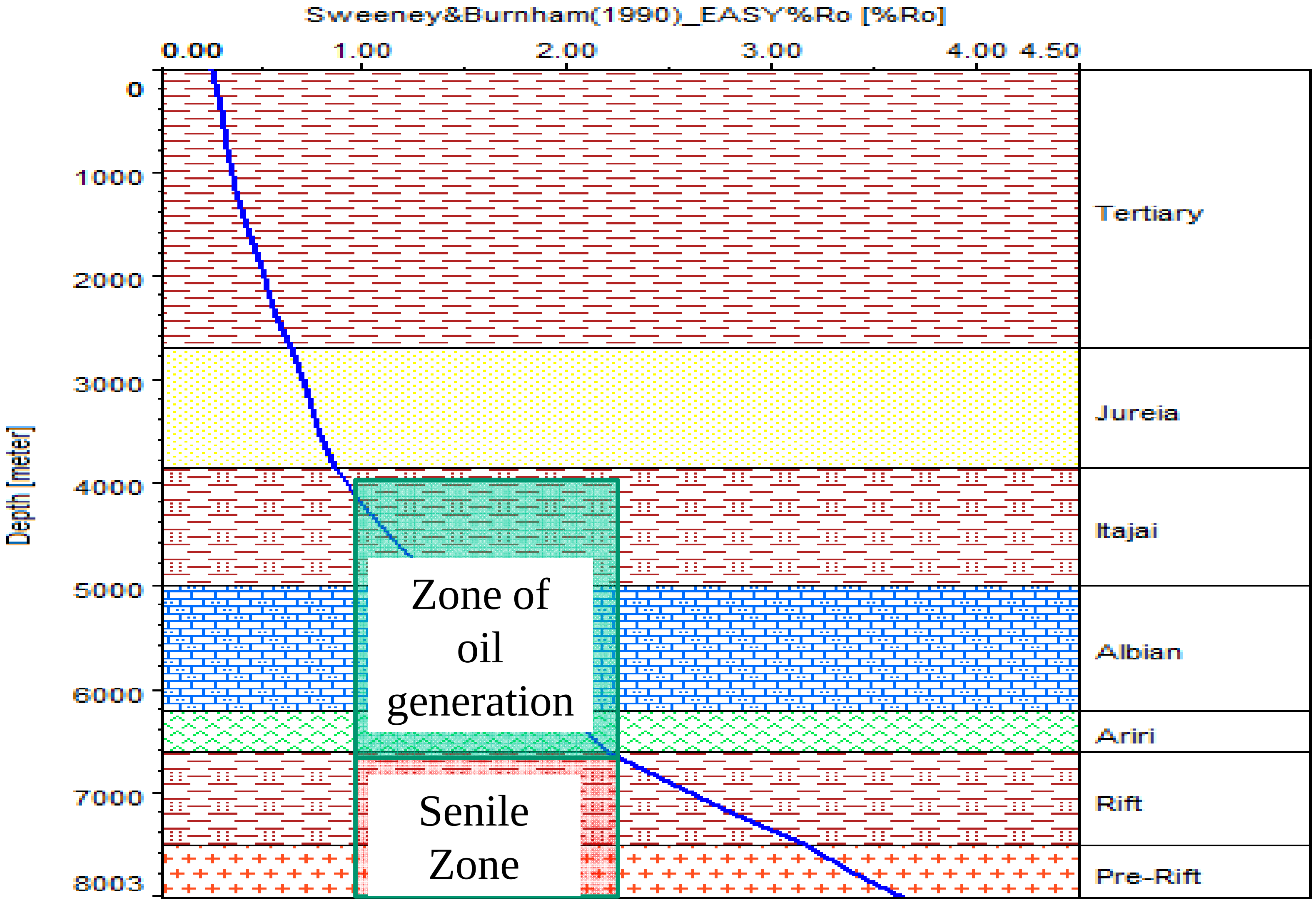
As a result the known oil fields are situated in dry gas zones.

3- A number of major oil fields are located outside zones with appropriate maturation levels.

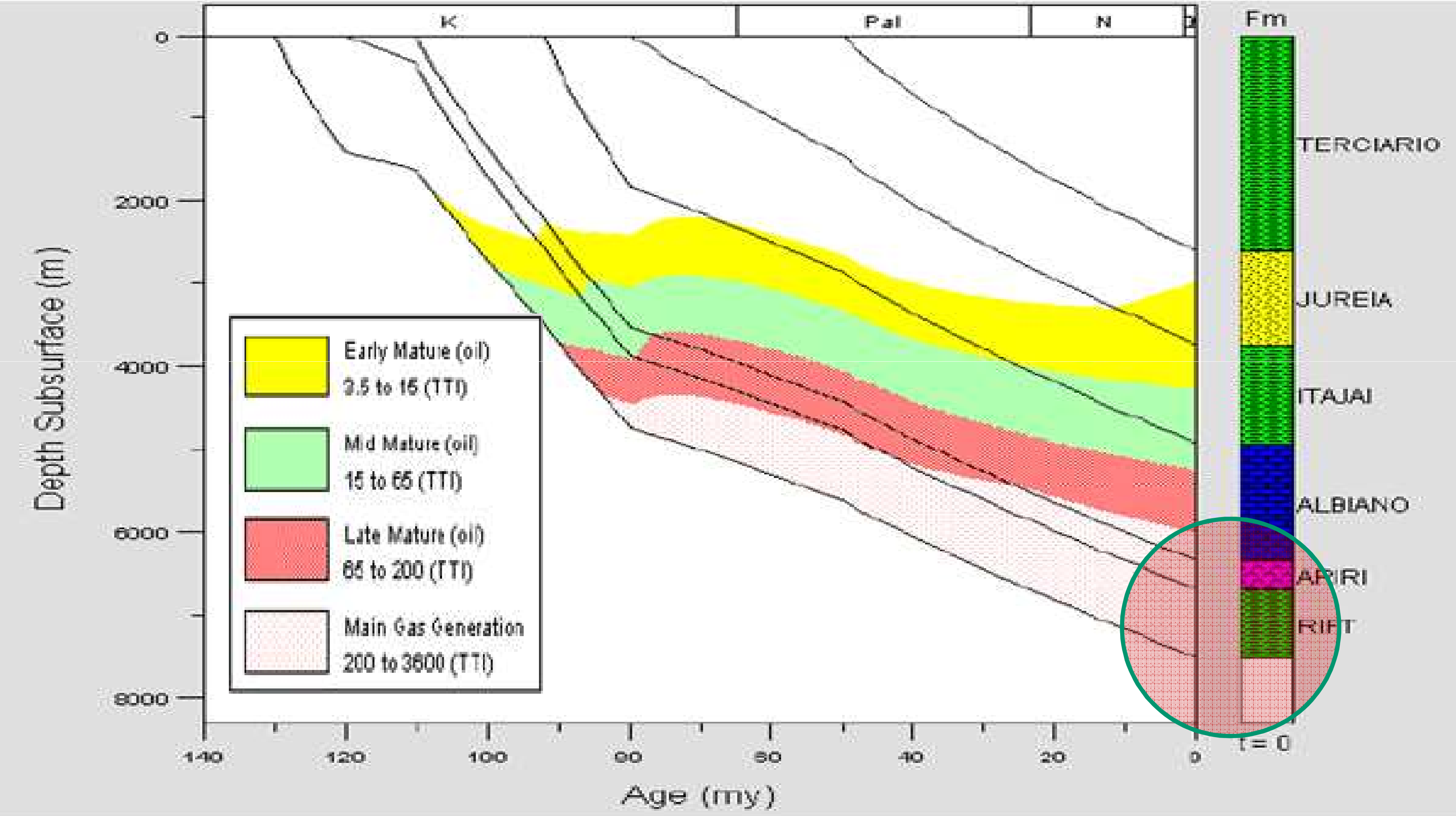
1- Evolutionary sequence of oil generation according to biogenic models. Note that peak occurs during 70-90 Ma. It PRECEDES formation of shallow turbidite reservoirs



2A- The Ro values are ABOVE the limits oil generation in pre-salt formations . As a result, source beds are situated in senile zones.

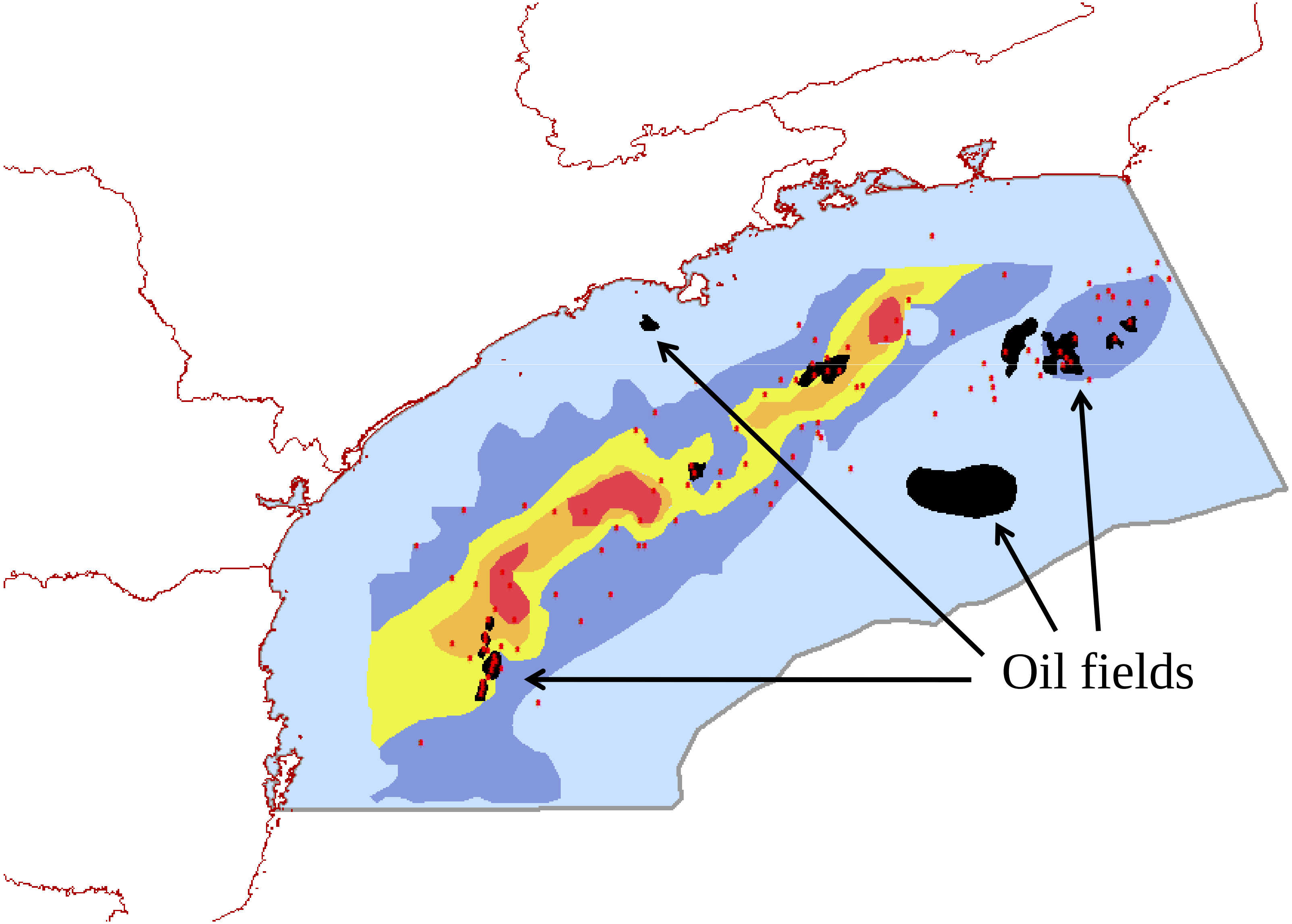


2B- The TTI values are ABOVE the limits oil generation in pre-salt formations . As a result, the source rocks are situated in dry gas zones, over the last 80 Ma.



Reference: http://www.anp.gov.br/brnd/round5/round5/Apres_SemTec/R5_Santos.pdf

3- Major oil fields are outside zones of optimal maturation, according to Biogenic models



The failure of the theory of Biogenic Origin of Petroleum (BOP) points to the need for a new model.

The models of Abiogenic Origin of Petroleum (AOP) can in principle overcome some of the difficulties of the BOP model.

However, the AOP models has not yet come up with a satisfactory explanation of how complex molecules of hydrocarbons can be generated, preserved and transported within dense crystalline structure of mantle minerals.

Solution? A new model of Petroleum Generation

Hypothesis of Mantle Root for Origin of Petroleum

Basic assumptions

1- Up flowing emanations (volatile gases and suitable transition elements) of mantle origin interact with organic matter present in sedimentary layers, setting off catalytic reactions that lead to intense oil generation.

2- The agents for catalytic reactions (Fisher-Tropsch process and schemes proposed by Mango) are released from the brittle segment of the upper mantle.

3- Time and temperature play only secondary roles in oil generation, since activation energy for catalytic reactions are much less than that for thermally induced reactions.

Implications of the Mantle Root hypothesis for the occurrence of oil fields

1- Mantle emanations move along structural discontinuities in the upper crust and hence zones where catalytic reactions occur are likely to be located near such paths.

2- Factors that control oil generation in mantle root model are:

a) Permeability of structural features in the crust;

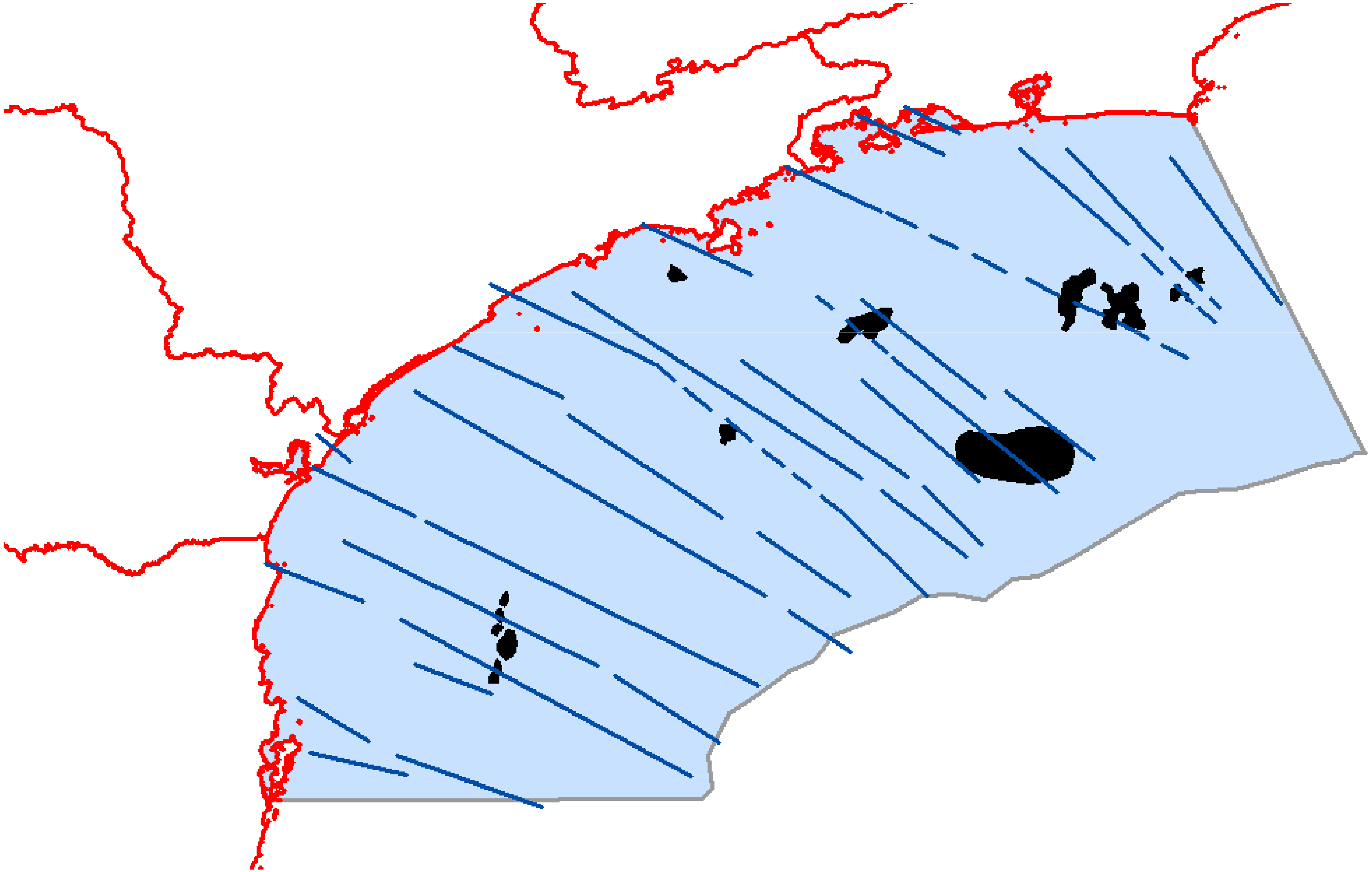
b) Intensity of mantle emanations

Test of the Mantle Root Hypothesis

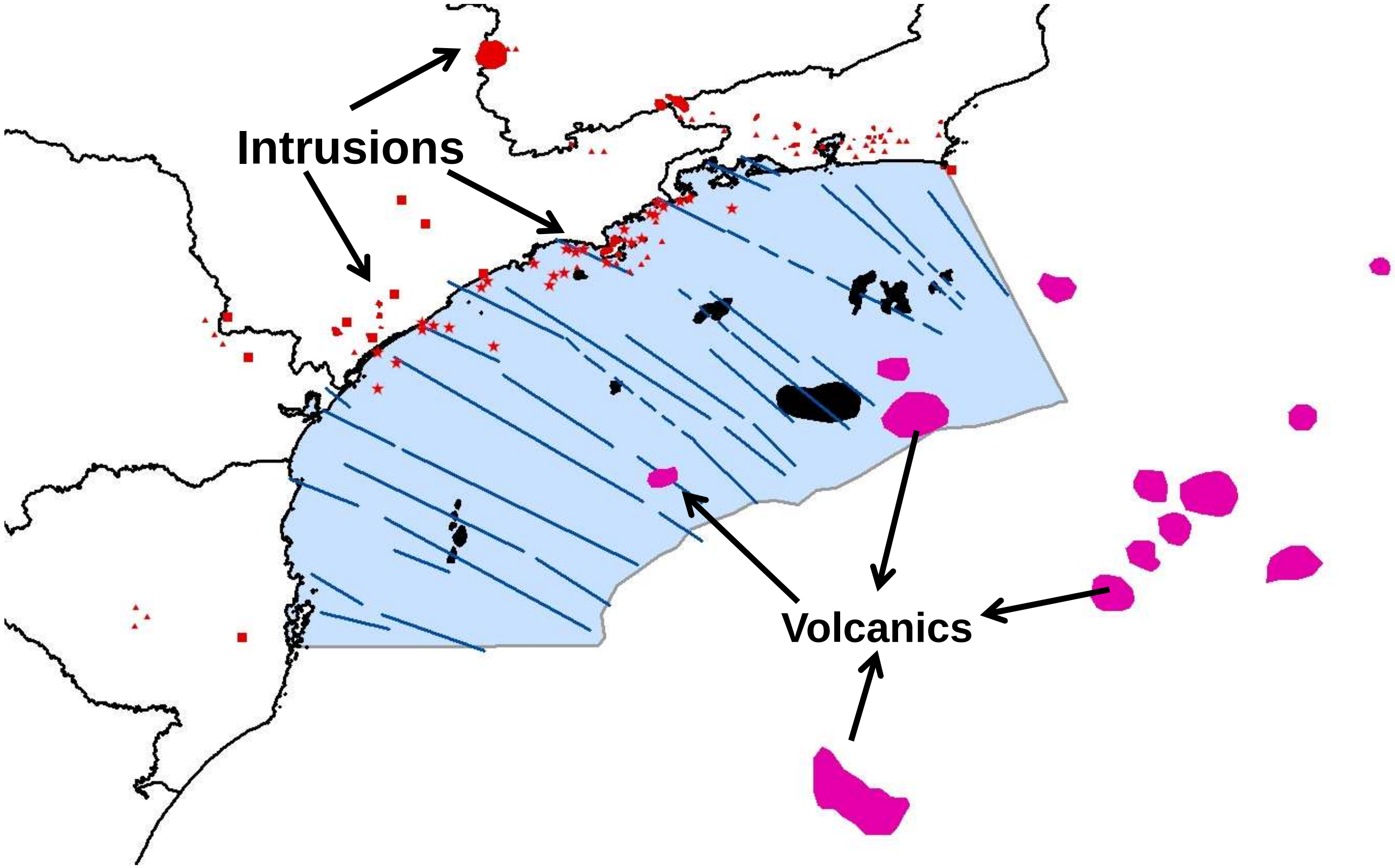
1- Evidences that support the hypothesis of Mantle Root origin of oil generation in Santos Basin

2- Modify maturation calculations allowing for effects of mantle root connections

1- Most of the known oil fields are situated on or close to lineaments identified in the basement rocks.



2- A number of volcanic structures are located in the interior and alkaline intrusions in the northern border.



These are believed to provide catalytic agents for oil generation over large areas of the upper crust beneath the basin.

Values of maturity (R_{om}) are recalculated in the Mantle Root Model using the following procedure

1- R_{om} inversely proportional to the distance from the nearest lineament or structural feature;

$$R_{om} = R_o \left[\frac{1}{\exp(x/B) - 1} \right]$$

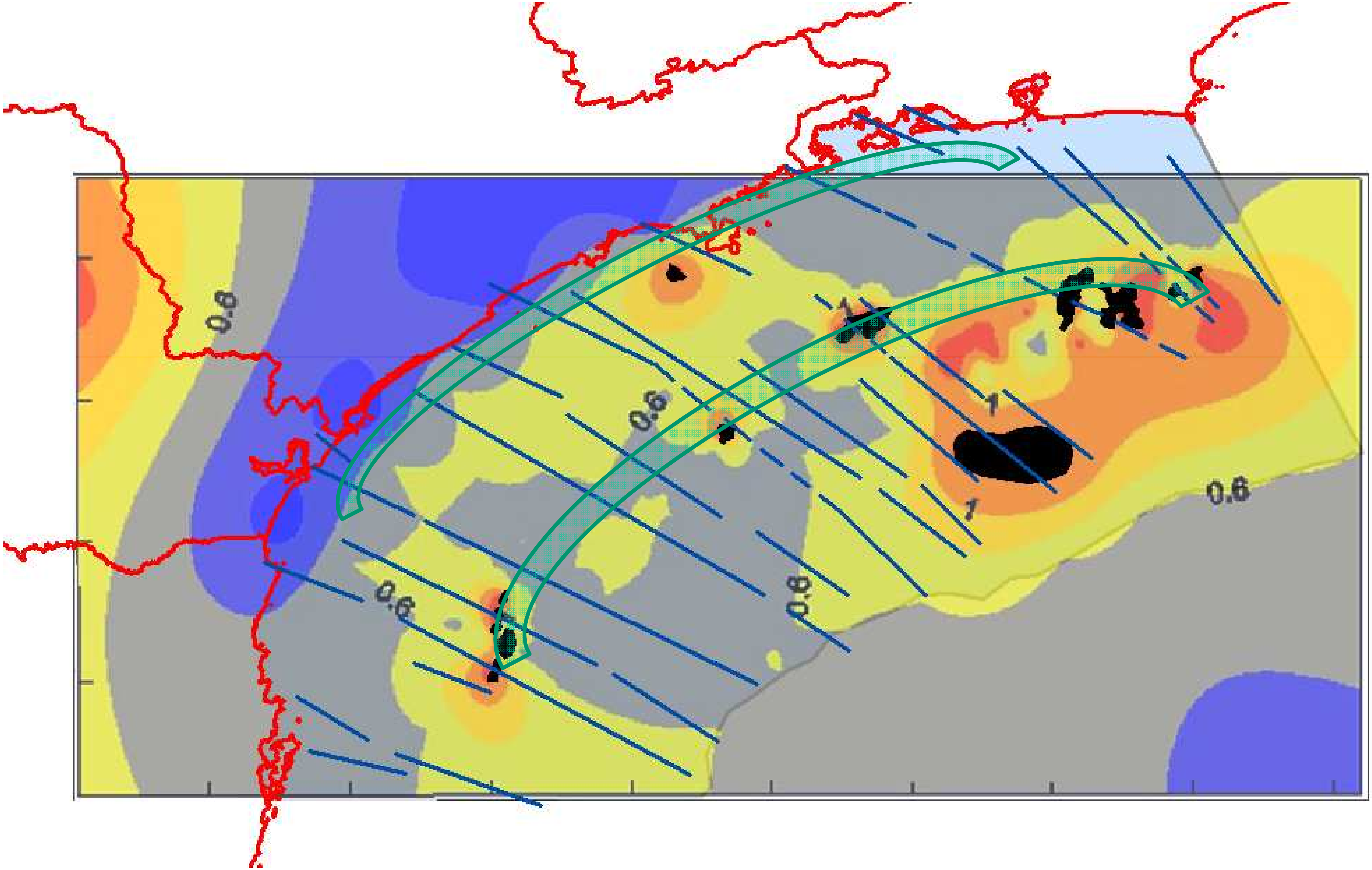
x → 0 R_{om} → Large
x → Large R_{om} → 0

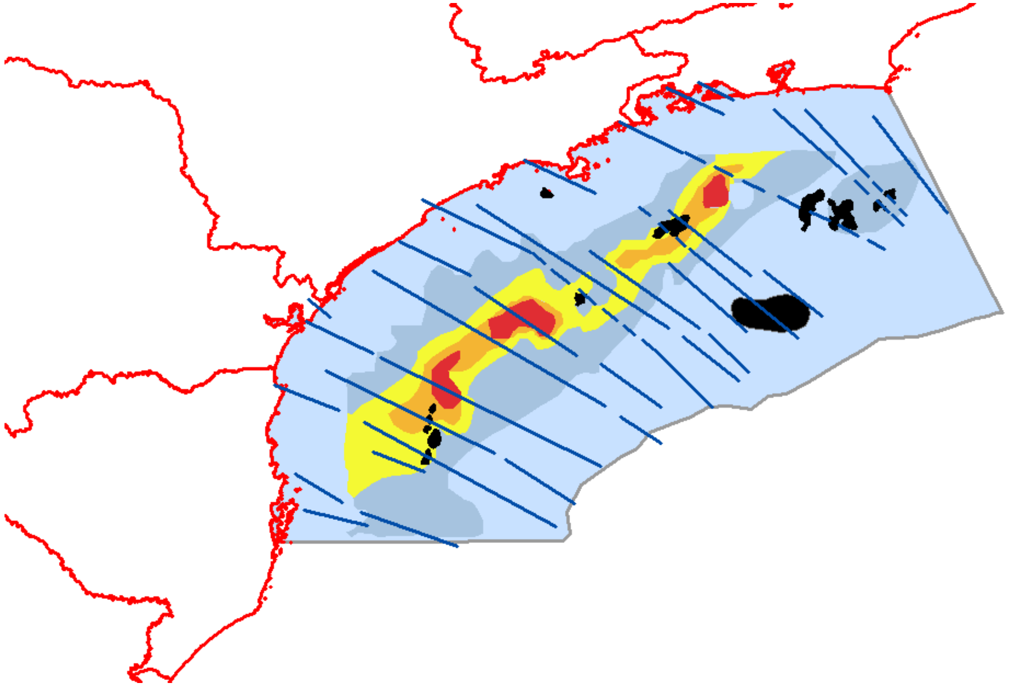
2- R_{om} directly proportional to intensity of mantle emanations (the spatial density of volcanics and intrusions).

$$R_{om} = R_o\,(1 + \rho / D)$$

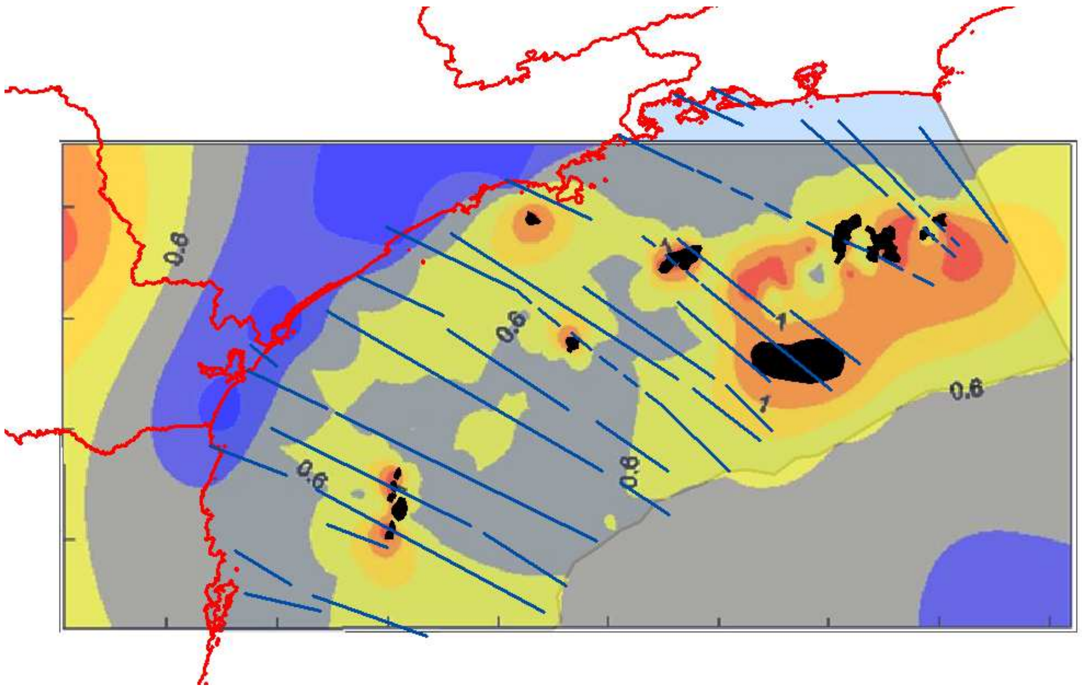
ρ → Small R_{om} → Ro
ρ → Large R_{om} → Large

Modified indices of maturation as per Mantle Root model





Biogenic model



Mantle Root Model

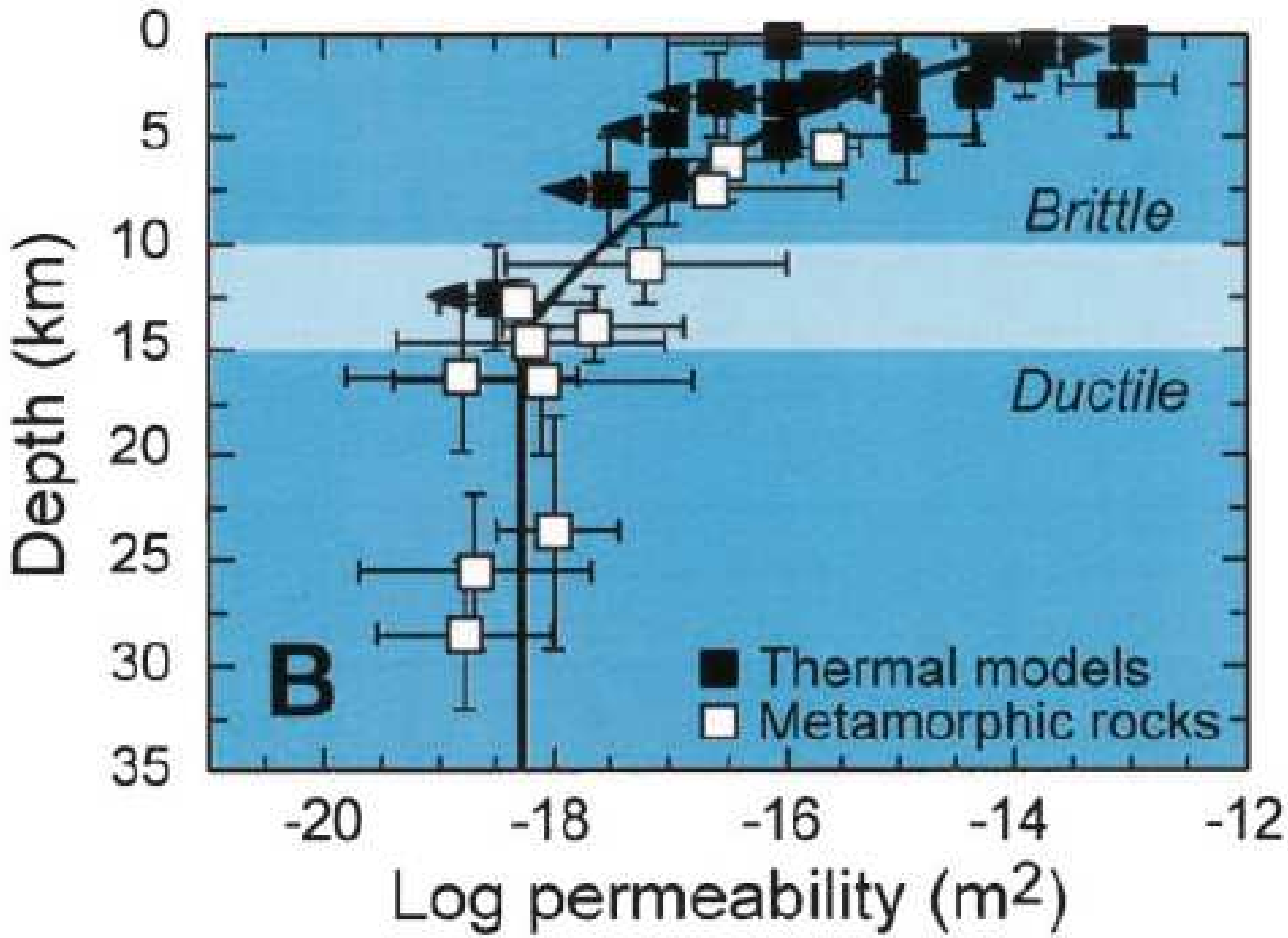
Timing of Oil Generation

Mantle root model predicts late stage oil generation, only after brittle regime sets in the upper parts of subcrustal lithosphere.

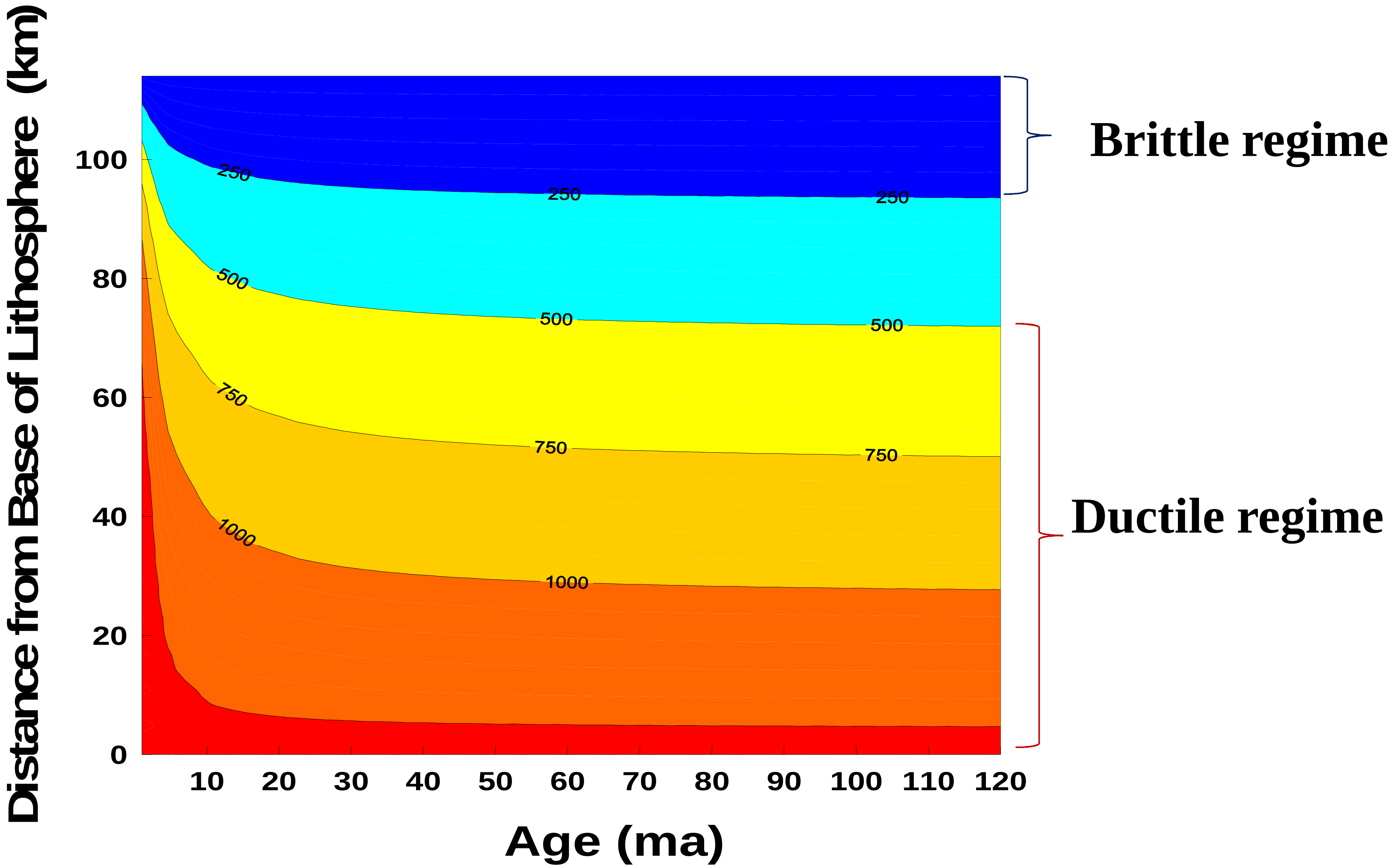
This is when permeability increases and flow of catalytic agents (gases and volatiles) becomes significant.

The time scale for installation of brittle regime is of the order of 50 Ma, after formation of lithosphere.

Permeability changes during Brittle – Ductile Transition
(Ingerbritsen and Manning, 2002)



Time scale for brittle regime in subcrustal lithosphere



Conclusions

1- Biogenic model leads to maturation levels incompatible with occurrences of hydrocarbons in Santos basin;

2- Mantle Root Model provides better account of the geographic distribution of known oil deposits;

3- Catalytic reactions by Hydrogen (Fisher-Tropsch process) and transition elements (schemes proposed by Mango) have lower activation energy and hence more important in oil generation, than normal reactions controlled by time and temperature.

Thanks for your attention